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16. Abstract

This report presents a summary of a study conducted for the Transportation Systems Center of promising access control techniques which are applicable to an aeronautical satellite system. Several frequency division multiple access (FDMA) and time division multiple access (TDMA) configurations are analyzed and compared which are capable of providing voice, data and independent surveillance services. One of the FDMA concepts and a burst TDMA system are rated highest and are presented in greatest detail. Procedures are outlined for different types of entry, beam switching and handling various types of interconnections. Included are preliminary designs of the avionics instrumentation.

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PREFACE

The Transportation Systems Center is conducting investigations to determine what avionics is needed for the implementation of an oceanic satellite air traffic control system. The study of System Access Control which pertains to how the communications services are allocated and managed provides a framework for establishing avionics requirements.

The study results were based on contributions made by the authors as well as other study team members, and has been supplemented by material from related IR&D projects. Particular acknowledgement is also made to Messrs. Robert Snow and Leslie Klein of the Transportation Systems Center for the critical reviews and the many helpful suggestions provided during the course of the study.

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1.0 INTRODUCTION AND SUMMARY

This final report presents a summary of the work accomplished during the study on System Access Control under the direction of the Transportation Systems Center, Contract DOT-TSC-539. The objective of the study was to obtain detailed descriptions of equipment and interfaces for promising access control techniques which are applicable to an aeronautical satellite system.

Emphasis in the study was placed on systems capable of providing voice, data and independent surveillance services. Six candidate configurations using either frequency division or time division techniques were investigated. The basic method of operation and sets of flow diagrams were developed so that comparative evaluations could be made of workable systems. Provisions are made for different types of entry, beam switching, and for setting up communications between mobiles anywhere over the oceanic area and various ground terminals. The interactions of the access control technique with signal design were considered wherever appropriate.

A queueing simulation and supporting analysis was carried out simultaneous with the formulation fo the systems concepts. The simulation verified that results obtained from the application of conventional queueing theory are valid. A set of charts developed from the theory is useful as a design tool in evaluating and comparing channel management strategies.

Descriptions of all the candidate configurations are presented in this final report. However, based on a comparative evaluation an FDMA concept, identified in the study as System C, and a TDMA system, identified as System F, rated highest and are presented in greatest detail. Preliminary designs of the avionics instrumentation for these two systems and a summary listing of element costs are included.

Compatibility with the Universal Digital Data Link (UDDL) is provided in the selected system. In FDMA, the UDDL is modified to include the transmission and reception of all supervisory data required for channel accessing as well as transmission of normal messages. The data-link channel is also used for surveillance polling. A surveillance signal is multiplexed in quadrature with the data carrier if independent surveillance service is desired. Full duplex channels are used for both data and voice. However, if further analyses indicate that the preponderance of data message traffic is in the A-G direction, extra one-way channels can be added or the data transmitted at twice the rate.

A separate supervisory channel multiplexed with a surveillance signal in a single framing burst is used in the selected TDMA system. All other bursts represent communications channels which can be used for either voice or data. The air-ground transmissions are handled as FDM. Corresponding to each burst in an uplink frame there is a downlink frequency channel. Extra A-G ground channels can be added as before.

The main advantage of the TDMA is the elimination of intermod products and operation of the satellite power amplifier at maximum efficiency. However, much of the advantage is lost because of the increased channel overhead associated with each burst.

The selected FDMA and burst TDMA systems described are comparable in operational capability. Access capability from any ASCC/ASET to any mobile anywhere over ocean is provided. In the TDMA system, time synchronization of each ASCC/ASET to the master which transmits a framing burst is required. This is achieved by monitoring the L-band transmission from the satellite. Rapid beam switching on a burst-to-burst basis is also required. Therefore, a command channel to the satellite which furnishes a timing reference and the switching sequence must be supplied. For FDMA, the satellite must have the capability of switching individual channels to various spot beams. Precise timing is not a requirement.

The FDMA system described uses distributed control wherein every ASCC/ASET in the system can be allocated data and voice channels to manage. This minimizes the number of G-G interchanges associated with channel assignments and ring-ups. However, if it is desired, the FDMA system can be converted to centralized control, wherein the master maintains a common pool of all voice channels. The use of either central or distributed control does not affect the avionics. It should be noted that full central control in an FDMA system implies that freedom exists in the satellite for switching any and all channels to any spot beam on command from the master ASCC.

In the TDMA system, each satellite transmits a multiplex at a separate frequency. The total available channels are, therefore, divided in two with each multiplex managed separately. An aircraft would normally monitor one or the other of the satellite signals. If central control is desired with a capability of assigning any channel from either satellite to any aircraft, then each aircraft must monitor two frequencies and decode both sets of TDMA bursts. This results in some added cost to the avionics.

The TDMA system dictates use of an all digital signal format including digital voice and ranging. In an FDMA, no such commitment is required. The access control concept design can proceed independently of the signal design. Analog or digital signals can be selected to best meet overall AEROSAT requirements.

The costs of the Avionics for either the FDMA or TDMA systems are not vastly different once the development has been completed. The FDMA system uses a double conversion receiver and a separate phase-lock demodulator for the voice and data channels. The TDMA avionics shown uses a single conversion and a phase-lock demodulator which is common to all channels. However, a double conversion receiver is equally applicable so that a common R-T design can be selected for experimentation with either FDMA or TDMA systems. In TDMA, channels are separated in a digital processor and the voice and data bursts converted to continuous streams. The overall processing for access control including display input/output are nearly identical. The downlink channels for both systems are essentially the same.

Based on studies to date, it is felt that either FDMA or TDMA can be used to provide AEROSAT service at approximately the same avionics cost. FDMA is somewhat further along in development status. Implementation of TDMA imposes additional avionics circuit complexity and additional development effort.

Other conclusions reached are:

1. FDMA allows greater flexibility in signal selection during the design phases of the program.
2. The use of digital data links for most of the communications services provides excellent channel utilization; i.e., queueing times are low, number of channels required is low.
3. Use of dedicated rapid access A-G channels operating through earth coverage satellite receiving antennas provides excellent emergency and random entry service.
4. The results obtained from standard queueing analysis are comparable to those obtained from the simulation.
5. Channel efficiency in terms of busy probabilities/waiting times is not seriously degraded when individual ASCC's each manage a small group of channels as compared to a central ASCC managing all the available channels provided at least three channels are in each pool.
6. The longest access times are in the A-G direction and are associated with polling epoch durations.
7. Although a typical message traffic load has been generated, it is felt that many new types of messages will be generated once the system goes into operation.

8. The same R-T assembly can be used for both FDMA and TDMA experiments.

9. The additional cost for providing independent surveillance service is small when added to an avionics assembly providing data and/or voice service.

10. Synthesizer complexity and cost is almost doubled if separate independent tuning is provided for uplink and downlink channels.

11. For most efficient and economical design only single carrier transmission at a time, from the aircraft, is recommended. Priority transmission of surveillance, data and voice in that order is feasible.

12. A cost reduction can be effected in a push-to-talk voice only system by eliminating the diplexer in the avionics. Signal acquisition complexities can result, however, if data and surveillance are also provided.

The report is subdivided as follows:

Section 2.0 presents a summary of the basic AEROSAT system characteristics and the communications services which were assumed for the study. Typical message characteristics are also presented.

Section 3.0 discusses multiple access concepts and channel management disciplines which are applicable to AEROSAT. A queueing analysis and sample calculation for 1980 AEROSAT communications is also shown.

Sections 4.0 and 5.0 present descriptions of the FDMA and TDMA studied including typical avionics instrumentation.

Section 6.0 presents a comparative evaluation of the systems studied which led to the selection of the particular FDMA and burst TDMA as best.

A brief discussion of maritime application is given in Section 7.0.

Section 8.0 presents recommendations for future experiments, tests and studies.

Appendices cover various supporting analyses including a tabulation of intermod losses, a queueing analysis and an analysis of phase lock loop acquisition characteristics applicable to AEROSAT.

2.0 SYSTEM REQUIREMENTS

2.1 AEROSAT Characteristics

The System Access Control Study has been kept general and not dependent upon a particular AEROSAT satellite design. Nevertheless, overall characteristics have been obtained from the recent AEROSAT performance specification and the many papers published on the subject to constrain the study to those schemes which are most applicable to aeronautical satellites of the early 80's. The parameters important to access control are discussed in this section.

2.1.1 Satellite Power/Channel Capacity

The signal quality standard for a communications channel is 43 db-Hz. This is compatible with any of the analog or digital voice modems being considered for AEROSAT. Such a channel can also be used for data transmission at a 1200 bit/second rate with an error probability of less than 10^{-5} in Gaussian noise.

To achieve the above quality, there are four microwave links involved. These are the C-band links from the ground terminal to the satellite and back and the L-band links from the satellite to the mobile and back. Of these, the link from the satellite to the mobile is the most critical. This is a consequence of the use of a broad beam aircraft antenna with a reference gain of only 4 db. The reference receiver noise temperature is specified as $1000^{\circ}K$.

Therefore, to meet the signal quality standards with a satellite the size of AEROSAT, the efficiency of hard limiting power amplifiers and the gain obtainable from spot beam antenna coverage are required. The exact number of spot beams is not specified and can vary from 3 to 7, depending on the particular design.

Sufficient power is radiated from the satellite to a mobile via a spot beam to provide the minimum signal quality of

43 db-Hz. This is defined as one (1) unit of satellite power; i.e., each G-A communications channel uses one (1) unit of satellite power. In the ground-air direction, the satellite is capable of transmitting a total of approximately 6 units of power simultaneously. If it is desired or required, units of power can be combined to provide higher quality channels. This includes combining all the power capability for TDM operation. On the other hand, if a unit of power is transmitted via an earth coverage antenna, the signal quality is reduced by the ratio of the spot beam gain to the earth coverage beam gain.

The ground terminals use very large antennas. Therefore, comparatively low transmitter power is required on these links to achieve adequate signal-to-noise ratios. Most of the satellite power is used in the satellite to mobile direction. Because so little power is used, A-G, more channels can be made available than from G-A. These additional channels can be used as part of an overall accessing scheme for emergency channels as well as for additional information transfer. On the other hand, it is important from an access control point of view to concentrate on effective use of the limited G-A channels.

In addition to the spot beams, it is assumed that the satellite is equipped with an L-band earth coverage antenna. This antenna can be used for either A-G or G-A transmission where the signal quality required is compatible with the reduced gain. A gain of approximately 17.0 db is assumed for this antenna.

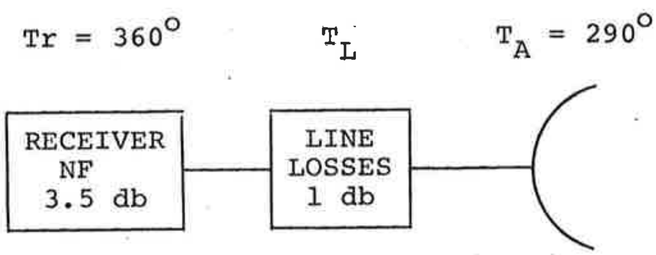
Another consideration in the synthesis of access techniques is the transmitter power advantage which the mobile has over the satellite on a per channel basis. This can be used either to obtain better signal quality or to permit A-G transmission via an earth coverage antenna. This is shown in Table 2-1, where simplified link budgets are shown for earth coverage and spot beam transmission. It shows that, under reasonable assumptions for satellite antenna gain and noise temperature, transmission from

TABLE 2-1

MOBILE-TO-SATELLITE LINK BUDGET

	EC	SPOT BEAM (Typical)
Mobile EIRP	+23 dbw	+23 dbw
Space loss	189 db	189 db
Pointing and Polarization Losses	1 db	1 db
Margin	5 db	5 db
Min. Satellite Antenna Gain, G	17.0 db	22 db
*Satellite Noise Temp, T	820°	820°
G/T	-12.1 db/$^{\circ}$K	-7.1 db/$^{\circ}$K
K	-228.6	-228.6
Resulting C/N_o	44.5 db-Hz	49.5 db-Hz

*



$$T_A = 290^{\circ}K$$

$$T_L = (L-1)\,290 = 75^{\circ}$$

$$T_e = T_A + (L-1)\,T_L + L\,T_r$$

$$= 290 + 75^{\circ} + 454^{\circ}$$

$$\cong 820^{\circ}$$

the mobile can be accommodated via the earth coverage antenna. This could result in a satellite transponder simplification. On the other hand, if transmission is via spot beams, higher quality and/or higher data rates are easily achievable.

2.1.2 Relationship of Antenna Coverage to Access

When spot beams are used for satellite to mobile access, several factors must be taken into account which are dependent upon the specific satellite design. These are as follows:

1. The minimum and maximum number of channels which can be switched into any beam.
2. The ability to switch any particular channel to any spot beam.
3. Channel switching speed.
4. The ability for switching total power from beam to beam.
5. Synchronization of satellite switching with channel transmission
6. Provision for lock-on and acquisition each time a channel is switched.

These affect channel management procedures and queueing algorithms and are discussed in conjunction with each access scheme.

2.1.3 Channel Bandwidth

The satellite channel bandwidths are more than sufficient to accommodate any of the modulation and/or access schemes being considered. In particular, TDM schemes proposed are not constrained by satellite bandwidth.

2.1.4 Independent Surveillance

Independent surveillance in the AEROSAT system is provided by the 2R+h method in which ranging signals are sent up via one satellite to all aircraft and returned from each aircraft via two satellites. Replies are transmitted from an aircraft whenever it is so addressed and contain the altitude information in conjunction with the surveillance signal reply. The interrogation signal emanates from a single ASET while the replies can be received by all the ASET's in the system. In general, a minimum of 120 interrogations per minute are required. The position location computations are made in the ASCC and supplied to the various ATCC's for their use in traffic control.

2.1.5 Ground-to-Ground Channels

The drain on satellite power for ground-to-ground channels is small. Two simplex channels per satellite are provided and these are available for the transfer of information among the AEROSAT ground facilities as required for overall channel management.

2.1.6 Eclipse Operation

The AEROSAT satellites are positioned such that only one satellite is eclipsed at a time during the seasons when eclipses occur. When an eclipse occurs, the G-A channels provided by the eclipsed satellite are removed from the system. On the other hand, the ground-to-ground channels remain in operation along with at least half of the air-to-ground channels.

2.1.7 Ground Facilities

The ground facilities are assumed similar to those described in the AEROSAT specification. The main facilities, which are treated as functionally separate, are:

1. Satellite Control Facility (SCF)
2. Aeronautical Services Earth Terminal (ASET)
3. Aeronautical Satellite Communications Center (ASCC)
4. Air Traffic Control Center (ATCC)
5. Company Message Centers

The satellite control facility is concerned with the satellite housekeeping functions. There is one facility per ocean. It interconnects with the ASCC via terrestrial or satellite ground-to-ground links to execute channel and power switching commands.

The ASET provides the communications link to and from the satellites. It contains all the RF hardware and all modems. It receives and transmits baseband voice and data from the ASCC. The particular frequency and/or satellite corresponding to a voice or data channel are selected based on control signals received from the ASCC. An ASET is always associated with an ASCC.

Depending on the signal structure used for surveillance, the digital range associated with each mobile is generated in the ASET and supplied to the ASCC for position location.

The ASCC is the focal point for the control and management of the communications network. It operates as either a Master ASCC or as a local ASCC. In the former case it can, depending on the particular access system, allocate voice and data channels to the other centers for their individual management. Some of the functions of an ASCC are:

1. Receive voice and data channel requests from mobiles and ground centers connected to it.
2. Set up queues.
3. Format the digital data stream for transmission.
4. Designate channels as either voice or data.
5. Transmit channel grants
6. Interface with SCF for channel and power switching.
7. Distribute all G-A and A-G message traffic.
8. Set up polling sequences.
9. Perform position location computation and transmit information to appropriate centers.
10. Interface with traffic control centers and company facilities for communications interconnection with mobiles.

There is a maximum of four ASCC's per ocean. Each ASCC is connected via ground link to a number of oceanic air traffic control centers and company facilities. All message traffic and channel requests from these centers flow through the ASCC.

The ATCC center performs the traffic control function and is considered in this study only to the extent of obtaining the communications services required for its task. The ATCC makes channel requests and receives messages from the mobiles it is controlling. It furnishes the ASCC with the aircraft address and the polling rate desired upon initial entry and then communicates as necessary by means of voice or data channels furnished by the ASCC.

The company message center is similarly a recipient of communications services which are provided via the ASCC.

An overall block diagram of the AEROSAT system is shown in Figure 2-1.

2.2 Communications Service Requirements

2.2.1 General

An important consideration in the selection of system access techniques is the type and quality of service which the AEROSAT system is to provide. The types of communications are voice, data and independent surveillance. The latter is considered as a separate communications service since a unique signal is involved. Dependent surveillance, on the other hand, is provided by either the voice or data transmissions. Each of the communications services is discussed below.

2.2.2 Voice Communication

Full duplex voice communications are provided between a controller and any aircraft under his control, and between a company office and any of its aircraft. Public correspondence is not included in this system.

BASELINE AEROSAT CONFIGURATION

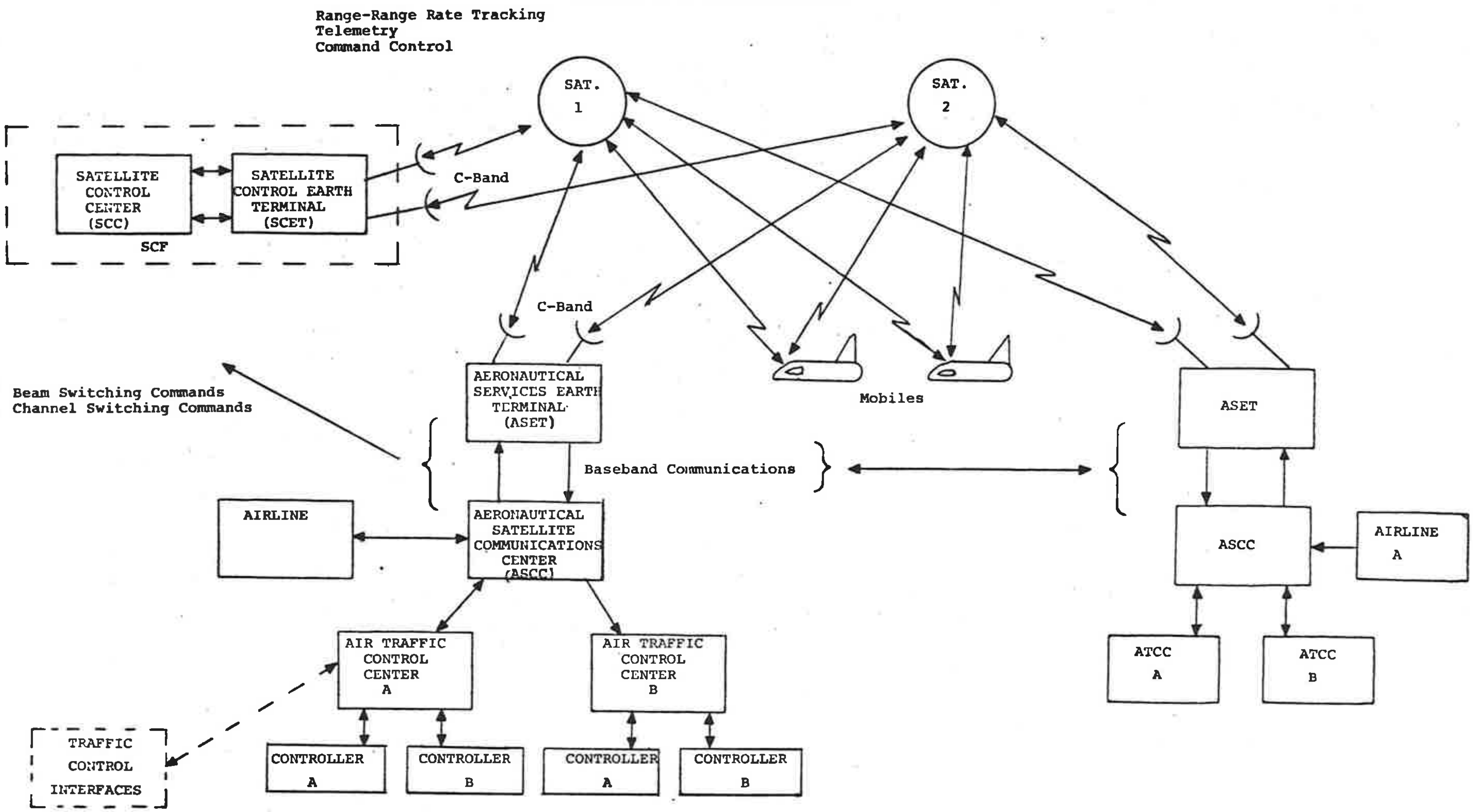


FIGURE 2-1.

For the systems studied, access is required from any controller or company office to aircraft located anywhere over the oceanic area of coverage. Similarly, each aircraft must be capable of establishing direct voice communciations with a controller or company office regardless of where located. More specifically, in the AEROSAT system, it is desired that any ASET/ASCC be capable of voice communications to aircraft located in any of the spot beams used to provide oceanic coverage.

Included in the above is the capability for voice broadcast transmissions to a group of aircraft in a given area. However, monitoring of transmission from other aircraft is not possible in a satellite system unless special provisions are made.

The methods and procedures used for "calling" from either the ground or air and the methods and procedures for assigning channels are a function of the various access systems concepts studied and are described in subsequent sections of this report.

The delay associated with obtaining access is one measure of the grade-of-service provided. It is a function of the number of channels available, the magnitude of the message traffic and the system organization. It is also a function of whether the channel request is air or ground initiated.

Ground requests will normally be funnelled to an ASCC having channel control via either a terrestrial link or a satellite G-G link. Because there are only a relatively small number of ground users, it is anticipated that the delay associated with this part of the request will be minimal (less than 1 second including propagation delays). The major part of the delay will, therefore, be due to any queues which are set up. In view of the relatively short voice messages normally associated with air traffic control, an average queueing delay equal to the average message length is considered to be a reasonable delay requirement for the AEROSAT system. This amounts to an average waiting time of 30 to 60 seconds.

For air initiated requests, the wait-time due to queues will be the same as that described above. However, in addition there will be delays associated with the procedure used for transmitting airborne requests. For example, when a polling system is used, each aircraft must wait for his turn in the poll to signal a request. Therefore, the total wait time equals the queueing time plus the average wait time in the poll.

A distinction must be made between the time for completing a connection and the acknowledgement of a request. Although a relatively long wait may be satisfactory for obtaining access to a voice channel, it is desirable that an aircraft be advised as rapidly as possible that his request has been received and that he has been placed in the queue. For purposes of this study, a maximum delay equal in time to the polling epoch, which may be on the order of 2 to 3 minutes, is considered satisfactory for request acknowledgement. Otherwise, a channel grant and assignment is transmitted as soon as a channel is available.

Waiting times which are satisfactory for routine message traffic are not acceptable for messages with high priority. For emergency communciations, "zero-access delay" is a goal. Therefore, for all systems considered, a means for rapid access to a voice channel is provided.

2.2.3 Data Communications

The standard for digital data transmission which has been selected for AEROSAT is a bit error probability of 10^{-5}. Based on this and on the assumption of the use of a modulation technique such as DPSK, a 43 db-Hz AEROSAT channel can accommodate any bit-rate equal to or less than 1200 bits/second. This is the rate which is used in the study, although it should be noted that channels and/or units of satellite power can be combined to allow higher bit rates. Simultaneous two-way transmission can be accommodated in the data channels. The format for the data transmission is generally in conformance with that being proposed for the Universal Digital Data Link.

The characteristics of data message transmission are sufficiently different from those of voice transmission that different criteria are used for evaluating grade-of-service.

The Universal Digital Data Link is highly organized. It is an addressed system under computer control. Data transfer, whether G-A or A-G is always initiated from the ground.

Ground generated messages are handled at each ASCC on a store and forward basis as received from multiple sources so that efficient continuous G-A transmission can be effected. Included in this transmission are messages generated by the computer requesting automatic readout of various airborne devices.

All messages contain bit check sequences for error detection and every data transfer, G-A or A-G, must be followed by an ACK/NAK reply. Messages are repeated in response to NAK. Because of the organization of the data stream, access in the sense of a direct connection between a company or controller and an aircraft is normally not provided. However, all systems access concepts studied provide a means for transmitting data to any aircraft from any ground terminal and receiving data from any aircraft to any ground terminal.

Queueing time is not a meaningful parameter for data messages. A delay which is long in terms of average message length is still short when measured in real time and is short when compared to the time for manual message preparation. Since readouts from automatic data readout devices are automatically programmed by the ground computer, the primary system delay factor is associated with airborne requests for transmission of manually inputted data messages. This is a function of the system design and in a polled system can be a maximum delay equal to the epoch time.

2.2.4 Surveillance

There are two types of surveillance services which can be provided by the AEROSAT system. Dependent surveillance is defined as the reporting of position location based on ownship navigation sensors. Either voice or data channels are used for this type of reporting. Independent surveillance is a new oceanic service which a satellite system can provide. It is based on the 2R+h technique in which ranging signals are sent up via one satellite to all aircraft in the system and returned from each aircraft via two satellites. Replies are transmitted from an aircraft whenever it is so addressed and must contain the altitude information in conjunction with the surveillance signal reply. Based on this raw information, position location computations are made in the ASCC and supplied to the various ATCC's for their use.

An rms two-way ranging accuracy of 150 meters with a maximum of 500 milliseconds observation time is the system requirement. The update rate is a function of aircraft location and general traffic conditions. Provision is included in the system for polling under computer control at a rate specified by the ATCC controller. In general, most aircraft are polled once every two or three minutes while a small percentage are polled at about five times that rate.

2.3 Mobile Users

All equipped aircraft entering the oceanic area will be provided the communications services described above. They will be handed-off to an oceanic control center which will in turn feed a pertinent data file to the appropriate ASCC. This might include such items as aircraft address, controller identity, company identity and required polling rate. The pilot will turn on his equipment and select channels as instructed by the hand-off controller. It is expected that the instantaneous airborne count over the Atlantic Ocean may reach in excess of 500 aircraft during the mid 1980's.

In addition to the normal entry as described above, provision is made for random or pop-up entry. This is an infrequent occurrance in which an aircraft enters controlled oceanic airspace in mid-ocean. On the assumption that such aircraft are equipped with suitable hardware, means are provided in the access techniques studied for handling such unorthodox entry.

2.4 Message Characteristics

To get a better understanding of the nature of the oceanic message traffic, the literature was reviewed to determine types of messages anticipated in the 1980's including their frequencies and priorities. It is borne in mind that these are estimated and are subject to wide variation. It is also anticipated that when an oceanic communications capability is available many additional types of messages such as passenger lists, and reservation requests may be transmitted. However, the tabulations obtained serve as input parameters for queueing simulation, data-link optimization and in formulating channel management procedures.

2.4.1 General Message Categories

Table 2-2 is a tabulation of message categories and is an amalgamation of information from three references (Refs. 1, 2, 3) with a few reasonable adjustments. The message categories have been listed as suggested by Reference 4. The message categories are mostly self-explanatory. Emergency messages include collision reports, faulty engine reports or solar flare warnings. Collision precaution messages are self-explanatory. Urgent clearance change messages include resolution of ambiguities and errors or urgent weather advisories. Urgent company messages might include the resolution of aircraft in-flight mechanical problems or urgent messages regarding aircraft servicing upon landing.

TABLE 2-2

MESSAGE LOADING

MESSAGE CATEGORY	PRIORITY	CHANNEL TYPE	DOMINANT DIRECTION	AVE. CONTACT DURATION VOICE	BITS/MESS DATA	ESTIMATED MESSAGES/ FLIGHT
Aircraft Messages			A-G			
Emergency	1	Voice/Data		Open	Open	1/7 R
Clearance Change Req.	3	Data			100	1 R
Routine Reports	3	Data			225	4 P
Met	3	Data			200	1 R
ATC Advisories & Messages			G-A			
Collision Precaution	2	Voice		30 Sec.		1 R
Clearance Changes						
Urgent	2	Voice		30 Sec.		2/3 R
Routine	3	Data			60	1.5 P
Vectoring Messages	2	Data			60	1.5 P
Airport Status	3	Data			100	1/16 R
Met	3	Data			200	12 P
Company Messages						
Urgent	2	Voice	G-A;A-G	20 Sec.		1/2 R
Routine	4	Data	G-A;A-G		325	5 P

R = Random
P = Periodic

Priority 1 messages preempt all other messages and are associated with emergency situations. Both voice and data transmissions are required. Priority 2 messages may be urgent company information, vectoring messages or aircraft advisories. Priority 3 messages may be Route Change Requests or Weather Advisories while Category 4 are General Company information messages. Factors to be noted are that messages are of several finite lengths and that some occur randomly while others are transmitted periodically. Most of the parameters such as message duration and number of accesses per crossing are very conservatively estimated. They are treated as parameters for the study. The dominant direction indicates where the access might originate although all messages usually require transmissions in both directions.

Other types of messages not listed above and not used in present operation have been listed in the minutes of the Seventh Air Navigation Conference[32] and could become a requirement of an oceanic system. These are:

1. Seat Occupancy, Flight Connections; 6400 bits, 2 messages per flight leg.
2. Immigration, Public Health and Customs; Variable length, 1 per flight.
3. Ground Service Reservations; 720 bits, variable per flight.
4. Passenger Communications; 720 bits, 10 messages per flight.

These are all data messages and their inclusion as part of the total message traffic affects the design of data-link parameters such as maximum message length and number of data channels required. These messages are generally of low priority.

The total message traffic to be handled by the system will be a function of the number of aircraft in the air at a given time. This generally has a diurnal as well as seasonal variation. The communication system must operate within satisfactory limits during the peak periods and, therefore, the analysis is primarily concerned with the high traffic density situation. It should be noted that the total message traffic may increase faster than the total aircraft traffic. This is because many more ATC messages are required when there are more aircraft in the air at a given time and separation distances are reduced.

Another question of importance is whether a high traffic situation can occur during an eclipse. Appendix A shows that the eclipse time for a satellite stationed near 60^{o}W longitude occurs very near one of the peak busy periods of the day.

2.4.2 All Voice Communications - 1980

If one assumes that the satellite channels in 1980 are all voice, an estimate can be made of message loading and communications capacity for such an expected communication load in 1980.

Dunmire, in Reference 1, estimates the 1980 loading based on present procedures but modified to account for independent surveillance. He envisions 3 types of pilot-controller messages which are:

- Type A: Random request for, or instructions pertaining to, change of flight level or route.
- Type B: ATC notification of position deviations.
- Type C: All other miscellaneous pilot/controller exchanges such as ad hoc weather, frequency assignment, confirmation of flight status.

Dunmire also assumes that certain messages which are now a part of the AIREP report will continue to be communicated on other than satellite channels. The three message types are basically only ATC messages. The word count for these messages estimated by Dunmire are:

Type A: - 1207 word/hr

Type B: - 1196 word/hr

Type C: - 3332 word/hr

It is interesting to compare the word rate assumed by Dunmire to the rate assumed by Boeing (Reference 3) for the three ATC message types. Table 2-3 shows the comparison.

TABLE 2-3

WORD RATE COMPARISON

MESSAGE TYPE	WORD/HR (BOEING)	WORD/HR (DUNMIRE)	RATIO
A	3010	1207	2.5
B	2150	1196	1.8
C	6730	3332	2.02

From Table 2-3, the word rates assumed by Boeing are double those of Dunmire for these message types. This inconsistency coupled with the fact that Dunmire does not include emergency type messages in his word rates shows the wide discrepancy in the message loading forecasts that can be obtained between two sources. For a baseline voice only system, the more pessimistic (higher) word rates are used.

Table 2-4 lists the voice message loading assumed.

During the transition period when experimental or a limited usage of a digital channel would be available various message types are likely candidates for testing the digital system. These message types include general company information, position reports and flight plan data. Later, as experience is gained in the use of data channels, messages normally transmitted by voice would be converted to a digital format. An order of logical conversion would be: (1) Routine weather advisory messages, (2) Route change requests, (3) Vectoring messages, and (4) ATC clearance control.

TABLE 2-4

BASELINE VOICE SYSTEM MESSAGE LOADING

MESSAGE TYPE	PRIORITY	DURATION (SEC)	MESSAGES/FLIGHT
Emergency	1	Open	1/14
Coll. Avoid.	2	30	1/2
Urgent ATC	2	30	1/3
Urgent Company	2	20	1/4
Aircraft Status	3	30	5
ATC Clearance	3	10	1.5
Vectoring	3	10	1.5
Route Change	4	20	1
Weather Advis.	4	10	4

3.0 SYSTEM ACCESS CONTROL CONCEPTS

3.1 Multiple Access Concepts and Definitions

3.1.1 General

The AEROSAT system is characterized by a large number of airborne users each requiring low duty cycle use of the satellite for communications via one of the ASCC/ASET terminals. The satellite power limitations, however, permit simultaneous use by only a limited number of aircraft at any given time.

There are two aspects involved in the system design. One is the modulation technique which allows simultaneous access to the satellite repeater. The other is the system management design and concerns the method of assigning channels to the aircraft and ASCC's, the type and quantity of message traffic carried by each, and the particular signalling waveforms chosen. In this section, the basic techniques for simultaneous access and channel allocation as they pertain to the AEROSAT system are discussed.

The techniques for multiple access to a satellite repeater have been widely discussed in the literature[5, 6, 7], where the term "multiple-access" is generally applied to the mixing of the RF signals at the satellite. (In contrast, the term "multiplex" applies to the mixing of signals at the baseband frequency.)

The purpose of the multiple-access modulation is to make possible separate reception of each message by any user with as little interference as possible from any other user simultaneously transmitting through the satellite. Three types of multiple access have been identified as follows.

In a frequency-division multiple-access system (FDMA), the available frequency spectrum is divided into discrete channels. During some interval of time, a particular ground terminal and aircraft have exclusive use of one of these channels.

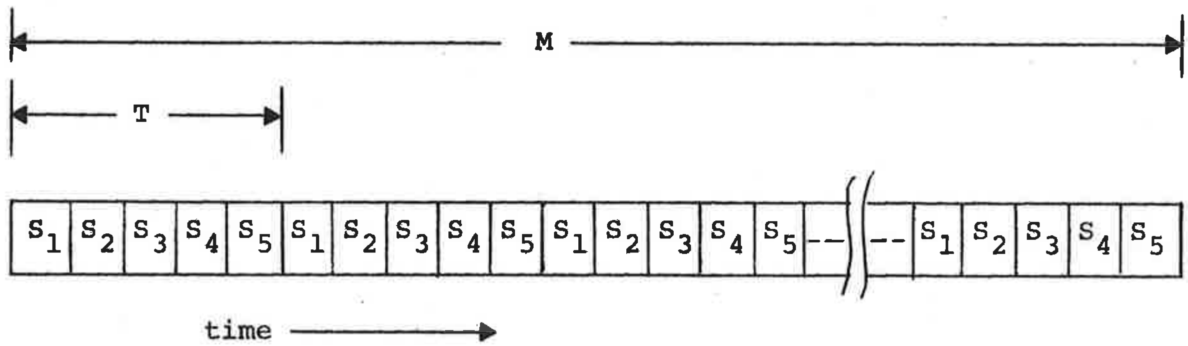
In a time-division multiple-access system (TDMA), as shown in Figure 3-1, each interval of time T seconds long is subdivided into discrete time slots. During a length of time equal to the duration of a message one or more specific time slots per frame are for the exclusive use of a ground terminal and aircraft. In a code division system (CDMA), a channel is characterized by a wideband coded signalling waveform which is assigned to a pair of users. The latter technique includes spread-spectrum multiple access and pulse address multiple access.

3.1.2 Frequency Division Multiple Access

Use of distinct frequency bands as a means for separating channels is a conventional and known communications practice. In AEROSAT a channel is used for a single carrier modulated by voice, data or surveillance signals and is associated with a particular frequency. However, certain complications arise in the power limited G-A direction, where to enhance satellite amplifier efficiency, signals are mixed in a hard-limiting repeater. The signals interact to cause intermodulation noise. Because of this, it is necessary to space the channels so that, effectively, all the noise falls outside the signal bands. Nevertheless, the out-of-band noise subtracts from the satellite output power available. The magnitude of this power loss has been calculated and tabulated for various combinations of equal level signals as a function of input signal-to-noise ratio. The results are tabulated in Appendix B, where it is shown that for the high signal-to-noise ratios expected the loss amounts to slightly over 1 db.

The above analysis assumed equal strength signals at the input. Otherwise, there is additional suppression of the weaker signal. However, since the signals in the G-A direction emanate from at most 4 ASETS, there would not appear to be any difficulty in maintaining power control.

In AEROSAT where operation to different parts of the ocean is via spot beams, up and downlink channel



T = Frame Time

M = Message Time

FIGURE 3-1. TIME DIVISION MULTIPLE ACCESS assignments requires coordination with satellite switching commands. However, these assignments are on a relatively long term basis so that timing is not critical. Channels operate in different spot beams simultaneously and are identified by their separate frequencies.

Transmission from the satellite to the ground requires relatively little of the available satellite power. Therefore, operation can be maintained nearly linear in the A-G direction resulting in negligible channel interaction. This factor, in conjunction with the low power drain, permits many more FDM channels to be available in A-G than G-A.

The major advantage of FDMA for the AEROSAT application is the compatibility of the system with any of the modulation techniques for voice, data or surveillance currently being investigated. Section 4.0 discusses the way in which FDMA systems can be organized to provide various combinations of AEROSAT services.

3.1.3 Time Division Multiple Access

In TDMA,[9,10] transmissions through the satellite from multiple sources do not overlap. A channel in this case consists of a particular time slot within a larger time frame.

A message signal, voice or data, is sampled periodically and transmitted at a high rate during the channel time slot. Transmissions from all terminals are at the same frequency. Digital modulation techniques are implied for all signals. There is no interaction between channels and all the satellite power is available to each channel on a sequential basis. The power amplifier can be operated at maximum efficiency with no intermods.

To remain within a particular channel slot each transmitter must be synchronized to the satellite time frame corrected for transmission delay. This is accomplished relatively easily by the ASET's in the G-A direction using fairly standard techniques. The ASET is required to monitor the L-band transmission to observe and time-correct one's own signal at the satellite output.

In systems tested to date this is achieved to an accuracy of 5-10 bits. However, carrier or bit sync is usually not implemented. Therefore, each transmission contains guard band to prevent overlap and a preamble signal for lock up.

Despite the fact that all the satellite power is available for each channel, the high rate of transmission necessitates use of spot beams to achieve the required signal quality. Therefore, to provide full oceanic coverage the satellite L-band transmission must be switched to the appropriate spot beam in synchronism with the generation of time slots corresponding to the location of the aircraft requiring service.

There are two main choices to be made in a TDMA system. These are the time frame length and the channel time within the frame. A great deal of freedom is available with the choices dependent on system and hardware considerations. For a fixed number of channels, long frame times lead to long burst lengths with attendant large intermediate storage capability. Short frame times impose synchronization complexities and loss of efficiency because the preamble duration remains constant. However, the storage requirements are simplified. In the limit the channel width can be shortened to equal the width of one bit. The transmission then becomes a time-division multiplex with the capability of real time transmission. For multiple access it would require complete carrier and bit synchronization and is not considered practical.

However, a TDM system with channels multiplexed at baseband can be used to take advantage of the single frequency operation and the good characteristics of the satellite power amplifier. Such operation is feasible for AEROSAT because there are two satellites available and relatively few ground terminals. Some possible systems are described in Section 5.

To use TDMA in the A-G direction requires that time synchronization be accomplished and maintained in each aircraft. However, the aircraft cannot monitor its own signal as it emanates from the satellite since there is a frequency change in the satellite from L to C band. The aircraft does not normally have a C-band receiver. Therefore, information for synchronization must be computed on the ground and supplied to each aircraft based on known or measured aircraft location. Secondly, the inherent duty cycle of TDMA implies high peak power and airborne transmitters consistent with this must be used.

The main advantage of TDMA is the absence of mutual interference between channels with the resulting power losses to intermod products. However, some inefficiency does arise from the guard times that must be provided between adjacent slots and the preamble that is inserted at the beginning of each burst for carrier acquisition and synchronization. At AEROSAT power levels and bit rates this amounts to about 3-5 percent or 0.5 - 0.7 db. Section 5.0 discusses organization of a baseline TDMA system for AEROSAT application.

3.1.4 Code Division Multiple Access

In CDMA the channel is defined by a particular wide-band signal structure which occupies the entire repeater bandwidth. The signal structure used for the multiple access modulation is either a psuedonoise or frequency hopping code which causes the transmitted signal to occupy a bandwidth much wider than that of the information being transmitted. All signals up to the maximum allowed are transmitted simultaneously and share the satellite power. The aircraft receiver employs a copy of the multiple access code to separate the desired signal from the complex signal structure.

The main advantage of CDMA is that minimal coordination and organization is required when the codes are associated with fixed addressed assignments. However, because of its increased complexity, the need for synchronization between transmitter and receiver, the requirement for splitting the satellite power among spot beams, and general lack of usage in commercial systems, CDMA has not been considered for a first generation AEROSAT application and is therefore not discussed any further.

3.2 Channel Management Concepts

3.2.1 General

An important aspect of system access control is the management discipline formulated for channel control. These are, in general, independent of the multiple access technique although some concepts may provide for more efficient operation in one than another. The particular types of channel control concepts applicable to AEROSAT are a function of the types of communications services provided, the number of airborne users and the number of ground terminals and their location. Channel control involves channel assignment and allocation and a means for calling or addressing. In this section various concepts are described and the types of services to which they are applicable are presented.

3.2.2 Seize When Available

A seize-when-available channel discipline applies to voice channels and implies operation similar to that currently in use over Continental United States. Each voice channel is preassigned to one or more controllers at an ATCC associated with a particular ASET/ASCC. Additionally, in AEROSAT, the channel coverage area is that defined by a particular spot beam. A group of aircraft in that area of the ocean continuously monitor that channel based on instructions received upon system entry. In a similar manner, voice channels can be assigned for company usage with the same rules relative to spot beam and aircraft monitoring. By monitoring the channel, an aircraft user is aware of when the downlink is not in use and originates a conversation on a seize-when-available basis. Assignments to controllers are made by the master ASCC and can be changed on an hourly, daily or monthly basis as the need requires.

Because of the frequency translation within the satellite, the aircraft user would not normally be able to monitor conversations emanating from other aircraft. He would not, therefore, know positively when the channel is unoccupied. To overcome this, all aircraft transmissions received at the ASET over the downlink could be retransmitted over the uplink, provided that the controller is not using the link at that instant. Thus, all transmissions, those originating at the controller, as well as those originating at an aircraft in that control area, are available for reception and monitoring at all aircraft.

Another method for advising the aircraft operator of the availability of a channel is to transmit a subaudible tone over the uplink when the downlink is in use (that is, when a carrier is detected on the downlink frequency), rather than to retransmit the voice signal itself. This tone, or another suitable code, can be used to operate a light in the cockpit. Operationally, this system is similar except that the aircraft operator cannot hear messages originating at other aircraft. He must still monitor the G-A transmissions to detect ring ups.

Channel organization and control on a seize-when-available basis is based on operator discipline and verbal instructions from the controller. It works well when the channel has about a 50%-60% occupancy or utilization giving an average waiting time of about 1-1.5 conversation lengths.

In summary, a seize-when-available system provides negligible intermediate control and is applicable to those cases where channels can be preassigned to specific ground terminals and specific spot beams. No queueing control is provided and calling and/or channel changes are handled by verbal transactions.

Emergency access and pop-ups are handled the same as ordinary transactions unless special provisions are made. The latter could include an emergency switch which generates a tone or other suitable emergency code which is transmitted on the same channel. This signal would get through to the controller whenever there is a break in aircraft transmission.

Another approach for providing emergency channel access is to take advantage of the fact that more channels can be provided from aircraft to ground. An extra channel from aircraft to ground is designated as an emergency calling channel, and is then always available for emergency use.

3.2.3 Selcal

To avoid the necessity for the aircraft continuously monitoring all conversations on a voice channel, Selcal is introduced into the uplink transmission.

Selcal typically is a selective calling technique which makes use of an audio tone coder on the ground and an audio tone decoder in the air. In one system thirty-six tones have been allocated, of which 12 are currently in use. The code consists of a sequence of tone pairs; that is, two tones are sent simultaneously, followed by a pause, followed by the next pair of tones. Activation of a Selcal decoder initiates a light on the cockpit panel or audio signal. Each Selcal code is unique, usually assigned to an aircraft by tail number or flight number. Other types of codes including subaudible tones might also be used. However, it is assumed that it is incorporated into the voice channel. The ground controller initiates a conversation with a particular aircraft by transmitting the appropriate code. However, the aircraft user initiates a conversation on a seize-when-available basis as described in the previous section and the allowable utilization is about the same. Pre-assignment or dedication of channels is implied.

3.2.4 In-Band Signalling

3.2.4.1 Pre-Assigned Channels

Selcal as described above is a form of in-band signalling. However, it only operates one way with the same difficulties as the seize-when-available scheme for a pilot initiating a conversation as the traffic density increases. A more effective means for the pilot to initiate a contact is accomplished by providing a Selcal (or signalling) system on the downlink as well as the uplink. To initiate a contact, the pilot throws a switch which transmits that aircraft's unique coded sequence over the downlink as soon as the downlink is not in use. In general, the downlink would not be in use when the controller is talking or the channel is idle. The code, when received on the ground, will operate a suitable display, which alerts the controller to the fact that a particular aircraft pilot wants to initiate a contact. The controller could then set up a queue for the channel so that airborne requests are handled in an orderly manner.

This extension of the simple Selcal system will materially alleviate the problem of initiating air to ground contact under conditions of high traffic density. There are several operational factors which must be considered. These are:

a. Acknowledgement - It is desirable to notify the pilot within some reasonable time that his request has been received. The G-A Selcal can be modified to include this capability.

b. Priority Access - The use of a coded Selcal system allows the pilot to indicate that he has an emergency or urgent message. Thus, other aircraft in the queue can be preempted.

The advantages of the use of two-way calling signals are that the pilot does not have to continuously monitor the channel and that airborne requests are processed in orderly manner. However, as long as only one channel is involved the allowable utilization remains the same. Nevertheless, two-way calling permits other channel disciplines to be implemented. These are discussed below.

3.2.4.2 Communications Center Control

The previous discussion assumed assignment of channels to specific controllers with address capability in the G-A direction. By extending the capability of the A-G Selcal to include ground addressing the channel can now be shared by more than one ground user. Control is transferred to the ASCC which manages the queues. Ground users, which may include controllers or company offices, request access to the channel from the ASCC. When an airborne request is transmitted, the ground addressee is included. This added complexity provides some additional flexibility to the system but does not increase the allowable channel utilization.

Overall control is maintained by the ASCC, but such items as new channel assignments are handled verbally by the controller.

3.2.4.3 Use of Multiple Channels

To increase the allowable channel utilization, while keeping the average waiting time constant, more channels are assigned to the ASCC for control. The aircraft within a given spot beam are required to monitor all assigned channels to permit receiving calls by means of Selcal on any open channel. In a TDMA system, it means monitoring more than one time slot while in a FDMA system it means monitoring several frequency channels. Calling from A-G could be accomplished as before using any of the channels being monitored. The A-G calling message must contain the addressee as well as the message priority.

The availability of channel control by the ASCC permits connecting airborne users to ground terminals which interface with other ASCC's. A link can be established by a temporary reassignment of a channel by the ASCC having control.

3.2.5 Data Channel Management

Data and voice channel operation differ quite widely because of the amount of information which a data channel can transmit per unit time. There is also a large amount of automaticity inherent in the handling of digital data. The standard Universal Digital Data Link Format such as described in ARINC Project Paper 586"Air-Ground-Air Data Link System,"[11] is basically self-managing. This format provides for aircraft addressing, message error checking, and ACK/NAK. It provides provision for G-A polling for readout from automatic data readout (ADR) devices. G-A messages are normally received from various sources where they are held on a store and forward basis and formatted under computer control into an uplink data stream. In AEROSAT is is a function of an ASCC. The data stream addresses the various aircraft assigned to the channel with the following types of messages.

a. ATC or company messages
b. Request for automatic readout of data
c. Poll for receipt of various airborne messages or message requests.

Transmission A-G takes place only in response to a G-A poll and each transmission of message text whether G-A or A-G is followed by an ACK/NAK message.

Data link channel management for the AEROSAT system is concerned with designation of available communication channels as data channels, assignment to centers, and organization of messages to maximize channel efficiency. The latter is concerned with simultaneous transmission and reception and choice between use of fixed block length messages or variable length messages. This is analyzed and discussed in greater detail in Section 4.0.

It should be noted that when both voice and digital data service is provided simultaneously, the volume of voice traffic drops considerably. In addition, advantage can be taken of the channel management capability which has been included in the mode and label format of the Universal Digital Data Link.

When both voice and data service are provided the data link channel can be used for voice channel accessing and assignment. In this case no calling signals are required in the voice channels nor is voice channel monitoring required.

3.2.6 Accessing by Means of Supervisory Channel

It becomes apparent that in an AEROSAT system as the number of airborne users increase and the number of ground terminals increase, the magnitude of the channel management function also increases. It becomes practical to consider the use of a separate supervisory channel for the management function in contrast to the simple systems described above. By providing centralized management of all available channels in a given area from a single ASCC, the allowable utilization per channel can be increased and the waiting time decreased. Secondly, by using a separate channel for supervision, the available communications channels can be easily redesignated for use as either a voice or data channel without interrupting the channel management function. Signal design for voice and data can proceed independently of the management function.

Another consideration is the requirement for independent surveillance service. This is accomplished by means of range interrogations. It, therefore, is convenient to directly associate or combine the signal used for polling with the surveillance signal. The polling signal then emanates from the same location as the surveillance signal. In particular, this polling is combined with the polling required for channel management when both functions are controlled at the same center. Data link transmissions, on the other hand, can emanate independently from any of the ASCC's in use.

As part of the surveillance signal reply, it is necessary to transmit mobile altitude. This data can be included in the supervisory channel return link. There is, thus, established a close relationship between supervision and surveillance on both the up and downlinks.

When a supervisory channel is provided, the data channels are used on a demand assignment basis easily accommodating both long and short messages. If the data traffic is high, such that channel utilization is high, the use of a separate channel for supervision may eliminate the need for an extra data channel. Satellite power may be conserved if the power requirements for the supervisory channel are less than for a normal communications channel. An analysis of the supervisory channel information requirements which is described later indicates that a bit rate of 200-300 bits/second is more than adequate. Thus, about 1/4 unit of satellite power is required if transmitted on a spot beam.

On the other hand, the low power requirement may permit transmission on an earth coverage antenna. In this case, approximately one unit of satellite power is required. This allows communication via the supervisory link to all aircraft in the system from the Master ASCC. Delays due to beam or channel switching are eliminated. Provision for emergency and random entry can also be easily provided from anywhere in the coverage area via this channel.

The use of a separate supervisory channel thus has several advantages insofar as channel management is concerned. Its functions are summarized in Table 3-1. However, it does

TABLE 3-1

FUNCTIONS OF SUPERVISORY CHANNEL

GROUND-AIR

- Address Aircraft for Surveillance Polling
- Transmit Ring-up Signals
- Transmit Channel Grants
- Acknowledge Channel Requests
- Advise Channel Occupancy
- Transmit Channel Assignment
- Provide for Emergency and Pop-Up Entry

AIR-GROUND

- Entry into System
- Transmit Mobile Altitude
- Transmit Channel Requests
- Transmit Emergency Notification

require satellite power, and a separate modem in the avionics. Its use is described in more detail in conjunction with the systems descriptions of Sections 4.0 and 5.0.

3.2.7 Random Access Calling Channels

The previous section described the use of a supervisory channel for channel management. Use of this approach implied polling of all airborne users on a periodic basis to ascertain needs for channel assignment. Such polling can involve periods as long as 2-3 minutes. A technique for reducing delays in transmitting airborne channel requests is to make use of A-G random access calling channels. This is feasible for AEROSAT because of the relative inexpense in terms of satellite power of the A-G channels. However, it is necessary to determine the busy probability associated with such a channel.

If a Poissan distribution is assumed for channel requests, then the probability of n requests in time t is given by

$$P_n(t) = \frac{e^{-\lambda t}(\lambda t)^n}{n!}$$

where λ = average request rate.

The probability of 0 requests during time t is given by

$$P_0(t) = e^{-\lambda t}$$

The busy probability is the probability of one or more requests occurring during a time to equal to the duration of a request message. Thus,

$$P_B = 1 - e^{-\lambda T}$$

where T = request message duration.

For λT small, $P_B \approx \lambda T$

The probability of interference is a function of the request rate and the duration of the request message. For example, with 500 channel requests/hour corresponding to two requests/hour from each of 250 aircraft, and a message duration of 1 second, the probability of overlap is about 0.14. This is a busy hour type of situation and could be bothersome since the pilot has no way of knowing immediately whether or not his request has been received. Therefore, several such channels might be required. In any case, provision for request acknowledge and/or channel ring-up is required in the G-A direction.

For emergency access and pop-ups the request rate is orders of magnitude lower than in the example above. Hence, the probability of simultaneous access is negligible so that the use of this type of channel for these purposes is operationally very useful.

3.2.8 Channel Allocation-Central vs. Distributed Control

3.2.8.1 General

An important aspect of channel management is the strategy used for allocating channels to the various ASCC's in the system. The options which are available are a function of the management discipline, the satellite transponder design, the thruput complexity and the resulting queueing impact. Political factors may also be involved.

The primary question is whether all available channels should be centrally controlled, i.e., kept in a common pool by the master ASCC and assigned on demand or whether the channels should be allocated to the ASCC's in the system for their individual management.

The former approach is defined as central control in this report while the latter is defined as distributed control. However, a distinction must be made between voice channels and data channels. When discussing voice channel access it is assumed that a channel is assigned on a message-to-message basis based on queue status. For a data channel the messages are too

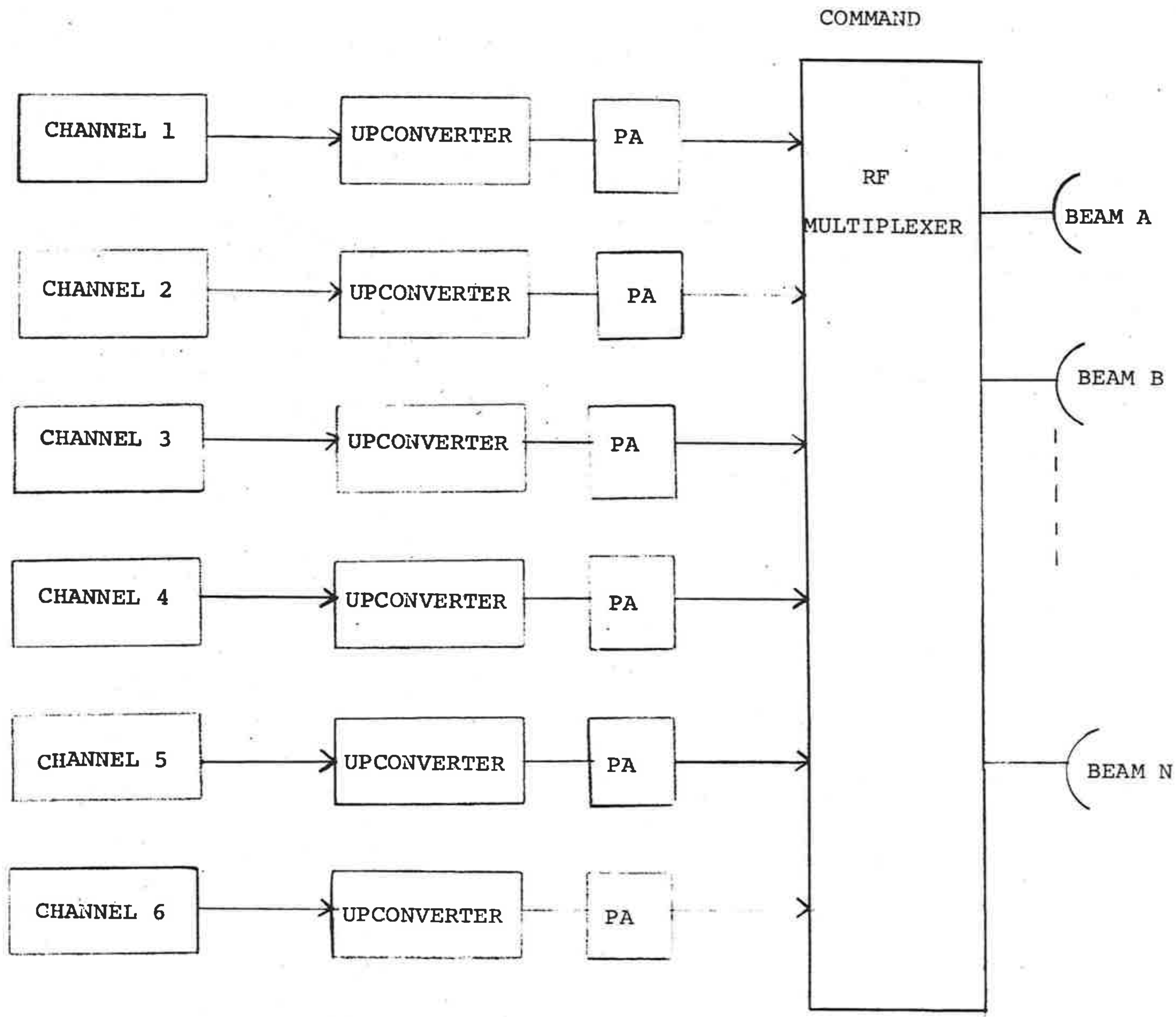


FIGURE 3-4. SIMPLIFIED TRANSPONDER BLOCK DIAGRAM
MONOCARRIER OPERATION

avionics simplicity considerations will normally monitor only one frequency in this system. Therefore, insofar as access is concerned the mobile user population as a minimum is split in two. Approximately half the aircraft are assigned to the channels associated with one satellite while the other half are assigned to those associated with the other satellite. If more than one frequency (or power amplifier) is used per satellite then a greater split of the mobile population is made. However, as with the FDMA systems discussed previously all ground terminals have access to all channels.

3.2.8.3 Effect of Management Discipline

The simple management disciplines described such as seize-when-available or Selcal are basically distributed control systems. Channels are assigned beforehand for small groups of users. When full services are supplied and a channel supervisory channel is used either central or distributed control can be implemented. For example, the use of a single supervisory channel controlled by the master ASCC lends itself to central control of the voice channels. On the other hand, if channels are allocated to various centers because of satellite constraints or political factors the ground-to-ground links can be used to transfer access requests received via the supervisory channel to the ASCC involved. On the other hand, separate calling channels associated with each ASCC lends itself to distributed control. Nevertheless, even with this arrangement, the ground-to-ground links can be used for implementation of a central channel control. There are different time delays associated with processing a message request for each implementation. These delays are primarily a combination of polling delays and G-G transmission delays.

For example, when a single supervisory channel is used with central control, the time required for polling all aircraft is in the order of 2-3 minutes. Hence, the delay in receiving an airborne request is relatively large. Furthermore, the G-G links must be used continuously to process requests and grants for users (ground and air) who interface with ASCC's other than the one controlling the supervisory channel. On the other hand,

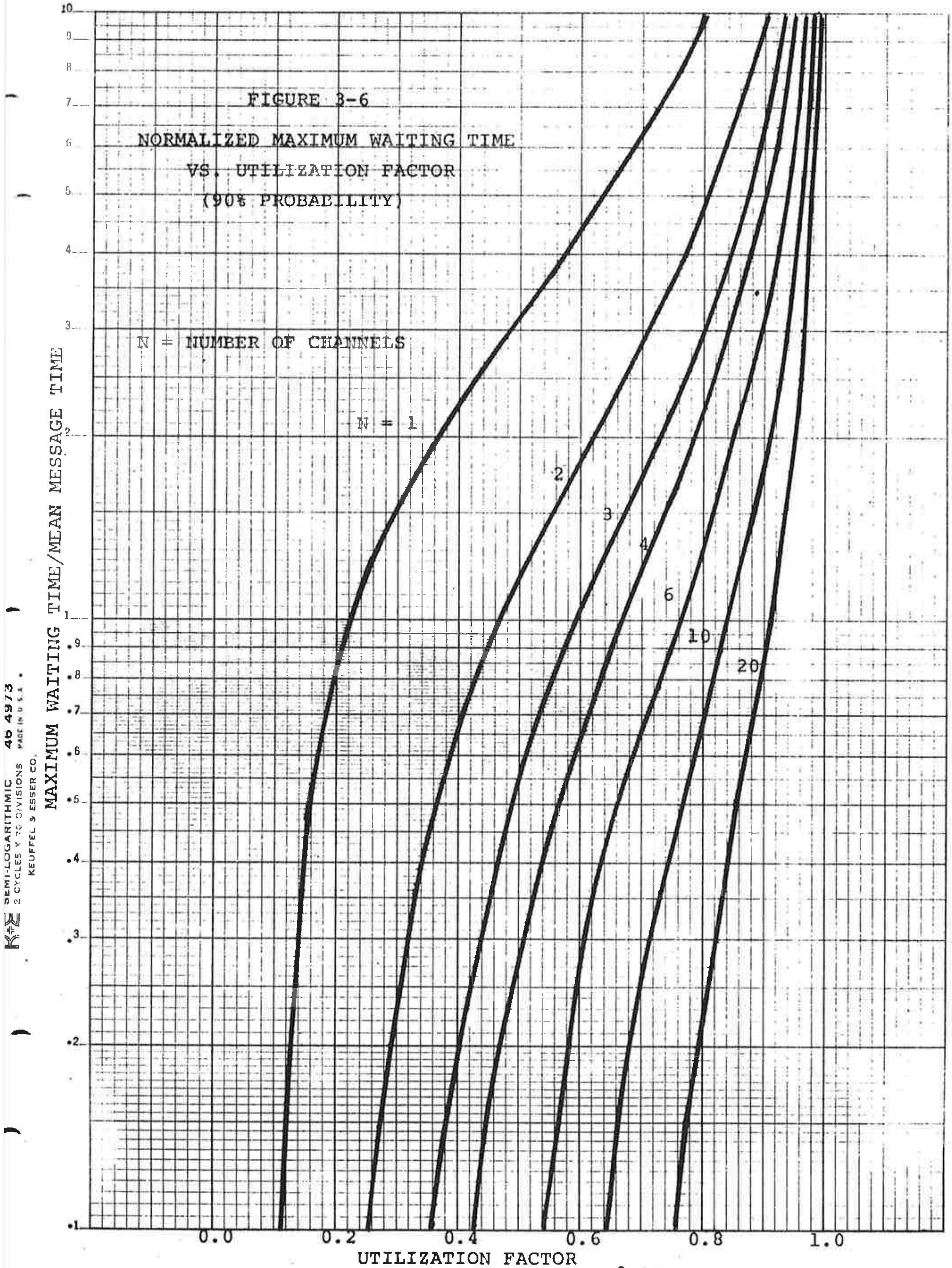


FIGURE 3-6
NORMALIZED MAXIMUM WAITING TIME
VS. UTILIZATION FACTOR
(90% PROBABILITY)
N = NUMBER OF CHANNELS
N = 1
2
3
4
6
10
20
MAXIMUM WAITING TIME/MEAN MESSAGE TIME
UTILIZATION FACTOR
0.0
0.2
0.4
0.6
0.8
1.0
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
SEMI-LOGARITHMIC 46 4973
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

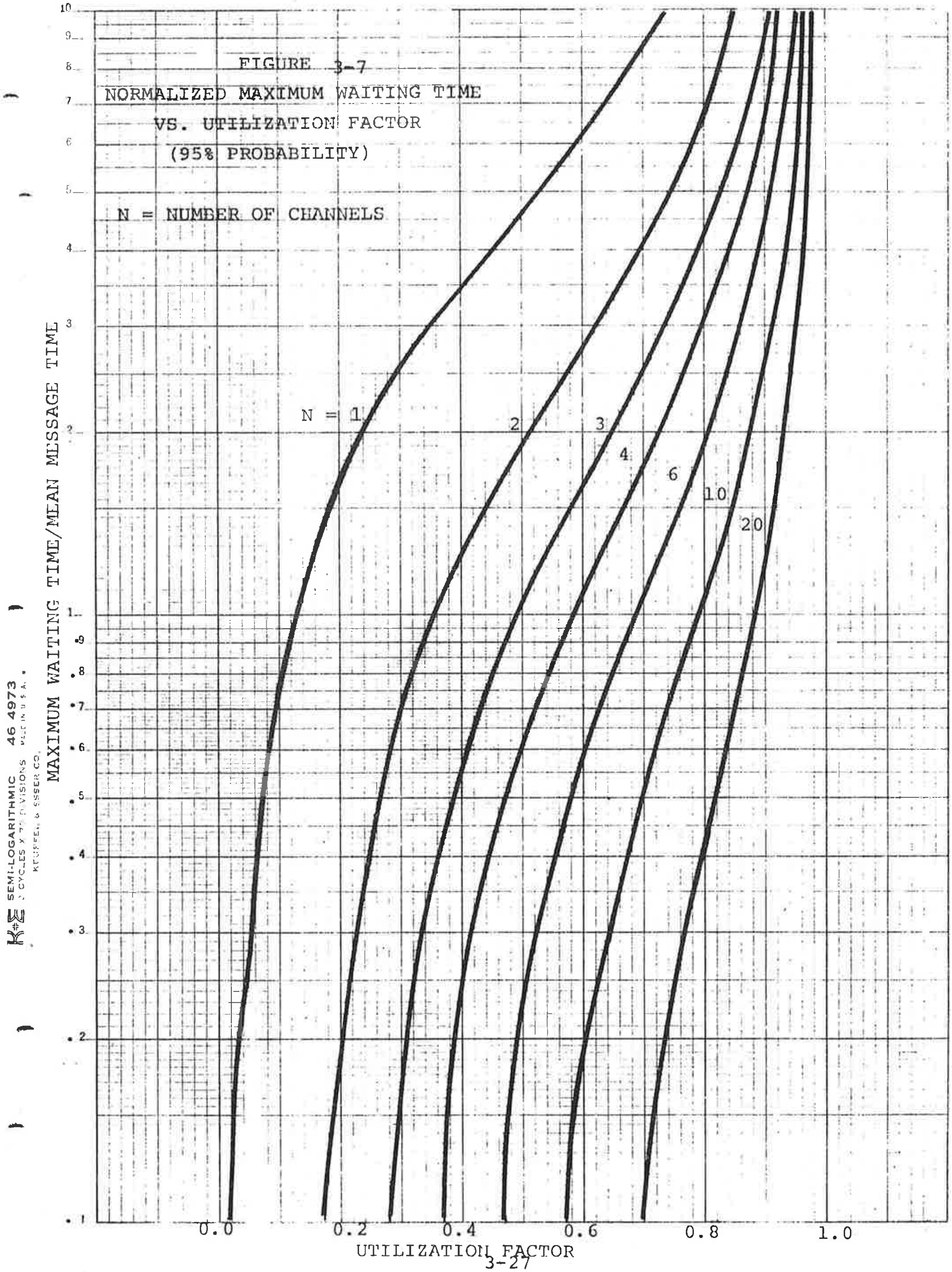
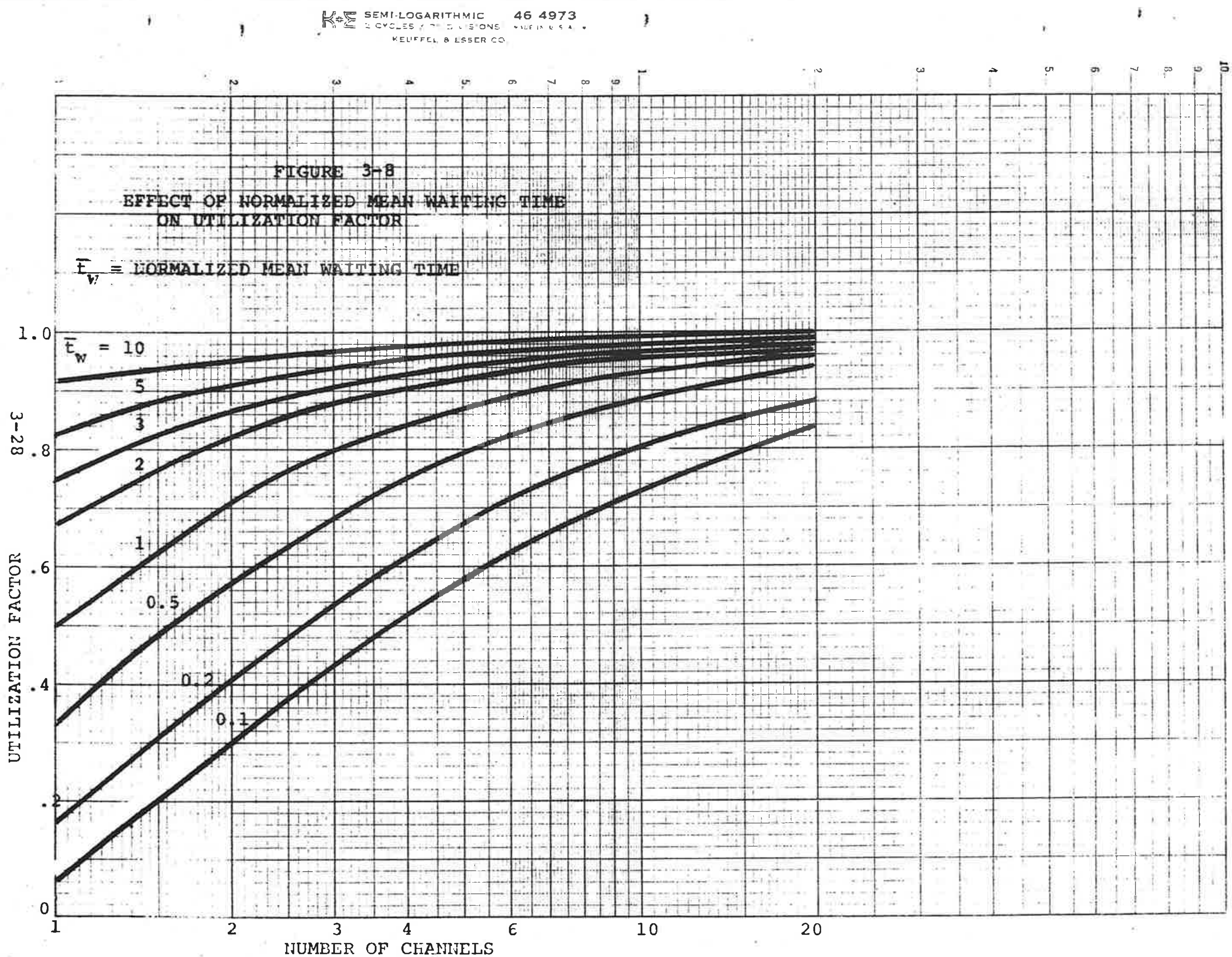


FIGURE 3-7
NORMALIZED MAXIMUM WAITING TIME
VS. UTILIZATION FACTOR
(95% PROBABILITY)
N = NUMBER OF CHANNELS
N = 1
2
3
4
6
10
20
MAXIMUM WAITING TIME/MEAN MESSAGE TIME
UTILIZATION FACTOR
0.0
0.2
0.4
0.6
0.8
1.0
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
SEMI-LOGARITHMIC 46 4973


K+E SEMI-LOGARITHMIC 46 4973
KEUFFEL & ESSER CO.
FIGURE 3-8
EFFECT OF NORMALIZED MEAN WAITING TIME
ON UTILIZATION FACTOR
$\overline{t_w}$ = NORMALIZED MEAN WAITING TIME
$\overline{t}_w$ = 10
5
3
2
1
0.5
0.2
0.1
UTILIZATION FACTOR
NUMBER OF CHANNELS
1.0
.8
.6
.4
.2
0
1
2
3
4
6
10
20

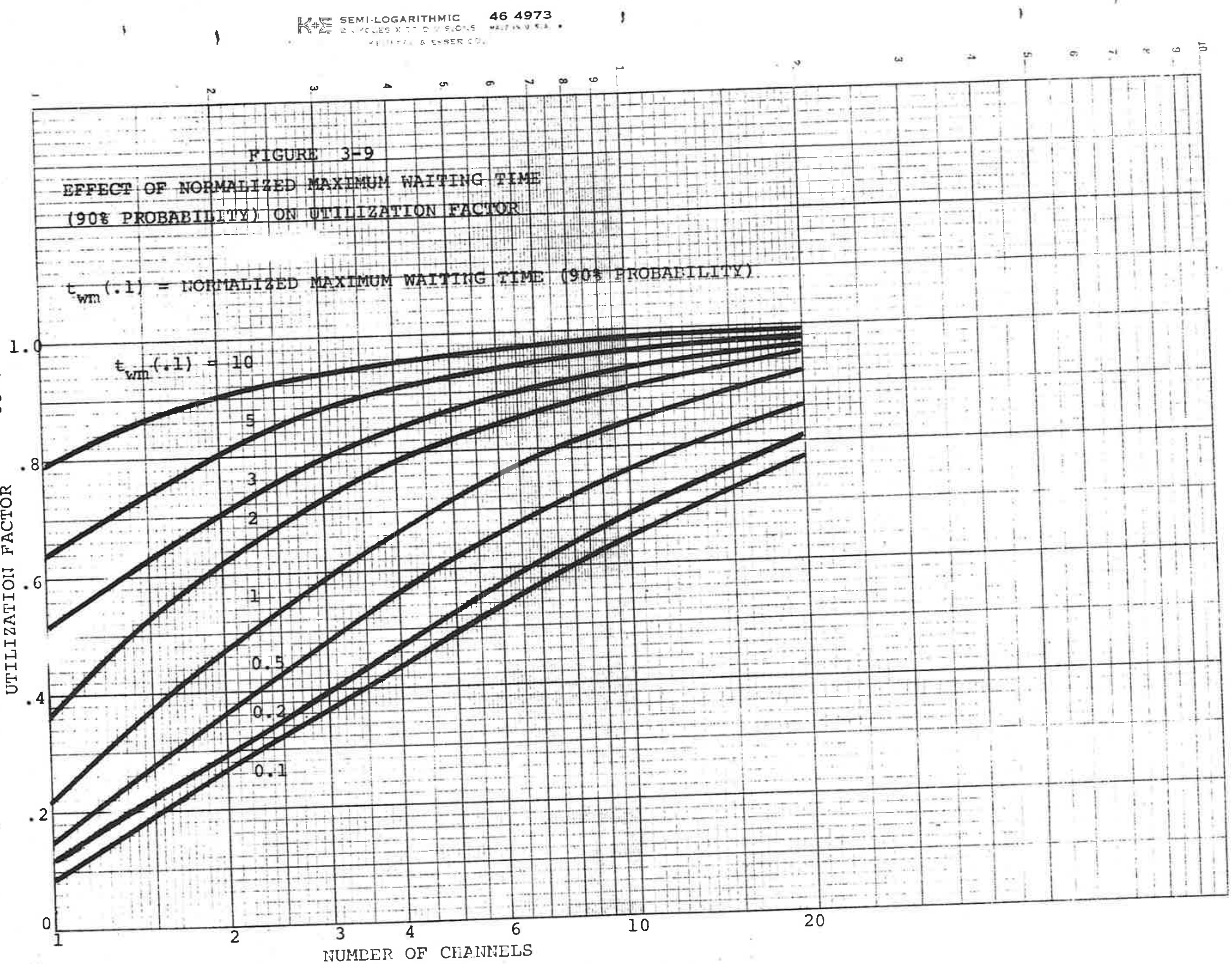


FIGURE 3-9
EFFECT OF NORMALIZED MAXIMUM WAITING TIME
(90% PROBABILITY) ON UTILIZATION FACTOR
$t_{wm}(.1)$ = NORMALIZED MAXIMUM WAITING TIME (90% PROBABILITY)
$t_{wm}(.1)$ = 10
5
3
2
1
0.5
0.2
0.1
UTILIZATION FACTOR
0
.2
.4
.6
.8
1.0
NUMBER OF CHANNELS
1
2
3
4
6
10
20
K+E SEMI-LOGARITHMIC 46 4973

3-8 to 3-10 that the allowable message loading per channel does not increase significantly. Since the allowable loading per channel is held to a maximum of 0.85, as discussed previously, the change in allowable utilization is practically negligible whenever three or more channels are available.

