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16. Abstract

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AN APPLICATION OF RF DATA TRANSMISSION IN FREEWAY RAMP METERING

by

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Research Report 210-9

Evaluation of Urban Freeway Modifications

Research Study Number 2-18-77-210

Sponsored by the Texas
State Department of Highways and Public Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
Texas A&M University
College Station, Texas

September 1981

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Abstract

ABSTRACT

A radio frequency (RF) transceiving system was employed as the interconnect between entrance ramp controllers on I-30 in Fort Worth, Texas. After the RF system was installed, a short and intensive study was conducted to determine if equipment failure or interference was occurring. After simulating more than 6 months of equivalent ramp control operation, no errors were detected.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

Summary

SUMMARY

To operate the entrance ramp controllers on a freeway system based on other than local conditions requires an interconnecting system. The interfacing circuits, control points and logic are available in the present ramp control equipment to provide system control. Utilization of the system control concept requires a master location (normally located at a bottleneck to freeway flow) and slave units (further upstream entry points). When flow conditions on the freeway worsen at the master location, a command will be issued via the interconnecting system to the slave locations. The metering of entering ramp traffic at the slave location will reflect the master command to modify the entry rate at the upstream points unless local conditions override the command. The use of RF equipment as the interconnecting system offers a viable alternative to the implementation of a direct wireline interconnect. RF equipment being manufactured and utilized as status monitoring and reporting systems was investigated.

The RF equipment was specified, purchased and installed by forces of the State Department of Highways and Public Transportation's (SDHPT) District 2 office on I-30 in Fort Worth. One monitoring/RF transmit, three RF receiver/annunicator and one RF receiver/thermographic printer units were included. Each unit, with the exception of the printer which was installed at the District's Signal Shop, was housed in an enclosure that was readily accommodated inside a larger controller cabinet, which also contained the regular components of a ramp metering unit which included the controller, loop detectors, etc. The transmitter (master) site required a 20-foot wooden pole for antenna elevation while the receiver antennae were attached to the top of 10-foot vertical sections of two-inch steel pipe. The interconnecting of the output control points from the ramp controller to the input side of the monitor circuits

completed the installation at transmitter site. Similar attachments were made between the outputs of the annunicators and the inputs to the ramp controllers at the receiver sites.

The RF equipment was placed under a license already issued to the SDHPT. An unmanned transmitter must adhere to the following general Federal Communications Commission (FCC) guidelines:

1) Station address must be given,
2) Message duration must not exceed 2 seconds,
3) Continous transmission must be inhibited,
4) A minimum of sixty seconds of silence must separate transmissions, and
5) The message can not be repeated more than three times.

A short and intensive study was designed whereby as many RF messages (transmissions) were to be made as possible. Station addresses remained in each message, but three transmissions were sent in 16 seconds. A test program was loaded into an unused portion of the ramp controller memory which enable the observer to program each test message and data set. The ramp controller issued selective messages to the monitoring transmitter unit at correct intervals of time. Observers were stationed at each slave controller to verify the accuracy of the received message. Differences were recorded as errors. The printer monitored and documented each transmitted message. The RF test was conducted over a three-day period at three time periods of the day; 6:30-8:30 AM, 11:00 AM to 1:00 PM, and 3:30-6:00 PM.

Throughout the test period, the printer was experiencing spurts of "false" messages. Comparisons of the "good" printer data with the transmitted data indicated all messages were accurate; i.e. all bits transmitted were received in the correct manner. The data collected at the slave (receiver) locations when compared with the transmitted data indicated small errors were present at the receiver sites. Since the printer experienced no errors, errors at field observed locations were attributable to human error. The RF test was successful in that the quantity of messages transmitted during the test represented 6 months of normal system control ramp metering operation without an error.

Exact costs can be given for the equipment used in the RF installation. The equipment compares favorably with an alternate direct burial wireline interconnect.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

METRIC CONVERSION FACTORS

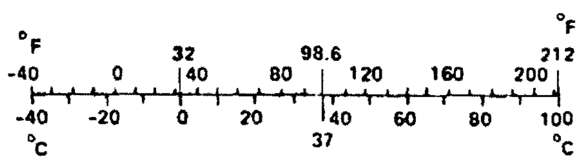
Approximate Conversions to Metric Measures

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

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

Approximate Conversions from Metric Measures

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



Section 1

Introduction

INTRODUCTION

The direct wireline interconnection of intersectional control signals on street systems for control purposed has been in use for a long time. Past and present entrance ramp metering systems have used different techniques of direct wireline interconnection to provide for system-wide control decision making. An entrance ramp control installation on I-30 in Fort Worth, Texas has ramp controllers for which an interconnect is warranted. As an alternate to a wireline interconnecting system, a data transmission system utilizing radio frequency (RF) equipment was specified, purchased and installed by District 2 of the State Department of Highways and Public Transportation (SDHPT). While the RF equipment has been in use in the oil and gas production industry for some years, the entrance ramp interconnect represents the first application for the SDHPT.

Section 2

Study Objectives

STUDY WORK TASK OBJECTIVES

1) Determine the data transmission needs and requirements for the selected surveillance and control equipment used in freeway operation.

The selected study site is described in detail in Section 3. The study plan emphasizes the use of the system control programmed logic as contained in the TransTronics ramp controllers (See Appendix A). Three points of input to the controller enables it to become remotely computer controlled. The 3 points provide up to five segmenter levels to be recognized. Therefore, the RF equipment must be capable of providing at least 3 points in a parallel manner. Since the freeway averaging time ranges from 0.5 minute to 7.5 minutes, the RF equipment should be capable of sensing, sending, receiving, and presenting information within the 0.5 minute as a minimum turnaround time. Particular emphasis was placed on insuring that the proposed RF equipment presented the 3 points in a parallel manner within milliseconds of each other. This is in contrast to a serial fashion point-to-point presentation where problems could be caused within the receiving ramp controller as to which control level is being transmitted.

Another requirement to be considered in the selection of the RF equipment is the state change condition. Under remote computer control, the states of the 3 input points at the slave controller must remain unchanged until the next notification from the remote computer is received. Therefore, the RF equipment should only function when a change is noted at the master location. The equipment at the slave location should constantly present the last received state of the 3 points. It is unnecessary for any RF transmission to occur except at the change of master location.

2) Survey existing manufacturers equipment and determine costs.

The data communications equipment normally linked with RF transmission equipment is designed to carry much larger and more complex telecommunications systems than required for this application. All such equipment far exceeds the requirements for signal control application and is not cost effective. Therefore manufacturers of fire and security alarms systems were questioned as to the operations of their equipment. As a general rule, these types of RF communication systems contain few inputs and outputs, provide simplistic communications schemes and retain a maintainability that can be provided by skilled personnel.

Two nationally known companies produce a line of alarm systems designed to operate with RF transmission from remote locations. The controller at the transmitter site continually samples sensor status. A sensor actuation causes the RF controller to code information and activate the RF transmitter. The coded information may be retransmitted several times as a redundant checking feature. The receiver provides the coded tones to a controller which decodes it into a meaningful message.

Each application area (security, fire, gas compressor operation, etc.) requires different sensor interfaces to the RF equipment. Although both companies were asked to consider the ramp control application and submit cost estimates, only one company did so.

3) Determine FCC Licensing requirements for unmanned transceiving equipment.

Volume 5, Title 47, Part 90, of the Code of Federal Instructions contains all the requirements for telecommunication utilizing radio frequency transmissions. The pertinent sections are given in Appendix B. The ramp control interconnect utilizing the RF transceiving equipment was within the FCC regulations.

The system was temporarily licensed to operate on voice channel (F3) for secondary signaling (F2). If the decision is made to designate the RF interconnect as a permanent operational tool, then a new license will be obtained for a splinter frequency that has only secondary signaling. All other FCC regulations have been met:

a. Transmitter Station has an identification code.

b. Protection circuit blows a fuse when the transmitter has been on longer than 10 seconds.

c. The silent time between transmissions is adjustable from 10 seconds to 120 seconds.

4) Develop field site requirements and document installation procedures.

The standards and practices employed by the SDHPT in both the Radio and Signal Divisions are excellent. Thus the installation of the RF equipment posed few problems. The antenna at the transmitter site was elevated to 20 feet on a wooden pole installed by the SDHPT. The receiving antennas were placed on top of a 10-foot section of 2" diameter steel pipe to prevent theft. These antennas are similar in appearance to CB mobile antennas. The encoding/decoding electronics for both the transmitter and and receivers were enclosed in a weatherproof fiberglass housing suitable for outside placement. The housing was placed inside a large standup controller cabinet to provide a secure, controlled environment. Space in the cabinet is minimal since the TransTronics ramp controller and four loop amplifiers are in this cabinet. Care must be exercised in routing the coaxial cable inside the controller cabinet from the transmitter to the antenna to prevent induced interference. There was concern about the possibility of induced RF causing the ramp controller to malfunction, but no problems were evident. All other procedures were routinely serviced by the SDHPT.

5) Develop operational guidelines, evaulation procedures and collect operational data on the implemented system.

The operational guidelines for the RF interconnect were governed by the goals to be achieved by the system control concept of entrance ramp metering and the requirements for RF operation as dictated by the FCC regulations. The system control concept is that flow rates approaching the master location should determine control levels for upstream slave units, provided local conditions are not more critical. The flow rate sampling time at the master location should not be faster than the response time of the RF system. Since the RF transmitter must allow for 1 minute of silence between transmissions., the ramp controller's sampling rate should be greater than once per minute. A sampling time of 1 minute may cause metering rates to fluctuate and result in spasmodic operation on the ramps and freeway. Experience has shown that for local control operation, a 2 minutes sampling rate provides adequate responsiveness to both ramp and freeway traffic. System control operation should be observed after the RF interconnect is installed to determine the sampling period at the master location. The metering of the upstream slave units should be observed to insure that the system metering levels provide restrictive control and local metering levels respond to local conditions. During the calibration of the systems control, the operation of the RF interconnect should not be noticeable; i.e., the reception of the Master's calls for metering levels at the slave units should be just as though the master were sitting next to the slave and wired directly to it. The only noticeable event will be the tone transmission as needed with a minimum of 1 minute of silence between transmissions.

