DOT/FAA/CT-82/31

Recommendations for Automated Monitoring of Radio Equipment Associated with Flight Service Stations

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August 1982

Final Report

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DOT/FAA
CT-82/31

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

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Technical Report Documentation Page

1. Report No. DOT/FAA/CT-82/31	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle RECOMMENDATIONS FOR AUTOMATED MONITORING OF RADIO EQUIPMENT ASSOCIATED WITH FLIGHT SERVICE STATIONS		5. Report Date August 1982
		6. Performing Organization Code ACT-100
7. Author(s) Albert J. Rehmann		8. Performing Organization Report No. DOT/FAA/CT-82/31
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 144-170-900
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		13. Type of Report and Period Covered Final Report February - October 1981
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The results of a study are contained in this report. The study examined in depth, the radio equipment associated with Flight Service Stations and Back-Up Emergency Communications (BUEC) radio equipment. In part I of the study, radio parameters critical to remote maintenance monitoring (RMM) were identified as necessary for remote certification, remote maintenance, or remote control. The parameters are grouped according to function. In part II of the study, the functional characteristics of Test Functional Modules (TFM) are defined according to the parameter grouping of part I. Finally, limited recommendations for the electrical characteristics and operating specifications of each TFM are given.

17. Key Words Remote Maintenance Monitoring Flight Service Stations BUEC		18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 65	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

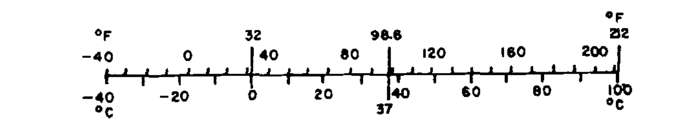
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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FOREWARD

This document contains the results of subtask 1 of a four-part remote maintenance monitoring system (RMMS) development effort, which is task 9 of 9550-AAF-501-78-002. The information contained herein was assimilated during a detailed parameter study of communications/navigation radio equipment associated with Flight Service Stations (FSS's) and Backup Emergency Communication Equipment (BUEC). The intent of this effort was to define the radio parameters required to enable remote certification and/or maintenance of the FSS and BUEC radio equipment. Throughout the text some limited hardware specifications and measurement techniques are given, but only for the clarification of certain parameters. A detailed investigation of monitor hardware and measurement techniques is reserved for subtask 2 of the four-part development effort.

This document includes radio parameters of communications and navigation systems in use by or interfaced with FSS. Although BUEC is not associated with FSS directly, the implementation schedule for a BUEC RMMS required that the effort be performed concurrently with FSS RMMS development. Therefore, the efforts were combined and carried out as subtask 1. Although the majority of the effort of subtask 1 was concentrated in FSS, for purposes of generality of text, this document grouped the BUEC equipment into the category of systems associated with Flight Service Stations.

Environmental parameters such as building temperature, security, etc., are not addressed in this report due to the number of universal commercial sensors which are available that perform these measurements.

INTRODUCTION

PURPOSE.

The purpose of this activity was to investigate communication/navigation equipment associated with Flight Service Stations (FSS's), and determine the radio parameters required for remote maintenance monitoring (RMM). This report is provided under subtask 1 of task 9 of 9550-AAF-501-78-002.

BACKGROUND.

The steady growth in aviation activity, as well as recent constraints in manpower, economics, and energy have forced a new look at the maintenance concept of the National Airspace System (NAS) facilities and equipment. Under the current concept, Federal Aviation Administration (FAA) equipment is kept operational through the use of periodic, single level maintenance by personnel stationed onsite, or at numerous Airway Facilities Service (AFS) sector work centers. However, the duties of the technicians are primarily preventive maintenance activities which are performed on a regularly scheduled basis. This routine was adopted to insure minimum outages on the older (and less reliable) vacuum tube type equipment. As the tube equipment is gradually replaced with more reliable solid-state equipment, the periodic inspections become less necessary and more wasteful of technician time. Yet, as a matter of course, the maintenance procedures of the older systems are being continued in the newer solid-state systems. Recently, growing system complexities, along with economic pressures to limit the growth of the maintenance workforce and operating costs, mandated a reevaluation of the present maintenance concept.

In 1976, AFS commissioned the Maintenance Philosophy Steering Group (MPSG) to study the present concept, assess future changes in the NAS, and develop a maintenance concept based on the expected NAS requirements for the period 1980 to 1990. The final report of the group, "Transmittal of Maintenance Philosophy Steering Group" (reference 1), presented the concept for future maintenance of NAS equipment and facilities and established the concept as AFS policy. This concept calls for more efficient utilization of resources and workforce through the use of more reliable solid-state equipments, RMM, and, where possible, changes in the schedules of performance checks of the newer solid-state equipment. One outcome of the new concept will be the consolidation of AFS sector work centers along with the relocation of technicians, stationed at remote sites, to these work centers. The MPSG envisioned the concentrated staffing as well as the centralization of expertise, coupled with RMM to result in a greatly improved operating efficiency for AFS maintenance personnel.

PHILOSOPHY OF REMOTE MAINTENANCE MONITORING.

Under the 1980's maintenance concept, a system structure is proposed which will provide remote maintenance and control of significant parameters of NAS facilities. The proposed remote maintenance monitoring system (RMMS) would allow a growing inventory of equipment to be maintained without a corresponding growth in the AFS technical staff. For example, many sites that are now manned will require only infrequent visits for repairs, security checks, etc. Moreover, the technician's job can be made more meaningful by assigning repetitive maintenance tasks to the RMMS, freeing him for higher level decision-oriented tasks.

As attractive as RMM sounds, it must still be implemented; effective implementation of a complete RMMS requires a great deal of planning. One of the primary reasons for the formation of the MPSG was to establish a framework for RMM. The essence of the MPSG philosophy (FAA Order 6000.27 (reference 1)) for RMM is the standardization of RMMS equipment so as to avoid a self-defeating proliferation of new monitoring equipment.

One approach to standardization of RMMS equipment is the test functional module (TFM) concept. In this concept, a family of standard functional modules would function as stimulators and/or sensors in all RMM applications. Each module would be designed to perform a particular function. For example, one module may measure transmission line radiofrequency (RF) power, another module may measure the transmit frequency of pulsed systems, etc. The actual functions of each TFM can be assigned only after a detailed parameter study of those equipments which are to be monitored. Where possible, any test functions or sensors built into the equipment should be used as TFM's or portions of TFM's.

A major constraint in the development of the TFM's is cost. Therefore, throughout this document, selected radio parameters will be identified as necessary for remote performance assurance, remote maintenance, and control. Economically, remote performance assurance is the least expensive to implement, and remote maintenance and control the most expensive. A secondary influence in the TFM selection is the life cycle of the equipment to be monitored. No tube equipment will be monitored because virtually all of the tube equipment currently in use is due to be replaced by solid state versions, in accordance with the 1980's maintenance concept. Similarly, new equipment with no built-in monitoring function will require extra attention.

One benefit of the TFM approach is that each time an RMMS is to be implemented for a specific site, AFS engineers are faced with only a site adaptation effort. An additional benefit is the ease of restoring the monitor to operation after a failure by removing the TFM and replacing it with another.

Control of the TFM's along with associated timing and data transfer will be accomplished by equipment monitors (EQM). The EQM will be microprocessor-based, and will contain onboard all necessary program memory, data input/output circuitry, and standardized interfaces to the TFM's. Thus, an RMM for a particular equipment may be built by selecting the appropriate TFM's and interconnecting them with an EQM.

ORGANIZATION

Several types of radio equipment are in use by or interface with FSS's (figure 1). These equipments include:

- Backup emergency communications (BUEC)
- Remote communications outlet (RCO)
- Limited remote communications outlet (LRCO)
- Single frequency outlet (SFO)
- Direction finder (DF)
- Very high frequency omnirange/tactical air navigational aid (VORTAC)
- Communications air-to-ground
- Very high frequency omnitest (VOT)

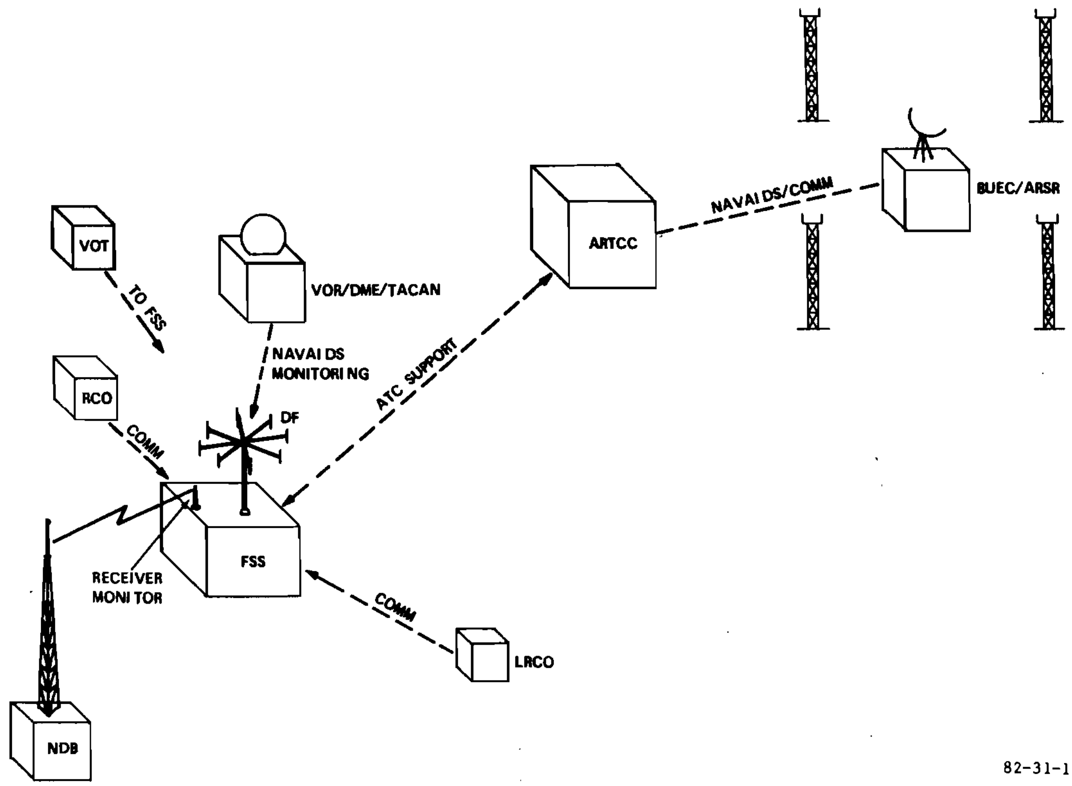

FIGURE 1. FLIGHT SERVICE FACILITIES INTERFACING DIAGRAM

In the first part of this report each equipment will be analyzed separately, and their parameters critical for RMM will be defined. The second part of this report will be a grouping of like parameters.

PART I — PARAMETER STUDY

BACKUP EMERGENCY COMMUNICATIONS.

BACKGROUND. The BUEC facility consists of solid-state ultra high frequency (UHF) transceivers, solid-state very high frequency (VHF) transceivers, a remote control system to allow access to any of the transceivers, and a communications circuit, either telephone lines or a remote microwave link. A brief description of the BUEC system operation follows (reference 2).

The air traffic controller has up to 10 UHF and 10 VHF BUEC transceivers available to provide supplementary radio communications in the event of a loss of normal air-to-ground communications. These transceivers are not all located at one facility. A BUEC facility has, typically, two VHF and two UHF transceivers. Each facility has an assigned priority code. This code is assigned in a computer in the air route traffic control center (ARTCC). When a controller selects the BUEC function, the computer uses the priority code to decide which BUEC facility would provide the best radio coverage for the controller's area of jurisdiction. However, if all radios at that facility are busy, the computer automatically searches through the facility priority codes to find the next best. The radios at the next facility are polled. If there is a free radio, it is captured. If the facility is busy, the priority selection repeats until all 10 radios are polled.

The radio equipments are types FA-8191 VHF and FA-8190 UHF transceivers (figure 2) manufactured by International Telephone and Telegraph Corporation (ITT) in Fort Wayne, Indiana. The first transceivers were delivered to the FAA circa 1970 with an expected life cycle exceeding 25 years.

The transceivers contain built-in test equipment (BITE) circuitry, which uses the outputs of an internal directional power detector and several monitor points to drive a front panel meter. The meter indication is used primarily in tuning the transceiver, and also to provide a quick look at several circuit parameters (e.g., regulated B+). The BITE circuitry is not, however, easily adapted to provide the sensor function in an RMMS.

The manufacturer of the equipment was contacted concerning the availability of built-in RMM capability. Cognizant project engineers indicated that no work had been done in RMM, but that ITT would investigate the extent of modification required, if requested to do so by the FAA. They also noted that the transmitter portion of the BUEC equipment is very similar to other ITT UHF and VHF communications transmitters in FAA usage for which internal monitoring is available by means of an add-on circuit card (see section on "Remote Communications Outlet"). For this reason, ITT engineers could foresee no extreme difficulties in developing a similar card for the BUEC equipment. Information on the estimated development cost of a RMM for BUEC's was not available.

TABULATION OF CRITICAL RADIO PARAMETERS. Parameters listed in table 1 are those required for performance assurance of the BUEC equipment (reference 3). If these parameters are remoted, then the maintenance technician will be able to complete the facility equipment log (FAA form 418-32) from a central work center, and perform remote certification (minus flight check) of the BUEC transceivers.

The additional parameters (listed in table 2) are necessary to perform remote maintenance on the BUEC transceivers. (For explanation of this subdivision see the section entitled "Philosophy of Remote Maintenance Monitoring.")

METHOD OF TRANSMITTER PARAMETER MEASUREMENT. All transmitter parameter data may be collected when a given transmitter is keyed. A convenient place for the monitor to sense the keying command is the 2423 hertz (Hz) keying tone, which is received on the audio frequency input line to the transceiver.

Parameters Required for Remote Certification. Forward and reflected antenna feedline power may be measured using an external directional RF body with built-in detector. The RF body is installed in the antenna feedline at the transmitter output. The characteristics of the RF body should be such that forward power measurements with accuracies of +3 percent and reflected power measurements with accuracies of ±8 percent are possible, with an apparent antenna voltage standing wave ratio (VSWR) of up to 2.5:1 as seen at the transmitter antenna terminals. The rationale for these limits may be found in appendix B. Reflected power will not be reported by the monitor, but the measured value will be used to calculate antenna VSWR. The reporting increment for the forward power measurement should be 0.1 watt; the reporting increment for the VSWR should be 0.1.

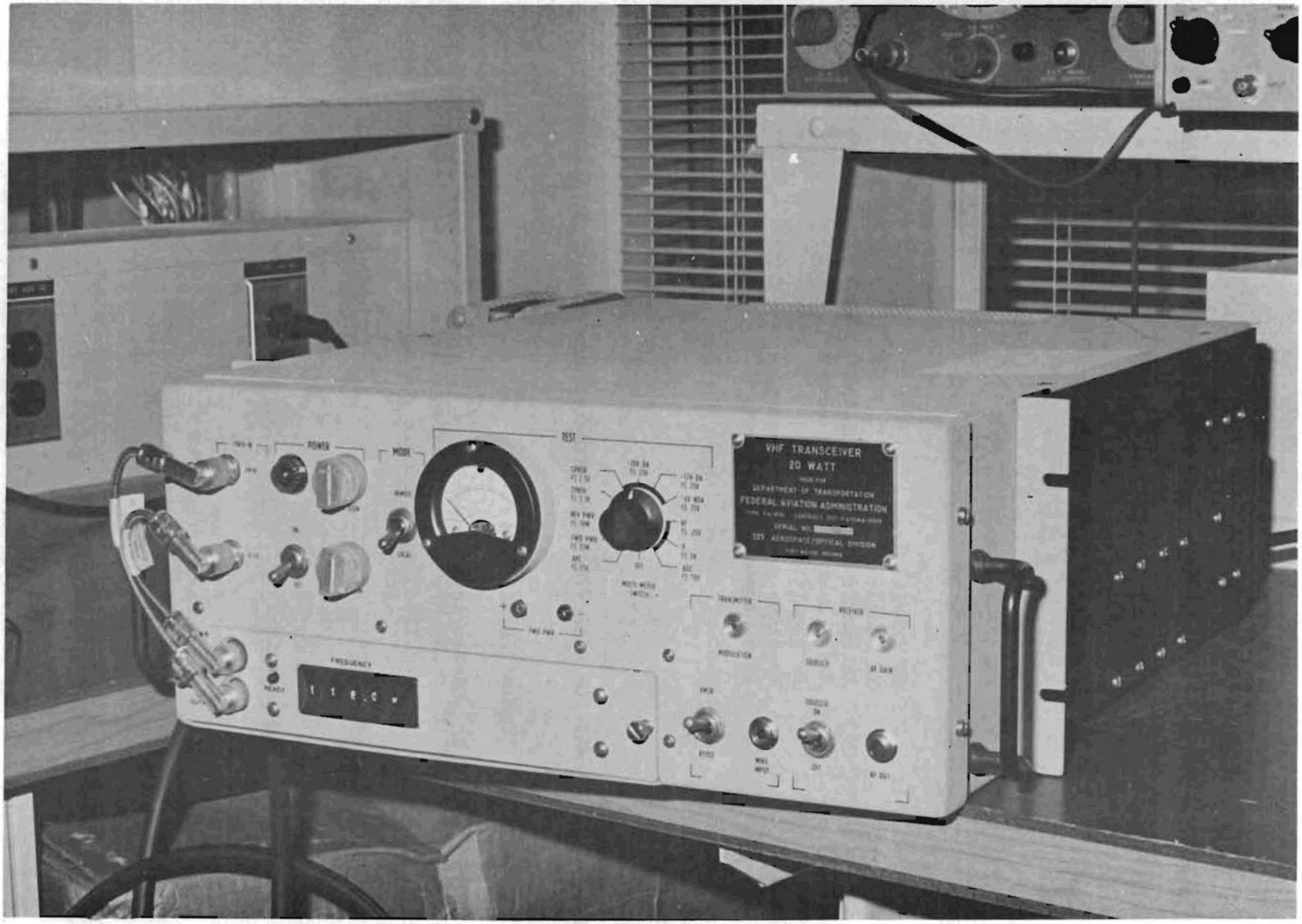

FIGURE 2. BUEC TRANSCEIVER FRONT VIEW

TABLE 1. SUMMARY OF PARAMETERS REQUIRED FOR PERFORMANCE ASSURANCE

Transmitter:

- Forward power
- Reflected power
- Transmit frequency
- Percentage modulation

Receiver:

- RF sensitivity
- RF squelch threshold
- Automatic gain control (AGC) level control
- Audio frequency power output
- IF sensitivity
- Receiver center frequency
- IF nonsymmetry

TABLE 2. SUMMARY OF PARAMETERS REQUIRED FOR BUEC REMOTE MAINTENANCE

Transmitters:

- Audio input level
- Frequency synthesizer output level and frequency
- Regulated power supply voltage

Receivers:

- None

BUEC Remote Control Subsystem:

- Select function
- Tone generator checks
- Telephone line noise level check

The detected outputs of the RF body should be linear with respect to antenna line RF voltage. This would greatly simplify the VSWR calculation by reducing the equation to a simple ratio of terms and eliminating the square root operations required. Recommended RF body specifications may be found in appendix B; simplified mathematical expressions for VSWR and percentage modulation calculations are presented in appendix A. A delay of 150 milliseconds minimum should elapse between the occurrence of the keying tone and the forward and reflected power measurements to allow the transmitter to stabilize.

The RF body detected outputs are direct current (d.c.) voltages proportional to forward and reflected antenna feedline RF power and will have an audio component superimposed when the transmitter is modulated. This audio component will cause erroneous analog-to-digital conversion and must be removed before forward or reflected power measurements can be made. A low pass active filter with 10 Hz cutoff frequency and 20 decibels (dB) per decade response (reference 4) is sufficient to remove any audio components.

The percentage modulation and transmit frequency measurements should commence approximately 0.5 seconds after the keying tone. The percentage modulation measurement should be a peak and an average measurement. A peak percent modulation measurement has been found to be a good indication when taken along with an average percent modulation measurement; standard operating procedure requires the transceiver overmodulation clipping circuitry to be aligned with a sinewave of known level. Under the steady state conditions of sinewave input, the transmitter will not overmodulate even when overdriven. However, the time constant of the limiting circuitry in the transmitter is such that the transient peaks of voice audio can cause overmodulation of the transmitter. Thus, a properly aligned transmitter may actually be overmodulating; an effect invisible in an average percent modulation measurement but apparent in a peak modulation measurement. Using digital signal processing and current technology, both peak and average modulation measurements are readily attained.

