

SANTA MONICA FREEWAY SMART CORRIDOR

LOW POWER HAR EVALUATION

Prepared by:

JHK & Associates
80 South Lake Avenue
Suite 680
Pasadena, CA 91101

In association with:

Frank Thatcher Associates

August, 1993

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APPENDIX A

1. INTRODUCTION

1.1 BACKGROUND

The Santa Monica Freeway Smart Corridor in Los Angeles, California, is an integrated network of freeway and surface street routes comprised of the Santa Monica Freeway (Interstate 10) between the Santa Ana Freeway (Interstate 5) and the San Diego Freeway (Interstate 405) and five major parallel arterials including Adams, Venice, Washington, Pico and Olympic Boulevards. A variety of traffic and data management systems are being integrated to provide real-time traffic management capabilities for this freeway and surface street network. The provision of timely, accurate and specific motorist information, so that motorists may make educated routing decisions, is key to the successful management of traffic in this congested 13 mile long corridor.

A variety of motorist information dissemination strategies are being employed in the corridor to convey the needed information to the travellers. These include changeable message signs (CMS), highway advisory radio (HAR) and highway advisory telephone (HAT) systems. The focus of this report will be on the evaluation of a low power AM simulcast HAR system for the provision of motorist information.

1.2 OBJECTIVES

The objective of this test is to assess the viability of providing clear, easy to understand messages specific to traffic in small geographic zones within the Corridor, without interfering with other broadcasters. Specifically, the pilot test is geared towards assessing the viability of emerging low power (100 milliwatt) synchronized broadcast technology in the AM broadcast band of 530 Khz to 1710 Khz. One of the key objectives of the project is to convey information to as many of the motorists travelling in the selected zone as possible. Hence, radio transmissions must be receivable by standard broadcast receivers. Additional objectives of the test include assessing the potential for interference with commercial radio broadcasts, identifying usable radio frequencies and studying compliance with FCC regulations.

The test plan developed to meet these objectives addresses the following:

- Compliance with FCC Standards
- Audio Quality
- Transmission Range
- Field Strength
- Transmitter Phasing
- Antenna and Grounding System Considerations
- Interference from adjacent zones or stations
- Frequency Allocation Requirements
- Installation Considerations
- Factors Influencing Signal Propagation

Where appropriate, test objectives are quantified using radio field strength measurements and circuit merit assessments. Qualitative discussion is employed when the phenomena subject to study does not lend itself to quantitative analysis.

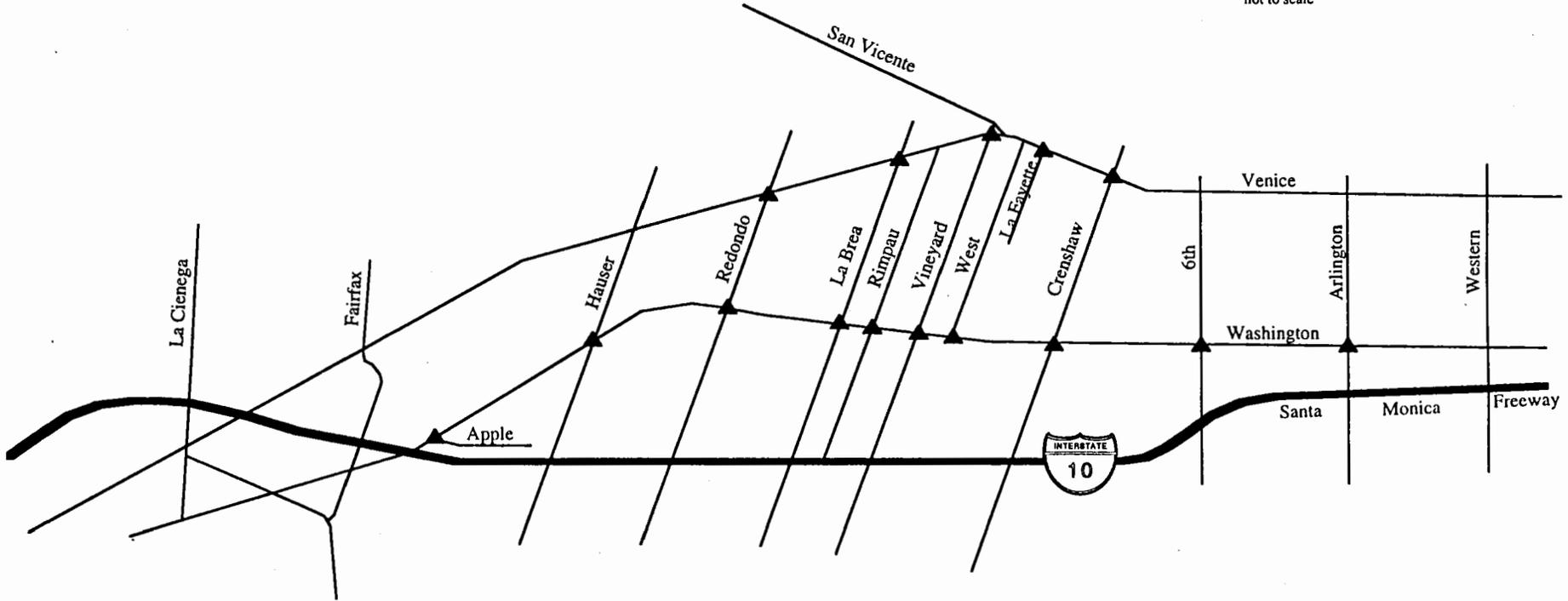
1.3 PILOT PROJECT DESIGN OVERVIEW

The HAR pilot test consisted of 15 low power (100 milliwatt) synchronized radio transmitters broadcasting at 1520 Khz. The transmitter units were placed in two zones in the Smart Corridor. The first zone comprised of 10 transmitters was designed to provide motorist information on Washington Blvd. While the second zone comprised of 5 transmitters was designed to provide messages on Venice Blvd. (See Exhibit 1.1) The close physical proximity of the zones was intentional in order to study the impact of dissimilar messages on the same frequency in a nearby location.

Transmitter mounts were typically located on existing signal mast arms. With communication provided to the transmitter by twisted copper pair. Electrical service for transmitters was obtained from the equipment outlets in the adjacent Type 332 or 337 traffic signal control cabinets.

Base controller units were located in the communication hub facility at Fire Station 66 at Washington Blvd. and Orange Ave. The base controller unit serves as a reference for transmitter synchronization and housed a digital recorder for the recording and broadcast of audio messages.

Transmitter Locations



▲ Transmitter location

Exhibit 1.1

1.4 INSTALLATION CHRONOLOGY

The HAR equipment was first delivered to the City on February 22, 1993. Product orientation and site investigation followed on February 23, 1993. Equipment installation and network optimization including phase adjustments took place from February 24, 1993 to March 3, 1993. An evaluation kick-off meeting was held on March 4, 1993. Extensive field strength measurements were conducted as a part of the data collection effort that took place from March 5, 1993 to March 10, 1993.

1.5 ORGANIZATION OF THIS REPORT

Following this Introduction, the report is organized as follows:

- Chapter 2:** Provides detailed equipment descriptions for each unit comprising the HAR system including the base controller unit, transmitter controllers and the transmitters themselves.
- Chapter 3:** Describes the test plan including the test methods, measurement equipment employed and the measures of effectiveness used to assess the HAR installation.
- Chapter 4:** Presents test results which include assessments of compliance with FCC requirements, field strength measurements and circuit merit assessments in a number of test configurations. A discussion of test results is also provided.
- Chapter 5:** Documents a recommended approach to the design methodology for full scale installation of a low-power HAR system.
- Chapter 6:** Draws conclusions about the test and the feasibility of low power HAR implementation.

2. HAR EQUIPMENT

This chapter provides detailed explanations of each of the units which comprise the HAR system including the individual transmitters, the transmitter controllers and the base controller units. Theory of operation for each of the units is discussed. In addition, the use and adjustment of the equipment and its control panels is discussed along with appropriate mounting and installation methods.

2.1 TRANSMITTER

The individual transmitter under test was a Triangle Digicom (Model 1601 BCB) Low Power AM Radio Broadcast Transmitter. The unit is specifically designed for use as part of a low-power transmitter network in which the coverage area is largely determined by the placement of multiple transmitters. The transmitter housing contains a Transmitter Module (Model TA1), Synchronizer Module (Model SS1) and an optional rechargeable battery.

Transmitter controls include an antenna trimmer to optimize antenna matching, power and modulation adjustments. Test points are also provided to permit current and voltage measurements to the final radio frequency (RF) amplifier stage to ensure compliance with Federal Communications Commission (FCC) requirements. Light Emitting Diodes (LEDs) are provided to indicate that RF output is present and to assist with the modulation and synchronization adjustments. The transmission frequency is pre-set at the factory, but may be altered to any frequency within the Amplitude Modulation (AM) broadcast band with jumpers within the transmitter housing if desired.

The modulation LEDs indicate when a modulated signal is present. A second overmodulation LED located directly above the modulation LED indicates 110% modulation. RF and synchronization LEDs are also provided to indicate that the transmitter is generating RF emissions and that the frequency synthesizer is unlocked. Respectively, loss of synchronization will suspend transmitter operations.

The equipment is installed in a fiberglass National Electrical Manufacturers Association (NEMA) standard outdoor enclosure approximately eight inches square. The enclosure is sized

to accommodate two transmitter modules if desired. (See Exhibit 2.1) A 96" fiberglass whip antenna is provided on top of each transmitter housing.

2.2 SYNCHRONIZER MODULE

The synchronizer module is designed to provide an interface between the base controller unit and the individual transmitter. Connections between the Synchronizer module and the transmitter unit are accomplished using a small ribbon cable. Terminals on the Synchronizer for signal and 16 VAC power input are provided. A 12 VDC output is also provided to charge a back-up battery if desired. Each Synchronizer may control up to two transmitters located within a single housing.

Switches are provided to enable the unit, select modes and to select a unique identification code to allow central control functions to be implemented.

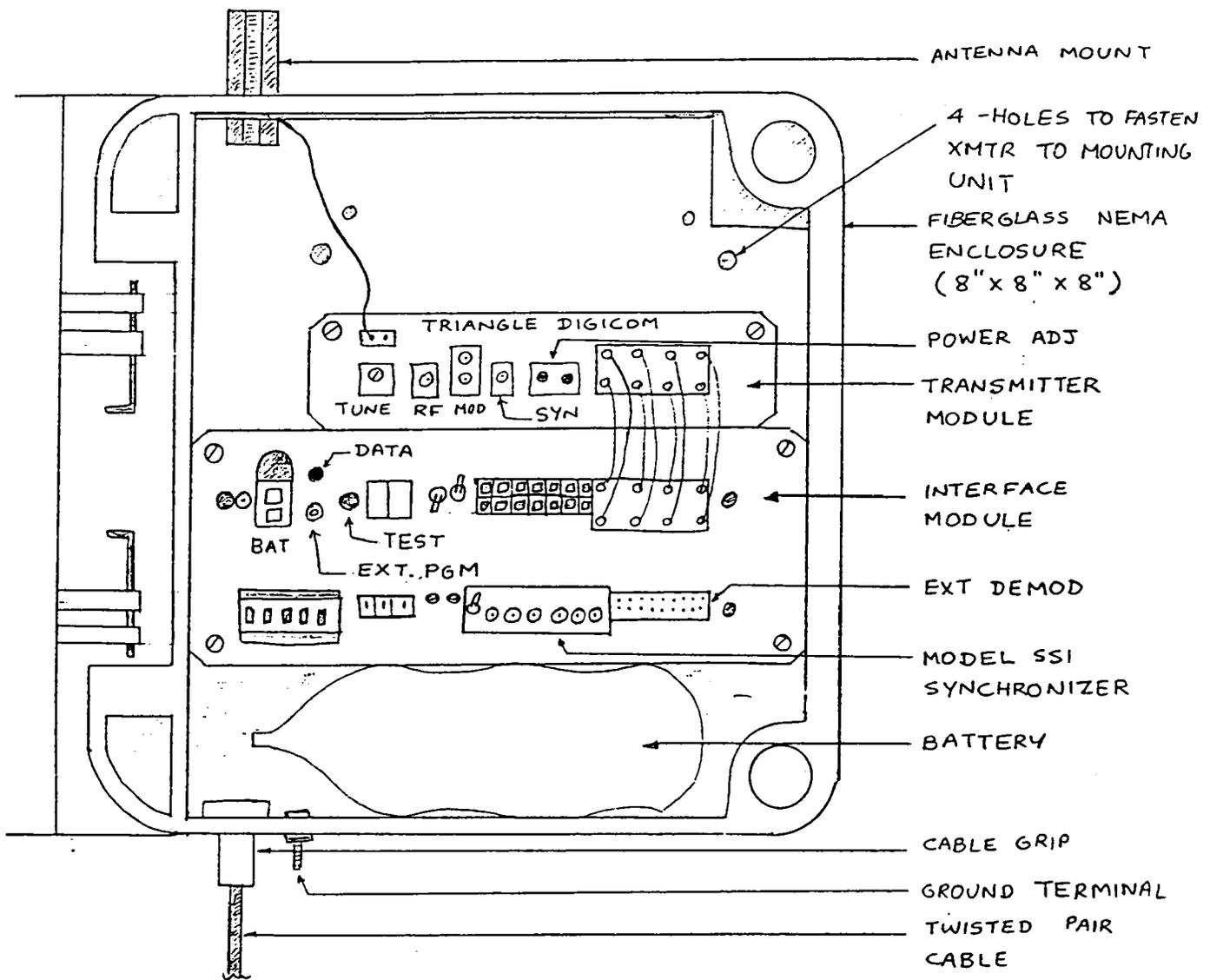
The unit may operate in normal, local, tune and tone modes. The default mode, normal, allows control of the unit from the base controller unit and permits message transmission. The local mode switch overrides any commands issued by the base controller unit. The transmitter will revert to normal operation after the last keyboard entry. When the unit is in the local mode the DATA LED will flash every two seconds.

The tune mode provides an unmodulated carrier to permit transmitter tuning and adjustment. The tone mode provides a 110% modulated carrier to permit transmitter modulation adjustments.

The unit will also generate a tone sequence when the tone and test switches are concurrently activated. This feature is designed to assist with transmitter site selection and optimization. By using this feature and a battery to provide power, transmitter range can be determined before permanent installation takes place.

The normal mode provides remote transmitter operation from the base controller unit. The synchronizer is designed to receive information from any one of three FM channels transmitted on a single twisted pair at a distance of up to two miles without repeaters. Each channel conveys commands and audio messages to the synchronizer. Signals include FM, clock and pilot tone signals. LEDs on the synchronizer indicate that valid FM, clock and pilot tone signals are received. A data LED is also provided to indicate that the unit is sending or

**Exhibit2.1
LOW POWER HAR TRANSMITTER**



receiving Dual Tone Multi Frequency (DTMF) tone commands. The synchronizer uses these DTMF tones to provide monitoring status information to the base controller. The unit is also designed to disable the transmitter to prevent undesirable operation in the absence of the required signals.

If a back-up battery is installed, the Battery LED will light to indicate that the battery is charged. In the absence of a battery, the light will also signify the presence of Alternating Current (AC) power. The LED will flash during battery charging operations.

Detailed specifications and system tuning procedures are documented in Appendix A for both the transmitter and the synchronizer unit. Tuning circuitry uses the 20 khz clock signal as a reference frequency for a frequency synthesizer, which permits the radiated phase to be adjusted without changing the output frequency or power.

2.3 BASE CONTROLLER UNIT

The base controller is designed to mount into a standard 19" EIA rack. The unit must be housed in an environmentally protected enclosure. The base controller unit is provided with a battery back up feature that allows two hours continuous operation in the event of power loss. Each base controller unit provides the 20 Khz synchronization clock to all the transmitters located in a particular zone. The synchronization process is designed to minimize constructive wave interference through phase adjustments of individual transmitters. Phase adjustments are intended to minimize rumble, signal dropouts and nulls between adjacent transmitter locations.

Audio messages are broadcast using a frequency modulated carrier in the 100-200 khz range (user selectable 120, 150 180 khz) over the twisted pair cable. Each base controller is also equipped with a digital recorder and voice processing system to provide the message content for each zone and can be programmed for a continuous playback mode. External audio input signals may also be provided to the base controller unit. Signal levels may range from 50 mv peak-to-peak to 10 volts peak-to-peak at an impedance of 10 K ohms for 100% modulation. The system is designed to provide high quality audio transmission with a 4 - 5 khz bandwidth. Transmission line interfaces are designed to suppress transients while permitting bi-directional signal transmissions.

The production base controller unit will be designed to incorporate a two-track digital recorder and test and pilot tone generation functions. The unit will be capable of storing and selecting up to 120 messages for a total of 58 minutes of playback time in the unit's solid state memory. The unit will also incorporate audio compression and automatic level control features.

The base controller unit that was tested during this evaluation was a pre-production model assembled using bread board techniques. As a result, not all features of a production unit were incorporated in the unit. Two distinct limitations include the ability to store only a two minute message and a single track digital recorder.

The production base controller unit will be designed to provide significant status monitoring capability for the base controller unit itself and the associated transmitters. Up to 300 transmitters per base controller unit may be controlled and monitored. One-hundred transmitters per channel will be assigned unique identification codes from 00 to 99 to isolate faults to individual transmitters. Remote monitoring of the base controllers will be possible using PC equipment and the base controller unit's RS232 interface. Information to be available for the base controller itself includes:

Power	On/off
ID Code	XX
FM Carrier	On/Off
Synchronization Clock	On/Off
Audio Signal	On/Off
Battery	Ok/Fail

Transmitter status data includes:

Power	On/off
Transmitter ID Code	XX
FM Carrier	On/Off
Synchronization Clock	On/Off
Audio Signal	On/Off
Frequency Error	On/Off

Faults will also be returned for major malfunctions such as frequency error, antenna fault and failure of the final RF stage.

2.4 INSTALLATION METHODS

Installation methods, techniques and hardware employed in the implementation of the Pilot Test HAR system are discussed in the following sections.

2.4.1 - Transmitters

In a typical installation, HAR transmitters were attached to steel signal mast arms and located approximately five feet from the vertical pole. To limit the need for aerial work, transmitter mounting hardware was pre-assembled on the ground. Details of the mounting hardware, electrical connections and the type of installation are discussed below. In some instances, HAR transmitters were installed on Marblelite poles using a custom crossbar assembly to maintain two or more feet of clearance between the crossbar assembly and the transmitter. Mount types at each location are shown in Exhibit 2.2.

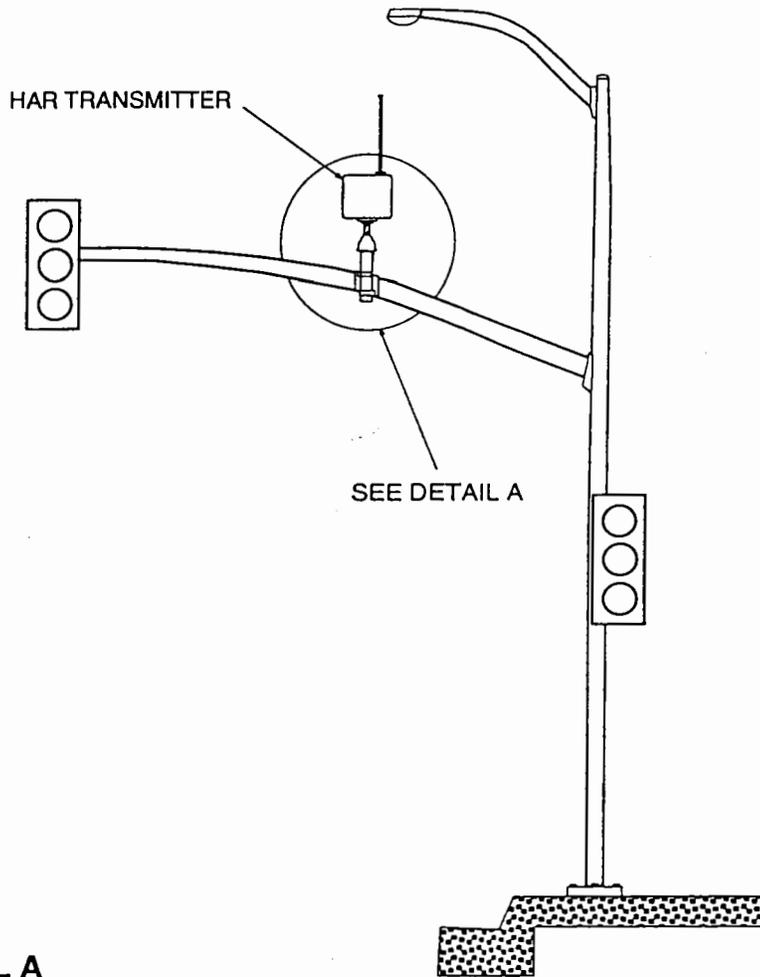
To install the transmitters, each was fitted to an 'L' shaped 0.15" thick aluminum mounting bracket fitted with a bottom flange. The bottom flange mated with a 1" pipe nipple, which in turn was fitted to a 1 1/2" diameter galvanized pipe threaded at both ends, by means of a standard pipe reducer. A Pelco Standard Astro-Brac clamp kit was fitted to the other end of the pipe. The Pelco Kit included a swirling unit which facilitated orientation of the tube in any direction along the longitudinal plane. To complete the mount, the swirling unit was clamped to the mastarm with stainless steel bands. (See Exhibit 2.3)

Transmitters were wired using 18 gauge dual shielded twisted pair cable (Detector Lead-In Cable) which provides connections to a 16 VAC power source and the base controller unit. For this temporary installation, the cable was run external to the mast arm to a side-mounted vehicle head terminal compartment, which was drilled and grommetted to accommodate the cable. The cable was then routed through the traffic signal pole and the conduit network to the traffic signal control cabinet. One pair was terminated on a Type 66 punch-down block to provide communication service. To provide electrical service, the other pair was terminated at a small (Apx. 500 ma) 120 VAC to 16 VAC step-down transformer. The transformer was plugged into an equipment outlet of the Type 337 cabinets or into a power strip in Type 332 cabinets.

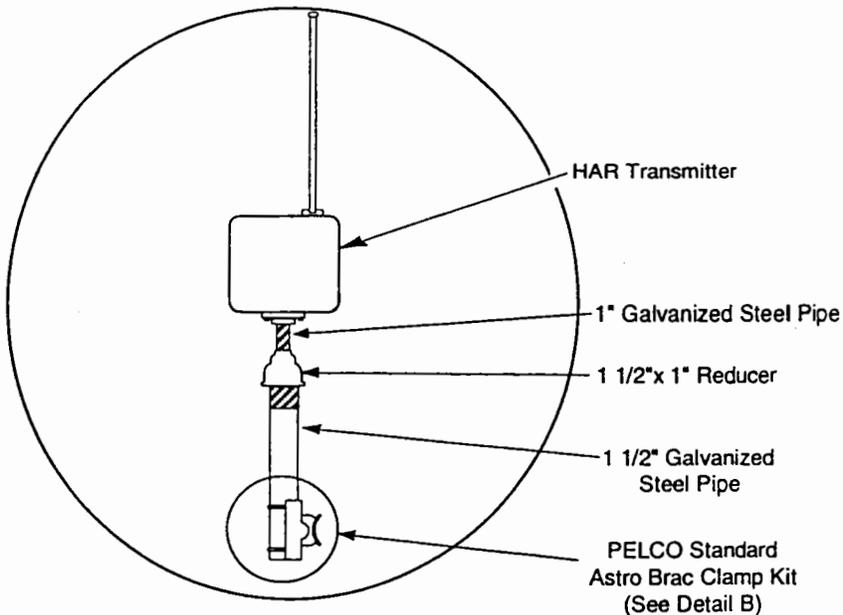
**Exhibit 2.2
POLE INSTALLATION TYPES**

Washington Installations			
Intersection	Corner	Pole Type	Installation
Apple	N/W	Marbelite	90° From Mast Arm Over Washington
Hauser	S/E	Marbelite	On Mast Arm Over Washington
Redondo	S/W	Marbelite	90° From Mast Arm
La Brea	N/E	Steel	Typical
Rimpau	S/E	Steel	Typical
Vineyard	S/E	Steel	Typical
West	S/E	Steel	Typical
Crenshaw	S/E	Steel	Typical
6th Ave.	S/E	Steel	Typical
Arlington	S/W	Steel	90° From Mast Arm
Venice Installations			
Intersection	Corner	Pole Type	Installation
Crenshaw	N/W	Steel	Typical
Lafayette	S/E	Steel	Typical
San Vicente	N/W	Steel	Typical
La Brea	N/W	Steel	Typical
Redondo	N/W	Steel	Typical

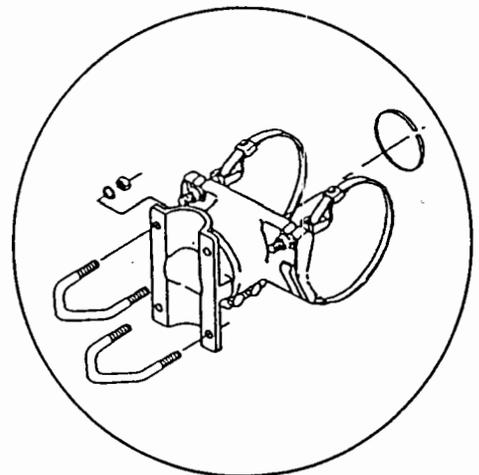
**Exhibit 2.3
TYPICAL INSTALLATION**



DETAIL A



DETAIL B



For permanent installation, a means of switching the power to the HAR transmitter would be particularly useful. In addition, permanent installation would require drilling and grommeting of the mast arm near the ultimate transmitter location to avoid unsightly external cable runs.

2.4.2 - Base Controller Unit

The base controller unit is intended for mount in a standard 19" EIA rack. The unit is 2 EIA units (3.5 inches) high. The unit requires connection to communications facilities using a punch down block and 120 VAC power. Power consumption is minimal. (Apx. 500 ma) Provision of appropriate rack space is recommended for permanent installation.

2.5 COST ESTIMATES

Equipment costs for the low power HAR are \$2,400 per transmitter and \$5,000 per base controller unit. Installation costs will vary widely based on the communications infrastructure in place and the availability of existing poles and electrical services.

3. TEST PLAN DESCRIPTION

The basic problem statement is to assess the viability of providing clear easy to understand messages specific to traffic in small geographic zones, without interfering with other broadcasters through the use of low power AM radio transmission technology.