To evaluate the RF operation a study plan was developed to collect information on the type of errors to be found in the RF equipment, to determine their effect on system control operation and to develop corrective actions that could be taken. The description of the study plan and results are presented in the following sections.

6) Determine the maintenance requirements and reliability of the implemented system and prepare a technical report.

Information from an oil and gas production company in Texas that used the same equipment suggests that the RF transmitters will require servicing one or two times per year. No information was obtained on the RF receivers and their associated decoding electronics, although maintenance should be no worse than the transmitting equipment. The SDHPT will document the maintenance activities of the system in Ft. Worth.

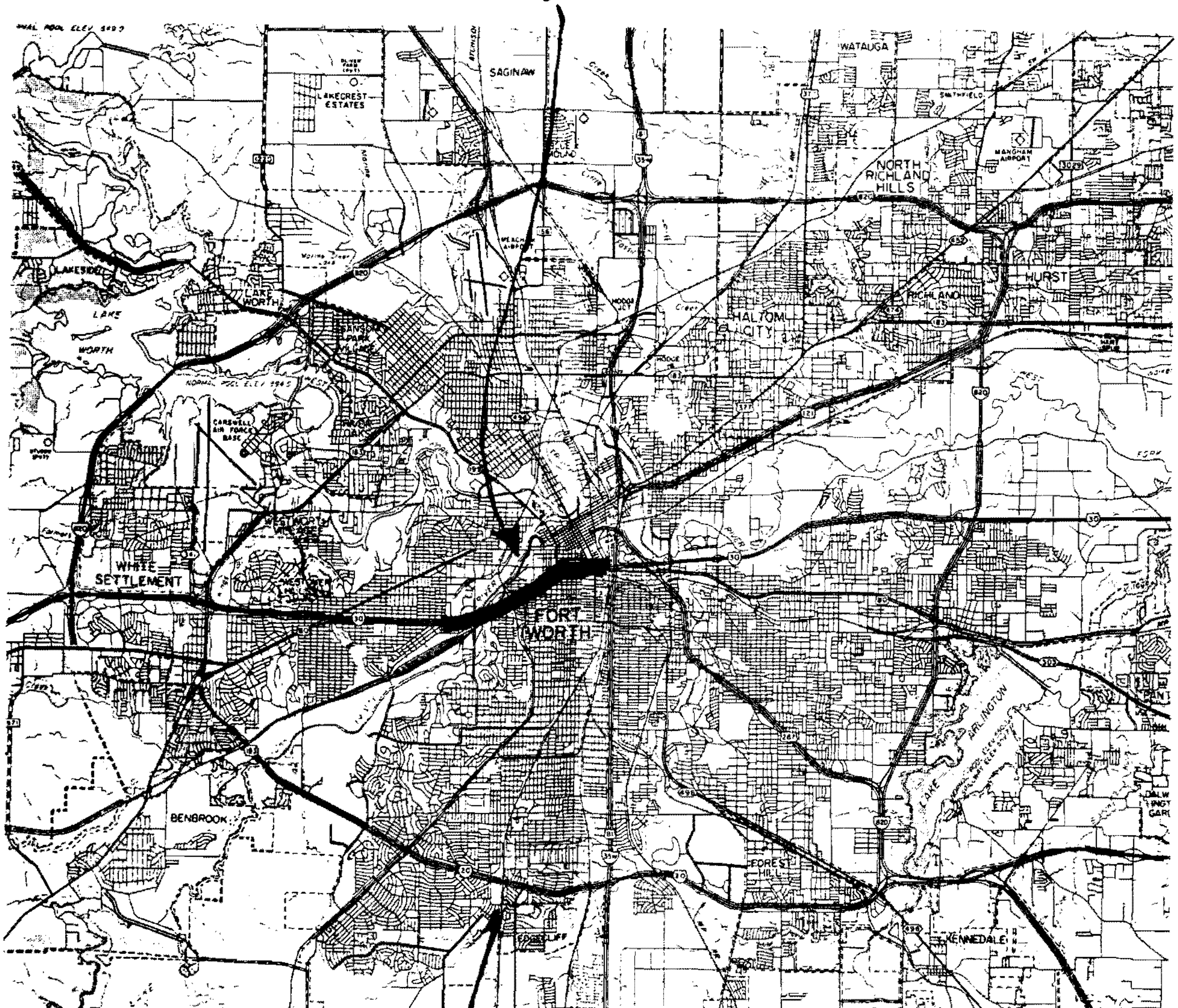
Section 3

Study Site Description

Study Site Description

The site chosen to install the RF transceiving equipment is on westbound Interstate 30 in Fort Worth, west of the central business district (CBD) (Figure 1). The cross section for the westbound lanes varies; there are three lanes leaving the CBD, a fourth lane is added at the Summit entrance ramp and dropped at the Forest Park exit ramp, and the third lane is dropped at the Montgomery Street exit ramp and University Drive entrance ramps. The fourth entrance ramp in the system serves Montgomery Street. All four entrance ramps for Summit, Forest Park, University Drive, and Montgomery have ramp metering controllers that operate on local freeway conditions. The Montgomery Street entrance ramp was chosen to be the master location in the system control scheme, because if the flowrate in the two-lane section at the Montgomery entrance ramp approaches or exceeds the two-lane capacity for a period of time the freeway operations will breakdown. The resulting queueing will send shockwaves upstream towards the other three entrance ramps. With the RF transmitter installed at Montgomery (Figure 2) and the receivers at the other three entrances, restrictive metering could be employed by the slave units. This restrictive metering will reduce total demand to the two lane section thereby enabling traffic to resume smooth flow which results in greater throughput. The geometric design of the ramp-freeway merging junction at Summit and Montgomery entrance ramps are excellent with long acceleration lanes and good sight distances (Figures 3 and 4). Limited acceleration lanes are provided at the other two entrance ramps. When freeway speeds drop and the freeway queue has formed in the area of the lane drop at Montgomery, freeway traffic concentrates in the inside two lanes. After the traffic enters the two-lane section, speeds increase and the drivers arrange their desired headway

RF Study Site I-30



SDHPT District 2 Headquarters

Figure 1. Study Site - I-30 Fort Worth

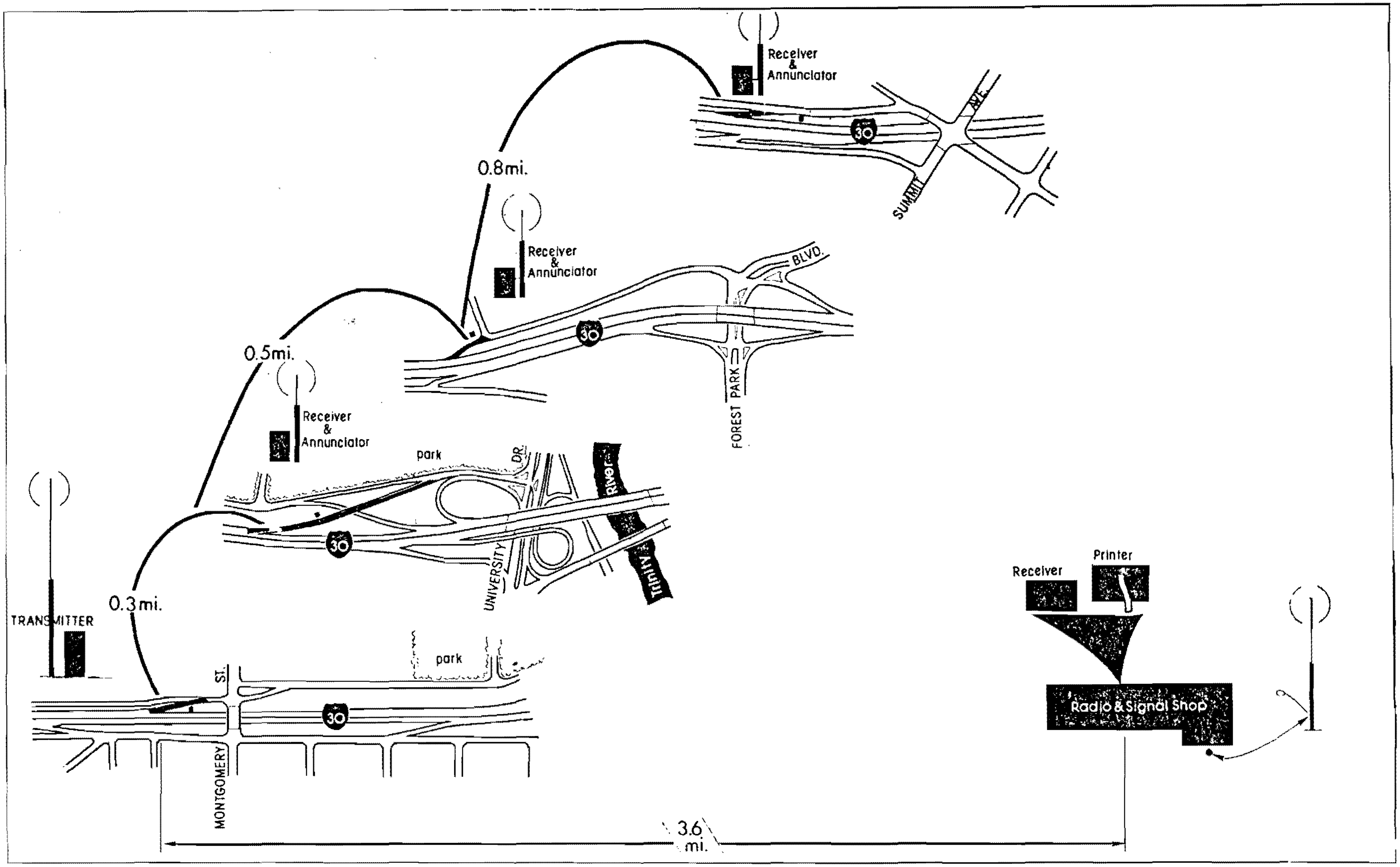


Figure 2. RF Equipment Locations

Figure 3. Summit Entrance.