Percentage modulation measurements may be made using the forward output of the RF body used in the antenna feedline power measurement. For this measurement, the RF body should have a detected output which is linear, with respect to antenna line RF voltage. This characteristic greatly simplifies the actual percentage calculation (see appendix A). The modulation measurement should be made in 1-second intervals (reference 4). That is, the monitor should sense the detected modulation voltage from the RF body for 1 second, read the peak and average value which occurred during the interval, then clear the audio detector of residual voltage. After clearing the audio detector, the monitor should sense the modulation voltage for another second and read the peak and average values. This process should repeat for each contiguous second that the transmitter is keyed.

Transmit frequency may be measured by sampling the RF along the antenna feedline. The sampling probe should be directional to minimize the effect of voltage variations along the RF feedline produced by standing waves. The directivity of this sampling probe should be 15 dB minimum. The frequency counter should be capable of a total accuracy of 1 part in 10 million. This accuracy figure refers to resolution, short term time base stability, and long term time base drift. In addition, the frequency counter should exhibit an input sensitivity of at least 0 decibels above 1 milliwatt (dbm) with an input AGC range of at least 35 dB. Input AGC is required because higher levels of modulation may cause the counter input to be overloaded during modulation peaks and starved during modulation valleys. The AGC circuitry is needed to smooth out these variations. An AGC range of 35 dB will enable the counter to measure the carrier frequency with peak carrier modulation levels of 96 percent.

Each of the tests described above should be repeated once per second (after the initial 0.5 second delay) in order to detect a transmitter failure during transmission.

The monitor's push to talk (PTT) sensing circuitry should check PTT immediately before and immediately after a test cycle to insure that the transmitter remained keyed for the entire test cycle. Failure to check PTT at the end of a test cycle could result in erroneous measurements if the controller unkeys the transmitter during a test cycle.

Parameters Required for Remote Maintenance. The parameters which are discussed next are listed in table 2 and are necessary for remote maintenance of the BUEC transmitters, but are not necessary for remote performance assurance.

1. Audio Input Level. The audio input level to the transceiver is a useful tool in making percentage modulation measurements as well as ascertaining the condition of the audio channel feeding the BUEC. The monitor should sense the average audio input levels to the transceiver during the 1-second intervals when the average percentage modulation measurement is being made. Then, by comparing the two average values in each interval, abnormalities in the transmitter modulator may be detected. For example: an average peak percent modulation measurement coupled with a low average audio input level would not indicate a transmitter fault, but simply a lack of voice transmission during the interval. However, a low modulation percentage with a high audio input level clearly indicates a transmitter fault.

Variations in the audio channels feeding the BUEC transceivers may be statistically observed by tabulating the peak values of the audio input to the transceivers. Thus, trends in audio channel performance due to weather, etc, may be established. After a history is established on a particular channel, the monitor may use the information to detect degraded performance in the audio channel.

An alternate technique for determining the condition of the audio channel feeding the BUEC is being considered. This technique uses the receive level of RMS modem pilot tones to determine channel loss when RMS FSK data are transmitted over the audio channel to the BUEC using the speech plus data technique. At this time, however, sufficient networking information is not available to predict for certain that each BUEC audio channel will contain frequency shift keying (FSK) data. Therefore, this report recommends that initial monitor design contain an option to incorporate either technique (FSK pilot level or peak audio tabulation) for determining the performance of the audio channel.

2. Frequency Synthesizer Output Level and Frequency. The measurements of the frequency synthesizer output level and frequency provides access to two important transceiver parameters: FPA/LO drive level and transmit frequency. Experience has shown that many problems in transceiver operation can be traced to insufficient output voltage from the frequency synthesizer. By monitoring this

parameter, the maintenance technician may be able to pinpoint the specific cause of an equipment alarm without disassembling the equipment.

The frequency of the synthesizer output is the actual transmit frequency of the transceiver when it is keyed. Therefore, one of the transmitter certification parameters (transmit frequency — see table 1) may be monitored at the synthesizer output rather than using a pickup probe in the antenna feedline. An advantage of monitoring the transmitter frequency at the synthesizer output is that the frequency counter design is simplified because the synthesizer output is not amplitude modulated and no AGC action is required to level it. A disadvantage to this technique is that transceiver modification is required. The modification would consist of removing the miniature coaxial connector from the synthesizer output and inserting a miniature directional coupler in the RF path. The loss in the coupler would be negligible and the coupling port would provide a means for the monitor to sample the synthesizer output.

3. Regulated Power Supply Voltage. The +20 volt high current power supply is activated when the transceiver is selected by a controller and is switched off when the transceiver is deactivated. This supply furnishes the power for the RF amplifier and is, therefore, critical to transmitter operation. The benefit derived in monitoring this parameter, in conjunction with monitoring the synthesizer output, is in isolating the cause of a transmitter fault. The +20 volts direct current (Vdc) supply is sensed at terminals 8 (positive voltage) and 1 (reference potential) of TB1 on the power supply module.

METHOD OF RECEIVER PARAMETER MEASUREMENT. During the periods when the transceivers have not been selected by a controller, they are in an inactive standby mode. In this mode, neither the transmitter nor the receiver portions of the transceiver are operative because the power supply which supplies the +20 volts (low current) to the frequency synthesizer is switched off. Consequently, the transceiver must be activated before any remote parameter measurements can be made. There are three ways for a monitor to remotely activate a transceiver: (1) by injecting, via tones, the appropriate digital activation code into the audio input of the transceiver; (2) by supplying a d.c. activate signal at the remote control module output pin (thereby bypassing the module); and (3) by jumping the terminals on the front panel mode-remote-local switch.

A disadvantage of the first technique is in the complicated circuitry required to generate the proper stream of tone encoded data. A major disadvantage of the second technique is that the monitor has no way of determining the status of several of the transceiver operating parameters. The third technique, jumping the front panel mode switch, is the preferred method of transceiver activation. There are two benefits to be derived from this technique. First, the transceiver remote control circuitry is disabled when in local mode. If a monitor failure caused the transceiver to remain in local mode, an error indication would be generated at the ARTCC by the BUEC remote control subsystem processor. Second, the frequency dialed on the front panel thumbwheel switches is entered as the transceiver operating frequency. This latter point simplifies monitor design because the thumbwheel switches can be set to a predetermined test frequency.

A BUEC transceiver may be remotely programmed to operate on any of 10 frequencies, depending upon which controller position accesses the radio. The monitor has no simple way to determine the operating frequency that is remotely programmed into the transceiver remote control circuitry at the time of a receiver test. An assigned test frequency eliminates the extra circuitry required to enable the monitor to ascertain the transceiver operating frequency.

A common disadvantage to all three techniques is a difficulty in making the monitor failsafe. This means that a monitor failure could possibly incapacitate a transceiver (note that the loss of a transceiver does not incapacitate the BUEC function; the controller has access of up to 10 BUEC channels). This situation raises the philosophical question of whether to allow the receiver monitor to operate independently, making periodic checks, or to place the monitor under remote control of a maintenance technician.

In remote control, the technician may coordinate the testing with air traffic control (ATC) personnel and perform scheduled receiver checks at times when the impact of the loss of a transceiver due to a monitor failure would be minimized. In automated operation it is possible to program the monitor software such that a monitor operating independently, would perform receiver checks at times when the impact of a failure would be minimized. Also, through careful design (see appendix C) the risk of transceiver loss resulting from monitor failure may be minimized. Because one of the functions of an RMMS is remote control, this report recommends that the remote control capability be incorporated in initial monitor design. Such a monitor would be capable of operating in both automated and remotely controlled modes and would be useful as an evaluation tool for future modifications in the RMMS. Furthermore, the benefits in political acceptability alone would justify the cost of implementation.

All receiver tests should be performed on a periodic basis (e.g., once per hour). Of primary importance, however, is the requirement that the monitor abort any current testing and release the transceiver if an attempt is made, by a controller, to access the transceiver. The monitor can discern the attempt by detecting the presence of the incoming activation command on the transceiver's audio input circuit. This activation code is comprised of an 1800 Hz attention signal followed by a programming command. The duration of the attention signal is 20 milliseconds. During this time the monitor must restore the transceiver operating mode to remote in preparation for the programming command. The monitor's detection and switching process should take no longer than 2 milliseconds (ms).

All receiver tests listed in table 1 should be performed by injecting test RF signals into the transceivers.

Several of the tests require the frequency of test signals to be the same as the center frequency of the transceiver under test. Therefore, the monitor must have access to the frequency that the transceiver is tuned to. When the monitor is performing receiver tests under remote control, the transceiver tuning information shall be uplinked via keyboard entry from a maintenance technician located at a sector work center. The frequency data will be transmitted to the monitor over the audio channel to the BUEC facility. Data modems used to transmit the data should operate on pilot frequencies that will cause no interference to existing BUEC communications and remote control. When the monitor is operating independently, performing automated receiver tests, the transceiver frequency information may be stored in the monitor's memory. Recall that the transceiver front panel thumbwheel switches establish the frequency in local mode. Thus, the thumbwheel switches should be set to a predetermined test frequency, which will be used in the automated receiver measurements.

Directional couplers should be installed in the antenna feedline at the transceiver's antenna terminals for use as injection ports. The directional couplers are necessary for impedance matching to the receivers (reference 5), as well as preventing excessive stray test RF from being radiated by the BUEC antennas. Characteristics of the directional coupler should be: 20 dB coupling, 30 dB directivity, ±0.5 dB coupling tolerance over the frequency range of interest, a maximum insertion VSWR of 1.05:1, and a maximum insertion loss of 0.2 dB.

During the receiver testing it is necessary to insure that ambient noise, such as radiation from nearby transmitters, does not affect the receiver measurements. Several steps to minimize interference to the receiver tests are given.

1. Preset the front panel thumbwheel switches to a "quiet frequency" so that when the transceiver is placed in local mode, its operating frequency is away from busy frequencies.

2. Perform the receiver tests at quiet times (e.g., night) in areas where atmospheric and/or static noise is a problem.

3. Monitor the AGC testpoint (available on TB-3 on the rear panel of the transceiver) before and after each test to ensure that the AGC voltage is at its quiescent value. Any interference of sufficient level to affect the receiver measurements would cause the AGC voltage to deflect, and the monitor can sense the condition and delay the test.

Parameters Required for Remote Certification. The following parameters are those required for remote certification.

1. RF Sensitivity. The sensitivity of the receiver is defined as the RF input level required to obtain a signal plus noise (modulation on) to noise alone (modulation off) ratio of 10 dB in the receiver audio output (reference 3).

The sensitivity test is performed by injecting a test signal, at the receiver's center frequency, into the directional coupler. The procedure for this test is somewhat different than one might expect. The reason is the audio frequency power output (table 1) and the RF sensitivity tests may be combined so that both measurements are made by performing only one test. The essence of the audio frequency power output test is to determine that the receiver can deliver +20 dBm of undistorted audio into 600 ohms with an RF input signal level of -99 dBm.

Under current maintenance procedures the sensitivity measurement is performed with the sequelch control off. Therefore, this report recommends that an option to switch the squelch control off under monitor control be provided in the initial monitor design. This feature may be necessary at facilities where high ambient RF noise levels forced maintenance personnel to raise the operational squelch threshold past the receiver sensitivity figure.

The procedure for the RF sensitivity test for receivers whose squelch threshold for RF levels is set less than -93 dBm is given first. The procedure for receivers with squelch thresholds required to be set for RF levels higher than -93 dBm follows at the end of this section. The monitor programs a signal generator to inject a 30 percent (1000 Hz) modulated -110 dBm signal into the transceiver antenna terminals at the receiver center frequency. Subsequently, the audio power output of the receiver is measured, and the squelch testpoint is checked for an indication of squelch break. If the audio power output is less than +20 dBm and the squelch is unbroken, the monitor programs the signal generator to increase the level of the test signal 1 dB. Again, the audio power output is measured and the squelch testpoint is checked. This sequence repeats until either the receiver audio output reaches (or exceeds) +20 dBm, or squelch breaks. If squelch breaks during the test, the current level of the test RF signal is logged, to be used later in the squelch threshold tests. If, during the sequence iteration, the receiver audio output reached or exceeded +20 dBm without distortion, the monitor stops the iteration and programs the test signal generator to switch off the 30 percent modulation, but maintain the test signal RF level and frequency.

The level of the receiver audio output will now be lower without the 1000 Hz component. The monitor measures the audio output now due to receiver noise alone, and calculates the ratio of audio level with modulation on to audio level with modulation off. If the ratio equals or exceeds 10 dB, the monitor considers the current test RF signal level to be the RF sensitivity of the receiver. If the ratio was less than 10 dB, the monitor programs the signal generator to increase the test signal level by 1 dB, and to switch back on the 30 percent modulation of the test signal. The audio level (modulation on) is measured, the modulation is switched off, the audio level measured (modulation off), and the ratio of these levels is again computed. This sequence continues until the ratio reaches or exceeds 10 dB. The current level of the RF test signal (in dBm across 50 ohms) is considered to be the receiver sensitivity.

The distinction between dBm as applied to RF levels and dBm applied to audio levels is that audio levels expressed in dBm refer to power levels referenced to 1 milliwatt into 600 ohms; whereas, RF levels expressed in dBm refer to power levels referenced to 1 milliwatt into 50 ohms.

For the tests just described, a maximum level of the injected test signal was established as a receiver failure level. If a receiver cannot pass either test by the time the level of the test signal reaches -70 dBm (at the receiver antenna terminals) the test should cease and the receiver should be declared inoperative.

A delay should be incorporated into these tests to allow the receiver time to stabilize. A delay of 100 ms should elapse after the signal generator output stabilizes (following a programming command from the monitor) before any audio or squelch measurements are made (reference 4).

Current maintenance procedures require the audio output level of the receiver to be set at +10 dBm measured at the demarcation point of the audio channel. In order to automate the audio power output test, a deviation from the current procedure is required. For this test, the receiver audio gain control must be adjusted to the fully clockwise position (maximum audio output) and an attenuator must be installed at the receiver audio output terminals to avoid overloading the audio channel. The loss in the attenuator should be adjusted such that an audio level of +10 dBm is developed by the receiver at the audio channel demarcation point, with a -73 dBm test signal modulated 30 percent at 1000 Hz injected into the transceiver front end. The receiver audio output level may be measured on terminals 1 and 2 of terminal board 3 on the rear of the transceiver chassis. (Note: this is a balanced output and should not be grounded.) Audio level measurements should be made by bridging.

The sensitivity measurement for receivers with squelch thresholds set higher than -93 dBm is essentially the same as previously described except that the monitor switches the squelch circuit off before performing the test. Then, during the test, the monitor omits checking the squelch testpoint. After the sensitivity measurement, the monitor should reactivate squelch.

2. Squelch Threshold. The squelch threshold of the receiver should be measured after the RF sensitivity test. The value of the squelch threshold obtained in the RF sensitivity test (see previous section) should define a starting point for the signal generator output level setting only, and not the actual squelch threshold. The reason is the squelch threshold value from the RF sensitivity test was measured with the injected RF test signal modulated at 30 percent. The actual squelch threshold should be measured with an unmodulated test signal. The difference in squelch threshold values measured with and without modulation may be, in some types of receivers, 2.3 dB.

The process for measuring squelch threshold is very similar to the RF sensitivity measurement. The signal generator is programmed to inject an unmodulated test signal into the transceiver at the receiver operating frequency. The initial level of the injected test signal should be 3 dBm less (-3 dB) than the threshold value obtained in the RF sensitivity test. As before, 100 ms should elapse after the generator output stabilizes and before the squelch testpoint is checked. If squelch is unbroken, the monitor programs the signal generator to increase the test signal level by 1 dB, and after the appropriate delays, checks the squelch testpoint. This sequence repeats until squelch breaks. The monitor then stops the iteration and reports the level of the RF test signal required to break squelch as the squelch threshold.

3. AGC Threshold and Range. This measurement should be made with the receiver squelch off (see "RF Sensitivity"). The AGC threshold is considered to be the RF input level where audio output throttling action starts.

The AGC threshold measurement procedure differs slightly from the procedures described in the two previous sections. When measuring the AGC threshold, it is necessary to employ a slope detection process. In the beginning of measurement, when the injected RF test signal level is in the range -110 to -105 dBm, the receiver audio output is comprised mostly of IF noise; 1 dB increase in the level of the RF test signal produces approximately 0.25 dB change in the receiver audio output. When the injected signal level increases to a point about 6 dB below the AGC threshold, a 1 dB increase in the level of the input RF test signal causes a 1.5 to 2.5 dB increase in the audio output level. When the injected signal level is increase to AGC threshold, a 1 dB increase in the injected test signal level produces only a 0.25 to 0.5 dB change in the audio output. Thus, the audio output level increments in fractional dB steps with insufficient RF input levels, increases to multiple dB steps just before AGC threshold, and increments in fractional dB steps at AGC threshold and beyond. The monitor processor must sense this increase in the audio voltage increments to avoid confusing the fractional dB audio increments at insufficient input RF with the fractional dB increments at AGC threshold; hence, the term slope detection.

The procedure for the AGC threshold measurement is given next. The monitor programs the signal generator to inject a 30 percent 1000 Hz modulated test signal into the transceiver at the receiver center frequency. The initial level of the test signal is -110 dBm. The monitor delays 100 ms after the signal generator output stabilizer, and measures the level of the receiver audio output voltage. The monitor stores the measured value and programs the signal generator to increase its output level by 1 dB. After the 100 ms stabilization delays, the monitor measures the receiver audio output voltage, stores the value, and subtracts the stored measured value from the new value. The monitor repeats this process of increasing the signal generator output and determining the difference between successive audio voltage measurements. At the AGC threshold, the difference in successive audio level measurements will decrease quickly from approximately 1.8 volts RMS to approximately 0.3 volts RMS. When the monitor detects this decrease, it momentarily stops the measurement sequence and stores the current value of the signal generator RF output level (to be reported as the AGC threshold level) and the last measured value of the receiver audio output voltage.

AGC range is measured using a sequence similar to that described in the previous paragraph. The function of the AGC control is to keep the receiver audio output voltage constant with large changes in the incoming RF signal level.

The measurement procedure is given next. The monitor programs the signal generator to inject a test RF signal modulated 1000 Hz at 30 percent into the transceiver at the receiver center frequency. The initial signal level is -95 dBm. The monitor allows the generator to stabilize, and after a 100 ms delay measures the receiver audio output voltage. This voltage is stored by the monitor to be used in the remainder of the test. The monitor then programs the signal generator to increase the level of the test RF signal by 10 dB, waits for the receiver to stabilize and measures the receiver audio output voltage.

This sequence repeats until the RF output level of the signal generator reaches -7 dBm. Each time the receiver audio voltage is measured, it is compared to the stored audio voltage that the receiver produced with the injected -95 dBm test signal. If, in any sequence iteration, the measured audio voltage differs by 4 dB from the stored value of the audio voltage, the receiver is considered faulty. The maximum value of the audio voltage that occurs in the test is stored by the monitor to be reported along with go/no go indication of AGC action.

4. <u>IF Selectivity</u>. The value for the squelch threshold obtained previously will be used in this test. This test should be performed with the squelch control on. The measurement procedure is as follows. The monitor programs the signal generator to tune 100 kilohertz (kHz) below the operating frequency of the receiver under test, and output an unmodulated RF signal whose amplitude is 60 dB greater than the squelch threshold for the receiver. The monitor then programs the signal generator to increase its output frequency by 1 kHz. After the 100 ms receiver stabilization delay, the monitor checks the squelch testpoint. If squelch is unbroken, the test RF signal frequency is again increased by 1 Hz. This sequence repeats until the monitor detects squelch break. The sequence iteration is momentarily stopped and the signal generator output frequency is stored as the lower 60 dB IF skirt frequency. Before the sequence iteration is restarted, the monitor programs the signal generator to change the level of the test RF signal to 6 dB greater than the receiver squelch threshold. The frequency stepping iteration is restarted and continues until the monitor again detects squelch break. This time the signal generator output is stored as the lower 6 dB skirt frequency. The monitor stops the current sequence iteration, programs the signal generator to 100 kHz above the receiver's operating frequency, and decreases the frequency of the test signal in 1 kHz increments. In this portion of the test, the upper 60 and 6 dB IF skirt frequencies are measured and stored. The four skirt frequencies

obtained in this test will be used to compute the receiver center frequency and IF nonsymmetry.