The above is illustrated by an example which could be applicable to AEROSAT. Consider a total of eight voice channels available with a desired average waiting time equal to the average message length. If these are allocated among two ASCC's such that each manages at least four channels then the allowable message loading per channel from Figure 3-8 is 0.84. If these are allocated such that one ASCC only has three channels then its allowable utilization is .8. The other ASCC with 5 channels available is restricted by practical consideration to .85. There is a benefit in keeping channels in a common pool. However, it is not a large increase in utilization, but a decrease in waiting time. If the actual utilization is .8 then the average normalized waiting time is .75 for the split allocation and .3 for the pooling arrangement. However, since both waiting times are below the design value the difference is not considered of great significance.

From the channel allocation point-of-view, the above considerations state that if the allowable time is kept reasonable, any allocation to ASCC's which includes at least three channels will permit high utilization. For sparse areas where traffic is low, one or two channels are sufficient. The allocation of channels should therefore take into account the message loading anticipated for any given area so that the waiting time criterion is met or bettered.

3.3 Queueing Analysis and Simulation

3.3.1 General

In dealing with the problem of determining the effect of system parameters on waiting time and access two approaches have been taken. The first is a classical queueing analysis which is based on certain assumptions and approximations of questionable validity. The second approach is a simulation in which every effort has been made to insure realistic inputs and procedures. The simulation results are presented in Appendix D.

The most important result of the simulation has been a demonstration that the classical analytic approach, despite the fact that it is based on questionable assumptions, does yield good answers. Based on the classical approach, a set of charts have been prepared which can be used for the analysis of any reasonable system, and from which a number of general conclusions can be drawn. This analysis is presented in Appendix C. Using these charts, an example queueing analysis has been performed in which a variety of systems and channel allocations have been considered for communications in the 1980 time period. In this example, predicted message loading for that period has been used.

3.3.2 Sample Analysis for 1980 AEROSAT Communications

The theory described in Appendix C will now be applied to a specific post-1980 message loading forecast for the principal North Atlantic area. The message loading is based on studies published in References 1 and 2.

Table 3-2 summarizes the assumed voice message loading. For the first six message categories, those concerned with voice signals, it lists priority rating, dominant direction, and mean message length in seconds. (It is recognized that, where the dominant direction is, say, up, or ground-to-air, there will be downlink acknowledgements, but these are expected to be brief, and are neglected in the following.) The following columns list the message frequency in terms of messages per hour, both for uplink and downlink messages. The message load, in seconds per hour, is just the product of the mean message length and the message frequency. The final columns, listing the number of access requests per aircraft crossing, are based on an average crossing time of 2.7 hours and 196 aircraft; i.e., they are computed by multiplying the message frequency by 2.7 and dividing by 196. Totals for message frequency, message load and number of access requests per aircraft crossing are also shown, separately for uplink and downlink and combined.

TABLE 3-2

VOICE MESSAGE LOADING

Msg. Ctgy.	Priority	Dominant Direction	Mean Msg. Lgth. (sec)	Freq. (msg/Hr) Up	Freq. (msg/Hr) Dn.	Load Sec/Hr Up	Load Sec/Hr dn.	Acc.Eq/Ac Xing. Up	Acc.Eq/Ac Xing. Dn.
1	1	both	30	5	5	150	150	.07	.07
2	1	Up	30	70	-	200	-	.96	-
3	2	Up	30	50	-	1500	-	.69	-
4	2	Up	20	35	-	700	-	.48	-
5	2	Up	10	20	-	200	-	.28	-
6	2	Up	5	5	-	25	-	.07	-
Totals				185	5	4675	150	2.55	.07
				190		4825		2.62	

TABLE 3-3

DATA MESSAGE LOADING

Msg. Ctgy.	Priority	Dominant Direction	Mean Msg.Lgth. (bits)	Freq. (Msg/Hr) Up	Freq. (Msg/Hr) Dn.	Load (kbits/Hr.) Up	Load (kbits/Hr.) Dn.	Acc.Eq/Ac Xing. Up	Acc.Eq/Ac Xing. Dn.
7	2	Both	60	50	50	3	3	.69	.69
8	2	Up	60	100	-	6	-	1.38	-
9	3	Both	100	35	35	3.5	3.5	.48	.48
10	3	Both	200	300	600	60	120	4.14	8.27
11	3	Down	225	-	300	-	67.5	-	4.14
12	4	Both	325	170	170	55.25	55.25	2.34	2.34
13	4	Down	150	-	70	-	10.5	-	.96
Totals				655	1225	127.75	259.75	9.03	16.88
				1880		387.5		25.91	

Table 3-3 contains similar information for data messages, categories 7 through 13. While message categories 1 and 2 may provide both voice and data messages, they are included in the voice message listing since voice messages create more stringent requirements of the system. In Table 3-3, mean message length is stated in bits rather than in seconds, and message load in kilobits per hour. These are actual information bits; the effect of preambles, acknowledgements, lock time and propagation delay as discussed later in this section.

The mean message length for voice messages is easily found from Table 3-2 by dividing the total message load by the total message frequency:

$$D_v = 4825 \text{ sec/hr} \div 190 \text{ msg/hr.} = 25.4 \text{ sec},$$

and the message arrival rate is just the frequency in messages per second:

$$\lambda_v = 190 \div 3600 = 0.0528 \text{ msg/sec.}$$

The message load factor is the product of these two, or 1.34. So we need at least two voice channels.

For the data link, we will first compute the various delays. We will assume that data are transmitted on a 1200 bit/sec channel. If one assumes that the data channel is used in a pure conversational mode, so that each message must be acknowledged before the next is sent, the delays for an uplink message are as follows:

uplink preamble	0.12 sec
uplink propagation delay	0.25 sec
Ground receiver lock time	0.10 sec
downlink acknowledge preamble	0.12 sec
downlink propagation delay	0.25 sec
Total uplink delay	0.84 sec

The downlink delays are:

uplink request preamble	0.12 sec
uplink propagation delay	0.25 sec
ground receiver lock time	0.10 sec
downlink preamble	0.12 sec
downlink propagation delay	0.25 sec
Total downlink delay	0.84 sec

Since uplink and downlink delays are the same, we can get the mean message time directly from Table 3-3 and add to the delay:

$$D_d = (387.5 \text{ kbits/hr} \div 1880 \text{ msg/hr}) \div 1.2 \text{ kbits/sec} + 0.84 \text{ sec} = 1.01 \text{ sec},$$

$$\lambda_d = 1880 \div 3600 = 0.522 \text{ msg/sec.}$$

The message load factor is, then, 0.517. This mode of operation is quite inefficient, and may be considered to provide an upper limit for mean message length and load factor.

Since the data channels in the AEROSAT system are duplex channels which permit simultaneous transmission of uplink and downlink messages, it is possible to organize the uplink message timing separately from the downlink message timing so that the data messages can be "packed" together going in both directions. This mode of operation requires a priori knowledge of the message lengths; thus, for downlink channel requests, the poll request includes message length information. The duplex channels are now really two separate sets of channels, the uplink set transmitting the uplink messages, the downlink set the downlink messages. The total mesaage loading is split; but, more importantly, the effective average message length is shortened by removing the gross propagation delays. The uplink delay is now only the preamble, or 0.12 second; the downlink delay is as follows:

uplink request preamble	0.12 sec
ground receiver lock time	0.10 sec
downlink preamble	0.12 sec
guard time	0.05 sec
	0.39 sec

We now compute the mean message lengths separately for uplink and downlink from Table 3-3, obtaining 0.16 sec for the former and 0.18 for the latter, or adding the delays, 0.28 sec for uplink and 0.57 sec for downlink. The message rates are 0.182 msg/sec uplink, 0.340 msg/sec downlink. The total message load factor is, then, the sum of the products: 0.28 x 0.182 + 0.57 x 0.340 = 0.245, and the mean message length is 0.245 x 3600 ÷ 1800 = 0.47 sec. These values may be taken as a lower limit for the system.

The message load factors given here correspond to 196 aircraft in the area served by the system. It is assumed in the analysis that the message load factor is proportional to the number of aircraft; this is not strictly true, since some types of messages (notably categories 2,5, 8 and 11) tend to be transmitted at a rate more nearly proportional to the square of the number of aircraft.

Another assumption is made that the message lengths are exponentially distributed with the mean computed above. This is not strictly true; even if the message lengths in each category were exponentially distributed, the total set of messages would not be. However, it is felt that this assumption will not introduce a significant error.

3.3.3 Analysis Results

An analysis was performed using the results of Appendix C in conjunction with Figures C-1 and C-3 to provide busy probability and maximum (90%) waiting time for voice and data transmission as a function of the number of aircraft. As described in the previous section the mean message length of the voice signal is taken as 25.4 seconds, the message frequency is 0.058 messages per second for 196 aircraft, or 2.69×10^{-4} messages per second per aircraft. The upper limit for mean message length of the data signal is 1.01 second, the lower limit 0.47 second; the message frequency is 0.522 messages per second for 196 aircraft, or 2.66×10^{-3} messages per second per aircraft.

Figures 3–11 and 3-12 display busy probability and maximum waiting time for the case of a single voice channel and a single data channel. This situation is realistic only if the number of aircraft handled by one ASCC is small; if, for instance the North Atlantic area is subdivided into several areas, each handled by one ASCC. It is noted immediately from Figure 3-11 that 146 aircraft is the limit that the voice channel can handle - any greater number would cause the waiting time to increase without limit. A realistic number of aircraft to be served by this system would be 60; the busy probability for the voice channel would be 41%, for the data channel between 7 and 16%; the maximum waiting time for the voice channel would be 60 seconds, for the data channel less than half a second.

For the remainder of the analysis, it will be assumed that five communication channels are available. We will first assume that three channels are used for voice communications, the remaining two for data. Figures 3-13 and 3-14 show busy probability and maximum (90%) waiting time for this case. (Note the zero suppression of the abscissa.) It is seen that over the range of interest the busy probability is greater for a voice signal than for a data signal, and that the maximum waiting time is also greater for the voice signal. For example, if 250 aircraft are in the area, the busy probability for a voice transmission is 32%, for a data transmission between 2 and 16%. Maximum waiting time for the same condition is 23 seconds for voice, less than 0.35 second for data.*

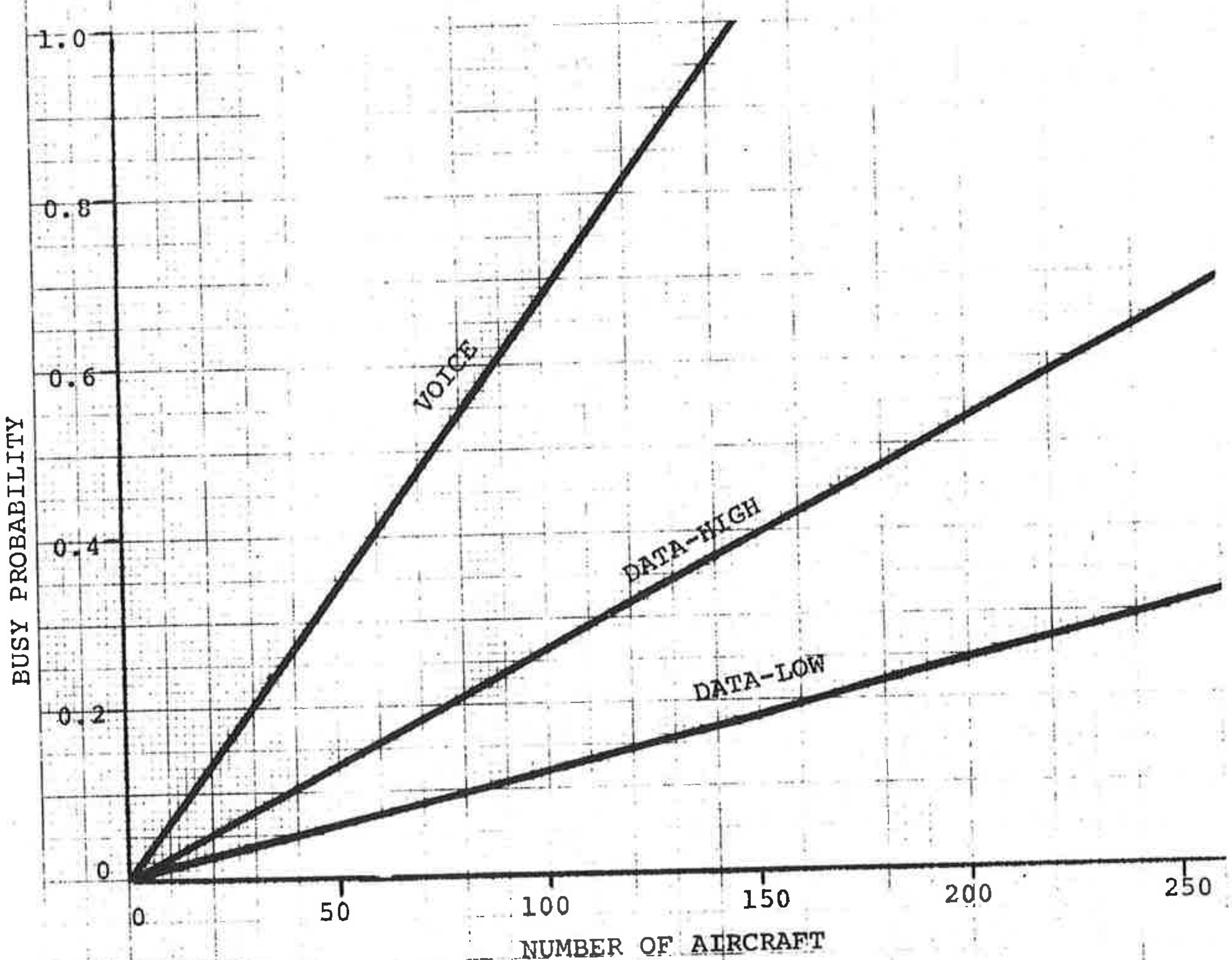
If it appears desirable to decrease the busy probability and waiting time for voice signals, one can analyze the effect of re-distributing the data channels by assigning

*In Figure 3-14 no curve is shown for the lower limit of estimated mean data message length. The reason is that the busy probability for fewer than 400 aircraft is less than 10%, hence there is more than a 90% probability of not having to wait at all, and the maximum waiting time, defined as the waiting time not exceeded 90% the time, is zero. Zero can, of course, not be shown on a logarithmic scale.

FIGURE 3-11

BUSY PROBABILITY VS. NUMBER OF AIRCRAFT

1 VOICE CHANNEL, 1 DATA CHANNEL



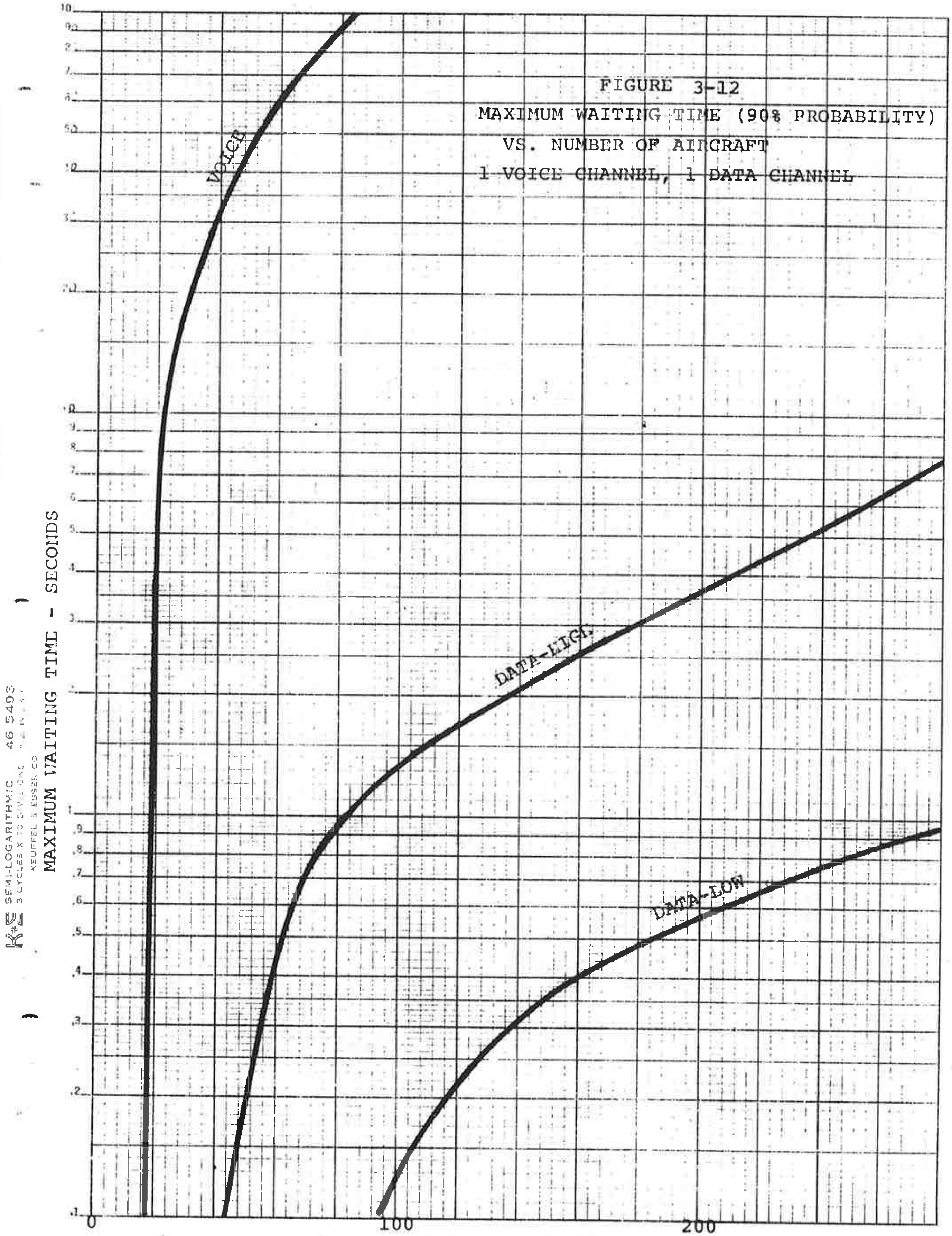
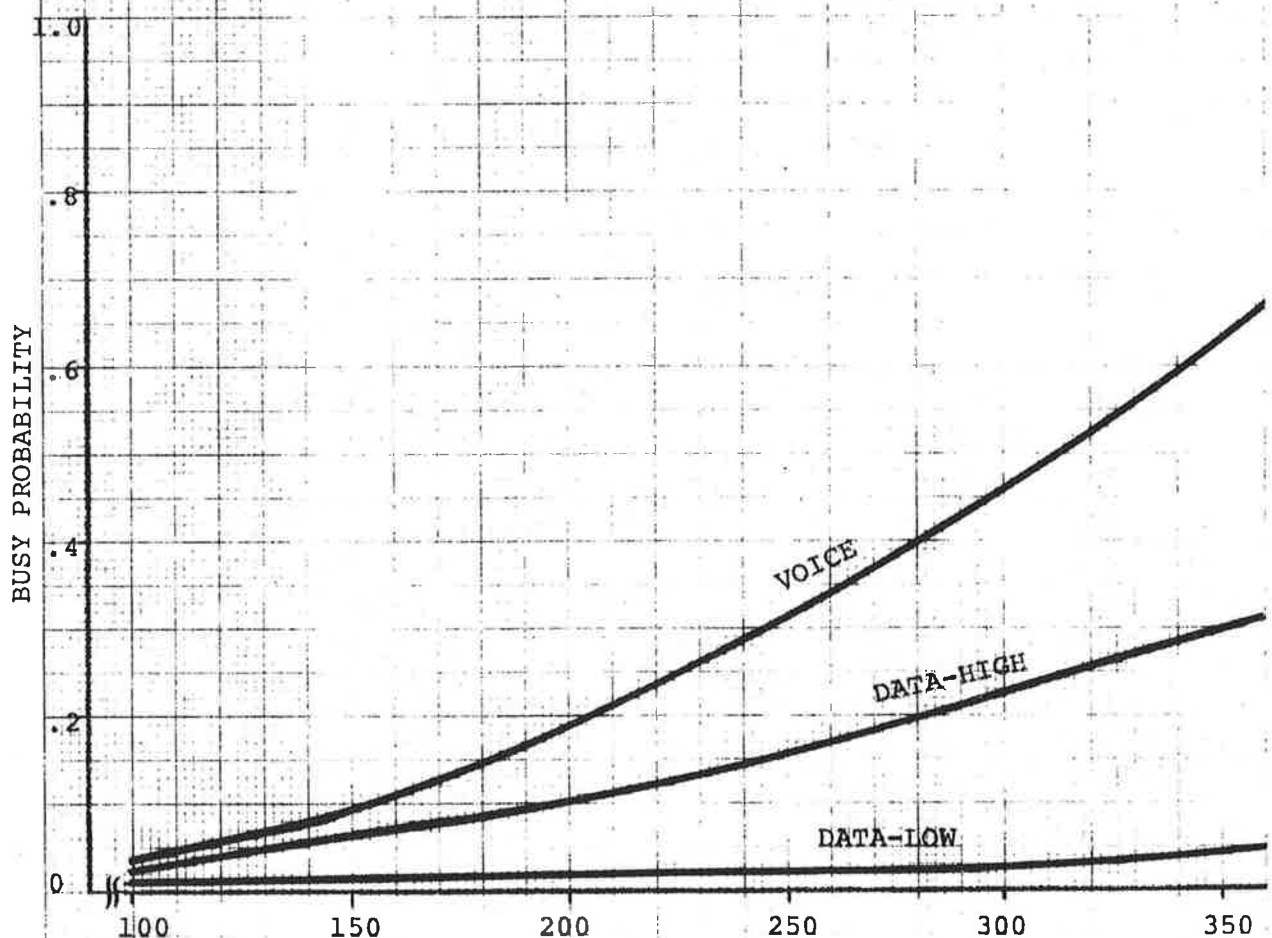


FIGURE 3-12
MAXIMUM WAITING TIME (90% PROBABILITY)
VS. NUMBER OF AIRCRAFT
1 VOICE CHANNEL, 1 DATA CHANNEL
VOICE
DATA-HIGH
DATA-LOW
MAXIMUM WAITING TIME - SECONDS
NUMBER OF AIRCRAFT
0
100
200
SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

FIGURE 3-13

BUSY PROBABILITY VS. NUMBER OF AIRCRAFT - 3 VOICE CHANNELS, 2 DATA CHANNELS



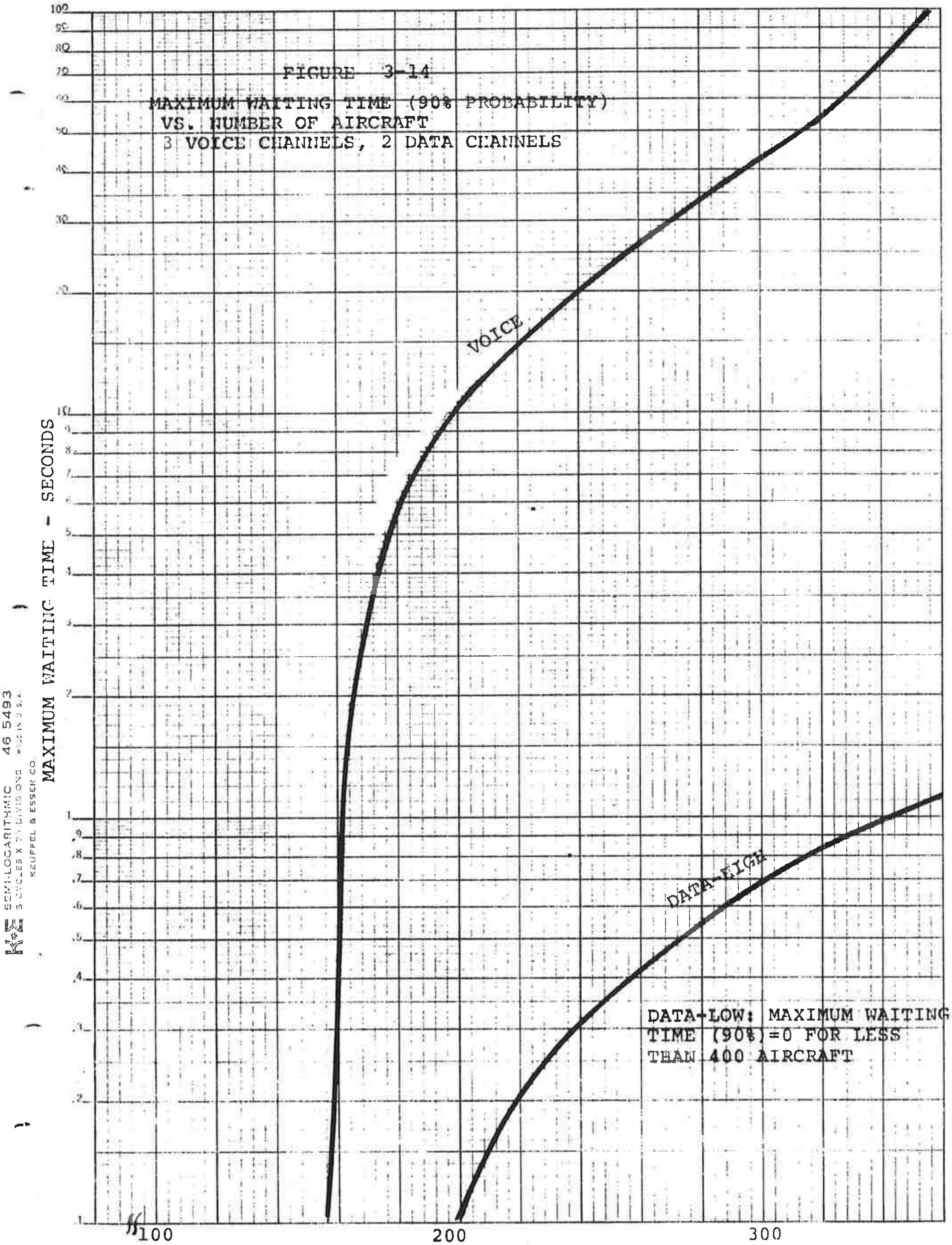


FIGURE 3-14
MAXIMUM WAITING TIME (90% PROBABILITY)
VS. NUMBER OF AIRCRAFT
3 VOICE CHANNELS, 2 DATA CHANNELS
VOICE
DATA-HIGH
DATA-LOW: MAXIMUM WAITING
TIME (90%)=0 FOR LESS
THAN 400 AIRCRAFT
MAXIMUM WAITING TIME - SECONDS
NUMBER OF AIRCRAFT
100
200
300
46 5493
SEMI-LOGARITHMIC
3 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

four voice channels and one data channel. This is shown in Figures 3-15 and 3-16. The curves show that, for the region of interest, busy probability for the voice signals is now lower than for the data signals, and maximum waiting time for voice is also lower than for data for fewer than about 260 aircraft, and of about the same magnitude as data above that figure. Looking again at the values for 250 aircraft, the busy probability for voice transmissions is 11%, for data between 31 and 66%; the maximum waiting time for voice is less than one-twentieth of a second (below the limits of the graph shown in Figure 3-16), while that for data is between 0.76 and 5.7 seconds.

It would seem that, for 250 aircraft, the assignment of four voice channels and one data channel provides an unnecessarily short waiting time for voice signals and possibly too long a waiting time for data; the assignment of three voice and two data channels seems better for this number of aircraft. Similar results for other channel assignments can be obtained by further use of the curves of Appendix C.

3.4 Communications System Design Aspects

In any communication system prior to establishment of communications, there is always some error between the transmitted frequency and the frequency to which the receiver is tuned. When the receiver or transmitter is on a moving vehicle there is an additional error due to doppler. In AEROSAT, the one way aircraft-to-satellite doppler can be as high as 3.9 kHz at L-band for aircraft speeds to Mach 2.5. The satellite-to-ground doppler can be as large as 0.6 kHz at C-band for 4.3 degree inclination and 0.0001 eccentricity.

Because of the frequency misalignment, it will be necessary to go through a search and acquisition phase each time a link is established based on the types of modulation schemes currently anticipated for AEROSAT. The time required is critical when a data channel is involved since the average message duration

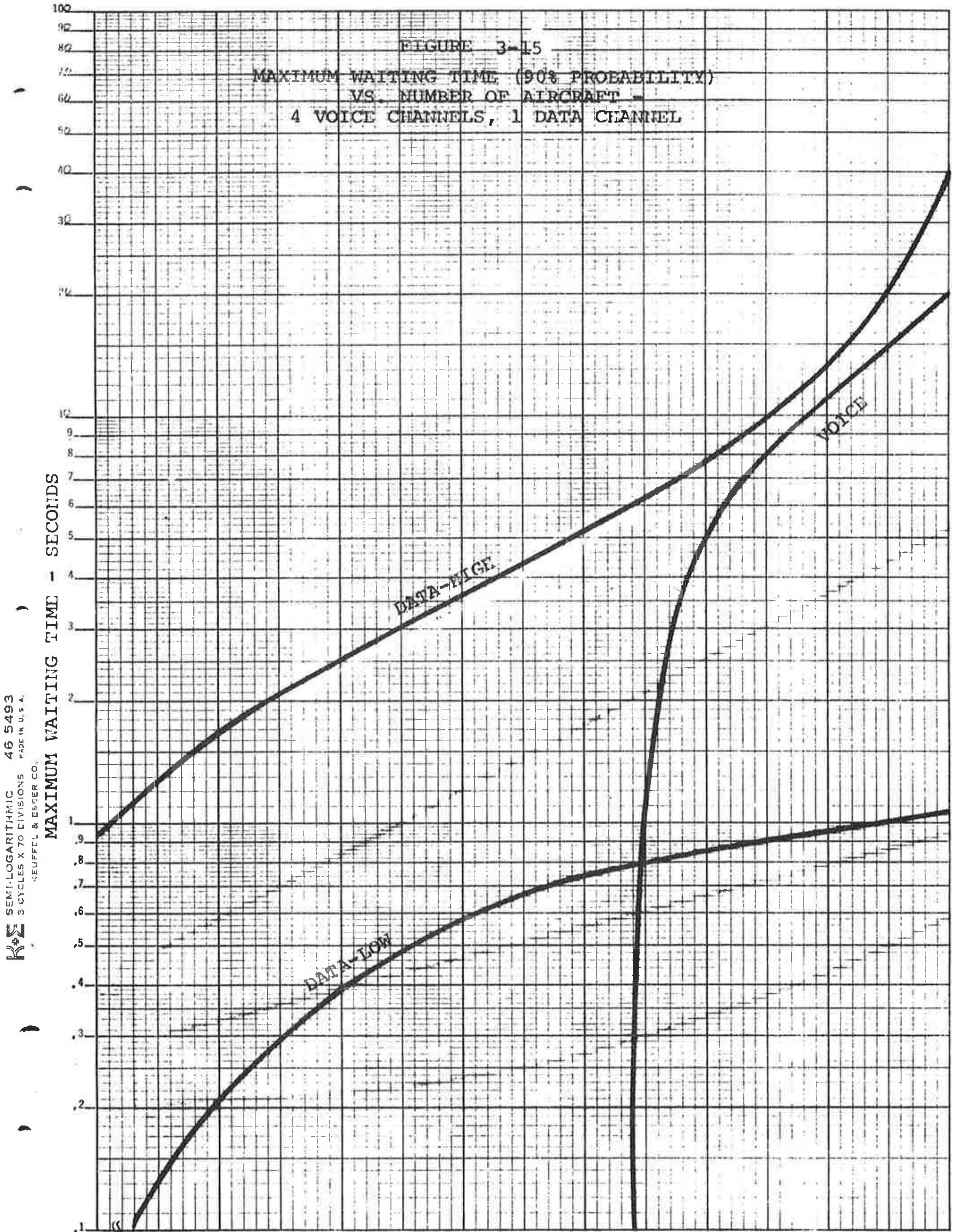
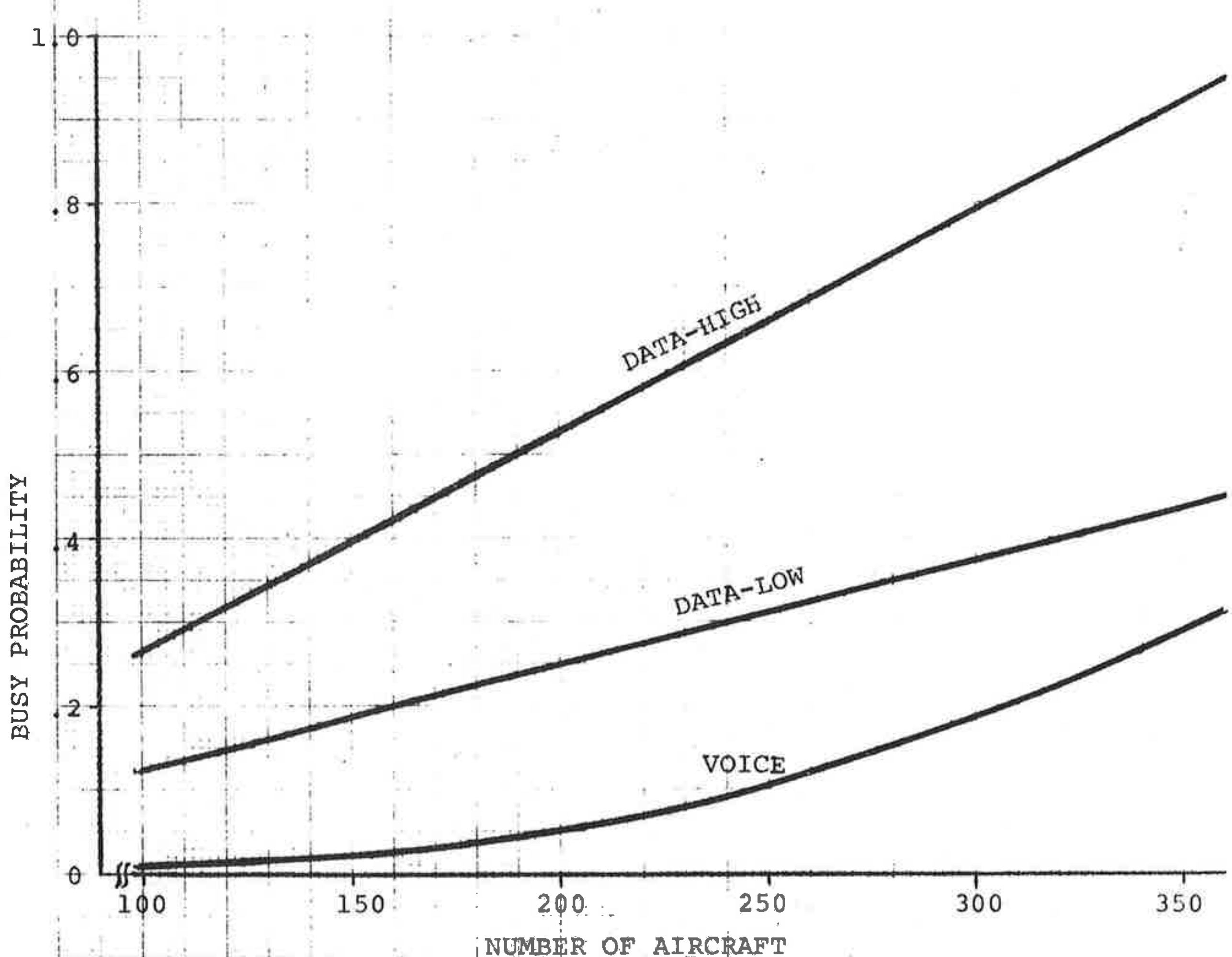


FIGURE 3-15
MAXIMUM WAITING TIME (90% PROBABILITY)
VS. NUMBER OF AIRCRAFT -
4 VOICE CHANNELS, 1 DATA CHANNEL
MAXIMUM WAITING TIME - SECONDS
NUMBER OF AIRCRAFT
DATA-HIGH
DATA-LOW
VOICE
100
200
300
SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIGURE 3-16

BUSY PROBABILITY VS. NUMBER OF AIRCRAFT - 4 VOICE CHANNELS, 1 DATA CHANNEL



is short. For digital modems bit and message synchronization is required in addition to frequency search, acquisition and phase-lock.

In the ground-to-air link, the problem is minimal because the ground station is assumed to transmit more or less continuously. Time is required for initial entry and whenever a channel is switched into a new beam. In the former case, each aircraft on entering the system is advised of what frequencies to monitor and searches and locks up to that frequency. In the latter case, time must be allowed for all aircraft in the beam to acquire the channel before communications begin. When more than one ground station share a channel there will be a doppler frequency shift because of satellite eccentricity. This must also be accounted for. However, the search range is appreciably smaller.

In the case of the air-to-ground link the potential error in tuning can pose a more difficult problem which must be given careful consideration. Here, the time on the air for any user at any given time is relatively small, and if the time required for search and acquisition is large, the system efficiency will be poor. An approach which can help ease the problem is to store in the ASET/ASCC computer the doppler frequency for each aircraft. For a multiple access system which is organized in such a way that it is known which aircraft is addressing the ground at any given time, the receiver is tuned accordingly. However, the doppler is not generally known for those aircraft entering the system, or for those requiring emergency access to the system. Therefore, special consideration must be given to these aircraft to permit the doppler information to be obtained.

Solution of the search, acquisition and lock-up problems are handled by the design of phase-lock loops and the transmission of special signals. To facilitate lock-up pure carrier and special bit and message sync sequences are transmitted.

Appendix E provides an analysis and discussion of phase-lock loop designs which are applicable to AEROSAT for both the avionics and ground-based hardware. It includes an analysis of second order and third order loops and their search and acquisition characteristics. Substantiation is provided in the appendix for the specific parameters used for preamble transmissions associated with the various FDMA and TDMA schemes described in Sections 4.0 and 5.0. Verification was in many cases obtained by laboratory experiments. Some of these phase-lock loop studies and laboratory experiments were performed in conjunction with Bell IR&D programs.

4.0 FDMA SYSTEMS

4.1 General

In this section, the FDMA systems analyzed during the study program are described. On the basis of a comparatrive evaluation (References 26 and 27), one of these, designated as System C, scored highest of all systems studied. This is described in greatest detail including preliminary estimates of avionics costs and instrumentation. However, the other systems have technical merit and are described in sufficient detail to indicate the method of operation.

The three frequency division multiple access systems all provide voice, data and either independent or dependent surveillance services as desired. Compatibility with the UDDL in all cases is also assumed. The differences between the three systems are associated primarily with the manner in which the supervisory control data is handled and secondarily, the manner in which channels are allocated among the ASCC's of the system. The variations may be summarized as follows:

System A. Separate supervisory channel transmitted via an earth coverage antenna; central management of voice channels.

System B. Separate supervisory channel transmitted via spot beams; central management of voice channels.

System C. Supervisory data for AEROSAT integrated into standard data-link; distributed management of channels.

It is apparent that the differences are evolutionary rather than revolutionary. In System A, the supervisory data, in digital form, is multiplexed with the surveillance signals on a separate carrier and transmitted from the master ASCC to all aircraft on an earth coverage beam. Quadrature modulation is one efficient technique for combining the two signals (Reference 28) which conserves satellite power. System B is similar to System A except that the surveillance and supervision (S&S) signals are transmitted via spot beams thereby taking advantage of the extra antenna gain. The S&S signals are sequentially switched from beam to beam to obtain oceanic coverage. In System C, the supervisory data is transmitted in combination with other data on a "standard format" data channel. Each aircraft continuously receives an assigned data channel and monitors a sequence of fixed length messages transmitted thereon for own-ship address signifying independent surveillance polling commands and a normal data-link interchange. Surveillance signals are multiplexed onto the data-link carrier. By multiplexing both the supervision and surveillance on to the data-link channel, satellite power usage for these functions are minimized. Each ASCC manages its own channels and performs its own surveillance.

The following sections describe in more detail the method of operation for the above systems. The polling and supervisory functions presented for System A are, in general, typical of that required for all systems.

4.2 Method of Operation of System A

4.2.1 General

The distinguishing feature of System A is the use of separate supervisory channel on which are transmitted low data-rate signals for channel access control and surveillance polling. The supervisory signal is multiplexed with the surveillance signal and transmitted via an earth coverage antenna for simultaneous reception by all mobiles. The ASET/ASCC, designated as the Master, transmits and receives the supervision/surveillance signal to and from all mobiles equipped to utilize the service. Uplink transmission is continuous. All aircraft in the system continuously monitor this S&S channel, maintain lock-on and synchronization and respond when sequentially polled via a system address. Fixed length polling slots are used in the supervisory data channel with a duration which is compatible with the surveillance signal processing requirements and the information to be transmitted. The data rate is selected to minimize satellite power requirements. Details of this channel design are discussed in the next section.

All polling is under ground computer control. There are provisions in the supervisory channel for four types of polls. These are:

Initial Entry
Normal Poll for Surveillance and Access
All Call Emergency
All Call Random Entry

An initial entry poll is used whenever a mobile enters the system to establish initial conditions and a reference doppler for subsequent acquisition of A-G communication transmission.

A normal polling message is sent the majority of the time and is usually sent to command position surveillance ranging. The system computer will determine the interval between polling for position determining purposes based on requests from the ATCC.

Requests for voice and/or data channel access, along with the priority, are received when polling an aircraft for position surveillance. Any request for voice or data channel is acknowledged in the next poll if the channels are busy or granted in the next available slot.

The emergency signalling slot message is sent uplink periodically to ascertain whether an airborne emergency exists. This message consists of a unique address that any aircraft, having signalled an emergency, will automatically decode. Upon such decoding, the aircraft will send ownship address downlink identifying self and indicating to the ground computer that an emergency condition exists.

The all-call random entry poll is transmitted periodically to determine whether an aircraft which has not been cleared through normal channels desires to enter the system. Upon decoding the interrogation the aircraft will transmit its address so that it can be granted voice and data channels to a controller for air traffic control processing.

The communication channels in the system are designated by the master ASCC as either data or voice. They are transmitted G-A via spot beams in each of the satellites to the areas of the ocean requiring communication service in response to switching commands received by the satellite control facility (SCF) from the ASCC. In the A-G direction, either earth coverage or spot beams are used depending on the particular satellite design.

Digital data links are assigned to each of the ASCC's for relatively long periods and are managed separately at each center. All aircraft are assigned a data link channel to monitor corresponding to the ATCC-ASCC having responsibility for their control. The message formatting and queue management is accomplished by the local ASCC. However, queue status information is transmitted to the master from each local ASCC for overall system management. Data channels can be assigned or reassigned based on overall demand. All data transfer is handled on a priority basis in accordance with standard data-link practices. Ground requests and messages funnel directly into the ASCC while airborne requests for data transmission are received by the master and forwarded to the appropriate ASCC for entry into the queue.

Because of the existance of the separate supervisory channel, periodic polling via the data-link is not required. Message traffic is handled purely on a demand assignment basis. Either variable length or fixed block length messages can be used.

The uplink data transmission is continuous so that all aircraft can stay locked-on and synchronized and reply when the correct address is received. In the downlink transmission, provision is made for guard time, acquisition and synchronization. The acquisition time can be held to a minimum if the supervisory/surveillance signals are coherent with the data transmission so that doppler information obtained from the former can be used.

Voice channels are allocated on a request/grant (with priority) basis entirely under control of the master ASCC. Thus, a central queue is maintained for all the voice channels in the system. The ground-to-ground link is used to receive and transmit requests and make temporary assignment of voice channels among the ASCC's of the system. The actual voice transmission takes place between the local ASET/ASCC to the mobile involved. System operation is summarized in Table 4-1.

The next section discusses the mechanization of the supervisory and surveillance channel which is then followed by a description of system procedures for the various access modes.

4.2.2 Mechanization of Supervisory and Surveillance Channel

A continuous digital data stream sent uplink to all subscriber aircraft forms the basis for system supervision. This digital data stream is segmented into messages or "slots". The slot must be long enough to provide adequate time for surveillance signal processing and yet be short enough to accommodate a large aircraft population with acceptable update rates. It must also be long enough to permit reception of a sufficient number of supervisory bits to perform its function. On the other hand, a low bit rate is desired to minimize satellite power requirements.

The duration of the individual time slot is determined primarily from a consideration of the air-ground transmission rather than the ground-to-air transmission. This is true because the efficiency of the uplink is greater in as much as all

TABLE 4-1

METHOD OF OPERATION

ALL AIRCRAFT CONTINUOUSLY MONITOR S&S CHANNEL

CONTROL OF SUPERVISORY CHANNEL IS FROM MASTER ASCC

SUPERVISORY CHANNEL IS ADDRESSED SYSTEM UNDER COMPUTER CONTROL

DATA CHANNELS OPERATE AT 1200 BITS/SEC.

EACH AIRCRAFT MONITORS AN ASSIGNED DATA CHANNEL

QUEUES FOR VOICE MAINTAINED AT MASTER ASCC

QUEUES FOR DATA MAINTAINED AT EACH ASCC IN SYSTEM subscriber aircraft can stay locked up to the continuous uplink supervisory data stream. The downlink supervisory transmission emanates from individual aircraft as polled and hence each aircraft's slot time must include an acquisition transmission interval as well as a no-transmission "guard band" of 40 milliseconds to prevent transmission overlap.

Table 4-2 presents a summary of the content of a typical downlink message. The bit allocation includes provision for indicating an addressee category such as company or controller and for data message length. This may be an aid to channel management. The slot duration corresponding to different bit rates is as follows:

Bit Rate	Min. Slot Duration	C/N_o Req.
200 b/s	410 msec	34.2
300 b/s	300 msec	36 dB-Hz
600 b/s	190 msec	39 dB-Hz

A transmission rate of 600 bits/second would require the most satellite power. However, either 200 bits/second or 300 bits/second are satisfactory for this application. The latter is used as a typical example for System A because it is compatible with the use of earth coverage antenna and permits higher polling rate.

The duration of the surveillance signal received from each aircraft corresponding to a 300 msec slot is 220 msecs. This is compatible with tone ranging and other surveillance signals having rapid acquisition properties.

Table 4-3 shows a listing of a typical message format common to all uplink messages corresponding to a slot duration of 300 msec. No provision for acquisition is included because a continuous transmission is assumed. Twenty-one bits plus parity are utilized for system unique aircraft addressing. Two bits are required to handle polling type designation.

TABLE 4-2

NORMAL ENTRY OR REACQUISITION
DOWNLINK ORDER WIRE RESPONSE

1.	Guard Time	40 msec
2.	Acquisition time	40 msec
3.	Sync Bits	32 Bits
4.	Altitude	11 Bits
5.	Voice Request	1
6.	Data Request	1
7.	Voice Priority	2
8.	Data Priority	2
9.	Voice Addressee Category	2
10.	Data Addressee Category	2
11.	Ack/NAK	1
12.	Data Message Length	6
13.	Check Bits	6
		66 Bits

TABLE 4-3

SUPERVISORY G-A MESSAGE DESIGN

1.	Synchronization	16 Bits
2.	Aircraft Address	22 Bits
3.	Poll Type Designator	2 Bits
4.	Voice Ring-Up	1 Bit
5.	Voice Request Acknowledge	1 Bit
6.	Voice Grant/Vacate	2 Bits
7.	Voice Channel Address	5 Bits
8.	Data Request Acknowledge	1 Bit
9.	Data Grant/Vacate	2 Bits
10.	Data Channel Address	5 Bits
11.	Emergency Acknowledge	1 Bit
12.	Random Entry Req. Ack.	1 Bit
13.	Spare and Check Bits	30 Bits
	TOTAL	90 Bits

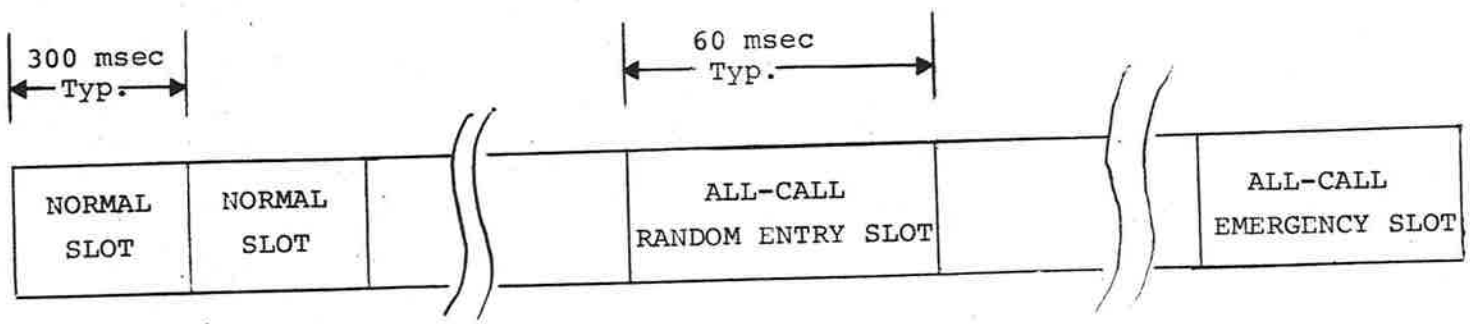
Voice and data channel management are similar. Nine bits are required for voice and eight for data (items 4 thru 7 for voice and items 8 thru 10 for data). One bit is used to indicate to the aircraft logic that a ring-up exists (item 4). Two bits are required to indicate either grant or no grant and vacate or no-vacate situation (item 6). Assertion of either of these two bits are, of course, mutually exclusive. One bit (item 5) is sent asserted whenever the ground recognizes a channel request whether a grant is sent simultaneously or not. If a grant is not sent simultaneously, it is implied that the request is in queue.

One bit is used as acknowledgement (item 11) to a specific aircraft responding to emergency polling. The assertion of this bit would typically be accompanied by a ring-up on a voice and data channel to further coordinate emergency procedures.

One bit is used to indicate acknowledgement of a random access to a specific aircraft. This would typically be accompanied by a voice channel ring-up to coordinate insertion of at least minimum details of desired flight plan into the ground computer by manual means.

Message check and spare bits complete the format.

In Table 4-2, 40 msecs have been allowed for acquisition of the downlink transmission. This assumes the availability of stored doppler information at the ASET/ASCC. However, during initial emergency or random entry, this information is not available. Therefore, a longer transmission period for the carrier acquisition is required. This is accomplished by using a double length slot for these types of polls. In this manner, the aircraft can reply with 340 msec of carrier. A double slot is indicated by the poll type designation in the uplink message. The uplink sequence is shown in Figure 4-1. With the slot width indicated, 300 aircraft can be handled in a 2 minute epoch permitting several to be polled at high rate. Other slots are also interspersed for special ring-ups. The average delay in receipt of an airborne request is 1 minute.



SLOT TYPE	FUNCTION	RATE
NORMAL ADDRESS SLOT	ORDERS RANGING REPLIES UPLINK RING-UP INTERROGATES FOR ACCESS REQUEST	188/MIN.
RANDOM ENTRY	INTERROGATES FOR POP-UP	1/MIN.
EMERGENCY ENTRY	INTERROGATES FOR EMERGENCY	5/MIN.
INITIAL ENTRY	INTERROGATES FOR NORMAL ENTRY	AS REQUIRED

FIGURE 4-1. SUPERVISORY SLOT ARRANGEMENT

A distinction must be made between initial entry and emergency or random entry. In the former case, the aircraft address is known while in the latter two instances, it is not. Therefore, the downlink message must be modified for these two cases to permit inclusion of an aircraft address. A message format for emergency and random entry reply message is shown in Table 4-4. The transmission of altitude information is suggested as an aid to the traffic control process for these situations.

TABLE 4-4

RANDOM AND EMERGENCY MESSAGE FORMAT

Guard Time	40 msec
Acquisition Time	340 msec
Sync Bits	32 Bits
Aircraft Address	22 Bits
Altitude	11 Bits

4.2.3 Power Requirements for S&S Channel

An important consideration in the design of the supervisory and surveillance channel is the satellite power required. To achieve an error rate of 10^{-5} at a 300 bit/second rate, a C/N_o of 36 dB-Hz must be provided. To this must be added power needed for the surveillance signal. As an example, a six tone set with frequencies from 25 Hz to 25,600 Hz provides the required accuracy at a C/N_o of 30 dB-Hz.[28] The combined power is, therefore, 37 dB-Hz based on the assumption of an efficient multiplexing technique. At this power level, one (1) unit of satellite power transmitted via an earth coverage antenna is sufficient. However, there is no extra margin at this signal level. Furthermore, the use of ranging signals requiring more than 30 dB-Hz is excluded. It is, therefore, concluded that to provide additional design margin for the concept formulation, 1.5 to 2.0 units of power should be assumed.

4.2.4 System Procedures

To illustrate operation of System A, several procedure flow diagrams are presented in Figures 4-2 to 4-5. They illustrate provision for master ASCC management of voice channels and local ASCC management of data channels. Additional procedures and details are contained in Reference 26.

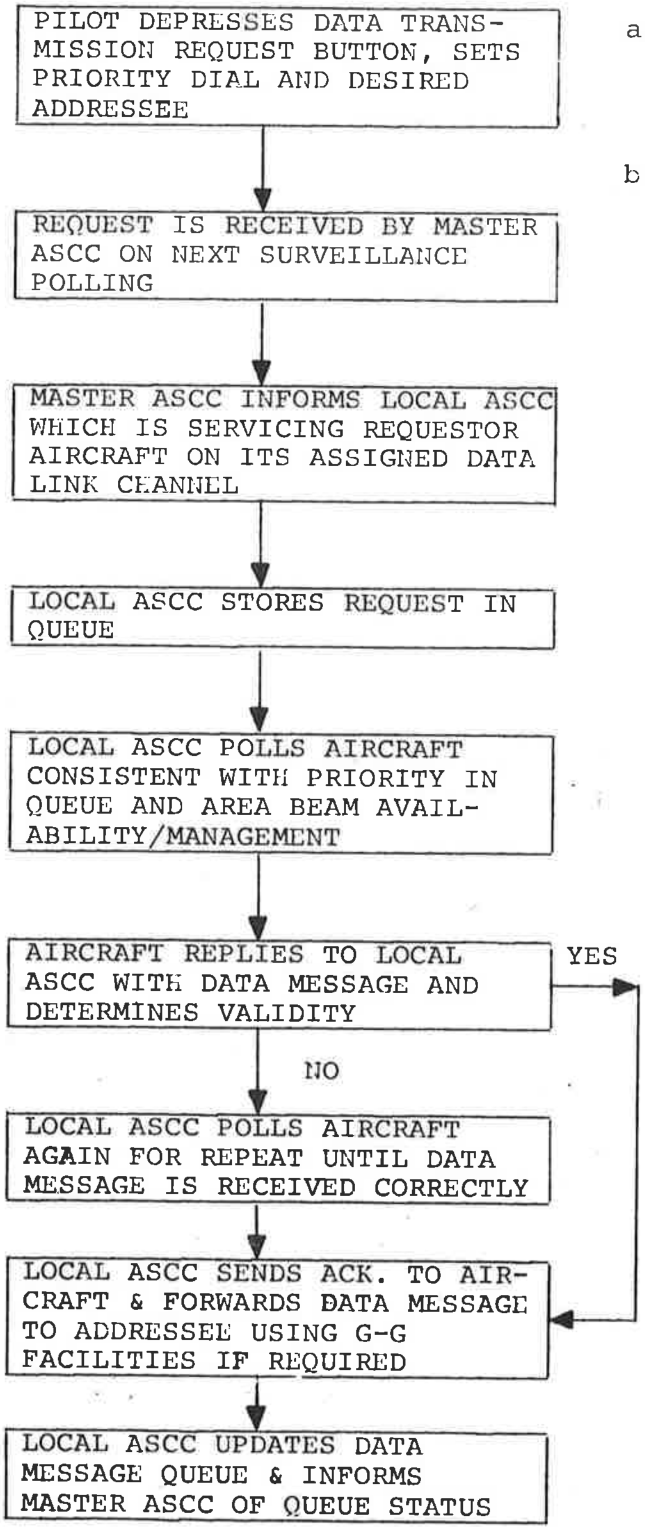
It is observed that in this system whenever a local ASCC requires use of a voice channel for communicating with a particular mobile, the request must be sent to the master ASCC. This is done via the G-G link. When a channel becomes available, the master rings-up the mobile via the supervisory channel and notifies the local ASCC via the G-G channel of the satellite channel assignment.

All airborne initiated requests are received at the master ASCC. Therefore, if the communications must be channeled through a local ASCC, the master again uses the G-G link for ground terminal ring-up, the temporary assignment of the channel to the local ASCC.

4.2.5 Avionics Instrumentation

A simplified block diagram of the Avionics instrumentation is shown in Figure 4-6. Simultaneous reception of the voice, data and S&S carriers is implied. However, continuous monitoring of the data and S&S signal is required. The access control processor decodes the incoming signal, recognizes ownship address and transmits signals for activating the display. It also formats the reply message and gates the output of the surveillance processor. The voice channel is tuned automatically to the correct channel when "rung-up" on the supervisory data-link.

The data and S&S demods have a search capability which permits them to lock-up to the data stream upon entry into the system. They are also designed to lock-up in one (1) second when a special acquisition preamble is transmitted as described in Appendix E.



ASSUMPTIONS

a) Each aircraft monitors one data channel as assigned by master ASCC queue management

b) All final grants to transmit are via ground polling on data link

FIGURE 4-2. AIRCRAFT PROCEDURES AND DATA FLOW FOR TRANSMITTING AIRCRAFT DATA MESSAGE IN SYSTEM A.

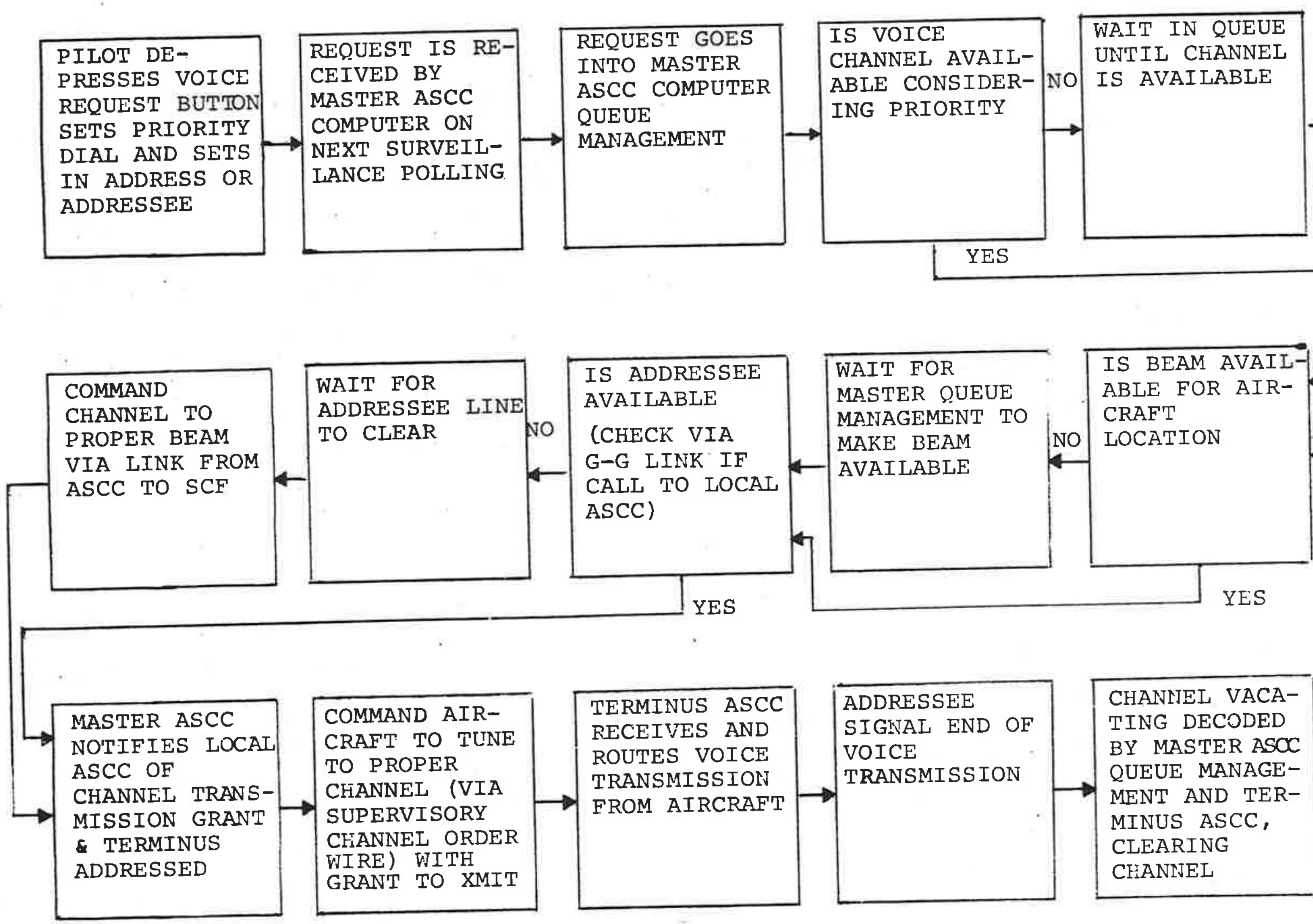


FIGURE 4-3. AIRCRAFT VOICE REQUEST PROCEDURE AND DATA FLOW FOR SYSTEM A

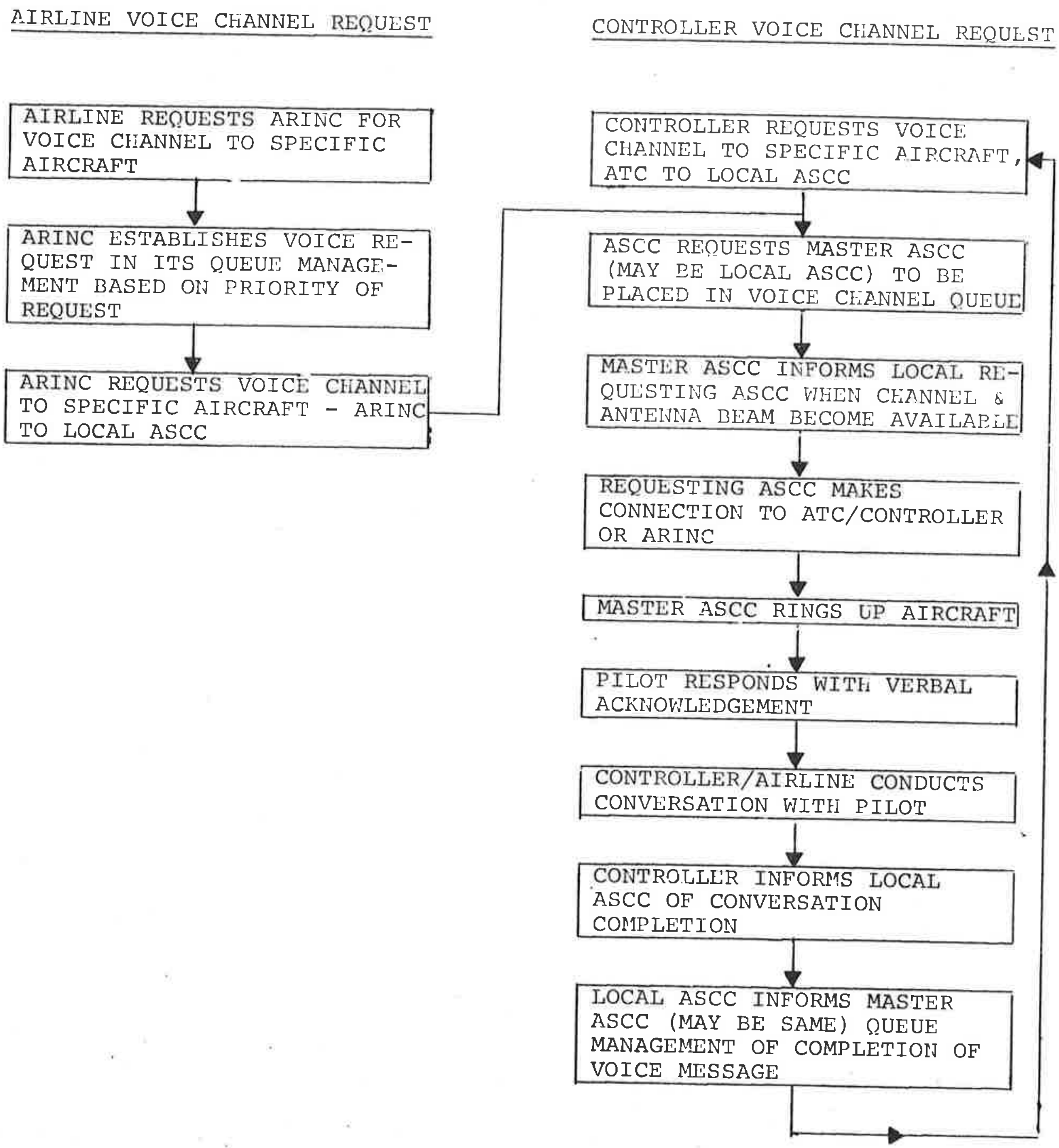


FIGURE 4-4. AIRLINE OR CONTROLLER VOICE REQUEST PROCEDURE AND DATA FLOW DIAGRAM FOR SYSTEM A.