Figure 4. Montgomery Street Entrance Ramp.

spacing. The ramp traffic entering the two lane section at University Drive and Montgomery Street ramps cause further adjustments to be made in the headway spacings. If the flowrate is too high, the freeway traffic will begin to slow its speed and queueing begins again. The system control concept is to maintain the maximum steady-state flowrate in the two-lane section by limiting the entrance ramp traffic.

The typical peak period extends from 4:30 PM until 5:30 PM. There are two peaking demand patterns; the first peaks around 4:45 dropping off until another starts just before 5:00 PM that peaks around 5:15 PM.

Section 4

Equipment Description

EQUIPMENT DESCRIPTION

The transceiving equipment selected for this installation has been used for many years in other applications as a status reporting system that monitors and automatically reports changes from remote locations to a central site. The two major components of this system are the transmitter and receiver. The transmitting device is functionally composed of 1) a series of monitoring circuits that detects a change-in-state of some external process, 2) electronic components designed to generate coded information about the monitored process, 3) a radio transmission circuit and 4) a precise radio frequency generator that modulates a carrier signal based on the coded input information. The modulated signal is amplified and fed into the antenna for radiation. The receiving device basically reverses this process by 1) amplifying the received radio signal via a tuned circuit that employs electronics and a crystal excitable for the same precise frequency as produced by the transmitter, 2) converting the modulated audio signal into coded information, and 3) outputting the status of the monitored process based on the coded information. The general specifications of the transceiving equipment are given in Table 1 along with information about the thermographic printer that provides a permanent record of the monitored process at the transmitter location.

Off-the-shelf equipment was secured for the RF interconnect and the component packaging was not altered. All transmitting equipment, with the exception of antennas, is contained in a fiberglass housing suitable for outdoor employment. The power source for all electronics in the transmitter is supplied by a DC storage battery pack. Since AC power is available in the ramp controller cabinet, a DC trickle charging circuit was added by the RF vendor to insure that full DC power is always

TABLE 1. General Specifications of RF Equipment

TRANSMITTER
POWER: 12 VDC supplied by sealed lead calcium batteries. Trickle charged.
OPERATING VOLTAGE: 10.5 VDC Min 14.5 VDC Max.
CURRENT DRAIN: 15-20 microamperes (μA) at 25°C (100 μA at 65°C) in the prealarm "monitor" mode. 400 μA per alarm closure in the post alarm mode. 600 millamperes (MA) during alarm transmission.
POWER DEPLETION: Approximately 0.05 AH per alarm cycle.
OPERATING TEMPERATURE: -30°C to 65°C (-22°F to 149°F).
ENCODER SIGNALING: Binary 3 tone frequency shift keying (FSK), 1020 Hz center "CLOCK", 820 Hz "ZERO" and 1220 Hz "ONE". Signaling at 16 bits per second.
ALARM CYCLE: One or 2 twenty bit messages send (REDUNDANT) per transmission. One sync bit, 7 bits station address and 4, 8 or 12 status points sent per message. One, three or five transmissions per alarm at 10 to 120 seconds intervals (adjustable).
ALARM INPUT: Parallel inputs sensing switched low or dry contact closure with a common return and a maximum 20,000 ohms loop resistance.
FREQUENCY: 151.055 MHz
FREQUENCY STABILITY: ±0.0005% (-30°C to +60°C).
RF POWER OUTPUT: 8 W @ 12.5 VDC.
EMISSION TYPE: 15F2, 16F3.
POWER SUPPLY VOLTS: +12.5 VDC±15% nominal.
POWER SUPPLY CURRENT: 1.8 Amps @ 12.5 VDC.
AUDIO INPUT IMPEDANCE: 4,700 ohms @ 1 kHz.
AUDIO INPUT LEVEL @ 1 kHz FOR ±3.3 kHz DEVIATION: 7 mV rms.
AUDIO RESPONSE (300-3000 Hz): +1, -3dB of std. EIA 6 dB/octave pre-emphasis characteristic.
AUDIO DISTORTION (MAX): 6% @ 2/3 rated system deviation with 1kHz modulation.
FM HUM & NOISE: 50dB below 2/3 rated system deviation.
SPURIOUS & HARMONICS: 60dB below carrier.
DUTY CYCLE (W/O DEGRADATION): 10% (max transmission 1 minute).
DIMENSIONS: 16" high, 14" wide, 6" deep.
WEIGHT: 26 lbs. NET, 31 lbs. GROSS
HOUSING: Fiberglass enclosure is oil, water, and dust proof with stainless steel hinges and clasp.

TABLE 1 (CONTINUED). General Specifications of RF Equipment

RECEIVER-MONITOR

POWER: 121 VAC ± 20%, 60 cps.

AUDIO INPUT SENSITIVITY: -18 db to +18 db (97 Millivolts to 6.2 volts RMS). Single conversion with fixed squelch. (Best operation with 0 db to 18 db signal strength.)

INPUT IMPEDANCE: 10,000 ohms, bridging D.C. Blocked.

SINAD: 6 db (noise 300-3000 Hz, 6 db/octave power, equivalent FM squelch noise).

DECODER SIGNALING: Binary three tone FSK, 1020 Hz "CLOCK", 820 Hz "ZERO", 1220 Hx "ONE" frequencies at 16 bits per second.

FREQUENCY: 151.055 MHz.

FREQUENCY STABILITY: ±0.001% (-30°C to $+60^{\circ}$C).

SENSITIVITY: 0.35μV: 12 dB SINAD
0.5 μV: 20 dB Quieting.

SPURIOUS & IMAGE REJ.: 70 dB below carrier.

NOISE SQUELCH SENSITIVITY: 0.25 μV.

ADJ. CHANNEL REJECTION: 80 dB (20 dB Quieting).

MODULATION ACCEPTANCE: ±7 kHz.

AUDIO OUTPUT POWER: 500 MW @ <10% distortion.

AUDIO OUTPUT IMPEDANCE: 25 ohms resistive.

RF INPUT IMPEDANCE: 50 ohms nominal.

DUTY CYCLE: Continuous.

OPERATING TEMPERATURE: 0 to 50°C.

DIMENSIONS: Height 8"; Width 17¼'; Depth 9-7/8".

WEIGHT: 19 lbs gross, 11 lbs net.

PRINTER

POWER: 117 VAC ± 20 %, 60 Hz.

AUDIO INPUT SENSITIVITY: -18 db to +18 db (97 mv to 6.2 volts RMS). Single conversion with fixed squelch.

INPUT IMPEDANCE: 15K ohms, bridging, D.C. Blocked.

SINAD: 6 db (noise 300 - 3000 Hz, 6 db/octave power spectrum, equivalent FM squelch noise).

DECODER SIGNALING: Binary three tone FSK, 1020 Hz center "CLOCK", 820 Hz "ZERO" and 1220 Hz "ONE" frequencies at 16 bits per second.

RECORDING FEATURES: Thermographic paper (1-3/4 inches wide and 150 feet long). Up to 128 transmitter station addresses with a maximum of 12 monitor points per station. Twenty-four hour military time notation.

OPERATING TEMPERATURE: 0°C to 40°C.

DIMENSIONS: 17.9" long, 16.5" wide, 5.25" high.

WEIGHT: 21 lbs.

available. The DC power source cannot be eliminated without redesigning the total transmitter package. Whereas the transmitter can be stationed at any remote point with its DC power source, the receiver monitor must operate from AC which is available at all slave controller stations. There is a standby NICAD battery pack in the receiver unit that enables memory retention and update during AC power failure. If a monitored process changes during AC power failure, the change will be presented after AC restoration. Both the receiver and transmitter enclosures can be placed inside the present larger type controller cabinets.

One adjustment to the transmittting equipment was made after the installation and test so as to meet the FCC regulation of a maximum 2 seconds of transmission (See Appendix B, Section 90.235(4)). The coded information is sent by the transmitter at a rate of 16 bits per second. Twenty bits of information is the largest message that can be sent. Monitoried points are added in groups of 4 points (or bits) to the group with a maximum of 3 groups or 12 bits. A 20 bit message will have 12 monitored points. The remaining 8 bits of information is composed of one bit for sync and 7 bits for the station address. The delivered transmitter equipment was instrumented with 8 bits of information. One message length is therefore 16 bits (1 sync plus 7 address plus 8 information) long and would take 1 second to transmit. The timing circuits in the decorder portion of the receivers must have sufficient time to be activated before message arrival, therefore a "porch" is built onto the front of the message. The carrier frequency is present 50 milliseconds before the arrival of the sync bit and remains on the same length of time after the last bit of information is sent. This method is used to trigger the decoding sequencing. The total message transmission time is therefore longer than 1 second with the added timings. With no adjustment to the transmitting equipment, two complete messages are sent each time a monitored point changes thus a total transmission time in excess of a 2-second duration. The FCC regulations allow for 3 or 5 repetitions of each message for redundancy. With an interval adjustment to the transmitter enabling only one message to be sent in less than two seconds, it can be repeated two more times without violating the regulations. Therefore, in the regular day to day operation, only one message is sent by the transmitter each time a monitored point changes. This message is then repeated twice more as a redundancy check.

Section 5

Test Theory

THE TEST THEORY

The testing of the RF interconnect system was to satisfy the basic question, could the RF equipment perform in lieu of a direct wireline interconnect? For this test, a RF system was installed according to specifications developed by the Traffic Engineering Section of District 2 of the SDHPT with technical support from File D-18T and TTI. The total system was installed and declared operational in early January, 1981. A test sequence was devised to require as many messages to be transmitted as possible in a short period of time. Other conditions of the test were that 1) the testing should occur within the normal peak traffic demand periods (6:30 AM to 8:30 AM; 4 PM to 6 PM) and one midday period, 2) a minimal number of electromechanical changes would be made to the ramp controller/RF equipment to initiate and terminate the test sequence and 3) human observers would be used for message verification. The errors and their sources were to be analyzed and corrected if possible during the test sequence.

