Report No. FHWA/RD-81/056

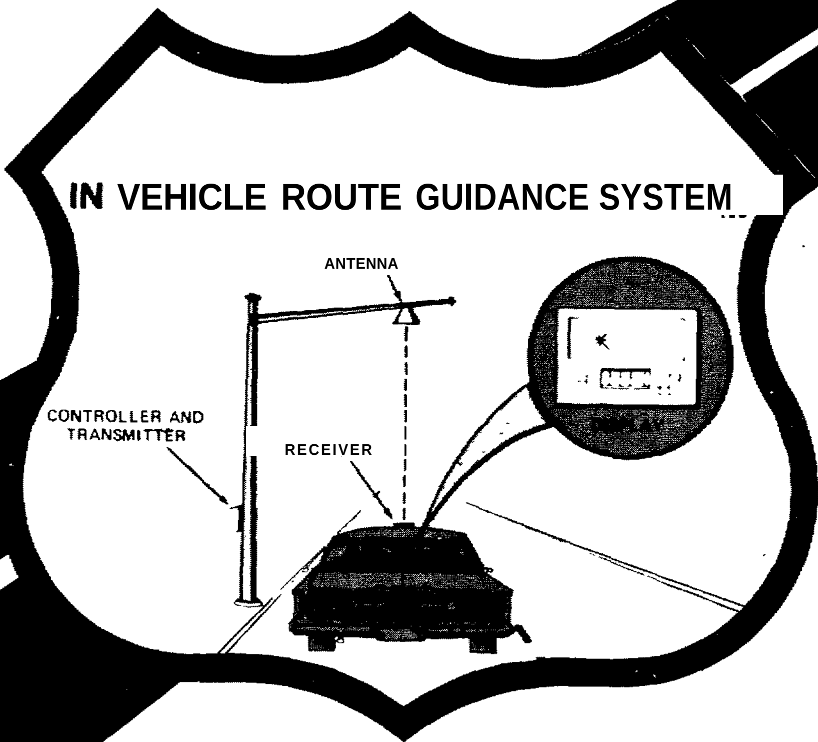
~~1200~~ 1310

STUDY OF THE FEASIBILITY AND DESIGN CONFIGURATION FOR IN-VEHICLE ROUTE GUIDANCE

Vol. II

May 1981

Final Report



Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Traffic Systems Division
Washington, D.C. 20590

150023

FOREWORD

This report presents the results of a research effort entitled "Study of the Feasibility and Design Configuration for In-Vehicle Route Guidance" performed by Sperry Systems Management Division, Great Neck, New York. The work'was conducted for the Federal Highway Administration under Contract Number DOT-FH-11-9522.

The study analyzed the need for and the feasibility of installing an In-Vehicle Route Guidance (IVRG) System in the United States. Several system concepts were studied. The concept recommended for further consideration features information transmission in one direction, from the roadside to each vehicle, using either microwave or optical communications. The study concluded that a system of appropriate design would satisfy a significant portion of the need for route guidance with a favorable benefit to cost ratio.

Basically, the recommended system would allow a driver to encode a specific destination code into the vehicle electronics at the beginning of a trip. The system would provide routing information to the driver via a dash mounted visual display, such that appropriate guidance would be provided from trip origin to destination.

Charles F. Scheffey
Director, Office of Research

NOTICE

Technical Report Documentation Page

1. Report No. FHWA/RD-81/056	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle STUDY OF THE FEASIBILITY AND DESIGN CONFIGURATION FOR IN-VEHICLE ROUTE GUIDANCE VOLUME II: FINAL REPORT		5. Report Date May, 1981
		6. Performing Organization Code
7. Author(s) R. L. Gordon, B. Soicher, E. Donaldson		8. Performing Organization Report No. GF-3704-1083(NP)
9. Performing Organization Name and Address Sperry Systems Management Sperry Corporation Great Neck, New York 11020		10. Work Unit No. (TRAIS) FCP 32L3-043
		11. Contract or Grant No. DOT-FH-11-9522
12. Sponsoring Agency Name and Address Office of Research Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code T-0412

15 Supplementary Notes

FHWA Contract Manager: King Roberts (HRS-32); Subcontractor: Georgia Institute of Technology, Engineering Experiment Station, Atlanta, Ga. 30332

16 Abstract

This study analyzed the need for and the feasibility of installing an In-Vehicle Route Guidance System.

The study concluded that a system of appropriate design would satisfy a significant portion of the need for route guidance with an appropriate benefit to cost ratio and appropriate net benefits.

Several systems were studied and two were considered in great detail. The system which was recommended for further consideration features information transmission in one direction, from the roadside to the vehicle. Either microwave or optical communications may be used. Vehicle equipment consists of a receiver and display and control equipment.

An alternative concept utilizing broadcast mode voice transmission in a fashion similar to CB communication was also considered in detail. Studies indicated that it was neither cost effective nor could handle the quantity of information necessary to satisfy the motorists' need for route guidance.

This report contains two volumes. Volume I contains an executive summary and Volume II contains the final report.

17. Key Words In-Vehicle Route Guidance Electronic Vehicle Guidance Route Guidance	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Va. 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	211	

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

INTRODUCTION

In the past years a number of programs in this country and abroad have investigated the concept of in-vehicle route guidance and have concluded that such a system is feasible from a technical and human factor's viewpoint and will serve a significant need of the motoring public. The previous studies, however, have not significantly addressed the question as to whether in-vehicle route guidance can satisfy a socioeconomic need in a cost effective manner. It is the purpose of this In-Vehicle Route Guidance Feasibility and Design Study to answer that question, and in the process to define those design and system deployment characteristics which a cost effective system would require.

The report indicates that the majority of route guidance needs relate to urban areas and that a significant "excess" in time and mileage is present. Therefore there is significant improvement potential for an IVRG system. Cost effective IVRG systems may be implemented over a fairly wide parametric range of urban geographies. The system, however, must improve "strategic guidance" in order to effectively satisfy guidance needs. That is, it should plan and control a trip route rather than just provide a local guidance assist at a point or at a limited series of points.

In this study a spectrum of systems was synthesized using both two-way communications between the vehicle and roadside and one-way roadside to vehicle communications with message selection in the vehicle. The communication technologies that were considered for such systems included microwave band, kilohertz band and optical band communications.

The system utilizing one-way data communications was selected, along with a system utilizing a 900MHZ CB radio type of system for an in-depth analysis. In this analysis the technical characteristics, the cost, and the benefits of these systems were identified.

The one-way data communication scheme was found to meaningfully impact the route guidance problem in a cost effective way. Communication schemes using both microwave and optical technology were determined to be feasible. A general program plan for further development of their concept was generated.

The CB radio type of system was investigated and found to have a number of serious limitations. Chief among them was 1) the labor intensity of the system from the municipality's viewpoint which led to poor cost effectiveness and 2) the limited number of motorists handled on one channel which could in turn limit the ability of the system to satisfy the demand for guidance.

A recommendation to proceed with a program for further developing the one-way communications IVRG scheme using both optical and microwave technology was made, and a general program plan was defined.

Key topics discussed in this report are:

- Assessment of route guidance needs
- Historical and current IVRG systems
- Methodology for estimating of IVRG benefits
- Market acceptance of IVRG
- Design of candidate IVRG systems
- Benefit and cost studies of the candidate systems

Appendices containing detailed information on the topics discussed in the main body of this report are provided.

SECTION 2

BACKGROUND - IVRG SYSTEMS

Various IVRG systems have been proposed in the United States, Europe, and Japan during the past several years. These systems were developed in response to differing traffic needs and hence they utilize different techniques and provide several levels of traffic functions.

This section provides background information on several of these IVRG systems. The history and operational features are summarized. In Appendix A a detailed analysis and comparison of five of the previously noted systems are provided in matrix table format.

2.1 THE DAIR SYSTEM

The DAIR (Driver Aid Information and Routing) System [(1)] was developed by the General Motors Corporation in the mid 1960's. This system contains four basic subsystems. They are:

1. Motorist Aid - This subsystem allows the motorist to summon aid from an Aid and Information Center via two-way voice and coded communications over the CB radio band.

2. Visual Sign Minder - This subsystem reproduces roadside traffic signs on a display panel in the car through magnetic field coupling between the vehicle and magnets mounted in the roadway in a coded pattern.

3. Audio Sign - This subsystem provides reception over the CB radio of voice messages pertaining to traffic conditions and emergency situations on the road ahead. This subsystem falls under the overall heading of Highway Advisory Radio.

4. Route Minder - This subsystem provides directional guidance to the motorist via an onboard trip computer. The motorist at the start of his trip, uses a punchcard to load his destination into a computer located in the car. A vehicle's location is determined as it passes over roadway traps containing magnets arranged in a binary code. The arrangement, unique to that location, is decoded by the vehicle's processor which actuates the appropriate instruction on a display unit. The instruction directs the motorist to either continue straight, turn left or turn right. The In-Vehicle Display unit is shared with the visual sign minder subsystem.

(1) Hanysz, E. A.; Quinn, C. E.; Stevens, J. E.; Trabold, W. G., "DAIR - A New Concept in Highway Communications for Added Safety and Driving Convenience" Research Publication No. GMR-600, General Motors Corporation, October 5, 1966

Demonstration equipment was produced but no attempt was made to design production equipment,

2.2 THE ERGS SYSTEM

The ERGS (Experimental Route Guidance System)(2,3,4,5) was designed by General Motors under contract to the Federal Highway Administration in the late 1960's. This system provides the motorist with directional guidance. In its initial static configuration, ERGS consisted of an in-vehicle display and data entry device and a roadside communication and control unit. The motorist at the start of his trip, enters a five letter code word via thumbwheel switches into a console mounted in his vehicle. As the vehicle approaches an instrumented intersection it receives a trigger from a pre-intersection transmitter. The vehicle's destination is then transmitted via near field radio to the roadside unit containing a processor which computes and then transmits instructions back to the vehicle's display. The display consists of 16 back lighted elements containing symbols and words. The routing instructions are formed by lighting combinations of these elements. A field version of the equipment designated as ERGS II was field tested at an intersection in the Washington, D C. area in 1968. A prototype system was to be installed at 100 intersections in the Washington, D. C, area beginning in late 1969. This system designated ERGS III was to contain circuitry in the roadside units to allow dynamic operation of the system, a capability the earlier systems did not have. In the dynamic mode traffic surveillance would be utilized to provide a traffic responsive capability by remote update of the route selection parameters. This updating capability allowed for the selection of a route with minimum travel time. The program was terminated prior to the installation of the ERGS III system.

(2) General Motors Research Laboratory, "A Design for an Experimental Route Guidance System - Volume I - System Description", FHWA PB-197-090 - November 15, 1968

(3) General Motors Research Laboratory, "A Design for an Experimental Route Guidance System - Volume II - Hardware Description", FHWA Pub. PB-197--091 - November 15, 1968

(4) General Motors Research Laboratory, "A Design for an Experimental Route Guidance System - Volume III - Driver Display, Experimental Evalution", FHWA Pub, 197-092 - November 15, 1968

(5) Rosen, D. A.; Mammano, F. J.; and Favout, R., "An Electronic Route Guidance System for Highway Vehicles", Federal Highway Administration October 10, 1969

2.3 THE CAC SYSTEM

The Comprehensive Automobile Traffic Control System (CACS)[6, 7, 8] has been developed by the Japanese "Agency of Industrial Science and Technology, Ministry of International Trade and Industry". This system consists of the following five subsystems.

1. Route Guidance - This subsystem provides directional instructions to the motorist. The subsystem is similar in operation to the ERGS system using nearfield radio as the communications medium between the vehicle and the roadside unit and with route processing occurring in the roadside unit. The roadside units are linked to a control center, over a wire interconnect. Thus the system has a dynamic routing capability.

2. Driving Information - This subsystem is similar to the DAIR visual sign function. In the CAC implementation, roadside signing is displayed on a panel mounted inside the vehicle. The messages are transmitted by the nearfield radio communication technique used in the Route Guidance System.

3. Public Service Vehicle Priority - This subsystem locates and traces equipped public vehicles on a display at the control center. This system also grants priority to emergency vehicles at signalized intersections.

4. Traffic Incident Information - This subsystem transmits advisory messages concerning traffic conditions and emergency situations on the road ahead to the motorist via his car's broadcast radio. Transmitters with limited range are located along the road. Audio messages are transmitted from the control center to the roadside unit where a transmitter and modulator are housed. This system is similar to DAIR's "Audio Sign" subsystem.

5. Route Display Board - This subsystem displays traffic advisory messages on variable message signs mounted along the roadway.

   Development of the CAC system started in 1973. A pilot test system covering 103 intersections in a 12 mi^2 (30 km^2) section of southwest Tokyo has been evaluated.

------

(6) Onda, M., "Comprehensive Automobile Traffic Control Project - Part I Outlines of the Pilot *Test* System", Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Japan

(7) Onda, M., "Comprehensive Automobile Traffic Control - Route Guidance and Other Subsystems", VIIIth IRF World Meeting C-2-7

(8) Agency of Industrial Science and Technology. "The Comprehensive Automobile Traffic Control System - A General Description of Pilot Test System", The Ministry of International Trade and Industry, Japan, October 1977

2.4 THE ALI SYSTEM

ALI Destination Guidance System[9,10] is a directional guidance system similar to ERGS but with a dynamic capability. It is designed primarily as a freeway guidance system. The system developed by the West German Blaupunkt/Bosch group, is currently undergoing testing on 100 km of the autobahn network in the Ruhr area. The motorist keys in his 7 digit destination code through a data entry keyboard. The route is computed in roadside units located at key intersections and directions are transmitted back to the vehicle to be displayed in a visual format. The novel feature of this system is the use of a ferrite antenna mounted in the mudguard instead of the loop antennas mounted under the car as was used in the ERGS system. The ferrite antenna is easier to install than the loop antenna. This system has a driving information system similar to CACS where advisory information such as the speed limit and messages such as "FOG", "ICE" and *'CONGESTION" are transmitted with the guidance message.

2.5 THE ARI SYSTEM

ARI (Automotive Road Information) Traffic System[11] for VHF/FM Transmitters was developed by Blaupunkt in the early 1970's, for use in West Germany. This system transmits traffic information over the State owned FM broadcast system. This system differs from the DAIR and CACS in that it is a regional informational system. The ARI transmissions occur on specified broadcast stations which interrupt normal programming. The motorist may manually tune his car FM radio to the proper frequency or he can install a scanner that automatically tunes his radio when a traffic broadcast occurs. It is interesting to note that functionally equivalent systems are in development or in use in several of the European countries and in Japan as well. The primary reason for this is the state ownership or the significant degree of state control of the broadcast systems. This would appear to imply that a major institutional impediment toward adoption of this type of system in the United States is the private ownership structure of the broadcast system.

2.6 THE AWARE SYSTEM

"AWARE" (Advance Warning Equipment)[12] is a highway advisory system developed by the Transport and Road Research Lab, Crowthorne, England. Messages selected at a control center are transmitted by wire to a specified roadside unit where the message is stored and transmitted. A vehicle equipped

(9) Blaupunkt, "Make Better Use of the Roads Reach Your Destination Quicker Electronically", Bosch Group - West Germany, July 1975

(10) Braegas, Peter, "Function, Equipment, and Field Testing of a Route Guidance and Information System for Drivers (ALI)", IEEE Transactions on Vehicle Technology, Vol VI-29 No. 2, May 1980

(11) Braegas, Von Peter; "Verkehrsrundfunk", Bosch Techn. Berichte 4 (1973)5 West Germany

(12) Transport and Road Research Lab., "AWARE an In-Vehicle Visual Communication System for Drivers", Crowthorne (England) P276 833, 1977

with a loop antenna mounted under the car receives the message as it passes over an antenna, buried in the roadway. A "Visual Display Unit" mounted in the car displays the appropriate message by illumination of combination of words or the display of numerals. The display contains combinations of words to define the hazard (such as "CONGESTION") gives its location (such as 1 MILE) and advises any action to be taken (such as "KEEP LEFT MAX SPEED 30"). This system, as does ERGS and CAC, utilizes near field radio as the communications medium to the vehicle. Prototype equipment was constructed and tested in the 1970's.

SECTION 3

ASSESSMENT OF ROUTE GUIDANCE NEEDS

This section describes the need for an IVRG system, presents a needs mode3 and discusses the capability of fixed guide signing to satisfy motorist navigation needs.

3.1 Highway Use Characteristics

Table 1 describes the percentage of highway travel on the various facilities as obtained from Reference (13). The relative figures for the entire U.S. system are provided. In addition, the comparative figures for a state (*New* York) with a higher preponderance of urban travel than the national average is shown.

TABLE 1. 1975 HIGHWAY USE STATISTICS

CLASSIFICATION CATEGORY	VEHICLE MILE % IN CATEGORY NATIONAL	VEHICLE MILE % IN CATEGORY NEW YORK STATE
Interstate Rural	9.3	6.1
Interstate Urban	10.0	11.2
Primary Rural	16.0	14.1
Primary Urban	12.0	17.7
Secondary & Local Rural	11.9	7.1
Secondary & Local Urban	3.6	3.5
Federal Aid Urban	12.2	8.4
Rural - not on FAS*	7.6	7.2
Urban - not on FAS*	16.8	24.5
Urban - Total % Veh mi.	55.2	65.0
National Urban paved mileage %	20.0	
National Rural Interstate % of paved mileage	1%	
*Federal Aid System		

(13) "Highway Statistics, Summary to 1975", FHWA, PB 273520

From this data it is seen that most of the VMT (Vehicle Miles of Travel) is in urban areas. In addition, the ratio of total VMT to rural Interstate Highway System mileage is also high. From this data it may be concluded that the bulk of the route guidance needs occur in urban areas, and the higher traffic to roadway mileage ratios tend to make the likely benefit cost relationship from instrumentation in these areas highest. Even the bulk of the guidance problems eventually encountered by motorists travelling the rural Interstate Highway System occur in urban areas as these serve as the principal destinations for these motorists.

The basic data in Table 2 is also obtained from Reference(13). It indicates data on vehicle registrations, miles driven, and drivers' licenses. The following assumptions for the model were based on this data:

- o Most research studies have been performed on passenger vehicle drivers. While these only constitute 80% of the total vehicles and vehicle mileage, all vehicle mileage was assumed to generate a guidance need (the somewhat lower route guidance need for commercial drivers being partly offset by the greater economic penalty for errors).

- o The close to unity ratio of driver licenses and vehicle registrations fortuitously permits an identical quantitative expression for "route guidance need per licensed driver" and "route guidance need per vehicle".

TABLE 2. 1975 MOTOR VEHICLE USE STATISTICS

Motor Vehicle Registrations	
Autos -	106,000,000
All* -	133,000,000
Driver Licenses in effect -	130,000,000
Total vehicle miles travelled -	1330×10^9 miles (2141×10^9 km)*
Average annual mileage per vehicle -	10,000 ($1.61 * 10^4$ km)
Ratio of driver licenses to motor vehicle registrations -	0.98
Ratio of passenger cars to all registered vehicles -	0.80
Ratio of passenger car mileage to mileage of all registered vehicles (1965)	0.80

*Excluding motorcycles

Figure 1 shows a plot of urban area population distribution. The 1974 Census Bureau estimates and rankings based on the 1970 census data are shown for the 100 largest Standard Metropolitan Statistical Areas (SMSA's) along with their cumulative populations.

This figure shows that well over the majority of the U.S. population is located in less than 100 urban areas. Furthermore, the geographics and demographics of the urban areas above this rank may in fact generate much lower route guidance needs.

Thus the location of greatest route guidance need appears to be within urban areas, and in particular in those urban areas represented by the SMSA ranks of Figure 1 or even by a subset of these ranks. The modeling effort therefore concentrated on this problem.

It is again noted that the vehicle miles per mile of highway for the rural Interstate Highway System are substantial and that if an IVRG candidate system design can be easily extended to cover these and similar rural highways, the benefits of such a system might be enhanced.

3.2 MOTORIST NEEDS MODEL FOR ROUTE GUIDANCE

3.2.1 Types of Guidance Needs

When the needs of the individual driver are discussed, it must be recognized that these needs will vary, both qualitatively and quantitatively as the driver's environment is altered. Table 3 describes a number of sources of motorist's route guidance needs.

A model was developed to quantify the route guidance needs of motorists in major urban areas*. The model was based on a classification system of needs described as strategic and tactical. Briefly stated, strategic guidance needs relate to the route planning aspects of route guidance. The motorist does not know (route designations and cardinal directions) the best route to the destination and requires assistance to perform this function. Dynamic strategic route guidance is an optimal route planning function which accounts in real time for the additional travel times developed as a result of congestion on certain links of a candidate route.

Tactical guidance reflects the guidance requirement when the desired route is known, including its identification and cardinal direction, but encounters a problem in making the appropriate directional change, because of a deficiency in signs, markings, lighting, or motorist recognition of the area, proper lane, ramp or intersection.

*SMSA's of population rank 100 or less

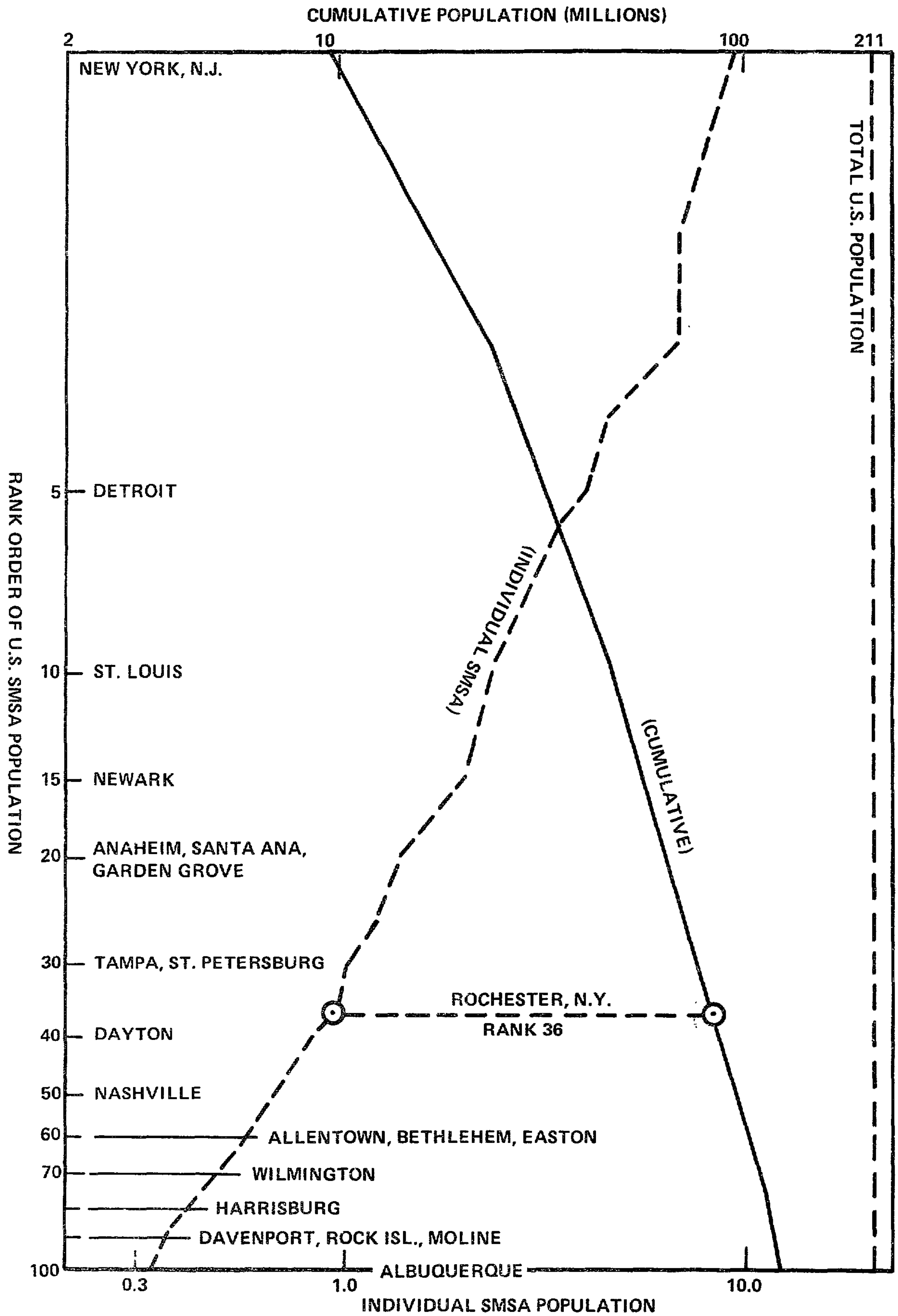


Figure 1. Metropolitan Statistical Area Profiles

TABLE 3. SOURCES OF MOTORIST NAVIGATION PROBLEMS

Problem Source	General Nature of Problem
1. Driver is unfamiliar with the immediate local area 2. Driver does not know location or sequence of major decision points	Local familiarity Driver cannot relate to local highway system
3. Driving conditions (light level, sole vehicle occupant, need for repeated reference) preclude successful use of map 4. Driver does not read maps well or did not have map	Map Problems Driver cannot make use of information normally obtained from road maps
5. Misunderstanding of guide sign message or lack of sufficient guide sign information 6. Driver misunderstood designation of highway facility referenced by guide sign. He knew the facility by another name or designation 7. Street names not posted or not sufficiently large or visible 8. Building address numbers not posted or not sufficiently visible or legible	Static Information Problems Sign or other written highway information not adequate on a static basis, i.e. the basic information is insufficient or confusing
9. Sign not sufficiently far enough in advance or required action to allow for safe performance or required maneuver 10. Missed sign because of inattention, information overload, high vehicle blockage, etc. 11. Driver confused as to appropriate lane or turn because of poor lighting, visibility unexpected geometrics, inappropriate markings or delineation	Dynamic Information Problems Appropriate information is available but the real time driving problems encountered at the moment precluded sucessful identification and execution of the maneuver

TABLE 3. SOURCES OF MOTORIST NAVIGATION PROBLEMS (Continued)

12. Alternate route information needed to avoid congestion delay 13. Same as 12 - delay caused by construction 14. Driver didn't know where access to parking was located	<u>Other Problems</u>
15. Driver didn't know which parking facilities had available space	
16. Driver was unable to pre-plan (by using maps, personal knowledge, or other information) the best static route to his destination.	<u>Limits of Human Analysis</u> The complexities of estimating route length and probable speed lead to a certain level of error in the pre-planning. This is usually not received, even after the journey.

3.2.2 Strategic Route Guidance Needs in Urban Areas

Stcatagic route guidance needs have been separated into three components --

- o Enroute Static Guidance Needs
- o Terminal. Static Guidance Needs
- o Dynamic Guidance Needs

Each of these components is addressed in the following paragraphs.

Enroute Static Guidance Needs

The enroute portion of the journey is considered to be that portion from its origin to the vicinity of the destination about 3 mi (4.8 km). For working purposes it was assumed that the enroute trip portion extended to the intersection of major arterials (including freeways) which is closest to the destination,

The studies and data described in numerous References(14, 15, 16,17,18) were reviewed and the following figures were developed to describe what is believed to be a fairly conservative view of enroute travel excess and its reduction potential.

- o Familiar trips - 5 percent time and distance excess
- o Unfamiliar trips - 15 percent time and distance excess
- o Potential reduction in excess resulting from motorists desire for shortest or quickest route - 75 percent

(14) Armstrong, B.D., "The Need for Route Guidance", TRRL Supplementary Report 330, Transport & Road Research Laboratory 1977

(15) Gordon, D. & Wood, H., "How Drivers Locate Unfamiliar Addresses - An Experiment. in Route Finding", Public Roads June 1970 - Vol. 36 No. 2 p. 44ff

(16) Ratcliffe, E. A., "A Ccmparison of Drivers' Route Choice Criteria and Those Used in Current Assignment Processes", Traffic Engineering and Control, March-April 1972

(17) Catholic University of America, "Benefit Measurements on Highway ERGS", Bureau of Public Roads PB 1.92169

(18) Schoppert, Moskowitz, Hulbert, Berg, "Some Principles of Freeway Directional Signing Based on Motorists' Experiences" Highway Research Board Bulletin 24 1960 p. 30ff

Table 4 shows the urban "familiar" and "unfamiliar" average annual mileage for a vehicle on both a national basis and for New York State. This table has been generating using the data presented in Tables 1 and 2, data presented in Reference(G) relating trip distance to trip familiarity and data presented in Reference(19).

Using the set of data in Table 4 along with the other various data in this paragraph, the following expression was utilized to compute the enroute motorist needs in urban areas.

Potential annual savings for enroute guidance in urban areas (miles per vehicle) = (Potential savings factor) x ((.05) x familiar miles + (.15) x unfamiliar miles)

292 = (.75) x ((.05) x 4098 + (.15) x 1232) mi as a national average (470 km)

344 = (.75) x ((.05) x 4825 + (.15) x 1451) mi in N.Y. State (554 km)

Time was quantified based on the mileage saving (the model uses the same access speed of 49 MPH (13) (78 kph) and urban area surface street speeds of 20 MPH (32 kph), the associated annual potential time savings are 11.4 hours per vehicle per year on a national basis and 13.4 hours for vehicles in New York State.

Terminal Static Guidance Needs in Urban Areas

Guidance needs in the area of trip termination, a region generally considered to range up to 3 miles (4.8 km) from the actual destination, represents a somewhat separate problem and one which has not been researched to the same extent as the enroute problem. The credible quantitative data based on Gordon and Wood's research(15) indicates an average time loss of 7.6 minutes and a distance excess of .5 miles (.8 km) for unfamiliar motorists. This research, however, involved trips considerably longer than the average urban trip. As a result, the average level of terminal route guidance information need for the motorists involved in this research was judged to be greater than for most of the urban trips which are actually made.

The model developed for this project, therefore, reduced Gordon and Wood's time and distance excesses by 50%. This yields the following per vehicle annual terminal guidance needs.

	Time Penalty	Distance Penalty
National	11.5 hr.	45.5 mi (72.8 km)
N.Y. State	13.5 hr.	53.6 mi (85.8 km)

(19) Creighton, R. L., "Urban Transportation Planning", p. 220 - University of Illinois Press 1970

TABLE 4. ENROUTE URBAN AREA TRIP ANALYSIS

Average Trip Length Mi.	Fraction of Trips	Fraction of Urban Vehicle Miles Travelled	Cumulative Enroute Mileage Fraction	Average Vehicle Mileage in Urban Areas (National)	"Familiar" Urban Enroute Mileage (National)	"Unfamiliar" Urban Enroute Mileage (National)
<2	.45	.120	.120	662	635	26
2-4	.22	.176	.296	972	855	116
4-6	.12	.160	.456	883	706	194
6-8	.08	.149	.605	822	600	222
8-10	.06	.144	.749	795	532	262
10-12	.03	.088	.837	486	296	190
12-14	.02	.069	.906	381	221	156
14-16	.01	.040	.946	221	119	102
716	.01	.053 est.	1.000	292 est.	134 est.	158 est.
Average urban annual enroute mileage					4098	1232 {national)
Average urban annual enroute mileage					4825	1451 (N.Y. State)

Note: 1 mile = 1.6km

Dynamic Guidance Needs in Urban Areas

The previous paragraphs have described models for the static strategic needs. Underlying these models is the implicit assumption that motorists in urban areas need a generally similar core of route guidance information.*

However, the need for dynamic guidance (the guidance systems' capability to assess highway travel conditions in real time and integrate these results into the total guidance information package provided to the motorist) is highly dependent on the highway network and traffic conditions in each area, therefore, it is not considered feasible to develop a generalized needs model as was done in the case of static needs. Factors which make dynamic guidance needs area specific are the frequency, severity, and location of congestion, the geometric availability and spare capacity of alternate facilities and the availability of suitable transfer facilities between alternative routes.

An area specific methodology for evaluating benefits resulting from traffic responsive reassignment has been developed under the FHWA Integrated Motorist Information System program and is described in References[20] and [21].

3.2.3 Tactical Guidance Needs

Tactical guidance needs arise when the motorist has an adequate strategic plan (he knows the name or designation and the approximate cardinal direction of the subsequent highway), but is unfamiliar with or unable to recognize the location, geometrics or appropriate lane to use to access the connecting route desired, or in some cases even to remain on the same route. The tactical guidance needs may arise from the motorists' unfamiliarity or reduced prior expectancies or from deficiencies in the highway signs, markings, or lighting.

As route guidance system candidates become more universal in scope and more ubiquitous in coverage they will usually imbed the response to tactical guidance needs in the system design. Nevertheless, it is fairly clear that the previously cited experiments used to develop the static strategic enroute models did not really study or account for those tactical navigation errors of the type described above which motorists experience.

*It is recognized that the increased highway network irregularity characterized by many of the older cities in the eastern U.S. develops additional route guidance needs. These needs, however, often tend to be of a tactical nature and are more properly considered in Section 3.2.3.

(20) Sperry Systems Management, "Integrated Motorist Information System (IMIS) Application of Feasibility Study Handbook", FHWA Report RD-78-24. May 1978

(21) Sperry Systems Management, "Integrated Motorist Information System (IMIS) Feasibility Study Handbook", FHWA Report RD-78-23 May 1978

The literature(22,23,24) describes (particularly for limited access highways) many instances of driver error, erratic maneuvers, and sometimes conflicts caused by some combination of signing and marking techniques and driver perception, cognition, and interpretation.

However, because of the specific experimental site, the nature of the experiments) the variability of experimental conditions and results, and because many highway types of interest in this program are not covered by these experiments, no quantitative model of tactical guidance needs could be developed from this body of literature.

In order to assess the relative importance of this need it was decided to record data on the driving experiences of a number of SSM employees. The results, are summarized in Table 5. Because of the nature of the experimental procedure (above average subjects, possible data omissions during collection period) the results are believed to tend towards under-estimation. Since the types of penalties experienced by tactical guidance errors are difficult to classify in terms of excess mileage and the fact that a portion of the lost time might be utilized in a stopped rather than in a moving state, no attempt was made to quantitatively model the excess distance.

TABLE 5. TACTICAL GUIDANCE NEEDS MODEL

Type of Facility	Percent of Tactical Navigation Errors Made on Facility Type	Cumulative %
1. Limited access highways & complex interchanges	30.0%	30%
2. Arterials including freeways frontage roads	32.5%	62.5%
3. Business districts	10.0%	72.5%
4. Distributor streets & minor streets	27.5%	100%

Average Tactical Error Rate: 27.9 errors/year/vehicle

Average Excess Time: 8.67 minutes/error/vehicle
or
4.03 hours/year/vehicle

(22) Taylor, J. I. and McGee) H. W., "Improving Traffic Operations and Safety at Exit Gore Areas", NCHRP Report No. 145, 1973

(23) Transporation Research Record 414, "Motorist Information Systems", 1972

(24) Transportation Research Record 600, "Motorist Information Systems and Services", 1976

3.2.4 Summary of General Guidance Needs Model

A guidance needs model has been developed and is summarized in Table 6. Three of the four components have been quantified. The dynamic strategic guidance needs component must be determined on a site specific basis.

TABLE 6. GUIDANCE NEEDS MODEL

Type of Need	Potentially Salvageable Hours/Year Per Vehicle		Potentially Salvageable Miles/Year Saved Per Vehicle	
	National	Urban Area Motorists (NY State)	National	Urban Area Motorist (NY State)
1. Static-Strategic-Enroute	11.4	13.4	292	344
2. Static-Strategic-Terminal	11.5	13.5	45.5	53.6
3. Dynamic-Strategic	*	*	*	*
4. Static-Tactical	4.0	4.0	**	**

* Location Dependent

** Not Estimated

Note: 1 mi = 1.6 km

Although studies seem to indicate that a certain number of accidents are caused by unsatisfied route guidance needs which lead to excess mileage, erratic maneuvers, and traffic conflicts, the literature does not establish a quantitative relationship. One might postulate a model of accident reduction resulting from excess mileage. However, to be conservative, the proposed model does not attempt to quantify accident reduction as a route guidance system benefit.

Where the data required was incomplete or inconsistent a conservative assumption was made.

In applying the model to a specific site for the evaluation of candidate IVRG systems, the quantities in Table 6 were used as general guidelines for evaluation purposes.

Reviewing Table 6 it is seen that only those IVRG system configurations which can significantly address the strategic guidance requirement in urban areas have the potential to satisfy over 85% of the quantifiable guidance requirements,

3.3 CAPABILITY OF FIXED GUIDE SIGNING TO SATISFY STATIC NAVIGATIONAL NEEDS

This section discusses the extent to which the present state of the art in highway guide signing presently serves as a motorist information system to satisfy motorist navigational needs. The service improvements which will be obtained through an upgraded guide signing system are also discussed.

The principle areas of discussion are concerned with:

o Adequacy of Fixed Guide Signing

o Static Guide Signing - Opertional Problem Areas

o Static Guide Signing - Benefit/Costs of Navigational Improvements

3.3.1 Adequacy of Fixed Guide Signing

King and Lunenfeld[25] have extensively analyzed driver information needs. Those informational needs have been classified into the following categories:

(1) Destination - Directional Information

(2) Route - Directional Information

(3) Cardinal Direction Information

(4) Maneuver Direction Information

(5) Lane Change Information

(6) Speed Change Information

(7) Location Information

Of these seven informational categories (1), (2), (3) and (7) address strategic guidance needs and categories (4), (5) and (6) satisfy tactical guidance needs,

------

(25) King, G. F., and Lunenfeld, H,: "Development of Information Requirements and Transmission Techniques for Highway Users", NCHRP Report No. 123 1971

3.3.1.1 Satisfaction of Strategic Needs

The literature indicates that guide signing appears to be mostly deficient in satisfying strategic needs[25] because guide signing is generally route orientated rather than goal or destination orientated. Route orientated guide signs are required in order to service motorists, with their varied trip destinations, at a decision point. Thus motorists must provide the basis for strategic guidance through pretrip or enroute guidance. It is the inefficiency with which a motorist defines and executes this trip plan that is the inherent limitation of guide signing to satisfy the motorists' strategic navigational needs. For the work trip this inefficiency is on the order of 5%[16] of route miles. For those trips where the motorist is less familiar with the roadway network, the inefficiency is on the order of 10% to 15%[14,15] of route miles.

3.3.1.2 Satisfaction of Tactical Needs

The tactical guidance needs of motorists are more consistent with the capability of the highway guide signing system. Tactical guidance is important in those situations where the motorist has an adequate strategic trip plan but is unfamiliar with or unable to recognize the location, geometrics or appropriate lane use and speed for access to a connecting route or to verify continuance on the present route. These needs arise at a specific interchange or intersection from motorist unfamiliarity with the geometric design of the roadway. Guide signing's ability to structure the motorist's route expectancies and to guide him through the intersection is conditioned on the assumption that the motorist has a knowledge of the routes which connect him to his destination. How closely individual motorists follow this assumption is one factor governing the quality of the transfer. Other factors which affect the quality of the transfer are information deficiencies, and geometric deficiencies. Specific deficiencies of each of these factors are Listed below:

- Motorist Deficiencies
    1. Insufficient attention with respect to information provided
    2. Decision made without sufficient time or distance for implementation
    3. Inadequate trip planning
- Information Deficiencies
    1. Sign legend
    2. Insufficient advance warning

3. Inadequate sign visibility

4. Inadequate road marking or delineators

o Geometric Deficiencies

1. Visibility of ramp area

2. Other inadequate design features

One signing approach which is finding increased acceptance is diagrammatic signing. These signs, through the use of visual graphic techniques, are designed to minimize information deficiencies inherent in conventional guide signing. Based on the published literature[22,23,24,26] the ability of diagrammatic signing to provide a consistent improvement in signing performance has not been established. In particular the work reported by D A. Gordon and the work reported by A. W. Roberts and F. R. Hanscom reach essentially different conclusions.

The frequency of erratic maneuvers is sometimes considered an indication of the inability of static guide signing to meet the motorists tactical guidance needs. By usin frequency data on the causes of erratic maneuvers, presented in Reference [22], and under the assumption that the occurrence rate for erratic maneuvers is directly proportional to errors in tactical guidance, the conclusion can be drawn that approximately 35% of tactical guidance errors cannot be eliminated by improvements to fixed guide signing. This of course represents an unsatisfied need which, if it is addressed at all, will require a new system of control devices not based on the route-oriented guide signing approach.

3.3.2 Static Guide Signing - Operational Problem Areas

In this section the guidance problems associated with the present system are identified and ranked in importance. The basis for this is an extensive survey of motorists. The results of this survey are reported in Reference [27]. The surveyed motorists were self-classified into two groups defined as follows:

Stranger group - "Where you are unfamiliar with the area and would consider yourself a stranger"

Local Stranger group - "Where you are familiar with the area but have rarely or never driven to this specific destination.

------

(26) Hanscom, F. R., and Berger, W. G., "Motorist Response to Guide Signing", NCHRP Research Results Digest No. 91, January 1977

(27) King, G. F., and Lunenfeld, H., "Urban Guidance, Perceived Needs and Problems", Transportation Research Record 503, 1974

A combined total of 62% of all motorists surveyed prepared a trip plan in some form Thus approximately 1/3 of motorists did not prepare a trip plan, a significant percentage given the fact that trip planning is a key element of the present highway guidance system.

The percentage of motorists feeling lost or who were actually lost was also significantly high. Table 7 reproduces the results for the combined motorists groups. The factors of most importance are:

(1) approximately l/2 of the motorists reported feeling lost at some point in their trip

(2) approximately l/4 of the motorists reported actually being lost at some point in their trip

These numbers indicate that a significant segment of motorists from the group most dependent on the highway guidance system is not being adequately served.

TAB-LE 7. PERCENT OF SURVEYED MOTORIST FEELING LOST OR ACTUALLY LOST

		ACTUALLY LOST		
		YES	NO	TOTAL
	YES	28.5	28.1	56.6
FEELING LOST	NO	0.7	42.7	43.4
	TOTAL	29.2	70.8	100.0

Finally the surveyed motorists were asked to identify in importance a set of 12 guidance problems. Table 8 lists these problems in a rank order derived by combining the rank order of problems from each group. Seven out of the first nine ranked problems point to deficiencies in the arterial and urban non-freeway signing system. Thus the greatest need for improved route guidance is on the non-freeway portion of the roadway system.

TABLE 8. RANK ORDER OF NAVIGATION PROBLEMS

RANK ORDER	DESCRIPTION OF PROBLEM
1	City directional signs that did not provide the information you expected to see.
2	Entrance ramp to a freeway or expressway was hard to find from city streets.
3	Finding the best exit off-ramp in a city was hard to do.
4	If wrong turn was made or got lost, it was hard to get back on right route.
5	Road maps did not give enough details or were hard to read.
6	Road maps were not available.
7	Signs at city exit ramp from freeway did not give enough information to find way.
8	Following a route on city streets was hard to do.
9	Street addresses were hard to locate.
10	Following a route on a freeway to a city destination was hard to do.
11	Decision on routing hard to make when signs indicate more than one route to destination.
12	Locally used road and place names were confusing or had no meaning.

3.3.3 Static Guide Signing - Benefit/Costs of Navigational Improvements

The previous sections indicated that:

(1) The tactical guidance need is the only guidance need which can be addressd in a significant manner by guide signing.

(2) Guidance problems exist for all segments of the present highway guidance system. This includes trip planning, maps and guide signing.

(3) The need for improvement in the highway guidance system is greatest on the non-freeway portion of the urban network.

Based on those factors the following paragraphs describe the cost required to improve the guide signing system up to MUTCD standards. Upgrading to MUTCD standards, will generate benefits for several traffic operational measures of effectiveness. These include accident reduction, and traffic flow improvements as well as route guidance improvements. Using the work presented in Sections 3.1 and 3.2 it is possible to identify a benefit associated with the satisfaction of the tactical guidance needs of the motorists. The benefit values are derived within the environment of the urban roadway system. In this manner, a comparison can be made to the IVRG benefit/cost values which were also derived within an urban environment.

From the data, given in Table 1, 2, and 5, 55% of the VMT occurs on urban classified highways with a corresponding 7.315×10^7 vehicles generating that mileage. The average tactical error rate for a typical urban vehicle driven 10^4 miles ($1.6*10^4$ km) per year is 27.9 errors/year/vehicle. The average excess time traveled to rectify each error is 8.7 minutes/error/vehicle. Thus the average excess time due to inadequate tactical guidance is approximately 40 hours/vehicle/year. Multiplying the number of urban vehicles by the excess time yields 2.926×10^8 hours of excess time resulting from inadequate tactical guidance, These hours can be converted to an equivalent dollar loss by multiplying these hours by a transportation planning time value factor such as the $3.42/hour (which is used by New York State D.O.T.). Thus the total economic loss attributable to tactical guidance deficiency is $1 x 109. If the upgrading and optimization of guide signing to MUTCD standards were to result in the total elimination of tactical errors then the total economic loss given above would transform into a recoverable benefit.

However, based on the work published in References (22, 23, 24) 28) it has not been conclusively shown that quantifiable benefits, such as accident reduction, erratic maneuver reduction or tactical error reduction are consistently achieved with improved signing. Restricting the analysis to those reported results[22,28], which show a positive benefit relationship over several interchanges, a typical accident or erratic maneuver reduction on the order of 25 to 35 percent is achievable with improved signing based on MUCTD standards. While no results exist for tactical error reductions, if it is assumed that variations in the occurrence rate for tactical errors is directly proportional to accident and erratic maneuver rate variations, a 25 to 35 percent reduction due to improved signing is indicated. Applying this reduction factor to the economic loss value results in a tactical guidance benefit of $\$2.5 \times 10^8$ to $\$3.4 \times 10^8$. This value represents an assumed achievable benefit based on an upgrading and optimization of all signing to MUCTD standards on the urban roadway network.

Based on the work given in Reference (28) the corresponding cost expenditure to upgrade the signing system for the urban network is $\$8.83 \times 10^8$ This results in a benefit cost ratio in the range from .28 to .40.

This ratio is significantly less than 1.0 and leads to the conclusion that improvement to guide signing on an overall system wide basis should not be attempted in order to principally satisfy the transportation planning objective of improved navigation. This is not to imply that MUTCD conformance does not accomplish other worthy objectives such as safety improvement; such benefits themselves provide sufficient justification for conformance.

(28) Lunenfeld, H., "Improving the Highway System by Upgrading and Optimizing Traffic Control Devices", U.S. DOT/FHWA, Report No. FHWA-TO-77-1 April 1977

SECTION 4

MARKET ACCEPTANCE OF IN-VEHICLE ROUTE GUIDANCE

The success of the in-vehicle route guidance system to improve the operational performance of an urban roadway traffic network is a function of its acceptance by the motoring public, This is true to a greater extent than for other traffic control devices since the motorist must purchase the in-vehicle equipment. If some minimal percentage of motorists do not perceive that the intrinsic value of the IVRG system is greater than their out of pocket cost to purchase the in-vehicle equipment, the total system benefit will not exceed total system costs and no net societal benefit will result. This section discusses the motorist demand cost relationships for the in-vehicle equipment. These relationships were developed from three sources; the driver acceptance study performed as part of the FHWA Electronics Route Guidance System Program(29) a motorist survey performed as part of the pilot test of the Japanese domprehensive Automobile Control System(30) and an opinion questionnaire performed by Sperry Systems Management prior to the present contract (see Appendix B).

The demand-cost data obtained from the ERGS driver acceptance study, the Japanese survey results and the SSM questionnaire results are shown in Figure 2. A direct comparison analysis of these results is clouded by many factors including the year the study was performed, social and attitudinal differences in survey populations and the implied meaning of the survey questions. The questions asked by each survey which resulted in Figure 2 are given as follows:

o ERGS Survey

"How much do you think a machine that could give you this information would cost you to buy?"

0 CAC Survey

"How much do you think is a reasonable price for the vehicular device including cost of installation?"

o SSM Questionnaire

"What would you be willing to pay for the vehicle equipment to provide the indicated capabilities?"

The data in Figure 2 was inferred from the responses to these questions* Since the questions asked during the first two surveys are somewhat literally different from the inferences there would appear to be considerably more opportunity for error from these factors alone for those surveys.

(29) Eberhard, John W. "Driver Information Requirements Display Concepts and Acceptance Factors For Electronic Route Guidance System", Serendipity Inc., February 1969

(30) "Outline of Test Results of Pilot System" - Industrial Science and Technology Agency, October 1978. Translated by Berlitz Translation Service under contract to SSM for IVRG project

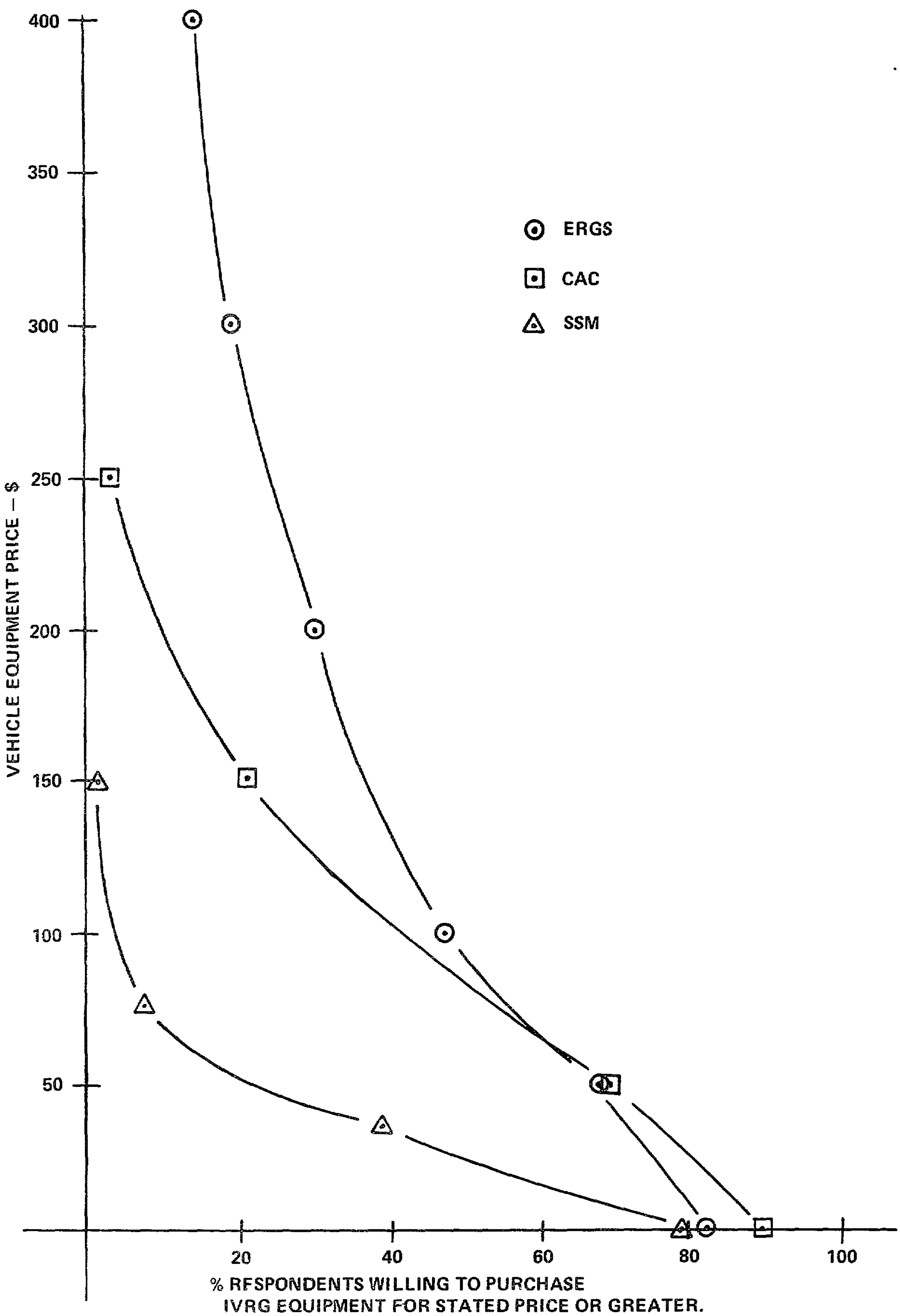


Figure 2. Price Demand Curves-Dynamic IVRG

Surveys of this sort are subject to two types of errors. They might tend to overestimate the sales price for variations of fairly conventional products because the customer, when confronted with the purchase decision, simply fails to pay the price. On the other hand, when a radically new product is involved, market surveys often underestimate the demand because actual exposure to the product might be necessary before the customer can perceive the benefits.

Basing the benefit cost studies on the demand curve of the SSM survey leads to a basically conservative approach to IVRG design. Candidate systems which show positive net benefits for this curve are assured of much better benefit/cost performance for the less conservative curves. Thus this curve was used in the studies described in Section 8.