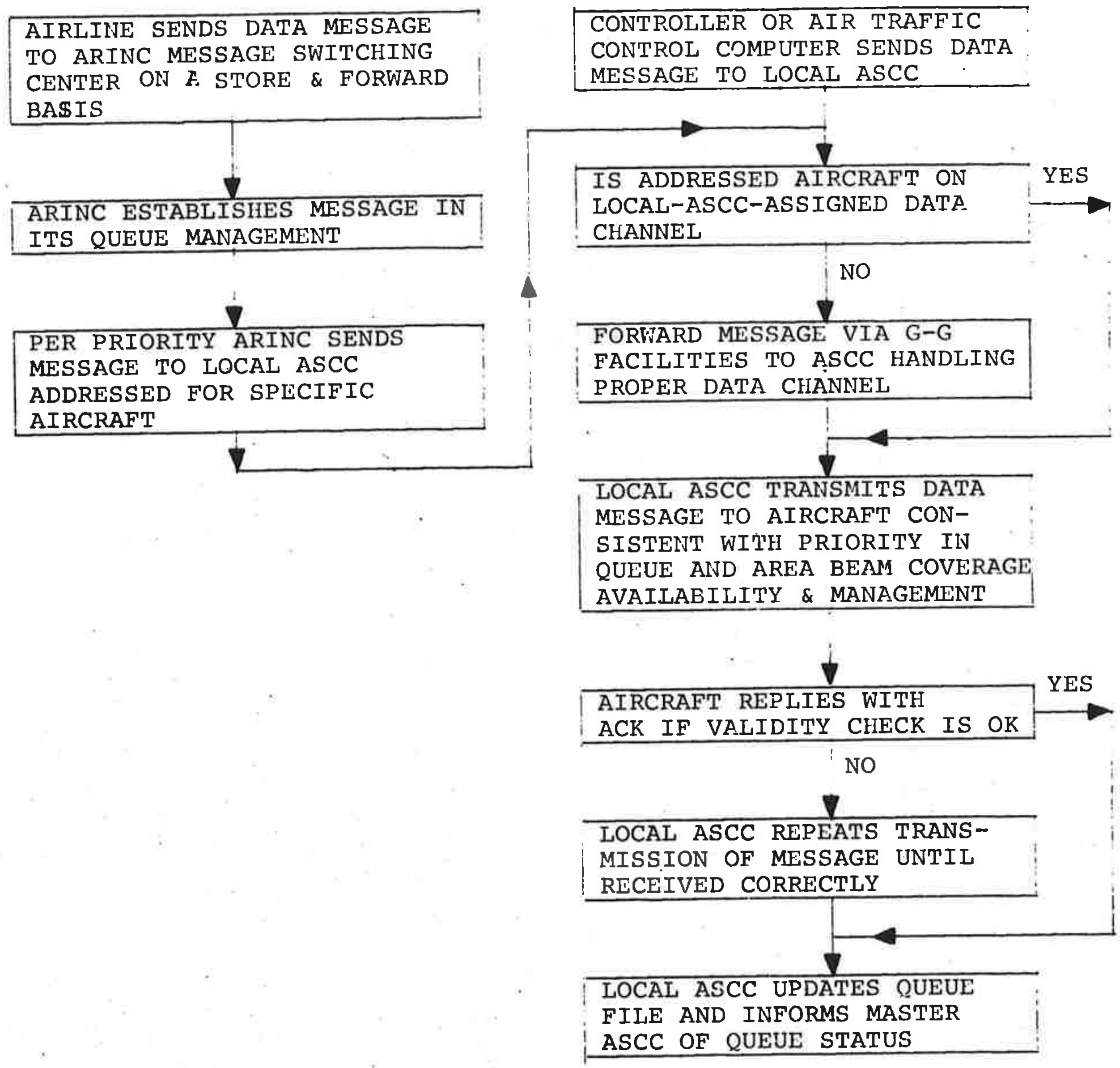


FIGURE 4-5 AIRLINE OR CONTROLLER PROCEDURE FOR TRANSMITTING A DATA MESSAGE FOR SYSTEM A

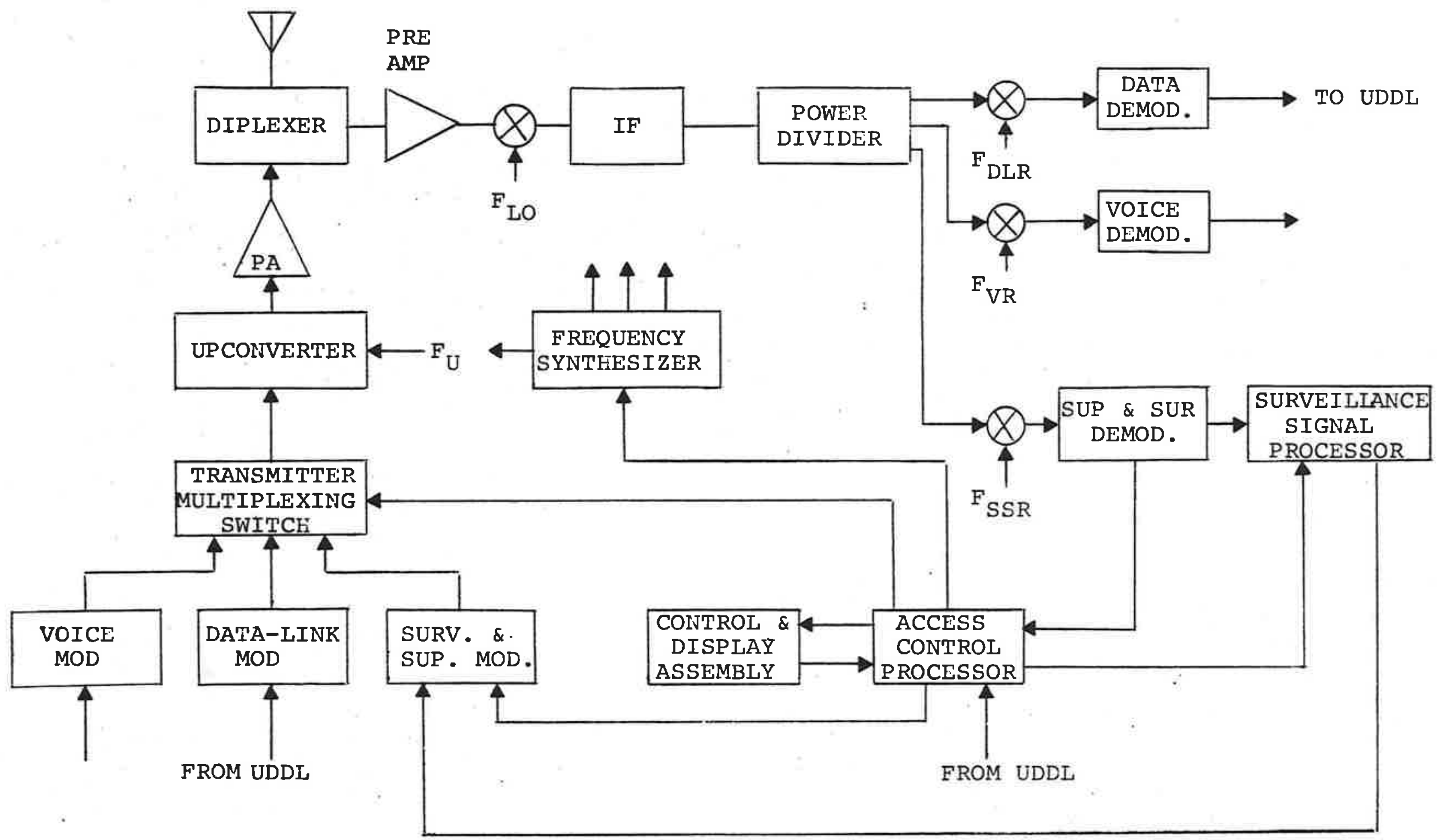


FIGURE 4-6. SIMPLIFIED BLOCK DIAGRAM, SYSTEM A AVIONICS

Only one carrier is transmitted at a time. Either the data or S&S signals would interrupt the voice signal for the duration of the reply message. It is not likely that a data and an S&S reply would occur at the same time. However, it is felt that data should be given priority in which case the ground would repoll the aircraft.

4.3 Description of System B

4.3.1 System Concept

System B differs from System A in the manner in which the supervisory and surveillance (S&S) channels are transmitted to, and received from the aircraft in the system. In System A, the S&S signals are transmitted and received via an earth coverage satellite antenna. To enable some savings of satellite power and/or provide additional margin for the G-A link, a system instrumentation was investigated wherein the S&S signal at one unit of power level is transmitted sequentially via the contiguous spot beams to all areas of the ocean. The capability of switching the S&S channel amplifier in the satellite to the individual spot beams is assumed. The S&S signal is received in only a single spot beam area at any given time at a very adequate power level. The need for an earth coverage antenna in the satellite for surveillance signal transmission is eliminated. The principle drawback in this instrumentation is that quite frequent beam switching is required to provide high rate polling to several aircraft each of which may be in a different spot beam. This results in attendant delays while aircraft in an area reestablish synchronization. The lengthening of total S&S servicing time (Epoch) for all aircraft, with a typical distribution of some aircraft on high rate is, however, not severe and the concept is quite workable. It was felt that since regular surveillance polling would not optimally be programmed in one or more areas any more frequently than once per epoch (no aircraft in area on high polling rate), that it would be best to provide emergency signalling over a separate low speed A-G channel. An earth coverage receiving antenna in the satellite is utilized.

The supervisory data channel format for System B is essentially identical to that for System A. The emergency signalling channel is added and requirements for same is discussed along with a description of the changes in system operational procedures from System A in the sections which follow.

4.3.2 Supervisory and Surveillance Signal Format

As in System A, the supervisory and surveillance (S&S) signals are multiplexed on a common carrier using a quadrature modulation or similar technique. The carrier is transmitted via a spot beam also handling area communications. The S&S signals are generated and transmitted by the master ASCC.

A table of possible combinations of data rates in the S&S channel with different resultant power divisions between supervisory data and surveillance signals is given in Table 4-5. The first column in the table lists the assumed power for each combination yielding the basic channel quality as indicated in the second column. The third column lists the data rates assumed for each combination and the fourth column lists the power required for each supervisory data rate to obtain a 10^{-5} error rate. The last column then lists the remaining power that may be utilized for the surveillance signals. Utilization of one-half unit of power at a supervisory data rate of 300 bits-per-second would appear to be a satisfactory arrangement. It is also seen that with an allocation of a full unit of power the data-rate can be increased to 1200 bits/second. The implication of this is discussed in conjunction with System C.

In System B, a single unique frequency is used for the S&S channel with all aircraft continuously monitoring this channel. One second lock-up time is allowed each time the S&S

TABLE 4-5

S&S CHANNEL POWER/DATA RATE CONSIDERATIONS

SATELLITE POWER ALLOCATED TO S&S CHANNEL	CHANNEL C/N_o	SUPERVISORY DATA RATE	SUPERVISORY C/N_o	SURVEILLANCE SIGNAL C/N_o
1 UNIT	43	1200	42	36
1 UNIT	43	600	39	41
½ UNIT	40	600	39	33
½ UNIT	40	300	36	37.8

signal is switched into a new beam. The dwell time in each beam is proportional to the number of aircraft in the beam and the number of high rate polls which the system is required to make. For example, if there are only a few high rate polls required and if these are confined to only 1 or 2 beams at any given time, then the switching delays result in only a small increase in the epoch period.

4.3.3 Emergency Signalling

Emergency signalling for System B is accomplished via an earth coverage antenna. Although such an antenna would have approximately 6 dB less gain than a spot beam antenna, the power advantage in the mobile allows voice transmission to be used. However, a low data-rate canned message (150 - 300 bits/second), provides much less chance for interference and greater reliability. When signalling, the canned message would minimally consist of a message as shown in Table 4-4 . It is repeated at irregular intervals so that if, in rare instances, more than one aircraft was transmitting each would be decoded with high probability in a short time.

The emergency signalling procedure is handled in a manner quite different from System A described previously. It should be noted that the procedure described here making use of a one-way channel is usable in System A instead of the one described. Its immediate thruput gives it certain advantages. Figure 4-7 shows a flow diagram of the procedures for Emergency Signalling.

4.3.4 Avionics Instrumentation

The avionics instrumentation for System B is similar to that shown in Figure 4-6. The only difference would be the addition of an emergency message formatter and data modulator. The emergency message is transmitted on a fixed preset frequency which would naturally preempt all other transmissions.

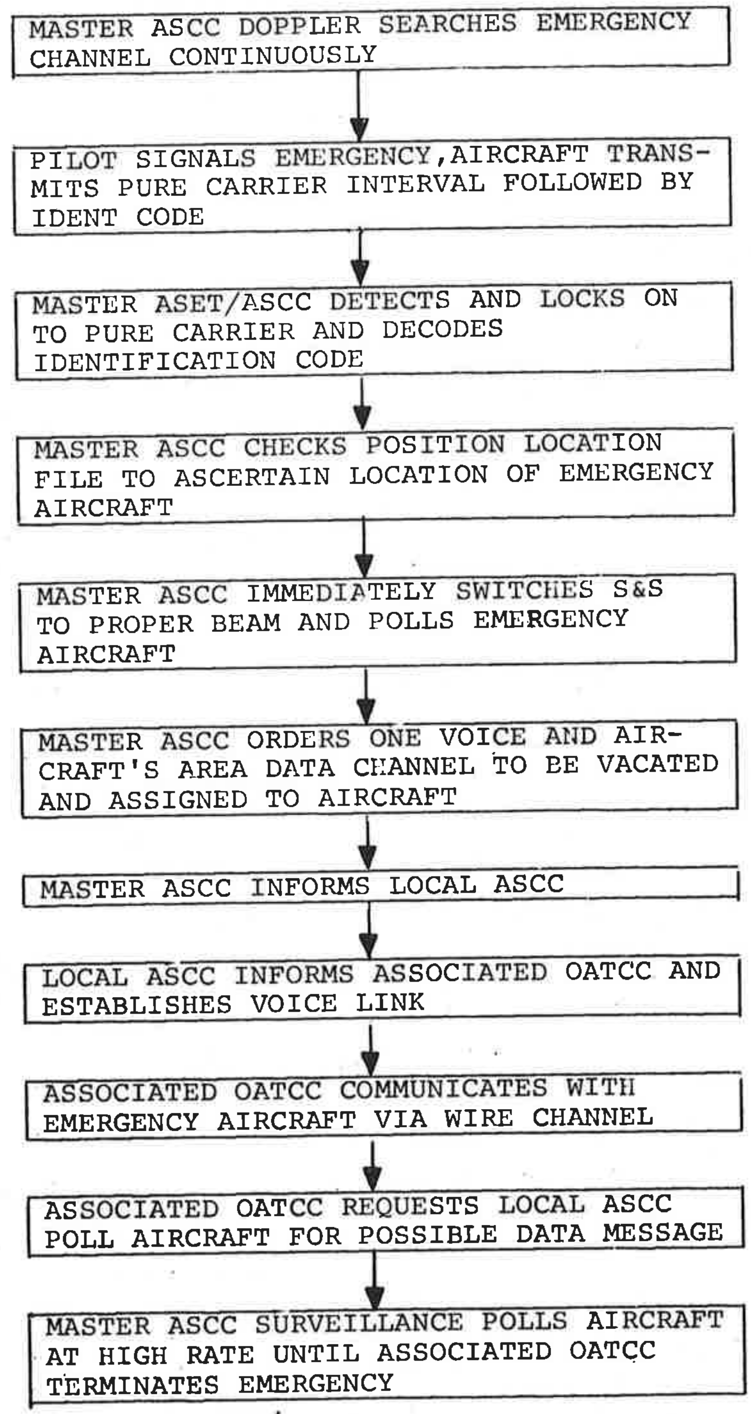


FIGURE 4-7 EMERGENCY SIGNALLING PROCEDURE FLOW DIAGRAM FOR SYSTEM B

4.4 Detailed Description of Selected FDMA System (System C)

4.4.1 Introduction

The design of System C follows as a logical extension to Systems A and B described in previous sections and is based on the following rationale.

1. The Universal Data-Link duplicates within its format many of the channel management functions required of the supervisory signal and is transmitted via spot beams. Since, as in System B, the supervisory signal is also transmitted via spot beams, it is efficient to combine the two signals into a single 1200 bit per second stream based primarily on the UDDL format.

2. Most of the communications to and from a mobile will be to a particular control center via a local ASCC. If that ASCC is allocated a group of voice channels in addition to a data-link/supervisory channel for management most ground or airborne requests can be handled on a local basis. This distributed control will eliminate the necessity for processing of all ring-up and grants from the master ASCC and reduce G-G supervisory message traffic.

3. It is shown in Appendix C and in Section 3.2.8.4 that if the waiting time allowances are not too restrictive the implementation of a distributive control discipline does not impose severe penalties on the allowable message loading per channel.

4. If the surveillance signal is quadrature modulated on the data-link carrier, the additional satellite power for this signal is negligible. This is shown on Table 4-5 which indicates that required quality for both data and surveillance can be obtained with one (1) unit of satellite power. The surveillance signal can be easily dropped if not needed or desired for system operation.

5. An important consequence of combining data, supervision and surveillance on a single carrier is that the number of simultaneous receiving and transmitting channels in the Avionics instrumentation is reduced.

6. If each ASCC separately polls a segment of the total aircraft population, the polling epoch duration can be reduced, thereby reducing the average delays in transmitting and acknowledging airborne channel requests. The use of separate polling channels by each ASCC will also reduce the amount of beam switching required. This is especially the case if spot beam coverages are coincident with traffic control area coverage.

7. Each ASCC performs its own surveillance polling and position-location computation. Therefore, the need for transfer of this data via satellite G-G links is eliminated.

4.4.2 Overall System Organization and Operation

The Frequency Division Multiple Access System, which was selected for detailed study, provides for management and control of the satellite communications services and position surveillance ranging by means of a polled data link channel. A baseline system is described in which the supervisory information transmission required for satellite operation is incorporated into the Universal Digital Data Link (UDDL) format currently being developed. Also, under the concept, the surveillance ranging signal is multiplexed onto the data link carrier utilizing a quadrature modulation technique. Thus, the digital data-link carries digital message data, a signal for surveillance ranging, and supervisory data for controlling voice channel assignments and surveillance polling.

One of the ASCC's in the system is designated as master with the following responsibilities:

1. Allocation of communications channels to each of the local ASCC's in the system.

2. Reallocation of channels on the basis of varying queue status.
3. Allocation of one or more one-way A-G channels for rapid access.

Each local ASCC designates at least one of the channels assigned to it as a supervisory/surveillance/data (SS&D) channel and uses it to manage the voice channels allocated, transmit and receive digital data, and control surveillance polling. The aircraft under control of the oceanic traffic control centers (OATCC) which interface with a given ASCC continuously monitor the data-link channel emanating from that ASCC thereby maintaining lock-on and synchronization. The SS&D signal is transmitted as a continuous 1200 BPS bit stream which is sub-divided into fixed-block length messages whose minimum duration is compatible with the surveillance signal.

Figure 4-8 shows the system SS&D signal flow or routing. Two ASET/ASCC combinations, one a master and the other a local, are shown for discussion purposes. The system concept is however not limited to two ASET/ASCC's. As shown in the diagram, each ASCC transmits the SS&D signals to all aircraft under its control via spot beams. Each aircraft returns the surveillance signals via both satellites on a separate frequency associated with the SS&D channel to which the aircraft is assigned. Thus, each satellite provides a separate A-G surveillance reply channel for every ASCC in the system.

The local ASCC's may thus compute position location for the aircraft under their individual supervision. Each time an aircraft is polled, it sequentially replies on a single frequency with multiplexed SS&D information. This is shown in Figure 4-9. Each transmission contains guard band and acquisition preamble consisting of 13 msec of carrier followed by 27 msec of bit synchronization signal. This assumes availability of doppler offset information.

All A-G SS&D messages are transmitted via two paths providing full downlink supervisory and data message redundancy.

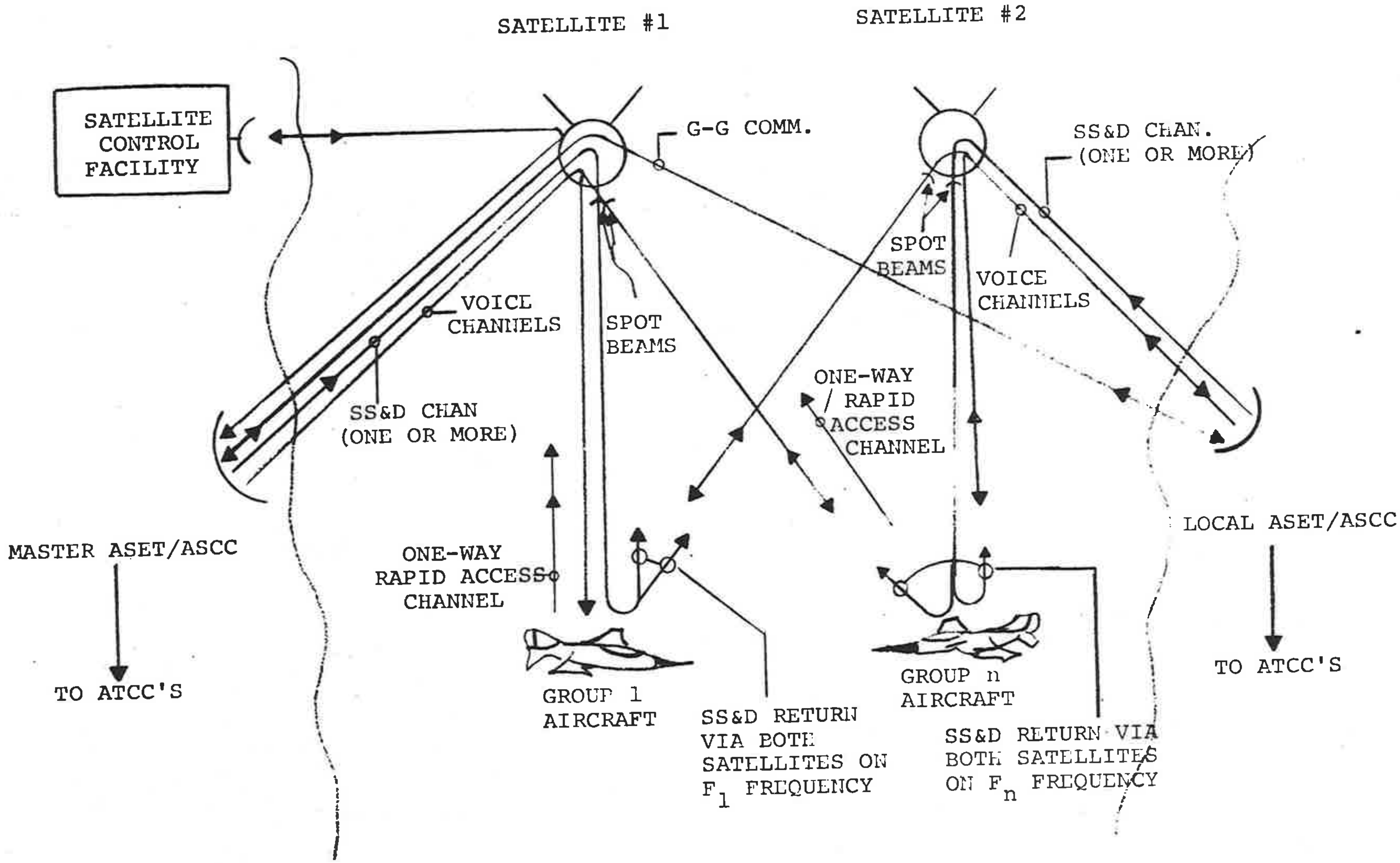


FIGURE 4-8. VOICE AND SUPERVISORY, SURVEILLANCE AND DATA SIGNAL FLOW DIAGRAM

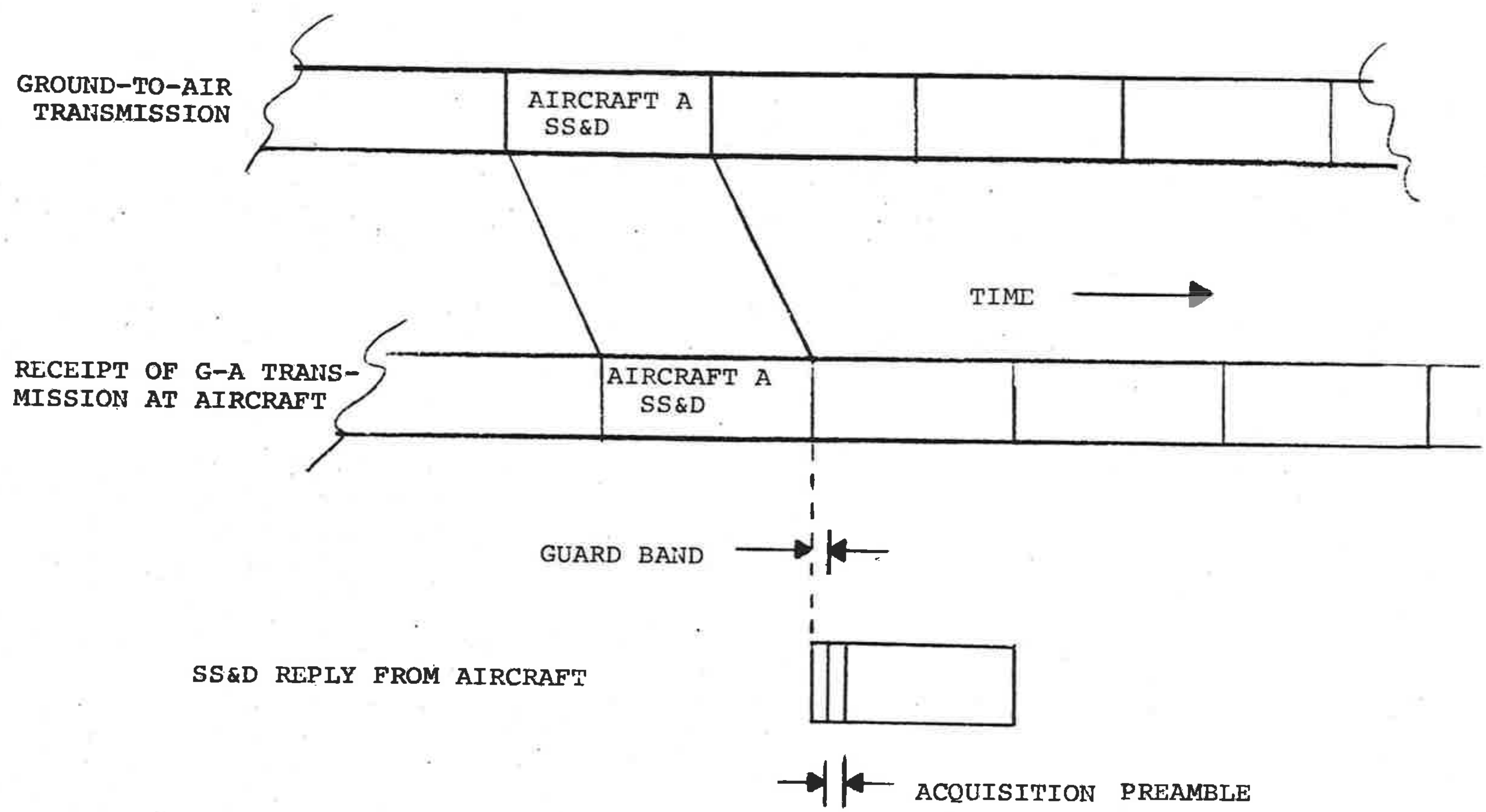


FIGURE 4-9. SS&D SIGNAL FORMAT

While each transmission of an SS&D message contains its own error checking, the redundant transmission of supervisory and data message will considerably enhance the probability of receiving correct messages.

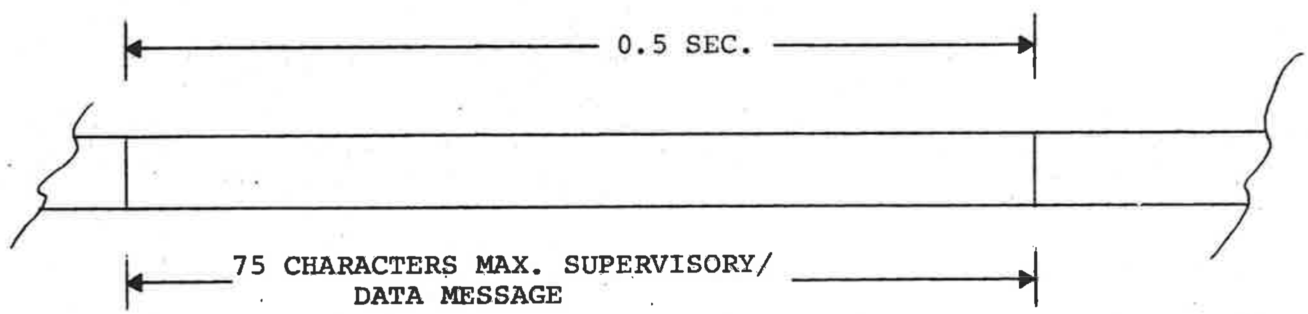
Beam or channel switching in this system is minimized. For the SS&D channel, it is only required where the oceanic area serviced by a particular ASCC is covered by more than one spot beam and it is not resource effective to put a channel in each beam. Voice channels are switched among beams subject to the constraints of the satellite design as discussed in Section 3.2.8.2. Whenever an SS&D channel is switched to a new beam, one second of preamble (See Appendix E) is transmitted to permit all aircraft in that beam to lock-up.

4.4.3 SS&D Format

Primarily, the message block length was selected to be most compatible with the expected data message characteristics and to permit processing of a maximum number of aircraft for a given allowable surveillance up-date rate. Based on message statistics available, a slot duration equal to about 75 characters (one-half second slot) appears to be a reasonable choice for a baseline system. It will permit transmitting most messages in a single slot although some messages would require multiple blocks. In the G-A direction, 57 characters are then available for message text and supervision over and above the characters required for overhead (see Figure 4-10).

In the A-G direction, guard time is required as well as time for lock-on and acquisition (see Figure 4-11). For each of these, about 40 milliseconds is allowed or a total of about 80 milliseconds. The resulting message length is 63 characters with 45 characters available for message text, altitude reply and supervisory information.

At the above message rate, there are 240 message slots in a two minute epoch. For this, in excess of 190 aircraft

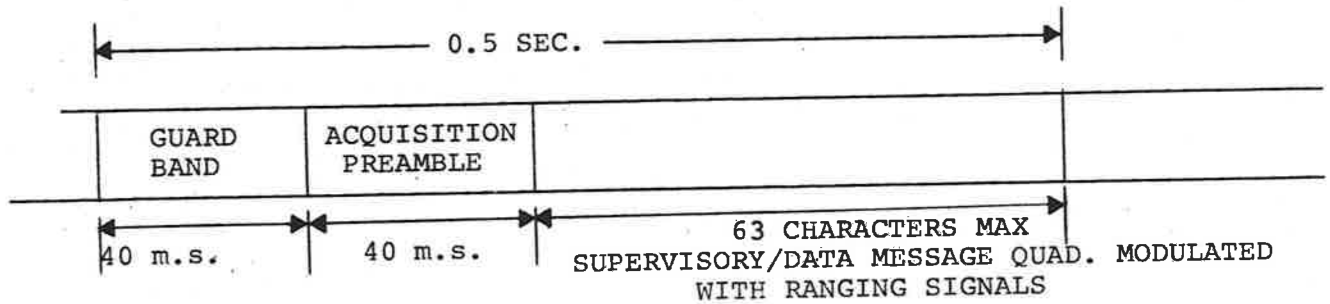


SUPERVISORY/DATA MESSAGE FORMAT QUAD. MODULATED WITH RANGING SIGNALS

ITEM	UDDL CHARACTERS
Character Sync	2
Start of Header	1
Mode	1
Aircraft Ident.	7
Technical Acknowledgement (ACK/NACK)	1
Label	2
Start of Text	1
Data Message Text.	57
End of Text (or Block)	1
Block Check Sequence	2
TOTAL	75

NOTE: A standard pattern is transmitted to fill unused slot time.

FIGURE 4-10. UPLINK SS&D FORMAT



SUPERVISORY DATA MESSAGE FORMAT

ITEM	UDDL CHARACTERS
Character Sync	2
Start of Header	1
Mode	1
Aircraft Ident.	7
Technical Acknowledgement (ACK/NACK)	1
Label	2
Start of Text	1
Data Message Text	45
End of Text (or Block)	1
Block Check Sequence	2
TOTAL	63

FIGURE 4-11. DOWNLINK SS&D FORMAT FOR REACQUISITION POLLING

can be handled on a low-rate poll while several are polled at a higher rate, with sufficient slots remaining to handle multi-block messages and any other special supervisory call-ups. Based on this, no more than three (3) data channels assigned to up to three ASCC's would be required to handle 1980 expected peak airborne count.

4.4.4 Supervisory Information

In addition to serving the function of addressing aircraft for message transmission and surveillance polling, it is required that the supervisory information also be transmitted via the data-link channel. The mode, label and ack/nak characters of the UDDL, which are contained in the message overhead, perform many of these required functions. It is, therefore, felt that the AEROSAT supervisory requirements can be provided within a common or compatible format with some modifications and/or additions to the message overhead.

The additional AEROSAT supervisory information required is shown in Tables 4-6 and 4-7. This information can be handled in two ways. One method is to use the standard UDDL label characters to transmit and receive specific data messages. The altitude return can be included as part of the standard preamble for an A-G message.

However, it is probably more desirable to incorporate the supervisory data as part of the standard message in such a manner that other message information can be included in the same transmission. This will increase overall channel utilization efficiency by eliminating the requirement for special supervisory messages. One way of accomplishing this is to modify the standard format somewhat for satellite operation. For example, 3 character spaces reserved for AEROSAT supervision functions can be made part of the overhead of a satellite message. The 24 bits involved can be easily encoded to handle the information in Table 4-6 and Table 4-7. A set of mode characters can be used to identify the

TABLE 4-6

SATELLITE DATA-LINK SUPERVISORY FUNCTIONS

AIR-GROUND

		BITS
1.	Voice Channel Request/Priority	2
	Voice Addressee Category	2
2.	Multiple Data Transmission Request	1
	Data Priority	1
3.	Aircraft Altitude	11
		17 Bits

TABLE 4-7

SATELLITE DATA-LINK SUPERVISORY FUNCTIONS

GROUND-AIR

		BITS
1.	Voice Request Acknowledge	1
2.	Voice Ring-Up/Vacate	2
	Channel Address	5
3.	Data Channel Reassignment	1
	Channel Address	5
4.	Random Entry Acknowledge	1
5.	Initial or Reacquisition Designator	1
		16 Bits

transmission of the special satellite format and hence complete compatibility with non-AEROSAT data message can be maintained. This method of handling AEROSAT supervisory information is essentially a multiplexing of an AEROSAT supervisory channel into the data-link channel. An overall information transmission saving is obtained by eliminating duplication of addressing, polling and bit check sequences.

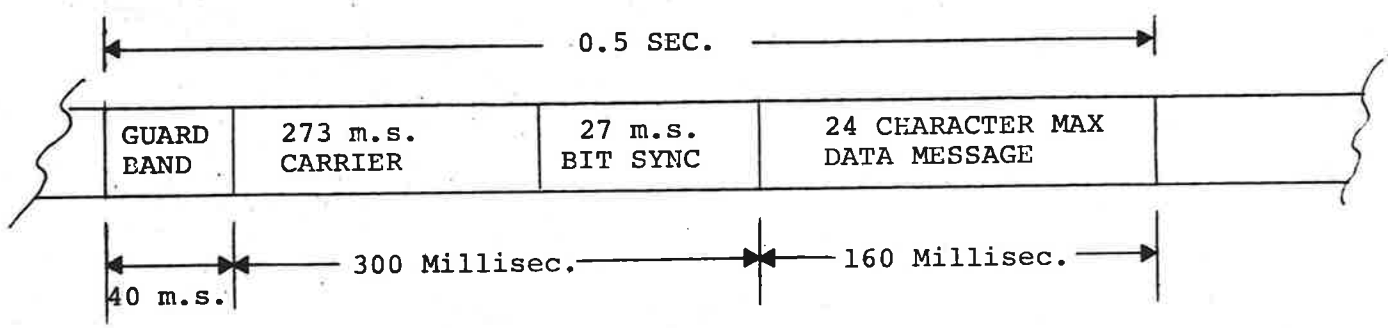
Either of the methods of handling supervisory information via the data-link channel is feasible. The final choice will depend to a great extent on the ease with which either can be handled in typical UDDL format instrumentation.

4.4.5 Acquisition Format

Because of unknown doppler and drift tuning effect, the reply from an aircraft must begin with transmission preamble. As shown in Appendix E, with use of modestly sophisticated acquisition tuning techniques at the ASET/ASCC, it will be possible to obtain reliable initial acquisition on receipt of approximately 273 milliseconds of pure carrier transmission for maximum doppler and drift detuning followed by 27 msec of bit sync characters. The doppler, information as determined by this initial acquisition, is stored in memory in the ground computer for use in setting up receiver tuning for the next polling acquisition of the same aircraft. A typical downlink format for acquisition for initial entry is shown in Figure 4-12. 300 milliseconds of preamble is followed by 160 milliseconds of data, which is sufficient to accommodate 24 eight bit characters (including character parity). In the standard UDDL format, a six character maximum data message is provided. This is more than adequate to accommodate the AEROSAT supervisory message as listed in Table 4-6 and would thus be sent.

4.4.6 Rapid Access Channel Signal Format

Signalling a request for emergency or random (pop-up) entry, is handled by a dually redundant one-way slow-speed data channel. This special channel is transmitted aircraft-to-ground via



DOWNLINK REPLY DATA FORMAT (NO RANGING SIGNAL MODULATION)

TYPICAL INITIAL ACQUISITION REPLY DATA MESSAGE

	UDDL CHARACTERS
Character Sync	1
Character Sync	1
Start of Header	1
Mode	1
Aircraft Ident.	7
Technical Acknowledgement (ACK/NACK)	1
Label	2
Start of Text	1
Text	6 max (AEROSAT Supervisory)
End of Text	1
Block Check Sequence	2
MAX. TOTAL	24 Characters

FIGURE 4-12. INITIAL ACQUISITION DOWNLINK SS&D FORMAT

an earth coverage antenna operating at 300 bits per second. This signal quality attainable is about 43 dB-Hz (See Table 2-1). To maintain the lowest possible avionics cost in providing one-way emergency or random access signalling, it is suggested that the standard UDDL Automatic data readout (ADR) feature be utilized to form the message. The AEROSAT accessing instrumentation would be so arranged that when the pilot signals either an emergency or random entry request (via pushbutton), the UDDL instrumentation is commanded to emit a standard position-report-formatted ADR data stream to the AEROSAT instrumentation for transmission. The data is clocked out at the 300 bits/second rate following the transmission of a suitable transmission preamble. A special label is automatically selected to indicate either the signalling of an emergency or a desire for random entry. This special label could be inserted in the UDDL instrumentation on AEROSAT command.

4.4.7 System Accessing

4.4.7.1 General

The total number of SS&D channels in the system is a function of the total aircraft population and the number of ASCC's. The number of beams and the particular coverage they provide also influence the number required. Although control area boundaries do not necessarily have to be coincident with beam boundaries, it seem obvious that conveniences will result if any given control area is wholly within a beam. Switching problems and allocation are simplified if SS&D channels can be more or less permanently allocated to a particular beam. Nevertheless, traffic patterns are such that switching and/or change in channel allocation among centers will be required.

For example, a North American ASET/ASCC controlling the Carribean area and the North Atlantic, each covered by a separate beam, could utilize an SS&D channel per beam. However, at peak traffic in the Carribean zone, the SS&D channel from the North Atlantic might be switched back and forth to help relieve queues. Aircraft monitoring the channel which is switched back and forth between beams must reacquire each time the channel is switched. If, at times, the traffic in the total area controlled by an ASCC can be handled by a single SS&D channel switched at intervals between beams, an extra channel could be freed for voice service.

The waiting times associated with voice channel accessing is more critical than for data traffic. The queueing analyses indicate that for acceptable waiting times the message load per channel must be kept below prescribed limits. Therefore, channel allocation among centers must be sensitive to message loading so that some channels are not overloaded. Appendix F discusses the effect of unbalanced allocation and presents a suggested procedure for reallocation when unbalances occur.

4.4.7.2 Eclipse Operation

For eclipse conditions it is assumed that the eclipsed satellite has no G-A transmission capability but does have sufficient A-G transmission capability, using stored energy, to support the reply transmission for the SS&D channels. Depending on traffic conditions and the number of SS&D channels required, the remaining voice channel facility can drop to a low of two or three during an eclipse. It seems desirable, therefore, to operate with as few SS&D channels as possible at all times thus saving more of the scarce channels for full duplex voice service at occurence of an eclipse.

Referring to Figure A-1 in Appendix A, we note that the eclipse of the satellite at 60° occurs at a peak traffic period. Thus, it seems a best strategy would be to avoid use of this satellite entirely for uplink SS&D channel transmission. This avoids the shifting of many aircraft to a new channel for SS&D service at a peak traffic time. However, voice channels may be in short supply during this period so that the number of SS&D channels may also have to be reduced.

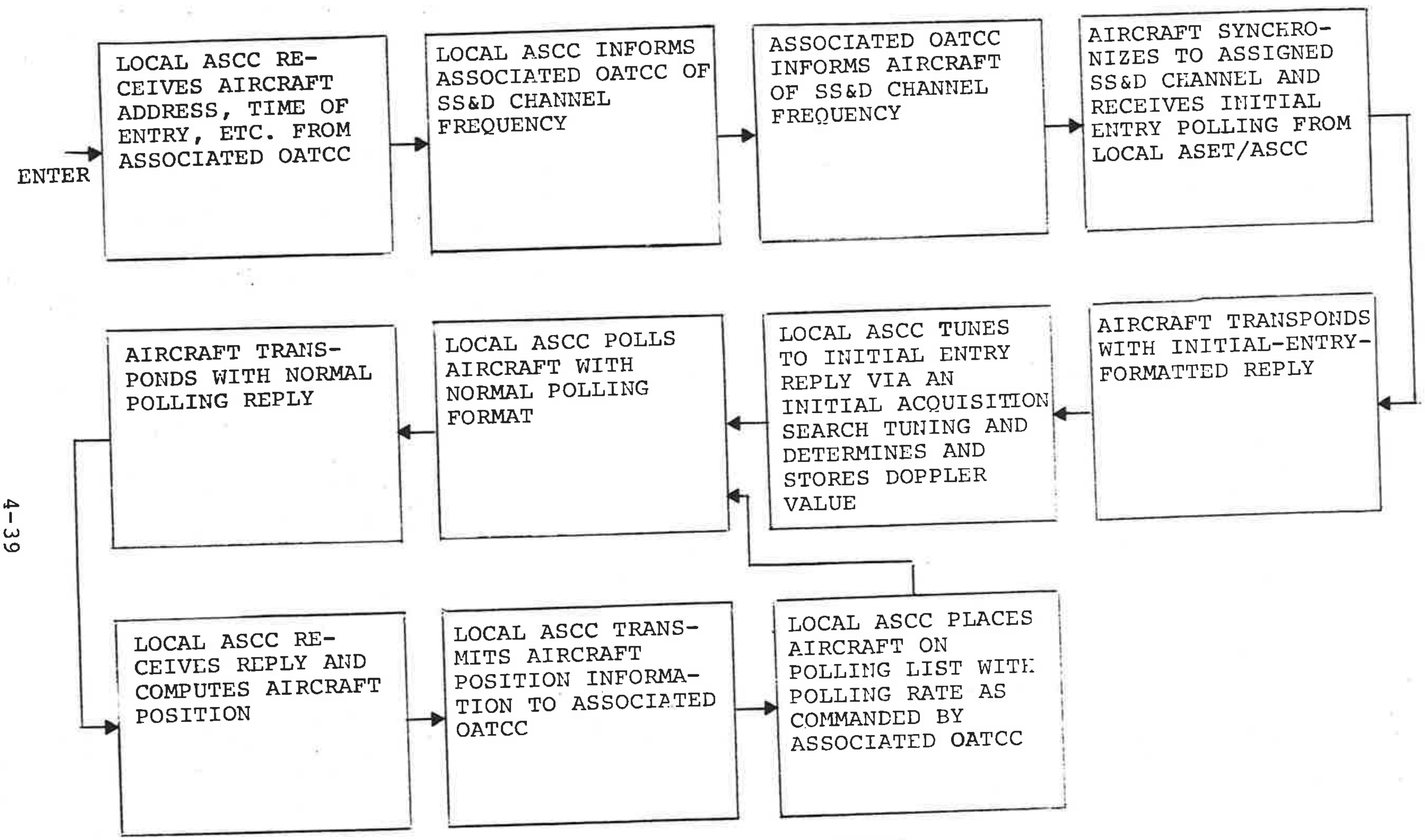
4.4.7.3 System Accessing Procedures

System accessing procedures, for an AEROSAT system, basically involve system entry and communications facilities management. Entry accessing includes the initial entry of aircraft into the system either as a normally coordinated entry or as a random entry. The latter is signalled by a request via an A-G rapid access signalling channel also useable by any aircraft, already in the system, to signal an emergency situation. Communication facilities management involves the control and assignment of voice and data channels for transmission of information between controllers or airline offices and any aircraft supervised by the AEROSAT system. Based on the system design features and operating strategies as described in preceding paragraphs, flow diagrams and accompanying descriptive narratives of the procedures for system entry and communications facilities management are presented in the following.

4.4.7.3.1 Procedures for Normal Entry

The procedures flow diagram, of Figure 4-13, shows the process of normal entry beginning with the local ASCC receiving all pertinent data on the aircraft about to leave continental control and entering the oceanic control system area. The local ASCC then informs the associated OATCC to which SS&D channel/frequency the entering aircraft shall tune. The associated OATCC in turn informs the aircraft of the SS&D channel for his flight area. The entering aircraft could, for example, be assigned to the proper SS&D channel by a data link command included in the continental VHF UDDL system for a completely automatic hand-off, or alternatively could tune manually per voice relayed information.

The aircraft then synchronizes automatically to the continuously received SS&D channel data stream and receives an initial entry polling command from the local ASCC. The aircraft transponds with an initial-entry-formatted reply (See Figure 4-12). A tuning correction is stored in computer memory and is used in subsequent normal polling. The local ASCC receives the reply via two satellites and uses the ranging modulation information multiplexed onto the composite carrier, to determine range via the



OATCC - OCEANIC AIR TRAFFIC CONTROL CENTER
ASSOCIATED OATCC - OATCC DIRECTLY CONNECTED TO ASCC
LOCAL ASET/ASCC - ASET/ASCC SUPERVISING SUBJECT AIRCRAFT

FIGURE 4-13. NORMAL ENTRY PROCEDURE FLOW DIAGRAM FOR SELECTED FDMA SYSTEM two satellite paths. Aircraft altitude received as part of the supervisory data is then used with the ranging information to compute aircraft location. The local ASCC then transmits aircraft position coordinates to the associated OATCC. The local ASCC now continues the newly acquired aircraft on the active polling list at a rate as specified by the associated OATCC.

4.4.7.3.2 Random Entry or Emergency Signalling

A separate A-G frequency channel is set aside for transmission of a UDDL formatted and generated message at a lower, 300 bit-per-second data rate via an earth coverage antenna through both satellites. Flow Diagrams, showing procedures for signalling via the rapid access channel, are shown in Figures 4-14 and 4-15.

As shown in Figure 4-14, the pilot, after synchronizing to the SS&D channel serving the area of his location (presumed known by the pilot), initiates an automatic entry process by depressing a pushbutton. This causes the UDDL instrumentation to emit a position report read out on automatic data readout (ADR) suitably labeled as a random entry request. All ASCC's in the system monitor and receive the rapid access channel call. Based on the location of the aircraft, the appropriate ASCC transmits an initial acquisition poll addressed to the signalling aircraft. The aircraft transponds with an initial acquisition poll reply enabling the ASCC to acquire the aircraft and store its doppler value. Using this tuning information, the ASCC transmits a normal poll to which the aircraft transponds with a full format reply and a data message indicating desired flight plan. The ASCC receives the reply, computes aircraft position, and forwards the aircraft position coordinates along with the data message to the associated OATCC. The ASCC also rings up the aircraft on a voice channel, notifies the associated OATCC and completes the voice connection. The OATCC then coordinates full entry of the aircraft into the system using voice and data facilities as appropriate.

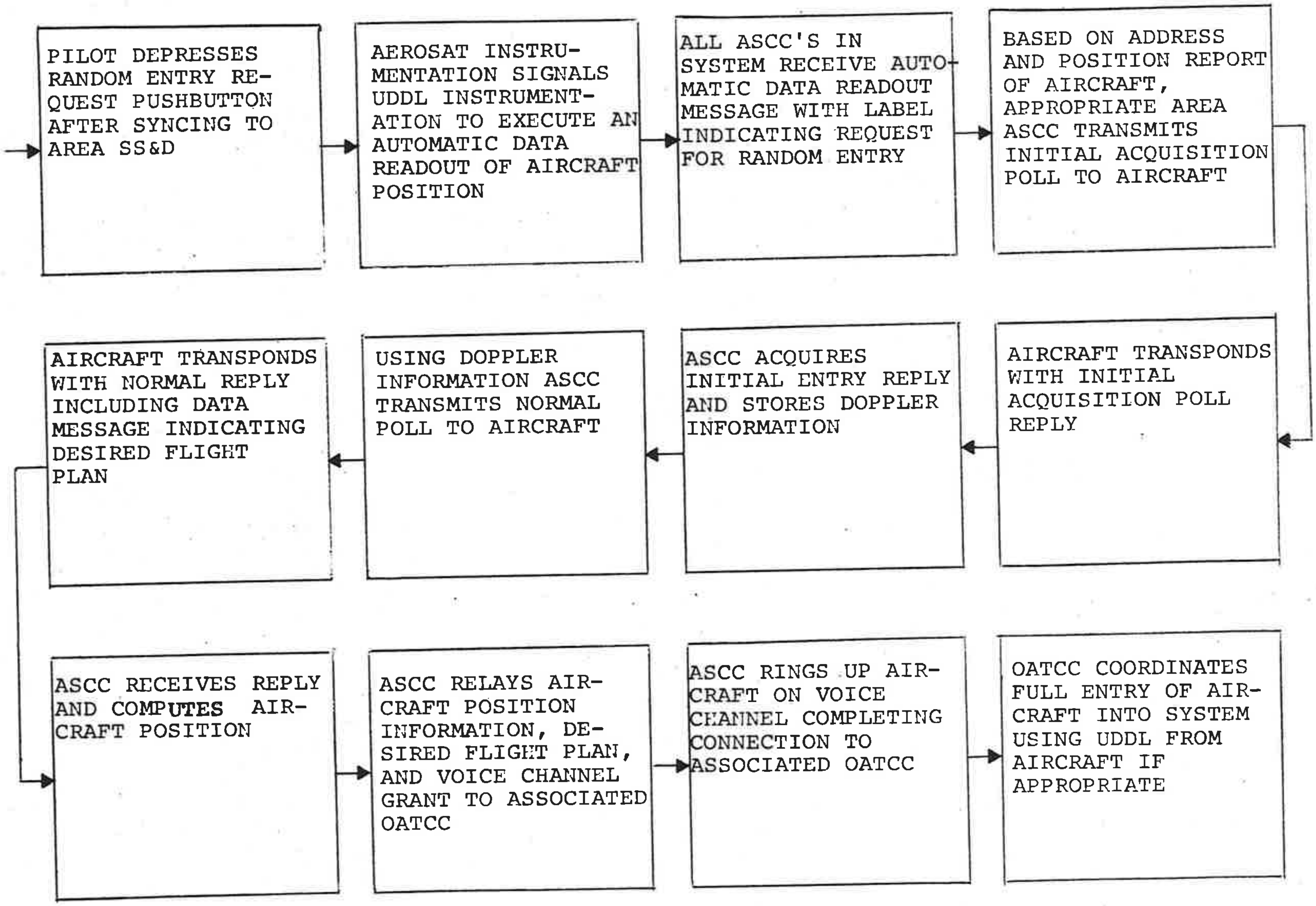


FIGURE 4-14. RANDOM ENTRY SIGNALLING VIA RAPID ACCESS CHANNEL

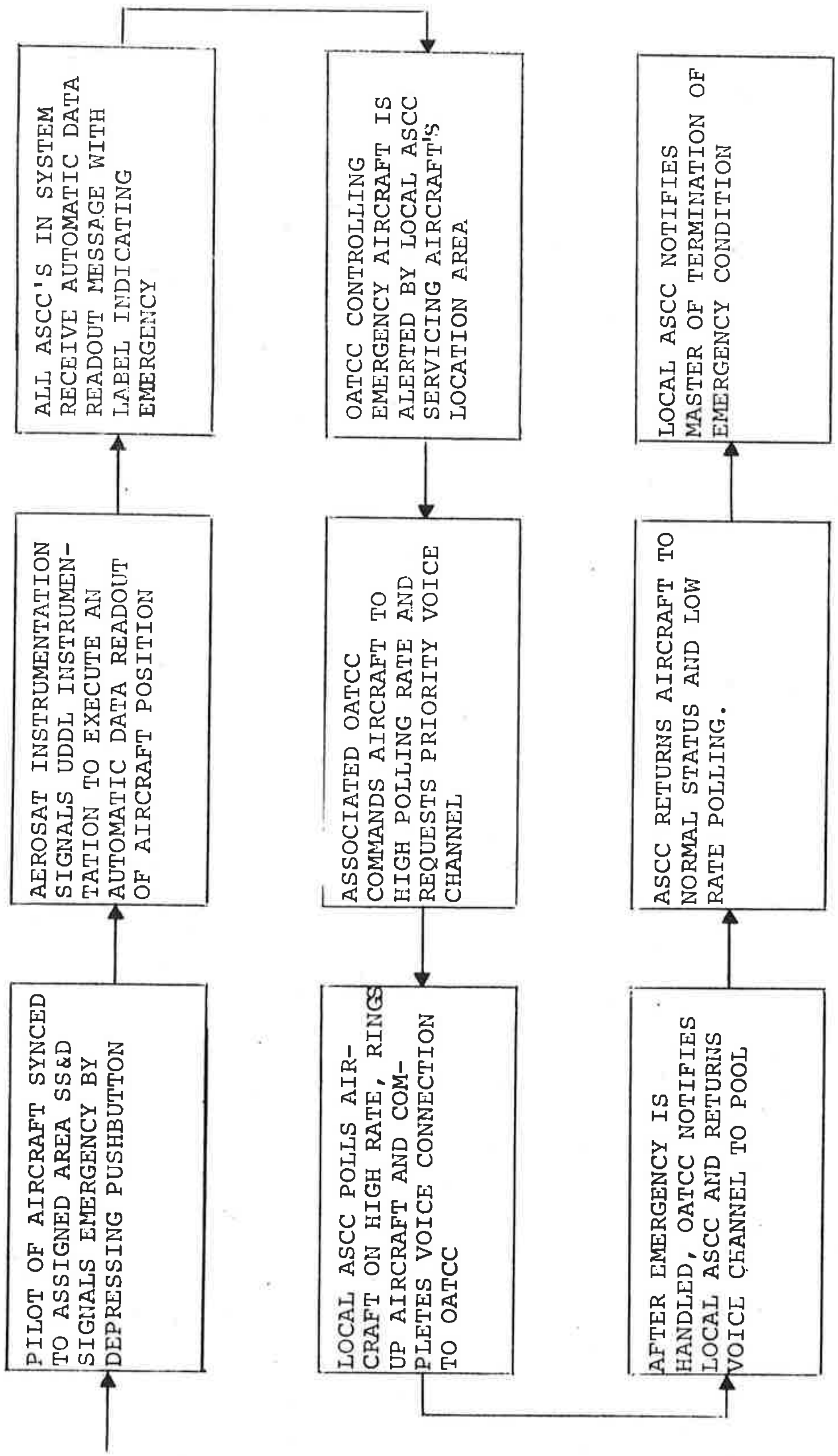


FIGURE 4-15. EMERGENCY SIGNALLING VIA RAPID ACCESS CHANNEL

Referring to Figure 4-15, an emergency is signalled by the pilot depressing a pushbutton. The AEROSAT instrumentation signals the UDDL instrumentation to execute an automatic data readout of aircraft position as read from on-board navigation gear. Although the AEROSAT systems also determines position of the aircraft independently, aircraft position as read from on-board navigation gear should be of value. All ASCC's monitor the emergency channel.

The ASCC covering the area in which the aircraft is located alerts the associated OATCC. The associated OATCC commands a high polling rate for the aircraft and requests a voice connection to the aircraft and the local ASCC complies.

The emergency is then handled by the OATCC, and when alleviated, notifies the local ASCC. The voice channel is returned to the pool, the aircraft is returned to normal polling rate as appropriate, and the master is notified of clearing of the emergency.

4.4.7.3.3 <u>Communications Facilities Accessing</u>

Flow diagrams and narrative descriptions for procedures involved in use of the communications facilities are presented in the following paragraphs. The procedures as given assume the master allocates channels to the ASCC's in the system and is kept informed at all times of queue status at each ASCC for possible adjustments in facilities allocation as already discussed.

The procedures and data flow for servicing an aircraft voice request in System C is shown in Figure 4-16. The procedure begins with the pilot setting up the address and message priority and depressing a voice request button. The request is received by the aircraft's supervising ASCC on the next surveillance polling and the request goes into the voice request queue.

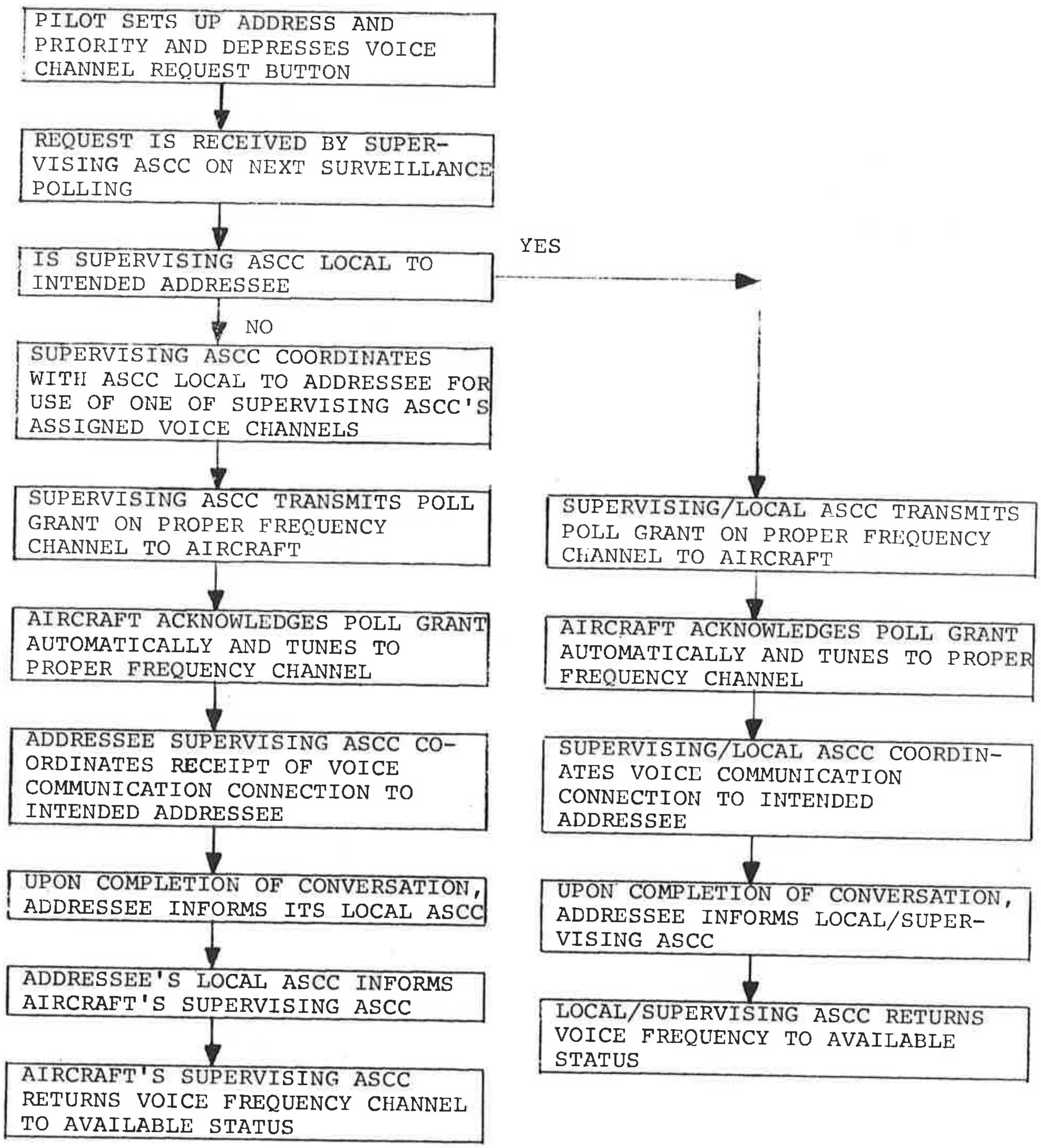


FIGURE 4-16. AIRCRAFT VOICE REQUEST PROCEDURE AND DATA FLOW FOR SELECTED FDMA SYSTEM

The supervising ASCC checks to determine if the intended addressee is local to itself (i.e., is addressee directly connected) and if it is, and consistent with channel availability and priority, transmits a grant stating frequency channel to the aircraft. The aircraft acknowledges on downlink poll response and automatically tunes to the proper frequency channel. The supervising and, also the local ASCC for this case, coordinates establishing a voice communication connection to the intended addressee. Upon completion of the connection, the addressee informs the local ASCC. The local ASCC then returns the voice channel to available status for further assignment.

For the case where the supervising ASCC is not also the ASCC for the intended addressee, the supervising ASCC must coordinate with this ASCC, local to the intended addressee, to tune to one of the aircraft supervisory ASCC's voice channel frequencies to receive the voice communication. After so doing, the aircraft-supervising ASCC transmits a poll grant indicating which frequency to contact addressee's local ASCC. The addressee's ASCC coordinates establishment of connection to addressee. Upon completion of conversation, the addressee informs it's local ASCC which in turn informs the aircraft-supervising ASCC of vacating of channel frequency. Supervising ASCC then returns the voice channel frequency to available status for further assignment.

Data transmission from the aircraft is initiated on a regularly polled basis over the SS&D channel as previously described. Procedurally, the aircraft crew sets up the message for transmission in some aircraft storage. The means for composing the message is the subject of other previous studies and will no doubt vary from aircraft to aircraft. Whatever the specific means the aircraft crew or automatic equipment uses to compose a message, it must be completely composed in proper format for automatic transmission at the instant of polling. If the message is longer than can be handled in the fixed block length, the on-board instrumentation must automatically format same into multiblock form. Also, if the aircraft has additional messages ready for transmission, the instrumentation raises the Multiple Data Transmission Request bit to the true state (and the priority bit if appropriate) in the supervisory message. The ground will thus repoll the aircraft immediately if the message has a priority tag or otherwise repoll typically at the end of the polling epoch.

The received data message would be transmitted to its intended destination under ASCC computer control per UDDL format addressing on a store-and-forward basis. Depending on the location of the message addressee, forwarding of the message may require use of G-G satellite communication facilities.

The procedures and data flow, for either an ATC controller or an airline to request a voice channel to a specific aircraft, is shown in Figure 4-17. It is assumed that airline voice requests are processed through an ARINC message switching terminal where queue management for such requests may first be applied. For either airline or controller, the voice channel request is sent to the local ASCC and the local ASCC determines first whether or not the addressee is assigned to one of the supervisory/data channels under its command. If the aircraft is so assigned, the local ASCC rings up the aircraft via the appropriate supervisory/data channel. The aircraft acknowledges automatically by a poll response and a verbal acknowledgement on the assigned voice channel. The airline or controller electrically signals the local ASCC of completion of conversation to dismiss the channel, whereupon the ASCC computer automatically returns the voice channel to available status.

If the addressed aircraft is not supervised by the local ASCC, the local ASCC must coordinate with ASCC that is supervising the addressed aircraft to command it to tune to one of frequency channels assigned to the local ASCC. The ASCC supervising the aircraft rings up the aircraft, assigns it to the

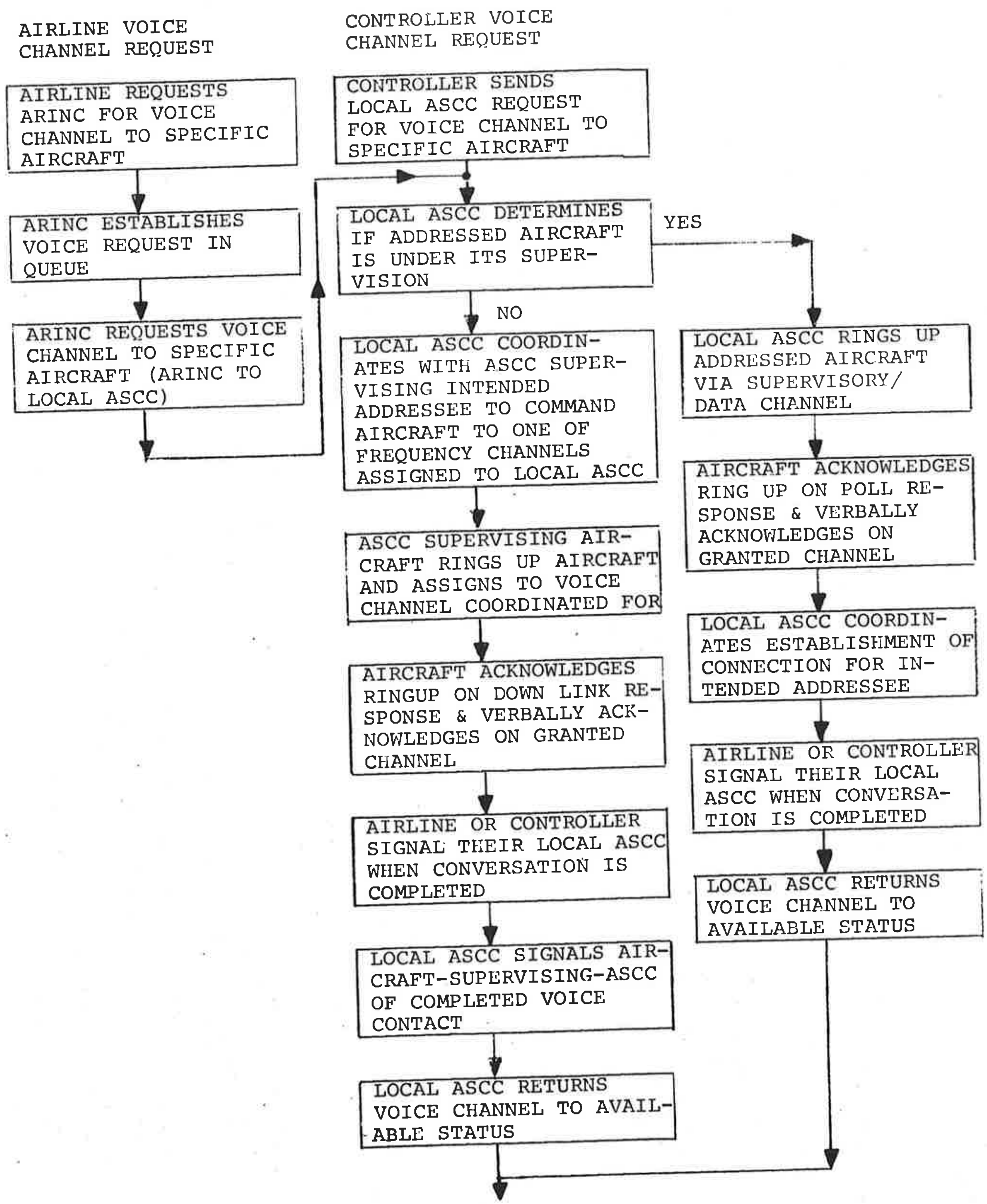


FIGURE 4-17. AIRLINE OR CONTROLLER VOICE REQUEST PROCEDURES DIAGRAM FOR THE SELECTED FDMA SYSTEM

voice channel arranged for with the local ASCC. The aircraft acknowledges the ring-up on downlink poll response and verbally acknowledges on the granted channel directly to the party requesting the voice channel via the requestor's local ASCC. The local ASCC will have established a connection from its receiving facility to the requesting facility, either the controller or airline.

The airline or controller signal their local ASCC when conversation is completed. This local ASCC informs the aircraft-supervising ASCC of completed voice contact (so this facility knows the aircraft can be reached on voice by another party) and the local ASCC returns the voice channel to available status.

The procedure and data flow for an ATC controller or an airline operator to send a data message to an aircraft is shown in Figure 4-18. Again, as in other systems investigated, it is assumed that the airline sends any data message via a local ARINC message switching center. With priority considered and affixed, ARINC or the controller sends any data message to the local ASCC. The local ASCC checks to see if the aircraft to which the data message is addressed is assigned to any one of its supervisory/data channels. If it is, this local, and, also supervising ASCC for this case, sends the message on the next regular uplink polling or on special polling if priority of message warrants it.

If the aircraft is not assigned to a supervisory/data channel managed by the local ASCC, the local ASCC forwards the data message to the ASCC supervising the aircraft on a store and forward basis via G-G facilities. The supervising ASCC relays the data message to the aircraft with full consideration for priority of the message.

4.4.8 Avionics Instrumentation

An overall block diagram of the Avionics system instrumentation for the selected FDMA system is shown in Figure 4-19.

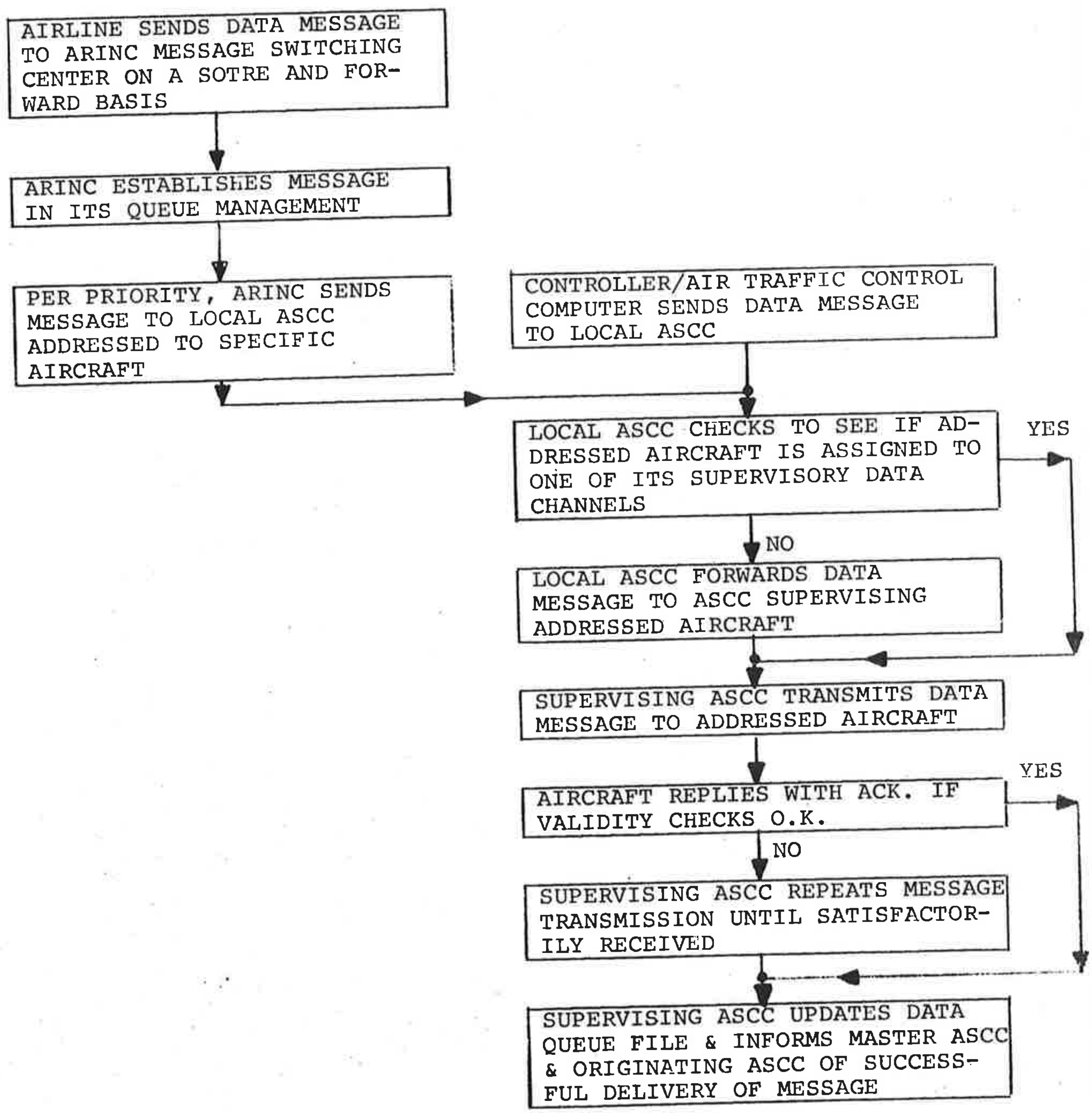


FIGURE 4-18. AIRLINE OR ATC CONTROLLER PROCEDURE FOR TRANSMITTING A DATA MESSAGE TO AN AIRCRAFT IN THE SELECTED FDMA SYSTEM

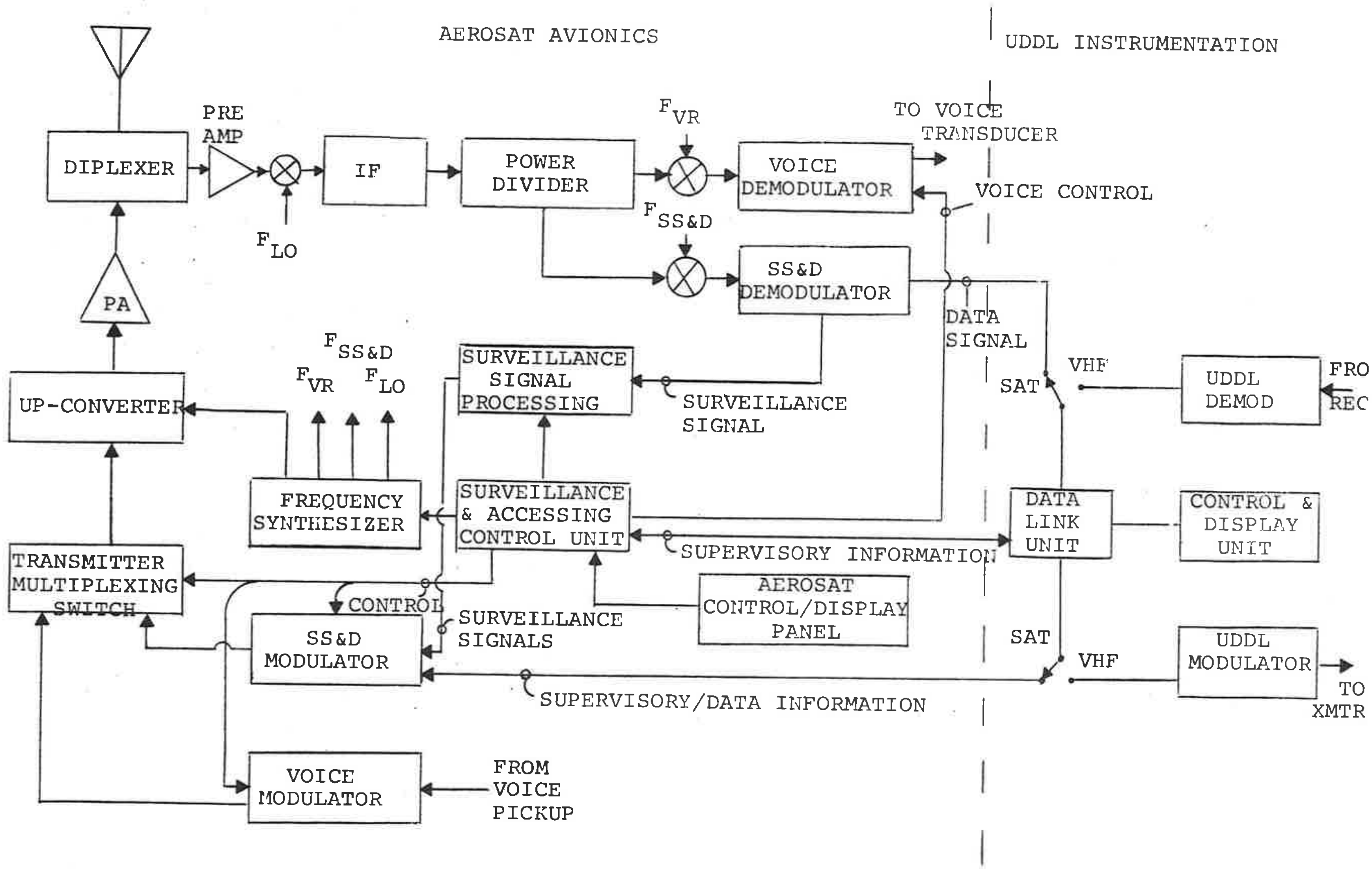


FIGURE 4-19. AVIONICS SYSTEM OVERALL BLOCK DIAGRAM (SYSTEM C)

The system has the capability of receiving two signals simultaneously with separate tuning capability for each. The signals received are voice and the SS&D data and surveillance composite. The voice signal is fed to a standard modem compatible with any of the modulation techniques proposed for AEROSAT. The SS&D modem processes DCPSK data and the surveillance signal multiplexed in quadrature with it. On downlink, only one signal is transmitted at a time. Voice transmission will always be interrupted momentarily to allow transmission of a reply to uplink polling. This procedure is chosen to allow use of a Class C power amplifier for greater efficiency and power output.