To study the problem, 15 low power (100 milliwatt) synchronized AM broadcast transmitters were configured in a two zone network. The first zone comprised 10 transmitters and was designed to provide motorist information on Washington Blvd. The second zone, comprising 5 transmitters was designed to provide messages on Venice Blvd.

3.1 TRANSMITTER DEPLOYMENT FOR EVALUATION

By deploying the transmitters in these zones it was possible to carry out tests aimed at meeting the detailed objectives of the test plan described below. However, it should be kept in mind that placement of the transmitters during the test plan was limited largely by the stage of construction of the communication network at the time of the test. Thus transmitters were deployed to take advantage of the availability of communications on Washington and Venice. With this limitation, it was not possible to deploy transmitters in order to optimize message transmission to motorists either from a traffic engineering or radio propagation perspective. It should be kept in mind that infrastructure limitations will typically play a significant role in the deployment of HAR equipment. Thus the limitations imposed by the construction staging are not unrealistic.

3.2 TEST OBJECTIVES

This pilot test was geared towards assessing the viability of emerging low power (100 milliwatt) synchronized broadcast technology in the AM broadcast band of 530 Khz to 1710 Khz. To that end, the following objectives were chosen for study:

- To determine if the system as deployed meets the requirements of Part 15 of the FCC regulations for license free operation.

- To determine usable range of the low power HAR transmitters.
- To study the audio quality provided by the HAR transmitters.
- To correlate measured field strength to audio quality.
- To assess the impact of transmitter phase adjustment on audio quality.
- To identify factors affecting the propagation of low power AM radio broadcasts in an urban environment. Factors to be considered included, but were not limited to:
 - Power Lines
 - Physical Obstructions (i.e., bridges, overpasses and buildings)
 - Time of Day
- To assess the potential for interference to or from commercial broadcasts and HAR stations operating on the same frequency or on adjacent channels.
- To identify how the use of different car radio receivers affects the motorist's perception of audio quality.
- To develop optimum installation techniques for the equipment including:
 - Antenna Elevation Requirements
 - Antenna Orientation Requirements
 - Grounding Requirements
 - Transmitter Spacing Requirements
- To identify practical constraints which may influence the ability to achieve optimum installations. (i.e., available mounting facilities, need to protect from tampering or vandalism.)
- To develop criteria for selection of optimum frequencies for future HAR installations.
- To identify field testing, engineering, and design specification requirements to implement future low power HAR systems.
- To identify potentially useful equipment design improvements and enhancements that may be desired for large scale deployment of this type of radio system.

3.3 MEASURES OF EFFECTIVENESS (MOEs)

Two primary measures of effectiveness were considered in the conduct of the test: field strength measured in millivolts per meter and audio quality measured in terms of the five point Circuit Merit scale. Qualitative reporting is used to address issues which do not lend themselves to quantification using the above criteria.

In addition to field strength, measured in millivolts per meter, audio quality was noted as received by the field strength meter at each test location. The Circuit Merit (CM) method of audio quality ranking was used for audio tests. CM is a 1 to 5 scale rating system that allows the subjective evaluation of how intelligible the audio signal is. The CM used for these tests is as follows:

- CM 5 - Speech perfectly understandable, negligible noise (excellent).
- CM 4 - Speech easily understandable, some noise (good).
- CM 3 - Speech understandable with slight effort; occasional repetitions needed for conversation clarification (fair).
- CM 2 - Speech understandable only with considerable effort; repetitions needed for intelligible conversation (poor).
- CM 1 - Speech not understandable (unusable)

3.4 TEST EQUIPMENT DESCRIPTION

The test equipment consisted of a Potomac Instruments Inc. Model FIM-21, AM broadcast band field strength meter. Also included for audio quality evaluation were several factory installed automobile radios. The primary automobile test radio was a factory installed unit in a late model Ford Tempo.

The FIM-21 field strength meter reads directly in units of volts per meter. This unit has been calibrated at the factory and, prior to these tests, was checked against a more recently calibrated companion unit. This instrument is a portable, battery operated unit that can tune the AM broadcast band continuously from 535 to 1605 Khz. The unit has a built-in, directional loop

antenna that was used for all of the field strength measurements in this report. The FIM-21 has a built-in antenna calibration circuit that ensures an accurate field strength indication. An antenna calibration sequence was used prior to each test day and periodically during the testing sequence. This instrument also has a built-in audio amplifier and speaker that was used to note the quality of transmitted audio at each test location. The published FIM-21 specifications are as follows:

Accuracy	-	± 0.5 dB
Selectivity	-	7 Khz, at -3 dB typical 15 Khz at -60 dB typical
Scale	-	Meter scale is divided into six ranges. Minimum indication: 10 microVolts per meter Maximum indication: 10 Volts per meter
Operating Temperature Range	-	-10° F to +130° F

Several factory-installed standard-model type automobile radios were used during the field strength measurement tests to provide signal quality checks throughout the testing sequence. The factory installed whip antennas were used.

3.5 TEST METHOD

All field strength measurements were taken outside of the vehicle and away from large metallic objects. The test vehicle was equipped with a distance measuring device driven from the automobile's odometer. Test measurement interval distances were determined prior to testing. The interval distance ranging from 250 to 1000 feet was chosen based on the resolution of the data required. At each test location, the FIM-21 field strength meter, with its built-in loop-type antenna, was rotated for maximum signal strength while maintaining the loop antenna in a vertical plane. The meter range switch was adjusted for proper indication. At each test location the received audio quality was noted on the test vehicle's factory-installed radio. The field strength meter's audio amplifier gain was adjusted to allow an evaluation of the signal quality level of the transmitted prerecorded message.

4. TEST RESULTS

This chapter documents results of field measurements and inspections conducted from March 8 to March 14, 1993. This section focuses on compliance with FCC Part 15 Regulations, field strength and circuit merit tests for individual and multiple transmitters, interference between HAR zones and various factors affecting the propagation of the radio signal.

4.1 PART 15 COMPLIANCE

The Code of Federal Regulations Title 47, Part 15, is divided into two major categories; "intentional radiators" and "unintentional radiators". The equipment used in this pilot project is an intentional radiator, since it is designed to radiate electromagnetic energy. The following evaluates the Triangle Digicom Model 1601 design against each of the applicable sections of Part 15. Bold print is Part 15 text, quoted or paraphrased.

PART 15 RADIO FREQUENCY DEVICES

Subpart C - Intentional Radiators

§15.201 Equipment authorization requirement

The applicable paragraph of this section is "(b)". This paragraph requires that intentional radiators operating under the provisions of this part shall be "certificated" by the Commission. Triangle Digicom satisfies this requirement as the Model 1601 has received FCC type acceptance.

§15.203 Antenna requirement

This section requires that the device use a permanently attached antenna, i.e., does not employ a "standard antenna jack or electrical connector".

Triangle Digicom's Model 1601 design, by using an antenna that is bolted to the top of the NEMA enclosure, satisfies this requirement.

§15.207 Conducted limits

The applicable paragraph of this section is (a). This paragraph states that for an intentional radiator that is designed to be connected to the public utility ac power line, the radio frequency voltage (within the 450 Khz to 30 Mhz band) that is conducted back into the ac power line shall not exceed 250 microVolts. This voltage shall be measured at the power terminals between each leg of the power line and ground.

Triangle Digicom certifies that its Model 1601 design satisfies this requirement. Company tests show that the conducted RF voltage is below 250 microVolts with the transmitter operating at 530 Khz and 1610 Khz.

§15.209 Radiated emission limits; general requirements

Part 15 provides the manufacturer with two different methods with which to satisfy Part 15 requirements. This section, 15.209, requires that the intentional radiator provide a specified field strength of no more than 15.8 microVolts per meter at a distance of 30 meters (98.4 feet) at 1520 Khz. Alternatively, section 15.219, specifies a maximum of 100 milliwatts power input to the final amplifying stage and limits the total length of antenna, transmission line and ground lead to a maximum of three meters. The transmitter is designed to comply with the alternative section, 15.219. Therefore, 15.209 section of the rules is not applicable.

§15.215 Additional provisions to the general radiated emission limitations.

- (a) **The regulations in § 15.217 through 15.251 provide alternatives to the general radiated emission limits for intentional radiators operating in the specified frequency bands. Unless otherwise stated, there are no restrictions as to the types of operation permitted under these sections.**

This section provides an alternative to the radiated emission limits for intentional radiators as set forth in section 15.209.

§15.219 Operation in the band 510-1705 Khz

- (a) **The total input power to the final radio frequency stage (exclusive of filament or heater power) shall not exceed 100 milliwatts.**

Triangle Digicom's Model 1601 design satisfies this requirement. The input voltage and current of a randomly selected transmitter were field-checked and verified to be within the limits set forth in this section of the rules.

- (b) **The total length of the transmission line, antenna and ground lead (if used) shall not exceed 3 meters.**

Triangle Digicom's Model 1601 design satisfies this requirement. The length of the antenna plus transmission line plus ground lead were field-checked. The length of the antenna is 96 inches (2.44 m). The transmitter and synchronizer equipment are grounded via a short wire attached to the galvanized floor-flange at the bottom of the enclosure, used to mount the transmitter to the signal mastarm. The wire is approximately 6 inches (0.15 m) long providing a total length of transmission line, antenna and ground lead of 2.59 meters. The system design was thus verified to conditionally be within the limits of this section of the rules. The mounting pole itself was considered as a separate and distinct metallic structure to which the ground lead was fastened. However, the definition of what constitutes a "ground lead" could be open to multiple interpretations. To mitigate these concerns, antenna systems which do not require a separate ground may be appropriate to consider.

- (c) **All emissions below 510 Khz or above 1705 Khz shall be attenuated at least 20 dB below the level of the unmodulated carrier. Determination of compliance with the 20 dB attenuation specification may be based on measurements at the intentional radiator's antenna output terminal unless the intentional radiator uses a permanently attached antenna, in which case compliance shall be demonstrated by measuring the radiated emissions.**

Triangle Digicom certifies that the Model 1601 design satisfies this requirement.

4.2 INDIVIDUAL TRANSMITTER TESTS

Individual transmitter tests were conducted at a number of locations with several objectives in mind:

- Identify Audio Quality Requirements
- Identify Field Strength Requirements
- Study Effect of Different Radio Receivers
- Identify Usable Range
- Identify Factors Affecting Signal Propagation

4.2.1 - Audio Quality

Audio quality requirements were quantified using the circuit merit scale by three observers comparing the HAR signal to other broadcasts in the AM band. These assessments resulted in a recommendation of CM 4 as a minimum acceptable audio quality for an HAR installation. CM 4 is defined as easily understandable, speech with some noise (good reception).

4.2.2 - Field Strength

Maximum radio frequency field strength parameters were established to avoid interference. The 0.50 mV/meter threshold is the maximum value that is acceptable for other, on-channel RF emissions such as adjacent HAR zones or distant commercial broadcasters. A signal at this level is barely perceptible with a typical receiver. Minimum field strength design requirements to achieve the acceptable audio quality are discussed in Section 4.2.4.

4.2.3 - Field Strength vs. Audio Quality

While some correlation between field strength and audio quality exists certain factors affect their relationship. One significant factor in the signal strength to audio quality relationship is the amount of background noise present.

Another factor influencing the correlation is the quality of the radio receiver and its automatic gain control circuitry. The automatic gain control circuitry within the receiver is designed to accept a wide range of radio frequency field strengths and adjust the gain of the receiver's amplifiers to assure a consistent audio signal for the listener. This radio design feature provides the ability to receive various stations whose signal strengths may be significantly different from each other, but provide the same volume level from the speaker.

4.2.4 - Typical Radio Receivers

The purpose of this test was to determine how automobile radios of different manufacture performed. The test was conducted with 2 separate transmitters, operating first individually and then concurrently with different messages. The scope of the test was limited to a small selection of automobile radios in order to determine if more extensive testing with a larger and more representative sampling of radios was warranted based on substantial differences in performance.

In order to assure that all radios used in the evaluation process were operating satisfactorily, adjacent commercial broadcast stations were tuned in prior to conducting this test. Radio No. 1 (installed in the Ford Tempo) was used as the primary radio for all aspects of the HAR audio quality evaluation as it was representative of a typical factory installed radio.

Exhibit 4.1 shows the test results of four automobile radios, three of which are standard factory installed units. The fourth radio was an after-market customer installed product. A cross-street location was chosen so that a moderate signal level, 0.7 to 0.8 mV/meter, would be present from each transmitter operating individually. The data shows that the after-market radio gave the least favorable results, yielding only a CM 1 while each of the factory installed radios yielded a CM 4 or better. The after-market radio was the oldest of the radios and did not provide audio quality better than CM 3 in any portion of the corridor. All of the factory installed automobile radios performed similarly although the Honda radio had a slightly lower audio quality (CM 3+) while receiving the Venice test signal. The other factory installed radios provided a CM 4 rank in all of the tests based on an individual transmitter. It should also be noted that none of the radios performed favorably (CM 2 or lower) when both transmitters were simultaneously transmitting different messages. This is an expected result because the test location was chosen

	Circuit Merit			
	Radio #1 Ford Tempo	Radio #2 1990 Honda Prelude	Radio #3 1993 Plymouth Sundance	Radio #4 GM Van- Marantz Computuner
Washington Transmitter Only	4- (some noise)	4	4-	1
Venice Transmitter Only	4+	3+	4 (some noise)	3
Both Transmitters	Both Audible	Both Audible	Both Audible	Both Audible
Washington:	2	1	2+	1
Venice:	2	2+	2+	1

Location: 1770 Vineyard
850± ft North of Washington

Field Strength: Venice Zone: 0.7-0.8 mV/m
Washington Zone: 0.7-0.8 mV/m

Exhibit 4.1
AUTOMOBILE RADIO TEST

to provide equal field strengths from two distinct transmitter locations that generated different audio signals.

The primary conclusion to be drawn from the above testing is that a 0.7 mV/meter field strength is the lower limit of field strength to achieve a CM 4 audio quality for a wide range of car radios. Because of variation in the sensitivity of automobile radios of different manufacture and the affects of the surrounding electrical background noise a 1.0 to 1.5 mV/meter field strength is recommended as a design criteria.

4.2.5 - Usable Range

Studies to determine the usable range of the low power HAR transmitters were made at several locations along Washington and Venice Boulevards.

4.2.5.1 - Washington Blvd. Transmitters

The Washington Blvd. test site is characterized by an absence of high voltage transmission lines limiting RF propagation to atmospheric transmission. Three individual transmitters on Washington Blvd. were studied including:

- West Street
- Arlington Avenue
- Hauser Boulevard

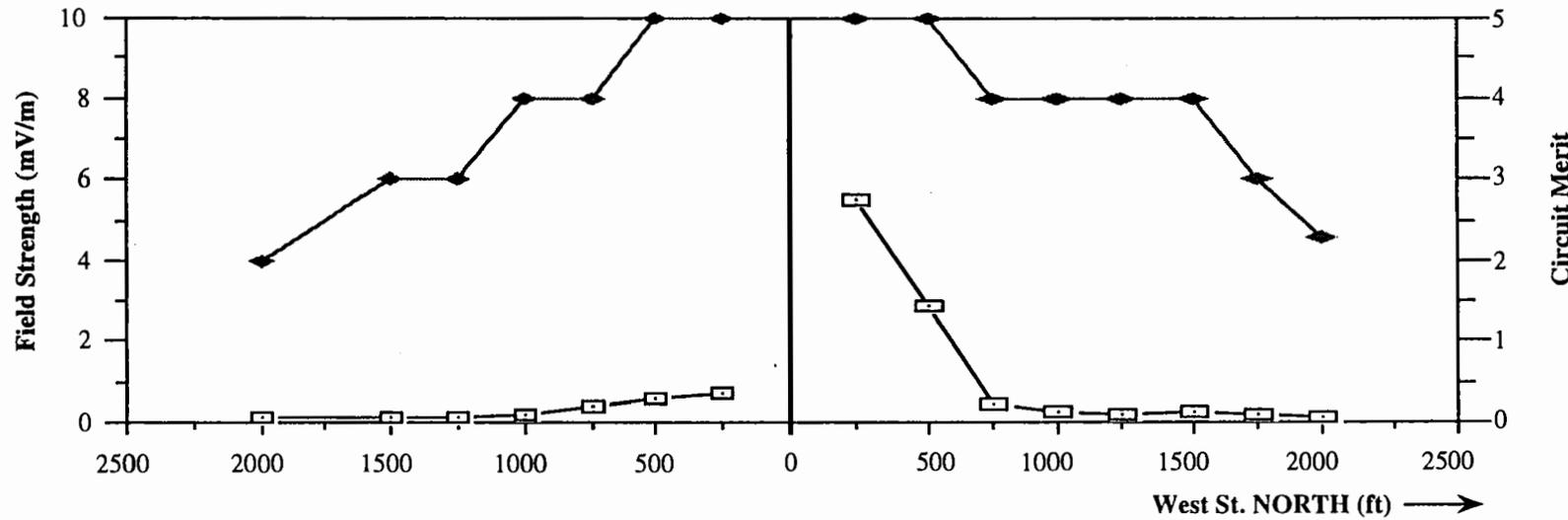
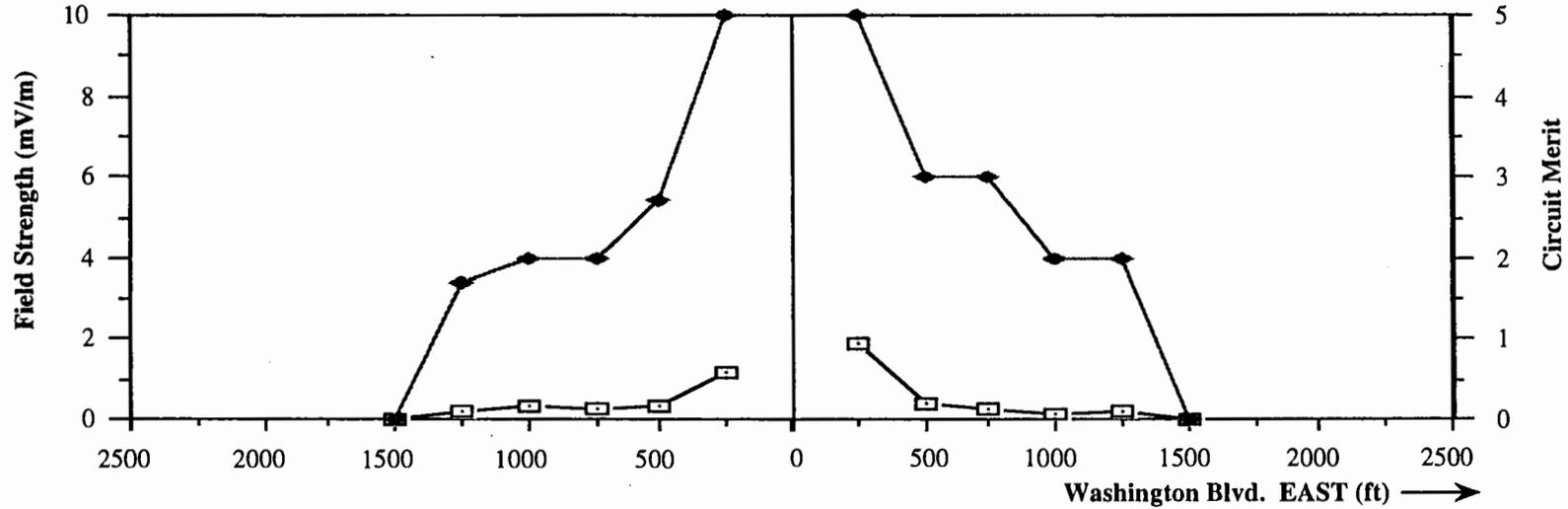
Each of the transmitter sites chosen for individual transmitter tests was chosen to assure a diversity of site characteristics for evaluation. For example, the West Street site was chosen because the transmitter performed less favorably than the remainder of the sites. The Arlington Avenue site was chosen because the transmitter was located on Arlington rather than on Washington. Finally, the Hauser Boulevard site was chosen because the transmitter was located on a Marbelite pole.

Exhibit 4.2 documents the results of the West Street test. The Arlington and Hauser transmitter tests are documented in Exhibits 4.3 and 4.4. Results are tabulated and summarized

Individual Transmitter Data

Washington & West

Time: 2:00pm



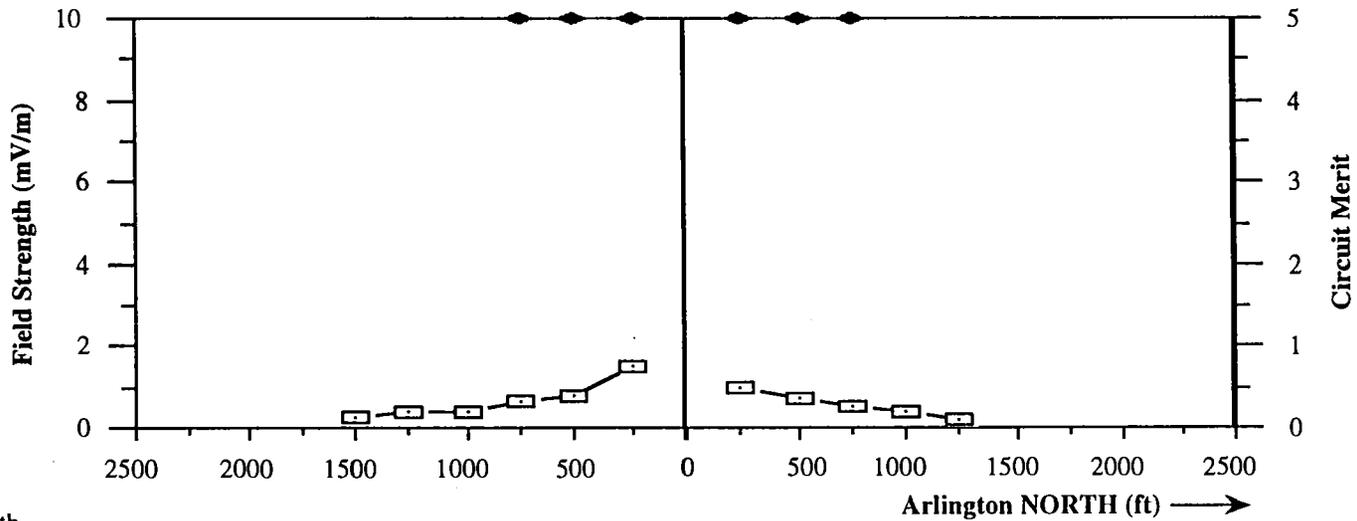
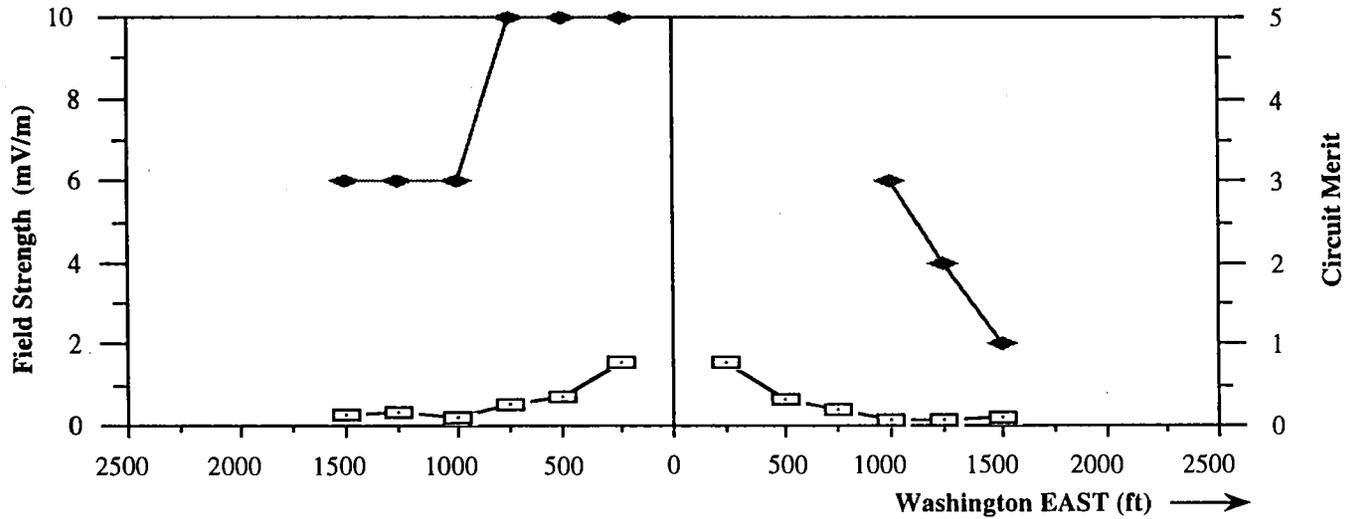
—□— Field Strength
—◆— Circuit Merit

Exhibit 4.2

Individual Transmitter Data

Washington & Arlington

Time: 10:00am

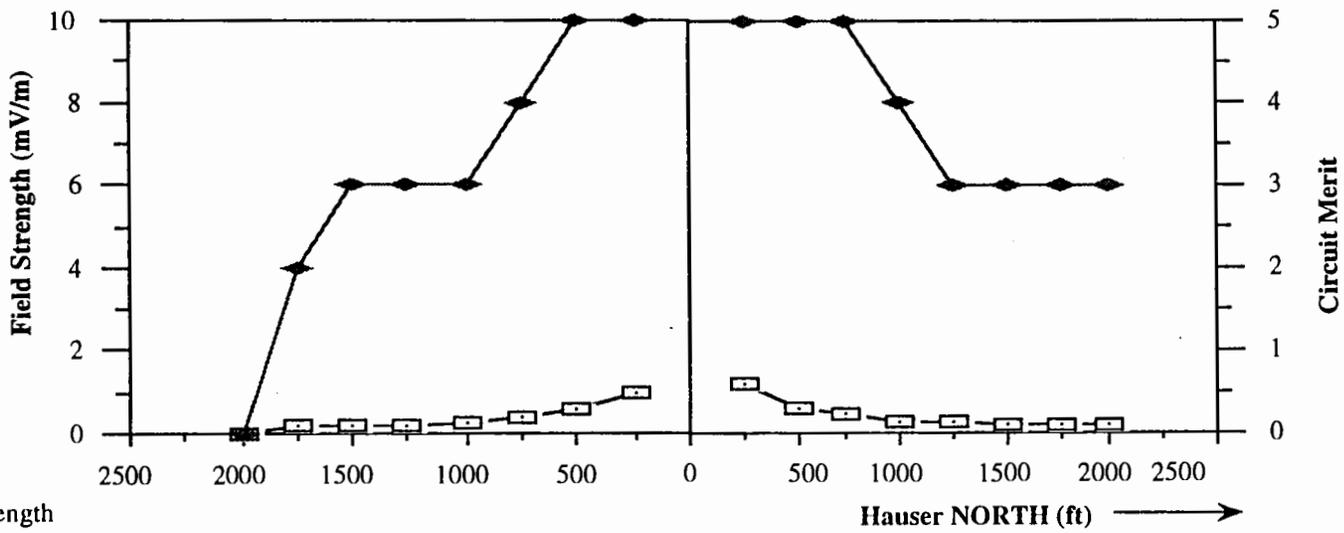
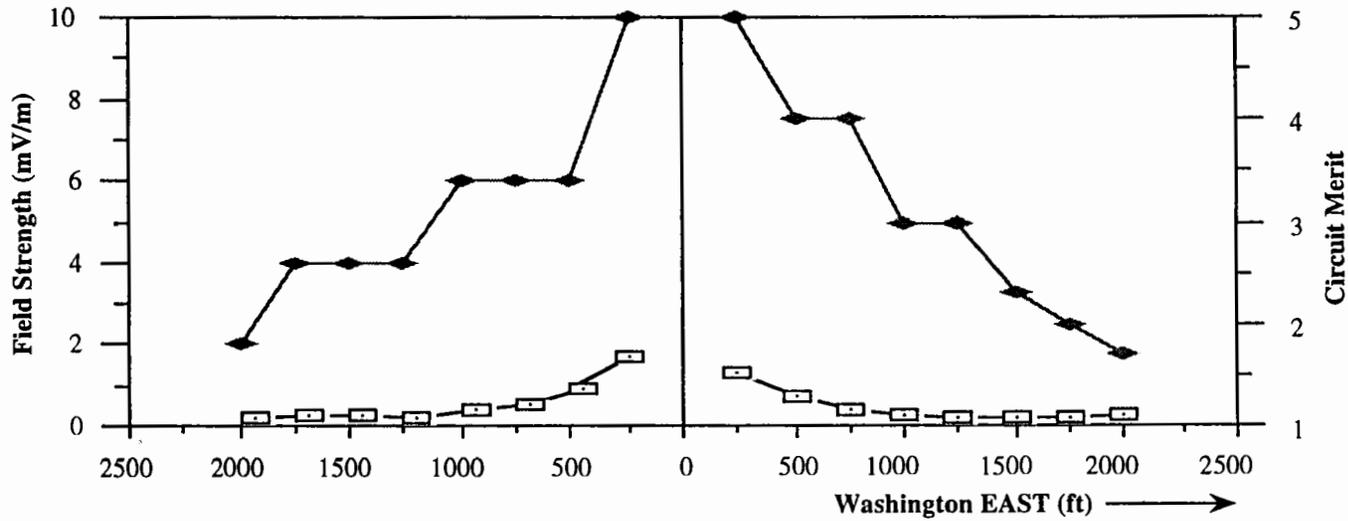


—□— Field Strength

Individual Transmitter Data

Washington & Hauser

Time: 2:00pm



—□— Field Strength
—◆— Circuit Merit

Exhibit 4.4

in Exhibit 4.5. The exhibit shows that CM 4 can be achieved as far as 1500 feet from one location. While another transmitter provides a CM 4 at a distance of 400 feet. This wide range of performance is shown in the large standard deviation values (Standard Deviation for CM 4 = 390 feet) for circuit merit. Field strength contour locations tend to be more predictable than audio quality contours with standard deviations for each field strength contour in the 120 to 140 foot range.