SECTION 5

METHODOLOGY FOR ESTIMATION OF IVRG BENEFITS

This section describes methodologies for the estimation of benefits for the static IVRG needs (strategic enroute, strategic terminal, and tactical). A series of analytical models were developed for the purpose of estimating the benefit of the candidates. These models, described in Appendix C, assume a regular grid highway structure.*

This section also describes the relationship of IVRG systems to dynamic guidance requirements.

5.1 ESTIMATION OF ENROLJTE STRATEGIC STATIC GUIDANCE BENEFITS FOR IVRG

The ability to reduce the strategic excesses for the enroute trip depends on how intensively the area is covered by the guidance network. Sparse coverage will lead to circuitous routes which in turn will develop excesses and thus may result in no saving.

Although many urban areas have irregular street networks it is convenient to analyze the concept of a simple, regular network to quantify, to a first approximation, the benefit of route guidance as a function of route spacing.

The following equation, developed in Appendix C-l relates the excess distance a motorist must travel, with guidance, E , as a function of the spacing, L, between parallel guidance routes:

$$E = L/2 \qquad (1)$$

A "benefit" will result when the guidance system excess is less than the "unguided" excess. Using the criterion (developed in section 3.2.2) of 5% excess for familiar and 15% excess for unfamiliar trips, Table 9 describes the trip lengths for which guidance provides a benefit.

TABLE 9. TRIP LENGTHS FOR WHICH GUIDANCE PROVIDES A BENEFIT

Arterial Spacing L	Trip Length for Familiar Trips	Trip Length for Unfamiliar Trips
.25 mi	> 5 mi	>1.7 mi
.5	>5	>1.7
1.0	>lO	>3.3

*Such a structure is, of course) typical of many major U.S. metropolitan areas.

TABLE 9. TRIP LENGTHS FOR WHICH GUIDANCE PROVIDES A BENEFIT (Cont)

Arterial Spacing L	Trip Length for Familiar Trips	Trip Length for Unfamiliar Trips
2.0 mi	> 20 mi	> 6.7 mi
3.0	> 30	> 10.0
4.0	> 40	> 13.3

Note : 1 mile = 1.6 km

An analysis of the potential reduction in excess travel using IVRG was made. This analysis was performed using this table in conjunction with equation 1 and with the urban area trip analysis data in Table 4.

Figure 3 shows a plot of reduction in distance excess due to IVRG as a function of guidance route spacing. System efficiency (the ratio of the excess reduction by IVRG to unguided excess) is also shown. The reduction in time excess is assumed to be proportional to the reduction in distance excess.

5.2 ESTIMATION OF TERMINAL STRATEGIC BENEFITS FOR IVRG

The terminal guidance problem has been principally reported by Gordon and Wood and that work is the basis for the terminal guidance needs model described in Section 3. The important terminal excesses described by Gordon and Wood are time excesses. They are based on the definition of the terminal area in two specific cases as driving distances of 2.3 and 1.5 miles (3.7 and 2.4 km). Assuming a driving distance of 2 mi (3.2 km) in the terminal area, a reasonable approximation of the terminal distance excess in the absence of guidance is an excess of 1 mi (1.6 km) for each of the X and Y axes. This describes a terminal area uncertainty of 4 sq mi (10.2 sq km). The following equation, developed in Appendix C-2, computes the efficiency of strategic terminal guidance for IVRG. Efficiency is the ratio of distance excess reduced by IVRG to total terminal excess distance.

$$TGE = \frac{4g - As}{4g}$$ where g is the number of guidance terminal locations

in region of area As and As is in square miles (1 square mile = 2.6 square kilometers).

5.3 ESTIMATION OF TACTICAL GUIDANCE BENEFITS FOR IVRG

The IVRG system is assumed to eliminate tactical guidance errors in all situations where the motorist is using the system. Therefore, on highways covered by the system, tactical guidance errors will be made only by unfamiliar motorists. Assuming comprehensive network coverage (that is, the coverage is in sufficient depth and breadth to enable the motorist in an instrumented

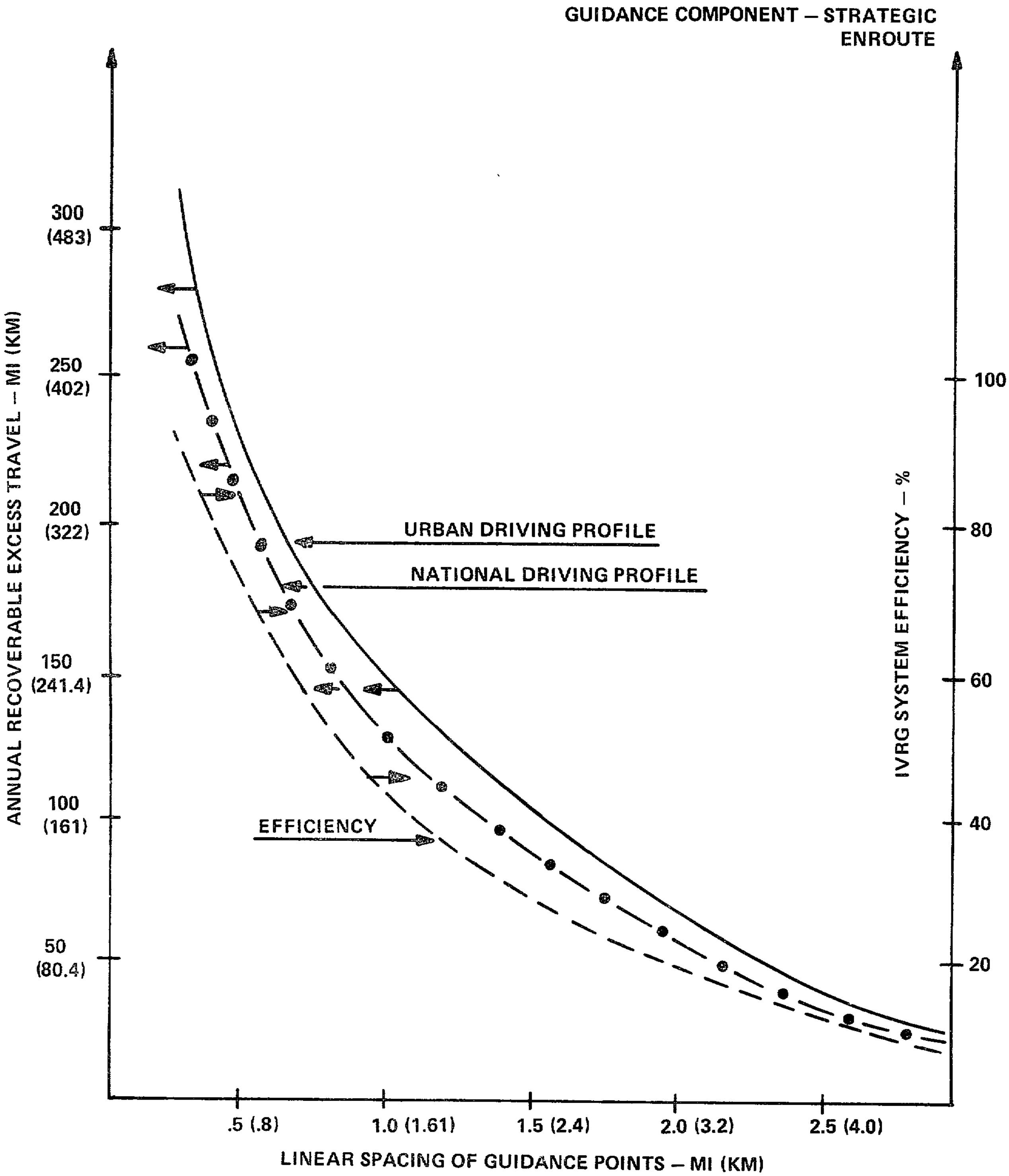


Figure 3. IVRG Motorist Benefits as a Function of Guidance Point Spacing

area to be guided to an intersection or other point close to his destination) the only opportunity for tactical errors will be in connection with those terminal guidance needs for the unfamiliar motorist which may not be covered by the system.

The following formula, deveioped in Appendix C-3, relates the benefits of guidance, BET, to the terminal guidance efficiency, TGE, discussed in Section 5.2.

BET = 4-1.1(1-TGE) in hours per vehicle per year.

5.4 DYNAMIC GUIDANCE

The basis for a static guidance benefit model for IVRG has been described in Section 3.2. Under many conditions the extension of IVRG concepts to dynamic guidance (the use of IVRG for optimal guidance in real time traffic environments) is desirable.

The development of relatively simple general benefit assessment models for the dynamic case is not possible because the benefits are strongly dependent on the geometry of local freeway and surface street networks, the levels of congestion and the alternate routes available.

Ratcliffe(16) indicates that for journeys to work in the CBD 10% of total excess time can be reduced. After removing static benefit, it would appear that approximately 4% of this excess may be attributed to traffic conditions.

A set of very interesting test results has been developed from the Japanese CAC project(30). A series of travel time tests for four different origin-destination pairs was performed in the congested area of Tokyo in which the GAC pilot system is installed. A set of "professional drivers" (drivers having specialized knowledge of the area and its traffic conditions) and a set of "ordinary drivers" were used. The summary results of the travel time tests are shown in Table 10. The results show the importance in reducing excesses of driver familiarity and the ability to dynamically reroute traffic.

TABLE 10. RESULTS OF GAC SYSTEM TESTS

ORIGIN-DESTINATION PAIR	1	2	3	4	Average
Ordinary driver travel/time w/o guidance	2064.7	1879.8	1528.1	1503.1	
Ordinary direct travel time with guidance	1771.3	1652.8	1238.9	1322.4	
% Difference	14.2	12.0	18.9	12.0	14.2%

TABLE 10. RESULTS OF CAC SYSTEM TESTS (Gont)

ORIGIN-DESTINATION PAIR	1	2	3	4	Average
Professional driver travel time w/o guidance	1811.3	1742.7	1359.9	1393.8	
Professional driver travel time with guidance	1746.7	1655.7	1238.1	1334.6	
% Difference	3.5	4.4	8.9	4.2	5.2%

Travel times shown are the sums of the travel time experience for each O-D pair in seconds.

The results of both Ratcliffe's work and the GAG tests show that in congested surface street areas, excess reductions of approximately 5% of the travel time over what would be available by using static IVRG only are possible by dynamic in-vehicle route guidance techniques. While these benefits appear to be substantial for the time periods and locations described, they must be moderated somewhat when one considers the application of IVRG to U.S. urban areas. The following statements are made in the context of an IVRG design being potentially implemented in an entire urban area (because of the in-vehicle equipment involved and the variety of candidate destinations for each vehicle it is difficult to envision an IVRG involving additional in-vehicle expenditure which is confined only to a section of a city or to a single traffic corridor).

- o The incidence of traffic congestion varies widely in U.S. urban areas. In some urban areas freeway congestion is predominant while other urban areas often suffer from both freeway and surface street congestion. Although there are certain U.S. urban areas with high levels of surface street congestion for long periods of the day, in the more general case congestion is experienced in limited areas and for limited times of the day. Thus, in most candidate locations for IVRG networks, congestion will not usually be prevalent over most of the network most of the time (in contrast to static needs which are present everywhere all of the time).

- o Under some circumstances, alternative routings to relieve congestion may exist; in other cases they may not. The concept of spare capacity on alternate routes such as was investigated under the IMIS program(31) is an important element in this determination.

(31) “Integrated Motorist Information System (IMIS) Feasibility and Design Study” - Sperry Systems Management, GF-3701-1043 - April 1977

- Although dynamic guidance may, in principle, be used to address the congestion problem by providing individual vehicle guidance under dynamic roadway constraint conditions, other types of systems may, under certain circumstances, be more effective in relieving traffic congestion. For example systems such as IMIS (which include visual changeable message signs and roadside radio) and the "message boards" (changeable message signs of the CAC system)(32) may in fact be more effective in reducing congestion because all motorists (not only those carrying IVRG equipment) are now subject to guidance and control.*

Based on the preceding remarks, it is concluded that the primary basis for implementing IVRG in most urban markets would be derived from static rather than dynamic requirements. Most urban areas have a limited number of locations where congestion is frequently encountered. In those locations, a dynamic capability would be a welcome increment to the system, particularly if roadway surveillance is already present or can be shared with other traffic control system functions.

The general conclusion stated above with regard to dynamic guidance might not be applicable to certain of the largest U.S. cities where congestion is prevalent in wide areas for extended periods of time. These areas would have to be examined on an individual basis (along with alternative traffic control measures) and might, in fact , provide a basis for dynamic guidance as the principal reason for IVRG.

*It is recognized that "control" may not be as effective for unfamiliar motorists with the non-destination oriented information provided by changeable message signs.

(32) Yumoto et al, "Outline of the CAGS Pilot Test System", presented at the 58th Annual Meeting of the Transportation Research Board, Washington, D.C. January 1979

SECTION 6

SYNTHESIS OF IVRG SYSTEMS

This section describes the approach taken to synthesize a broad classification of functional in-vehicle route guidance systems. From this classification, several systems were selected for in-depth analysis.

6.1 DEFINITION OF CLASSIFICATION PARAMETERS

A matrix was developed to synthesize this array of in-vehicle route guidance systems. This matrix, presented in Table 11 lists parameters defining certain basic guidance requirements, guidance functions and system design configurations. Various classes of systems were then defined based upon the level of technology required for implementation.

6.1.1 Basic Guidance Requirements

An in-vehicle route guidance system may provide any or all of the following types of information to the motorist:

1. Lane information
2. Direction information
    a. Relative bearing information
    b. Maneuver instruction information
3. Speed information particularly where driver expectancy is low
4. Position or distance information

Guidance information may be provided to the motorist by means of visual or oral displays. Previous in-vehicle route guidance system projects have concentrated almost entirely on the vehicle display and field tests have substantiated the viability of this approach.

6.1.2 System Coverage Level

Certain systems are intended for only local area coverage (e.g., navigation through an interchange or highway segment). Others can provide service to a larger area (e.g., a significant portion of a central city or metropolitan area) or an entire country. As systems grow more complex, their capability to encompass all coverage types increases.

6.1.3 Route Guidance Function

6.1.3.1 Level of Need Addressed - Tactical or Strategic

Many IVRG candidates in part satisfy both the strategic and tactical needs defined in Section 3.2.1. However, some systems , particularly the simple ones, may emphasize one aspect rather than the other. The same motorist information presentation device may, in general, be used to present both types of information.

6.1.3.2 Strategic Guidance Need - Dynamic

As described in Section 3.2.2, dynamic guidance addresses a subset of strategic needs which relates to changes in an otherwise preferred routing arising from temporary states of the highway or traffic congestion status, such as traffic flow conditions, highway contruction and maintenance. Dynamic guidance requires additional informational sources to provide the basic information.

6.1.4 System Design Configuration

The design characteristics of In-Vehicle Route Guidance Systems which are most likely to span the range of system characteristics, costs and benefits are the following:

- One-way vs two-way data communication with the motorist
- The level and type of data which can be inserted into the system by the motorist. This characteristic determines the systems ability to address the specific guidance needs of a particular motorist.
- The extent to which traffic responsive information is provided on key portions of the system. This determines the ability to provide a dynamic system.
- The type of highway for which the system is to be implemented
- The type of supplementary information which the motorist requires to input the appropriate destination information
- The type of information which is communicated; data or voice

6.2 CLASSIFICATION OF SYSTEMS

Table 11 describes a set of system variations or "systems" in terms of the design characteristics described above. The table describes a static option (labeled "a") for each candidate and a dynamic option (labeled "b"). In practice) it is more likely that only those portions of a system which are somehow related to the traffic congestion problem will be implemented on a dynamic basis.

A significant parameter in the determination of both system benefit and cost is the extensiveness of implementation of route guidance on the highway system, or as viewed by the motorist, the level of "penetration" which it achieves. Table 11 describes the breadth and depth of penetration which appears to be most consistent with the technology employed.

The second column designates a "Class" of system. This designation generally represents &he level of technology required to implement the system. Class 1 systems feature one-way voice communication to the vehicle. All

TABLE 11. IVRG SYSTEM VARIATIONS AND CHARACTERISTICS

IVRG SYSTEM VARIATIONS	SYSTEM CLASS	SYSTEM COVERAGE LEVEL			SYSTEM DEPLOYMENT AREA INTENSITY			TYPE OF NEED SATISFIED (SEE CODE)								
		LOCATION SPECIFIC	URBAN AREA COVERAGE	NAT'L COVERAGE	LOCATION SPECIFIC	MODERATE	HEAVY	LANE GUIDNCE	EXIT RAMP INIT PT	EXIT RAMP FINAL PT	GUIDNCE FWY ENT	INTERS DRCTN	DIRECTION THRU 1-WAY SYSTEM	CONGES-TION	TERMINA-TION	OPTIMAL ROUTE
1. POINT LOCATION COMMON MESSAGE AUDIO	1	X			X			P	P	P	N	Limited Capa-bility	N	N-P	N	N
2. AREA-WIDE COMMON MESSAGE AUDIO	1		X		X			N	P	N	N	N	N	N-P	N	N
3. SYSTEMS 1 & 2 COMBINATION	1	X	X		X			P	P	P	N	Limited Capa-bility	N	N-P	N	N
4. LIMITED MOTOR-IST MESSAGE SELECTIVITY	2	X			X			S	S	P	N	P	P	N-P	N	N-P
5. SIGNIFICANT MOTORIST MESSAGE SELECTIVITY	2		See Note			X		S	C	C	S	S	S	N-C	S	S
6. FULL MESSAGE SELECTION, MODERATE DEPLOYMENT	3			See Note		X		S	C	C	S	S	S	N-C	S	S
7. FULL MESSAGE SELECTION, FULL DEPLOYMENT	3			X			X	C	C	C	C	C	C	N-C	S-C	C
8. TWO WAY	4		X		NA	NA	NA	P	C	C	S	C	C	P	S	S

NEED SATISFACTION CODE:

C - COMPLETE OR NEAR COMPLETE COVERAGE
S - PRINCIPAL MOTORIST NEED ADDRESSED
P - PARTIAL
N - LITTLE OR NONE
NA - NOT APPLICABLE

TABLE 11. IVRG SYSTEM VARIATIONS AND CHARACTERISTICS (Continued)

IVRG SYSTEM VARIATIONS		SYSTEM CLASS	COMMUNICATION TO VEHICLE		DATA INSERTION			MOTORIST INST TECHNIQUE		TRAFFIC RESPONSIVE*		
			ONE WAY	TWO WAY	NONE OR MINIMAL	LIMITED	MAJOR	READ SIGNS	VEHICLE CARRIED MATERIAL	NO	YES	
1. POINT LOCATION COMMON MESSAGE AUDIO	a / b	1	SHORT RANGE LINK	NONE OR ENABLE & TUNING	X			X		X	X	
2. AREA-WIDE COMMON MESSAGE AUDIO	a / b	1	LONG RANGE LINK	NONE OR ENABLE & TUNING	X			X		X	X	COVERAGE LIMITED TO STRATEGIC NEEDS WITH AREA EMPHASIS
3. SYSTEMS 1 & 2 COMBINATION	a / b	1	X	NONE OR ENABLE & TUNING	X			X		X	X	
4. LIMITED MOTORIST MESSAGE SELECTIVITY	a / b	2	X					X		X	X	
5. SIGNIFICANT MOTORIST MESSAGE SELECTIVITY	a / b	2	X				X		X	X	X	SYSTEM CAN ALSO BE USED FOR INTERCITY AND SPECIAL PURPOSES
6. FULL MESSAGE SELECTION, MODERATE DEPLOYMENT	a / b	3		X			X		X	X	X	RURAL FREEWAYS URBAN AREAS
7. FULL MESSAGE SELECTION, FULL DEPLOYMENT	a / b	3		X			X		X	X	X	
8. TWO WAY VOICE COMMUNICATION	a / b	4								X	X	

*A TRAFFIC RESPONSIVE CAPABILITY IS AVAILABLE FOR EACH SYSTEM VARIATION messages are presented sequentially to the motorist who then selects the appropriate guidance in real time. Class 2 systems feature one-way data communication to the vehicle. The motorist pre-selects an appropriate guidance objective and vehicle equipment selects (from all transmitted messages) the appropriate message based on the guidance objective and displays it to the motorist. Class 3 systems utilize two-way data communications, The motorist selects an appropriate destination which is communicated to roadside equipment. Appropriate guidance information is then returned to the vehicle. Class 4 systems utilize two-way voice communications. The motorist requests guidance instructions and receives a response from a central operator. The following paragraphs describe each of the systems in greater detail.

6.2.1 System 1 - Motorist Interpreted Local Area Audio Message

1. General Nature of System

   This system will utilize in-vehicle equipment which is currently on the market or which is a product of previous research. Thus, this equipment is currently used mainly for a purpose other than the reception of guidance information and its presentation to the driver. In this system, the motorist is presented with all information transmitted in a communication sequence.

2. Location of Information Sites

   Principal use is envisioned at a relatively small number of complex or major freeway interchanges and highway segments and possibly at major or complex high type highway interchanges or intersections.

3. Motorist Guidance Needs Addressed

   Greatest application appears to be in addressing local area problems of a tactical nature, e.g., in areas where an unfamiliar motorist needs assistance to navigate a close succession of exit ramps, particularly if accompanied by lane drops. Dynamic strategic aspects might inform motorists of downstream congestion on major highways.

   Depending on factors such as local geography, it might be possible to arrange a related wider area system of such information points which can provide a limited capability for static strategic coverage.

4. Type of Communication

   Communication is to the vehicle over a short range communication link.

5. Type of Motorist Data Insertion or Message Selectivity

   This system class is envisioned to have an extremely limited capability (which is restricted by channel selection considerations). Frequency allocation considerations may limit the system to just one channel, and no selectivity would be possible for this case.

6. Type of Presentation to Motorist

Only audio presentation is possible with currently operational vehicle equipment.

7. Type of Motorist Instruction or Reference Material

Highway signs are envisioned to be the principal source of information which informs the motorist as to the use of the system.

8. Examples of Possible Systems

Systems which can perform the stated functions include AM or FM roadside radio. In addition, CB systems with a local base station broadcasting relevant traffic information and operating on one or more dedicated channels would be a system in this class.

9. Related Variations

FHWA has conducted previous research on self-tuning adapters for roadside radio(33). (Although not currently operational, such vehicle equipment is functionally similar to that described.)

6.2.2 System 2 - Motorist Interpreted Areawide Audio Message

1. General Nature of System

See System 1

2. Location of Information Sites

Not site specific. Information will probably be most useful for addressing real time traffic congestion problems. Generally covers freeway, interchange, high type highway problems.

3. Motorist Guidance Problems Addressed

This system will typically provide the type of routing and congestion information usually provided by AM radio reports. The reporting of these problems will enable the motorist to work out a new strategic plan. Emphasis in this system is on dynamic strategic problems.

4. Type of Communication

Communication is to the vehicle over a long range voice communication link.

------

(33) "Study and Development of Highway Advisory Information Radio", FHWA RD 74-73, Atlantic Research Corp.

5. Type of Motorist Data Insertion or Message Selectivity

See System 1

6. Type of Presentation to Motorist

See System 1

7. Type of Motorist Instruction or Reference Material

As this is an areawide system, information as to its presence might be presented on highway maps, on signs at certain locations in the area, and by media publicity.

8. Examples of Possible Systems

The traffic helicopter report on commercial AM radio is one example. A more sophisticated approach to the dynamic problem is represented by the system operated by the Illinois Department of Transportation in the Chicago area. In this approach, freeway surveillance data is processed into travel time reports which are broadcast at frequent intervals by cooperating commercial AM radio stations.

9. Related Variations

The West German ARI system is an example of a related system which utilizes a tuning adapter in connection with PM auto radio equipment (designed to West German radio transmission standards).

6.2.3 System 3 - Combination of Systems 1 and 2

This system is a functional combination of Systems 1 and 2. It combines the local guidance capability of System 1 with the wide area dynamic coverage emphasized by System 2.

6.2.4 System 4 - Limited Message Selectivity

1. General Nature of System

This sytstem will provide the motorist with the capability of receiving only that message which relates to his requirement. Through a data insertion device, he will select one of a limited number of information options which are available.

2. Location of Information Sites

Principal use is envisioned at complex or major freeway interchanges and possibly at other freeway interchanges and at major or complex high type highway interchanges or intersections. There may, in addition, be opportunities to provide limited purpose guidance through at grade street systems.

3 Motorist Guidance Problems Addressed

This system is principally intended to provide guidance at the local level (for example, through complex interchanges). It can also possibly provide a very limited capability for area-wide static strategic guidance.

4 Type of Communication

Communication is to the vehicle over a short range communication link. All possible guidance messages at a site are communicated to the vehicle. No communication from the vehicle is provided.

5 Type of Motorist Data Insertion or Message Selectivity

The motorist will select a single guidance choice from a limited number of options which are communicated to the vehicle at a guidance site. Selection devices may include push buttons or selector switches. The device will select the appropriate message requested by the motorist from the ensemble of messages transmitted to the vehicle.

6. Type of Presentation to Motorist

The presentation may be audio or visual.

7. Type of Motorist Instruction or Reference Material

Selection of the appropriate message requires the driver to first be provided with reference information. This is probably best done by means of highway signs designed for this purpose. A series of such signs might be necessary at communication sites. This approach might be supplemented with appropriate references on highway maps.

8. Examples of Possible Systems

No installation of this type of system is currently known to exist. Such a system might contain a five-position selestor or set of push buttons in the vehicle. Messages in audio form might be presented through the power amplifier and speaker of the auto's radio using preemptive switching. Visual display techniques are also possible.

6.2.5 System 5 - Extensive Message Selectivity

1. General Nature of System

System 5, as does System 4, selects a single appropriate message from an ensemble of messages transmitted to the vehicle. System coverage is in sufficient depth and breadth to enable the motorist in an instrumented urban area to input a guidance code for an intersection or other target guidance point close to his destination.

2. Motorist Guidance Problem Addressed

This system addresses all urban area strategic and tactical requirements. Terminal guidance is provided to acceptable accuracy.

3. Type of Communication

Preliminary studies have shown that several techniques for one-way communication with the required data burden to accommodate the message ensemble may be feasible. Current studies and those described in Section 7 further assess the viability of this approach.

4. Type of Motorist Data Insertion

The motorist will insert a guidance target point code by means of a thumbwheel, keyboard, or indicator slew type instrument.

5. Type of Motorist Instruction or Reference Material

Printed material carried in the vehicle glove compartment or attached to the sun visor will provide necessary code references.

6. Type of Highway Emphasis

Emphasis is on freeway and arterials in selected urban areas. Guidance to rural limited access highway interchanges and guidance to remote urban areas can also be provided.

7. Examples of Possible Systems

No known system of this type has been designed. Technology alternatives for the systems components are discussed in Section 7.

6.2.6 System 6 - Full Message Selectivity - Limited Deployment

1. General Nature of System

Two-way communication is used. Target destination selections are transmitted from the vehicle to roadside and guidance information is transmitted back to the vehicle. The system may accept a nationally-oriented destination coding approach.

2. Type of Highway Emphasis

Emphasis is on urban area freeways and arterials as for System 5. Extension to other areas can probably be achieved more easily and with a more universal coding approach than is possible with System 5.

3. Motorist Guidance Problems Addressed

   The system is intended to address all of the strategic and tactical guidance problems.

4. Type of Vehicle Communication

   Communication to the vehicle will be two-way using short communication paths.

5. Type of Motorist Data Insertion or Message Selectivity

   The motorist will insert data corresponding to a national numerical designator for a location near his final destination. All requirements are imbedded into the same coding and data insertion scheme.

6. Type of Presentation to Motorist - Audio or Visual

7. Type of Motorist Insertion or Reference Material

   Data insertion information will probably be carried by prepared materials (map or other format) location in the glove compartment.

8. Examples of Possible Systems

   The ERGS System, the Japanese CAC System, and the German ALI System when deployed as described above would be examples of this system.

6.2.7 System 7 - Full Message Selectivity - Intensive Deployment

This system is similar to System 6 except that deployment is envisioned as being somewhat more complete. Guidance can be considered down to the intersection level, particularly in CBD or dense urban population areas, or to a somewhat less intense level such as the collector street level in suburban areas. AADT and the area's population density level will influence the final choice.

6.2.8 System 8 - Two-Way Voice Communication

1. General Nature of the System

   Two-way voice communication is used. One or more radio channels are uniquely assigned to the IVRG application. Motorists requiring guidance request the guidance information from a central operator. The operator uses personal information, maps and other prepared information to assist in responding to the inquiries. Repeaters are provided at strategic locations to relay the motorist request to the central site. These repeaters are connected to the central site via telephone lines.

2. Location of Information Sites

Principal use is envisioned in urban areas where coverage can be provided through a network of strategically located repeaters.

3. Motorist Guidance Problems Addressed

This system is intended to satisfy all urban area guidance needs. However, the ability of such a system to satisfy these needs is limited by its ability to only service a few motorists at a time.

4. Type of Communication

Communication between the vehicle and the roadside units is over a radio link.

5. Examples of Possible Systems

It is envisioned that this system will utilize the type of radio services characterized by CB. The system would require the use of one or more dedicated channels uniquely assigned to IVRG. The proposed 900MHZ CB system, offers the opportunity to reserve such channels.

6.3 FUNCTIONAL SYSTEM RECOMMENDATIONS

A broad range of IVRG system concepts has been considered in this section. The possibility of configuring an IVRG system around the concept of LORAN has also been considered (Appendix D) and rejected as impractical due to severe technical and cost problems. Table 12 describes the capability of the eight IVRG candidates, synthesized in this section, to address guidance requirements according to the requirements and classification scheme developed and quantified in previous sections.

In Section 3, destination oriented (strategic) needs ware shown to characterize over 85% of the static excesses. Thus, the satisfaction of strategic needs is the key to the effectiveness of an IVRG system. Table 12 shows that Systems 1 through 4 provide little or no strategic guidance information. They, therefore, cannot address those guidance needs which are specifically related to this requirement.

Thus , these systems should be considered as information assists for specific problems and specific sites (rather than as a "system" which can provide consistent and reasonably ubiquitous information to the motorist).

Note that Systems 1, 2 and 3 are not tied to IVRG concepts and are currently being used as the communication element for other types of traffic management and control systems (e.g., urban traffic signal systems and freeway traffic surveillance and control systems). It would appear that their capabilities are more appropriate to these roles than to IVRG. Thus, research on these systems is warranted under programs for which their role is better suited.

TABLE 12. IVRG SYSTEM CAPABILITY TO SATISFY QUANTIFIED GUIDANCE NEEDS

TYPE OF SYSTEM	STATIC GUIDANCE STRATEGIC GUIDANCE ENROUTE	STATIC GUIDANCE STRATEGIC GUIDANCE TERMINAL	TACTICAL GUIDANCE	DYNAMIC GUIDANCE DESTINATION ORIENTED GUIDANCE	DYNAMIC GUIDANCE NON-DESTINATION ORIENTED CONGESTION INFO.
1. Motorist interpreted local area audio message	Little or None	None	Some	Little or None	Good where available
2. Motorist interpreted areawide audio message	None	None	None	None	Poor to Fair
3. Combination 1 and 2	Little or None	None	Some	Little or None	Good where available
4. Limited motorist message selectivity	Little	None	Good where available	Some	Good where available
5. Significant motorist message selectivity	Good	Good	Good to Excellent	Good	Not applicable
6. Full message selection moderate deployment	Good	Good	Good to Excellent	Good	Not applicable
7. Full message selection full deployment	Excellent	Good to Excellent	Good to Excellent	Excellent	Not applicable
8. Two-way voice communication	Limited	Limited	Limited	Limited	Not applicable

Systems 6 and 7 differ only in their intensity of deployment. Although the delineations between these systems are somewhat arbitrary, system 6 may be considered to have an approximate average guided arterial spacing in the central city external to the CBD in the range of 0.4 mi to 1.1 mi (.64km to 1.77 km). System 7 would be considered to have a closer spacing about 0.05 mi to 0.4 mi (0.08km to .64km). System 5, utilizing a one-way communication scheme, meets the destination oriented guidance needs at a potentially lower cost for in-vehicle equipment than either system 6 or 7. Thus, it offers a potentially higher benefit to cost ratio than either System 6 or 7. However, System 5, at this point must be considered to have the higher technical risk, principally because previous research has concentrated on the mechanization of Systems 6 and 7.

System 8, utilizing 900MHZ CB radio, has the attractiveness of utilizing in-vehicle equipment that the motorist might purchase and utilize for non IVRG functions. Such a system, although not as responsive to the IVRG as Systems 5, 6 or 7, offers the opportunity for a "building block" approach to IVRG. Such a system might have initial, but limited, deployment and could eventually be expanded to full deployment.

In subsequent sections Systems 5 and 8 are analyzed in detail. These two candidates offer examples of two different approaches to IVRG. The first approach, System 5, offers a system that is responsive to route guidance needs but requires a major investment before the benefits will be obtained. The second approach, System 8, is less responsive to route guidance needs but offers the capability of incremental investments with benefits increasing as the investment increases.

SECTION 7

IN-DEPTH ANALYSIS OF IVRG CANDIDATES

In this section the two IVRG candidates selected for detailed study (one candidate utilizing a one-way data transmission approach and the second candidate using a CB type of CB radio scheme operating in the 900 MHZ band) are discussed in detail.

To simplify system designation the system utilizing one way data transmission (previously designated as System 5) has been redesignated as IVEC (In-Vehicle Electronic Guidance).

7.1 IVRG SYSTEM

The block diagram for the IVEG system approach is shown in Figure 4. The roadside equipment required at each decision point consists of a route guidance controller and a communication transmitter. The vehicle equipment consists of a communication receiver, control logic destination encoder and display. In a dynamic system the roadside equipment is linked to a control center via a communication link. Guidance instructions are stored in the route guidance controller for all guidance target points and are continuously transmitted from the roadside terminal. A vehicle receives the instruction when its receiver intercepts the transmitter's field. The vehicle's control logic decodes the message and selects the guidance instruction for the target point.

In subsequent sections the message format, the network coding technique and two communication techniques, microwave and optical, are discussed. The technical aspects of implementing such a system using each of these techniques are described as well as deployment, problems, maintenance, reliability and cost.

7.1.1 <u>Network Coding Techniques and Message Formats</u>

Studies have been made under other projects to consider appropriate network destination entry codes on a national basis for systems such as CAC [32] and ERGS [34]. These are representative of IVRG Systems 6 and 7 discussed in Section 6.2. IVRG concepts similar to IVEG have reduced capability for universality of coverage. In this system a guidance message is transmitted to all vehicles, and message selection is made in the vehicle. Depending on the communication approach selected, transmission limitations may dictate an upper limit to the combination of number of bits which are required for a single intersection and the number of destinations required. A study was therefore undertaken to determine whether a coding scheme could be developed which would identify an approximate design point for data quantity requirements for the IVEG system. This study was made using the urban area deployment principles described in Sections 3 and 5.

(34) "Highway Coding for Route Designation and Position Descriptions," Philco - Ford WOL-TR3580 July 1, 1968

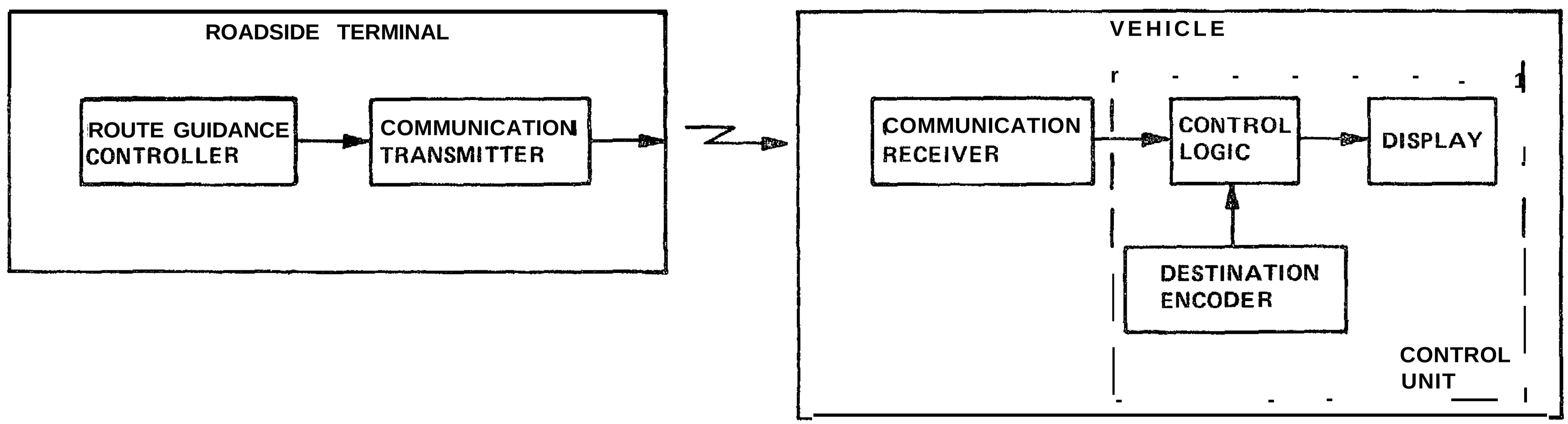


Figure 4. One Way Data Communication Approach - IVEG (Block Diagram)

This preliminary study of coding requirements used the Rochester N"..., - metropolitan area as well as the geographic and demographic structures of other urban areas to identify the basic coding requirements. Figure 5 is a map showing the boundaries of the area studied.

7.1.1.1 Assessment of Guidance Target Point Requirements

The particular deployment alternative selected for the coding study used a central city (exclusive of CBD) arterial spacing of about .72 mi (1.16km) r This particular deployment led to a guidance point* density of approximately 2 points per sq. mi (2.6 sq. km) in cities and 1.25 targets per sq. mi (2.6 sq. km) in suburban locations. The Rochester CBD contains approximately 30 guidance points. The total number of guidance points for this scenario was therefore approximately:

Location	Guidance Target Points
CBD	30
Rest of Central City	110
Suburban Areas Included	150
Total	290

The same guidance target point density requirements were applied in a preliminary way to five major U.S. cities by assuming an acceptable portion of the SMSA for guidance purposes. In each case a map of the area was used to identify the specific boundary of the guided area to be studied. The CBD was then outlined on a map. The area was then divided (as in Figure 6) into a number of radially oriented sections outside the CBD not exceeding 8. The reason for the sector subdivision relates to a possible coding format and is explained later. An assessment of the number of guidance points was then made based on the central city and suburban areas using the same guidance point densities as for the Rochester scenario. The number of guidance points in the CBD for the largest metropolitan area considered (Chicago) was taken as equal to the number of points in a non-CBD sector (163). The number of guidance points for the other CBD was then scaled to the approximate size and complexity of Chicago's CBD. Although these assumptions appear to be some&ate arbitrary, the analysis is relatively insensitive to assumptions relating to the CBD. Table 13 shows the results of the analysis. Chicago, the most complex area analyzed, requires 1466 guidance points spread through one CBD sector and eight remote sectors. With the exception of New York and possibly Los Angeles**, this represents the most severe design condition for an IVEG system in the U.S.

* A guidance point represents a destination as well as a location at which guidance is provided. In central cities the most common type of destination is represented by the intersection of guidance arterials. Several instrumented approaches are generally required to instrument a single guidance target point.

**Both of these cases may require unique treatment

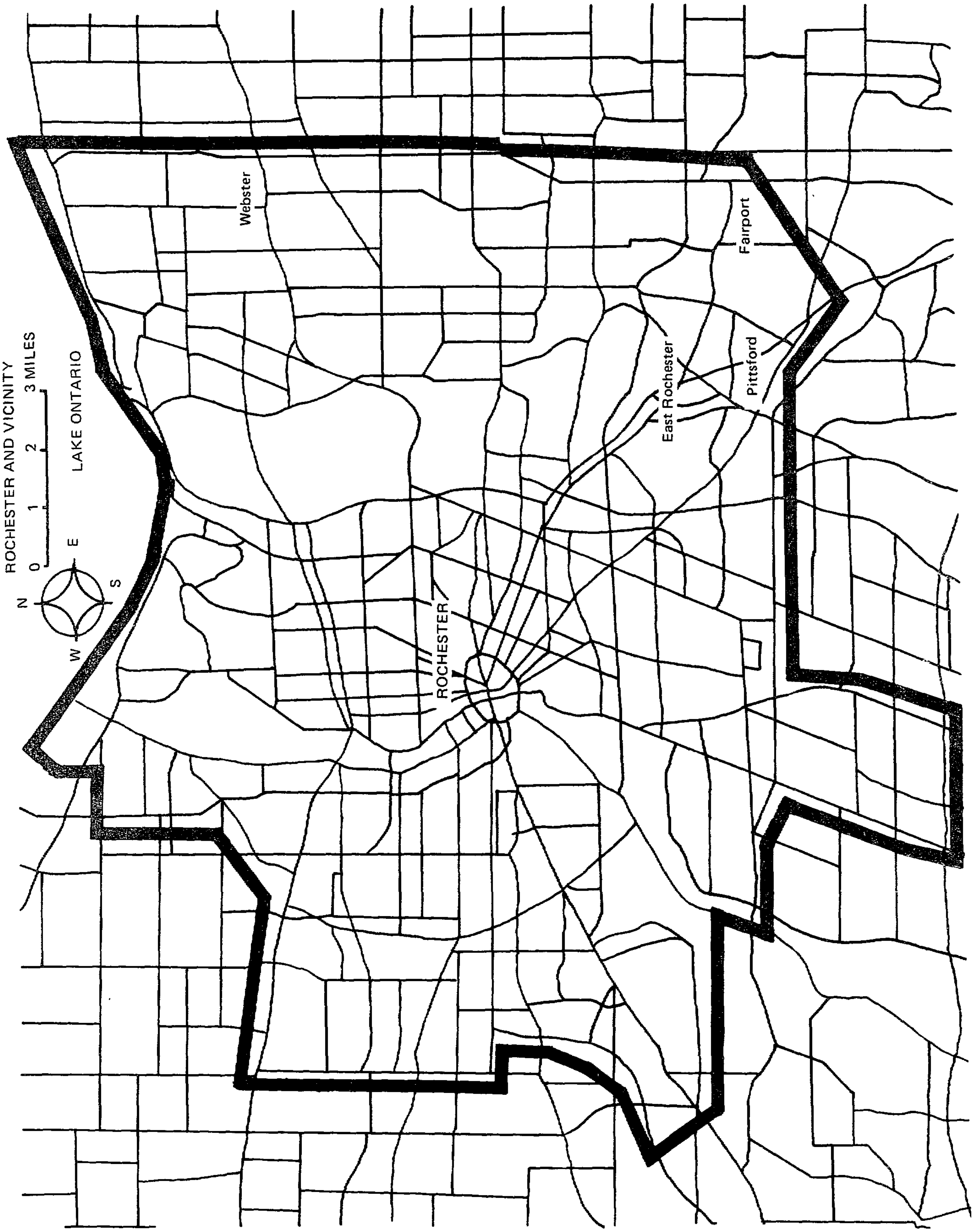
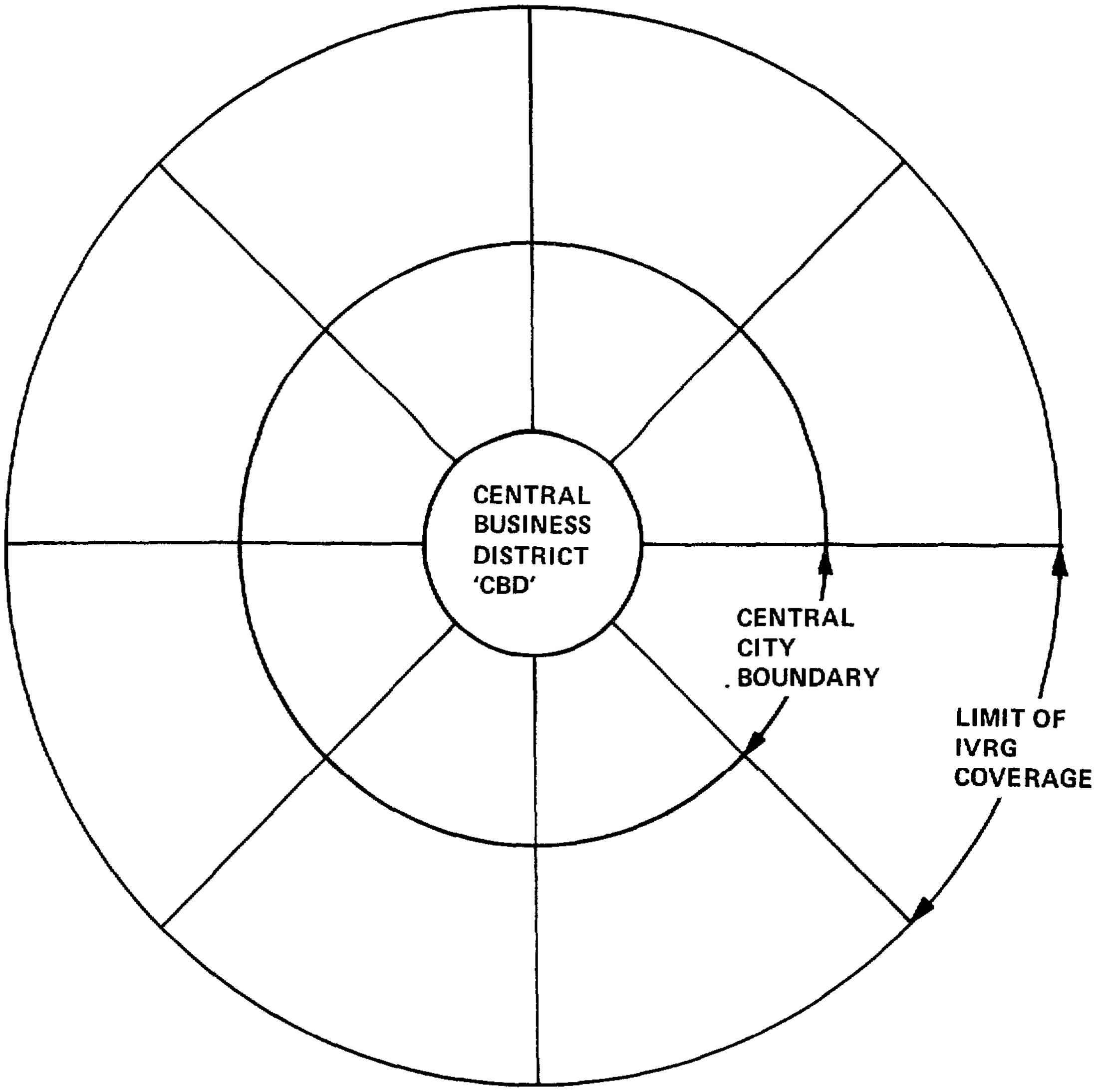


Figure 5. Rochester Urban Study Area



NOTE SPACING OF RADIAL BOUNDARIES IS DEPENDENT ON DENSITY OF GUIDANCE POINTS.

Figure 6. IVRG Urban Area Map

TABLE 13. GUIDANCE POINT REQUIREMENTS

Metropolitan Region	Chicago	Detroit	Washington	Baltimore	Denver
Central City Area (sq mi)	223	138	61	78	95
Guidance points in central city @ 2/sq mi	445	276	123	157	190
Area of Region less central city (sq mi)	686	480	394	292	304
Guidance points in suburban area @ 1.25/sq mi	858	600	493	365	380
Number of non CBD sectors	8	8	7	6	6
Number of guidance points in CBD	163	110	120	87	60
Total number of guidance points	1466	986	736	609	630
Number of guidance points per remote sector	163	109	88	87	95

NOTE: 1 sq mi = 2.6 sq km

7.1.1.2 Coding Requirements

A coding scheme enabling motorist information input into the vehicle IVEG system and accomodating the guidance point requirements described in Section 3 is described in the following paragraph. The scheme achieves an economy of data transmission demands, particularly for large cities, while at the same time it provides the capability to handle a number of special guidance functions. The system is generally based on a geographical division of metropolitan areas into radial sectors and a CBD as shown in Figure 6. The motorist inserts (by reference to previously prepared information) information representing the destination sector and the guidance point within that sector. When the vehicle is located in a non-CBD sector the guidance point messages for the current sector and the adacent non CBD sectors are transmitted to the vehicle from roadside equipment. Guidance to the CBD sector for a vehicle in a non CBD sector may be accomplished by transmitting guidance information to intermediate surrogate points which lie just within the CBD boundary and along the optimum approach path. When the CBD boundary is crossed, guidance information to the appropriate destination point is provided, Guidance to a vehicle in a non CBD sector which is destined for a non adjacent CBD sector is accomplished initially by messages providing surrogate guidance to one of several locations in the remote sector. When an adjacent sector is reached, detailed guidance is provided. When a vehicle is in the CBD sector and is destined for a non CBD sector, initial guidance is provided to one of a number of surrogate points in the appropriate sector. Detailed guidance is provided when the sector boundary is crossed. This system may be implemented by means of a four decimal digit code and a data insertion panel.

Table 14 describes a coding scheme consistent with the concept described. When the conventional requirement for guidance within an urban area is required, the motorist inserts a four digit code into the data insertion panel. Digit 1 represents the sector address and digits 2, 3, and 4 represent the destination guidance point within the sector. In the instances described above where surrogate guidance points are communicated to the vehicle, only the first and fourth digit information is actually communicated.

In order to obtain initial guidance to remote urban areas, the first digit is set to zero by the motorist, the second digit to 2 and the last two digits to a remote area destination code (universal throughout the U.S.).

When entering a limited access highway in a particular state, it is possible to select a particular non-urban interchange as a guidance destination point. The codes for accomplishing this are shown on the third row of Table 14.

The coding system is capable of adapting to the guidance for certain local functions on special highway networks. The code address shown in the fourth row may be used. Address data may be provided to the motorist through special highway signs erected for this purpose.

7.1.1.3 Message Data Requirements

In the IVEG system, messages for the guidance commands to each appropriate destination are transmitted to the vehicle. The vehicle equipment selects the specific command for the particular destination target point which had previously been selected by the motorist.

TABLE 14. IVEG CODING SCHEME

	DIGITS				
	1	2	3	4	Code info provided by
Principal Function					
Metropolitan Area guidance	1 thru 9	0, 1	0 thru 9	0 thru 9	Metro Area Guidance Chart
Special Functions					
(a) Remote Metropolitan Areas	0	2	0 thru 9	0 thru 9	All printed motorist aids
(b) Rural interstate exits	0	3	0 thru 9	0 thru 9	State highway maps and oil co. maps
(c) Local functions (parking, national parks, airports, special roadway networks)	0	3	0 thru 9	0 thru 9	Road signs or special printed material

Some communication technologies have more message size capability than others. In order to assist in the evaluation of acceptable technologies, it became necessary to determine the minimum message content which would suffice. The study described in the following paragraphs was performed for that purpose and is not intended to finalize a code structure. The requirements for the Chicago area in Table 13 and the destination code structure of Table 14 were used as the basis for this study.

The study assumed a synchronous technique. Each message is continuously repeated. The message whose format is shown in Figure 7 contains one word for each destination sector. Each word consists of two or more characters, the number depending upon the instruction requirements. Each character consists of 8 data bits and 1 parity bit.

At the start of each word a synchronization (sync) character is transmitted. This allows the receiver to lock on at the start of any word, eliminating the need to wait for the start of a message. When the sync character is detected all registers in the receiver are initialized. The next character received is the sector character. The first 4 bits of this character identifies the "Destination Sector" whose instructions are contained in this word. If this is the sector set on the Destination Encoder the receiver examines the second four bits, otherwise it searches for the next word's sync character. Assuming that there is a sector match, the second four bits identifies whether this is a local, or adjacent sector, or remote (non-adjacent) sector. If it is a local, or adjacent sector then many additional characters follow. Each character contains instructions for each guidance point in sequence. Thus the first character after the sector character contains data for points one and two (four bit instructions for each of two points plus a parity bit) and the next character for points three and four, etc. If it is a nonadjacent sector then a maximum of five characters follows. The receiver, for this case, searches for the character which contains the instruction to direct the motorist to the appropriate surrogate guidance point for that sector. The location in the message of this instruction corresponds to the last digit in the destination code.

A calculation of the maximum number of bits that would have to be transmitted from roadside to the vehicle is shown below. Note that a word will contain only the number of characters required.