5. Receiver Center Frequency. This frequency is calculated by adding the two 6 dB IF skirt frequencies and dividing by two (reference 3). The result of this calculation is stored for reporting by the monitor.

6. IF Nonsymmetry. The percentage of IF nonsymmetry is calculated by the equation:

$$\% \text{ Nonsymmetry} = \left[\frac{\Delta F_1}{\Delta F_2} - 1\right] \text{X } 100\% \text{ (reference 7)}$$

Where

ΔF_1 = difference between receiver center frequency and lower 60 dB skirt frequency.

ΔF_2 = difference between receiver center frequency and upper 60 db skirt frequency.

if $\Delta F_2 > \Delta F_1$ use $\left[\frac{\Delta F_2}{\Delta F_1} - 1\right]$ X 100%

Method of Remote Control Subsystem Check. The following parameters are required for remote maintenance of the remote control subsystem and are discussed below.

1. Select Function. This parameter may be checked by incorporating the decoding circuitry required into the monitor. Each time the transceiver is selected, the decoding circuitry can check the message format and provide a positive error indication in the event of erroneous activation code transmission.

2. Tone Generator Check. The outputs of the tone generator in the BUEC transceiver may be checked for output level and frequency.

3. Audio Channel Noise Level Check. During the periods when the transceivers are not selected, the RMS noise on the audio channel may be measured. This parameter is especially important when the audio channel is formed by a telephone circuit.

REMOTE COMMUNICATIONS OUTLET.

BACKGROUND. A remote communications outlet is a facility that contains air-to-ground (A/G) radio equipment which is operated remotely from an FSS. Usually, the facility is a former FSS where the A/G positions have been removed (reference 6), and the transmitters and receivers are operated remotely from another FSS. The remote control function is provided by voice frequency signaling systems (VFSS) via telephone circuits between the FSS and RCO (reference 8). The radio equipment found at RCO's is currently a mixture of tube type and solid-state equipment, depending on the location. This document will not address the tube equipment (see "Philosophy of Remote Maintenance Monitoring"). The solid-state radios are type

AN/GRR-23 VHF and AN/GRR-24 UHF receivers and AN/GRT 21 VHF and AN/GRT 22 UHF transmitters, manufactured by International Telephone and Telegraph Corporation, Fort Wayne, Indiana. The first transmitters and receivers were delivered to the FAA circa 1972, with an expected life cycle exceeding 25 years.

The transmitters contain circuitry using several monitor points, in addition to the outputs of an internal directional power detector, to drive a front panel meter. A total of 23 parameters are selectable for viewing on the meter. The meter indication is used primarily for tuning the transmitter, but also displays the status of a substantial number of other circuit parameters.

The FAA provides sensors which are used to monitor several critical transmitter parameters. The sensor is a printed circuit board which plugs into the A-3 card slot in the transmitter. The A-3 Inboard Monitor/Keyer Card contains the electronics to provide conditioning of signals available within the transmitter, and provides d.c. output voltages proportional to certain transmission parameters. These include: forward power, reverse power, percent modulation, audio input level, PTT indication, and EXCITER/LPA operation.

A task was assigned to the Technical Center to validate the design and performance characteristics of the card. The results of the validation tests (reference 9) indicated that the performance of the card was within FAA specification (reference 10) for all parameters except reverse power, which is to be used by the monitor to calculate antenna VSWR. Figure 3 shows the range of antenna VSWR calculations using the forward and reverse outputs of a prototype A-3 card, along with specified error limits.

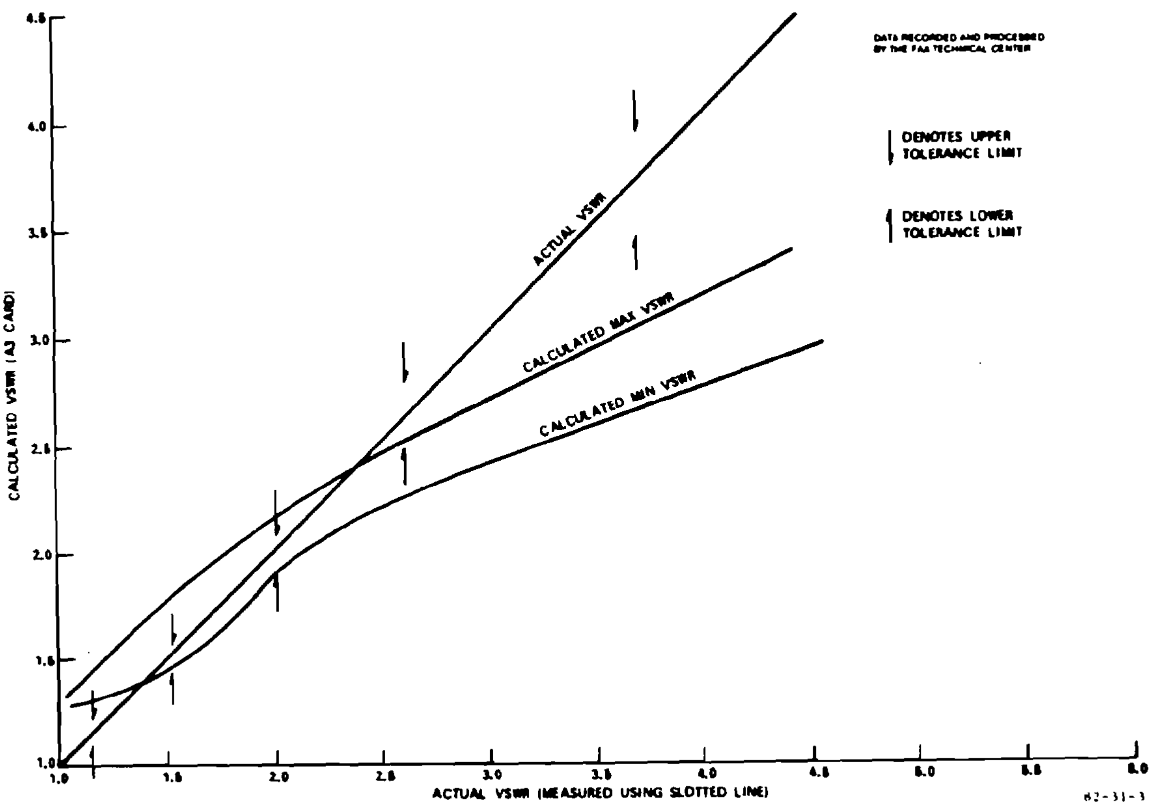

FIGURE 3. VARIATION IN A-3 VSWR MEASUREMENTS

Further work revealed that the chief source of error in the A-3 reverse power indication was the tolerance in the input signal to the card. This signal is routed to the card from the "reflected" output of the directional power detector (DPD) in the transmitter. Under certain antenna VSWR conditions there is sufficient variation in the DPD output to cause out-of-tolerance VSWR measurements (figure 3).

Several DPD manufacturers offer direct replacement units with considerably tighter tolerances on their DPD outputs. This document recommends that the existing DPD's be replaced with the improved units if the A-3 card is to be implemented as the transmitter sensor. See appendix B for recommended replacement DPD specifications.

The modulation sensor portion of the A-3 card derives a modulation index measurement by rectifying and integrating the detected modulation component of the transmitted RF signal. The time constant of the integrator is about 150 ms. The A-3 modulation measurement offers accurate and precise indication of steady state sine-wave carrier modulation, but may not be able to indicate the occasional transient peaks of voice modulation (see section discussing the percent modulation measurement for BUEC equipment, page 7). Therefore, this report recommends that the A-3 circuitry be modified to decrease the attack time of the integrator (making it a peak detector). The modification involves soldering a diode in parallel with R-39, the cathode pointing toward C-4. The same modification should be made to the audio input level measurement circuitry. The diode should be soldered in parallel with R-53, the cathode pointing toward C-9.

TABULATION OF CRITICAL RADIO PARAMETERS. The parameters listed in table 3 are those required for performance assurance of the RCO communication equipment (references 11 and 12). If these parameters are remoted, then the maintenance technician will be able to complete the facility equipment log (FAA form 6530-1) remotely from a central work center, and, by so doing, perform remote certification (minus flight check) of the RCO communications equipment.

The parameters listed in table 4 are necessary to provide remote maintenance on the RCO communications equipment.

TABLE 3. SUMMARY OF PARAMETERS REQUIRED FOR RCO PERFORMANCE ASSURANCE

Transmitter:

- Forward power
- Antenna VSWR
- Transmit frequency
- Modulation level

Receiver:

- Sensitivity
- Squelch threshold
- AGC threshold
- AGC control
- Selectivity
- Audio power output
- Receiver center frequency
- IF nonsymmetry

TABLE 4. SUMMARY OF PARAMETERS REQUIRED FOR RCO REMOTE MAINTENANCE

Transmitter:

- Audio input level
- Regulated +20 Vdc power supply
- Oscillator output frequency
- PWR AMPL
- VSWR LPA

Receiver:

- Oscillator output frequency
- On-Line receiver sensitivity
- On-Line receiver selectivity (6 dB)
- Main standby status

METHOD OF TRANSMITTER PARAMETER MEASUREMENT. The A-3 card is a government furnished equipment (GFE) sensor which is an add-on to existing GRT transmitting equipment. Under the 1980's maintenance concept, all existing GRT series transmitters will be retrofit, and all new transmitters will have the card installed. In the interim, however, before all existing transmitters are retrofit, RMM at RCO's may be implemented by using the transmitter sensor recommended for the BUEC equipment. In fact, this document recommends that both the A-3 card and the recommended BUEC sensor be installed as the sensors for the transmitter monitor in initial monitor design. Initial monitor design should also allow for the selection of either sensor (or both) by the EQM by means of a wire strapping function.

All transmitter parameters may be measured each time a given transmitter is keyed. The monitor may sense PTT at the A-3 card PTT output in transmitters equipped with the card. At RCO facilities where RMM will be implemented before the A-3 retrofit is completed, the monitor may sense PTT via a contact closure on the keying relay of the transmitter.

Caution must be exercised in the design of the PTT sensing circuitry because the excessive noise spikes generated by VFSS relay coils and contacts, power line noise, etc., could cause a false PTT indication.

PTT should be sensed by the monitor before and after each transmitter parameter measurement cycle to insure that the transmitter remained keyed during the entire test cycle. Failure to check PTT at the end of a test cycle could result in erroneous data collection or false alarm reporting by the monitor if the FSS specialist unkeys during a test cycle.

Parameters Required for Remote Certification.

1. Forward Power. A delay of 150 ms minimum should elapse between the occurence of PTT and the forward power measurement to allow the transmitter to stabilize.

If the forward power measurement is made using the A-3 card output, the transfer characteristics shown in figure 4 should be used to convert the card output voltage to RF feedline power expressed in watts.

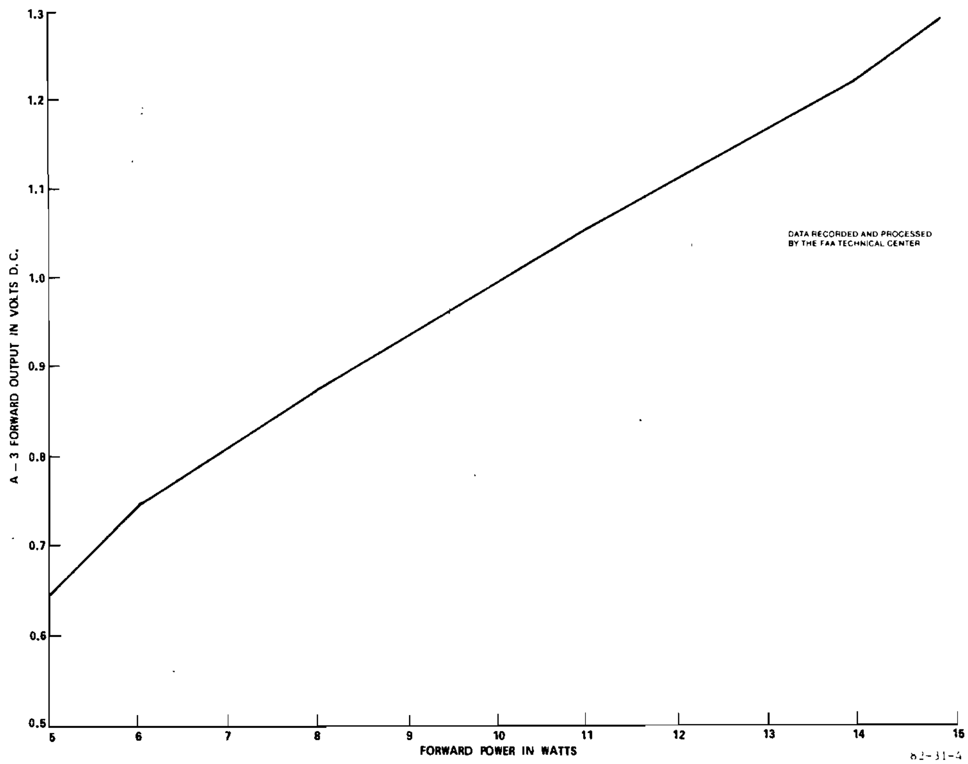

FIGURE 4. A-3 FORWARD POWER TRANSFER CHARACTERISTIC

If the BUEC sensor is used to measure forward power, low pass filtering is required to remove the audio components that appear at the sensor output when the transmitter is modulated. The low pass filtering is necessary for accurate analog to digital (A-D) conversion, and may be provided by a low pass, two-pole active filter (-3 dB frequency = 10 Hz) preceding the A-D converter or by an averaging routine in the monitor software. This report recommends the latter technique. The transfer characteristic for conversion of sensor output voltage to forward feedline power (in watts) is shown in appendix A.

The accuracy of the forward power measurement should be +3 percent (see appendix B) and the measurement increment should be 0.1 watt.

2. VSWR. This parameter is not measured directly, but is calculated using the measurements of forward and reflected antenna feedline power. If the A-3 card is used to make the reflected power measurement, antenna VSWR is calculated using the equation:

$$\text{VSWR} = \frac{1 + A}{1 - A} \quad \text{where } A = \sqrt{\frac{P_r}{P_f}}$$

Figure 5 shows the transfer characteristic which is used to convert the A-3 reverse output voltage to reflected feedline power expressed in watts.

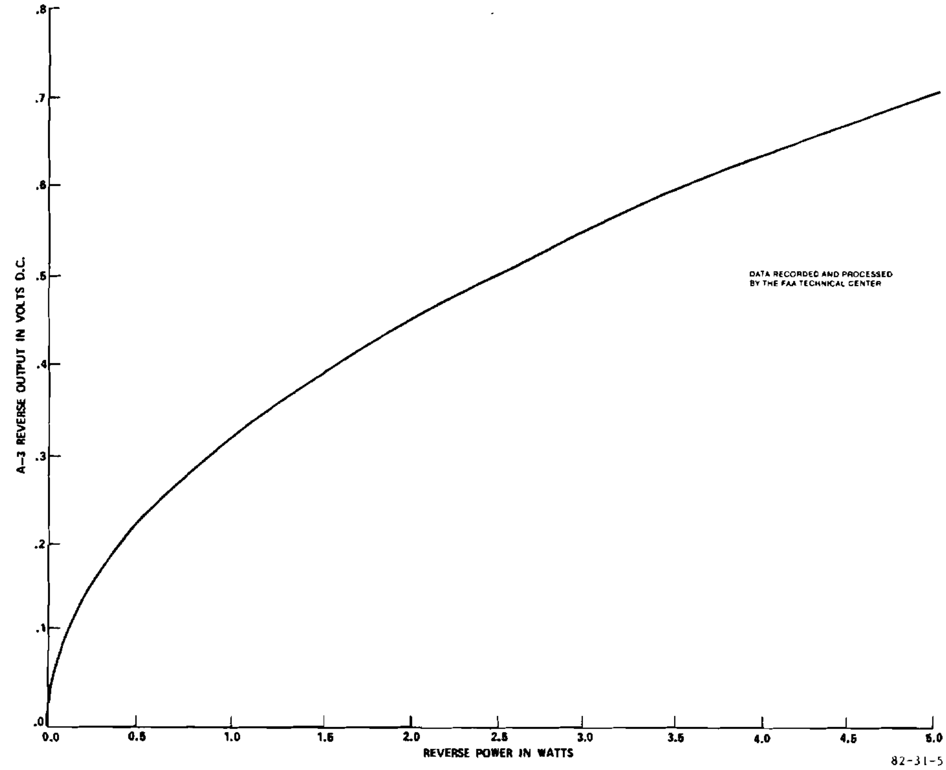

FIGURE 5. A-3 REVERSE POWER TRANSFER CHARACTERISTIC

If the BUEC sensor is used to make the reflected power measurement, the sensor output must be low pass filtered to remove any audio components that appear when the transmitter is modulated. The filtering may be accomplished by the same method chosen for the forward power sensor. Antenna VSWR may be calculated using the equation:

$$VSWR = \frac{V_i + V_r}{V_i - V_r}$$

Where

V_i = sensor forward output

V_r = sensor reflected output

A delay of 150 ms minimum should elapse after the transmitter is keyed and before the reverse power measurement is made. This report recommends that the reflected power measurement and VSWR calculation be made immediately after the forward power measurement. This suggested sequence will aid in preventing false alarm reporting. For example, the alarm condition of low forward power could be caused by a transmitter fault or a high antenna VSWR. (The GRT series transmitters automatically lower their output power upon sensing excessive reflected power.)

The error in the VSWR measurement should not exceed +7 percent for VSWR's up to 2.5:1 (at the transmitter); the value should be reported in 0.1 increments.

3. Transmit Frequency. The A-3 card has no provisions for measuring transmitter frequency. Therefore, the technique recommended for frequency measurement of the BUEC transmitters is recommended here. Transmit frequency may be measured by means of a directional coupler installed in the antenna feedline at the transmitter output. The purpose of the coupler is to provide a sample port for the transmitter RF. The suggested characteristics of the directional coupler are: -40 dB coupling, insertion VSWR of less than 1.05, and 15 dB minimum directivity. The directivity of the coupler helps to minimize variation in RF voltage caused by standing waves on the antenna feedline.

The frequency counter should include AGC circuitry in its front end (reference 4). The AGC circuitry is necessary to smooth out the peaks and valleys in the RF carrier when the transmitter is modulated. An AGC range of 35 dB would enable transmit frequency measurement with up to 96 percent carrier modulation. The counter should also have a total accuracy of 1 part in 10 million. This figure includes resolution, short term time base jitter, and long term time base drift. The transmit frequency measurement should commence 0.5 second after PTT to allow for transmitter stabilization.

4. Percent Modulation. The percentage modulation measurement should be peak and average, rather than only an average measurement (reference 4; see also the discussion of modulation measurement for the BUEC equipment). The percentage modulation measurement should commence approximately 0.5 seconds after detection of PTT, and should repeat each second thereafter for the duration of transmission. The measurement sequence is as follows: the monitor should delay for 0.5 second after PTT, then clear the audio detector of any residual voltage. After an additional 1 second delay, the monitor should read the audio detector to obtain the modulation voltage which occurred during the 1-second interval. The monitor, after reading the audio detector, clears it in preparation for the next 1-second sampling interval. This sequence repeats for each contiguous second of transmission. The modulation index for a given sampling interval is determined immediately after the audio detector is cleared following the interval.

Percentage modulation measurement may be made by using either the A-3 card output or the BUEC sensor. If the A-3 modulation output is used, the modulation index of the transmission interval is determined by using the transfer characteristics shown in figure 6. Note that the curve shown in figure 6 applies when the transmitter is operating at a 10 watt forward power level. For other power levels, the monitor must correct the modulation index indication.

If the BUEC sensor is used to measure percent modulation, the interval index may be calculated using the equation shown in appendix A. The accuracy of the percent modulation measurement should be within 5 percent of the actual value.

