TASK D/E REPORT

ASSESSMENT OF CANDIDATE COMMUNICATIONS SYSTEMS AND TECHNOLOGIES FOR USE WITH INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

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1. INTRODUCTION

This report summarizes the efforts performed under subtasks D&E of the ATIS Communications Technology Alternatives Task for the FHWA Turner Fairbank Highway Research Center. Tasks D & E were to facilitate further examination of wireless communications technologies identified during Task C activities. Specific emphasis was placed upon technologies which are candidates for prototyping, modeling, or other in depth analysis. For those, operational concepts, test objectives, and modeling requirements were developed as appropriate.

2. OVERVIEW OF WIRELESS TECHNOLOGIES IDENTIFIED DURING TASK C

During Task C, extensive research was performed to catalog wireless and wireline technologies which could be used to support ITS applications. Technologies were characterized at a level which allowed identification of promising technologies and highlighting of areas for which additional study could yield benefit to the implementation of ITS.

For purposes of organization, we used the National Architecture Team's methodology of dividing technologies into the following categories: wide area communications, vehicle to vehicle communications, and dedicated short range communications (DSRC). Each of these areas are categorized by the type of services which they can support. In general, discriminators include the size of the communications coverage area, what items are being interconnected, and whether or not the application is location dependent.

Wide area communications links provide either one- or two-way connectivity between mobile users and ITS fixed subsystems in a manner which supports nearly "free roaming" access to these ITS fixed subsystems. The most familiar example of wide area communications is cellular telephony - cellular subscribers are able to travel nearly anywhere and receive service. An example of a one-way wide area communications link is the use of AM or FM broadcast stations to disseminate traffic information.

In contrast to wide area communications, DSRC provides communications only within a very small "footprint" - in the order of tens to hundreds of feet. The user services that require DSRC links rely on having immediate access to information, in order to meet "hard" deadlines for the exchange of information. Toll booths, parking facilities, and to some degree in vehicle signs base their utility on the ability to communicate with a user during a brief window of opportunity, and the information they exchange with the vehicle is typically only of value at that geographic location.

Vehicle to vehicle links are used to support collision avoidance and Automated Highway System (AHS) applications. Information that is exchanged between vehicles includes vehicle velocity, acceleration, and intent to merge or switch langes. Vehicle-to-vehicle requirements include very short delays, similar to the DSRC links. Latency is particularly critical for AHS, where vehicle separations are expected to be in the order of fractions of a meter.

Based upon the recommendations made at the conclusion of Task C, and the priorities established by the FHWA, ARINC concentrated its efforts during Tasks D&E in one or two key technology aspects of each of the three categories of wireless communications, as shown in Table 2-l.

Table 2-1. ITS Communications Technology Actions Under Tasks D and E		
Link Category	**Technology**	**Action**
Wide Area Communications	CDPD 220 MHz Channels PCS	Conducted field testing to verity modeling results of Mitretek and Architecture Teams. Results reported in this report Studied vehicular antenna performance; white paper prepared Tracked progress in PCS implementations
Dedicated Short Range Communications	Microwave Beacon	Prepared extensive analysis of potential operating concepts for DSRC applications, and estimated required spectrum based upon those applications and concepts. Assisted ITS-America and FHWA in preparation of a Petition for Rulemaking to obtain needed spectrum.
Vehicle-to-Vehicle Communications	Ultra-Wideband, Microwave, Wireless LAN	Prepared white papers outlining potential design approaches for multi-lane vehicle to vehicle communications. Made recommendations for further study and protoyping of a IEEE 802.11 based inter-vehicle network.

The analyses undertaken and results of each of these actions is discussed in turn in the following sections of this report.

3. WIDE AREA COMMUNICATIONS

3.1 CELLULAR DIGITAL PACKET DATA

By late 1995, the ITS National Architecture Team had examined CDPD technology analytically and felt it could support many wide-area applications. Even though this looked promising, most of the Architecture Team's predicted performance results were determined using modeling and simulation; no field results were available to the ITS community. Additionally, there were unanswered performance questions concerning the use of CDPD in a "hopped mode" where it shares channels with existing voice users (see technology description below).

Within the past year or so, a number of cellular service providers around the country have initiated CDPD service, including one in the Washington, DC/Baltimore area. This particular network contains both shared and dedicated channels (see the technology description below for an explanation of these terms). This provides a convenient opportunity to examine the technology directly. In early 1996, the FHWA and ARINC decided to set up a testbed to empirically evaluate CDPD utilizing this network. The testbed was designed to model a real-world ITS implementation by interconnecting mobile units with an information service provider (ISP).

In summary, the data collected in this field test can be used to verify predictions made by the Architecture Team and others on the ITS community.

3.1.1 CDPD Technology Description

CDPD (Cellular Digital Packet Data) is a cellular industry developed system for providing packet switched data service to cellular customers. The service is being developed under the CDPD Forum, with key memberships of Ameritech Mobile Communications Inc., Bell Atlantic NYNEX Mobile, GTE Mobilenet Inc., Contel Cellular Inc., McCaw Cellular Communications Inc, PacTel Cellular, and Southwestern Bell Mobile Systems.

CDPD operates on the same channels that Advanced Mobile Phone System (AMPS) uses[1], but it is designed to be transparent to AMPS so as not to effect its voice customers. This is accomplished in one of two ways First, some CDPD systems use dedicated channels. In this case, excess voice channels are set up for *data* use only. Because of this, the CDPD devices never try to access the channels that the voice users occupy (and vice-versa). The second method of transparency is achieved by permitting CDPD devices to share channels with voice users in a special way. The sharing is accomplished by hopping between channels which are not in use at a particular point in time. In this scenario, the frequency hopping is controlled by a CDPD entity called the Mobile Data Base Station (MDBS) which resides at each cell site. The MDBS receives RF signals from the same antenna as the AMPS base station and scans the AMPS channels to detect the presence of voice traffic. If two channels are idle (CDPD operates in full duplex), the

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1 With AMPS, base units transmit on 869-894 MHz (with a 30 MHzchannel spacing); mobiles transmit on 824-849.

MDBS establishes an RF link between itself and a mobile wireless data system wishing to exchange data.

The MDBS is fast enough to detect when an analog voice signal is ramping up on an established channel. Since it takes approximately 40 milliseconds from beginning of transmission to the point where actual exchange of voice signals occurs, there is time for the MDBS to gracefully disconnect the data circuit and establish another circuit on another frequency. This hopping from unused carrier to unused carrier has thus far proven to be difficult to accomplish smoothly in “real world” conditions.
CDPD is a packet-switched service rather than a circuit-switched service - the precise path the data takes between end systems may change from packet to packet. The protocols to accomplish this are built on the standard TCP/IP protocols used in fixed wireline service, simply extended to handle the mobile RF interface. This makes CDPD attractive from an interface and interoperability viewpoint.

3.1.2 Project Overview

This project was designed to obtain a better understanding of the performance and characteristics of commercial CDPD networks. In furtherance of this objective, test assets were configured to emulate realistic ITS scenarios. A fixed end system (F-ES) operates like an Information Service Provider (ISP). It supports multiple mobile end system (M-ES) units by forwarding them data upon demand. Additionally, the F-ES can send unsolicited data to the mobile units. Another scenario being tested , is that of vehicle polling. During portions of the test the M-ES units were configured to provide polling information to the F-ES. In summary, test configurations produce both single and bi-directional message traffic.

All of the M-ES and F-ES units are equipped with GPS receivers. This provides a common time reference which is used to measure throughput delay. All messages are time tagged before transmission and then again upon reception at the receiving end. During data analysis, differences between the two time tags are computed to determine end-to-end delay. In order to calculate if and when messages are lost, messages are recorded at the transmitting and receiving ends. Post processing is performed to determine which messages were lost.

Another objective of this test is to observe the differences in performance between dedicated and shared channels. During certain portions of the test, an M-ES used a dedicated channel. The time delays associated with this configuration are compared against those seen for another M-ES operating with shared channels.

In order to minimize testbed development time and effort, the CDPD project leveraged off of existing software. ARINC had already developed communications software capable of polling multiple mobile units and recording transmitted/received data. This software was ported to a UNIX environment to provide multi-tasking capability.

3.1.3 Physical Configuration

The CDPD service provider operates a network which connects fixed and mobile systems as shown in Figure 3-l. The M-ES devices have wireless interfaces to the network facilitating their mobility. The F-ES accesses the CDPD network via a leased-line.

Each M-ES consists of a laptop and a CDPD modem. Additionally, each laptop is equipped with a Rockwell PCMCIA GPS receiver. The Serial Line Internet Protocol (SLIP) defines the interface between the laptop and modem pairs.

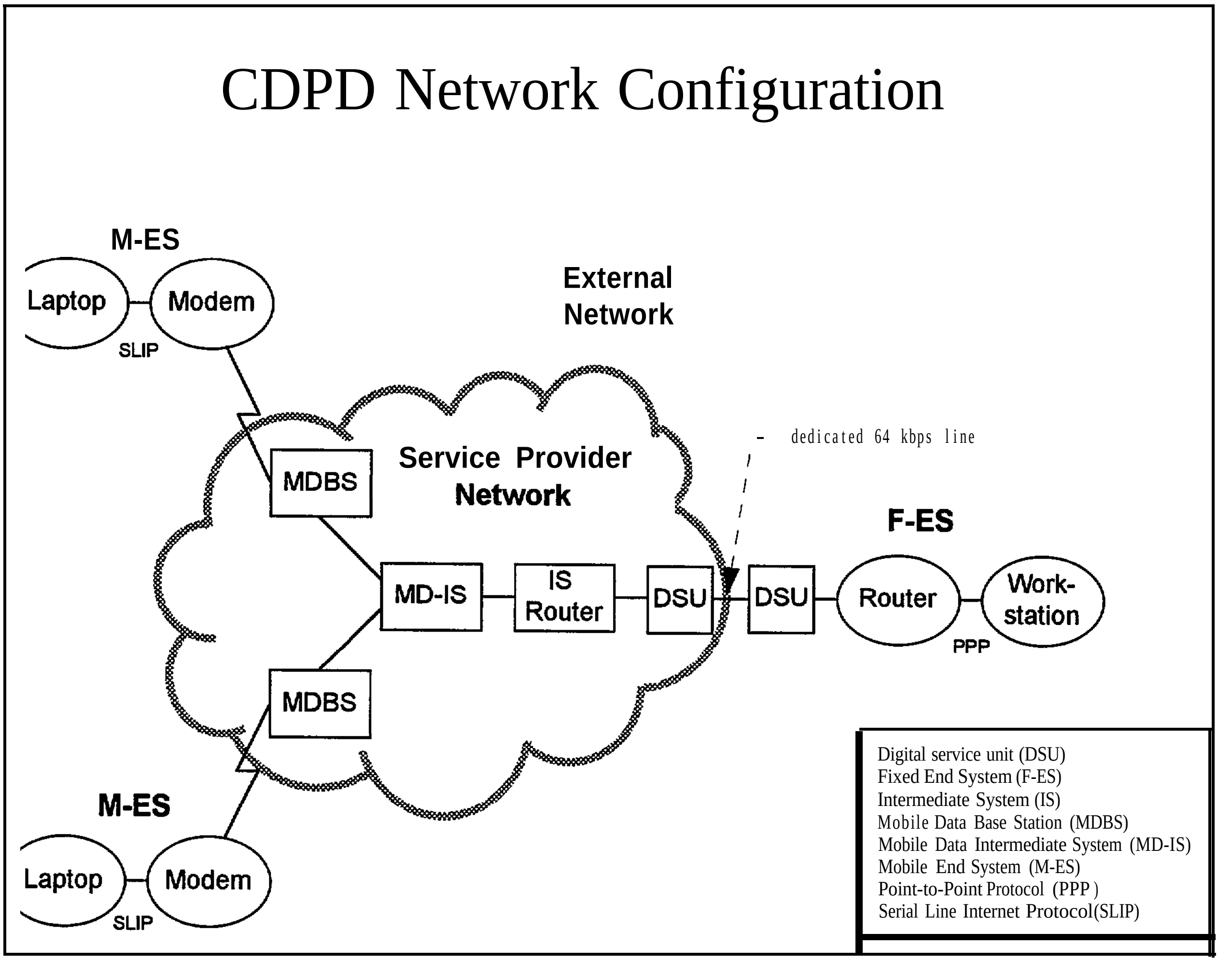


Figure 3-l. The CDPD Test Network Configuration

The F-ES contains a CISCO router, pentium workstation and an external Magellan GPS receiver. The GPS receiver interfaces to the workstation via an RS-232 serial port. Because of the data rates involved, the workstation cannot access the leased-line directly. The CISCO router provides the functionality necessary for this to occur. The router and workstation communicate using a standard Point-to-Point Protocol (PPP). In order to maintain signal conditioning over the leased-line, Digital Service Units (DSUs) are used.

From an end-to-end perspective, TCP and IP are being utilized to establish logical circuits between F-ES and M-ES devices. The F-ES workstation acts as a network "server" to the "client" M-ESs. This means that all of the connections are initiated by the mobile units.

3.1.4 Message Traffic

Before general message traffic may be passed, the M-ES initiates a communications session with the F-ES. It contacts the F-ES through the CDPD network and establishes a communications link using TCP. Once this has been performed, various types and lengths of messages may be transferred. Message types are divided into two categories: messages requiring a response, and messages which are one-directional in nature and do not require a response. Since either the M-ES or the F-ES can send these messages, there are a total of 4 message types being used in the test as shown below.

Message Type	Message Definition
M2BN	M-ES to F-ES, no response required
M2BY	M-ES to F-ES, response required
B2MN	F-ES to M-ES, no response required
B2MY	F-ES to M-ES, response required

All of the message traffic between a single M-ES and the F-ES is choreographed using "event files". Event files script the flow of events, message types used, and length of messages. For example, in Figure 3-2, CONNECT is used to establish the initial connection. Any number of connects and disconnects can occur within a single event file. In the next line, a message is defined which will flow from the M-ES to the F-ES. 10 seconds will elapse between each transmission; 20 transmissions will be sent; and each transmission will be 144 bytes in length. Below this line another message is defined in which the M-ES will receive a response from the F-ES. The default response message is 16 bytes in length. This is a configurable parameter and can be set to any desired length during testing. A DISCONNECT statement is found in the last line. This terminates the logical connection between the M-ES and F-ES.

```
CONNECT
MESSAGE M2BN 00010 00020 00144
MESSAG[redacted]00009 00216
DISCONNECT
```

Figure 3-2. Sample Event File

3.1.5 Test Operations

A number of hours were spent on the lab bench testing end-to-end connectivity from the M-ES to the ISP using shared channels. Once it was apparent that the system was operating correctly from end-to-end, mobile data was collected during a number of different time periods including: morning rush hour, lunch hour, and evening rush hour. Other off-peak times were also selected during the day and on the weekend to observe CDPD operation under different network loading conditions.

Additional scenario parameters included collecting data under static conditions, when the vehicle was parked, or alternatively while the vehicle was moving. Once in motion, the RF path was subject to a more rapidly changing mulitpath environment, and the CDPD modems had to complete handoffs between cells. It should be noted that there was only one dedicated channel available. Because of this, it was not possible to examine handoff performance between multiple cells using dedicated channels.