Maximum number of destination points per local sector (PLS) = 163:
Maximum number of surrogate guidance points per remote sector (PRS) = 10:
Maximum number of special function points (PSF) = 100:
Maximum number of characters per local sector word (CLSW):
Maximum number of characters per remote sector word (CRSW):
Maximum number of characters per special function word (CSFW):

$$CLSW = 1\text{ sync} + 1\text{ sector} + \frac{PLS}{2\text{ points/character}} = 2 + \frac{163}{2} = 84\text{ characters}$$

$$CRSW = 1\text{ sync} + 1\text{ sector} + \frac{PRS}{2\text{ points/character}} = 2 + \frac{10}{2} = 7\text{ characters}$$

$$CSFW = 1\text{ sync} + 1\text{ sector} + \frac{PSF}{2\text{ points/character}} = 2 + \frac{100}{2} = 52\text{ characters}$$

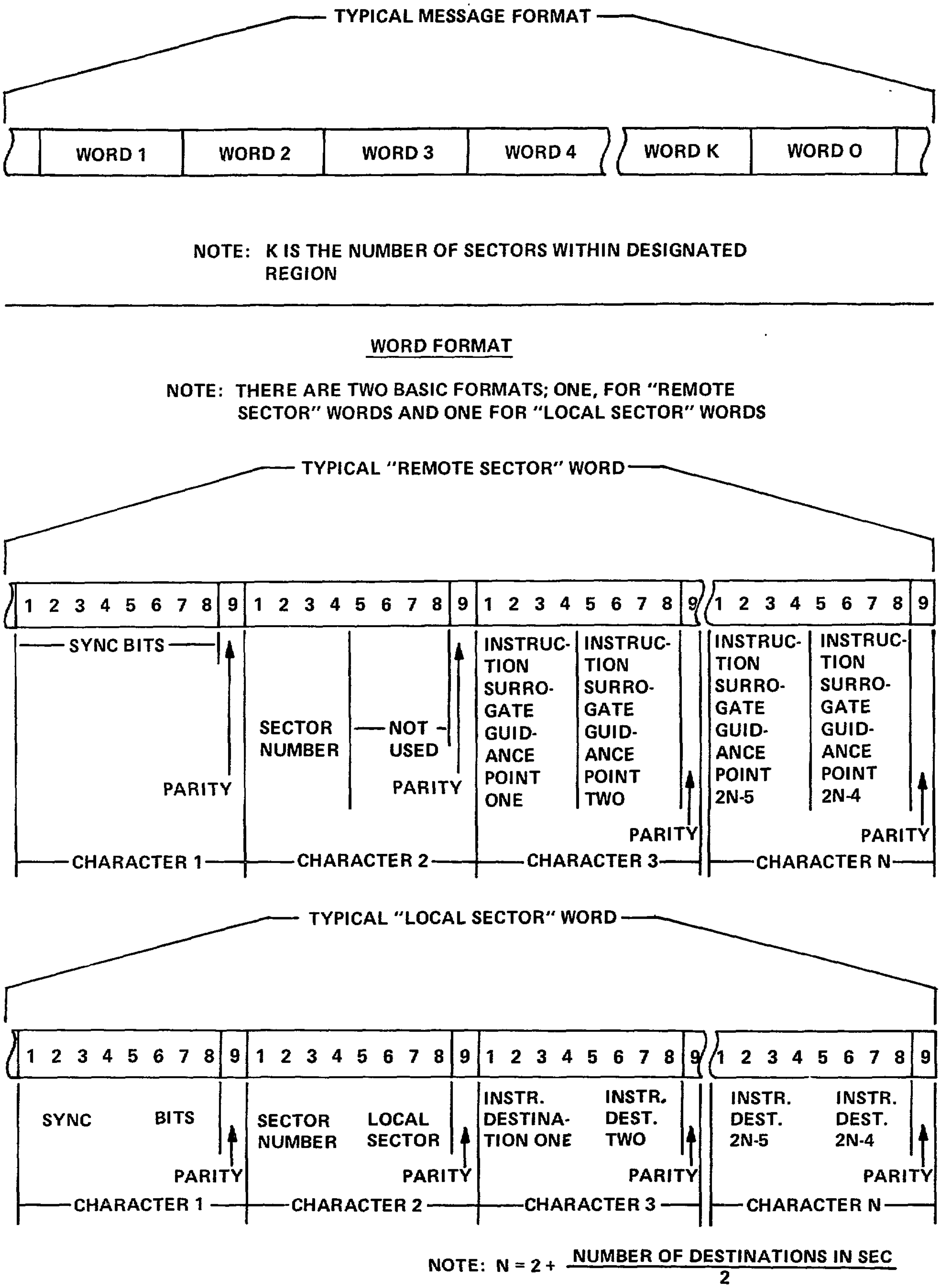


Figure 7. IVEG Roadside to Vehicle Message Format

Longest message (M) consists of 4 local sector words + 5 remote sector words + 1 special function word

M = 4 CLSW + 5 CRSW + CSFW
  = 4 (84) + 5 (7) + 52
  = 423 characters

Synchronization is not established until the sync character is detected. Thus to be assured of message reception it is generally necessary to receive one complete message plus the first character twice. Since the message is continuously transmitted, the first character varies depending upon when the vehicle entered the transmitters field. In the worst case this would be the 84 character local zone word, the longest word. Thus to insure reception of a complete message 423 + 84 = 507 characters must be received during each vehicle passage.

This is equal to (507 characters) (9 bits/characters) = 4563 bits/transmission including sync and parity.

This scheme uses simple parity for error detection. Each eight bit character has a parity bit appended to it. Synchronization is not established if a parity error is detected in the sync character. The detection of a parity error in the "sector" character or in the instruction character for the desired destination point causes the receiver to ignore that word and search for the next sync character. The legend "MESSAGE ERROR" is displayed if a valid instruction is not received during a subsequent transmission from the roadside guidance unit to the vehicle. This message alerts the driver to the lack of a valid guidance message.

7.1.2 Roadside To Vehicle Communication

The IVEG System requires a one-way transmission of information from the roadside terminal to the vehicle. The basic elements of such a communication link are the roadside transmitter, vehicle receiver, and transmitter and receiver antennas. The antennas to be employed are critical to the system design, and will dictate to a large extent not only the overall system design requirements but also the system costs.

As explained in the following sections, point-to-point communication is best suited for the IVEG application. Two techniques for implementing such a point-to-point communication link, microwave and optical, have been evaluated.

7.1.2.1 Types of Communication Links Considered

Three types of communication links, point-to-point, omnidirectional broadcast and directive broadcast, were considered.

In a point-to-point link transmission is directed from the roadside terminal to a single vehicle. Such a link can be implemented by using loop antennas. This technique has been utilized in several of the previous IVRG systems. A point-to-point link can also be established by using small directional narrow beamwidth antennas which restrict transmission to a single vehicle. Narrow beamwidth and small antenna size can be obtained by transmitting either in the 5-15GHZ microwave band or in the optical spectrum. The geometrics of the roadside installation can be configured to limit shadowing and multipath effects by mounting the transmitting antennas directly over the traffic lanes.

In the omnidirectional broadcast link, transmsission from the roadside terminal is received by all vehicles on all approach routes within a limited range of the intersection by the use of monopole antennas at the intersection. This technique transmits simultaneously to all vehicles at the intersection, thus an auxiliary technique would be required to establish the directional of vehicle travel in order to select the proper route guidance instructions.

In the directive broadcast technique communication is established between the roadside terminal and all vehicles on one approach to the intersection. This technique may utilize either a slotted coax cable mounted along each approach to the intersection or directional antennas aimed at each approach. Use of slotted coax may present difficult installation problems as well as unreliable directional separation. Directional antennas may be subject to multipath and shadowing problems.

The point-to-point type of link using small directional antennas is the best choice for the IVEG application. This technique offers the possibility of using a low cost receiving antenna that is easy to install and may even be incorporated into the vehicle unit. In the following sections the implementation of a point-to-point broadcast link using microwave and optical techniques are explored.

7.1.2.2 Microwave Point-To-Point Link

Figure 8 illustrates the conceptual configuration for a microwave IVEG system that utilizes directive antennas for establishing a terminal-to-vehicle communication link. The terminal antenna is mounted above a roadway traffic lane with the antenna beam oriented vertically downward. A directive vehicle receiving antenna is mounted such that its beam is oriented directly upward. The communication link is established during the time of intersection of the two beams.

An operating frequency in the 10 to 15GHZ (SHF) frequency spectrum has been selected. This selection is a trade off between equipment cost, cost increases as frequency increases, and antenna size, size decreases as frequency increases.

7.1.2.2.1 Antenna Requirements

The antenna system design for a microwave IVRG data link is critical in order to restrict route guidance information to a specific number of lanes of traffic in a particular direction so that the system delivers the correct information to the user. False instructions will be displayed, if a motorist erroneously receives data from the roadside transmitter intended for the opposing direction.

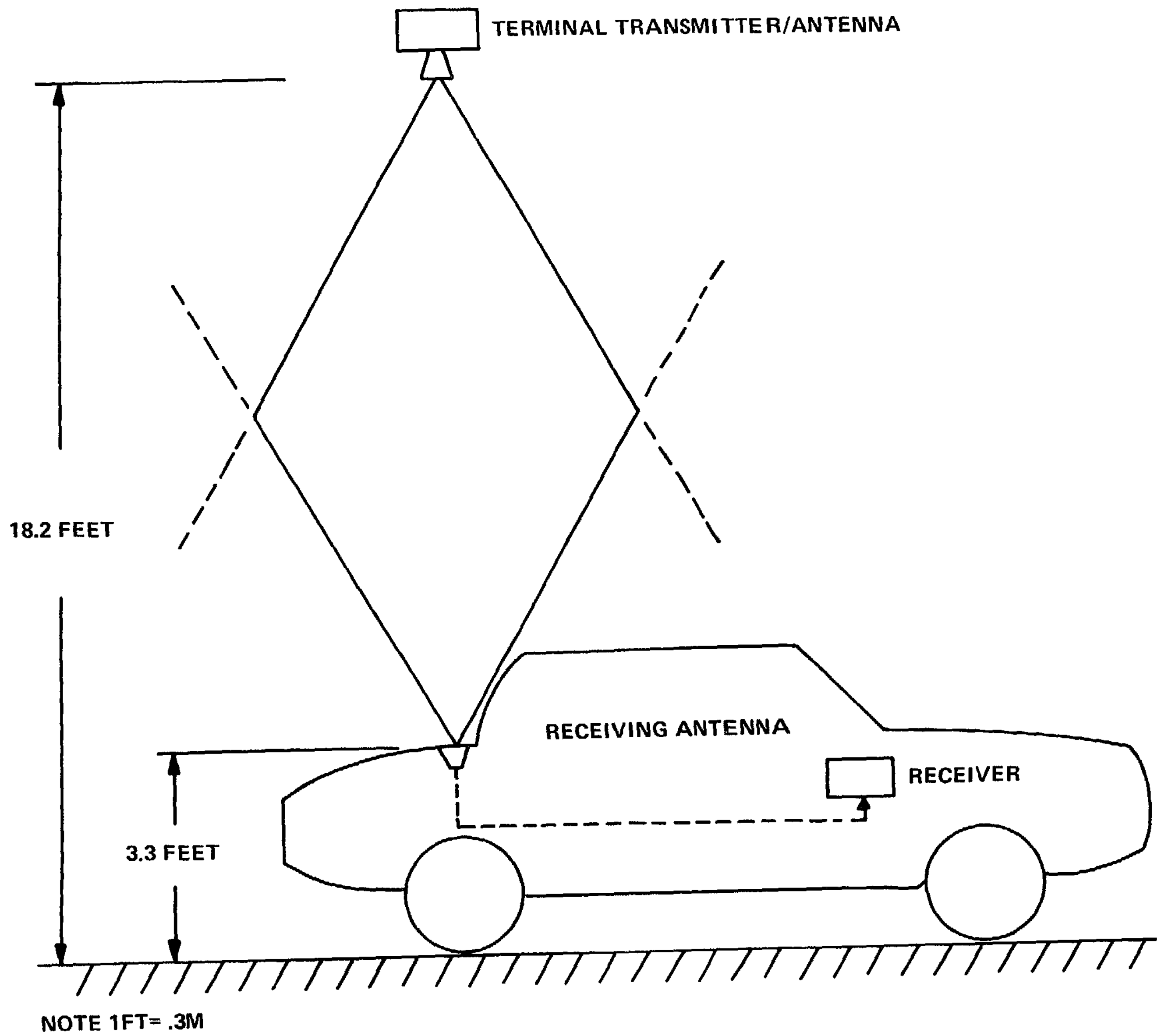


Figure 8. Point-to-Point Link Configuration Using Directive Antennas

To prevent this problem, the antenna beamwidth and orientation for both the transmitter and the receiver must be controlled. Other antenna design parameters, that need to be considered include polarization, sidelobe levels, physical dimensions, and cost.

Antenna beamwidth is perhaps the most critical design parameter of the microwave system. This requirement implies the selection of antennas with relatively narrow beamwidths and low sidelobe levels. Antennas meeting these requirements inherently possess high gain characteristics. In the system design the emphasis is on the selection of antennas that meet beamwidth and sidelobe level requirements. Transmitter output power and/or receiver sensitivity may be adjusted to maintain desireable signal levels.

Figures 9 and 10 illustrate desirable antenna radiation patterns for a microwave IVEGS data link.

The worst case condition for antenna beamwidth in a direction orthogonal to vehicular motion (a_t, a_r) (see Figure 9) occurs for the following geometry:

- Narrow Lane Width
- Narrow Vehicle Width
- Maximum deviation across lane (vehicle antenna position relative to center of lane).

A narrow beamwidth antenna tends to cause increased variation of the received signal level. A compromise, therefore, is necessary in order to satisfy the link requirements.

The vehicle receiver antenna must remain illuminated by the overhead transmitter antenna for various receiver antenna positions in the lane corresponding to the position of the vehicle relative to the curb or centerline (see Figure 11). If the transmitter and the vehicle antennas are mounted in the center of the lane and vehicle respectively, a direct path from the transmitter antenna to the receiver antenna for the extreme (curb to centerline) vehicle positions in a given lane requires a transmitter antenna beamwidth (a_t) of 16 and 28 degrees for lane widths of 9 feet (2.7m) and 12 feet (3.7m) respectively assuming an antenna separation of 14 feet (4.3m) and a vehicle width of 5 feet (1.5m). If, however, the transmitter antenna height is allowed to be increased, a single antenna design with a beamwidth of 16 degrees can be employed independent of lane width.

Antenna beamwidth is, by definition, the angular distance between the rays for which the power radiated (or received) is one-half the maximum power. If a transmitter antenna with this 16 degree beamwidth is employed in the IVEG system, the signal level in the desired lane varies from 0 dB at the lane center to -3 dB at the extreme receiver antenna lane positions. The signal level from the same transmitting antenna into the opposite lane is at least 15 dB less than the maximum signal level in the desired lane (see Figure 12). Use of vehicle receiver antennas with beamwidths less than 90" provide additional lane isolation without significantly increasing signal variation in the desired lane. For example, if the vehicle receiver antenna

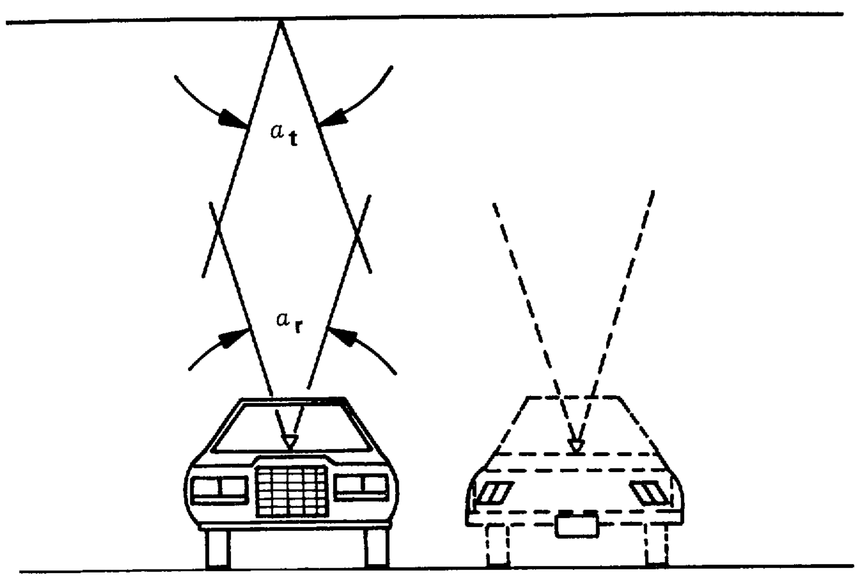


Figure 9. Ideal Antenna Radiation Pattern Orthogonal to Vehicular Motion. Note that the vehicle in the Opposing Lane Will Not Receive the Signal Even While in the Worst Case Position (against the centerline).

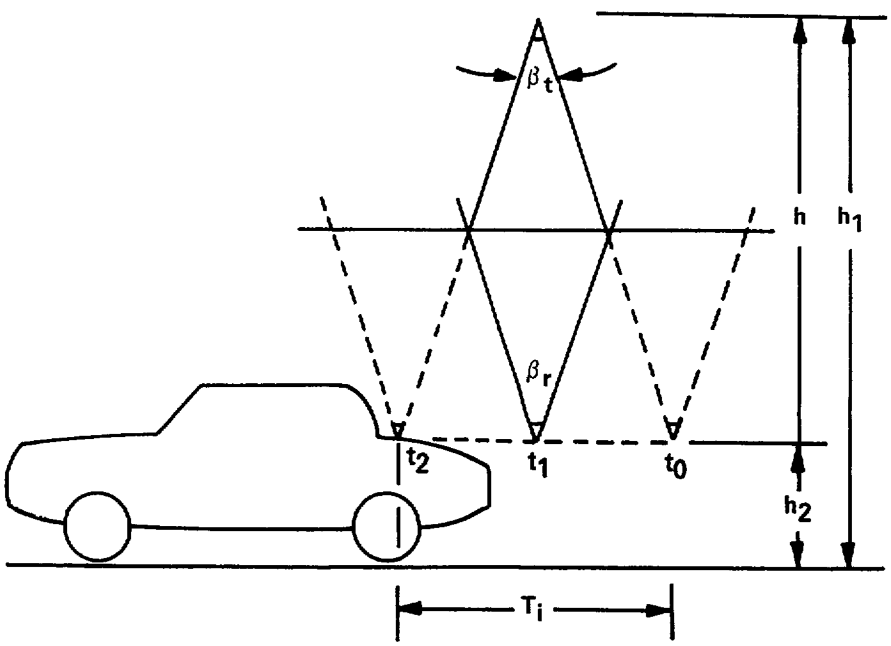


Figure 10. Ideal Antenna Radiation Pattern in the Direction of Vehicular Motion. Intercept Time (T_i) is Defined as Leading Edge Entry to Trailing Edge Exit Time

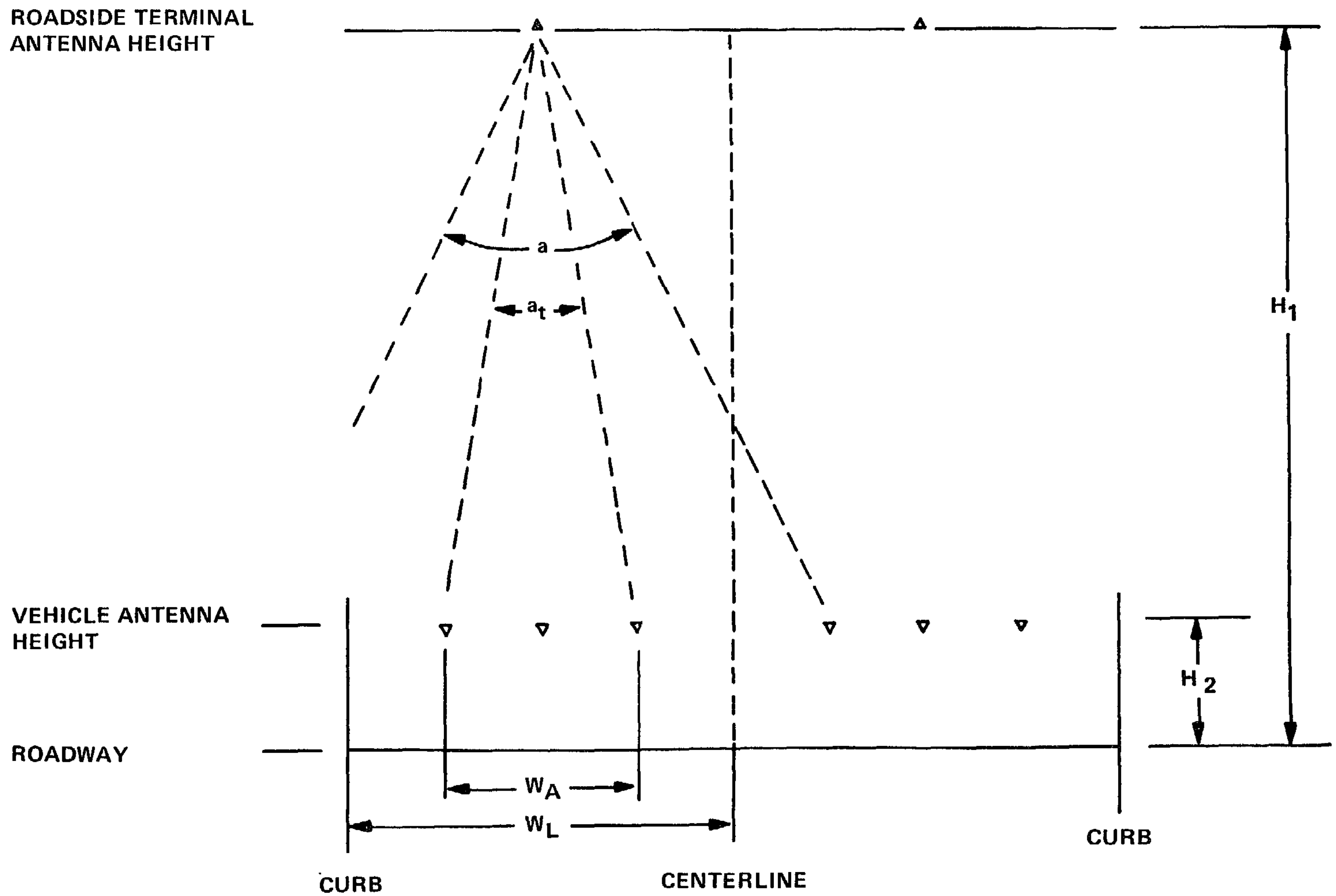


Figure 11. Antenna Beamwidth Analysis Orthogonal to Vehicle Motion

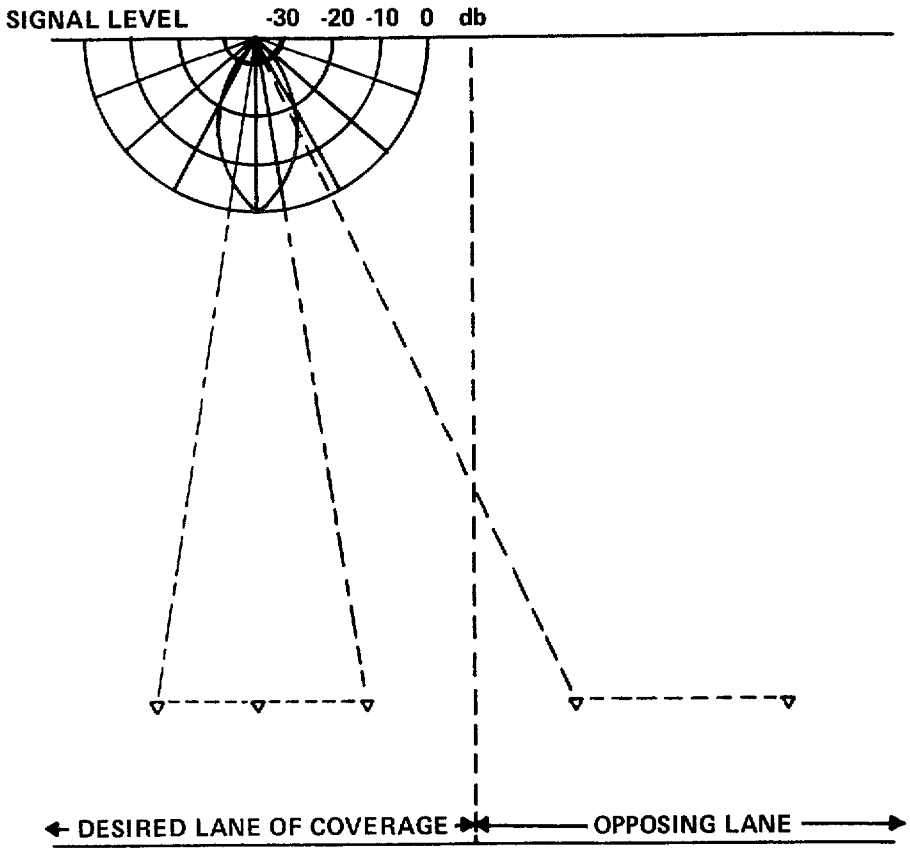


Figure 12. Radiation Pattern of the Transmitting Antenna

beamwidth (a_r) is chosen to be the same as the transmitter antenna beamwidth (a_t), 16^o in the above analysis, the signal level variation increases from 3 dB to 6 dB while the isolation increases from 15 dB to over 30 dB. Therefore, the vehicle receiver has to distinguish between a signal level of -3 dB and -15 dB in the first example ($a_t = 16^o, a_r = 90"$) and between -6 dB and -30 dB in the second example ($a_t = 16^o, a_r = 16^o$). The receiver threshold requires adjustment to a level below the lowest expected signal level from the desired transmitter, and at the same time above the highest expected signal level from the transmitter in the opposite lane. As shown in the above analysis, a system employing narrow beamwidth antennas for both the transmitter and receiver is preferred in order to provide a greater difference in the signal levels of desired vs. undesired transmissions. Thus, by judiciously selecting antenna beamwidths, the specifications on the vehicle receiver's ability to discriminate between desirable and undesirable signals can be relaxed to a more practical value.

The beamwidth of the antennas in the plane of vehicular motion (B_t, B_r), see Figure 10, is constrained by two factors, the time of intercept (Ti) (or the amount of time necessary for the reception of the signal) and the problem of multipath propagation.

The intercept time (see Figure 10) can be calculated as the time elapsed between the leading edge entry and the trailing edge exit of the receiver antenna radiation pattern into the transmitter antenna radiation pattern. The received signal slowly increases in magnitude until at $t = t_0$, it is at -6 dB from the maximum which is reached at t = tl and is again at -6 dB at $t = t_2$. The receiver threshold is set to a level below the weakest anticipated signal for desired reception (somewhere below -6 dB from maximum).

In Appendix E the intercept time, Ti, is computed for the following configuration:

h = 13.9 ft (4.25 meters)

Bt = Br = 16 degrees

V = 62.5 mph (100 km/hr)

Ti is computed to be 43.0 msec. Thus, as a worst case condition the entire transmission must take place in 43.0 msec, or less, for a vehicle with a maximum permissible velocity of 62.5 mph (100km per hour) and antenna beamwidths of 16 degrees.

Multipath propagation modes can severely affect system performance if relatively broad beamwidth antennas are used. As an example, a signal from a transmitting antenna might be reflected off of a large truck directly into the opposite lane where a receiving antenna might potentially intercept it. If, however, narrow beamwidth receiving antennas of less than 40 degrees are used, the undesired signal is attenuated by the radiation pattern of the antennas since a reflected signal arrives at an increased angle relative to the direct path.

The antenna bandwidth also has to be considered in the selection of an antenna. At SHF frequencies, the bandwidth requirements of a single channel digital data communications link are seldom severe enough to limit the performance of microwave antennas. If, however, the data rate (R) and the frequency deviation (D) of a system, employing, for example, FSK type modulation, are not carefully selected, the required bandwidth can be large enough to eliminate potential antenna configurations. Using the previously calculated value of Ti, assuming one repeat of the 5K bit message and a peak carrier deviation of 20 MHZ

$$R = \frac{10 \text{ K Bits}}{T_i} = \frac{10 \text{ K Bits}}{43.0 \times 10^{-3} \text{sec}} = 233 \text{ K Bits/Sec}$$

The bandwidth of an FSK signal can be approximated by the following:

$$BW = 2D + R$$

D = Frequency deviation of the carrier

for a channel with no fading. Based on the above assumptions and calculations, the bandwidth is:

$$BW = 2D + R = 2(20 \times 10^6 \text{ Hz}) + 233 \times 10^3 \text{ Hz}$$

$$= 40.2 \text{ MHz}$$

or less than .5% of the 10GHz carrier frequency. Thus, since most practical antennas in this frequency range have bandwidths on the order of 1% and higher, bandwidth does not significantly affect antenna selection.

As previously mentioned, the sidelobe levels of both the transmitter and receiver antennas must be kept minimal to prevent unwanted interference from transmitting units intended for opposing traffic directions. The beamwidth analysis found that the gain of antennas with a 16 degree beamwidth was approximately 15 dB less than the maximum at angles approximating a direct path into the opposing traffic lanes. In keeping with this beamwidth analysis, the maximum sidelobe levels from either antenna should be at least 15 dB below the mainbeam maxima. This requirement can be easily achieved.

Although many different electric field polarization geometries exist, linear polarization is the recommended choice. Linear polarization requires less complex antennas and associated feed systems than other polarizations and is less expensive. Since the propagation path is extremely short, other polarizations such as circular or elliptical offer little or no advantages over linear polarization.

The microwave IVEG system calls for an antenna configuration with a roadside transmitting antenna mounted vertically over the lane center directed downward toward the vehicle receiving antenna. Horizontal polarization provides the proper field pattern.

The physical dimensions of both the transmitting and receiving antennas must be kept relatively small in order to facilitate ease of mounting, present aesthetic appeal, and maintain low cost.

At SHF frequencies most antennas are small enough to meet the above requirements for the transmitting case, and some are available that appear attractive for the vehicle receiver.

Of the many possible microwave antennas in existence today, there are two promising candidates, corrugated horn and microstrip antennas.

Horn antennas(35), for which design information is given in Appendix F, are extensively used in the SHF band. A typical horn antenna meeting the requirements for this application measures less than 8 inches (20 cm) on a side, less than 10 inches (25 cm) long and weighs only 6-10 ounces (170 -284 g).

A disadvantage of the conventional horn is that for certain flare angles, sidelobe levels might be as high as -10 dB relative to the mainbeam maxima (which will not satisfy the sidelobe level requirements of at least 15 dB below the maximum). Thus, the conventional horn antenna appears to be marginal for sidelobe level requirements.

Sidelobe levels can be reduced by using a variation on the conventional, smooth-wall electromagnetic horn(36). This antenna differs from conventional horns in that it is constructed from a copper-plated dielectric foam material with corrugated E-plane walls. Figure 13 illustrates the structure of the corrugated horn and gives radiation patterns for both a conventional smooth-wall horn and the corrugated horn. With this design, sidelobe levels can be reduced from 10 dB down with the conventional horn to over 30 dB down with the corrugated design.

The dimensions of the corrugated horn, shown in Figure 13, are a 5 x 5 inches (12.7 x 12.7 cm) aperture and a length of about 8 inches (20.3 cm). Due to its copper-plated foam construction, the total weight is only 6 ounces (168g). From the radiation patterns for this horn, measured at 10.2 GHz, the beamwidth is about 16 degrees in both the E and H planes and the gain is approximately 20 dB over isotropic.

The dielectric foam material comprising the form for the antenna is inexpensive and easily fabricated to any desired shape. The plating is on the order of 0.002 - 0.004 inches (.05 - .1 mm) thick. These antennas are, therefore, relatively inexpensive to manufacture and are attractive as candidate transmitting or receiving antennas.

- - - - - -

(35) H. S. Jones, Jr., "Horn Design Saves Weight Without Performance Loss", Microwaves, October 1973

(36) Howard W. Sams & Co., "Reference Data for Radio Engineers", Indianapolis, Indiana 1977

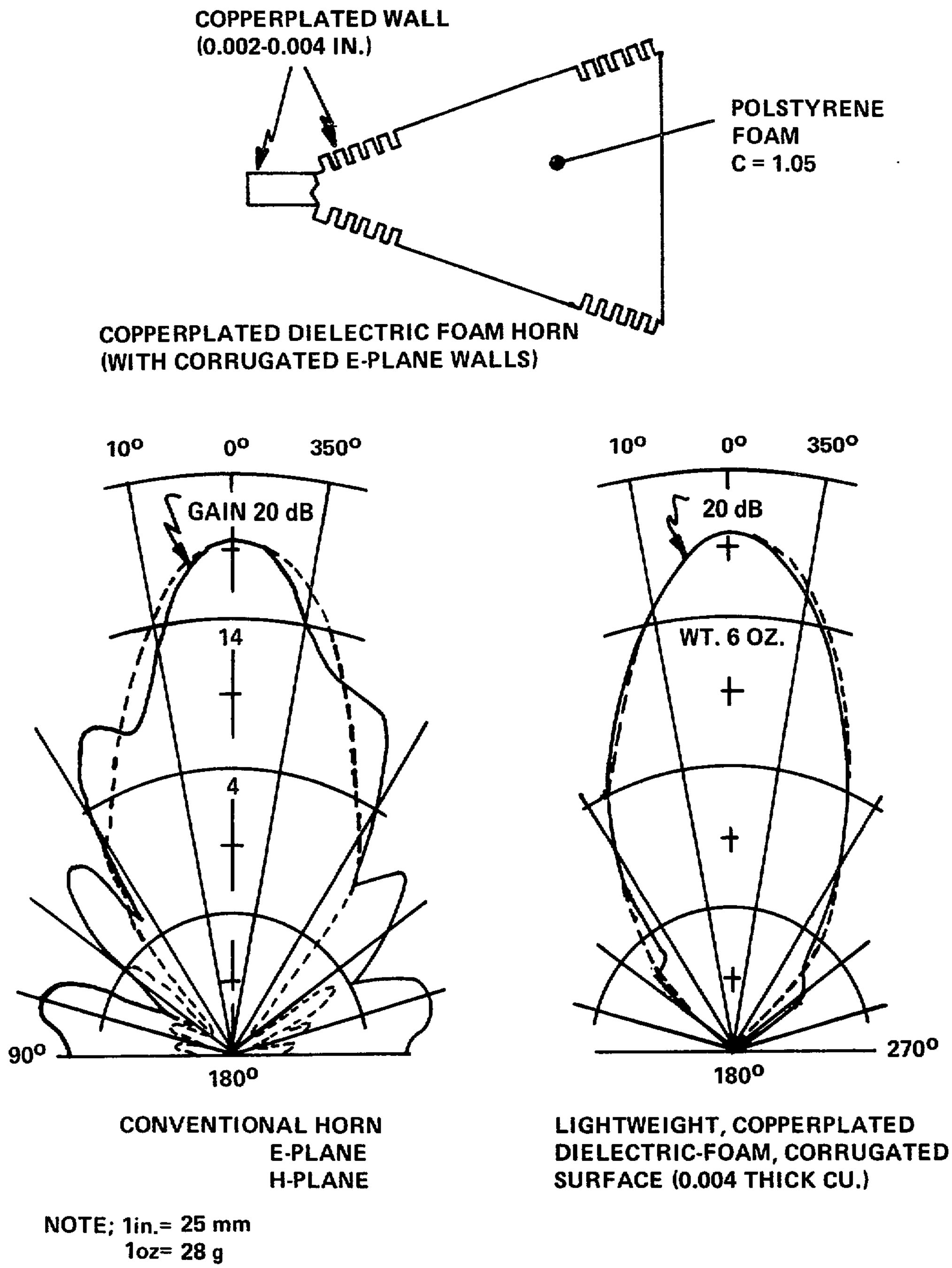


Figure 13. Corrugated Electromagnetic Horn Antenna and a Comparison of the Radiation Patterns of a Conventional Smooth-Wall-Horn (left) and A Corrugated Horn (right)

A relatively new class of antennas called microstrip phased arrays[37, 38] are recommended for vehicle receiving antennas. These antennas can be fabricated in much the same manner as conventional printed circuit cards. They are very thin, rugged, and easy to mount making them candidates for both the transmitting and receiving antennas. Shortcomings of microstrip antennas include narrower bandwidth and slightly higher sidelobe levels than conventional electromagnetic horns.

Microstrip antennas are constructed in a thin (t<<X) dielectric sheet over a ground plane. The antenna element can be square, rectangular, or circular and can be fed directly from semi-rigid coaxial transmission line through the backplane or through a microstrip transmission line to a transmitter or receiver. Appendix G contains details of the construction of these microstrip antennas.

A 4 x 4 element microstrip array has approximately a 20 dB gain and E and H plane beamwidths of approximately 20 degrees. These specifications make the microstrip array an excellent candidate antenna for use as a vehicle receiving antenna. Because of its small size, light weight, and mechanical rigidity, this antenna can be mounted in a variety of vehicle locations and is quite inexpensive to produce. Although sidelobe levels from microstrip arrays might reach 10 dB the sidelobe levels from corrugated horn transmitting antennas are sufficiently low to insure the required overall system performance.

The transmitting antenna must be mounted vertically over the center of the desired lane of coverage and oriented such that the mainbeam is normal to the roadway surface with the E-plane parallel to the direction of motion. The transmitting antenna height for an arbitrary beamwidth antenna should satisfy the following equation:

$$HT = \frac{(W_L - W_V)}{2 \tan \left(\frac{a}{2}\right)} + H_R$$

where H_T and H_R represent the respective transmitting and receiving antenna heights, W_L and W_V are-the lane width and typical vehicle width respectively, and a is the transmitting antenna beamwidth. If the transmitting antenna height, HT, is excessive for a particular lane width or for coverage of multiple lanes, then the recommended approach is to use multiple transmitting antennas providing overlapping coverage in the center of the desired lane, or lanes, arranged such that the transmitting antenna nearest to the opposing traffic lanes does not interfere with vehicles traveling in the opposite direction. The 3 dB beamwidth of the composite antenna arrangement thus remains at least one-half vehicle width inside the centerline.

------

(37) John Q. Howell, "Microstrip Antennas", IEEE Transactions on Antennas and Propagation, January 1975

(38) Michael A. Weiss, "Microstrip Antennas for Millimeter Waves", ECOM Report ECOM-76-0110-F, October 1977

The deployment of vehicle receiving antennas must be such that its mainbeam is directed upward and normal to the road surface. It must be mounted in a location free from metallic obstructions in the path of transmission. At the same time, it is desirable to locate the receiving antennas as close as possible to the display unit, located in or on the dash panel. A dashboard location is therefore attractive. An experimental evaluation, however must be performed to ensure that windshield diffraction does not significantly alter the radiation pattern. A mounting location on the roof of the vehicle is also attractive, since microstrip array antennas are very thin. Rain or a thin layer of ice or snow will probably not significantly affect antenna performance at or around 10.0 GHz, if it does, however, a low cost deicer can be used.

7.1.2.2.2 Modulation Requirements

Key system parameters which affect the modulation format include link distance, EM noise environment, system complexity, equipment cost, and system reliability. A highly complex modulation format with error correcting codes optimizes the information bandwidth and provides a low BER (bit error rate) under marginal signal-to-noise conditions while a simple modulation format provides reliable data communications only under favorable link conditions. The cost and complexity of the equipment depends on the format.

In the IVEG system it is necessary to transmit considerable information from a road-side transmitter to an in-vehicle receiver during a relatively short intercept time. Data rates and associated bandwidths are therefore important.

Modulation processes fall into two general classifications: amplitude or linear modulation, and angle or nonlinear modulation. Within each of these general classifications there are numerous subsets and a specific modulation format may utilize several subsets as well as combination of both linear and nonlinear processes.

Possible basic modulation formats for the IVEG microwave candidate include:

- AM which occupies double the baseband bandwidth so the theoretical band rate is reduced by one-half, extreme signal level variations can introduce errors.

- VSB or vestigal sideband provides for more efficient spectrum utilization but is more complex than AM and detection can be somewhat more difficult, as with AM large variations in signal level can be troubleshome.

- FM, which for data transmission is generally referred to as FSK, provides improved performance in a noisy environment provided the system is operating above the threshold; binary FSK systems require a bandwidth at least twice that of the ba seband signal ,considerably greater for large mark-space frequency deviations.

- PM, like FM, requires a bandwidth of at least twice the bandwidth of the baseband signal, assuming a BPSK (binary phase-shift keying) format; in a noisy environment phase modulation techniques will provide improved characteristics over linear modulation systems.

Binary FSK offers a reasonable compromise between implementation cost and performance. Straight amplitude modulation, on/off keying is the least costly to implement but is more subject to interference than either PSK or FSK. Variation in signal level can also add to errors in the demodulated binary data when AM is used. The PSK provides slightly improved noise rejection than FSK. The PSK modulating and demodulating equipment are, however, more complex and costly than FSK.

7.1.2.2.3 Bandwidth

The required channel bandwidth is determined by the total number of message bits, the antenna beamwidths, the receiver to antenna distance and the velocity of the vehicle. The following table, utilizing the procedure developed in Appendix H, summarizes the bandwidth requirements for binary PSK and binary FSK modulation. The calculation assumed a maximum speed of 62.5 mph (100 KM/H) a message length of 5K bits, two repeats of the message and a transmitter mounted 17 feet (5.2 meters) above the roadway.

Required Bandwidth

Vehicle Receiver Antenna Height	Modulation Technique FSK	PSK
3.3 ft (1.0 m)	40.2 MHz	471 KHz
6.6 ft (2.0 m)	40.3 MHz	587 KHz

7.1.2.2.4 Transmitter

There are a number of devices and techniques that can be used as the source of microwave energy in this application. Factors in the selection of a suitable device include cost, frequency stability, output power, and modulation capability. A number of devices and techniques are possible for implementing the microwave source including crystal controlled oscillators with varactor or SRD multipliers, tunnel diodes, IMPATT diodes, and Gunn-effect devices.

A crystal controlled oscillator has high frequency stability but requires complex circuits. The Gunn oscillator offers a number of attributes which are attractive for this application. These include small size, low cost, good reliability and easy adaptation for FSK modulation. The major disadvantage of the Gunn oscillator is its frequency variation as a function of temperature. This is on the order of -350 kHz per degree C. Methods for improving the frequency stability of a Gunn oscillator include the use of a temperature controlled chamber and the use of the phase-lock loop (PLL).

Gunn oscillators with a moderate RF power range, up to a few watts CW and in the range of 100 watts for pulsed versions, can be packaged within a volume of about 90 cubic centimeters. The housing, a waveguide cavity with mounting holes for attaching a horn antenna can, be adapted for the roadside transmitter.

The Gunn oscillator is recommended for this application because of its many attributes and the simplicity of temperature compensation.

The extremely short link distance in the IVEG system, coupled with antenna gains on the order of 15 to 18 dB, results in low RF power needs. RF power in the range of 5 to 20 milliwatts provides a high signal-to-noise ratio at the receiver front end.

The free space attenuation, A, for a line-of-sight link, as is the case for this application, can be computed from the following formula:

$$A = 92.5 + 20 \log F + 20 \log D$$

where F is in GHz and D is in kilometers. Using values typical for the IVEG application: D = 14 feet (4.5 m) and F =10.25 GHz, the free space attenuation is 66 dB. The power at the receiver front and over a 14 ft (4.5 m) link, using a Gunn oscillator with an RF output power of 10 mW and antennas with a gain of 17 dBm is:

Transmitter power	+10 dBm
Transmitter antenna gain	+17 dB
Path gain	-66 dB
Receiver antenna gain	+17 dB
Power at receiver front end	-22 dBm

Thus, a signal level of considerable magnitude is available at the receiver front end even for a low power, 10 mW, transmitter.

Data Input Interface

The 5k bit message, derived from the Route Guidance Controller's PROM and associated message register discussed in section 7.1.4.2 is used to key the Gunn oscillator. This portion of the transmitter consists of a TTL driver buffer and a DC controller as shown in Figure 14. The TTL driver/buffer provides output mark-space voltage levels that are essentially independent of temperature as well as input mark-space level variations. The DC controller is adjusted to provide the desired center frequency (space) and frequency deviation (mark). Temperature stabilized controls are used to maintain the required frequency stability.

7.1.2.2.5 Receiver

The receiver, whose block diagram is shown in Figure 15, utilizes a passive approach to the demodulation of the FSK signal by using strip line techniques. This results in a small, low cost receiver.

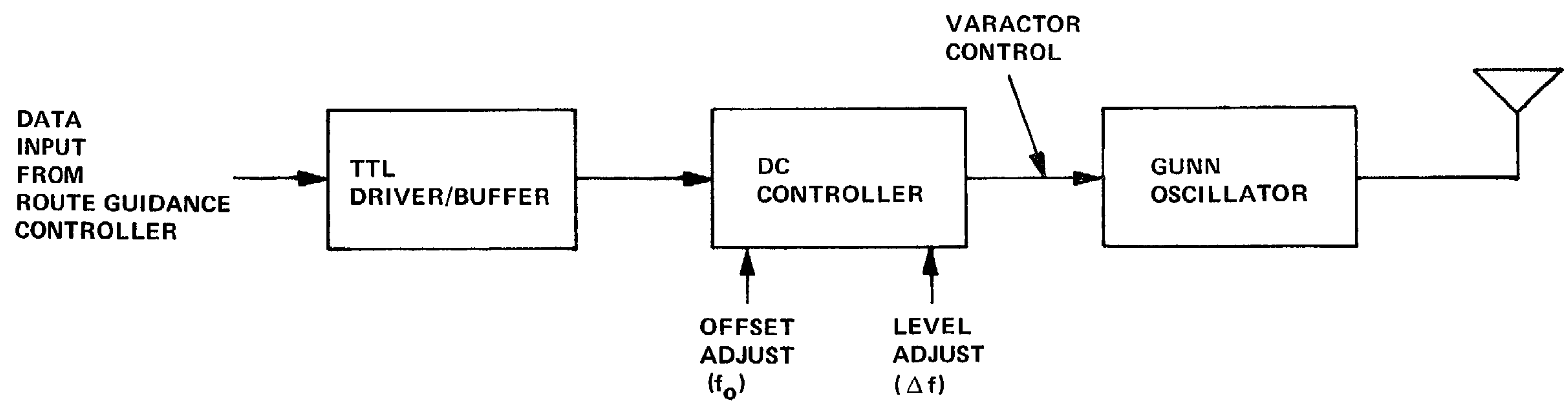


Figure 14. Transmitter Drive Configuration

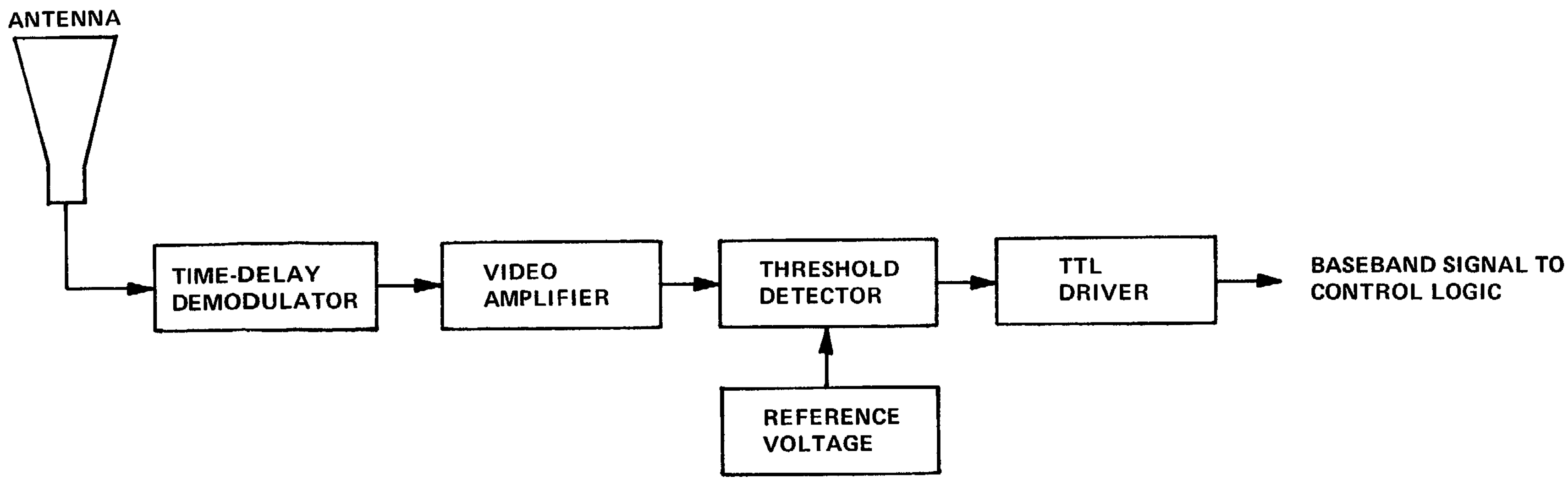


Figure 15. Microwave Receiver Block Diagram

The microstrip antenna is incorporated into the stripline. Frequency discrimination at RF is implemented by using a time delay differentiation demodulation approach. This demodulator, discussed in Appendix I uses passive components mounted on the same board as the antenna. This board may be mounted in a weather-proof housing located on the roof of the vehicle or incorporated into the dash mounted control unit (See Section 7.1.2.3). Video amplification following the time delay demodulator is required to increase the level of the baseband signal. It is then fed to the digital processing portion of the receiver. Magnitude discrimination is used to minimize the possibility of decoding signals transmitted to vehicles traveling in the opposite direction. Because of the narrow beamwidth of the transmit and receive antennas, a minimum difference of 24 dB is expected between in-lane and adjacent lane signals, the required level discrimination may be achieved by a using a voltage threshold detector.

Bandwidth

The two major considerations for determining receiver bandwidth are that the bandwidth must be sufficient for the information signal bandwidth and that excessive bandwidth should be avoided to minimize the potential for interference. In this IVEG configuration, however, interference should not be a problem due to the short link distances and received signal level on the order of -20 dBm. If an undesired signal is picked up by the receiver when the vehicle is not passing under a transmitter, the resulting baseband signal would not be accepted as a valid word by the digital processor and would be rejected. If an interfering signal is to cause a problem when the vehicle is moving through the field of the pole-mounted transmitter, the level of an in-band interfering signal must be on the order of -35 dBm or greater. For the majority of transmitter locations, interfering signals of this magnitude are unlikely.

Should an extensive field evaluation show that additional receiver selectivity improves overall performance characteristics, then a microstrip bandpass filter can be added as an integral part of the circuit board.

The minimum required receiver bandwidth, is therefore, based on the signal information bandwidth. For this microwave data link approach to IVEG the required data rate has been earlier established as 233 kbs and a peak carrier deviation of 20 MHz. The deviation ratio, B, is

$$B = \frac{\Delta f}{f_m}$$

or B = 86. From this value of B, the required receiver bandwidth can be approximated, by using Carson Rule,

$$BW = 2(B + 1)\, f_m,$$

as 41 MHz.

Signal-to-Noise Ratio

The in-vehicle microwave receiver is designed to receive and process signals in the general range of -10 to -35 dBm. The short link distances and high signal levels preclude any serious constraints on signal-to-noise ratio. The receiver noise figure is determined primarily by the noise figure of the square-law detector plus RF insertion loss prior to the detector. The first amplifier stage of the video processor also has a bearing on the system noise figure. Based on characteristics of known devices, the receiver noise figure is expected to be on the order of 10 to 12 dB with an aforementioned tangential sensitivity of approximately -40 dBm.

Data Output Interface

The in-vehicle receiver receives and processes the BFSK signal from the pole-mounted transmitter. The RF portion of the receiver demodulates the BFSK signal while the video processor amplifies, filters and provides signal magnitude discrimination. The resultant signal from the video processor is a reconstructed form of the original signal used for modulation of the transmitter. This resultant signal is provided to the "control logic" in a serial binary format.

Receiver Synchronization

The vehicle's reference clock must be synchronized to the transmitter's clock. Synchronization in the microwave system is established by locking the control logic's clock to the baseband data that was recovered by the receiver portion of the vehicle electronics.

A phase-locked loop (PLL) in the control logic, shown in Figure 16, performs this synchronization. The output from the phase-locked loop's voltage controlled oscillator is used as the receiver's reference clock. Since the baseband data has a non return to zero format the clock's frequency must be halved prior to the phase detector.

The received signal must be tracked with a zero frequency error. A loop known in the industry as a Type 1 PLL(39) provides such a capability. However, the use of a Type 2 PLL, which provides zero phase error simplifies design of the loop.

The loop must have a capture frequency range sufficient to lock to the transmitter's signal and a settling time short enough to lock and still provide time for data demodulation during the intercept time. Since the transmitter has a data rate of 233 kbs and a minimum intercept time of 43 ms and the transmitter's clock will have a frequency stability of greater than 10%, a capture frequency range of 47 KHz and a settling time of 1 msec are required.