For the sites evaluated, the conclusions that can be drawn from this analysis suggest that a maximum range of 1500 feet can be obtained from an individual transmitter with CM 4. To analyze typical and minimum ranges, the average location of the midpoint of the CM 4 and CM 5 contours was determined. The typical range of a transmitter was found to be approximately 750 feet in each direction and the minimum range observed was 325 feet. A key observation is that transmitter range tends to vary within a wide range and is not strongly correlated to field strength making prediction of individual transmitter performance difficult.

4.2.5.2 - Venice Boulevard

The individual transmitter testing on Venice Blvd. was limited to a single transmitter at San Vicente. Test data were collected at measured intervals along the street at a distance of 11,000 feet to the east and west of the transmitter location. The measurements on Venice, east of San Vicente, were taken on the south side of the Venice Boulevard. Measurements to the west of San Vicente were obtained on the north side of Venice Boulevard.

Exhibit 4.6 shows the plots of the signal strength level and audio quality along a section of Venice Boulevard. The field strength plot shows that the signal level approximately decreases as to the inverse of the distance from the transmit site. Each doubling of the distance, results in a signal level decrease of approximately one-fourth. This inverse square relationship is expected radio wave propagation behavior.

The exhibit's plot of the received audio quality indicates that the audio is clearer for a longer distance to the west of San Vicente than to the east of this cross street. Further, the plot shows that the intelligibility does not degrade in direct proportion with signal strength when traveling to the west; in fact it remains at a constant CM 5 for the entire 11,000 feet surveyed.

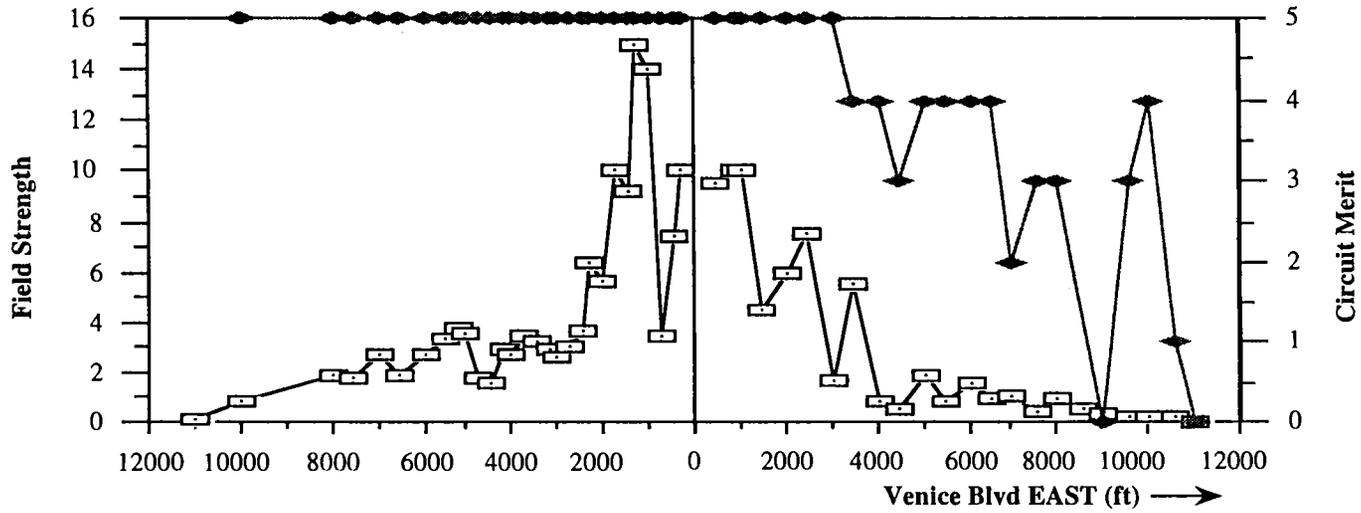
During these tests, the eastern side of the Zone was experiencing noticeable power line-

HAR Propagation Distance (ft)

Location	CM5	CM4	1.5 mV/m	1.0 mV/m	0.5 mV/m
Washington & West (E)	250	400	300	400	500
Washington & West (W)	250	400	250	300	400
Washington & West (N)	550	1500	600	700	750
Washington & West (S)	500	1000	100	250	700
Washington & Hauser (E)	250	750	200	300	600
Washington & Hauser (W)	250	1100	300	450	700
Washington & Hauser (N)	800	1100	250	400	800
Washington & Hauser (S)	600	750	200	300	750
Washington & Arlington (E)	500	750	250	500	750
Washington & Arlington (W)	750	1500	250	500	800
Washington & Arlington (N)	750		150	250	750
Washington & Arlington (S)	750		250	500	900
Average (ft)	516.67	925.00	258.33	404.17	700.00
Standard Deviation (ft)	220.88	390.33	122.16	133.92	138.17
Minimum (ft)	250.00	400.00	100.00	250.00	400.00
Maximum (ft)	800.00	1500.00	600.00	700.00	900.00
Sample Size (n)	12	10	12	12	12

Exhibit 4.5

Individual Transmitter Data Venice & San Vicente



 Field Strength
 Circuit Merit

spawned noise. This noise was strong enough to affect the listening quality of the HAR message. Even though the signal strengths to the east and west were comparable, the audio quality was significantly degraded by the presence of this noise.

The conclusion reached from this test is that high voltage transmission lines (Shown in Exhibit 4.7) will propagate the RF signals for a significant distance. Although RF propagation occurs some noise is introduced into the signal by this method of propagation. No further individual transmitter tests were conducted on Venice Boulevard because an individual transmitter propagated the entire length of the zone with a single transmitter active.

Comparing the CM 4 contours for Washington Boulevard and Venice Blvd. with the field strength contours for each roadway suggests that a CM 4 requires 0.7 mV/meter on Washington Blvd. while CM 4 audio quality requires 1.0 to 1.5 mV/meter field strength on Venice Blvd. This can be attributed to a higher background noise level on Venice Blvd. Venice Boulevard background noise was spawned by the same power lines that were responsible for the increased transmission range.

4.2.6 - Power Line Propagation

Based on the large discrepancy in the results for the Venice Blvd. transmitter (located adjacent to 35 KV distribution lines) and the Washington transmitter (not located in the proximity of power lines) an effort was made to further explore the impact of power lines on radio transmission. In order to verify that the power lines were affecting the propagation of the signal, several tests were conducted.

The first test focused on the Venice and Crenshaw transmitter site. Field strength measurements were conducted near the transformer serving the commercial center at the intersection. Field strength measurements confirmed a significant increase in field strength directly under the transformer, confirming that RF emissions were in fact being propagated by the power distribution system.

Tests at Washington Blvd. and West Blvd. also indicated that an overhead power line caused the direction of the maximum field strength to change. Specifically the power line located approximately 100 feet from the transmitter site, crosses from the south-east to the north-west corner of the intersection (see Exhibit 4.7). In the area between the transmitter and the power

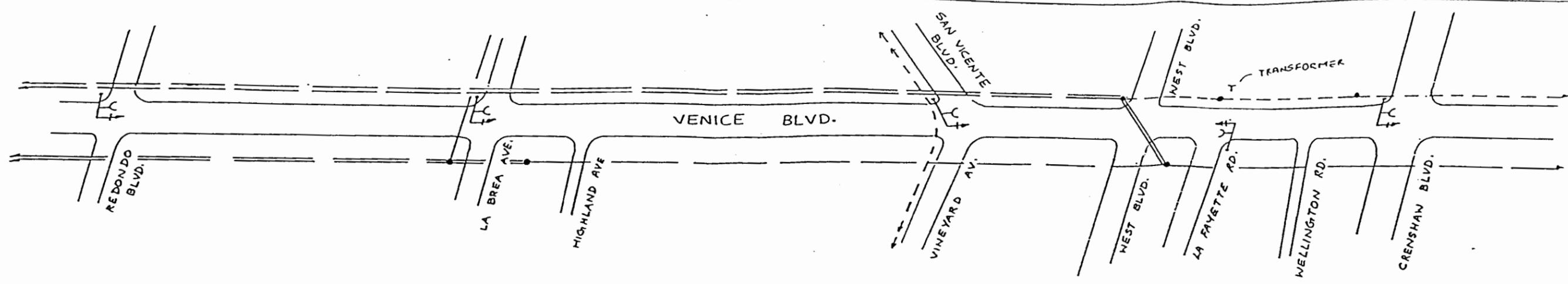
line, the direction of the maximum field strength was towards the antenna. However, the direction of maximum field strength became parallel to the power line when the power line was located between the field strength meter and the transmitter.

A anomalous field strength behavior was also noted in the vicinity of a number of service risers. Specifically, the north-west corner of Washington and West Boulevards had an uncharacteristically high field strength level of 5.5 and 2.9 mV/meter at distances of 250 and 750 feet, respectively. This can be attributed to a 4,800 Volt overhead power line and associated service risers located on two of the power poles for this line. Each riser radiated the HAR signal with a field strength of approximately 70 mV/meter when measured to within about 6 to 12 inches of riser.

The conclusion based on these tests is that the power lines in the vicinity of the HAR transmitters will absorb RF energy and reradiate it from the electrical circuits at considerable distances from the transmitter. Distances as large as 10,000 feet were observed for major transmission lines, but distances for local distribution lines tend to be lower due the presence of transformers which shunt the RF signal.

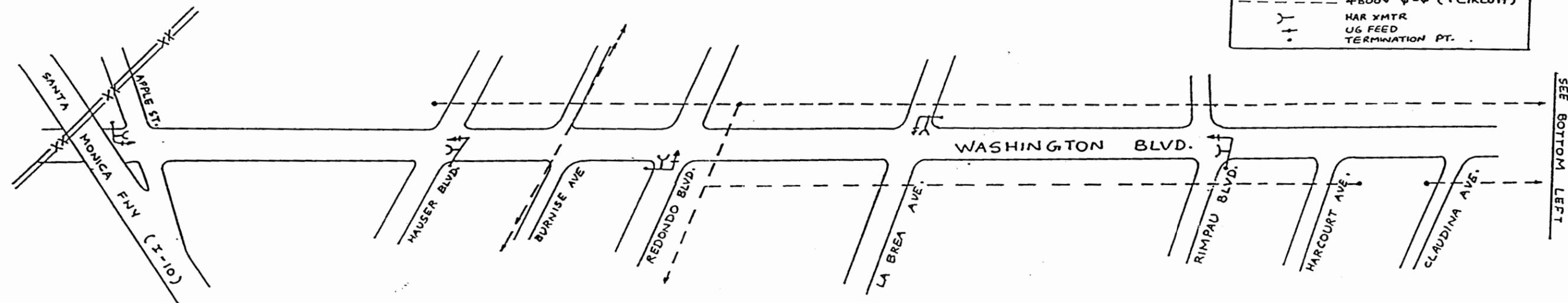
4.2.7 - Night-Time Commercial Broadcast Interference Effects

Radio frequency propagation characteristics in the AM broadcast band during the night time are substantially different than during the daytime. During the tests, that effect was first noticed at 3:30 in the afternoon when an international station became strong enough to be heard over the HAR signal. As the afternoon progressed, the strength of the station continued to increase and caused interference to weak(0.5 mV/meter) HAR signals. This effect can be observed by comparing field strength characteristics of the HAR transmitter at Washington and Hauser at 2:00 PM and at 5:30 PM (Exhibit 4.8). Circuit Merit values are shown in Exhibit 4.9. This effect can be minimized by designing the HAR system to provide signals greater than 0.7 mV/meter and by verifying that field strengths for on channel signals are well below the 0.5 mV level at all times of the day.

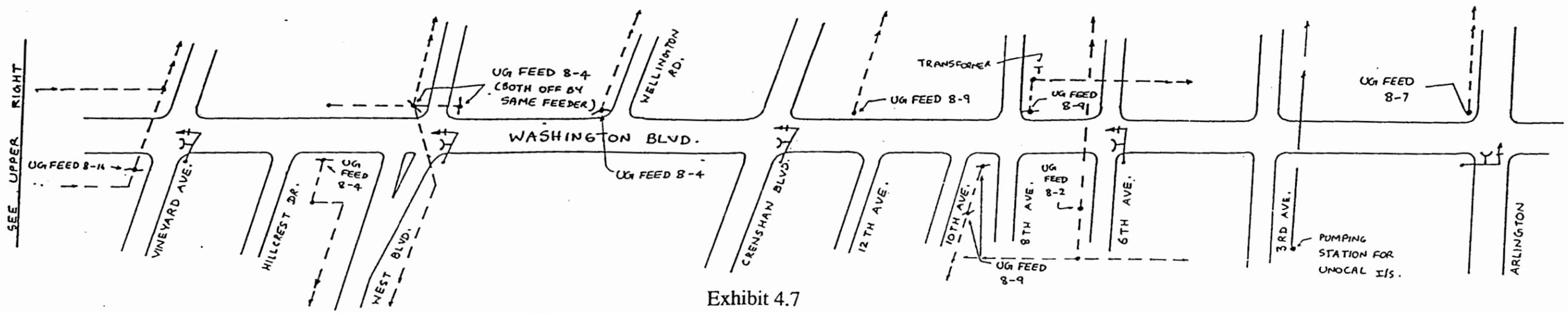


VENICE BLVD. POWER DISTRIBUTION

LEGEND	
== XX ==	230 KV ϕ - ϕ (2 CIRCUITS)
== ==	35 KV ϕ - ϕ (2 CIRCUITS)
— — —	35 KV ϕ - ϕ (1 CIRCUIT)
- - - - -	4800V ϕ - ϕ (1 CIRCUIT)
Y	HAR YMTR
+	UG FEED
.	TERMINATION PT.



SEE BOTTOM LEFT

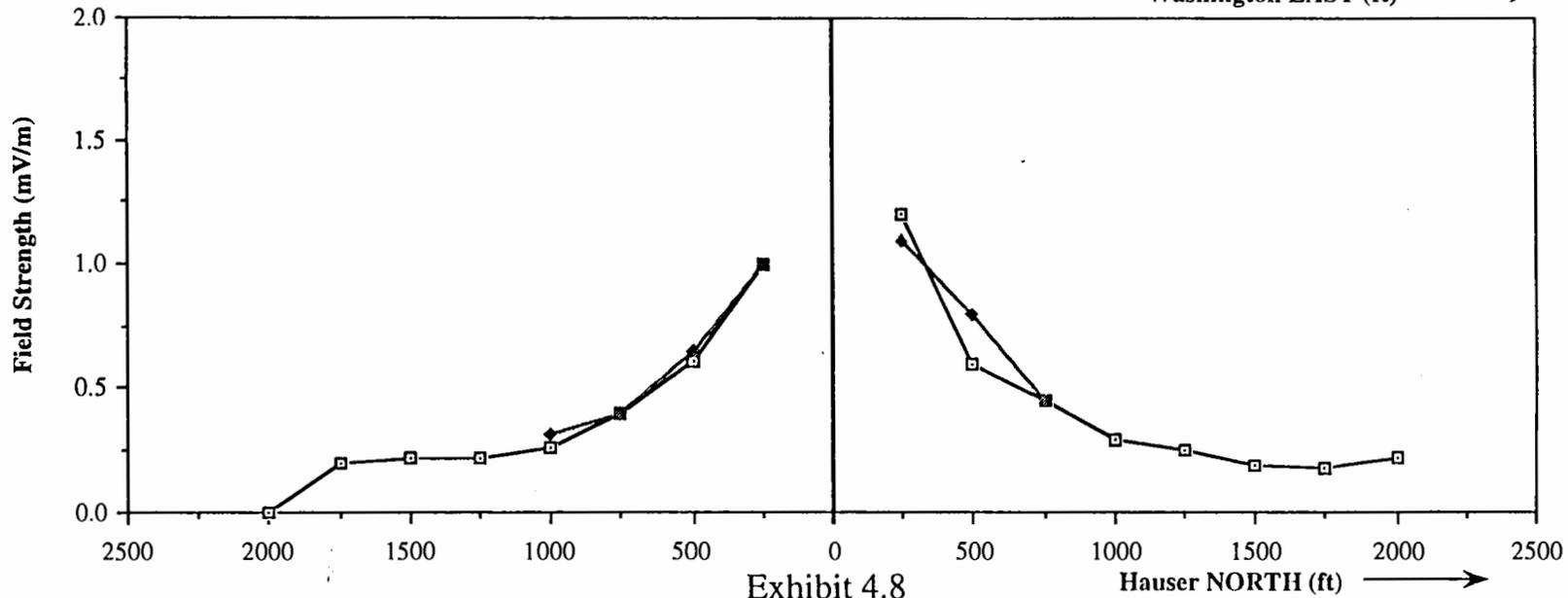
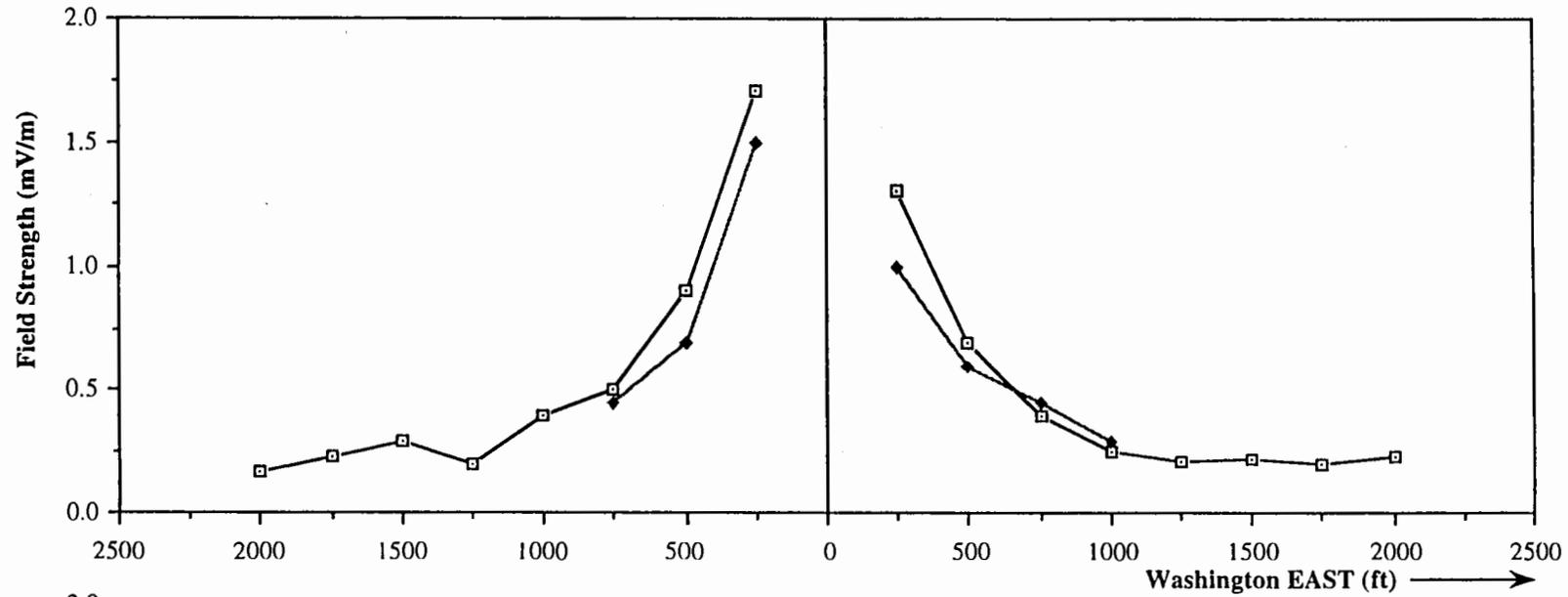


SEE UPPER RIGHT

Exhibit 4.7
WASHINGTON BLVD. POWER DISTRIBUTION

Field Strength Comparison By Time of Day

Washington & Hauser



2:00 PM

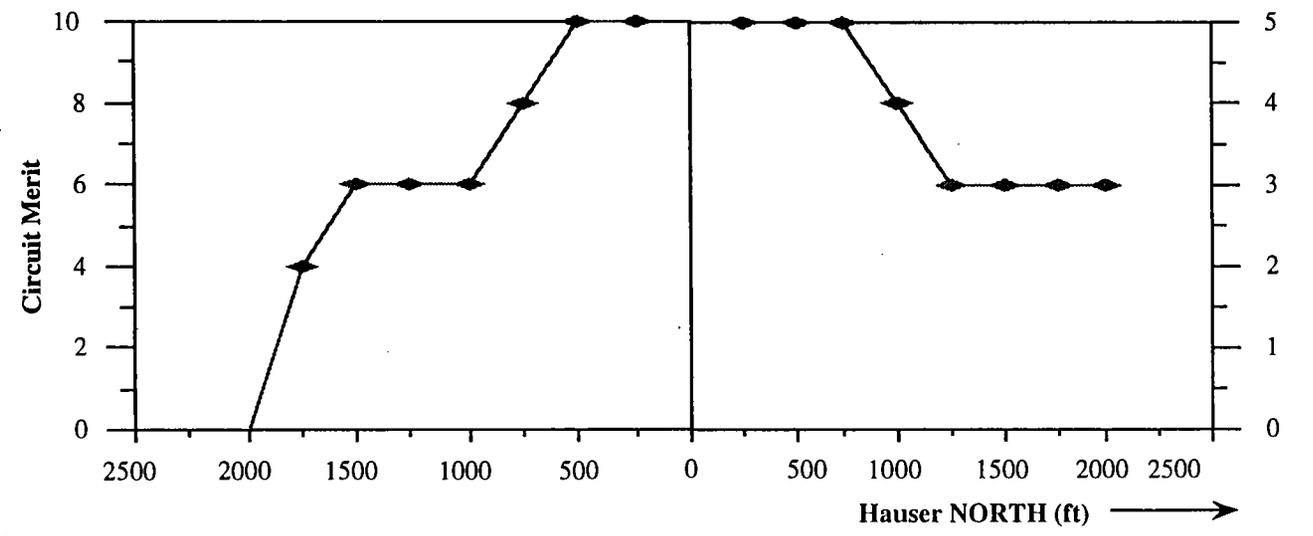
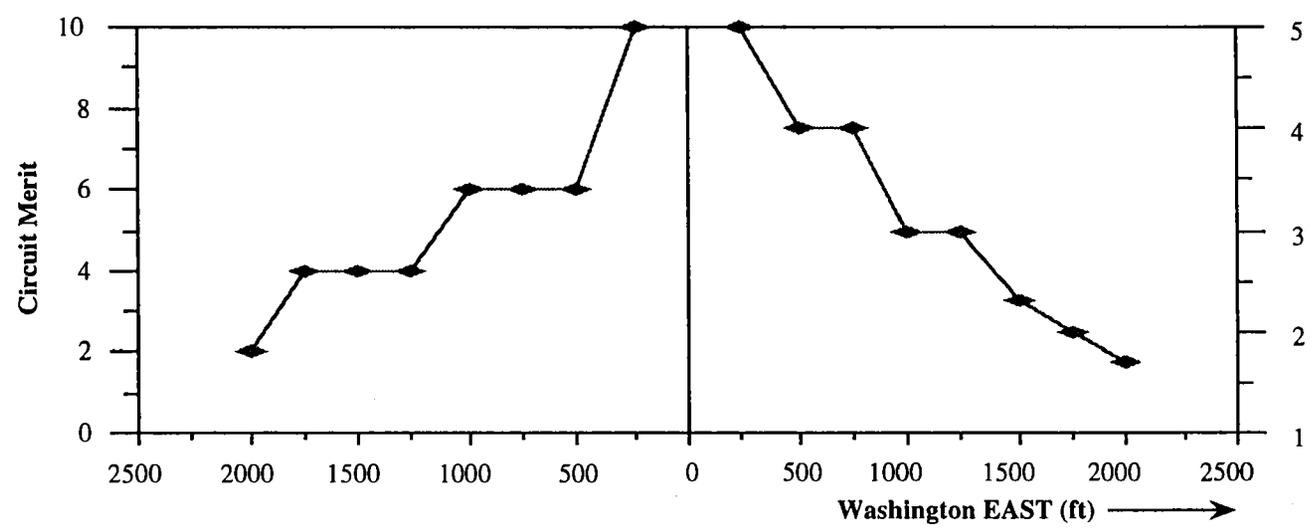
 5:30 PM

Exhibit 4.8

Individual Transmitter Circuit Merit Data

Washington & Hauser

Time: 2:00pm



● Circuit Merit

FIGURE 1.0

4.3 ZONE TESTS

A premise in the design of a low power HAR system is that area specific coverage is desired and that multiple transmitters would be employed to determine the area of coverage. Early in the design of the system, it was recognized that it was necessary to provide frequency locked signals to avoid a heterodyne or beat tone. It was also recognized that signal interaction and phasing could be a potential problem in the deployment of the multi-transmitter system. This section first explains the concepts of frequency and phase lock and finally documents tests used to study these effects within a zone.