TEST PROGRAM

To create as many messages as possible with the existing equipment, a special test program was installed in the ramp controller's microcomputer. The present ramp control logic requires less than 1024 bytes of programmable read only memory (PROM). The PROM size used by the supplier contains 2048 bytes of memory. In the other "half" of PROM, the supplier normally places test programs for their use during equipment and ramp control program checkout prior to delivery to the SDHPT. A request was made to the ramp controller supplier to provide a special program that could "exercise" the

RF equipment at the highest rate permissible. A RF test program was designed, programmed and installed in the transmitter at the Montgomery Street ramp controller.

The normal ramp control logic is documented by the supplier's manual of operations. The frontal face of the ramp controller (Figure 5) contains lamps that provide a positive verification of some occurrence: i.e. segmenter level, a detector being occupied, etc. Also, the central processing unit, CPU, program module contains pin slots for various ramp control program options as well as its mode of operation. The interpretation of the lamps and pin slots directly reflect the program logic that illuminates the lamps and renders values to the pin slots. By changing the program logic (from ramp control to RF test), the front face must be re-interpreted as shown in Figure 6.

The RF test logic programmed into the second half of the PROM reflects the desired test operation (as many messages as possible) but is restrained by the operational modes of the RF transmitter. Appendix C contains a description of the external inputs and outputs from the ramp controller. The four vehicle presence detector outputs were selected to provide the points to be monitored by the first four-bit group of the RF equipment. If anyone of the four points change states ("0"-off and "1"-on) then a new message must be transmitted (because the transmitter logic is wired in this manner). The RF test logic begins by reading the condition of four pin slots of Group 1 (G1) on the CPU module board (Figure 6). If a pin slot has been pinned, a "1" or "on" condition is set. The RF equipment constantly looks at these four points as presented by the RF test (ramp) controller. The RF transmitter notifies the test program that it has sent the last message and is now ready for the next message. The RF test program

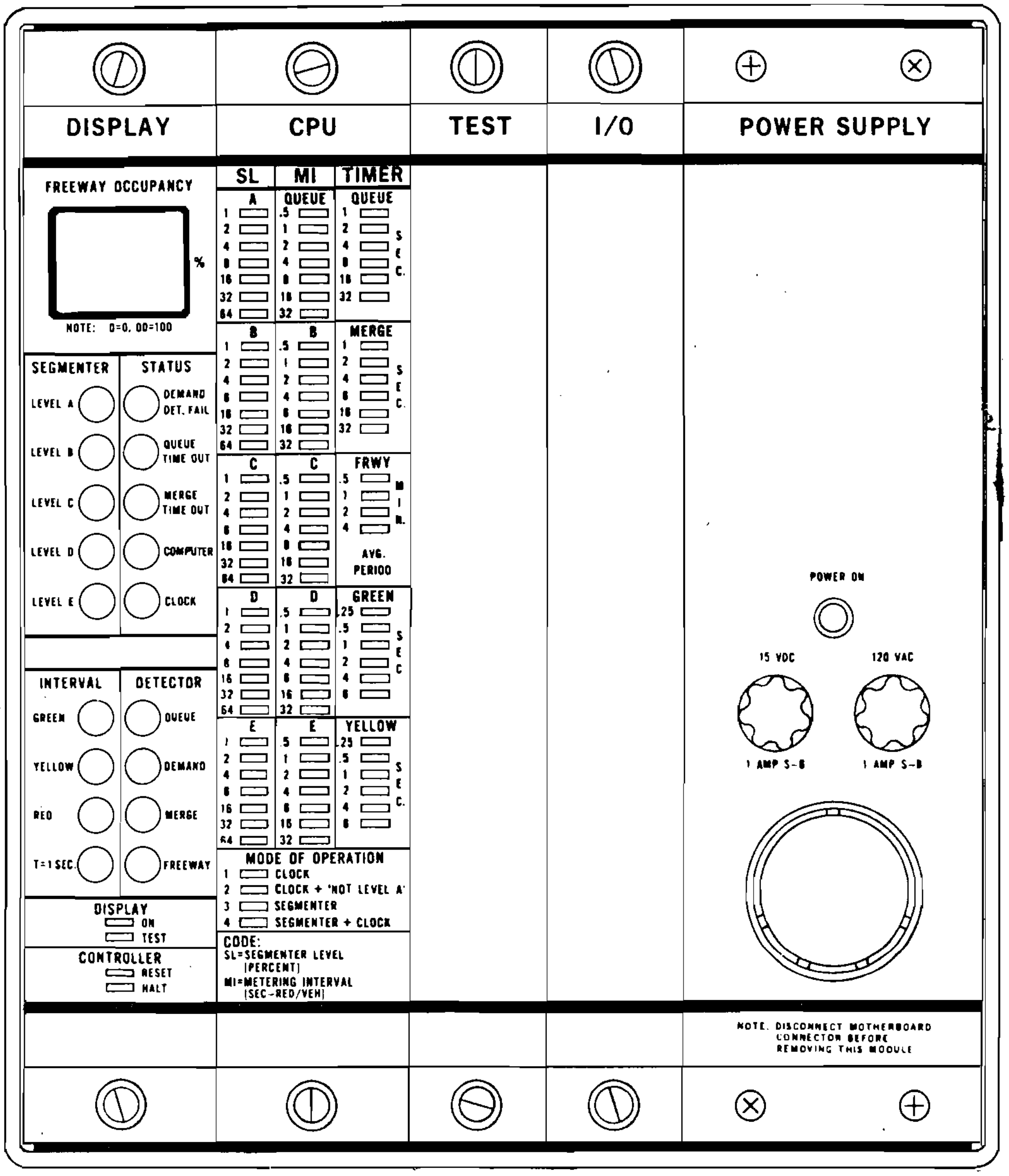
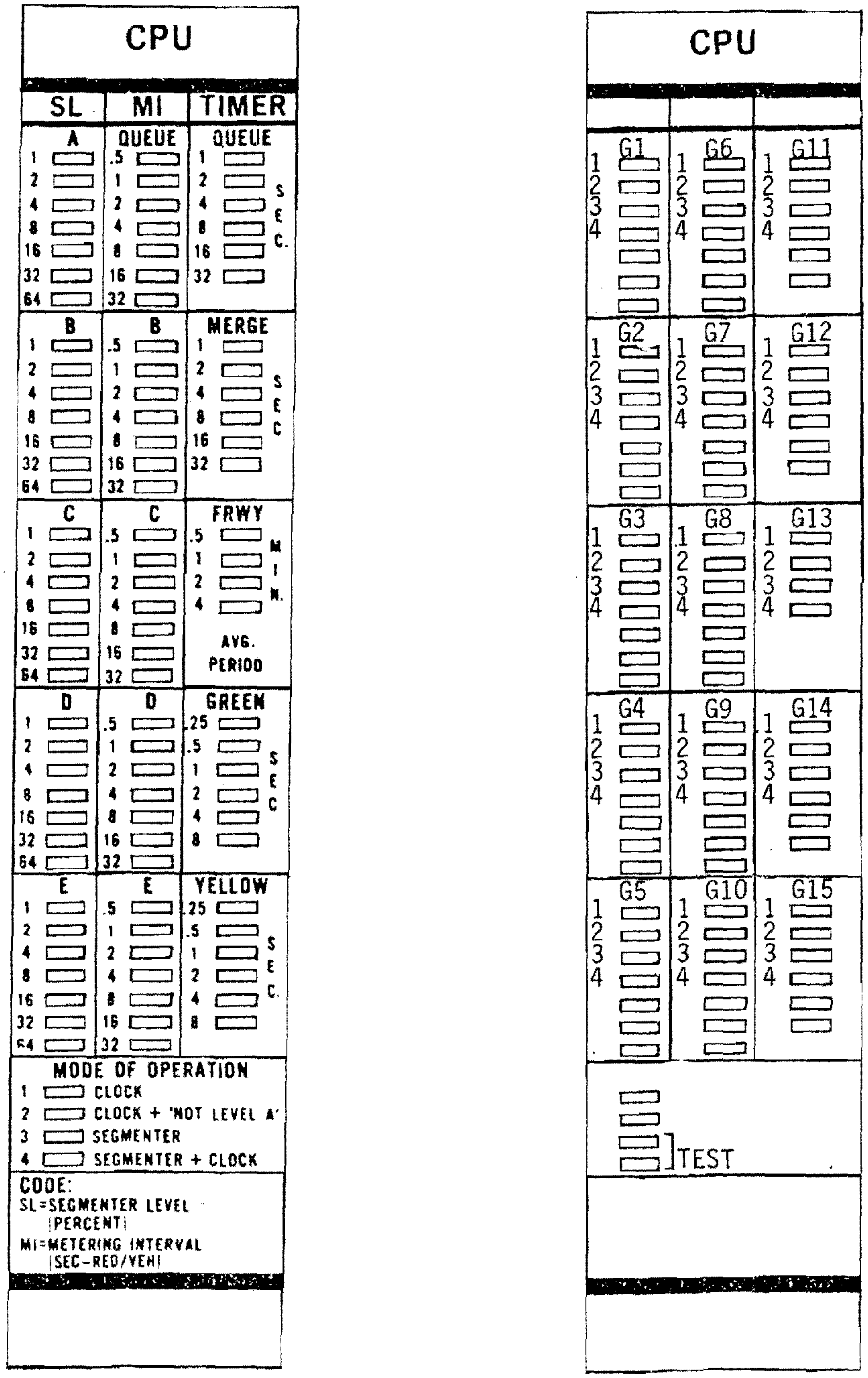


Figure 5. Frontal Face of RMC-3 Ramp Controller



During Ramp Control

During RF Test

Figure 6. CPU Panel Module Assignments at Transmitter Site

then reads Group 2 and the RF transmitter again responds by sending and clearing for another message. The RF test program continues in this manner until all 15 groups have been read and sent. Before reverting back to Group 1 a sixteenth group is sent. One operational feature of the RF transmitter is that no new message will be sent unless it is different than the last message sent. As programmed, no new message will be made available by the RF test program unless the last message is sent and cleared by the RF transmitter. This "handshaking" logic prevents a RF test logic runaway. Due to this handshaking feature, it is imperative that the message content of each group (G1-G15) be different from its predecessor. Table 2 presents a typical RF test data set.