The phase locked loop is incorporated into the control logic's custom LSI chip.

7.1.2.2.6 Regulatory Constraints

At present, there is no service (and hence no FCC rules and regulations) which specifically address IVRG systems. Depending upon spectrum availability and usage, the FCC might establish an IVRG service or assign IVRG

(39) Motorola, "Phase Locked Loop Data Book", August 1973

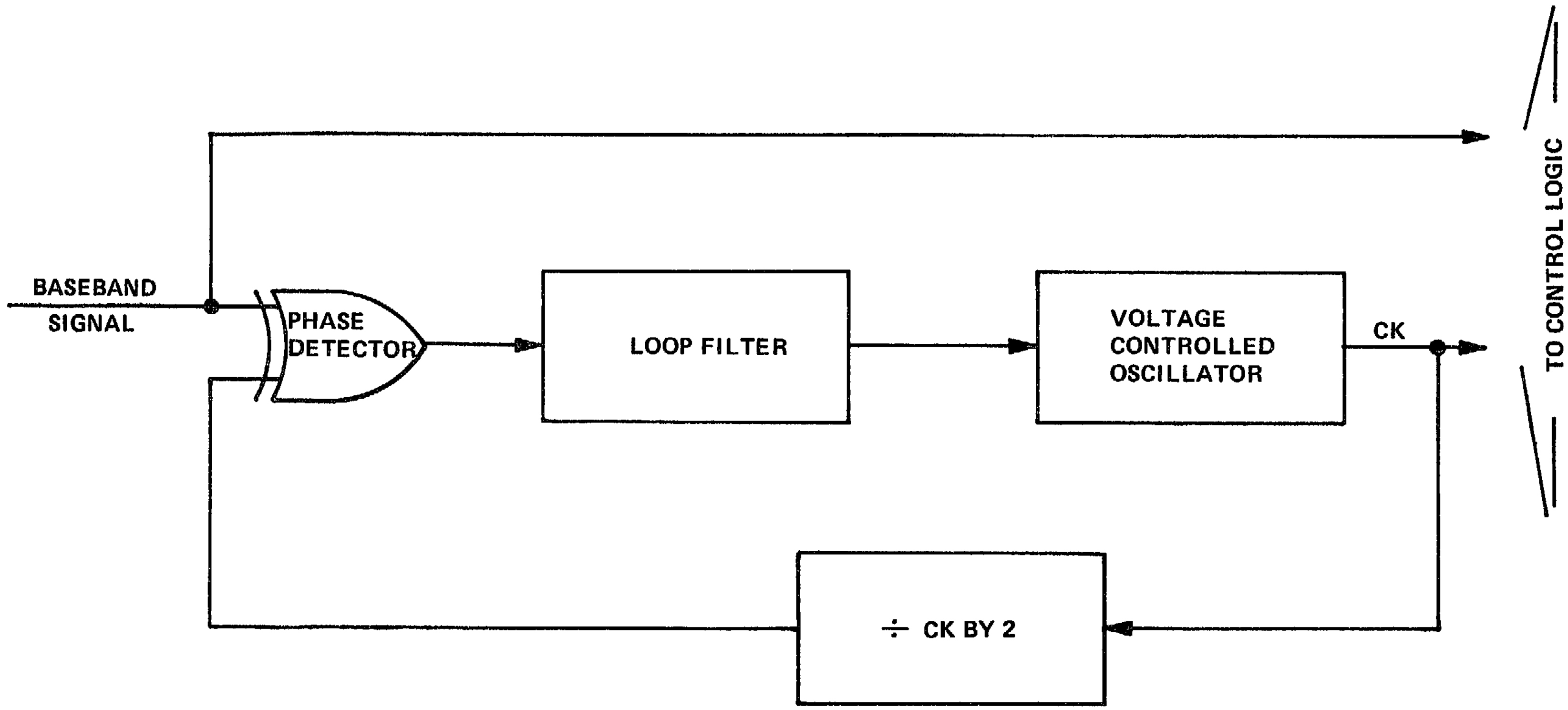


Figure 16. Receiver Synchronization

operations to one of the other services (e.g., Industrial, Scientific, or Medical Devices). If the radiated field strength of the system transmitters were sufficiently low, it might be possible to operate without FCC licensing.

As discussed in Sections 7.1.2.2.1, 7.1.2.2.4 and 7.1.2.2.5 with the antenna, transmitter, and receiver requirements a relatively high transmitter output power (+10 dBm) and a relatively low receiver sensitivity (-40 dBm) is used.

For a 10 mW transmitter output power, and a transmitter antenna gain of 100 (20 dB), the field intensity level at a distance of 30 meters from the IVRG transmitting antenna is:

$$F.I \left(\frac{\text{volts}}{\text{meters}}\right) = \sqrt{\frac{P_t \; G_t \times 120\pi}{4\pi \; R^2}}$$

$$= \sqrt{\frac{(.01)(100)(120\pi)}{4\pi \; (30)^2}}$$

$$= 185 \times 10^{-3}$$

The requirements to license a transmitter operating in the 10 GHz frequency range depends upon the radiated field level. For example, Part 15D of the FCC rules and regulations specify that for all frequencies above approximately 500 MHz, the radiated field is to be less than 50 microvolts per meter at a distance of 30 meters from the radiator (antenna). The field strength limitations vary depending upon the type of transmitter and the specific operating frequency. Part 15F of the FCC rules and regulations specify that field disturbance sensors may be operated at 10.525 GHz with field strength levels at 30 meters of up to 250,000 microvolts per meter. Thus it might be possible for the IVRG transmitter to operate without license, particularly since the specific operating frequency is not critical. Although 10 GHz is used as an example design frequency throughout this report, operation can be anywhere in the 10-15 GHz frequency range or possibility at higher frequencies without a significant impact on the design requirements or cost.

Even if licensing were not required, it might be desirable to obtain an IVEG system license simply as a protection against unlicensed users. An example licensing procedure is presented in Appendix J. This particular procedure is applicable to the licensing of a station in the industrial microwave service; however, the licensing of transmitters in other services involves a similar procedure.

7.1.2.2.7 Conclusions

Microwave communications utilizing an overhead horn antenna and a horizontal mounted receiver antenna offers a viable communications scheme.

The techniques and equipment required for the microwave communications approach is available and currently used for other applications.

Testing is required to determine whether the receiving antenna can be mounted in the vehicle or on the roof of the vehicle.

7.1.2.3 Optical Communications

An alternate to radio communication for the IVEG system is a short range optical data link.

7.1.2.3.1 Approaches Considered

The initial approach pursued in this study was to transmit the data from the fixed mounted transmitters about 20 feet (6.1 m) above road level and tilted slightly downward so as to be visible to on-coming vehicles in one approach direction.

The vehicle would have a small receiver package attached to the inner surface of the windshield facing toward the transmitters.

Figure 17 shows a representative geometry of this near-horizontal approach that clears the tops of most trucks and vans in front or on either side of small cars moving behind them.

A transmitter elevation angle of -5 degrees (i.e., aimed down at roadway) and a beam width of about 20 degrees illuminates vehicle windshields 4 or more feet above road level from about 75 feet (228 m) minimum to over 500 feet (152 m) maximum (the latter is determined by the useful receiver signal-to-noise ratio).

Tests conducted by driving a test vehicle over New York City and Long Island roadways found that direct solar illumination of the detector and geometric line of sight interference presented problems which were best resolved by the use of an overhead transmitter. In the overhead approach, the data is essentially transmitted as the vehicle passes under an overhead support along which is distributed a laser diode transmitter array.

Transmission distances are shorter than for the near-horizontal approach, thus simplifying the solar illumination problem. A more favorable geometry solves the vehicle masking problem.

Since it is required to prevent traffic in opposing lanes from receiving a local IVEG data message, beam shaping and shading can be readily employed to confine the optical signal to a highly localized zone.

As the system normally operates in direct sunlight, it is also immune to interference from other light sources such as vehicle headlights and emergency vehicle strobe lights. The following sections describe this communication concept and implementation approach.

7.1.2.3.2 Overhead Transmitter System Geometry

The maximum message content at each transmitter location is 5 kilobits. The design concepts developed during this study show that one feasible geometric configuration for the system is an overhead mounted downward directed transmitter configuration which illuminates the vehicle

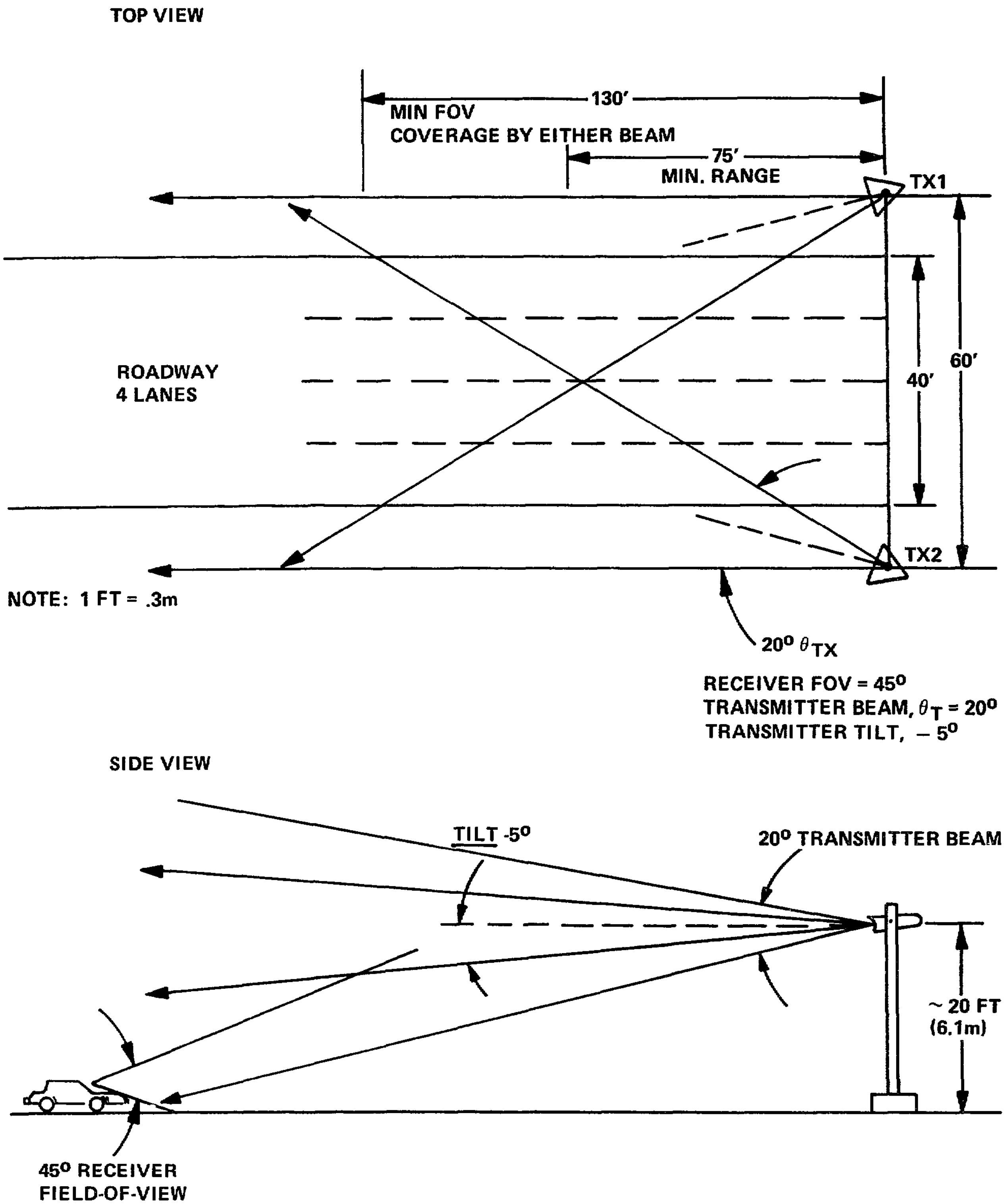


Figure 17. Optical Link Geometry - Near Horizontal Approach

for at least one second. With a vehicle speed of 55 mph (88 kph) the vehicle covers 80.7 feet (24.2 m) in one second. Thus the transmitter must illuminate a longitudinal path of approximately 80 feet (24 m). Since the vehicle's roof is an appropriate detector mounting location for a passenger car, the 80 foot path is chosen for this height (approximately 5 feet (1.5 m)).

With this vehicle height and the elevation of the transmitter support of 20 feet (6 m) the beam spread must be approximately 140 degrees to cover the appropriate length. For an average directional roadway width of 40 to 50 feet (12 m to 15 m) max (4 lanes) the transmitted beam should not spread out in a circular fashion, but should have a pattern width of roughly half the longitudinal length.

Figure 18 shows an elevation view of this geometry. The IVEG receiver must also match this beam pattern with its field-of-view in order to maximize dwell time. Thus when it enters the transmitter pattern 40 feet (12 m) from its center, it must detect rays 70 degrees from the vertical. If the receiver were to be mounted inside the windshield (instead of on top of the roof but with the detector facing nearly straight up) the maximum coverage available would be only about half the pattern width, or 1/2 second dwell time at 55 mph (88 kph). This would provide inadequate coverage; the roof mounted case thus appears to be the best approach for obtaining the necessary wide angular coverage. Other mounting locations such as the front part of the hood might be advantageous for high trucks.

7.1.2.3.3 Operating Wavelength of Optical System

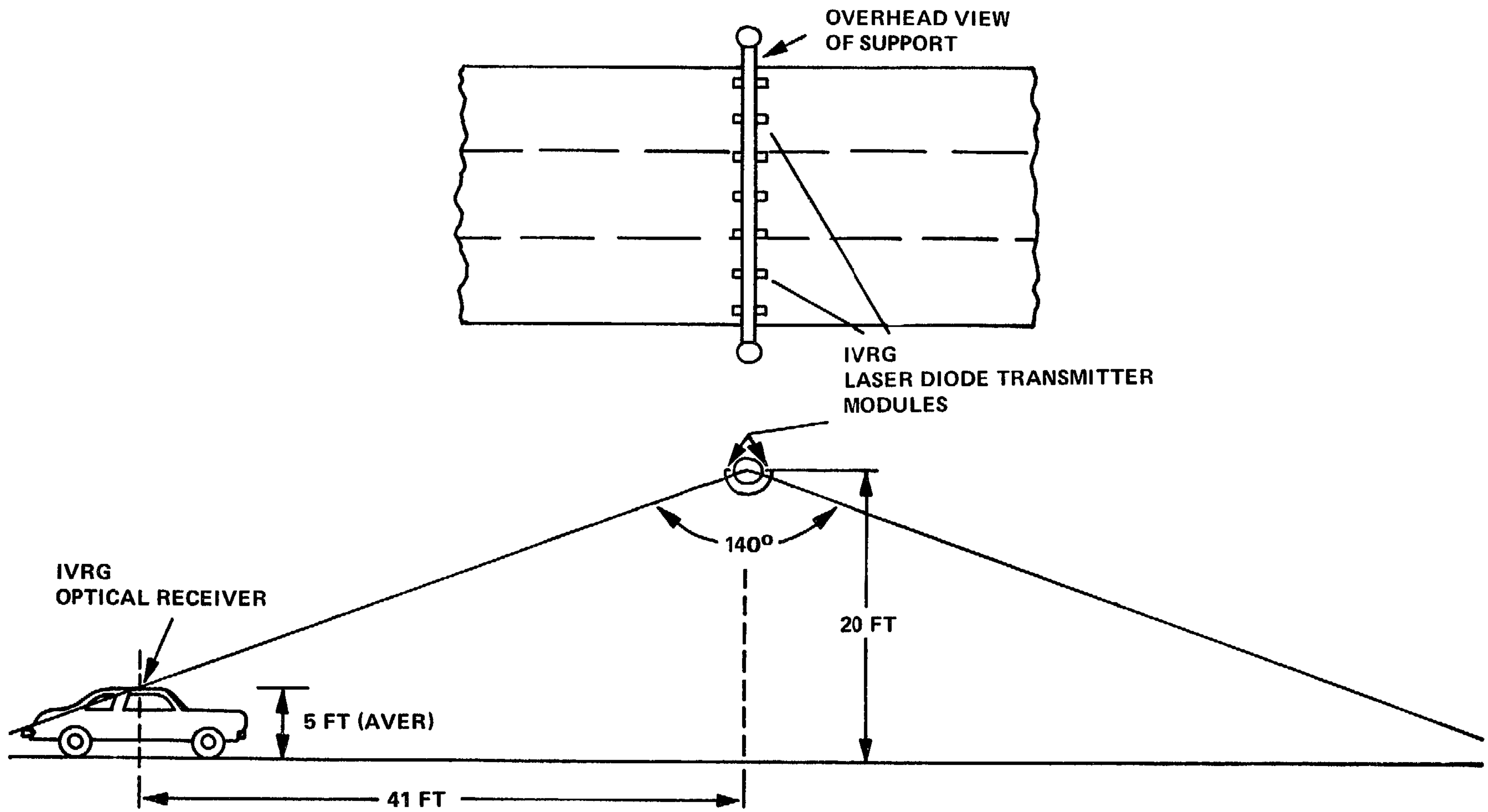
The system transmitter consists of pulsed Galium Arsenide laser diodes, which operates in the near infrared spectrum at a wavelength of 904 nanometers.

This wavelength enables the IVEG receivers to function with direct sunlight background in the day time.

By using a near infrared long wave filter over the detector all wavelengths shorter than 800 - 900 nanometers are cut off. The amount of solar background power reaching the detector is then about one tenth that of visible spectrum opertion. Transmissions at those wavelengths are invisible to the-human eye.

7.1.2.3.4 Data Rate

As described in section 7.1.1.3, 5 K bits of data must be transmitted during each one second intercept at 55 mph (88 kph). Due to vehicular interference, it is possible to miss data bits at the extremities of the transmitted pattern but transmission rate increases to at least two frames per second assures detection of at least one complete message frame. The design investigation therefore utilized 10 KBS as for the microwave case.



- AT VEHICLE V = 55 MPH (81fps) DWELL TIME WITHIN 140° LONGITUDINAL COVERAGE IS 1 SEC. (20 KILOBITS OF DATA CAN BE RECEIVED IN THIS TIME.
- TRANSMITTED DATA RATE = 20 kb/SEC.

NOTE: 1 FT = .305M

Figure 18. Overhead Transmitter Geometry

7.1.2.3.5 Receiver Design

Silicon PIN photodetectors are best suited for the overall IVRG requirements. Two design areas, optics design and detector choice, are discussed below.

A. Optics Design

If the receiver were to use a collecting lens before the detector, the laser transmitter power may be reduced as the lens employed is made larger. However, the only lens system that can cover the 140 degree F.O.V. is a "fish eye" type system, which is an extreme wide field negative primary/positive secondary lens set. For energy collection, a minimum of 2 to 3 elements might be feasible. However, the separation of several inches required between primary and secondary elements for a one inch (25 mm) aperture leads to a larger package. The lens system would also introduce a significant cost even with the use of mass produced replica lenses and additional costs would result from mounting hardware and assembly of multiple elements. Thus, the receiver design should, if possible avoid the use of a collecting lens.

B. Detector Design

Several alternative detector types were considered, a large area detector, a mosaic detector and a small area detector. Since a high peak power laser diode (or diode array) can only operate at short pulse widths (20 nanoseconds maximum to keep duty cycle within 0.04 percent), the PIN detector pre-amp combination must have a band width of 20 MHz or more. The largest silicon PIN device with the necessary rise and fall time response has a junction diameter of approximately one centimeter. However, this detector is relatively expensive ($25 - $50 in small quantities). 5 x 5 millimeter devices give the desired 10 to 15 nsec rise time response and can be produced for under $1.00 each.

This detector element may be used with a collecting lens as described above or without it. In the latter case a much higher transmitter power level is required. By placing a flush mounted I.R. filter and entrance window directly over the chip, the full 140 degree F.O.V. can be readily achieved. The transmitter power is set at a high enough level to give the desired S/N ratio with a detector area of 25 mm^2, or less, in the presence of direct solar background. The price of this type detector is estimated at approximatley $2.00 each in quantities of 200,000.

7.1.2.3.6 Laser Transmitter Power

The required laser transmitter power for the IVEG receiver with no lens and a simple PIN photo detector in the receiver with an area of 25 mm^2 is calculated in Appendix K.

This calculation is based on breaking up the total transmitter pattern into individual contributions, or beam patterns. This configuration offers the following advantages:

- The total peak laser power required to cover the entire 70 x 140 degree pattern is over one kilowatt. This is not achievable from individual laser diodes, but only from other more expensive lasers that can produce this power level from a single device. Such lasers are far less eye safe. Thus, an array of laser diodes is required to cover the entire area. The calculated required power for the maximum range is 46 watts in a 20 x 20 degree beam. At least 25 such devices are required to cover the entire 70 x 140 degree zone.

- A number of separate laser diode units distributed along the support structure over the roadway assures that interference to reception from adjacent vehicles, such as trailer trucks and vans does not occur.

- For eye safety considerations, and efficient illumination coverage, the best array geometry results from using 60 degree beam components in the center of the pattern and 20 degrees at the outer extremities. These items are discussed below.

Almost all laser diodes, or diode stacks, in the 10 - 100 watt peak power range emit light into 15 to 20 degrees solid angles. Hence, the 20 x 20 degree elemental pattern was chosen as the typical pattern for single devices. Wider angles can be achieved by interposing a simple negative lens.

The most severe power requirement occurs at the maximum slant range case of approximately 44 feet (13.2 m) therefore, the Appendix calculations are based on this range. Since the receiver can only collect energy from one component in the overall transmitter pattern at a given instant, laser diode required power is calculated only for this individual beam component. This determines the number of laser diodes in the transmitter array, which in turn leads to the total power requirements for the entire array. For reliable, low bit error rate communications (BER < 10-8) the minimum acceptable signal-noise out of the receiver should be at least 20 dB.

In Appendix K the peak transmitted power per diode is calculated to be approximately 46 watts.

This power level is readily available in individual laser diode devices manufactured, for example, by Laser Diode Labs, (LDL), and Spectronics. These are comprised of diode "stacks", or multple chips in a single package, that produce peak powers in the range of 10 - 120 watts. Maximum duty cycles for these devices are in the range of .01 to .06 percent. For example, Laser Diode Lab type LD-166 is rated at a minimum peak power output of 50 watts with a duty cycle of .02 percent.

7.1.2.3.7 Laser Diode Pulse Modulation

Pulse modulators are currently available to drive the laser diodes at the required repetition rates and to produce the short (nanosecond) pulse widths. One manufacturer's diode pulsers operate at up to 30 KHz pulse rates. They can provide 2 - 40 nsec pulse widths and can drive the 50 watt devices described above.

A number of these units are required to drive the entire array of laser diodes. A possibly more efficient approach is to integrate the pulse modulator circuits into higher powered units.

The installation requires up to seven separate groups of diodes to be distributed along a support. In this case, seven separate pulse modulators may be used, each driving about four diodes.

Consolidating the modulators into a single package is not normally possible due to the short rise time and high peak currents required to drive each laser diode. These constraints require that the connecting leads to a laser diode be under 1 inch (2.5 cm) in length; thus, each device must be in close proximity to its modulator.

7.1.2.3.8 Eye Safety

Since lasers are employed in the proposed transmitter, attention must be given to the question of public eye safety. The proposed approach uses a sufficiently high transmitter power to overcome the effects of a direct sunlight background and to give the required signal-to-noise ratio from the receiver with its very small detector collecting (25 mm^2).

Public exposure to laser radiation is governed by standards promulgated by the Bureau of Radiological Health of HEW. In Appendix L calculations are peformed in accordance with these standards (21 CFR-1040-pars. 10 & 11). It is assumed that the shortest range between the laser array mounted 20 feet (6 m) (min) above road level and a truck driver is 10 feet (3 m). Actually no driver in a conventional truck cab comes this close; other machines such as cranes, or large earth moving equipment, may, however, place the operator ten feet off the ground.

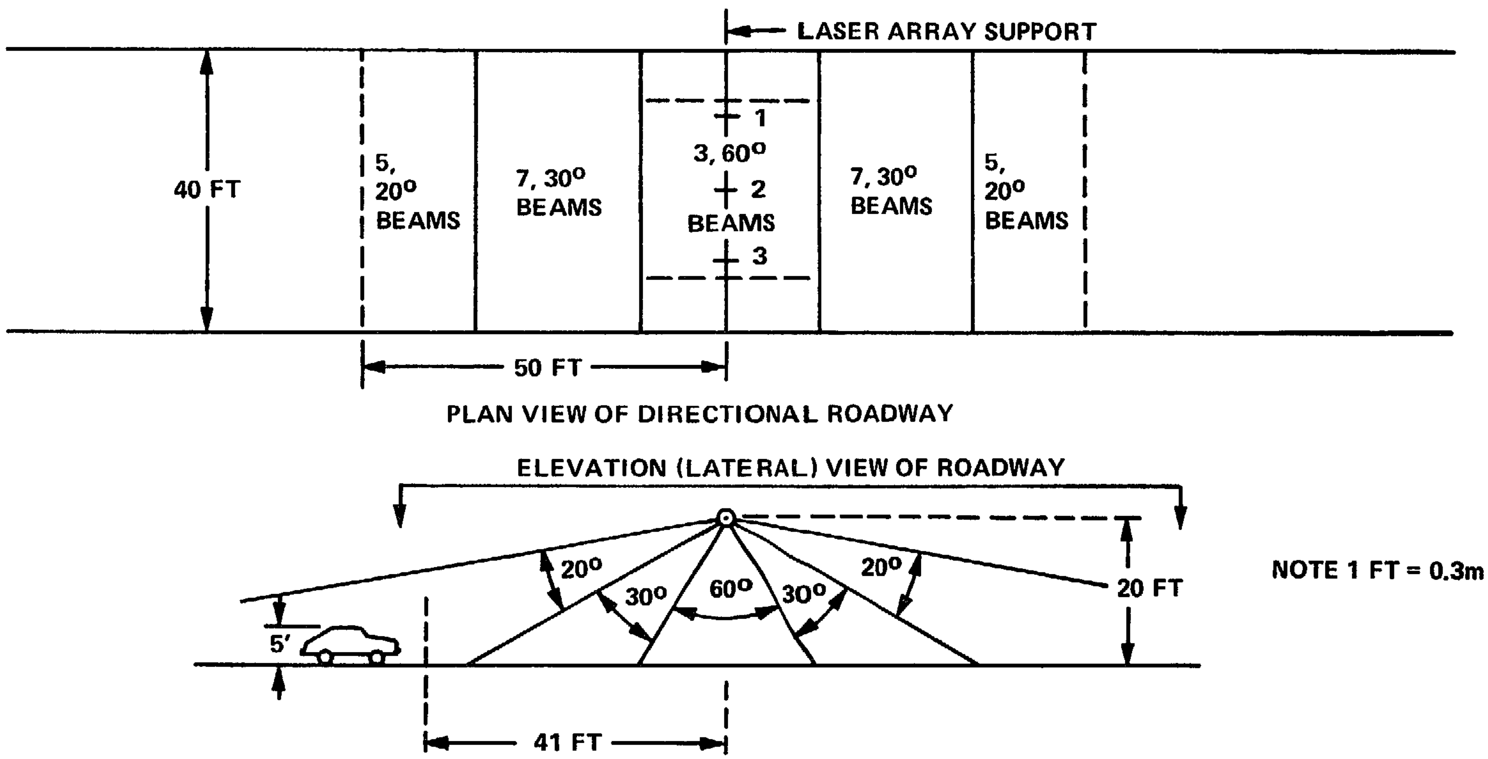
The typical power into a given beam can be as high as 65 watts if an LDL-166 stacked laser diode is used. With a directly overhead beam pattern (a 60 x 60 degree spread as indicated in Section 7.1.2.3.9), a bit rate of 10 KBS and a pulse width of 20 nanosecs, the average power output for each stacked diode is 13 milliwatts.

BRH specifies a Class I emission limit of 95.2 microwatts at a wavelength of 904 nanometers using an 80 mm diameter collecting optics. The calculated radiant energy into such a collecting optics located 10 feet (3 m) from the proposed transmitter, computed in Appendix L, is 6.5 microwatts. The eye safety standards are thus met with a substantial margin.

It is possible that maintenance and technical personnel will work in close proximity to the diode lasers, even while on. The lasers, in this case, are treated as Class III devices where workers exercise the normal precaution of not looking directly at the sources at close range without protective eyewear. Even without the protective goggles, there is no real danger to eyesight from milliwatt level radiation, when operated with such large beam spreads.

7.1.2.3.9 Transmitter Beam Geometry

Figure 19 shows a layout of the transmitter beam contributions. In this example, of a 40 foot approach width (12 m) the 140 x 70 degree pattern is made up of 27 separate stacks using 60, 30 and 20 degree beams. Since the direct laser (stack) emission pattern is nominally rectangular (not conical), this beam shape is easily achievable. This emission pattern provides complete



BEAM SPREAD ANGLE	NUMBER LASER STACKS THIS ANGLE	INCLIN. ANGLE	AVER RAY LENGTH	MAX. RAY L TO 5 FT CAR
60 DEGREES	3	0 DEG	30 FT	18.5 FT
30 DEGREES	14	±49 DEG	30 FT	31 FT
20 DEGREES	10	±70 DEG	60 FT	40 - 50 FT (CONTROL RAY)
	27 DIODE STACKS, TOTAL			

Figure 19. Overhead Laser Transmitter Beam Geometry

coverage and is easy to combine to create the approximately 40 feet wide by 80 feet (12 m x 24 m) long overall rectangular coverage required.

Not shown in this layout is distribution of the individual contributions. Considerable overlap is required to provide gap free illumination to a height of at least 12 feet (3.6 m). The table at the bottom shows the number of stacks for each beam angle and the elevation view shows their cross sectional distribution.

The outer 20 degree beams are not shown cut off longitudinally for the 40 to 50 feet (12 to 15 m) maximum range. Thus the total longitudinal pattern shown is 160 degrees instead of 140 degrees in order to be consistent with the detector stacks employed. The actual 140 degree coverage can either be shaped by edge shades, or the full 160 degree beam can be allowed to extend to a maximum distance of about t-95 feet (28.5 m) for a 5 foot (1.5 m) high car. Alternatively, the vehicle receiver's field-of-view can be limited to prevent detection of any rays significantly greater than 140 degrees (70 degrees from the vertical).

It is important to constrain the transverse beam spread in order to keep the beam pattern for the desired directional roadway from illuminating the opposing traffic lanes. The use of beam masking and cut-off shades are discussed in the following section.

The central three beams in Figure 19 are aimed straight down and use a 60 degree beam spread in order to obtain the greatest coverage with the least number of stacks. This angle also reduces laser intensity at the shortest distance to an observer in order to satisfy the HEW Class I emission limits. This large angle is also permissible, since the required receiver signal-noise ratio is obtained at the shorter ranges with a larger angle than at the longer ranges.

Various angles were investigated for the second zones shown using 30 degree beams. Angles larger than 30 degrees resulted in inadequate S/N at the beam's outer rays. Smaller angles required too many additional laser stacks.

Figure 20 shows receiver S/N versus range from the transmitter support to the top of a 5 foot (1.5 m) high vehicle, Curves are plotted for each of the three beam angles.

Stacks are located along the support rather than at the center of the support to prevent trucks from shading smaller vehicles in the inner or outer lanes. With 3 - 60 degree, 7 - 30 degree and 5 - 20 degree beams in each direction there are 7 groups of laser diodes spread 4 to 5 feet (1.2 to 1.5 m) apart across a 40 foot (12 m) wide, 3 or 4 lane, roadway, This assures gap free illumination to a height of 12 feet (3.6 m) - 13 feet (3.9 m) and virtually precludes shading of small vehicles by high ones, such as adjacent trailer trucks.

Narrower roadways may use fewer laser stacks. Stack aiming would be adjustable to give the desired coverage for given road dimensions.

Shading, or ray occluding, in the longitudinal direction was also considered. Assume, for example, the very severe situation of a 5 foot (1.5 m) high car "sandwiched" between two trailer trucks with heights of up to

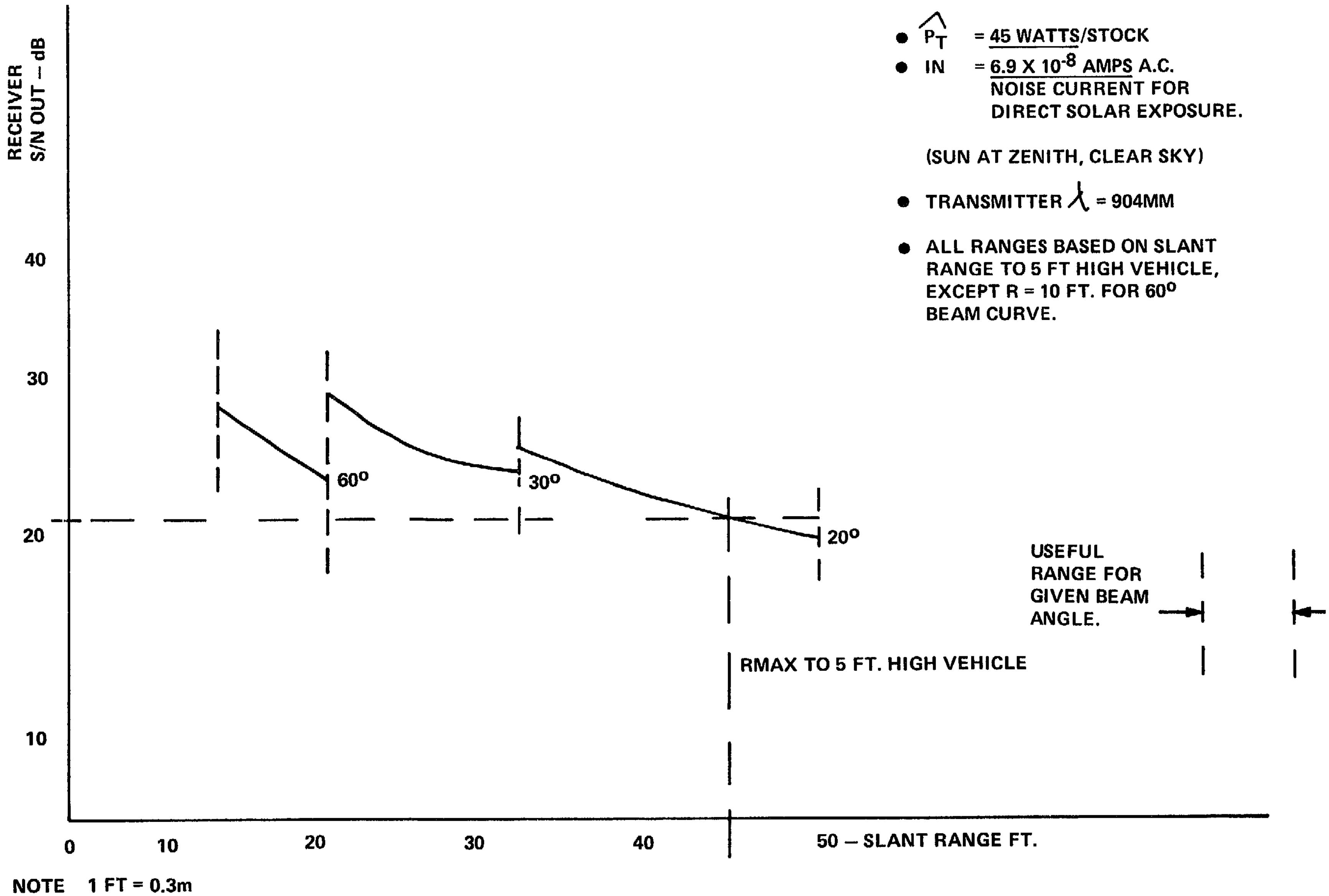


Figure 20. Receiver S/N vs Slant Range for the Three Beam Angles 20, 30 & 60°

12 feet (3.6 m) (12 feet is nominal max. trailer-height). With one truck 8 feet (2.4 m) behind the car and another 8 feet (2.4 m) in front, the car has an approach window of about 17 feet (5.2 m) where the 20 foot (6 m) high transmitted energy can reach the car's receiver. After passing under the transmitter array it will have a departure window of about 33 feet (10 m). Its total window distance is then 50 feet (15 m). Assuming a maximum speed of all vehicles of 30 mph, (48 kph) the car will have an open window interval of 1.14 seconds. This is enough time to acquire more than two full data frames*. Thus there appears to be no real shading problem for the overhead transmitter geometry when individual laser stacks are distributed along the support, as described, to prevent transverse shading.

7.1.2.3.10 Transmitter Array Masking

It is important to prevent the transmitted pattern for one roadway direction from illuminating the opposite lanes where different IVRG directions are required. When the illumination pattern as defined by the transmitters does not exactly conform to the desired illumination pattern, the desired pattern may be achieved by the use of vertical shades that can be made to cut off all rays extending beyond the roadway centerline.

The tolerance for such an adjustment is easy to achieve. Shades can be easily adjusted to an angular tolerance of less than one degree which satisfies IVEG requirements. Since shade lengths are 2 to 4 inches (5 to 10 cm), wind resistance is not a significant factor.

In some cases support of the transmitter mounting bar might be required at both ends to prevent wind deflection of the entire array.

7.1.2.3.11 Receiver Requirements and Design

From the foregoing description and analysis of the overhead transmitter system the optical IVEG receiver parameters can be defined.

The receiver does not use a lens for the receiver. This permits the receiver package to be very flat. The detector itself can be packaged in a small PC board mounted flat pack. All other major circuit elements are standard IC components that are under .25 inch (6.3 mm) thick.

Hence the receiver package thickness may be .5 inch (13 mm) or less. Specifications for the electro-optical portion of the receiver are:

- Receiver field-of-view: 140 degrees
- Detector size (Receiver Aperture): 20-25 mm^2
- Background: Direct sunlight with intensity through the spectral filter of 1.3 $m.w./cm^2$ (nominal maximum).
- Electronic Bandwidth: 25 MHz

------

*The headway assumed is actually unrealistically low; however, the example serves to show the wide level of service coverage which is obtained.

- o Detector rise time: 10 nanosecs max.

- o Minimum detectable power: 1.25 x 10^{-7} watts (peak) for above background intensity.

- o Wavelength of Detected Signal: 900 - 950 nanometers,

- o Spectral filter Cut-on Wavelength: 800 - 850 nanometers with transmission 90% at 900 nm.

- o Supply voltage: +12 volts from vehicle battery. Lower, regulated, voltages for the pre-amp and the other TTL level circuit elements may be readily achieved by means of Zener diode regulators.

- o Power consumption: 1.5 watts max.

- 0 Receiver Package size: 2 inch w x 0.5 inch H x 4 inch L (50 mm x 13 mm x 100 mm).

- o Detected pulsed data level to logic circuits: TTL or CMOS.

Figure 21 shows a simplified schematic of the electro-optical portion of the receiver (the decoding and display logic is separate from this; but may be included, at least in part, in this same package).

A mechanical cross sectional layout is shown at the bottom of this figure.

A silicon PIN detector is shown with an active area of 20 - 25 mm^2. It is back biased from the +12 volts battery input in order to minimize junction capacitance and thereby have the required speed of response to detect 20 nanosec pulses.

Several sources of this size PIN detector are currently available with the needed speed of response, for example, Silicon Detector Corp. type SD-200-11-21-041 and RCA C30844. Another detector, the TRW-Optron, Inc. type OP-915 needs to be increased in size, but the manufacturer advises that this poses no difficulty. The latter is the only one presently configured in the desired flat pack configuration; but Silicon Detector and Motorola have indicated they could easily do this. The desired PC mounted flat pack is also the lowest cost package to manufacture, using plastic encapsulation of the PIN diode chip.

The pre-amplifier shown uses a transimpedance amplifier. This employs two transistors with feedback resistance from the output emitter follower. This provides higher gain at the required large bandwidth than a single stage, low noise, FET amplifier. The transimpedance pre-amp has a low impedance input; and with feedback resistor of 12 - 15K ohms, the two stage voltage gain is about 40:l.

An intermediate amplifier is used to provide the required signal level at the input of the regenerator/comparator. The latter permits setting up a signal-noise threshold level below which no signal (pulses) reaches the

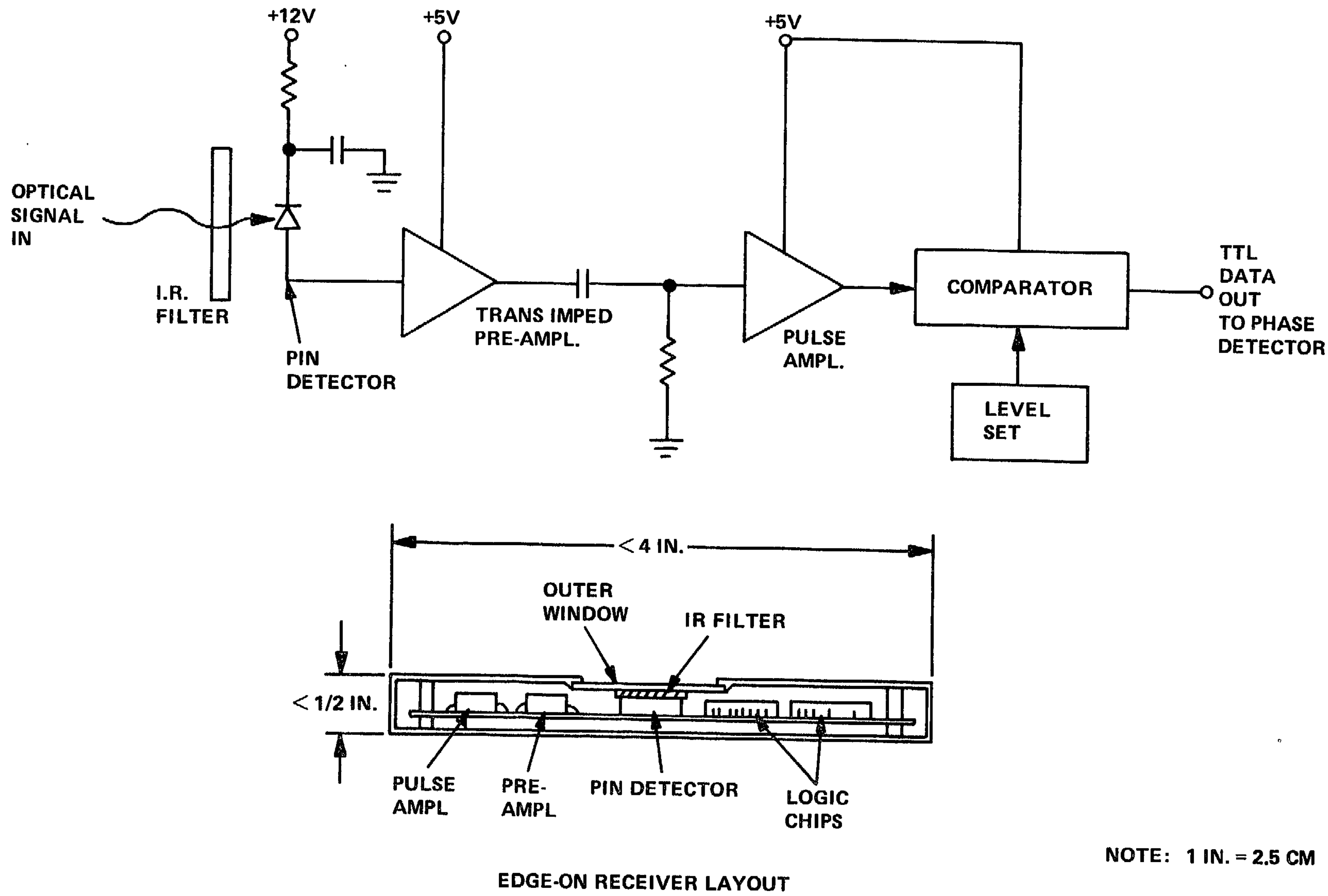


Figure 21. IVEG Optical Receiver

decoding logic. Thus a threshold S/N of 10 or 20:1 can be set up so that no noise, or extraneous signals, below this level reaches the decoding logic. The comparator chip, also serving to square-up the detected and amplified pulse waveform, is commercially available.

This overall circuit approach is currently widely used in many modern fiber optics receivers. It has a wide dynamic range (greater than 30 dB detected signal level range can be readily handled) by virtue of the pre-amp negative feedback and the design of the comparator.

7.1.2.3.12 Weather Effects

Snow accumulation, while the vehicle is standing for some time, of course occurs on the roof, as well as on any other horizontal surface. The motorist, on starting his journey would normally be expected to brush a significant snow accumulation from this surface as he would from the vehicle's windows.

Snow accumulation, is generally not a problem with the receiver mounted on the vehicle roof for moving vehicles. Prudent design, however, probably dictates that a simple de-icer heating element be attached to the receiver case and actuated from the dash board in geographic locations that are subject to significant snow and ice situations.

Since the maximum transmission range is so short, virtually no other weather condition has a significant impact on receiver S/N ratio. For a heavy rain of 25 mm per hr. the atmospheric transmission over a 50 ft (15 m) path is about 97 percent at the designated infra red wave length. For a cloudburst of 100 mm/hr. precipitation the transmission is still as high as 92 percent for this path. This represents a loss in S/N of less than 0.5 dB, which is inconsequential.

7.1.2.3.13 Receiver Synchronization

Detection and decoding of the guidance message requires the vehicle's reference clock to be synchronized with the roadside transmitter's clock.

The optical system uses a pulse modulation scheme converting the baseband signal to pulses of light. The optical receiver converts the light pulses back to electrical pulses. Synchronization is established by locking the receiver’s clock to these electrical pulses.

Pulse position modulation (PPM) is recommended. It is simple to implement and has excellent noise immunity. In a PPM system a train of pulses, derived from the transmitter's clock, is transmitted. The position of each pulse is shifted by the baseband modulating signal. In the IVEG optical system the data pulses have a fifty percent duty cycle and are shifted plus or minus forty-five degrees as illustrated in Figure 22.

As was the case for the microwave technique (Section 7.1.2.2.5) the receiver uses a phase-locked loop (PLL) to synchronize to the transmitter. The optical scheme's receiver uses, a sampling circuit to demodulate the data. Figure 23 is a block diagram of the receiver's synchronization and demodulation circuits.

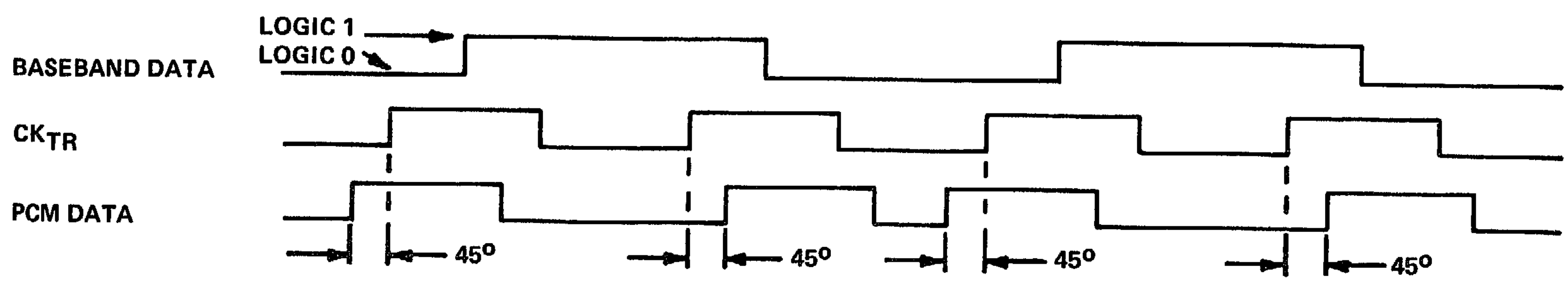


Figure 22. PPM Modulation - Roadside Transmitter

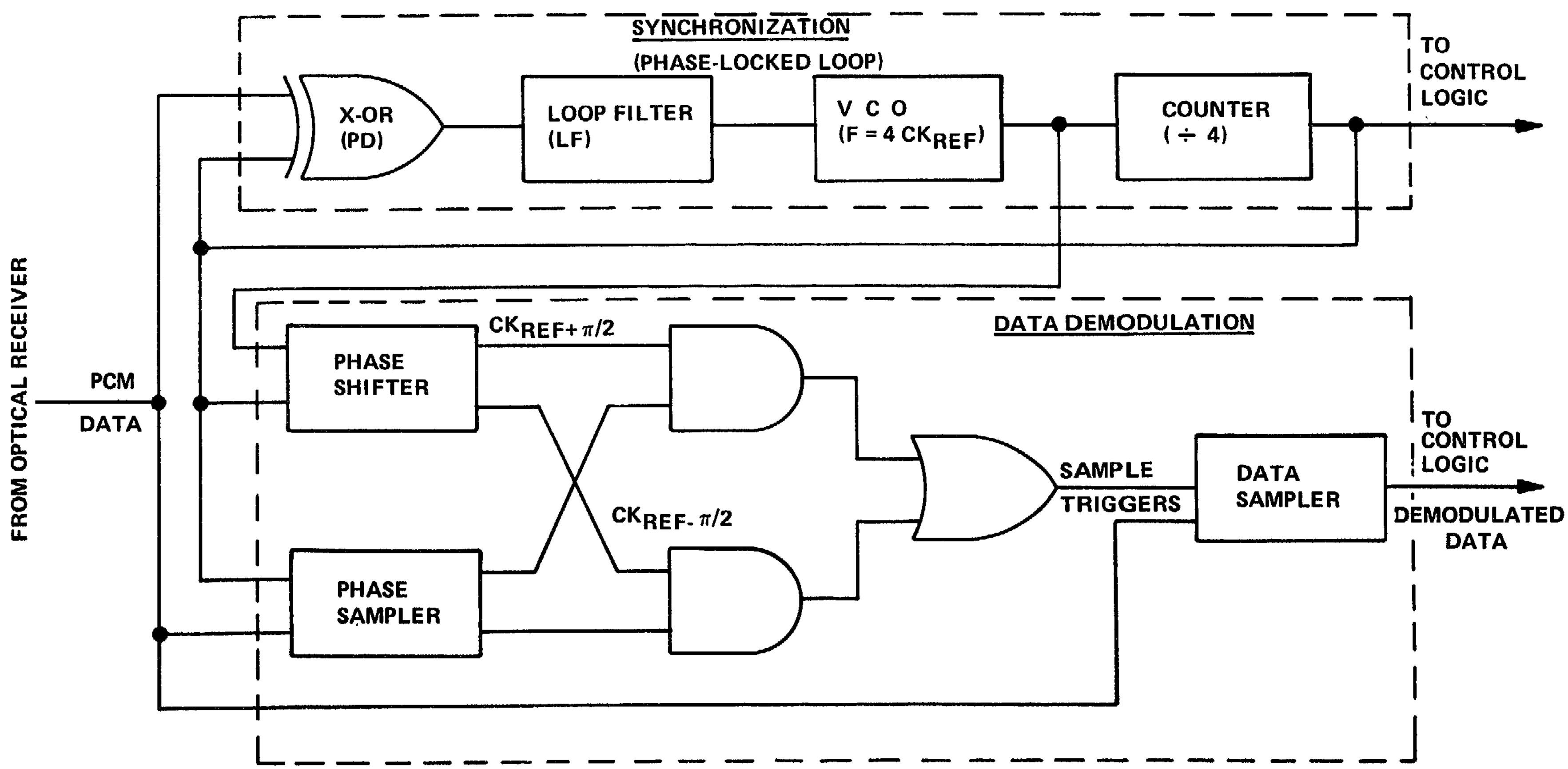


Figure 23. Receiver Synchronization and Data Demodulation

The PLL consists of a phase detector (PD), loop filter (LF), voltage controlled oscillator (VCO) and counter. The phase detector performs the exclusive-or, X-or, function. When the reference clock (Ckref) is either plus or minus ninety degrees out of phase with the transmitter's clock (Cktr) the output wave form from the phase detector has a fifty percent duty cycle and the loop is locked. The optical receiver's VCO locks at four times the frequency of Cktr. Locking at this frequency and using a counter to reduce this frequency to Ckref permits generation of sampling triggers leading and lagging Ckref by ninety degrees. These sample triggers Ckref+ /2 and Ckref- /2 are used by the sampling circuit to recover the data.

The plus or minus ninety degree ambiguity between Ckref and Cktr is resolved by the sampling circuit. Figure 24 illustrates these timing relationships. Ckref+ /2 is selected when Ckref is lagging Cktr by ninety degrees and Ckref, /2 is selected when Ckref is leading by ninety degrees. Data is recovered by sampling the received signal with the selected sampling triggers. The recovered data is processed by the control logic to provide the guidance commands.