4.3.1 - Transmitter Frequency

The frequency of a transmitter is defined as the number of cycles per second (Hertz) of a radio frequency signal. The phase of one signal in relation to that of another is shown in Exhibit 4.10 as a displacement of one frequency's cyclic starting point in relation to the other signal. The exhibit documents constructive interference resulting in maximum amplitude when signals are in phase. Destructive interference results when the signals are completely (180 degrees) out of phase as shown in Exhibit 4.11. Signals which are completely out of phase will cancel out and cause dead spots, due to destructive interference. While signals that are 90 or 270 degrees out of phase will cause degradation of the signal (rumble); Exhibit 4.12 shows the resultant phase shift. In the context of this report, the detrimental phase difference occurs when two signals of the same frequency are displaced by between 90° to 270°.

4.3.1.1 - Frequency Selection

No field research was conducted to determine a preference for HAR operation in the lower frequency portion (530 khz to 1000 khz) of the AM broadcast band or the higher frequency portion of the AM broadcast band (1000 khz to 1710 khz). However, a theoretical analysis of the HAR system characteristics and RF propagation characteristics suggests that broadcasts in the higher frequency portions of the AM broadcast band may be preferable. The first reason for this is that electromagnetic interference due to presence of power lines and insulators is more

Constructive Interference

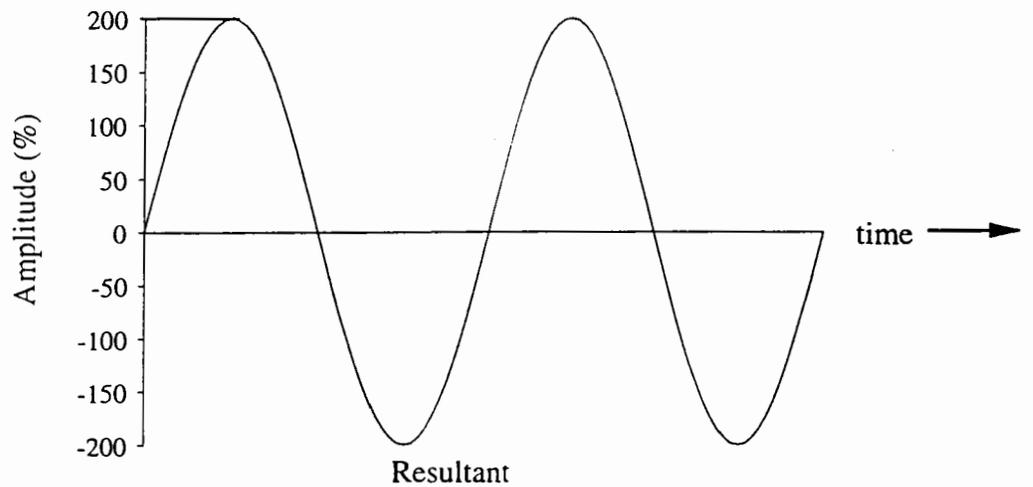
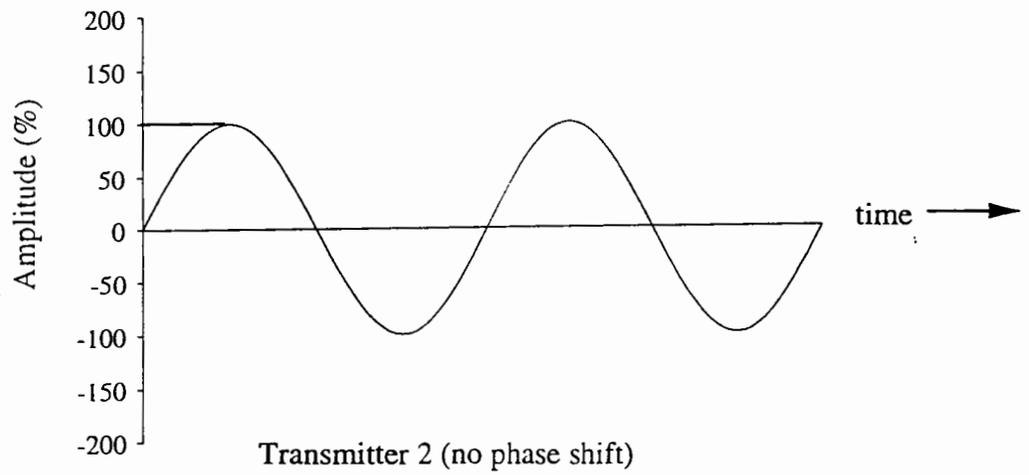
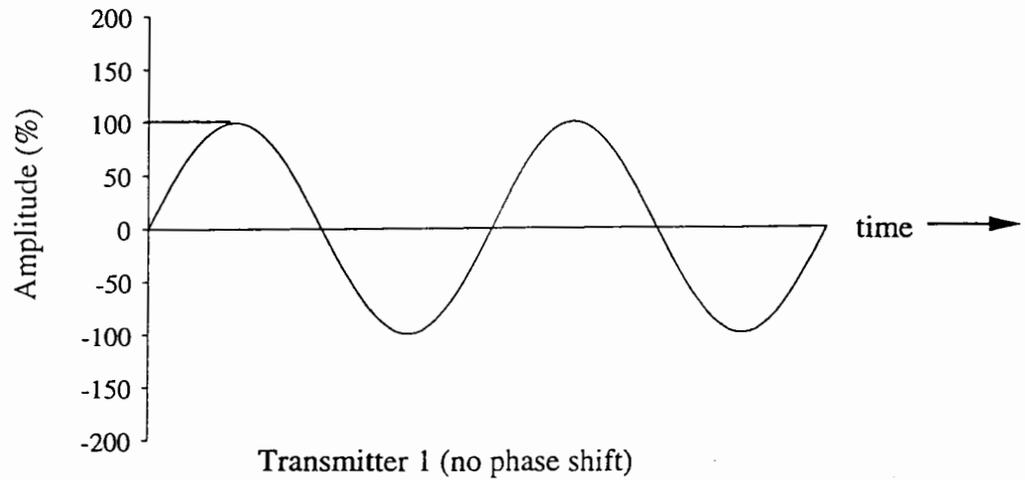


Exhibit 4.10

Destructive Interference

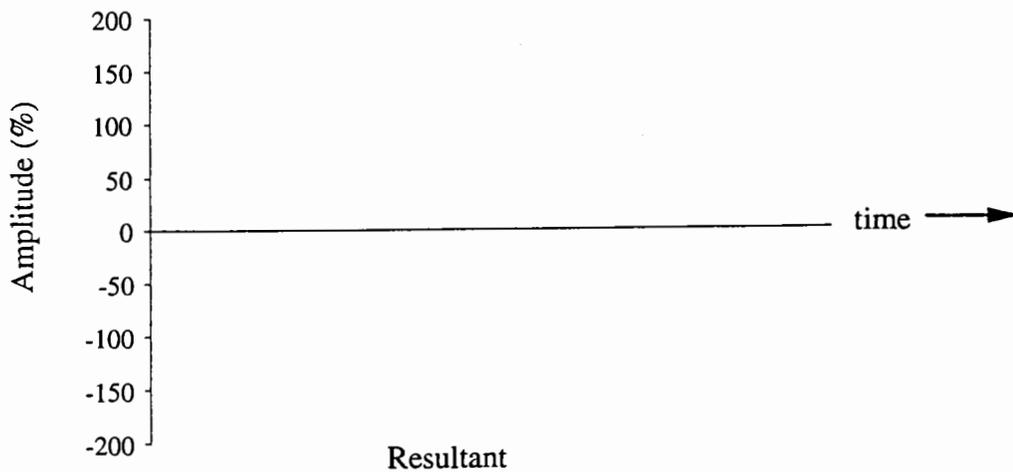
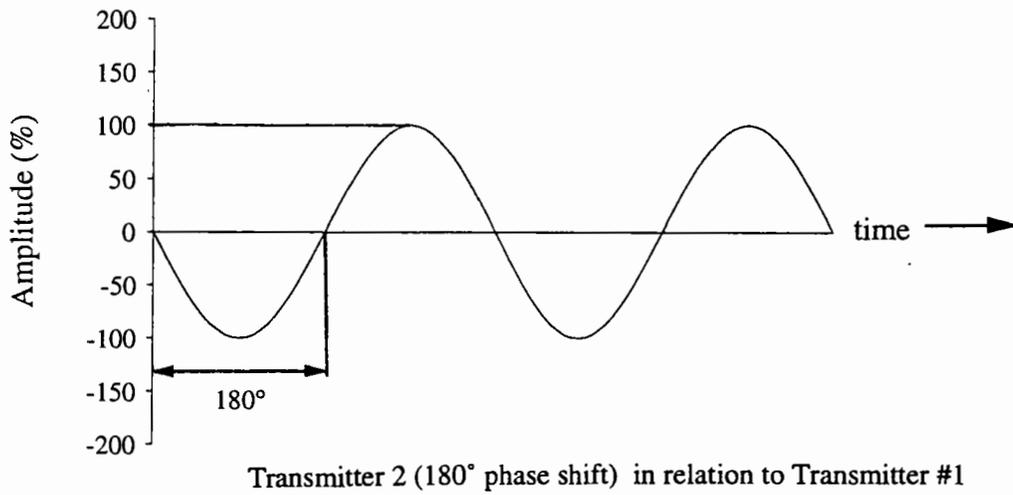
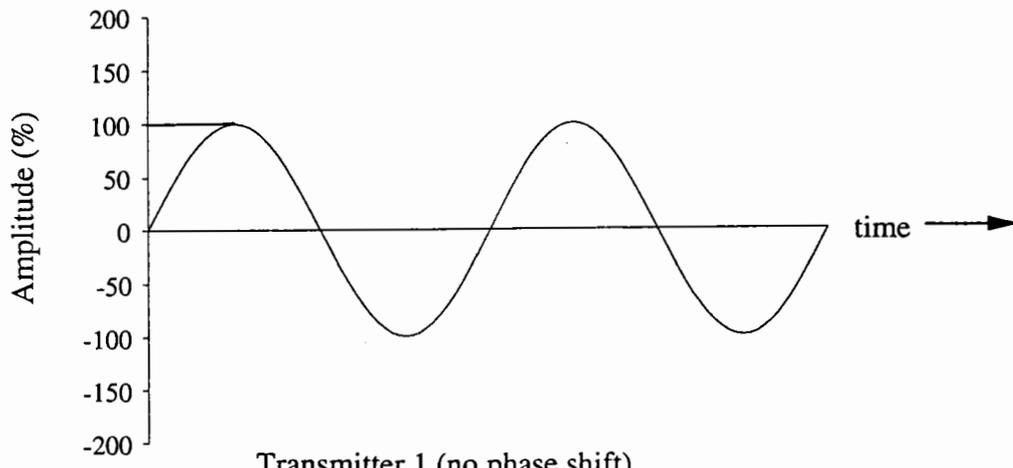


Exhibit 4.11

140° Phase Shift

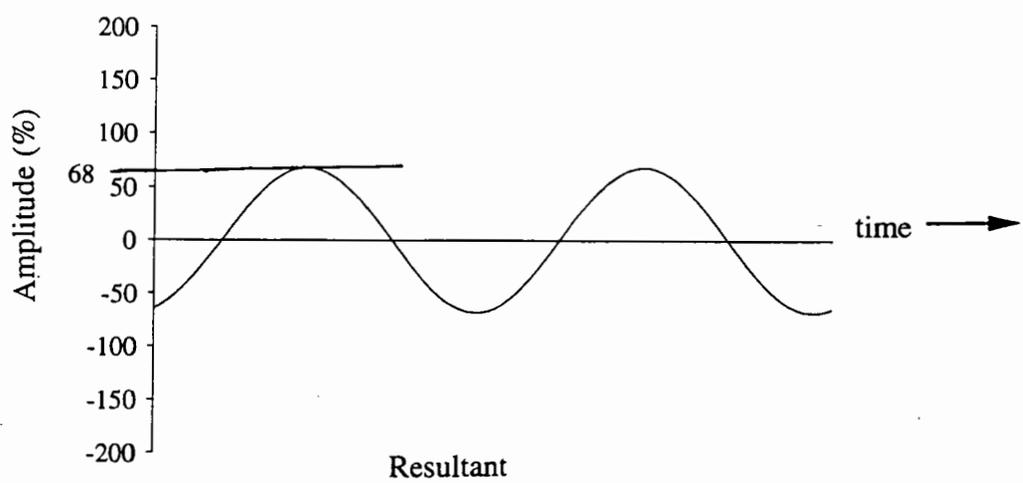
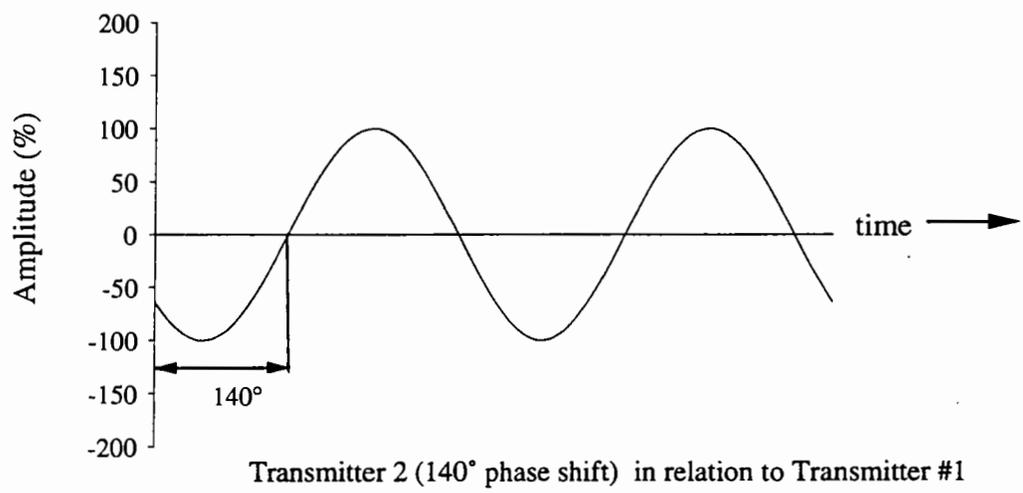
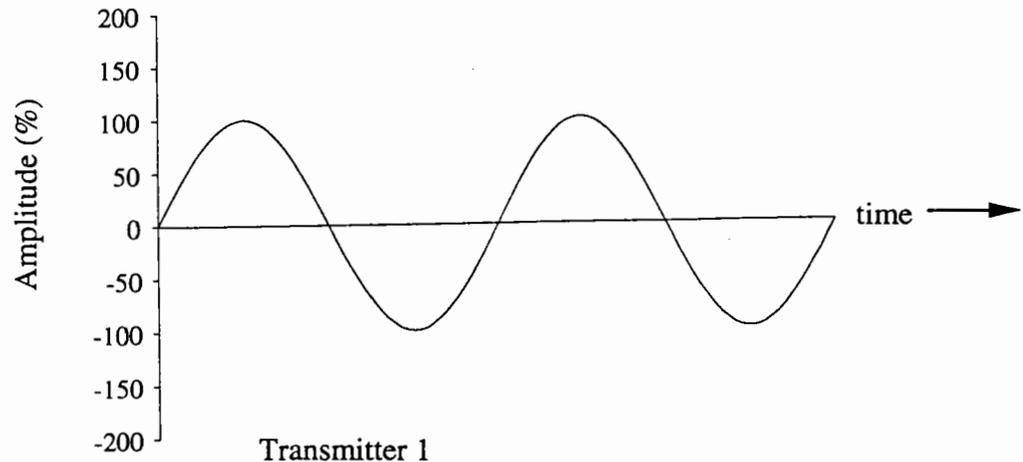


Exhibit 4.12

likely to occur at the lower frequencies. In addition, wave lengths are shorter at the higher frequencies permitting more efficient design of antennas.

For example the wavelength for a station operating at 530 khz will be 566 meters, while a station operating at 1710 kilohertz will have a wave length of only 175 meters. A fundamental antenna form that offers excellent performance characteristics is a dipole antenna whose length is approximately one-half of a wave length. However, this would result in an antenna which could be as long as 283 meters. However, antennas for HAR installations are limited to more practical lengths, 96 inches or 2.44 meters in this case. Thus to achieve an electrical match, loading coils and balancing circuits must be used. These circuits are most efficient if the mismatch between the physical antenna structure and the desired antenna length is small. Shorter wave lengths and higher frequencies result in a better match to a short antenna (96 inch). Thus it may be preferable to operate HAR equipment in the higher frequency portions of the broadcast band when feasible.

4.3.1.2 - Frequency Lock

Field tests demonstrated that all transmitters within the zone were frequency locked, based on the absence of any noticeable heterodyne in the audio output.

4.3.1.3 - Phase Lock

The system was designed to allow phase offset adjustments between adjacent transmitters. The intent of adjustment was to minimize the disruptive effects of phase noise, a low pitched rumble, in the desired coverage area. As a practical matter, phase offset adjustments proved to be tedious and subjective, relying on the human ear for optimization. To eliminate some of the difficulty associated with the phase adjustment, the use of an AM receiver with carrier output to an oscilloscope would be recommended during the phase adjustment process to assure that destructive interference is minimized at key locations. This approach would remove the subjective influence of the listener's perception from the adjustment process. In addition, a remote phasing adjustment method is recommended, as there is some difficulty in accessing transmitters installed on signal mast arms for phase adjustment and fine tuning purposes.

While the discussion above has focused on two transmitters, phase interaction among multiple transmitters is possible and will result in highly complex wave forms making analysis and fine tuning a delicate process. To minimize this effect, excessive overlap in transmission zone coverage should be avoided. During the tests, locations that did not have phase coherence exhibited the characteristic low-pitched rumble. This was experienced at several places along Venice Boulevard but was not noticed along the Washington Boulevard zone. This may be attributed to the greater range of the Venice Boulevard system causing the radiated field from adjacent transmitters to interact more readily.

4.3.2 - Venice Blvd. Zone Tests

A series of tests was structured to determine the minimum transmitter coverage requirement along Venice Boulevard. Data collected for all of these tests were taken at identical points spaced at midpoints between transmitter locations. The presence of high voltage transmission lines proved to be a major contributing factor in the results of these tests. The tests were structured as follows:

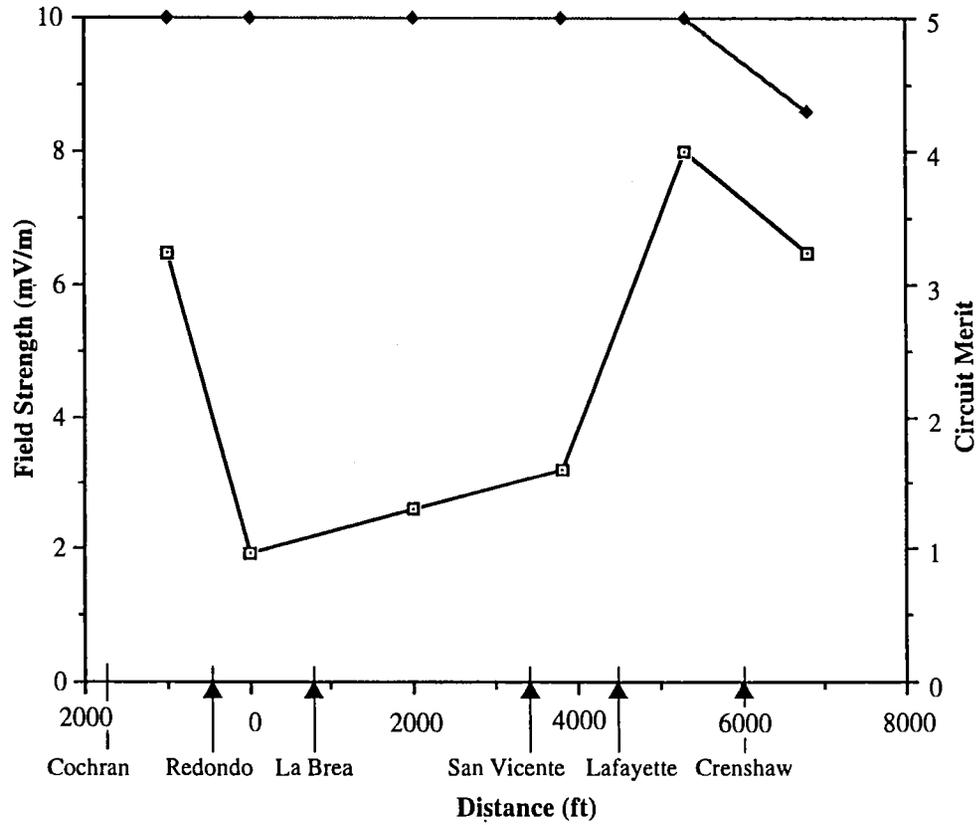
- All Transmitters Operating (5 Transmitters)
- Alternate Transmitters Operating (3 Transmitters)
- End Transmitters Only Operating (2 Transmitters)

4.3.2.1 - All Venice Transmitters Operating

All five transmitters of the Venice Zone were enabled for this test. Exhibit 4.13 shows plots of the signal level and audio quality along the section of Venice Boulevard that was tested. The field strength plot along the length of the street shows that there is a large variation in field signal level but with an essentially constant audio quality. The signal level dip occurring between the Redondo and La Brea sites, shown on the exhibit as the zero point reference location, indicates that, at this position, the relative phase from these two sites could be causing destructive interference. Conversely, the peak in signal strength between the Lafayette and

Venice Blvd

All Transmitters On



- ▲ Transmitter
- Field Strength
- ◆— Circuit Merit

Exhibit 4.13

Crenshaw sites could be caused by the phase of the transmitters being such that constructive interference exists and hence a peak in measured signal level results.

4.3.2.2 - Alternate Transmitters Operating

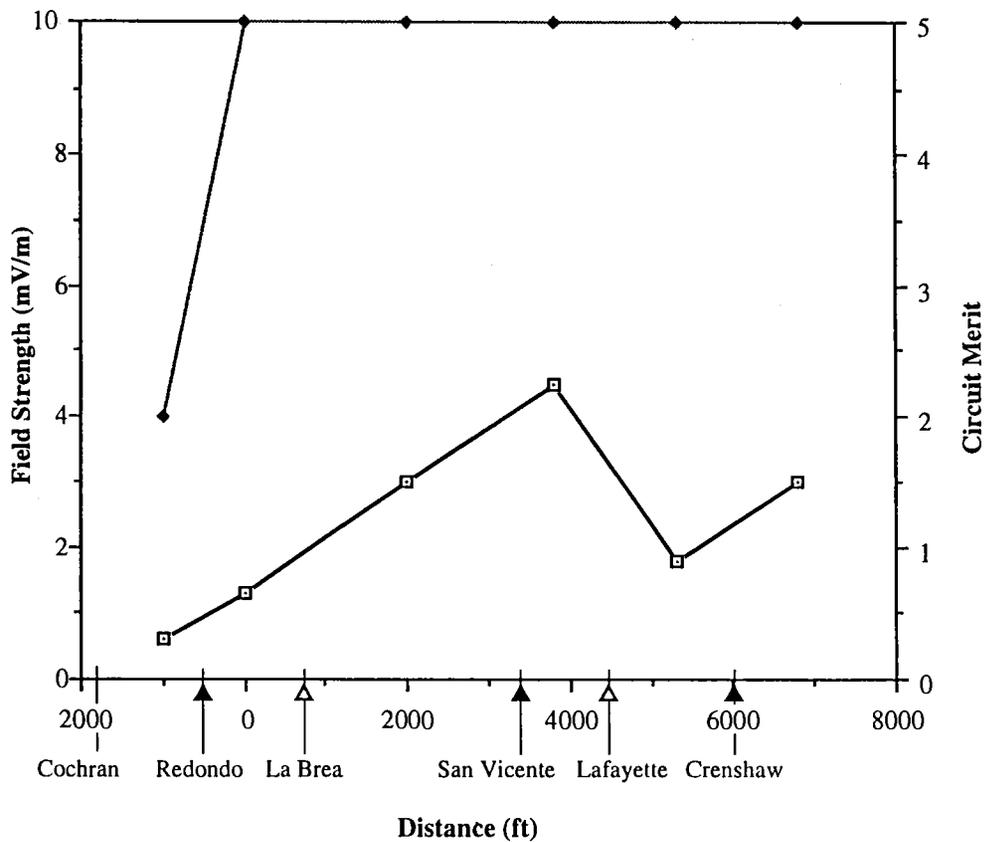
This test was conducted to determine the resulting coverage when every other transmitter was operating. Three of the five transmitters in this zone were enabled for this test: Redondo, San Vicente and Crenshaw. Exhibit 4.14 shows the plots of the field strength level and the audio quality versus distance along the section of Venice Boulevard that was tested. The dips and rises shown here are likely to be caused by transmitter frequency phasing which causes constructive and destructive interference at various locations along the tested route. The audio quality remains at a constant CM 5 until the western most transmitter is approached, where it then drops to CM 2. The audio quality, in this case, drops in the western part of the zone as opposed to the eastern part, as it did when all Venice Boulevard transmitters were operating.