Before the last two slots on the Mode of Operational are pinned for TEST (Figure 6), each group must be pinned as per test data set. During each time period, there were seven data sets each different in the order and makeup of each group. Each data set was sent four times, i.e. Groups 1-15 were cycled four times before another data set was pinned. As shown in Figure 7, an observer is pinning a new data set.

While the ramp control logic had to be bypassed at the transmitter site because of the RF test program, ramp control logic was enforce at the receiver sites. The only changes that had to be made were for the four bits of information being monitored, sent and received to be made available to the frontal face of the ramp controller in a convenient location. Since the four detectors were used at the transmitter site, a special wiring by-pass harness was implemented by District 2 at all three slave units. This bypass enabled the observer to see the four bits received on the four lamps labeled under Detectors (Figure 8).

Table 2. Typical Test Data Set

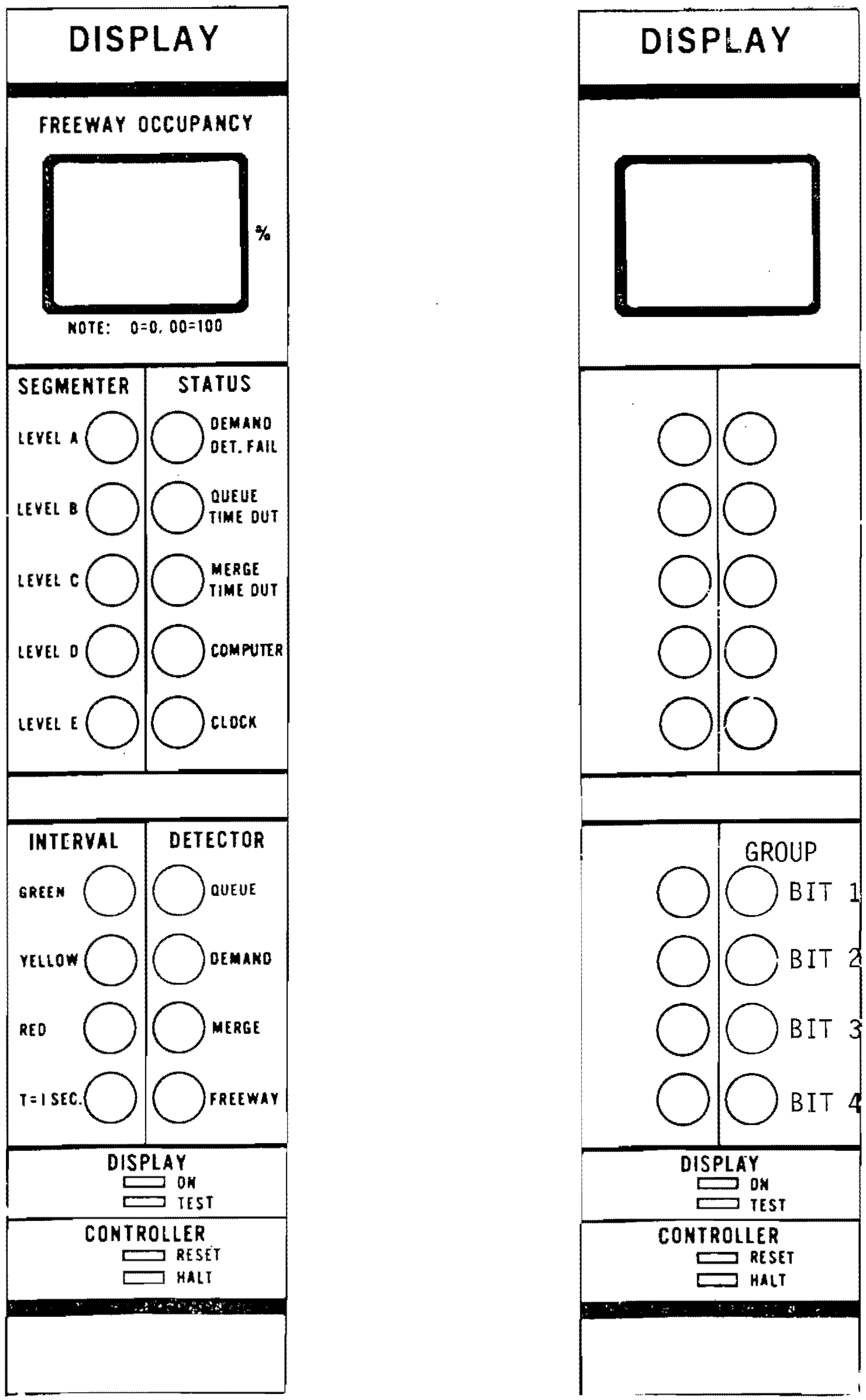
Date 17Feb 81 Tues

Time Period PM

1 = Pinned
0 = Unpinned

Group	Run #1 (Time Start 3:17)	Run #2 (Time Start 3:22)	Run #3 (Time Start 3:26)	Run #4 (Time Start 3:30)
G1	0	0	0	0
	0	0	0	0
	0	0	0	0
	1	1	1	1
G2	1	1	1	1
	0	0	0	0
	0	0	0	1
	1	1	1	1
G3	0	0	0	0
	0	0	0	0
	1	1	1	1
	1	1	1	1
G4	1	1	1	1
	0	0	0	0
	1	1	1	1
	1	1	1	1
G5	0	0	0	0
	0	0	0	0
	1	1	1	1
	0	0	0	0
G6	1	1	1	1
	0	0	0	0
	1	1	1	1
	0	0	0	0
G7	1	1	1	1
	0	0	0	0
	0	0	0	0
	0	0	0	0
G8	1	1	1	1
	1	1	1	1
	0	0	0	0
	0	0	0	0
G9	0	0	0	0
	1	1	1	1
	0	0	0	0
	1	1	1	1
G10	1	1	1	1
	1	1	1	1
	0	0	0	0
	1	1	1	1
G11	0	0	0	0
	1	1	1	1
	1	1	1	1
	1	1	1	1
G12	1	1	1	1
	1	1	1	1
	1	1	1	1
	1	0	1	1
G13	0	0	0	0
	1	1	1	1
	1	1	1	1
	0	0	0	0
G14	1	1	1	1
	1	1	1	1
	1	1	1	1
	0	0	0	0
G15	0	0	0	0
	1	1	1	1
	0	0	0	0
	0	0	0	0

Figure 7. New Data Set Being Pinned.



Ramp Control

RF Test

Figure 8. Display Panel Module Definitions at Receiver Sites

A TYPICAL TEST SEQUENCE

As each of the four observers arrived to their respective locations, there was voice communication contact with each other via hand held walkie-talkies operating on a different frequency than the RF interconnect. The slave location observers would employ the bypass connection and pin the ramp controller to keep the ramp signals from inadvertent operation. Before the first message is sent, the observer at the master site (transmitter) notifies each slave as to which data set is used. Each slave location has a copy of each group in each data set for verification. After the RF test is initiated and group sequencing has begun, little voice communication is required. The master location observer notifies each slave location at the start of a new data set (Figure 9). To keep the slave observers from becoming unattentive, the observer at the master location will change a group makeup from the intended message thus creating an "artificial error" for the slave observers. At the District 2 headquarters the thermographic printer provided a hard copy documentation of all messages received from the transmitter.

Section 6

The Test Sequence

THE TEST SEQUENCE

As each observer arrived at their respective location, the controller cabinet was opened and the materials to record the test results were readied. The slave location observers had to employ the bypass connection and program the ramp controller to inhibit the entrance ramp signals from operating during the test. The observer at the master site stopped the ramp controller while the test data set was programmed. The master site observer would initiate voice contact with each slave site observer over hand held radios that operated on a different frequency than that employed by the RF system.

When all was ready, the master site observer would notify the slave sites as to the data set to be sent. The observer at the master site would then initiate the RF test program contained within the ramp controller's memory. Each slave location observer was provided a copy of the data set for verification. After the RF test was in operation and automatic group sequencing had begun, little voice communication was required. As the last repeat of the data set was being sent, the observer at the master site would install the next data set. The observers at the slave sites were notified when the first group of a new data set was sent so that the proper verification could be made (Figure 9). Each data set contained sixteen different groups and was repeated four times. Each slave observer had to check off the successful (or unsuccessful) reception of the various groups within each data set. To keep the slave observers from becoming unattentive, the observer at the master location would deliberately change a group makeup from the intended message provided on the verification sheets. This provided an "artificial error" for the slave observers to record. This process continued until all seven data sets were programmed, sent and received.

Figure 9. New Data Set--Initial Transmission.

While each slave observer was verifying the received RF message, the same RF signal was being received at the District 2 headquarters. The thermographic printer provided a copy of the received messages sent from the master location (transmitter). By comparing the messages programmed by the master observer with the verified messages recorded at the slave sites and the District 2 printer tapes, any errors could be found and analyzed.

Section 7

The Test

THE TEST

The RF test was conducted the week of February 16-20, 1981. A preliminary trial run was scheduled for Monday afternoon, February 16, 1981. The personnel were dispersed to their respective locations for a trial period of becoming familiar with the equipment and determining modifications of the testing sequence. Approximately one hour of full scale test operation was conducted without errors. All ramp control settings were reinstated at the close of the trial test (as they were at the close of every test period) to their prior settings.

The RF testing began Tuesday, February 17, 1981 at 6:30 AM. A log of each test period is included in Appendix D. The early AM peak periods were characterized as being moderately cool but the temperature warmed up in the midday and PM peak periods. Emphasis was placed on observing the points in time when outdoor advertising lighting, freeway illumination, etc. were changing. There was concern that spurious RF emission from these outdoor sources might provide interference to the reception of the transmitted signals, but not interference was observed.