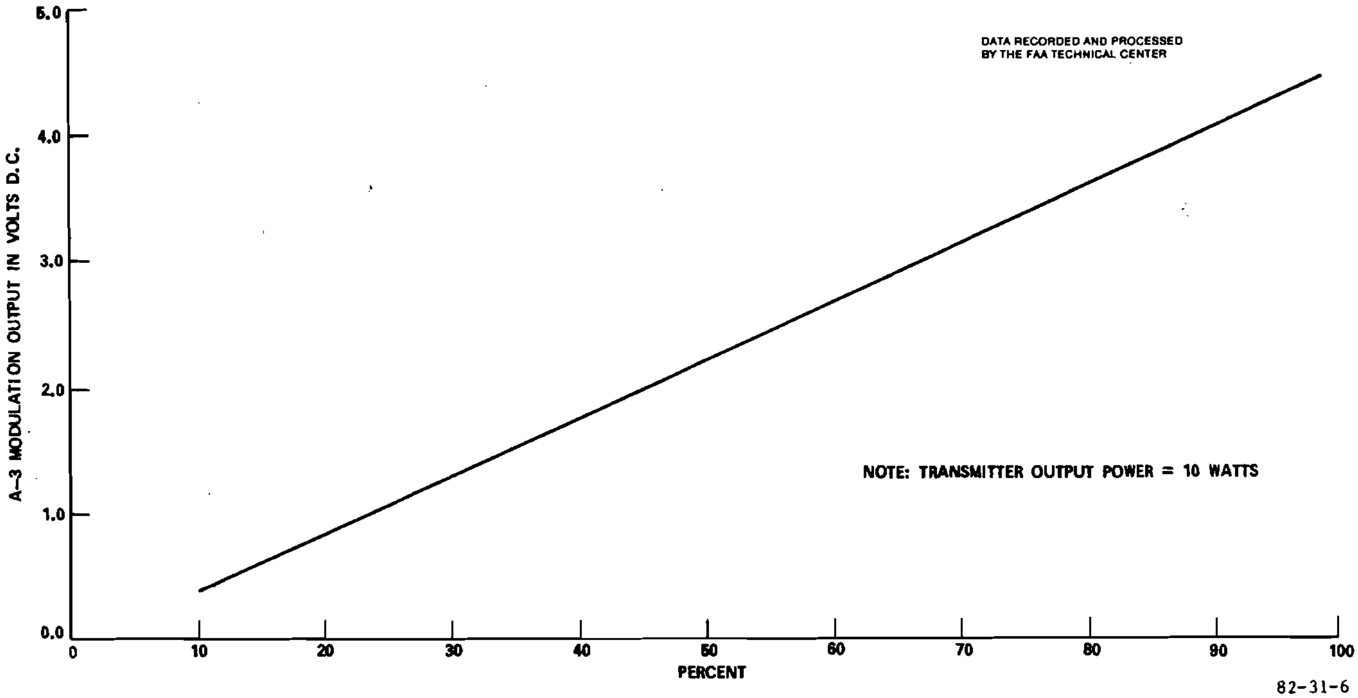

FIGURE 6. A-3 PERCENT MODULATION TRANSFER CHARACTERISTIC

Parameters Required for Remote Maintenance. The parameters which are discussed next are listed in table 4 and are considered necessary for remote maintenance of the RCO communications transmitters.

1. Audio Input Level. The audio input level to the transmitter is a useful parameter in the percentage modulation measurements as well as in determining the condition of the audio channel feeding the RCO.

After numerous conversations with maintenance personnel, it is concluded that a major cause of all remote facility outages is loss of telephone line communications. Therefore, a technique is necessary whereby the monitor can sense the condition of the telephone circuit feeding the transmitter. The technique recommended in this report is to monitor the audio input level to the transmitter during PTT in 1-second intervals in the same manner as percent carrier modulation measurement. By sampling the peak audio input values that occur during 1-second intervals of transmission, trends in telephone line performance due to weather, etc, may be established. After a history is established on a telephone circuit, the monitor may use the stored information to detect degraded performance in the telephone lines.

The monitor should also make use of the peak audio input measurements to prevent the reporting of false percent modulation alarms. Comparison of the peak value of carrier modulation in a given 1-second interval with the peak value of the audio input level for the same interval, will aid in detecting any abnormalities in the transmitter modulator circuitry. False alarm reporting will be prevented because the alarm conditions of over or under modulation caused by improper telephone levels could be distinguished by the monitor from alarm conditions caused by transmitter failure.

2. Regulated +20 Vdc Power Supply. The +20 Vdc supply powers all the modules in the transmitters and is consequently subject to overloading. To prevent internal damage, the power supply has built-in circuitry that shuts down the supply in case of an overload. The most common overload condition observed in testing GRT series transmitters at the Technical Center has been caused by opening the feedback loop of the automatic power control (APC) circuit. The outputs of the DPD in the transmitter are part of the APC loop. If a nearby lightning strike should destroy the PIN diodes in the DPD, the APC loop would be opened, and the next time the transmitters were keyed the supply would be overloaded and shutdown. Also, an RMMS which uses the A-3 card as the transmitter sensor, would detect incredible values for the transmission parameters because the d.c. bias applied to the diodes would be shifted. This would cause the d.c. bias of the A-3 signal conditioning electronics to be shifted to the extent that RMMS reports would be nonsense (unless software limits are used). Therefore, by observing the +20 Vdc indication, and by noting the validity of the reported data, the maintenance technician at a remote work center can determine the probable cause of a transmitter failure.

The transmitter modification required to provide a sampling point for the +20 Vdc power supply consists of installing a jumper wire from pin 5 terminal board 2 to an unused pin on the rear panel interface connector (K-5).

3. Oscillator Output. The oscillator in the VHF transmitters operates at one-half the transmit frequency and one-fourth the transmit frequency in the UHF transmitters; the actual carrier frequency is obtained by doubling and quadrupling, respectively. Therefore, to measure carrier frequency, the technique described in the certification parameter discussion is required. However, measurement of the oscillator output frequency provides a quick look at the carrier frequency of a transmitter whose multiplying circuits are functional. In several cases, test GRT series transmitters at the Technical Center were found to be slightly off frequency. Subsequent investigation revealed that the transmit crystals drifted off frequency. In other cases, test transmitters were found to be substantially off frequency due to doubler or quadrupler stage tuning error. Thus, by measuring the oscillator output frequency, the cause of carrier frequency errors may be determined remotely.

The required transmitter modification for this parameter would consist of removing the coaxial connector from the oscillator output and inserting a miniature directional coupler in the RF path. The coupler characteristics should be: coupling -20 dB, insertion VSWR not exceding 1.15:1, directivity exceeding 10 dB, and insertion loss not exceeding 0.25 dB.

METHOD OF RECEIVER PARAMETER MEASUREMENT. In the present RCO configuration, some frequencies, but not all, have stand-by receivers to backup the primary receivers. Under the 1980's maintenance concept, all RCO receive frequencies will be backed up. This point is worthy of consideration because the receiver certification parameters cannot be measured without temporary receiver seizure by the RMMS. Therefore, this document recommends an initial monitor design which will perform remote certification of the RCO standby receivers only in order to minimize the risk of loss of communications due to monitor failure. To perform remote certification of the primary receivers, the FSS specialist selects the standby receiver for on-line operation, thereby, placing the primary receiver in standby. The next occurrence of the certification routine performed by the RMMS would measure the certification parameters of the primary receiver.

All routine receiver tests listed in table 4 should be performed on a periodic basis. The recommended interval between tests is 1 hour maximum. However, this report does recommend a remote control feature for initial monitor design, whereby maintenance personnel may initiate a receiver certification procedure from a remote work center. The tests should be performed by injecting test RF signals into the receiver front end via a directional coupler installed in the feedline at the receiver antenna terminals. The use of the directional coupler is necessary for impedance matching to the receiver (reference 5). The coupler characteristics should be: 20 dB coupling, 30 dB directivity, ±0.5 dB coupling tolerance over the frequency range of interest, insertion VSWR not exceeding 1.05:1, and insertion loss not exceeding 0.2 dB.

During a receiver test, it is necessary for the monitor to continually sense PTT of the associated transmitter. If PTT occurs, the monitor should immediately abort the receiver test in progress and commence the transmitter measurement sequence. The data from the particular receiver test that was interrupted by PTT should be discarded.

Parameters Required for Remote Certification. The parameters discussed below are those required for remote certification.

1. Sensitivity. Receiver sensitivity is defined as the RF test level required to obtain a ratio of signal (modulation on) to noise (modulation off) of 10 dB in the receiver audio output (reference 9). The receiver must be capable of a minimum audio power output at the sensitivity threshold. For the GRR series receivers, the sensitivity measurement should be combined with the minimum audio output measurement. Combining these two tests greatly simplifies the problem of automating the sensitivity measurement. One disadvantage of combining the two tests is that the receiver audio gain control must be adjusted for a maximum (full clockwise). At this gain setting, the receiver supplies full audio output typically exceeding +20 dBm. However, the required telephone interface levels are 0 to -10 dBm. Therefore, it is imperative that attenuators be installed at the receiver audio output terminals in order to equalize the receiver audio output level to the required telephone line input levels.

The monitor initiates a receiver test by programming the signal generator to inject an RF test signal at the receiver's center frequency and modulated 1000 Hz at 30 percent into the receiver's front end. The level of the test signal is -110 dBm. The monitor delays 120 ms after the generator output stabilizes (to allow for AGC action in the receiver), checks the receiver's AGC and squelch testpoints, and measures the audio output level. The reason for sensing the AGC testpoint is given in the section entitled "AGC Threshold." If the squelch is unbroken or the audio level is less than +19.5 dBm, the monitor programs the signal generator to increase its output by 1 dB. All other programmed parameters remain unchanged.

After the subsequent 120 ms delay, the squelch and AGC test points are checked and the audio level is again measured. This sequence repeats until squelch breaks. The sequence iteration is stopped momentarily and the test RF level that caused squelch break is stored as the squelch threshold. The iteration is restarted, and continues until the audio output level reaches or exceeds +19.5 dBm. The monitor stops the sequence iteration and programs the signal generator to remove the modulation from the test RF signal. The receiver audio output level is again measured. The level should be below +9.5 dBm. If it is not, the sequence of increasing the unmodulated test RF level and measuring the receiver audio level is restarted and repeats until the audio level falls below +9.5 dBm due to receiver quieting. The test RF level at which this happens is considered to be the sensitivity rating of the receiver.

The maximum RF test signal level used in this test should not exceed -90 dBm. If a receiver cannot pass the sensitivity test at this level it should be considered faulty, and the RMMS should report the failure as alarm condition.

The receiver audio output level may be measured on pins C and D in connector J-2 on the rear of the receiver chassis. This is a balanced output. Therefore, the measuring device should have a high impedance balanced (ungrounded) input.

Receiver modification is required to provide a monitor point for the squelch indication. The modification would consist of installing a wire on the squelch testpoint, which is located behind the receiver front panel access door, and routing the wire to a terminal board on the rear of the receiver chassis. Note that the technique described for making the maximum power output measurement is subject to verification in subtask 2 of the task 9 effort.

2. Squelch Threshold. The level of the sequch threshold was obtained in the sensitivity measurement. For details, see the previous section.

3. AGC Threshold. The AGC threshold of the receiver is defined as the RF input level where audio throttling action begins (reference 9). The AGC threshold of the GRR series receivers may be measured by observing the receiver AGC voltage (pin F of the remote interface connector J-2) on the rear of the receiver chassis. The quiescient value of the AGC voltage is typically 1.7 ± 0.1 volts (squelch on) or 2.9 ± 0.3 volts (squelch off). At the RF input level where audio throttling action begins, the AGC voltage deflects up to 4 ± 0.5 volts.

During the receiver sensitivity test, the monitor senses the AGC testpoint. By doing so, the AGC threshold test may be performed concurrently with the sensitivity test. The threshold measurement occurs in the portion of the sensitivity test where the level of the test RF signal is increased in 1 dB steps and the test points are checked. The RF level (about -100 dBm), which causes the AGC voltage to increase suddently from its quiescient value up to approximately 4 volts, is tagged by the monitor as the AGC threshold.

4. AGC Control. The function of the AGC control of a receiver is to keep the receiver audio output voltage constant with large changes in the incoming RF signal level. The measurement procedure is as follows. The monitor programs the signal generator to inject a test RF signal modulated 1000 Hz at 30 percent into the receiver at the receiver's center frequency. The level of the RF signal is -91 dBm. The monitor waits 120 ms after the generator output stabilizes, and measures the receiver audio output voltage. This value is stored. The monitor then programs the signal generator to increase its output by 10 dB. After the 120 ms delay, the receiver audio voltage is measured, and is compared with the stored

audio voltage lever produced by the receiver with an RF input level of -93 dBm. This sequence repeats until the output of the signal generator reaches 0 dBm. If, in any sequence iteration, the measured audio voltage differs from the stored value by more than 4 dB, the test is aborted and the receiver is considered faulty. The maximum value of the audio voltage that occurred in the test is stored by the monitor to be reported along with a go/no go indication of AGC action.

5. Selectivity. The receiver selectivity test makes use of the squelch threshold measurement obtained previously. The measurement procedure for this test is identical to the IF selectivity measurement procedure for the BUEC equipment and will not be repeated here.

6. Receiver Center Frequency. This parameter is calculated, not measured. The calculation is made by adding the two 6 dB IF skirt frequencies and dividing by two (reference 9). The result of this calculation is stored for reporting by the monitor.

7. IF Nonsymmetry. The percentage of IF nonsymmetry is calculated using the equation:

$$\left[\frac{\Delta F_1}{\Delta F_2} - 1\right] \text{ X } 100 \text{ percent}$$

Where

ΔF_1 = difference between receiver center frequency and lower 60 dB skirt frequency

ΔF_2 = difference between receiver center frequency and upper 60 dB skirt frequency

if $\Delta F_2 > \Delta F_1$ use $\left[\frac{\Delta F_2}{\Delta F_1} - 1\right]$ X 100 percent

Parameters Required for Remote Maintenance. The parameters which are discussed next are listed in table 4 and are considered necessary for remote maintenance of the RCO receivers.

1. Oscillator Output Frequency. Several factors exist which can cause a receiver to be off frequency. One of these is mistuning of the filter and/or frequency multiplier modules (see next section), and another is drift in the local oscillator (LO) module. To distinguish drift in the LO requires measuring the LO output frequency by means of the frequency counter used to measure transmit frequency. The receiver modification required to provide an LO output testpoint consists of removing the coaxial cable from the oscillator output and installing a miniature directional coupler in the RF path. The modification is simple because the cable mates the oscillator output via a threaded type SMC RF connector.

2. On-Line Receiver Sensitivity. Based on work performed at the Technical Center, it has been shown that it is both technically and economically feasible to monitor certain receiver parameters without seizing the receiver (reference 4). The measurements described in the reference cited were performed while the receiver was on-line, and at no time caused interference to simulated ATC operations.

The on-line sensitivity measurement is made by injecting a low level (typically -125 dBm) modulated RF signal into the receiver's front end. A phase locked loop (PLL) detector sensing the audio testpoint of the receiver provides an indication when it locks onto demodulated audio from the test signal. The measurement procedure is as follows. The monitor programs the signal generator to inject a test signal modulated 1000 Hz at 100 percent. The signal generator is tuned to the receiver center frequency and the initial level is -130 dBm. The monitor delays 100 ms after the generator output stabilizes and checks the PLL for lock indication. If the PLL is not locked, the RF output is increased by 1 dB. After the 100 ms delay the PLL is again checked. This sequence is repeated until either the monitor receives a PLL lock indication or the RF generator output reaches -110 dBm. At no time should the maximum signal level injected into an on-line receiver, at the receiver's center frequency, exceed -110 dBm. If, during a sequence iteration the monitor receives a lock indication, the RF level of the signal generator is stored by the monitor. The monitor then uses the stored value to calculate a sensitivity figure equivalent to one, determined in a 10 dB signal plus noise-to-noise ratio measurement. See appendix E for the relationship of the two measurements. If the receiver cannot pass this test, it should be considered marginal and a warning reported from the monitor.

3. On-Line Selectivity. The on-line selectivity test is made by injecting a low level test RF signal modulated 1000 Hz at 30 percent into the receiver. The test RF signal amplitude is 6 dB higher than the sensitivity measurement obtained in the previous test. The frequencies of the test signal are predetermined 6 dB skirt frequencies of the receiver, and are stored in monitor memory.

The test sequence is as follows. The monitor programs the signal generator to inject the test signal into the receiver at the lower 6 dB skirt frequency. After a 100 ms delay, the monitor checks the PLL for a lock indication. If the loop is locked, the monitor issues a programming command to the RF signal generator to tune to the upper 6 dB skirt frequency of the receiver. Again, the monitor delays 100 ms and checks for lock indication. Failure to detect PLL lock at either skirt frequency constitutes a failure of this test and a warning should be issued by the monitor.

Evaluation of the on-line bandwidth measurement using test receivers at the Technical Center has proven the technique effective in detecting local oscillator drift in addition to asymmetrical failure in the crystal filter assembly. The purpose of the on-line sensitivity and bandwidth tests is to alert the FSS specialist to possible degraded performance in his primary RCO equipment. He may then select the backup receiver and initiate a request for a full certification measurement by the RMM.

Both the on-line sensitivity and selectivity tests should be performed while the monitor checks the receiver squelch and AGC outputs. The squelch output should be constantly checked during a test because the tests must be aborted immediately whenever an incoming signal is being received, which is indicated by squelch break, to prevent interference to FSS functions. The AGC output should be checked before and after each test in case ambient noise levels are sufficient to affect the low level measurements, but are not sufficient to break squelch. The monitor may use the AGC information to distinguish a low level test failure caused by ambient noise from a receiver fault.

4. Main/Standby Status. The main/standby status of a receiver is essential information for the monitor to prevent a full certification test to be performed on an on-line receiver. A convenient method for the monitor to sense the status of the receiver is by sensing the contacts on the antenna transfer relay. If spare relay contacts are not available, the monitor may detect the relay coil voltage.

LIMITED REMOTE COMMUNICATIONS OUTLET.

BACKGROUND. The term LRCO is no longer used officially in the FAA, even though many still recognize it. The term has been replaced by "RCO with VORTAC."

At RCO (with VORTAC) facilities, the transmit function is provided by the broadcast function of the VOR transmitters; the receive function is provided by one or two fixed frequency receivers. Thus, an additional communications channel is provided to the FSS.

Monitoring of the VOR transmitter certification parameters will be provided by the internal RMM capability of the second generation VORTAC/distance measuring equipment (DME) systems (reference 13). The internal monitoring is sufficient to encompass required certification parameters for the communications function provided by the VOR. Therefore, this document will not address the certification parameters of the LRCO transmitter.

The LRCO receive function is provided by GRR series receivers identical to those at RCO facilities. Currently, supplementary standby receivers are not required at all LRCO facilities. Under the FSS modernization program, however, standby receivers will be required making the LRCO receiver configuration identical to the RCO. Consequently, the technique for providing RMM for RCO receivers applies also to the LRCO receivers. The discussion of the Monitoring technique will not be repeated here, but may be found in the section entitled "Method of Receiver Parameter Measurement," (page 23).

SINGLE FREQUENCY OUTLET.

BACKGROUND. The SFO is used primarily for ground-to-ground communications between FSS specialists and pilots. A secondary function of the SFO is to provide ground-to-air communications when the aircraft is below the coverage of the primary frequency.

The SFO is either a wall-mounted or a pole-mounted facility which consists of a shelter and an antenna assembly. The shelter contains a solid-state transmitter (AN/GRT-21-22 series) and a solid-state receiver (AN/GRR-23/24 series). One-for-one backup of the transmitting and receiving equipment is not required. Also, certification of the equipment is not required, and restoration (after an outage) is given the lowest priority possible (reference 14).

The SFO radio parameters which require monitoring were not selected with the intent of providing remote certification because the facility does not require it. Rather, an attempt was made to provide maximum parameter information at minimum cost by using the GFE sensors in the transmitters. The A-3 Inboard Monitor/Keyer Card is installed in the transmitters and enables monitoring of several key transmission parameters. Refer to the section "Remote Communications Outlet" for a more complete discussion of the A-3 card.

TABULATION OF RADIO PARAMETERS. The parameters listed in table 5 are those recommended to provide a performance profile of the SFO facility.

TABLE 5. SUMMARY OF SFO PARAMETERS RECOMMENDED FOR REMOTE MONITORING

Transmitter:

- Forward power
- Antenna VSWR
- Percent modulation
- Audio input level
- Transmit frequency

Receiver:

- Audio output level
- Sensitivity

METHOD OF TRANSMITTER PARAMETER MEASUREMENT. All transmitter parameters except transmit frequency (discussed separately) may be measured each time a given transmitter is keyed. The monitor may sense PTT at the A-3 card PTT output. PTT should be sensed by the monitor before and after each transmitter parameter measurement cycle to insure that the transmitter remained keyed during the entire test cycle.

The discussion for the measurement of parameters including forward power, antenna VSWR, percent modulation, and audio input level is identical to the discussion for the RCO parameters. To avoid repetition, the discussion is not presented here. For reference see the section "Remote Communications Outlet."