AEROSAT supervisory information is fed to and from the Data Link Unit (DLU) of a UDDL airborne terminal. This terminal must be suitably designed to extract and add this information, on uplink and downlink transmission respectively in format as given in Tables 4-6 and 4-7 . The DLU is the central control and distribution unit of the UDDL terminal. As shown in Figure 4-18, it is assumed the UDDL instrumentation is shared between VHF and AEROSAT service.

Although it may be technically feasible to include all AEROSAT control and display functions on a combined UDDL control and display unit, it is shown separately here.

4.4.8.1 Avionics Instrumentation and Cost Analysis

For purposes of analyzing the avionics in greater detail, the block diagram of Figure 4-19 has been broken into major assemblies. These are then used to establish preliminary cost estimates. They assume limited production in the late 1970-1980 time period and are based on our experience in building similar equipments. They are subject to major refinements as the system design is detailed. The overall costs are summarized in Table 4-8 .

4.4.8.1.1 RT Assembly

Figure 4-20 is a block diagram of the RT assembly. It is typical of FDMA systems and is essentially independent

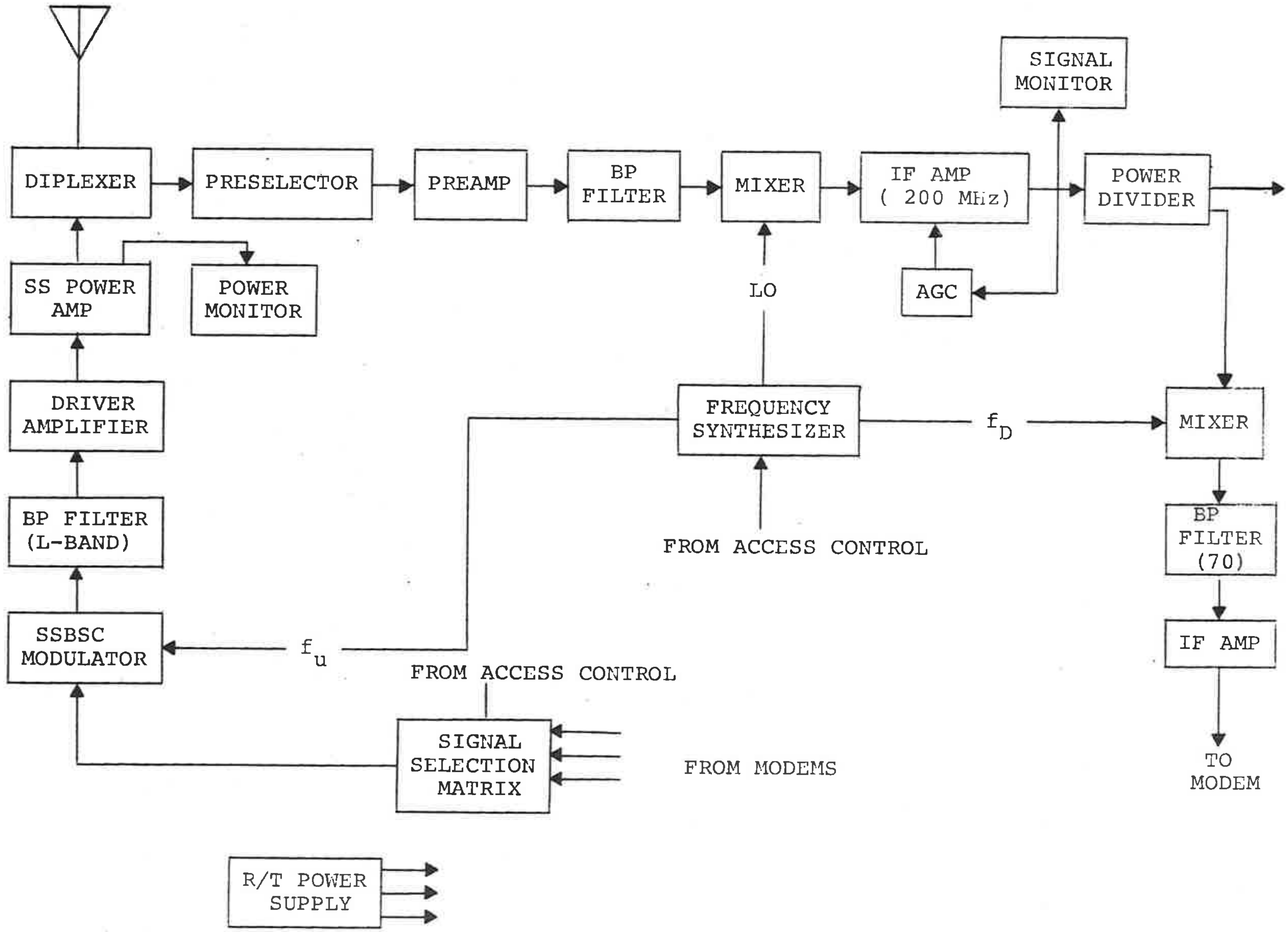


FIGURE 4-20. AVIONICS RT ASSEMBLY

of the details of the accessing scheme. It is expected to be all solid state with power amplifiers and low noise preamps readily available in the time frame of concern. The diplexer is included to permit simultaneous transmission and reception.

A double conversion receiver is shown permitting independent tuning of the voice and assigned SS&D channels. The modem interface is at 70 mHz.

A single up-converter and Class C solid state power amplifier is used in the transmit portion. The signal to be amplified is selected based on inputs from the access control assembly. As shown, only one of three signals is selected. However, if additional A-G channels are used, this switch matrix is enlarged.

The frequency synthesizer is capable of being tuned either manually or automatically from data-link commands. It is assumed that the total number of channels is limited and that any channel can be used for voice or SS&D service. There is a fixed difference between uplink and downlink voice and a fixed relationship between uplink and downlink SS&D channel carriers. To provide independent uplink and downlink tuning would almost double the cost of the synthesizer. The rapid access A-G channel frequency is independent of any uplink frequency and is set in manually upon system entry. The major components are given as follows:

The RT assembly is common to all FDMA instrumentations:

QUAN	
1	Diplexer/Preselector
1	Preamp
1	Bandpass Filter
1	1st Conversion Mixer
1	Wideband IF Amplifier/AGC
3	2nd Mixer/Divider
3	70 mHz Filter
3	70 mHz Amplifier
1	Frequency Synthesizer

QUAN	
1	3 Channel Signal Selection Matrix
1	Single Sideband Suppressed Carrier Modulator
1	Bandpass Filter
1	Driver Amplifier
1	Power Amplifier (100 Watt)
1	R/T Power Supply

4.4.8.1.2 Modems

The voice modem is not detailed for this system since it does not have to be selected at this time. The FDMA system is compatible with any of the modulation techniques currently being considered. The SS&D modem contains a Costas Loop which provides demodulated data and a surveillance signal from its quadrature channels as outputs. The loop has provision for search which permits lock-on to a one (1) second preamble transmission at a C/N_o of 43 dB-Hz. It also contains logic to prevent lock up to side bands. The modulator portion combines a PSK signal with an AM signal modulated on to a quadrature carrier. The requirements are for:

QUAN	
1	Voice Modem
1	1200/2400 BPS data/surveillance signal quadrature modem

4.4.8.1.3 Access Control and Display Assembly

The Access Control and Display Assembly consists of circuitry interfacing the AEROSAT and UDDL instrumentations and a display/control panel required for the control and display functions not attainable via use of the built-in UDDL control and display capabilities. The AEROSAT supervisory function is carried as part of each data link message. It is tentatively proposed that this information be encoded in approximately three characters (24 bits) following the second label character along with the use of a special mode/character set designating the message as an AEROSAT SS&D message. The UDDL digital control circuitry for ocean-going aircraft must be designed (or if processor based, programmed) to recognize this special mode/characters in uplink messages and route the supervisory message out of a suitable port to the AEROSAT Access Control Unit. Similarly, the UDDL instrumentation installed in ocean-going aircraft must be able to accept an encoded supervisory message for each downlink SS&D message transmission. Aircraft equipped with UDDL systems with these features can receive non-AEROSAT relayed data link messages also. This can be done by interpreting all messages with non-AEROSAT mode/label as of regular format not therefore containing the three characters of AEROSAT supervisory information. It may, in fact, prove to be most cost effective to manufacture only one type of UDDL instrumentation equipped to handle either AEROSAT or non-AEROSAT data messages. Suitable switching controls either manual or automatic, must be incorporated somewhere in the instrumentation to enable switching the output of either the VHF or AEROSAT demodulators to the input of the data link unit of the UDDL instrumentation. Similarly, switching controls must be provided to switch the output of the UDDL data link unit to either the UDDL modulator or the AEROSAT data link monitor, respectively.

Tables 4-6 and 4-7 show the supervisory information required to be encoded and sent downlink and uplink respectively. Instrumentation for decoding and handling five categories of uplink supervisory information is required and is shown in Figure 4-21. In Table 4-7, item one, a decoded acknowledgement of a previous voice channel request sent downlink, is displayed on the AEROSAT control/display panel to inform the pilot he has been heard and is in queue. If a channel is immediately available, he receives the information of item 2, encoded as a ring-up, granting the aircraft a channel and providing the channel address. Item 2 is also sent encoded as a ring-up for a call initiated on the ground. Finally, item 2 information is sent,

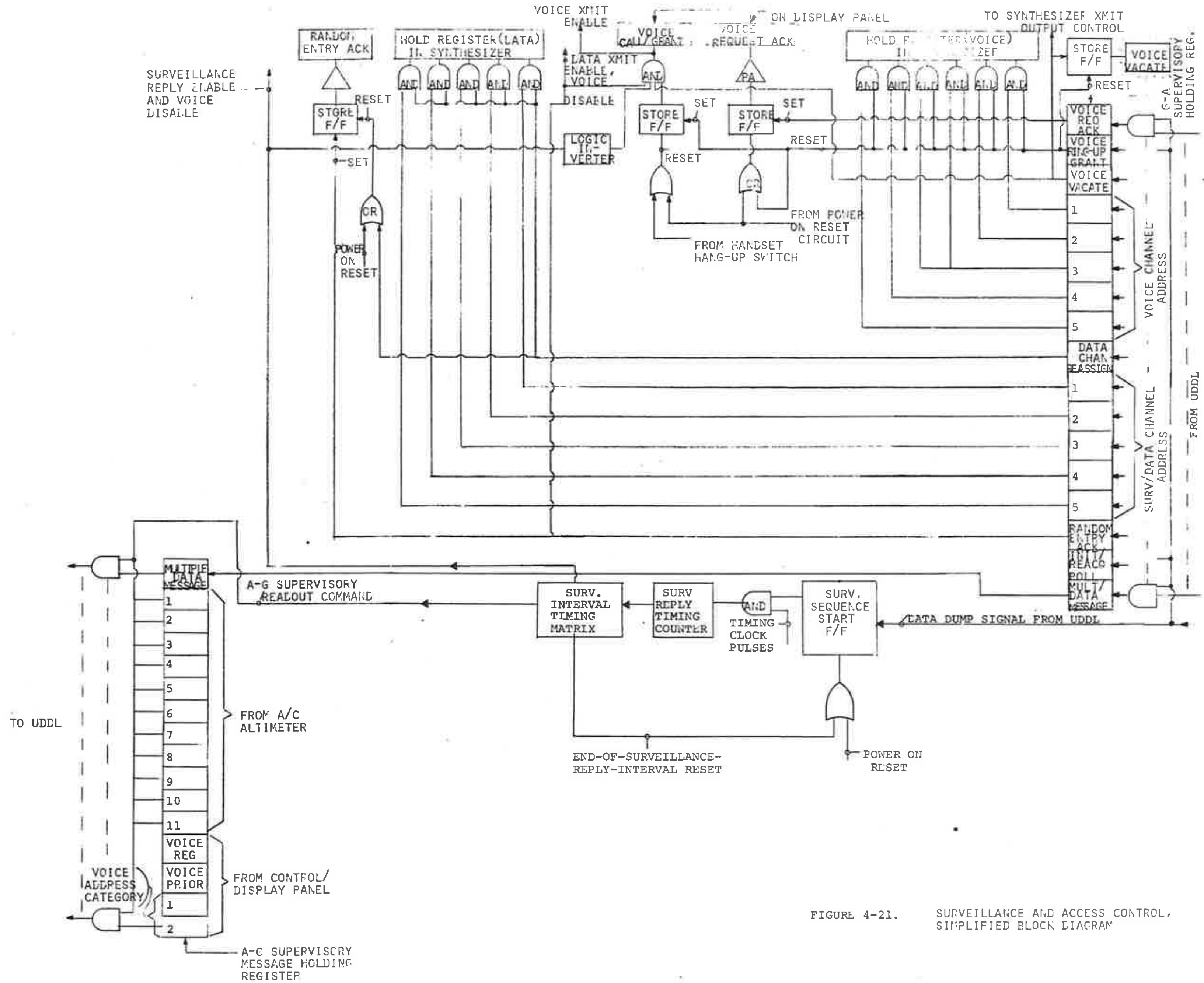


FIGURE 4-21. SURVEILLANCE AND ACCESS CONTROL, SIMPLIFIED BLOCK DIAGRAM

encoded as a vacate, when an emergency occurs and the addressed aircraft must vacate a particular channel to permit its use by an aircraft signalling an emergency.

The voice ring-up/vacate bits would likely be instrumented to operate two visual signalling indicators. For fully automatic timing instrumentation, the ring-up indicator might be, for example, a green light typically face-labeled "Voice" while the vacate signal would be a flashing red light face-labeled "Emergency Vacate" to indicate to the pilot that his voice channel has been arbitrarily preempted and that he will be rung-up again as soon as the emergency situation is over. When the voice ring-up/vacate bits are encoded "ring-up", circuitry would be required to read the 5 bit channel address and automatically tune a modem to the proper frequency for duplex voice service.

Item 3 is received as a one-bit designator indicating to the circuitry to read the channel address and automatically tune a modem to receive supervisory/data messages on a new frequency channel. No visual indicator would be required although a visual time-out indicator, indicating excessive length between SS&D polling, would likely be highly desired or required.

Item 4 is a single bit acknowledgement designator sent in a special uplink message to the aircraft that has a desire to enter the system randomly as it has signalled via the one-way calling channel. This random entry request acknowledgement facility is necessary because such entry will usually require not only an initial acquisition polling (which could be done in the same time as it takes to send the acknowledgement polling message) but also assignment of a voice channel and such channel may or may not be available immediately. The acknowledgement would be visually displayed to the pilot by the lighting of the second half of a two-label back-lit random entry request push-button typically labeled "ACK".

Finally, item 5 is a one bit designator indicating to the circuitry whether an initial entry or a re-acquisition downlink surveillance reply shall be sent.

Instrumentation for encoding and handling at most just three categories of downlink supervisory information is required (see Table 4-6). Item one, voice channel request, is encoded in two parts. Voice channel request is encoded as a two bit code from two pushbuttons labeled typically "Voice Regular" and Voice Priority". One bit will, when true, indicate the request and the other bit will be used to indicate either regular or priority classification of the request. A two bit address will be read from a four position switch indicating addressee category. The four categories could be, for example, air traffic controller, current; air traffic controller, next handoff; airline office, US; airline office, Europe.

Item two is used only to indicate, with priority classification, that an aircraft has more than one data message in storage and thus requries not an extended message polling but a differently labeled polling to reach a different storage for readout. An extended length message facility is already inherent in the proposed standard UDDL instrumentation.

Finally, item three requires an interface with the aircraft altimeter separate from that already provided between it and the UDDL instrumentation. This is to permit its readout on each downlink data transmission as opposed to a standard automatic data readout polling in UDDL format especially for altitude alone.

4.4.8.1.4 Costing Summary for FDMA System

The costs have been summarized in Table 4-8. To account for such factors as special test equipment, spares, installation design, support and profit the costs presented are multiplied by a factor based on experience to arrive at a selling price. The factor used here is 2 to obtain a selling price of $14,610. It should be noted that there is only a small increase in Avionics cost for providing independent surveillance service.

TABLE 4-8

FDMA COST ESTIMATE

		COST
1	Diplexer/preselecter	$ 350
1	Preamp	300
1	Bandpass filter	80
1	1st conversion mixer	200
1	Wideband IF amplifier	175
1	2 stage 2nd mixer assy	150
1	Frequency synthesizer	800
1	3 channel selection matrix	50
1	Single sideband modulator	300
1	Bandpass filter	80
1	Driver Amplifier	100
1	Power Amplifier	1,000
1	R/T Power Supply	100
1	Voice Modem	500
1	SS&D Quadrature Modem	1,500
1	Surveillance processor	400
1	Rapid Access Modulator	200
1	Access Control & Display Assy	600
1	Power Supply	100
	Chassis and wiring	200
	Assy and Test	120
TOTAL		$7,305

4.4.9 Ground System Design

The ground system is shown in the functional block diagram of Figure 4-22. It may be conveniently divided into the portions as shown. The Aeronautical Services Earth Terminal (ASET) works in an intimate fashion with the Aeronautical Services Communication Center (ASCC). The instrumentation shown assumes the ASET and ASCC are at different geographical locations although there is no particular technical requirement that would prohibit their colocation. The other portions of the ground system are the users, the airlines and the Air Traffic Control Centers (ATCC).

4.4.9.1 Ground System Data Interchange

The ASET provides the communications link to and from the satellites. It contains the voice and data modems, all the RF circuitry including frequency conversion, receivers, transmitters and antennas plus the ranging signalling and processing circuitry. Both C-band and L-band equipment are included. The ASET is under computer control based on inputs received from the ASCC computer. The individual voice and data signals are received at baseband on individual circuits from the ASCC. A separate data circuit is used for inter-center computer-to-computer communication and system control. In addition, the G-G communication among the ASCC/ASET's are transmitted as baseband data between the ASET and ASCC. The information flow between the ASET and ASCC is summarized in Table 4-9.

The ASCC consists of communication and control lines, buffering terminals, a voice and data line switching matrix and a system control computer. The ASCC provides all the system communications switching including bidirectional storing and forwarding of all data messages. The data messages are formatted into the "standard" format with provision for AEROSAT system supervision included.

Some of the major functions performed by the ASCC computer are given as follows:

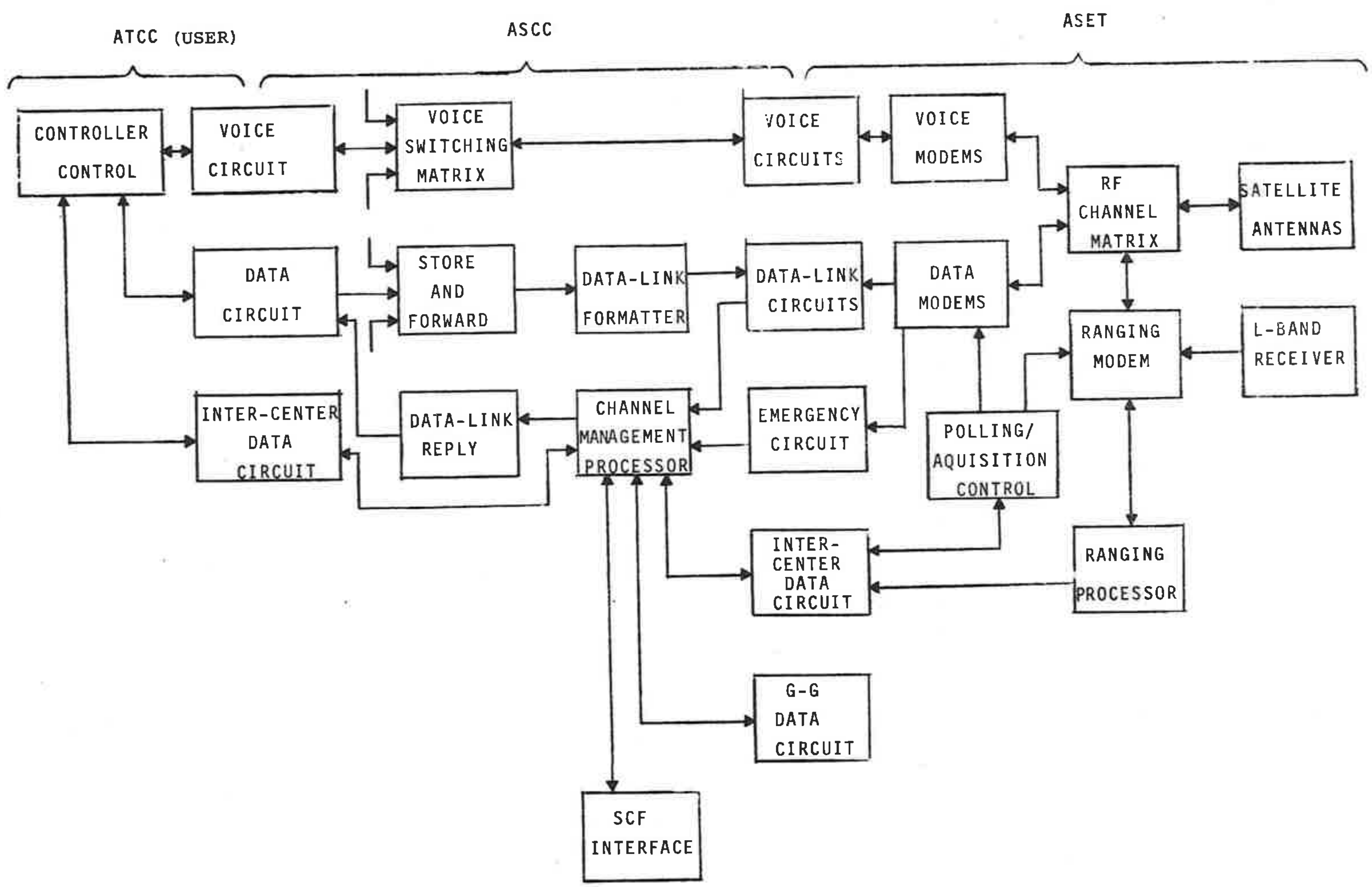


FIGURE 4-22. SIMPLIFIED GROUND SYSTEM FUNCTIONAL DIAGRAM

TABLE 4-9

INFORMATION FLOW BETWEEN ASET AND ASCC

ASCC TO ASET

Frequency Channel assignment corresponding to each communications channel

Designation of channel as Voice or Data

Polling synchronization signals for acquisition and ranging processing which includes:

- Timing
- Mobile Address
- Type of Poll

Baseband Voice to Mobiles

Baseband Data to Mobiles

Baseband Rapid-Access channel data

Base G-G communications

ASET TO ASCC

Digital range from each satellite for each mobile polled

Data-link reply from each mobile polled

Baseband Voice

Baseband G-G communications

1. Queue management of voice channels assigned to it which includes:
   - Processing of requests, acknowledgements, grants
   - Interconnection of ground and mobile users
   - Beam switching coordination

2. Control of data-link polling including
   - Processing of airborne and ground requests
   - Message formatting
   - Ranging up-date rates
   - Distribution of data-link reply
   - Coordination of ASET switching and processing
   - Initial entry
   - All-call polls
   - Beam switching coordination

3. Position location computation and distribution

4. Emergency and random entry processing

5. Maintenance of Mobile file

Each of the user equipments, either airline or ATCC, related to AEROSAT would consist primarily of suitable buffering and connecting control and data lines to message switching control and Air Traffic Control Computers respectively. The information transfer between an ATCC and ASCC is given in Table 4-10.

The ground system has been described above as three distinct facilities interconnected by means of standard circuits. The ASCC function is primarily one of channel and data management. It, therefore, primarily requires the use of computing, processing and interface equipment.

4.4.10 System Variations

4.4.10.1 Central Control

The FDMA system described uses distributed control. All the duplex communication channels are

TABLE 4-10

INFORMATION FLOW BETWEEN ATCC AND ASCC

ATCC TO ASCC

Mobile entry information including

- Mobile address
- Company address
- Controller address
- Initial conditions

Voice channel requests including addressee, addressor and priority

Baseband data messages including addressee, addressor and priority

Handover requests

Baseband Voice Communications

Voice Channel Termination

ASCC TO ATCC

Position location information

Baseband data messages

Voice channel acknowledgements, grants and ring-up

Baseband voice communications

Notification of emergency

Notification of random entry

allocated by the master to each of the ASCC's in the system where any channel could then be used for either voice or SS&D service. It has been shown that such a configuration, with a low number of ASCC's, does not introduce a serious disadvantage with respect to longer queueing times and was recommended primarily because of its inherent flexibility and minimization of required trans-oceanic relay of centrally acquired data and surveillance information. In this section, the possibilities for employment of central control, using FDMA with voice and composite SS&D channel service is presented.

Central control as used here implies that all communications channels are assigned from a central pool on an as-needed basis with surveillance and supervision also being handled centrally at and by the master ASCC. However, it does not seem logical to operate all of the SS&D service from the master if the bulk of data traffic is expected to generate from the ASCC to which the controlling OATCC is connected. Such operation would appear to require excessive use of G-G satellite facilities.

The voice channels on the other hand are handled from a master ASCC-controlled central pool to service queues at all ASCC's. Aircraft requests for voice channels with intended addressee category, would be received during regular polling by each ASCC's channels assigned for SS&D service. Permission to use a channel for voice would then be requested from the master ASCC for each access request and granted as available. Voice contact to an ASCC other than the one supervising the aircraft, would require coordination with the receiving ASCC via the master to complete the connection.

Uplink or voice calls from a controller or airline office also involves the two cases, one where the aircraft is supervised by the ASCC to which the controller (OATCC) or airline office is directly connected and the other where the desired connection is via another ASCC. For the former, the controller or airline office requests a connection to a particular aircraft. The ASCC in turn request and obtains a grant from the master ASCC for use of a channel. The local ASCC then rings up the aircraft via an SS&D channel poll to establish the connection. For the latter case, the requesting controller or airline office requests the connection to a particular aircraft from its local or connected ASCC. The local ASCC contacts the master and requests a voice channel grant and requests that it contact the ASCC controlling the aircraft and command it to ring up the aircraft with a command to communicate on the frequency channel granted to the ASCC connected to the controller or airline office. The voice contact can then be made via transmission from the ASCC to which the requesting controller or airline office is connected.

In summary, with distributed SS&D channel service, central voice channel control has the advantage of somewhat less potential for queue buildup during busy times. This advantage, when weighed against the disadvantage of a greater amount of coordination required to establish a voice contact, does not appear sufficiently great to recommend central voice channel control. Finally, also operating the data channels from central control retaining the selected concept of supervision, surveillance and data (SS&D) carried on a single carrier, would really mean transmitting all SS&D channels from the master because it is illogical to allocate a channel to an ASCC for only a single message as for a voice contact. Such centralization of control for all SS&D polling channels does not appear attractive.

4.4.10.2 Multiple Data Reply Links

Multiple A-G data links are of interest if the A-G message traffic is of greater volume than the G-A traffic. Also, there is some loss of efficiency in A-G transmission because of the requirement for guard band and preamble transmission on each polling slot. Less data can be sent per time slot A-G than G-A. Since A-G channels are in general easily available, this concept is sufficiently practical to be considered for instrumentation. A discussion of the concept and its advantages and disadvantages are presented.

The concept is illustrated in the diagram of Figure 4-23. Illustrated is the case where two frequency channels are used A-G to reply to a single G-A polling channel. The concept is equally applicable for more than two A-G reply links. Each additional frequency adds approximately another 0.5 second of transmission time for the A-G polling reply. For this two-frequency example, the A-G reply is two slots in time length, less an allowance of approximately 40 milliseconds for guard band. The advantage for this concept is of course, that approximately double A-G data transmission time is made available for reply to a polling.

There are two principle disadvantages to this concept. One, the addition to synthesizer complexity is approximately proportional to the number of added downlink reply frequencies. Two, all aircraft must either be assigned, on a longer term, to one or the other of two frequencies (in our example with two reply frequencies) for reply or be commanded to either frequency, for reply, via each uplink polling. Long term assignment of an aircraft to a reply frequency places a moderate restriction on polling sequence in that two aircraft, so permanently assigned to the same frequency, cannot reply in immediate sequence. Command assignment on each polling retains flexibility but requires additional supervisory information transmission on polling.

In summary, the matching of uplink polling channels with multiple downlink channels each, is an effective means for increasing A-G data capacity. Its implementation involves increased frequency synthesizer cost and some increase in supervisory format or reduction in polling flexibility.

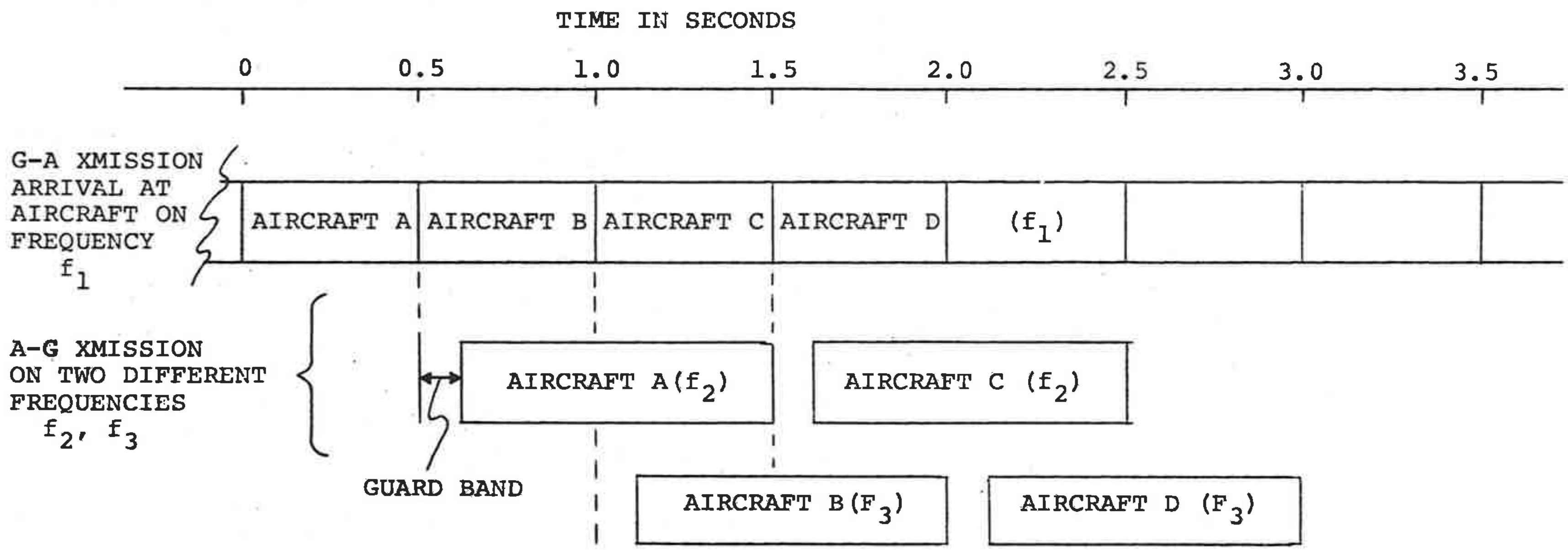


FIGURE 4-23. MULTIPLE REPLY LINK CONCEPT

4.4.10.3 Increased Transmission Rate

Another method of handling the requirement for increased data traffic A-G is to take advantage of the excess power available A-G. From Table 2-1, it can be seen that there is about a 6 dB advantage in signal quality over the G-A direction when spot beams are used for the return link. Therefore, the bit rate can be increased by at least a factor of two to 2400 bits/second in the A-G direction. This will clearly permit about twice as much data to be trasmitted A-G as G-A.

4.4.10.4 Reduced Services

There is the possibility that the full service system described in previous sections may not be desired. Therefore, it is interesting to consider the effect of reduced communication service on system instrumentation. This is considered in the next section.

4.4.10.4.1 Voice and Data Only

If the requirement for independent surveillance is eliminated, the overall instrumentation for System C does not change substantially. Instead of an SS&D with quadrature modulation, the data signal becomes a straight DCPSK bit stream. The supervisory data is still required for channel management. However, the altitude reply in the A-G link can be omitted. The SS&D modem in the Avionics assembly is simplified and clearly, the surveillance processor is no longer needed.

Another consequence of removing the surveillance function is the requirement for transmitting a fixed block length polling message. The option now exists for operation of the data-link in a variable message length discipline. This may lead to more efficient use of the channel if message length information is available.

Elimination of the independent surveillance signal does not preclude provision for dependent surveillance. The data-link in its normal operating mode provides for dependent surveillance polling.

4.4.10.4.2 Data Only System

If the satellite is operated as a data only system further simplifications occur. The data link can be operated in conformance with the UDDL format without modification.

The avionics is simplified in that only one frequency channel need be monitored in the receiving end and all processing can be accomplished by a UDDL common processor. It is probably still desirable that provision for a one-way rapid access channel be included in the system.

Data plus independent surveillance can be handled as described previously. This still retains the feature of monitoring only one frequency channel in the Avionics instrumentation.

4.4.10.4.3 Voice Only System

If voice only service is to be provided then other channel management techniques need to be considered. Some of these have been described in Section 3. The exact technique recommended would depend on whether the system would always remain as a voice only system or whether it will grow into the full service FDMA system described. It would also depend on the number of ASCC's and ground user terminals in the system. Some of the management disciplines applicable are summarized below:

a. Seize-When-Available. - Applicable when channels can be pre-assigned to controllers and there are relatively few airborne users.

b. Basic Selcal. - This is similar to (a) except that mobile does not have to listen continuously to all conversations to know when he is being called.

c. Two-Way Selcal. - This essentially incorporates a two-way supervisory channel into the voice channel. It facilitates pilot initiation of a conversation without interference. A channel can accommodate a greater number of airborne users. It is pre-assigned to the mobiles so that each mobile monitors only one channel.

   On the ground, processing of calls can be handled by an ASCC thereby facilitating sharing of the channel by ground users as well. The ASCC can set up queues for orderly processing of airborne and ground requests. With two-way selcal the system can be easily automated.

d. Separate Supervisory Channel. - The use of a separate low-data rate supervisory channel permits greater flexibility. The system becomes similar to Systems A and B described previously. All voice channels are now available to all users from a common pool. This system does not require any modifications to the voice modulation signal and can grow into a full service system when data-link and surveillance service are added.

   It requires monitoring of the supervisory channel in the Avionics instead of a voice channel. However, it is necessary for the avionics instrumentation to be able to receive two signals simultaneously.

4.4.10.4.4 Simplex Operation

Operation in a simplex mode eliminates the requirement for a diplexer. It is most applicable to a push-to-talk voice only system. For systems which include data and/or surveillance services, a reacquisition cycle must be initiated following each transmission.

5.0 TDMA SYSTEMS

5.1 General

This section presents a review of the general category of time division multiple access (TDMA) types of instrumentation evaluated during the study. Although time division techniques were considered for both up and downlink transmission they are used uplink only. This is because of the complexity in synchronizing the transmissions from the mobiles. Thus, the options described are hybrids using time division uplink and frequency division downlink.

Two basic types of time division techniques were considered. These are a bit-by-bit multiplex and a burst multiplex. Two different instrumentations for the bit-by-bit multiplex and one burst concept were detailed to permit comparison. The burst multiplex instrumentation ranked highest in the comparison. The two bit-by-bit multiplex concepts are presented first in this section while a more complete description of the selected burst TDMA concept is presented last.

5.2 Single Multiplex Per Satellite (System D)

5.2.1 System Concept

The basic uplink digital multiplex is illustrated in Figure 5-1. It consists of a bit-by-bit multiplex of a number of communication channels and is framed by a synchronization, surveillance and supervision (SS&S) channel. A separate supervisory signal is thus used for channel management. The bit rate per channel is shown at 19.2 kilibits per second corresponding to that used in delta voice modulation systems being proposed for AEROSAT. A channel used for data is transmitted at 16 chips per information bit to provide 1200 bits/sec. with the same power as a voice channel. The uplink multiplex is formatted at the ASCC. It is composed of the voice and data inputs forwarded to the ASCC from the ATCC and company terminals connected to it.

Corresponding to each multiplexed uplink channel, including SS&S, there is a separate downlink frequency channel to

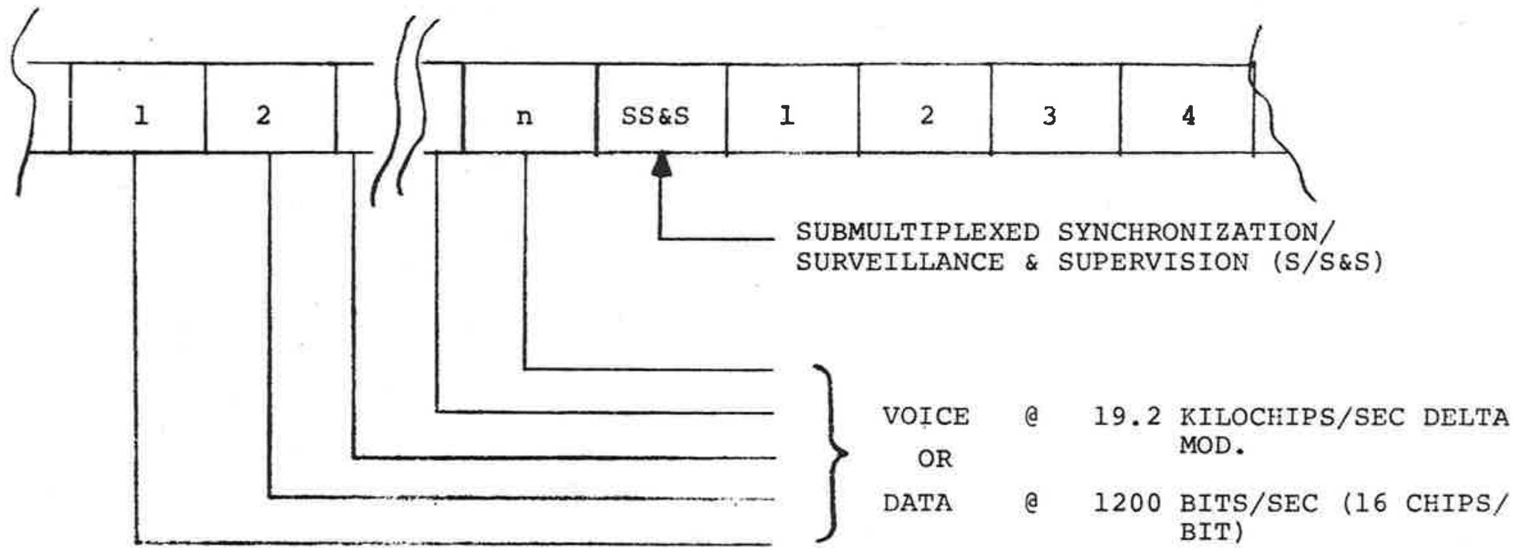


FIGURE 5-1. BASIC TDM UP-LINK MULTIPLEX

provide a full duplex capability. Voice and data are transmitted downlink on separate carriers using the same type digital modulation system. A typical S&S reply consists of a multiplex of supervisory data and a ranging signal. The basic operation of the system is given by the following:

1. One communications and surveillance multiplex per satellite, or a total of two, each on different frequencies, are available during non-eclipse times. Each multiplex uses full satellite power.

2. Each uplink multiplex carries a combination surveillance, supervision and multiplex-synchronization (SS&S) channel plus a fixed number of communication channels dependent on satellite power available. Each communications channel may be used for either voice or data information and has a quality of at least 43 db-Hz.

3. Since only two multiplexes are available they can conveniently be transmitted from at most two ASCC's. Therefore, all ATCC's and company terminals in an oceanic area must interface with one of the ASCC's which generate the multiplex. System supervision is distributed between the two ASET/ASCC's. Interfacing of an ATCC to the ASCC may be accomplished by means of a terrestrial data-link or by means of a satellite G-G link.

4. Each aircraft is assigned a multiplex frequency/channel to tune to while in a given area. Additionally, each aircraft is assigned a digital channel within the multiplex to monitor. The aircraft in the high traffic primary area could typically be covered by a single beam, assigned on a full-time basis during non-eclipse times. One of the multiplexes could be assigned semi-permanently to this beam and area. The aircraft in other areas could be typically serviced by the other multiplex. Each time service is required in a new antenna beam or area the

entire multiplex is switched to that area. The exact arrangement is a function of the location of ASCC's having control and the control regions associated with the ATCC's connected to them.

5. All aircraft in the oceanic area would be provided with a rapid access channel that could be used to signal either a desire to enter the system on a random (pop-up) basis or to signal an on-board emergency situation. Upon actuation of a pushbutton for either service, the universal digital data link (UDDL) would be signalled to emit a specially labeled automatic data readout of a position report. This message would go A-G via a special channel set aside for one-way rapid access signalling. The message would be read out repetitively until the aircraft is serviced by an uplink polling on the supervisory channel. The message would be preceded by an adequately long pure carrier transmission to ensure ground acquisition. Each ASCC in the system would monitor the rapid access channel, as carried via earth coverage antenna, and would recognize the address of aircraft under its control and provide immediate uplink polling.

6. During eclipse time the single remaining multiplex services the entire oceanic area. It may be noted that while the primary area traffic reaches a peak during eclipse, fortunately the other area traffic is at a minimum. Hence voice and data service for the primary area would typically be diminished very little, only low priority service being held in queue in the secondaty areas.

7. Each of the two multiplexes transmitted uplink, and containing one SS&S channel has a companion downlink frequency channel for transponding SS&S information from the aircraft. The downlink SS&S channels will typically consist of a sequence of 40 msec of guard band, 40 msec of preamble for carrier acquisition followed by a sequence of surveillance

ranging return and supervisory data impressed on a 19.2 kilochip per second digital data stream.

8. The downlink voice or data channels also operate at 19.2 kilochips/sec. Each channel uses a separate downlink frequency.

9. In total for downlink each satellite must provide two SS&S channels (for dual return from each of uplink surveillance polls), one rapid access data channel, and one matching channel for every communication channel in the uplink.

10. The uplink supervisory data message provides for initial acquisition discrete address polling as well as regular repeated discrete address surveillance polling.

11. Each ASET/ASCC, transmitting and receiving its own SS&S signals, processes the returns and computes the position of all aircraft under its jurisdiction. It passes the position coordinate information along to their associated ATCC's.

12. The division of oceanic area into flight information regions (FIRS) (individual air traffic control responsibility areas) is not necessarily directly related to multiplex areas. The multiplex area is related to the FIRS associated with the ATCC's interfacing with the ASCC generating the multiplex.

5.2.2 Control and Data Flow Mechanization

The data stream shown in Figure 5-1 is multiplexed among voice or data channels with one channel used in a submultiplexed fashion to achieve a multiplicity of functions. The multiple functions are multiplex synchronization, surveillance ranging and transmission of supervisory data. Figure 5-2 shows a representative format. The supervisory channel is divided intc 300 millisecond time slots.

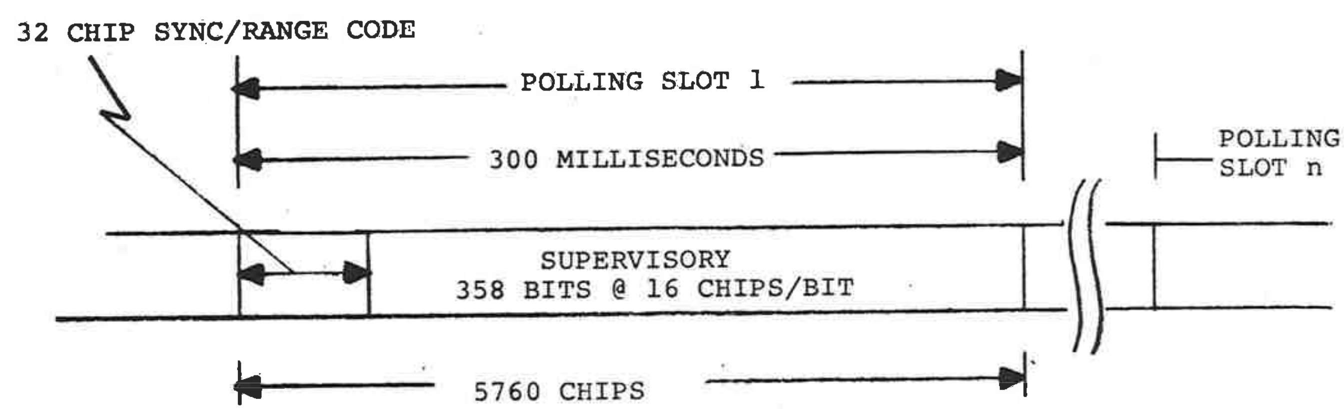


FIGURE 5-2. S/S&S CHANNEL SLOT FORMAT

The formats of Figure 5-1 implies an instrumentation as shown in simplified block diagram form Figure 5-3. The incoming video chip stream is at a minimum of 43 dB-Hz per channel. It appears reasonable to extract chip timing from the composite video waveform for use in demultiplexing and ultimately in fine ranging. In the example SS&S format shown in Figure 5-2, it is postulated that a 32-chip sequence differing sufficiently from the anticipated delta channel sequences (i.e., 1111....,0000...., 0101... etc.) and some selected 16 chip structures for the 1 and 0 data bits, can be generated to provide a unique and precision time mark. It is further postulated that the unique characteristic of the code can first of all be used to identify tne SS&S channel and other channels in the multiplex (i.e., only the SS&S channel has the code) and also provide data bit and message or slot frame synchronization. Initial investigation shows the above to be a sufficiently technically feasible SS&S scheme to permit proceeding with investigation of the system's multiple access characteristics. Other signal structures are, of course, feasible. The essential idea is that precision timing is obtained from the entire chip stream.

The downlink SS&S data information transmission is carried on a separate carrier as are the individual voice or data channel encoded bit streams. Figure 5-4 shows a representative encoded SS&S bit stream for one slot. Again the SS&S message reply is slot oriented (300 milliseconds slot length) and starts with a period of 40 milliseconds of no transmission or "guard band" to prevent overlap of sequential transponding replies from two aircraft at furtherst and closest round trip ranges, respectively. A preamble is transmitted for a period of 40 milli-seconds to allow reacquisition of the carrier. The pure carrier transmission interval is followed by a fine and coarse range code sequence consisting of a relatively long transmission of alternate one and zero chips followed by a 128 chip code sequence. The fine code transmission allows the lock-up of a local clock to the pre-cision required for fine range accuracy. The 128 chip code is decoded in a shift register decoder providing a gate for a fine range code leading edge from which is determined the fine range

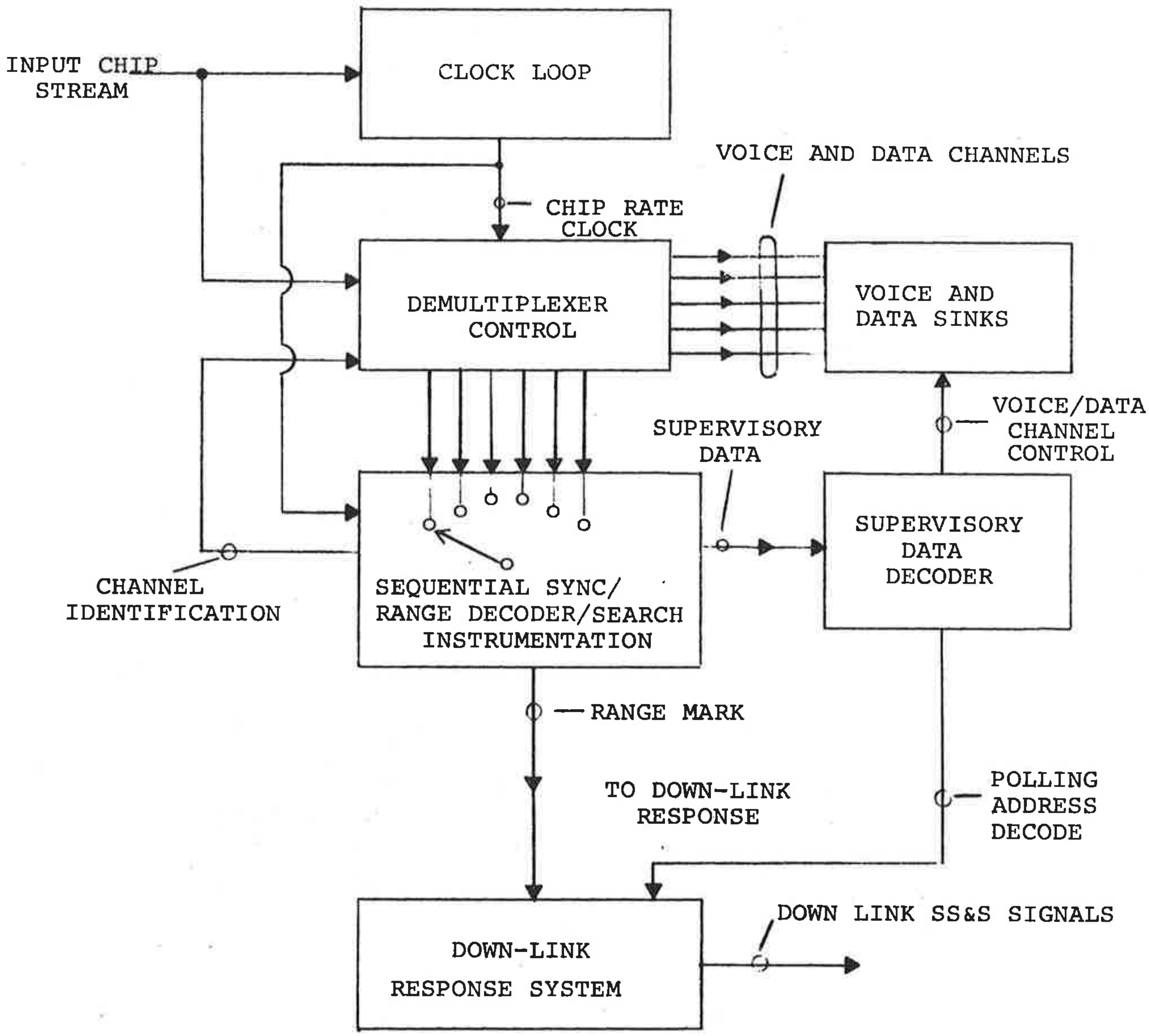
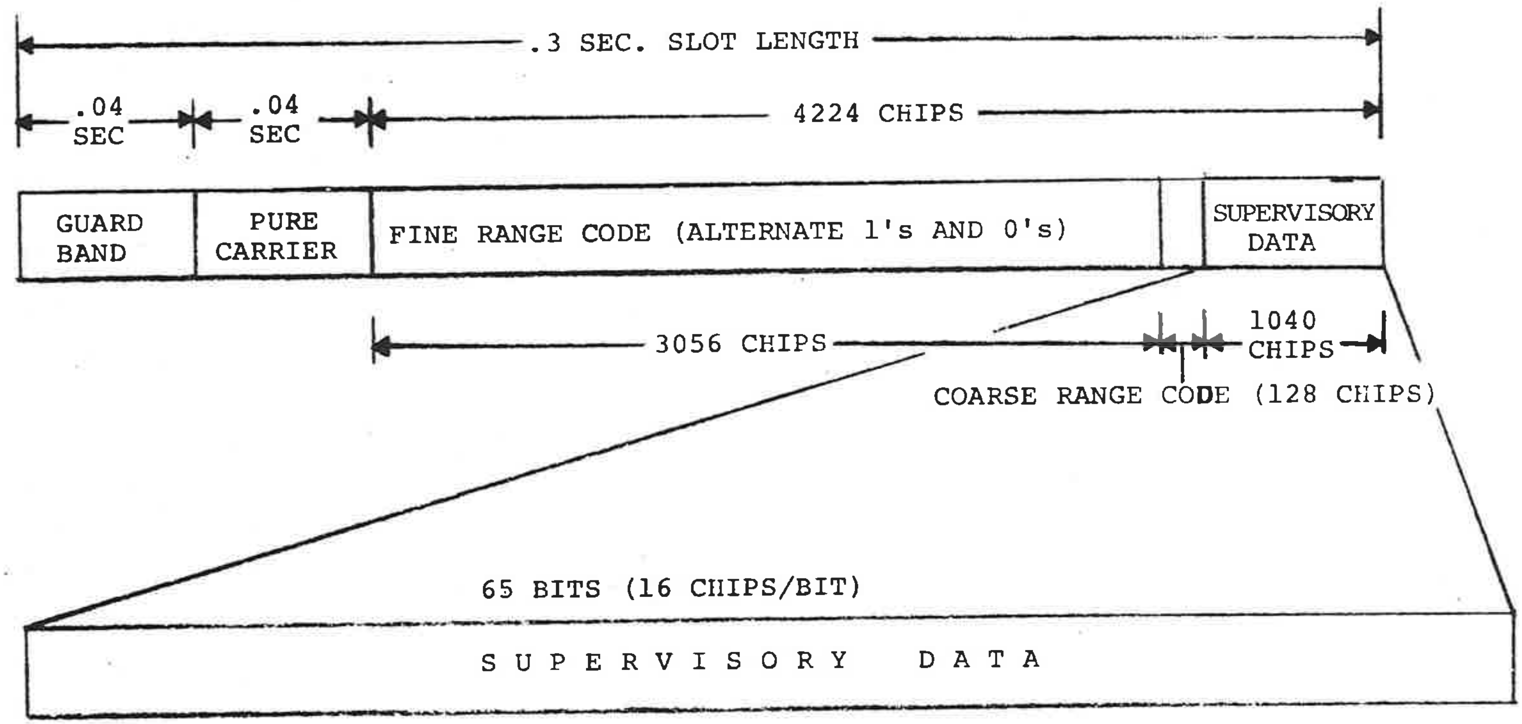


FIGURE 5-3. SIMPLIFIED BLOCK DIAGRAM FOR SYSTEM D AVIONICS INSTRUMENTATION



NOTE: Coarse Range Code also provides supervisory chip/bit and character sync.

Supervisory Data:
a) 10 bits, system address of aircraft
b) 11 bits, aircraft altitude
c) 44 bits, communication facilities control

FIGURE 5-4. TYPICAL SS&S DOWNLINK TRANSMISSION (NORMAL REACQUISITION) 19.2K CHIPS/SEC.

delay measurement. A two slot sequence is used for initial acquisition in which a pure carrier is transmitted for the entire first slot followed by a nearly standard SS&S downlink format transmission.

Figure 5-5 shows a simplified block diagram for the avionics instrumentation. Figure 5-5A shows the ground SS&S processor instrumentation required for precision range measurement and supervisory data decoding. The video or baseband data at 19.2 kchips per second is fed to a local clock loop to establish precision bit lock of a local clock. The leading edges of this local clock are used to generate very short pulses for final precision ranging working with the coarse range gate. The local clock is also used to clock the incoming data stream into a 128-bit coarse range code shift register. When the 128-bit code is fully clocked into this register decoder it emits a correlation peak above threshold and is used to read the count in a 50 millisecond range ambiguity counter, into a range ambiguity store from which the range ambiguity word is transmitted to the system computer. The 50 millisecond range ambiguity counter is synchronized with the start of uplink slot timing. Thus, it repeats its full 50 millisecond count six times per slot and adequately enables resolution of the maximum range ambiguity of 40 milliseconds. The same downlink SS&S channel is received via both satellites and hence two SS&S processors are required on the ground. The second processor need not be equipped to decode the supervisory data however.

5.2.3 Communications Facilities Management

5.2.3.1 General

Since satellite power limitations and required geographic coverage necessitate the use of multiple beams to provide the communications and surveillance service desired, it is not possible for all areas to have continuous voice and/or data coverage for the single uplink multiplex per satellite TDM/FDM system configuration. All communications channels are inherently contained in two equal size groups. Thus, to provide service to all areas of the ocean requires moving all surveillance and

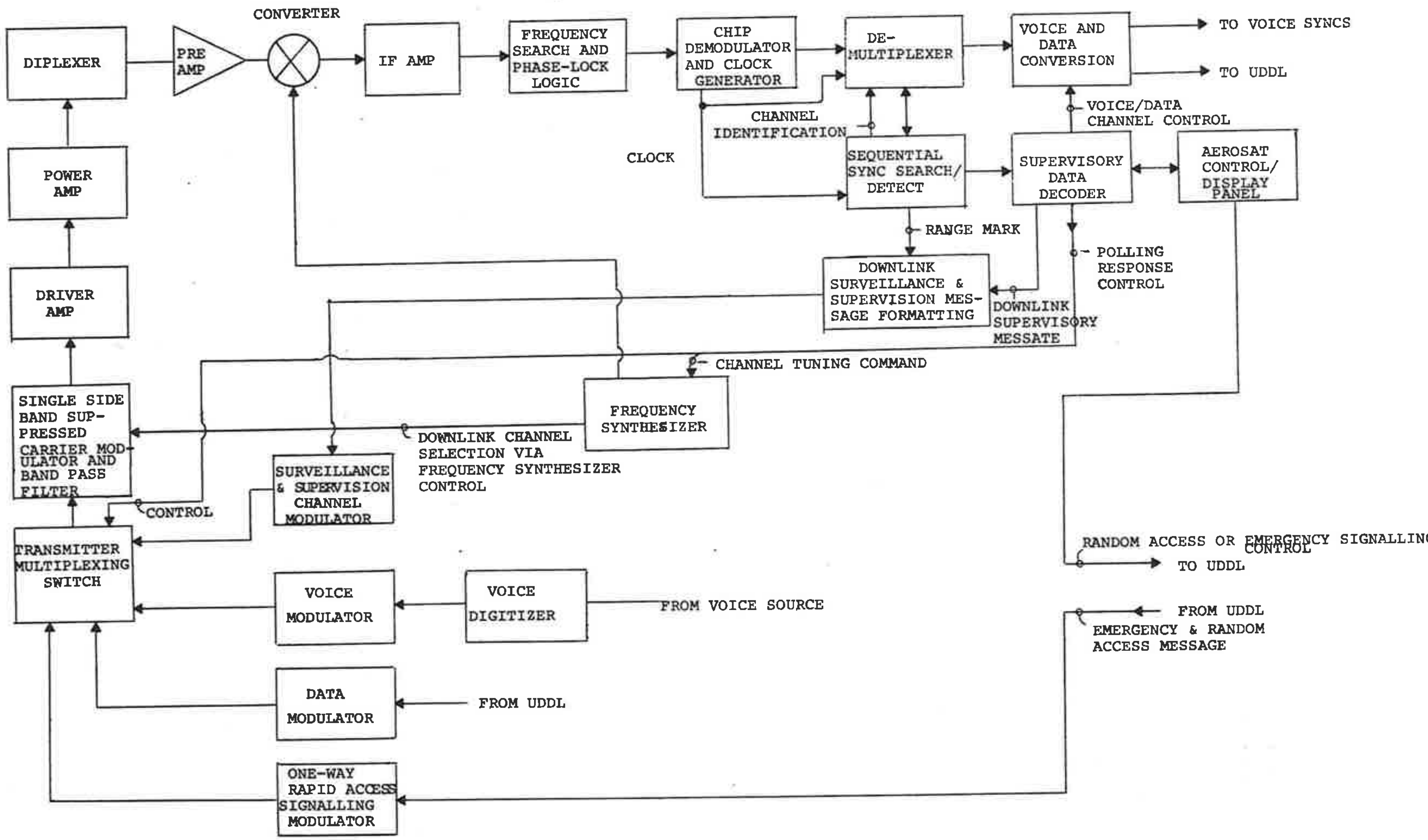


FIGURE 5-5. AVIONICS SYSTEM FOR BIT-BY-BIT MULTIPLEX TYPE SIGNALS (SYSTEM D OR E)

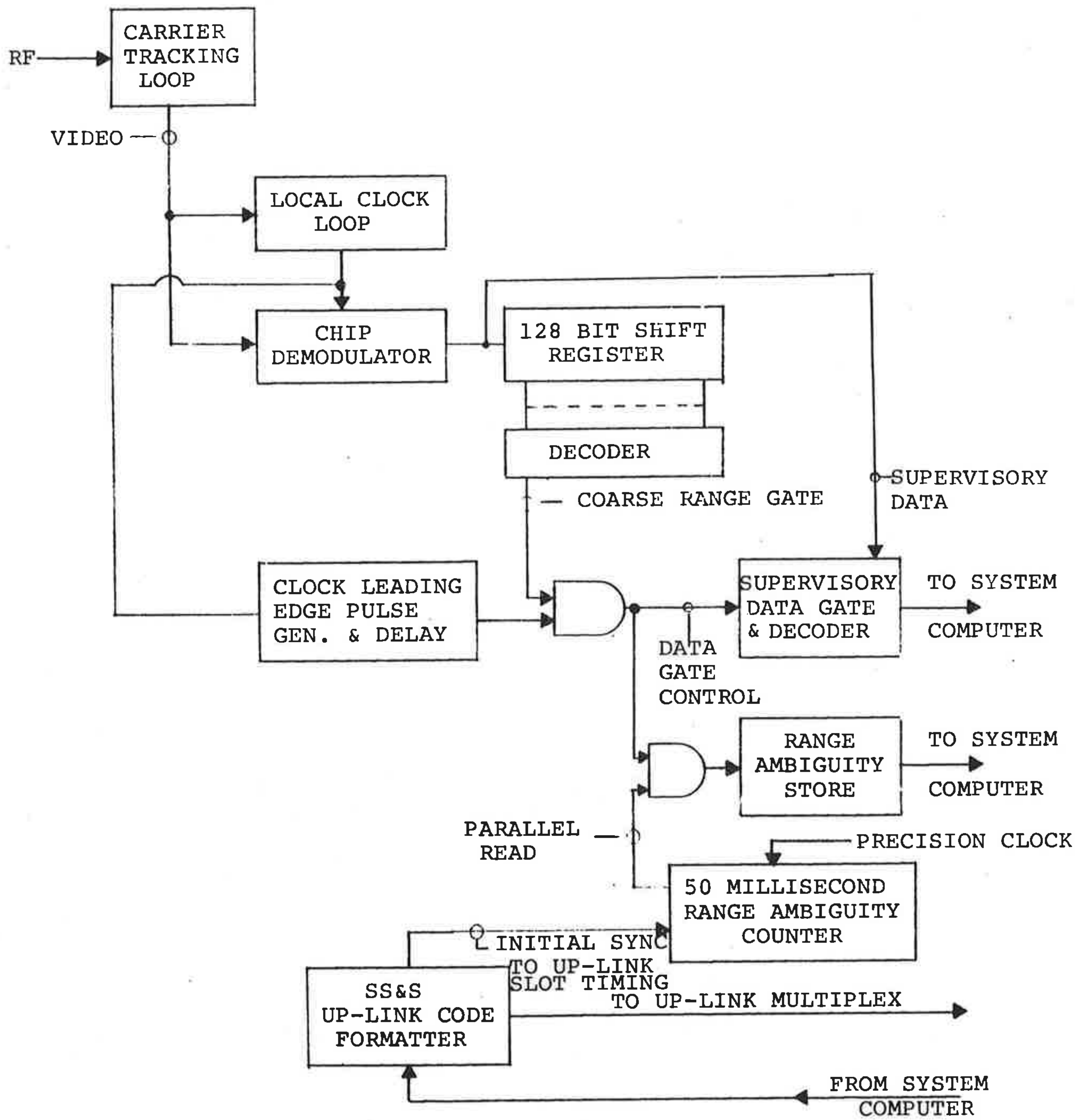


FIGURE 5-5A. TYPICAL GROUND SS&S PROCESSOR INSTRUMENTATION.

communication facilities in one of the multiplexes via switched beams. The inconvenience and inefficiency in this procedure is exacerbated during the short biannual period of nightly eclipses when the uplink multiplex from the eclipsed satellite is temporarily inoperative. The seriousness of this is very dependent on traffic flow for the areas each of the two multiplexes serves the majority of the time.

It is obvious that when such a gross amount of communications capability is switched simultaneously, it is desired to do so only after reasonable queues have built up for each of voice/data channels of the multiplex for the area switched to. Knowledge of queue build-up for G-A service requests for voice or data in any area is known but there is no means for knowing the queue build-up of A-G service requests in an area until a multiplex link is actually established in that area. However, the traffic flow G-A is anticipated to be heavier than A-G and thus perhaps the more pertinent or required queue build-up information is available to permit more efficient "wholesale" transfer of surveillance and communications facilities.

5.2.3.2 Pilot Procedures for Requesting a Voice Channel

As shown in the flow diagram of Figure 5-6 requests for a voice is initiated by the pilot by depressing a proper priority voice request pushbutton. This action stores the request in instrumentation storage awaiting the next surveillance polling command as received via the supervisory channel. The request is transmitted as part of the downlink supervisory channel message format to the ASCC and the ASCC enters the request into queue. If the addressee is on the opposite side of the ocean from which the ASCC is located, G-G communication facilities will have to be employed. The ASCC informs the associated ATCC or ARINC switching center of the intended addressee and the control for the intended addressee indicate availability to talk when ready. The ASCC polls the requesting aircraft and grants voice

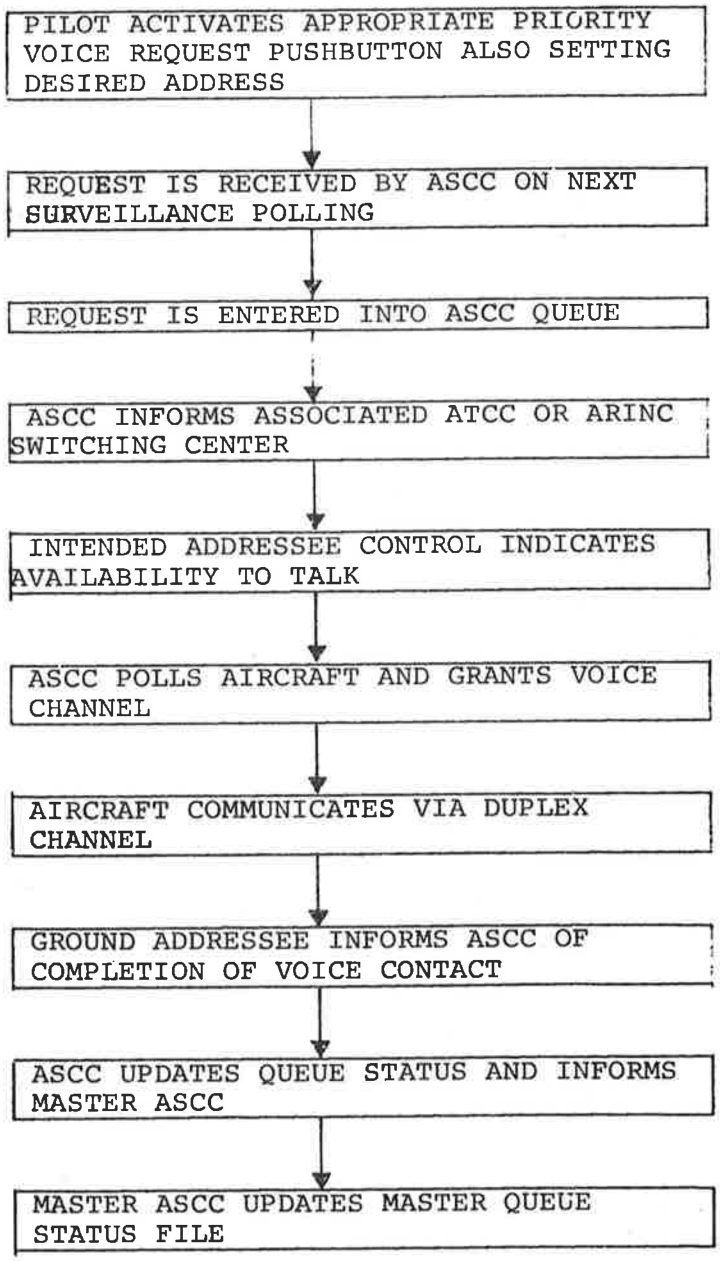


FIGURE 5-6. BIT MULTIPLEX TDM/FDM AEROSAT FLOW DIAGRAM FOR AIRCRAFT VOICE REQUEST

communication over the indicated multiplex channel. The aircraft can then communicate via a duplex channel. When the conversation is completed the ground addressee informs the ASCC of completion. Finally, the ASCC updates its queue status and informs the master ASCC to enable updating of its master queue status file.

5.2.3.3 Pilot Procedures for Sending Data Message

Figure 5-7 shows a flow diagram for procedures required for aircraft to send a data message to a ground addressee. The sequence begins by the pilot setting in the address code for the desired addressee and depressing the appropriate priority data request pushbutton. This request is received by the ASCC on the next surveillance polling and the request is entered into data request queue. When the A-G channel is available,ASCC sends aircraft a data poll on the data channel which the aircraft is monitoring. The ASCC receives the data message and sends an acknowledgement polling if message is received with proper check. The ASCC's handle the data message on a store and forward basis to deliver the message to the desired addressee.

5.2.3.4 ATC Controller or Airline Procedure for Requesting a Voice Channel

Procedures for requesting a voice channel by either of the ground elements, the ATC controller or the airline office, are shown in the flow diagram of Figure 5-8. In accordance with current practice. it is assumed that requests for voice channel service by the airline will be processed via an ARINC message switching center. Queue management with respect to airline serivce requests, ground-to-aircraft, are indicated on the diagram but it is quite conceivable that this could alternatively be included in the ASCC queue management.