Cell handoff was investigated for shared channels where practical. In general, tests monitoring cell handoffs of shared channels measure more of a "worst-case" channel access situation than for dedicated channels, because of the additional time constraints inherent in the hopped approach.

3.1.6 Test Results

Shared Channels As a whole, when using shared channels, gaining channel access was difficult during time periods normally associated with a high volume of voice traffic. In many cases the modem spent most of its time trying to acquire channels and once it had a channel it could not hold on to it for more than one transmission. Note that transmissions were spaced at 1 to 10 second intervals.

Figure 3-3 shows the round-trip time from the point when a message was sent from the M-ES and a F-ES response was received back at the M-ES. This sample was taken at the start of evening rush hour and acquiring the channel was difficult because of the high volume of voice traffic that was occurring. Also important to note, the M-ES was parked so it did not have to contend with cell handoffs.

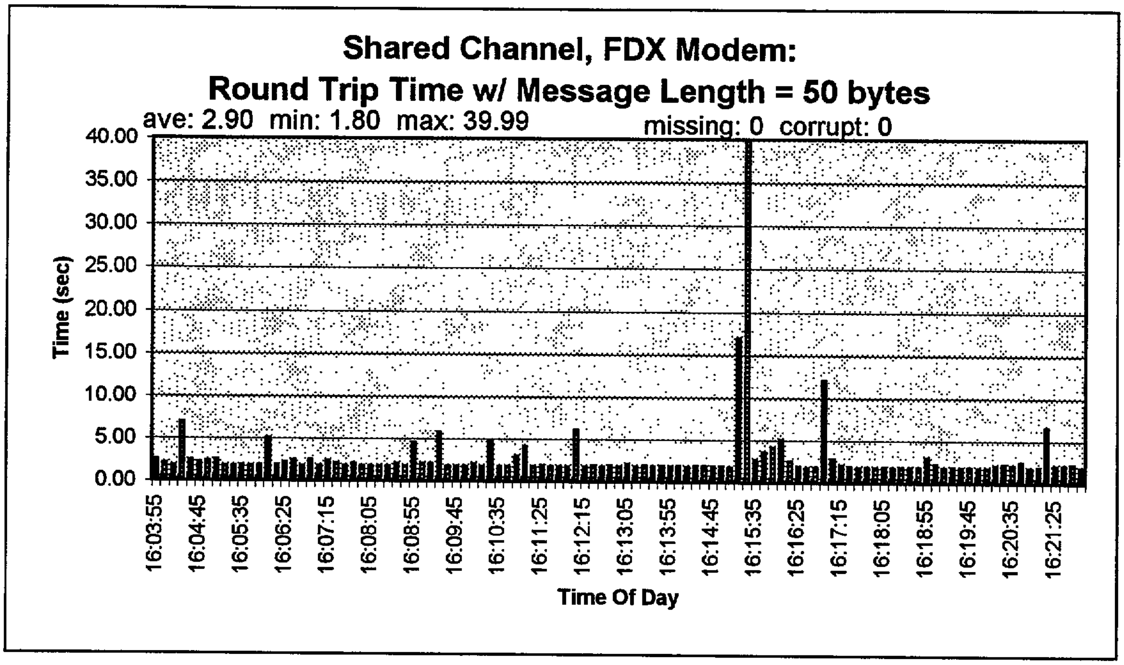


Figure 3-3. Round Trip Delay, in a Shared Channel Full Duplex Modem

During testing two different types of modems were used. One type is half-duplex (HDX) and while the other is full-duplex (FDX). There were extremely noticeable differences in performance between the two. The HDX modem spent much more time acquiring channels than the FDX modem. This was especially true during times of high voice activity. After talking with the manufacturers, it appears that a major disadvantage of the HDX modem is that does not always switch channels as quickly as the FDX modem because of difficulty receiving messages from the base station. By definition, the FDX modem can listen to the forward channel while it is transmitting on the reverse channel. It can receive a "directed hop" message from the base station while it is transmitting. The directed hop message tells the modem that the channel is no longer available and that the modem must switch to another. However the HDX modem cannot listen to the forward channel while it is transmitting, thus it sometimes misses the same "directed hop" message. Figure 3-4 shows the round-trip time seen from a HDX modem during the start of evening rush hour. This data was collected during the same time period as the FDX modem shown in Figure 3-3. Comparing the two, one can see that the HDX round-trip time was much higher than that of the FDX modem. A number of messages were also lost or corrupted during HDX testing as illustrated by the figure.

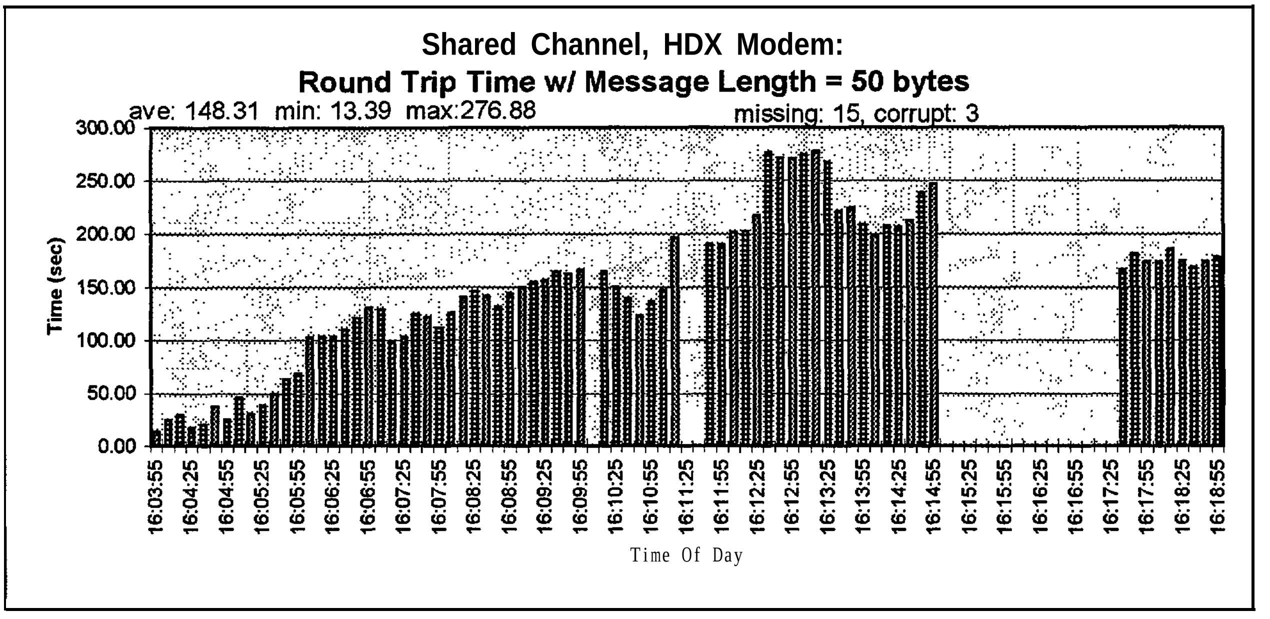


Figure 3-4. Half Duplex Modem Round Trip Delay in a Shared Channel

Initially, a substantial proportion of the data collection was intended to be collected while the vehicles were in motion and traveling between cell sites. It quickly became apparent that there were a large number of "holes" in cellular coverage where the modem could not get adequate signal strength from the base station (and presumably vice-versa). Because of these holes, it was difficult to measure the effects of handoff vs. the issue of being outside of cellular coverage altogether. Interestingly enough, the lack of continuity between cells provided an excellent environment to examine the ability of the system to buffer and re-transmit messages using the TCP/IP protocol. Results of this examination are discussed below.

Dedicated Channels

As indicated earlier, there was only one dedicated channel available for testing. Therefore all of test scenarios had to be conducted without traveling between cell sites. Though data was collected at different times of the day, there was no noticeable increase in message delay due to rush hour users. Of course voice users were not a problem because they were not using the channel. However, there was some question whether or not a significant increase of CDPD traffic would occur during particular time periods.

As shown in Figures 3-5 and 3-6, round-trip times remained consistent throughout the day. Also of note, the many times the HDX modem round-trip time was about the same as the FDX modem (< 1 second). However, almost just as often it was approximately 6 seconds. At this time it is unclear why the HDX modem shows this bi-level distribution[2].

2 Two HDX modems where used during testing and both exhibited the same bi-level behavior. For this reason the possibility of having a faulty modem was ruled out.

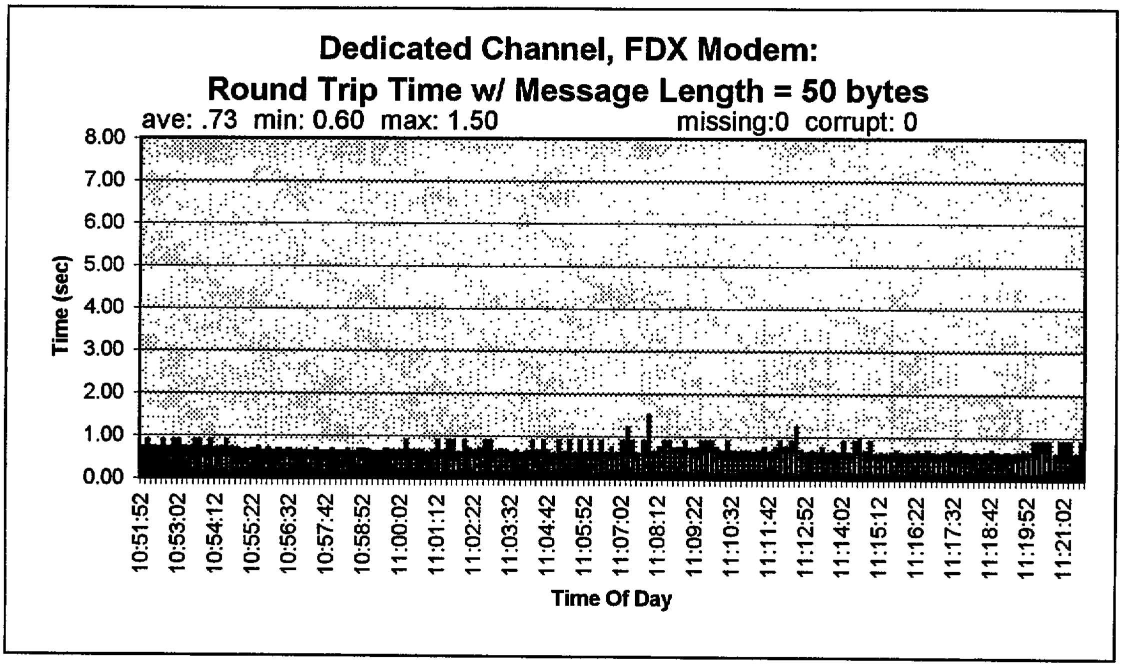


Figure 3-5. Full Duplex Modem Round Trip Delay in a Dedicated Channel (late morning)

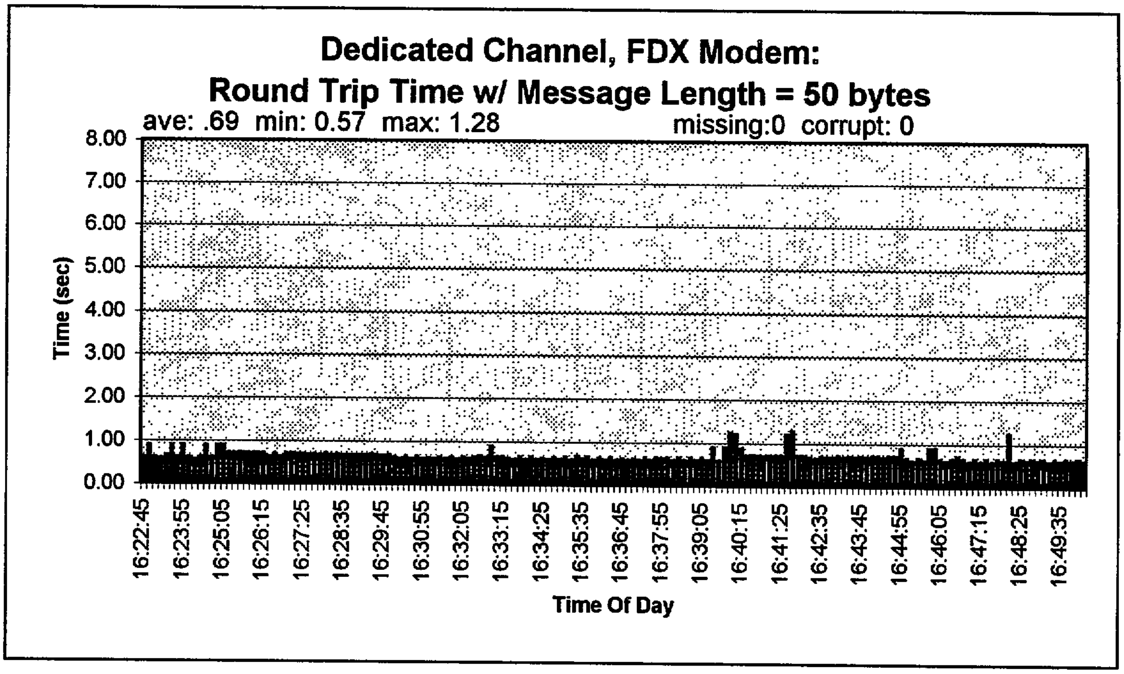


Figure 3-6. Full Duplex Modem Round Trip Delay in a Dedicated Channel (start of rush hour)

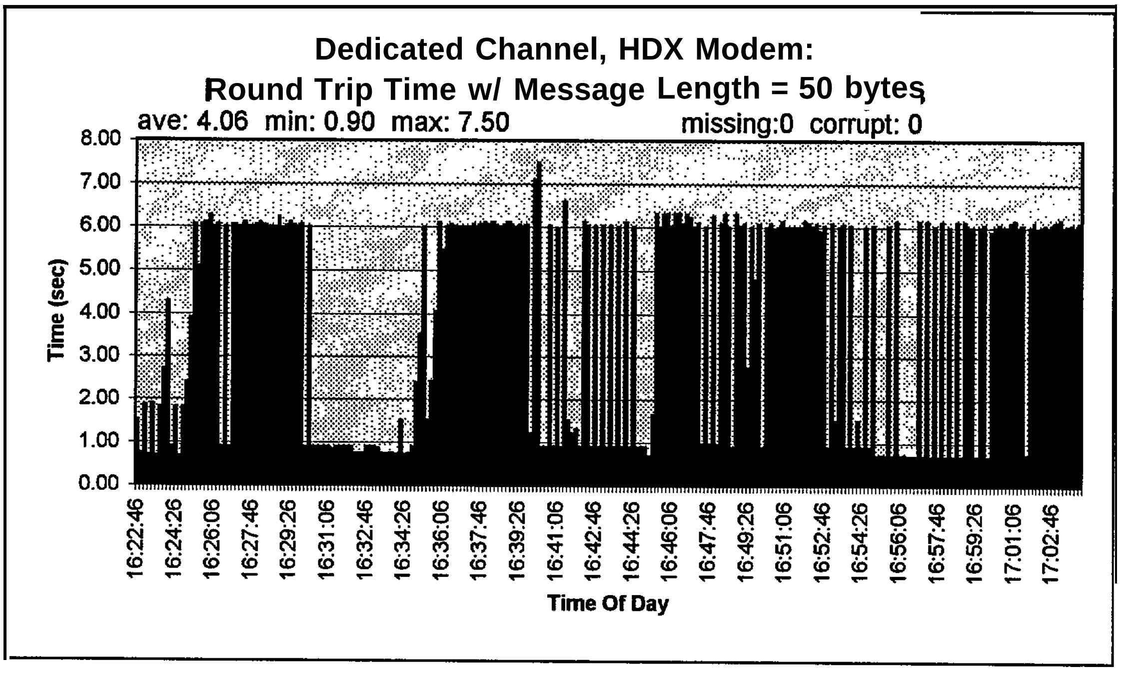


Figure 3-7. Half Duplex Modem Round Trip Delay in a Dedicatd Channel (start of rush hour)

3.1.7 TCP/IP

One of the characteristics of TCP/IP is the ability to establish a logical circuit between communications devices. Successful receipt of packets can be acknowledged, and unsuccessful reception can prompt re-transmission of packets. During the course of testing, M-ESs were in coverage holes and in some cases outside of a cell altogether. In order to examine system reaction, a M-ES was sometimes taken outside of cellular coverage, parked for a pre-determined amount of time, and then returned within the cell boundary. It was noted that message traffic could be buffered for up to 15 minutes, in some cases without destroying the logical connection between end systems. This resulted in a flood of packets once the M-ES returned to the cell site.