While the high band frequency (151.055 MHz) assigned to the ramp metering interconnect is not used within District 2, it is used for voice communication in the adjacent District 18 (Dallas). Infrequently, portions of voice conversations would be picked up by the RF receivers at the slave locations. Though the signals were weak, sufficient energy remained activating the receivers. The voice modulations did not contain the correct frequencies and timing patterns to activate the decoder circuits. The RF signal when transmitted from the Montgomery Street entrance ramp location superceded all other signals at the assigned frequency because of signal strength (power) and the closeness of the receivers to the transmitter. Even with signals of equal strength, the decoding circuits would not activate unless the "front porch" of the center tone was present for the exact required time.

The controllers were carefully monitored for induced interference between the transmitter and ramp controller, but none was observed. Adequate protection of circuits, packaging methods and good installation procedures resulted in this electronically "clean" installation.

In the RF test, the transmitter and its controller repeated two complete 16 bit messages three times. At the end of the third repeat, the "handshake" between the RF device and the RF test program controller would occur. Then a new message would be presented to the RF controller and another transmission sequence would occur. A variation in the message pattern received and presented at the slave locations was observed. At the beginning of the testing most new messages were observed to change on the first transmission. Later on in the studies, observations of the message content found changes on the second transmission and occasionally on the third (See Appendix D). When the message content did change, it conformed to the expected pattern; i.e. what should have been present, was present. The suspected fault was thought to be some variance or maladjustment in the performance of the decoding circuits in the receivers. Inquiries made of District 2 personnel, as well as a representative of the RF equipment supplier, suggested that the signal level into the decoding circuits was not adequate and a volume adjustment on the RF receiver would solve this problem.

As shown in Figure 10, each RF receiver has a volume adjustment. This solid state (electronics), single conversion receiver with a fixed squelch is commonly used as a voice communication's monitor. The volume adjustment is included to vary the loudness (amplitude) of the received speech. In the

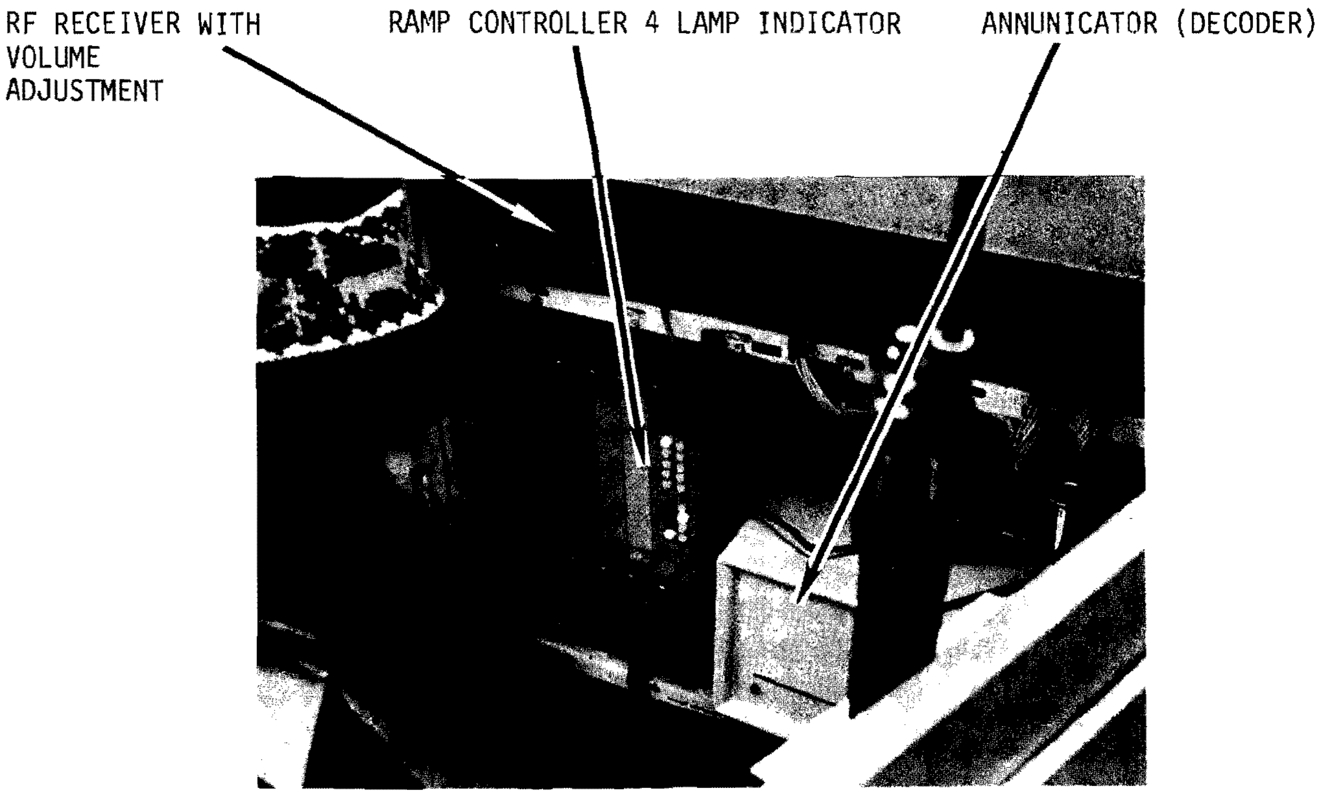


Figure 10. Typical Slave Unit Observation During RF Test.

RF interconnect application, the audio input into the decoding circuits was also connected to the output side of the volume adjustment as is the self-contained speaker. When the observers at the slave locations opened the controller cabinet and positioned themselves so as to observe the lamp indications during the RF tests, it was sometimes necessary to adjust the volume on the RF receiver. The background freeway traffic noise, the nearness of the controller cabinet to the freeway and the necessity to remain close to the frontal face of the ramp controller often required large volume adjustments. It was necessary for the observer to hear the audio tones so that a decision could be made as to whether the message pattern changed on the first, second, or third transmission. It is possible to under or overdrive the audio input signal to the decoding circuits, just as it is possible to similarly affect an audio speaker system. The results are the same; a signal level so weak an observer cannot hear, or overdriven to the point where distortion is prevalent. In most cases, the audio signal had been reduced to the point where the decoding circuit just barely could "hear" the "message". During the testing of the RF system, the volume was adjusted so that decoder changes were noted on the first transmission. A permanent solution to the adjustment problem would be to install a circuit that provides a constant audio input signal level to the decoder circuits.

The coordination of human activity proved to be difficult. Each observer had to compare the received 4 bits message with the correct data set and group number message for that data set. It was impossible at times for voice contact via the walkie-talkies. For instance, University or Forest Park locations would have to relay voice instructions from Montgomery (master and transmitter location) to Summit and back. This caused several observers to get out-of-sequence. It would be several messages before the observer would realize that the received message was not even close to the expected message. The observer would be recording errors for each case where the received message was not matching the expected message. Knowing that multiple errors were highly unlikely, the observer would re-establish the observation point in the data set by waiting for the initial group 1 or instruction from the master location. In all cases of re-orientation, the observer clearly documented on the verification records as to when the out-or-sequence began and where correct matching took place. While this may appear to be unattentiveness on the observers part, very few out-of-sequence occurances actually happened. Most occurred when the observer had an outside influence such as a hitchhiker from the freeway conversing with the observer. In these cases, not only was the observer concerned about the message pattern and sequence, but a certain fear factor for personal safety that precluded the relative importance of message observation.

Section 8

Test Results

TEST RESULTS

An objective of the RF test was to determine the failure rate of the installed RF equipment acting as a direct wireless interconnect and its potential effect on the ramp control operation. Statistical tests had been devised to apply to the errors that were found. Throughout the RF tests, the printer at the District 2 Signal Shop had been recording all received messages from the master location. This record plus the records from the three other slave locations (University, Forest Park, and Summit) provided the information that was compared against the recorded information sent from the master location. Table 3 indicates the total number of transmitted messages and bits of information sent. Comparisons were made of individual messages sent from the transmitter site and received at the Signal Shop printer. This comparison was tedious because the printer was experiencing sporadic periods of what appeared to be self-induced messages. This diagnosis was later verified by the supplier. These false messages were easily detectable on the printer's printout because of non-existent station addresses being given and information in the second 4 bit group (Figure 11). None of these false messages were used in the analysis because the printed information occurred without a received transmission. The messages would be printed without tones being heard from the RF receiver. These false messages were occurring between the received tones. Thus, no transmitted information was lost or mixed with the false information. All transmitted information was received and recorded correctly.

During each time period seven data sets of test information were transmitted four times. There were sixteen messages in each data set and each message contains four bits of information. As shown in Table 3, there were 3,648 four bit messages or 14,592 bits of information transmitted

TABLE 3.

RF TEST RESULTS

Day	Period	Sets		Messages Per Set		Total Messages		Bits Per Message		Total Bits
Tue.	AM	30	*	16	=	480	*	4	=	1920
Tue.	NOON	28	*	16	=	448	*	4	=	1792
Tue.	PM	30	*	16	=	480	*	4	=	1920
Wed.	AM	28	*	16	=	448	*	4	=	1792
Wed.	NOON	28	*	16	=	448	*	4	=	1792
Wed.	PM	28	*	16	=	448	*	4	=	1792
Thur.	AM	28	*	16	=	448	*	4	=	1792
Thur.	NOON	28	*	16	=	448	*	4	=	1792
TOTALS		228	*	16	=	3648	*	4	=	14,592

Figure 11.

Comparison of Messages at Printer Site

	Messages		
	Real	False	Real
Time of day	1218	1218	1218
Station address	001	062	0001
First 4 Bits	0101	1001	0001
Second 4 Bits	0000	0111	0000

over the 3-day test period. Analysis of the printer's record in comparison to the transmitted pattern indicated that no errors were present. The planned statistical tests were not run because without an error, the error rate results are meaningless.

The message patterns recorded by the observers at the three slave locations did not compare as well as the printer's results when taken at face value. There were 31 cases in which one of the 4 bits in the received message did not match the transmitted message for all three locations. These errors represent approximately a 0.2% error rate over the total number of transmitted bits. Human error rates are task oriented; i.e. the more tasks required by the observer, the more chance an error will be produced. Informed sources indicated error rates of up to 5% are not uncommon for similar tasks as performed by the observers in the RF test (1). Therefore, the 0.2% errors recorded by the observers could probably be attributable to human error and not to interference or equipment malfunctions. There were no multiple errors for the same bit at the same location or similar errors by time of day or location. Since the printer did not record an error and the same decoding circuits and components were used in the four receiver locations, it is reasonable to assume that the errors found by the observers were human errors; not associated with the equipment functions.