In this case the received signal must be tracked with zero phase error. A Type 2 PLL[39] is therefore required. Since the roadside transmitter's clock operates at 10KHz with a timing accuracy of better than 10% and the intercept time is a minimum of one second, the phase lock loop requires a tracking range of 2KHZ and a settling time of 2 msec.

The PLL and sampling circuit can be realized using MOS technology and thus can be incorporated with the control logic on a custom LSI chip.

7.1.2.3.14 Conclusions

An IVEG communications system using the overhead transmitter appears to be a viable design approach. It virtually eliminates problems due to large vehicle shading. The receiver cost is held to a minimum by elimination of any form of collecting lens, and continuous communication appears assured in the presence of direct solar exposure of the reciever during daylight.

Short metal masks can be designed to control the illumination field of the laser transmitter modules, so that vehicles in opposing traffic lanes do not receive unwanted IVEG data.

Roof mounting of the receiver appears to. be the most practical approach for passenger cars. Widespread use would doubtless lead to standard mounting provision options in production vehicles of all types.

7.1.3 In-Vehicle Guidance Unit

The In-Vehicle Guidance Unit consists of the Display, Destination Encoder, Control Logic and the Communications Receiver. All of these components, with the exception of the Communications Receiver and the receiver synchronization circuit, are independent of the communication technology utilized.

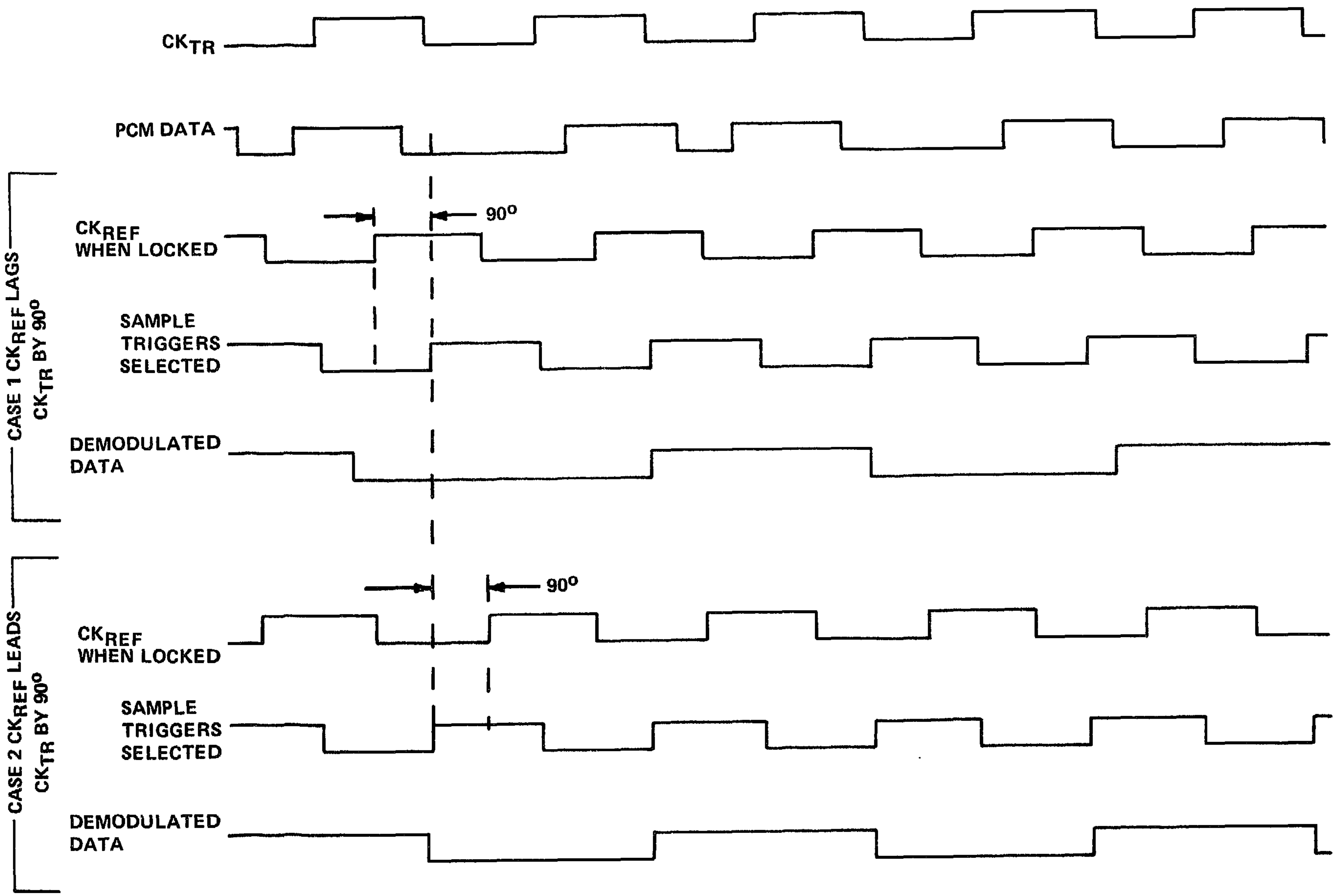


Figure 24. Receiver Timing Waveforms

7.1.3.1 Displays

An important consideration in the design of the in-vehicle unit is how to transmit the instructions to the driver. This may be accomplished by audio messages or by a visual display.

7.1.3.1.1 Audio

In the past, audio messages did not receive much attention due to hardware limitations. Recently, however,several manufacturers have developed speech synthesis MOS-LSI chips (40) that use linear predictive coding. Interface logic allows the selection of the appropriate message from 100 seconds of stored speech. The audio output stage and speaker from either in the vehicle's radio or in the guidance unit would be used to transmit the stored messages. Examples of several possible IVRG messags are "NEXT RIGHT", "TURN LEFT" and "NEXT EXIT".

The speech synthesis chips are currently being used in "Talking Calculators" and "Language Translators" and are being introduced into home appliances. It would appear that future price reductions would make this technology compatible with IVRG cost objectives. However, based on experiments conducted during the CACS study(41) which concluded that audio messages are not suitable for the IVRG application, the IVEG design was based on a visual display.

7.1.3.1.2 Visual

In selecting a visual display technology for the in-vehicle guidance unit, several characteristics need to be considered. These characteristics can be grouped into environmental, electrical, aesthetic, reliability and compatibility.

An in-vehicle display has to operate over the temperature extremes encountered in the vehicle. These temperatures can vary from -30°C to +80°C. It also has to be capable of surviving the shock and vibration encountered by a moving vehicle.

The display technology should be electrically compatible with the vehicle's 12 volt electrical system and with the MOS technology used by its driving logic circuits. Displays which operate at fourteen volts or less can use the vehicle's supply either directly or with a simple voltage converter. Those which require a high operating voltage require voltage converters. Many displays can be interfaced either directly or through simple drivers incorporated in the MOS control logic circuitry.

(40) Behrens, C.W., "The Reality of Appliances that Talk," Appliance

Aesthetics is very important in a vehicle display. The display must be bright enough not to washout in bright light and be provided with a means to prevent it from overwhelming the driver in low light. The technology must permit the display of symbols unique to route guidance. To enhance driver appeal, the symbols should be uniformly illuminated in a pleasing color.

The display must be reliable. It should have a life expectancy of that of a car (ten years = 85,000 hours).

Compatibility with the technology used by the automobile manufacturers in the fabrication of other in-vehicle electronics is important in implementing the IVRG concept. Thus manufacturers would be more willing to offer as a standard option or even incorporate into their electronic dash panel a device which utilizes a familiar technology.

Table 15 is a comparison of the various candidate display technologies.

Light emitting diodes (LEDs) have found wide application in digital readouts and alphanumeric displays. LEDs are semi-conductor diodes that emit light by the transfer of current across its junction. This technology is capable of operating over a wide temperature range from a five volt power supply. It has a very high life expectancy and is relatively low in cost. While this display has good visibility in low light, it "washes out" in bright light. Displays are only available in a limited repertoire of symbols and have poor brightness uniformity. LEDs are only available in a limited number of colors. They have been used as digital readouts in automotive radios and clocks, but their automotive use is being limited due to visibility problems in bright light(42).

Liquid Crystal Displays (LCDs) are also widely used in digital readouts. The displays consist of transparent electrodes etched on glass separated by a liquid having crystaline properties. When a voltage is applied to the electrodes, the molecular orientation of the crystal is changed, changing the amount of light passing through it. These displays, while having very good visibility in bright light, are poorly visible in dim light. The color of these displays is illumination and temperature dependent, washing out at low'temperatures. The display can be formatted into custom symbols and easily interfaced with MOS logic. A major problem in using liquid crystal displays in automobiles is its relatively narrow temperature range of 0°C to +60°C. At low temperature the display loses its liquid-crystal properties. The liquid crystal display used in the CAC system contains a heater to permit operation below this temperature. It does however, require a period of time to heat up before it is operable. The CAC display also contains a fluorescent lamp for backlighting in low light. The fluorescent requires an inverter to derive its 100 volt power from the cars 12 volt electrical system(43).

------

(42) "Displays," Interface Components, Electronic Buyers Handbook and Directory, Volume 5, June 1978

(43) "In-Vehicle Display Unit (Liquid Crystal Type) for CACS Pilot System," Toshiba Corporation

TABLE 15. IVEG DISPLAY TECHNOLOGY

TECHNOLOGY CHARACTERISTIC	LED	LCD	GAS DISCHARGE	BACKLIT INCANDESCENT	VACUUM FLUORESCENCE
Operating Temperature Range ("C)	-40 to I-85	-10 to +60	0 to +55	-55 to +100	-55 to +100
Operating Voltage (volts DC)	5	3 to 7	180	Varies	I2 to 25
MOS Compatibility	Good	Good	Good	Poor	Good
Visibility in Bright Light	Poor	Good	Good	Good	Good
Visibility in Low Light	Good	Poor	Good	Good	Good
Custom Symbols Available	Limited	Yes	Yes	Yes	Yes
Brightness Uniformity	Poor	Fair	Good	Poor	Good
Colors Available	Limited	No	Yes	Yes	Yes
Life Expectance (hrs)	100,000	50,000	85,000	20,000	100,000
Use in Autos	Limited	No	No	Limited	Yes
cost	Low	Moderate	High	Moderate	Moderate

U.S. manufacturers have also made improvements in liquid crystal technology. Displays capable of operating down to -10°C without heaters are currently being introduced. The problem of storing liquid crystal displays at temperatures above 65°C with a 40% relative humidity has yet to be solved. Under these conditions the display suffers permanent crystal damage. While other improvement can be expected in this display technology, liquid crystal's current inherent lack of good contrast and aesthetic appeal diminishes its attractiveness for the IVRG application.

Gas Discharge Displays (Plasma) is a glass tube containing neon gas in which are mounted shaped segments. When an electrode is energized by a high DC voltage (160 - 180 volts), the adjacent gas becomes ionized and glows. It has excellent visibility in bright and low light conditions, good brightness uniformity and can display custom symbols(44). Its main shortcoming is its limited temperature range, high operating voltage of 180 volts and high cost.

Backlit incandescent displays utilize incandescent lamps to backlight symbols etched on a panel. This display has good visibility and can operate over a wide range of voltages. Drivers are required to interface with the MOS logic and the life expectancy of the lamps are less than that for other technology. Difficulty can also be encountered in uniformly illuminating certain of the symbols required for route guidance. They have been used as status indicators in autos.

Vacuum-Fluorescent Displays contain segments composed of fluorescent materials that glow when bombarded with electrons. This occurs when a small positive voltage is applied to the segment. The display operates over a wide temperature range and is compatible with automotive voltages. It can be provided with custom symbols, has good brightness uniformity and good visibility in bright and dim light conditions. Color filters can be utilized to change its characteristic blue-green color. The displays have a long life expectancy and can be easily interfaced with MOS logic(45, 46, 47) The "big three" automotive manufacturers -- GM, Ford and Chrysler -- are currently using vacuum fluorescent displays in their instrument panels and expect to use them for the foreseeable future.

Currently however, a great deal of research is being conducted in display technology. This might lead to the development of a display superior to vacuum fluorescent in an automotive application. For the present, however, vacuum fluorescent technology is the best choice for the IVEG system.

(44) "Screened Image Displays," Beckman Series SP-4000

(45) "Vacuum Fluorescent Displays Chosen by "Big 3" Auto-Makers," Circuit News, - January 15, 1979, page 18

(46) "West, Raymond A. Vacuum Fluorescent Displays for Automotive Applications," Society of Automotive Engineers, International Automotive Congress and Exposition, February 28 - March 4, 1977; 770275

(47) "Vacuum Fluorescent Displays," Futaba Corporation

Research has been conducted during ERGS and CACS into visual presentation of route guidance instructions[41, 48]. Both studies recommend that symbols be used to provide routing instructions supplemented by legends to alert the driver to special situations such as an exit or a loss of guidance. The symbols used should be unambiguous and easily recognizable. Figure 25 shows the display developed for ERGS-II. The legends are formed by illuminating various combinations of words. Thus, the message "TAKE 2^{D} RIGHT" would be displayed by lighting "TAKE" from the top line "2^{D}" from the bottom line and "RIGHT" from the middle line. This checkerboard method of presenting messages is confusing and should be avoided. The CACS display, shown in Figure 26 has overcome this problem by displaying fixed messages. This display also contains legends used with the drivers information subsystem.

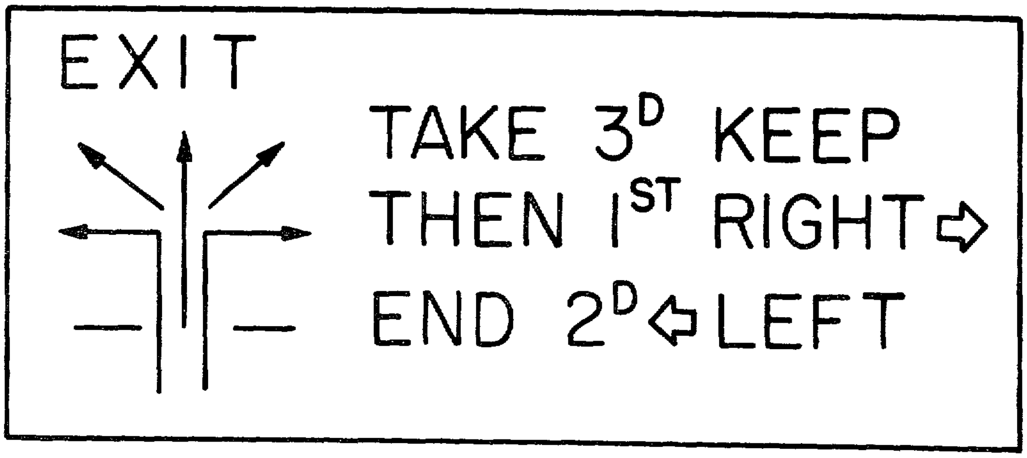


Figure 25. ERGS Display

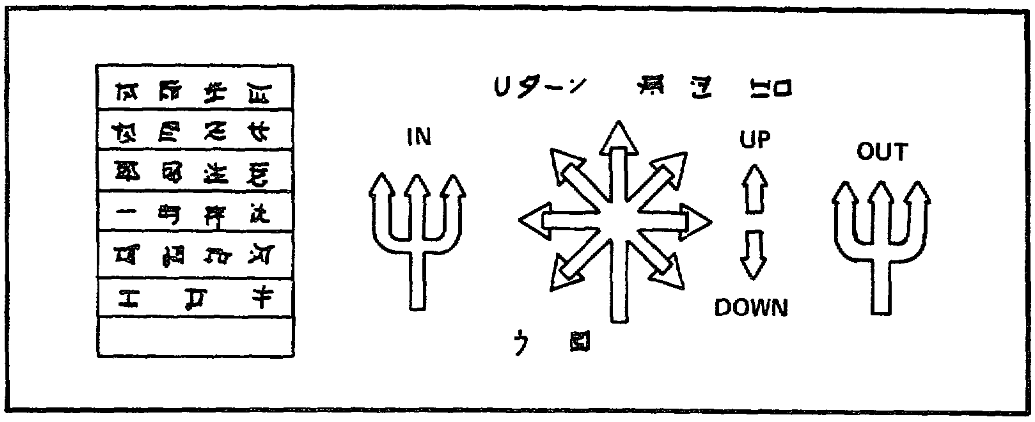


Figure 26. CACS Display

- - - - - -

(48) General Motors Research Laboratory, "A Design for An Experimental Route Guidance System - Volume III - Driver Display, Experimental Evaluation," FHWA Pub. 197-092, November 15, 1968

Under the CACS program[41], the use of a heads-up windshield display was evaluated. This display projects instructions on the vehicle's windshield. It was found that the heads-up display was distracting to the driver, reducing his concentration on the road. The best type of visual display was found to be a panel mounted above the dashboard near the car's radio with the information displayed to the driver ten to fifteen seconds prior to the maneuver.

Figure 27 is a possible functional layout of such a panel. Symbols and fixed legend messages are formatted by illuminating combinations of segments. A chime or other pleasing tone would be incorporated to alert the driver when the displayed information is updated. The possible messages and their meanings are defined in Table 16. Directional commands, displayed as symbols, are transmitted when the vehicle passes a guidance point. The "continue straight" symbol means no turning movement is to be executed. The "turning movement symbols" direct the driver to change direction, The "EXIT" and "ENTER" legends, used in combination with direction symbols, guides the motorist on or off expressways. The "KEEP RIGHT" and "KEEP LEFT" are positioning commands directing the motorist into the appropriate lanes prior to receiving a directional command. The remaining legends are advisory messages. "ZONE CHANGE" is transmitted when the motorist has entered a new area and needs to insert a new destination code. "DESTINATION" is displayed when the motorist has reached the point specified by the destination code. "MESSAGE ERROR", displayed when an invalid message has been received and detected by the vehicle guidance unit, alerts the driver that he is without guidance and should act accordingly.

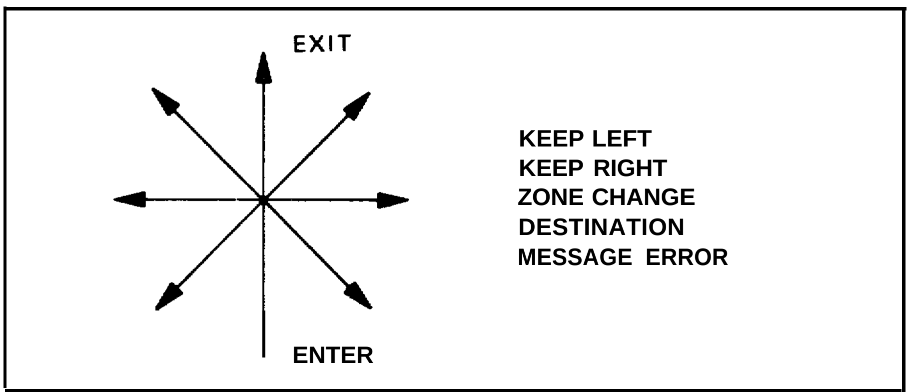


Figure 27. IVEG Display

TABLE 16. IVEG VISUAL MESSAGES

SYMBOL/LEGEND	DEFINITION
	continue straight
	execute indicated turning movement
EXIT 	exit from expressway on the right
EXIT 	exit from expressway on the left
ENTER 	enter expressway to the right
ENTER 	enter expressway to the left
KEEP RIGHT	move to the right lane
KEEP LEFT	move to the left lane
ZONE CHANGE	insert new destination code
DESTINATION	arrived at destination
MESSAGE ERROR	error in received message

7.1.3.2 Destination Encoder

The "Destination Encoder" is the device through which the motorist sets his desired destination code into the vehicle guidance unit. It should be easy to operate and as foolproof as possible. The device should remember the destination when the ignition is off and should give the motorist, on command, a positive indication of the destination set. It should also be reliable, easy to interface with the control logic and low in cost.

Several encoding technologies have been selected as prospective candidates for the IVEG application. These prospective candidates, summarized in Table 17 include thumbwheel switches, keyboards and electronically slewable counters.

TABLE 17. DESTINATION ENCODER TECHNOLOGY

Characteristic Method	Thumbwheel	Keyboard	Electronic Slew
Ease of Operation	Very Good	Good	Good
Reliability	Very Good	Good	Good
Interface with MOS/LSI	Simple	Difficult	Simple
Interface with Microprocessor	Moderate/Difficult	Moderate	Difficult
Set Code-Ignition Off	Yes	NO	NO
Remember Code-Ignition Off	Yes	NO	NO
cost	Moderate	Moderate	Low

Thumbwheel switches are electromechanical devices consisting of one or more segments. Each segment consists of a plastic disc mounted in a frame. The edge of the disc contains engraved numerals which are visible through a window. As the operator rotates the wheel different symbols are displayed and metallic contacts on the disc contact spring fingers fixed to the frame. The combination of spring fingers selected corresponds to the symbol displayed. In the IVEG system each segment corresponds to a binary coded decimal digit, that is the switch uses an 8-4-2-l code to decode each digit set on the switch. Thumbwheel switches are extremely reliable and rugged(49). Since the code is stored and displayed mechanically it does not require electrical power for memory. Thus the code is remembered with the ignition off and the motorist always has a positive indication of the setting. The switch outputs can be directly interfaced with TTL and MOS logic. Four connections are required per digit. Interfacing with microprocessors is, however, more complex requiring the use of a multiplexer.

A keyboard consists of a matrix of pushbutton switches(50). A scratch pad board type keyboard would be used for IVEG. This is similar to the type of keyboard used in a calculator. Eleven pushbuttons would be required, ten for the numerals and one for “ENTER”. The operator would set

(49) “Interface Components,” Electronic Buyers handbook & Dir., Vol. 5, June 1978

(50) Howell, D., "Solid State Keyboards," Electronic Products, May 1978

his destination, as he would load a number into a calculator, by pressing the buttons corresponding to his destination in the appropriate sequence and then the "ENTER" key. While the keyboard approach is appealing to the motorist from an operational point of view, it presents many problems. The interfacing of a keyboard to a micro-processor is relatively simple. A routine in the processor causes each key to be periodically scanned and read. The value of the depressed key would be decoded and stored by the processor. Interfacing with a custom MOS/LSI control chip is, however, quite complex. Low cost keyboards are available. The output of each key is a contact closure. Decoding and debounce circuitry has to be provided externally. LSI chips to serve this function are available. These chips also convert the serial keyboard entry format into the BCD parallel format required by the MOS/LSI control chip. Keyboards with internal BCD encoding are also available. These boards are, however, quite expensive[51]. They also require external circuitry for debouncing and serial to parallel conversion; thus, they do not offer an advantage over the low cost keyboard. Another problem is the need to provide a readout to display the destination code. While the display can be driven from the LSI decoders, provision still must be made for a digital readout. The keyboards do not have the inherent memory of thumbwheel switches and a separate register using keep alive power must be provided to store the destination code while the vehicle's ignition is off. This further increases the cost and complexity of the control logic. Another complicating consideration is the possible need to activate the digital display while the ignition is off. This would occur if the driver wants to know the destination code stored or load a new destination code and could be accomplished by providing a momentary switch allowing the driver to momentarily illuminate the display. The advantage of the keyboard is that its cost is not proportional to the number of digits in the destination code.

The "Electronically Slewable Counter" technique is an adaptation of the method used to set digital clocks. The destination code is stored in a counter whose contents are displayed on a digital readout. The user increments the counter by a front panel slew switch until the count, as displayed on the digital readout, corresponds to the destination code. This technique is easy to integrate with the control logic, possibly including the counter in the custom MOS/LSI control chip if that approach is implemented. If a microprocessor is used, a multiplexer would have to be provided to interface the counter with the I/O bus. This technique also requires a digital readout and a slew switch. The cost would be from five to ten dollars. The "Electronically Slewable Counter" suffers from the problem of storing and displaying the destination code when the ignition is off. It also takes longer to set the destination into the vehicle guidance unit using this technique than with either thumbwheel switches or a keyboard.

Of the three analyzed techniques the thumbwheel switch is considered the best for the interfacing with a custom MOS/LSI control logic chip.

7.1.3.3 Control Logic

The system's control logic decodes the data from the Roadside Guidance Unit, checks the data for errors in transmission and selects,

(51) "Special Report Switches and Keyboards," Circuit News, March 15, 1979

according to the received data, the guidance instruction to be displayed. As discussed in Section 7.1.1.3 a synchronous serial data format (see Figure 7) containing encoded directions to all pertinent destinations is used. From this serial data the control logic selects the coded guidance instructions for the destination point set on the encoder.

Figure 28 is a flow chart for this detection process. Synchronization must first be established between the control logic and the data. This is accomplished by searching for a sync character. The sync character, appearing at the start of each data word, has a unique bit pattern to differentiate it from the other characters in the message. When a sync character whose parity has been verified is detected, all registers in the control logic are initialized. The control logic then examines the first four bits of the next character. These bits identify the sector whose guidance data is contained in the word. When the word corresponds to the encoded sector and the character's parity is verified, the next four bits are examined to determine if this is a remote sector or a local sector. If a parity error is detected or the sector does not correspond to the encoded one, the control logic searches for the sync character which identifies the start of the next word and repeats the process. If the character is valid the logic searches for the character containing the guidance instruction. These instructions are transmitted sequentially, two instructions per character. The control logic performs this task by counting the characters and comparing the count with the sector code. For a remote sector the character count is compared with the last digit of the destination code.

If the parity for the character containing the instruction is valid, the four bit instruction code is loaded into a register, the display is enabled and the message corresponding to the decoded contents of the register is displayed. The legend "MESSAGE ERROR" is displayed when a valid instruction has not been received during a transmission from the Roadside Unit.

Three techniques of implementing the control logic have been considered. They are: a custom MOS/LSI integrated circuit, a dedicated microprocessor and a shared microprocessor.

MOS (metal oxide semi-conductor) type logic is currently being used in automotive devices such as radios and clocks. This type of integrated circuit technology offers high noise immunity, high packing density and the ability to operate over the large voltage and temperature ranges found in cars. One custom MOS/LSI (large scale integration device) can perform all of the control functions and the synchronization of the-receiver's clock to the transmitter. This reduces the number of components required, reducing system complexity and costs while increasing system reliability. Figure 29 is a block diagram of the control logic using an MOS/LSI integrated circuit.

The second technique is the use of a microprocessor[52, 53], since the control logic does not require a large instruction set, a large

------

(52) "Microprocessor Directory", EDN, November 20, 1978

(53) "The complete Motorola Microcomputer Data Library", Motorola, 1978

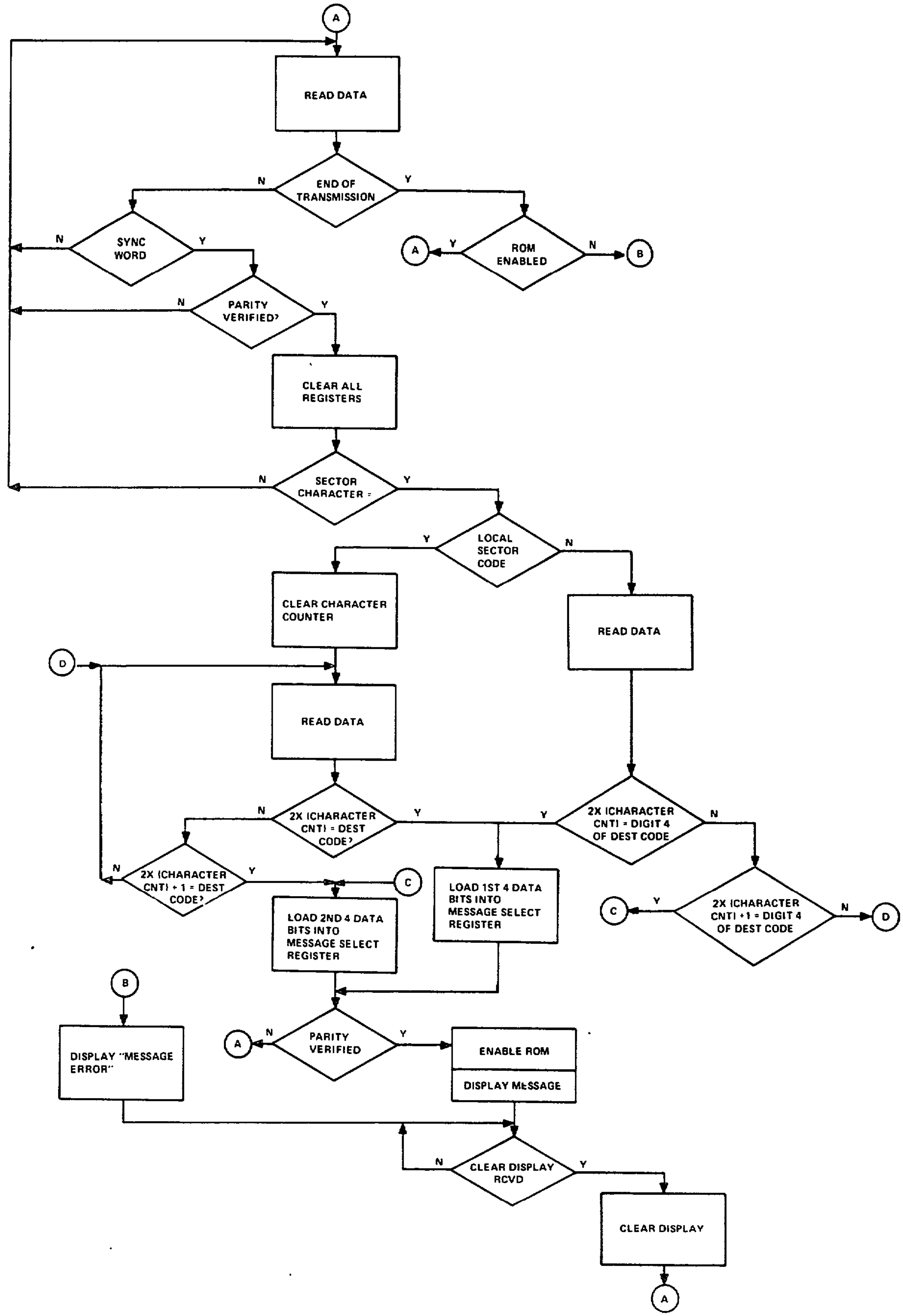


Figure 28. IVEG Control Logic (Flow Chart)

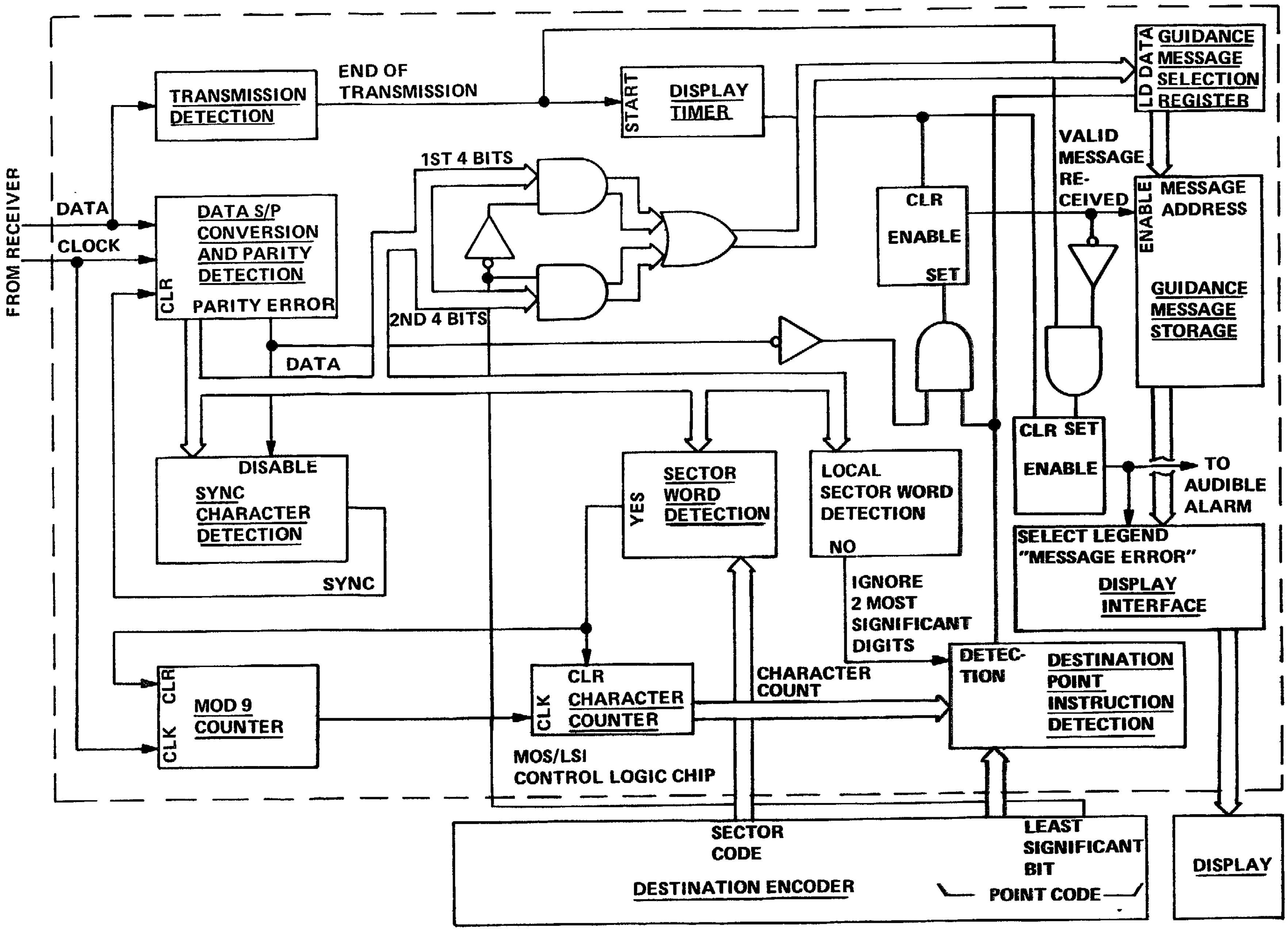


Figure 29. IVEG Control Unit (Block Diagram)

memory or many registers to implement; a low end microprocessor is suitable. These devices, stripped down versions of the more powerful microprocessors, are lower in cost. MOS versions suitable to the automotives application are available. The use of the microprocessor does, however, require support chips to interface with the communications, the display and the encoder. The estimated cost of the microprocessor and its support chips is somewhat higher than the MOS/LSI integrated circuit.

The third implementation technique is to utilize an in-vehicle microprocessor. The automotive manufacturers are planning to introduce microprocessors as part of the vehicles integrated dashboard. These processors would be utilized to calculate speed, elapsed mileage, travel time, gas consumption and other parameters. The simple processing performed by the control logic should not burden the processor. Support chips would be required, however.

Of the three implementation alternatives the custom MOS/LSI chip is considered the most viable due to its low cost and simplicity.

7.1.3.4 Control Unit Packaging

The Control Unit, approximately 6 inches (15 cm) wide by 3 l/2 inches (9 cm) high, can either be incorporated into the vehicle's dashboard, when purchased as a factory installed option, or mounted on the dashboard.

Figure 30 depicts a layout for the Control Unit's front panel. Guidance instructions are displayed on a display as discussed in Section 7.1.3.1. Destination encoding is through a thumbwheel switch assembly, discussed in Section 7.1.3.2. Panel illumination and display dimming, for night use, are controlled by either the dashboard's light dimming switch or a separate switch on the Control Unit's panel. Other switches turn the control panel on and control the receiver's roof mounted heater, if one is required. The use of preformed solder terminals on the front panel components simplify assembly by permitting direct soldering to the printed circuit board.

The printed circuit board, mounted behind the front panel contains the control logic, communications interface, and audible alarm. The control logic consists of a custom MOS/LSI chip, discussed in Section 7.1.3.3, with external resistors and capacitors. The audible alarm alerts the driver when a new message is to be displayed.

The IVEG control unit functions can be incorporated into an integrated electronic dash panel. These panels, recently introduced by the automotive manufacturers, utilize microprocessors, keyboards and electronic readouts to provide the motorist with information such as speed, fuel consumption, status of various vehicle systems and expected time of destination. Many of the IVEG control logic functions can be implemented by the microprocessor and the keyboard can be used for data insertion. The instructions can be displayed on either a dedicated IVRG display or possibly incorporated into other displays provided as part of the electronic dash panel.

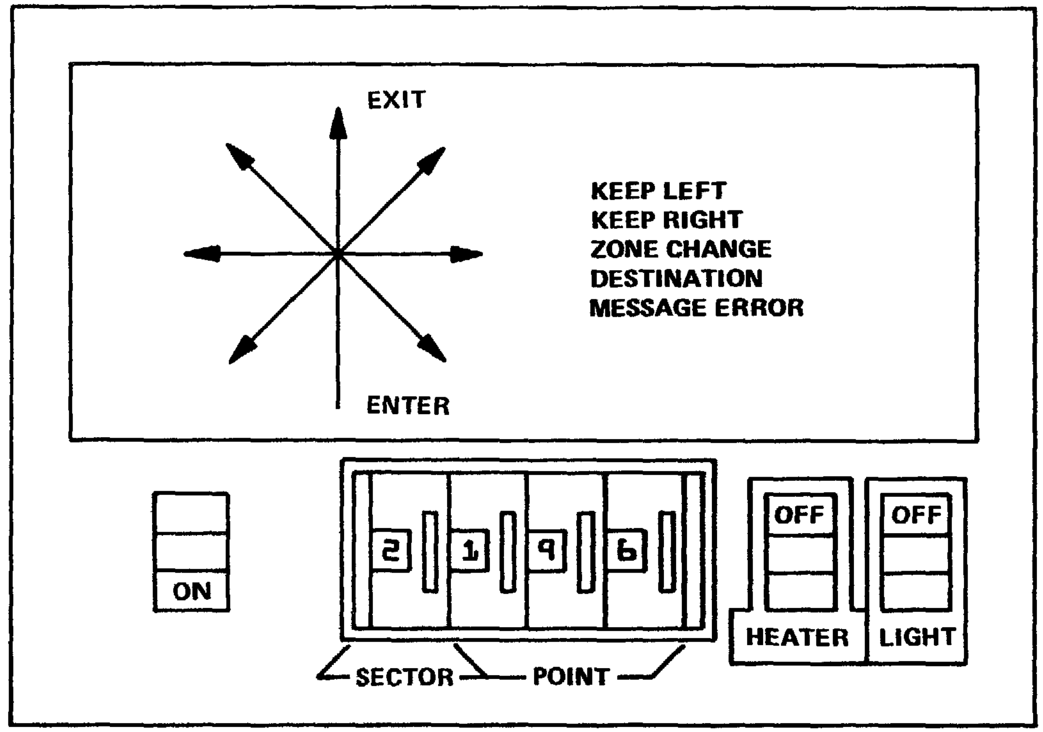


Figure 30. Vehicle Control Unit Front Panel

As original equipment supplied and installed by the vehicle manufacturer, the opportunity to integrate IVEG functions with other control and display functions should serve to reduce the manufacturing cost of the Control and Display Unit.

Future developments in vacuum fluorescent displays or the selection of an alternative display technique may, also, serve to reduce the cost of the Control and Display Unit.

7.1.3.5 Reliability of Maintainability of Vehicle Equipment

The control unit, utilizing highly reliable MOS technology, a vacuum fluorescent display with a life expectancy of one hundred thousand hours, a thumbwheel switch with a rating of one million detent operations and sophisticated fabrication techniques, has a life expectancy of ten years which is equivalent to the life of the vehicle. The unit does not normally require maintenance. All repairs, other than the replacement of light bulbs must be performed by the manufacturer.

The microwave receiver, utilizing solid state components, has a design life of ten years. It does not normally require maintenance.

The optical receiver, utilizing solid state components, also has a design life of ten years. The only normal maintenance the receiver requires is an occasional cleaning of its glass window. The frequency of cleaning, from several times a year to once in several years, depends upon the prevalence of atmospheric pollutants.

Both the optical and microwave receivers are sealed units and will probably be returned to the manufacturer for repair.

The installation complexity of installing the IVEG equipment is equivalent to that of installing a CB radio.

7.1.4 Roadside Equipment

The roadside equipment consists of the transmitter, either microwave as discussed in Section 7.1.2.2 or optical as discussed in Section 7.1.2.3, and the Route Guidance Controller. In a dynamic system the controller is linked to a control center via a data link permitting modification of the guidance instructions stored in the controller to reflect changing traffic conditions.

7.1.4.1 Deployment

The deployment of the transmitters for a typical intersection is shown in Figure 31. The distance the transmitters must be deployed from the decision point is a function of the time required for the driver to react to an instruction and his speed of travel. For example, if the reaction time and lane adjustment time is ten seconds and the vehicle is traveling at thirty miles per hour (48 kph), a typical legal speed for central city surface streets, the transmitter must be located 440 feet (134 m) from the decision point.

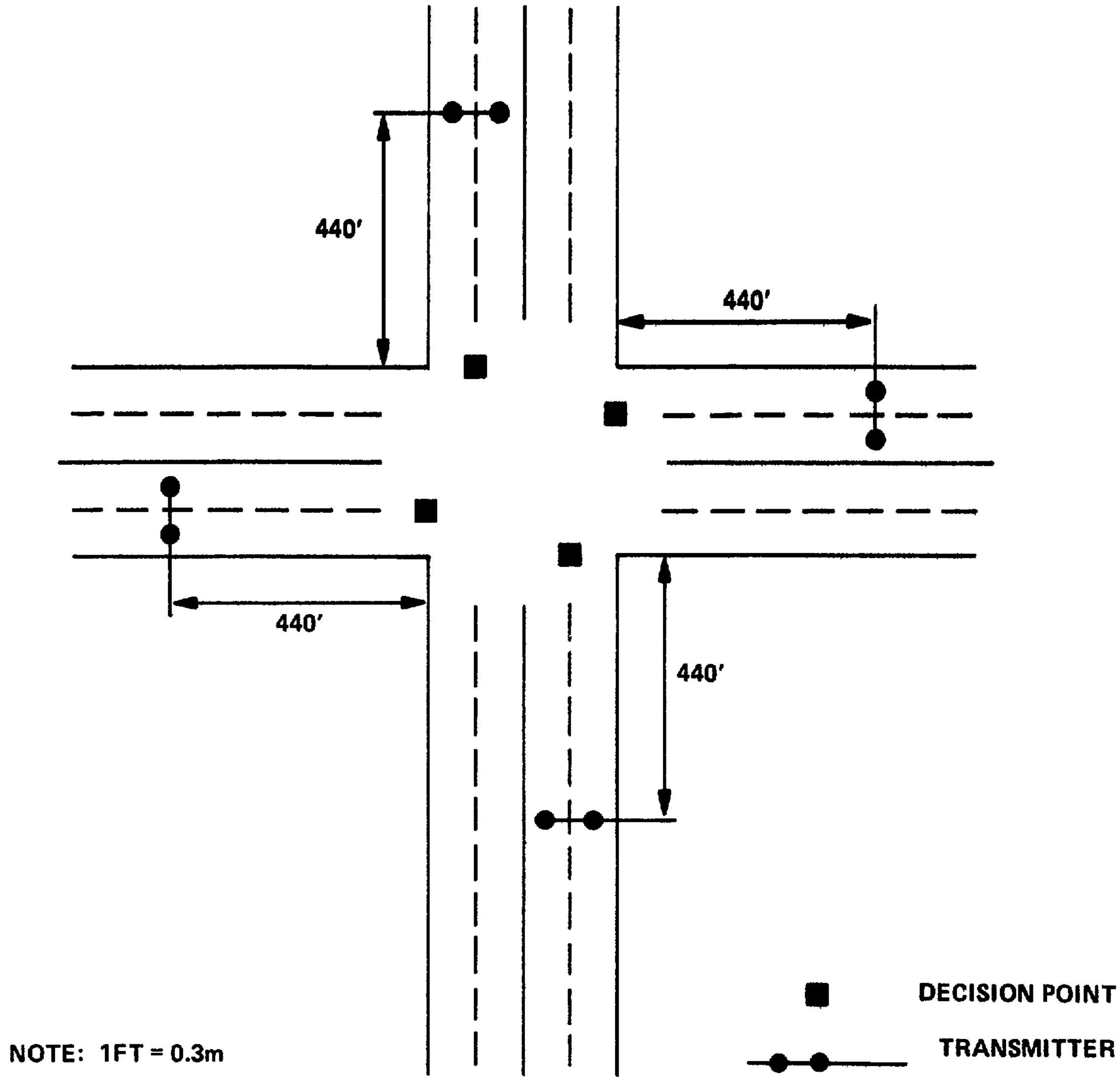


Figure 31. Transmitter Deployment at a Typical Intersection

One route guidance controller has the capability of servicing up to eight transmitters. This, however, requires the installation of conduit and cable between the controller and the remote transmitters. The cost of furnishing and installing 2" (5 cm) conduit and restoring the surface can vary from $12 a foot for installation in dirt to over $30 a foot for installation in concrete. Placing the transmitter at an intersection decision point requires 440 feet (134 m) of conduit. If a typical cost of $20/foot is assumed, the cost of installing this conduit is $8800. The cost of the cable, line drivers and receivers required in the controller and transmitter, and increased controller memory capacity to store the additional guidance instructions is approximately $500 for each remote transmitter. Thus, the approximate cost of using a controller to drive a remote transmitter is $9300. The cost of furnishing and installing a controller and cabinet is approximately $5000.

The use of separate controllers for each transmitter is not only cost effective but also eliminates the disruption caused by the installation of the conduit and enhances system operation by limiting to one the number of transmitters placed out of service by a controller outage.

7.1.4.2 Route Guidance Controller

The route guidance controller, located at guidance decision points, stores and formats the guidance instructions. Figure 32 shows the controller's block diagram. Each controller contains a microprocessor, memory storage, interface logic, data conversion logic and parity generation logic. The controller, similar in size and complexity to the Type 170 traffic controller, includes a display and keypad to facilitate maintenance and instruction change. The design of the controller, with the exception of the transmitter interface, is independent of the communications technique selected.

Each controller can be configured to service up to eight transmitters. Deployment considerations, discussed in Section 7.1.4.2, dictate, however, that most controllers will probably service only one transmitter. The microprocessor's program instructions are stored in ROM. In a static system the guidance instructions are stored in a PROM. In a dynamic system, these guidance instructions are stored in RAM - new instructions being received through the modem and the Communications Interface Adapter (CIA). Battery backup preserves the data stored in the RAM in the event of a power failure. The PROM used in the static system is nonvolatile not requiring battery backup. The memory, either PROM or RAM, can store the approximately five hundred - 8 bit words required for the longest guidance message. Data, read out of the memory in a continuous loop, is transmitted through a Program Interface Adapter (PIA) to a parallel to serial converter that generates the parity bit and converts the data into the serial format required for transmission, The Transmitter Interface converts the data's voltage level to the level required by the transmitter.

The microprocessor has the capability of monitoring the transmitter's performance. In a dynamic system this status is transmitted to the control center.

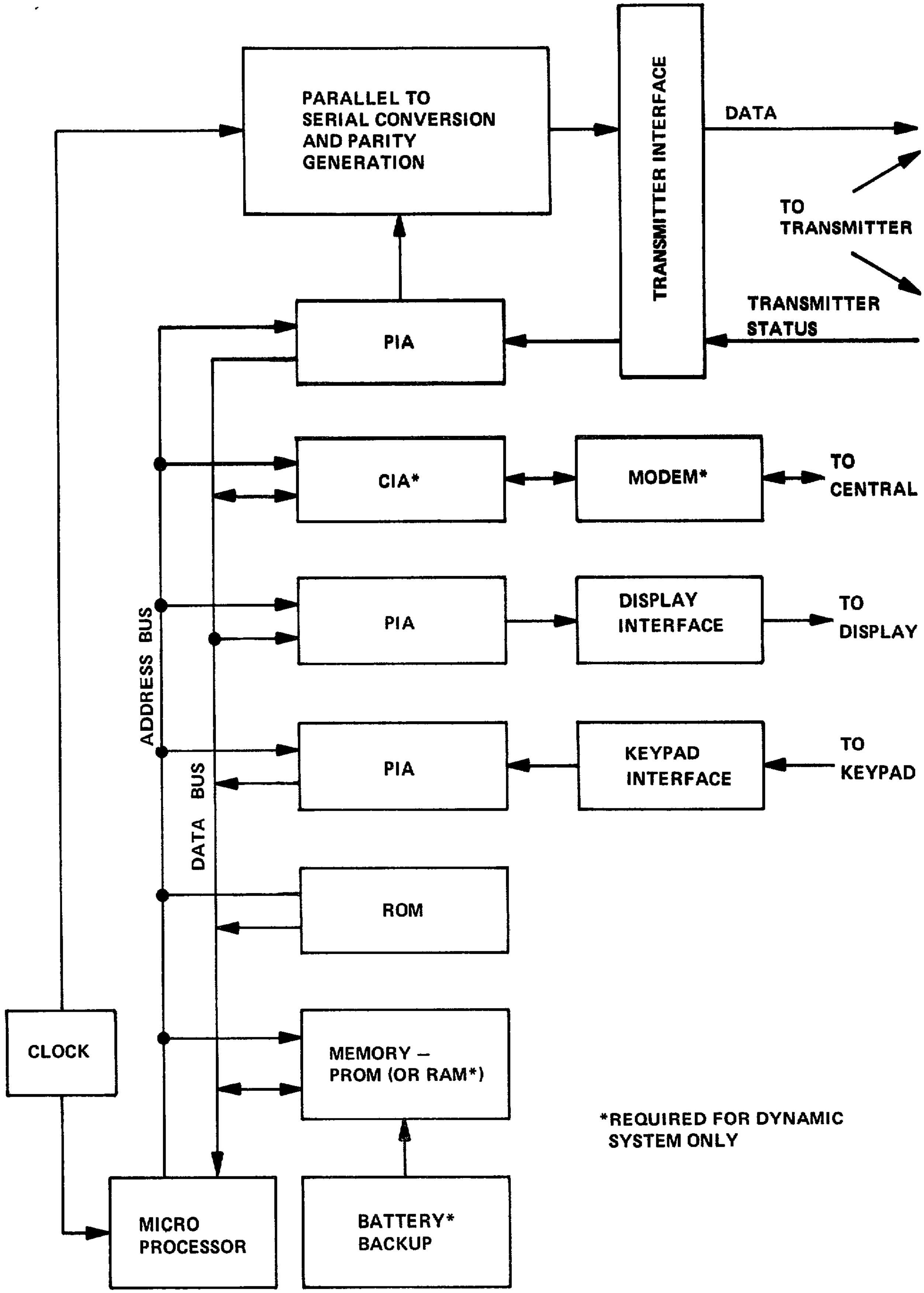


Figure 32. Route Guidance Controller (Block Diagram)

7.1.4.3 Reliability and Maintainability of Roadside Equipment

The route guidance controller is similar in complexity and design to a microprocessor traffic controller and has an equivalent reliability. The route guidance controller utilizes functional groupings of components and modular construction to facilitate fault isolation to the modular level. It can be serviced by a technician of the same skill level required to service microprocessor traffic controllers. The defective module is replaced and is either repaired in a shop or returned to the manufacturer for repair.

The microwave communication equipment consists of horn antennas, modulators) power supplies and TTL driver buffers. All of the equipment using solid state techniques has a life expectancy of at least fifteen years. One antenna is required for each lane. The 10 GHz transmission frequency dictates that the modulator and power supply be located as close to the antenna as possible. The antenna design is such that the modulator and power supply can be located within the antenna housing, thereby eliminating the need for additional weatherproof housings and simplifying maintenance. Servicing may be accomplished in the field by replacing the entire transmitter which will subsequently be repaired in a shop. A bucket truck would be required to service the pole mounted transmitter.

The optical communication equipment consists of laser stacks, laser pulsers, a power supply - including trigger circuits and beam shaping shades. Since the lasers are pulsed at a relatively low data rate, 10 KBs, transmission distance between the pulsers and laser stacks is not critical and the pulsers need not be located on the mast arm adjacent to the laser stacks. Locating the pulsers and power supplies in the pole mounted controller cabinet eliminates the need for an additional weatherproof enclosure to house the equipment and for a bucket truck to service the equipment. The power supply, trigger circuits and pulsars have a life expectancy of over fifteen years. The laser stacks have a life expectancy of in excess of 5 years. All of the equipment is modularized and can be serviced by the same maintenance personnel who service the route guidance controller. The only maintenance normally required is the cleaning of the laser stacks lenses. A bucket truck or similar vehicle used to service traffic signal heads is required for this task.