Transmit Frequency. This parameter is not measured directly. The measurement will be made by feeding a sample of the transmitter oscillator output into the receiver front end. Note that the oscillator frequency is one-half the operating frequency of the transmitter. The oscillator output contains a second harmonic however, thus, no doubling circuitry is required.

Detection of the injected oscillator output at the receiver's audio output testpoint (see section "Receiver Sensitivity") provides an indication that the transmitter oscillator is operating on frequency.

The transmitter modification required to bring out the oscillator output consists of installing a miniature directional coupler in the transmitter at the oscillator output. For details and recommended coupler specifications see the section "Remote Communications Outlet."

Before the sampled oscillator output is injected into the receiver, it must be conditioned. The level of the second harmonic of the sampled oscillator output is nominally -45 dBm. The "on frequency" RF signal level required in the receiver sensitivity test is -125 dBm. Therefore, additional attenuation of 80 dB is required. Also, additional circuitry is required to provide modulation and on/off switching of the sampled oscillator output. The modulation capability is required in the receiver sensitivity test, and the on/off switching capability is necessary so that the monitor can switch off the RF injected into the receiver, thereby, preventing interference to FSS communications.

The measurement of the transmitter frequency should occur on a periodic basis, e.g., once per hour. The measurement must not occur while the transmitter is keyed or while receiver squelch is broken. Therefore, the monitor must sense the A-3 PTT output and the receiver squelch testpoint. If either becomes active, the monitor must immediately abort the test and switch off, via the previously described conditioning circuitry, the RF sample injected into the receiver.

METHOD OF RECEIVER PARAMETER MEASUREMENT.

1. Audio Output Level. This parameter should be monitored while the transmitter is keyed, because the transmitter modulation will be detected by the receiver and provides a vehicle for measuring the audio power output. The audio output level measurement should be both a peak and an average power measurement, easily implemented using digital signal processing.

2. Receiver Sensitivity. This measurement will be primarily a go/no go indication of receiver performance. The measurement technique is very similar to the on-line sensitivity measurement described for the RCO receivers, in that both measurements are made by injecting a low level test RF signal into the receiver front end and detecting it using a PLL at the receiver audio testpoint. In the RCO measurement, it is fixed at -125 dBm due to limited sophistication in the monitor circuitry.

The SFO receiver measurement sequence is as follows. The monitor checks PTT and squelch. If neither is active, the monitor programs the oscillator conditioning circuitry to inject a test RF signal into the receiver via a directional coupler in the antenna feedline at the receiver antenna terminals. For details and coupler specifications see the receiver measurement discussion in section "Remote Communications Outlet." The RF test signal is modulated 1000 Hz at 100 percent and the RF level at the receiver antenna terminals is -125 dBm. The monitor delays 150 ms after issuing the programming command, and then checks the PLL for lock indications. If the PLL is locked, the monitor reports a "go" indication for this test. If the PLL is not locked, the monitor checks the receiver AGC voltage. AGC voltage of 3 volts or more indicates the presence of ambient noise or RF of sufficient amplitude to affect the sensitivity measurement, but not sufficient to break squelch. Therefore, the sensitivity measurement cannot be performed until the interfering signals and/or noise abates, and the monitor indicates this by reporting a no go indication along with the measured AGC voltage. In case the PLL did not lock and AGC was 3 volts or less, the monitor reports a no go condition and issues a warning of marginal receiver performance.

The receiver modification required to perform this test consists of installing leads to the squelch and AGC testpoint (located on the rear of the receiver front panel access door), and routing them to a terminal strip on the rear of the receiver chassis.

If, during a sensitivity measurement, the receiver squelch breaks, the test should be aborted immediately.

DIRECTION FINDER.

BACKGROUND. A DF is a system which provides unambiguous bearing information of aircraft. The purpose of the DF is to assist air traffic personnel in locating lost or distressed aircraft and vectoring aircraft to an airport by the most direct route.

There are four types of DF equipment currently in use by the FAA:

FA-9964
FA-5530
CA-3300
FA-7000

The last two, CA-3300 and FA-7000, are older units due to be replaced. The FA-5530 is a tube type DF and is not specifically considered for RMM. The FA-9964 is a solid-state DF intended to replace all existing tube units. The theory of operation of the FA-9964 is identical to the FA-5530. Therefore, if RMM of some existing FA-5530 DF's is required in the interim before they are replaced, the recommendations for remote monitoring of the FA-9964 may be applied to both systems. The remainder of this section will be concentrated on the FA-9964 DF. Any use of the term "DF system" will refer to the 9964 unless otherwise noted.

The DF system employs a 16-dipole antenna array with electronic switching to simulate antenna rotation. Thus, the antennas are stationary, but the point of reception rotates, imparting a phase modulation to the incoming signal, according to the Doppler principal (reference 15). By comparing the phase of this modulation component with the phase of a reference signal synchronous with the antenna rotation, the bearing of the incoming signal may be unambiguously determined.

The DF system (figures 7 and 8) is manufactured by Servo Corporation, Hicksville, New York. The first 9964 DF's were delivered to the FAA in 1981, with an expected life cycle exceeding 20 years.

The DF's contain BITE which provides the operator with an automated performance check of the system (reference 16). The DF BITE is capable of detecting failures in the system parameters and/or functions listed in table 6.

The description of each monitor function is given in the discussion of the pertinent DF subsystem presented next.

The 9964 DF is comprised of four subsystems:

Antenna Assembly
Receiver/Bearing Processor Assembly
Bearing Display/Control Assemblies
Target Transmitter Assembly

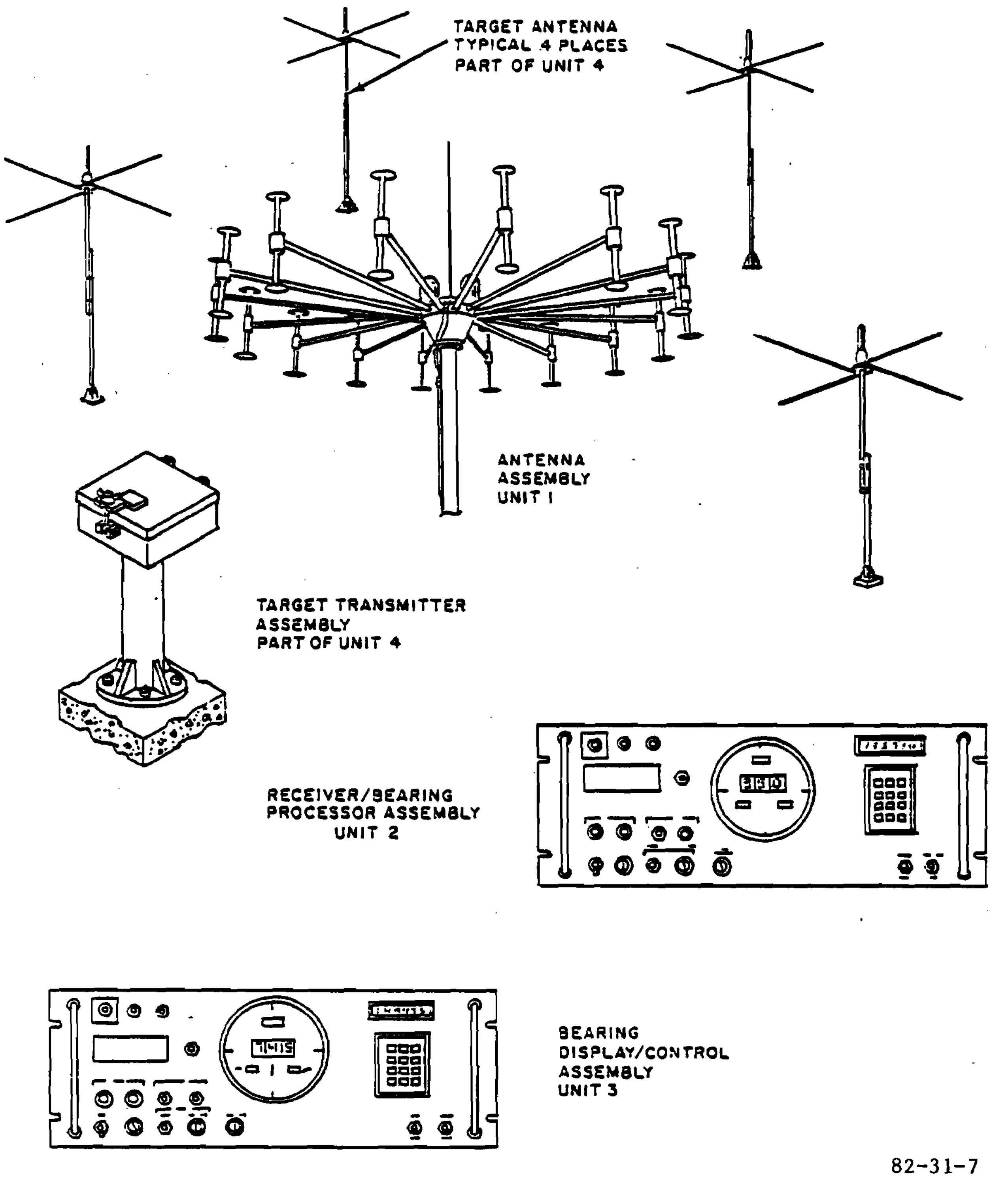

FIGURE 7. DIRECTION FINDER SYSTEM

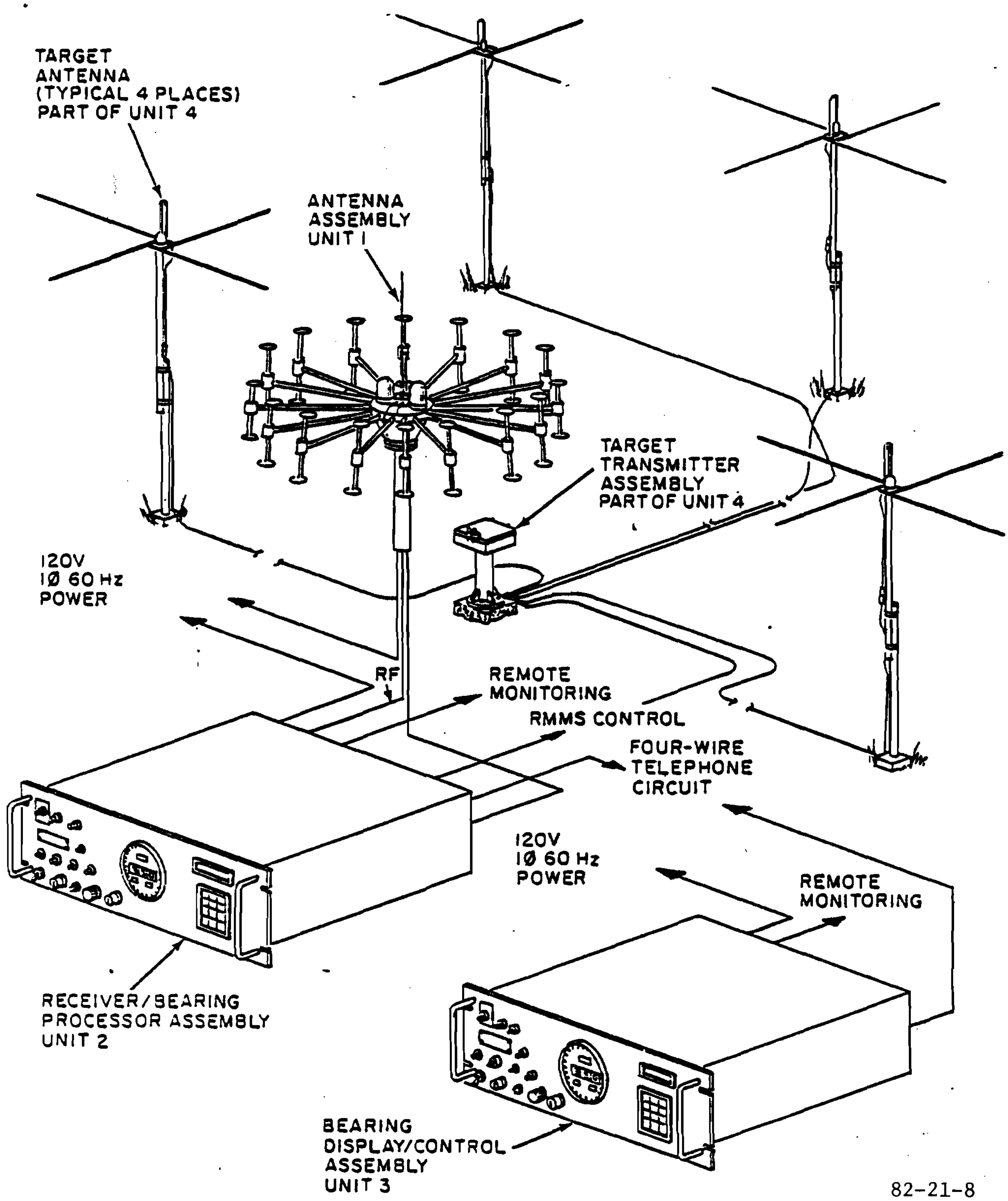

FIGURE 8. DIRECTION FINDER SYSTEM INTERCONNECTION

TABLE 6. BITE-MONITORED DF SYSTEM FUNCTIONS

1. Digital remote control and indicator modems
2. Synthesized local oscillator
3. Monitored power supplies
4. Antenna
5. Receiver RF and IF stages
6. All analog to digital encoding/decoding

1. Antenna Assembly. This assembly is comprised of 16 vertical dipoles evenly spaced in a circle, a hub assembly which contains an RF preamp along with commutation circuits, and a supporting mast. The antennas are sequentially switched on and off (commutated) by applying a train of d.c. pulses to the commutation circuitry in the hub assembly. The circuitry that generates the d.c. commutation pulses has a built-in monitoring function which measures the average current of the pulses. If 1 or more of the 16 dipoles are either open or shorted, the monitoring function will detect the decrease or increase in the commutation current. Thus, limit failure of any of the 16 dipoles in the antenna assembly is detected.

Degraded antenna performance not detected in this test is detected through the use of the Test Target assembly which sequentially injects RF into the DF from four survey points, causing bearing information to be displayed by the DF. Incorrect bearing information from any of the four survey points indicates either a failure in the bearing processor or degraded condition of one or more dipoles. Self-checks in the bearing processor assembly eliminates processor suspicion when the antenna assembly is actually at fault. Thus, antenna condition (table 6) is established through the use of the DF BITE. Antenna failure is indicated by displaying dashes in the digits of the front panel bearing display.

2. Receiver/Bearing Processor Assembly. This is actually two assemblies: a communications receiver and a data extractor and processor. The receiver is a VHF receiver which may be tuned to any of 720 channels spaced every 25 kHz. The LO for the receiver is derived from a frequency synthesizer. The synthesizer performs self-checks to detect an "out-of-lock" condition which would result in LO output at an incorrect frequency. The synthesized LO is phase locked to a stable reference oscillator. Instability or drift in the reference oscillator would also cause incorrect LO frequency, hence, receiver mistuning. This condition would not be detected by the synthesizer self-check, but would be detected in the Test Target check. Thus, the tuning of the receiver (table 6) is monitored by the DF BITE. The BITE indicates an out-of-lock condition by blanking the digits in the front panel frequency display.

The receiver RF and IF stages are monitored by measuring the noise at the IF output in the absence of an incoming signal. A sudden decrease in the RMS noise from a predetermined level indicates a failure in an RF or IF stage and is detected by the BITE. The condition is indicated by blanking the digits in the front panel bearing display.

The bearing processor (part of the receiver/bearing processor assembly) consists of analog and digital circuitry which processes the DF information at the receiver IF output. The DF information is contained in a 216-Hz phase modulation component (imparted by the antenna rotation) in the incoming RF signal. The bearing processor extracts the phase of the 216-Hz modulation component and compares it to the phase of the antenna commutation pulse train. The phase difference is converted directly to bearing information. The performance of the phase extractor and phase comparator/bearing indicator is monitored by the DF BITE. The comparator/indicator is tested by injecting a BITE generated variable phase signal (simulating an incoming RF signal) into the bearing processor. When the System Test function is actuated, the front panel bearing indicator displays the bearing of the simulated RF signal, which precesses at 3° increments throughout the full 360°. The bearing processor (table 6) is monitored by the BITE.

3. Bearing Display/Control Assemblies. These assemblies provide display of bearing information, as well as keyboard entry of DF control functions (e.g., receiver frequency control). Remote control and indication between the local and remote displays is established via FSK data modems in each indicator. Tone encoded digital data is transmitted at 300 baud using the speech over data technique. Loss of data due to telephone line noise, carrier loss, modem failure, etc., is detected by the BITE and displayed via a front panel incandescent lamp labeled "Alarm."

Power supply failure in any of the assemblies is detected by BITE and indicated by causing all bearing display assembly front panel lamps to illuminate and flash at regular intervals.

4. Target Transmitter Assembly. This assembly consists of a crystal oscillator operating at 135.850 megahertz (MHz), four monopole antennas, and an RF switch. Activation of the DF RMMS Test causes power to be applied to the oscillator and the RF switch to route the oscillator output to one of the four monopole antennas. That antenna becomes a target at a known bearing which the operator can use to verify the DF bearing indication. The remainder of the RMMS test consists of sequentially activating the other three target antennas while the operator inspects the bearing display. The entire DF is checked at four survey points.

TABULATION OF CRITICAL RADIO PARAMETERS. The parameters listed in table 7 are required for performance assurance of the DF equipment (reference 13). If these parameters are remoted, then the maintenance technician will be able to complete the Facility Equipment Log (FAA form 6530-2) remotely from a central work center and, thereby, perform remote certification of the DF.

TABLE 7. SUMMARY OF PARAMETERS REQUIRED FOR DF PERFORMANCE ASSURANCE

1. Ground check
2. Sensitivity
3. Selectivity
4. Squelch threshold
5. Control oscillator error
6. AFC

Additional parameters necessary for remote maintenance of the DF are monitored by the DF BITE. These parameters (table 6) are sufficient to perform remote maintenance. Therefore, no additional parameters are recommended.

METHOD OF PARAMETER MEASUREMENT. All measurements by the external monitor will be performed by injecting an RF test signal into the DF receiver front end. The injection port should be a directional coupler installed in the antenna feedline at the receiver antenna terminals. The test signal must be phase modulated at a rate of 216 Hz as if it were received by the DF antenna assembly.

To integrate the external monitor performance checks with the DF BITE, it is necessary to provide remote control of all external monitor functions. Also, interconnection between the monitor and the DF should be provided so that the monitor can activate the DF BITE function. This interconnection consists of two wires.

All tests of the external monitor should be performed on at least three frequencies in use at the DF facility. If less than three frequencies are normally used, then each frequency should be certified at least once weekly.

1. Ground Check. Current FAA policy requires a ground check at a minimum of 4 survey points (and a maximum of 16) equally spaced around the DF (reference 13). This test is accomplished by the DF BITE. Test data and control are transferred via FSK data between the remote receiver/bearing processor and the local bearing display/control assembly. The format for the FSK data is 11-bit ASCII and is shown in tables 8 and 9. The monitor should sense the data transmitted from the remote site by detecting the FSK pilot tones at the remote telephone lines interface in order to extract the transmitted bearing data. Then, during a ground check the monitor may verify the bearing information from a test target antenna.

2. Sensitivity. The sensitivity of the DF receiver is defined in FAA "Blue Sheet" standards from a communications viewpoint. The acceptance criterion is the ability of the receiver to produce a minimum signal-to-noise ratio in the audio output with a threshold RF input level. This document recommends that the acceptance criterion be changed to include the requirement that the correct DF bearing must be indicated at the threshold RF input level.

The sensitivity measurement should be made during the BITE RMMS test to minimize interference to operations. All automated sensitivity and squelch testing by the monitor requires slightly over 1 second. By combining the BITE RMM with the external monitor RMM, the time required to certify the DF is minimized.

The sensitivity test should be performed by injecting an RF test signal into the directional coupler installed in the antenna feedline. The test signal should be phase modulated to cause a DF bearing indication, other than the bearing of any of the test target transmitters. The sensitivity and squelch measurement sequence is essentially identical to the sequence described for the GRR series receivers described in the section entitled "Remote Communications Outlet," and only the procedural difference is presented here. At the sensitivity threshold of the receiver, the monitor should delay 0.4 seconds and verify the bearing indication by sampling the transmitted bearing message of the DF FSK data.