This may or may not be desirable, depending upon the application. Some ITS applications are time and position oriented. If a message a request is sent from an M-ES, but does not get processed for 15 minutes, the response may no longer be of use. And in some cases a “stale” response could be undesirable to the user. In other instances, such as vehicle tracking, it may be advantageous for all of the data to get through even if an extended delay occurs. The bottom line is that communications software has to be implemented with a particular application in mind.

CDPD can be used with the Universal Datagram Protocol (UDP) instead of TCP though UDP was not implemented in this test. UDP has substantially less overhead than TCP, but does not implement a logical connection. Therefore, there is no mechanism employed at this level to ensure that packets are re-transmitted when necessary. In order to successfully utilize UDP, the developer has to implement “communications smarts” at the application level. One advantage of using UDP is that the effective user datarate will increase because there is less overhead needed.

In some instances it may also be an advantage *not* to retransmit a packet. This is especially true when data is repeated or is so time critical that a re-transmitted packet may be of little use.

3.1.8 CDPD Summary

Dedicated channels seem to adequately support currently identified applications which require two-way wide-area communications. However, the type of CDPD modem selected affected over all performance. Specifically, the FDX modem showed a consistent round-trip time under 1 second whereas the HDX modem had round-trip times ranging from 1 to 6 seconds. For many ITS user applications 6 seconds may be adequate.

Shared channels are not appropriate for most ITS applications because of the difficulty which can be associated with acquiring a channel during times of peak voice traffic. Typically during evening rush hour and during lunchtime, the CDPD modems had a difficult time acquiring channels, and once they were on a channel, they often could not stay on it for any extended period of time. This resulted in a lot of time where the modem was simply searching around trying to find an available channel. Generally speaking, channel access is far from guaranteed. One might note that ITS data users will often need their applications the most during times of the day when voice traffic is the highest.

The CDPD application developer has a choice of implementing TCP and UDP. TCP has the benefit of keeping track of packets, but at the price of a higher overhead. The can translate to a lower effective user data rate. Additionally users are generally charged by the packet. Therefore it is economically advantageous to minimize the amount overhead used. UDP on the other hand does not directly support the tracking of packets. If a packet is lost, it provides no notification and the packet is not resent automatically. These features can be incorporated into the application layer, but adds complexity to software development.

3.2 220 MHZ CHANNELS

The FHWA has obtained access to five frequency pairs in the recently established 220 MHz mobile radio service band. The specific use of these frequencies is still to be determined. However, there are a number of issues which require investigation in order to determine their potential for ITS deployment. One of these issues is the manner in which 220 MHz systems could be implemented in vehicles. This section describes the results of a numerical study performed by ARINC to determine the effectiveness of automotive whip antennas to receive frequencies above their normal operating range. More specifically, the receiving characteristics of a 30 inch whip antenna at 220 MHz are compared with those characteristics at 100 MHz (the antenna design frequency).

3.2.1 Background

The receiving ability of an antenna system is both a function of the antenna's diiectivity and its driving point impedance (input impedance). For an antenna system to be effective, the system must maintain a strong directivity in the desired direction of reception (for automobiles, usually greater than 0 dBi and omni-directional) and a driving point impedance approximately equal to that of the receiver (usually 50 ohms). Failure of an antenna system to meet either of these requirements will result in a poor receiving system. For antenna systems mounted on automobiles, these characteristics (diiectivity and input impedance) are functions of the highway conditions on which the automobile is operating. Depending on the construction of the highway and the weather conditions, the highway may have electrical properties that vary from free space (no effect) to a perfect metal ground plane (full reflection).For this reason, all of the following analysis are performed over a perfect metal ground plane and in free space to provide upper and lower bounds on the antenna's performance characteristics. The differences between the upper and lower performance bounds between 100 and 220 MHz is then used to evaluate the ability of the whip antenna system to receive 220 MHz.

3.2.2 Approach

The antenna analysis was performed by generating a 3-dimensional wire mesh model of a Ford Taurus. The Ford Taurus was selected simply as a common automobile which may need to receive 220 MHz in the near future. The dimensions for the automobile were obtained from Viewpoint Datalabs (www.viewpoint.com) and the model was meshed at approximately 8 inch resolution. The meshed model is shown in Figures 3-8 and 3-9. The geometry of the models is as follows. The Z-axis is normal to the car roof, and the X-axis is normal to the rear of the car. The angle Phi moves about the car counter clock wise in the XY plane with Phi=0/360 degrees pertaining to the rear of the car and Phi=1 80 degrees pertaining to the front of the car. The angle Theta is measured from the Z-axis with Theta=90 degrees pertaining to the horizon.

Four numerical analyses were performed: the automobile in free space at 100 MHz, the automobile above a perfect metal ground plane at 100 MHz, the automobile in free space at 220 MHz, and the automobile above a perfect metal ground plane at 220 MHz. For the two analyses performed in free space, the far-field antenna patterns were recorded about the center of the automobile in 5 degree steps. For the two analyses performed above the ground plane, the far-field antenna patterns were calculated in 5 degree steps only for angles above the horizon because of the absence of electric fields below the ground plane. For each analysis both the horizontal and vertical polarizations were computed; however, only the vertical polarization was analyzed in depth because of the dominant vertical polarization of the whip antenna. 2-dimensional images for each of the four far-field antenna patterns are depicted in appendix A. In addition to the far-field patterns, the driving point impedance of the antenna was computed for each analysis. The combination of the predicted antenna patterns and the calculated driving point impedance were then used to evaluate the ability of the existing whip antenna to receive frequencies higher than its design frequency.

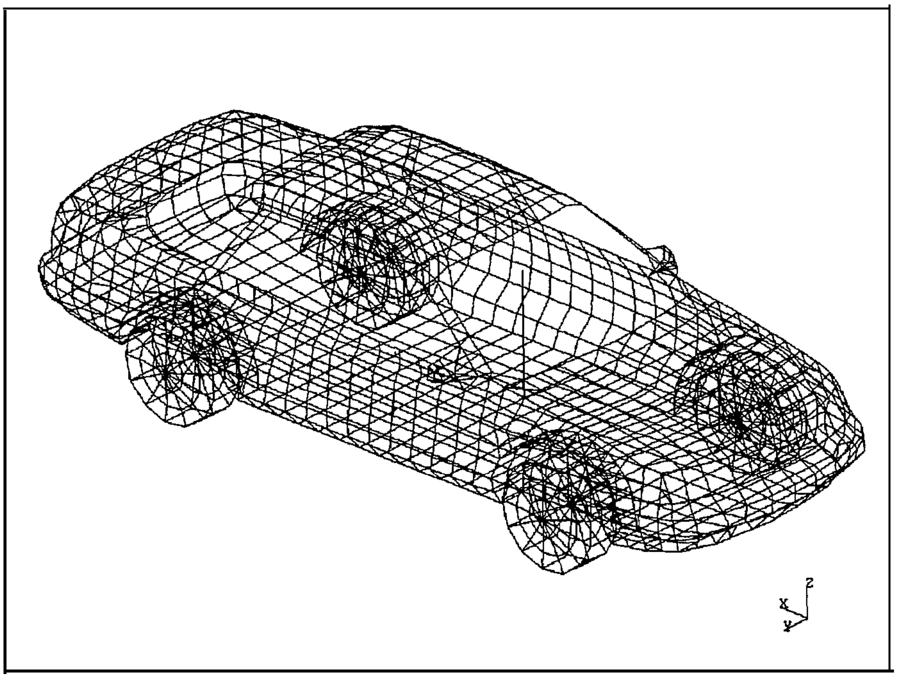


Figure 3-8. Wire Mesh Model - 3D View

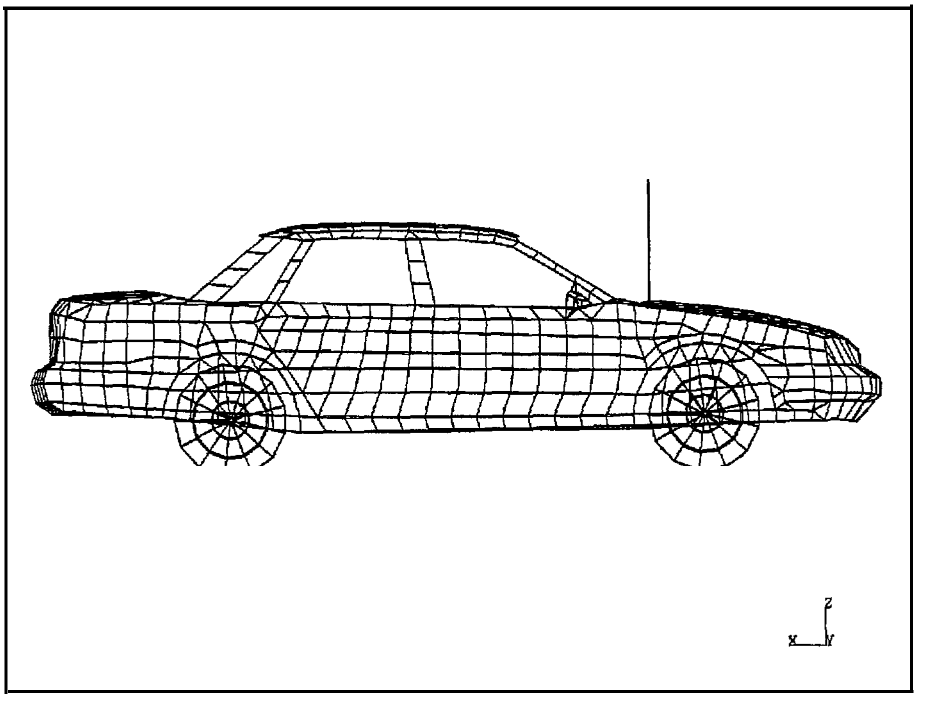


Figure 3-9. Wire Mesh Model - Lateral View

3.2.3 Results

Figures 3-10 through 3-13 depict the azimuthal (Phi angle) far-field antenna patterns obtained fiom each of the four analyses. The Theta angle was held constant for each plot at Theta=85 degrees (5 degrees above the horizon). All of the far-field patterns present depict the dominant vertical polarization. Figure 3-10 illustrates the maximum and minimum far-field patterns (directivities) predicted for the whip antenna at its design frequency (100 MHz). The maximum pattern directivity is obtained from the ground plane case. Figure 3-11 illustrates the maximum and minimum far-fields patterns (directivities) predicted for the whip antenna at 220 MHz. The maximum pattern diiectivity is also obtained from the ground plane case; however, both patterns contain a variety of peaks and nulls. Figure 3-12 shows a comparison of the antenna diiectivities at 100 and 220 MHz in free space. While the pattern obtained at 220 MHz is predominantly greater than the pattern obtained at 100 MHz, the 220 MHz pattern does contain significant nulls which may interrupt communications. Figure 3- 13 shows a comparison of the antenna directivities at 100 and 220 MHz over a ground plane. The interaction of the ground plane amplifies the peaks and nulls observed in Figure 3-12, thus increasing the probability of interruptions in communications.

Table 1 provides the input impedances for each of the four antenna test cases. As may be seen from the table, the driving point impedances of the antennas are not sensitive to changes in the ground conditions; however, the driving point impedances (particularly the reactive component) of the antennas are extremely sensitive to changes in frequency.

Table 3-1. Whir, Antenna Input Impedances

Input Impedance	Free Space	Ground Plane
100 MHz	84+j23 Ohms	90+j22 Ohms
220 MHz	171-j270 Ohms	166-j23 7 Ohms