7.1.5 IVEG Equipment Cost

The procedure outlined in Appendix M has been used to estimate the cost of the IVEG equipment. These costs are summarized in Table 18.

TABLE 18. IVEG EQUIPMENT COST

Type of System	Vehicle Cost	Roadside Installation
Microwave	$60.05	$8,880
Optical	$60.78	$14,653

The microwave system's vehicle cost assumes a roof mounted antenna. If future testing, as discussed in Section 7.1.2.2.1, determines that the antenna can be incorporated into the control unit then the projected vehicle cost may be reduced to $54.35.

7.2 "CB-BASED" IVRG SYSTEM

In the following sections the technological requirements for implementing a "CB-Based" IVRG system are discussed, the findings of a human factors experiment to determine the ability of a motorist to handle verbally transmitted instructions are described and the cost of implementing such a system is presented.

7.2.1 CB Communication Technology

Under the concept of a "CB-based" IVRG system, route guidance information is provided to a motorist via a two-way voice communication link between the IVRG terminal and the vehicle. The communication link for this system consists of a terminal transmitter/receiver and antenna and a vehicle transmitter/receiver and antenna. In operation, the motorist states his present location and requests the route to a particular destination by voice transmission. The terminal operator selects an optimum route and provides the motorist with guidance information via voice transmission.

The terms "CB-based" IVRG system and "CB communication link" are used only to indicate a similarity between the operation of this type of IVRG system and present-day CB system (i.e., a two-way voice system with a broadcast radiation mode). The actual system differs from CB system operation in a number of respects. One difference is that an operating frequency on the order of 900 MHz is employed rather than the present 27 MHz range. Another difference is that a two channel IVRG link is proposed - one channel for vehicle-to-terminal tranmissions and one channel for terminal-to-vehicle transmissions. A third difference involves the use of repeaters to allow a single terminal to cover a large geographical area.

The characteristics of the CB communication link described in the following sections are dictated to a large extent by criteria which were specified for the link in Section 6.2.8, that is that the link be two-way, voice only, and operate in the vicinity of 900 MHz. A further criteria which was followed resulted from a tradeoff between system complexity and system cost. Emphasis was given to a simpler system where cost to the motorist is not significantly higher than current CB equipment costs.

7.2.1.1 Basic Configuration

The basic configuration of the CB-based IVRG link consists of a vehicle transmitter/receiver and antenna configured in a manner similar to present-day CB equipment, a manned control station from which guidance instructions are issued, and repeaters (transmitter/receiver/antenna) used as necessary to provide the desired range of coverage of the system.

Insofar as the motorist is concerned, the configuration and operation of the IVRG system is the same as a CB system. However, the communication link of the IVRG system should provide better service because of the different operating frequency (900 MHz), the restriction of channel access, and the use of repeaters.

7.2.1.2 Link Considerations

7.2.1.2.1 Equipment Capabilities

With present technology, the proposed 900 MHz Citizen's Band voice communications channel for use in IVRG applications is feasible and physically realizable with off-the-shelf components. The technical requirements of the transmitter, receiver, or the antenna are not a great deal more difficult to achieve at these frequencies than at 27 MHz. Police communications systems in the 800-900 MHz range are currently in operation in many metropolitan areas.

The transmitters for a 900 MHz CB IVRG system are expected to have requirements similar to the present 27 MHz CB transmitters. The power output level will most likely be in the 2 to 10 watt range, since additional power at these frequencies is not cost effective. Present 27 MHz CB transmitters are limited to 4 watts output power, however, the 900 MHz CB transmitter will probably be frequency modulated (FM) vs amplitude modulated (AM) as in the 27 MHz case. FM modulation reduces stability requirements of the transmitter and at the same time provides higher quality voice transmissions.

The receiver requirements for a 900 MHz CB IVRG system are similar to the present 27 MHz CB receiver in terms of sensitivity, selectivity and intermodulation. Other advantages of the 900 MHz band are that atmospheric and vehicle ignition noise are much less severe thereby improving voice reception and quality.

Antennas for use in the 900 MHz CB band are small, inexpensive, quarter-wavelength whips (approximately 4 inches (10 cm) long) or possibly higher performance 5/8 wavelength whips (approximately 8.2 inches (21 cm) long) and can therefore be mounted in almost any external location on the vehicle. Present 27 MHz CB antennas are much larger and more expensive to manufacture than the above antennas. Antennas for use in or near these frequencies are commercially available.

7.2.1.2.2 Radio Coverage

Reliable RF communication link distances for a 900 MHz system in an urban environment are difficult to accurately predict. With mobile equipment comprising a substantial part of an IVRG system, the calculations for link distances become less accurate primarily due to the shadowing effects of tall buildings and other tall structures typical of urban areas. Transmission paths between mobile and repeater stations can vary from a direct line-of-sight path to paths severely shadowed by large obstructions. Therefore certain isolated areas in a given urban area will be without coverage.

When a communications link is deployed in an environment containing reflecting objects and obstacles in or near the link path, link performance can be significantly affected by multipath and shadowing. Multipath is caused by signal reflection from surrounding objects (such as buildings, lamp posts or sign posts) which results in coupling between transmitter and receiver by more than one path. The amplitude and phase relationship of signals arriving at a receiver by more than one path may be such to cause signal cancellation. Shadowing can occur when an obstacle (such as a building, vehicle) comes between a transmitter antenna and receiving antenna. Thus both multipath and shadowing can cause fading of the signal at the receiver.

The specific effects of multipath and shadowing depend upon the operating frequency of the link, the link distance, the location of the link transmitter and receiver, directivity and orientation of the transmitting and receiving antennas, and the number, size, and shape of obstacles in the link environment, Although the general nature of multipath and shadowing is well understood, the specific effect of such factors is difficult to predict except for the most simplistic link environment. For a "mobile" IVRG communications link in a highly urbanized environment, the only practical method of assessing multipath and shadowing effects is from empirical data.

At an operating frequency of 900 MHz, multipath and shadowing have a definite impact on the performance of the "CB-based" IVRG system.

The best approach to minimizing multipath and shadowing effects for the "CB-based" IVRG system is by placing multiple terminals or repeaters throughout the area to be serviced by the system. The availability of more than one terminal-to-vehicle link significantly decreases the chances of link degradation due to fading.

The link distance obtainable with a 900 MHz CB system may not be sufficient for IVRG applications. For example, for the conditions of an urban environment where base and mobile antenna heights are 200 and 1.5 meters, respectively, and the system has a power output of 5 watts and a probability of 95% sentence articulation, the probable range of a reliable link is 6 miles (10 km)[54, 55]. For base station antenna heights of less than 200 meters the link distance is less. A greater area of coverage can be expected in an area relatively free of obstacles.

A need usually exists to extend the link distance beyond what can normally be achieved with a single base station. One method of extending the area of coverage is to increase transmitter power output. However, such an approach has several disadvantages.

The cost of providing transmitters with sufficient output power is prohibitive for CB type applications. Furthermore it is highly unlikely that FCC approval for the operation of such transmitters can be obtained. Shadowing will still restrict many receiving sites from obtaining adequate signal strength.

(54) Okumura, Y., Ohmori, E., Kawano, T., and FuKuda, K., "Field Strength and its Variability in VHF and UHF Land Mobile Service," Rev. Elec. Comm. Lab., 16, September - October 1968

(55) Jakes, Jr., W. C., "Microwave Mobile Communications," John Wiley Sons, New York

Another approach to extending link distance is through the use of multiple base stations. Depending upon the size and characteristics (i.e., urban, suburban, or rural) of the area to be served by the IVRG system, a number of relatively low power base stations providing overlapping coverage can be located throughout the area. This approach allows an area of any size to be covered by the addition of base stations. Shadowing is minimized since two or more base station-to-vehicle links is possible.

The use of multiple base stations also has disadvantages. One disadvantage is that a working space (i.e., an office) and an operator is required for each base station. This can be costly for a large service area where many base stations are required, Another disadvantage is that a motorist's request for route guidance can be received by more than one base station, This can create confusion as to which station should respond with appropriate guidance information, which may be compounded when the distances between vehicles prevent vehicle-to-vehicle links. Thus a motorist may attempt to communicate with a base station without knowing that other motorists are also asking for route guidance at the same time.

Rather than use multiple base stations, a single base station with repeaters may be used to extend the area of coverage. This concept is illustrated in Figure 33 which depicts a central base station operated in conjunction with several repeaters distributed throughout the area to be serviced. The repeater may be connected to the base station either through telephone lines or through the use of a repeater/base station microwave link. As an example of the operation of this system, consider User A and User B shown in the figure. User A, desiring route guidance instructions, normally activates and is connected to the control station through Repeater #1. User B, because of his proximity to both Repeater #4 and Repeater #5, activates both of these repeaters. A voting system at central control selects the repeater which provided the strongest User B signal, in this example Repeater #4. The use of a voting system allows the "best" vehicle-to-base station signal to be selected, thus improving the quality of received vehicle transmissions. It also identifies the repeater to be used for response to a motorist's request, and thus eliminates needless transmissions of route guidance information on other repeaters.

Neither the use of multiple-based stations or repeaters resolve the two basic problems associated with the use of CB radios for IVRG system application, the inability to accommodate simultaneous users on a given repeater and intentional channel abuse.

7.2.1.2.3 Multiuser Aspects

A 900 MHz CB-based IVRG system in a given metropolitan area is efficient only if the user can reliably communicate with the LVRG control operator without having to "wait in line" for other users to clear the channel, A single channel system obviously is not capable of handling simultaneous users in the same vicinity, thus a multiple channel system is required. The number of channels required depends upon geographical size of the area to be serviced, the traffic load through the service area, the complexity of street routing and the adequacy of signing, and the number of motorists with vehicle IVRG units. It is likely that the probable upper limit

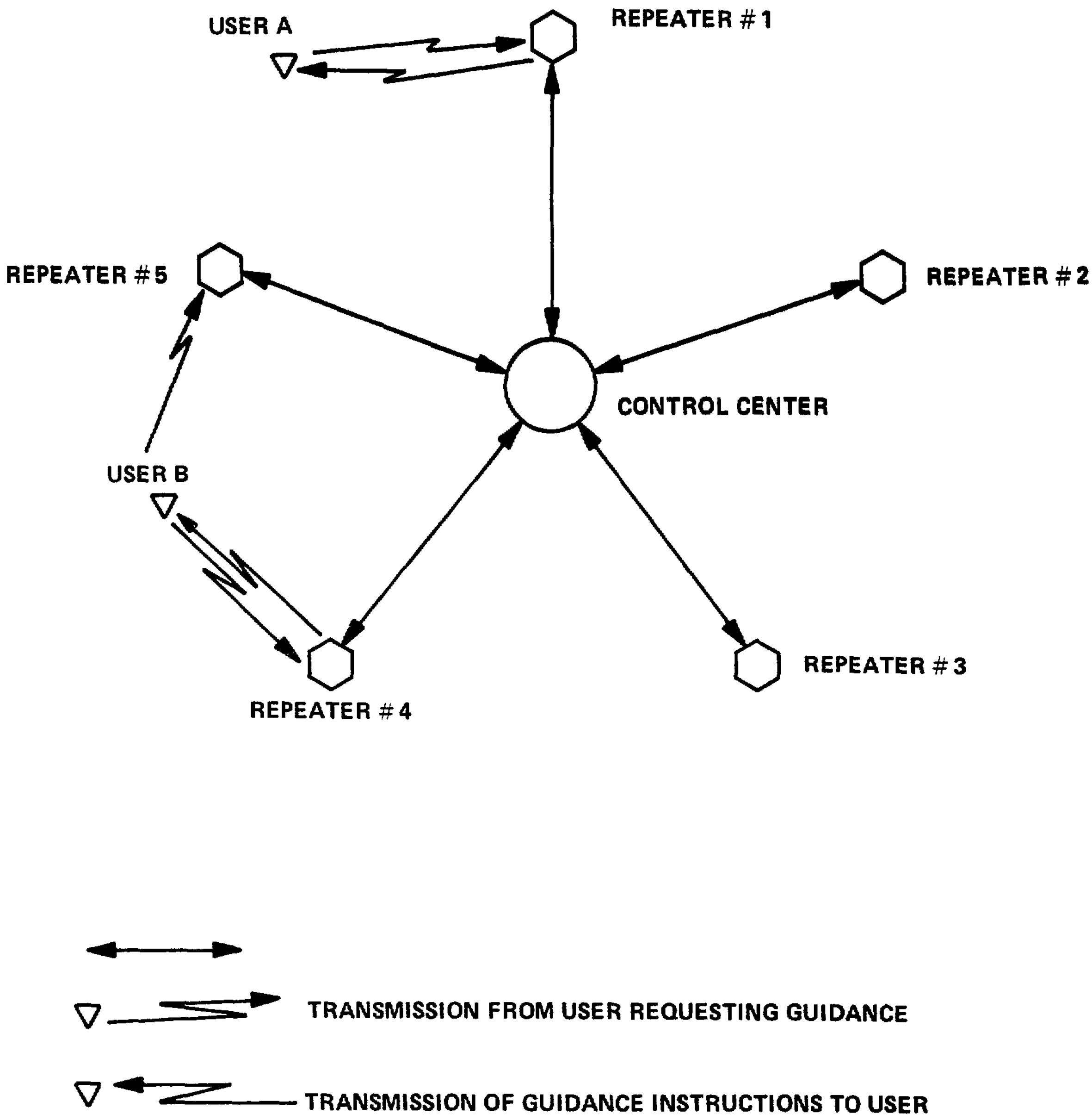


Figure 33. 900 MHz CB-Based IVRG System Handling Simultaneous Users

to the number of channels available precludes supplying many motorists with needed information.

Another serious problem to be considered in the design of a 900 MHz CB-based IVRG system is one that plagues the present 27 MHz Citizen's Band. The present CB band has a designated channel set aside by the FCC intended for emergency use only. There are, however, violators who freely use this emergency channel irrespective of the FCC regulations. This kind of channel abuse can create many problems for an IVRG system operating on a similar 900 MHz designated channel. Operators using the channel for personal conversation interfere with potential IVRG users and tie up the channel for valuable time.

The problem of channel abuse can be eliminated by creating an IVRG channel with different transmit and receive frequencies. The vehicle unit has only one receive channel. The vehicle transmitters do not have the capability to transmit on this frequency. Conversely, the vehicle units are capable of transmission to the IVRG repeaters, but not to other vehicles, Although this arrangement eliminates the channel abuse problem, it does not solve the problem of unintentional interference.

Both channel abuse and unintentional interference can be eliminated by combining a split-frequency IVRG channel, as described above, along with the capability of repeaters to transmit a "busy tone" while in use. The receiver voting system selects that repeater which provides the best signal from the motorist and once this signal is received, the IVRG repeaters broadcast a "busy tone" on the motorist's IVRG receive frequency. Thus, any motorist tuned to the IVRG channel near a busy repeater receives the busy signal until the motorist transmitting to the IVRG repeater completes transmission. The "busy tone" remains on until the IVRG controller begins transmission, at which time the voice of the controller takes over. Since the receiver voting system has already selected the "best" repeater station, the controller transmits on this repeater exclusively and all other repeaters identified as "in-use" by the receiver voting system continue with a busy signal until the controller completes message transmission. For a single split-frequency receive-transmit channel with busy signal capability, IVRG users must operate sequentially on a given repeater and they must not transmit during a busy signal on the IVRG frequency. At additional cost to the motorist, the CB units can be designed so that transmission on the IVRG frequency is "locked out" as long as the busy tone is in effect.

The advantages of a single split-frequency channel with busy tone capability are that channel abuse and unintentional interference problems are eliminated with a relatively simple system. The majdr disadvantage of this system is that simultaneous users cannot be accommodated on the same repeater and therefore users must "wait in line" for route guidance information.

By designating more than one split-frequency channel for IVRG use, the capability for handling more simultaneous users exists. The motorist selects an "open" IVRG channel for communications with the controller. The number of simultaneous users that can be accommodated are increased in proportion to the number of split-frequency IVRG channels. A system of this type requires more than one IVRG controller to handle the incoming calls at the IVRG control station.

A more sophisticated system that would automatically search for the "open" IVRG channel and handle numerous calls simultaneously can be designed similar to the Advanced Mobile Phone Service (AMPS) System 9 operating in Chicago(56), however,the cost of such a system is much more expensive.

7.2.1.3 Regulatory Considerations

As with the microwave IVRG system, it is difficult to speculate as to what action the FCC might take to provide channel space for a 900 MHz IVRG system. The radiation levels of the proposed 900 MHz vehicle, operator, and base station transmitters, would probably require the system to be licensed. It is also expected that the eligibility and requirements for licensing and operating this system falls under Part 10, Private Land Mobile Radio Services, of the FCC rules and regulations,

7.2.1.4 Operational Considerations

The major requirements for the successful operation of a CB-based IVRG system are the establishment of a reliable radio link and the use of operators within the central control station who have at their disposal the necessary road information for directing the motorist. It is equally important that the operators have an ability to verbally relay proper information to the motorist in an accurate and concise manner in order to minimize channel usage time.

The general concept of repeaters, receiver voting processor, and mobile-to-repeater voice links is well established as is the concept of split-frequency operation. Because all aspects of this CB-based IVRG system are well established, reliable operation may be achieved through proper system planning and good engineering judgement.

7.2.2 Human Factors Experiment

A limited scale experiment was performed to assess the ability of drivers to understand, remember, interpret,and act on guidance received from a system operator.

Instructions for reaching a destination were read by a test operator simulating the IVRG system operator in a CB-based IVRG system. Four subjects each driving the same four routes were used. All routes used major arterials exclusively, and were located in Nassau County, New York.

The experiment demonstrated that the subjects chosen were able to follow the audible instructions given and reach their destinations, but required an average of one call back to the "System Operator" for further instructions.

---

(56) Ehrlich, Nathan, "The Advanced Mobile Phone Service," IEEE Communications Magazine, March 1979

7.2.2.1 Design of Experiment

7.2.2.1.1 Subjects

As this experiment was conducted on a pilot scale rather than a full scale, only four subjects were used. The subjects were young (approx-imatley 25 years of age) men, all employed at Sperry. Two were college graduates, and the others currently attend college.

All subjects were unfamiliar with the details of the driving area.

Gatling, Reference (57), has found that younger people (25 years) demonstrate significantly more retention of auditory messages than elderly subjects (60 years and above), hence, the results of this experiment are probably somewhat biased in favor of a higher level of retention of information.

7.2.2.1.2 Routes and Driving Instructions

Four routes were chosen, in Nassau County, New York, and driving instructions were determined for each. The routes chosen are considered typical of those for which motorists would utilize the IVRG System, and are summarized on Table 19.

Major arterials were used exclusively in this experiment.

The number of information units, contained in each set of instructions is based on the Gatling criterion of Reference[57].

Routes chosen were test driven before the experiment began. It was quickly realized that signing in the test areas was inadequate. This required the instructions to contain additional information units to adequately describe the decision points.

7.2.2.1.3 Implementation

The experiment simulated in a reasonable fashion, the information transfer of a CB radio based IVRG System. The test operator sat in the rear seat of a late model full sized automobile and assumed the role of the IVRG System operator. He provided guidance to the test subject (driver).

On way to the first route, the test operator read a statement to the driver which described the operation of the IVRG System. Drivers were told that the purpose of the experiment was to test how well instructions which they received over the radio could be remembered and followed. They were directed to try to follow as well as they could by memory, but that they could “call back” for further directions if they so required. Location and direction of travel were required to be given by the drivers when calling back. The test operator then gave instructions from that point to the

(57) Gatling, F. P., “Auditory Message Studies for Route Diversion,” FHWA RD-75-73, June 1975

TABLE 19. HUMAN FACTORS EXPERIMENT ROUTE SUMMARY

Route Number	Starting Point	Destination	Typical Driving Time	Distance	Information Units
I	Long Island Expressway, East Bound Exit 37	Mid-Island Shopping Plaza in Hicksville	17 min.	8.7 miles	13
II	Hicksville Railroad Station	Nassau Veterans Memorial Coliseum	14 min.	5.4 miles	11
III	Roslyn Road at Jericho Turnpike (Rt 25)	Parking Lot for Nassau County Court House	4 min.	1.0 miles	7
IV	Jericho Turnpike, Garden City	Local Street (Earl St.) in Floral Park	7 min.	3.4 miles	10

Note: 1 mile = 1.6 KM

destination. A tape recorder was turned on and the subjects encouraged to "think out loud".

Directions for route number I were then given and immediately reinforced by giving an abridged version. At the conclusion of the route, the test operator directed the driver to the starting point of the next route, and the process continued for a total of four test routes. Table 20 indicates the time which it took to transmit each message to the motorist.

TABLE 20. TIME REQUIRED TO TRANSMIT MESSAGES TO MOTORIST (In Seconds)

Driver Route	A	B	C	D	Avg.
I		66 W.O. repeat 98 with repeat			66 98
II	46 73	48 70	40 59	41 59	44 65
III	35 37				35 57
IV	35 58				35 58
				Avg	45 seconds w/o repeat 70 seconds with repeat

7.2.2.2 Results

The data were examined and the results obtained are summarized in the following sections.

7.2.2.2.1 "Call Backs" and Information Retained

Table 21 shows the number of times each subject called back for further instructions during each run. Only three of these call-backs were made as the result of an error (i.e., missed turn) by the driver. For the majority of call backs, the drivers were on the correct route when they requested more information. The average number of call backs was found to be 0.94 per route.

TABLE 21. NUMBER OF CALL BACKS

Subject	Route Number			
	I	II	III	IV
A	2	2	0	2
B	2	1	0	1
C	0	1	0	1
D	1	1	0	1

Table 22 shows the number of information units successfully completed before the first time a call-back was made for each route that was run. The average number of information units completed was 6.25.

TABLE 22. NUMBER OF INFORMATION UNITS SUCCESSFULLY COMPLETED BEFORE CALL BACK

Subject	Route Number			
	I	II	III	IV
A	2	5	7	2
B	3	7	7	5
C	13	3	7	10
D	11	6	7	5

This latter result and the results of this experiment in general seem to indicate better performance than that given in Gatling's[57] results. For example, all four subjects remembered the seven information units of route number III (see Table 22), probably because in this route the drivers could actually see the Court l-louse (which was closely related to the destination) during the course of the experiment.

7.2.2.2.2 Errors and Stoppages

Table 23 shows the number of errors and stoppages occurring during the test runs. In all cases, the subjects recognized that they had made an error almost immediately and either called back for further instructions or recovered by themselves.

TABLE 23. NUMBER OF ERRORS AND STOPPAGES

Subject	Route Number			
	I	II	III	IV
A	1	0	0	0
B	1	0	0	1
C	2	2	0	0
D	0	0	0	0

The average time lost due to the errors is difficult to assess because of the experimental procedure used and variance in subject behavior. For example, one of the subjects preferred to try to work himself out of these situations and thus lost a considerable amount of time, whereas the others preferred to call back if they could not recover quickly. (See Section 7.2.2.3 for further comment on time lost).

7.2.2.2.3 Safety Considerations

Table 24 shows the number of erratic maneuvers made during the course of the experiment. The type of erratic maneuver involved in cutting across traffic lanes, the vehicle initially being located improperly for the turn.

TABLE 24. ERRATIC MANEUVERS

Subject	Number of Erratic Maneuvers
A	2
B	0
C	0
D	2

Two of these erratic maneuvers were made when further instructions were given close to a required turn and the subject was in the wrong lane. The other two occurred when the subject determined (without further instructions) that a turn was required but was in the wrong lane. This indicates indecision.

The test operator noticed that all subjects showed indecision while approaching a significant number of decision points. Although the subjects generally recovered soon enough to avoid the type of erratic maneuver described above, the indecision resulted in a slowing down in order to make their decision, sometimes impeding other traffic.

Based on the observations of the test operator and on the comments of several subjects, the major reason for the indecision was the lack of appropriate signing at major intersections. (Signing was also discussed in terms of instruction complexity in Section 7.2.2.1.2,)

7.2.2.3 Remarks

Usefulness of the CB based IVRG System was seriously affected by the lack of adequate signing throughout the test area.

- Excessive information had to be included in the instruction message to identify major aterials that have no signs.
- Indecision was present on the part of all drivers at major decision points, which in a large percentage of cases was due to the driver not being sure that the approaching intersection was, indeed, his decision point.

Erratic (i.e., hazardous) maneuvers sometimes occurred at decision points because:

- Recognition of a decision point was sometimes too late to prepare for a turn requiring a lane change.
- Further instructions from a call back were sometimes obtained too close to an intersection.

Although the pilot experiment sample size was small, the number of erratic maneuvers which were induced indicates that this type of system might actually induce accidents.

Although the effect on system performance due to errors or stoppages was small in this experiment, this was attributed to the immediate response of the "system operator" to a request by the driver for further information. In an actual system, the response is not immediate since the driver has to wait his turn before a response can be given thereby increasing the time lost, and decreasing the time saved benefit resulting from a successful run.

In Appendix N a Queueing analysis is presented to show the expected wait and service time before the motorist has been served. At a 50% load factor this time is 1.7 minutes while at a 90% load factor this time is 8.7 minutes.

Because each channel functions at a low message rate, use of a limited number of channels for IVRG will not significantly address the guidance demand in the larger Standard Metropolitan Statistical Area.

7.2.3 "CB-Based" Equipment

Table 25 summarizes the cost of a CB System to service a city the size of Rochester, N.Y. These costs are detailed in Appendix M.

The CB-based system incurs considerable annual operating costs, in addition to initial costs, due to its labor intensive nature.

TABLE 25. "CB-BASED" IVRG SYSTEM COSTS

	Initial Cost		Annual Cost	
Item	First Channel	Additional Channel	First Channel	Addition Channel
Fixed Site	$122,000	$53,400	$56,140	$46,960
Receiver	130	-	-	-

SECTION 8

BENEFIT COST STUDIES FOR IVRG IMPLEMENTATION

Benefit cost studies for in-vehicle route guidance systems have been conducted prior to this program. These studies have included the work of Armstrong(14), Favout(58) and the Japanese CAC team(30, 59). These studies have generally indicated favorable benefit cost relationships.

These previous studies have been based either on very simple benefit models or on detailed data in limited areas. The studies have generally not been based on the disaggregated needs models of the type developed in Section 5 nor do they generally reflect the probable deployment alternatives in an entire metropolitan area and the system efficiency models developed on this project.

Consequently, a benefit cost analysis was performed using a single metropolitan area as the basis for studying several deployment alternatives for the IVEG and the "CB-Based" systems. This section describes the basis for the study and the results which were obtained using the cost estimates presented in Section 7.

8.1 THE CASE STUDY SITE

The Rochester, New York metropolitan area was selected as the case study site. Candidate IVEG deployments were generated based on the street systems and demographic structure of the area. Table 26 describes statistical data used in the study.

The deployment plans considered included the City of Rochester and the nearby suburbs shown in items C and D of Table 26. These suburbs were selected for IVEG implementation on the basis of population density considerations. Figure 5, Section 7.1.1, is a map showing the boundaries of the most extensive candidate study area considered.

8.2 IVEG SYSTEM BENEFIT TO COST STUDIES

8.2.1 Deployment

Preliminary plans for two levels of IVEG deployment were developed for the Rochester area. SSM's previous knowledge of traffic volumes and route importance was used to plan the sections of highway to receive guidance treatment. The approach used to plan level 2 is described as follows:

------

(58) Favout, F.," Improving Urban Highway Transportation Through Electronic Route Guidance", Urban Transportation Innovation, Daniel Brand, ed. ASCE National Transportation Engineering Meeting, July 1970, Boston, Mass.

(59) Kobayashi, F., "Feasibility Study of Route Guidance System", Comprehensive Automobile Traffic Control System (unpublished)

TABLE 26. STUDY SITE DATA

A.	1979 Rochester SMSA population (Includes Monroe, Orleans, Wayne, Livingston Counties)	882,000
B.	Monroe County Population	709,000
C.	City of Rochester (in Monroe County)	265,000
D.	Nearby suburbs of Brighton, Chili, Gates, Greece, Henrietta, Irondequoit, Penfield, Perinton, Pittsford, Webster in Monroe county. IVRG suburban deployments were specified for these areas	378,000
E.	C + D =	643,000
F.	% Monroe County population in E	90.6%
G.	% SMSA population in E	72.9%
H.	Approximate number of vehicles registered in Monroe County in which IVRG may be installed	400,000
I.	Number of registered vehicles based in IVRG controlled areas (.906 x 400,000)	362,000

- An intensive guidance grid covering all major streets developed for the CBD (the area within the "inner expressway loop" of Figure 5).
- Guidance decision locations were included for all limited access highways within the study area.
- A guidance grid with an average guidance arterial spacing (based on a perfect grid geometry) of approximately .72 mile (1.2km) was developed in the remainder of the central city. If distances between intersections of guided arterials became excessive, additional guidance points were included.
- A moderate intensity suburban grid concentrating on radial flow but with reasonable-capability for circumferential flow was developed.

Level 1 deployment followed similar guidelines. CBD deployment was unchanged. Central city deployment was made more intensive, average guided arterial spacing was reduced to .5 mile (.8km), suburban deployment was made more intensive in addition to extending the limits of the guidance area in some locations.

In addition to these cases a third level of deployment was postulated. Unlike levels 1 and 2 which were established by synthesizing a realistic physical deployment based on traffic and guidance requirements, level 3 is a hypothetical variation of level 2 obtained through mathematical manipulation of the level 2 data base. Table 27 describes the characteristics for the various deployment levels.

TABLE 27. CHARACTERISTICS OF DEPLOYMENT LEVELS

	Level 1	Level 2	Level 3
Guidance decision locations	276	149	75
Instrumented approaches	1494	896	398
Average grid spacing in central city less CBD	.53 mile	.72 mile	1.02 mile
NOTE: 1 mile = 1.6 km			

8.2.2 Computation of Benefits

Models for analyzing the benefits of the IVEG system as a function of the geographic deployment of these systems were developed in Appendix C and described in Section 5. These models compute benefits in terms of excess distance and/or time reduced. For the benefit cost analysis, these excess reductions were converted to dollar values.

The following assumptions which are believed to be conservative were used to develop these dollar values:

- The value of motorist time was taken as $3.42 per hour per vehicle, a value used in recent years by the New York State Department of Transportation.

- The "value" of mileage saving was assumed to be based on the incremental. out of pocket costs saved by IVEG. At this writing a conservative estimate of these savings is $.07 per mi.

- No dollar values were attributed to such other benefits as commercial vehicle operator time savings, accident reduction benefits and reduction in highway maintenance costs. Although such benefits may be inferred through scaled projections of mileage saved, it is difficult to substantiate these figures with a high degree of confidence.

- Benefits were computed only for the static case and included enroute strategic, enroute terminal, and tactical benefits. Dynamic system benefits were not quantified.

The annual benefit equations used are described below:

o Enroute Strategic Benefit

$$\$ESB = E\left(.07M + 3.42\frac{M}{S}\right)$$

where M = excess mileage reduction (as a function of guidance arterial spacing) given by Figure 3.
S = average speed taken as 25.7 mph (41.4kmph)
E = communication efficiency of IVRG candidate

o Terminal Strategic Benefit

$$\$TSB = E\ (13.5)\ (TGE)\ (3.42)$$

13.5 is potential time saving from Table 6
TGE is terminal guidance efficiency (discussed in Section 5)

o Tactical Benefit

$$\$TTB = E\ (3.42)\ (4-1.1)\ (1-TGE)$$

Last term is discussed in Section 5

Total Annual Benefit = \$ESB + \$TSB + \$TTB

The value of E (system communication efficiency) was assumed as 0.9 for the IVEG system.

8.2.3 Computation of Costs

The system costs, presented in Table 28 are derived in Appendix M. The more expensive roof mounted antenna configuration has been assumed for the microwave approach.

TABLE 28. IVEG SYSTEM COST

Type of Equipment	Communications Microwave	Approach Optical
Vehicle	\$ 60	\$ 61
Roadside	\$8,800	\$14,653

8.2.4 Benefit Cost Analysis

The benefit model described in 8.2.2 was used in connection with the costs summarized in 8.2.3 to develop net benefits and benefit cost ratios for deployment level 2. Additional assumptions and parameters are identified in Table 29.

TABLE 29. BASIS FOR BENEFIT COST ANALYSIS COMPUTATIONS

Field equipment
0 Life 15 yrs. (no salvage value>
0 Interest rate - 10%
o Annual maintenance and repair at 10% of initial cost
Vehicle equipment
0 Life 10 yrs.
0 Interest rate - 10%
o Annual maintenance and repair at 5% of initial cost

In certain previous efforts[58] an implementation phasing relationship was introduced into the benefit cost analysis. This current analysis however, assumes a "steady state" condition for the following reasons:

- o It was assumed that if IVEG were to be introduced, it would become a permanent part of the highway information system. Thus an analysis treating a steady state benefit condition is more relevant for policy evaluation purposes as it represents the target condition and not the transient condition.

- o This analysis was performed with IVEG motorist equipment ownership fraction as a parameter. This would probably compound any errors made in the assumption of a particular motorist ownership phasing model.

The results are shown in Figures 34 and 35 for the microwave approach and Figures 36 and 37 for the optical approach.

Figure 34 shows that for a Level 1 microwave IVEG deployment scenario a positive benefit results when the penetration level exceeds 10%. For deployment levels 2 and 3 positive benefits accrue for lower penetration levels.

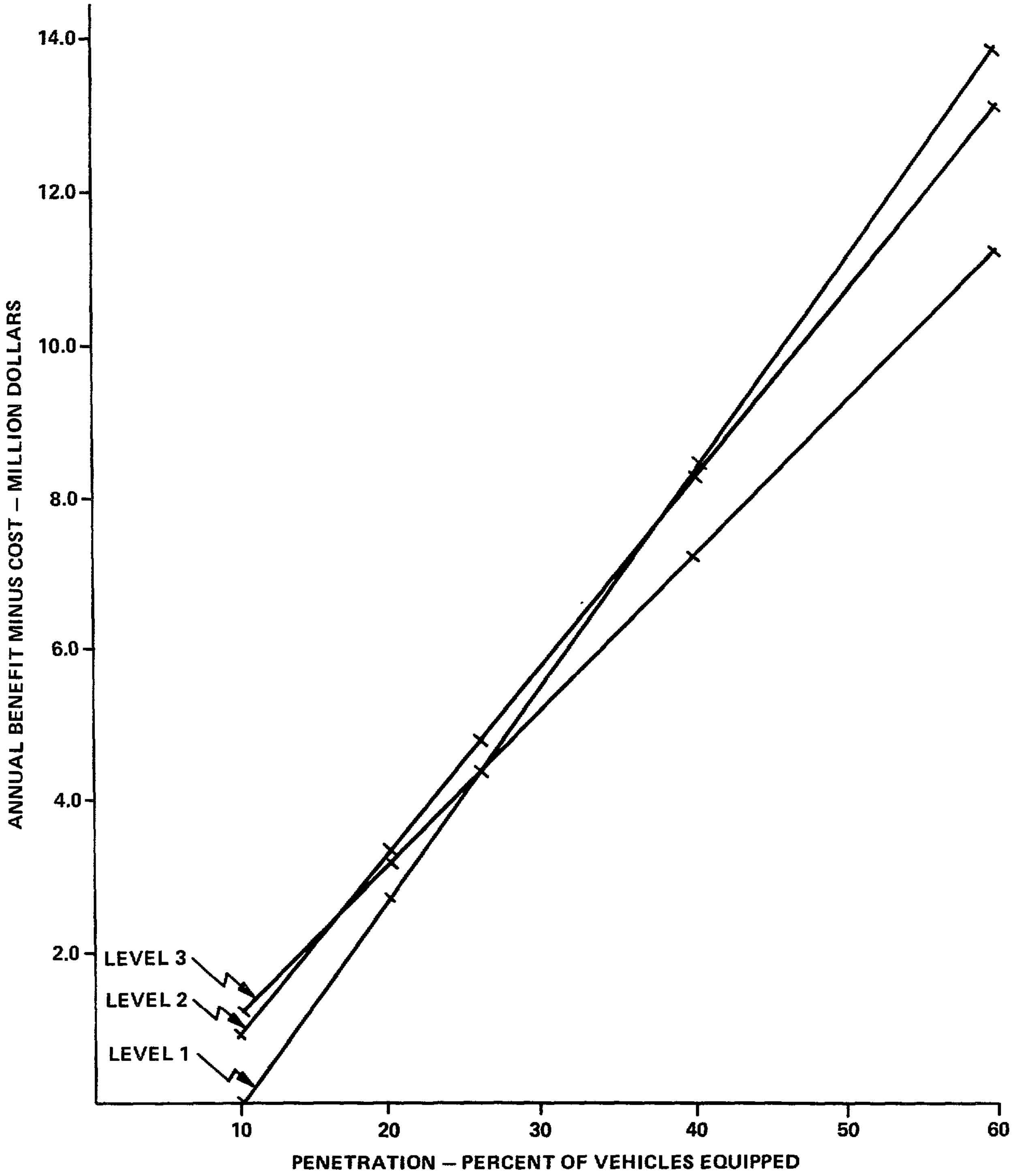


Figure 34. Benefit Minus Cost - Microwave System (Rochester N.Y. Urban Area)

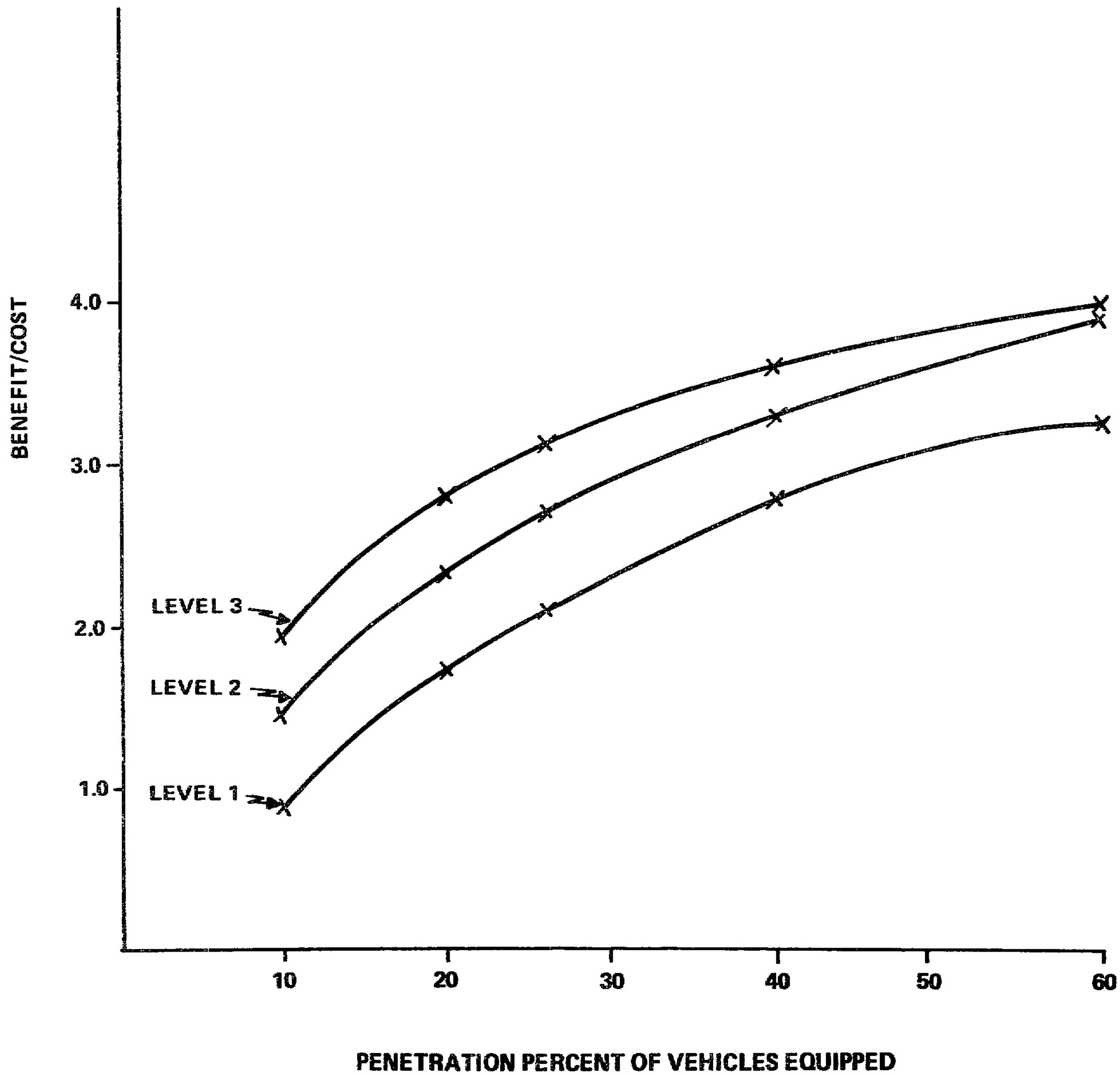


Figure 35. Benefit to Cost Ratio - Microwave System (Rochester N.Y. Urban Area)

Figure 36 shows that for a Level 1 optical IVEG deployment scenario a positive benefit results when the penetration level exceeds 14%. Positive benefits accrue for lower penetration levels for deployment levels 2 and 3.

8.2.5 National Benefits and Costs

The benefits that will accrue from the introduction of the IVEG system on a national basis has been computed utilizing the procedure presented in Appendix 0.

In arriving at the results, summarized in Table 30, the following assumptions were made:

- o The value of motorist time was taken as the $3.42 per hour per vehicle, a value used in Section 8.2.2 to compute the IVEG benefits for the Rochester scenarios.
- o A fleet fuel economy factor of 18 mpg was used in computing the fuel savings.
- o A penetration level of 17% was used. This is based upon an estimated selling price of $60 for the vehicle equipment, Section 7.1, and the results of the SSM marketing survey presented in Section 4.

The technology selected for the IVEG system only impacts the benefits to the extent that it influences the cost of the vehicle equipment and thus the percent of motorists willing to equip their vehicles.

TABLE 30. NATIONAL BENEFITS AND COSTS

BENEFITS	DEPLOYMENT LEVEL	OPTICAL	MICROWAVE
Travel Time - annual	1	$\$5.93 \times 10^8$	$\$5.93 \times 10^8$
	2	$\$5.31 \times 10^8$	$\$5.31 \times 10^8$
Fuel (annual gallons saved)	1	1.530×10^8	1.530×10^8
	2	1.260×10^8	1.260×10^8
COST			
Field Equipment	1	$\$4.894 \times 10^8$	$\$3.146 \times 10^8$
	2	$2.608 x 108	$\$1.677 \times 10^8$
Vehicle Equipment	1	$\$.943 \times 10^8$	$\$.932 \times 10^8$
	2	$\$.943 \times 10^8$	$\$.932 \times 10^8$

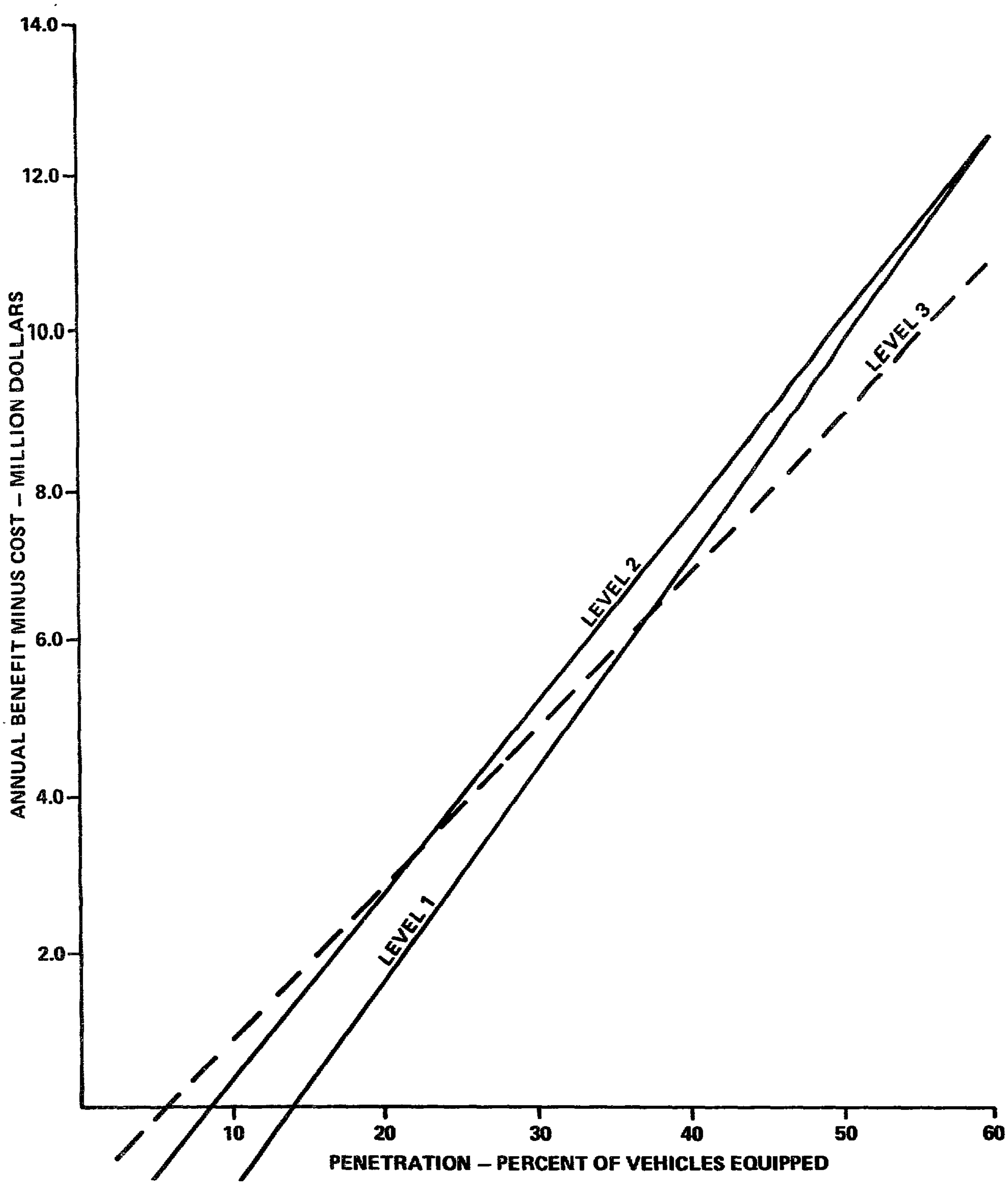


Figure 36. Benefit Minus Cost - Optical System (Rochester N.Y. Urban Area)

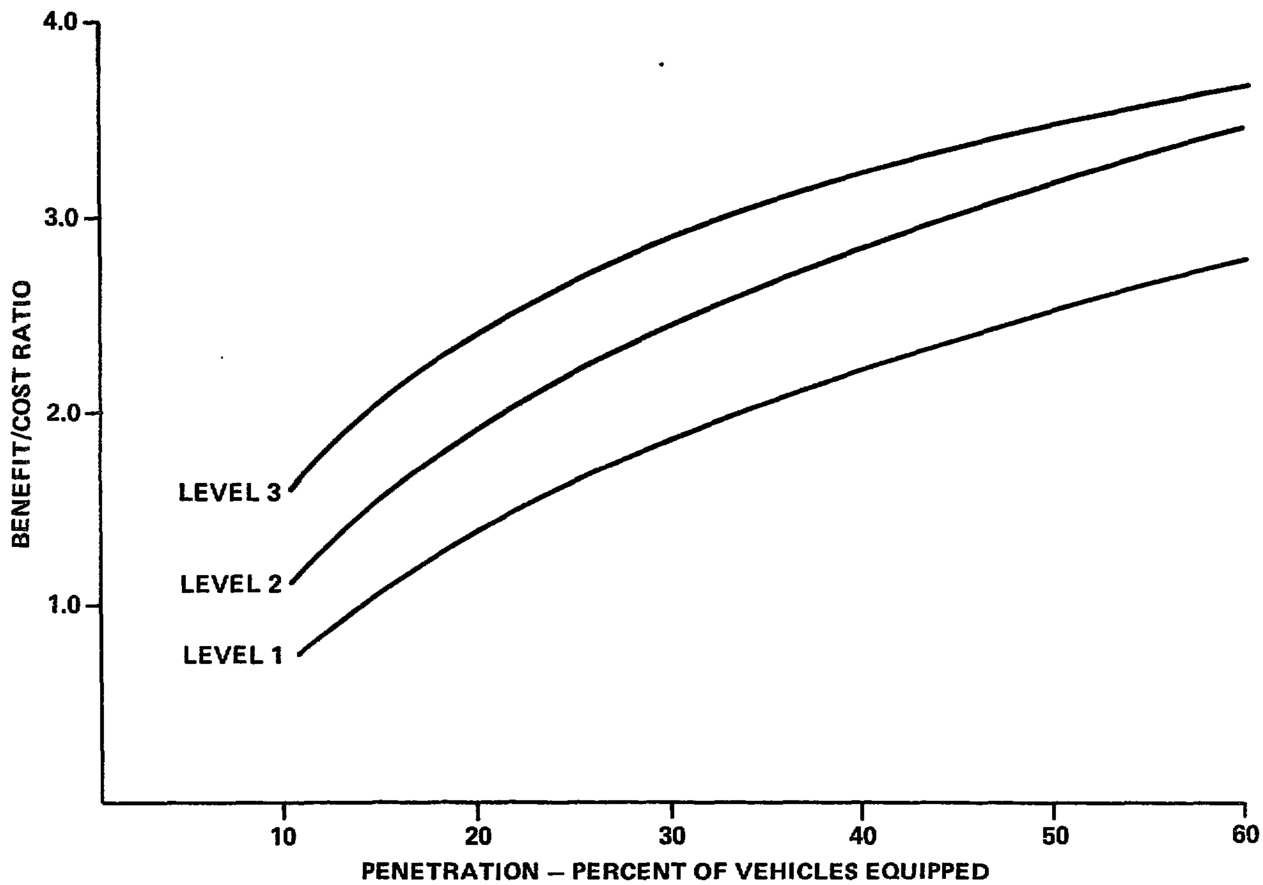


Figure 37. Benefit to Cost Ratio - Optical System (Rochester N.Y. Urban Area)

8.2.6 Relative Benefits of the Microwave and Optical IVEG Systems Approaches

Table 31 summarizes the characteristics of the IVEG system using the two communication technologies.

TABLE 31. COMPARISON OF OPTICAL AND MICROWAVE SYSTEMS

PARAMETER	OPTICAL	MICROWAVE
COMMUNICATIONS TECHNOLOGY		
Operating Frequency	Near Infrared	10 GHz
Modulation Technique	PPM	BFSK
Regulatory Requirements	None	FCC licensing probably required
Noise Immunity	Excellent	Excellent
ROADSIDE EQUIPMENT		
Antenna	Overhead distributed laser stack	Overhead corrugated horn one per lane
Controller - type	Microprocessor	Microprocessor
- quantity	One per approach	One per approach
Maintenance Normally Required	Cleaning of transmitter lens	None
Life Expectancy	Fifteen years - except for laser stack with life expectancy of over five years	Fifteen years
Installed Cost	$14,653	$8,800
VEHICLE EQUIPMENT		
Antenna - type	PIN detector	Microstrip
- location	Roof	Roof or dash
Control Unit		
Display	Vacuum fluorescent	Vacuum fluorescent
Destination encoder	Thumbwheel	Thumbwheel
Control logic	Custom MOS/LSI chip	Custom MOS/LSI chip
Design Life	Over ten years	Over ten years
Required Maintenance	Cleaning of antenna	None
Repair	Factory	Factory
Cost	$61	$60- roof mounted antenna $45- dash mounted antenna

Both systems utilize transmitters mounted over the roadway to eliminate shadowing and multipath interference. The optical system, operating in the near infrared spectrum, meets federal eye safety standards and does not require licensing. The microwave system, operating at 10 GHz, may require FCC licensing. Both approaches offer high noise immunity and very low error rates. Both systems utilize microprocessor based route guidance controllers. One controller is required for each guidance approach. The optical system requires periodic cleaning of the laser stack lenses. The laser stack, with an expected life of two years, requires replacement. The other optical candidate and microwave candidate equipment do not normally require maintenance. The installed cost of the microwave equipment is lower than the cost of the optical equipment.

The optical system utilizes a PIN diode detector, covered by an infrared filter, as the receiving antenna. This diode is mounted on the roof of the vehicle. The microwave system utilizes a microstrip antenna. The antenna will be mounted either on the roof of the vehicle or integrated into the dash mounted control unit. Future testing is required to determine the preferred location. Both systems utilize similar control units containing vacuum fluorescent displays, thumbwheel switches and custom MOS/LSI control logic. The vehicle equipment, for each candidate, has a design life of ten years. Normally, the only maintenance required for the optical candidate's vehicle equipment is the occasional cleaning of the receiver's filter. The microwave candidate's vehicle equipment does not normally require maintenance. The cost of the vehicle equipment for either approach with a roof mount is similar. The microwave vehicle equipment cost may be reduced somewhat with a dash mount.