4.3.2.3 - Single Enabled Transmitter at Each End

This test was conducted to determine the resulting coverage when one transmitter at each end of the test zone was enabled. The Redondo and Crenshaw transmitters were energized for this test. Exhibit 4.15 shows the plots of the field strength level and the audio quality versus the distance along the section of Venice Boulevard that was tested. Unlike the previous multi-transmitter tests, there is an absence of sharp peaks or valleys in the field strength along the tested zone. In this case the two operating transmitters are far enough apart to not interact, and therefore the relative phases of the two transmitters are not able to develop constructive or destructive field interference affecting the measured field strength or audio quality. The audio quality plot suggests that the lower limit of audio quality, CM 4, is yielded at approximately 1.5 mV/meter of field strength. The primary indication from these tests is that transmitter spacing must be sufficiently close to provide adequate field strength, but not so close so that complex phase interaction patterns limit the ability to tune out destructive phase interaction.

Venice Blvd

Alternate Transmitters On

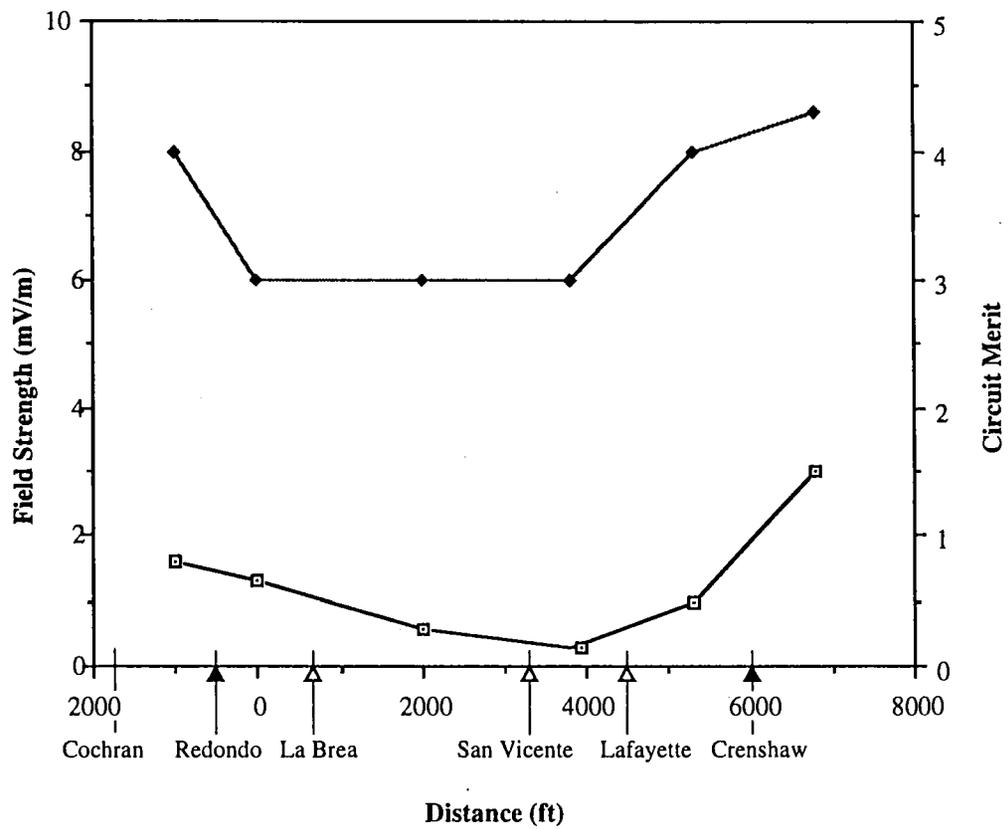


- △ Transmitter (Off)
- ▲ Transmitter (On)
- Field Strength
- ◆— Circuit Merit

Exhibit 4.14

Venice Blvd

End Transmitters On



- △ Transmitter (Off)
- ▲ Transmitter (On)
- Field Strength
- ◆— Circuit Merit

4.3.3 - Washington Blvd. Zone Tests

A single test with all transmitters on Washington Boulevard was conducted to determine if the system as deployed provided satisfactory coverage. All ten Washington Blvd. transmitters were enabled and driven with the same audio message. All ten Zone 1 transmitters were enabled for this test. Data was taken at measured intervals of 500 feet. Exhibit 4.16 shows the plots of the field strength level and the audio quality versus distance along the test section of Washington Boulevard.

The field strength plot shows variations in field strength of as much as 5.5 mV/meter along the length of the zone. Similar variations were experienced in the Venice Boulevard test where differences of 4 mV/meter were noted. The plot of the audio quality shows a complex profile. By comparison, it varied more in this test than in the corresponding Venice Boulevard test. This could be attributable to the increased number of transmitters used in this zone. As the number of same-frequency transmitters is increased, there are more opportunities to generate complex patterns of phase interference conditions along the zone. Both the audio and field strength can be affected by these out-of-phase situations. Equipment to measure the phase of the off-the-air signal was not available, therefore, further studies of the transmitter phase relationships could not be made.

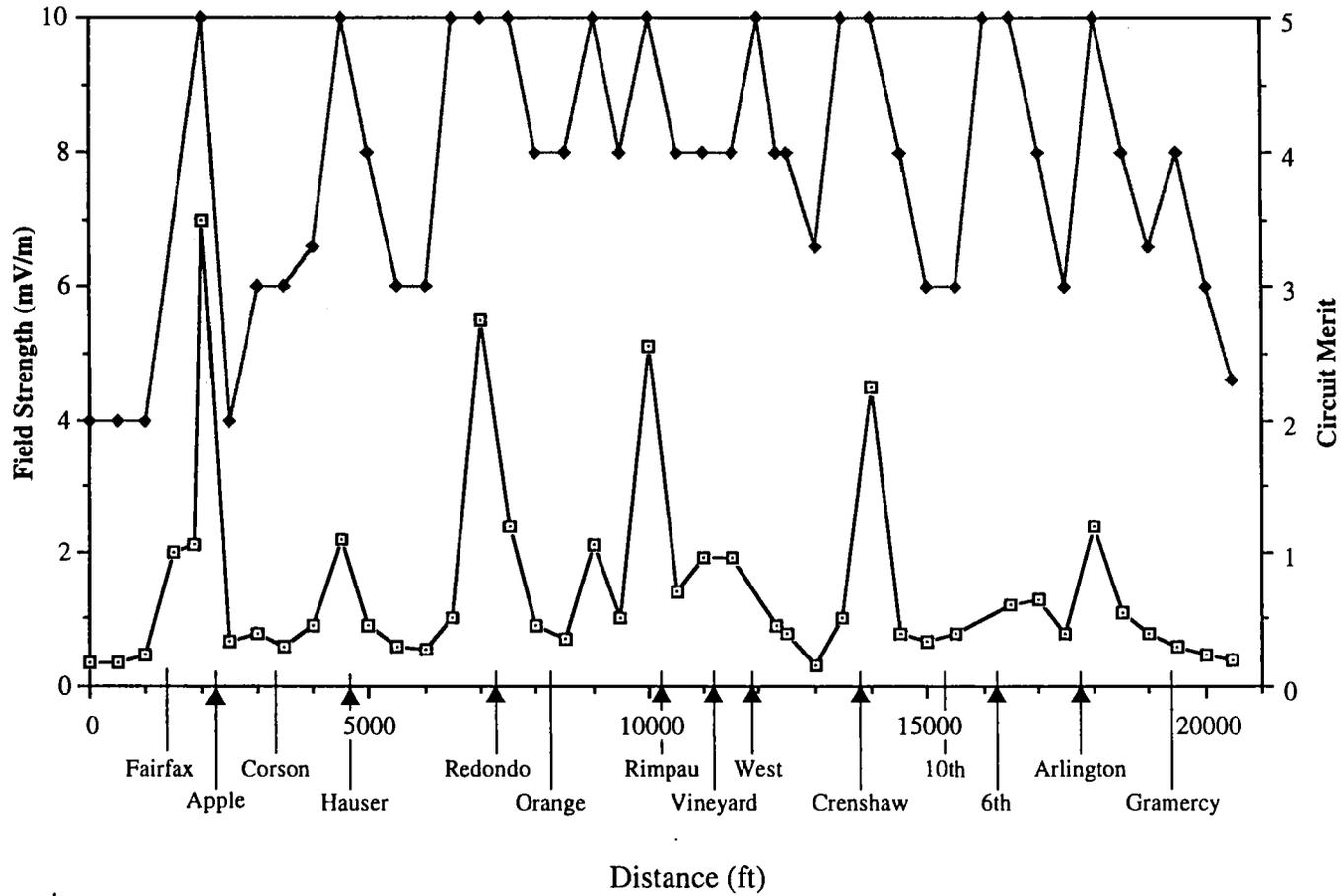
However, the conclusion that phase offsets between transmitters are causing a number of the rises and dips in signal strength is supported by the collected data.

4.4 MULTI-ZONE INTERACTION TESTS

Efforts were also devoted to studying multi zone interaction. The first step of the test was to study to what extent messages from two zones would intermix on cross streets between zones. The next step in the process was studying transmitter range in a direction perpendicular to a zone to determine how closely two parallel linear zones should be spaced. Finally, a third test that considered end to end spacing of linear zones was conducted. It should be noted that the results of this test reflect the affect of the power distribution lines on Venice Blvd.

Washington Blvd

All Transmitters On



- ▲ Transmitter
- Field Strength
- ◆— Circuit Merit

4.4.1 - Audio Intermix Tests Between Parallel Zones

The purpose of the following tests is to determine to what degree automobile drivers would hear both messages from two adjacent zones while traveling on cross streets perpendicular to the zones. A final test traveling the arterials was also performed to determine if messages from the other zone could be heard on the arterial itself.

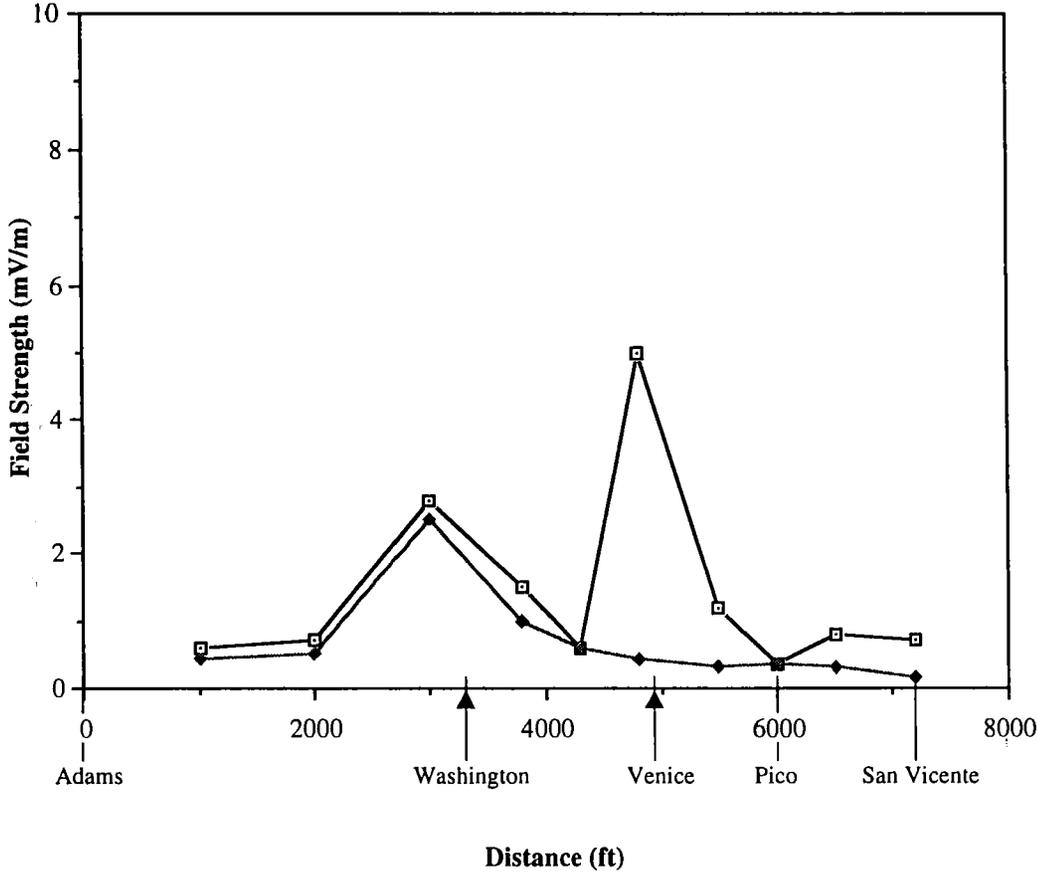
The test method was using a continuous-tone signal for Zone 2, the Venice Boulevard system, and a voice message for Zone 1, the Washington Boulevard system, to easily distinguish the signals. Tests were conducted on several cross streets which run between the two zones. The shortest distance separating the zones was 1,650 feet and the longest was 2,700 feet. Test results for each of the streets studied are presented below.

4.4.1.1 - Redondo Boulevard

On Redondo Boulevard the distance between Washington-to-Venice boulevards is 1,650 feet. Exhibits 4.17 and 4.18 show plots of field strength and circuit merit versus the measured intervals between Venice and Washington Boulevards. The test results revealed that message transition, the point where zone 1 and zone 2 messages could be heard equally well, was not quite midway between the two boulevards, but displaced by 300 feet towards Washington Boulevard. The performance of the Redondo-at-Venice transmitter was slightly better (5 dB difference) than the one at Redondo-at-Washington. On this cross street, the message transition location is closest to the desired midway point of all of the cross streets tested. Even though the distance between the two zones, on this cross street, is the smallest of all those tested, the Venice Boulevard transmitter is not significantly outperforming the one at Washington. Consequently, the distance to the transition point is not pushed as close to the Washington Boulevard end of the cross street as was found in the other cross street tests. Decreasing the Redondo-at-Venice transmitter power output would move the message transition closer to the midway point.

Redondo Blvd

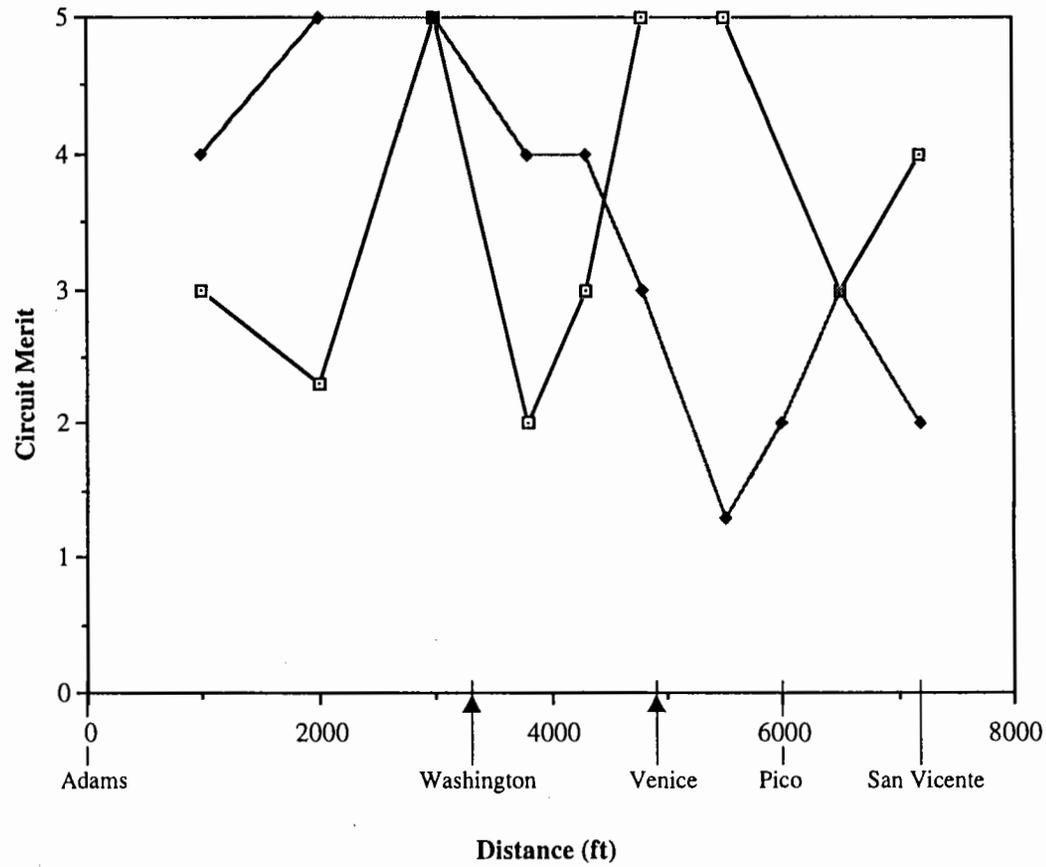
Field Strength



- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Redondo Blvd

Circuit Merit



- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Exhibit 4.18

4.4.1.2 - Crenshaw Boulevard

At Crenshaw Boulevard, the Washington-to-Venice boulevard separation is 1,950 feet. Referring to the field strength plot of Exhibits 4.19 and 4.20, the Crenshaw-at-Venice transmitter shows a higher field strength over the measured distance, nearly 10 dB better at its peak, and consequently yields greater coverage than the Crenshaw-at-Washington transmitter. The testing on Crenshaw Boulevard found that the Venice Boulevard tone was predominant throughout the distance between Venice and Washington. Only after passing the Washington Boulevard transmitter and continuing south towards Adams, did the voice message dominate over the Venice Boulevard tone-signal. The Venice Boulevard signal could be clearly heard to within 400 to 500 feet of the Washington Boulevard transmitter. A more desirable situation would be to have a message transition occur at the midway point, approximately 1000 feet between the two. This way the driver would begin to clearly hear one zone's message as a point midway between the two zones is reached.

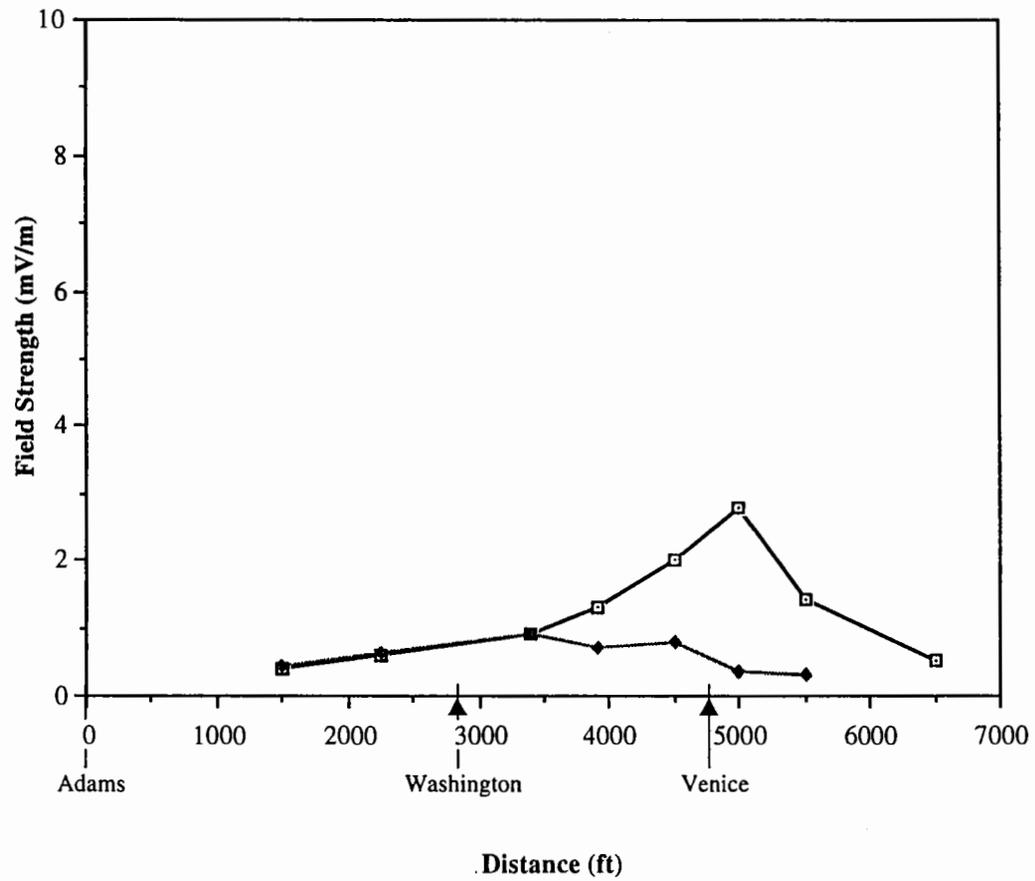
4.4.1.3 - La Brea Avenue

At La Brea Avenue the Washington-to-Venice Boulevard separation is 2,100 feet. The field strength plot of Exhibit 4.21 shows that the La Brea-at-Venice transmitter marginally outperforms (3.7 dB) the La Brea-at-Washington transmitter. The point at which the two messages are received with equal audio quality occurs approximately midway between the two zones (see Exhibit 4.22). This is the preferred situation to satisfy the intended operating goal of this HAR system.

4.4.1.4 - Vineyard Avenue

At Vineyard Avenue, the Washington-to-Venice Boulevard separation is 2,700 feet. Referring to the field strength plot of Exhibit 4.23, the Vineyard-at-Venice transmitter shows significantly higher field strength-distance profile (17 dB better at its greatest measured amplitude), and consequently greater coverage, than the Vineyard-at-Washington transmitter. Testing on Vineyard Boulevard showed that the Venice Boulevard tone was predominant for

Crenshaw Blvd. Field Strength

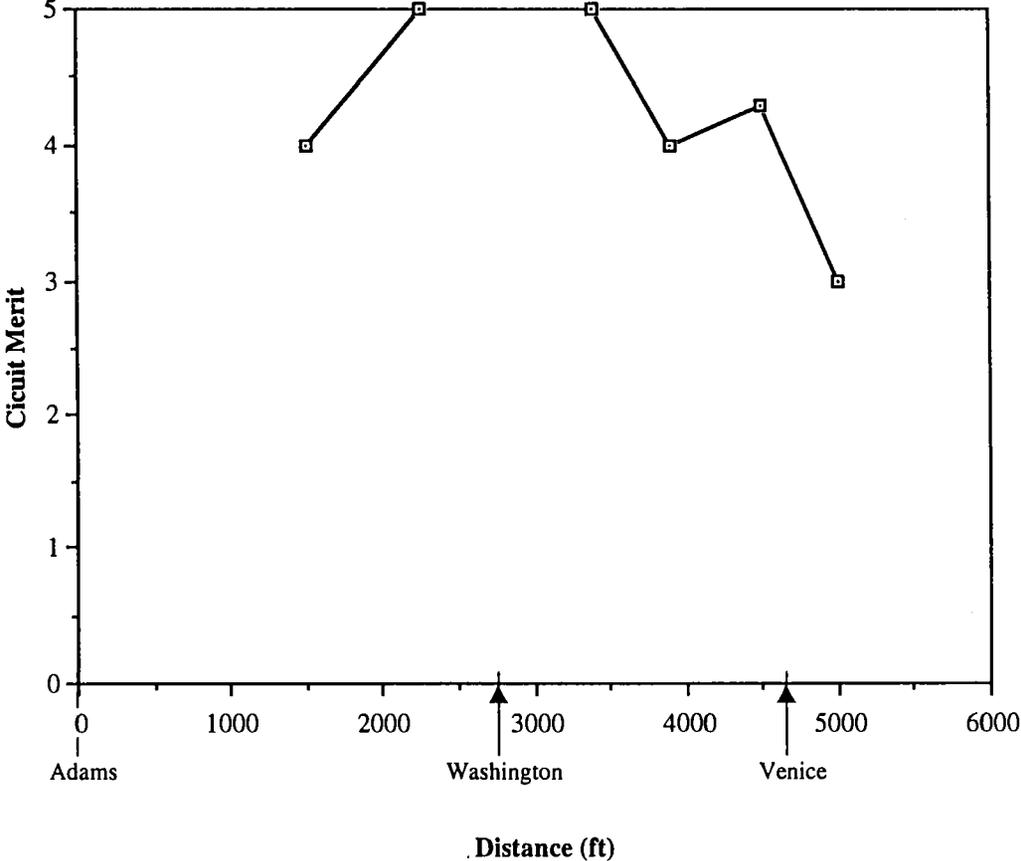


- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Exhibit 4.19

Crenshaw Blvd.