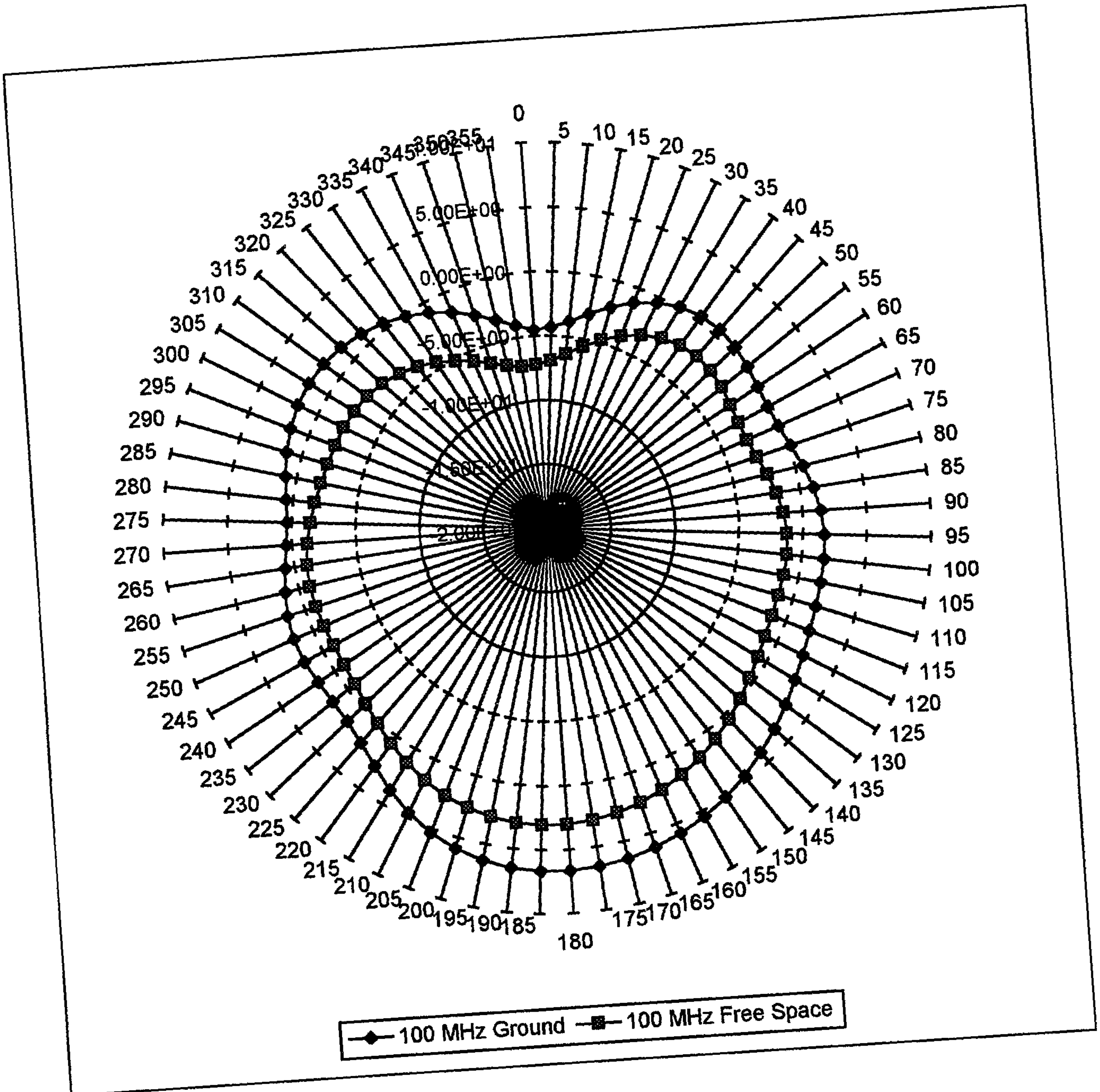


Figure 3-10. Far-Field Patterns for Whip Antenna at 100 MHz

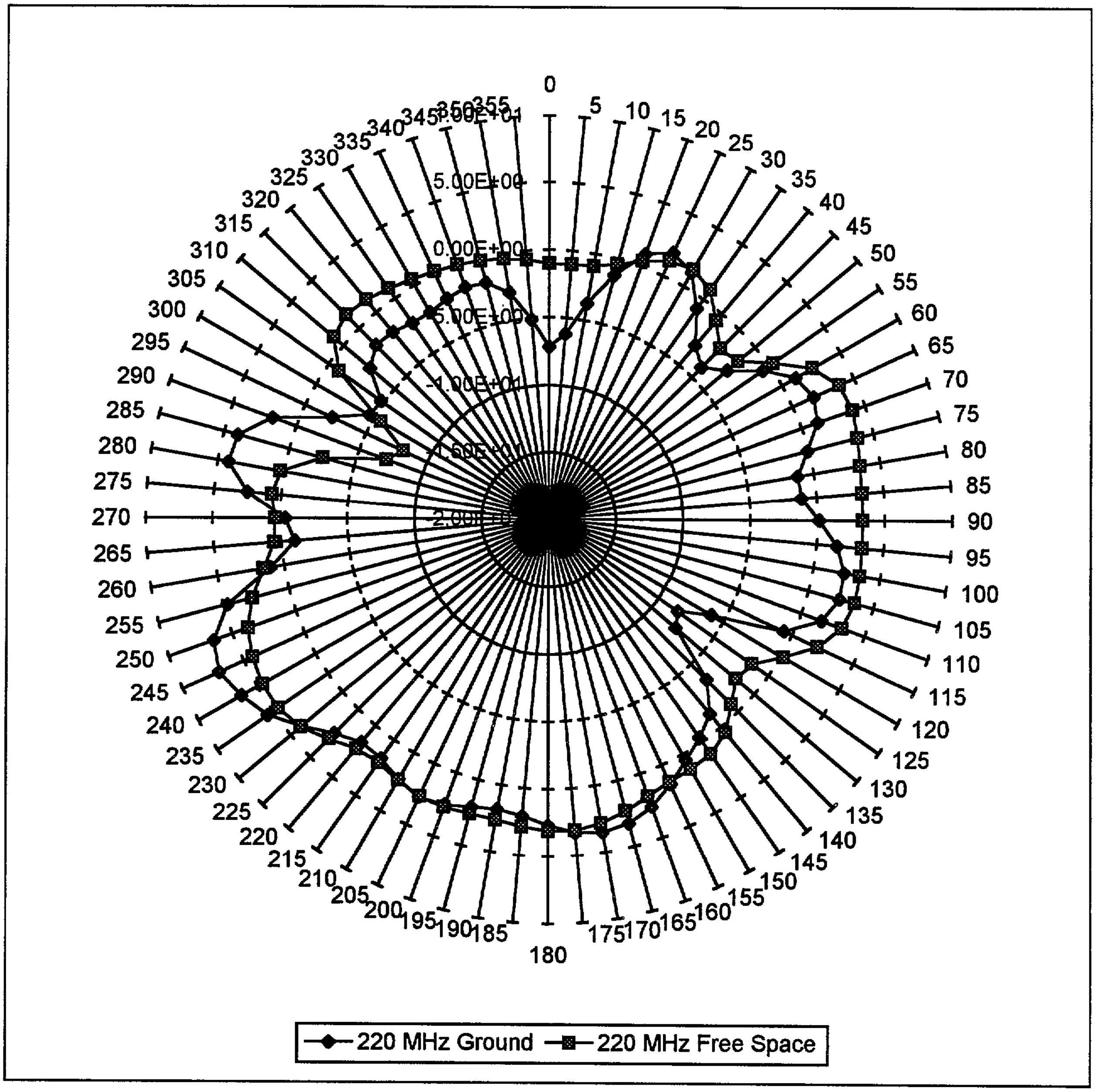


Figure 3-11. Far-Field Patterns for Whip Antenna at 220 MHz

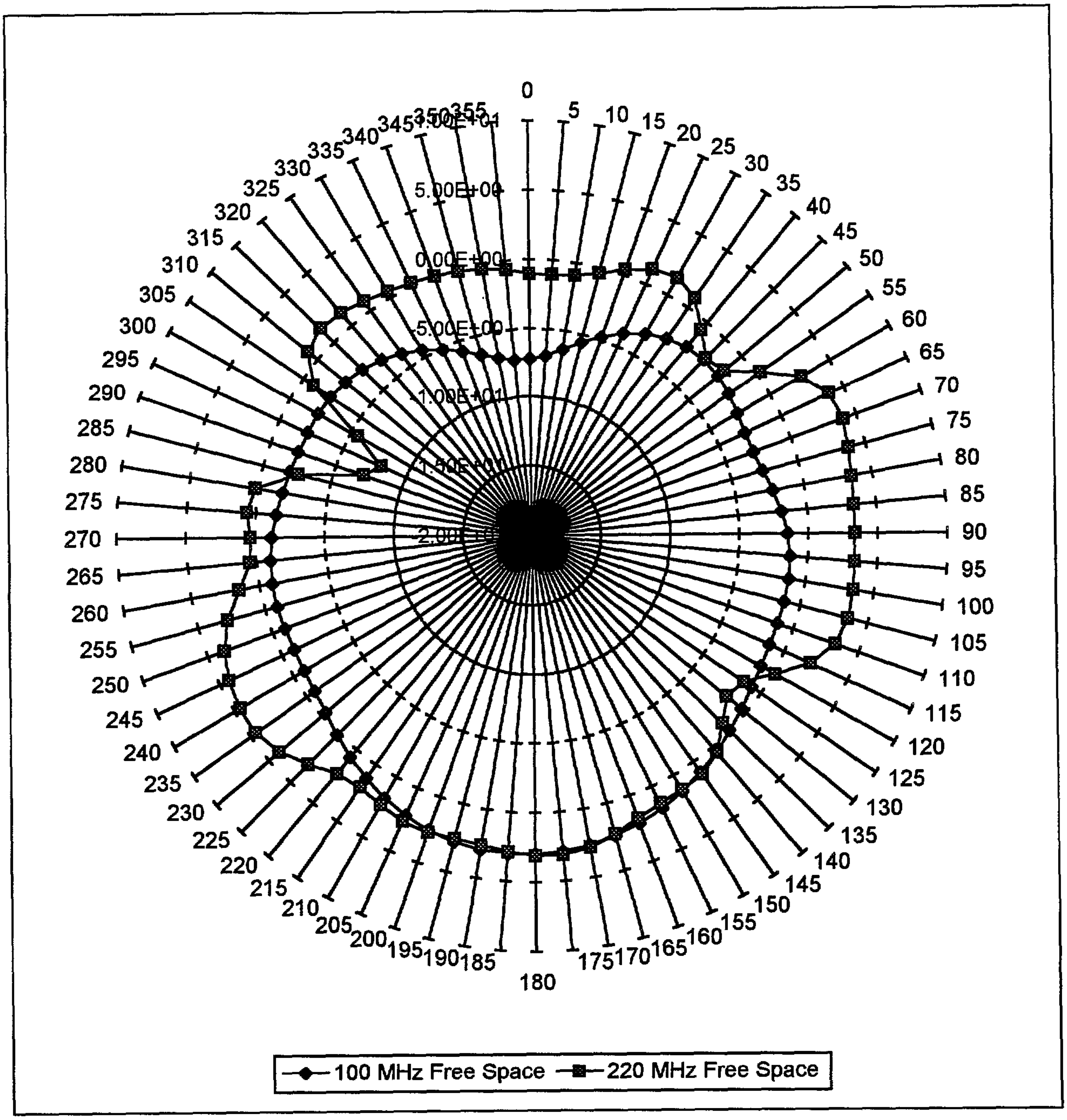


Figure 3-12. Far-Field Patterns for Whip Antenna in Free Space

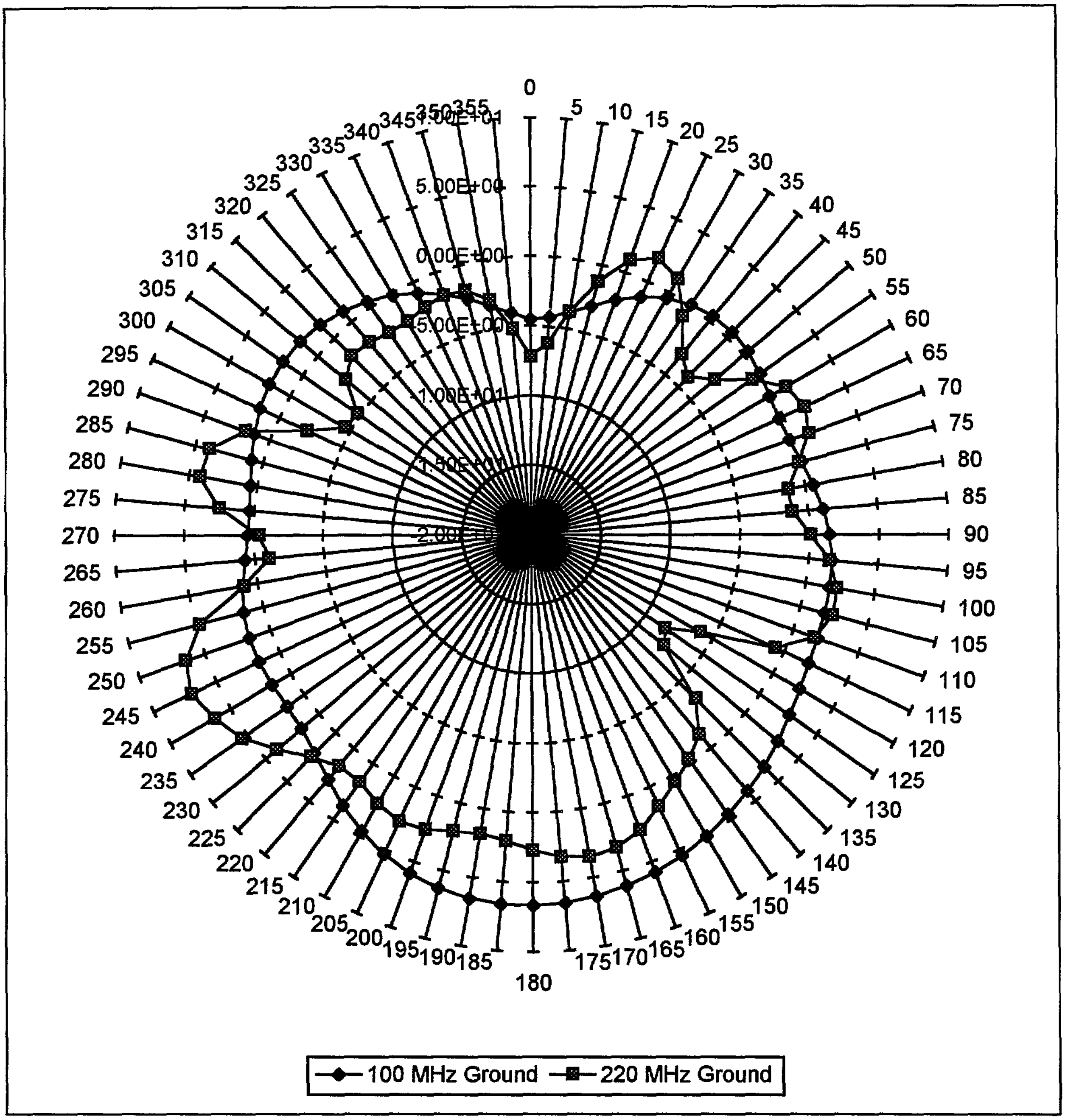


Figure 3-13. Far-Field Patterns for Whip Antenna over Ground Plane

3.2.4 Conclusions

Based upon the findings of the described study, ARINC concluded that the existing whip antenna system (designed to receive 100 MHz) can be used to receive 220 MHz; however, the following problems will exist. First, communications may experience fade outs and interruptions due to the nulls existing in the antenna patterns. The severity will be dependent upon the road surface and weather conditions. Second, the received signal may vary in strength by as much as 10 dB due to the rapid changes in the antenna patterns. Third, because of the whip antenna's large input impedance (200+ reactive ohms) an antenna matching network will be required to avoid severe miss-match loss at the antenna connection, These problems can be avoided by the simple introduction of a high frequency trap located at the center of the whip antenna. Such a trap would effectively divide the existing whip antenna into two antennas; one designed for 100 MHz and one designed for 220 MHz. Since the antennas are designed for the frequencies which they are receiving, the problems discussed above would be alleviated. For these reasons, a more in depth study into the use of trapped antenna technology is recommended if the 220 MHz technology is to be pursued.

3.3 PCS AND OTHER EMERGING WIDE AREA SOLUTIONS

ARINC has been monitoring the development of an array of wireless technologies by directly interacting with industry "players". This has included many one-on-one conversations with manufacturers, developers, and systems integrators; conference participation; research via industry literature; and interaction with academic institutions who are performing research of their own.

Quite a few wide area communications services are currently available and it is extremely apparent that many more are on the horizon. The majority of the ITS community feels that wide area communications technologies will continue to develop without needing tremendous investment in time, research, or money directly from FHWA. ARINC continues to support this position. Between terrestrial PCS, CDPD, satellite, and SMR, a large amount of communications infrastructure is being introduced throughout the country.

There are a number of emerging technologies competing for the commercial marketplace. The anticipated suplus of wireless services appears capable of handling ITS requirements. However, because the ITS data load will only be a small percentage of the service providers business, there is little incentive to provide special safety critical, low latency communications ability. Therefore it is likely that safety critical applications will require dedicated services (such as the dedicated CDPD services being negotiated by several police departments) to ensure access.

3.3.1 Personal Communications Systems (PCS)

Spectrum for PCS was made available for allocation by the FCC, partially in response to Congress's urging to convert federally held spectrum to commercial use, and partially in response to the urgings of several entrepreneurs who foresaw the use of "micro-cellular" technology to make truly portable (pocket size) telephones a reality. The FCC created a series of bands for PCS, and designated both narrowband (presumably for paging type applications) and broadband (voice or data services, for example) "blocks" of spectrum. Table 3-2 depicts the PCS broadband blocks; the narrow band blocks are in the 901- 902, 930-93 1, and 940-941 MHz bands.