After the local ASCC receives the request from the directly connected ATCC or ARINC, it first determines if the addressed aircraft is assigned to a multiplex it generates and controls. If it is, the local ASCC informs the controller when a voice channel is available and sets up a connection and the remaining operation sequence follows. If it is not, the local ASCC

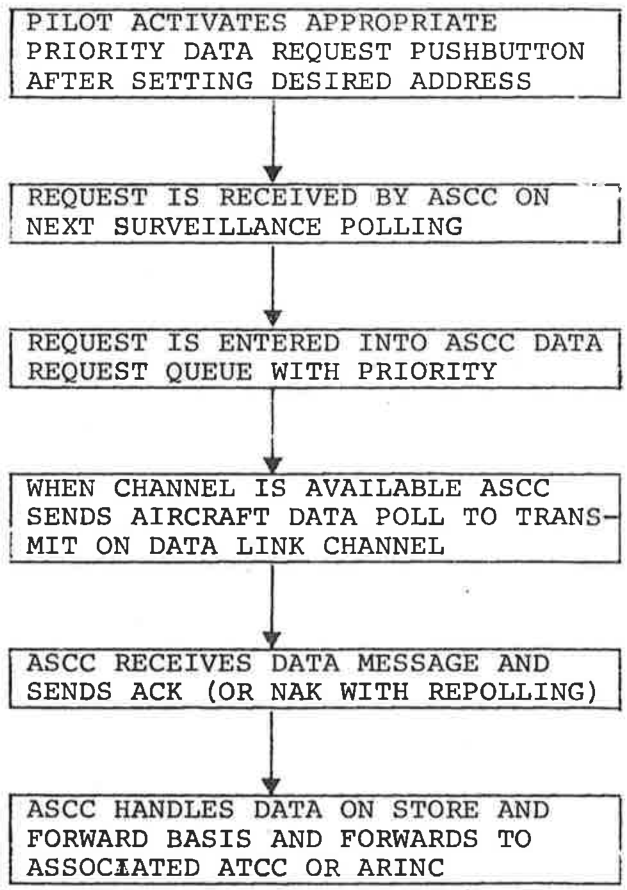


FIGURE 5-7. ALL-DIGITAL TDM/FDM AEROSAT SYSTEM D FLOW DIAGRAM FOR AIRCRAFT DATA MESSAGE TRANSMISSION

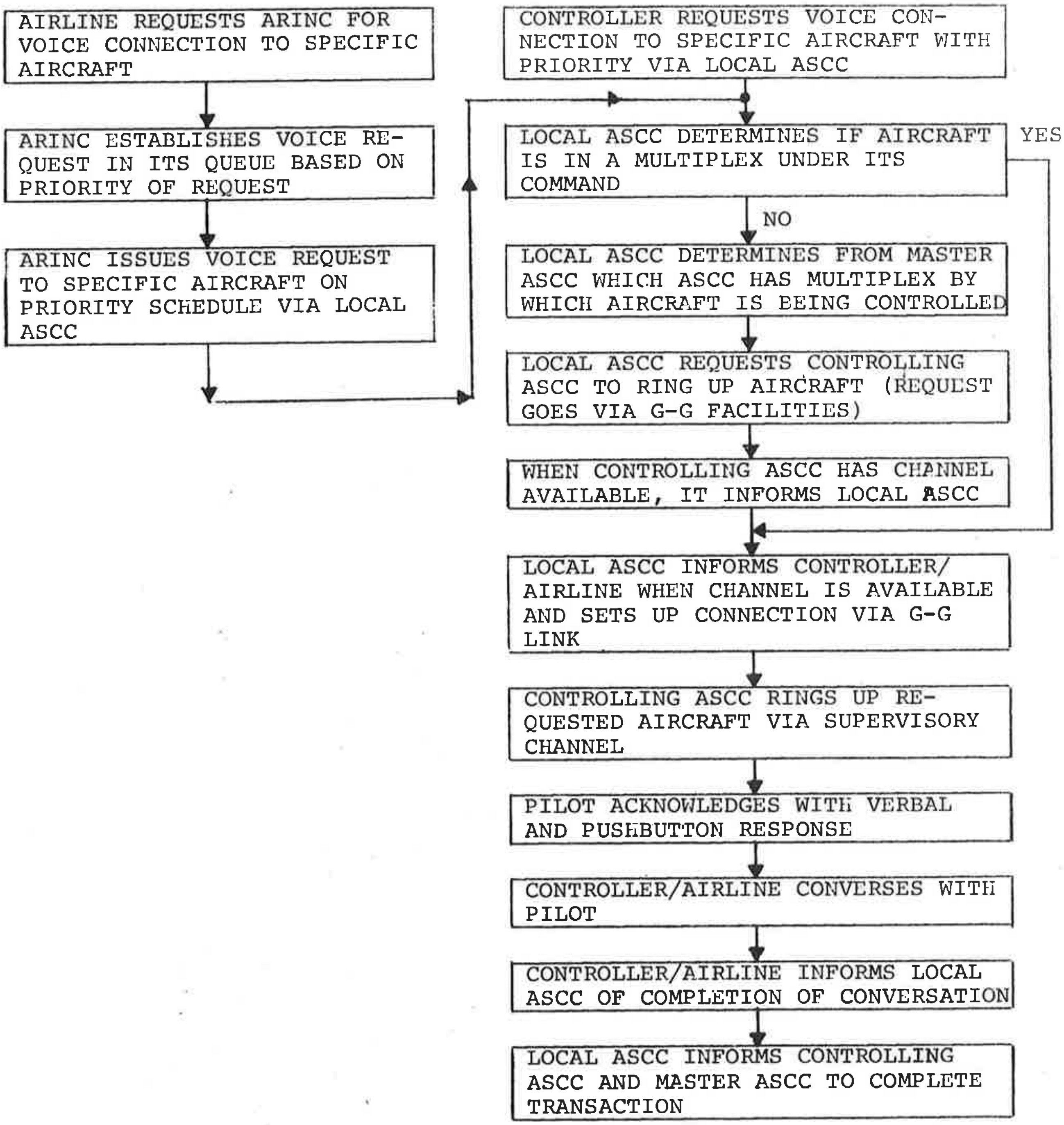


FIGURE 5-8 ALL-DIGITAL TDM/FDM AEROSAT SYSTEM D FLOW DIAGRAM FOR ATC CONTROLLER/AIRLINE VOICE REQUEST.

first determines from the master ASCC which ASCC is generating and controlling the multiplex to which the addressed aircraft is assigned. After being so informed, the local ASCC requests the controlling ASCC to ring up the aircraft (this request goes via G-G facilities). When the controlling ASCC has a channel available to ring up the aircraft, it informs the local ASCC. The local ASCC then informs the controller/airline when the channel is available and sets up a connection. The controlling ASCC then rings up the addressed aircraft via the supervisory channel and the pilot acknowledges with a verbal and pushbutton response. The controller/airline then carry on the conversation and when completed the controller/airline signal the ASCC of completion. The local ASCC informs the controlling ASCC and the master ASCC to complete the transaction and permit update of channel and queue status.

5.2.3.5 ATC Controller or Airline Procedure for Transmitting a Data Message

The procedure and data flow for an ATC controller or an airline operator to send a data message to an aircraft is shown in Figure 5-9. It is assumed that the airline sends the priority at this point. With the priority of message considered and affixed, ARINC or the controller sends the data message to the ASCC. The ASCC stores the data message in queue. When a data channel becomes available the ASCC transmits the data message to the aircraft on one of the voice/data channels.

Since many communications channels are available to the ASCC, where each of the channels may be used as a voice or data chennel, the ASCC must set up some strategy or plan to have aircraft connect to a given channel with its terminal equipment set to receive either voice or data as appropriate. Since one of the standard formats (ADIS or ARINC) is assumed to be used on the data channels, it would seem most desirable if the aircraft could be sent a message by the standard addressing already included in the data message without additional usage of the supervisory channel. To permit this, requires that groups of

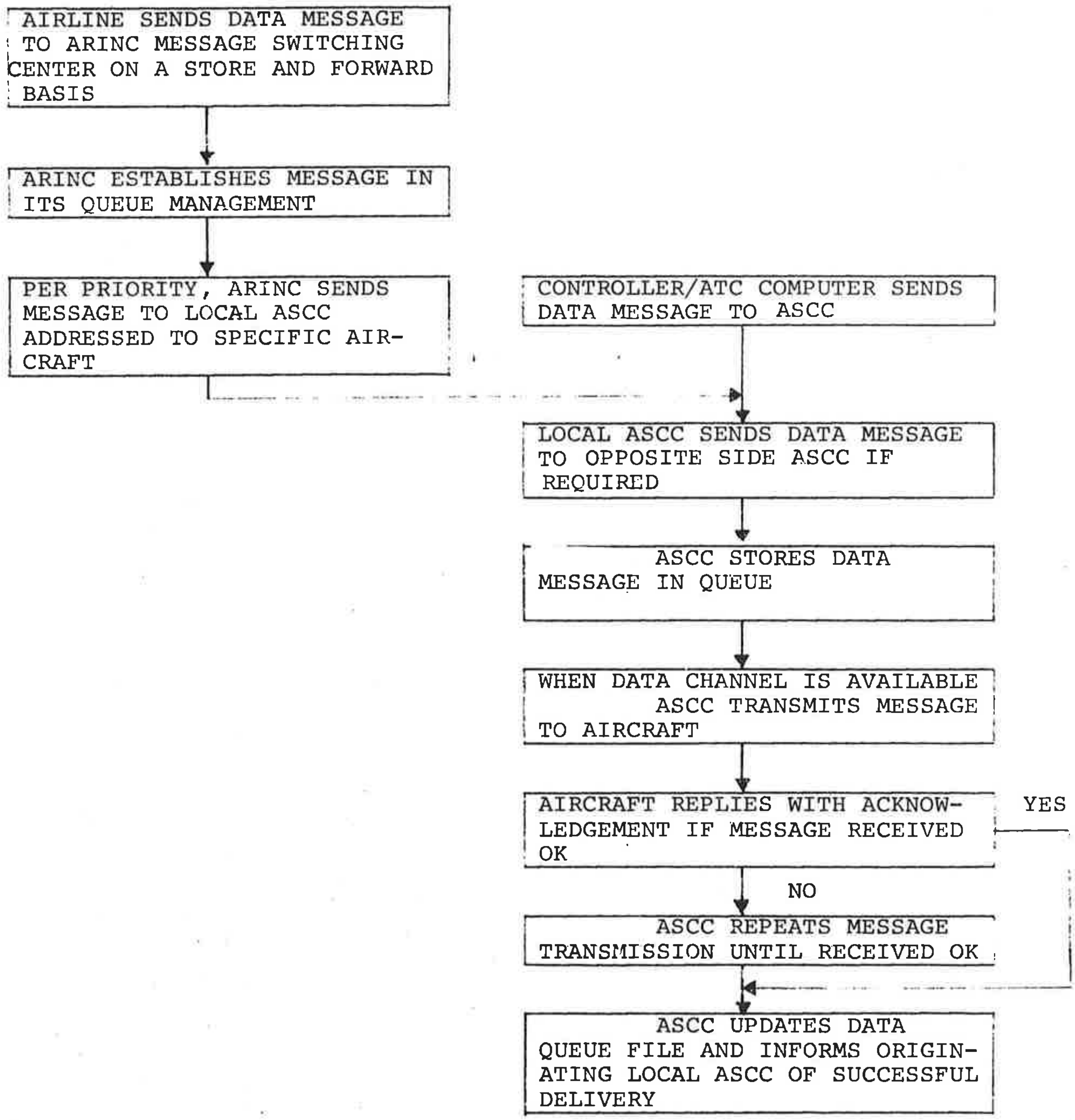


FIGURE 5-9. AIRLINE OR ATC CONTROLLER PROCEDURE AND DATA FLOW FOR TRANSMITTING A DATA MESSAGE TO AN AIRCRAFT IN SYSTEM D.

aircraft be assigned to a channel and that channel would have to be designated as a data channel on a longer term basis. Such a strategy would then permit addressing the aircraft directly via the data link. A facility of course would be required in the super-vsory format to so designate and assign channels to the groupings of aircraft.

Whatever the arrangement selected, the aircraft receives the message in standard format and replies with an acknowledgement indicating success or failure in receiving the message. The ASCC will repeat any message not received correctly by the aircraft. The ASCC then updates its queue file and informs the originating local ASCC of successful delivery of the message.

5.2.3.6 Procedures for Normal Entry

The procedures and data flow for normal entry, intra-system handover and exit from system are shown in flow diagram form in Figure 5-10. Some time before the aircraft desiring to fly an oceanic route arrives at the point of entry into the system, data with regard to expected time of arrival, aircraft address and other pertinent information will have been transmitted in some manner to the oceanic air traffic control center (ATCC). The approach to the entry point is assigned to the proper SS&S channel. The aircraft receives an initial -entry two-slot surveillance polling command and transponds with a two-slot reply consisting of one slot of pure carrier followed by a standard transponding slot. The ASCC receives this reply and, if a valid reply, computes aircraft position and then continues polling the newly entered aircraft at a rate as requested by the associated ATCC. The position data computed is in turn transmitted to the ATCC.

As the flight progresses, as monitored by regular surveillance polling, the associated ATCC continually checks to see if the aircraft is nearing a multiplex area boundary either between another multiplex or between a multiplex oceanic area and a continent. If neither case exists regular surveillance polling continues. When the aircraft is near a boundary between two oceanic

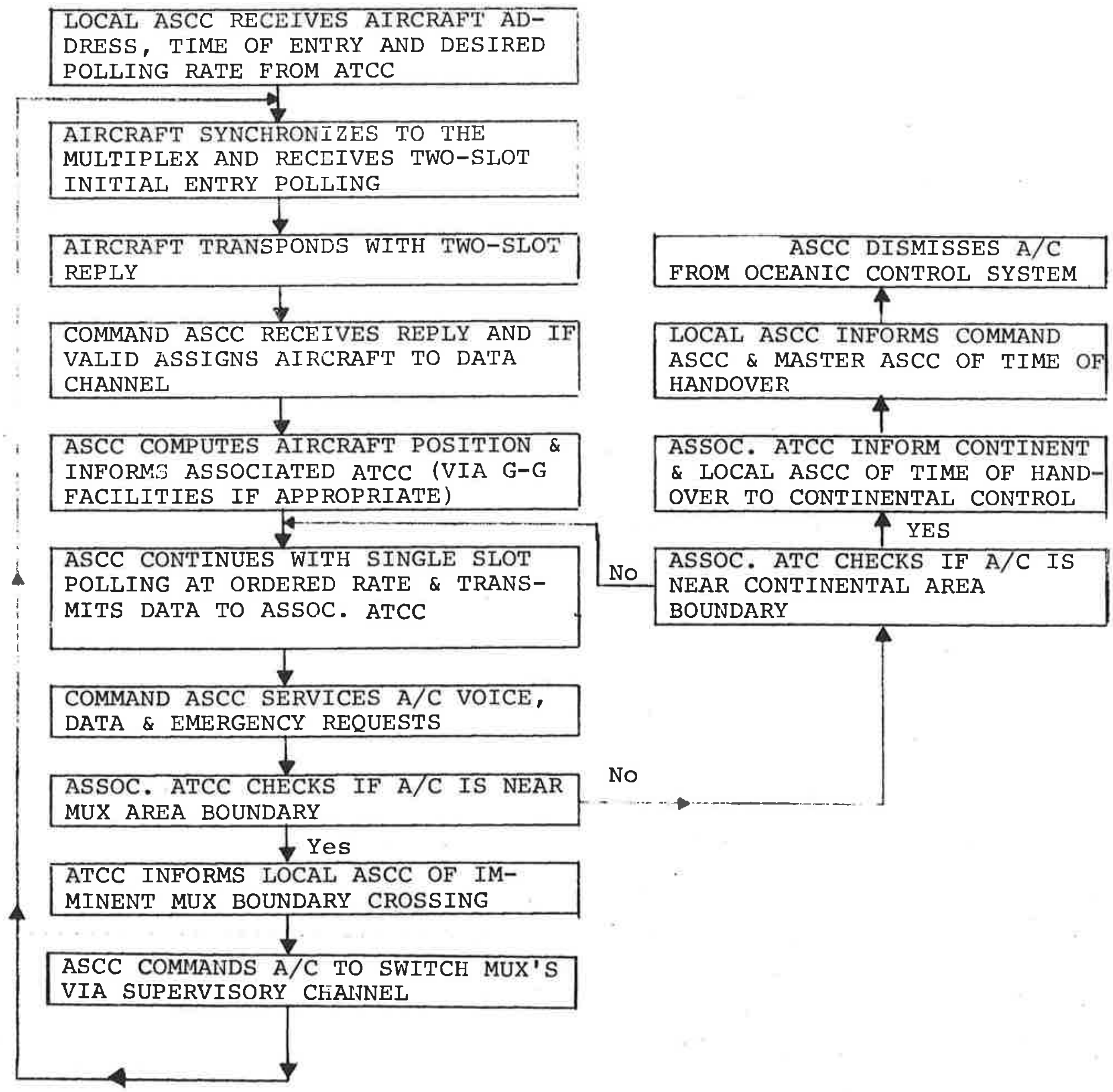


FIGURE 5-10. ALL-DIGITAL TDM/FDM AEROSAT SYSTEM D FLOW DIAGRAM FOR NORMAL ENTRY, INTRA-SYSTEM HANDOVERS AND EXIT FROM SYSTEM.

multiplex areas, the ATCC informs the local ASCC immediately. The ASCC then commands the aircraft to switch multiplex frequency channels via a command over the supervisory data channel. The ASCC informs the receiving or accepting ASCC and the master ASCC of handover. The aircraft then synchronizes to the new multiplex and the new ASCC commands an initial-entry two-slot surveillance polling. The aircraft transponds to the initial entry polling and is once again fully entered into the system in the new multiplex. Operation then continues as before.

If the associated ATCC upon checking finds the aircraft near a desitnation continental boundary, the ATCC informs Continental Control and the local ASCC of time of handover to Continental Control. The ASCC dismisses aircraft from the oceanic control system.

5.2.3.7 Random Entry and Emergency Signalling

The use of a rapid access channel for either random entry or emergency signalling was described in Section 5.2.1. As in the FDMA system, a separate downlink frequency channel is provided for transmission of a UDDL formatted and generated message at a lower, 300 bit per record, data rate via an earth coverage antenna. Referring to Figure 5-11 for random entry all ASCC's in the system receive this UDDL formatted message containing an automatic readout of aircraft position. Based on the location of the aircraft, the local ASCC transmits a two-slot initial acquisition poll to the aircraft. The aircraft transponds with an initial acquisition two-slot poll reply. The ASCC then assigns the aircraft to a data channel via the SS&S channel and informs the associated OATCC. The OATCC requests data polling of the aircraft and the ASCC polls the aircraft via the data channel. The aircraft replies with a data message containing information on desired flight plan. The OATCC then coordinates full entry of the aircraft using a voice channel if required. The ASCC informs the master when entry of aircraft is completed.

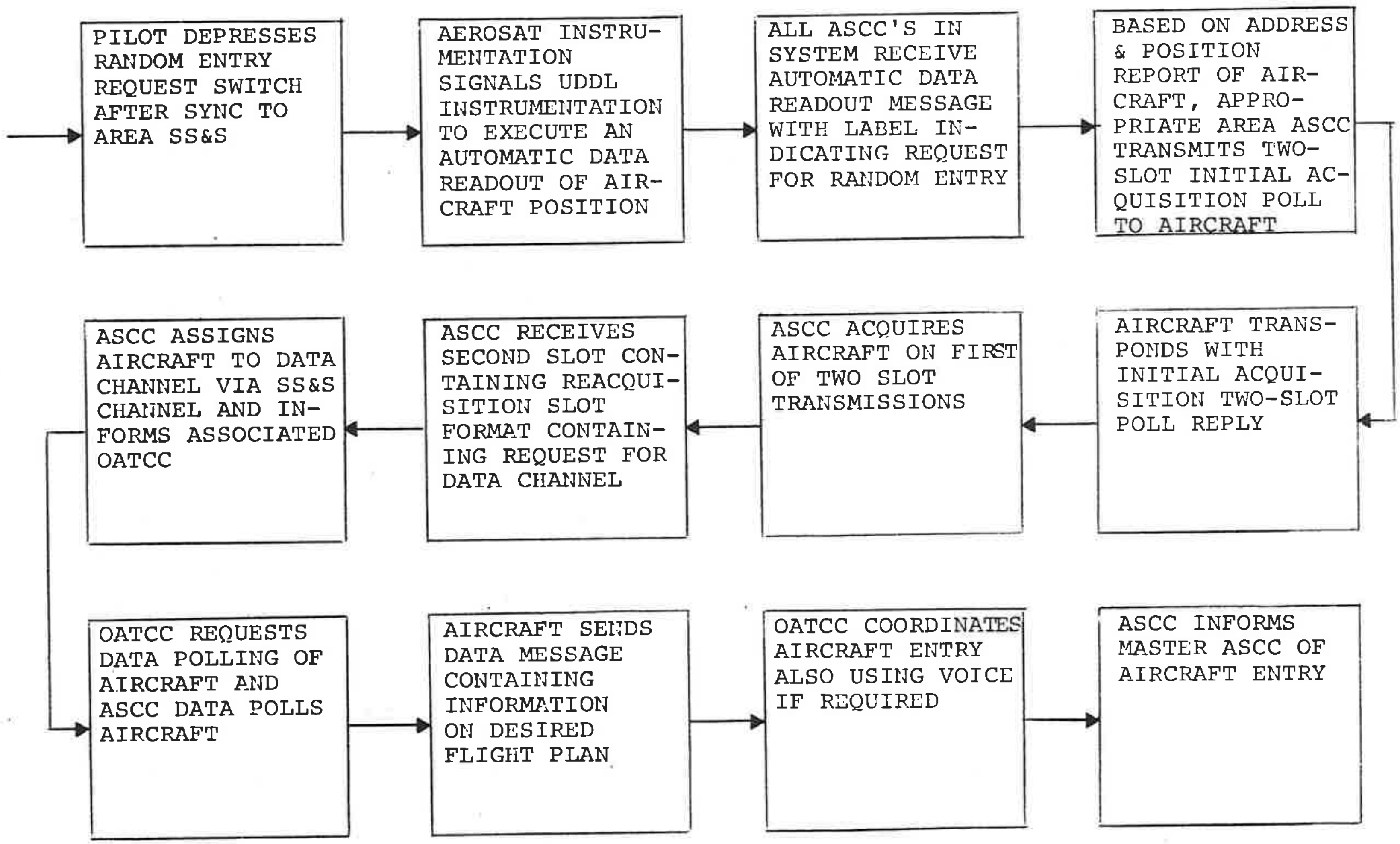


FIGURE 5-11. RANDOM ENTRY SIGNALLING VIA RAPID ACCESS CHANNEL

Downlink signalling for an on-board emergency condition is accomplished in a manner similar to that for random entry signalling. Handling, after the downlink signalling, is essentially identical to a normal poll. Since the aircraft is already entered into the system, its doppler will be known and a single-slot polling is adequate.

5.3 Two Multiplexes Per Satellite (System E)

5.3.1 System Concept

Use of a single bit-by-bit multiplex per satellite requires that all of the facilities of a satellite be beamed to a single area of the ocean. In some cases this results in more channels than are required in some of the sparsely populated areas of the ocean at a given time. When voice communication is involved, the multiplex could reside in a location for relatively long periods of time with many of the channels idle while other areas not then receiving service may experience heavy queueing.

To minimize the total number of channels switched and to permit greater overall flexibility, two uplink multiplexes per satellite are provided for the second bit-by-bit multiplex studied. They are similar to the first multiplex scheme except that each uses approximately half the satellite power. Each contains its own supervision, surveillance and synchronization channels. There are, thus available, a total of four multiplexes and these can be allocated to up to four ASCC's. For many allocations the multiplexes can be dedicated to particular beams where the aircraft population is high thereby minimizing the total switching required. During any period when a multiplex is switched, only half the satellite capacity is changed. This is advantageous during eclipse operation when a single satellite services an entire ocean. On the other hand, during some situations when both multiplexes in a satellite service a common oceanic area, and with transmission through a common amplifier, intermod products are not completely eliminated.

The gross system instrumentation details are given as follows:

1. Two communications and surveillance multiplexes per satellite, or a total of four are available during non-eclipse times. Each multiplex operates in a separate frequency channel.

2. Each multiplex carries a combination surveillance, supervision and multiplex synchronization (SS&S) channel plus communication channels that may be used for either voice or data information.

3. Each aircraft is assigned a frequency/channel to tune to while in a given area. Within a multiplex each aircraft monitors a data link channel.

4. As an example of an allocation for the Atlantic, the aircraft in the primary area, assumed covered by a single beam, are divided into an eastern and a western group, with one multiplex dedicated to each group. The aircraft in the secondary area, covered by a single beam, constitute another group covered by one multiplex dedicated to that group. The aircraft in the remaining oceanic area and coastal areas of South America and Africa, are handled by a single multiplex typically switched between three antenna beams.

5. System supervision can be distributed among up to four ASET/ASCC's or contained within a single ASET/ASCC depending on whether or not the multiplexes are transmitted uplink from a single ASET/ASCC.

6. One ASET/ASCC is designated as the master ASET/ASCC and has responsibility for allocating and reallocating of multiplexes and coordinating satellite switching commands.

7. Each multiplex transmitted uplink, and containing an SS&S channel, has a companion downlink frequency/channel for transponding SS&S information.

8. The downlink SS&S return would typically consist of a 19.2 kilochip bit stream carrying a sequential multiplex of synchronization, surveillance and supervisory return information.

9. The basic requirement for downlink voice and data communication is that one frequency channel is provided for each uplink channel for full duplex operation.

10. Each ASET/ASCC, transmitting and receiving its own SS&S signals, also processes them and computes the position of all aircraft under its jurisdiction. It passes the position coordinate information to the ATCC's which interface with it.

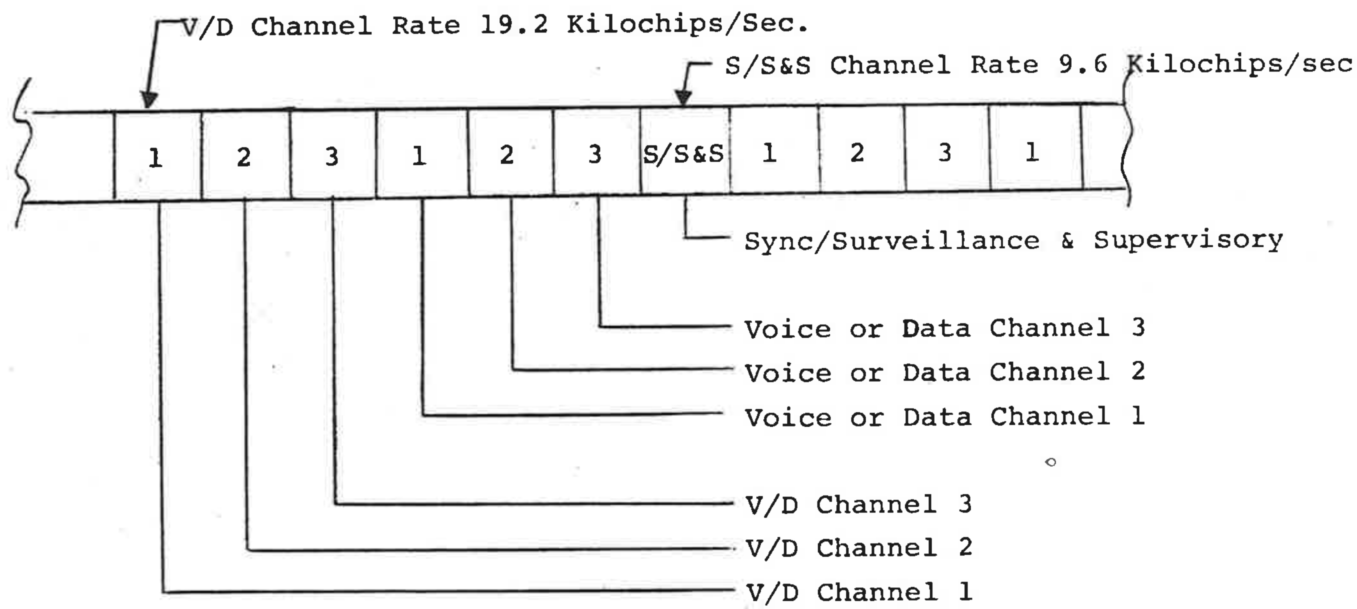
11. Random entry or emergency signalling would be done in a manner essentially identical to that for the single multiplex per satellite already described.

12. Discrete address polling is used for normal entry polling. For initial entry, two slots are used to permit one slot of pure carrier transmission downlink for a carrier acquisition doppler search, followed by one slot in which the normal supervisory and surveillance signals are transmitted.

5.3.2 Control and Data Flow Mechanization

Mechanization details for the two multiplexes per satellite configuration are presented in this section. Two multiplexes per satellite are assumed, each consisting of a 19.2 kilochip per second per channel data stream. Figure 5-12 shows the bit-by-bit multiplexing on the data stream for a system capable of three communications channels per multiplex. Approximately the same power is allowed per satellite for the SS&S function as for the single multiplex for satellite configuration. This is shown

A. Basic Multiplex @ 67.2 Kilochips/Sec



B. S/S&S Channel Utilization for Composing Slot Format

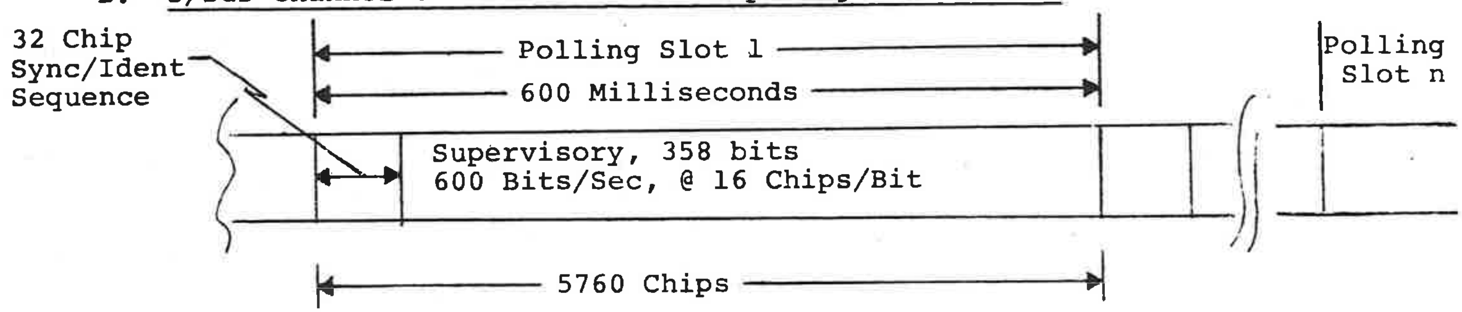


FIGURE 5-12. REPRESENTATIVE FORMAT FOR UPLINK MULTIPLEX FOR SYSTEM E

in the upper portion of Figure 5-12 where each communication channel is transmitted twice per frame. The lower portion shows how the 9.6 kilochip rate is used to format the SS&S slot data. Since in this configuration, there are twice as many supervisories (4 total) for the total AEROSAT system as for the single multiplex per satellite configuration, the slot time has been doubled to 600 milliseconds to keep the supervisory information data bits per slot constant at 358 without affecting the position update rate.

The formats of Figure 5-12 imply an instrumentation similar to that presented for the single multiplex per satellite configuration. However, some additional complexity is added to the avionics to handle the unsymmetric data flow. To maintain the same channel quality/error rate characteristics as for the first configuration, one unit of power is allocated to a voice/data channel and one-half unit of power to the SS&S channel operating at half the chip rate as for the voice/data channels. Degraded satellite operation at end-of-line can be accommodated by transmitting only a single multiplex.

The downlink SS&S data information transmission is carried on a separate carrier as are the individual voice or data channel encoded bit streams. The instrumentation for downlink SS&S transmission can therefore be similar to that for System D but with a slot length of 600 milliseconds. By using a 19.2 kilochip/second rate, an additional 360 bits of data carrying space is thus available in the downlink slot format and could be considered for use in air traffic control related functions as opposed to using the supervisory strictly for AEROSAT system supervision.

5.3.3 System Entry Procedures and Data Management

The operational procedures for either bit-by-bit multiplex configuration are quite similar and hence a description of these procedures for the two multiplex per satellite configuration would be repetitive and are therefore not included. As presented in the first interim report, the two multiplex per satellite configuration was rated higher than the single multiplex per satellite configuration. In summary, although some intermod product problems are again encountered in the two multiplex per satellite configuration, in cases where both multiplexes are routed to the same area advantages override this rather rarely-occurring and minor disadvantage.

5.4 Description of Burst TDMA System (System F)

5.4.1 Introduction

A burst TDMA concept is presented in sufficient detail to permit studying the system access characteristics. It is adapted to the peculiar requirements of AEROSAT. The concept utilizes a single burst TDMA per satellite incorporating in each a means for TDMA system supervision, a means for surveillance ranging and a means for communicating between any ground station to any aircraft located anywhere. A typical signal format is presented in the following sections to illustrate operation of the concept.

5.4.2 Uplink Control and Data Flow Mechanization

A peculiar requirement of the AEROSAT system, as distinct from those of a general multiple access communication system, is the provision for surveillance ranging. Consequently, the timing for the burst TMDA communication and surveillance system proposed for study is tailored around the surveillance signal processing requirements. Study has shown that approximately 0.3 second individual surveillance servicing interval is reasonable. Figure 5-13 shows timing diagrams for this uplink burst TDMA design. As shown in the first line of the figure, the data stream could typically consist of a sequence of eleven bursts in a 330 millisecond interval of time. One of the bursts serves as a synchronization, surveillance and supervision signal (SS&S) and the other ten serve five communication channels handling either delta modulation voice or digital data. The SS&S burst serves as the framing channel for the sequence. The individual channel is considered to operate at 43 dB Hz or the entire multiplex is supportable in a 51 dB Hz channel requiring approximately 5½ units of satellite power for the example being described.

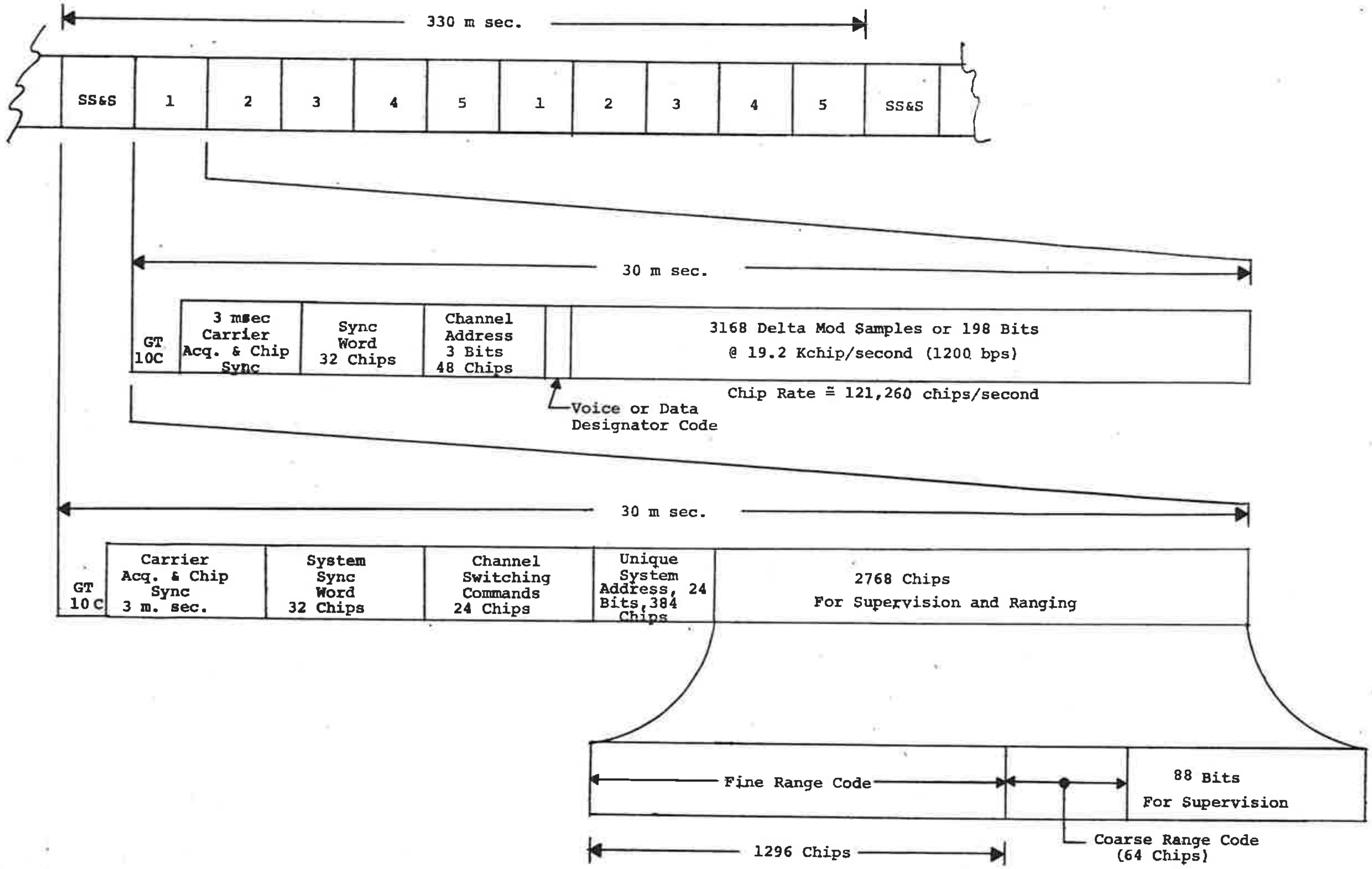


FIGURE 5-13. TYPICAL UPLINK BURST TDMA

Any of the bursts within a frame can originate from any ground station. By rapidly switching the satellite spot beam in synchronization with the bursts, a channel can be directed to a mobile located anywhere in the coverage area. To accomplish the above, synchronization of all ground stations in the system is required. It is assumed to be obtained by reception of own-station burst back from the satellite and making a timing comparison and adjustment in a technique similar to those used in current experimental systems. The L-band transmission from the satellite is used for this synchronization and must at times for this approach operate via L-band side lobes.

The framing burst generated by the master ASCC contains the supervisory information for channel management. For a voice channel grant, the aircraft is "rung up" or told which burst to connect to the appropriate decoder/converter. The latter thus requires coordination via the master ASCC generated supervisory on each call. A data call can be made directly from an ASCC providing a strategy is agreed upon where data channels are preassigned to a particular ASCC. A group of aircraft assigned to that channel on a semi-permanent basis monitor and decode the burst channel looking for and decoding ownship address in the digital messages. Such a strategy permits rapid uplink access on the data-link comparable to that obtainable in FDMA systems.

The second timing diagram in Figure 5-13 shows the burst format for any of five communications channels that can handle either 19.2 kilochip per second delta modulation voice or 1200 bit per second data at 16 chips per bit. A total of approximately 200 chip times (approximately 5% overhead) is allowed for the "Preamble" including, guard time, three milliseconds for carrier acquisition and chip sync, sync word, and channel address as shown. This overhead is based on the AEROSAT signal quality and is compatible with that used on other burst TDMA designs.

Three milliseconds to reacquire phase lock and chip sync is adequate providing frequency tuning is within approximately

1 KHz. With doppler and receiver mistuning equal to about ±5000 KHz, an initial longer pull-in time will, however, be required to establish carrier lock as discussed in more detail in Appendix E. This is the case at initial entry. When a burst is switched to a remote area after absence of signal for a long period a special 30 msec acquisition burst is transmitted. Once any burst is acquired by an aircraft any other burst from any other ASCC can be locked onto (carrier phase and bit lock) within the period allowed. This is based on the variation in satellite motion induced doppler being bounded at about 600 Hz for extremes in placement of different ASCC's.

The sync word following the pure carrier interval (referring again to the second timing diagram, Figure 5-13) consists of 32 chips and provides a unique communication message start signal required to decode the channel address and subsequent message fragment. The channel address, next to the format, consists of three data bits at 16 chips per bit to enable the aircraft to identify any channel burst uniquely. The final portion of the preamble is a one-bit designator indicating type of service carried in the channel (voice or data). The channel data message consists of 3168 chips to support the equivalent of a continuous 19.2 kilochip delta voice or 198 bits of a 1200 bps data channel at 16 chips per bit.

The third timing diagram in Figure 5-13 shows the burst format for synchronization, surveillance ranging and system supervision. Included in this burst is a facility for commanding the satellite channel amplifier to different beams on a burst-to-burst basis. After a guard time of the equivalent of ten chips, a three millisecond equally divided transmission of pure carrier and alternate one and zero chips are transmitted to permit the satellite and aircraft in the beam to acquire the carrier and achieve chip synchronization. This is followed by a 32 chip sync word unique to the SS&S channel burst and used by the satellite and aircraft in the beam to achieve message sync. This is followed by a 24 chip channel switching command sequence. This carries the information for channel-to-beam switching for the next SS&S channel burst and the ten communications channel bursts following this next SS&S channel burst. Eighteen chips are used, three chips at a time, for routing each of six TDM channels to one of five beams. The three chips would permit routing up to one of eight beams. The remaining six of the 24 bits are allocated for error detection and correction. The signal quality in uplink to the satellite is approximately 70 dB resulting in an error rate in excess of 10^{-7}. Error detecting provides additional accuracy for the switching command integrity.

The channel-to-beam switching chips are handled as three unused bits by the aircraft avionics and are followed by a 24 bit aircraft system address requiring 384 chips. The 24 bit addressing system is chosen as sufficient to encode all aircraft uniquely. Finally, 173 bits or 1384 chips remain in the rest of the burst and are allocated to the functions of system supervision and ranging as shown. Range measurement timing utilizes a fine/ coarse range code arrangement following the unique system address. The 1296 chips of the fine range code consists of alternate "1's" and "0's" to enable achieving very accurate local clock pulses. The coarse range code consists of a 64 chip unique sequence, decoded and used to gate in one of the shaped precision clock pulses for maximally accurage uplink ranging. The remaining 88 bits are more than adequate to cover the supervisory function as outlined in conjunction with other system configuration descriptions.

5.4.3 Downlink Instrumentation

5.4.3.1 Selection of TDM or FDM

The burst multiplex system proposed provides excellent channel and beam transmission flexibility for uplink transmission to the aircraft. The instrumentation for the aircraft must now be designed such that this flexibility is also provided for downlink transmission.

Since TDMA techniques are proposed for uplink transmission in the subject system concept, the choice of some form of TDMA technique for downlink transmission also might at first appear logical. While there are a number of reasons for such a choice, there are also disadvantages. One of the important reasons for using TDM in the uplink transmission does not exist to the same extent for downlink transmission. While there is a significant power savings in the avoidance of intermodulation products by use of TDM for uplink transmission, the same is not true for downlink transmission. This is so because large antenna size permits the power amplifier transmitting downlink to operate in nearly a linear mode. Hence, intermodulation products are much less severe and this factor becomes insignificant in the selection. A choice of either TDM or FDM can therefore be made based on overall complexity and avionics cost for the downlink transmission system.

There are a number of disadvantages in the use of TDM in downlink transmission. One is that individual aircraft adjustment of the time of burst reply is necessary to permit an efficient downlink burst multiplex. Aircraft reply time should be adjusted to an accuracy of approximately one-half to one millisecond to permit a small guard time between bursts from different aircraft and different channels. Although such individual aircraft time adjustment is required continuously as the aircraft moves, it can be computed on the ground and transmitted uplink, requiring a very small amount of data link capacity. However, it does require that aircraft location be known on the ground. Therefore, surveillance information of sufficient accuracy is a requirement. Random entry becomes even more difficult and requires the aircraft to calculate his own correction based on his estimated position.

Perhaps the most serious disadvantage is that analogous to a time-division-multiplex going uplink through the satellite where all the power is utilized in one multiplexed channel, the equivalent of all the power from n different aircraft, utilizing the n channels downlink, must be applied in each burst.

In practice, this means that the peak power from an aircraft must be n times the power emitted in an equivalent single channel of an FDM n-channel system for the same signal quality. Achieving such much higher peak powers, especially in solid state, could be a very challenging design problem. Peak power levels of 500 to 1000 watts in a solid state transmitter may be needed.

An additional factor for consideration is the manner and ease with which additional downlink channels may be added for one-way rapid access calling or for any other purposes. In FDM, such extra channels are quite easily added at any time new satellites are orbited without change to the aircraft avionics. Only additional channel tuning capability must be initially added to the avionics equipment. In the burst TDMA instrumentation, one-way calling channels may also be included but must, for all practical purposes, be included in the initial formatted instrumentation. Their inclusion requires transmission at even higher data rates and higher peak powers.

The major disadvantage of FDM for the downlink is the requirement for a more complex frequency synthesizer. However, this is somewhat offset by the processing complexity associated with generating the high rate bursts.

Based on the above factors, FDM has been selected for the downlink transmission.

5.4.3.2 Satellite Instrumentation

Two approaches for the instrumentation of an FDM A-G transmission appear practical. The considerably simplest of these two approaches is shown in the overall configuration diagram of Figure 5-14. Assuming that adequate aircraft transmitting EIRP margin is available as shown in Table 5-1 the return link transmission can be via an earth coverage antenna as shown. The L-band return would be received in the satellite by a broadband receiver picking up returns from FDM voice, data, SS&S, or rapid access channels. The returns are appropriately translated in

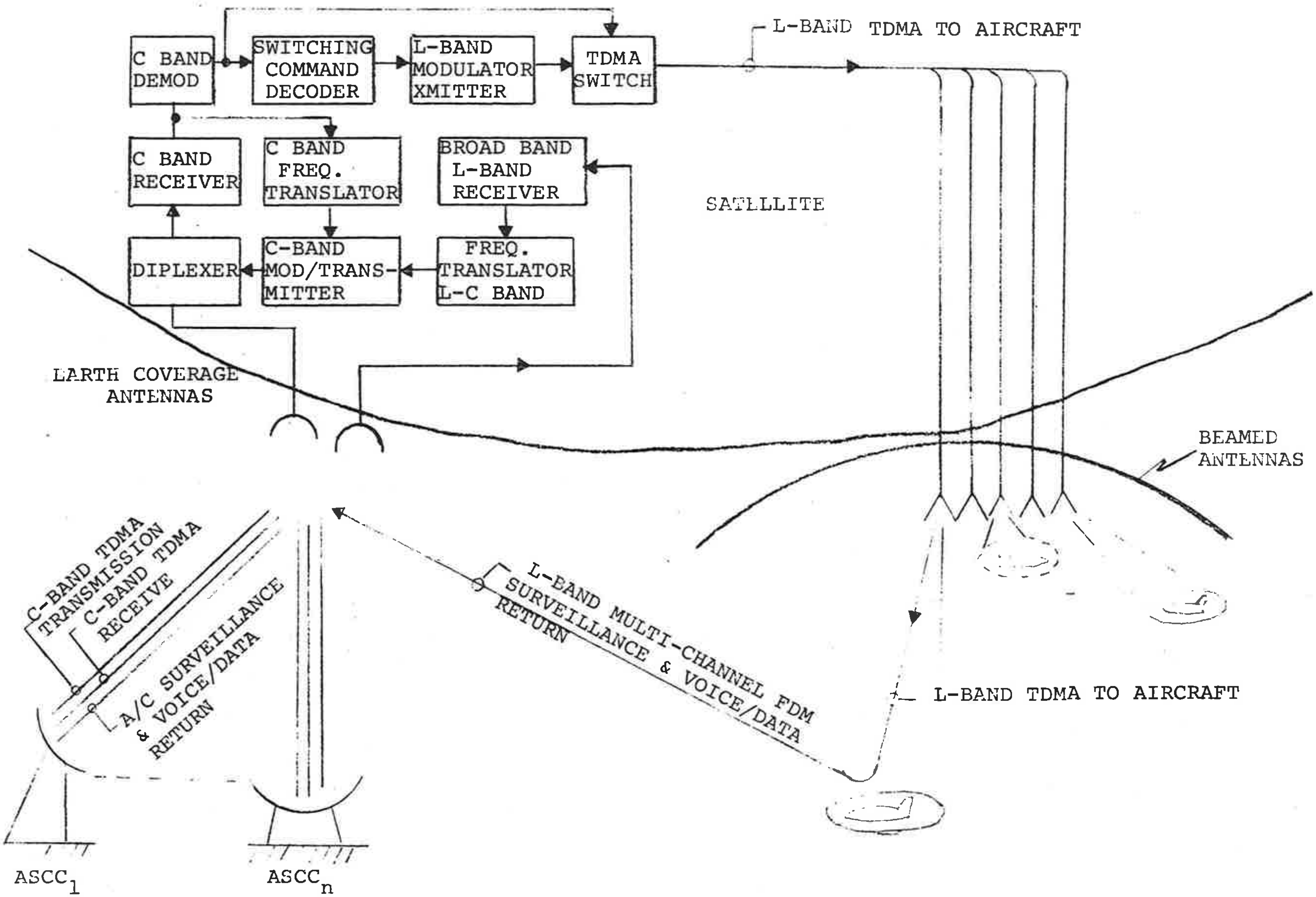


FIGURE 5-14. SYSTEM CONFIGURATION FOR BURST TDMA UPLINK AND DIGITAL/FDM DOWNLINK

frequency and returned on earth coverage beam to earth where they can be received by any ASCC and routed to the appropriate ground user. (See Table 2-1 for link budget.)

If return via earth coverage antenna is not feasible because of inadquate power, the returns could be handled via the spot beams. This would require a diplexer in each spot beam feed (see Figure 5-14) to accommodate the individual broadband (to accommodate all FDM surveillance and voice/data carriers) receivers. Such an arrangement may, however, require channelized receivers where individual channels are deactivated to prevent transmission of their noise power when not in use.

The preceding description has covered the basic system concept and overall instrumentation. A description of the technique for system supervision, communication channel and supervisory management will be presented in the following sections.

5.4.4 Basic System Organization

The chief consideration with respect to generation of the SS&S channel, for purposes of access study, is at which point(s) it is generated and how is the information received at the point(s) of generation.

There are two satellites and thus two burst TDMA systems supplying information channels in the AEROSAT system. Any ASET/ASCC is able to transmit uplink through either satellite on the assigned frequency for each satellite's burst multiplex. Therefore, an ASET/ASCC could at any time be required to transmit bursts at two different frequencies. The burst transmissions through one satellite would not necessarily have any synchronization with the burst transmission through the other satellite.

One ASCC is assigned to generate the SS&S framing burst for each satellite. There is, in effect, a separate master ASCC using a separate supervisory channel to manage and control the communication channels associated with each multiplex.

Each aircraft upon entering the system is assigned a frequency for monitoring one of the multiplexes. To keep avionics instrumentation simple an aircraft monitors only one frequency. Therefore, access is available only through those channels associated with the particular multiplex being monitored. Because of this, a distributed form of control results. Close coordination is required among the ASCC's to ensure that approximately equal loading in each multiplex is maintained. This could involve reassignment of master ASCC's as a function of time of day and/or time of year so that the ATCC's and the traffic they control is split between the two multiplexes.

Each master ASCC polls all the aircraft assigned to a multiplex for surveillance and supervisory interchange. The information and types of polls involved are similar to those described for systems A and B in Section 4.0. In general, the SS&S burst will be required to be switched to all the spot beams containing aircraft in the multiplex. However, since there are two SS&S polling channels the number of beams involved may be less than the total number of beams in a satellite. In this system, a single acquisition burst consisting or pure carrier is transmitted whenever the SS&S channel is switched into an area where there has not been any transmission for a long period of time.

The master receives channel requests only from those aircraft in a particular multiplex. However, ground requests are received from the terminals directly interfacing with the ASCC and from all the other ASCC's in the system including the other master ASCC.

In addition to the multiplex, each aircraft is assigned a data channel to monitor within the multiplex looking for ownship address in the UDDL format. This enables any ASCC controlling the data channel to transmit data uplink without any action via the supervisory channel. When an aircraft desires to send data downlink, it will signal the master ASCC via the supervisory channel.

5.4.4.1 Eclipse Operation

Operation during eclipse basically involves switching all aircraft in the system to the multiplex operating via the non-eclipsed satellite. If possible, a strategy should be employed where the majority of the aircraft in the system are serviced by the non-eclipsed satellite well before eclipse occurs.

The burst multiplex TDMA configuration has good adaptability for operation under eclipse conditions in that rapid channel-to-beam switching is a basic feature of the concept. This is unlike the bit-by-bit multiplex where multiple channels are switched beam-to-beam with a time required for all aircraft to reacquire the data stream.

5.4.4.2 System Entry Procedures

As an aircraft approaches the oceanic-continental boundary, information as to its address and point and time of entry into the system is transmitted to the oceanic air traffic control center (ATCC) (see Figure 5-15). The aircraft will also have been informed of the assigned multiplex frequency so that it can pull into lock after receiving a series of SS&S and communication channel bursts. A two-slot SS&S poll is sent to the aircraft for initial doppler acquisition. The ASCC receives the reply, assigns the aircraft to a data channel and computes the aircraft position. The ASCC informs the associated ATCC of aircraft position and continues thereafter to poll and position locate the aircraft at a rate as ordered by the ATCC. Also, all voice and data requests are serviced as received via the supervisory, subject to priority and queue status.

5.4.4.3 Random Entry or Emergency Signalling

Random entry or emergency signalling in the burst multiplex system is accomplished in a manner essentially identical to that for the bit-by-bit multiplex or FDMA configurations. Downlink signalling is accomplished via a UDDL formatted and generated message transmitted at a lower rate over a special

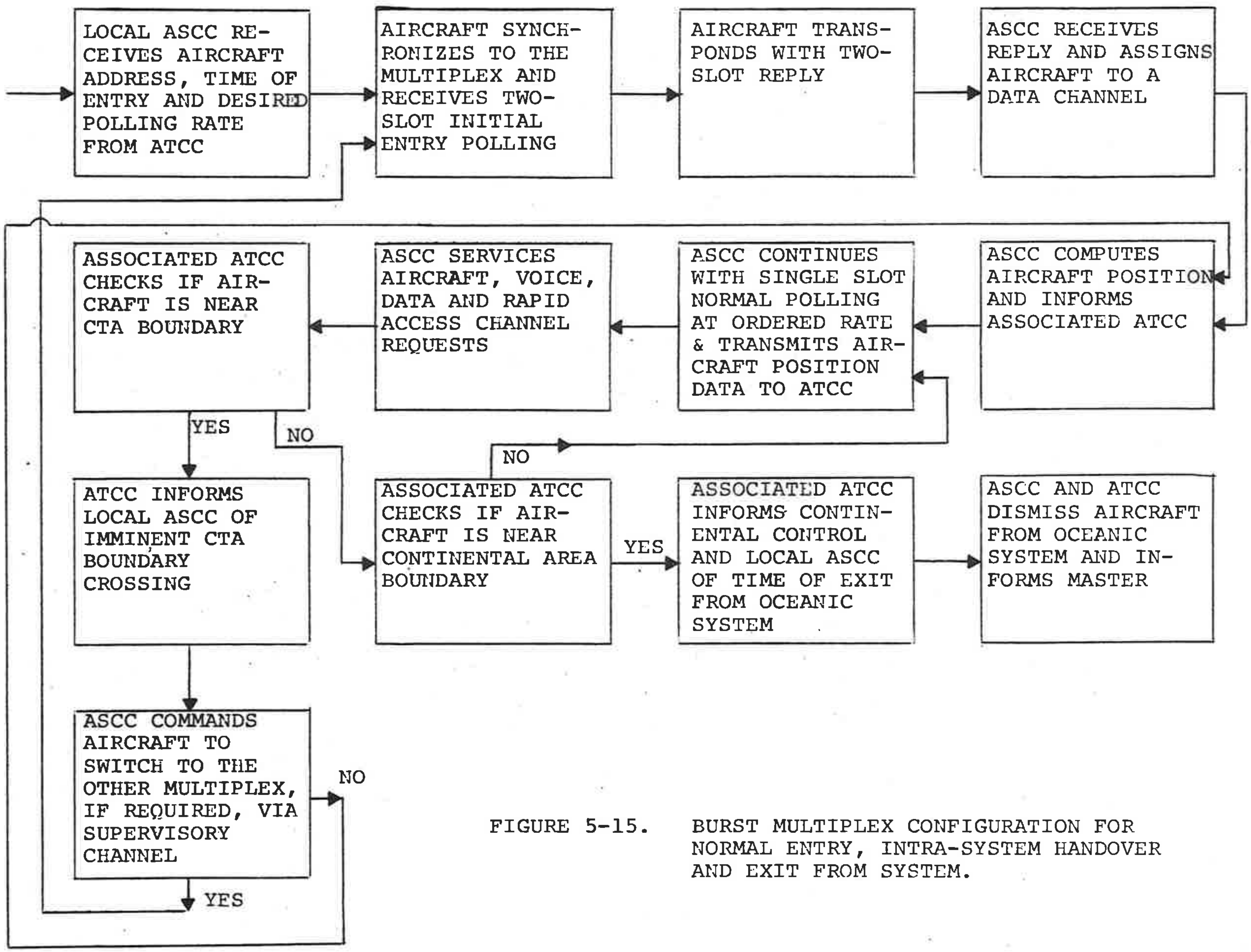


FIGURE 5-15. BURST MULTIPLEX CONFIGURATION FOR NORMAL ENTRY, INTRA-SYSTEM HANDOVER AND EXIT FROM SYSTEM.

channel received by all ASCC's. For random entry, the appropriate ASCC executes an initial acquisition two-slot poll. For emergency signalling, the aircraft may be polled on a single slot basis as doppler is known. For both cases, in this burst mutliplex configuration, if the aircraft is in an area that is sparsely populated it may be necessary to transmit a "pure carrier" SS&S burst in addition to the two-slot initial acquisition polling.

5.4.4.4 Communications Facilities Accessing

5.4.4.4.1 Introduction

It is desirable to be able to utilize all channels on a readily interchangeably basis for either voice or data service. Each channel burst is, therefore, coded by use of one bit to designate it as either for voice or data service and the proper end instrument automatically connected in the aircraft. Each aircraft is still assigned to monitor a given channel for data service looking for own ship address in the Universal Digital Data Link (UDDL) format. When it is desirable to occasionally use all channels for voice service, the aircraft assigned to monitor a particular data channel would continue to do so, awaiting change of the indicator bit returning it to data service.

5.4.4.4.2 Uplink Data Contacts

With the communications facilities administered as described, uplink data contacts can be made directly by addressed polling over the UDDL facilities. A number of ATCC's and airline offices will typically be connected to an ASCC controlling a data link channel. When either wishes to send a data message to an aircraft the ASCC simply stores the message and forwards same via direct address polling at a time based on when the message was received and its priority. If the aircraft is serviced in the other ASCC's data link, the data message would most efficiently be transmitted by sending the message via G-G facilities to the other ASCC and having this ASCC transmit it to aircraft on a direct data poll.

5.4.4.4.3 Downlink Data Transmission

Downlink data transmission requests are signalled by the aircraft when polled over the SS&S channel. Upon receipt of request, the master ASCC forwards this to the ASCC controlling the data link, if different. The aircraft is then polled and the data message is received on reply to the poll. The data message is then forwarded to the address contained in the message format using G-G facilities if required.

5.4.4.4.4 Uplink Voice Contacts

Uplink voice contacts from an ATCC or airline office are initiated by signalling the local ASCC (see Figure 5-16) giving aircraft address and priority of contact. The local ASCC must first determine on which multiplex the addressed aircraft is being supervised. If on its own multiplex, it rings up the aircraft on the SS&S channel as soon as other polling requirements and priority of message, against any other requests, warrant. The aircraft acknowledges electrically and verbally and the ASCC completes connection to caller.

If the aircraft desired to be contacted is on the other multiplex, the local ASCC requests the other ASCC to ring up aircraft via its SS&S channel. This ASCC to ASCC contact would be carried via G-G facilities. The other ASCC then informs the local ASCC on which burst channel, in the other multiplex, the voice contact is to be handled. The local ASCC then establishes a duplex voice transmission over the other multiplex and the local ASCC completes a connection to the airline or ATCC caller.

After completion of the voice contact, the airline or ATCC informs the local ASCC of completion of the voice contact. The local ASCC then returns the channel to service the queue.

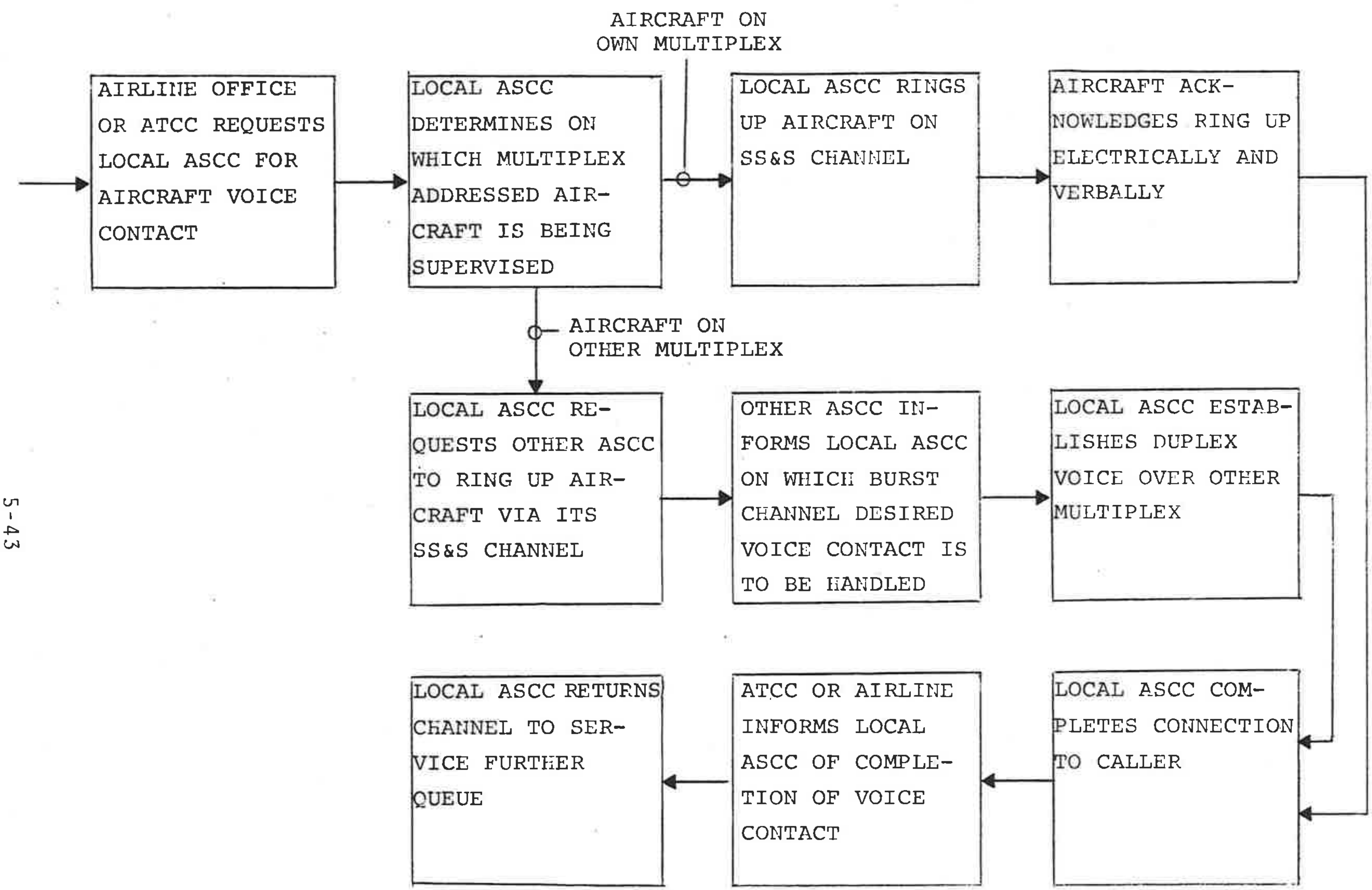


FIGURE 5-16. PROCEDURES FOR UPLINK VOICE CONTACT FOR BURST TDMA

5.4.4.4.5 Downlink Voice Contacts

Downlink voice contacts are handled identically to uplink contacts except for initiation of the contacts. To initiate the contact the pilot, under other than emergency conditions, sets up the address and priority and depresses a request button. The request is transmitted downlink on the next regular surveillance polling and a voice contact to any directly connected ATCC or airline office may then be set up by the ASCC assigning a burst channel to voice service and completing the connection from the ATCC to either the ATCC or airline address as appropriate. If the aircraft desires an address associated with the other ASCC in the system, such contact must again be coordinated with the other ASCC as described for uplink voice contact.

5.4.5 Instrumentation Description and Cost Analysis of the Selected Time Division Multiplex System

5.4.5.1 Avionics System

5.4.5.1.1 Overall System Description

The airborne system instrumentation for the selected burst multiplex configuration is shown in overall block diagram form in Figure 5-17. It is based on the example signal format which has been described in the previous section. It is presented as typical of TDMA avionics and not as finalized design. This AEROSAT avionics instrumentation is a single transmit and receive system. Only a single conversion is required on receive and only a simple up-conversion required on the downlink transmission. Two types of burst multiplex channels are received uplink, the SS&S framing channel and a communication channel (either voice or data). The received burst TDM chip stream from the diplexer is first amplified in a preamplifier to proper level for conversion to intermediate frequency (IF). After IF amplification, the signal is fed to a phase lock circuit (probably a Costas loop) wherein an initial acquisition, frequency search is required to correct for incidental receiver mistuning and doppler effect. After signal

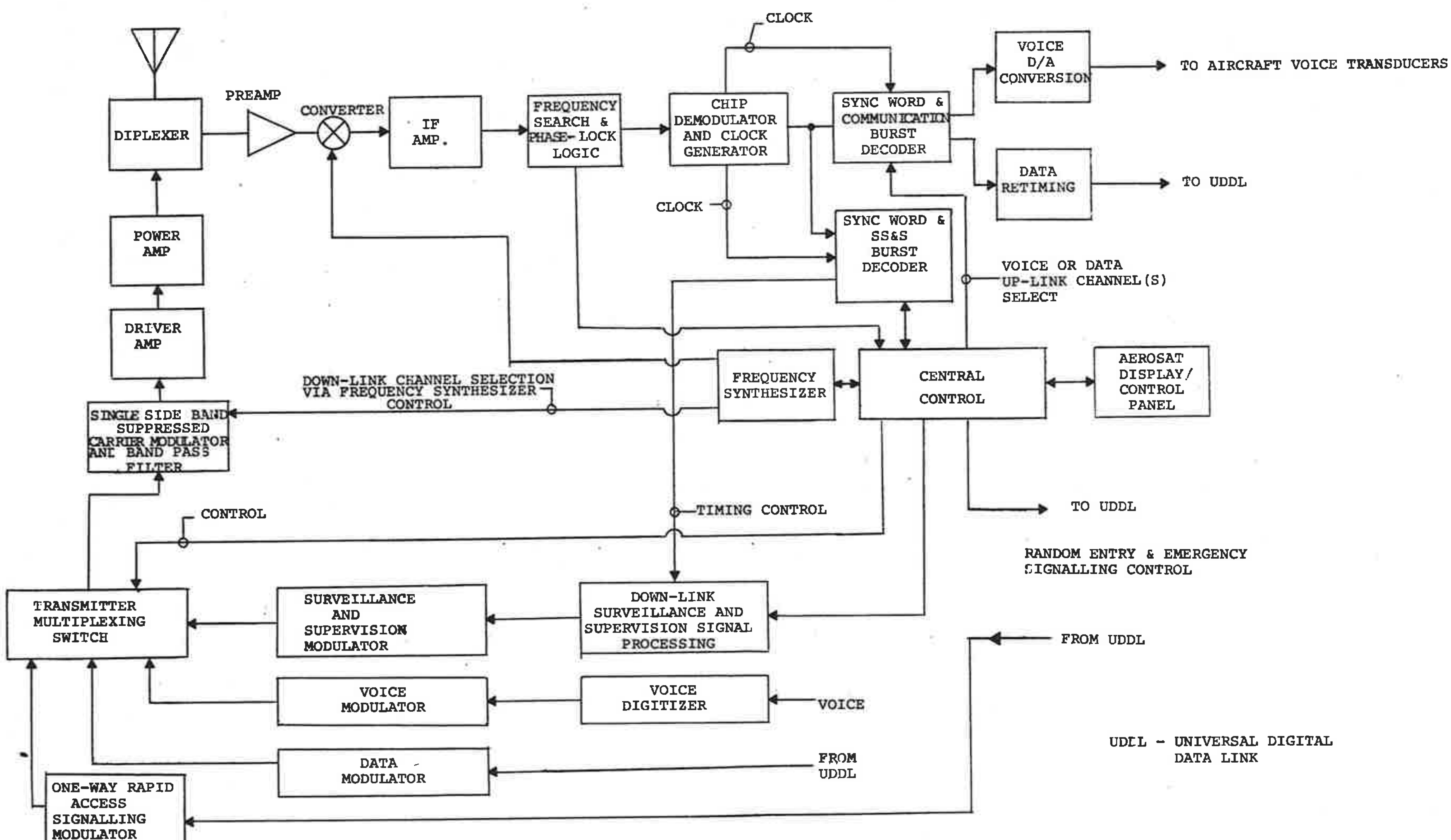


FIGURE 5-17. AVIONICS SYSTEM FOR TDMA (SYSTEM F)

acquisition, an aircraft would use each subsequent SS&S burst to trim its receiver tuning. The signal passes to a phase sensitive demodulator for chip demodulation, this demodulation process also resulting in the generation of a local clock used in clocking of the chip stream into a sync word detector and for use in clocking in the decoding of the burst content proper. The decoding of the sync word enables the clocking of the chip stream to a voice-or-data decoder where, depending on whether the voice/data designator code is decoded as voice or data, the chip stream is fed to either the voice D/A conversion circuitry of the data retiming circuitry. The voice D/A conversion circuitry handles successive received burst transmissions, using a dual register storage set to restore the initial delta modulation bit stream to a continuous and standard clock rate for conversion to analog voice in the delta demodulation circuit. The data retiming circuitry similarly handles successive received burst transmissions containing data, by storing the data portion of successive burst between two temporary holding registers from which, by appropriate clocking, the original continuous chip stream is restored (only delayed). This continuous chip stream is fed to a chip-to-bit conversion circuit where 16 chips are detected as a bit at the UDDL standard rate of 1200 bits per second.

The decoding of the SS&S burst is similar to that for the communication channel bursts. After carrier acquisition and chip synchronization is achieved the unique sync word is decoded enabling the unique address portion of the burst to flow to an aircraft address decoder. The decoding of proper address in turn enables the fine and coarse ranging code to flow to appropriate decoding circuitry. The precise range mark so obtained is used to initiate the downlink surveillance ranging code transmission. Finally, the last portion of the uplink SS&S burst containing the supervisory message is fed to a holding register from which it is shifted to appropriate decoding networks for system supervision signal decoding.

Downlink transmission is carried by conventional all-digiral FDM channels. A unique frequency is associated with every burst in the frame. Three downlink FDM channels are proposed plus a low-speed one-way rapdd-access signalling channel as shown. The SS&S downlink channel format is very similar to that described for System D and E in the previous section. A diagram of the approximate format for the SS&S signal is included here as Figure 5-18 for convenience. Voice is carried in delta modulation format at 19.2 kilobits per second chip rate while data is handled at 1200 bits per second and 16 chips per bit.

5.4.5.1.2 Detailed System Instrumentation Description and Costing Analysis

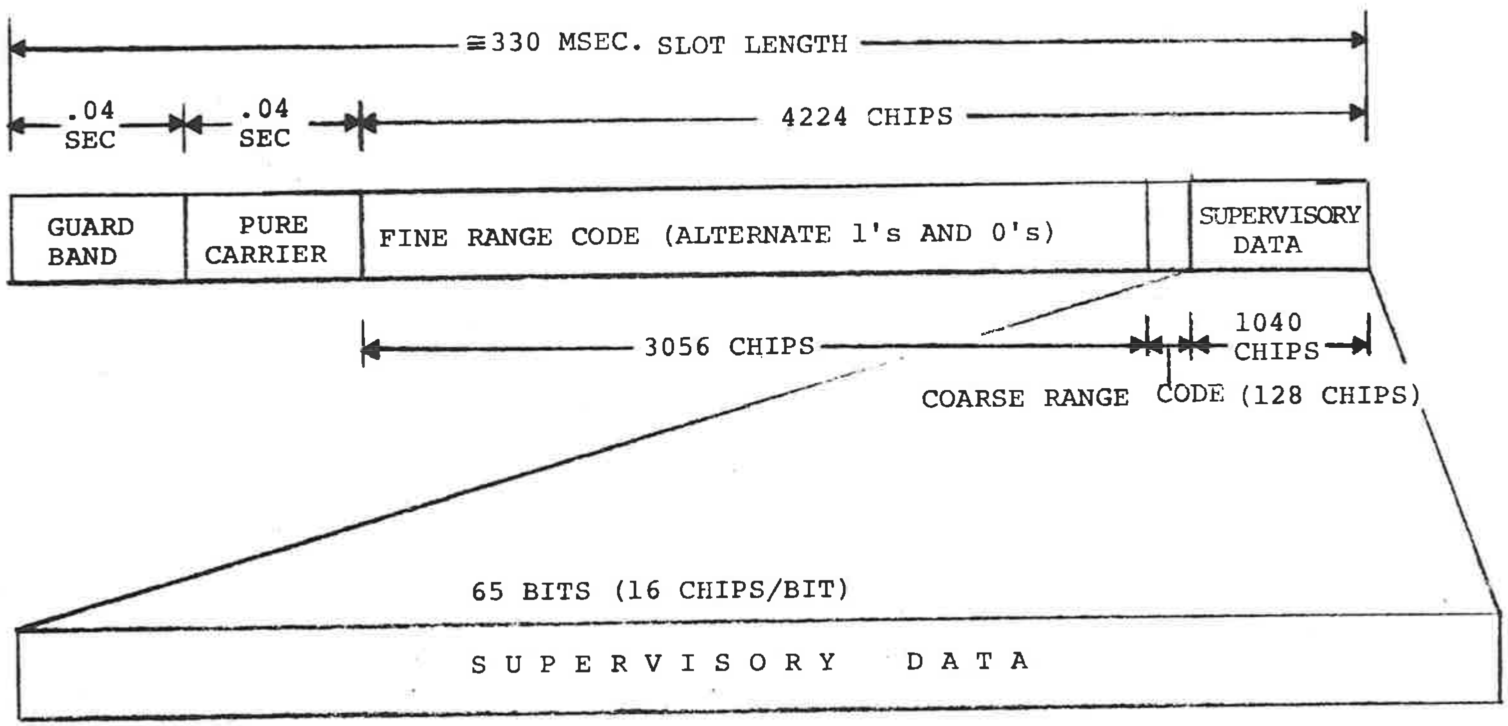
Typical instrumentation of circuit functions as shown in the block diagram of the avionics system have been prepared in preliminary design form to aid in arriving at a reasonably accurate cost estimate. More detailed block diagrams of most of the major circuit functions have been prepared in this preliminary design effort and some are included in the descriptive text following. Costing of the major as well as minor circuit functions rests in part on experience gained in the development of similar hardware at Bell. The major element breakdown for description and costing is given in Table 5-1. These are described and a cost summary presented in Table 5-2.