What would happen to the ramp control operation at the slave locations if a failure occurred in the RF interconnect system? The answers depend on where the failure occurred. Table 4 presents types of failures and the resulting effects on the ramp metering operation. The most reasonable results would be cases 2 and 3 where a slave unit would continue to meter ramp traffic unless the ramp controller has time clock limits.

TABLE 4.

RF Interconnect Failures and System Control for Ramp Metering Affect.

Case	Failure Type	Failure Location	Function Prohibition	Results
1.	AC Power Failure	Transmitter	No segmenter level	Slave units run on local conditions
2.	AC Power Failure	Slave	Received segmenter level not available for use	No ramp metering without AC power
3.	One of 3 bits always on	(Master) Transmitter	Remote computer control always on	Ramp metering continous unless time clock turns AC power off
4.	One of 3 bits always on	Slave	(Same as case 3)	(Same as case 3)
5.	One of 3 bits always off	Transmitter	Severity of segmenter at slave never as great as should be	Ramp metering could not be as restrictive as should be
6.	One of 3 bits always off	Slave	(Same as case 5)	(Same as case 5)

In other cases, the system control approach on interconnecting the ramp metering would not be operational.

The 3-day RF test was not long enough to establish a long term operation and maintenance pattern on the equipment. During the normal ramp control system operations, the RF interconnect on the test site in Fort Worth could require up to 30 transmissions per control period using 2-minute occupancy averaging for segmenter level selection. If the control period averaged one hour, the 3648 transmissions experienced during the test represents approximately 24 weeks (or 6 months) of run time without a failure. Based on similar equipment configurations in the oil and gas production industries, one of two maintenance calls per year is the norm. District 2 is cooperating in maintaining records on the installed RF equipment so that a better insight can be established on the equipment for the specific application for which it is being utilized.

Section 9

Cost Comparison

COST COMPARISON

Firm cost figures were established for the RF interconnect system based on the received bid quotes and documentation from District 2. Table 5 contains these general costs as well as the estimated costs for a comparable direct burial wireline interconnect. The comparison given in Table 5 for a wireline interconnect is for direct burial of cable extending from Montgomery entrance ramp (master) to each of the 3 slave locations. Crossings of the ramps, river, and intersectional bridges were figured based on using conduit fastened to superstructure or buried via jack and bore methods under the ramps. All distance figures were obtained using scaled drawings of the construction plans along the study site. The cost per unit quantity figures were gathered from recent price quotes for urban projects in and around the Houston area. All costs include installation. The quantity of pull boxes and other special hardware required in and around the receiver sites are not included. Whereas the wireline interconnect has the added value of unencumbered utilization, there is the threat of cable severage due to maintenance and construction activities. The direct buried cable has little maintenance, but repairs due to severage is costly. Wireline interconnect via leased telephone lines was not considered for this application.

TABLE 5.

System Costs and Estimates

RF SYSTEM (ACTUAL COST)		DIRECT WIRELINE (ESTIMATED COST)	
All RF equipment	$ 11,016.50	Approximately 8100 feet Direct burial cable @$3.00/foot	$ 24,300.00
1 extra antenna 1 wooden pole } antenna 3 2"x10' heavy conduit } supports	700.00	Jack & Bore under ramps Approx. 200 feet @$20./foot	4,000.00
Equipment Installation	2,600.00	Conduit over river & intersections. Approx. 1300 feet @$6./foot	7,800.00
5 Man-weeks engineering time	6,000.00	5 Man-weeks engineering time	6,000.00
	$ 20,316.50		$ 42,100.00

Section 10

Conclusions and Recommendations

CONCLUSIONS AND RECOMMENDATIONS

The RF system, as studied in Fort Worth, performed as an alternative to a direct wireline interconnect between entrance ramp controllers. The RF system performed as a one-way communications link. While the short and extensive study did not discover any major malfunctions or errors due to interference or equipment malfunctions, the total operational picture for this equipment has not been determined. Based on experiences in other industries using this equipment, one or two service calls per year are to be expected. As the SDHPT gains more experience through the use of this RF equipment, a more thorough understanding of the operational and maintenance requirements will be achieved.

One area that needs standardization is the selection of the RF frequency. The FCC has allocated several frequency bands specifically for State Highway agencies to be used for data communications. The SDHPT can utilize their expertise in selecting several frequencies which can be used throughout the state. More than one frequency could be needed in the event neighboring cities (for example Fort Worth and Dallas) operates several groups of RF interconnecting ramps. By selecting different frequencies for each city, interference between cities will be eliminated. Within a city, the same RF frequency can be used. Each ramp interconnect group (a transmitter and several receivers) can be given a unique station address. The receivers will only respond to the RF signal having the unique station address. Messages from all other transmitters on the same channel with different addresses will be disregarded.

The RF equipment, as utilized in the study, is currently in production and contains no unique components or circuits specifically installed for the SDHPT's use. Therefore, the RF equipment can be utilized as shipped from the factory. All installation expertise needed is presently available within the SDHPT. The RF equipment can be used as a cost effective alternative to a direct wireline ramp control interconnect.

REFERENCE

1. Van Cott, H.P. and Kinkade, R.G., "Human Engineering Guide to Equipment Design," American Institute of Research, Washington, D.C., 1972.

Appendices

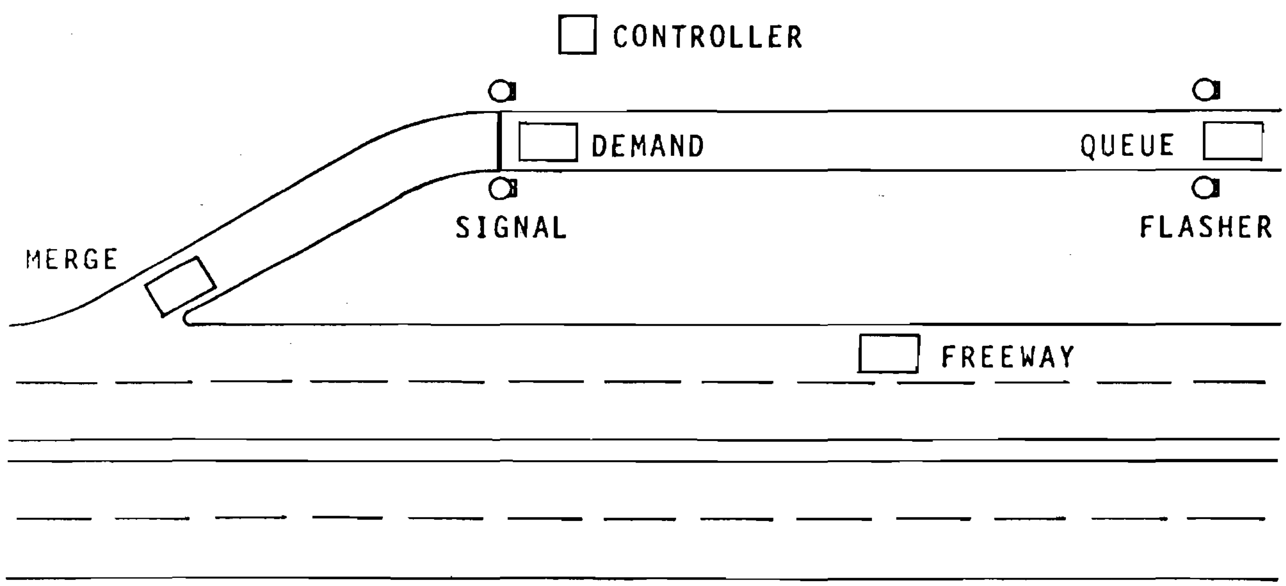
APPENDIX A.

INTRODUCTION

The Trans-Tronics Ramp Metering Controller was designed to control vehicle access to a freeway in relation to the level of freeway occupancy. It is a microprocessor based digital computer using the latest state of the art LSI processing components in conjunction with low power/high noise immunity CMOS integrated circuits. The controller is of modular design using 100% solid state components and will operate over a temperature range of -30°F to +165°F. All timing is digital and referenced to the 60 Hz line frequency. Controller programming is performed quickly and easily by inserting program pins into slots on the front of the CPU module. The controller is fully responsive to systems detector inputs and can operate stand-alone or as a master/secondary in an interconnected system. The controller may also be interfaced with and supervised by a remotely located master computer.

A typical ramp metering controller installation is shown below:

DETECTOR LOCATIONS



GENERAL DESCRIPTION

Introduction

The controller may be programmed to operate several different ways. It is capable of being either fully traffic responsive, enabled by a time clock, remotely controlled by a computer, or any combination of the above. Each mode of operation will be described in this section.

Actuated Operation

Basic Operation (Segmenter)

The controller continuously measures the percentage of freeway lane occupancy over a programmable interval from 1/2 minute to 7 minutes. Based on the freeway occupancy percentage, one of five segments (A thru E) will be selected from programmed segment percent levels. The controller will select the highest segment within a progrmmed level, not exceeding the measured freeway occupancy percentage. Once a segment level of B or greater has been selected, the controller will not return to level A until the freeway occupancy percentage has fallen below the level programmed for segment A.

When a segment level of B or greater is called for, the controller will initiate ramp metering operation. At the start of metering operation, a two circuit flashing beacon signal will be energized and remain on for the duration of metering operation. Metering will initiate with a green signal of 15 seconds, followed by a yellow signal for 3 seconds, and then rest in red.

The duration of the red signal interval is determined by the progrmmed metering rate for the selected segment (B thru E). After the red metering interval has timed out, the controller will respond to demand conditions. The subsequent green and yellow interval times will be as programmed.

Demand Conditions

Following the red timing interval, the controller will enter a ready state for a demand call. When a demand is present, the green interval will be started provided there is no vehicle present on the merge detector. Should a vehicle be present on the merge detector, the controller will remain in a red state until either the vehicle leaves the merge detector or the merge interval timer has timed out, at which time the vehicle on the demand detector will be serviced.