Table 3-2. Wideband PCS Blocks			
Block	**Bandwidth**	**License Area**	**Frequency (MHz)**
A	3oMHz	Maior Trading Area	1850-1865/1930-1945
B	30 MHz	Major Trading Area	1870-1885/1950-1965
C	3oMHz	Basic Trading Area	1895-1910/1975-1990
Unlicensed	20 MHz	Nationwide	1910-1930
D	10MHz	Basic Trading Area	1865-1870/1945-1950
E	10MHz	Basic Trading Area	1885-1890/1965-1970
F	10MHz	Basic Trading Area	1890-1895/1970-1975

Narrowband PCS is of interest to ITS for applications where high latency of data is permissible, such as dissemination of transit or rail schedules or other non-time critical information

The interest in Broadband PCS by the telecommunications industry has been sincere enough that the auctions for Blocks A and B have netted the US Treasury billions of dollars, and the other blocks appear to be of the same level of magnitude when factored for market size differences. Figure 3-14 shows the results of the first “wideband” PCS auction, for Blocks A and B.

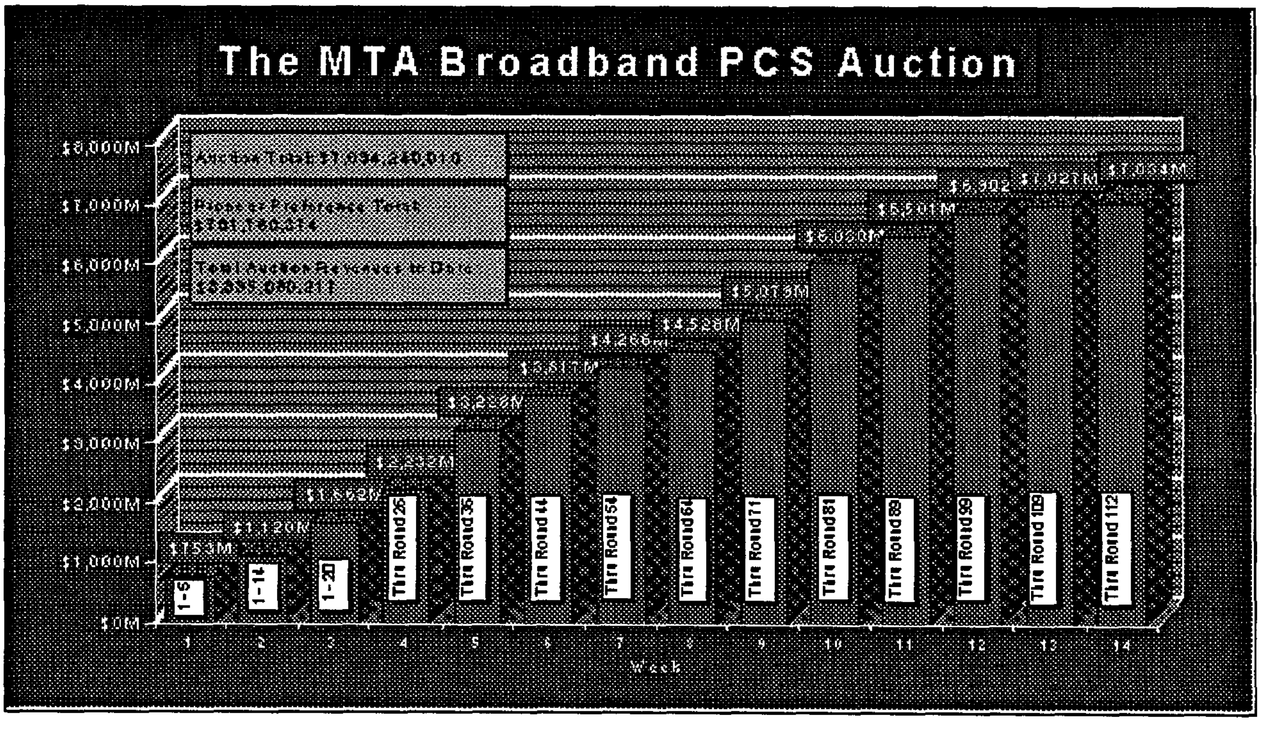


Figure 3-14. Summary of PCS Block A & B Auction Blocks

(Source -http:// www.fcc.gov/wbt/)

One note of caution must be expressed. There will likely be an extended period of time in which a multitude of different communication standards will be used in PCS (there are seven or so major standards being coordinated for PCS, although two of these are for low mobility application) , and this will restrict one's ability to obtain "seemless" service with PCS until either a single standard emerges nationally, or equipment capable of emulating multiple standards is available. Also, for ITS, the major interest in PCS is for mobile data applications. To date, there has been only limited interest in the PCS community in developing other than digital voice services - largely because there is not as large a perceived market for mobile data services as for voice.

3.3.2 Specialized Mobile Radio (SMR)

Traditionally, specialized mobile radio refers to shared trunking radio services for voice-only applications. This definition SMR has been extended to include commercial two-way wide area radio networks providing both data only or integrated voice/data services. The significant commercial networks currently deployed include 1) ARDIS, owned and operated by Motorola, 2) RAM Mobile Data, and 3) Nextel, operated by McCaw Communications. ARDIS and RAM provide two-way packet switched data-only communication services in all significant metropolitan areas across the country. Nextel is early in the development and deployment of its Enhanced Specialized Mobile Radio (ESMR) network which will offer integrated voice dispatch, wireless phone, text messaging, and two-way data transmission capabilities based on Motorola iDEN technology.

Spurred by Congressional activity in 1993 to reclassify SMR services, the FCC decided to divide the 900 MHz band into 20 ten-channel blocks in each of the 51 Major Trading Areas (MTA[3]). Earlier in 1996, the FCC auctioned the 1,020 licenses. The results of the auction process, while perhaps not as spectacular as those of the PCS spectrum nevertheless indicate that industry believes there is a market for SMR and ESMR services.

3 MTA is a Rand McNally term used to describe the geographic division of population areas.

Federal Communications Commission SMR Auction

Final Results

Net Revenue Excl. Withdrawal Payments: $204,267,144

Auction Closed in Round **168** Net Revenue: $311,690,531

Top 10 Current High Bids by Bid Size

MTA		Market	Round	Current High Bidder	Net High Bid
15	C	Miami	132	Paging Network of America, Inc.	$ 1,930,000
2	F	Los Angeles	81	Motorola SMR, INC.	$ 1,850,000
15	I	Miami	121	Paging Network of America, Inc.	$ 1,835,000
2	N	Los Angeles	101	Paging Network of America, Inc.	$ 1,660,000
15	F	Miami	129	Industrial Communications & Electroni	$ 1,467,900
2	K	Los Angeles	98	CHM, Inc.	$1,431,909
13	D	Tampa	93	Fleet Talk, Inc.	$1,418,000
2	D	Los Angeles	106	Motorola SMR, INC.	$1,381,000
4	D	San Francisco	87	Paging Network of America, Inc.	$1,375,000
5	D	Detroit	73	Fleet Talk, Inc.	$1,371,000

Top 10 Bidder Activity by Dollar Value of High Bids

Bidder Name	$ of Net High Bids	# of High Bids
Paging Network of America, Inc.	$45,534,000	126
Geotek Communications, Inc.	$30,965,290	181
FCI 900, Inc.	$29,079,464	177
Motorola SMR, INC.	$15,306,000	37
Fleet Talk, Inc.	$14,265,137	63
SGI Communications, Inc.	$9,691,650	25
Centennial Communications, Corp	$5,065,769	43
RAM Mobile Data USA Limited Partner	$4,715,135	83
Industrial Communications & Electroni	$4,108,095	13
American National Communications Co	$3,415,301	7

FCC Auctions Division 4/15/96

Figure 3-15. SMR Auction Results

(Source -http:// www.fcc.gov/smr/)

4. DEDICATED SHORT RANGE COMMUNICATIONS

This section synopsises the results of investigations into the operations and resulting RF spectrum requirements for DSRC. The interested reader should refer to the report "Spectrum Requirements for Dedicated Short Range Communications (DSRC), *Public Safety and Commercial Applications"*, July 1996 for a complete discussion of the subject.

Our analysis focused on three major issues: feasibility, capacity, and spectrum management.

On the issue of feasibility, the analysis demonstrated the following key points:

- Beacon - tag systems and RF beacon - tag systems in particular, have the underlying capability to support the ITS DSRC role. Our analysis indicates that the maximum data rate required to support ITS operations is less than the data rate supported by beacons.

- RF Beacons are not unduly affected by the normal environmental parameters encountered in highway situations, with the exception that standing water or compacted snow can reduce link operating margins in 5.8 GHz operations.

From the perspective of capacity, a careful consideration of deployment scenarios and functional groupings of ITS DSRC requirements has determined that eight channels will be needed to completely service foreseen requirements.

This is based upon the above eight channels, and a determination of the required channel bandwidth of 6 Mhz.

The channel bandwidth requirement value is based on:

- 600 Kbps data rate capability in the DSRC link.

- The path from Reader to Tag typically employs a simple modulation scheme to minimize the cost of the tag.

- Channel spacing required to prevent interference with adjacent channels and other services.

Reductions in the channel spacing can be achieved by trading spectrum for roadway efficiency or tag cost. More complicated and spectrally efficient modulation schemes will increase tag cost to the user, effectively "raising the entrance fee" into ITS. Restrictions on roadway operations, which would either increase the "read" zone or reduce the number of vehicles that could occupy the zone, could reduce the necessary data rate and hence spectrum. However, these restrictions would limit the overall highway efficiency, in direct opposition to the purpose of ITS.

DSRC applications, including In-Vehicle Signing, International Border Clearance, Electronic Clearance, Safety Inspection, Fleet Management, AEI, and Freight Management, Intersection Collision Avoidance, Emergency Vehicle Signal Preemption, Transit Vehicle Data Transfer, Traffic Network Performance Monitoring, Traffic Information Dissemination, Automated Highway System-to-Vehicle Communications, Electronic Toll Collection (ETC), and Parking Payments are being defined in the ITS architecture as functions to be implemented with RF beacon technology.

Even though installations of the applications were consolidated where possible, full implementation will require more bandwidth than is available in the current LMS 902 to 928 MHz band. Therefore, eight DSRC channels, 6 MHz each, should be allocated to the 5.850 to 5.925 GHz band. Intermodal Freight Management, which is already substantially deployed and involves equipment with different operating requirements, should continue to operate in the 902 to 928 MHz band. Electronic Toll Collection (ETC), Commercial Vehicle Operations (CVO), Traffic Network Performance Monitoring, Parking Payments and related activities which are already deployed in many areas, should continue to operate in the 902 to 928 MHz band until the user and manufacture communities decide to migrate to the 5.850 to 5.925 GHz band. New applications, such as In-Vehicle Signing (Hazard Warning), Emergency Vehicle Signal Preemption, Transit Vehicle Signal Priority, Transit Vehicle Data Transfer, Intersection Collision Avoidance, and Automated Highway System-to-Vehicle Communications should have the 5.850 to 5.925 band made available for use as soon as possible.

The 5.850 to 5.925 GHz band is generally free of interference and would provide a protected place for DSRC applications, many of which are safety-critical or safety-enhancing, to operate.

These results notwithstanding, there are several issues which would benefit from further empirical research and testing.

First, it should be noted that our analysis is based upon one approach to DSRC - a derivative of a Center for European Normalization (CEN) developed standard. While several US manufacturers have embraced this standard as a starting point for US DSRC standardization, not all manufacturers agree, and as a result, no US standard has yet emerged. The chosen standard will potentially affect the actual amount of spectrum required. The analysis conducted under this task is felt to represent a conservative approach, so that what ever standard is selected should be capable of satisfying all the applications within the 75 MHz recommended allocation. However, there should be further study of the spectral occupancy issues which arise from the various proposed standards. The information obtained from such studies will be invaluable in supporting spectrum allocation action before the FCC.

Second, there is considerable effort still required to definitize the operating concepts for several of the potential DSRC applications. The major uncertainty is the required range for DSRC when satisfying such applications as intersection collision warning, in-vehicle signing, and priority vehicle signal request. The range requirements will have an effect on frequency re-use distance, as well as a potential affect on the selected DSRC standards.

5. VEHICLE TO VEHICLE COMMUNICATIONS

This section outlines ARINC's concept of a vehicle-to-vehicle communication system for use in Intelligent Transportation Systems. The proposed system is designed to maximize the usage of an RF network based communication system such that the features of collision avoidance and driving environment visualization are included in the system. The network utilizes a carrier sensing - multiple access/collision avoidance (CSMA/CA) protocol with a fixed length message. By restricting the range over which each vehicle can transmit/receive, a floating local area network (LAN) is created such that only vehicles in the immediate vicinity of one another are in direct communication. This particular design provides for a pseudo-infinite number of mini-LANs which appear to follow traffic. In addition to the creation of these multiple floating LANs, each of the vehicles will independently monitor the flow of the messages being passed from one vehicle to another and use this information to ascertain information about the surrounding traffic. To monitor the message flow, each vehicle in the LAN is equipped with the following signal processing hardware: a direction finding antenna system a down range sensor, and a Doppler processor (see Figure 5-l).

The driving environment about each vehicle is determined from the communications which exist about the vehicle via the onboard signal processing equipment (the direction findiig antenna, the down range sensor, and the Doppler processor). The information obtained from the onboard signal processing equipment is combined with the information received via the existing communications and presented to the vehicle operator by a central processing unit. The information could be presented in a pictorial manner which would allow vehicle operators to visualize the driving environment about them. The direction finding antenna is used to locate the relative angle of the current vehicle transmitting information. The down range sensor is used to obtain the relative distance associated with the line of bearing obtained by the direction findiig antenna. The Doppler processor is used to identify the relative velocity of the transmitting vehicle. Since each vehicle operating in the LAN transmits at regular intervals and the communication protocol requires that only one vehicle may be transmitting a particular time, the onboard processor requires little computation abiity to track and display the location of the vehicles about it. The CSMA/CA networking protocol is outlined in Section 5.1. Sections 5.2 through 5.4 discuss the direction findiig antenna system, the down range sensor, and the Doppler processor, respectively. Each of the three sub-systems are discussed based upon "off-the-self' component capabilities for simplicity during proof-of-concept and prototype development.