5.4.5.1.3 Display/Control Panel Assembly

The AEROSAT Display/Control panel would hold all displays and controls peculiar to AEROSAT and not already provided on the Control and Display Unit in the Universal Data Link system assumed to be on-board also. The panel could be of small, simple construction providing the following signalling and display facilities as a minimum.

Two Voice Channel Request Pushbutton (Regular and Priority)

Two Data Channel Request Pushbutton (Regular and Priority)



NOTE: Coarse Range Code also provides supervisory chip/bit and character sync.

Supervisory Data:
- a) 10 bits, system address of aircraft
- b) 11 bits, aircraft altitude
- c) 44 bits, communication facilities control

FIGURE 5-18. TYPICAL SS&S DOWN-LINK TRANSMISSION (NORMAL REACQUISITION) 19.2K CHIPS/SEC.

TABLE 5-1

SYSTEM F AVIONICS SYSTEM ASSEMBLY

QUANTITY	
1	Display/Control Panel Assembly
1	R/T Assembly
1	Frequency Search and Phase Lock Loop
1	Chip Demodulation and Clock Generation Circuit
1	Sync Word and Communication Burst Decoder
1	Sync Word and SS&S Burst Decoder
1	Central Control Circuitry
1	Downlink Surveillance and Supervisory Signal Processing
1	Voice Modulator and Voice Digitizer
1	UDDL Data Message Buffer and Modulator
1	Rapid Access Signalling Formatter and Modulator
1	Frequency Synthesizer

One Emergency Signalling Pushbutton

One Random Entry Signalling Pushbutton

One Visual Ringup Indicator

One Aural Ringup Indicator

One "In Cue" Acknowledgement Indicator for Voice or Data Request.

One Surveillance Interval Timeout Indicator

One System Malfunction Indicator

5.4.5.1.4 <u>R/T Assembly</u>

The R/T assembly for the TDMA system is very similar to that used in the FDMA system and is shown in Figure 5-19. The main difference is in the receiver where only a single down conversion to 70 MHz is required. However, a double conversion receiver can be used. The 70 MHz output is fed to a phase-lock demodulator for conversion to baseband. The transmitter upconverter section is identical to that in the FDMA system while the synthesizer in this system is simpler. A listing of the R/T elements is as follows:

QUAN	
1	Diplexer/Preselector
1	Preamp
1	Bandpass Filter
1	Mixer Assembly
1	Wideband IF Amplifier/AGC
1	Power Divider
1	4 Channel Signal Selection Matrix
1	Single Sideband Suppressed Carrier Modulator
1	Bandpass Filter
1	Driver Amplifier
1	Power Amplifier (100 Watt)
1	Frequency Synthesizer
1	R/T Power Supply

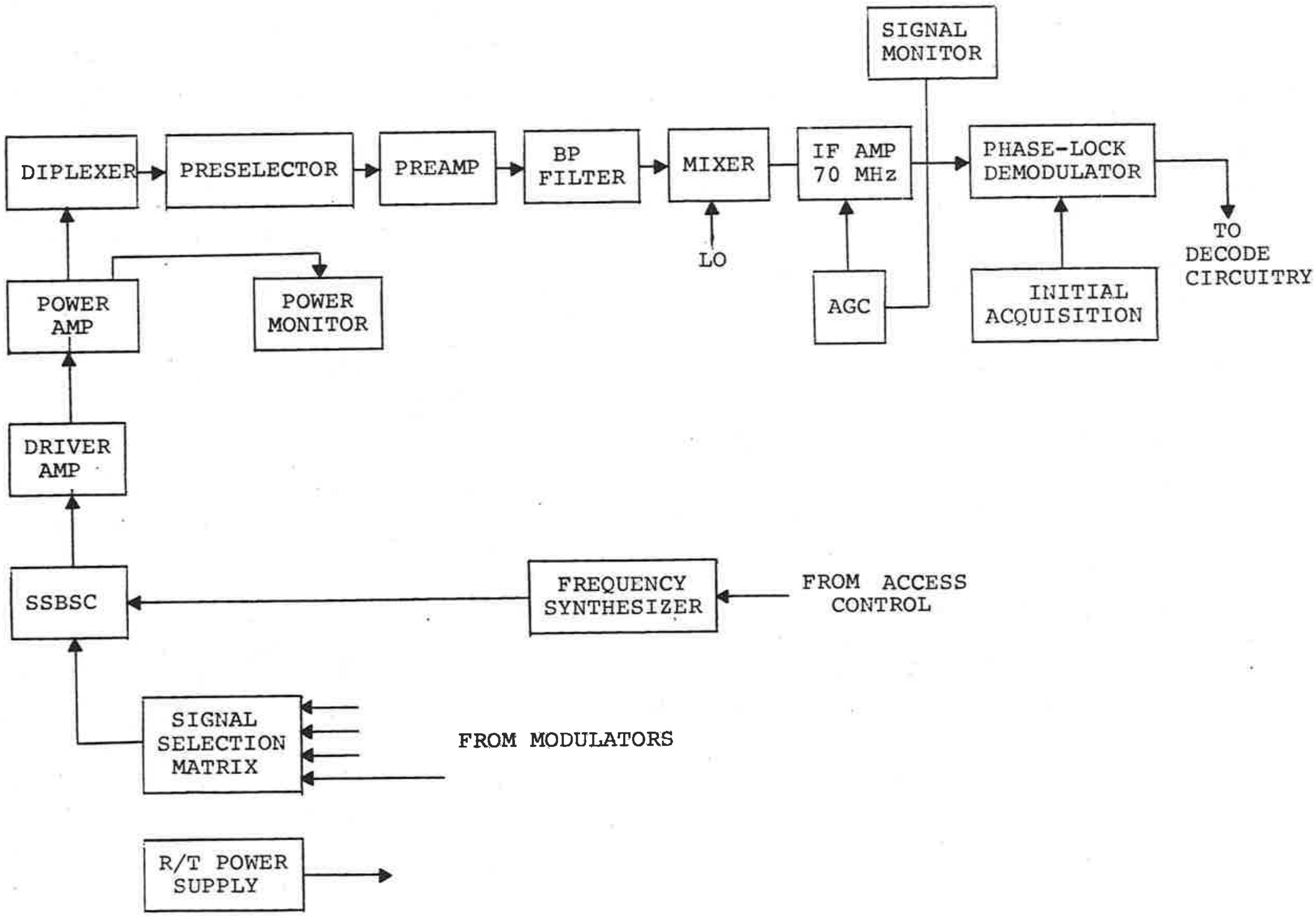


FIGURE 5-19. TDMA AVIONICS R/T ASSEMBLY

5.4.5.1.5 Frequency Search and Phase Lock Loop Circuitry

The PLL may be of conventional design employing a Costas loop to provide a phase reference for DPSK demodulation. Typical loops are discussed in Appendix E. The bandwidth of the PLL must be sufficiently wide to accommodate burst-to-burst phase-lock reacquisition. Sufficient bandwidth is provided to accommodate oscillator drift and doppler changes. Further, since an initial frequency search is required and the search time is related to the bandwidth of the loop, to minimize this search time the bandwidth of the loop must be made sufficiently wide to assure acquisition and lock-up in a reasonable time.

5.4.5.1.7 Sync Word and Communication Burst Decoder

The communication burst unique sync word and communication burst decoder consists of circuitry as shown in the block diagram of Figure 5-20. The local clock generated in the chip demodulation circuitry previously described, continuously clocks the chip stream into a maximum likelihood unique sync word decoder. When a correlation peak above a set threshold is detected, it sets a sync gating flip-flop allowing the chip stream to flow to the channel address register. A continuous comparison is made to own ship assigned channel address by the address comparison circuit which, in turn, receives the aircraft address from the Display/Control panel via central control. When the assigned channel address is detected, the message content is gated to the remainder of the message processing circuitry.

The voice-or-data decode circuit detects whether the message burst is of voice or data content and opens either the voice or data gate to allow the chip stream to flow to either the voice or data processing circuitry as appropriate. For data the chip stream is fed first to a chip-to-bit conversion circuit to obtain data in bit form. From this the data bits are sent to a pair of data retiming registers of 173 bits length each. The bit content of the first burst of a data message is sent to one of the registers. The second burst of the message is then

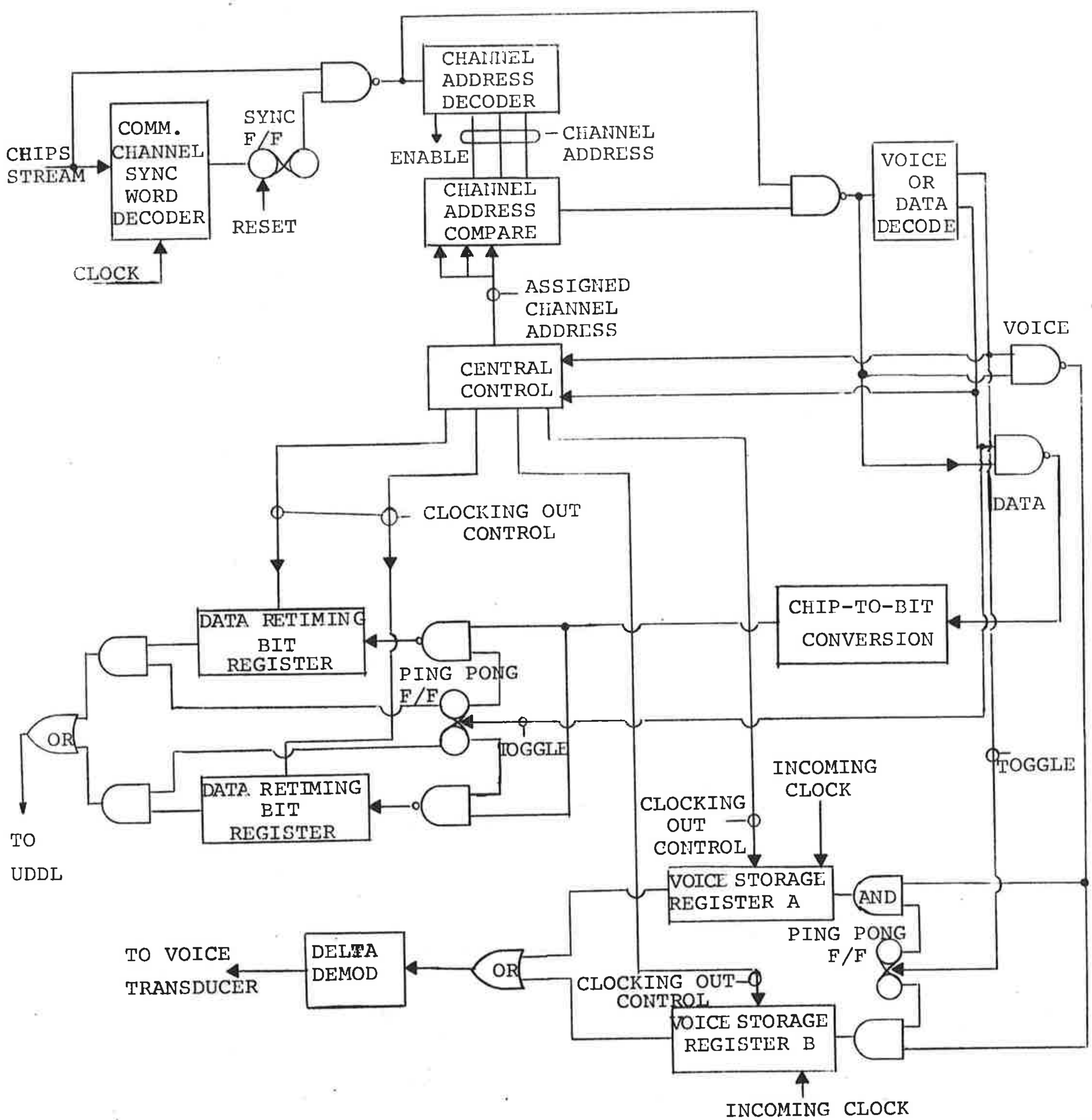


FIGURE 5-20. COMMUNICATION SYNC WORD AND BURST DECODE CIRCUITRY

sent to the other register. Under central control and deriving basic timing from the local clock generated from the incoming chip stream, while awaiting the arrival of the second burst and while the second register is being loaded, the first is being emptied at a clock rate of 1200 bits per second. This process continues, the storing registers being ping ponged between the service of receiving the incoming burst bit stream or clocking out already received bit data.

Similarly for voice, the chip bursts are shifted out of the storage register, not at the time receiving an incoming burst, at a continuous 19.2 kilochip per second rate in an appropriate delta code demodulation circuit, again under central control timing.

5.4.5.1.8 Sync Word and Burst Decoder

The SS&S unique syn word and burst decoder consists of circuitry shown in the block diagram of Figure 5-21. This circuitry is similar to that employed in communication burst decoding but somewhat simpler in one respect as it is not necessary to store several successive bursts to restore timing of received data. It is more complicated on the other hand by the necessity for function decoding of the supervisory message and the necessity for the ranging signal processing.

As for the communications bursts, the received chip stream is continuously clocked into an SS&S unique sync word decode circuitry by the local chip stream clock and when decoded, opens a gate feeding the burst to the aircraft address decoder register. Here, a comparison is continuously made of any received address and own ship address by an address compare circuit also connected to central control. When a received own ship address is detected, the ranging signal portion of the SS&S burst is gated to the range processing circuitry under control of the range code timer. The range processing consists of achieving five clock sync on 1296 of alternate "1" and "0" chips and gating out one pulse, of the very narrow pulses shaped from the finely synced local clock, using the appropriately shaped decoded pulse from the coarse sync

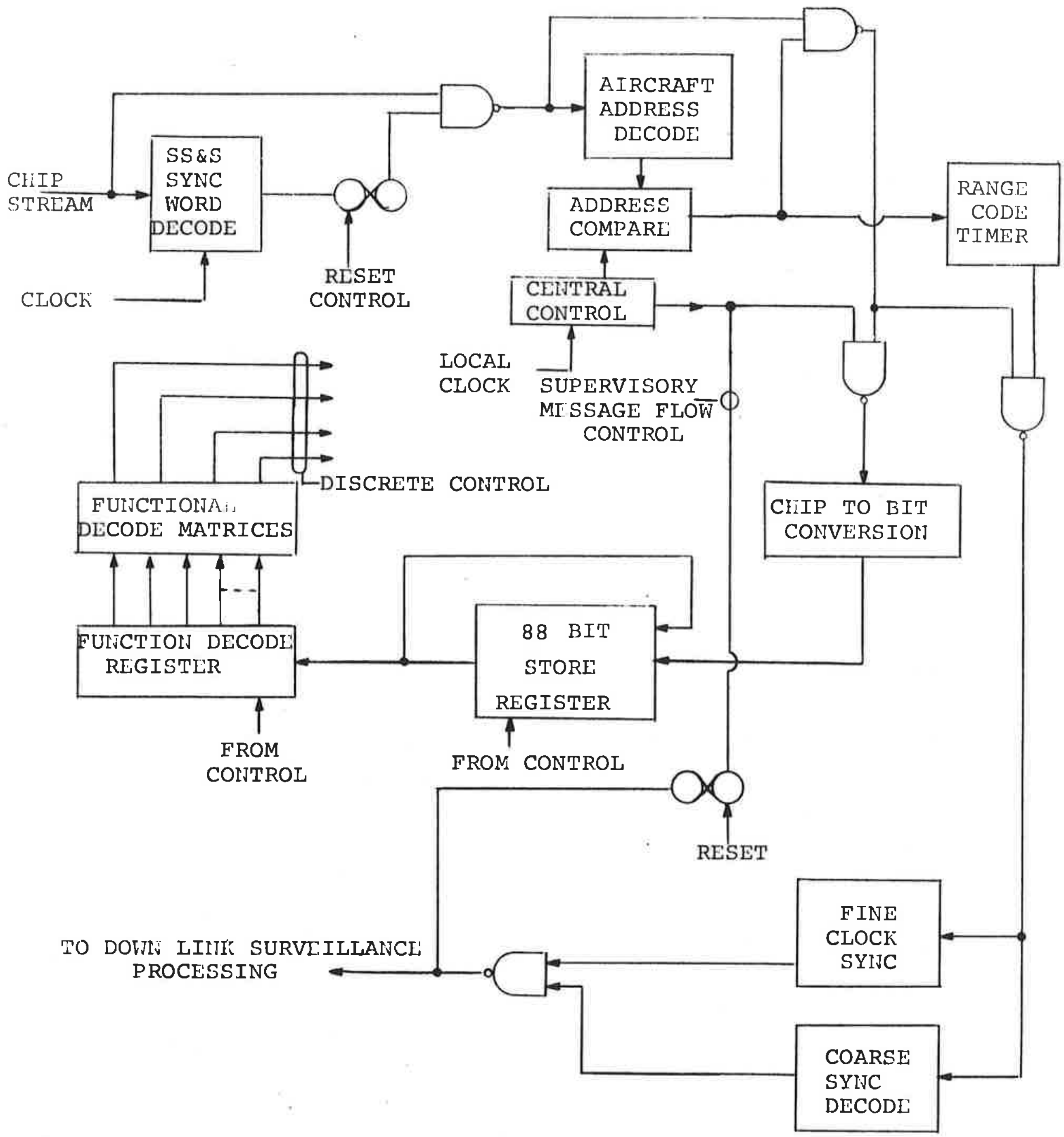


FIGURE 5-21. <u>SS&S SYNC WORD AND BURST DECODER</u>

code. The coarse sync code consists of a 64 chip unique code detected in a maximum likelihood detector and provides a sufficiently well-defined-in-time gate pulse to enable selection of a more precision and shaped fine precision synced clock pulse. The selected precision ranging pulse is fed to the downlink surveillance processing and is used to initiate transmission of the ranging reply code.

After receipt of the coarse and fine ranging code, the supervisory portion of the SS&S message burst is gated to an 88 bit circulatable store register after conversion from chip to bit format. Under central control, the contents of this register is examined and decoded in a shorter function decoding register to which is attached the appropriate function decode matrices and decoded supervisory command data storage.

5.4.5.1.9 Central Control Circuitry

The preliminary design for the avionics instrumentation is based on individual or discrete decoding and encoding circuits and the like. This is as opposed to the use of a small processor (mini or micro-processor) to accomplish all or nearly all of the functions assumed fully assigned to discrete circuitry. Investigation of the latter approach for technical and economic feasibility has not been made at this time. Considerable central control and timing circuitry is required in any discrete instrumentation approach. The function of such a central control is basically generation of the various system clocks and routing of discrete control signals decoded from the received chip stream and as read from the avionics display/control panel.

5.4.1.10 Downlink Surveillance and Supervisory Signal Processing

The task of the downlink SS&S signal processor is basically the generation of the SS&S data transmission as shown in Figure 5-18. The circuitry, taking timing from central control plus the decoding of uplink ranging signals, generates the fine and coarse ranging codes shown. The circuitry also functions to read inputs from the avionics Display/Control panel and the aircraft's altimeter and prepares the supervisory portion of the downlink SS&S message, properly formatted.

5.4.5.1.11 Voice Digitizer and Modulator

The voice digitizer circuitry consists of a relatively conventional variable-slope delta modulation encoder plus a modulator for phase modulating a communication channel carrier.

5.4.5.1.12 UDDL Data Message Buffering and Modulator

Under the assumption that the data from the AEROSAT system can be used to drive the AEROSAT data modulator directly, the buffering between the two systems will be very simple, requiring only line drivers or the like. Additionally, some signal interface is required between the two systems to indicate when and if a data message is ready for downlink transmission. The 1200 bit per second data information is converted to a 16-chip-per-bit format for phase modulation on a communication carrier for downlink transmission.

5.4.5.1.13 Rapid Access Signalling Modulator

A low-speed data link channel with a fixed format message is automatically sent from the UDDL instrumentation upon actuation of either an emergency or random entry signalling pushbutton. The UDDL instrumentation clocks out a specially labeled message indicating either a random entry request or an on-board emergency situation along with an automatic position readout message.

5.4.5.2 Avionics Costing Summary for TDMA System

The costs have been summarized in Table 5-2. To account for such factors as special test equipment, spares, installation design, training, support and profit, the costs presented are mutliplied by a factor based on experience to arrive at an overall selling price. The factor used here is two (2) to obtain an overall selling price of $15,450.

TABLE 5-2

TDMA COST ESTIMATE

		Cost
1	Diplexer/preselector	$ 350
1	Preamp	300
1	Bandpass filter	80
1	Mixer Assembly	200
1	Wideband Amp	125
1	Power Divider	20
1	4 channel signal selection matrix	50
1	Single side-band modulator	300
1	Bandpass filter	80
1	Driver Amplifier	100
1	Power Amplifier	1,000
1	Frequency Synthesizer	900
1	R/T power supply	100
1	Phase-lock demodulator	1,500
1	Voice Digitizer and modulator	150
1	Data buffer and modulator	100
1	Rapid Access modulator	200
1	Sync word comm. burst decoder	420
1	Sync word SS&S decoder	480
1	Central control and display	600
1	Downlink S&S Signal processor	220
1	Power supply	100
	Chassis and Wiring	200
	Assembly and test	150
	TOTAL	$7,725

5.4.5.3 TDMA Ground Instrumentation

5.4.5.3.1 Hardware Requirements

The ground system is shown in overall block diagram form in Figure 5-22. The users, the Air Traffic Control Centers (ATCC) and the Airline Offices are shown at the left of the diagram. The two major instrumentation components, the Aeronautical Services Earth Terminal (ASET) and the Aeronautical Services Communication Center (ASCC) are shown as merged elements in the TDMA system. In the case of a burst TDMA instrumentation, all information is formatted into a single data bit stream precisely timed for multiplexing through a common satellite and emanating from multiple ground points. The surveillance signal is, therefore, not separable from the rest of the data stream. All of this requires considerable computer control and most of the timing and formatting is, therefore, best done at the point of transmission.

The merged instrumentation in the block diagram is shown controlled by a single central control computer. Facilities for transmitting communication bursts via both satellites is indicated. The upper right portion of the block diagram shows a complete uplink SS&S and communication burst transmission and downlink FDM communication, SS&S and satellite synchronization signal reception facility for Satellite No. 1. Voice at baseband from either the air traffic control or airline office system user, is received by either of the G-A communication burst formatters via the communications channel switch and line buffering unit. User traffic is routed to either of the burst formatters based on which satellite is used to communicate with the aircraft the user is trying to reach. This routing is accomplished automatically by the communication switch under computer control from information it receives over the lines labeled surveillance Data/Communications Request/Acknowledge. Each of the communication burst formatters must have the capacity on input and internal processing storage to handle the five voice-modulated communications channels per satellite simultaneously as a maximum, or any mix of voice and

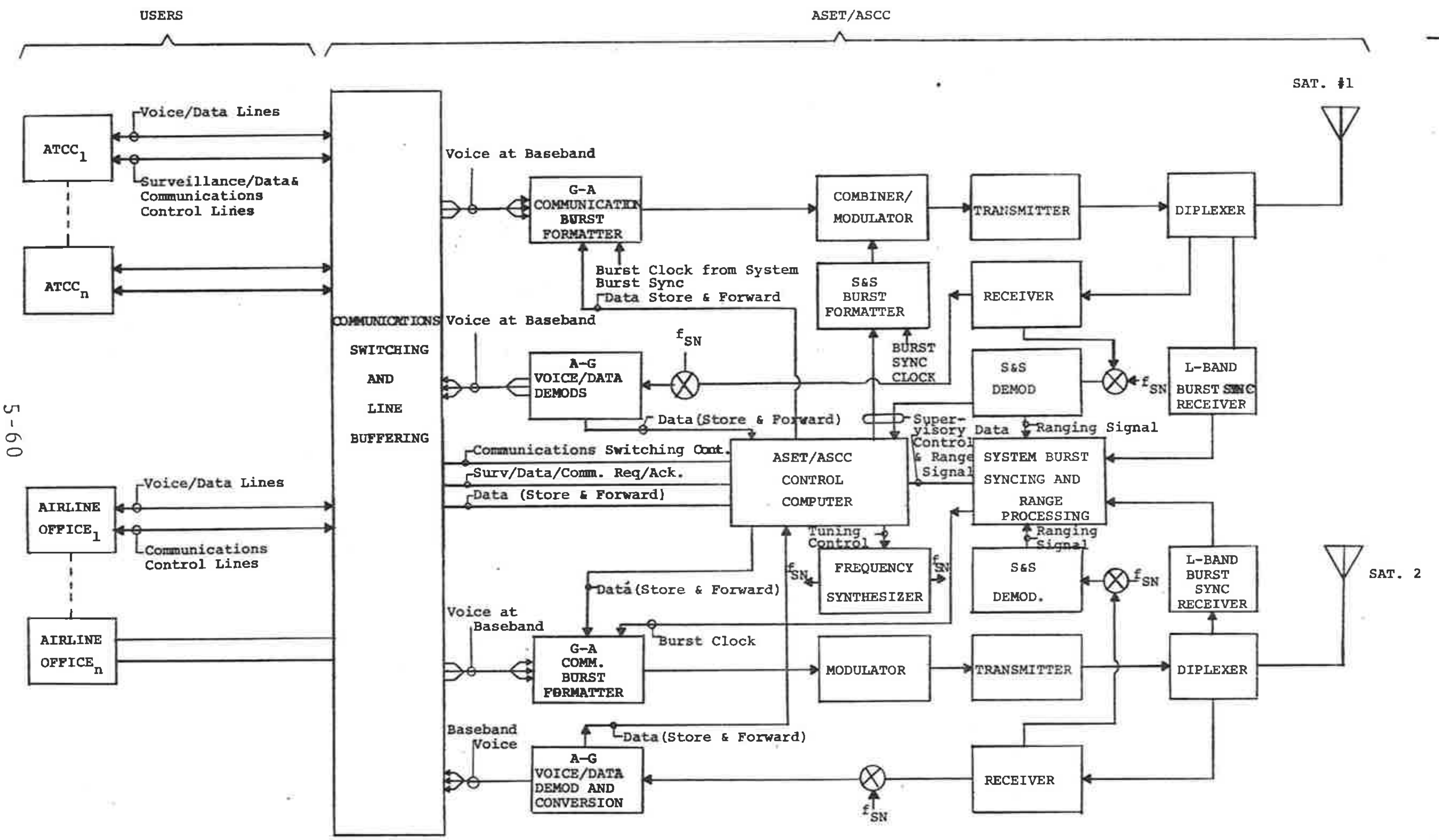


FIGURE 5-22. GROUND SYSTEM F OVERALL BLOCK DIAGRAM

modulation for the five channels. The data for uplink transmission is stored in the central computer for store and forward operation and is called into the formatter for burst transmission. The Communications Burst Formatter is clocked by a clock generated in the system Burst Syncing and Range Processing discussed a little later. The bursts for the Communications Burst Formatter are fed to a combiner/modulator which also accepts formatted SS&S bursts from the SS&S Burst Formatter.

The SS&S Burst Formatter is also clocked by a clock generated in the system Burst Syncing and Range Processing element and the basic SS&S data is received from the central control computer. The modulated burst carrier is then amplified in a power amplifier and fed to the system antenna via a diplexer also used in routing the return surveillance and downlink communications channel transmission to the broadband receiver. Since downlink transmission is FDM, a second frequency conversion takes place in each channel demodulator. The S&S demodulator demodulates the data stream feeding the ranging signal to the system burst syncing and range processing circuit element and the supervisory data to the central control computer. Precision range processing takes place in the Burst Syncing and Range Processing element and the processed range is fed to the central computer for use in position location computation. The information on computed position of aircraft is then routed to the appropriate ATCC all under computer control via the Communications Switching and Line Buffering element. The communications channel signals are demodulated in individual demodulators each equipped for tuning for doppler effects under computer control directing the various conversion frequencies F_{S_N}, generated by the frequency synthesizer. In voice communication, received in delta modulation format, conversion to analog voice is immediate and continuous. In data communication, the data is received, demodulated and temporarily stored in the computer memory before forwarding to the intended addressee.

An L-band burst sync receiver is shown for each satellite and is used to receive an ASCC/ASET's own burst transmission to permit automated correction in timing of such transmission with respect to the SS&S (or particular SS&S) transmission transmitted by the master ASET/ASCC.

The lower portion of the block diagram shows essentially an identical instrumentation for satellite No. 2 as was shown in the upper portion of the diagram for satellite No. 1, with the exception of an uplink SS&S Burst Formatter. Although not shown on the block diagram, G-G communications facilities are assumed to link all ASCC/ASET's to the master ASET/ASCC for such required coordination.

5.4.5.3.2 <u>Processing Facilities Requirements</u>

In any large highly-automated computer-based system such as proposed here, the computer hardware and software costs usually represent a major portion of the system cost. Some of the processing facility requirements are discussed.

The additional flexibility provided by the high accessing capability requires considerable inter-facility control. This is true for TDMA to a greater degree than for FDMA in that generation of communications burst or even SS&S bursts by any ASCC/ASET in either satellite multiplex to reach any aircraft is possible for the maximum multiple access capability instrumentation. For such an ultimate instrumentation somewhat more computational capacity for interfacility control would be required than for FDMA.

Instrumentation for burst-to-burst satellite beam switching provides rapid access to any area and does not require that any area be considered as being provided with a lesser service because of a shortage of total communication channels. Such a facility for rapid switching does require that a beam switching command profile being sent to the satellite each SS&S burst transmission.

The multiplexing of satellite relay service on a short burst basis requires continuous monitoring and control of burst timing by all ASET/ASCC's in the system. This involves monitoring of own transmission received directly back from the satellite along with other relay transmissions and checking proper burst occurrence timing all under computer control. Alternately, if sufficiently accurate world time becomes available it may be feasible to accomplish the burst timing from such timing knowing the location of the satellite and the ASCC precisely.

Finally, the communications processing is considerably more complicated especially in the case of voice which in an FDM system can operate without intimate computer processing or control. One way, burst formatting of voice could be performed, is to digitize incoming baseband voice, store it temporarily in memory and call out of memory completely formatted digital burst data. Although shown instrumented outside of the central processor or computer in the block diagram, the function performed is digital processing, be that processing accomplished in the central computer or external processor, and represents additional processing to that required in FDMA.

5.4.6 System Variations

As for other types of systems techniques considered, the selected time division burst multiplex system can be configured or operated in a variety of ways with little or no change in the actual instrumentation. These variations deal primarily with variations in control philosophy and variations to accommodate reduced service. Variations in control philosophy center on distribution of control to multiple points or maintaining control at a central point. Variations to accommodate reduced service consider voice and data only systems.

5.4.6.1 Control Variations

The baseline burst TDMA system described in Section 5.4, distributed management control of satellite channels to two ASCC's. Each of these generated the SS&S burst for one of the satellites and made assignments of channels in that satellite in response to airborne requests received via the supervisory channel and ground requests received via various G-G facilities.

System Control, distributed as just described, can alternatively be drawn in to a completely central mode but with the facility for direct multiple access via any communication channel being retained. For such an arrangement all the SS&S bursts for both multiplexes are generated by the master ASCC. The master thus accomplishes all ranging for position surveillance and services all requests for voice and data channel requests from the aircraft. Similarly, the master would ring up all aircraft via the SS&S channel for voice contact requests presented to it by any ATCC/ASCC combination (using G-G facilities as appropriate). Data channels would probably still be assigned to individual ASCC's by the master so that efficient G-A data transmission could be maintained by direct addressed data channel contact. All position surveillance information would have to be disseminated to the appropriate ASCC/ATCC combination via G-G facilities.

Implied in centralized control is the accessibility of any channel in either satellite to every aircraft. This implies monitoring the multiplex from both satellites. It, therefore, results in a more complicated avionics instrumentation. Basically, a double conversion receiver is required with two output channels. A duplication of the digital demodulating and processing hardware is also added.

5.4.6.2 Reduced Service

5.4.6.2.1 Voice and Data Only/Data Only

A principal mode for reduced service would employ some form of position reporting from on-board navigation gear. Such a reduced service mode would likely be utilized in early operational deployment of AEROSAT. In this case the SS&S channel could still be used as a separate supervisory channel for managing the available communications channel. The system then easily grows to the full service format.

In an alternate format configuration the SS&S channel is eliminated completely and the supervision is integrated into the data channels as was done in System C. All the satellite power is then essentially used for communications services. A special unique word or short code would be inserted into one of the bursts to identify it as the framing burst emanating from the multiplex master.

With the above type of arrangement, the system can easily operate as either "data plus voice" or data only.

5.4.6.2.2 Voice Only System

For voice only services several alternate formats are possible. If growth to full service operation is required then the SS&S channel is retained for channel supervision. However, if this is not the case the SS&S channel is eliminated and a system equivalent to Selcal becomes attractive. The preamble associated with every burst is modified to include an aircraft address. Since the aircraft can easily monitor all channels in a multiplex, it is not necessary to preassign the voice channels. As before, one of the bursts would contain some code to identify it as the framing burst.

For calling from the aircraft in a low or moderate traffic situation the use of A-G random access channels is suggested. A standard low data rate digital message is in order to minimize the number of conflicts. Alternately, a two way SELCAL can be implemented if voice channels are preassigned.

6.0 SYSTEM SUMMARY AND COMPARISON

6.1 General

The systems described in this report indicate that there are several approaches which could be used effectively for surveillance and communications facilities management in the AEROSAT system. Although each of the systems is workable, they all have relative advantages and disadvantages. To aid in system evaluation a comparison matrix was constructed during the early phase of the study. This is shown in Figure 6-1. A set of numerical evaluation factors indicating relative ranking are included. Grading from 0 - 4 was used with 4 representing a highest score.

The five major parameters chosen for the matrix are:

	Relative Weighting
Avionics Complexity	5
Operational Capability	4
System Flexibility	4
Satellite Complexity	3
Ground System Complexity	2

Each of these is broken down into several factors which characterize each parameter.

To obtain an overall rating, the sub-parameter numbers in each category were multiplied by the category weighting factors. The following results were obtained.

System A	245
System B	258
System C	291
System D	220
System E	235
System F	260

System C rated best primarily because of operational capability and avionics simplicity. System F was rated second and slightly above System B. The overall operational capability of

FIGURE 6-1

SYSTEM EVALUATION MATRIX

	A FDM SEP SUP EC	B FDM SEP SUP SWITCH BEAM	C FDM DATA/SUP	D TDM/FDM 1 MULTI/ SAT	E TDM/FDM 2 MULTI/ SAT	F BURST TDMA/FDM
Avionics Complexity (Wt = 5)						
R-T Assembly	2	2	3	4	4	4
Communications Modem	3	3	4	2	2	1
Supervisory Processing	3	3	4	3	3	3
Surveillance Processing	4	4	4	3	3	2
Operational Capability (Wt = 4)						
Channel Access Capability	4	4	4	2	2	4
Channel Request Times	2	1	4	3	4	3
Access Thruput	2	2	4	3	4	3
Busy Probability/Waiting Time	4	4	2	3	2	3
Effective Channel Utilization	4	4	3	1	2	4
System Overhead	1	2	4	2	2	3
Spectrum Utilization	2	2	2	4	3	4
Degraded Operation	4	4	4	1	2	3
Eclipse Operation	2	3	4	2	3	4
System Flexibility (Wt = 4)						
Designation of Channels Voice/Data	4	4	3	4	4	4
Allocation/Reallocation of Channels	4	4	3	1	2	4
Adding/Subtracting Channels	4	4	4	2	2	3
Changing Bit Rate	4	4	4	3	3	3
Satellite Complexity (Wt = 3)						
Beam Channel Switching	4	2	3	4	3	2
Antenna Coverage	3	4	4	4	4	4
Ground System Complexity (Wt = 2)						
ASCC Interfaces	2	2	4	3	4	4
ASCC/ASET Complexity	4	4	3	3	3	2

the burst TDMA is comparable to that of System C. However, it rated lowest in avionics complexity. Nevertheless, it should be remembered that the total cost differential is not excessive.

It is pointed out that the ratings used in the evaluation are subject to variations which depend on the relative importance attached to the parameters and tend to be highly subjective. They are also based on design and operational data available at this time. They could change as a result of other AEROSAT related design decisions not available during the study.

The following paragraphs discuss the parameters involved in the system comparison.

6.2 Avionics Complexity

6.2.1 General

Avionics complexity is considered the most important evaluation parameter. Complexity has been chosen rather than cost because it is felt that the overall avionics cost for all systems tends to be about equal. This is borne out by Tables 4-8 and 5-2. This is because the relative cost for antennas and RF components tends to be high while the production cost of solid state components tends to be low. Complexity is more of a measure of the total number of circuits or active elements. It reflects initial design difficulty and ease of check out and maintenance.

Figures 6-2, 6-3, 6-4 and 6-5 are the block diagrams for the systems studied. The same hardware is used for either System A or B. The instrumentation for System D and E is similar except that in E the multiplex processing involves fewer channels. Other similarities and differences are discussed next.

6.2.2 R/T Assembly

The FDMA systems use a double conversion receiver and are identical for all systems. The TDM systems as shown use

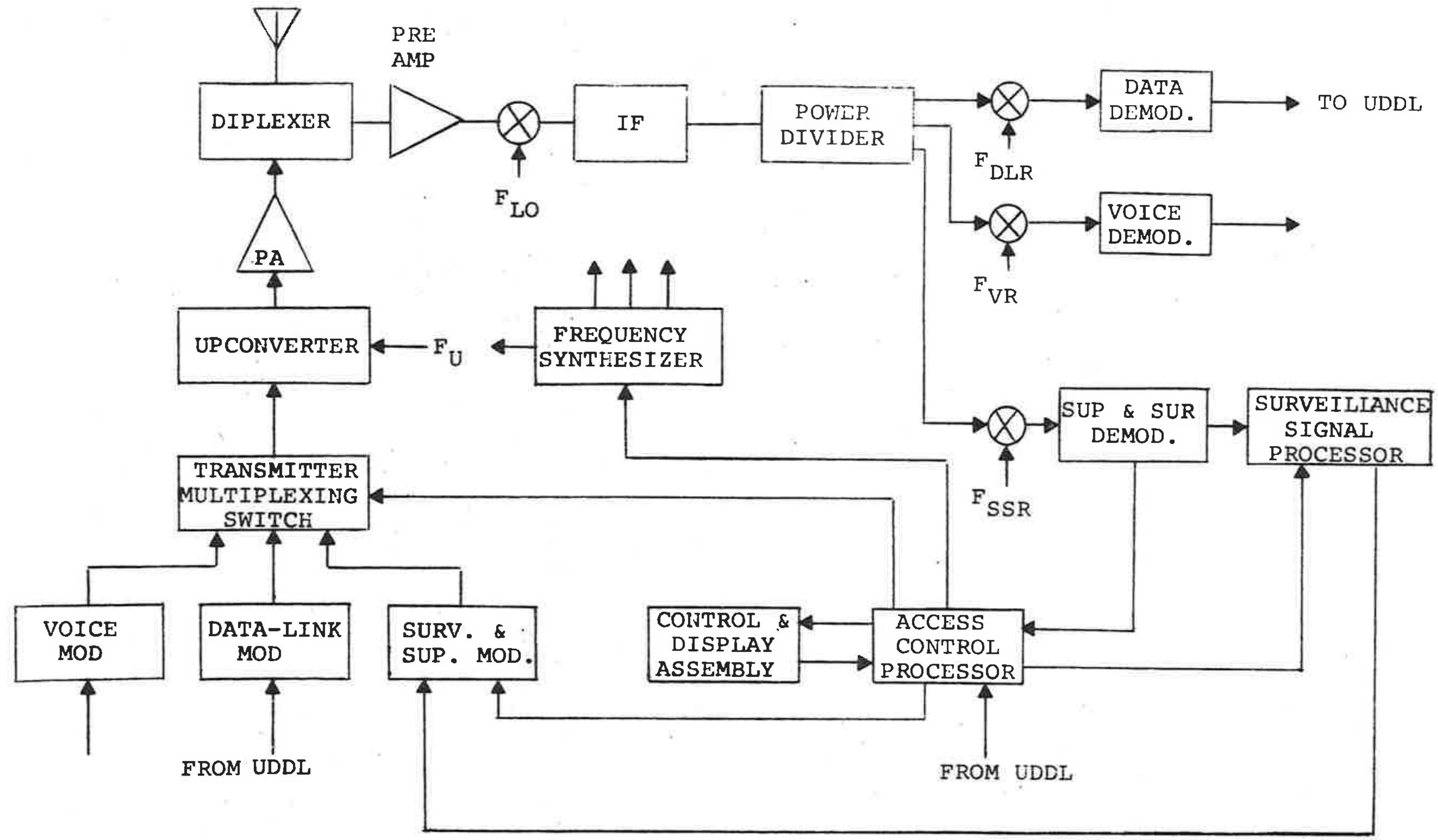


FIGURE 6-2. SIMPLIFIED BLOCK DIAGRAM, SYSTEM A AVIONICS

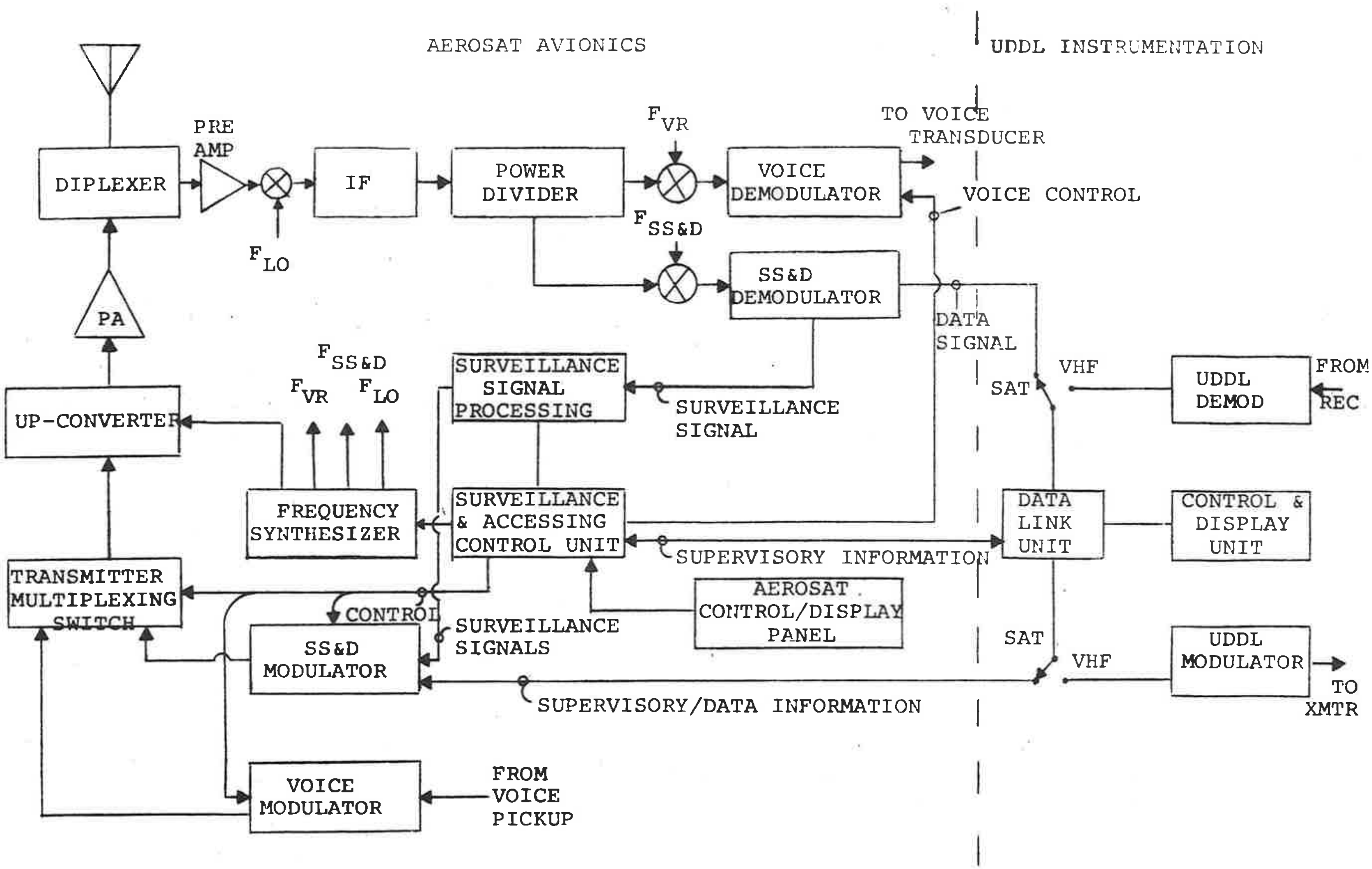


FIGURE 6-3. AVIONICS SYSTEM OVERALL BLOCK DIAGRAM (SYSTEM C)

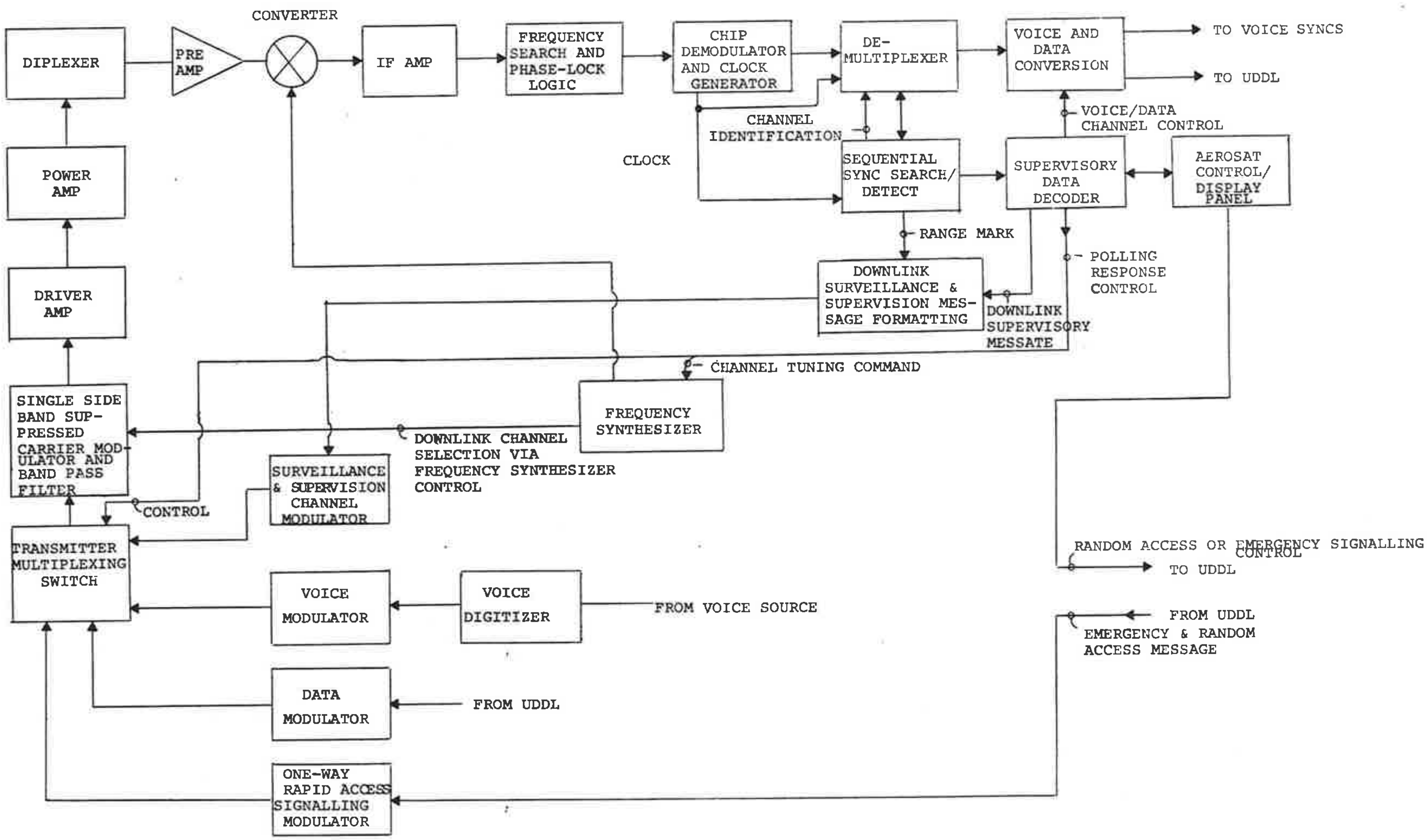


FIGURE 6-4. AVIONICS SYSTEM FOR BIT-BY-BIT MULTIPLEX TYPE SIGNALS (SYSTEM D OR E)

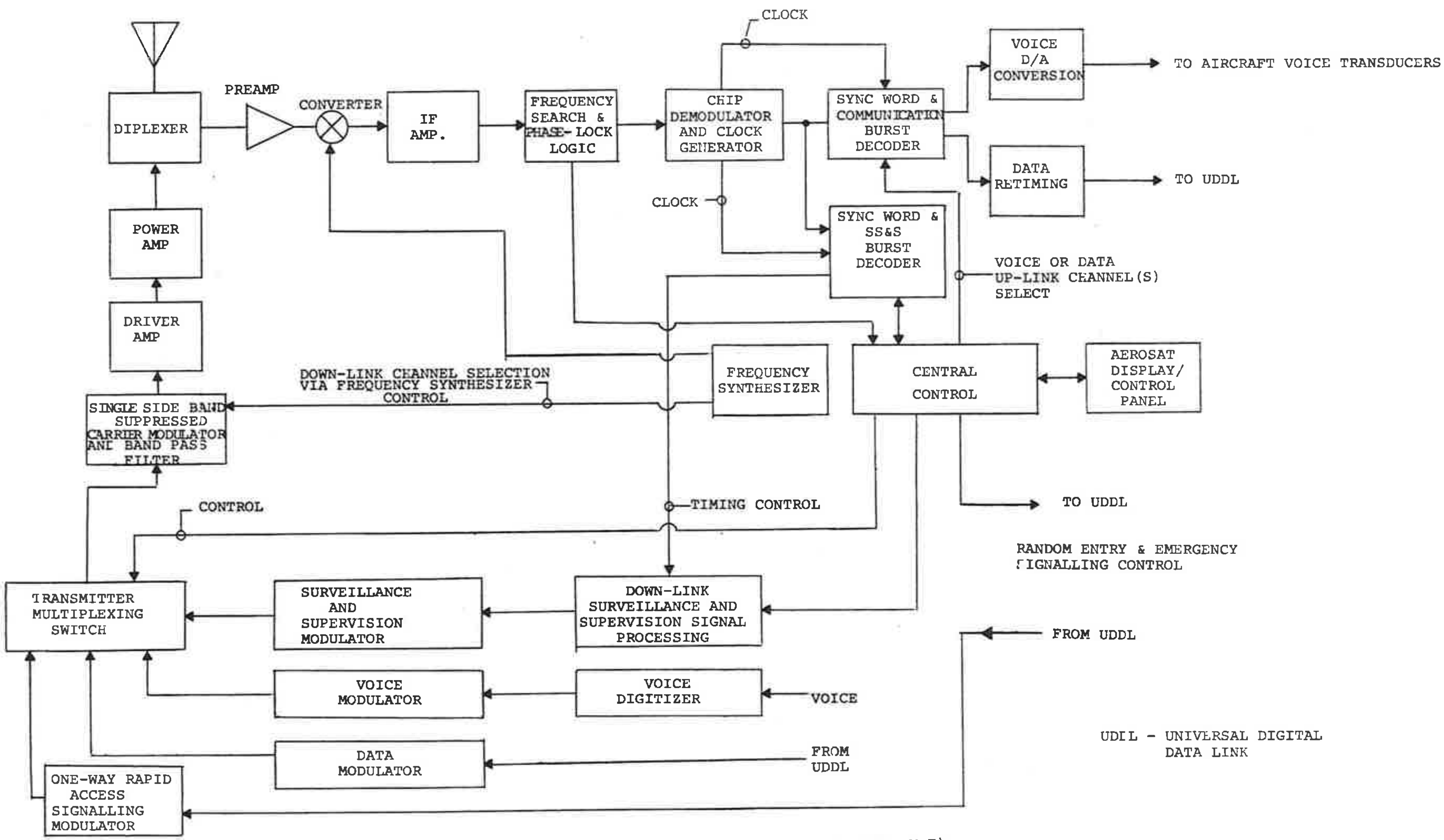


FIGURE 6-5. AVIONICS SYSTEM FOR TDMA (SYSTEM F)

only a single conversion receiver and are identical for both types of TDM configurations studied. However, a double conversion receiver is equally usable and may have some tuning advantages.

It is concluded that a single RT design is usable and valid for all configurations. The only difference from the various configurations is the number of channels supplied at the output of the second conversion. The number of independently tunable receiving channels are listed as follows:

Systems

A,B	C	D,E,F
1 Voice	1 Voice	1 Digital Multiplex
1 Data	1 Data/Surveillance	
1 Supervisory & Surveillance		

Simultaneous reception is provided with an overall noise temperature of $1000^{\circ}K$. In the FDMA systems the number of channels can be reduced if the communications services supplied are reduced along with a reduced channel management capability as discussed in Section 4.4.10.4. On the other hand, in the TDM systems the number of channels are increased if it is desired to monitor the output of both satellites.

The number of transmitting channels are:

A	B	C	D,E,F
1 Voice	1 Voice	1 Voice	1 Voice
1 Data	1 Data	1 Data/Surv.	1 Data
1 Sup & Surv	1 Sup & Surv	1 Rapid Access	1 Sup & Surv.
	1 Rapid Access		1 Rapid Access

Transmission of only one carrier at a time is implied thereby permitting use of a Class C amplifier. It is assumed that a surveillance reply preempts data and transmission of either of these interrupts voice. A missing data reply will automatically cause a ground request to repeat. An EIRP of 23 dbw is used in all systems.

6.2.3 Communications Modems

6.2.3.1 FDMA

The FDMA systems use separate modems for each received sub-carrier. In Systems A and B, therefore, a separate modem is provided for the voice, data and supervisory and surveillance signals. The configurations identified in the study permits use of any AEROSAT compatible modulation technique for the voice or data channels. The S&S modem is designed for 300 bit/second data which is quadrature modulated with a surveillance signal. PLL loops are required in the data modem and the S&S modem which permit search and acquisition of the carrier and bit sync within a 1 second time period when a special preamble is transmitted.

System C requires only two modems. These are an AEROSAT compatible voice modem and a surveillance and data modem. The latter is designed for 1200 bit/second data quadrature modulated with a surveillance signal. Search requirements are as indicated above and can be obtained using phase-lock loops as described in Appendix E.

6.2.3.2 TDM

The time division systems are constrained to the use of digital modulation for all signals. In all of these, a comparatively wide-band phase-lock loop is used.

In Systems D and E, the bit sync loop tracks a continuous incoming bit or chip stream. The rate is about 100 KHz. A special code is used in the SS&S channel to identify it and permit demultiplexing of the communications channels. The output of the demultiplexer as shown in Figure 5-3 provides 19.2 kchip/second delta mod voice or 16 chip/bit, 1200 bit/second data at the selected channel outputs. Subsequent demodulation is standard. Modulation for downlink transmission is accomplished in standard type AEROSAT digital voice and data modulators.

6.2.3.3 Burst TDMA

In the burst TDMA system acquisition of phase and bit sync within every burst is required subsequent to initial frequency search. Three milliseconds of preamble is provided for this in the burst. In addition, memory is required to reduce drift, frame-to-frame, for those aircraft operating in remote areas. Typical loops are discussed in Appendix E.

After chip demodulation, a unique word is decoded and the entire voice or data burst temporarily stored in a pair of retiming shift registers. For data, the chip stream is shifted out at a 1200 bit per second rate for transmission to the UDDL control unit. Voice is shifted out at a 19.2 kchip rate for standard delta demodulation. See Figure 5-20.

The modulators for downlink transmission are standard AEROSAT digital Voice and data modulators.

6.2.4 Supervisory Processing

All systems except System C use a separate two-way supervisory channel. In Systems A and B, a 300 bit per second data channel is used to perform the functions as outlined in Tables 4-2 and 4-3 and Figure 4-1. In Systems D and E, the same type of information is multiplexed into the communications bit stream as shown in Figures 5-1 and 5-2, while in System F it is contained in the framing burst as shown in Figure 5-13. Downlink, the supervisory information for the TDM systems are transmitted in a surveillance reply sequence as shown in Figure 5-4.

Typical processing of received supervisory data involves address detection, control of surveillance replies, automatic channel selection, transmitter control, and supply of information for the AEROSAT control panel. Typical downlink processing involves message formatting, control of surveillance reply, readout of control panel inputs and execution of rapid access procedures.

In System C, the supervisory information is multiplexed into the data-link transmission and contains the information shown in Tables 4-6 and 4-7. The processing involved is similar to that described above except that address decoding is done in the UDDL avionics. The interface for reception and transmission of the data is with the UDDL.

6.2.5 Surveillance Processing

6.2.5.1 FDMA

Analog or digital ranging can be used in the FDMA systems. In Systems A and B, the signal is multiplexed with the supervisory data. In System C, the signal is multiplexed with the data-link signal. A signal quality of about 30 dB-Hz is assumed for System A while 36 dB-Hz is assumed for Systems B and C.

Processing involves lock-on and synchronization to the incoming signal and generation of a reply signal.

6.2.5.2 TDMA

The TDM systems are constrained to the use of digital ranging techniques. Typical rapid acquisition waveforms were used in the study. In Systems D and E, a precision clock is locked to the incoming bit stream. A 32 chip code provides coarse ranging and ambiguity resolution.

The TDMA system uses the same principle except that the precision clock is synchronized during the framing burst. The format is shown in Figure 5-13 while typical circuitry is shown in Figure 5-21.

6.3 Operational Capability

This parameter is concerned with the effect of the multiple access scheme and channel management discipline on the overall ability of the AEROSAT system to provide communications and surveillance services.

6.3.1 Channel Access Capability

This describes the capability of accessing a mobile from any ground terminal. In Systems A, B, C and F, every ASET/ASCC can access every available satellite channel. In Systems D and E, access G-A must occur via the center generating the multiplex.

In the FDMA systems, access to a mobile is possible via any satellite channel subject only to any channel (or beam) switching limitations in the satellite. In the TDM and TDMA systems, access to a mobile is achieved only via one of the channels in the multiplex which the mobile is monitoring.

Since all systems use FDMA A-G, all ground terminals can be accessed from any mobile, subject only to antenna arrangements in the satellites.

6.3.2 Channel Request Times

This refers to the time required for requesting and obtaining use of a channel not including queueing time.

The major time delay in downlink access is the polling epoch time. This is greatest for System B and is about 20% less in System A. In Systems D and F, the polling epoch is cut in half while in Systems C and E multiple polls are used reducing the epoch time even more. Additional downlink access delays may occur due to G-G link delays in granting channels by the one ASCC to a local ASCC. However, this is on the order of seconds rather than minutes as in the above.

The delays in uplink access are minimal because of the direct connection via terrestial links between the ATCC's and the ASCC's.

Emergency access, via dedicated A-G channels on a random access basis, is about equal in all systems. In distributed control, granting of channels requires less delays since all the ASCC's monitor the emergency channel.

6.3.3 Access Thruput

An important aspect of the channel management concept is the number of interchanges involved in processing a request. When a single supervisory channel is used with centralized control, as in Systems A and B, all requests are processed through the master ASCC. All channel requests initiated from ground terminals associated an ASCC other than the master are transferred to the master via the G-G links. The grant is transmitted back over the G-G link. A similar situation exists for airborne requests to a terminal not connected to the master. The call to the ASCC must be transmitted via G-G links.

In Systems D and F, the number of such interchanges is reduced because of the use of two supervisory channels. Systems C and E have greatest flexibility in allocating channels to ASCC's for their direct control.

6.3.4 Busy Probability/Waiting Time

A key parameter which is a measure of how effectively the available channels are used by the various centers to handle the message traffic is the queueing time. It pertains primarily to the voice channels and is a function of whether the channels are all kept in a common pool or whether they are allocated among the centers. Allocation among centers or distributed control represents increased queueing time. Systems A and B use centralized control while System C (as presently described) uses distributed control. In Systems D, E and F, the channels are split into separate multiplexes. Systems D and F represent a 2-way equal split of channels while System E represents a 4-way equal split of channels. In System C, the channels are allocated to the various ASCC's in accordance with message traffic.

6.3.5 Effective Channel Utilization

This parameter is concerned with how messages and/or conversations are packed into the channel. All systems use the voice channels on a demand assignment basis. Therefore, the only loss in utilization comes about because of the set-up and ring-up time between conversations. In terms of message durations, this time is expected to be small in all cases. Channel switching capability affects efficiency in the following manner. In the FDM and TDMA systems, individual communications channels can be switched on a demand basis to antenna beams covering sparsely populated areas. In System D, an entire multiplex must be switched, so that needed capacity may be removed from one area while providing excess capacity in another area. System E mitigates this effect to some extent.

For data channels all systems use demand assignment without polling except System C. Therefore, variable length messages are transmitted on these channels. By utilizing the message length information, efficient message packing may be obtained by the ASCC formatting the data stream. However, there may still be gaps. In System C, fixed block length messages are used in polled sequences. Therefore, transmissions occur to particular aircraft regardless of whether data is to be sent or not. Some loss in channel utilization is therefore incurred.

For air traffic control application, most messages are expected to be fixed length. The difference between use of variable length and fixed length messages is apt to be small.

6.3.6 System Overhead

This parameter is used to characterize the magnitude of the system power lost because of the access and channel management discipline. This is shown in the following table.

	SYSTEM					
	A	B	C	D	E	F
Intermod Loss	1 db	1 db	1 db	0	1 db [1]	0
Transmission Preamble Loss	0	0	0	0	0	.7 db
Supervisory Power (Satellite Units)	1.5 [3]	.5 [2]	negligible [4]	2 [2]	1 [2]	1 [2]

[1] Loss depends on satellite amplifier/beam configuration

[2] Includes surveillance signal power

[3] Negligible power for surveillance signal

[4] Negligible power for both surveillance and supervisory signal.

It is observed that in System C, there is a substantial savings in satellite power by absorbing the supervision and surveillance signals into the data-link channel. The TDM systems generally do not have any intermod losses. In the burst TDMA substantial improvement in overall efficiency can be obtained by reducing the preamble preceeding each burst transmission. One approach for doing this is to maintain chip synchronization between bursts among all the ASCC's in the system.

6.3.7 Spectrum Utilization

In addition to the intermodulation power losses associated with FDMA systems there are also interference problems to be considered. Signal frequency plans have to be designed to ensure that any intermodulation product which falls on a signal frequency is sufficiently small that the interference is negligible. This generally requires that a greater portion of the electromagnetic spectrum must be allocated for the FDMA Systems A, B and C than for the TDM Systems D and F. System E, which is in a sense a hybrid, falls in the middle.

6.3.8 Degraded Operation

Factors to consider here are decrease in satellite power, extraordinary fading or scintillation. Systems which do not threshold, as is the case with some analog modulation techniques, are desirable under the above circumstances. Thus, this favors FDM systems. In FDM systems, channels can be easily dropped if there is an overall loss in satellite power. In Systems D, E and F which require digital techniques, there is more of a tendency toward thresholding. In System D, the entire multiplex degrades when the satellite power decreases. In System E, a multiplex can be dropped. In the burst TDMA channels can be dropped by simply not transmitting during a burst if the power supply can adjust to the above.

6.3.9 Eclipse Operation

During an eclipse, the available channels are reduced to 1/2. In Systems A and B, if surveillance service is to remain unchanged, the available communication channels are less than 1/2 normal. In System C, a reallocation of data-link/supervisory channels may be required to provide sufficient voice channels for the message traffic. In Systems D and F, one of the two multiplexes is disabled resulting in single ASCC control of the SS&S channels. In System D, all communications are curtailed in oceanic areas other than that covered by the single multiplex. In System F full area coverage is provided but with fewer channels. In System E, one of the two remaining multiplexes can be continuously used in the principal North Atlantic area and the other can be switched to other areas as needed.

6.4 System Flexibility

6.4.1 Designation of Channels for Voice or Data

All systems have this capability. However, in System C one or more channels are dedicated for combined data and supervision.

6.4.2 Allocation/Reallocation of Channels to ASCC's

Greatest flexibility for channel allocation on an individual channel basis is obtained with the FDMA and burst TDMA systems. As long as the master ASCC maintains queues or is appraised of queue status by other ASCC's channels can be allocated to relieve build-ups. In Systems D and E, an entire multiplex must be reallocated.

6.4.3 Adding or Subtracting Channels

Adding or removing individual channels is easy in the FDM systems. It is not feasible in Systems D and E. Individual channels can be deleted in System F but does not have the flexibility for adding channels as in A, B or C.

6.4.4 Changing Bit Rate

The bit rate can be changed from 1200 bits/second to 2400 bits/second by providing 2 untis of power in a given FDMA channel. In the TDM systems, two channels must be combined on a time basis resulting in a non-uniform bit stream which can be handled if provision is made before hand in the avionics.

6.5 Satellite Complexity

This parameter refers to design and/or control aspects of the satellite which may be peculiar to a particular access scheme. (NOTE: Additional satellite design data may influence some of the ratings.)

6.5.1 Beam/Channel Switching

Because spot beam coverage has been postulated, all systems require some degree of channel switching to provide full oceanic coverage. In System A, only individual communications channels need to be switched and only on the basis of demand. In System B, in addition, the supervisory and surveillance channels need to be switched perhaps as often as 15 to 20 tiems per two-minute epoch. Furthermore, switching of the S&S channel must be accomplished such that it adds capacity to the communications channels already connected to a particular beam. In System C, the switching is minimized for the supervisory because multiple data/supervisory channels are used. Hence, one or more may be dedicated to a beam. Although beam switching is required in System D, the switching function consists of moving the entire power amplifier output from one beam to the next. The System E switching function is minimized because of the availability of more multiplexes as in System C.

In System F, beam switching is required on burst-to-burst basis. Therefore, a rapid beam switching capability is required along with the means for processing the instructions for switching sequence contained in the framing burst.

6.5.2 Antenna Coverage

As stated previously, all systems use spot beam coverage. An earth coverage antenna is required in the G-A link in System A to transmit supervision and surveillance. No uplink EC antennas are required in the other systems. All systems use earth coverage antennas A-G for emergency access. System F employs earth coverage for the communciations reply channels. It can, however, be used in all other systems.

6.6 Ground System Complexity

6.6.1 ASCC Interfaces

Systems using centralized control such as A and B require processing of all requests and grants for voice channels at the master ASCC. The G-G links must be used for transmitting this information among the various ASCC for completing the circuit connections. In decentralized control, each ASCC manages its own channels and only queue status needs to be transmitted for possible periodic reallocation. Aircraft doppler must also be transmitted from the master to the local ASCC's to aid in data link lock-on and acquisition. In Systems C, D, E and F each ASCC having control determines aircraft doppler on its own. Position location is generated locally in Systems C, D, E and F while for Systems A and B the position data is transmitted via the G-G links.

Information transfer between the ATCC and the ASCC is comparable for all systems. In System D where only two ASCC's are possible, the links between some of the ATCC's may have to be quite long.

6.6.2 ATCC/ASET Complexity

The FDMA systems using single channel per carrier tend to require less information handling. Voice is transmitted straight through from the ATCC to the ASET at baseband. Data messages are handled on a store and forward basis. The ASCC formats the data stream. In the TDM systems, the separation between the ASET and ASCC becomes less clear. The ASCC must multiplex all the channels together before transmission of the baseband signal to the ASET. This includes incorporation of the surveillance signal and supervisory information into the multiplex.

7.0 MARITIME USER APPLICATIONS

Reference 29 is a comprehensive study of the provision of service to maritime users by means of a dedicated maritime satellite (MARSAT). The results of this study were that a total of 10 equivalent duplex voice channels were required to serve all the needs of SATCOM equipped vessels in the Atlantic region in 1980. These were to be allocated as follows:

- -Digital Telegraph: 7 x 100 WPM (75 bps) teletype channels in each direction (equivalent to 1 x 600 bps data link)
- -Business Radiotelephone: 5.5 duplex voice circuits
- -Personal Radiotelephone: 3.4 duplex voice circuits
- -Access Control Channel: 1000 bps data channel (orderwire)

The accessing system employed demand assigned multiple access using the orderwire for channel requests and allocations. To fulfill U. S. Coast Guard requirements, a special ship-to-shore 75 bps emergency access channel was proposed. This satisfied the U. S. Coast Guard requirement for completely random access in an emergency, with a 99.9% probability of immediate success.

It is clear that there will not be enough surplus capacity in the first generation AEROSAT to fulfill all the maritime requirements on an "as-available" basis. So, it will be necessary to examine the priorities of maritime users to choose those messages which could be passed through the AEROSAT.

7.1 Emergency Access

The most obvious use of the satellite channels will be for immediate use by vessels in distress. The coordination of subsequent search and rescue operations will be assisted by the use of common channels for ships and search aircraft. For initial call if an "immediate" access is required, then use of a special emergency channel for random access is the only approach, for any but a low density experimental system with few users. With other techniques, such as roll call, or sequential access to a channel when clear, then as for aircraft use some attempt must be made to define what is an "acceptable" finite delay in emergency. This is not likely to have to be any shorter than that derived for aircraft traffic. The referenced study gave a projected number of 13.4 distress messages per month for 1980 Atlantic maritime traffic. However, many of these would no doubt fall into the urgency category defined for aircraft with a less-than-immediate priority. It appears likely that the use of the common emergency facilities would be greater by ships than by aircraft.

7.2 Communications

Ship-to-shore communications are now handled mainly by CW telegraphy (Morse). The access times, governed largely by such factors as propagation conditions and time of radio watch on board, are such that transmission and receipt of a return message commonly occupies six hours. This figure, although not desirable, does appear to be "acceptable" in that no great pressure is being applied to use other techniques to improve it. But, there is a definite demand to increase the amount of data which can be put into each message. Teletype at 75 bps over HF channels is coming into increasing use for the larger vessels. Projected traffic loads indicate that 200 words/day will be required to be transmitted in each direction for business traffic (cargo scheduling, logistic support, refurbishment) for the large vessels.

For voice communications, much shorter access delays are required. The study showed the average call frequency would be one 12-minute business call every 5 days. Access delays of one or two hours might be acceptable. The MARSAT study indicated peak hour delays of 1.8 hours, with a mean waiting time of 18 minutes. Quite definite peaks are likely to occur during business hours at the ship's operators home offices. These are likely to coincide with peaks in aeronautical company traffic for the same reason.

An important factor in present maritime operations is that ship's radio officers are generally on duty eight hours per day in four 2-hour shifts; so the times when a ship can receive messages are limited. The increasing use of radiotelephone (or teletype) allows other, less skilled crew members to handle the traffic, when necessary.

For personal (crew and passenger) calls, the demand can more easily be shifted to off-peak hours. Study indicates an almost "open-ended" requirement for such calls if they can be provided at reasonable cost. About 0.5 calls per ship per day of 5 minutes average duration were predicted for the dedicated MARSAT.