3. Selectivity. The FAA order which contains DF maintenance procedures calls for a selectivity measurement at 40 kHz either side of the channel frequency. This requirement must be changed to ±12 kHz for the FAA-9964 because the IF bandwidth of the new DF is 25 kHz.

TABLE 8. REMOTE TO LOCAL CHARACTER FORMAT

11-Bit ASC II Format

	Data					Prefix					
Word/ Function	LSB Start	B1	B2	B3	MSB B4	LSB B5	B6	B7	Par	Stp	MSB Stp
C/R	0	1	0	1	1	0	0	0	0	1	1
L/F	0	0	1	0	1	0	0	0	1	1	1
100 MHz	0	X	X	X	X	1	1	0	X	1	1
10 MHz	0	X	X	X	X	1	1	0	X	1	1
1 MHz	0	X	X	X	X	1	1	0	X	1	1
0.1 MHz	0	X	X	X	X	1	1	0	X	1	1
0.01 MHz	0	X	X	X	X	1	1	0	X	1	1
Control	0	IS1	IS2	IS3	IS4	0	0	1	X	1	1
Control (Spare)	0	X	X	X	X	1	0	1	X	1	1
Spare	0	X	X	X	X	1	1	0	X	1	1
Spare	0	X	X	X	X	1	1	0	X	1	1
Spare	0	X	X	X	X	1	1	0	X	1	1

X = Data dependent

TABLE 9. STATUS CHARACTER FORMAT

Local-to-Remote Status Code			Remote-to-Local Control Code	
High	Low	Bit No.	High	Low
QDR	QDM	1S4	QDR	QDM
Signal present	Squelched	1S3	Squelch off	Squelch on
Antenna normal	Antenna alarm	1S2	Manual	Preset
Synthesizer lock	No lock	1S1	Normal	Test
Valid data	Invalid data	2S4		
Remote	Local	2S3	Not used all bits high	
Test OK	Test alarm	2S2		
Spare	Spare	2S1		

The selectivity measurement should be made immediately after the sensitivity measurement. The selectivity measurement procedure is given here. The monitor programs the signal generator to inject a test signal (RF level = -90 dBm, modulation same as sensitivity test) into the receiver first 12.5 kHz above the channel frequency used in the sensitivity test. After a 0.4 second delay, the monitor samples the bearing information in the DF FSK data message. The bearing indication must be within ±3° of the bearing indication obtained in the sensitivity test.

If it is, the test is repeated at 12.5 kHz below the channel frequency. Failure to pass this test indicates asymmetrical IF bandpass characteristics, which could result in degraded receiver sensitivity due to noise capture of the control oscillator (reference 13).

4. Squelch Threshold. This parameter is measured during the sensitivity test. For a description refer to the discussion of the "Sensitivity" test.

5. Control Oscillator Error. The FA-9964 does not employ a control oscillator as does the older FA-5530. Instead, the third local oscillator is phase locked to the incoming RF signal to keep it centered in the IF bandpass. Local oscillator error is indicated by degraded bearing sensitivity, and is detected in the receiver sensitivity test.

6. AFC. Complete automation of this parameter is not recommended. The tuning of the RF front end and IF stages is accomplished by components not subject to drift.

VERY HIGH FREQUENCY OMNIRANGE/TACTICAL AIR NAVIGATIONAL AID.

The existing VORTAC/DME systems in the field are due to be replaced by solid-state versions with internal RMM capabilities (reference 13). Therefore, VORTAC/DME systems will not be discussed here.

COMMUNICATIONS AIR-TO-GROUND.

The radio equipment and associated monitoring techniques used in A/G communications at FSS's are identical to the equipment at RCO's. Therefore, the discussion contained in the section about RCO applies and will not be repeated here.

VERY HIGH FREQUENCY OMNIRANGE EQUIPMENT.

BACKGROUND. The VOT facility provides a stable accurate means for determining the status of a VHF omnirange (VOR) receiver. The VOT operates in the range of 108 to 118 MHz, and is composed of a transmitter, antenna, monitor, and remote alarm unit. Existing VOT equipment, FAA type CA-1710, is tube equipment due to be replaced by new solid-state VOT's scheduled for late 1983 or mid-1984 delivery.

A contract for the development of the new generation VOT has been awarded but is currently in the early planning stage. Although the contract calls for RMM provisions in the new equipment, nothing definite has been established. Therefore, this report will address the VOT with the purpose of providing guidelines for the implementation of RMM.

TABULATION OF CRITICAL RADIO PARAMETERS. The parameters listed in table 10 are required for performance assurance of the VOT (reference 17). If these parameters are remoted, then the maintenance technician will be able to complete the Facility Equipment Log (FAA form 418-34) from a central work center and, thereby, perform remote certification of the VOT.

TABLE 10. SUMMARY OF PARAMETERS REQUIRED FOR VOT PERFORMANCE ASSURANCE

1. Power output
2. VSWR*
3. Modulation percentage

    a. Reference signal
    b. Variable signal
    c. Identification tone

4. Phase shift
5. Carrier frequency
6. Modulation frequencies

*Note: AFS plans to include a high power (35 W) option in new VOT's, making VSWR a critical parameter.

At this time, no parameters are recommended for remote maintenance of the VOT due to the lack of information concerning the design philosophy of the new equipment.

METHOD OF PARAMETER MEASUREMENT. The first three parameters in table 10, power output, VSWR, and modulation percentage are easily measured by using an inline DPD. The FWD and DPD outputs may be processed during either analog or digital techniques (the latter is recommended) to derive the parameter values. Recommended DPD specifications may be found in appendix B.

1. Phase Shift. This parameter refers to the difference in phase between the 30 Hz reference signal and 30 Hz variable phase signal. This phase shift must not exceed 1° in order to provide sufficient accuracy in the VOR receiver test function.

The phase shift measurement is made by sampling the transmitter RF output, and by frequency modulation (FM) and amplitude modulation (AM) demodulating the fixed and variable phase modulation components. Phase comparison of the demodulated components is performed at audio frequencies (30 Hz). The characteristics of the demodulator and phase comparator circuitry should be such to permit measurement in 0.5° increments with an accuracy of ±0.1°.

2. Carrier Frequency. This parameter is measured using essentially the same techniques described previously for the communications equipment and will not be repeated here.

3. Modulation Frequencies. The frequency of the 30 Hz fixed and variable phase signals, 9960 Hz subcarrier and 1020 Hz identification, tone may be measured at

the DPD output (30 Hz variable, 1020, 9960 Hz components) or the discriminator output (30 Hz fixed component) used in the phase shift measurement.

Plans for the next generation VOT's include voice modulation capability. This report recommends that the VOT contain circuitry to bandwidth limit the incoming voice modulation to a range 300 to 2400 Hz in order to prevent audio crosstalk at 30 or 9960 Hz.

PART II — TEST FUNCTIONAL MODULE DEFINITION

In this section, like parameters of the systems described in part I, will be grouped together to define a family of TFM's. Where possible, applications for the defined TFM's in systems other than those in part I will be pointed out.

The first group includes the following:

Forward Power
Reflected Power
Percent Modulation
Audio Input Level
PTT Detect (BUEC)
Telephone Line Noise Level

The recommended TFM for this group consists of an RF power sensor (defined in appendix B), bridging network for the transmitter audio input, and electronics to perform all analog to digital conversion, data processing, and input/output (I/O) data formatting. In monitors of GRT series transmitters, the RF power sensor and bridging network functions may be accomplished by the A-3 card (see "Remote Communications Outlet"). It is envisioned that the RF power sensor and bridging network (or A-3) card will be located at the transmitter, and all conditioning electronics will be contained on a printed circuit board (PCB) installed in the EQM chassis. At present, it is felt that one TFM will be capable of monitoring up to four transmitters operating simultaneously. This number may change as the TFM development phase proceeds. To the extent possible, processing of the raw parameter data will be done digitally, thereby, reducing cost by eliminating unnecessary hardware.

Although not developed in the study of part I, an additional parameter, voice quality, is being considered for remote monitoring. No additional sensors would be required for this parameter. The actual voice quality evaluation would be made in software by processing the percent modulation and audio input level data. The proposed technique for voice quality evaluation is to treat the transmitter's detected modulation and voice audio input as random processes, and determine each process characteristic (e.g., ensemble average). Comparison of the characteristics of each process will indicate whether the transmitter modulation is a faithful reproduction or a distorted version of the input audio. At this time, however, the cost versus benefits ratio of the voice quality evaluation is not known. Part of the TFM development phase will be to implement the measurement in order to determine its economic feasibility.

The TFM (defined in this section) comprised of the RF sensor, bridging network, and electronics may be also used to monitor certain key parameters of the markers, glide slope, and localizer of an instrument landing system (ILS).

The second parameter group which defines a TFM is given next:

TRANSMITTER FREQUENCY.

RECEIVER LOCAL OSCILLATOR FREQUENCY. This TFM would consist of an RF sampling probe, an electronic frequency counter, and associated timing and data formatting electronics. The sampling probe is either a directional coupler installed in the antenna feedline, or an isolation network connected to the transmitter or receiver oscillator output (see the discussion in part I). Inexpensive electronic frequency counters are available which afford sufficient accuracy over the range 10 Hz to 550 MHz. It is envisioned that the RF sampling probe will be located at the transmitter or receiver and the frequency counter PCB; the PCB containing the associated electronics will be installed in the EQM chassis. One frequency counter will be able to monitor five transmitters operating simultaneously.

This TFM may be used in other continuous wave (CW) systems, such as ILS, and may also be used with some additional hardware in pulsed systems of up to 1100 MHz carrier frequency. The additional required hardware consists of a PLL and a prescaler circuit. The PLL provides a CW signal identical in frequency to the RF pulses, and the prescaler circuit divides the PLL output frequency by two.

The third parameter group which defines a TFM is listed below.

ALL RECEIVER CERTIFICATION PARAMETERS.

This TFM consists of a signal generator, isolated pickup probes, and electronics for analog-to-digital conversion, data processing, and data I/O formatting. The isolated pickup probes must be high impedance nonloading probes necessary to prevent loading of receiver testpoints. The signal generator should be a synthesized signal source and must be able to accept programming commands. One possible signal generator configuration is to mix a low frequency synthesizer, operating at 30 MHz, with the receiver local oscillator output in order to derive the test frequency. This technique appears attractive because all the receiving equipment discussed in part I employs IF frequencies of 30 MHz or below. A frequency synthesizer operating at 30 MHz could be implemented with large scale integration (LSI) technology at reasonable cost.

The only foreseeable problem with this technique is spurious noise in the receiver local oscillators. If the phase noise in the test signal injected into the receiver exceeds -110 decibels below the carrier (dBc)/Hz, accurate, precise measurements of the 60 dB selectivity ratio of the receiver will not be possible. This technique of mixing a low frequency synthesizer with the receiver LO will be investigated in the TFM development phase.

The isolated pickup probes will be at the receiver. The signal generator PCB and associated electronics PCB will be installed in the EQM chassis. Note that the functions performed by the timing and formatting electronics associated with the frequency counter may be combined with the functions associated with the signal generator.

CONCLUSIONS

The development and production of remote monitoring equipment consistent with the guidelines established in this report is technically feasible. It is further concluded that remote certification, remote maintenance, and remote control is within the scope of the development effort for a Remote Monitoring System for communications/navigation systems associated with Flight Service Stations.

RECOMMENDATIONS

1. It is recommended that the TFM development phase (subtask 2 of task 9) proceed in order to verify the procedures and techniques described in this report.

2. The TFM development should be performed at the Technical Center to centralize expertise, and to create a data base as monitoring obstacles are overcome.

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13. VOR/VORTAC Equipment Replacement and Facility Modernization, Part 1, General Requirements, FAA Specification FAA-E-2678/1, February 1978.

14. Restoration of Operational Facilities, FAA Order 6030.31.

15. Maintenance of Direction Finder (DF) Equipment, FAA Order 6530.3C, February 1978.

16. Direction Finder, Instruction Book, TI6530.9.

17. Maintenance of VHF Omnitest (VOT) Equipment, FAA Order 6810.1, April 1975.

APPENDIX A

SIMPLIFIED EQUATIONS FOR PARAMETER MEASUREMENTS

Antenna VSWR is calculated using the expression

$$S = \frac{V_{max}}{V_{min}} \qquad \text{(A-1)}$$

where

V_{max} = peak of the standing wave

V_{min} = trough of the standing wave

S = VSWR

VSWR may also be expressed as

$$S = \frac{V_F + V_R}{V_F - V_R} \qquad \text{(A-2)}$$

where

V_F = forward RF voltage

V_R = reflected RF voltage

If a power sensor with an output directly proportional to antenna line voltage is used in the VSWR measurement, equation A-2 becomes

$$S = \frac{V_i + V_r}{V_i - V_r} \qquad \text{(A-3)}$$

where V_i and V_r are the forward and reflected sensor outputs.

Equation A-3 holds only if the sensor sampling probes are spaced less than 0.03 wavelengths apart on the transmission line. If the spacing condition is met, the line impedance at each probe is esentially the same. Therefore, VSWR caculations may be made using equation A-3 provided the sensor output is RF voltage linear and the probes are closely spaced.

Modulation percentage is calculated by:

$$\text{Percent Modulation} = \left[\frac{V'max - V'min}{V'max + V'min}\right] X\ 100 \text{ percent} \qquad \text{(A-4)}$$

where

$V'max$ = maximum RF voltage in modulation envelope
$V'min$ = minimum RF voltage in modulation envelope

$$\text{Percent Modulation} = \frac{(Vcarrier + Vpk) - (Vcarrier - Vpk)}{(Vcarrier + Vpk) + (Vcarrier - Vpk)} \times 100 \text{ percent} \quad \text{(A-5)}$$

where

Vcarrier = RF carrier voltage
Vpk = peak modulation voltage

$$\text{Percent Modulation} = \frac{2Vpk}{2Vcarrier} \quad \text{(A-6)}$$

$$\text{Percent Modulation} = \frac{Vpk}{Vcarrier} \quad \text{(A-7)}$$

If the power sensor has an output characteristic directly proportional to RF voltage, then equation A-7 becomes:

$$\text{Percent modulation} = \frac{Vipk}{Vi}$$

where

Vi = d.c. component of forward sensor output
Vipk = peak a.c. component of forward sensor output

The level of the forward and reflected power on the antenna feedline in given by:

$$Pfwd = \beta Vi^2 \quad \text{(A-8)}$$
$$Prev = \beta Vr^2 \quad \text{(A-9)}$$

where

Vi = forward sensor output
Vr = reverse sensor output
β = proportionality constant determined by the sensor characteristics

Equations A-8 and A-9 hold for sensors with voltage-linear output characteristics.

APPENDIX B

DERIVATION OF ERROR TOLERANCES FOR FORWARD AND REFLECTED RF POWER MEASUREMENTS

This discussion will emphasize maintaining the forward power output level to within 1 dB of the value reported by the monitor.

Figure B-1 shows the apparent antenna VSWR seen by the transmitter (horizontal scale) for several conditions of actual antenna VSWR (see curves) and feedline loss (vertical scale). Figure B-2 shows the limits of a change in VSWR required to produce a 1 dB change in radiated power. For example, if the actual antenna VSWR were 1.6:1, a 1 dB reduction in forward power would result if the VSWR changed to approximately 3:1. In an antenna system with 3 dB feedline loss, the transmitter would "see" the VSWR change from 1.26 to 1.67:1. Thus, excessive VSWR conditions may be masked by feedline loss. A power sensor located at the transmitter must be capable of accurately measuring reflected power.

Directivity and tolerance are two measures of the performance of a power sensor. Directivity refers to the sensor's ability to discriminate between forward and reflected feedline power; tolerance refers to the deviation in the sensor output from a specified transfer characteristic. Table B-1 shows the worse case expected VSWR measurement error resulting from the effects of directivity and tolerance. Note the error range in table B-1 is given as ±. This means that the calculated VSWR may be greater or less than the actual VSWR seen at the transmitter.

The error in the sensor forward power measurement is essentially a function of the tolerance. It may be shown that the error contribution from directivity is less than 1 percent for sensor directivities of 25 dB or more. Therefore, there are two major error causing mechanisms which could mask a 1 dB change in forward transmitter power. One is error in the forward power measurement itself, and the other is error in detecting return loss due to excessive VSWR.

Next, an attempt is made to use the information contained in figures B-1 and B-2 to derive maximum error limits for the forward power and VSWR measurements. The maximum tolerable combined error due to return loss and forward sensor tolerance is 1 dB or 26 percent. As a worse case condition, assume an antenna feedline loss of 4 dB and an antenna VSWR increase from 1:1 to 2.6:1 (figure B-1). The VSWR change seen at the transmitter is 1:1 to 1.4:1 (figure B-2). The percent VWSR change is:

$$V = \frac{S' - S}{S'} \qquad \text{(B-1)}$$

$$V = \frac{1.4 - 1}{1.4}$$

$$V = 28 \text{ percent}$$

where V = change in VSWR required to cause a 1 dB decrease in forward power (see figure B-2 then B-1).

VSWR measurement error of 28 percent could mask this change. Therefore, to illuminate the change and provide a 50 percent "gray region" on the VSWR measurement, a VSWR measurement error of ±14 percent is required. Next, the error in the forward power measurement is considered:

$$E_{rL} = |14| - |E_f| \qquad \text{(B-2)}$$

where

ErL = return loss measurement error
E_f = VSWR error contribution from forward sensor measurement error

Using 3 percent for E_f (Note: E_f = ±3 percent with VSWR = 2.5:1 and forward sensor error = ±3 percent), the allowable error in the VSWR measurement becomes:

$$E_{rL} = |14| - |3| = 11 \text{ percent} \qquad \text{(B-3)}$$

The absolute value brackets in equation B-3 are necessary because the magnitudes of the error terms are additive. Therefore, recommended error tolerances for the forward power and VSWR measurements are:

Error - forward power = ±3 percent
Error - VSWR = ±11 percent = 22 percent full range

Recommended power sensor specifications may now be derived from table B-1. For a worse case condition, assume a worse case VSWR seen by the transmitter = 2.5:1.

Tolerance = 3 percent (some manufacturers state this parameter as 1.5 percent power tolerance.