8.2.7 Capability for Incremental Introduction

The IVEG approach has significant fixed costs as well as variable (per vehicle) costs. Because of this it is necessary to make a substantial municipal investment before it can provide a sufficiently ubiquitous service to motivate motorists to purchase the vehicle equipment. Figures 35 and 37 of Section 8.2.4 show, for example, that an initial system deployment at Level 3 would be cost effective if only 10% of the motorists furnished their vehicles with equipment. On reaching this fraction of the motorists, municipal investment could be increased to Level 2, and perhaps further if motorists increased their purchases in response to the improved service.

The most beneficial initial installations are likely to be in cities whose geometric street layout tends to be irregular, where traffic routings may require direction changes which might not be expected by strangers or by "local strangers", and where street names offer few clues to relative direction. Initial deployment for a moderate size city will likely feature a general guidance grid spacing of approximately 1 mile (1.6 km) within the central city with increased emphasis in the CBD and other major activity centers. Related freeway coverage will also be provided. Limited coverage might be provided for the higher density suburbs. As described earlier, a favorable motorist response could lead to reducing the guidance grid spacing in the central city in increments to perhaps 0.5 miles (.8 km) and increased penetration in the suburban areas.

When a number of metropolitan areas have made installations, extension to the intercity Interstate Highway network might be appropriate.

8.3 "CB BASED" IVRG SYSTEM BENEFIT TO COST STUDIES

8.3.1 Computation of Benefits

A benefit model for the system may be postulated as follows:

$BPOHPO = N*C*T*($MT)

where

$BPOHPO is the benefits in dollars per operational hour per operator

N is the number of guidance messages per hour

C is the compliance; that is the probability that the motorist follows the message

T is the average travel time saved per message

$MT is the dollar value of motorist time

Based on data from the human factors experiment, Section 7.2.2, as well as other research, the following set of assumptions provides a probable upper limit on the performance expected:

- The average time per message is taken as 45 seconds.
- An additional 8 seconds per message is provided for message queue management and motorist recognition by the system operator. This is postulated on the basis of a leased telephone interconnect. If a switched telephone line system is used an additional delay of several seconds is incurred.
- The probability of the motorist arriving at the destination(57) is 50% based on any single message.
- The average time saved by a communication which results in successful guidance is 8.67 minutes.
- The value of the motorists time is $3.42/hr/veh.

Thus the maximum number of messages an operator may handle per hour, N, is-.

$$N = \frac{3600 \text{ sec/hr}}{(45 + 8) \text{ see/message}} = 67.9 \text{ messages per hour}$$

$$\$BPOHPO = (67.9)\,(.5)\,\frac{8.61}{60}\,(3.42) = \$15.10 \text{ per operational hour per operator}$$

This benefit value is, of course, based on a 100% time utilization of the system by the public, and therefore represents an upper limit.

If it is assumed that only a limited number of channels will be available in major metropolitan areas, an excess of basic demand over supply will probably occur if the system is perceived by the motorist to provide useful information. A utilization factor of 100% would, however, imply excessive message queuing and therefore poor system accessibility by the motorist. Therefore, for the purpose of benefit assessment a time utilization factor of 90% was assumed and benefits per operational channel hour were therefore estimated as .9 x 15.10 = $13.59.

8.3.2 Benefit Cost Analysis

Benefit cost analysis techniques were used to evaluate the system. The Rochester, N.Y. scenarios used for the IVEG systems were retained for comparison purposes.

The annualized system cost is the sum of the fixed facility costs (paid for by government agencies) and vehicle equipment costs paid for by the owner.

Table 48, Appendix M, summarizes the fixed site costs for the Rochester, N Y. scenario where it is estimated that ten repeaters are required to provide the coverage.

Table 32 summarizes the benefit and costs using the models and benefit and cost figures. The assumption shows that an unfavorable benefit/cost ratio is obtained for this labor intensive candidate. The computation assumes that the vehicle equipment is not charged to the IVRG program (on the basis that it will probably be a multipurpose instrument whose cost may be charged to other functions). An even less favorable ratio is obtained if the equipment is charged to the IVRG program.

TABLE 32. CB SYSTEM BENEFITS AND COSTS

			(Rochester Scenario)	
	Annual Benefit B	Annual cost C	Net Benefit B-C	Ratio B/C
One Dedicated CB Channel	$ 65,957	$ 82,052	(16,095)	.80
Two Dedicated CB Channels	$131,914	$140,353	(8,439)	.94

SECTION 9

CONCLUSION

The IVRG system concept based on IVEG, a one way data transmission to the vehicle, whether by means of optical communications or microwave communication has the following attractive properties:

- o Both approaches appear to be technically feasible. There appear to be no unresolvable licensing or health and safety problems.

- o The system can provide most of the route guidance information required by motorists in urban areas and on the rural limited access highway systems. Substantial savings in motorist driving time and fuel usage result,

- o Benefit cost analysis shows good net benefits and good benefit cost ratios providing in vehicle equipment cost is sufficiently low. It appears that the vehicle equipment cost for appropriate demand generation is within a range which is technically feasible.

The principal negative factors are that the system, in a given urban area, requires a fairly complete installation before it can become useful and attractive to motorists, Although an incremental implementation approach such as described in Section 8.2.7 can assist in staging the program, the initial outlay by the jurisdiction is high nevertheless (the magnitude of the cost may be a large fraction of the annual highway TIP budget for an MPO), In this respect it resembles such projects as a new computer traffic control system. A consensus and commitment by the community is required (it is assumed that federal aid funding would be available as for other highway projects).

In summary the approach appears to be sound but the funding requirements for operational implementations are substantial.

At the outset of the program it was hoped that there might be an alternative system which would be introduced as a scaled down installation of more modest cost and which, in time, could grow to a full scale system. The CB based approach was investigated with this issue in mind, however even a modest installation by a jurisdiction of such a system is not deemed desirable because:

- o The low message rate of each channel and limited number of channels severely restricts the ability of system to significantly address guidance demands in the larger Standard Metropolitan Statistical Areas and limits growth potential.

- o The labor intensive nature of this system results in high operating cost and consequentially an unfavorable benefit to cost ratio at all installation levels.

It should be noted that if such a facility could be operated with volunteer personnel, then the benefit cost ratio would improve significantly.

As a result of the study it was determined that IVEG or a system which performs similar functions at comparable costs is cost effective and would result in substantial fuel and time savings. It is recommended that a phased program be planned which would further refine the design, cost, market assessment and public acceptance issues. Such a program is outlined in Table 33.

TABLE 33. POSSIBLE FUTURE IVRG PROGRAM PLAN

PHASE 1 FEASIBILITY AND BASIC SYSTEM SELECTION (ACCOMPLISHED BY CURRENT STUDY)

OBJECTIVE: Identify the need for guidance and define system(s) which satisfy this need significantly and cost effectively

PHASE 2 IN-DEPTH DESIGN, DEMONSTRATION AND MARKET ANALYSIS

OBJECTIVES:
- o Refine the design, select optical or microwave technology
- o Reduce vehicle equipment cost
- o Demonstrate technical feasibility with a limited installation site
- o Establish cost benchmarks
- o Perform in-depth market analysis to assess features required and cost vs market share

PHASE 3. LARGE SCALE OPERATIONAL FIELD TEST

OBJECTIVES:
- o Quantitative benefit assessment
- o Public acceptance assessment
- o Technical assessment
- o Market reassessment

For this test choose an irregular older city (150,000-400,000 POP), preferably with a computerized TCS for "dynamic" guidance. Initial 1 mile (1.6 km) deployment.

APPENDIX A

IVRG HISTORICAL ANALYSIS

Five of the six systems discussed in Section 2 have been selected for detailed analysis. The five systems are ERGS, DAIR, CACS, ALI and AWARE. ARI was not analyzed further because its objectives do not closely parallel the objectives of this contract and because of significant differences in the ownership structure and control of broadcast stations between the U.S. and West Germany.

A two dimensional matrix comparison technique has been prepared to compare the features of these systems. The features have been grouped into four tables labeled "TABLE 34 - IVRG System Functions, Performance and Installation Status"; "TABLE 35 - IVRG Driver's Interface"; "TABLE 36 - IVRG Communication Systems" and "TABLE 37 - IVRG Equipment Configurations". These tables have been divided into separate sections for the Directional Subsystem {directional guidance function) and for the Advisory Subsystem (Advisory Radio, Visual Signs) to facilitate a consistent comparison of the IVRG systems. If a parameter is not applicable to a specific system, the abbreviation "NA" (Not Applicable) is placed in the table.

TABLE 34. IVRG SYSTEM FUNCTIONS, PERFORMANCE AND INSTALLATION STATUS

	ERGS (U.S.)	DAIR (U.S.)	CAC (JAPAN)	ALI (GERMANY)
Functional Subsystems	DG	DG, AR, VS, MA	DG, AR, VS, VL, VMS	DG, VS
Task Distribution-in-vehicle	display, destination encoding	display, route encoding	display, destination encoding	display, destination encoding
- roadside	destination decoding, route calculation and parameter storage	sign message and location transmission	travel time storage route calculation, AR modulation destination decoding	destination decoding, route calculation and parameter storage
- control center	**N.A.**	**N.A.**	travel time calculation AR message generation	parameter calculation
Development Status	prototype testing I969	prototype 1966	under test at 100 intersections	under test on 100km of autobahn
Directional Subsystem				
Best Route Selection Parameter	**travel time**	**travel time**	travel time	travel time
Dynamic Response Capability	**No but can be expanded to**	**N.O.**	Yes	Yes

AR - advisory radio
DC - directional guidance
MA - motorist aid
VL - vehicle location
VMS - Variable message sign
vs - Visual sign

N.A. - Not applicable
N.O. - data not readily obtainable

TABLE 34. IVRG SYSTEM FUNCTIONS, PERFORMANCE AND INSTALLATION STATUS (Continued)

	ERGS (U.S.)	DAIR (U.S.)	CAC (JAPAN)	ALI (GERMANY)	AWARE (G.B.)
Directional Subsystem (Cont)					
Frequency of Parameter Update	N.A.	N.A.	15 Min or Emergency	Emergency	N.A.
Advisory Subsystem					
Frequency of Update	N.A.	As Required	As Required	As Required	As Required
Priority Message Capability	N.A.	No	Yes	N.A.	Yes

AR - advisory radio
DG - directional guidance
MA - motorist aid
VL - vehicle location
VMS - Variable message sign
VS - Visual sign

N.A. - Not applicable
N.O. - Data not readily obtainable

TABLE 35. IVRG DRIVER'S INTERFACE

	ERGS	DAIR	CACS	ALI	AWARE
Directional Subsystem					
Destination Input	5 letter thumbwheel	punchcard	7 digit thumbwheel	7 digit via keyboard	N.A.
Display type	visual-back illuminated	visual	visual - LCD or plasma	visual - LCD	N.A.
Display format	Alphanumeric, symbolic	Alphanumeric	Alphanumeric, symbolic	Alphanumeric, symbolic	N.A.
Display Orientation	Intersection	Intersection	Intersection	Autobahn interchange	N.A.
Advisory Subsystem					
Display type	N.A.	Audio, Visual	Audio, Visual	Audio, Visual	Visual
Display format	N.A.	Alphanumeric	Alphanumeric	Alphanumeric	Alphanumeric

N.A. - Not applicable

TABLE 36. IVRG COMMUNICATION

	ERGS	DAIR (Note 1)	CACS (Note 2)	ALI	AWARE
Directional Subsystem					
Multivehicle Capability	16 lanes of traffic	Yes	16 Lanes of traffic	Yes	N.A.
Medium: vehicle - roadside	Radio	Magnetic field	Radio	Radio	N.A.
Roadside Central	N.A.	N.A.	Wire	Wire	N.A.
Transmission: vehicle - roadside	Duplex	Simplex	Duplex	Duplex	N.A.
roadside - central	N.A.	N.A.	Duplex	Duplex	N.A.
Baseband: vehicle - roadside	Digital	Digital	Digital	Digital	N.A.
roadside - central	N.A.	N.A.	Digital	Digital TDM	N.A.
Frequency: vehicle - roadside	Trigger - 230 KHZ, data - 170 KHZ	N.A.	172.8 KHZ/ 105.6 KHZ	92.36 KHZ/ 138.5 KHZ	N.A.
roadside - central	N.A.	N.A.	Not available	600 bps	N.A.
Modulation technique: vehicle - roadside	ASK	N/S	PSK	FSK	N.A.
roadside - central	N.A.	N.A.	N.O.	FSK	N.A.

N.A. Not applicable
N.O. Data not readily obtainable
Note 1: DAIR visual sign subsystem uses same techniques as directional subsystem.
Note 2: CACS visual sign subsystem uses same techniques as directional subsystem except it uses a simplex channel to the vehicle.
Note 3: 1" = 2.5 cm
1' = .3 m

TABLE 36. IVRG COMMUNICATION (Continued)

	ERGS	DAIR (Note 1)	CACS (Note 2)	ALI	AWARE
Directional Subsystem (Cont)					
Data Rate Vehicle - roadside	2 Kbs	N.A.	4.8 Kbs	4.9 Kbs	N.A.
Antenna vehicle	Trigger 1' x 7'; data 5' x 8' - 1 turn loop	coil 1500 turns 2" x 32"	30 Turn loop 100mm x 50mm	20cm-ferrite rod in mudguard	N.A.
roadway	Trigger 1"x 27"; data 6" x 35" 1 turn loop	N.A.	1 Turn loop 2.5m x 3m	2 Turn loop 2m x 25m	N.A.
Coupling Distance	14"	10"	45cm	N.O.	N.A.
Receiver Sensitivity Vehicle	140mv	1.8 gauss	.3mv	N.O.	N.A.
Roadside	70mv	N.A.	.5mv	N.O.	N.A.
Transmitter Power Vehicle	2W	N.A.	N.O.	N.O.	N.A.
Roadside	2W	N.A.	N.O.	N.O.	N.A.
Licensing	FCC Part 15	N.A.	N.O.	N.O.	N.A.

N.A. Not applicable
N.O. Data not readily obtainable

Note 1: DAIR visual sign subsystem uses same techniques as directional subsystem.
Note 2: CACS visual sign subsystem uses same techniques as directional subsystem except it uses a simplex channel to the vehicle.
Note 3: 1" = 2.5 cm
1' = .3 m

TABLE 36. IVRG COMMUNICATION (Continued)

	ERGS	DAIR (Note 1)	CACS (Note 2)	ALI	AWARE
Advisory Subsystem					
Medium: roadside to vehicle	N.A.	Radio	Radio	Radio	Radio
central to roadside	N.A.	Wire	Wire	Wire	Wire
Baseband: roadside to vehicle	N.A.	Audio	Audio	Digital	Digital
central to roadside	N.A.	Audio	Audio	Digital	Digital
Frequency: roadside to vehicle	N.A.	CB-27MHZ	Broadcast	92.36 KHZ/ 138.5 KHZ	150KHZ
central to roadside	N.A.	DC/Audio	Audio	600 BPS	N.O.
Modulation Technique: roadside to vehicle	N.A.	AM	FM	FSK	Pulse width
central to roadside	N.A.	DC/Baseband	Baseband	FSK	TDM
Antenna: vehicle	N.A.	Whip (CB)	Whip (car radio)	Ferrite	Loop (undervehicle)
roadside	N.A.	None	leaky coax (1300')	Loop	Loop

N.A. Not applicable
N.O. Data not readily obtainable

Note 1: DAIR visual sign subsystem uses same techniques as directional subsystem.
Note 2: CACS visual sign subsystem uses same techniques as directional subsystem except it uses a simplex channel to the vehicle.
Note 3: 1" = 2.5 cm
1' = .3 m

TABLE 36. IVRG COMMUNICATION (Continued)

	ERGS	DAIR (Note 1)	CACS (Note 2)	ALI	AWARE
Advisory Subsystem (Cont)					
Range: roadside to vehicle	N.A.	1000'	1300'	N.O.	coupling distance
Receiver Sensitivity: vehicle	N.A.	5MV Standard CB	Standard broadcast	N.O.	N.O.
Transmitter Power: roadside	N.A.	500mw	N.O.	N.O.	N.O.
Licensing Requirements	N.A.	FCC Part 89	N.O.	N.O.	N.O.

N.A. Not applicable
N.O. Data not readily obtainable

Note 1: DAIR visual sign subsystem uses same techniques as directional subsystem.
Note 2: CACS visual sign subsystem uses same techniques as directional subsystem except it uses a simplex channel to the vehicle.
Note 3: 1" = 2.5 cm
1' = .3 m

TABLE 37. IVRG HARDWARE

	ERGS	DAIR	CACS	ALI	AWARE
Directional Subsystem					
Control Center - Geographical Distribution	N.A.	N.A.	Regional	Regional	N.A.
Equipment Complement	N.A.	N.A.	computer, display, CRT, control console, modems	computer, modems	N.A.
Maintainability	N.A.	N.A.	N.O.	N.O.	N.A.
Reliability	N.A.	N.A.	N.O.	N.O.	N.A.
Cost	N.A.	N.A.	$1M (Note 1)	N.O.	N.A.
Roadside - Geographical Distribution	intersections	intersections	intersections	each junction and exit	N.A.
Equipment Complement	decoder, processor, memory transceiver, loop antenna	magnetic trap	decoder, processor, memory modem transceiver, antennas	decoder, processor, memory transceiver antenna	N.A.
Ease of Installation	fair	good	fair	fair	N.A.
Maintainability	fair	excellent	N.O.	N.O.	N.A.
Reliability	fair	excellent	N.O.	N.O.	N.A.

Note 1 - CACS cost under Directional Subsystem includes cost for advisory subsystem
N.A. - Not applicable
N.O. - Data not readily available

TABLE 37. IVRG HARDWARE (Continued)

	ERGS	DAIR	CACS	ALI	AWARE
Directional Subsystem (Cont)					
Invulnerability	good	excellent	good	good	N.A.
Cost	N.O.	N.O.	$54K (Note 1)	N.O.	N.A.
Vehicle - Equipment Complement	display, thumbwheel switch, transceiver, loop antenna	card vendor display, processor magsensor, decoder	display, thumbwheel transceiver	display, keyboard, transceiver ferrite antenna	N.A.
Ease of Installation	poor	poor	good	good	N.A.
Retrofit capability	poor	poor	fair	fair	N.A.
Maintainability	fair	poor	fair	fair	N.A.
Reliability	N.O.	N.O.	High	N.O.	N.A.
Cost	N.O.	N.O.	$162 (Note 1)	$115	N.A.
Advisory Subsystem					
Control Center - Geographical Distribution	N.A.	25 to 30 miles	Regional	Regional	5 for all of Britain

Note: 1 mile = 1.6 km
Note 1 - CACS' cost under Directional Subsystem includes cost for advisory subsystem
N.A. - Not applicable
N.O. - Data not readily available

TABLE 37. IVRG HARDWARE (Continued)

	ERGS	DAIR	CACS	ALI	AWARE
Advisory Subsystem (Cont)					
Equipment Complement	N.A.	Message selection console, microphone	Microphone, tape, library, message selection console	Part of directional guidance subsystem	Computer, TTY, modem
Maintainability	N.A.	Good	Fair	N.O.	Fair
Reliability	N.A.	Very good	Good	N.O.	Good
Cost	N.A.	N.O.	(see directional subsystem)	N.O.	$40,000
Roadside - Geographical Distribution	N.A.	critical locations	critical locations	directional guidance locations	rural - 2 miles urban - 1/2 mile
Equipment Complement	N.A.	modulator, transmitter, playback, message selector	modulator, transmitter, leaky coax antenna	same as directional guidance	Loop antenna, transmitter, communications module
Maintainability	N.A.	Fair	Very good	N.O.	Good
Reliability	N.A.	Fair	Very good	N.O.	Good

Note: 1 mile = 1.6 km
N.A. - Not applicable
N.O. - Data not readily available

TABLE 37. IVRG HARDWARE (Continued)

	ERGS	DAIR	CACS	ALI	AWARE
Advisory Subsystem (Cont)					
Ease of Installation	N.A.	Good	Fair	Fair	Fair
Invulnerability	N.A.	Fair	Good	Good	Good
Cost	N.A.	N.O.	(see directional subsystem)	N.O.	Not available
Vehicle -					
Equipment Complement	N.A.	CB radio, magsensor, adapter	car radio, radio adapter	Same as directional subsystem	Loop antenna, decoder, display
Ease of Installation	N.A.	Excellent	Excellent	Good	Poor
Retrofit capability	N.A.	Very good - requires CB	Excellent	Fair	Poor
Maintainability	N.A.	Good	Good	Fair	N.O.
Reliability	N.A.	Good	Good	N.O.	N.O.
Power Consumption	N.A.	N.O.	Not available	N.O.	N.O.
Cost	N.A.	N.O.	(see directional subsystem)	(see directional subsystem)	$50 - excluding display

N.A. - Not applicable
N.O. - Data not readily available

APPENDIX B

MARKET ACCEPTANCE SURVEY

Prior to the award of the contract, Sperry Systems Management conducted an attitude preference survey to determine motorist attitudes towards an IVRG package. Survey forms (Table 38), were distributed to motorists in several geographic areas. These areas were Miami, Florida, Atlanta, Georgia, Great Neck, N.Y., and Arlington, Reston and Fairfax, Virginia.

The data for the economic demand curves was drawn from the responses to questions 10, 11, 12 and 13. The respondent was asked what he would be willing to pay for a particular type of IVRG package. (There were four different packages offered,thus the four questions.)

For each question the numbers of positive responses to each of the five proposed price brackets were tabulated and represented with bar graphs. The positive responses to each price bracket were broken down by geographic origin. This was represented by color coding sections of the bars in proportion to geographic contribution.

Though 136 surveys were tabulated, each question did not receive 136 responses. Therefore, for each question, the percentages of positive responses to the proposed price brackets were calculated on the basis of total actual responses to that question.

For each IVRG package demand curve, the data points were placed to represent the total percentage of respondents who were willing to pay at least the price indicated. There fore, a point placed at the 36 $ mark would represent the percentage of positive responses the 36-75 $ bracket received plus the percentages the 76-150 $ and above 150 $ brackets received.

TABLE 38. MARKET SURVEY FORM

SPERRY SYSTEMS MANAGEMENT

TRAFFIC & TRANSPORTATION GROUP

Introduction

A system for improving information for the motorist and communication with him is currently under consideration. We are studying the requirements for such a system and we would appreciate your helping us, and perhaps yourself, by answering the questions on the attached pages. These questions are intended to help us determine the extent of the demand for systems of this type.

The types of systems under consideration would make use of equipment in the vehicle which would be purchased by the vehicle owner. Additional equipment external to the vehicle would be supplied and maintained by the appropriate highway authority. The equipment could be transferred if a new car were to be purchased.

We envision that the systems would be used on everyday trips of moderate length such as journeys to work, as well as long range vacation or visiting type trips.

The systems relate principally to providing the motorist with two types of services. The first, called route guidance would assist the motorist to select the best route to his destination, possibly taking into account all major traffic and weather problems. The second, called emergency services would allow the motorist to communicate with the authorities in the event of vehicle breakdown, accident, or other problems.

The system might use a car mounted version of the type of small keyboard found on miniature calculators. The driver would insert a destination by means of a code similar to a zip code.

TABLE 38. MARKET SURVEY FORM (Continued)

0 QUESTIONS ABOUT YOUR TRANSPORTATION NEEDS AND YOUR CARS

1. Do you drive yourself to work:

_____YES (even if you only drive once or twice a week)

_____NO

2. How many vacation or other trips do you make per year which take you 50 miles or more from your home?

_____O-4 trips

_____5 to 10 trips

_____more than 10 trips

3. How many cars does your family own?

_____1 car

_____2 cars

_____more than 2 cars

4. Do you have an AM only radio in the car which you drive to work?

_____YES

_____NO

5. Do you have an AM-M radio in the car which you drive to work?

_____YES

_____NO

6. Do you have a CB (Citizens Band) set in the car which you drive to work?

_____YES

_____NO

TABLE 38. MARKET SURVEY FORM (Continued)

o QUESTIONS ABOUT THE TYPE OF IMPROVED INFORMATIONAL SERVICES WHICH YOU AS A MOTORIST MIGHT DESIRE

	VERY IMPORTANT	MODERATELY IMPORTANT	LESS IMPORTANT	NOT IMPORTANT
Several possible services which the motorist might receive in his vehicle are briefly described below. Please indicate your evaluation of the importance of each service in the appropriate space.				
7. Information to provide a correct routing to your destination.				
8. Carefully prepared and timely information which will route you to your destination in the fastest way taking traffic and weather conditions into account.				
9. Capability of being able to communicate with the police by voice from inside the vehicle in the event of an emergency, vehicle breakdown, accident, etc.				

TABLE 38. MARKET SURVEY FORM (Continued)

o QUESTIONS ON THE PRICE WHICH YOU WOULD BE WILLING TO PAY

What would you be willing to pay for the vehicle equipment to provide the following capabilities (check appropriate space)	1 Nothing	2 Less than $35	3 Between $36 and $75	4 Between $76 and $150	5 Over $150
10. Routing to destination (see question 7).					
11. Destination routing with traffic and weather considerations (see question 8).					
12. Emergency service communication (see question 9).					
13. Functions described in questions 10, 11, and 12.					

o WHAT OTHER FUNCTIONS, IF ANY, WOULD YOU DESIRE IF THEY COULD BE ACCOMMODATED AT MODERATE ADDITIONAL COST. CHECK THOSE DESIRED.

15. _____ Motorist service information (food, gas, lodgings)

16. _____ Toll cost information

17: _____ Information on parking availability in difficult areas

18. _____ Other (write in)

APPENDIX C

MODELS FOR ESTIMATING IVRG BENEFITS

In this appendix models are developed for estimating the quantifiable benefits for an IVRG system which provides guidance at certain specified locations called guidance points.

C-1 MODEL FOR ESTIMATING ENROUTE STRATEGIC GUIDANCE BENEFITS FOR IVRG

Although many urban areas have irregular street networks, it is convenient to analyze the concept of a simple, regular network to quantify, to a first approximation, the benefit of route guidance as a function of route spacing. Thus in Figure 38, L is the spacing between parallel guidance routes. Guidance is assumed to be provided to the intersection of those guidance routes which are closest to the destination. x and y are the coordinates of the destination relative to the coordinate origin (the coordinate origin is taken as that guidance intersection which is closest to the destination). It is thus assumed that the guidance system will guide to the XY origin for those destinations in the region labelled A, B, C, and D in Figure 38. If the destination is in region B, such guidance information will not lead to an excess. However, if the destination is in region D, the guidance will cause the motorist to overshoot, or to develop excesses in both the X and Y directions. Consider a destination in region D. The excess travel in the X direction which may result due to the system's granularity is given by

$$\bar{\epsilon}_x = \int_o^{L/2} x\, p(x)\, dx \qquad (1)$$

where p (x) is the probability of the location of the destination along X. For a homogeneous distribution of destinations

$$p(x) = 1/L \qquad (2)$$

Substituting (2) into (1) and evaluating yields

$$\bar{\epsilon}_x = L/8 \qquad (3)$$

Similarly $\bar{\epsilon}_y = L/8$ (4)

and the total excess in region D is

$$\bar{\epsilon}_x + \bar{\epsilon}_y = L/4$$

- - - - -

*Such a structure is, of course, typical of many major U.S. metropolitan areas

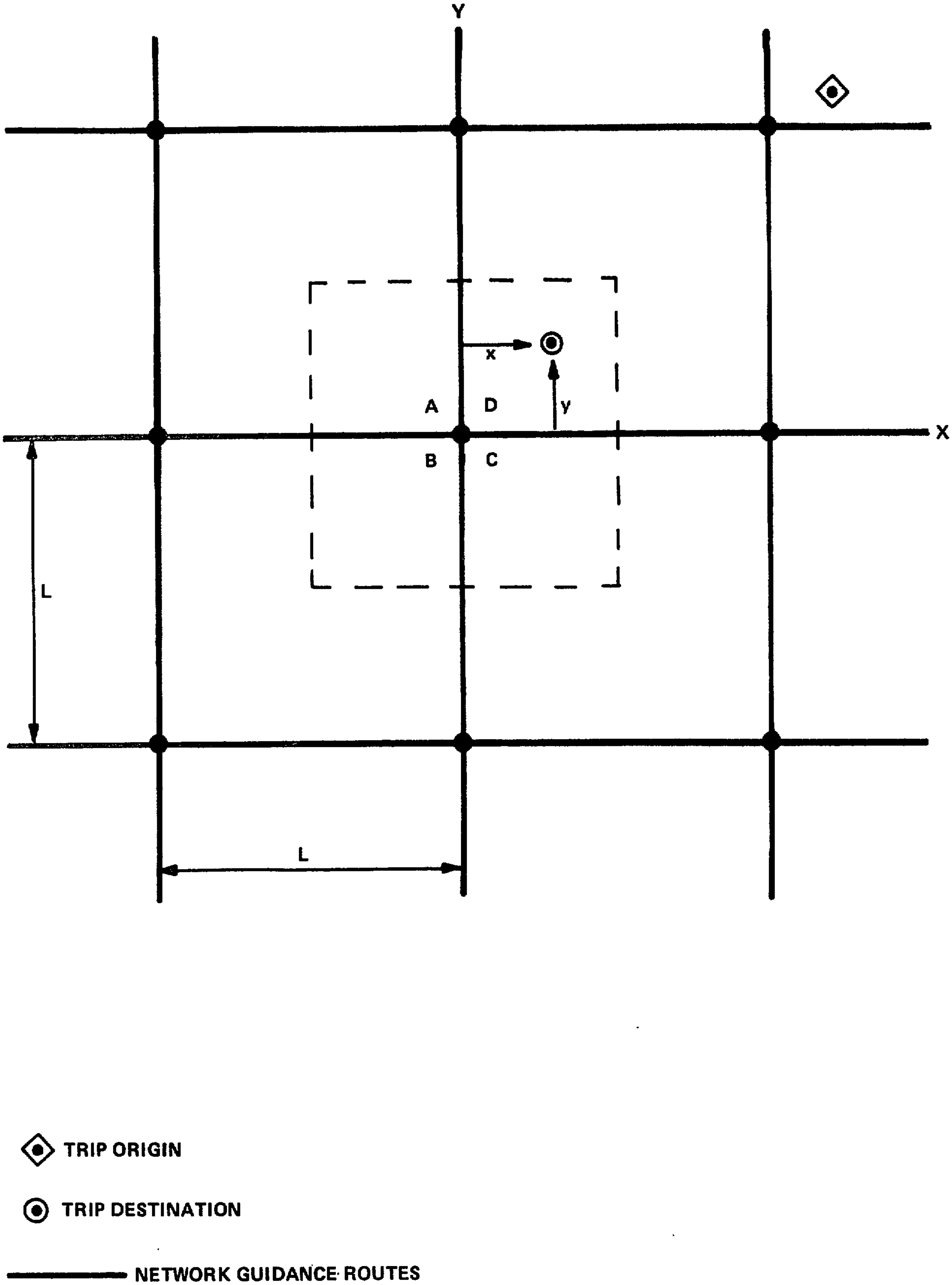


Figure 38. Network Geometry for Analysis of Excess Travel

In region A the excess is only in the Y direction ($\bar{\epsilon}_y$) while in region C the excess is only in the X direction. Summing all of the excesses for the four regions yields

$$\bar{\epsilon} = L/2 \qquad (5)$$

C-2 MODEL FOR ESTIMATING TERMINAL STRATEGIC BENEFITS

Consider that in a subregion of the urban area there are g guidance points, each of which may serve as a "destination" which the motorist may command (a surrogate for the true destination). Let the area of the subregion be As. The area served by each guidance termination location then is

$$A_g = \frac{A_s}{g}$$

where g is the number of guidance termination locations in the area.

A conservative model to express the search time required as a result of being guided closer to the destination than for the unguided case can be postulated, based on simple search theory, as proportional to the ratio of the respective search areas in the guided and unguided cases. Thus if TEg is the residual time excess with IVRG, TE_{tot} is the total excess (before guidance), and if 4 square miles is taken as the unguided search area (based on Gordon and Woods[15]):

$$\frac{TE_g}{TE_{tot}} = \frac{A_g}{4} = \frac{A_s}{4_g}$$, where A_s is expressed in square miles.

Benefit of IVRG = $TE_{tot} - TE_g = TE_{tot} \left(\frac{4g - A_s}{4g} \right)$

Terminal guidance efficiency of IVRG is TGE = $\frac{TE_{tot} - TE_g}{TE_{tot}} = \frac{4_g - A_s}{4_g}$ *

------

* TGE = $\frac{10.36g - A_s}{10.36g}$, when A_s is expressed in square kilometers

C-3 MODEL FOR ESTIMATING TACTICAL GUIDANCE BENEFITS FOR IVRG

Referring to Table 5 the tactical errors reduced by the guidance system will include the first three highway facility categories (72.5%) and a portion of the fourth category (distributor and minor streets). The reduction of fourth category errors may be assumed to follow the same type of search theory formulation as was employed for modeling the strategic terminal guidance errors. Thus, if ET is the magnitude of the tactical excess without IVRG the residual tactical excess when an IVRG is used is

$$RET = .275 \, (ET) \, (1-TGE)$$

where TGE is the terminal guidance efficiency (Section 3) and the benefit of guidance is

$$BET = (1-0275) \, (1-TGE) \, ET$$

Using the appropriate value of ET from Table 6 (4 hours per year per vehicle) yields

$$BET = 4 - 1.1 \, (1-TGE) \text{ in hours per vehicle per year}$$

APPENDIX D

USE OF LORAN BASED SYSTEMS IN IVRG

If radio based navigation systems such as Loran could be used in connection with in-vehicle equipment, the implementation of such a system would involve very little cost for municipally owned equipment. Thus, a study to assess the feasibility of such an approach for IVRG was made,

Several proposals have recent1y been advanced to utilize Loran-C as a land vehicle locating system(60, 61, 62). A system using Loran would obtain position in the vehicle and would generate guidance commands by comparison of position with desired destination.

Loran-C is a hyperbolic radio navigation system operated and maintained in the U.S. by the Coast Guard. This system allows airborne marine and terrestral users equipped with Loran receivers to determine their positions. Loran is an acronym for Long Range Navigation. Transmitters located at numerous sites around the world, transmit groups of eight or nine Loran-C pulses at a carrier frequency of 100KHZ. These transmitters are organized into chains of three or more transmitters with one transmitter in each chain designated as a “master” and the others as “slaves”. The “slaves” are synchronized to the “master”, transmitting its pulses a fixed time after the “master” transmits. The receiver measures the time difference (TD) between the arrival of the “master” and each of the two “slaves”. The locus of all points having the same difference in arrival time is a hyperbola and hence the term hyperbolic navigation system. In Loran these hyberbolas are designated as “lines of position” (LOP). The intersection of two LOP’s locates the position of the user.

Since the Loran receiver provides TD, and not an absolute position, a means has to be provided to execute this conversion. In the IVRG application the conversion would be directly to guidance instructions according to a look up table stored in the receiver. The table is a matrix of TDs and possible destination codes. With the two TDs and the direction of change in TDs (increasing or decreasing) measured, the position and direction of travel is theoretically known and the appropriate instruction can be read from the table according to the destination code set by the user and displayed. Since

-----

(60) “Loran-C Conceptual Analysis”, DOT-HS-801-952, Contract No. DOT-HS-5-01234; July 1976, Final Report; U.S. DOT, NHTSA, Washington, D.C.

(61) Blood, B.E., Klein B.W.A.; “Experiments on Four Different Techniques for Automatically Locating Land Vehicles - A Summary of Results,” Report No. LJMTA-MA-06-0041-77-2; U.S. DOT Transportation Systems Center, Cambridge, MA 02142

(62) Williams, D.R., Chatterjee, A. Wegmann, F.J., "Tennessee Experience with Loran-C "November 1978. Department of Civil Engineering, The University of Tennessee, Knoxville, Tenn.

commercial Loran receivers utilizing microprocessors are being introduced the search of the table can be combined with the TD calculation process.

Several problems would, however, have to be overcome before Loran could be utilized for IVRG. These include system coverage, positional accuracy, equipment cost and dynamic capability.

In 1974 Loran-C was designated by the U.S. Government as the primary navigation system in the coastal conference zone. While by 1980 coverage is to be provided for about 2/3 of the land area of the contiguous states[63] several large metropolitan areas including Denver, phoenix and Tucson will not be covered. An additional three to five stations would be required for national coverage. Loran was tested as an AVL candidate by UMTA[61] $a Philadelphia. This study showed that coverage problems exist in the vicinity of high rise structures where the signals are severely attenuated possibly precluding TD measurements. In the Philadelphia study several areas had to be provided with augmentors, very low power transmitters that simulate Loran transmitters, to fill in the gaps. These transmitters were mounted on utility poles[61]. Since the benefits from IVRG would primarily accumulate in urban areas, the need to provide local augmentors in part reduces the principal benefit of Loran in the IVRG application - the elimination of roadside equipment.

The positional accuracy of Loran C is a function of the geometry of the Loran grid. If two LOPs intersect at right angles the positional error is less sensitive to a TD error than if the LOPs are sharply skewed. Current receiver designs provide a 2o accuracy (95% of the readings are within this number) under conditions of unfavorable geometry of 1400 feet (427m)[63]. The Philadelphia tests had a 2o of 325 ft. (99m) in low rise areas[61], with higher errors in high rise areas. Most of this error is, however repeatable, being caused by such factors as high rise structures and power lines. These repeatable errors can be eliminated by conducting Loran surveys. Prior to the generation of the position table Loran TD measurements would be made at all guidance points. These TD readings, rather than the predicted reading, would be used in the matrix. This is, however, a costly process and would have to be repeated when new structures or power lines are erected. Another problem is ambiguity. It is possible that two points can have the same TD as a result of phase shifts introduced by buildings or power lines. This ambiguity can only be resolved by augmenting the Loran with a form of dead reckoning. Non-repeatable errors is another type of positional error. These errors caused by seasonally related changes in ground wave conductivity results in different TD measurements at different times. These terrestrial effects are only recently being investigated but it'is expected to be in the order of from 50 feet (15m) to 300 feet (91m) 2o[63] - inadequate for IVRG applications.

Loran information is basically positional information. The development of guidance signals requires not only position but some knowledge of direction. In a Loran based system this might be inferred from past positional information. For example,at a particular location a "guidance table" stored in the vehicle's computer would combine Loran generated information on present position and past position and compare it to desired

------

(63) Goldsmith, A., "Department of Transportation National Plan for Navigation" DOT-TST-18-4, November 1977, Department of Transportation, Washington, D.C.

destination. The guidance table is developed by pre-correlating these quantities. Storage requirements for such a table for the Chicago scenario described in Section 7.1.1 would exceed 1 million bytes.

The cost of the in-vehicle Loran guidance unit is quite high. It has been estimated that the cost of a Loran-C receiver with coordinate conversion would be between $600 and $900 in quantities of 100,000[60]. The cost of the memory requirement for the guidance tables would be a minimum of several hundred dollars additional using current technology. Future technology advances may reduce this figure significantly.

It is recommended that a Loran based IVRG concept not be considered for IVRG for the following reasons:

1. Current Loran accuracy is not high enough in portions of urban areas to be suitable. The cost of local calibration and maintenance of the calibration to achieve the requisite accuracy is high and may not be operationally practicable. In addition, there is no assurance that the requisite accuracy will, in any case be achieved. Furthermore, performance is different in the various metropolitan areas and in different parts of metropolitan areas.

2. Vehicle equipment costs are currently sufficiently high to limit potential ownership to a very small fraction of vehicle owners. Although technology advances which result in lower costs are likely, the timing and extent of these cost reductions are uncertain.

3. Loran-C - IVRG systems do not have the dynamic guidance capability of other techniques. Systems using roadside guidance equipment have the inherent capability of being modified into a dynamic system where the routing instructions are changed in response to changing traffic patterns. In a Loran-C -1VRG system all guidance fnformation is contained in the vehicle equipment and no capability for traffic based updates is possible.

4. The guidance tables are specific to an area. Thus the system cannot be used in other areas without a hardware change. The practicality of this is marginal and the marketability of this concept is questionable.

5. Because this system requires the use of past as well as current position, it is no longer a "state determined" system. It thus becomes subject to special problems resulting from possible motorist deviation from the guided path. In addition it may be quite difficult to work out a scheme which can provide proper "initial conditions". Feasible solutions might not be available for these special problems.

APPENDIX E

COMPUTATION OF BEAM INTERCEPT TIME FOR MICROWAVE CANDIDATE

From Figure 10 Section 7.1.2.2.1, it can be shown that the intercept time, T_i, bears the following relationship to the antenna beamwidths, β_t and β_r, and vehicle velocity, V,

$$T_i = T_D\,(\beta_t,\beta_r)/V \qquad (1)$$

where $T_D\,(\beta_t,\,\beta_r)$ is the intercept distance as a function of antenna beamwidths. The intercept distance is found to be the following:

$$T_D = 4h\left[\frac{\tan\frac{\beta_t}{2}\cdot\tan\frac{\beta_r}{2}}{\tan\frac{\beta_t}{2}+\tan\frac{\beta_r}{2}}\right] \qquad (2)$$

where h is the antenna separation in meters ($h = h_1 - h_2$), β_t is the transmitter antenna beamwidth, and β_r is the receiver antenna beamwidth. Combining equations 1 and 2, the intercept time in milliseconds can be expressed as:

$$T_i = \frac{1.44 \times 10^4\left(\tan\frac{\beta_t}{2}\cdot\tan\frac{\beta_r}{2}\right)}{V\left(\tan\frac{\beta_t}{2}+\tan\frac{\beta_r}{2}\right)}$$

where V is in km/hr, h is in meters, and the angles are as defined previously. As an example calculation, with the following assumptions:

$h = 14$ feet (4.25m)

$\beta_t = \beta_r = 16$ degrees

$V = 62$ mph (100km/hr)

T_i is equal to 43.0 msec

APPENDIX F

DESIGN OF AN ELECTROMAGNETIC HORN ANTENNA

Figure 39 gives information for the design of an electromagnetic horn having a specified gain and the shortest possible length.

The length L_1 is defined as:

$$L_1 = L - (a/2A) - b/2B$$

where a is the wide dimension of the waveguide in the H-plane, B is the dimension of the waveguide in the E-plane, and L, A, and B are the dimensions shown in Figure 39.

If $L \geq A^2/2$ where A is the longer aperture dimension, the gain (Reference[(64)]) is defined as:

$$G = 10AB/\lambda^2$$

The 3 dB beamwidth in the E-plane is given by:

$$\beta_E = 51\ \lambda/B \text{ degrees}$$

and the 3 dB beamwidth in the H-plane is given by:

$$\beta_H = 70\ \lambda/A \text{ degrees}$$

where E is the electric field vector and H is the magnetic field vector. For example, if a 16 degree beamwidth in both E and H planes is desired, the corresponding values for dimensions B and A would be approximately 3.8 in. (95mm) and 5.2 in. (13mm) respectively. Figure 40 gives experimentally determined horn antenna lengths as a function of flare angle and 3 dB beamwidth. The flare angles, θ_o, ϕ_o are defined as:

$$\theta_o = \tan^{-1} B/2L$$

$$\phi_o = \tan^{-1} A/2L$$

where L, A and B are as defined in Figure 39. Thus, from Figure 40, it is determined that a length of approximately 5 wavelengths (6 inches (150mm) at 10.06 GHz), will yield E-plane and H-plane beamwidths of 14 and 17 degrees respectively.

- - - - -

(64) Kraus, J.D., "Antennas", McGraw-Hill, New York

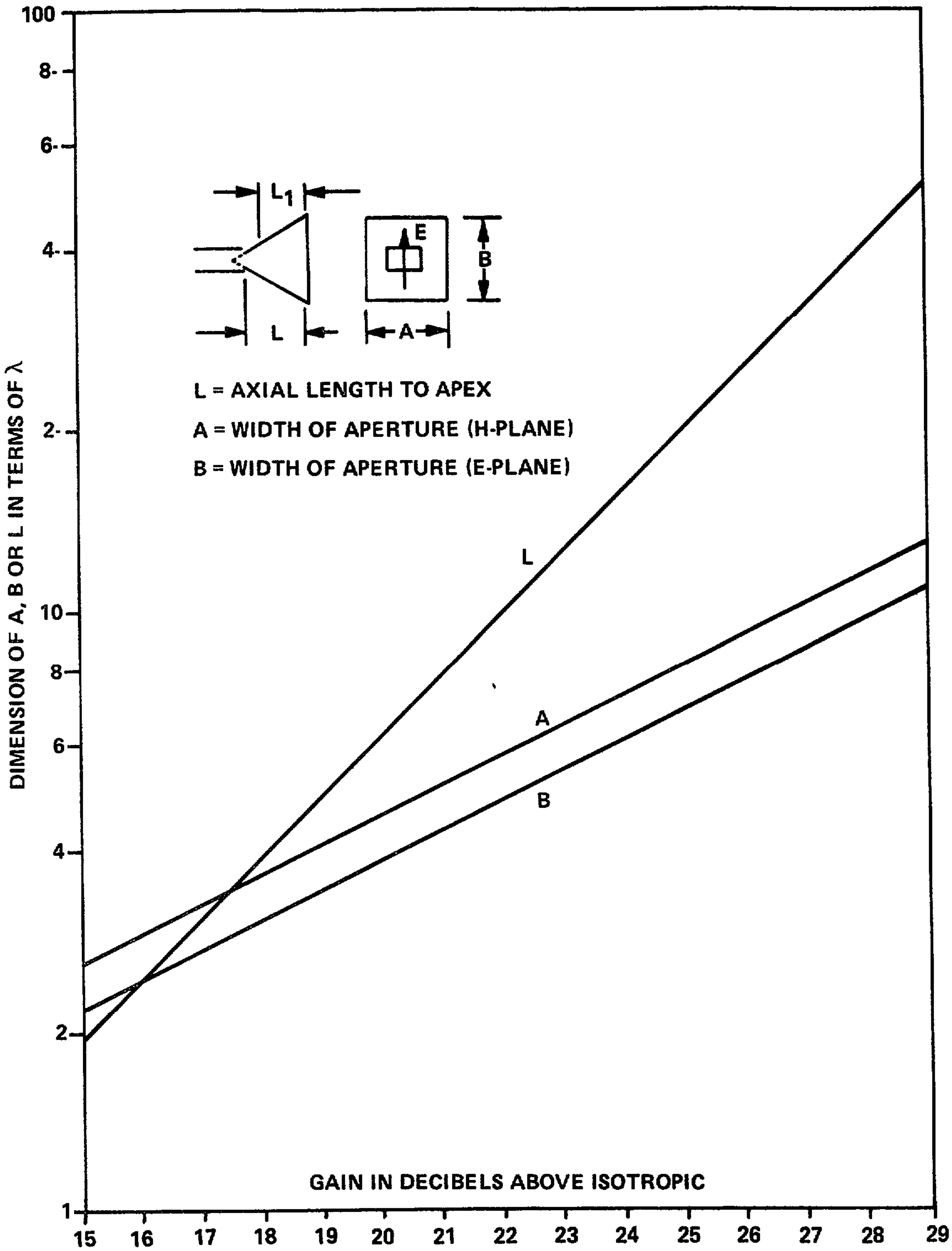


Figure 39. Design Data for the Shortest Possible Electromagnetic Horn Antenna

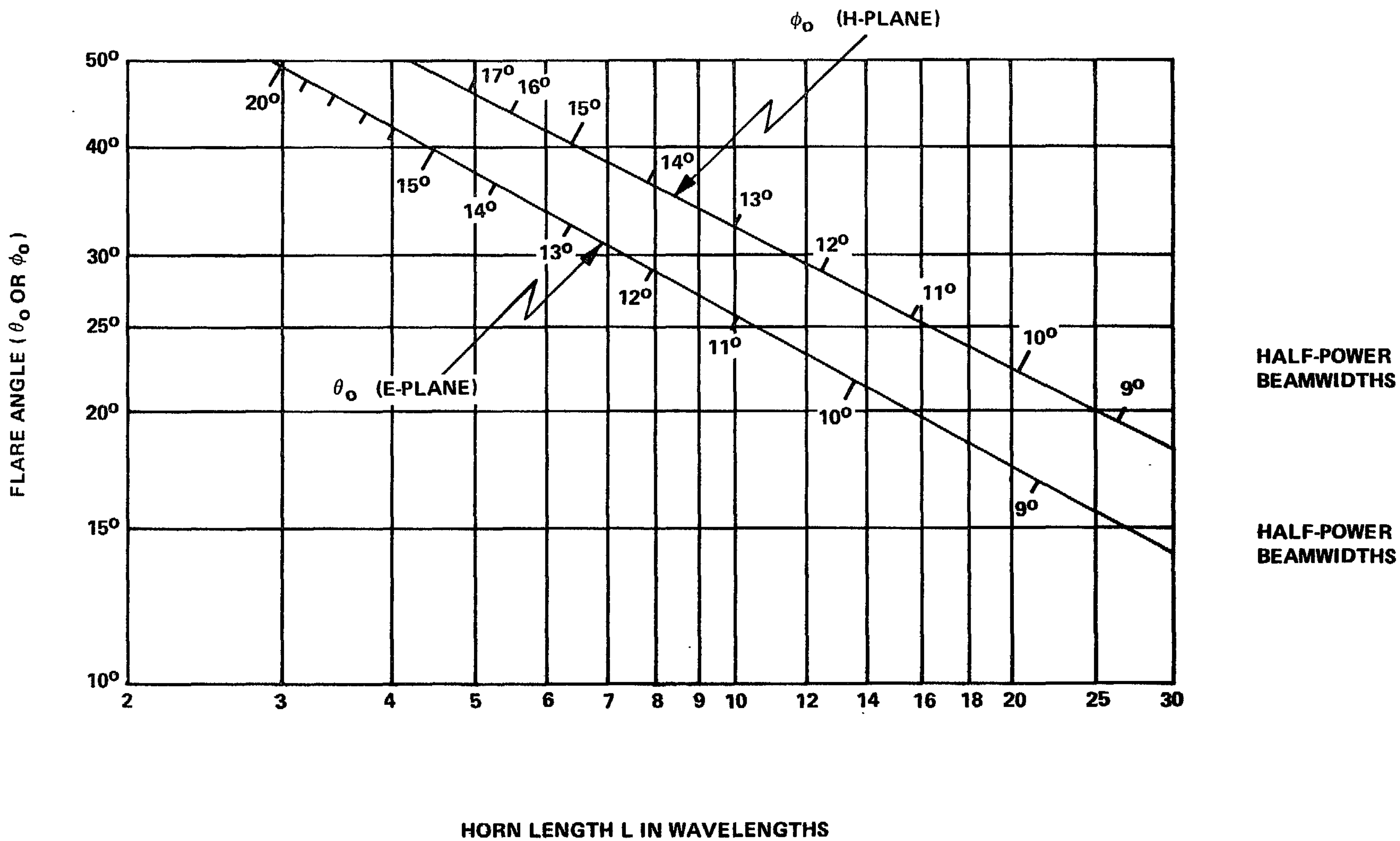


Figure 40. Experimentally Determined Electromagnetic Horn Antenna Lengths as a Function of Flare Angle and Beamwidth

APPENDIX G

MICROSTRIP ANTENNA CONSTRUCTION

Figure 41 illustrates the dimensions and construction of a typical single element microstrip antenna. The quarterwave transformer is necessary to transform the high antenna impedance down to 50Ω. However, by making a rectangular antenna element, λd by λd/2, it is possible to match directly to 50Ω. In Figure 41, λd represents the wavelength in the dielectric material and is equal to the free space wavelength, λ, multiplied by the velocity factor of the dielectric material. For rectangular or square antennas, the resonant frequency, f, is given by

$$f = \frac{c}{2d\sqrt{\epsilon r}}$$

where c is the speed of light in meters per second, d is the distance from the feed point to the opposite side of the antenna element in meters, and r is a dimensionless quantity representing the relative dielectric constant of the substrate. For example, a microstrip antenna element designed for resonance at 10.0 GHz using a substrate material called polyguide would have the following dimensions: (Polyguide has a relative dielectric constant of 2.20 at this frequency.)

$$d = \frac{c}{2f\sqrt{\epsilon r}} = \frac{3 \times 10^8}{2(10 \times 10^9)\sqrt{2.2}} = 1.01 \text{ cm}$$

Thus a square microstrip element would be only 0.40 inch by 0.40 inch (1cm x 1cm).