7.3 Surveillance

The requirement for a maritime surveillance system is not as well defined. It is really only required in a few high-density confluence areas. The surveillance problem is complicated compared with aeronautical users by the more diverse mix of vessel types (many of which are not likely to be SATCOM equipped) and the almost random nature of the routings. A definite value of continuous surveillance would be in emergency situations, where the position of the vessel in distress would be known for SAR purposes. In such SAR operations, cooperating ships and aircraft can also use a common position reference for control by a shore rescue agency.

Surveillance of a particular vessel on the high seas would be primarily required by the operating companies. In such cases, a once-per-day fix would probably be acceptable, with the accuracy requirement relaxed from the 1 n.mi. specified for aircraft. For commercial reasons, owners and ships masters often desire to maintain some degree of secrecy from other operators in the movements of their vessel. This would be a negative factor in the introduction of general surveillance.

7.4 Access Techniques

The types of system described can easily be modified to provide for a limited population of maritime users. This can be accomplished by reserving one or more slots in each frame of a supervisory channel for maritime use. If there are few users, the first slot in each frame can be reserved for maritime users to request the use of a communication channel. It is identified as a special maritime access slot. Since ship use of such channels is relatively infrequent, and if there are few users, the probability of two ships requesting such use in the same time slot will be very small. If more users have to be accommodated, more slots can be reserved for channel requests and acknowledgements. In general, these slots should be dispersed throughout the frame to minimize the probability of interference. Ships, on requesting the use of a channel, would be assigned a priority and the channel would be assigned to them in accordance with that priority.

If the number of users increases, it will probably be necessary to provide a two-step entry into the system. The ships would first request entry into a polling sequence and then request service from that polling sequence. This can be accomplished, for example, by reserving the first ten slots in each frame for maritime use and organizing a maritime frame to consist of 100 aircraft frames.

The epoch sync code at the beginning of the first maritime frame would be coded so as to identify it. Thus, a maritime frame would consist of 1,000 time slots. Some of these time slots could be characterized as entry slots and some of them could be emergency slots. A ship desiring entry into the system could do so on one of the entry slots. On entering, it would be assigned a place in the polling sequence from which it could request channel use. Those ships that frequently use the channel would remain in the system; those requiring relatively infrequent use would first request entry into the system before requesting an available channel. The emergency slots would be available for emergency channel requests. While an access system of the type just described can be devised, it is based on the assumption that there is sufficient channel capacity to accommodate the maritime users as well as the aeronautical users. This assumption will have to be carefully investigated.

evaluation of system operation would be made including pilot or controller acceptance and reaction, effect of spot beams, propagation delay, and delays in G-G transfer of information. Verification of the supervisory techniques and comparisons of centralized and distributed control would also be obtained under more realistic conditions.

Following this step in simulation, the avionics would be installed in actual test aircraft and the full instantaneous airborne count of aircraft again simulated in the system computer. Operation would be via actual or possibly balloon carried simulated satellites. For both steps in these proposed more full scale simulations, the full aircraft population would be simulated as a first step, with respect to communication facilities requests and thus the effect on queueing more fully evaluated. As a final step in simulation, a more realistic scenario could be included in which aircraft would be programmed to "fly" along assigned tracks with some simple error or drift rate profile for their assumed on-board navigator. The controller would thus occasionally issue vectoring commands in this extended simulation. Random entry and emergency signalling would also be programmed to test system effectiveness for handling this type of request.

8.3 Instrumentation Verification Experiments

The instrumentation required for the various candidate systems identified, has been detailed in the course of this study only to the extent required to indicate technical feasibility and to permit a reasonably accurate estimating of cost. Many of the techniques are indeed well established and much information was available from actual in-house hardware experience. This is especially the case for FDMA techniques. Some further verification of techniques in the FDM area can however be recommended as warranted. To a greater degree, much of the avionics for the TDM systems warrant breadboard experimental verification. The following section lists some suggested items for further analysis and for experimental breadboard verification.

8.3.1 Experiments for FDMA System

a) Analyze and build experimental breadboards to verify techniques for multiplexing tone ranging signals with the UDDL data on a carrier.

b) Analyze and build experimental breadboards to verify techniques for multiplexing various types of digital ranging signals with the UDDL data on a carrier.

c) Investigate changes to UDDL format to optimumly accommodate AEROSAT supervisory information. Coordinate this with ARINC/Aerospace/TSC/FAA and other interested parties.

d) Further study impact of various feasible satellite designs on intermod product generation and effect of ease of operation on various candidate configurations.

8.3.2 Experiments for TDM Systems

a) Investigate symmetrical and unsymmetrical bit-by-bit multiplexing techniques. Analyze and build experimental breadboard modulator and decoder to test acquisition characteristics under typical satellite transmission conditions.

b) Investigate signal design for uplink ranging on bit-by-bit multiplex. Analyze and include in experimental breadboard of item a).

c) Investigate burst multiplexing technique. Analyze and build breadboard generator for both SS&S and communication channel bursts in bread-board form. Test acquisition characteristics under typical satellite transmission conditions. Investigate signal design for ranging in the SS&S burst, check ranging accuracy attainable and check voice and data fidelity attainable under typical satellite transmission conditions.

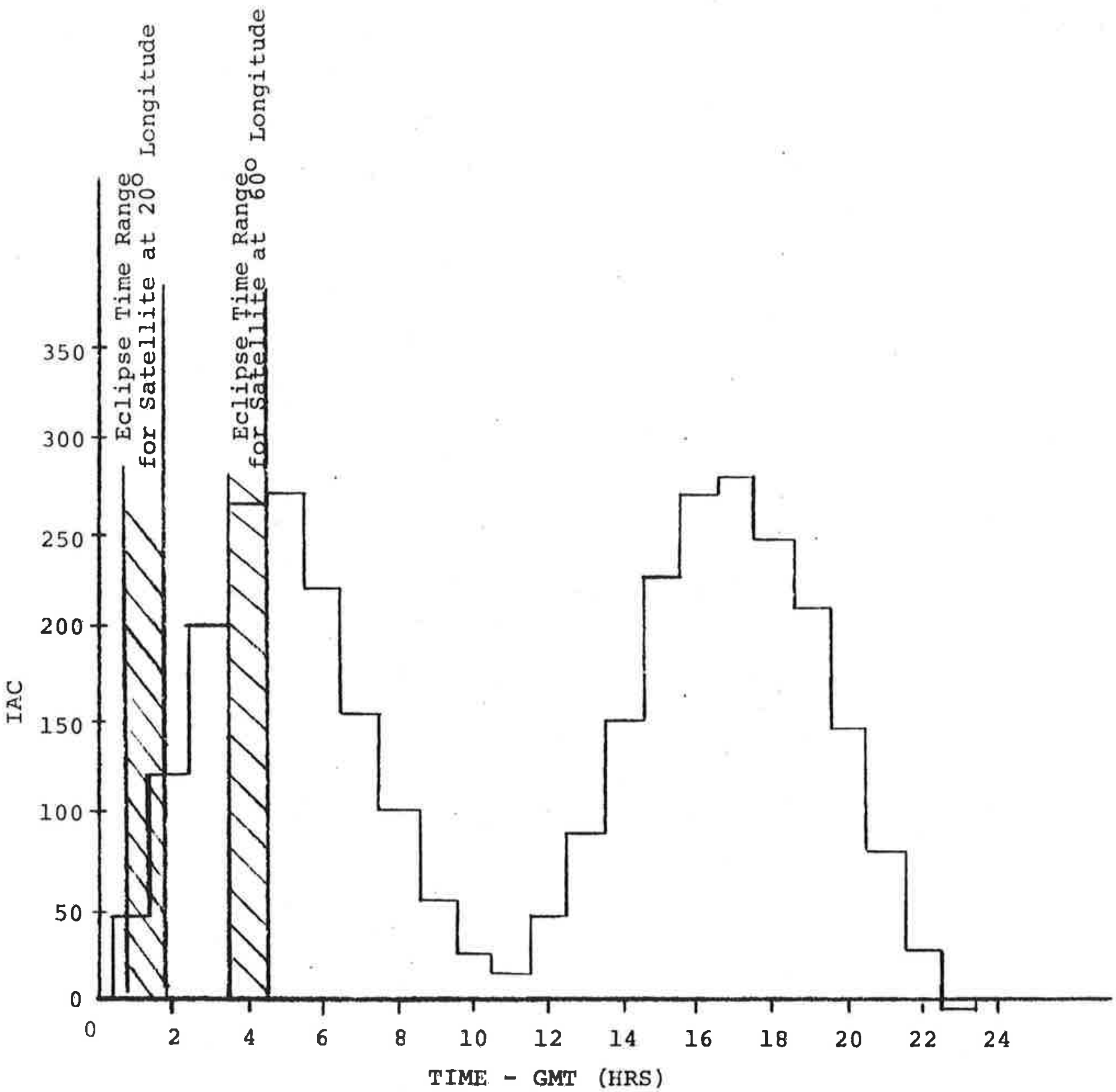


FIGURE A-1. INSTANTANEOUS AIRBORNE COUNT VS. TIME

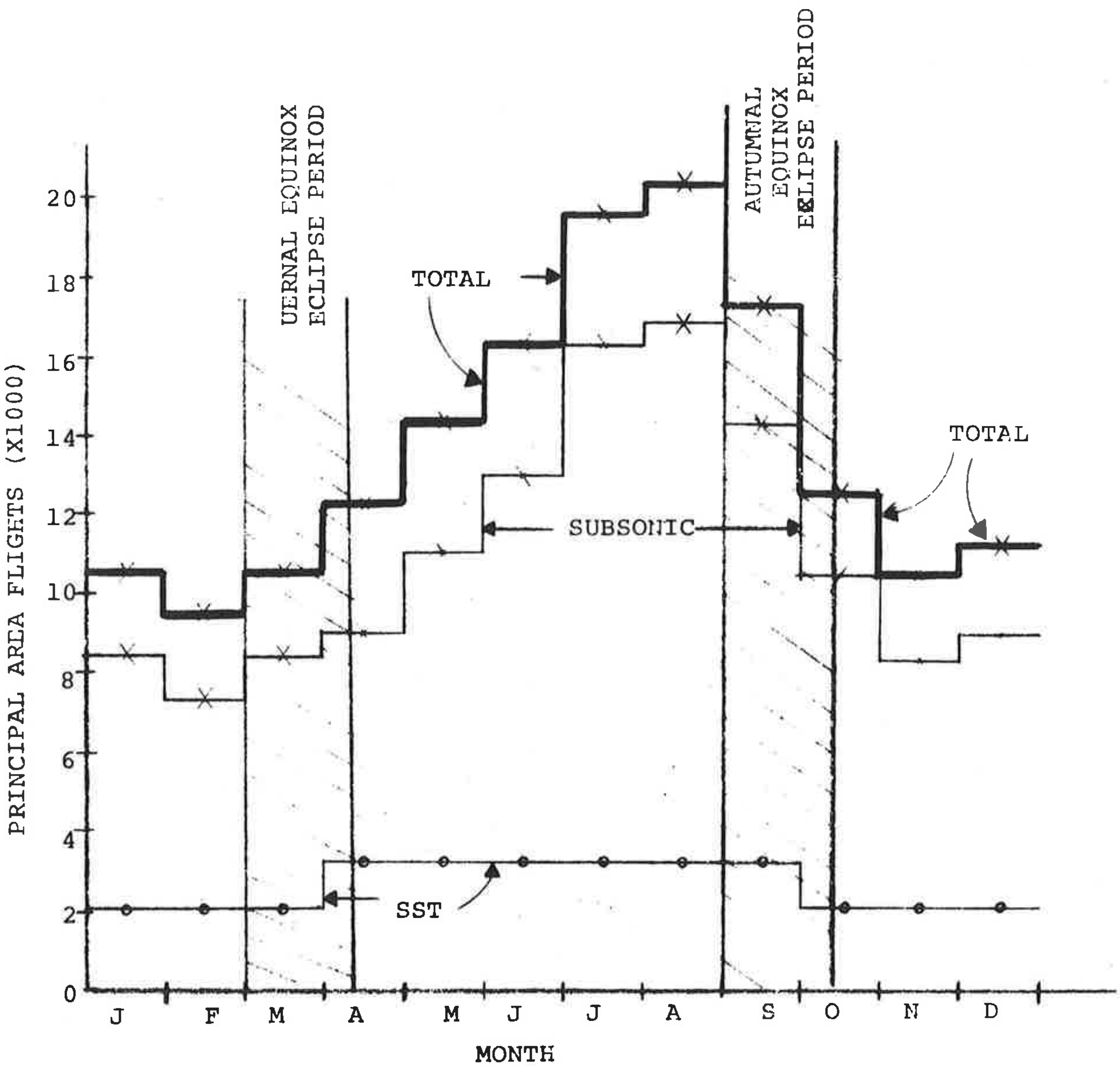


FIGURE A-2. FLIGHTS VS. MONTH OF THE YEAR

APPENDIX B

INTERMOD PRODUCT LOSS IN A HARD LIMITER

A computer program has been developed[30] to determine the frequency and magnitude of fundamental and intermodulation products in the first zone output of a bandpass limiter for 2-10 frequencies. The magnitude calculations are after Shaft[31]. The results of a calculation to determine intermod losses are tabulated below. With an ASET EIRP of 55 dbw and an 80 KHz channel bandwidth, it is expected the S/N will be in the region of 15-20 db. Hence, the loss to the intermods is expected to be on the order of 1 db.

EQUAL SIGNALS THROUGH A HARD LIMITER
HIGH INPUT SIGNAL/NOISE

NUMBER OF SIGNALS, N	OUTPUT DB BELOW TOTAL 1 SIGNAL	N SIGNALS	DB LOSS
2	3.98	0.97	0.97
3	5.58	0.81	0.81
4	6.94	0.92	0.92
5	7.92	0.93	0.93
6	8.74	0.96	0.96
7	9.42	0.97	0.97
8	10.01	0.98	0.98
9	10.53	0.99	0.99
10	10.99	0.99	0.99
	INPUT S/N = 20.00 DB		
2	3.97	0.96	0.96
3	5.64	0.87	0.87
4	6.99	0.97	0.97
5	7.97	0.98	0.98
6	8.78	1.00	1.00
7	9.46	1.01	1.01
8	10.05	1.02	1.02
9	10.57	1.03	1.03
10	11.04	1.04	1.04

EQUAL SIGNALS THROUGH A HARD LIMITER
INPUT S/N = 10.00 DB

NUMBER OF SIGNALS, N	OUTPUT DB BELOW TOTAL 1 SIGNAL	N SIGNALS	DB LOSS
2	4.30	1.29	1.29
3	5.98	1.21	1.21
4	7.33	1.31	1.31
5	8.32	1.33	1.33
6	9.14	1.36	1.36
7	9.82	1.37	1.37
8	10.42	1.38	1.38
9	10.93	1.39	1.39
10	11.40	1.40	1.40

APPENDIX C

STATISTICAL QUEUEING ANALYSIS

C.1 Queueing Equations

The classical queueing equations assume a message arrival rate which is Poisson distributed, and a message length which is exponentially distributed. If the mean message arrival rate is denoted by λ, and the mean message length by D, the product λD is a measure of the communication load which the system must handle; it will be referred to as the message load factor. Unless the number of communication channels, N, is greater than λD, the system cannot take care of the load, and the queue will build up indefinitely. The ratio $\lambda D/N = \rho$ is called the utilization factor. It is the fraction of time that a given channel will be busy. Since the number of channels must be greater than the message load factor, the utilization factor must be less than one.

We will use the symbol P_n to denote the probability that the total number of messages in the system; i.e., waiting to be transmitted or being transmitted, is equal to n. If at a given time the maximum number of messages possible (i.e., the number of aircraft in the area) is M, we have (see, for instance, Reference 14, p. 30, eq. 4.2)

$$\begin{aligned} P_n &= \frac{(Np)^n}{n!} P_o, & 0 \leq n \leq N, \\ P_n &= \frac{N^n}{n!} \rho^n P_o, & N \leq n \leq M \end{aligned} \qquad (1)$$

To obtain P_o, we use the knowledge that the P_n's must sum to one:

$$\sum_{n=0}^{M} P_n = 1 = \sum_{n=0}^{N-1} \frac{(Np)^n}{n!} P_o + \sum_{n=N}^{M} \frac{N^N}{N!} \rho^n P_o =$$

$$= P_o \left[\sum_{n=0}^{N-1} \frac{(N\rho)^n}{n!} + \frac{N^N}{N!} \frac{\rho^N - \rho^{M+1}}{1-\rho} \right] =$$

$$= P_o \left[\sum_{n=0}^{N-1} \frac{(N\rho)^n}{n!} + \frac{(N\rho)^N}{N!} \frac{1-\rho^{M+1-N}}{1-\rho} \right],$$

$$P_o = \left[\sum_{n=0}^{N-1} \frac{(N\rho)^n}{n!} + \frac{(N\rho)^N}{N!} \frac{1-\rho^{M+1-N}}{1-\rho} \right]^{-1} \qquad (2)$$

The busy probability, P, is defined as the probability that all communication channels are busy, which is the probability that N or more messages are in the system:

$$P = \sum_{n=N}^{M} P_n = P_o \frac{N^N}{N!} \sum_{n=N}^{M} \rho^n = P_o \frac{N^N}{N!} \frac{\rho^N - \rho^{M+1}}{1-\rho} =$$

$$= P_o \frac{(N\rho)^N}{N!} \frac{1-\rho^{M+1-N}}{1-\rho}$$

Substituting the previously obtained value for P_o in this equation, we obtain

$$P = \left[1 + \frac{1-\rho}{1-\rho^{M+1-N}} \sum_{n=0}^{N-1} \frac{N!}{n!} \frac{(N\rho)^n}{(N\rho)^N} \right]^{-1} =$$

$$= \left[1 + \frac{1-\rho}{1-\rho^{M+L-N}} \sum_{n=1}^{N} \frac{N!}{(N-n)!\,(N\rho)^n} \right]^{-1} \qquad (3)$$

It is clear that, as the number of aircraft increases, the system will be loaded more heavily. It is, therefore, conservative to let the number of aircraft increase to infinity; this assumption also facilitates the mathematics. As we let M approach infinity, we have

$$P = \left[1 + (1-\rho) \sum_{n=1}^{N} \frac{N!}{(N-n)!\,(N\rho)^n} \right]^{-1} =$$

$$= \left[1 + \sum_{n=1}^{N} \frac{N!}{(N-n)!\,(N\rho)^n} - \sum_{n=1}^{N} \frac{N\rho\,(N-1)!}{(N-n)!\,(N\rho)^n} \right]^{-1}$$

$$= \left[1 + \sum_{n=1}^{N} \frac{N!}{(N-n)!(N\rho)^n} - \sum_{n=0}^{N-1} \frac{(N-1)!}{(N-n-1)!(N\rho)^n} \right]^{-1} =$$

$$= \left[1 - \frac{(N-1)!}{(N-1)!(N\rho)^0} + \sum_{n=1}^{N-1} \left\{ \frac{N!}{(N-n)!} - \frac{(N-1)!}{(N-n-1)!} \right\} \frac{1}{(N\rho)^n} + \frac{N!}{0!(N\rho)^N} \right]^{-1} =$$

$$= \left[\sum_{n=1}^{N} \frac{(N-1)!}{(N-n)!} \frac{n}{(\lambda D)^n} \right]^{-1}, \tag{4}$$

where, in the last expression, we used the identity $N\rho = \lambda D$.

The probability that the waiting time in the queue is greater than some time t_w is (Reference 14, p. 106, eq. 8.4)

$$W(t_w) = P e^{-(N/D-\lambda)t_w}. \tag{5}$$

We see that the waiting time is exponentially distributed with a mean

$$\bar{t}_w = \frac{P}{N/D-\lambda} \tag{6}$$

In addition to the mean waiting time, it is also of interest to consider a practical "maximum" waiting time, say a waiting time which will not be exceeded more than 10% of the time. This will be denoted by $t_{wm}(.1)$ or, in general, by $t_{wm}(q)$, where q is the probability that the waiting time is greater than $t_{wm}(q)$. We can, then, substitute q for $W(t_w)$ and $t_{wm}(q)$ for t_w in equation (5) and solve for $t_{wm}(q)$:

$$t_{wm}(q) = \frac{\ln P - \ln q}{N/D-\lambda}, \quad q \le P \tag{7}$$

It is often convenient to present equations (6) and (7) in non-dimensional terms:

$$\bar{t}_w/D = \frac{P}{N-\lambda D}, \tag{6a}$$

$$t_{wm}(q)/D = \frac{\ln P - \ln q}{N - \lambda D}, \quad q \le P. \tag{7a}$$

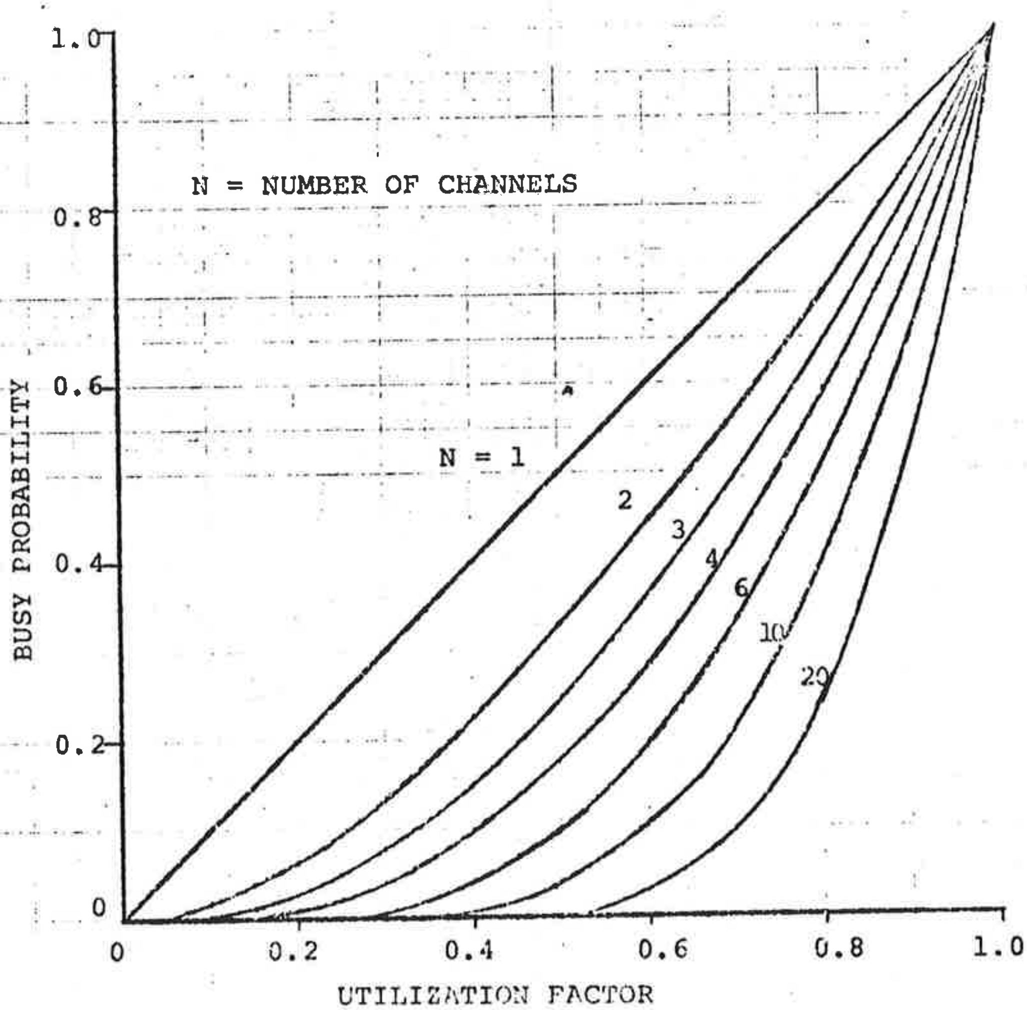
C.2 Queueing Analysis and Applications

The following discussion describes a series of graphs which are useful in the analysis of the type of queueing system encountered in the present study.

Figure C-1 is a graph of equation (2), plotting the busy probability versus the utilization factor with the number of channels as parameter. This figure may be used to compare busy probabilities for various allocation systems. Assume, for example, a message load factor of 3.6. Clearly, the number of channels, N, must be an integer greater than 3.6. If we pick N = 4, the utilization factor is 3.6/4 = 0.9, and we find from Figure C-2 that the busy probability is 79%; this would seem to be too high. Let us try N = 6; the utilization factor is now 0.6, and the busy probability 20%. This assumes that all voice channels are in a common pool for assignment to aircraft by the master ASCC, as described earlier in System A. Suppose we had two ASCC's, each controlling half the aircraft and each having three channels available, as in System C. The utilization factor is still 0.6, but not, with only three channels available, the busy probability increases to 35%. Again, if the aircraft were allocated equally among 3 ASCC's with two voice channels allocated to each, the busy probability would increase to 45%. In comparing systems, one would need to weigh the disadvantage of increased busy probability resulting from pre-allocation of voice channels among the ASCC's against the advantage of independent control of its area by each ASCC.

A more important criterion than busy probability is the waiting time. Figure C-2 is a plot of equation (6), showing the normalized mean waiting time as a function of the utilization factor, with the number of channels as a parameter. Figures C-3 and C-4 are similar plots of equation (7), showing normalized maximum waiting time with probabilities of 90% and 95%, respectively, of the waiting time

FIGURE C-1
BUSY PROBABILITY VS. UTILIZATION FACTOR



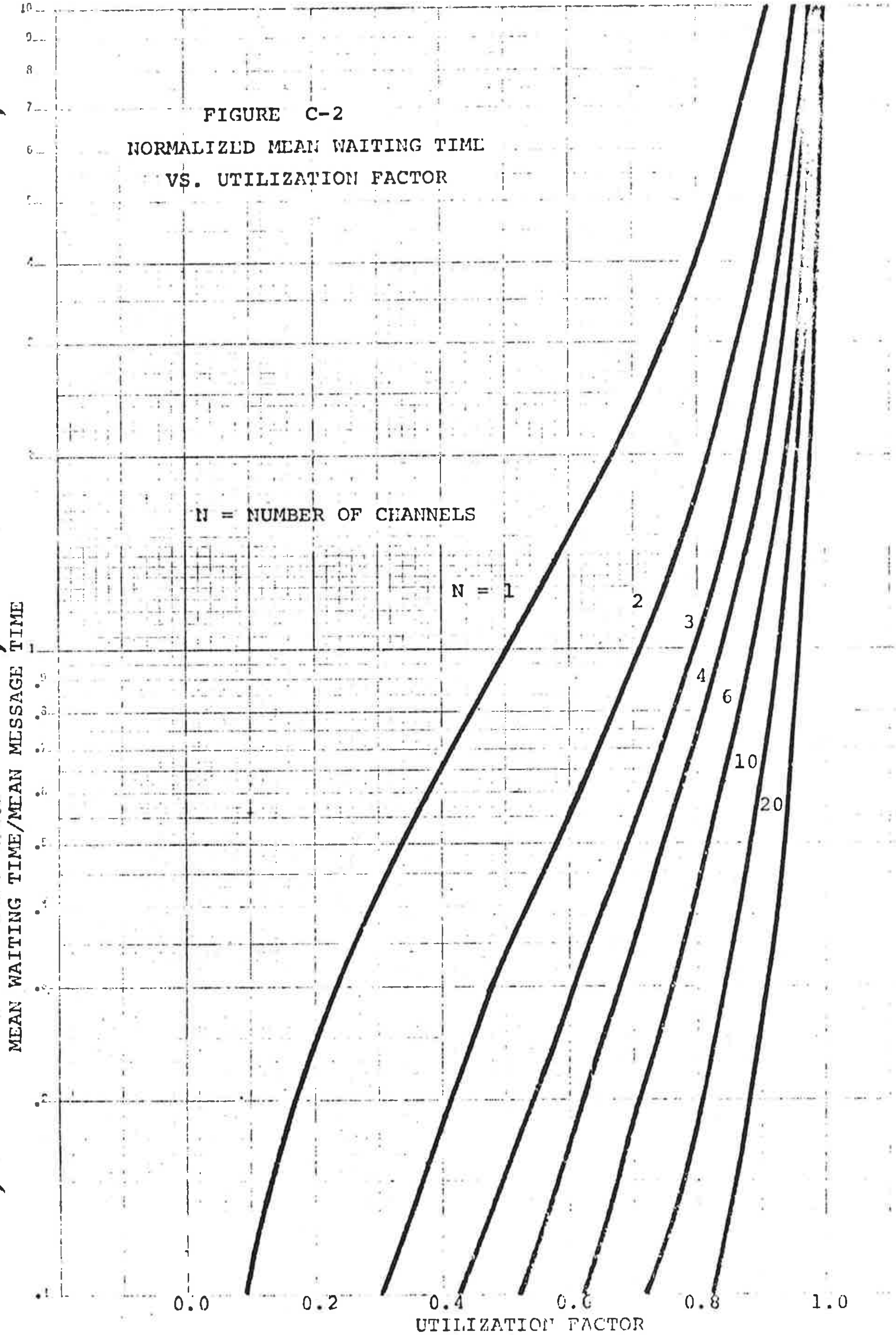


FIGURE C-2
NORMALIZED MEAN WAITING TIME
VS. UTILIZATION FACTOR
N = NUMBER OF CHANNELS
N = 1
2
3
4
6
10
20
MEAN WAITING TIME/MEAN MESSAGE TIME
0.0
0.2
0.4
0.6
0.8
1.0
UTILIZATION FACTOR

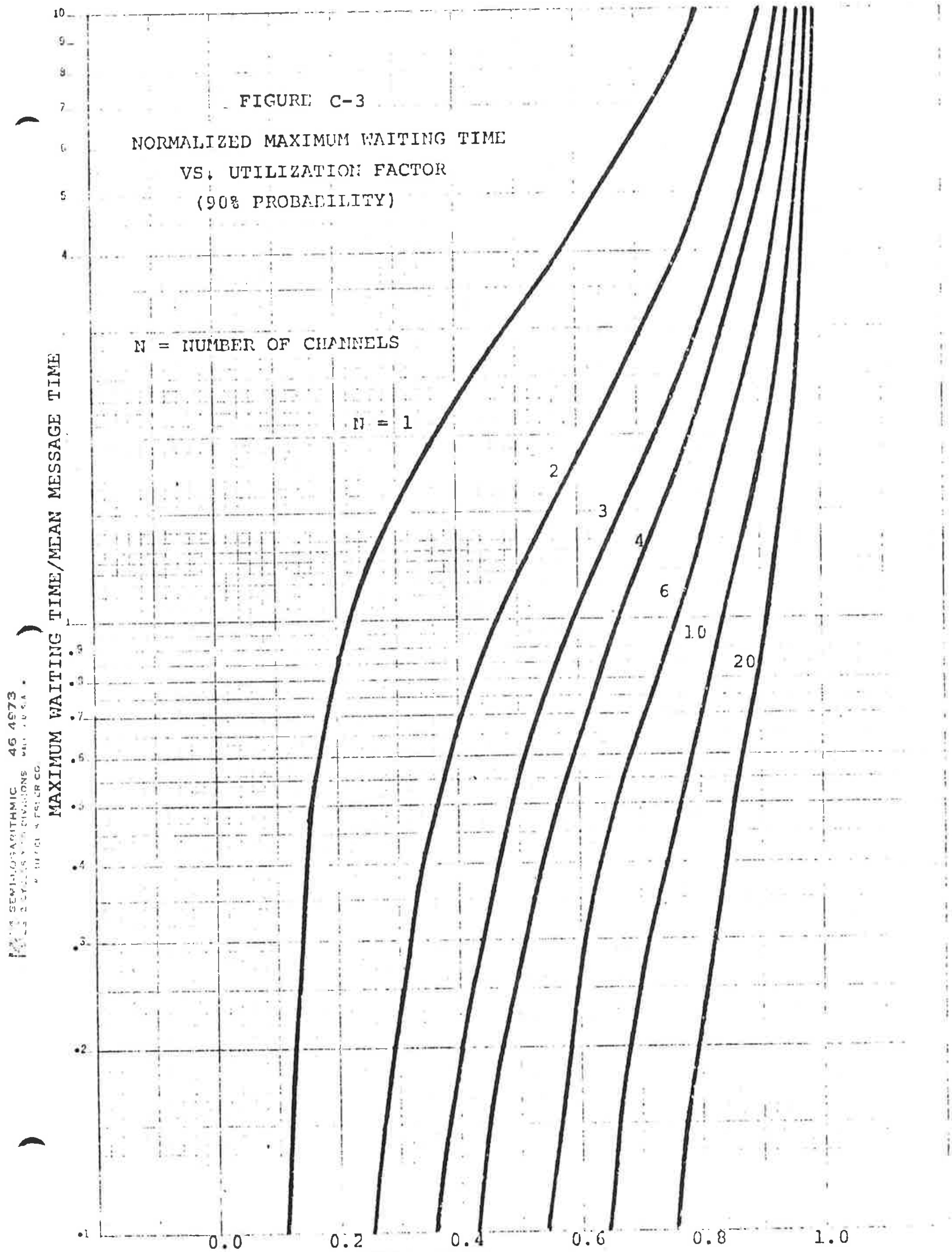


FIGURE C-3
NORMALIZED MAXIMUM WAITING TIME
VS. UTILIZATION FACTOR
(90% PROBABILITY)
N = NUMBER OF CHANNELS
N = 1
2
3
4
6
10
20
MAXIMUM WAITING TIME/MEAN MESSAGE TIME
UTILIZATION FACTOR
0.0
0.2
0.4
0.6
0.8
1.0
46 4973

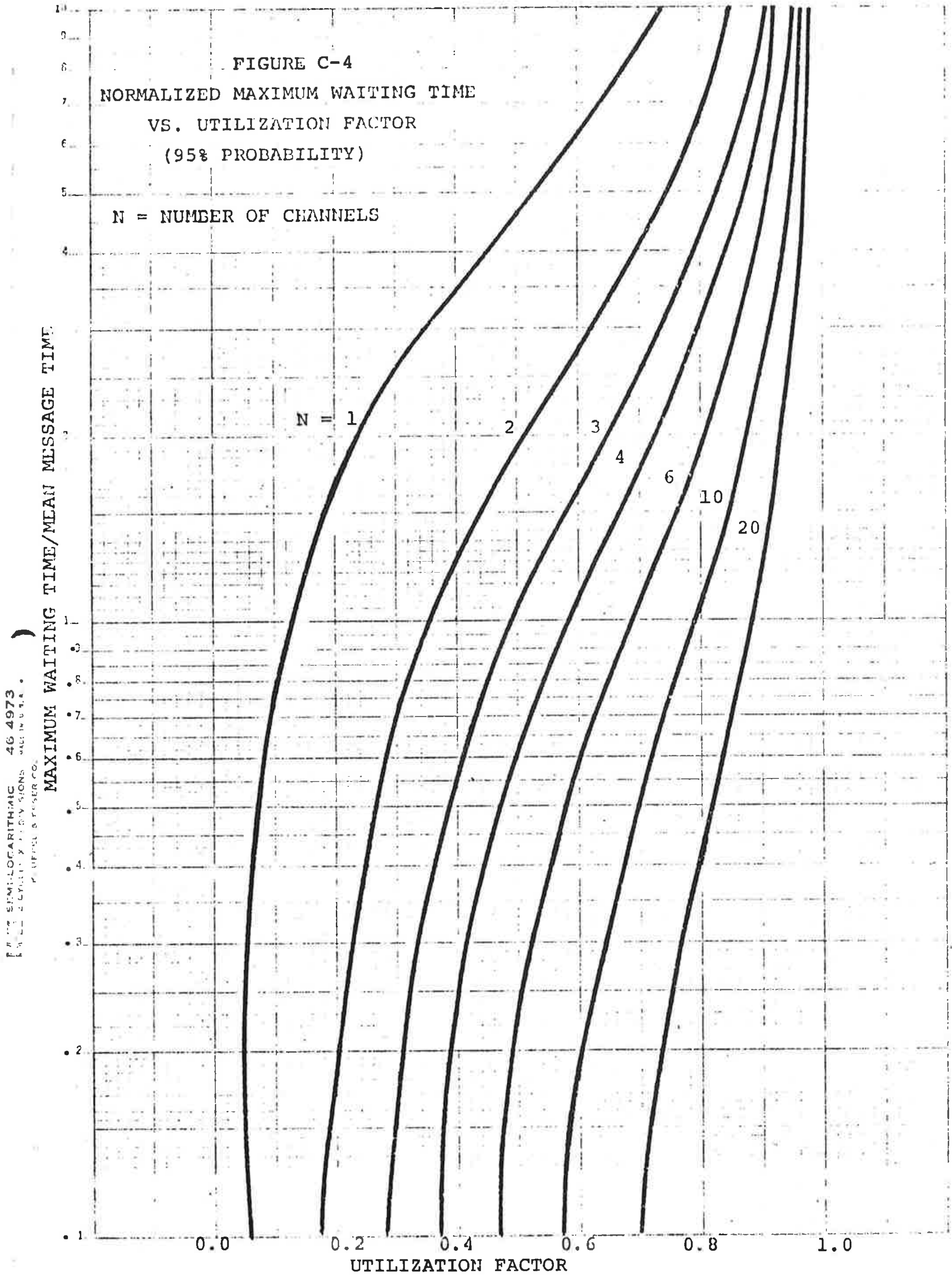


FIGURE C-4
NORMALIZED MAXIMUM WAITING TIME
VS. UTILIZATION FACTOR
(95% PROBABILITY)
N = NUMBER OF CHANNELS
N = 1
2
3
4
6
10
20
MAXIMUM WAITING TIME/MEAN MESSAGE TIME
0.0
0.2
0.4
0.6
0.8
1.0
UTILIZATION FACTOR

being less than indicated (q = 0.1 and 0.05, respectively). These figures may be used to compare waiting times for various allocation systems. Let us choose as the criterion for comparison the waiting time not to be exceeded in 90% of the cases; this leads us to use Figure C-3. If, as before, we assume a message load factor of 3.6, and again try N = 4, we find that the maximum waiting time for a utilization factor of 0.9 is 5.2 mean message lengths; if the average message is 25 seconds, the maximum waiting time is 130 seconds. If, on the other hand, we choose N = 6, we have a utilization factor of 0.6 and a maximum waiting time of only 0.28 message lengths, or 7 seconds. For System C, with two ASCC's allocated three channels each, the maximum waiting time increases to 1.06 message lengths, or 26 seconds; if three ASCC's are used with two channels each, the maximum waiting time is 1.88 message lengths, or 47 seconds. Or, if two ASCC's are used, the first assigned one-third of the message load and two channels, the second two-thirds of the load and four channels, the maximum waiting time for the first is 1.88 message lengths or 47 seconds, that of the second 0.66 message lengths or 16 seconds.

C.3 General Conclusions

A question of considerable interest in this study is the effect of channel allocation on waiting time. The answers can be found from Figures C-2, C-3 and C-4; however, Figures C-5, C-6 and C-7 present the same information in a more convenient form for the present purpose. Whereas Figures C-2 - C-4 show plots of waiting time against utilization factor with number of channels as parameter, Figures C-5 - C-7 show utilization factor against number of channels with waiting time as parameter. (Clearly, when interpreting these curves one must understand that the values are meaningful only at integral values for the number of channels; the curves were drawn as continuous functions merely to indicate the trend in a graphic manner.)

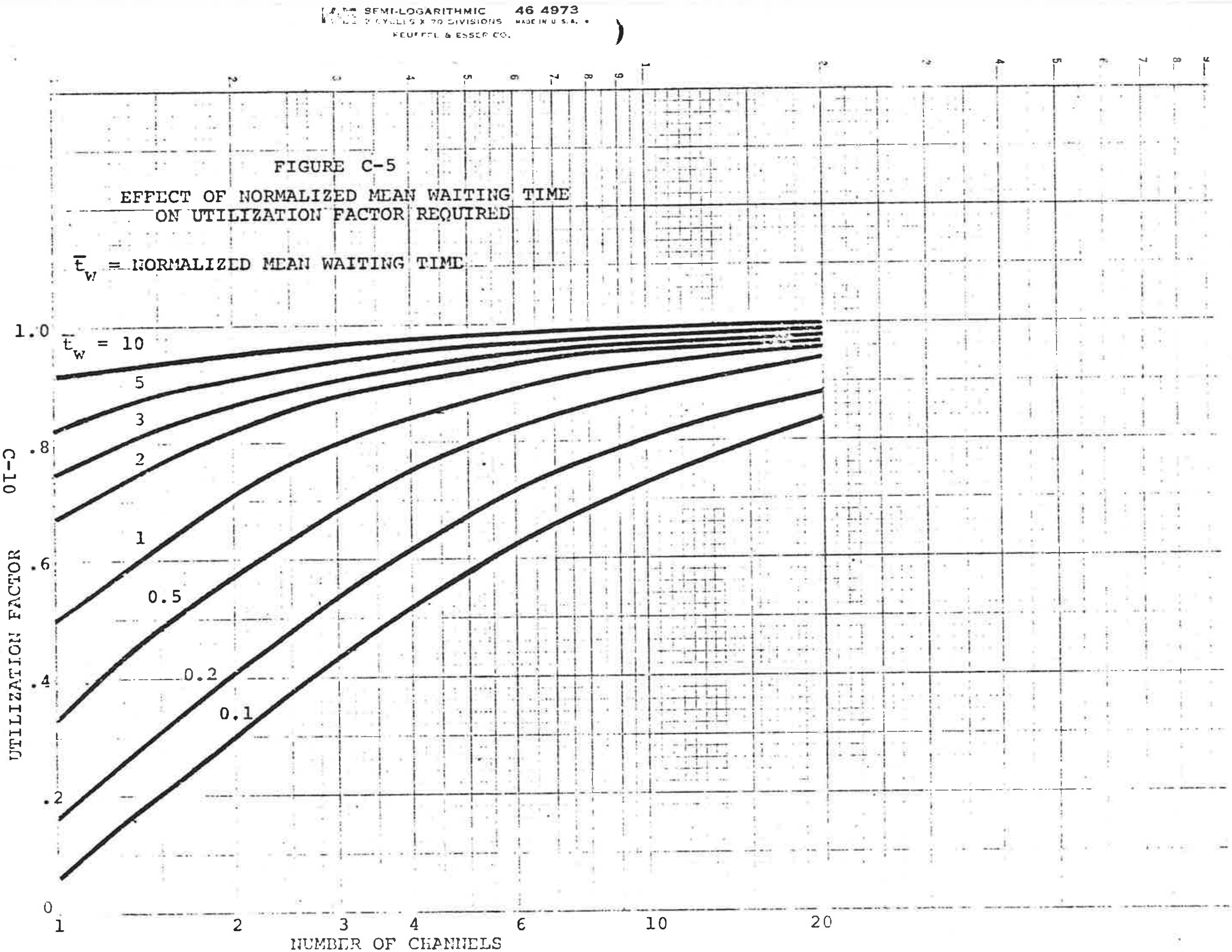


FIGURE C-5

EFFECT OF NORMALIZED MEAN WAITING TIME ON UTILIZATION FACTOR REQUIRED

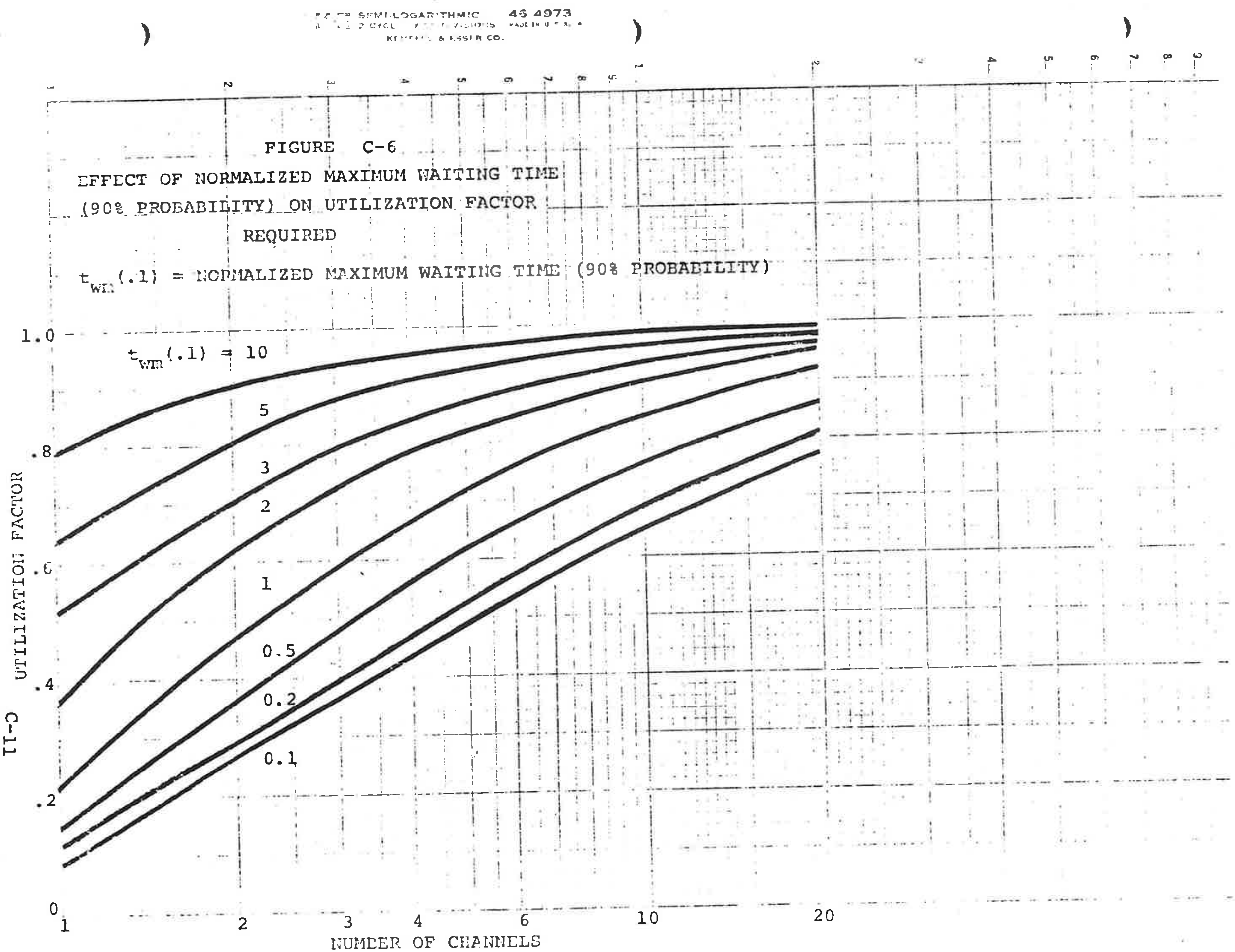


FIGURE C-6

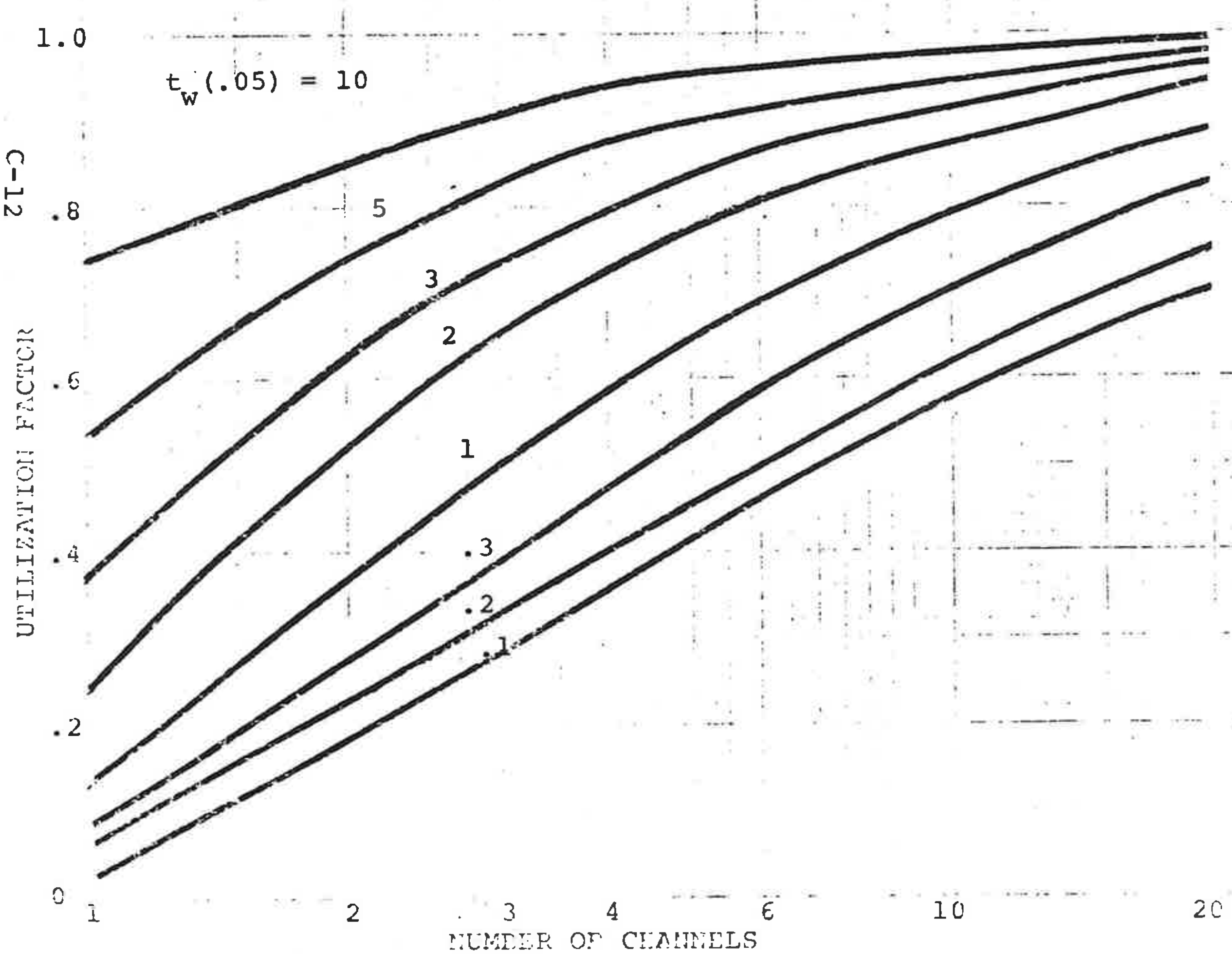
EFFECT OF NORMALIZED MAXIMUM WAITING TIME (90% PROBABILITY) ON UTILIZATION FACTOR REQUIRED

$t_{wm}(.1)$ = NORMALIZED MAXIMUM WAITING TIME (90% PROBABILITY)

FIGURE C-7

EFFECT OF NORMALIZED MAXIMUM WAITING TIME (95% PROBABILITY) ON UTILIZATION FACTOR REQUIRED

$t_{wm}(.05)$ = NORMALIZED MAXIMUM WAITING TIME (95% PROBABILITY)



From Figure C-6, it would appear that, if a maximum waiting time of three message lengths is satisfactory, and if the number of channels is at least three, a utilization factor of 0.8 will be at least adequate. On the other hand, conservative design would prohibit a utilization factor much greater than 0.8 lest an unexpectedly high message load increase the queue beyond tolerable bounds. Therefore, if the above criteria hold (and they do hold nearly always), the number of channels should be chosen to obtain a utilization factor of about 0.8. This design rule may be one of the important results of this study.

Let us consider now an AEROSAT system using two ASCC's, each responsible for a specific geographic area. The message loading in these two areas is not necessarily the same. Assuming as before a total message load factor of 3.6, and six channels available, let us assume that ASCC-1 has 60% of the message load, ASCC-2, 40%. This means that the message load factor of ASCC-1 is 0.6 x 3.6 = 2.16, that of ASCC-2, 0.4 x 3.6 = 1.44. If each ASCC is assigned three channels, the utilization factor of ASCC-1 is 2.16/3 = 0.72, that of ASCC-2, 0.48. Using Figure C-3, we get maximum (90%) waiting times of 2.04 and 0.50 message lengths, respectively. If instead ASCC-1 is assigned four channels and ASCC-2 two, the utilization factors are 0.54 and 0.72, respectively, and the maximum waiting times 0.43 and 3.32. The assignment of three channels each is therefore better, resulting in a maximum waiting time of 2.04 message lengths, as against 3.32 for the four-two split. It is, of course, not as good as it would be if each ASCC had 50% of the load; the result for this case was shown in Section C.2 to be 1.06 message lengths. If the geographic areas could be changed to retain 50-50 loading by moving the hand-over boundary in accordance with aircraft activity in each area, the waiting time could be cut by half. This may, however, not be acceptable from a practical standpoint of implementation.

APPENDIX D

DESCRIPTION OF AEROSAT SIMULATION

D.1 Introduction

There are three methods of approach available for a computer solution to a complex queueing system such as the AEROSAT communications network under study. The first of these is to describe the statistical elements of the system such as message generation and service times as accurately as possible and then use a computer technique to solve the simultaneous integral equations that specify the system operation. A second approach is to take these same statistical descriptions and simulate the probability functions describing the system operation and observe the operation of the simulation. Both of the above methods have ben advantage over the classical closed form solutions of not requiring the restriction of the statistical descriptions to Poisson type functions. However, they still have disadvantages that can be eliminated by the third approach which was selected for simulation.

In the classical approach, or either of the two computer solutions above, a significant problem still exists when the techniques are attempted in a design situation as opposed to a purely analysis task. The description of the message statistics as a probability function, whether a classical Poisson or any other, reduces both the confidence in the model and the ability to vary the system parameters. Once any of the elements of the model have been reduced to a probability function, describing as an example the message interarrival times, it is extremely difficult to determine the effect of small parametric changes. Variations in items like number of aircraft, changes in priority, time-of-day, adding or eliminating certain message categories, fixed length messages and similar changes that might want to be evaluated are not easily reflected back into interarrival times. Additionally, the question always remains as to the accuracy with which the selected probability function, whatever it is, really represents the parameter of interest. Verification of this would of course require an analytic description and solution or a simulation of the actual system components responsible for the parameters and the repetition of this after each significant change. It is these considerations which motivate the approach actually used in the AEROSAT communications network simulation.

When a simulation is being conducted for the purpose of analysis and design, it is best to simulate the system at as near as possible the level where design parameters are to be varied. This is the approach selected for the AEROSAT simulation. Rather than attempt to reduce the descriptions of the system elements to statistical distributions, the physical system elements are themselves simulated directly from their descriptions. As an example of this approach, the IAC (Instantaneous Airborne Count) is one of the system elements directly simulated from the description of the physical process. Rather than describe the IAC by a probability density with derived parameters, the aircraft flights are themselves simulated. Using the 1980 busy day predictions, a computer program module is designed to provide simulated flights within the communication system according to the hourly predicted rates. Using this modular program approach, the simulation has available directly as parameters for variation such things as hourly rates, daily rate, subsonic-supersonic ratio, east-west ratio, and aircraft transit velocity.

With the computer programs organized to simulate at the physical variables level, the effects of changes in these variables may be directly evaluated. In contrast, if the simulation were at a higher level, the effect of these changes on the simulation would have to be incorporated as best as possible and then the incorporated changes are what is evaluated.

The simulation as operated has used the approach described in all the elements of the communications network and queueing system. Five basic physical features of the simulation are programmed in individual functional modules in the programs.

D.2 Simulation Structure

The first functional block in the simulation is the flight generation module which provides the system entry times of all the flights. These times are derived in accordance with the 1980 predicitons of the North Atlantic Planning Group. The simulation is run over the four hour period representing the highest Instantaneous Airborne Count (IAC). The four hour run allows for preloading the airspace with all the flights making up the IAC. These properly distributed entry times are required for correct distribution of the periodic and skew distributed messages generated by the flights. An overall use factor is incorporated into the generation statistics to provide for variations in the total number of aircraft and consequently the IAC. At the use factor value of 1.0 corresponding to the nominal 1980 predictions, the mean value of the maximum IAC is 317. There is no attempt made to distinguish between East-bound and West-bound flights since their message traffic is essentially the same.

The system entry times of the individual flights are used as inputs to the second module of the simulation which generates the message traffic for each flight. Each flight has six voice and seven data message categories or classes as shown in Figures D-1 and D-2, respectively. In the tables, each message class is given a category number designation such as 2/4. The first number indicates the priority of the class, in this case 2, and the second is an identification number within that priority. Each message category is independently specified and described in the simulation module. The module provides for each flight the category, time and duration of all messages over the transit time of the flight in the communications system.

Within each message category, there are three basic parametric descriptions that are selected for each individual category to best simulate the actual message traffic expected from the flight. The

FIGURE D-1

VOICE MESSAGE STATISTICS

CATEGORY NUMBER	MESSAGES PER FLIGHT	MESSAGE DURATION	POLLING DELAY	CHANNEL DELAY
1/1	0.28	30	3.0	2.0
1/2	2.40	30	1.4	1.0
2/1	0.66	30	16.5	2.9
2/2	0.50	20	1.4	1.0
2/3	0.60	10	1.4	1.0
2/4	0.14	5	1.4	1.0

FIGURE D-2

DIGITAL MESSAGE STATISTICS

CATEGORY NUMBER	MESSAGES PER FLIGHT	MESSAGE DURATION	POLLING DELAY	CHANNEL DELAY
2/5	1.5	0.20	16.5	3.0
2/6	3.6	0.20	0.0	2.2
3/1	1.0	0.33	16.5	3.0
3/2	12.0	0.67	22.0	3.3
3/3	10.0	0.75	33.0	3.9
4/1	5.0	1.08	16.5	3.0
4/2	1.0	0.50	16.5	3.0

discrete density function describing the number of messages per flight is independently derived for each category and has a mean value for the number of messages per flight as given in the tables of Figures D-1 and D-2. For example, in the class of Vectoring messages, type 2/6, in Figure D-1, the mean value is 3.6 messages per flight. The discrete density function for this class has a 10% chance of two messages, a 20% chance of three messages and a 70% chance of four messages. The second distribution that is independently provided for each class is the description of the time of occurrance of the message within the flight. For the Vectoring messages of category 2/6, they are uniformly distributed over the flight. However, categories 3/2 and 3/3 are semi-periodic and category 2/5 is skewed toward the beginning of the flight. The final variable in the message generation module is the message duration for each class. These again are derived independently and have the mean values given in the tables. In the present programs, the message categories each have a uniform variation around the nominal. The magnitude of the variation is an independent parameter for each type. For the Vectoring messages of category 2/6, the variation is ±10% of the nominal value.

The portions of the simulation described above provide the message traffic environment in which the communication system must operate. The following modules are the descriptions of what the communication systems are and how they operate. In the descriptions that follow, a baseline system using a supervisory channel with polling of each aircraft at least once per epoch is used. This is the system simulated. Variations in this mode of operation have been examined and simulated by variation in polling and channel delay parameters. For each message category provided by the message generation module there are two significant times which are introduced before the message can be serviced by the system. The polling delay is the time from actual message origination until the access controller is aware that the message exists. This time is an additive factor in the message delay. A second critical time is the channel delay caused by a combination of factors such as message transit time ground to air and return, and lock-up times for receivers. This time has an effect upon channel usage since some portion of it is direct lost time. Both of these times are generated independently for each message types with the nominal values given in Figures D-1 and D-2.

The final element of the simulation is the service module which maintains the message queues and makes channel assignments. This module also contains the data collecting programs which observe the operation of the network over the busy hour and tabulated the results. The discipline that has been simulated is a first-in, first-out queue with a single queue serving all channels. Priority class one has a preemptive ability and is immediately given the channel with the shortest queue if no open channel exists. All other priority classes are assigned to the first available channel in their order of arrival. For each channel individually and for the overall system, the data collection programs provide the following:

Channel Number:	The designating number of each full channel. The last row is the overall system.
Percent Used:	The percent of the total messages that used a particular channel.
Usage Factor:	The percent of the total channel (system) capacity that the queueing discipline tried to use. A value greater than 100.0 indicates an overload of the channel (system).
Percent Busy:	The percent of the time the channel (system) was busy out of the total number of times it was used.
Average Wait:	The maximum wait in seconds for the channel (system) when a wait was required.
Maximum Wait:	The maximum times in seconds any message had to wait for service in the channel.

In addition, the programs compile the average message length, the average polling delay, and the average channel delay for the particular day being simulated. These numbers are available for comparison with the nominal values from Figures D-1 and D-2 and for use in computing corrected waiting times as utilization factors for comparison with the classical results.

D.3 Simulation Results

Figures D-3 and D-4 present the results of two simulated days for the voice and digital portions of the message traffic as described by the message statistics of Figures D-1 and D-2. Day A and Day B are both typical of the results obtained when operating the system over numerous simulated days of operation. The message traffic for Day A was 308 voice messages and 2432 data messages. For Day B, there were 306 voice messages and 2329 data messages during the one hour of observed operation.

D.3.1 Comparison with Classical Queueing Theory

Because all time delays are included in the simulation, it is necessary to adjust the usage factor and the average wait outputs shown in Figures D-3 and D-4 for comparison with the classical results. The first adjustment in the utilization factor is to account for channel delays due to preamble messages and propagation times in the physical channels. This adjustment is based on load factors given in Figure D-5 and is as follows:

$$\text{ADJUSTED Utilization} = \text{UTILIZATION X } \left(\frac{\text{MESSAGE LOAD + DELAY LOAD}}{\text{MESSAGE LOAD}}\right)$$

The load factors of Figure D-5 are the computed number of channels required for the peak-load one-hour period for message and channel delays. The adjustment is required since the utilization factor in the computer results only takes into account the actual message length transmitted by the system. However, the channel delay is a time that is lost in the transmission and in the classical approach, must be added to the message duration. In the voice case, this is

FIGURE D-3. DIGITAL MESSAGE TRAFFIC SIMULATION RUN RESULTS

DAY A

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	34.41	15.57	78.45	29.6	85.7
2	33.47	15.15	79.85	29.5	88.5
3	31.62	14.51	82.05	30.4	97.0
		15.08	80.06	29.8	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	29.85	13.63	33.33	25.6	70.8
2	27.30	11.96	33.89	24.8	71.0
3	23.68	10.84	39.41	25.6	70.8
4	19.16	8.80	79.70	24.2	70.1
		11.31	36.14	25.1	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	28.41	12.53	9.99	24.2	64.9
2	25.00	11.08	12.17	24.6	69.6
3	20.48	9.44	15.46	25.8	69.4
4	15.46	7.08	16.22	24.2	70.5
5	10.65	4.80	15.44	25.0	66.9
		9.05	13.20	24.7	

DAY B

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	34.80	15.16	71.62	29.6	81.7
2	33.56	14.43	76.76	27.7	81.3
3	31.64	13.67	74.46	28.2	81.9
		14.42	73.24	28.5	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	30.35	13.27	30.56	25.5	73.1
2	27.53	11.57	31.68	24.6	71.1
3	23.69	10.25	33.21	25.2	71.3
4	18.43	8.17	35.27	24.3	73.8
		10.81	32.36	25.0	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	28.82	12.61	10.68	25.1	70.9
2	25.48	10.83	12.92	23.6	62.7
3	20.69	8.91	13.43	24.7	71.9
4	15.13	6.62	15.25	24.1	71.5
5	9.88	4.28	16.88	26.1	67.3
		8.65	13.13	24.6	

FIGURE D-4. VOICE MESSAGE TRAFFIC SIMULATION RUN RESULTS

DAY A

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	32.51	88.56	45.71	7.9	60.7
2	32.82	83.52	55.66	9.5	54.2
3	34.67	79.33	66.96	14.5	63.6
		83.80	56.35	9.3	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	31.27	85.94	34.65	7.1	47.7
2	28.79	62.49	29.03	7.2	45.1
3	19.20	55.98	25.81	6.8	57.6
4	20.74	46.99	32.34	7.7	52.2
		62.85	30.96	7.2	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	31.27	71.78	15.84	5.6	40.3
2	17.96	56.34	6.90	4.9	12.3
3	21.98	48.41	18.31	6.2	24.6
4	17.34	40.43	21.43	5.0	27.7
5	11.46	24.45	40.54	10.1	42.0
		50.28	18.58	6.0	

DAY B

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	27.60	85.42	40.00	6.5	34.6
2	37.99	80.98	53.85	7.6	43.8
3	34.42	73.47	55.66	7.3	45.5
		79.96	50.65	7.2	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	22.73	78.51	12.86	6.2	35.2
2	31.32	68.58	24.49	5.2	29.9
3	26.30	53.68	32.10	5.8	32.7
4	19.16	39.11	23.73	4.9	34.3
		59.97	23.70	5.5	

CHANNEL NUMBER	PERCENT USED	USAGE FACTOR	PERCENT BUSY	AVERAGE WAIT	MAXIMUM WAIT
1	22.08	75.45	7.35	5.2	2.0
2	29.22	62.71	8.89	5.2	3.3
3	21.10	45.62	9.23	5.4	28.9
4	16.88	33.74	7.69	3.5	6.5
5	10.71	22.35	18.18	4.5	20.5
		47.98	9.42	4.8	

	VOICE			DATA		
	DAY A	DAY B	NOMINAL	DAY A	DAY B	NOMINAL
MESSAGE DURATION	28.0	28.0	25.6	0.67	0.67	0.67
POLLING DELAY	3.79	3.31	3.70	21.3	21.2	21.5
CHANNEL DELAY	1.32	1.24	1.34	3.27	3.28	3.28
MESSAGE LOAD	2.51	2.40	2.45	0.45	0.43	0.47
DELAY LOAD	0.12	0.11	0.13	2.21	2.13	2.31

FIGURE D-5. UTILIZATION FACTORS

a rather minor change since the actual message lengths are long compared to the delays, but in the digital cases the delays are on the order of the message lengths.

The second adjustment is to account for the polling delay in the access scheme which also is not accounted for in the classical approach. This adjustment involves subtracting the average polling delay from the average waiting time to obtain the corrected average waiting time value.

$$\text{ADJUSTED AVERAGE WAIT} = \text{AVERAGE WAIT} - \text{POLLING DELAY}$$

Some sample calculations will be demonstrated and the related comparisons made with the classical results.

Example 1:

Day B, Digital Messages, Four Channels

From Figure D-3

Usage Factor	=	10.81
Average Wait	=	25.0

From Figure D-5

Message Load	=	0.43
Delay Load	=	2.13
Polling Delay	=	21.2

Yielding

$$\text{Utilization} = 10.81 \left(\frac{0.43 + 2.13}{0.43}\right) = 64.4$$

$$\text{Average Wait} = 25.0 - 21.2 = 3.8$$

These values may now be checked against the results predicted by the classical approach by reference to Figures C-1 and C-2. Using Figure C-2, for $N = 4$, $\rho = 64.4$, the value for average wait is found to be 2.5 seconds. Using Figure C-1 for the same values of N and ρ, the value of the busy probability is .34. These values compare very closely with the corresponding values of 3.8 seconds and .32 obtained from the simulation run for Day B with a four channel system.

Using the adjustment techniques described, comparisons may be made between the simulated system and a modified classical system. The modification is such that the average message length in the classical system is taken to be the actual average message length plus the average channel delay, and the average waiting time in the classical case is the actual average waiting time minus the polling delay. These modifications are not perfectly legitimate in an analytic sense, but the results of the simulation runs to date has indicated that the variations are of a relatively small magnitude compared to the day to day variations experienced in the simulation. That is, the typical variation from Day A to Day B is at least as significant as the difference between Day B and the modified classical prediction.

APPENDIX E

CARRIER ACQUISITION

E.1 Phase Lock Loop Acquisition Characteristics

For both FDMA and TDMA access control systems, modulation techniques are proposed which require the coherent detection of received signals. A phase locked loop is commonly used to provide carrier synchronization at the coherent detector. The time required by the phase lock loop to acquire the received signal in frequency and phase will be the determining factor in the allocation of time for synchronization versus communication. The phase locked loop must be configured for rapid carrier acquisition over a given doppler frequency error. At the same time, the performance of the phase lock loop as a coherent demodulator must not seriously degrade the error rate performance of the respective data channel.

For the transmission of digital data in either a PSK or DCPSK format, the phase locked loop must be configured as a Costas Loop to provide tracking of the suppressed carrier signal. After data demodulation, an efficient means of acquiring bit synchronization must be implemented to provide a synchronous data clock for the matched filter data detector. Here, again, a phase locked loop is commonly used to provide a rapid means of obtaining bit synchronization. Various phase locked loop configurations are presented which will meet the acquisition requirements of an AEROSAT System in either FDMA or TDMA configuration.

E.1.1 Second Order Phase Locked Loop (PLL)

The transient characteristics of a second order PLL have been well documented in various technical books and articles by Viterbi[15], Gardner[16], and Lindsey[17], to name a few. The acquisition behavior of a PLL may be sub-divided into two areas: phase acquisition (lock-on) and frequency acquisition (Pull-in). For frequency errors within the PLL noise bandwidth, the loop only has to provide phase acquisition of the received carrier. The time required to lock-on in phase to the carrier is given by:

$$T \text{ (lock-on)} = 1/\omega_n \tag{1}$$

where ω_n is the loop natural frequency.

For frequency errors outside the PLL noise bandwidth, the loop must first acquire the received signal in frequency prior to phase acquisition. The pull-in characteristics of the second order PLL have been analyzed by Viterbi[15]. The frequency pull-in range is given in equation (2) and the respective pull-in time is given in equation (3).

$$\Delta\omega_p \approx \sqrt{2}\ (2 \cdot \delta \cdot \omega_n \cdot K_v - \omega_n^2)^{\frac{1}{2}} \tag{2}$$

where ω_p = pull-in frequency (rad/sec)
δ = loop damping factor
ω_n = loop natural frequency
K_v = loop D.C. gain

and

$$T_p \approx \frac{(\Delta\omega_p)^2}{2\delta\omega_n^3} \tag{3}$$

From the above equations, it is clear that for large frequency errors, $\Delta\omega_p$, with respect to the loop natural frequency, ω_n, that the PLL pull-in phenomena is a time consuming method for acquisition. An alternative method of acquisition is to sweep the VCO over the expected frequency range of the received carrier and allow the PLL to lock up as the loop is swept into the received carrier frequency. The maximum sweep rate for a second order PLL is given by:

$$\dot{\omega} = \omega_n^2, \quad \text{where } \dot{\omega} = \text{sweep rate (radians/sec}^2) \tag{4}$$

It has been shown by Viterbi, that even for sweep rates less than ω_n^2, the probability of acquisition is not absolutely certain if the sweep rate is greater than $\omega_n^2/2$. For a given second order PLL, with known damping factor and loop natural frequency, the maximum sweep rate may be plotted in terms of respective loop noise bandwidth, where

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$$T\ (\text{lock-on}) = 1/\omega_n \qquad (1)$$

where ω_n is the loop natural frequency.

For frequency errors outside the PLL noise bandwidth, the loop must first acquire the received signal in frequency prior to phase acquisition. The pull-in characteristics of the second order PLL have been analyzed by Viterbi[15]. The frequency pull-in range is given in equation (2) and the respective pull-in time is given in equation (3).

$$\Delta\omega_p \approx \sqrt{2}\ (2\cdot\delta\cdot\omega_n\cdot K_v - \omega_n^{2})^{\frac{1}{2}} \qquad (2)$$

where ω_p = pull-in frequency (rad/sec)
δ = loop damping factor
ω_n = loop natural frequency
K_v = loop D.C. gain

and

$$T_p \approx \frac{(\Delta\omega_p)^2}{2\delta\omega_n^{3}} \qquad (3)$$

From the above equations, it is clear that for large frequency errors, $\Delta\omega_p$, with respect to the loop natural frequency, ω_n, that the PLL pull-in phenomena is a time consuming method for acquisition. An alternative method of acquisition is to sweep the VCO over the expected frequency range of the received carrier and allow the PLL to lock up as the loop is swept into the received carrier frequency. The maximum sweep rate for a second order PLL is given by:

$$\dot{\omega} = \omega_n^{2}, \quad \text{where } \dot{\omega} = \text{sweep rate (radians/sec}^2) \qquad (4)$$

It has been shown by Viterbi, that even for sweep rates less than ω_n^2, the probability of acquisition is not absolutely certain if the sweep rate is greater than $\omega_n^2/2$. For a given second order PLL, with known damping factor and loop natural frequency, the maximum sweep rate may be plotted in terms of respective loop noise bandwidth, where

$$B \text{ (Noise Bandwidth)} = \frac{\omega_n}{2} \left(\delta + \frac{1}{4}\,\delta\right) \tag{5}$$

In Figure E-1, the sweep rate is set equal to $\omega_n^{\ 2}/2$ and plotted against the loop noise bandwidth for various damping factor. Figure E-1 is a general diagram which shows the swept frequency acquisition characteristics of a second order phase locked loop.