Forward Directivity = 30 dB

Reverse Directivity = 33 dB minimum

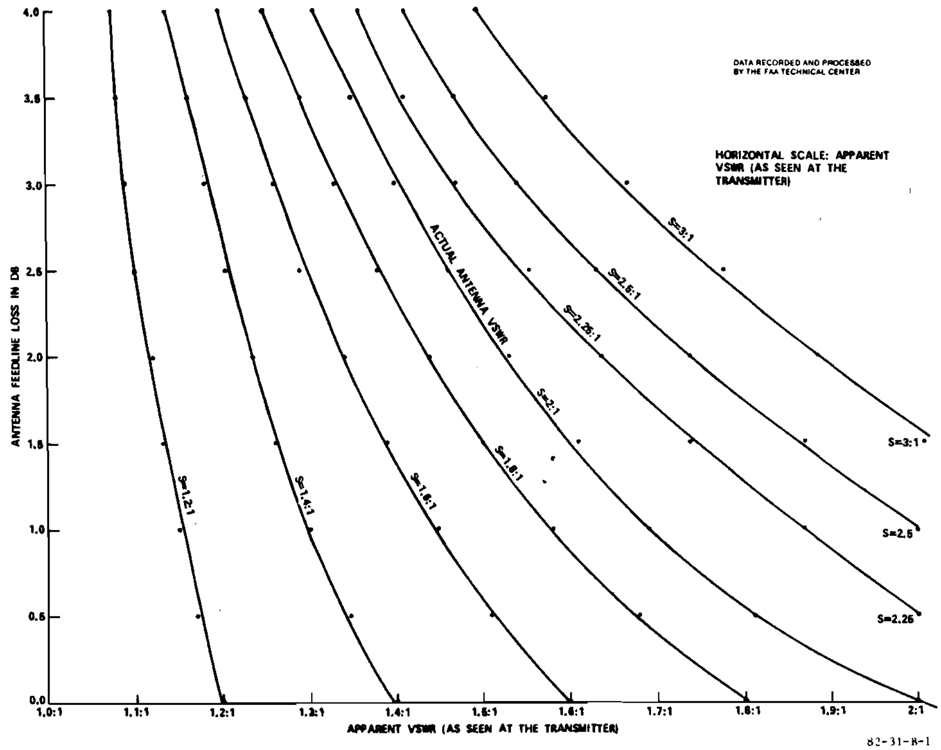


FIGURE B-1. APPARENT VSWR FOR ACTUAL ANTENNA VSWR AND FEEDLINE LOSS

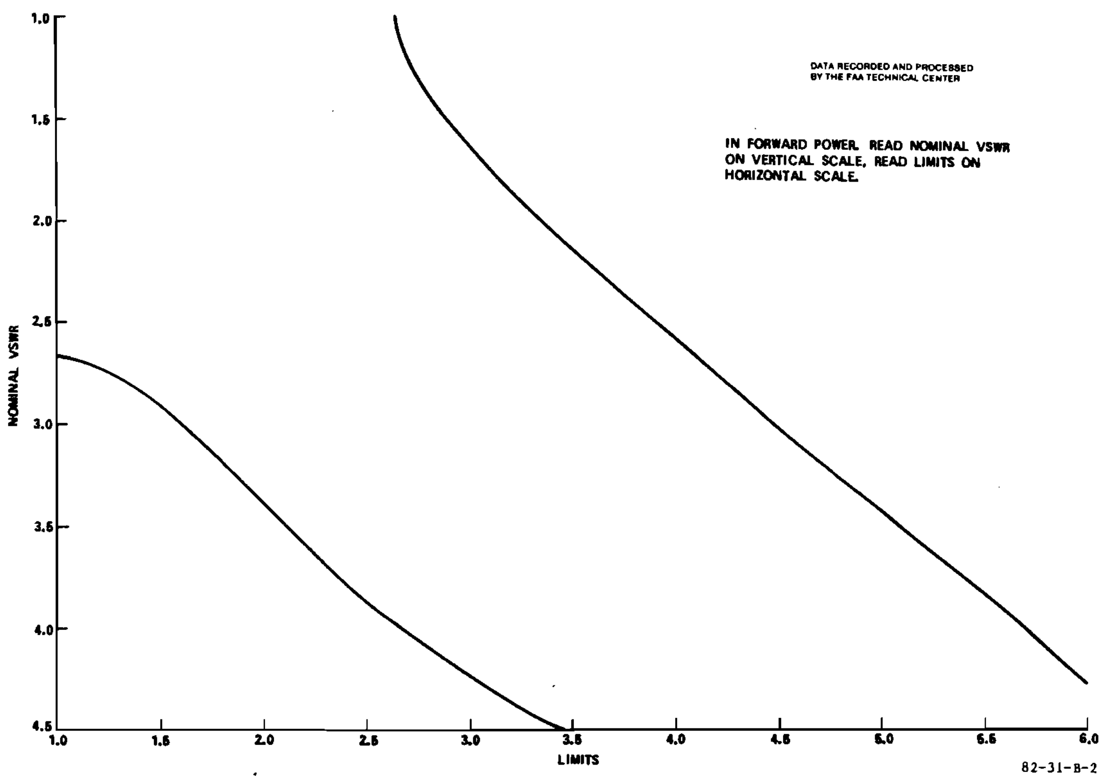


FIGURE B-2. VSWR LIMITS REQUIRED FOR 1 dB CHANGE

TABLE B-1. WORSE CASE ERROR VERSUS SEVERAL CONDITIONS OF VSWR, COUPLER TOLERANCE AND COUPLER DIRECTIVITIES (SHEET 1 OF 4)

VSWR OF 1.5:1

REVERSE DIRECTIVITY

ERROR %

FWD. DIR.	TOL. ±%	25	27	29	31	33	35	37	39	41	43	45	47	49	51
	1.0	31.05	25.78	20.92	17.13	14.13	11.77	9.90	8.40	7.22	6.29	5.54	4.95	4.49	4.11
	2.0	33.61	27.38	22.52	18.71	15.71	13.34	11.46	9.97	8.78	7.85	7.10	6.51	6.04	5.67
20	3.0	35.20	29.01	24.14	20.31	17.30	14.92	13.03	11.54	10.35	9.41	8.67	8.07	7.60	7.23
	4.0	36.80	30.67	25.77	21.93	18.90	16.51	14.62	13.12	11.93	10.98	10.24	9.64	9.17	8.80
	5.0	38.79	32.35	27.42	23.55	20.51	18.11	16.21	14.71	13.51	12.57	11.82	11.22	10.75	10.37
	1.0	31.43	25.24	20.42	16.62	13.63	11.27	9.39	7.91	6.73	5.79	5.05	4.46	3.99	3.62
	2.0	33.06	26.86	22.01	18.21	15.21	12.83	10.96	9.47	8.29	7.35	6.60	6.01	5.54	5.17
25	3.0	34.74	28.49	23.62	19.80	16.79	14.41	12.53	11.03	9.85	8.91	8.16	7.57	7.10	6.73
	4.0	36.43	30.14	25.24	21.40	18.38	16.00	14.11	12.61	11.42	10.48	9.73	9.14	8.67	8.29
	5.0	38.14	31.80	26.89	23.03	19.99	17.59	15.70	14.19	13.00	12.06	11.31	10.71	10.24	9.87
	1.0	31.14	24.96	20.13	16.34	13.35	10.99	9.11	7.63	6.45	5.51	4.77	4.18	3.71	3.34
	2.0	32.78	26.57	21.72	17.92	14.92	12.55	10.67	9.19	8.01	7.07	6.32	5.73	5.27	4.89
30	3.0	34.44	28.19	23.33	19.51	16.50	14.12	12.24	10.75	9.57	8.63	7.88	7.29	6.82	6.45
	4.0	36.12	29.84	24.95	21.11	18.09	15.71	13.82	12.32	11.14	10.20	9.45	8.86	8.39	8.01
	5.0	37.83	31.50	26.58	22.73	19.70	17.30	15.41	13.91	12.72	11.77	11.02	10.43	9.96	9.58
	1.0	30.90	24.80	19.97	16.10	13.10	10.83	8.96	7.47	6.29	5.36	4.61	4.02	3.56	3.18
	2.0	32.62	26.40	21.56	17.76	14.76	12.39	10.52	9.03	7.85	6.91	6.17	5.58	5.11	4.74
35	3.0	34.27	28.03	23.17	19.35	16.34	13.97	12.08	10.59	9.41	8.47	7.73	7.13	6.66	6.29
	4.0	35.96	29.67	24.78	20.95	17.93	15.56	13.66	12.16	10.98	10.04	9.29	8.70	8.23	7.85
	5.0	37.66	31.33	26.42	22.57	19.53	17.14	15.25	13.75	12.56	11.61	10.86	10.27	9.80	9.42
	1.0	30.80	24.71	19.88	16.00	13.11	10.74	8.87	7.38	6.20	5.27	4.53	3.94	3.47	3.10
	2.0	32.52	26.31	21.47	17.67	14.67	12.30	10.43	8.94	7.76	6.82	6.08	5.49	5.02	4.65
40	3.0	34.18	27.94	23.07	19.26	16.25	13.88	11.99	10.50	9.32	8.38	7.64	7.05	6.58	6.20
	4.0	35.86	29.57	24.69	20.86	17.84	15.46	13.57	12.07	10.89	9.95	9.20	8.61	8.14	7.76
	5.0	37.56	31.23	26.32	22.47	19.44	17.05	15.16	13.66	12.47	11.52	10.77	10.18	9.71	9.33
	1.0	30.84	24.66	19.83	16.04	13.06	10.69	8.82	7.33	6.16	5.22	4.48	3.89	3.42	3.05
	2.0	32.47	26.26	21.42	17.62	14.62	12.25	10.38	8.89	7.71	6.77	6.03	5.44	4.97	4.60
45	3.0	34.13	27.89	23.02	19.21	16.20	13.83	11.94	10.45	9.27	8.33	7.59	7.00	6.53	6.15
	4.0	35.80	29.52	24.64	20.81	17.79	15.41	13.52	12.02	10.84	9.90	9.15	8.56	8.09	7.71
	5.0	37.50	31.18	26.27	22.42	19.39	17.00	15.10	13.60	12.42	11.47	10.72	10.13	9.66	9.28
	1.0	30.81	24.63	19.81	16.02	13.03	10.66	8.79	7.31	6.13	5.19	4.45	3.86	3.39	3.02
	2.0	32.44	26.23	21.39	17.59	14.60	12.23	10.35	8.86	7.68	6.75	6.00	5.41	4.94	4.57
50	3.0	34.10	27.86	22.99	19.18	16.17	13.80	11.92	10.42	9.24	8.30	7.56	6.97	6.50	6.13
	4.0	35.77	29.49	24.61	20.78	17.76	15.38	13.49	12.00	10.81	9.87	9.12	8.53	8.06	7.69
	5.0	37.47	31.15	26.24	22.39	19.36	16.97	15.08	13.58	12.39	11.44	10.69	10.10	9.63	9.25

TABLE B-1. WORSE CASE ERROR VERSUS SEVERAL CONDITIONS OF VSWR, COUPLER TOLERANCE AND COUPLER DIRECTIVITIES (SHEET 2 OF 4)

VSWR OF 2 : 1

FWD. DIR.	TOL. ±%	25	27	29	31	33	35	37	39	41	43	45	47	49	51
		REVERSE DIRECTIVITY — ERROR %													
20	1.0	31.27	25.93	21.74	18.43	15.82	13.75	12.11	10.81	9.78	8.96	8.31	7.80	7.39	7.06
	2.0	33.93	28.54	24.31	20.98	18.35	16.27	14.62	13.31	12.29	11.46	10.80	10.29	9.80	9.55
	3.0	36.63	31.18	26.91	23.55	20.90	18.81	17.15	15.84	14.80	13.97	13.32	12.80	12.38	12.06
	4.0	39.39	33.87	29.56	26.17	23.49	21.38	19.71	18.39	17.34	16.51	15.86	15.33	14.91	14.58
	5.0	42.19	36.61	32.24	28.82	26.12	23.99	22.30	20.97	19.91	19.07	18.41	17.88	17.46	17.13
25	1.0	29.79	24.39	20.22	16.92	14.32	12.26	10.63	9.33	8.30	7.49	6.84	6.33	5.92	5.59
	2.0	32.33	26.97	22.76	19.45	16.83	14.76	13.12	11.82	10.79	9.97	9.32	8.80	8.39	8.07
	3.0	34.90	29.59	25.34	22.00	19.37	17.29	15.64	14.33	13.29	12.47	11.82	11.30	10.89	10.56
	4.0	37.71	32.24	27.96	24.59	21.93	19.83	18.17	16.86	15.82	14.99	14.33	13.81	13.40	13.07
	5.0	40.47	34.94	30.61	27.21	24.53	22.41	20.74	19.42	18.37	17.53	16.87	16.35	15.93	15.60
30	1.0	28.02	23.53	19.37	16.00	13.48	11.43	9.80	8.50	7.48	6.66	6.01	5.50	5.09	4.77
	2.0	31.43	26.10	21.90	18.69	15.99	13.92	12.28	10.99	9.96	9.14	8.49	7.97	7.57	7.24
	3.0	34.08	28.89	24.47	21.14	18.51	16.44	14.79	13.49	12.45	11.63	10.98	10.46	10.05	9.72
	4.0	36.78	31.33	27.07	23.71	21.07	18.97	17.32	16.01	14.96	14.14	13.48	12.97	12.55	12.23
	5.0	39.52	34.01	29.79	26.32	23.65	21.54	19.87	18.56	17.50	16.67	16.01	15.49	15.08	14.75
35	1.0	28.34	23.05	18.89	15.61	13.01	10.96	9.33	8.04	7.01	6.20	5.56	5.04	4.63	4.31
	2.0	30.94	25.61	21.42	18.12	15.51	13.45	11.81	10.52	9.49	8.67	8.02	7.51	7.10	6.78
	3.0	33.57	28.20	23.99	20.66	18.03	15.96	14.32	13.01	11.98	11.16	10.51	9.99	9.58	9.26
	4.0	36.28	30.83	26.57	23.22	20.58	18.49	16.84	15.53	14.49	13.66	13.01	12.49	12.08	11.76
	5.0	38.99	33.49	29.20	25.82	23.15	21.06	19.38	18.07	17.02	16.19	15.53	15.01	14.60	14.27
40	1.0	28.06	22.78	18.62	15.35	12.75	10.70	9.07	7.78	6.75	5.94	5.29	4.78	4.37	4.04
	2.0	30.66	25.33	21.15	17.85	15.25	13.19	11.55	10.25	9.23	8.41	7.76	7.25	6.84	6.51
	3.0	33.29	27.92	23.71	20.39	17.77	15.69	14.05	12.75	11.71	10.90	10.24	9.73	9.32	8.99
	4.0	35.97	30.54	26.29	22.95	20.31	18.22	16.57	15.26	14.22	13.40	12.74	12.23	11.81	11.49
	5.0	38.69	33.20	28.91	25.54	22.86	20.70	19.11	17.79	16.75	15.92	15.26	14.74	14.33	14.00
45	1.0	27.91	22.63	18.47	15.20	12.60	10.55	8.92	7.63	6.60	5.79	5.14	4.63	4.22	3.89
	2.0	30.50	25.18	21.00	17.70	15.10	13.04	11.40	10.11	9.08	8.26	7.61	7.10	6.69	6.37
	3.0	33.13	27.76	23.55	20.24	17.61	15.54	13.90	12.60	11.57	10.75	10.10	9.58	9.17	8.85
	4.0	35.80	30.38	26.14	22.79	20.15	18.07	16.42	15.11	14.07	13.25	12.59	12.08	11.66	11.34
	5.0	38.52	33.04	28.75	25.39	22.72	20.62	18.96	17.64	16.60	15.77	15.11	14.59	14.18	13.86
50	1.0	27.82	22.54	18.39	15.11	12.52	10.47	8.84	7.55	6.52	5.71	5.06	4.55	4.14	3.82
	2.0	30.41	25.09	20.92	17.62	15.02	12.95	11.32	10.02	9.00	8.18	7.53	7.02	6.61	6.29
	3.0	33.04	27.68	23.47	20.15	17.53	15.46	13.82	12.51	11.48	10.66	10.01	9.50	9.09	8.76
	4.0	35.71	30.29	26.05	22.71	20.07	17.98	16.33	15.02	13.99	13.16	12.51	11.99	11.58	11.25
	5.0	38.43	32.95	28.66	25.29	22.64	20.53	18.87	17.56	16.51	15.69	15.03	14.51	14.09	13.78

TABLE B-1. WORSE CASE ERROR VERSUS SEVERAL CONDITIONS OF VSWR, COUPLER TOLERANCE AND COUPLER DIRECTIVITIES (SHEET 3 OF 4)

VSWR OF 2.5:1

REVERSE DIRECTIVITY — ERROR %

FWD. DIR.	TOL. ±%	25	27	29	31	33	35	37	39	41	43	45	47	49	51
	1.0	36.09	30.44	26.03	22.58	19.83	17.68	15.97	14.62	13.55	12.70	12.03	11.49	11.07	10.73
	2.0	39.83	34.00	29.60	26.00	23.33	21.15	19.43	18.06	16.98	16.13	15.45	14.91	14.40	14.14
20	3.0	43.67	37.81	33.25	29.60	26.90	24.68	22.94	21.56	20.46	19.60	18.91	18.37	17.94	17.60
	4.0	47.61	41.63	36.90	33.36	30.51	28.27	26.50	25.11	24.00	23.12	22.43	21.90	21.44	21.10
	5.0	51.68	45.56	40.82	37.12	34.22	31.94	30.15	28.73	27.60	26.72	26.01	25.45	25.01	24.66
	1.0	33.15	27.58	23.22	19.79	17.00	14.96	13.25	11.91	10.85	10.01	9.34	8.80	8.38	8.05
	2.0	36.81	31.15	26.73	23.27	20.53	18.38	16.67	15.32	14.25	13.40	12.72	12.19	11.77	11.43
25	3.0	40.55	34.80	30.31	26.80	24.03	21.85	20.13	18.76	17.68	16.83	16.15	15.61	15.18	14.84
	4.0	44.39	38.52	33.96	30.40	27.59	25.38	23.64	22.26	21.16	20.30	19.61	19.07	18.64	18.29
	5.0	48.34	42.35	37.70	34.07	31.22	28.98	27.21	25.81	24.70	23.83	23.13	22.58	22.14	21.80
	1.0	31.53	25.99	21.66	18.25	15.56	13.43	11.74	10.40	9.34	8.50	7.83	7.30	6.88	6.55
	2.0	35.15	29.53	25.15	21.70	18.98	16.84	15.14	13.79	12.72	11.88	11.21	10.67	10.25	9.92
30	3.0	38.84	33.14	28.69	25.20	22.45	20.29	18.57	17.21	16.14	15.29	14.61	14.07	13.65	13.31
	4.0	42.63	36.82	32.30	28.76	25.98	23.78	22.05	20.68	19.59	18.73	18.05	17.51	17.08	16.74
	5.0	46.52	40.59	35.99	32.39	29.57	27.34	25.59	24.20	23.10	22.23	21.54	20.99	20.56	20.21
	1.0	30.63	25.11	20.79	17.39	14.70	12.58	10.89	9.56	8.50	7.66	6.99	6.46	6.04	5.71
	2.0	34.22	28.63	24.26	20.83	18.12	15.97	14.28	12.94	11.87	11.03	10.36	9.83	9.40	9.07
35	3.0	37.89	32.22	27.79	24.31	21.57	19.41	17.70	16.35	15.28	14.43	13.75	13.22	12.79	12.45
	4.0	41.65	35.87	31.38	27.85	25.08	22.89	21.17	19.80	18.72	17.86	17.18	16.64	16.21	15.87
	5.0	45.50	39.62	35.04	31.46	28.65	26.43	24.68	23.30	22.21	21.34	20.65	20.11	19.67	19.33
	1.0	30.12	24.62	20.30	16.90	14.22	12.10	10.42	9.08	8.02	7.18	6.52	5.99	5.57	5.24
	2.0	33.70	28.13	23.77	20.34	17.63	15.49	13.80	12.46	11.39	10.55	9.88	9.35	8.93	8.59
40	3.0	37.36	31.70	27.28	23.81	21.08	18.92	17.21	15.86	14.79	13.94	13.27	12.73	12.31	11.97
	4.0	41.10	35.34	30.86	27.34	24.58	22.40	20.67	19.31	18.23	17.37	16.69	16.15	15.72	15.38
	5.0	44.94	39.07	34.51	30.94	28.13	25.92	24.18	22.80	21.71	20.84	20.16	19.61	19.18	18.84
	1.0	29.84	24.34	20.03	16.63	13.95	11.83	10.15	8.82	7.76	6.92	6.25	5.72	5.30	4.97
	2.0	33.41	27.86	23.49	20.06	17.36	15.22	13.53	12.19	11.13	10.28	9.61	9.08	8.66	8.33
45	3.0	37.06	31.41	27.00	23.53	20.80	18.65	16.94	15.59	14.52	13.67	13.00	12.46	12.04	11.70
	4.0	40.80	35.05	30.57	27.06	24.30	22.12	20.39	19.03	17.95	17.10	16.42	15.88	15.45	15.11
	5.0	44.62	38.77	34.21	30.65	27.85	25.64	23.90	22.52	21.43	20.56	19.88	19.33	18.90	18.56
	1.0	29.68	24.18	19.87	16.48	13.80	11.68	10.00	8.67	7.61	6.77	6.10	5.57	5.15	4.82
	2.0	33.25	27.69	23.33	19.91	17.20	15.07	13.38	12.04	10.98	10.13	9.46	8.93	8.51	8.18
50	3.0	36.90	31.25	26.84	23.38	20.65	18.49	16.79	15.44	14.37	13.52	12.85	12.31	11.89	11.55
	4.0	40.62	34.88	30.41	26.90	24.14	21.96	20.24	18.88	17.80	16.94	16.26	15.72	15.30	14.96
	5.0	44.45	38.60	34.04	30.49	27.69	25.48	23.74	22.36	21.27	20.41	19.72	19.18	18.75	18.40

TABLE B-1. WORSE CASE ERROR VERSUS SEVERAL CONDITIONS OF VSWR, COUPLER TOLERANCE AND COUPLER DIRECTIVITIES (SHEET 4 OF 4)