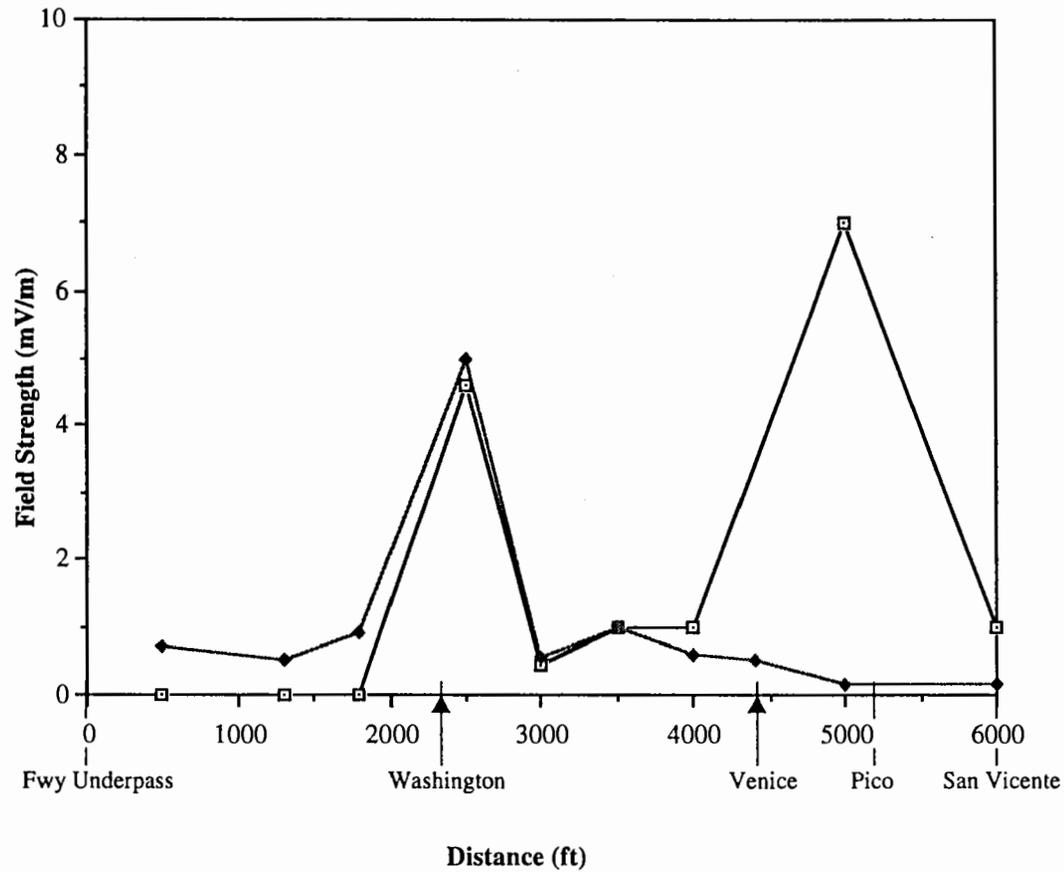
Circuit Merit



▲ Transmitter

—□— Washington Zone On

La Brea Ave Field Strength

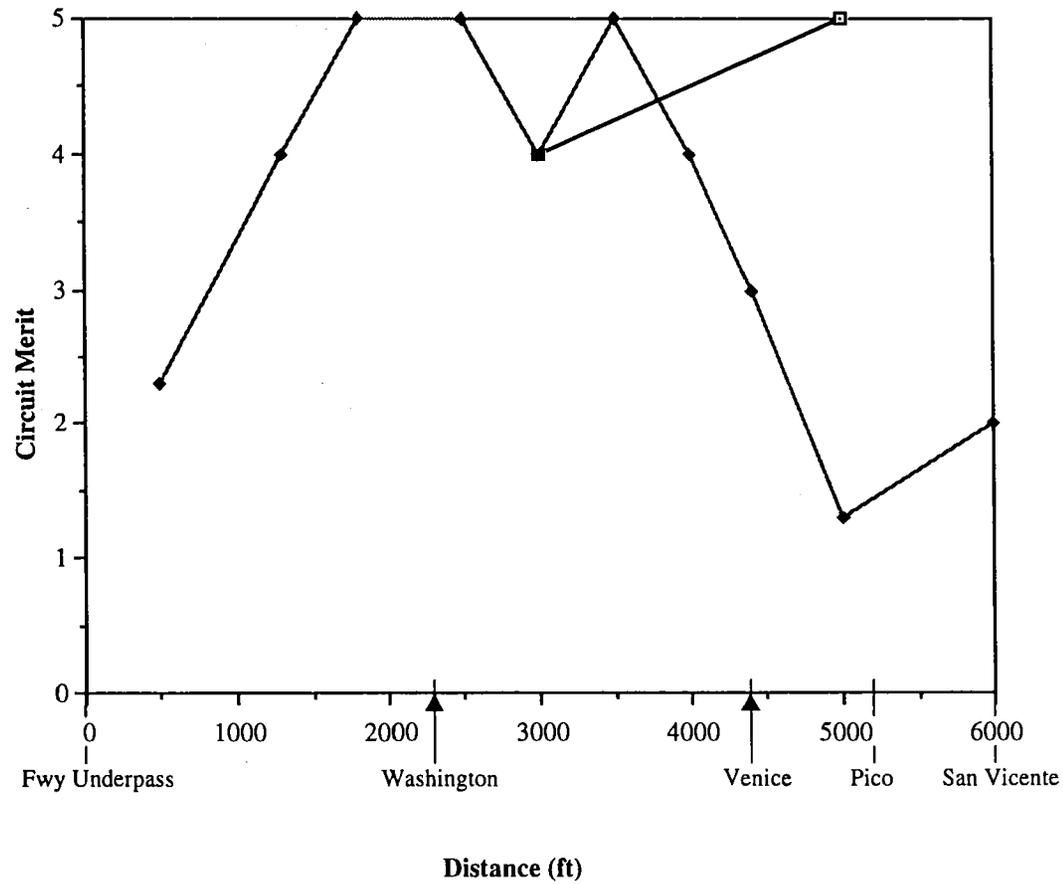


- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Exhibit 4.21

La Brea Ave

Circuit Merit

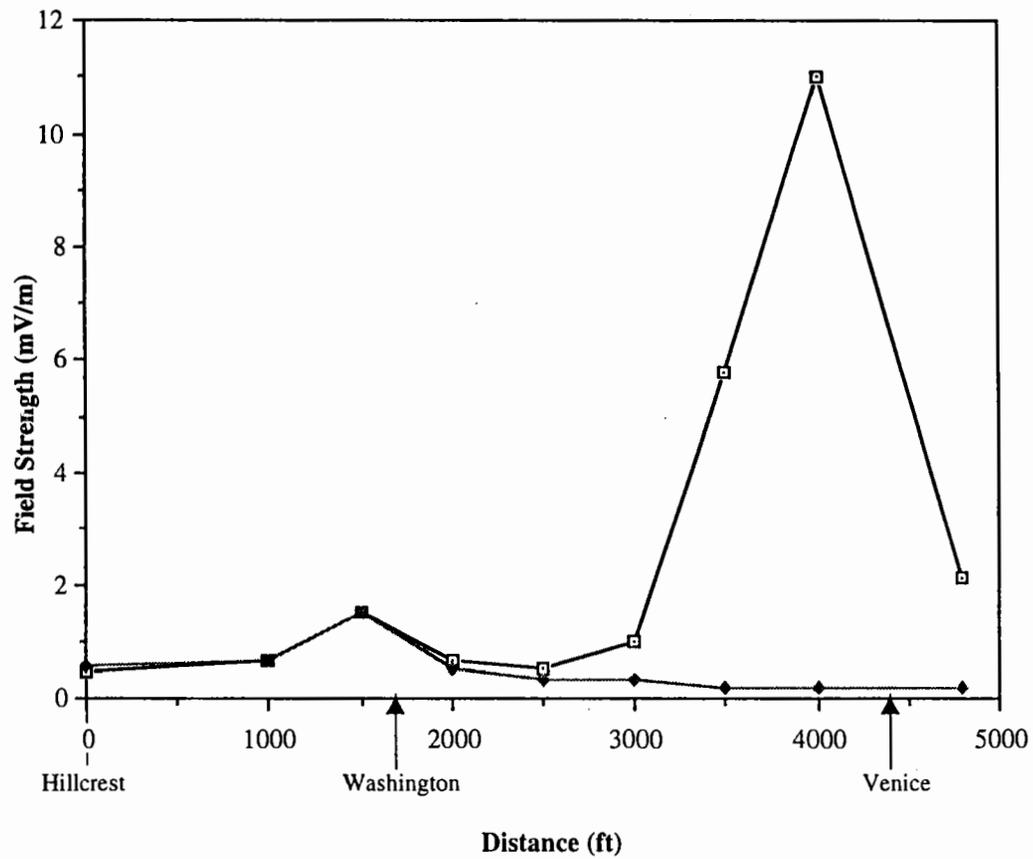


- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Exhibit 4.22

Vineyard Ave

Field Strength



- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Exhibit 4.23

nearly the entire distance between Venice and Washington. Traveling from Venice Boulevard to Washington, the message was clearly heard at a point 300 feet before reaching the Washington Boulevard transmitter (see Exhibit 4.24). The preferred location of the message transition is midway between the two, this would be approximately 1,350 feet away from either transmitter, not 300 feet. Again, the better performance of the Venice Zone relative to the Washington Zone, influences the desired results. The point of transition can be repositioned by reducing the Venice transmitter power output.

4.4.1.5 - Cross Street Performance Summary

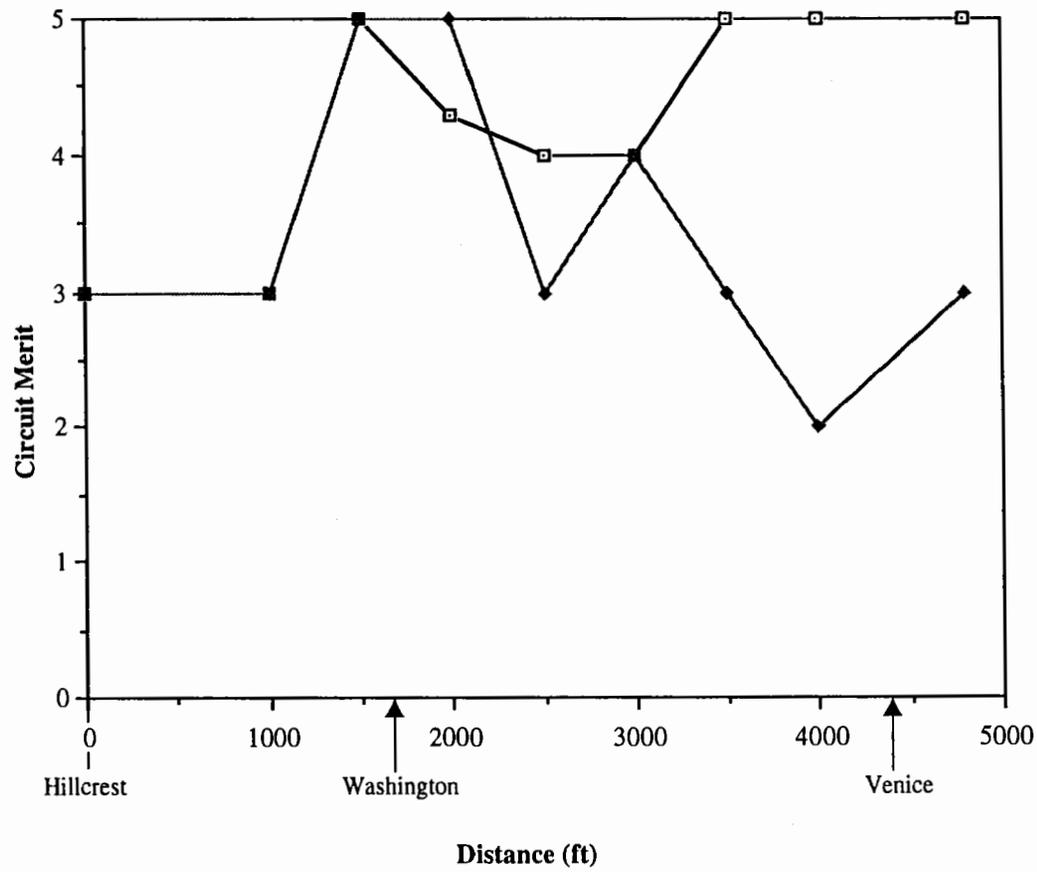
Because of the overall superior performance of Venice Boulevard's transmitters, the message transition points did not occur exactly half-way between the two zones. This results in the Venice Zone message being heard only 400 to 500 feet away from Washington Boulevard, a situation that is not desirable with respect to the intended operating goal of this HAR system. A solution would be to reduce the power output of selected Venice Boulevard transmitters until messages could be heard equally well at point midway between the two zones. Possible reasons for the Venice Boulevard Zone performing better than the Washington Boulevard system are described above. With the close spacing between zones, overlap in the audio messages cannot be avoided between adjacent streets and further separation of zones would be recommended to eliminate this concern.

4.4.1.6 - Venice and Washington Blvd. Audio Intermix Tests

This test was structured to determine to what extent the driver would hear a Washington message while traveling along Venice and conversely to determine to what extent the driver would hear a Venice message while traveling along Washington. The test comprised feeding both zones with different voice messages and recording the quality of signal at measured intervals along the route. The test was conducted on a qualitative basis to study the amount of message intermixing or bleed-through heard from one zone while driving through another zone. For example, a driver on Washington Boulevard noted when a message from the Venice Boulevard HAR system was heard. All of the transmitters in both zones were enabled for these tests, and

Vineyard Ave

Circuit Merit



- ▲ Transmitter
- Both Zones On
- ◆— Washington Zone On

Exhibit 4.24

each was fed a different audio message to facilitate the detection of each zone's message. Qualitative data were taken at or near every cross street location. The data consisted of noting whether the adjacent zone was heard and a qualitative evaluation of it's signal strength. The Ford Tempo test vehicle radio was used for these tests.

Venice Boulevard

The Venice Boulevard test started at Normandie and ended at Fairfax. Normandie is located approximately 1.6 miles beyond the eastern-most transmitter, and Fairfax is located about 1.1 miles beyond the western-most transmit site. The test results showed that no Washington Zone signal was heard along the entire test route although the Venice Zone coverage exhibited a number of weak signal locations.

Washington Boulevard

The Washington Boulevard test route started at Fairfax and ended at Normandie. Fairfax is about one-tenth of a mile west of the first Washington Boulevard transmitter, located on Apple Street, and Normandie is about nine-tenths of a mile past the eastern-most transmitter, which is located at Arlington. The test results showed that the Venice Zone signal was able to be heard at two locations. A strong Venice Zone signal was heard at the 3rd Street intersection, and a weak Venice Zone signal was heard at the Western Avenue intersection. Although the Washington Zone test results revealed that there were many other spots where the Washington Zone's signal strength was weak or nonexistent, none of these locations experienced message bleed-through from the Venice Zone.

Even though the Venice Boulevard system was noted to be the better performer of the two and the Washington Boulevard coverage was less than optimum for continuous CM 4 reception, overall, the amount of bleed through detected from the Venice system was limited. The one location that yielded strong bleed through could be improved by reducing transmitter power output from the Venice Boulevard sites that are nearest this site. Although bleed through on the parallel arterials was limited, bleed through was evident on the cross streets.

Two factors are considered in determining the appropriate separation distance between transmitters in different zones. First, the inverse square relationship between radio frequency field strength and distance. This relationship causes the area near the transmitter to provide strong good quality reception, but as distance increases signal strength decreases in proportion with the inverse of the square of the distance resulting in a zone where the signal is not strong enough for good reception, but where it can still interfere with other broadcasts on the same frequency. (Refer to Exhibit 4.25) In addition, engineers deploying the HAR system must determine whether dead spots or overlapping signals are preferred on the streets perpendicular to the zones. If zone overlap on cross streets is not acceptable, then zone separation should be at least one-mile. However, if some overlap of signals on the cross streets is acceptable, one-half mile zone spacing may be appropriate. (Refer to Exhibit 4.26)

4.4.2 - Transmitter Range Perpendicular to Zones

Several transmitters on Washington Boulevard were studied to determine the resulting north-south cross street coverage so that the potential for multi-zone audio intermixing could be determined. These tests were conducted for the Redondo Boulevard, Crenshaw Boulevard, La Brea Avenue, and Vineyard Avenue sites. Field Strength and Circuit Merit results are represented by the grey line in Exhibits 4.17 to 4.24. Each of these transmitters was separately enabled and tested. Data was taken at measured intervals ranging from 250 to 500 feet, for a total distance of about 2,000 feet or more to the north and south of each transmitter location.

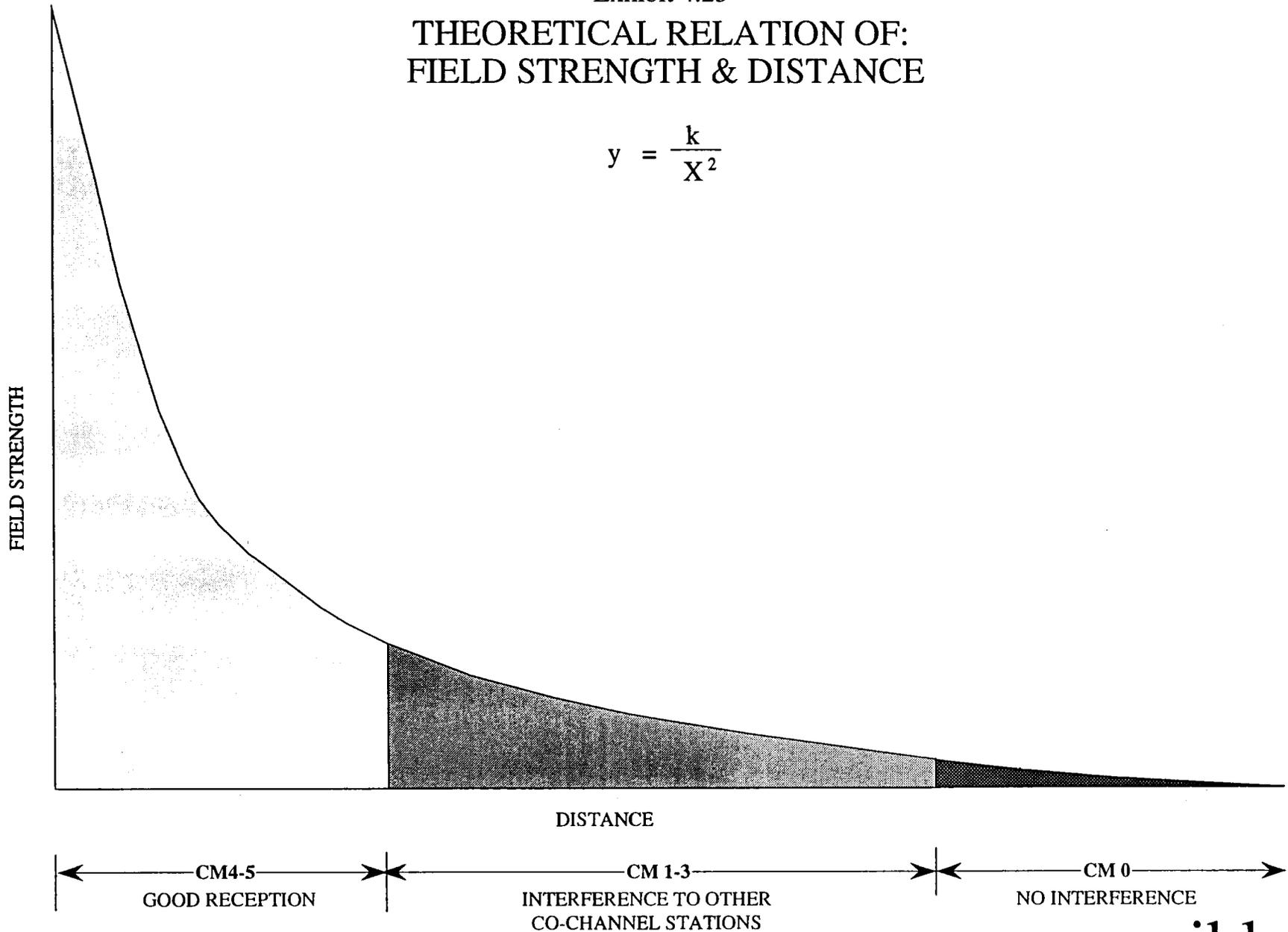
Field test results for some of the cross-street tests show that only 0.5 mV/meter was needed for reception with acceptable audio quality, CM 4 rank. This typically represents a coverage distance of 750 feet to the north and south of the transmit site.

The Crenshaw site however exhibited a range of 1800 feet to the north and 1350 feet to the south. There are no power lines over this site to explain the increased coverage here, as is the case at the Washington at the West Boulevards and along the Venice Zone. Based on the test results, one-half mile to one mile spacing between adjacent transmitters in different zones on the same frequency would be recommended.

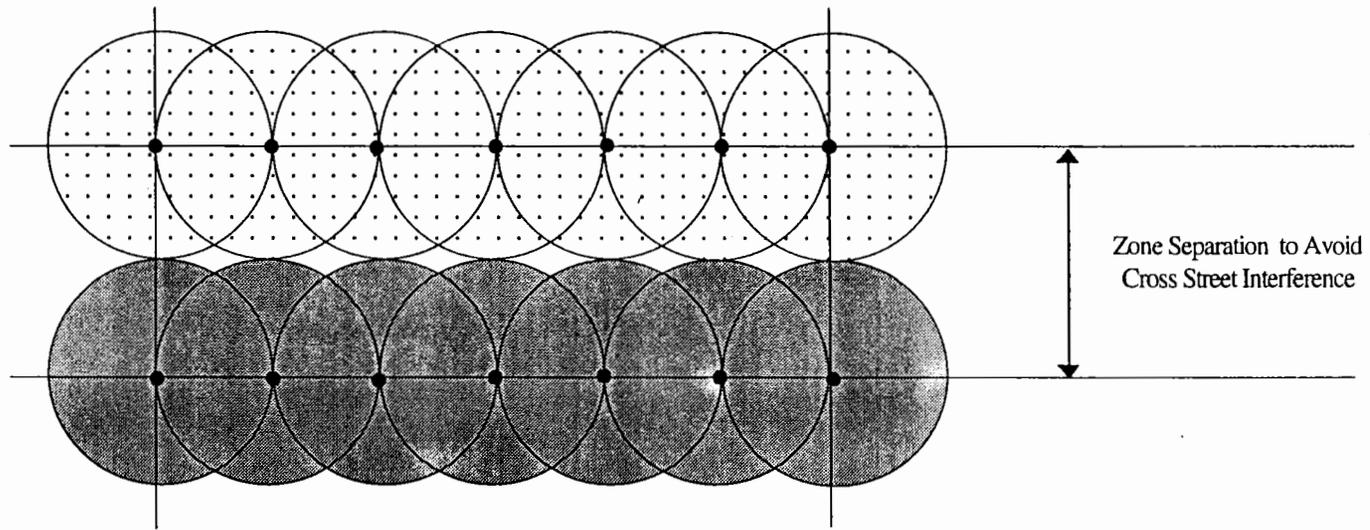
Exhibit 4.25

THEORETICAL RELATION OF:
FIELD STRENGTH & DISTANCE

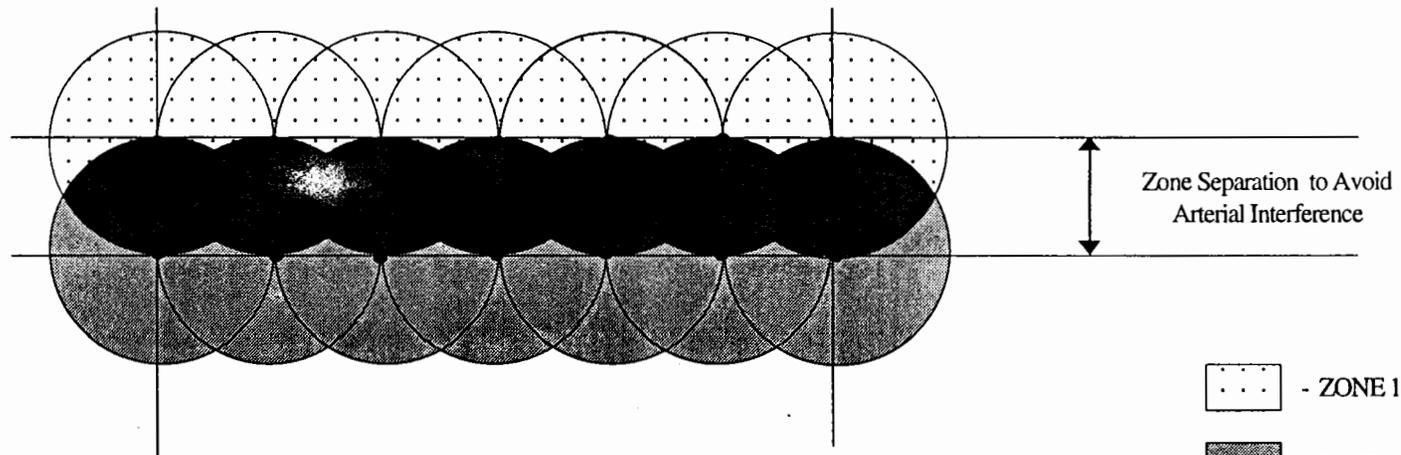
$$y = \frac{k}{X^2}$$



ZONE SPACING
CASE 1 - NO CROSS STREET INTERFERENCE



CASE 2 - CROSS STREET INTERFERENCE PERMITTED



NOTE: CIRCLES REPRESENT 0.5 MV / M CONTOURS

-  - ZONE 1
-  - ZONE 2
-  - OVERLAP

Exhibit 4.26

4.4.3 - End to End Spacing between Linear Zones

Two tests were conducted to determine the need for end to end zone separation in an area with power lines influencing propagation. The research question asked was "To what extent would a driver at one end of the Venice Zone hear a message from the other end?" Two tests were conducted, first with one transmitter at each end enabled and then with two at each end. The results of these tests are documented below.

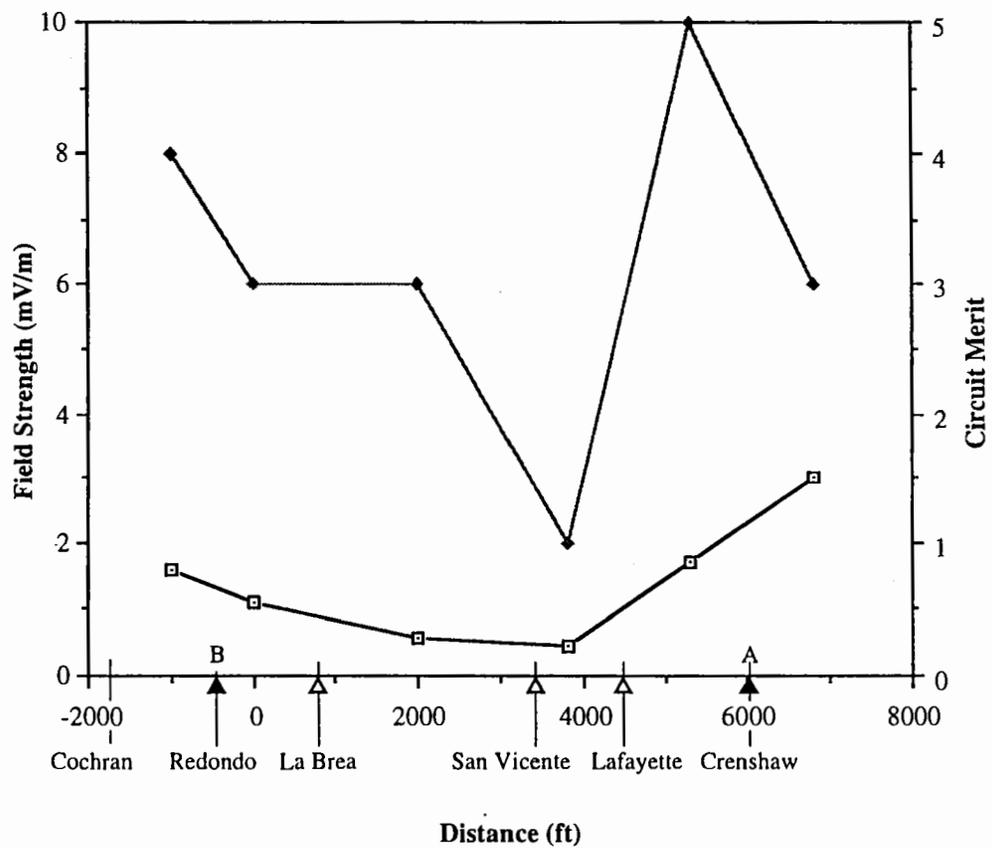
4.4.3.1 - Power Line Propagation 6,500' Separation

This test created linear transmission zones relying on power line propagation of the radio signal and two transmitters on Venice Boulevard separated by approximately 6,500 feet. Each transmitter was driven with a different message. Field strength and circuit merit measurements were taken at measured intervals of 2,000 feet.