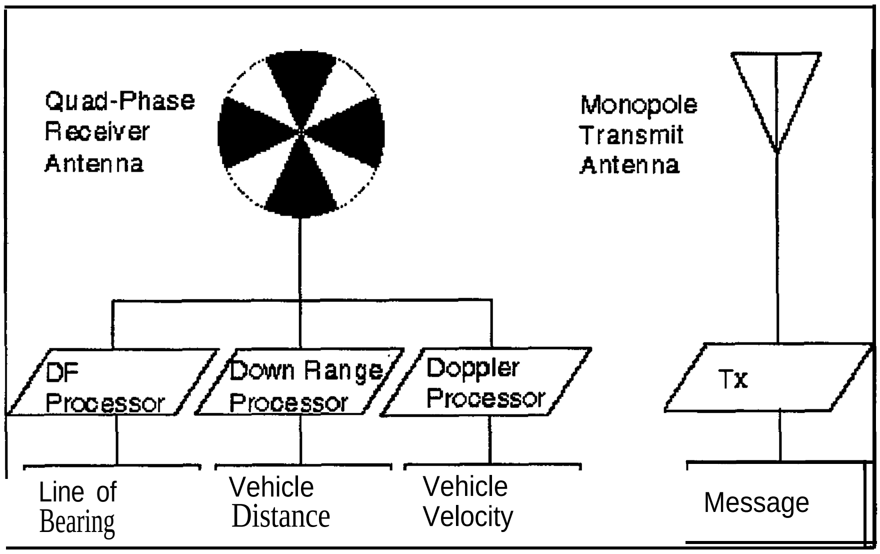


Figure 5-1. Proposed Vehicle-to-Vehcile Communication System

5.1 VEHICLE TO VEHICLE NETWORKING WITH THE CSMA/CA COMMUNICATION PROTOCOL

A vehicle operating in an ITS environment needs to have the ability to transmit and receive information from the other vehicles operating about it in a flexible manner which permits autonomous operation. A communication network must be created that supports global message passing in various environments free of interference from other vehicles.The network must support near instant access and multiple users. The network must also appear to be centered about each vehicle and appear to be dedicated to each vehicle. For all of these reasons, the CSMA/CA networking protocol is selected as a basis for the following ITS prototype communication based system. In addition, the CSMA/CA protocol is currently being considered as the standard for wireless LANs by the IEEE.

Each vehicle operating in the given floating LAN will broadcast a fixed length information update to the other vehicles about in regular intervals provided that no other vehicle in the immediate vicinity is transmitting at that particular time. Each vehicle's transmit mode will work as follows. When the pre-set time between the vehicle's updates has elapsed, the vehicle will listen to see if any other vehicles are transmitting information at this particular time. Since the vehicle is in receive mode as a default state, this check is just a matter of checking the receiver for the presence of a carrier. If the transceiver detects the presence of a carrier, it will not transmit until the carrier is no longer present and then proceed with its transmission. If the transceiver does not detect the presence of a carrier, the transceiver will wait a short random time and recheck for the presence of a carrier. If the presence of a carrier is still not detected, the transceiver will begin transmission. The additional random wait time and second carrier check is used as a method for collision avoidance.' After transmission, the vehicle will then return to its receive mode for its required wait time before it attempts to transmit its next information update. Because the wait time is computed after the fixed length message has been delivered, and not based upon a pre-set schedule, a certain amount of randomness is automatically introduced into the transmit times of each vehicle operating in floating LAN. The combination of random transmit times, quick turn around times between receive and transmit mode, and message lengths which are short compared to the wait time between updates allows for information transfer to occur between the vehicles with a minimum of collisions and without any complex login/out procedure. Figure 5-2 provides an illustration of the selected protocol.

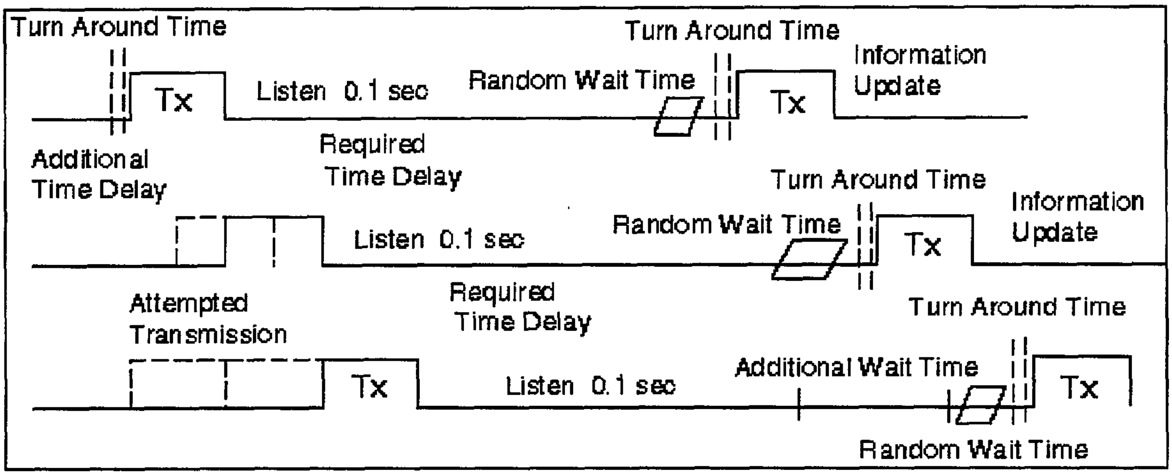


Figure 5-2. Information Protocol

Each vehicle in the floating LAN is capable of identifying the distance, relative angle, and relative velocity of the other vehicles in the floating LAN. This information is analyzed by the vehicle's onboard processor and presented to the vehicle operator. The onboard information processor will act as follows. First, the vehicle will DF the received message signal to provide angular resolution on the transmitting vehicle. Next, the information processor will perform an amplitude range measurement on the received signal to obtain the distance of the transmitting vehicle. The information processor will then perform a Doppler analysis on the received signal to obtain the relative velocity of the transmitting vehicle. The processed information will be utilized by the vehicles collision avoidance system and retransmitted to the other vehicles in the floating LAN. The retransmission of the processed information provides the network with the unique feature such that the detection abilities of a given vehicle actually increases as the traffic about the vehicle increases. The retransmission of the processed information also serves as an iterative filter which reduces errors in the detection and location to the surrounding vehicles. The information processor will use the received information from each of the surrounding vehicles to validate the position of an existing vehicle, correct the position of an existing vehicle, or add a new vehicle to the list of existing vehicles. The entire communication process is treated as an iterative converging process which utilizes all of the processors about it. Because the resolution of this system (or any system) is not perfect, it would be prudent to occasionally include another sensor's view of the vehicle situation. Tracking radars, located approximately every 20 miles (for high density highways) can be included into the network to provide "ground truth" to the passing vehicles via the existing communication network. This additional infrastructure based sensor will provide a reference point for the floating LAN and reduce the probability of errors propagating along the network.

The system requires information describing each vehicle to be transferred by all vehicles operating in the floating LAN. The message describing each vehicle will contain the vehicle's location within 10 cm, the vehicle's heading within one degree, the vehicle's velocity within 10 cm/s, and the vehicle's acceleration within 10 cm/s^2. Including additional bits for error correction coding, a message size of approximately 256 bits is required. The total message length passed by each vehicle is the length of the message describing each vehicle (256 bits) times the number of vehicles operating in the floating LAN. This breakdown is presented below:

Vehicle Address:	10 number address	34 bits
Location:	DD.MM.dm, DD.MM.dm	64 bits
Heading:	1 degree	16 bits
Car Dimension:	128 dm, 512 dm	32 bits
Velocity:	4 e6 dm/s, 4 e6 dm/s	44 bits
Acceleration:	128 dm/s^2, 128 dm/s^2	14 bits

A representative floating LAN configuration can be defined as a center vehicle surrounded by eight other vehicles (see Figure 5-3). For this particular LAN configuration, each vehicle would be required to pass nine message (one describing itselfand eight describing the vehicles about it). The total message length passed by each vehicle would be 2,304 bits and the total information passed within the LAN per update would be 20,736 bits. Human performance studies have indicate that on the average a human being can not react faster than 0.1 seconds. This suggests a refresh rate of 10 updates per second and an information transfer rate of 207,360 bits per second. Due to the nature of the CSMA/CA protocol, for the network to appear collisionless, the network must operate at approximately 10 times the rate at which information is required to be transferred. This rule of thumb places the required network speed at approximately 2 Mps. This minimum speed requirement is consistent with current CSMA/CA hardware. Accordingly, as the network size (i.e. number of vehicles) and message length increase, the network speed will also have to increase accordingly.

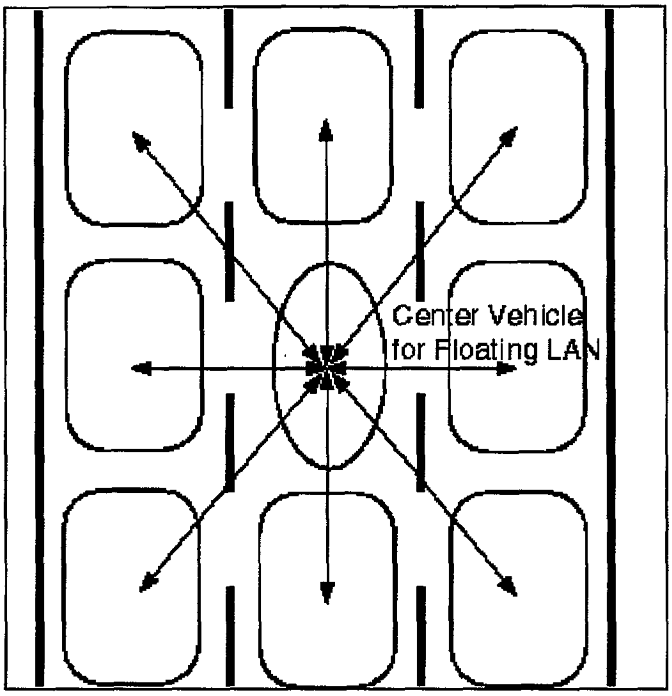


Figure 5-3. Representative Floating LAN Configuration

5.2 DIRECTION FINDING ANTENNA SYSTEM

A quad-phase patch antenna configuration is recommend as a basis for the direction finding antenna system required by the floating LAN design. The quad-phase antenna configuration consists of four resonant patches located 90 degrees apart (see Figure 5-4). The patches are mounted on a dielectric substrate which in turn is mounted upon a ground plane. The antenna is only a few millimeters in height, allowing it to be installed upon the roof of most vehicles with minimal aerodynamic and cosmetic degradations. The antenna may be recessed into the vehicle roof or a small raydome may be used to seal the antenna to the roof. For a carrier frequency of 5.8 GHz, the direction finding antenna dimensions are approximately 15 cm by 15 cm.

The direction finding processor can operate in one of two modes: carrier phase analysis or time of arrival message analysis. In the carrier phase analysis mode, the phase of the carrier at each of the four resonant patches is compared to one another. Because the resonant patches are located 90 degrees apart, the relationship between the four recorded phases yields an unique solution for the direction of the incident signal. In the time of arrival message analysis mode, the message received by each of the four resonant patches are correlated to obtain the relative time difference in the arrival of the message at each of the four resonant patches. Again, because the resonant patches are located 90 degrees apart, the relationship between the time of arrival of the message at each of the resonant patches yields an unique solution for the direction of the incident signal.

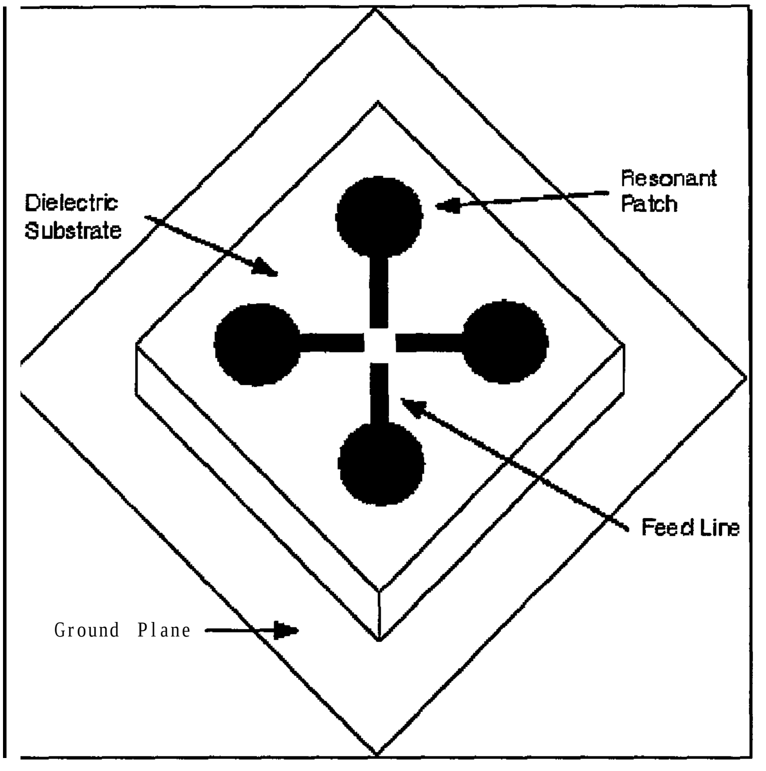


Figure 5-4. Quad-Phase Patch Antenna Configuration

While both modes of operation perform equally well under laboratory conditions, the presence of severe multipath and the combination of high noise levels and short message lengths places different limitations on the direction finding accuracy of each mode of operation. Presence of multipath is the fundamental limitation for the carrier phase comparison mode. Multipath degradations occur when additional versions of the transmitted signal reach the direction findiig antenna via multiple reflections from other structures (usually urban buildings). Because the direction finding antenna is expecting only a single signal, the antenna returns an angular direction corresponding to the amplitude weighted average of the received signals. The effect of noise on the correlation process is the primary limitation for the time of arrival message comparison mode. Ideally, the correlation of the messages received at each of the four resonant patches will filter out the noise received at each of the patches (noise being uncorrelated); however, if the message lengths are short and the resonant patches are located near one another (both are true in the currently proposed system) the amount of noise removed by the correlation process is significantly reduced. Hence, the presence of high noise levels at the receiver may introduce large errors in the predicted angular direction.

Both of these direction finding limitations need to be addressed in the overall floating LAN design. Multipath degradations can be minimized by reducing the power transmitted such that signals propagating beyond the floating LAN of interest attenuate below a pre-set level of detection. Errors introduced by noise during the correlation process can be minimized by increasing the lengths of the messages transmitted by each vehicle. Finally, the direction finding antenna may be operated in both modes, providing a self check on the predicted angular direction.

5.3 DOWN RANGE MEASUREMENT SYSTEM

The relative distance between each vehicle operating in the floating LAN is computed using a down range measurement system. The down range system provides the radial distance that each transmitting vehicle is from the receiving vehicle and provides range gates by which each vehicle operating in the floating LAN may be categorized (see Figure 5-5). The system simply consists of an RF power meter tuned to the carrier frequency of the floating LAN and a processor which converts the received power level to the appropriate distance. The processor performs the conversion by utilizing an appropriate propagation loss model for the floating LAN carrier frequency. Figure 6 depicts the propagation loss curve for a carrier frequency of 5.8 GHz. A unique characteristic of propagation loss is the non-linear behavior of the rate of attenuation relative to distance. This characteristic may be easily exploited to obtain increasing range accuracy as vehicles approach one another. This feature ensures that vehicles in the immediate vicinity of one another are accurately described by the floating LAN system and greatly reduces the probability of vehicles colliding due to noise induced errors in the received signal level. For the propagation loss curve depicted in Figure 5-6, range accuracies increase ten fold between predictions made at 500 meters and 50 meters. Likewise, range accuracies increase another ten fold between predictions made at 50 meters and 5 meters.