A VSWR OF 3 : 1

REVERSE DIRECTIVITY

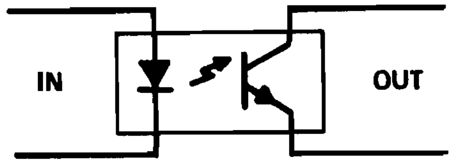
ERROR %

FWD. DIR.	TOL. ±%	25	27	29	31	33	35	37	39	41	43	45	47	49	51
	1.0	43.40	36.06	31.98	28.00	25.04	22.63	20.74	19.24	18.05	17.11	16.37	15.70	15.31	14.94
	2.0	48.44	41.82	36.72	32.74	29.63	27.18	25.25	23.73	22.53	21.57	20.82	20.22	19.74	19.37
20	3.0	53.68	46.85	41.60	37.52	34.34	31.84	29.87	28.32	27.09	26.12	25.35	24.74	24.26	23.88
	4.0	59.14	52.07	46.65	42.46	39.19	36.63	34.61	33.02	31.77	30.78	30.00	29.37	28.88	28.49
	5.0	64.87	57.62	51.91	47.50	44.21	41.57	39.50	37.87	36.59	35.57	34.77	34.13	33.63	33.23
	1.0	38.70	32.50	27.83	23.91	20.82	18.45	16.50	15.11	13.93	13.01	12.27	11.68	11.22	10.85
	2.0	43.64	37.21	32.23	28.35	25.30	22.90	21.01	19.51	18.32	17.39	16.64	16.05	15.58	15.21
25	3.0	48.67	42.06	36.96	32.99	29.90	27.44	25.51	23.99	22.79	21.83	21.09	20.49	20.01	19.63
	4.0	53.89	47.07	41.83	37.76	34.59	32.09	30.12	28.57	27.34	26.37	25.60	25.00	24.51	24.13
	5.0	59.33	52.27	46.96	42.69	39.41	36.95	34.94	33.26	32.01	31.02	30.24	29.61	29.12	28.73
	1.0	36.26	30.06	25.24	21.46	18.49	16.14	14.28	12.81	11.65	10.72	9.99	9.41	8.95	8.58
	2.0	41.03	34.70	29.78	25.94	22.92	20.54	18.66	17.18	16.00	15.07	14.33	13.74	13.28	12.91
30	3.0	45.96	39.45	34.43	30.51	27.44	25.02	23.12	21.61	20.42	19.47	18.73	18.13	17.66	17.29
	4.0	51.05	44.36	39.21	35.20	32.06	29.60	27.66	26.13	24.91	23.96	23.20	22.59	22.12	21.74
	5.0	56.36	49.44	44.14	40.02	36.81	34.29	32.31	30.74	29.51	28.53	27.76	27.14	26.66	26.27
	1.0	34.86	28.71	23.91	20.15	17.19	14.85	13.00	11.53	10.37	9.45	8.72	8.14	7.68	7.31
	2.0	39.50	33.30	28.42	24.68	21.68	19.23	17.36	15.88	14.71	13.78	13.04	12.46	11.99	11.63
35	3.0	44.46	38.02	33.03	29.14	26.08	23.68	21.79	20.29	19.10	18.16	17.42	16.83	16.36	15.98
	4.0	49.50	42.87	37.76	33.78	30.67	28.22	26.29	24.77	23.57	22.61	21.86	21.26	20.78	20.41
	5.0	54.72	47.89	42.63	38.55	35.37	32.87	30.90	29.35	28.12	27.15	26.38	25.78	25.29	24.91
	1.0	34.09	27.95	23.17	19.41	16.46	14.13	12.28	10.81	9.65	8.73	8.00	7.42	6.96	6.60
	2.0	38.70	32.52	27.66	23.85	20.86	18.50	16.63	15.15	13.98	13.06	12.32	11.74	11.27	10.91
40	3.0	43.63	37.21	32.25	28.37	25.33	22.93	21.04	19.55	18.36	17.43	16.69	16.09	15.63	15.25
	4.0	48.63	42.04	36.95	32.99	29.89	27.45	25.53	24.01	22.81	21.86	21.11	20.51	20.04	19.66
	5.0	53.82	47.02	41.88	37.74	34.57	32.08	30.12	28.57	27.35	26.38	25.62	25.01	24.53	24.15
	1.0	33.65	27.53	22.75	19.00	16.05	13.72	11.87	10.41	9.25	8.33	7.60	7.02	6.56	6.20
	2.0	38.34	32.00	27.23	23.43	20.44	18.08	16.22	14.75	13.58	12.65	11.92	11.33	10.87	10.50
45	3.0	43.16	36.77	31.81	27.94	24.90	22.51	20.62	19.13	17.95	17.01	16.27	15.68	15.22	14.85
	4.0	48.15	41.57	36.50	32.55	29.46	27.02	25.10	23.59	22.39	21.44	20.69	20.09	19.62	19.25
	5.0	53.31	46.54	41.33	37.28	34.12	31.64	29.69	28.14	26.92	25.95	25.19	24.59	24.10	23.72
	1.0	33.41	27.29	22.52	18.77	15.82	13.49	11.65	10.19	9.03	8.11	7.39	6.80	6.34	5.97
	2.0	38.09	31.86	26.99	23.20	20.21	17.85	15.99	14.52	13.35	12.42	11.69	11.10	10.64	10.27
50	3.0	42.90	36.51	31.56	27.70	24.67	22.28	20.39	18.90	17.72	16.78	16.04	15.45	14.99	14.62
	4.0	47.07	41.31	36.25	32.30	29.21	26.78	24.87	23.35	22.15	21.21	20.45	19.86	19.39	19.01
	5.0	53.03	46.27	41.07	37.03	33.87	31.39	29.43	27.89	26.68	25.71	24.95	24.34	23.86	23.49

APPENDIX C

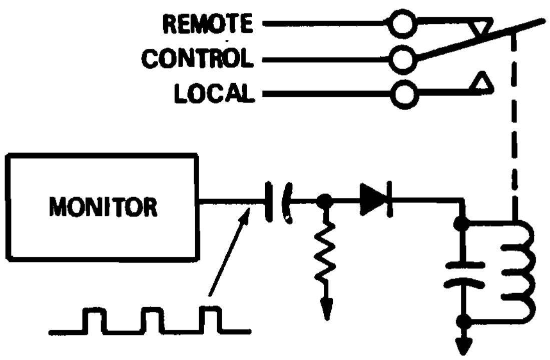
MONITOR FAILSAFE DESIGN TECHNIQUES

1. The use of optical isolators is recommended anytime a connection is to be made to facility equipment.



The optical isolator can transmit analog or digital information with virtually no metallic connection, reducing RFI, ground loops, etc.

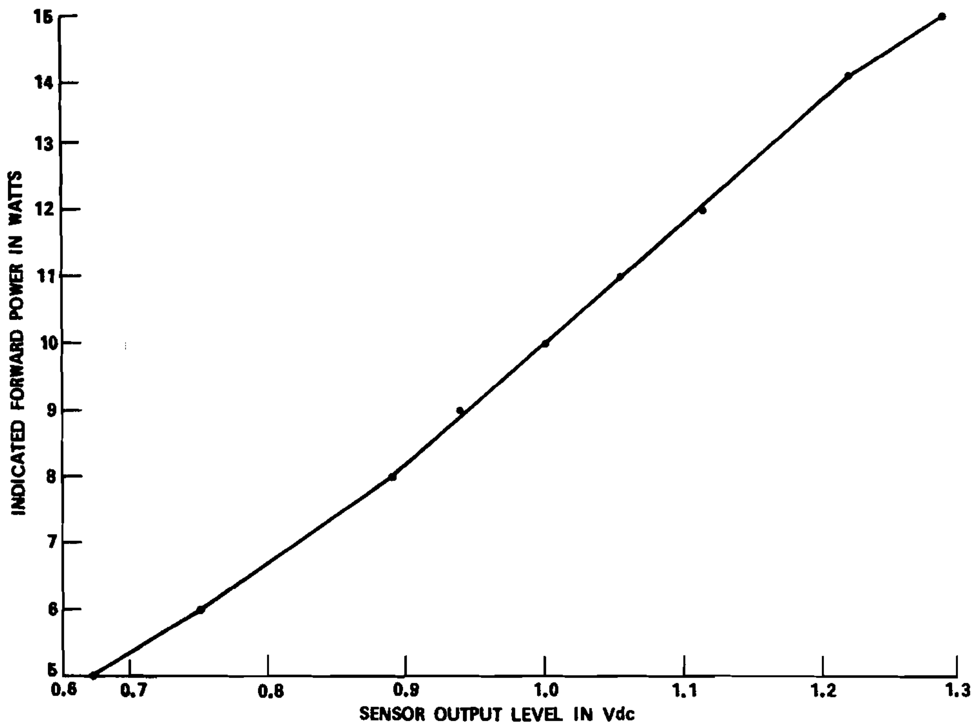
2. The circuit shown below can be used to provide seizure of radio equipment by the monitor.



To activate the relay and seize the radio, the monitor outputs a pulse train under program control. The pulses pass through the capacitor, and are rectified and filtered providing voltage to energize the relay. If, for any reason, the monitor fails to execute the program required for seizure, the pulse train ceases, the relay drops out, and the radio is restored to normal operation. For redundancy, two interlocked relays may be employed.

APPENDIX D

A-3 CARD SPECIFICATIONS



1. Output level is set for 1 Vdc ±5 mV for a 10 watt unmodulated RF carrier into a 50 ohm load. The output will change with a change of forward RF power.

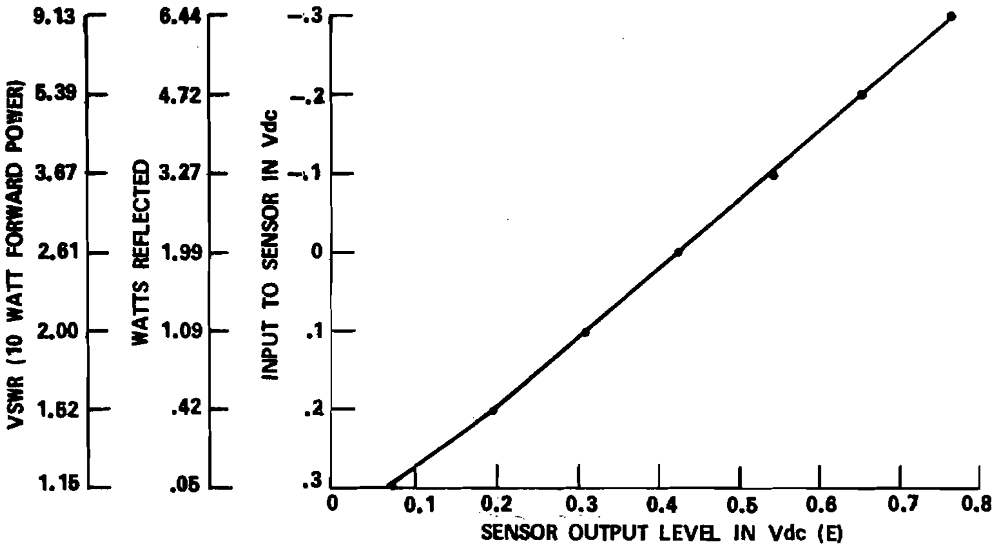
RF Power In (watts)	Sensor Output in Vdc (25° C)
5	0.650 ± 0.030
6	0.750 ± 0.030
8	0.880 ± 0.020
9	0.940 ± 0.020
10 (Set Reference)	1.000 ± 0.020
11	1.055 ± 0.020
12	1.115 ± 0.020
14	1.220 ± 0.030
15	1.290 ± 0.030

2. With the RF carrier modulated at 90 percent for test tones over the range of 0.3 to 3.0 kHz, monitor output will vary no more than ±6 mV from the 1.000 Vdc set reference level for a 10 watt unmodulated carrier.

3. Low (-29° C)/high (+55° C) temperature deviation from set reference level.

-29° C 10 watts	1.000 Vdc ± 40 mVdc
+55° C 10 watts	1.000 Vdc ± 49 mVdc

FIGURE D-1. FORWARD POWER SENSOR CHARACTERISTICS



1. Power Sensor

Input Level (Vdc)	Sensor Output in Vdc (25° C)
-0.3	0.765 ± 0.020
-0.2	0.655 ± 0.020
-0.1	0.545 ± 0.020
0 (Set Reference)	0.425 ± 0.020
+0.1	0.315 ± 0.020
+0.2	0.195 ± 0.020
+0.3	0.070 ± 0.020

2. With the RF carrier modulated at 90 percent for test tones over the range of 0.3 to 3.0 kHz, monitor output will vary no more than ±6 mV from the 0.425 Vdc set reference level for a 10 watt unmodulated carrier.

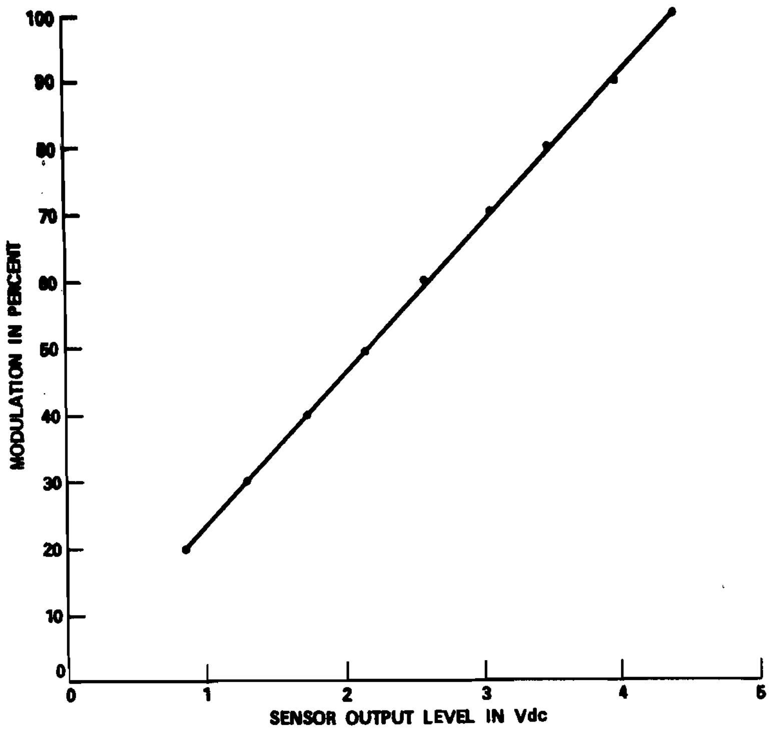
3. Low (-29° C)/high (+55° C) temperature deviation from set reference level.

-29° C 0 Vdc input	0.525 Vdc ±30 mV
+55° C 0 Vdc input	0.425 Vdc ±49 mV

4. $E^2 \times 11.0$ = watts (reflected)

5. $$VSWR = \frac{1 + \frac{\text{reflected power}}{\text{forward power}}}{1 - \frac{\text{reflected power}}{\text{forward power}}}$$

FIGURE D-2. REFLECTED POWER SENSOR CHARACTERISTICS



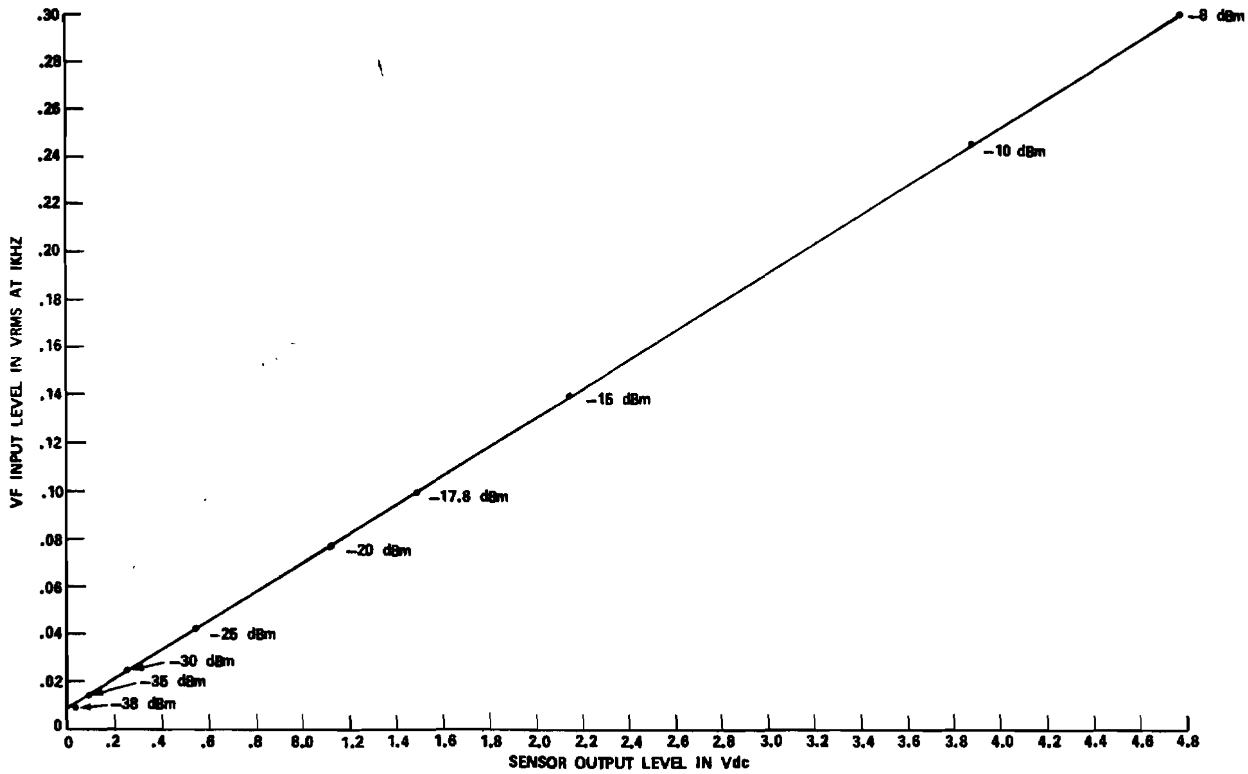
1. The modulation sensor is adjusted for 4.00 Vdc ±20 mV with a 10 watt carrier modulated at 1 kHz. A change in modulation is represented in a linear change in the monitor output level.

Percent Modulation	Sensor Output in Vdc (25° C)
20	0.85 ± 0.090
30	1.30 ± 0.090
40	1.73 ± 0.090
50	2.18 ± 0.090
60	2.60 ± 0.090
70	3.06 ± 0.090
80	3.50 ± 0.090
90 (Set Reference)	4.00 ± 0.090
100	4.42 ± 0.090

2. Low (-29° C)/high (+55° C) temperature deviation from set reference level.

-29° C 90% modulation	4.00 ±150 mV
+55° C 90% modulation	4.00 ±150 mV

FIGURE D-3. PERCENT MODULATION SENSOR CHARACTERISTICS



1. VF Input Level. The sensor output is set for 1.5 Vdc ±8 mV for an audio input of 100 mV RMS ±1 mV @ 1 kHz into an active transmitter with an RF output of 10 watts into a 50 ohm load.

Audio Input VRMS	Sensor Output in Vdc (25° C)
0.01	0.028 ± 0.010
0.014	0.080 ± 0.020
0.0245	0.245 ± 0.030
0.042	0.540 ± 0.030
0.0775	1.120 ± 0.030
0.100 (Set Reference)	1.500 ± 0.030
0.14	2.150 ± 0.040
0.245	3.900 ± 0.040
0.300	4.800 ± 0.040

2. Low (-29° C)/high (+55° C) temperature deviation from set reference level.

-29° C 100 mV RMS	1.5 Vdc ±90 mV
+55° C 100 mV RMS	1.5 Vdc ±90 mV

FIGURE D-4. VF INPUT SENSOR CHARACTERISTICS

APPENDIX E

RELATIONSHIP OF OFF-LINE TO ON-LINE RECEIVER SENSITIVITY

The signal-to-noise ratio (SNR) of the receiver audio output at the sensitivity threshold is 9.6 dB. (Note: In a 10 dB signal plus noise/noise measurement, the ratio of signal only (minus noise) to noise is 9.6 dB.) The SNR becomes 13.34 dB when the modulation of the test RF signal is increased from 30 to 100 percent. Additional SNR improvement is provided by a phase locked loop (PLL) detector able to lock onto detected audio whose amplitude is below the noise:

$$13.34 - D = \text{dB SNR}$$

where D is the PLL detection threshold.

Typically, the off-line receiver sensitivity threshold occurs at -100 dBm RF input level. If the PLL detection threshold is -10 dB, then the on-line sensitivity threshold (Ts) would be:

$$Ts = -100 \text{ dBm} - (13.34 \text{ dB} -(-10 \text{ dB}))$$
$$Ts = -100 \text{ dBm} - (13.34 \text{ dB} + 10 \text{ dB})$$
$$Ts = -123.34 \text{ dBm}$$

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