The Redondo and Crenshaw transmitters were active during this test. Exhibit 4.27 shows the plots of the field strength level and the audio quality versus distance along the section of Venice Boulevard that was tested. The field strength recorded is similar to the results obtained when the transmitters were operated in a linear zone configuration with a single message as anticipated. The audio quality plot, however, is very different from the single zone configuration. When each transmitter is driven with a different message the region of the zone where both messages can be heard is the point where the intelligibility of an individual message deteriorates and neither can be clearly understood. This location, as depicted on the plot, is a little more than 4,000 feet from the Redondo transmitter and 2,000 feet from the Crenshaw transmit site. The location of hearing both messages equally well, or poorly, would, in a uniform and ideal environment, be expected to be spaced equally between the two sites. In this real-world situation, the Crenshaw site is shown to be a better performer than the Redondo site. It is unclear what specifically might be influencing the Crenshaw site making it a better performer. The only observable difference is that an overhead 4,800 volt power line runs parallel to this part of the zone only, while a 35 kiloVolt distribution circuit runs down Venice Boulevard beginning at West Boulevard, two blocks west of Crenshaw.

Venice Blvd

End Transmitters On with Two Separate Messages



- △ Transmitter (Off)
- ▲ Transmitter (On)
- Field Strength
- ◆— Circuit Merit

Exhibit 4.27

4.4.3.2 - Power Line Propagation 3,600' Zone Separation

This test was conducted to determine the resulting coverage when two transmitters at each end of the test zone were enabled and driven with a different audio message. Measurements were taken at regular intervals of 2,000 feet.

This test differed from the previous test because the La Brea and Lafayette sites were also energized. Both Redondo and La Brea were driven with one audio message, and Crenshaw and Lafayette were driven with a different one. Exhibit 4.28 shows the plots of the field strength level and the audio quality versus distance along the tested section of Venice Boulevard. The field strength plot is shown to be significantly different than the previous test. The Crenshaw side of the zone is once again proven to be the better performing of the two ends and the addition of the Lafayette transmitter magnifies this situation. By comparison, the Redondo-La Brea side of the zone has achieved only a modest gain in field strength. Other than the power line circuits described above, there does not appear to be any particular characteristic of one zone that would explain why it performs differently than the other zone.

The tests documented above show the difficulty in prediction of results for a particular transmitter configuration and demonstrate the need to conduct site specific propagation tests to verify the system performance.

4.5 INSTALLATION TESTS

A number of tests were conducted to address installation details such as antenna height, antenna orientation and transmitter grounding.

4.5.1 - Grounding

Two distinct grounding methods were used. For installations on metal signal standards, each transmitter was grounded via a six inch-long wire connection from the equipment to the signal mast arm. For the Marbelite concrete composition poles, the transmitter was grounded using a wire inside the pole terminating at a ground in the nearest vehicle head terminal compartment.

Venice Blvd

Two End Transmitters On
with Two Separate Messages

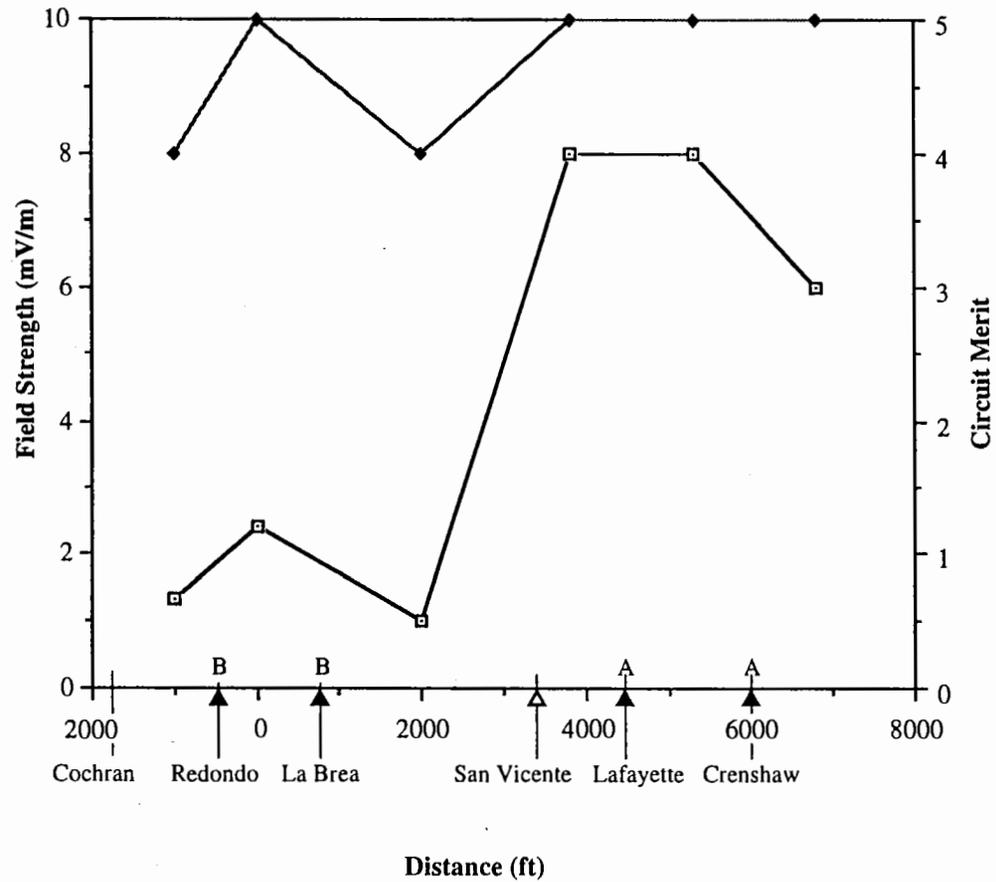


Exhibit 4.28

Grounding tests were conducted at Washington and West Boulevard which employed an HAR transmitter mounted on a metallic signal standard. The initial condition tested did not include a ground rod in the grounding system. To include the ground rod in the system, a copper strap was temporarily fastened to the pole and connected to the existing ground rod. A technician connected and disconnected the ground lead from the transmitter, while energized. The resulting field strength, monitored about 75 feet away, showed that little if any change occurred. This could possibly indicate that the transmitter's ground system may not be as effective as it could be, or that an alternate ground path was already present in the pole foundation. Further research with grounding systems would be recommended. Systems that should be considered would include:

- Existing Conduit Bonding/Ground Systems
- Copper Rods
- Conductivity Enhancing Treatments
- Radial Grounding Systems

The existing traffic signal conduit network has the potential to provide a highly effective ground system in some instances when properly bonded because these conduits run parallel to the streets creating a radial grounding system. This situation may be another reason (in addition to the power lines) why some sites exhibited better coverage than others. Also, there is no guarantee that any two runs of conduit will provide an equally effective RF ground. To be an effective RF ground, the length of a conductor should be some multiple of 1/4 wave length of the transmit frequency. Some of the conduit runs may present a more efficient RF ground than others, because the total length of conduit varies and the condition of the galvanic connection between each section will define the total effective length.

During these field tests the existence of an adequate ground path was assumed. However, field experience proved that such an assumption could be unreliable. Thus, verification of an adequate ground at each site prior to installation of the HAR transmitter would be recommended, as some older installations may not be grounded in accordance with the current specifications for traffic control equipment.

4.5.2 - Antenna Systems

Two assessments of the currently deployed antenna system were conducted. Studies to determine the impact of varying antenna height, and studies of alternate antenna orientations were conducted at the Washington and Arlington site. To avoid interference all other transmitters were disabled.

A test of how coverage would be enhanced or diminished with different antenna orientations, was conducted. Field strength measurements were first taken with the antenna tip pointing up, and a second set of data was taken with the antenna inverted. In each case, data were collected at the same measured intervals from the site. Test data were collected up to 1,500 feet away from the site in each of four directions; north and south along Arlington Boulevard, and east and west on Washington Boulevard. Exhibits 4.29 and 4.30 show the plotted test results for both field strength and circuit merit with a normal antenna orientation and with an inverted antenna orientation.

The resulting coverage with the antenna tip pointing up showed that CM 4 was obtainable up to about 700 feet in the east-west direction and approximately 1250 feet in the north-south direction. The results with the antenna inverted showed that coverage dropped to approximately 250 feet in the east-west direction, and decreased to about 500 feet to the north and south of the intersection. The greater distances covered in the north and south directions, indicate that the omnidirectionality of the antenna is perturbed slightly and as a result favors the north-south direction. The modification of the antenna pattern is most likely due to the metal signal standard adjacent to the antenna.

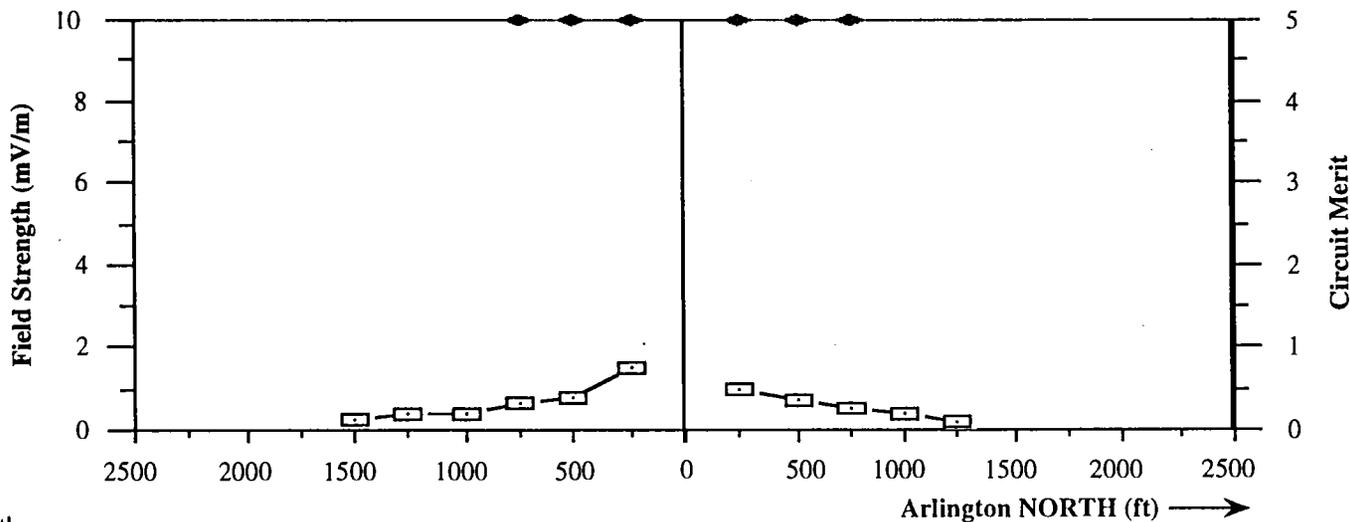
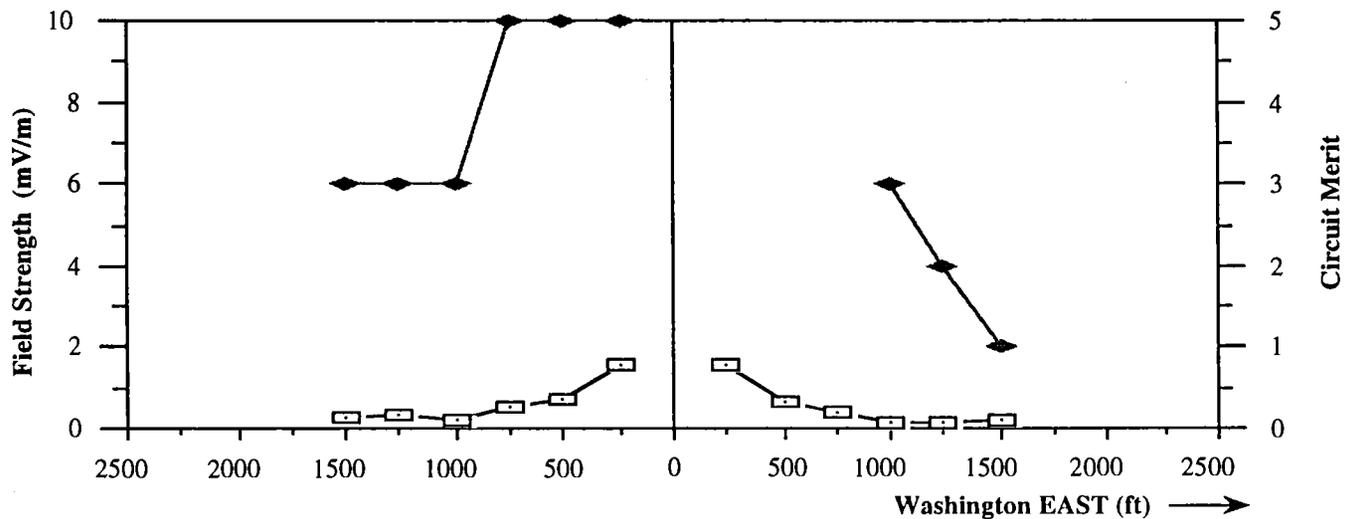
A test was also conducted to determine the radiation pattern in the vertical plane of a typical HAR antenna installation, and how, it changes when the antenna orientation is changed, antenna tip up versus the tip inverted. The field strength measurements for the test were taken at six different heights: 5, 11, 19, 30, 38 and 48 feet above ground. A bucket truck with a fiberglass bucket was used to lift personnel and equipment to the various test heights.

Exhibit 4.31 shows the two test results plots. The top plot shows how the pattern changes height while the antenna tip is pointing up, and the lower plot shows the test results when the antenna tip is pointing down. With the tip pointing up, the field strength was four mV/meter higher than with the antenna tip pointing down.

Individual Transmitter Data

Washington & Arlington

Antenna Up

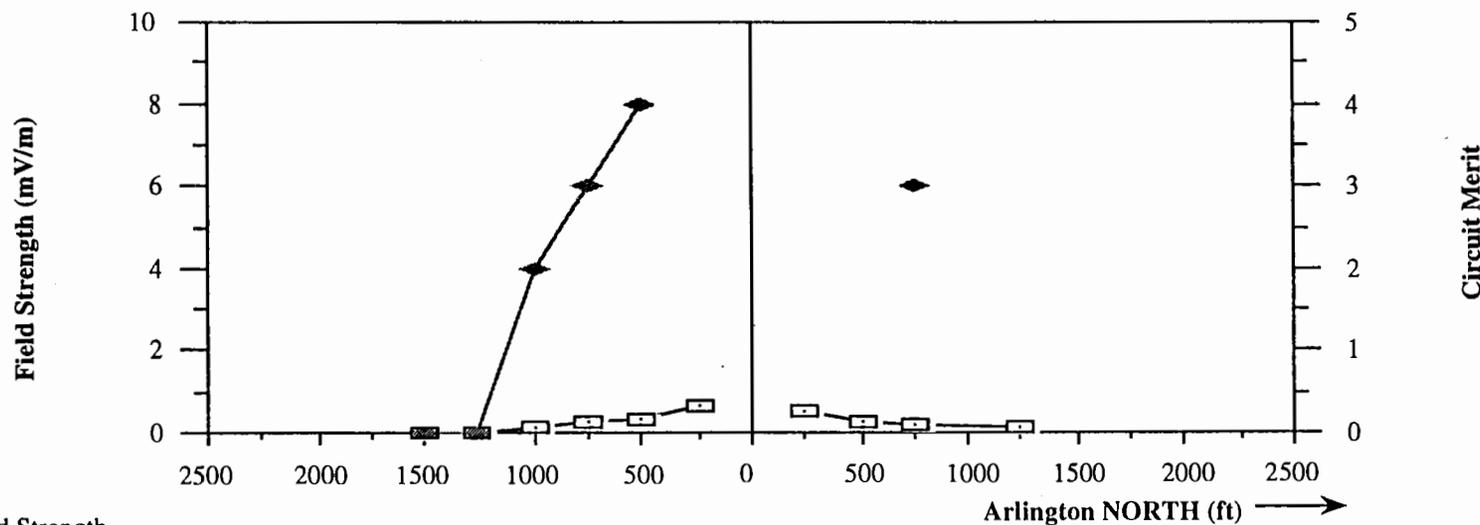
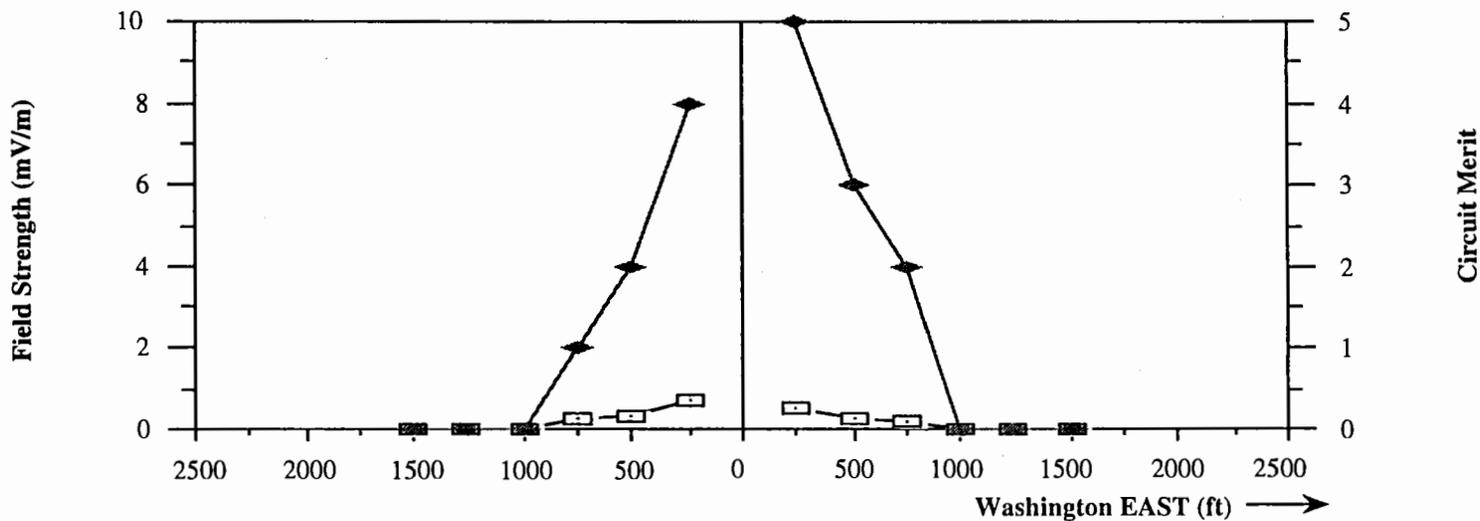


—□— Field Strength
—◆— Circuit Merit

Individual Transmitter Data

Washington & Arlington

Antenna Down

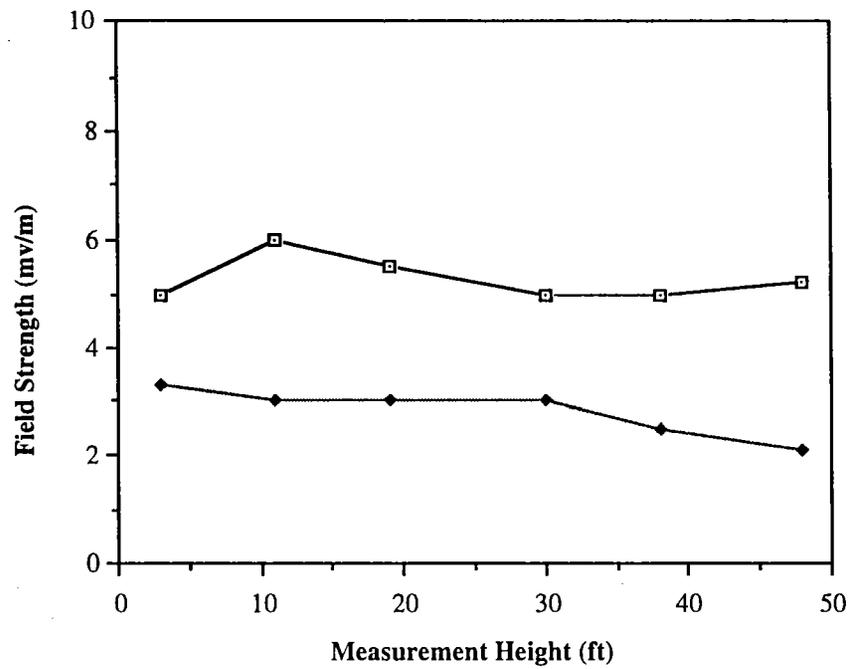


Field Strength

 Circuit Merit

Exhibit 4.30

Field Strength vs. Measurement Height



—□— Antenna Tip Up
—◆— Antenna Tip Down

The conclusion to be drawn from these tests is that the antenna radiates most efficiently when it is not inverted. This is the preferred antenna orientation for HAR installations of this type. The antenna orientation was with the tip up for all of the other tests in this study. In addition, little difference in field strength was observed at the various measurement heights suggesting that antenna elevation is not critical in this type of installation. A confirmatory test to verify this theory was also conducted at Washington and West Streets by taking field strength measurements with the transmitter installed on the mast arm for the first test and installed on the controller cabinet for the second test. No significant differences in field strength were observed using the different mounting locations.

5. DESIGN METHODOLOGY

Based on the experience gained from this evaluation, a step by step approach to the design and implementation of a low power HAR system is presented below.

5.1 STEP 1 - ZONE SPACING

A traffic engineering analysis should be conducted to identify desired zone coverage to complement the traffic management objectives that the system is intended to achieve. However, the traffic engineer must keep in mind that radio signals can not be confined into well defined and specific areas, thus consideration must be given to adequately separating zones operating on the same frequency. Zone separation is defined as distance between adjacent transmitters of two different zones. The field tests confirmed that one mile separation between zones will be adequate in most cases, to prevent overlapping messages on cross streets between zones. One-half mile spacing may be acceptable in some instances when, overlapping messages on cross streets are permissible. It is important to recognize that test results are based on studies at a frequency of 1520 khz and that results could be substantially different in the low portion of the AM broadcast band.

5.2 STEP 2 - FREQUENCY SELECTION

Field experience gained from these tests, revealed that a transmitter's surroundings play an important part in determining transmit range. The process for selecting a candidate frequency, or frequencies, normally begins by searching an FCC generated data base. Independent service agencies and proprietary computer programs are often employed to "read" and manipulate the data base. The required steps in the process are:

- Perform all calculations necessary to obtain a 0.5 mV/meter ground-wave field strength contour (day time signal behavior) for licensed AM radio stations on the same frequency and adjacent channels (both 10Khz and 20Khz separation).

- Perform all calculations necessary to obtain the resultant sky-wave field strength (night time signal behavior) contours for licensed AM broadcast stations yielding 0.5 mV/meter signal strength on the same frequency and adjacent channels (both 10Khz and 20Khz separation).
- Analyze the results of items above, and make a recommendation of candidate frequencies.

Field studies should also be conducted during day and night time conditions to verify field strengths and noise levels on candidate frequencies. Particular attention should be devoted to the identification of foreign broadcast signals in the Southern United States as these stations are licensed by foreign authorities and little information is available from the FCC.

Field test results suggest that signals of the same frequency with a field strength greater than 0.5 mV/meter would be expected to interfere with the low power HAR installation.

5.3 STEP 3 - PRELIMINARY ENGINEERING

The next step in the design is to superimpose zone coverage maps on maps showing the availability of service, communications and mounting standards. Locations of major power transmission lines should also be identified. Efforts are then made to balance transmitter range and locations with service availability. One-fourth of a mile transmitter spacing would be a reasonable criteria for transmitter spacing at a preliminary engineering stage.

5.4 STEP 4 - PRELIMINARY FIELD ENGINEERING

The testing shows that the range of an individual transmitter can vary depending upon the surroundings, particularly with the presence of overhead power lines. The test results show that range of a transmitter (at a CM 4 quality level) can vary from about 300 to 1,500 feet, in the absence of power lines. However, longer distances were provided by the Venice Boulevard zone which has an extensive overhead 35 KV power distribution system. As a result of these observations, a temporary test transmitter is recommended to determine the range of a proposed installation.

The transmitter would be temporarily installed using an internal tone generator and power source. A ground would be attached and its adequacy would be verified using an ohmmeter. If the resistance of the ground path exceeds that of an AWG 8 conductor, installation of a new grounding cable would be recommended. Although, providing a good DC ground using an AWG 8 copper conductor does not necessarily assure a good radio frequency ground in all instances, field experience with ten Watt HAR transmitters has shown that an AWG 8 conductor connected to a group of three ground rods provides an effective ground for such installations. The ground can be further enhanced by using copper pipe for grounding and adding a solution of copper sulfate and water to enhance conductivity of the soil in the vicinity of ground rods. Typically, fifteen pounds of copper sulfate is used for each ground rod.

Once the transmitter has been set up, field strength measurements would be taken at 250 to 500 foot intervals until the signal drops below the 0.5 mV/meter contour and CM 4. This test would be repeated for each site identified in the initial deployment plan and repeated for any additional sites identified by the other portions of the field engineering effort.

5.5 STEP 5 - PLANS, SPECIFICATIONS & ESTIMATES

The next step in the process is the preparation of Plans, Specifications & Estimates (P. S. & E.) for the system. Transmitter locations, mounting poles and cable routes would be shown on the plans. In addition, the provision of a 20 percent allowance for additional transmitters with installation is recommended in the event these would be required during the network optimization phase of the work. The specifications should also call for network optimization to be conducted by a broadcast engineer. Furthermore, the vendor should be required to supply a certificate of compliance with Part 15 of the FCC regulations as they apply.