The down range measurement system can be operated in one of two modes: absolute and diierential. In the absolute mode, the power at the receiver is averaged over a short period of time (significantly less than the relative speed of the vehicles) and the relative distance between the vehicles is computed directly by utilizing the known power of the transmitter, the antenna gains of the transmitter and receiver, and the computed propagation loss curve. In the differential mode, the power at the receiver is recorded over a longer period of time (ideally, relative motion should occur between the two vehicles) and the relative distance is obtained by fitting the recorded power curve to the computed propagation loss curve. While a priori knowledge of the transmitter power and the gains of the transmitting and receiving antennas is only required by the absolute mode, knowledge of these characteristics is useful to obtain a starting locating for the curve matching process used by the differential mode. Range errors obtained from the absolute mode of operation are primary due to noise bursts and multipath propagation distortion. Range errors obtained from the differential mode of operation are primary due to short signal durations and insufficient relative motion between the transmitting and receiving vehicles. Both modes of operation may be used simultaneously to provide the down range measurement system with built in redundancies and error checking.

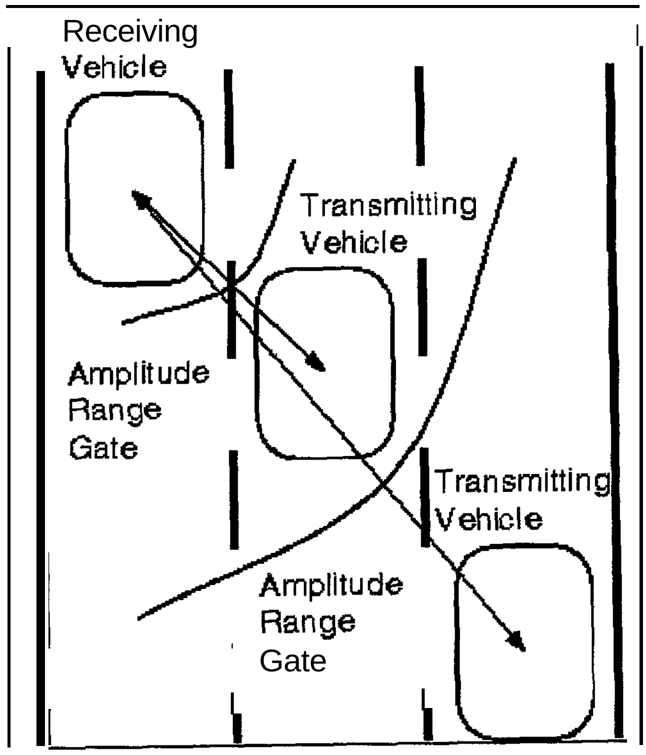


Figure 5-5. Down Range Vehicle Detection

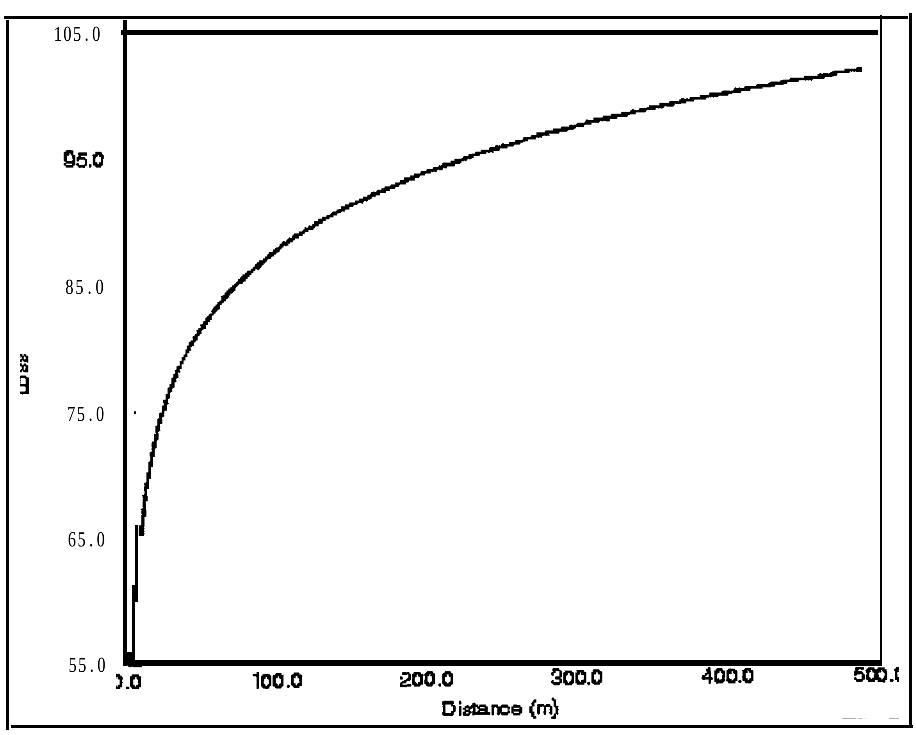


Figure 5-6. Propagation Loss Curve for 5.8 GHz Carrier Frequency

5.4 DOPPLER PROCESSOR SYSTEM

In addition to each vehicle transmitting its velocity to the other vehicles in the floating LAN, each vehicle will have the ability to determine the relative velocity of the other vehicles in the floating LAN by Doppler processing the received message signals. The Doppler processor will serve a two fold purpose. First, the Doppler processor will serve as a built in redundancy to ensure that each vehicle is correctly transmitting its velocity. Second, and more importantly, the Doppler processor will serve as a first order collision avoidance capability.

The Doppler processing is performed by mixing the carrier frequencies received from the surrounding vehicles with the receiving vehicle's local oscillator. Since all of the vehicles operating in the floating LAN are transmitting on the exact same frequency, the beat frequency obtained from each of the received signals corresponds directly to the relative velocity of the transmitting vehicle. The relationship between the beat frequency (Hz) and the vehicle's relative velocity (mph) is given in Equation 1. A graph of beat frequency vs. relative velocity for a 5.8 GHz carrier frequency is depicted in Figure 5-7. It should be noted that Equation 1 differs from the standard Doppler radar equation by a factor of two. This factor of two is removed from the equation due to the one way propagation distance associated with communication systems instead of the round trip propagation distance associated with radar systems.

$$f_{Doppler} = 0.447 v_{relative} \left(f_{carrier} / c \right) \qquad (1)$$

Questions as to the feasibility of the Doppler processing system are based primarily on the stability of the local oscillators to be installed in each of the vehicles. For the Doppler processing system to function correctly, the Doppler frequency must be detectable from the frequency drift associated with the local oscillators. For "head on" approaches, where the relative velocity between the two vehicles can approach 100 mph, the associated Doppler shift, of approximately 850 Hz, can easily be detected, even in the presence of significant oscillator drift. However, for "rear end" approaches, where a consequential velocity between the two vehicles may be as low as 15 mph, the associated Doppler shift of 150 Hz may become lost in the local oscillator drift.

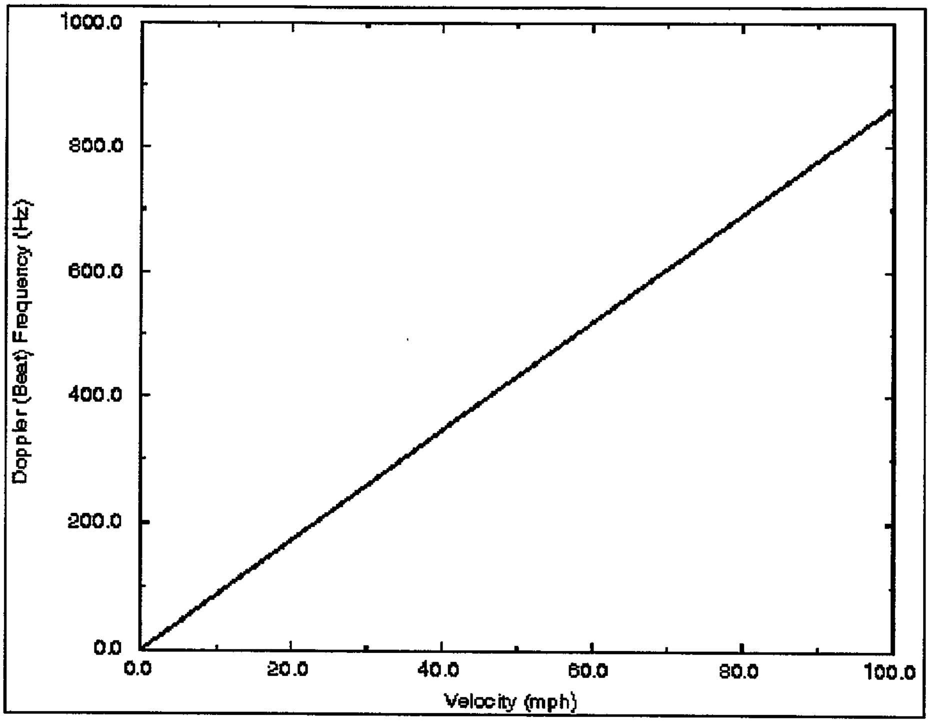


Figure 5-7. Doppler (Beat) Frequency (Hz) vs. Relative Velocity (mph) for an 5.8 Ghz Carrier

5.5 DISCUSSION AND FUTURE WORK

A communication based approach to the intelligent transportation system has been described in the above work. The approach uses an RF network based CSMA/CA protocol, in conjunction with various signal processing methods, to develop floating mini-LANs which follow the vehicles as they progress along the ITS infrastructure. Direction finding antennas need to be incorporated on every vehicle operating in the ITS infrastructure. These antenna systems allow the vehicles to determine the relative angular direction for which information is being received. A down range measurement system also needs to be incorporated on every vehicle operating in the ITS infrastructure. The down range system allows each vehicle to determine the radial distance of the vehicles about them. The features of direction finding and down range measurement, in addition to the information transferred using the CSMA/CA protocol, provide a redundant and interactive method for each vehicle to determine precisely the location of surrounding vehicles. The introduction of the Doppler processor into the floating LAN allows vehicles to determine the relative velocity of the surrounding vehicles in addition to their location. The Doppler processor provides a redundant method of obtaining the relative speed of the surrounding vehicles, and can be used as a first order collision avoidance system. By queuing the vehicles anti-collision response system by Doppler shifts above a given threshold, additional time is available for the driver to initiate collision avoidance actions.

In general, the communications system outlined in the above appears to be a reasonably robust and expandable system which can be easily implemented using "off the self" technology. However, there is additional research and analysis which must be performed on each of the subsystems before a complete prototype can be assembled. In many cases, prototypes for each of the subsystems need to be built and tested to ensure that the entire system will perform correctly when all of the subsystems are integrated. The following discussion outlines the additional tasking recommended to achieve the overall goal of constructing a fully integrated ITS prototype.

<u>CSMA/CA Protocol Implementation</u> While it has been shown that the CSMA/CA protocol, using current hardware, is capable of handling the amount of data necessary to implement the communication based approach in its initial stage, an in depth study of how the protocol is to be implemented is still required. This study would include computer modeling of the floating LAN to determine probability of collision curves and through-put curves for various network loads. In addition, both a modulation scheme and an error correction scheme need to be selected for the implementation of the protocol. Finally, a turn around time between receiver and transmitter must be specified such that message collisions are minimized. Each of these requirements are essential because their selection will directly effect the implementation of the direction finding, down range, and Doppler subsystems.

<u>Direction Finding Antenna Implementation</u> As discussed earlier, there are many factors which effect the performance of direction tiding systems (message duration, multipath effects, noise bursts, etc.). It is therefore suggested that once the CSMAKA parameters are selected, an industrial survey be conducted to determine the optimum direction finding system for the particular parameters selected. The performance level of the selected direction finding system then needs to be evaluated and modifications to the selected CSMAKA parameters may be necessary if the direction finding system does not perform at the level required by the integrated design.

<u>Down Range Measurement System Implementation</u> A prototype down range measurement subsystem needs to be constructed and field tested to determine the operational characteristics associated with both the absolute and differential modes of operation. Field tests would include sensitivity and error analysis for each of the two systems along with comparisons of the measured power levels received and the power levels predicted using numerical analysis. The effects of multipath fading, length of transmission, and noise bursts need to be closely examined to ensure that the down range measurement system selected for the integrated design is sufficiently robust to perform at an expectable level regardless of the driving environment encountered.

<u>Doppler Implementation</u> Police Doppler radar units are a time tested Doppler implementation which has proven to perform reliably and with the accuracy required for the purposed system. It is therefore suggested that the manufactures of these Doppler radar units be consulted and the knowledge obtained from these consultations be utilized to design and build a prototype communication based Doppler subsystem. In addition, the existing performance specifications for the police radars can be used as bench marks for the prototype Doppler system.

6. CONCLUSIONS AND RECOMMENDATIONS

Based upon the studies and analyses described in this report, ARINC offers the following conclusions and recommendations.

CDPD field performance tends to validate the Architecture team assertion that CDPD should provide adequate performance; however there are some caveats. As suggested by the MITRETEK simulations, the use of a "dedicated" (i.e., not shared with AMPS voice service) CDPD channel will be necessary to help ensure adequate response time. Even in these circumstances, users may experience periods in which performance does not meet their response time expectations; this is a manifestation of the "common user access" nature of CDPD - all users are equal, and there is a level of activity (i.e. number of users or user message activity) above which performance will be degraded. For these reasons, CDPD should not be employed where such delays cannot be tolerated (for certain emergency management functions, for example).

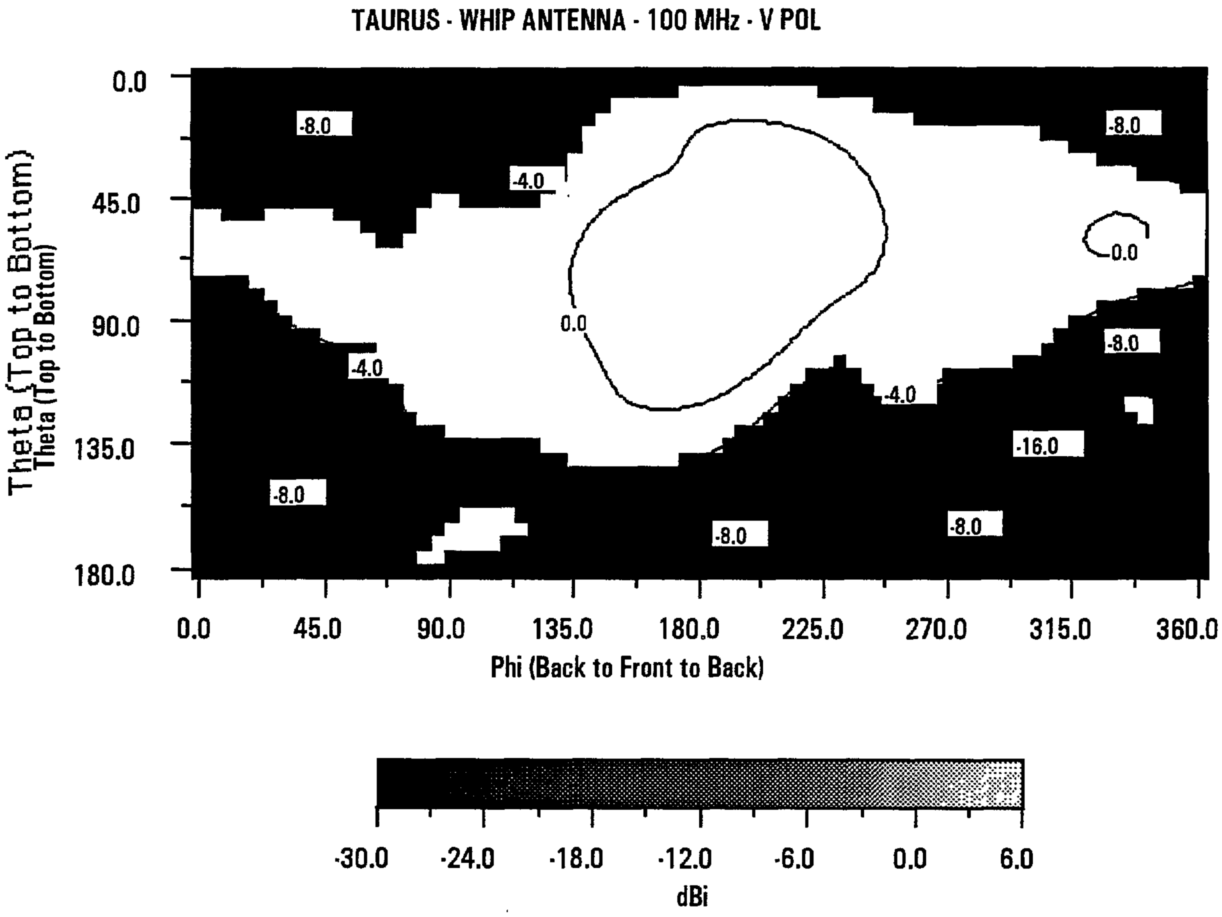
Although questions still remain about the appropriate use of the narrowband 220 MHz channels reserved for FHWA, our study of antenna performance showed that integration of 220 MHz into vehicles will not necessarily require an additional antenna. Our investigations indicated that it is feasible to employ the same antenna to receive 220 MHz signals as is employed for FM broadcast reception. However, there are some performance issues which should be addressed if use of 220 MHz is pursued further. These issues relate to matching the driving point impedance of the antenna at 220 MHz to the impedance of a 220 MHz receiver front end.