E.1.2 Costas Loop

For carrier signals, where digital data is PSK modulated onto the carrier, an ordinary PLL is not adequate for tracking the suppressed carrier signal. A Costas loop is commonly used for the coherent detection of the PSK signal. The acquisition characteristics of a Costas loop, however, are not equivalent to the performance of a PLL. In a Costas loop quadrature coherent detectors are used to demodulate the respective in-phase, I_o, and quadrature components Q_o, of the received PSK signal. The output of each coherent detector is given by

$$\begin{aligned} I_o &= A \cos \phi \\ Q_o &= A \sin \phi \end{aligned} \tag{6}$$

where $A = \pm 1$ for the respective data modulation.

The respective outputs, I_o and Q_o, are multiplied together to generate a phase error signal, which is fed through the loop filter to the VCO. Since,

$$I_o \times Q_o = A^2 \cos\phi \ \sin\phi = \tfrac{1}{2} \sin 2\phi \tag{7}$$

the Costas loop will have two stable lock-on points at $\phi = 0$ and $\phi = \pi$. The ambiguity in the lock on points for the Costas loop will result in a polarity ambiguity of the demodulated data. This polarity ambiguity is resolved by differentially encoding the data prior to PSK modulation. The differentially encoded data may then be decoded at the demodulator regardless of polarity from the Costas loop.

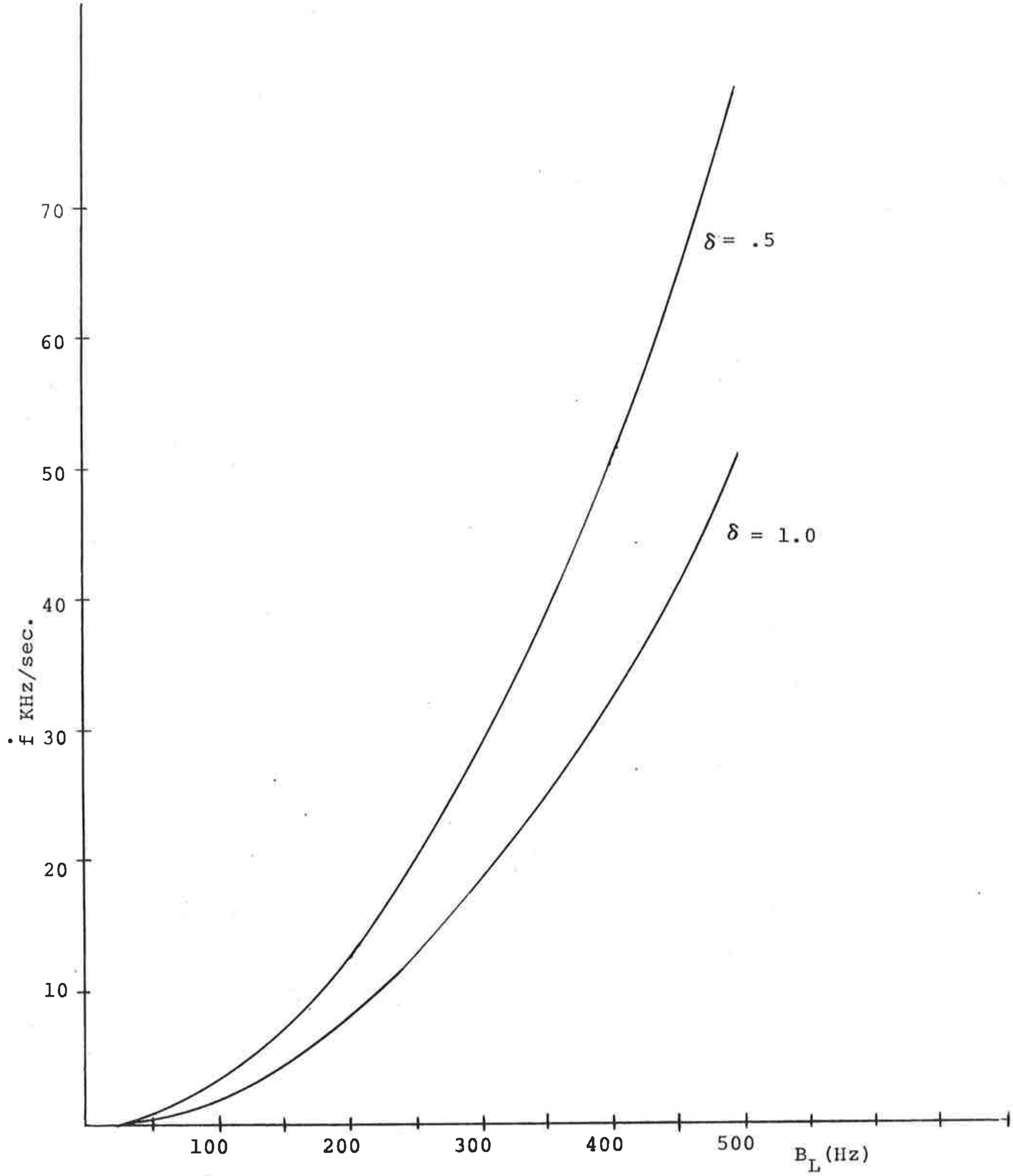


FIGURE E-1. SWEEP RATE VS. PLL NOISE B.W.

Because the Costas loop is in essence tracking the second harmonic of the carrier, the lock-on and pull-in characteristics are limited with respect to an ordinary PLL. The phase error signal of a Costas loop, equation (7), is decreased by a factor of one-half. This decrease in phase detector gain corresponds to a proportional decrease in the loop bandwidth of the Costas loop. The net result is that the Costas loop requires longer acquisition times with respect to the PLL. For the AEROSAT system, where rapid acquisition times are required in addition to the demodulation of the DCPSK data carrier, a hybrid loop can be designed to accommodate both problems. A block diagram of the hybrid loop is shown in Figure E-2. The hybrid loop consists of a PLL, which is designed for the rapid acquisition of a C.W. Preamble carrier. The preamble is then followed by a DCPSK modulated signal. The PLL is designed to rapidly acquire the preamble through the swept search technique or some other acquisition aid. Upon acquisition detection of the received carrier, the Hybrid loop is switched to the Costas loop configuration. The loop has now acquired the carrier and is prepared to demodulate the DCPSK data signal which will follow the preamble.

The remainder of this appendix will expand on the acquisition characteristics of a PLL as it applies to the AEROSAT System. Improved acquisition techniques will be presented and an analysis of the performance of the PLL as a demodulator will be presented.

E.2 Demodulator Error Performance versus Loop Noise Bandwidth

Once a phase locked loop has been designed to rapidly acquire the received carrier, then that PLL must operate as an efficient coherent detector of the modulated carrier. Any phase noise on the coherent reference will contribute to a deterioration in the received bit error rate. To minimize phase noise at the coherent VCO reference, it is necessary to maintain a loop signal-to-noise ratio, $(SNR)_L$, which is high with respect to received energy per bit-to-noise spectral density E_b/N_o. For an ordinary PLL, the $(SNR)_L$ is given by

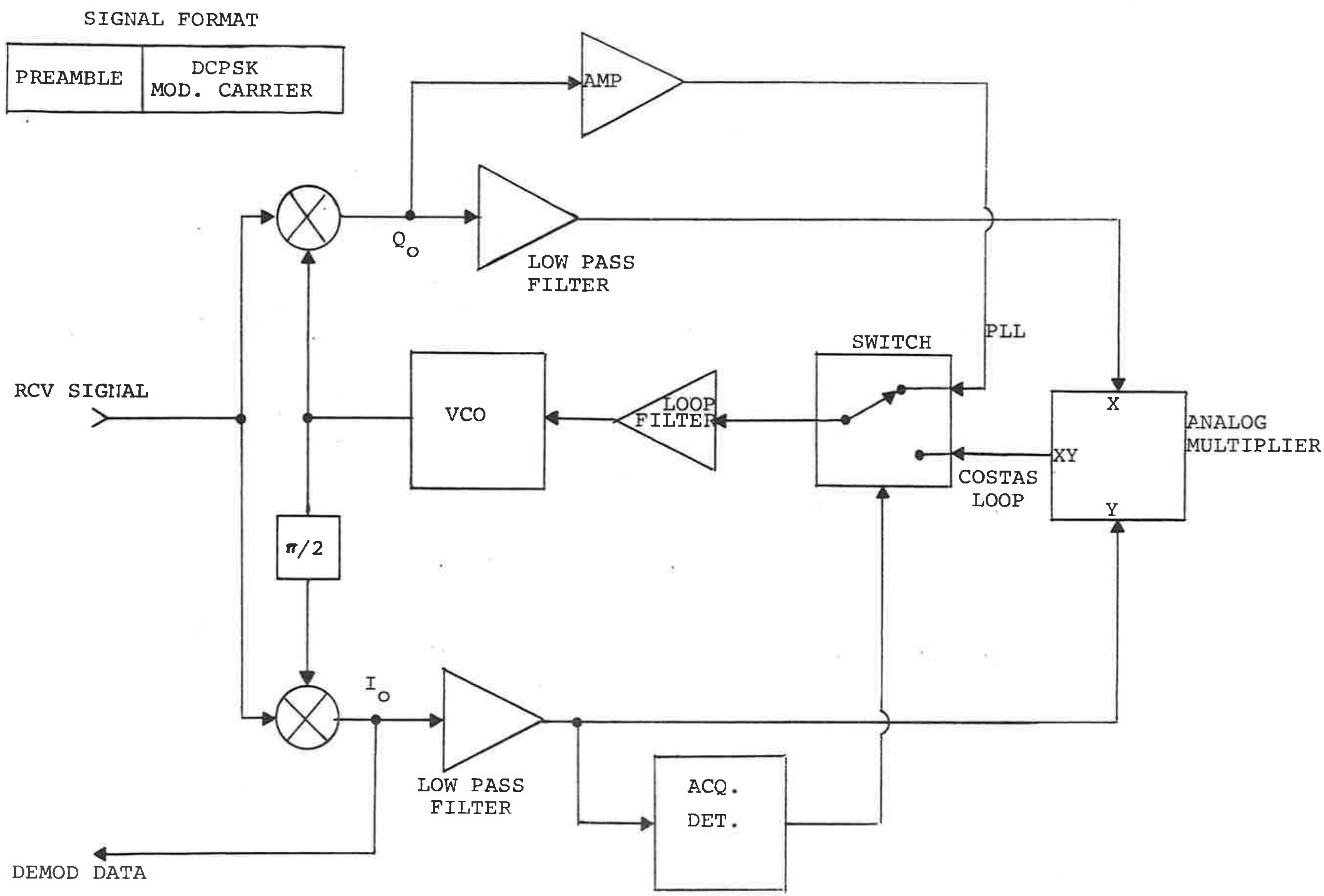


FIGURE E-2. HYBRID LOOP BLOCK DIAGRAM

$$(SNR)_L = \frac{C/N_o}{B_L} = \frac{(E_b/N_o)}{B_L} \times B_r \quad (8)$$

where B_R = data bit rate

B_L = PLL noise bandwidth

C/N_o = carrier-to-noise spectral density

For a Costas Loop, the respective $(SNR)_L$ deteriorates because of the squaring loss at the multiplier in the feedback path of the loop. The in-phase, I_o, and the quadrature, Q_o, components of the detected DCPSK signal must be pre-filtered prior to multiplication of the two terms. The $(SNR)_L$ of a Costas loop[15] is given by

$$(SNR)_L = \frac{E_b/N_o}{B_L} \times B_R \left[\frac{1}{1 + \frac{1}{2(E_b/N_o)} \times \frac{W}{B_R}} \right] \quad (9)$$

where W = bandwidth of I_o and Q_o filters.

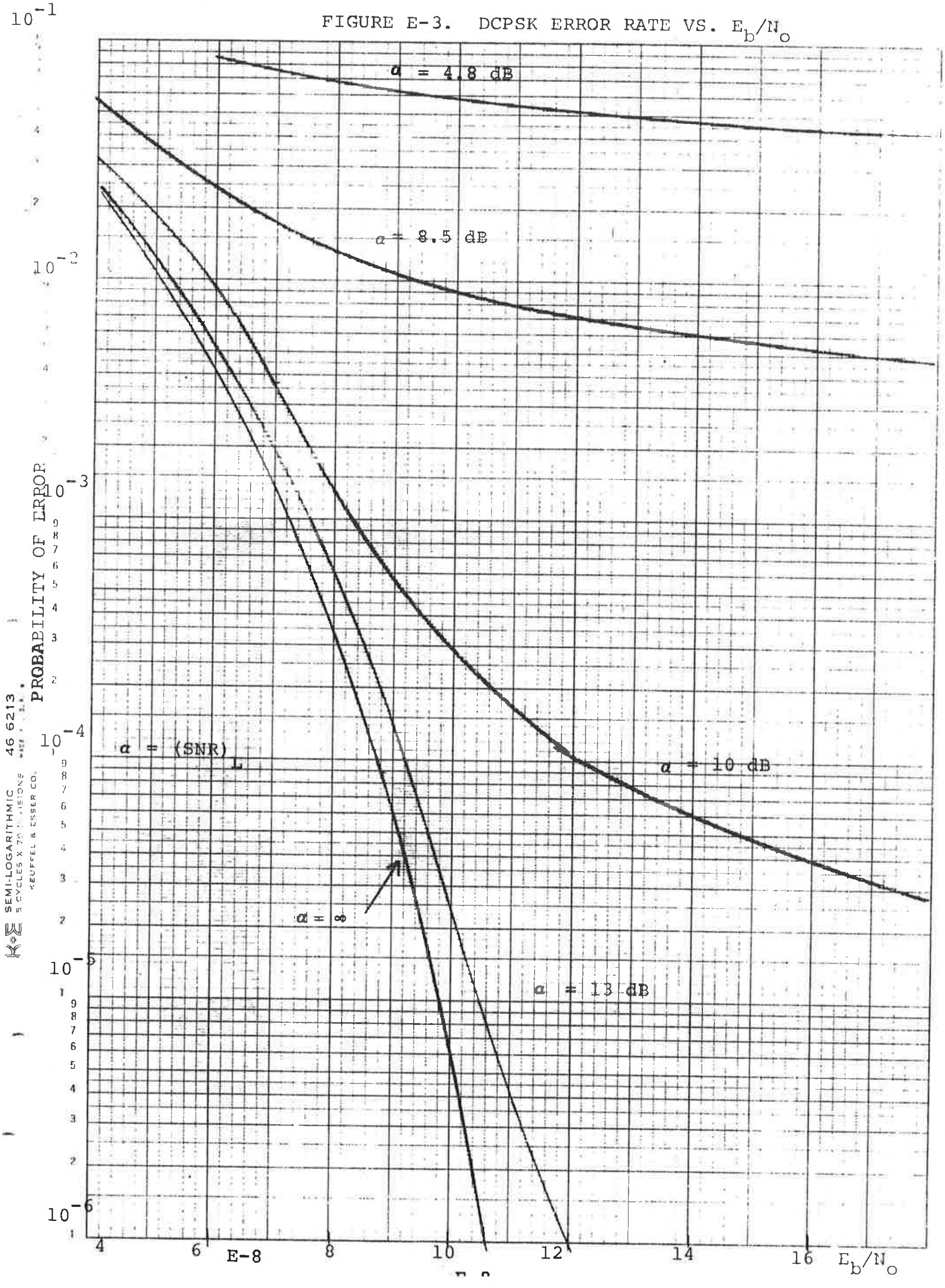
For a Costas Loop where W is set equal to the bit rate, B_R, of the system, the $(SNR)_L$ deteriorates little at high E_b/N_o ratios. In both equations (8) and (9), it is seen that in order to maintain a high $(SNR)_L$ with respect to the received E_b/N_o, that it is necessary to keep B_L small in comparison to B_R.

Once the $(SNR)_L$ of the Costas loop has been determined for a given set of operating conditions, it is important to know what effect the phase variance of the VCO has on the received bit error rate. A plot of the DCPSK error rate versus E_b/N_o is shown in Figure E-3 for various $(SNR)_L$[18].

E.3 Acquisition Techniques

From the previous analysis a minimum PLL signal-to-noise ratio is required to guarantee a certain error rate performance at the received signal E_b/N_o. The loop bandwidth required for this performance is not always consistent with the acquisition requirements for the PLL. There are various acquisition techniques which are available for decreasing the acquisition time. One class of

FIGURE E-3. DCPSK ERROR RATE VS. E_b/N_o



acquisition techniques[19], automatically changes the loop D.C. gain or loop filter components during the acquisition period. The selection of components being switched provides for a wide loop bandwidth during acquisition and a narrow bandwidth during tracking. Another class of acquisition techniques operate on the basis of a swept receiver design[20], where the receiver is swept over the range of the expected received signal frequency. As the signal is swept to within the bandwidth of the receiver or PLL, a narrow-band filter and square law detector is used to detect the received signal and stop the sweep signal. The PLL can now lock-on to the received carrier. An approach mentioned previously in Paragraph E.1.1, was where the VCO of the PLL is swept over the expected frequency range of the received signal. As the VCO sweeps to within the lock-in range of the PLL, the loop will acquire lock. This method was limited by the fact that for a second-order loop, the maximum sweep rate is $W_N^2/2$ (100% lock-on probability). All of these approaches require the detection of phase lock, either for the switching of loop components or for the removal of the external sweep signal. Even for the case of second-order PLL with a swept VCO, it is advisable to remove the sweep signal after lock-on, to reduce the phase error in the loop. For a second order PLL with a sweep rate of $\dot{\omega}$, the phase error is given by

$$\phi_e = \frac{\dot{\omega}t}{K_v} + \frac{\dot{\omega}}{\omega_N^2} \tag{10}$$

E.3.1 Third Order Phase Lock Loop

The third order PLL offers an alternative to previously mentioned acquisition techniques. Because of the potential instability of a third order loop and because the overall characteristics of the loop are not clearly understood, there had been little application of the third order loop in receiver designs. Recently, several articles have been written on the tracking and acquisition characteristics[21], and the transient response[22] of the third order PLL.

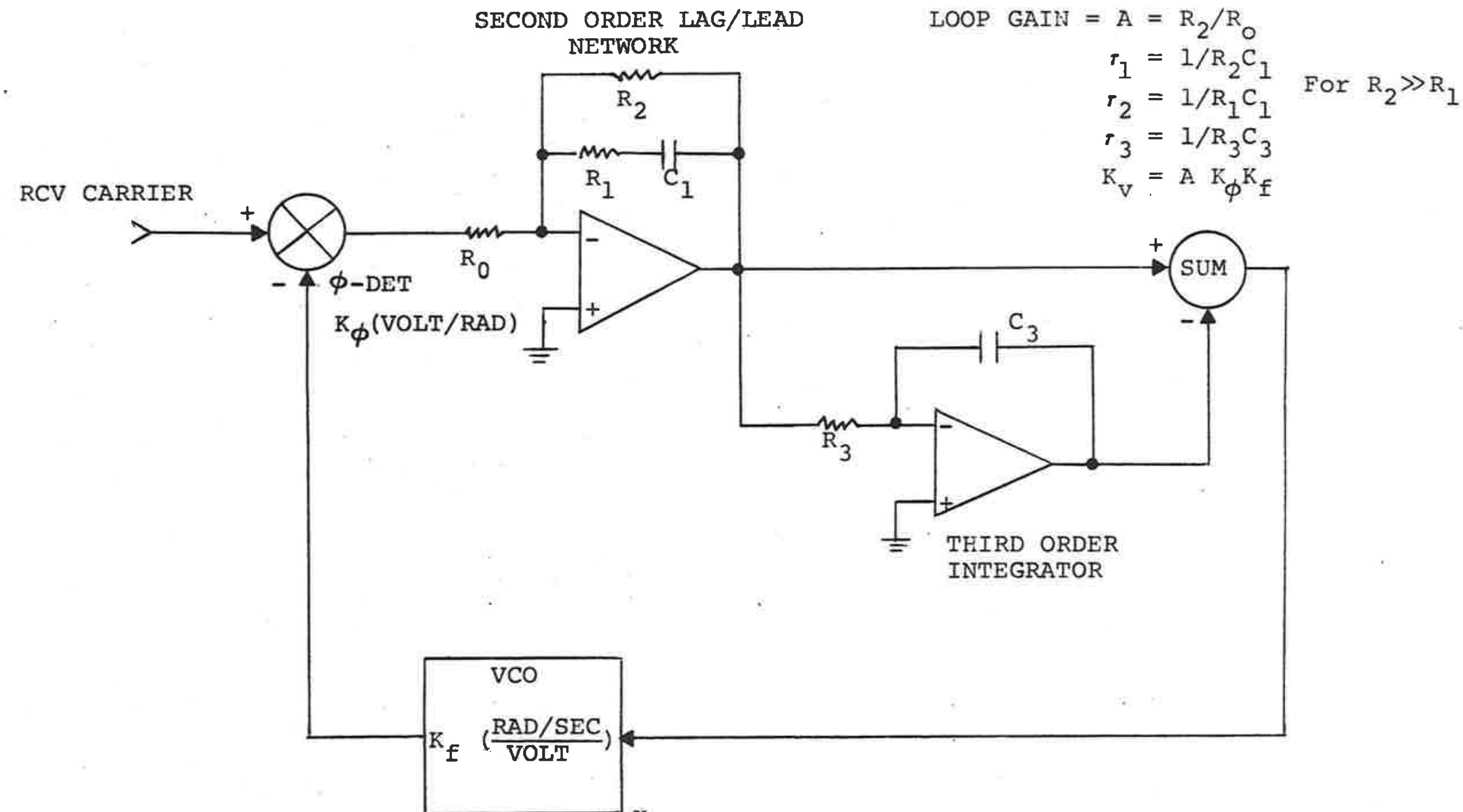
A block diagram of a typical third order PLL is shown in Figure E-4. The loop is similar to a second order loop, but an integrator network is added in parallel with the second order lag-lead network. It has been shown that the acquisition range[21] of third order loop is increased by the square root of the integrator's D.C. gain over the pull-in range of a second order loop. While the acquisition time of third order loop is considerably less than a second order loop, the pull-in time from large frequency offsets is still large when compared with $1/B_L$. The swept acquisition characteristics of a third order loop were studied to determine the maximum sweep rate at which a third order PLL would acquire phase lock with 100% probability. A third order loop similar to the one shown in Figure E-4 was constructed in the laboratory. A fixed reference signal was applied to the phase detector, and the VCO was swept by applying a fixed D.C. voltage through a resistor to the summing port of the integrator network. Once phase lock of the swept VCO is acquired, it is not necessary to remove the sweep signal at the VCO. For the loop filter in Figure E-4, with an imperfect second order filter, the static phase error ϕ_e is given by:

$$\phi_e = \frac{\dot{\omega}}{K_v/\tau_3} \tag{11}$$

where K_v = Loop D.C. Gain

τ_3 = Integrator time constant

With proper loop design, the static phase error can be reduced to 1° or less. The results of laboratory tests for swept acquisition of a third order loop are plotted in Figure E-5. All points plotted are for sweep speeds which resulted in a 100% probability of acquisition. A third order loop cannot be characterized in terms of δ and ω_N, as was done for a second order loop.



CLOSED LOOP TRANSFER FUNCTION $= G(S) = \frac{H(S)}{1 + H(S)} = \frac{\frac{K_v}{\tau_1 \tau_3}(1 + \tau_2 S)(1 + \tau_3 S)}{S^3 + S^2(\frac{1}{\tau_1} + K_v \frac{\tau_2}{\tau_1}) + S\frac{\tau_2 + \tau_3}{\tau_1 \tau_3} K_v + \frac{K_v}{\tau_1 \tau_3}}$

FIGURE E-4. THIRD ORDER PLL BLOCK DIAGRAM

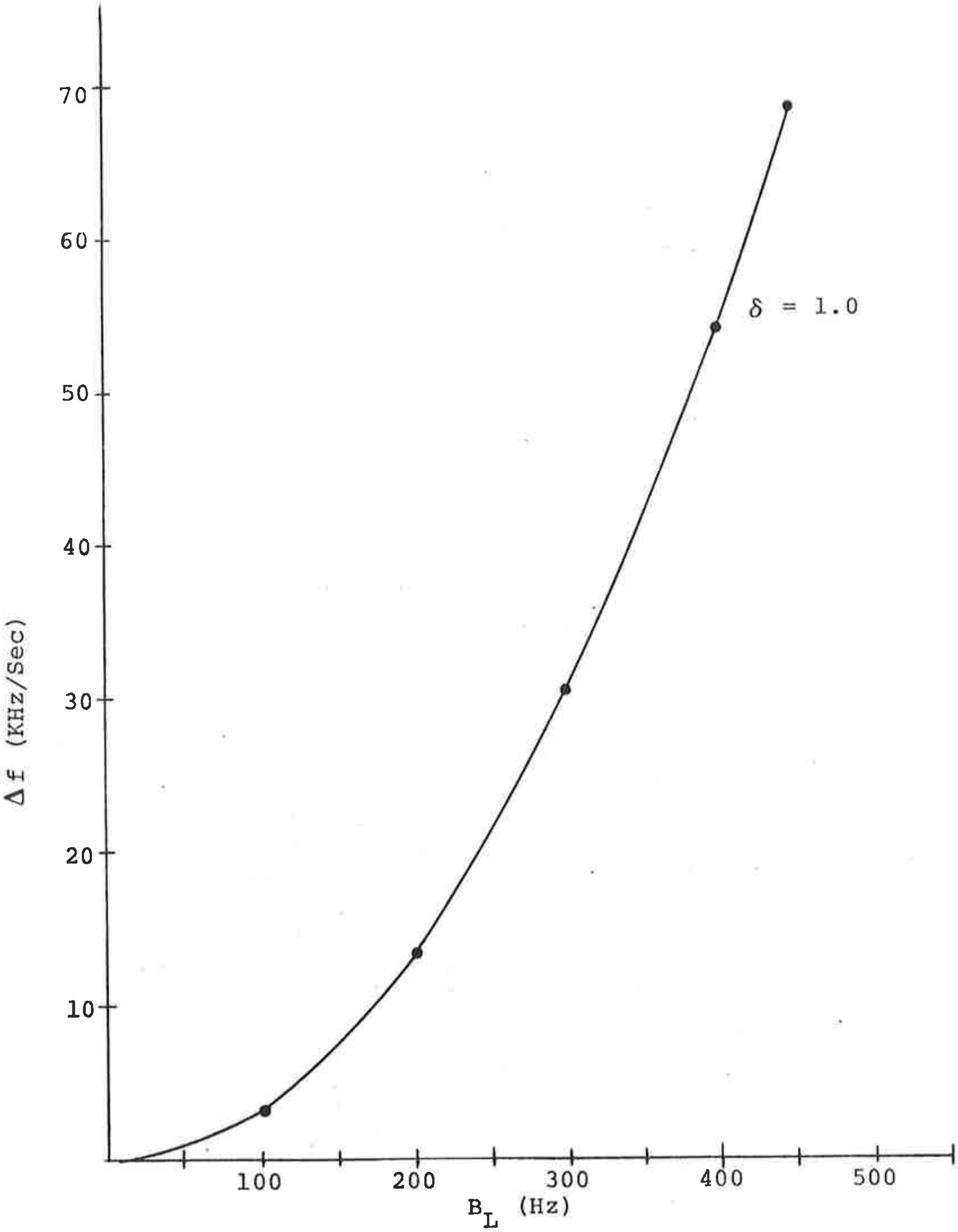


FIGURE E-5. THIRD ORDER PLL SWEPT ACQ. VS. LOOP NOISE B.W.

For the loop in Figure E-4, the expression for loop noise bandwidth may be calculated from the closed loop transfer function, given in Figure E-4. The one-sided noise bandwidth is given by

$$B_L = \frac{r}{4\tau_2} \left[\frac{r\left(\frac{\tau_2 + \tau_3}{\tau_3}\right) - k + \left(\frac{\tau_2 + \tau_3}{\tau_3}\right)^2}{r\left(\frac{\tau_2 + \tau_3}{\tau_3}\right) - k} \right] \qquad (12)$$

$$r = K_v \, \tau_2^{\,2}/\tau_1$$

$$k = \tau_2/\tau_3$$

The closed loop response of the third order loop under test was measured for each swept acquisition test. The peak response of loop was characterized with respect to the peak response of second order loop in terms of the parameter, δ. For the one curve plotted in Figure E-5, it is seen there is an increase in acquisition performance over the second order loop shown in Figure E-1.

E.3.2 Coherent AGC

Coherent AGC is often used to improve the acquisition performance of a PLL. The received carrier is coherently detected by multiplying together the quadrature component of the VCO signal and the received carrier. The detected D.C. level of the received carrier is fed back as a control voltage to the receiver's I.F. amplifier. When no signal is being received the gain of the I.F. amplifier is a maximum. At the time of signal reception, the signal level to the PLL will be a maximum and there will be a corresponding increase in loop B.W. After signal acquisition, the coherent AGC will reset the PLL to its nominal input signal level and operating noise bandwidth.

The use of coherent AGC is advantageous when using a third order PLL. A constant signal is always maintained into the loop, thus preventing the D.C. gain of the loop from dropping to a point where a Third Order loop will oscillate. Despite the use of coherent AGC, most third order loops are designed with at least 20 dB of gain margin. When using coherent AGC, it is necessary to ensure that the I.F. amplifiers, mixers or phase detectors preceding the phase locked loop do not become over-loaded with noise. Since coherent AGC operates on detected signal, the input SNR to phase locked loop could become very small without adequate I.F. filtering of the received signal.

The respective change in loop noise bandwidth when using coherent AGC can be calculated from Equation (5) and for a second order PLL,

$$B_L = \frac{K_v}{4} \times \frac{\tau_2}{\tau_1} + \frac{1}{4\tau_2} \quad \text{(second order loop)} \qquad (13)$$

where $\omega_N = \left[\frac{K_v}{\tau_1}\right]^{1/2}$

$$= \frac{\tau_2}{2}\left[\frac{K_v}{\tau_1}\right]^{1/2}$$

τ_1 = filter lag point

τ_2 = filter lead point.

From equation (12), it is also seen that the loop noise bandwidth of a third order loop is directly proportional to the D.C. gain of the loop. While the increase in bandwidth is directly proportional to an increase in signal level, the increase in ω_N is proportional to the square root of the increase in signal level. The corresponding increase in sweep rate will then increase proportional to the square root of the increase in signal level.

E.4 Airborne Carrier Acquisition (FDMA)

The data presented in the previous sections can be applied to the acquisition and error rate requirements of an airborne demodulator in the AEROSAT FDMA system. The data channel signal to the airborne receiver is a quadrature modulated signal, where DCPSK data at 1200 BPS is modulated onto in-phase portion of the carrier. The nominal signal characteristics at the airborne receiver are:

1. Total signal C/N_o = 43 dB-Hz
2. DCPSK C/N_o = 42 dB-Hz
3. Surveillance Signal C/N_o = 36 dB-Hz
4. Doppler - ±5 KHz
5. Continuous Transmission
6. 1 second allowed for rapid initial carrier and bit synchronization.

E.4.1 Carrier Acquisition

To provide for initial carrier acquisition at the airborne receiver, a preamble of pure carrier is sent to the aircraft. The pure carrier preamble is followed by a set of bit synchronization characters. The carrier acquisition and bit synchronization time is set to one second. From Figure E-5, a third order loop with a noise bandwidth of 200 Hz can be swept at a rate of 13.5 KHz/sec. Assume a third order hybrid loop (PLL/Costas) is used to acquire then track the carrier, and that the fixed B.W. of the loop is 200 Hz. The sweep period for carrier acquisition would be 750 msec over a frequency range of -5 KHz to +5 KHz. After acquisition, the hybrid loop would become a Costas loop for demodulation of the data. The $(SNR)_L$ of the Costas loop may be calculated from equation (9), for the following conditions

C/N_o (DCPSK) = 42 dB-Hz
E_b/N_o = 11.2 dB-Hz
B_L = 200 Hz
B_r = 1200 Hz
W = 1200 Hz

The Costas loop $(SNR)_L$ is equal to 18.8 dB and the resulting degradation in error rate performance is negligible as seen from Figure E-3.

E.4.2 Bit Synchronization

A remainder of 250 msec is provided at the airborne receiver for bit synchronization. Since the bit rate of the data signal is well known, the problem of bit synchronization is one of phase lock-on rather than frequency pull-in. If a phase locked loop is used for bit synchronization, the performance of the particular phase locked loop is restricted by acquisition time versus loop noise bandwidth (error rate degradation).

Any bit synchronization phase lock loop is restricted to tracking the transitions of digital data stream. While there are several schemes for tracking data transitions in digital communication systems, the tracking loop shown in Figure E-6 will be presented for the purpose of analysis. A detailed analysis of the type of bit sync loop shown in Figure E-6 has been done by Lindsey and Tausworthe[23] and Simon[24]. The operation of the bit sync loop in Figure E-6 is similar in form to the operation of a Costas Loop. The demodulated data is fed to two I&D filters. At I&D filter #1, the data bit is integrated over the full length of the bit. At I&D filter #2, the data bit is inverted half-way through the bit prior to integration. If the received data is in-phase with the clock, the output of I&D #2 will return to zero at the end of the bit period. If the VCO clock leads or lags the demodulated data, the output of I&D filter #2 will be positive or negative, respectively. The detected levels of filters #1 and #2 are multiplied together at an exclusive or network, and the +1 or -1 volt correction signal is fed through the loop filter to the VCO. Because a discrete level decision is made at each bit transition with respect to the phase of the VCO clock, it is very easy to implement a digital filter for controlling the phase of the reference clock. The combinations of digital and analog tracking loops which may be used with the basic tracking loop are numerous.

At Bell Aerospace, various bit synchronization loops have been built around the format of the loop shown in Figure E-6.

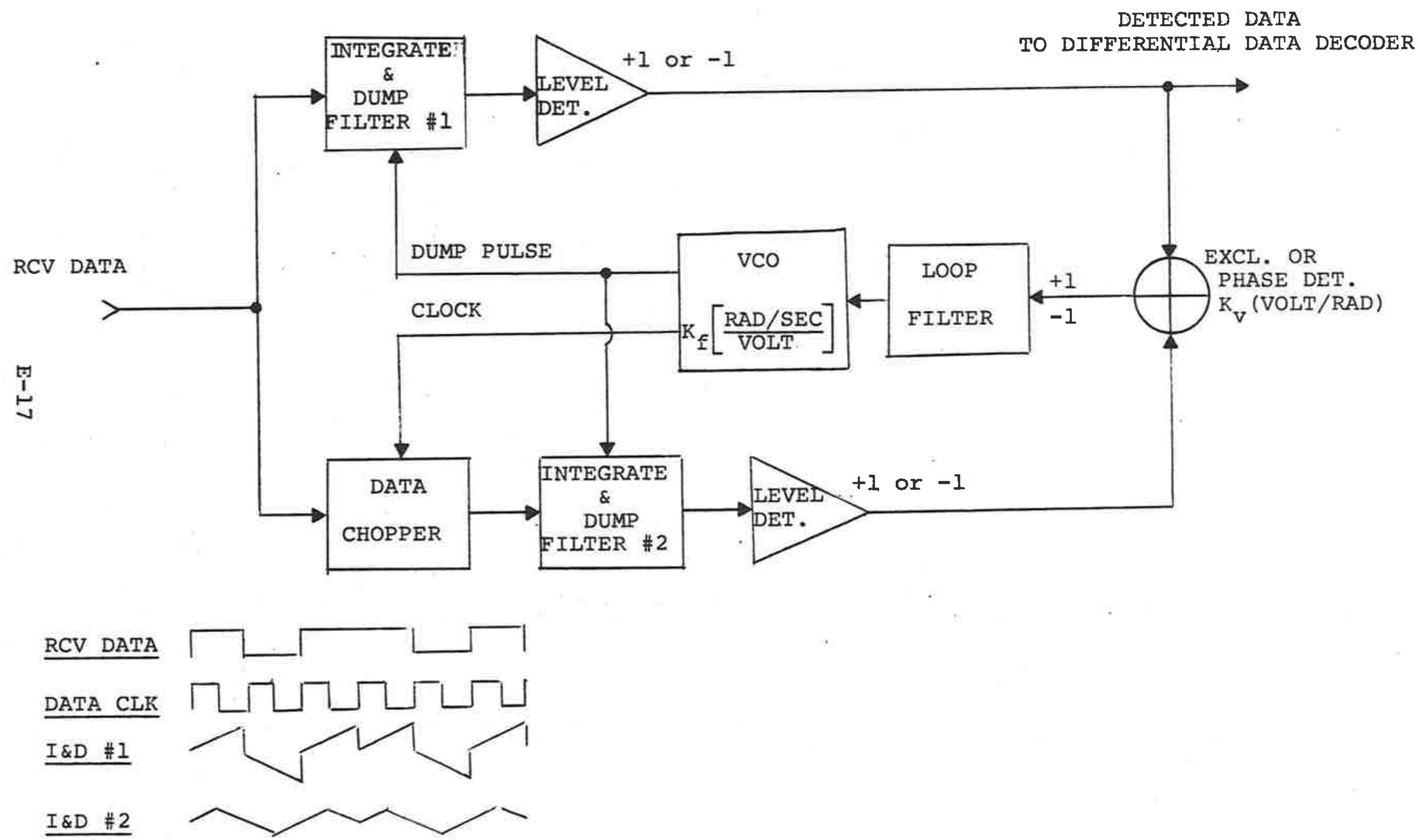


FIGURE E-6. BIT SYNC PLL

For applications where bit error rate performance was the important factor, sync loops with digital loop filters prove most effective. Laboratory measurements and computer simulations have shown that the error rate degradation due to sync error is less than 0.2 dB for sync loops with digital loop filters. The lock-in time for such loops can be on the order of several hundred bits. Combination of digital and analog loops provide good error rate performance and decreased lock-in times.

An analog bit sync loop has been built at Bell Aerospace for a 1200 BPS data communication link. The sync loop was designed with a noise bandwidth of 40 Hz. The phase variance, σ^2, of the reference signal is calculated[24] for the following set of conditions:

Bit Sync Loop Tracking Conditions

1. Bit Rate = 1200 BPS
2. C/N_o = 42 dB-Hz (E_b/N_o = 11.2 dB)
3. Loop Noise B.W. = 40 Hz

$$\sigma^2 = .004^8 \text{ (radians)}^2$$

For the calculated phase variance, the degradation in error rate is minimal (<.5 dB).

As a general rule the lock-in time of a phase locked loop is equal to $1/\omega_n$. In actuality, this is only an estimate of time to lock. Assume there is no initial frequency error at the bit sync loop, and there is an equal probable distribution of initial phase errors, over a range from -180^o to $+180^o$. The time to phase lock varies considerably for a particular initial phase error. Laboratory tests have shown that for an initial error of 180^o (conditionally stable point) the time to phase lock within $\pm 10^o$ of final lock is $5/\omega_n$. For the 40 Hz sync loop in question, the respective damping coefficient, δ, and loop natural frequency, ω_n, are 1.0 and 62.8 rad/sec. The lock in time for an initial phase error of 180^o would be 80 msec. A complete study of the probability of time to phase lock has been done by Keblawi.[25]

From the previous analysis, it is clear that at the airborne receiver that 750 msec of pure carrier preamble followed by 250 msec of bit sync characters is sufficient to provide both carrier and bit synchronization. The SNR within the carrier tracking loop and the bit sync loop is high with respect to the received E_b/N_o ratio. The degradation in error rate due to the respective loop SNR's should be small. At an expected C/N_o level of 43 dB-Hz for the data channel plus surveillance tones, there is a 1.3 dB margin between the theoretical DCPSK error curve at a C/N_o of 42 dB-Hz and the required error rate performance of 10^{-5}.

E.5 Ground Carrier Acquisition

In the AEROSAT FDMA system, the time requirements for acquisition of the data channel are more restricted than at the airborne receiver. The signal characteristics of the received signal are as follows:

Air/Ground Signal Parameters - Data Channel

1. Total Signal C/N_o = 43 dB-Hz
2. 1200 BPS Data C/N_o = 42 dB-Hz
3. Surveillance Signal C/N_o = 36 dB-Hz
4. Doppler Error = ±5 KHz

When the doppler component of the received signal is unknown, a pure carrier preamble is transmitted for 273 msec to provide time for carrier acquisition doppler measurement. The preamble is followed by 27 msec of bit synchronization characters. During the 27 msec bit sync period the measured doppler frequency error is stored in a computer for succeeding air/ground communications.

When the doppler component of the received signal is known, the stored computer number is used to tune the ground demodulator to the expected received signal frequency. A 40 msec preamble is transmitted at the beginning of each air/ground communication. The first 13 msec of the preamble is pure carrier and provides for carrier acquisition. The pure carrier is followed by 27 msec of bit sync characters. The 40 msec preamble is followed by 260 msec of air/ground communications.

E.5.1 Carrier Acquisition with Unknown Doppler

For carrier acquisition over ±5 KHz a third order PLL with a noise bandwidth of 380 Hz could be swept for a period of 250 msec and provide reliable frequency acquisition. A hybrid loop (PLL/Costas) would provide for the dual operation of rapid acquisition followed by data demodulation. Coherent AGC would be implemented to provide the wide 380 Hz acquisition bandwidth and also a narrower 150 Hz tracking bandwidth. At a signal C/N_o of 43 dB-Hz (1200 BPS data signal = 42 dB-Hz), the respective loop SNR would be about 19 dB as defined by equation (9) for a noise bandwidth of 150 Hz. The degradation in error rate would be less than 0.5 dB, as seen from Figure E-3.

E.5.2 Carrier Acquisition with Known Doppler

Once the doppler frequency error of a known aircraft has been stored in the computer, the coherent demodulator may be tuned to the expected carrier frequency on successive aircraft transmissions. Since the doppler error is known, it is assumed the initial frequency error is within the lock-in range of the PLL. A 13 msec pure carrier preamble is transmitted to allow for carrier acquisition. The initial conditions for acquisition consist of an initial phase and frequency error. In Section E.4.2, it was shown that for an initial phase error of 180^o and no frequency error, the time to lock was $5/\omega_n$. In terms of lock-in performance, this initial condition is the worst possible starting point. Under normal conditions, there is an initial frequency error which always offsets the PLL from the conditionally stable lock point. The combination of initial frequency and phase error considerably reduces the lock-on acquisition time of the PLL. While, there is a finite probability of zero initial frequency error and 180^o phase error, the probable rate of occurrence is small.

For a second and third order PLL with equal noise bandwidth, the time to acquire a carrier within the loop noise bandwidth is about equal for each type loop. In general, a maximum time of $4/\omega_n$ is required for the transient phase error to settle within $\pm 10^{\circ}$ of the final static phase error. For a second order loop with a tracking noise bandwidth of 150 Hz (δ = .707 and ω_n = 282 rad/sec), the use of coherent AGC could provide an acquisition bandwidth of 380 Hz (δ = 1.29 and ω_n = 514 rad/sec). The respective maximum acquisition time would be $4/\omega_n$ = 8 msec. The change in D.C. loop gain during acquisition would be 10 dB. The acquisition performance of a third order loop would be similar to the above described second order loop. The use of a hybrid loop (PLL/Costas) with coherent AGC would provide for adequate acquisition performance within the 13 msec pure carrier preamble period.

E.5.3 Bit Synchronization

A total of 32 bits at 1200 BPS for a period of 27 msec is allowed for bit synchronization. A bit sync loop, similar to the one described in Figure E-6 of Section E-4, may be designed with a loop noise bandwidth of 120 Hz. At a received data E_b/N_o of 11.2 dB, the phase variance of the loop VCO is .015 $(\text{radians})^2$, and the degradation in error rate performance is less than 0.5 dB. For the noise bandwidth of 120 Hz, the corresponding damping factor and natural frequency are set at 1.0 and 187 rad/sec., respectively. From Section E.4.2, it was shown that for zero initial frequency error and a 180° phase error, the phase lock on time was equal to $5/\omega_n$. For the present loop this lock on time is 27 msec which is within the alloted 27 msec bit synchronization time. Keblawi has shown that the average time to phase lock, given an equal probable distribution of phase errors, is $2.5/\omega_n$ or 13 msec. The problem in acquisition is that at phase errors close to the conditionally stable lock point, the detected error voltage is small, and the loop filter takes considerable time in developing an error correction voltage to steer the VCO. If faster bit sync time were required, one solution is to widen the loop bandwidth of sync loop at the sacrifice of decreased error rate performance. For the particular system this is not a desirable solution. Another approach is to measure by analog detection the magnitude of the phase error at the end of the integration period at I&D filter #2 in Figure E-6. For rapid acquisition, gross phase corrections can be made to the VCO reference signal during initial phase acquisition. After bit sync acquisition, the magnitude of the phase error from I&D filter #2 would always be small and not require large magnitude corrections.

The previous analysis for carrier acquisition at the ground station of an AEROSAT FDMA system shows that all acquisition times for carrier and bit synchronization can be met. In all cases external acquisition aides (sweep signals, coherent AGC) were required to meet performance specifications. In addition, the bandwidths of each demodulator or bit sync network were analyzed to verify error rate performance within the 10^{-5} specification at a received data signal C/N_o of 42 dB-Hz.

E.6 Carrier Acquisition (TDMA)

For the AEROSAT TDMA System, the receiver at the aircraft must provide for the rapid acquisition of burst transmissions from the ground. Each burst consists of a preamble for carrier and bit synchronization followed by high data rate communication signal. The received signal characteristics are given as follows:

1.	Burst length ≈ 30 msec	
2.	Minimum repetition rate	≈ 3 burst/sec
3.	Preamble length	= 3 msec
4.	Data Rate	= 1.21×10^5 bits/sec
5.	Data C/N_o	= 51 dB-Hz
6.	Initial Acquisition Doppler Error	= ±5 KHz
7.	Burst-to-burst Doppler Error	= ±500 Hz

For initial rapid acquisition a single burst of pure carrier over the 30 msec period is provided for the aircraft receiver to obtain carrier lock over a doppler frequency range of ±5 KHz. Once the aircraft receiver has obtained initial carrier lock and stored the doppler frequency error, the doppler acquisition range on subsequent bursts will be ±500 Hz. Because of the ON/OFF operation of the TDMA system, the aircraft must store and update the received doppler error at each burst reception.

E.6.1 Carrier Acquisition (Unknown Doppler)

A straight-forward approach to the carrier acquisition of a 30 msec burst of pure carrier at 51 dB-Hz with a ±5 KHz frequency error is build a wide-band loop which will rapidly pull-in to frequency lock. From equation (3), it can be calculated that a second order loop with a noise bandwidth of 1600 Hz (δ = 1.0 and ω_n = 2560 rad/sec) can acquire a carrier with ±5 KHz frequency error in 30 msec. The loop signal-to-noise ratio for such a second order PLL would be 19 dB.

A third order PLL would offer increased acquisition and tracking performance. From empirical data taken in the laboratory, a third order loop provides 30% faster pull-in time for the preceding initial conditions.

E.6.2 Carrier Acquisition (Known Doppler)

On successive bursts following initial acquisition the PLL must store the previous carrier frequency. For a second order or third order phase locked loop, the voltages stored on the loop filter during the 30 msec tracking period will decay, once the signal reception is terminated. The decay rate of the loop filter capacitors determine how long the PLL can remember the previous burst's frequency. For high gain second order loops where the D.C. gain of the loop filter is very large, the decay time constant upon removal of the received signal is given as follows:

τ_d (2nd order loop) = Filter D.C. Gain x τ_2 (14)

where τ_2 = Loop filter lead point.

For the loop previously described, with a noise bandwidth of 1600 Hz, (δ = 1.0 and ω_n = 2560), the corresponding value of τ_2 is .78 msec. To provide loop filter memory at the minimum burst rate of 3 bursts/sec., the loop filter D.C. gain must be at least 1000.

For a third order loop, memory of the loop is dependent on the D.C. gain of the third order integrator. During tracking, the voltage across the second order loop filter is essentially zero, while the voltage across the third order integrator represents the doppler frequency error. The decay of the third order integrator is again dependent on the integrator time constant and respective D.C. gain as shown below.

τ_d (third order loop) = Integrator D.C. gain x τ_3 (15)

where τ_3 = Integrator time constant.

For the third order loop previously described with a noise bandwidth of 1600 Hz, the corresponding value of τ_3 is 7.8 msec. To provide a loop filter memory at the 3 burst/sec reception rate, the integrator D.C. gain must only be 200.

On succeeding bursts the doppler frequency of the first acquisition burst has been stored in the loop filter, and the PLL must acquire only the change in doppler from one burst to the next (±500 Hz). Each successive burst consists of a 3 msec preamble followed by data communication signals. The preamble is subdivided into a 1.5 msec pure carrier portion for carrier acquisition followed by a 1.5 msec bit sync portion. For the third order loop previously described, B_L equals 1600 Hz, the received doppler error of ±500 Hz is well within the phase acquisition range of the loop.

It has been previously shown that the acquisition time of a loop with a frequency inside the loop bandwidth is a maximum of $4/\omega_n$. For the present loop conditions, the maximum time to acquire would be about 1.5 msec. To provide for data demodulation after carrier acquisition, a hybrid loop (PLL/Costas) would be implemented for the reception of successive bursts. The noise bandwidth of this hybrid loop during tracking may be calculated by equation (9). The respective loop SNR is 17 dB for a received data rate of 1.21×10^5 bits/sec., a noise bandwidth of 1600 Hz and a signal C/N_o of 51 dB-Hz. The respective $(SNR)_L$ should have no measurable degradation on the error rate which is approaching a 10^{-1}.

E.6.3 Bit Synchronization

The remaining 1.5 msec of the 3 msec preamble provides for the transmission of 180 bits for bit synchronization. The bit sync loop proposed for use would be similar to the circuit shown in Figure E-6. For a bit sync loop with a one-sided noise bandwidth of 2000 Hz, a damping factor of 1.0 and a natural frequency of 3200 rad/sec., the maximum acquisition time is $5/\omega_n$ for an initial phase error of $\pm 180^o$. The respective bit sync time is 1.5 msec. The phase variance of the clock reference under the following conditions may be determined from data presented in Reference 24.

1. Data C/N_o = 51 dB-Hz
2. Bit Rate = 1.21×10^5 bits/sec.
3. Loop Noise B.W. = 2000 Hz (one-sided).

The phase variance is .015 $(\text{radians})^2$ and the respective degradation in bit error rate performance should be negligible with respect to the anticipated error rate of 10^{-1}.

APPENDIX F

UNBALANCED MESSAGE LOADING EFFECTS

General conclusions which were drawn from Appendix C are:

1) For a normalized average waiting time ($T_w \geq 1.0$) and a large number of channels ($N \geq 6$), the penalty in maximum allowed channel utilization by splitting channels between 2 ASCC's is less than 10%.

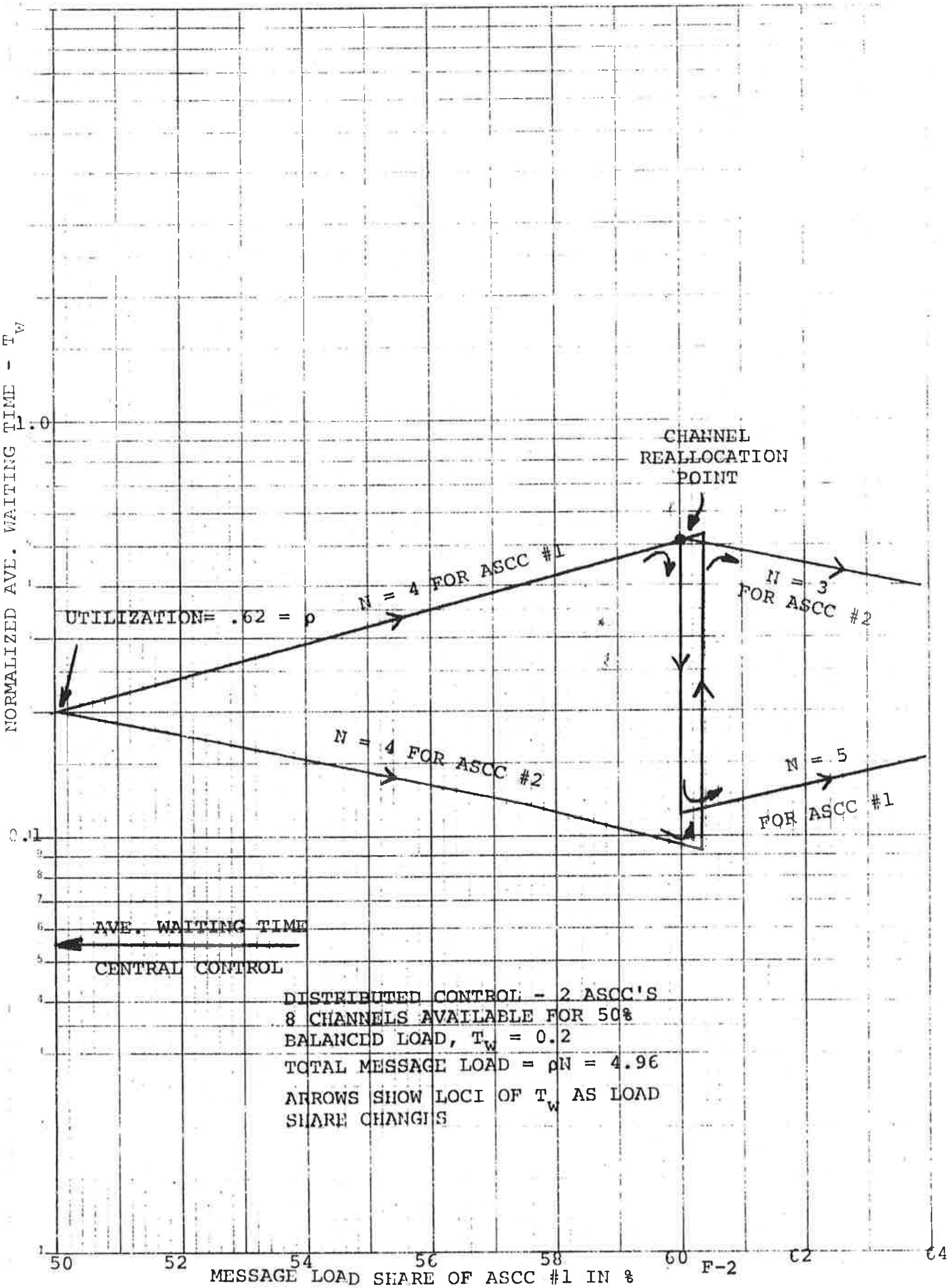
2) For smaller allowable normalized average waiting times, the penalty in utilization is greater (31% less for $T_w = 0.1$ for a 3-3 channel split).

3) The above conclusions apply only for an equal message loading between the two ASCC's, but because of the high slope of the plots of Figure C-2 at high utilizations, small changes in utilization from unbalanced loadings produce large changes in average waiting times.

The unbalance problem may be a severe one if the relatively few available channels are separately allocated among ASCC's. This is graphically illustrated in Figure F-1. The abscissa is the percentage of the total message loading on one ASCC of a pair. As the message loading increases for one ASCC, the loading decreases a corresponding amount for the other ASCC. A total of 8 voice channels are assumed available and are split 4 and 4 between the two ASCC's. As the unbalance approaches a 60-40 percentage ratio, the normalized average waiting time builds to a level of 0.5 at which point, the master ASCC would decide to reallocate the 8 channels giving 5 to the ASCC with the high loading. For loading unbalances greater than 60% - 40%, the new allocation improves the average waiting times.

Certain conclusions from Figure F-1 can be made. First, the unbalanced maximum normalized average waiting time is about 2½ times that of the balanced case. Also shown is the normalized average

FIGURE F-1


NORMALIZED AVE. WAITING TIME - T_W
1.0
0.1
CHANNEL
REALLOCATION
POINT
N = 4 FOR ASCC #1
N = 3
FOR ASCC #2
UTILIZATION= .62 = ρ
N = 4 FOR ASCC #2
N = 5
FOR ASCC #1
AVE. WAITING TIME
CENTRAL CONTROL
DISTRIBUTED CONTROL - 2 ASCC'S
8 CHANNELS AVAILABLE FOR 50%
BALANCED LOAD, T_W = 0.2
TOTAL MESSAGE LOAD = ρN = 4.96
ARROWS SHOW LOCI OF T_W AS LOAD
SHARE CHANGES
50
52
54
56
58
60
62
64
MESSAGE LOAD SHARE OF ASCC #1 IN %

waiting time if all channels were in a common pool under centralized control. This normalized value of .056 is about 1/9 the maximum average waiting time. These numbers apply to a total message load of 4.96, for a normalized waiting time of 0.2 (balanced). If a normalized waiting time of 1.0 were assumed, the new message loading corresponding to this value is 6.64--a 34% increase. Figure F-2 shows corresponding plots for the higher loading. The maximum average waiting time reaches a value of $T_w = 6.3$ before channels would be reallocated. The normalized waiting time for 8 channels under central control is .37 which is 1/17 the maximum.

Perhaps the best way to compare central and distributed control of voice channels is to determine the allowed utilization given a fixed number of channels and a specified normalized average waiting time. Figure F-3 shows plots of allowed utilization versus normalized average waiting time for the three cases:

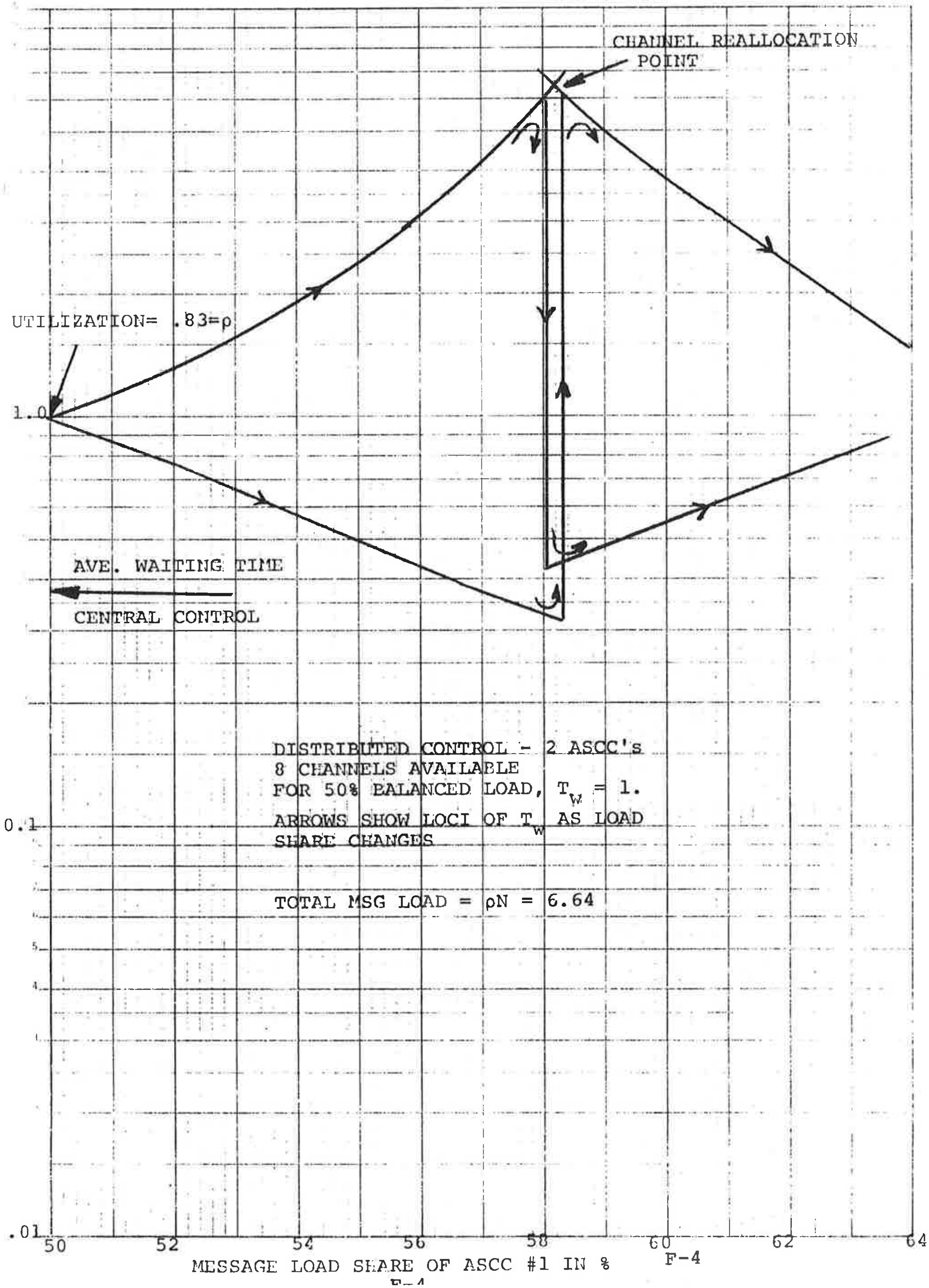
1) 8 channels under central control of one ASCC
2) 8 channels split 4 channels each to two ASCC's with balanced message loading
3) 8 channels assigned to two ASCC's with an unbalanced message loading.

From these plots one can determine the maximum channel utilization allowed if maximum average waiting times are specified. If one knows the average message length and the expected number of messages required per aircraft, one can determine the number of aircraft the system can accommodate. An example calculation follows.

Let the average voice message length be 30 sec. If the specified maximum average waiting time is 30 sec, then $T_w = 1.0$. For the unbalanced distributed control of 8 channels between two ASCC's, the allowed utilization is $\rho_m = .72$. From the equation

$$\rho N = \lambda D_{ave},$$

FIGURE F-2



CHANNEL REALLOCATION POINT
UTILIZATION= .83=ρ
1.0
AVE. WAITING TIME
CENTRAL CONTROL
DISTRIBUTED CONTROL - 2 ASCC's
8 CHANNELS AVAILABLE
FOR 50% BALANCED LOAD, T_W = 1.
ARROWS SHOW LOCI OF T_W AS LOAD SHARE CHANGES
TOTAL MSG LOAD = ρN = 6.64
0.1
.01
50
52
54
56
58
60
62
64
MESSAGE LOAD SHARE OF ASCC #1 IN %

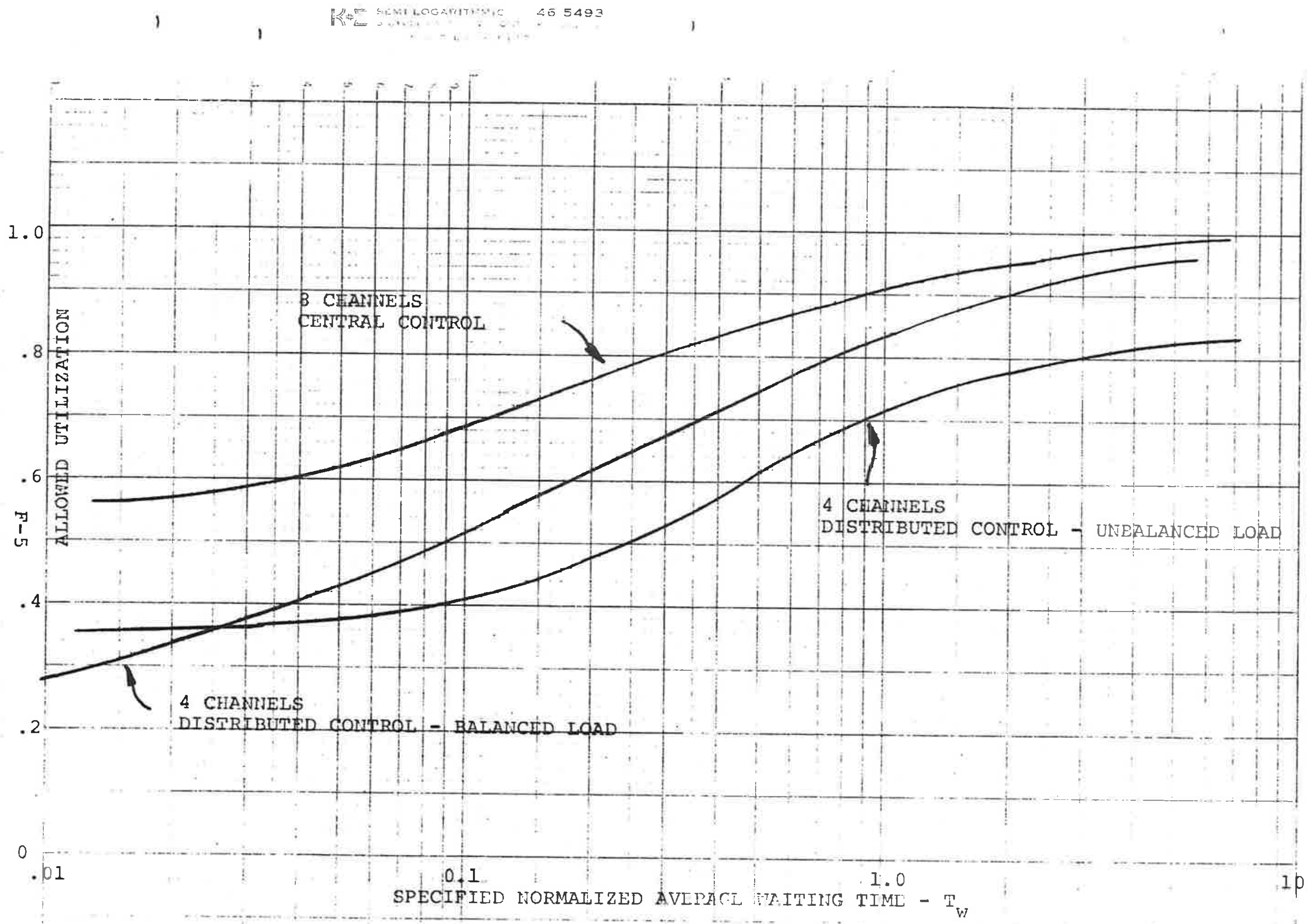

K+E SEMI-LOGARITHMIC 46 5493
1.0
.8
.6
.4
.2
0
ALLOWED UTILIZATION
8 CHANNELS
CENTRAL CONTROL
4 CHANNELS
DISTRIBUTED CONTROL - UNBALANCED LOAD
4 CHANNELS
DISTRIBUTED CONTROL - BALANCED LOAD
.01
0.1
1.0
10.
SPECIFIED NORMALIZED AVERAGE WAITING TIME - T_W

FIGURE F-3

where N = number of channels

λ = average system message rate

D_{ave} = 30 = average message length

$$\lambda_m = \frac{\rho_m N}{D_{ave}} = \frac{.72(8)}{30} = .192 \text{ messages/sec.}$$

Let β = average number of voice messages/aircraft/crossing then for a 3 hour crossing, the message rate per aircraft is

$$\lambda\text{/aircraft} = \frac{\beta}{3(3600)} \text{ messages/sec.}$$

The system message loading for NA aircraft is

$$\lambda = \frac{\beta}{10800} \text{ (NA)}$$

For $\beta = 10$, $\lambda = .192$

$$NA = \frac{10800\ (.192)}{10} = 203 \text{ aircraft.}$$

Under central control, $\rho_m = .85$, $\lambda_m = .226$

and

$$NA = 244 \text{ aircraft.}$$

There is a 20% increase in the number of aircraft the 8 channel system can handle under central control compared to distributed control. Comparisons similar to that illustrated above can be made for a fewer or greater number of channels.

REFERENCES

1. C. E. Dunmire, Satellite Communications Channel Requirements in the Atlantic, Dept. of Transportation, Washington, D. C., October 1969.

2. D. Leverington, An Appraisal of an Aeronautical Satellite System, Space and Instrumentation Group, British Aircraft Corporation, Ltd., Filton House, Bristol BS997AR, England, 1971.

3. T. K. Foley, R. W. Sutton, Experimental L-band SST Satellite Communications/Surveillance Terminal Study, for NASA by Boeing Commercial Airplane Division, Renton, Washington, November 1968.

4. E. A. Emerson, Message Loading Estimate, FAA Report No. 736-26, 21 May 1973 (Working Draft).

5. J. W. Schwartz, J. M. Aein and J. Kaiser, Modulation Techniques for Multiple Access to a Hard-Limiting Satellite Repeater, Proceedings of the IEEE, May 1966.

6. John H. Wittman, Categorization of Multiple Access/Random Access Modulation Techniques, IEEE Transactions on Communications Technology, Oct. 1967.

7. Irwin L. Lebow , Kenneth L. Jordan, Jr., and Paul R. Drouilhet Jr., "Satellite Communications to Mobile Platforms", Proceedings of the IEEE, Feb. 1971.

8. W. C. Hanneman, Special North Atlantic Meeting, Submission to ICAO of an Updated Ten Year Forecast of North Atlantic Air Traffic, Interagency Group on International Aviation, Dept. of Transportation, Washington, D. C., March 1971.

9. T. Sekimata, J. G. Puente, A Satellite Time-Division Multiple Access Experiment, IEEE Transactions on Communication Technology, August 1968.

10. O. G. Gobbard, Design of a Satellite Time-Division Multiple Access Burst Synchronizer, IEEE Transactions in Communication Technology, August 1968.

11. Project Paper No. 586, Draft No. 5, Air-Ground-Air Data Link System, Aeronautical Radio, Inc., Annapolis, Md., August 7, 1972.

12. J. A. Bandenkerchove, Major Factors Influencing the Design of an AEROSAT System for Evaluation, International Conference on Satellite Systems for Mobile Communications and Surveillance 13-15 March 1973.

13. A. E. Atia and A. E. Williams, "New Types of Waveguide Bandpass Filters for Satellite Transponders", Comsat Technical Review, Volume 1, Number 1, Fall 1971.

14. P. M. Morse, Queues, Inventories and Maintenance, Wiley, New York, 1958.

15. Viterbi, A. J., "Principles of Coherent Communications," McGraw Hill, New York, 1966.

16. Gardner, F. M., "Phaselock Techniques," John Wiley & Sons, New York, 1966.

17. Lindsey, W. C., "Synchronization Systems in Communication and Control," Prentice-Hall, New Jersey, 1972.

18. Lindsey, W. C., "The Detection of PSK Signals Using a Noisey Phase Reference," Proceedings of the National Telemetering Conference, First Edition, April 1965, pp 50-53.

19. Richman, D., "D. C. Quadricorrelator: A Two Mode Sync System," Proc. IRE, Vol. 42, pp. 288-299, January 1954.

20. Bunce, R. C., "Automatic Carrier Acquisition System," Patent Application, NASA-CASE-NPO-11628, Dec. 1971.

21. Tausworthe, R. C., "Improvements in Deep-Space Tracking by Use of Third Order Loops, " JPL Quarterly Technical Review, Volume 1, No. 2, July 1971, pp. 96-106.

22. Johnson, A. C., "Numerical Evaluation of the Transient Response for a Third Order Phase-Locked System," JPL Technical Report, Vol. IV, No. 32-1526.

23. Lindsey, W. C. and Tausworthe, R. C., "Digital Data-Transition Tracking Loops," JPL Space Programs Summary, Vol. III, No. 37-50, pp 272-276.

24. Simon, M. K., "Optimization of the Performance of a Digital-Data-Transition Tracking Loop," IEEE Transactions on Communication Technology, October 1970, pp 686-689.

25. Keblawi, F. S., "Probability Distribution of Time to Phase Lock for a Second-Order Phase-Locked Loop," RCA Review, March 1968, pp 106-121.

26. System Access Control Study, Interim Technical Report, Bell Aerospace Co., Buffalo, N.Y., Report No. 6500-933018, May 1973.

27. System Access Control Study, Interim Technical Report, Bell Aerospace Co., Buffalo, N.Y., Report No. 6500-933019, Sept. 1973.

28. PLACE Final Report, Bell Aerospace Company, Buffalo, N.Y., Report No. 6225-950002, June 1970.

29. Maritime Services Satellite System Definition Study by Automated Marine International, DOT-TSC-98, July 1971.

30. E. B. Clausen, "Bandpass Limiter First Zone Intermodualtion Product Frequencies and Magnitudes," Bell Aerospace, IR&D Interim Report No. 6500-927061, 1 June 1970.

31. P. D. Shaft, "Limiting of Several Signals and its Effect on Communication Performance", IEEE Transactions on Communication Technology, December 1965, pp. 504-512.

32. Report of Committee A on Item 1, Seventh Air Navigation Conference, Montreal, Canada, April 1972.

REPORT OF INVENTIONS

After a diligent search, it has been determined that there were no inventions or innovations under this contract.