5.6 STEP 6 - NETWORK OPTIMIZATION

Network optimization should be included in the specifications to assure an operational system with a single entity responsible for implementation. It is anticipated that network optimization will take up to 8 hours per transmitter. A broadcast engineer should be available to adjust transmitter phase offsets, make field strength measurements, audio quality checks and

locate dead spots. The broadcast engineer should have a frequency selective volt meter, field strength meter and a radio receiver with a carrier output and an oscilloscope available for network optimization. Adjustment and fine tuning of the radio network may be time consuming but will be essential to proper operation of the HAR system. The use of a radio receiver with carrier output in conjunction with an oscilloscope should help to eliminate the subjective signal phase offset adjustments which were relied upon during the pilot test.

Finally, additional transmitters should be deployed in dead spots and the network should be reoptimized to maximize performance.

6. CONCLUSIONS

This chapter presents a brief summary of conclusions and recommendations derived from the field test of the HAR system.

6.1 TEST RESULTS

The testing of the two zones showed that Venice Boulevard had a more consistent CM 4 level of performance and the distance covered was greater, than the Washington Boulevard zone. The transmitter spacing for the Venice Zone appeared to be adequate from the listening tests conducted. The Washington Boulevard Zone experienced a limited number of "dead" spots, areas where the signal faded out between transmitters. This indicated that the transmitters needed to be placed at still closer intervals, possibly closer than that for the Venice Boulevard Zone or that improvements are needed in the installation. The only obvious difference between the two zones is the presence of overhead power lines along the Venice Boulevard Zone; there were none running parallel to Washington Boulevard.

6.1.1 - Audio Quality

The minimum audio quality requirements were quantified using the circuit merit scale by three observers comparing the HAR signal to other broadcasts in the AM band. These assessments result in a recommendation of CM 4 as a minimum acceptable audio quality for the HAR installation. CM 4 is defined as easily understandable, speech with some noise. (Good reception.) CM 4 provides an audio quality that is comparable with licensed broadcasters operating within the band and does not permit repetition of the message to overcome reception problems.

6.1.2 - Field Strength

Based on the test results, radio frequency field strength parameters were established. A 0.50 mV/meter threshold is the maximum value that is acceptable for other, on-channel RF

emissions such as adjacent HAR zones or distant commercial broadcasters. A signal at this level is barely perceptible with a typical receiver. The minimum recommended field strength to achieve an audio quality of CM 4 or better is 1.0 to 1.5 mV/meter. However, in some instances it is possible to obtain satisfactory audio quality (CM 4) with field strengths as low as 0.7 mV/meter. System design should be based on the 1.0 to 1.5 mV/meter field strength to assure adequate reception with inexpensive or older receivers and to overcome possible background noise.

6.1.3 - Relationship Between Field Strength and Audio Quality

While some correlation between field strength and audio quality exists, certain factors affect the relationship. One significant factor in the signal strength to audio quality relationship is the amount of background noise present. Another significant factor influencing the correlation is the quality of the radio receiver and its automatic gain control circuitry.

6.2 RANGE

Field experience gained from these tests revealed that a transmitter's surroundings play an important part in its ability to cover a zone. Individual transmitter range based on atmospheric transmission varied from as little as 325 feet to 1,500 feet with a typical value of 750 feet. Power line propagation can result in propagation for distances as large as 10,000 feet. Other factors that played an important role in the range of the transmitters included time of day and the grounding system employed. Further research regarding grounding systems is recommended.

The range of an individual transmitter can be predicted well enough to support a general planning effort, but field tests of each site would be recommended to pin-point the range of each transmitter. Once the transmitters are installed and operating, a follow-on system optimization effort would be required. This optimization could involve relocating transmitters, adding transmitters, adjusting the relative phase of transmitters or possibly decreasing transmitter power output, to ensure uniform audio quality throughout a given zone. The range of a single, low-power, Part 15, AM broadcast band transmitter is limited, making the units well suited to zone

type coverage. The spacing of these low-power transmitters is critical for uniformly high audio quality. One-quarter mile spacing is a reasonable initial estimate of transmitter separation requirements. The research also suggests that separation between adjacent transmitters in separate zones should be approximately one mile. This will assure that the 0.5 mV/meter contours of the transmitters do not overlap on the cross streets between linear zones, to prevent audio intermix. If overlapping messages are permissible, zone separation may be reduced to as little as one-half mile.

6.3 TRANSMITTER PHASING

The simulcast concept, two or more transmitters operating on the same frequency, at the same time, without noticeable interference, relies on careful adjustment of the relative phase of the transmitter's signal. Such adjustment and optimization of relative transmitter phasing provides an otherwise limited range system with the ability to cover distances on the order of miles. Field tests demonstrated the need for a remote phase adjustment mechanism to complete the optimization process efficiently.

6.4 RECOMMENDATIONS

The tests carried out on Washington and Venice Boulevards have confirmed the suitability of the Triangle Digicom Model 1601 BCB low power HAR system for use within the Smart Corridor project. The equipment, when suitably located, will provide the required radio transmission of highway information within well-defined zones. Further recommendations regarding equipment enhancement, system design strategies and staged implementation of the HAR system in the Smart Corridor area are presented below.

6.4.1 - Equipment Enhancement

Several enhancements to the current version of the low-power transmitting equipment should be considered before further deployment takes place. One enhancement that would be particularly useful during the network optimization process would be a remote phase adjustment

feature to eliminate the need for access to the aerially installed equipment. In addition, it may be desirable to install a digital recorder within each transmitter to provide independent local operation of transmitters. Furthermore, some concern remains about the need to ground the transmitter. Exploration of antenna options, which may not require grounding should be considered. One potential approach would be to evaluate and test a dipole antenna with counterpoised elements to eliminate the need for an independent ground. However, altering antenna configurations may substantially alter the performance of the equipment, require changes to the transmission equipment and may subject the equipment to additional scrutiny from the FCC before type acceptance can be granted.

6.4.2 - System Design

Comprehensive system engineering is recommended for the design of a low power HAR system. The system design process would encompass the steps listed below:

- Study Zone Spacing Requirements
- Conduct Frequency Search/Select Frequency
- Preliminary Engineering
- Field Engineering/Measurement of Propagation Characteristics
- Prepare P. S. & E.
- Install System and Optimize Network

The nature of the equipment does, however, require the adoption of an equipment specific design and implementation approach.

6.4.3 - Staged Implementation

Because of the desire for additional research on the antenna and grounding systems for the low power transmitters, JHK recommends staged implementation of the Smart Corridor HAR program.

6.4.3.1 - Stage I

The first stage would include additional research on antenna and grounding systems for the low power HAR equipment. The installation of one 10 watt transmitter in the mid-corridor area to provide freeway and surface street coverage is also recommended during this first implementation stage.

6.4.3.2 - Stage II

Stage II would expand the HAR program beyond the pilot test area and 10 watt freeway HAR transmitter. This would be accomplished by deploying low power transmitters to serve Washington and Adams. Initial plans would call for installation of low power transmitters at every intersection within the corridor along Washington and Adams, where transmitters were not deployed during the pilot project. This limited low-power transmitter deployment would be evaluated before proceeding to Stage III.

6.4.3.3 - Stage III

Stage III of the deployment program may expand low power HAR coverage to freeway specific zones and would consider further deployment of low power HAR equipment through out the surface street network for full surface street coverage in accordance with the Preliminary Design. However, the recommendations of the Preliminary Design would be modified based upon the experience gained during the evaluation of the Stage II deployment.

APPENDIX A

**MODEL 1601
BCB TRANSMITTER
OPERATING MANUAL**



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DESCRIPTION

The 1601 transmitter is designed to be used as part of a low-power transmitter network where the coverage area is determined by the placement of multiple transmitters. Each has limited range due to FCC restrictions on antenna size and rf power for license-free operation.

Up to 100 transmitters may be placed in a network and controlled by a single base controller. The base controller transmits multiple signals to each transmitter over a twisted pair transmission line. Audio messages are transmitted over a frequency modulated carrier in the 100 to 200 kHz range. A 20 kHz clock synchronizing signal is also generated to allow each transmitter's carrier frequency to be synchronized. The base controller can control and monitor each transmitter with a dtmf data transceiver, since each transmitter has a unique addressable ID code.

A typical application is a highway advisory radio network that may be used to deliver traffic related information to motorists in specific zones. Multiple networks may operate simultaneously within a city, since the coverage can be controlled by the placement of the networks.

Figure 1 shows an interior view of the 1601 transmitter. It contains a TA1 transmitter module, an SS1 synchronizer module, and a backup battery. A shielded dual twisted pair cable connects the SS1 module to a 16 vac power source, and the network base controller.

Figure 2 gives a closer view of the modules and their indicators and controls. The various leds indicate the status of the transmitter to aid in installation and servicing. The controls are normally only adjusted during installation or after a module replacement.

LOCAL MODE

The transmitter is normally controlled by the base controller, and will not transmit if the required signals

are not detected. However, a test mode is provided to allow field testing without a base controller. This local mode is selected by the switches on the SS1 module, and overrides the mode selected by the base controller. The local mode times out after about 30 minutes and reverts back to the normal mode selected by the base controller. The timer starts when any switch changes state (MODE, TX, or TEST). The DATA led flashes approximately two times per second to indicate the local mode.

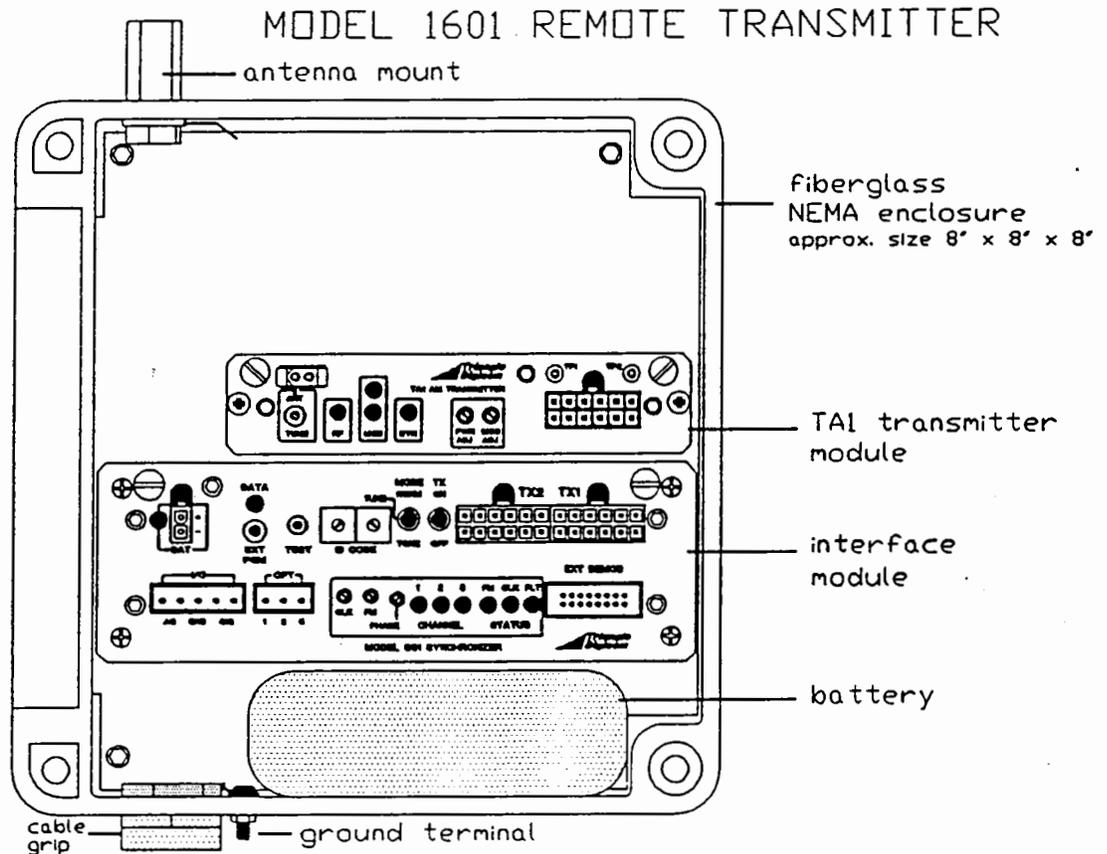


Figure 1

The TX switch either enables or disables the TA1 module. It must be ON to enable the test modes.

The MODE SWITCH on the SS1 module selects the operating mode. NORMAL is the default mode, meaning the transmitter operation is controlled by the base controller. TUNE is a test mode that enables the TA1 module to transmit an unmodulated carrier to facilitate tune-up. TONE mode causes the

TA1 module to transmit a 110% modulated carrier to set the modulation level on the transmitter.

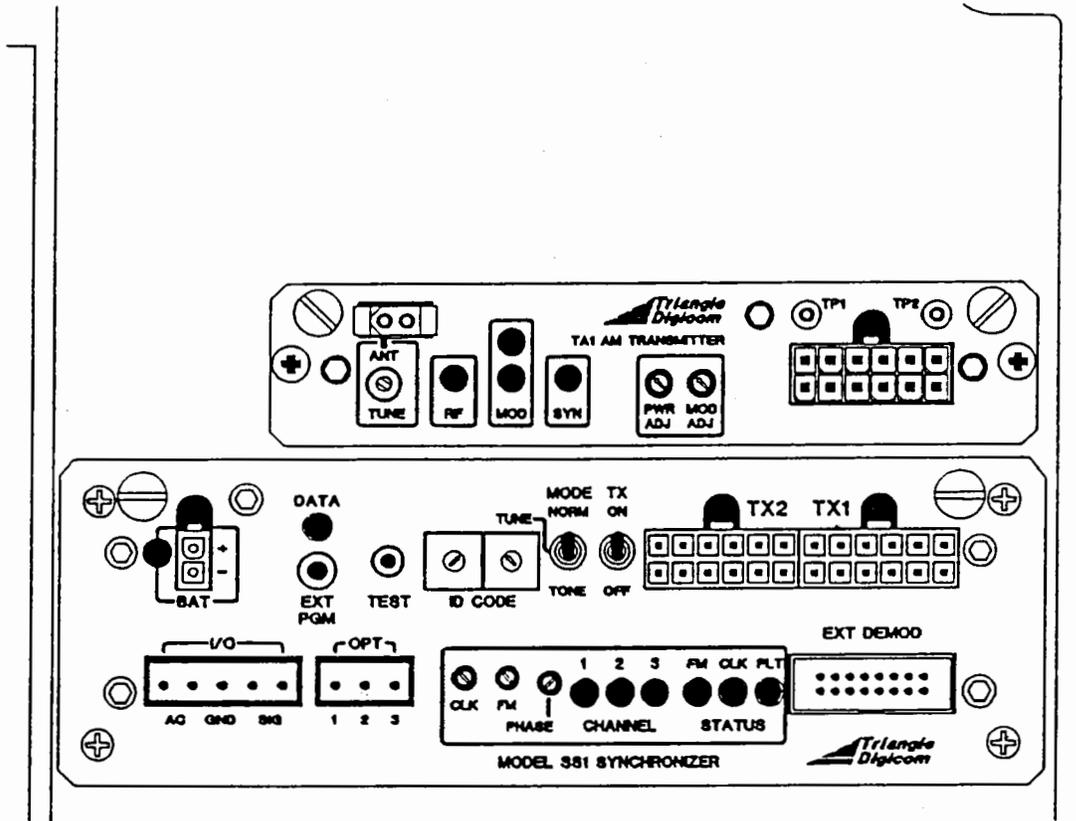


Figure 2

If the **TONE** mode is selected, and the **TEST** switch is pressed, a tone sequence is generated to aid in performing range testing. A single transmitter may be placed in a location put in the **TONE** test mode to assist in finding an optimum site before permanent installation. No base controller is required, but an external power source (approx. 15-22 v ac/dc) is required to power the unit.

NORMAL MODE

The 1601 transmitter automatically operates in the **NORMAL** mode when the transmitter is powered up. *Normal* simply indicates that the transmitter is controlled by a base controller. The base controller selects the fm channel (channel 1, 2 or 3), and may enable or disable one or all transmitters with simple commands. The base monitors the status of all transmitters in a network, and may alert technicians of a problem.

Each transmitter monitors various conditions and signals and will shut down automatically to avoid undesired operation. The fm and clock signals must be valid. If ac power is lost, and the backup battery is depleted, the transmitter will shut completely off until ac power is restored. This prevents damage to the battery.

Remote transmitters may be configured to operate only if a **PILOT** tone is detected. This feature enables the base controller to control multiple transmitters simultaneously without affecting transmitters not configured for pilot tone operation.

The SS1 module has leds to indicate the current status. The **CHANNEL** leds indicate the receiver channel. Channels 1, 2, and 3 correspond to zones 1, 2, and 3, respectively, in a multi-zone network. The **FM**, **CLK**, and **PLT** leds turn on when the fm, clock, and pilot signals are valid. The **DATA** led indicates dtmf data being received or transmitted when it flashes, unless the transmitter is operating in the *local mode*. The **BAT** led is on when the battery is charged, but it flashes when the battery is being charged.

The TA1 module also has status leds. If the transmitter is operating, and the output power is above a preset threshold, the **RF** led turns on. The **MOD** leds indicate the modulation level. The bottom led indicates a modulating signal, while the top led lights at approximately 110% modulation to indicate overmodulation. This led should light on voice signal peaks. The **SYN** led should normally be off. If it is on, the TA1 frequency synthesizer is unlocked, and the transmitter has shut itself down.

INSTALLATION

CHOOSE A LOCATION

The Model 1601 remote transmitter is a self-contained remotely controllable am broadcast band transmitter. It is a very low power transmitter with very limited range, so proper installation is important for optimum performance. The transmitter is designed for reliable low-maintenance operation when installed outdoors, however, it should be placed where it may be conveniently serviced.

The transmitter may be attached to almost any structure; however, some guidelines must be followed for proper operation and safety. **IMPORTANT!...** The antenna must be kept away from all power transmission lines for safety, and maximum range. The antenna location may determine the performance of the transmitter, so its placement should be carefully planned. It should be placed in the open, away from, or at least above metal structures and wires. Allow for any flexing of the whip antenna due to high winds or vibration. Try to place in a location that will offer minimal signal blockage from buildings, metal structures, trees, and vehicles.

The transmitter should be mechanically secured and protected, if possible, from any severe mechanical vibration or shock. The internal circuitry is sensitive to vibration, and constant vibration should be avoided. Consideration should be given to strong winds flexing the antenna.

GROUND THE TRANSMITTER

The structure should be grounded to provide a ground path for any static electricity accumulated by the antenna, and to allow a proper antenna match. A good ground makes the antenna match much better. It is better to mount the transmitter near the ground, connected to a ground rod, than to mount it on an isolated pole with no ground. The transmitter has internal transient protection circuits, but they will not survive a direct hit by lightning. A ground lug on the bottom of the transmitter box may be attached to a grounded structure with a short length of heavy copper wire.

CONNECT TO AC AND BASE CONTROLLER

AC power and remote control signals are supplied via a shielded cable containing two twisted-pairs. The length of the cable should be kept as short as possible (max. length approx. 100 ft. for 22 ga. wire) to keep the voltage drop in the wires to a minimum. One twisted pair connects to a network (22 ga. shielded twisted pair). The other twisted pair connects to an ac transformer that may plug into a standard ac outlet. The shield should connect to a good ground. If a better ground is not available, the transformer ground may be used. This provides some additional transient protection.

A high-quality cable should be used. Two acceptable cables are Belden types 1269A and 1268A. These cables have two 22-ga. wire pairs surrounded by both a foil and a 90% copper braid shield. It has a drain wire that may be used to connect to ground terminals. Keep unshielded wire lengths to a minimum. The wires are color coded... red/blue for I/O signals, and yellow/black for 16vac power.

SS1 MODULE SETUP (refer to FIG 1.)

Connect the backup battery to the *BAT* connector.

Connect the I/O and AC power and ground leads from the shielded cable to the terminal block connector. Plug it into the SS1 module. If the AC power is ok, the SS1 module should turn on. Leds light up to indicate the status of the transmitter. Unless programmed otherwise, the CHANNEL 1 led should light. If the battery is not charged, the *BAT* led will flash. If the battery is charged or not installed, the *BAT* led will light continuously to indicate AC power is ok.

The base controller must be connected and transmitting its signals over the network for the SS1 module to be set up. Set the *TX* switch to the OFF position. Turn the *CLK* and *FM* controls fully counter-clockwise. Slowly turn the *CLK* control clockwise. The *CLK* led should light. Continue to turn the control slightly. If it is turned too far, the *CLK* led may turn off. This feature may be used to indicate the approximate strength of the synchronizing clock signal. Leave the control set midway where the led is on.

Turn the *FM* control clockwise until the *FM* led lights. The trimpot position may be used to indicate the approximate level of the received fm (audio source) signal strength. Turn the control approximately 1/4 turn past the point where the *FM* led turns on.

Set the *ID CODE* switches to indicate 00 to 99, corre-

sponding to the assigned remote transmitter identification code.

TRANSMITTER TUNE-UP (refer to FIG. 1)

Transmitters are factory preset and tuned for a particular radio channel, however, the transmitters must be fine-tuned for each location due to different antenna and ground conditions. The power and modulation levels may be set to desired levels as well.

FIRST-TIME INSTALLATIONS

Each remote transmitter may be tuned independently with or without the base controller. The transmitter is tuned in three steps. First, match the antenna.

- 1) Be sure interconnect cable is securely attached to both the TA1 module and the SS1 module at the TX1 connector.
- 2) Be sure antenna is attached to enclosure, and the antenna connector is attached to the TA1 module.
- 3) Insert test probes from a digital voltmeter (DVM) to TP1 and TP2 on the TA1 module. Set the meter to measure up to 3 volts.
- 4) Turn *PWR ADJ* fully clockwise (for max. output).
- 5) Set the *MODE* switch on the SS1 module to the TUNE position. Set the *TX* switch to the ON position.
- 6) Adjust *ANTENNA TUNE* for minimum voltage on the DVM. If a minimum cannot be achieved, the antenna or ground may be improperly connected. The *RF* led should light when the antenna is close to being properly matched. This led should be on.

If the *SYN* led (synthesizer unlock error) is on, the internal frequency synthesizer is unlocked, and the transmitter is disabled. This led should be off. The *MOD* leds should be off now.

Transmitter power may be verified by a simple calculation. An FCC requirement under Part 15 limits the dc power to the final stage to 100 milliwatts. Record the voltage measured between the test points (V1). Move the test probe from TP2 to any convenient ground connection. This reading (V2) should be between 2 and 5 volts. The dc power to the final stage may be calcu-

lated by the formula:

$$\text{DC INPUT POWER} = 100 \cdot (V_1 \cdot V_2) \text{ milliwatts}$$

7) Once the antenna is matched, adjust the modulation level.

Without base controller: Set the *MODE* switch to the *TONE* position. Turn *MOD ADJ* on the *TA1* module until the top *MOD* led begins to light brightly. When the top led is on, modulation peaks are about 110%. With voice modulation, the top *MOD* led should only light sporadically, while the bottom *MOD* led should be on much of the time. The bottom led indicates that a modulating signal is present, and the top led indicates overmodulation. It is normal for the top led to light on audio peaks.

With base controller: Set the *MODE* switch to the *NORM* position. If the base controller is transmitting a calibration tone, adjust *MOD ADJ* on the *TA1* module until the top *MOD* led lights. Turn back the control slowly until the top led turns off. If the base controller is transmitting voice messages, adjust *MOD ADJ* until the top led lights sporadically.

8) If less transmission range is desired, the power may be cut back up to about 6 dBs by turning the *PWR ADJ* control counter-clockwise. If the power is adjusted, repeat step 7 (modulation adjustment).

9) If the transmitter is to be operated as part of a synchronized network, the *PHASE* control on the *SS1* module may be adjusted to minimize destructive interference between adjacent transmitters. This must be the last adjustment. Be sure the transmitter is tuned properly before adjusting the *PHASE* control.

The phase setting on the first transmitter in the network, may be left alone, and all other transmitters will be adjusted to match its phase.

A test receiver with a signal strength indicator or a spectrum analyzer should be placed between two transmitters to be synchronized. It should be placed in or near the path where maximum signal strength is desired. A monopole type antenna should be used to measure signal strength. Tune the receiver to the operating frequency, and be sure it is placed so that it may receive signals from both transmitters. Adjust the *PHASE* control on the *SS1* module until the received signal strength peaks.

IMPORTANT! Once the phase is set, do not adjust it again. This is a one-time adjustment, and if it is set correctly, it should not have to be re-adjusted. Normally, the transmitters in a network will be installed in a linear manner along a street or surrounding a parking area. Designate one transmitter as the origin and use its signal as a phase reference. This transmitter would typically be the first one in a string. Next, adjust the closest adjacent transmitter. Continue until all transmitters have been set.

Also, do not adjust the *CLK* control after the *PHASE* control has been set.

FINAL CHECK

Check all ports for mechanical integrity before closing and fastening the cover. Be sure the antenna is securely tightened. Be careful to tighten the antenna while gripping the antenna mount with a wrench. Do not allow stress to weaken the seal between the antenna mount and the enclosure. The cable grip should be tightened to secure the power/signal cable, providing a watertight seal.

Close the cover and tighten the two locking screws. The screws must be tightened sufficiently to seal the enclosure.

MODEL 1601 REMOTE TRANSMITTER SPECIFICATIONS

TA1 TRANSMITTER MODULE

DC POWER INPUT	10 - 14 VDC, 100 mA typ., 150 mA max with 100 % modulation, 1kHz tone
AF INPUT FOR 100% MOD	adjustable, 200 mV to > 4 Vpp
AF INPUT IMPEDANCE	10K ohms
FREQUENCY RANGE	530 to 1700 kHz (internally set by jumpers)
DC INPUT TO FINAL STAGE	100 milliwatts
EXTERNAL REF FREQUENCY	20.000 kHz, CMOS level square wave
POWER ADJUST RANGE	approx. 6 dB
ANTENNA	will match into a 96 to 102" whip when properly grounded

SS1 SYNCHRONIZER MODULE

PWR REQ	13-17 VACrms, 130 mA, standby 270 mA, with TA1 module (100% mod) 530 mA max (battery charging current = 260 mA)
FM CHANNEL FREQUENCIES	1) 115.312 kHz 2) 154.375 kHz 3) 193.437 kHz
FM RECEIVER SENSITIVITY	< 1 mVrms for 12 dB SINAD (-50 dBm, Zo = 110 ohms)
CLOCK REF FREQUENCY	20.000 kHz +/- 5 Hz
CLOCK SYNCH SENSITIVITY	< 50 mVpp
DTMF RCVR SENSITIVITY	< 200 mVpp
DTMF TX OUTPUT	3 Vpp into 600 ohms
TEMP RANGE	-40 to +85°C