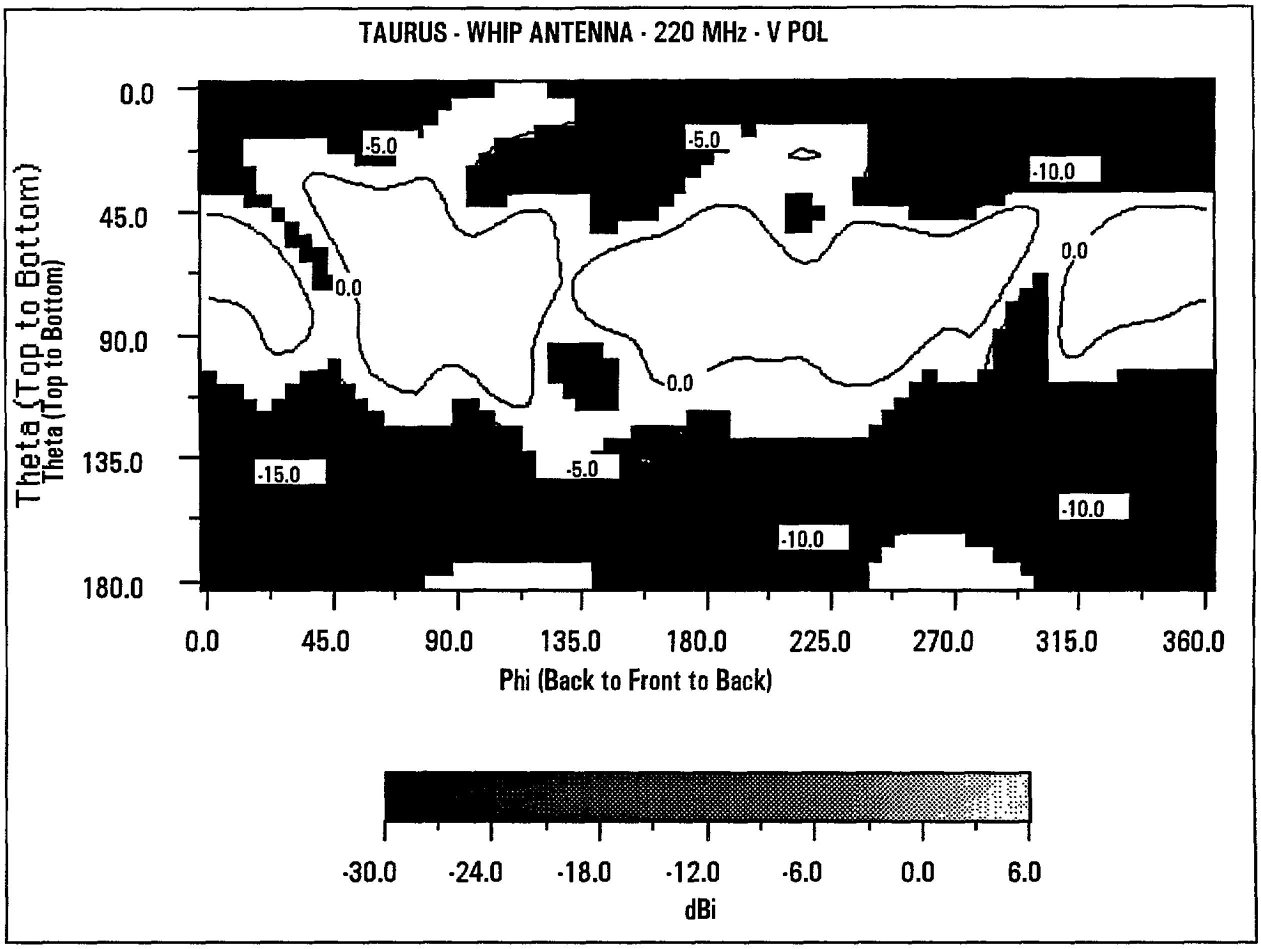
Dedicated Short Range Communications is one of the more critical communications technologies employed in ITS. Our analyses indicated that there is not currently sufficient spectrum allocated at the current operating band for toll and CVO facilities (902-928 MHz) to meet the requirements for future applications of DSRC. ITS-America, with the assistance of FHWA, is preparing a petition for rulemaking to obtain an allocation for DSRC in the 5850-5925 MHz band. The petition process will require technical insight into DSRC equipment operation, both from a physics of operation perspective, and from an applications concept perspective. The detailed understanding of DSRC necessary to provide this insight is best developed by testing of prototype hardware, both in a laboratory environment, and in a "real world" application scenario. Consequently, ARINC recommends that a DSRC test program be established to provide the hardware, software, and facilities to develop the detailed technical insights necessary for FCC petition support. The program would also support the refinement of operating concepts for many new DSRC applications such as in-vehicle signing and intersection collision warning and avoidance.

ARINC has proposed the application of Wireless Local Area Networks to multi-lane Vehicle to Vehicle communications. There are a number of issues which require further investigation before a final evaluation of the concept can be rendered; these fall into four general areas. First, the issue of the basic performance of the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) must be assessed by simulation and analysis to determined optimum performance capabilities Second, there is a trade-off to be made between message size, packet collision probability, and direction finding capability. These two aspects (protocol performance and direction finding) must be evaluated first, Assuming that the trade off can be made successfully, further studies of range and speed estimation are necessary. The range and speed studies should be deferred until the results of the earlier evaluation are available and indicate the basic feasibility of WLAN for this vehicle to vehicle application.

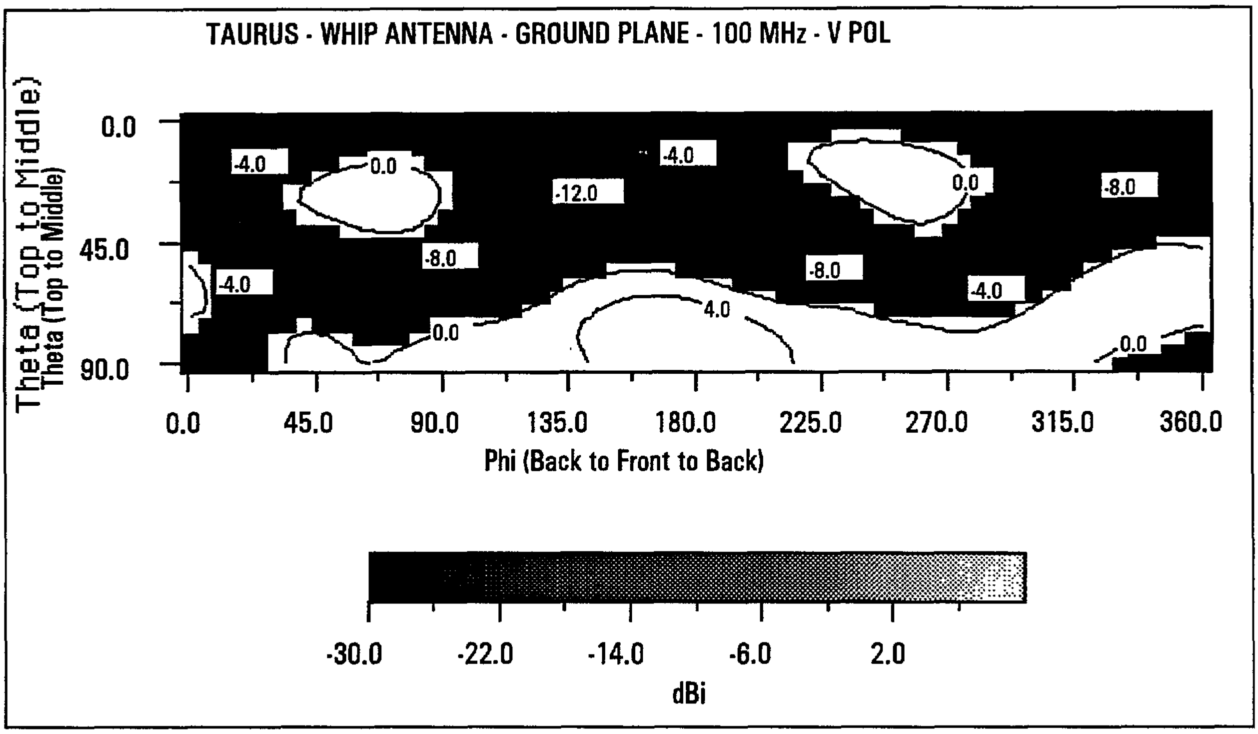
APPENDIX A

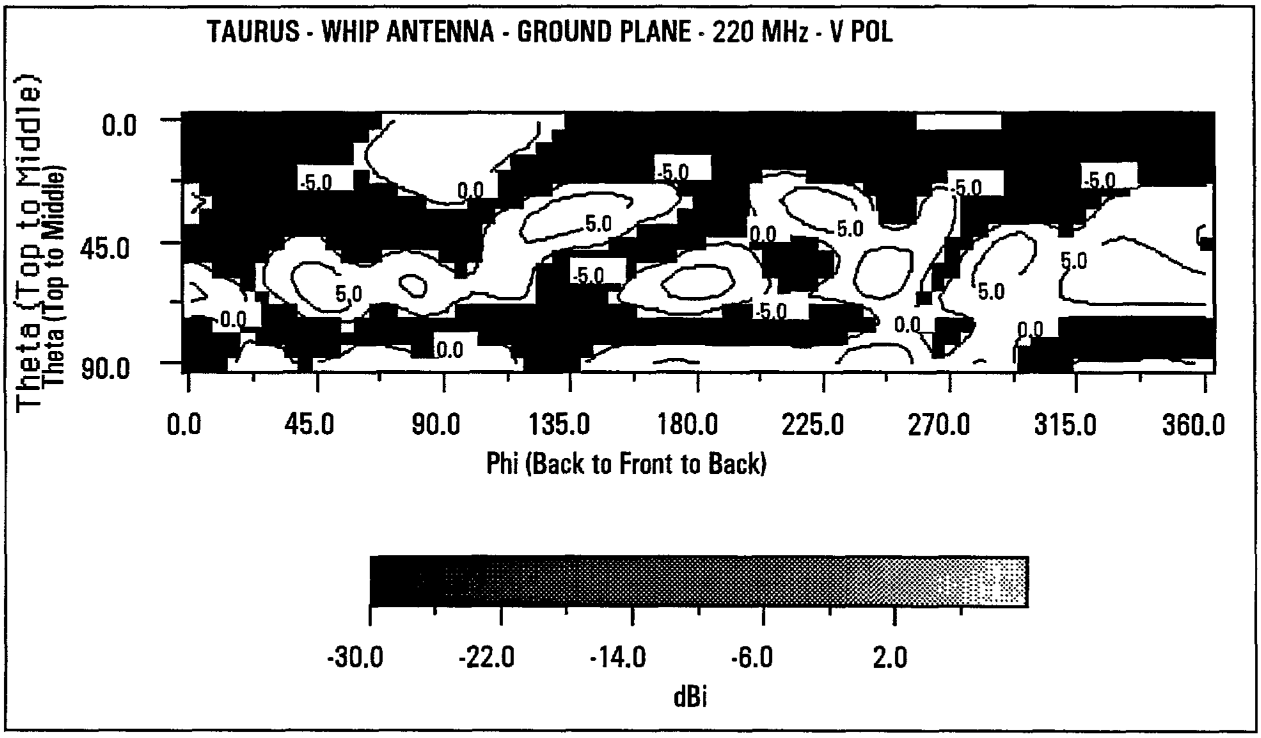
2-Dimensional Far-Field Patterns for a Vehicle Radio Antenna Operated at 220 MHz


TAURUS - WHIP ANTENNA - 100 MHz - V POL
Theta (Top to Bottom)
0.0
45.0
90.0
135.0
180.0
-8.0
-4.0
0.0
-16.0
0.0
45.0
90.0
135.0
180.0
225.0
270.0
315.0
360.0
Phi (Back to Front to Back)
-30.0
-24.0
-18.0
-12.0
-6.0
0.0
6.0
dBi



TAURUS - WHIP ANTENNA - 220 MHz - V POL
Theta (Top to Bottom)
0.0
45.0
90.0
135.0
180.0
-5.0
-5.0
-10.0
0.0
0.0
0.0
-15.0
-5.0
-10.0
-10.0
0.0
45.0
90.0
135.0
180.0
225.0
270.0
315.0
360.0
Phi (Back to Front to Back)
-30.0
-24.0
-18.0
-12.0
-6.0
0.0
6.0
dBi


TAURUS - WHIP ANTENNA - GROUND PLANE - 100 MHz - V POL
Theta (Top to Middle)
0.0
45.0
90.0
-4.0
0.0
-4.0
-12.0
0.0
-8.0
-8.0
-4.0
-8.0
-4.0
4.0
0.0
0.0
0.0
45.0
90.0
135.0
180.0
225.0
270.0
315.0
360.0
Phi (Back to Front to Back)
-30.0
-22.0
-14.0
-6.0
2.0
dBi


TAURUS - WHIP ANTENNA - GROUND PLANE - 220 MHz - V POL
Theta (Top to Middle)
0.0
45.0
90.0
-5.0
0.0
-5.0
5.0
-5.0
-5.0
5.0
0.0
5.0
5.0
-5.0
5.0
-5.0
0.0
0.0
0.0
0.0
5.0
0.0
0.0
45.0
90.0
135.0
180.0
225.0
270.0
315.0
360.0
Phi (Back to Front to Back)
-30.0
-22.0
-14.0
-6.0
2.0
dBi