The bandwidth, Δf in MHz, for microstrip antennas has been empirically derived to be

$$\Delta f = 128f^2t$$

where Δf is the bandwidth in MHz, f is the frequency in GHz, and t is the substrate thickness in inches. For a 10.0 GHz antenna with a typical substrate thickness of 0.0625 inches (1.6mm), the bandwidth calculates to be approximately 800 MHz or roughly 8%. A bandwidth of 8% should not impose any restrictions on an IVRG system operating at or around 10.0 GHz.

Square or rectangular microstrip antenna elements can be used in arrays to produce radiation patterns with increased gain, narrow E and/or H plane beamwidths, and relatively low sidelobe levels. Figure 42 illustrates a 4 x 4 element microstrip antenna array designed for a frequency of 10.0 GHz along with the theoretical E and H plane radiation patterns. From this drawing, it can be seen that the 4 x 4 element array for 10.0 GHz can be fabricated on a card measuring only 3.5 x 3.5 inches (88mm x 88mm). It should also be noted that the theoretical E and H plane radiation patterns are almost identical with sidelobe levels on the order of about 13 dB below maximum. In reality, the E plane radiation pattern has a slightly wider beamwidth and a small increase in sidelobe levels. For this reason, the E plane of both transmitting and receiving antennas should be oriented parallel to the direction of motion to enhance lane isolation.

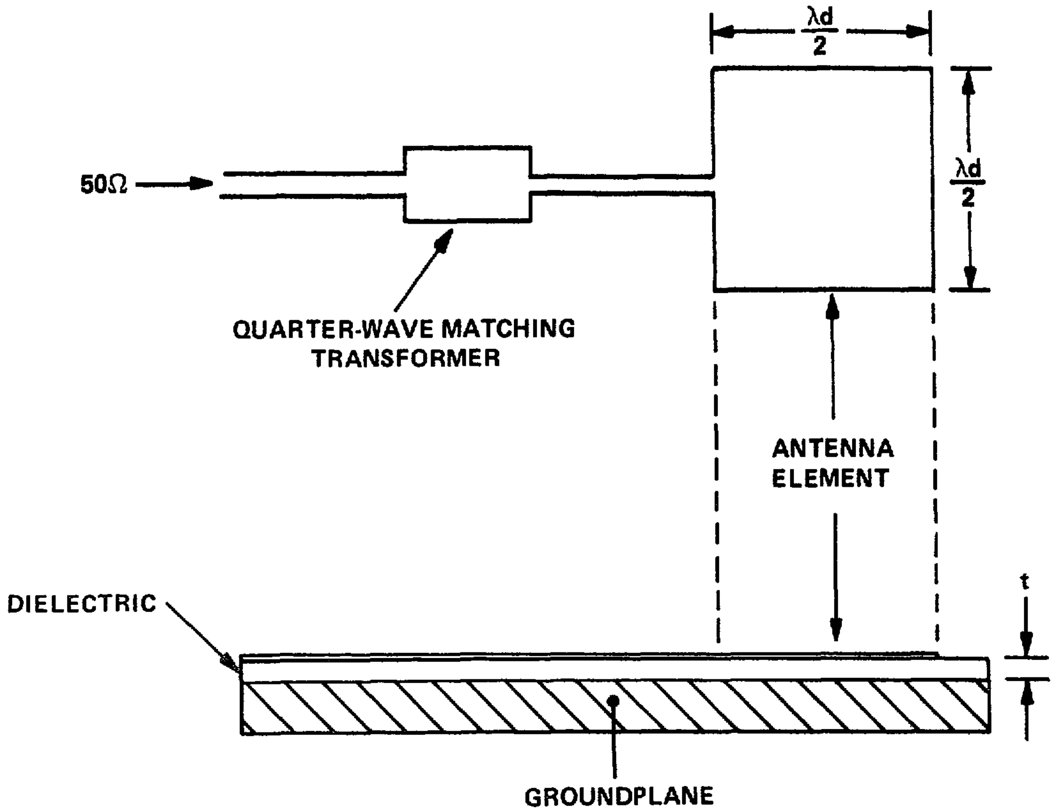


Figure 41. Typical Microstrip Antenna Element - Top and Side View

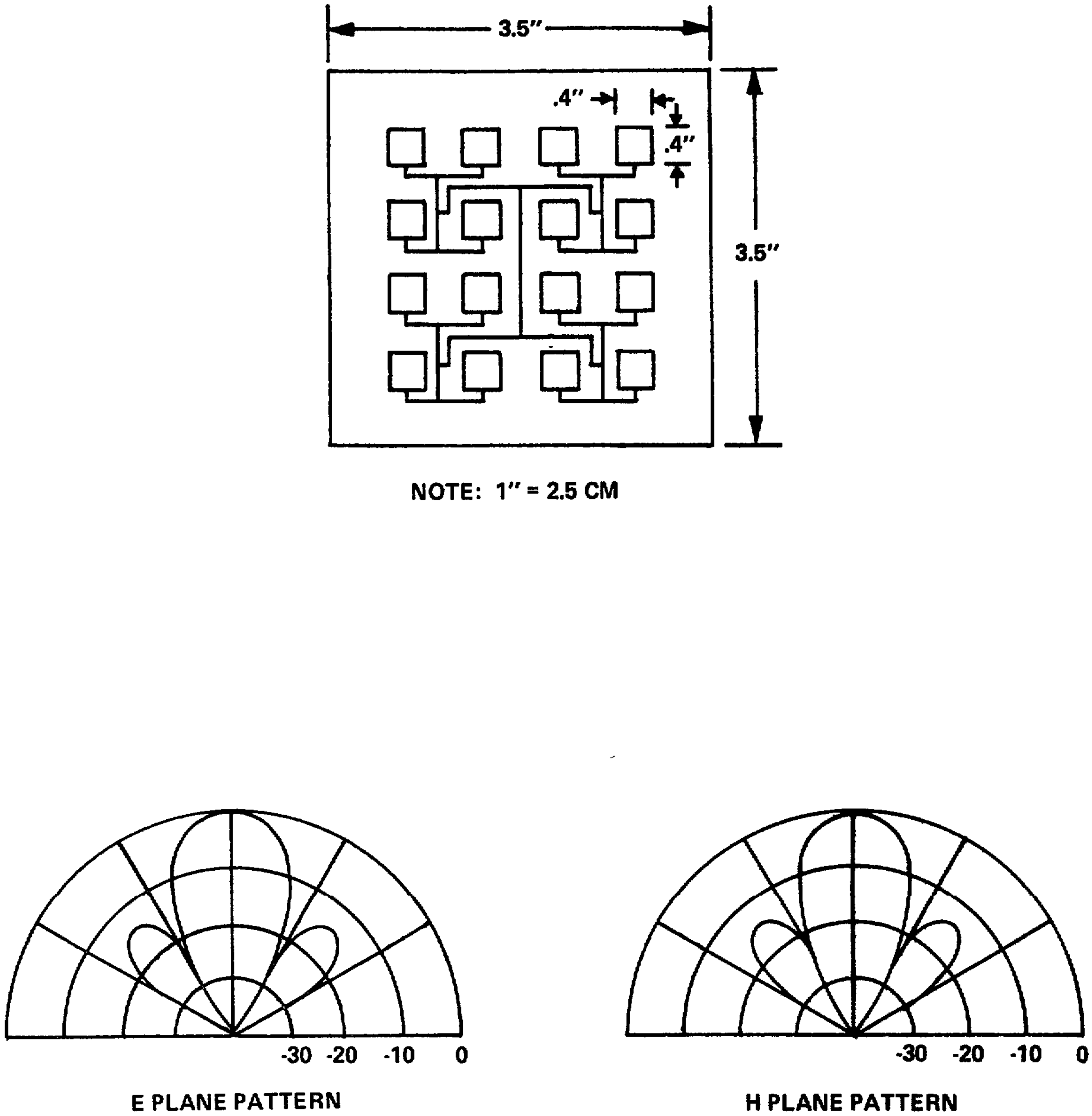


Figure 42. 4 x 4 Element Microstrip Array - Top View and the Associated Theoretical Radiation Patterns

APPENDIX H

CHANNEL BANDWIDTH

The required channel bandwidth for this system is determined by four factors: total number of message bits, antenna beamwidths, receiver-transmitter antenna distance, and velocity of the vehicle.

Variations in antenna spacing is small since the transmitter antenna is generally fixed at approximately 17 feet (5.2 meters) above the roadway; the in-vehicle antenna is about 3.3 feet (1 meter) above the roadway. Deviations about this 3.3 feet (1 meter) distance are -1.6 feet to +3.3 feet (-0.5m to +1m) for the vast majority of cases. Antenna beamwidths are fixed. The vehicle speed can range from zero to about 62 mph (100 km/h).

A message frame length of 5k bits has been established as the upper bound. However, it is possible that the vehicle might miss some of these data bits at the extremities of the transmitter pattern due to vehicle interference. Therefore an increase to at least two frames per intercept assures detection and logic storage of at least one complete message frame. Therefore:

$$L_w \leq \frac{T_i}{2}$$

where L_w is the word length in seconds and Ti is intercept time; also in seconds.

Working within system bounds the required channel bandwidth for a vehicle moving at the maximum allowable speed can be determined. Knowing the minimum separation between the transmit and receive antenna, i.e. when the vehicle is directly under the transmitter and the antenna beamwidths, the intercept distance, Di in meters, is given by

$$D_i = 4h \left[\frac{\tan \frac{\beta t}{2} \cdot \tan \frac{\beta r}{2}}{\tan \frac{\beta t}{2} + \tan \frac{\beta r}{2}} \right]$$

where H = transmitter-to-receiver antenna separation in meters

B_t = beamwidth of transmit antenna

B_r = beamwidth of receive antenna.

This intercept distance begins when the 3 dB points of the two antenna patterns first intersect and ends when the 3 dB points again cross as the vehicle moves away from the transmitter. On this basis, the intercept time, T_i in milliseconds can be expressed as

$$T_i = \frac{3.6 \times 10^3 (D_i)}{V}$$

where V is the velocity of the vehicle in km/h.

A "typical" situation is when the beamwidth of both antennas are 16 degrees, the transmitting antenna is mounted 17.2 feet (5.2 meters) above the roadway, the receiving antenna is 3.3 feet (1.0 meter) above the roadway, and the vehicle is moving at 62.5 mph (100 km/h). For these conditions, the intercept time is 42.5 milliseconds. For a situation where all system parameters remain the same except the receiving antenna height is raised to 6.6 feet (2m) above the roadway, the intercept time decreases to 34.1 milliseconds.

The bandwidth required for FSK digital transmission over a non-fading channel of the quality which will exist for this short microwave link is

$$B_f = \frac{S}{\log_2 S} + 2D$$

where B = channel bandwidth in Hertz

R = data rates in bits per second

S = number of signaling states

D = peak deviation of the carrier in Hertz.

Under similar conditions but for PSK digital transmission, the required bandwidth is:

$$B_p = \frac{2R}{\log_2 S}$$

Knowing the intercept time and the total number of bits in a single digital word, the minimum channel bandwidth for an FSK modulation format is:

$$B_{df} = \frac{NB \cdot 10^6}{\log_2 S \cdot T_i} + 2D$$

where Bdf = required bandwidth in Hz

N = number of message transmissions

B = message length in k bits

S = number of signaling states

T_i = intercept time in milliseconds

D = peak deviation of the carrier in Hz.

For PSK modulation the minimum bandwidth is:

$$B_{dp} = \frac{2NB \cdot 10^6}{\log_2 S \cdot T_i}$$

Using as an example the 34.1 millisecond intercept time, a fixed word length of 5 k bits, one repeat of the transmission and a frequency deviation of 20 MHz (i.e., Af>>carrier drift) the required bandwidth for BFSK modulation is 40.3 MHz. In contrast, for the same intercept time of 34.1 milliseconds but with BPSK modulation, the required bandwidth is 587 kHz.

APPENDIX I

TIME DELAY DIFFERENTIATOR

The time-delay differentiator is a linear network which provides the basic definition of a derivative, i.e.,

$$\frac{dv(t)}{dt} = \lim_{t_o \to 0} \frac{V(t) - V(t_o)}{t_o}$$

The function of this time-delay, differentiation process is to convert variation in instantaneous frequency into envelope variations where the input frequency modulated signal $V_i(t)$ has the form

$$V_i(t) = A \cos \left[\omega_o t + \Delta\omega \int^t f(\theta)\, d\theta \right]$$

When $V_i(t)$ is processed by the power splitter, delay network and hybrid combiner as shown in Figure 43, the resulting signal into the square-law detector, $V_\Delta(t)$ is expressed as:

$$V_\Delta(t) = A \cos \left[\omega o t + \Delta\omega \int^t f(\theta)\, d\theta \right]$$

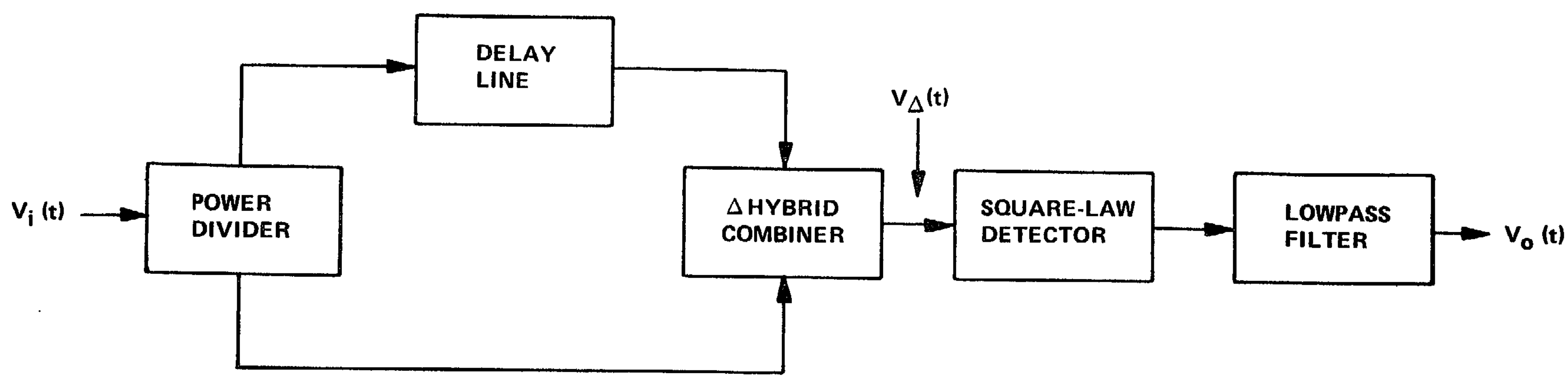
$$- A \cos \left[\omega o t + \Delta\omega \int^{t-t_o} f(\theta)\, d\theta + \theta \right]$$

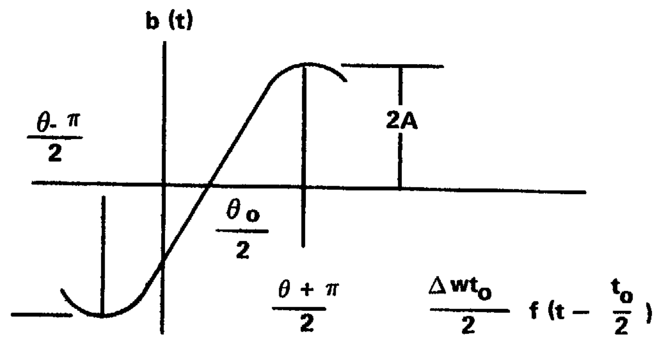
$$= 2\, A \sin 1/2 \left[\Delta\omega \int_{t-t_o}^{t} f(\theta)\, d\theta - \theta \right] \bullet$$

$$\bullet \sin \left\{ \omega o^t + \int^t f(\theta)\, d\theta - 1/2 \left[\Delta\omega \int_{t-t_o}^{t} f(\theta)\, d\theta - \theta_o \right] \right\}$$

Where θ_o is the phase shift through the delay network at ω_o and where the first term is the resulting envelope, b(t), i.e.,

$$b(t) = 2A \sin 1/2 \left[\Delta\omega \int_{t - to}^{t} f(\theta)\, d(\theta) - \theta_o \right]$$





TRANSFER CHARACTERISTICS RELATING g (t) AND ($\Delta wt_o/2$) f (t − $t_o/2$).

Figure 43. Time-Delay Demodulator for FM Signals

If the modulation term is now rewritten into a form which more explicitly defines the envelope dependence on delay, t_o, then through Fourier transformation the envelope term can be simplified to an expression which relates envelope magnitude to time delay, specifically

$$b(t) = 2A \sin\left[\frac{\Delta\omega\, to}{2} \quad f\left(t - \frac{t_o}{2}\right) - \frac{\theta_o}{2}\right]$$

This resultant transfer function which relates b(t) to ($\Delta\omega$to/2)(f(t - to/2) is illustrated in Figure 43. For b(t) to vary in proportion to f(t - to/2) as desired,

$$\frac{\Delta\omega\, to}{2} \quad f\left(t - \frac{t_o}{2}\right) << 1$$

for all values of t. For this condition to be satisfied

$$t_o < \frac{2}{\omega_m}$$

where ω_m is the limit on the spectrum of F(w).

APPENDIX J

LICENSING OF A STATION IN THE INDUSTRIAL MICROWAVE SERVICE

1. Interference Analysis (See S94.15b)

The actual licensing process begins with an engineering analysis of the potential for interference between the service being proposed and any existing or pending radio services. The applicant must demonstrate that the proposed service will not produce harmful interference, as defined by FCC specifications,to other licensed services, or the applicant must reach an agreement with the affected parties that the interference level caused by the proposed service is acceptable to them even if above the maximum acceptable level defined by the FCC.

2. Application Filing (See S94.15c, S94.25c, S94.27a, S94.31b, S94.31h, S94.31i)

Application for a license in this service should be submitted on FCC Form 402 dated July 1976 at least 90 days prior to the desired date of approval, and the form should be submitted to the FCC's offices in Washington, D.C. In addition to the information requested on the form, the applicant should provide the following information:

- A system diagram,
- Information on the construction, lighting, and marking of any associated towers,
- The required environmental impact statement,
- An indication of the basis for frequency selection,
- An indication of the basis for bandwidth selection, and
- A schedule for implementation of the bandwidth utilization.

3. Station Construction (See S94.27e, S94.51)

Station construction must be completed within one year of the granting of the station license, and the licensee should notify the FCC of completion of construction using Form 456.

4. License Term and Fee (See S94.39a, S94.27f0)

The term of a license in this service is five years, and the license may be renewed by submitting Form 405A to the FCC at least 90 days prior to the expiration of the current license. At present, there is no fee for a license in this service.

5. Verification Requirements (See S94.82a, S94.85b)

The operating characteristics of the station shall be determined by the licensee at least annually by measuring and recording the following parameters:

(1) Carrier frequency,

(2) Transmitter output power, and

(3) Effective radiated power (ERP).

Deviation from the nominal values indicated on the station's license shall be promptly corrected.

6. Operation Requirement8 (See S94.103a, S94.103b, S94.111a, S94.113)

The routine operation of a station in this service may be performed by an unlicensed individual; however, the installation, testing, and servicing of a station must be done by an individual holding either a First Class or Second Class Radio Telephone or radiotelegraph license.

Part of the routine operation of a station in this type is the verification that all tower lighting is functioning properly. This must be done at least every 24 hours.

Another aspect of routine station operation is maintaining the station log. The log must record

(1) The results of all required tests,

(2) A description of all maintenance activities, and

(3) An entry indicating the time of the tower lighting observations.

This log must be retained for a period of one year after its last entry.

APPENDIX K

REQUIRED LASER PEAK POWER

The radiant flux incident on a silicon PIN detector with a long wave optical filter (the spectral pass band is 0.8 - 1.1 microns) was measured at Sperry to be Pb = 1.3 milliwatts/cm2 for clear blue sky conditions of direct over head sunlight.

For a maximum detector area of $25mm^2$ the detected background (sunlight) power is:

$$P_B = (1.3 \times 10^{-3}) \left(\frac{25mm^2}{100mm^2}\right) = 3.25 \times 10^{-4} \text{ watts}$$

The average responsivity of a good state-of-the-art silicon PIN detector is R = 0.55 amps/watt; then the detector current due to the sunlight is:

$$I_B = R \times P_B = 1.79 \times 10^{-4} \text{ amps}$$

The total a.c. noise current from the PIN detector for a detector/ preamplifier band width of B is:

$$i_n = \sqrt{2e\ (I_B + \hat{I}sig)\ B + 4K\,\Gamma eff\ B/Req +\ i_{nampl}} \times \sqrt{B}$$

Dark current noise is so small, as compared to I_b, that is not a factor in this calculation.

- o e = electronic charge = 1.6×10^{-19} coulombs.
- o ISIG is the peak signal current expected to be of the order of 10^{-5} amps for a 50 watt laser source at a range of 40 ft. (12m).
- o B = 25 MHz from above based on detection of a 20 nanosec pulse width. (Detector/Pre-ampl. electronic band width.)
- o The next term represents thermal noise in the pre-ampl., where a transimpedance amplifier is assumed.

  Here Γeff = 300°K, Req = 300 ohms, typical input resistance, and Boltzmann's constant K = 1.38×10^{-23} Watt-sec/degree.

o For this bandwidth a TIEF 152 trans-Z amplifier has a max rated input noise,

$i_{nampl} = 3 \times 10^{-12} ampl \times \sqrt{B}$ rated max value

Total detector/preamp noise, in =

$$\sqrt{3.2 \times 10^{-9}\ (1.8 \times 10^{-4} + 1.10 \times 10^{-5})\ (25 \times 10^{6}) + (1.4 \times 10^{-15})} + 1.5 \times 10^{-8} = 6.9 \times 10^{-8} amp$$

A. Received peak signal power from a laser diode transmitter element with solid beam angle Ω_t steradians is:

$$\hat{P}r = \frac{\hat{P}t \cdot Ai \cdot \varepsilon o}{R^2 \cdot \Omega t}$$

where, $\hat{P}t$ = peak transmitted power into Ω_t steradians.

Ωt = solid beam angle transmitted in a given part of the pattern.

Ar = detector collecting area = 25mm^2 max, or 0.039 inch^2.

and Ai = Intercept area = 5mm x (sinθ x 5mm), $\theta = 90^o - 70^o = 20^o$,

Ai = 8.55mm^2 = .0133 in^2.

εo = receiver optical efficiency = 70% typ.

R = range from transmitter to IVEG receiver.

o Calculate $\hat{P}t$ for the maximum range which is half of 81 ft./COS20^o, or slant range of 44 ft. (14m). Ωt = 20 x 20 degrees squared, or 0.122 steradian.

B. Then solving for:

$$\hat{P}t = Pr\left(\frac{R^2 \cdot \Omega t}{Ai \cdot \varepsilon o}\right)$$

$$= \hat{P}r\ \frac{((44\ ft)^2 \times 144 \times (.122))}{0.0133 \times 0.7} = \hat{P}r\ (3.65 \times 10^{6})\ watts$$

C. An acceptable signal - noise ratio of 20 dB is assumed for the maximum range of 44 ft. Then S/Nr = 20 dB = 100:1

$$S/Nr = \frac{R \cdot \hat{Pr}}{in}, \text{ where } R = .55 \text{ amps/watt}$$

Then $$\hat{Pr} = S/Nr\ (in/R) = (100)\left(\frac{6.9 \times 10^{8} \text{ amps}}{0.55}\right)$$

$= 1.25 \times 10^{-5}$ watts, peak received signal power.

D. Then the required peak transmitted power in a 20 x 20 degree^2 element from B. is

$$\hat{Pt} = \hat{Pr}\ (3.65 \times 10^{6}) = (1.25 \times 10^{-5})\ (3.65 \times 10^{6}) =$$

45.6 watts

E. This then is the required power to achieve a 20 dB S/N at the receiver output with direct sunlight into the receiver and a range of 44 ft (13.2m).

This can be accomplished with a Ga:As laser heterojunction stack, such as an LDL type LD-166 with a rated minimum output power of 50 watts, and 65 watts typical.

The maximum rated duty cycle of the LD-166 stacked diode laser is .02% at +70°C max, or 2×10^{-4}.

o Duty cycle, Du = PRF x Tp, PRF = 10 KBS and Tp = pulse width.

$$\therefore Tp = \frac{Du}{PRF} = \frac{2 \times 10^{-4}}{10 \times 10^{3}} = 2 \times 10^{-8} = 20 \text{ nanosec.}$$

o If the laser stacks are cooled (as recommended), using compact thermoelectric coolers, the pulse width may also be increased to Tp = 20 nanosecs, and possibly up to 50 nanosecs. The ambient temperature can also reach 140°F (60°C) and still achieve full power out and long life time with a thermoelectric cooling device.

APPENDIX L

LASER EMISSION CALCULATIONS TOWARD MEETING THE BUREAU OF RADIOLOGICAL HEALTH (BRH) EYESAFETY STANDARD

The LDL, LD-166 stacked laser diode has a typical peak power out = 26 m.w.

At a minimum distance of 10 feet (3m) from transmitter to observer, a 60 x 60 degree^2 pattern may be employed. This is a solid beam angle of $\Omega tx = 1.096$ steradian.

Since the BRH radiant energy standards permit an 80mm (3.149 inches) diameter collecting optics (as for a telescope), the collected power at R = 10 feet (3m), Po = 26 mw and $\Omega tx = 1.096$ steradian is:

$$\overline{Pr} = \frac{\overline{Pt} \times Ar}{R^2 \times \Omega_{TX}} = \frac{(13 \times 10^{-3})\ (\Pi/4\ (3.149\ in)^2)}{(10\ ft)^2\ (144\ in^2)\ (1.096)} = 6.5 \times 10^{-6} \text{ watts}$$

The BRH Class I power limit at $\lambda = 904$ nm is $3.9 \times 10^{-7} K_1 K_2$ watts, where $K_1 = 2.44$ and $K_2 = 100$ for exposure time $t > 1.0 \times 10^4$ seconds.*

The Class I accessible emission limit is then $E\lambda = (3.9 \times 10^{-7}) \times (2.44)\ (100)$ watts $= 95.16 \times 10^{-6}$ watts.

Hence, the IVRG level for 10 feet (3m) range is 6.5 uw/95.2 uw = 6.8 percent of the allowable level; it is therefore "eyesafe" by a substantial margin.

------

*Federal Register, Vol. 40, No. 148, Part II, pp 32101 - 32104, July 31, 1975.

APPENDIXM

COST OF IVEG AND "CB-BASED" IVRG EQUIPMENT IVEG - VEHICLE EQUIPMENT

Studies of automotive electronic equipment sold in retail electronics stores indicate that probable retail cost of a new equipment can be estimated by the following expression:

$$C = 1.545\ P + .129N \qquad (1)$$

where C is the retail cost in dollars for large scale production

P is the retail cost of the parts in sizeable quantities

N is the number of separate parts to be assembled.

The microwave system's and optical system's control unit costs are expected to be similar. These costs are delineated in Table 39.

TABLE 39. IVEG CONTROL UNIT COST

Component - low cost	Unit cost	Qnty	Total cost
Custom MOS/LSI chip	3.00	1	3.00
PC Board	1.00	1	1.00
Resistor - l/4 W	.02	16	.32
Capacitor - disc	.02	6	.12
Capacitor - mylar	.10	2	.20
Switch - SPDT	.50	1	.50
Audio Indicator	.50	1	.50
Light Bulb & Housing	.25	1	.25
Housing with bezel & panel - plastic	1.00	1	1.00
Jack	.50	1	.50
Display - Vacuum Fluorescent	10.00	1	10.00
Thumbwheel switch - 4 digit BCD	5.00	1	5.00
Total		33	22.39

Table 40 describes the cost of the microwave receiver. The roof mounted antenna configuration, discussed in Section 7.1.2.2.1, requires a weatherproof housing for the antenna and an antenna leadin cable, with jack. The cost of these components are listed separately in Table 40. The heater-deicer option for the microwave roof mounted antenna requires the components listed in Table 42 for the optical candidate.

TABLE 40. IVEG MICROWAVE RECEIVER COST

Component	Unit cost	Qnty	Total cost
PC Board with microstrip antenna	1.50	1	1.50
Diodes	.30	4	1.20
Capacitors (high frequency)	.20	8	1.60
Resistors (film)	.06	8	.48
Video Amplifier	.50	1	.50
Threshold Detector	.95	1	.95
Diode - Zener	.08	1	.08
Capacitor - bypass	.lO	6	.60
Capacitor - coupling	.02	6	.12
Total		36	7.03
Additional Components Required for roof mounted antenna configuration			
Housing (weatherproof for roof mounting)	.30	1	.30
Cable (15 feet)	1.00	1	1.00
Connector	.30	1	.30
Total (Roof mounted antenna configuration)		39	8.63

Applying equation (1) to the microwave candidate costs yield.

Unit	cost
Control and Display Unit	38.85
Receiver Unit	15.50
Total (dash mounted antenna)	54.35

Additional costs for roof mounted antenna	
Antenna housing + leadin cable	2.86
Heater	2.83
Total (roof mounted antenna)	60.05

Tables 41 and 42 describe the equipment and parts cost for each of the major in vehicle components for the optical system.

TABLE 41. IVEG OPTICAL RECEIVER UNIT COST

Component	Unit cost	Qnty	Total cost
Infra Red Filter - LR-85N	.42	1	.42
Glass Window 1.5 x 1.5 cm square	.10	1	.10
Silicon Diode, PIN, 5 x 5mm	2.31	1	2.31
Preamplifier	.72	1	.72
Intermediate Amplifier	.38	1	.38
High Speed Comparator	.95	1	.95
Resistors - 1/4 Watt	.02	8	.16
Potentiometer - miniature	.25	1	.25
Capacitors - bypass	.10	10	1.00
Capacitor - coupling	.02	8	.16
Diode - Zener	.08	1	.08
PC Board	.86	1	.86
Housing - weatherproof for roof mounting plastic	.30	1	.30
Cable - 15 ft. - 2 pair - shielded	1.00	1	1.00
Connector	.50	1	.50
Total		38	9.19

TABLE 42. IVEG RECEIVER DE-ICING HEATER UNIT COST

Component	Unit cost	Qnty	Component cost
Switch, SPST, on control panel	.50	1	.50
Fuse and holder	.25	1	.25
Heater element	.50	1	.50
Cable - 15 feet - 1 addition pair	.25	1	.25
Total		4	1.50

Applying equation 1 to these tables yields:

Unit	cost
Control and Display Unit	$38.85
Receiver Unit	19.10
Heater Unit	2.83
Total	$60.78

The task of installing such equipment for either the optical or microwave system is probably similar in difficulty to a CB installation.

IVEG Roadside Equipment

Each roadside installation requires a Route Guidance Controller and a transmitter.

Table 43 lists the microwave system transmitter components and their estimated cost. The estimated installed price of $1880 includes the cost of aligning and testing the transmitter.

TABLE 43. COST TO FURNISH AND INSTALL MICROWAVE SYSTEM TRANSMITTER

Component	Unit cost	Qnty	Total Cost
Horn Antenna	$400	2	$ 800
Modulator	16	2	32
Power Supply	24	2	48
Housing & Mounting Hardware	500	2	1,000
Cost to furnish & install			$1,880

Table 44 tabulates the cost of furnishing and installing the equipment for a microwave system roadside installation to service a twenty-foot wide roadway. Quantity costs for traffic control equipment of similar complexity were used where applicable. The Route Guidance Controller's cost is similar to the cost of a microprocessor traffic controller. Software development costs (assumed to be covered by a research effort) are not included. In a dynamic system the modem communications interface and the RAM increase the controller cost by approximately $500. The estimated cost of each installation for a static system is $8800.

TABLE 44. ROADSIDE INSTALLATION COST-MICROWAVE SYSTEM

(ALL EQUIPMENT FURNISHED AND INSTALLED)

Equipment	cost
Mast Arm -20'	$ 500
Mast Arm Pole	1,300
Pole Foundation	200
Cabinet	2,000
Controller	3,000*
Microwave Transmitter	1,880
Total	$8,880*

*Increase cost by $500 for dynamic system.

Table 45 lists the optical system transmitter's components and their cost. The quantities are those required to provide coverage over a twenty-foot wide roadway. The unit costs used are based upon budgetary prices obtained from manufacturers for lots of five thousand. Maintenance costs are based upon considerations discussed in Section 7.1.4.3. The installed price of $5,288 includes the cost of aligning and testing the transmitters. Maintenance, projected at $50 per year for the cleaning of the lens and $1980 for the replacement of the laser stack every five years adds $2373 to the cost of the transmitter over a fifteen year period. The present worth cost of the installation is thus $7653.

TABLE 45. COST TO FURNISH AND INSTALL OPTICAL SYSTEM TRANSMITTER

Component	Unit Cost	Qnty	Cost
Laser Stack	$180	11	$1,980
Laser Pulser	128	11	1,408
Power Supply with Trigger Circuit	900	1	900
Housing and Mounting Hardware	500	1	500
Beam Shaping Shades	500	1	500
Total			$5,288
Maintenance (15 year present worth)			
Cleaning of laser stack lenses $50/year			380
Replacement of laser stacks every five years			1,993
			$7,653

Table 46 tabulates the cost of furnishing and installing the equipment for an optical system roadside installation. Where applicable, the costs for installing large quantities of traffic control equipment of similar complexity are used. This procedure was utilized in estimating the costs for the mast arm and pole; controller cabinet, which houses the optical transmitter's power supply and laser pulser in addition to the controller; and the Route Guidance Controller. The optical system's Route Guidance Controller is similar in complexity and cost to the microwave system's Route Guidance Controller. Software development costs are not included. The estimated cost of each installation for a static system is $14,653.

TABLE 46. ROADSIDE INSTALLATION COST - OPTICAL SYSTEM

(ALL EQUIPMENT FURNISHED AND INSTALLED)

Equipment	cost
Mast Arm - 20'	$ 500
Mast Arm Pole	1,300
Pole Foundation	200
Cabinet	2,000
Controller	3,000
Optical Transmitter	7,653
Total	$14,653

*Increase cost by $500 for a dynamic system.

"CB-BASED" SYSTEM COST

Estimates of the equipment costs associated with implementing a CB based IVRG system are given in Table 47. Table 48 summarizes the cost of the CB-Based system for the Rochester scenario used in the Section 8.3.2 benefit and cost analysis.

TABLE 47. COST TO FURNISH AND INSTALL CB-BASED IVRG COMMUNICATION EQUIPMENT

FIELD EQUIPMENT		
CENTRAL CONTROL	First Channel	Additional Channel
o Receiver Voting Processor	$10,000	$5,000
o Busy Signal Controller	1,200	600
o Control Station Apparatus (console, microphone, speakers, telephone line control panel, etc.)	12,000	1,000
Total Estimated Cost for Central Control Equipment	$23,200	$6,600
REPEATER		
0 Antenna	1,600	0
o Transmitter	2,400	1,200
o Receiver	2,400	1,200
o Multicoupler	1,600	800
o Cabling and Telephone Interface	800'	400
Total Estimated Cost for One Repeater	$ 8,800	$3,600
VEHICLE EQUIPMENT		
0 Antenna	$ 20	
o 5-watt, 900 MHz Transceiver with Split-Frequency Capability	110	
Total Estimated Cost for Vehicle Equipment	$ 130	

TABLE 48. CB FIXED SITE COSTS

Item	Initial Cost		Annual Cost	
	First Channel	Additional cost	First Channel	Additional Channel
Control Center	$ 23,200	$ 6,600	$ 2,320	$ 660
Repeaters (10 Req'd)	88,000	36,000	8,800	3,600
Leased Telco Lines	1,400	1,400	5,200	5,200
Operator Salary 6 Overhead			37,500	37,500
Operator Training Cost	9,400	9,400		
Total	$122,000	$53,400	$53,820	$46,960

The cost estimates are based on costs of related types of equipment, such as antennas, transmitters and repeaters, from discussions with equipment manufacturers and from experience in the installation of similar types of equipment.

The receiver cost is for a receiver with split frequency capability. This feature must be built into the receiver. The use of an adapter to modify a receiver for this capability is not feasible. The receiver has the inherent capability to handle multiple channels and hence an additional channel capability does not entail additional costs.

APPENDIX N

EXPECTED WAITING TIME FOR SERVICE IN A CB-BASED SYSTEM

Figure 44 is a plot of the expected time a motorist must wait before his request for guidance is served as a function of the system load. The wait time includes the time he must wait for a clear channel and the time for the operator to service the request.

The following steady state queing system equation was used to compute the expected waiting time W:

$$W = \frac{1}{u\ (1-P)}$$

u is the mean service wait reciprocal. In this computation a u of 1.132 was used. This is based on an average time of 45 seconds to transmit a message, determined in the human factors experiment section, plus 8 seconds assumed for message queue management and motorist recognition.

p is the load factor - fraction of time the system is in use.

W is the expected waiting time, including service time.

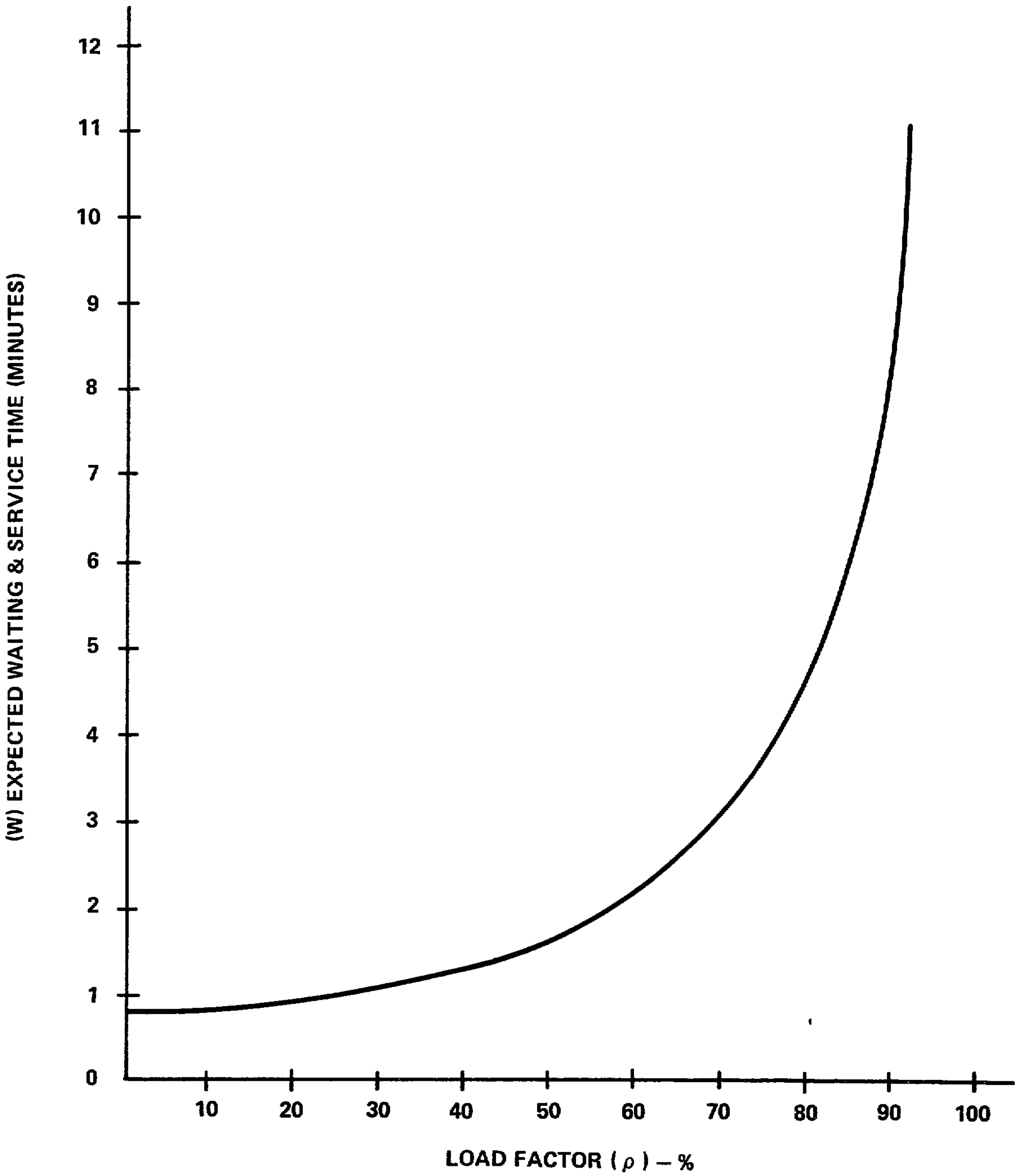


Figure 44. Expected Waiting Time for Service in a CB-Based System

APPENDIX 0

BENEFIT COST EXPANSION TO A NATIONAL BASIS

BENEFIT COST EXPANSION PROCEDURE

The expansion of the benefit/cost analysis given in Section 8.2 to a national basis, is based on the following set of assumptions:

- o The baseline benefit and cost factors are based on the Rochester New York study site. (See Section 8.1.)
- o Expansion of the baseline benefit factor is accomplished by a multiplication of that factor with IVRG service areas vehicle populations.
- o Expansion of the baseline vehicle equipment cost factor is accomplished by a multiplication of that factor with IVRG service areas vehicle populations.
- o Expansion of the baseline field equipment cost factor is accomplished by a multiplication of that factor with the geographic size of each IVRG service area.

It was previously determined that the bulk of the route guidance needs occur in urban areas and in particular urban areas represented by SMSA populations greater than 500,000. This level of population is equivalent to an SMSA rank order of about 70. The demographics and geographics of the urban areas above this rank generate much fewer route guidance needs. Hence for purposes of determining national benefits and costs the SMSA's of rank 70 and below will be considered to represent all areas in the USA where IVRG systems will satisfy a significant guidance need.

The equation set used to calculate the IVRG national benefit is:

$$\text{National Benefit} = \sum_{i=1}^{70} \frac{NVEH(i)}{NVEH(36)} (BBR)$$

where

BBR = Baseline benefit computed for the Rochester SMSA (rank = 36) for a specified system configuration.

NVEH (i) = Number of registered vehicles in the urbanized area of rank i SMSA.

NVEH (36) = Number of registered vehicles in the urbanized area of Rochester, N.Y. (SMSA rank = 36)

In order to perform the required operations, a value for the number of registered vehicles within the urbanized areas of each SMSA must be specified. To obtain these values a relationship between urbanized area registered vehicles and SMSA population was estimated using a linear least square regression technique. Based on compiled data generated by the 1970 census(9) the relationship is:

$$NVEH(i) = [NSMSA(i)]^{0.932}$$

where

NSMSA(i) = Population for SMSA of rank i.

The population of the SMSA's out to rank 70 was obtained from Reference 10, for the base year 1974 as defined by the Bureau of the Census.

The computation of the in-vehicle equipment cost on a national basis is obtained in a similar procedure (with respect to the weighting by vehicle population). The major variation is that the baseline benefit (BBR) is changed to BCVR - the baseline vehicle cost derived for a specified in-vehicle equipment configuration.

The cost on a national basis of the field equipment is obtained with the following equation set:

$$\text{National Cost} = \text{Field Equipment} \quad \sum_{i=1}^{70} \frac{NSM(i)}{NSM(36)} (BCFR)$$

where

BCFR = Baseline field equipment cost, including installation, for a specified system configuration.

NSM (i) = IVRG service area specified for SMSA of rank i. Square miles of urbanized area.

NSM (36) = IVRG service area specified for Rochester, New York SMSA. Square miles of urbanized area.

The computation of square miles SMSA urbanized area NSM is obtained as previously, by estimating the relationship between urbanized area square miles and SMSA population. The equation describing this relationship is:

$$NSM(i) = (.384*10^{-3}) \; [NSMSA(i)]^{0.969}$$

REFERENCES

(1) Hanysz, E.A.; Quinn, C.E.; Stevens, J.E.; Trabold, W.G., "DAIR - A New Concept in Highway Communications for Added Safety and Driving Convenience", Research Publication No. GMR-600, General Motors Corporation, October 5, 1966

(2) General Motors Research Laboratory, "A Design for an Experimental Route Guidance System - Volume I - System Description", FHWA PB-197-090 - November 15, 1968

(3) General Motors Research Laboratory, "A Design for an Experimental Route Guidance System - Volume II - Hardware Description", FHWA Pub. PB 197-091 - November 15, 1968

(4) General Motors Research Laboratory, "A Design for an Experimental Route Guidance System - Volume III - Driver Display, Experimental Evaluation", FHWA Pub. 197-092 - November 15, 1968

(5) Rosen, D.A.; Mammano, F.J.; and Favout, R., "An Electronic Route Guidance System for Highway Vehicles", Federal Highway Administration October 10, 1969

(6) Onda, M., "Comprehensive Automobile Traffic Control Project - Part I Outlines of the Pilot Test System", Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Japan

(7) Onda, M.," Comprehensive Automobile Traffic Control - Route Guidance and Other Subsystems" VIIIth IRF World Meeting C-2-7

(8) Agency of Industrial Science and Technology. "The Comprehensive Automobile Traffic Control System - A General Description of Pilot Test System" The Ministry of International Trade and Industry, Japan, October 1977

(9) Blaupunkt, "Make Better Use of the Roads Reach Your bestination Quicker Electronically"; Bosch Group - West Germany, July 1975

(10) Braegas, Peter, "Function, Equipment, and Field Testing of a Route Guidance and Information System for Drivers (ALI)", IEEE Transactions on Vehicle Technology, Volume VT-29 No. 2, May 1980

(11) Braegas, Von Peter, "Verkehrsrundfunk"; Bosch Techn. Berichte 4 (1973)5 West Germany

(12) Transport and Road Research Lab.; "AWARE an In-Vehicle Visual Communication System for Drivers", Crowthorne (England) PB-276 833, 1977

(13) "Highway Statistics, Summary to 1975", FHWA, PB 273520

(14) Armstrong, B.D., "The Need for Route Guidance", TRRL Supplementary Report 330, Transport & Road Research Laboratory 1977

(15) Gordon, D. & Wood, H., "How Drivers Locate Unfamiliar Addresses - An Experiment in Route Finding", Public Roads June 1970 - Volume 36 No. 2 p. 44ff

(16) Ratcliffe, E.A., "A Comparison of Drivers' Route Choice Criteria and Those Used In Current Assignment Processes", Traffic Engineering and Control, March-April 1972

(17) Catholic University of America. "Benefit Measurements on Highway ERGS", Bureau of Public Roads PB 192169

(18) Schoppert, Moskowitz, Hulbert, Berg, "Some Principles of Freeway Directional Signing Based on Motorists' Exerpiences" Highway Research Board Bulletin 244 1960 p. 30ff

(19) Creighton, R.L., Urban Transportation Planning, p. 220 - University of Illinois Press 1970

(20) Sperry Systems Management, "Integrated Motorist Information System (IMIS) Application of Feasibility Study Handbook", FHWA Report RD-78-24, May 1978

(21) Sperry Systems Management, "Integrated Motorist Information System (IMIS) Feasibility Study Handbook", FHWA Report RD-78-23, May 1978

(22) Taylor, J.I. and McGee, H.W., "Improving Traffic Operations and Safety at Exit Gore Areas", NCHRP Report No. 145, 1973

(23) Transportation Research Record 414, "Motorist Information Systems", 1972

(24) Transportation Research Record 600, "Motorist Information Systems and Services", 1976

(25) King, G.F. and Lunenfeld, H., "Development of Information Requirements and Transmission Techniques for Highway Users", NCHRP Report No. 123, 1971

(26) Hanscom, F.R. and Berger, W.G., "Motorist Response to Guide Signing", NCHRP Research Results Digest No. 91, January 1977

(27) King, G.F. and Lunenfeld, H., "Urban Guidance, Perceived Needs and Problems", Transportation Research Record 503, 1974

(28) Lunenfeld, H., "Improving the Highway System by Upgrading and Optimizing Traffic Control Devices", U.S. DOT/FHWA, Report No. FHWA-TO-77-1, April 1977

(29) Eberhard, John W., "Driver Information Requirements Display Concepts and Acceptance Factors For Electronic Route Guidance System", Serendipity Inc., February 1969

(30) "Outline of Test Results of Pilot System" - Industrial Science and Technology Agency, October 1978. Translated by Berlitz Translation Service under contract to SSM for IVRG project.

(31) "Integrated Motorist Information System (IMIS) Feasibility and Design Study" - Sperry Systems Management, GF-3701-1043 - April 1977

(32) Yumoto et al, "Outline of the CACS Pilot Test System', presented at the 58th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1979

(33) "Study and Development of Highway Advisory Information Radio", FHWA RD 74-73, Atlantic Research Corp.

(34) "Highway Coding for Route Designation and Position Descriptions", Philco Ford WOL-TR3580, July 1, 1968

(35) Jones, Jr., H.S., "Horn Design Saves Weight Without Performance Loss", Microwaves, October 1973

(36) Sams, Howard W., "Reference Data for Radio Engineers", Howard W. Sams & Co. Inc., New York

(37) Howell, John Q., "Microstrip Antennas", IEEE Transactions on Antennas and Propagation, January 1975

(38) Weiss, Michael A., "Microstrip Antennas for Millimeter Waves", ECOM Report ECOM-76-0110-F, October 1977

(39) Motorola, "Phase Locked Loop Data Book", August 1973

(40) Behrens, C.W., 'The Reality of Appliances that Talk', Appliance Manufacturer, November 1978

(41) Onda, M., "Safety Design in the Comprehensive Automobile Traffic Control System", Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Japan

(42) "Displays", Interface Components, Electronic Buyers Handbook and Directory, Volume 5, June 1978

(43) "In-Vehicle Display Unit (Liquid Crystal Type) for CACS Pilot System", Toshiba Corporation

(44) "Screened Image Displays", Beckman Series SP-4000

(45) "Vacuum Fluorescent Displays Chosen by "Big 3" Auto-Makers", Circuit News, January 15, 1979, page 18

(46) West, Raymond A., "Vacuum Fluorescent Displays for Automotive Applications", Society of Automotive Engineers, International Automotive Congress and Exposition, February 28 - March 4, 1977; 770275

(47) "Vacuum Fluorescent Displays", Futaba Corporation

(48) General Motors Research Laboratory, "A Design for An Experimental Route Guidance System - Volume III - Driver Display, Experimental Evaluation", FHWA Pub. 197-092, November 15, 1968

(49) "Interface Components", Electronic Buyers Handbook & Directory, Volume 5, June 1978

(50) Howell, D., "Solid State Keyboards", Electronic Products, May 1978

(51) "Special Report Switches and Keyboards", Circuit News, March 15, 1979

(52) "Microprocessor Directory", EDN, November 20, 1978

(53) "The Complete Motorola Microcomputer Data Library", Motorola, 1978

(54) Okumura, Y., Ohmori, E., Kawano, T., and FuKuda, K., "Field Strength and its Variability in VHF and UHF Land Mobile Service", Rev. Elec. Comm. Lab., 16, September - October 1968

(55) Jakes, Jr., W.C., "Microwave Mobile Communications", John Wiley & Sons, New York

(56) Ehrlich, Nathan, "The Advanced Mobile Phone Service", IEEE Communications Magazine, March 1979

(57) Gatling, F.P., "Auditory Message Studies for Route Diversion", FHWA RD-75-73, June 1975

(58) Favout, F., "Improving Urban Highway Transportation Through Electronic Route Guidance", Urban Transportation Innovation, Daniel Brand, ed. ASCE National Transportation Engineering Meeting, July 1970, Boston, Mass.

(59) Kobayashi, F., "Feasibility Study of Route Guidance System", Comprehensive Automobile Traffic Control System (unpublished)

(60) "Loran-C Conceptual Analysis", DOT-HS-801-952, Contract No. DOT-HS-5-01234; July 1976, Final Report; U.S. DOT, NHTSA, Washington, D.C.

(61) Blood, B.E., Klein, B.W.A., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles - A Summary of Results", Report No. UMTA-MA-06-0041-77-2; U.S. DOT Transportation Systems Center, Cambridge, Mass. 02142

(62) Williams, D.R., Chatterjee, A, Wegmann, F.J., "Tennessee Experience with Loran-C", November 1978. Department of Civil Engineering, The University of Tennessee, Knoxville, Tenn.

(63) Goldsmith, A., "Department of Transportation National Plan for Navigation", DOT-TST-18-4, November 1977, Department of Transportation, Washington, D.C.

(64) Kraus, J.D., "Antennas", McGraw-Hill, New York

GPO 881 272

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Consideration8 in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

8. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analyses (HRD-3), Offices of Research and Development, Federal Highway Administration. Washington, D.C. 20590.