A demand call will be registered in the controller memory for any of the following conditions:

1. A vehicle is present on the demand detector.

2. A vehicle is present on the queue detector and the programmed queue interval has timed out.

3. There have been five actuations of the merge detector without an actuation of the demand detector. This situation is defined as a demand detector failure and will remain until there is either an actuation of the demand detector or the controller is reset.

Selectable Modes of Operation

The controller may be programmed to operate in one of the following four modes using combined conditions of the segmenter and the time clock:

1. CLOCK: When the clock input is off, the segmenter output is forced to level A. When the clock input is on, the level is the segmenter level output based on freeway occupancy.

2. CLOCK + NOT LEVEL A: When the clock input is off, the segmenter output is forced to level A. When the clock input is on, the level is forced to B or the segmenter output, which ever is greater.

3. SEGMENTER: When the segmenter level is greater then A, ramp metering will occur.

4. SEGMENTER + CLOCK: When the clock input is off, the level is the segmenter output. When the clock input is on, the level is forced to B or the segmenter output, which ever is greater.

Once the segment level is determined for the programmed mode of operation, the remote computer level input is examined and the controller state will be set to the greater of the two levels. If the ONLINE CONTROL input is true, the controller state will be set to the remote computer level. Online Control will also force a freeway averaging period of 1/2 minute.

Non-Actuated Operation

Provisions are made for control of the ramp signal using a manual push button. When the push button cable jack is connected, the controller goes into manual mode at the red condition. Activation of the push button will advance the signal one interval.

Removal of the jack or returning manual switch back to auto will return the controller to the automatic mode of operation.

By-Pass Service

Interface signals for the addition of a by-pass control module have been defined for future expansion. (See section 7).

Re-Start

The ramp metering controller has been designed to continue normal operation for a loss of AC line voltage up to 1/2 second duration. Re-start from a power loss of greater than 1/2 second will occur with all conditions reset.

A voltage monitor circuit within the controller will halt operation when the AC line voltage falls below 90 VAC.

A watchdog timer circuit will reset the controller if a fault occurs in the normal sequence of program execution.

TECHNICAL DATA

Introduction

The ramp metering controller is a microprocessor based digital computer using low power TTL processing components and high noise immunity CMOS input/output components. These devices are configured in three removable printed circuit board modules which connect to a common motherboard. A spare slot on the motherboard is provided for future expansion and is covered with a blank panel during normal operation.

CPU Module

The CPU module contains all the components and circuitry necessary to perform the controller logic functions, TTL to CMOS buffering and program panel inputs. The microprocessor chip obtains instructions from 1024 by 8-bit bytes of programmable read-only memory (PROM). Information is brought in through input buffers, stored and manipulated in 128 by 8-bit bytes of random-access memory (RAM), and then sent out through output buffers. Timing accuracies are maintained by using the 60 Hz power line frequency as a reference.

I/O Module

The I/O module contains the interface to external control signals. Provisions are made for 16 optically-isolated inputs and 32 latched transistor-buffered outputs.

Display/Power Supply Module

CPU control functions and status indicators are contained on the display module. The display lights may be disabled during unattended operation to conserve power and prolong lamp life.

DC voltages are generated on the power supply module and monitored for a brown-out condition should the AC line voltage fall below the specified operating range. The watchdog timer continously monitors the controller for proper operation. An invalid program sequence will generate a controller reset to restore proper operation.

CONTROLLER OPERATION

Introduction

The ramp metering controller is designed to control vehicle access to freeway traffic in response to the freeway occupancy level. Access is controlled by limiting the rate at which vehicles are allowed to enter the freeway using a three-section signal (red, yellow, green). Vehicular traffic information is sent to the controller from four detector inputs. One detector responds to the presence of vehicles on the freeway to determine the percentage of occupancy during a programmable period of 1/2 minute to 7 minutes. The remaining three detectors sense vehicles at different locations on the entrance ramp. The demand detector is located to sense vehicles at the stop line of the ramp control signal. The merge detector is located downstream from the stop line to sense vehicles just prior to entering the freeway. The queue detector is located upstream of the stop line, at/or near the intersection of the entrance ramp and the frontage road.

There are five programmable levels of freeway occupancy percentage, identified as level A through level E. During level A, the controller is not metering ramp traffic and the signal is off. In level B or above, ramp traffic is metered and the signal is operating. If the controller is in level A, the occupancy percentage must equal or exceed bevel B to initiate operation. If the controller is at/or below level B, the controller will not cease to meter traffic until the occupancy percentage falls below the value set for level A.

For each operating segmenter level B through E, there is an associated programmable metering rate B through E, in the range of 1/2 to 63 1/2 seconds of red per vehicle.

In addition to signal head control outputs, the controller will output status information for a remote computer. This information consists of binary data as follows:

1. Segment Level (3-bits)
2. Freeway Occupancy (7-bits)
3. Freeway Volume (7-bits)
4. Detector Status (4-bits)
5. Green Confirm (1-bit)

Occupancy is updated once each freeway averaging interval and volume is updated once each 30 seconds.

APPENDIX B. FCC REGULATIONS

PART 90 -- PRIVATE LAND MOBILE RADIO SERVICES

Subpart B - Public Safety Radio Services

. . . .

Subpart A - General Information

§ 90.1 Basis and purpose.

(a) Basis. The rules in this part are promulgated under Title II of the Communications Act of 1934, as amended which vests authority in the Federal Communications Commission to regulate radio transmission and to issue licenses for radio stations. All rules in this part are in accordance with applicable treaties and agreements to which the United States is a party.

(b) Purpose. This part states the conditions under which radio communications systems may be licensed and used in the Public Safety, Special Emergency, Industrial, Land Transportation, and Radiolocation Radio Services. These rules do not govern radio systems employed by agencies of the Federal Government.

§ 90.3 Organization and applicability of the rules.

The rules in this part are divided in 17 subparts as follows:

(a) Subpart A contains general information and definitions for use in this part.

(b) Subparts B, C, D, E, and F set forth the radio services governed under this part and include eligibility provisions, listing of frequencies available for each radio service, and special requirements and limitations applicable to a particular radio service.

(c) Subpart G describes the procedures and requirements for filing applications and licensing radio stations under this part.

(d) Subpart H provides requirements for selection of frequencies.

(e) Subpart I contains general technical standards for use of equipment under this part.

(f) Subpart J contains standards for certain specialized uses.

(g) Subpart K contains standards for the use of certain frequencies or frequency bands.

(h) Subpart L contains special regulations for operation in the 470-512 MHz band.

(i) Subpart M contains special regulations for operations in the 806-821 and 851-866 MHz bands.

(j) Subpart N sets forth system operating requirements.

(k) Subpart O contains special regulations for operation in the Chicago Land Mobile Spectrum Management District.

(l) Subpart P contains regulations for the authorization of developmental operations.

(m) Subpart Q contains regulations for emergency operations in the Industrial Radio Services (ICEP), and in the Land Transportation Radio Services (LATICEP).

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Subpart B - Public Safety Radio Services

§ 90.15 Scope.

The Public Safety Radio Services include the Local Government, Police, Fire, Highway Maintenance and Forestry-Conservation Radio Services. Rules as to eligibility for licensing, frequencies available, and any special requirements as to each of these radio services are set forth in the following sections.

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§ 90.23 Highway Maintenance Radio Service.

(a) Eligibility. Any territory, possession, State, county, city, town, and similar governmental entity is eligible to hold authorizations in the Highway Maintenance Radio Service to operate stations for transmission of communications essential to official highway activities of the licensee.

(b) Frequencies available. The following table indicates frequencies available for assignment to stations in the Highway Maintenance Radio Service, together with the class of station(s) to which they are normally assigned and the specific assignment limitations which are explained in paragraph (c) of this section:

Highway Maintenance Radio Service Frequency Table

Frequency or band	Class of station(s)	Limitations
Megahertz:		
33.02	Base or mobile	1
33.06	....do	1
33.10	....do	1
37.90	....do	1
37.92	....do	....
37.94	....do	1
37.96	....do	....
37.98	Base or mobile	1
45.68	....do	....
45.72	....do	....
45.76	....do	....
45.80	....do	....
45.84	....do	....
47.02	....do	2
47.04	....do	2
47.06	....do	2
47.08	....do	2
47.10	....do	2
47.12	....do	2
47.14	....do	2
47.16	....do	2
47.18	....do	2
47.20	....do	2
47.22	....do	2
47.24	....do	2
47.26	....do	2
47.28	....do	2
47.30	....do	2
47.32	....do	2
47.34	....do	2
47.36	....do	2
47.38	....do	2
47.40	....do	2
72.00 to 76.00	Operational fixed	3
150.995	Base or mobile	4
151.010	....do	4
151.025	....do	4
151.040	....do	4
151.055	....do	4
151.070	....do	4
151.085	....do	4
151.100	....do	4
151.115	....do	4
151.130	....do	4
156.045	Mobile	14
156.060	....do	14
156.075	....do	....
156.105	Base or mobile	....
156.120	....do	....
156.135	....do	....
156.165	....do	5,14
156.180	....do	14
156.195	....do	5
156.225	....do	5
156.240	....do	5
157.050	....do	6
157.110	....do	6
158.985	....do	5
159.000	....do	5
159.015	....do	5
159.045	....do	5
159.060	....do	5
159.075	....do	5
159.105	Base or mobile	5
159.120	....do	5
159.135	....do	5
159.165	....do	5
159.180	....do	....
159.195	....do	....
450-470	Fixed	7
453.050	Base or mobile	8
453.100	....do	8
453.150	....do	8
453.200	....do	8
453.250	....do	8
453.300	Base or mobile	8
453.350	....do	8
453.400	....do	8
453.450	....do	8
453.500	....do	8
453.550	....do	8
453.600	....do	8
453.650	....do	8
453.700	....do	9
453.750	....do	8
453.800	....do	8
453.850	....do	8
453.900	....do	8
453.950	....do	8
458.050	Mobile	8
458.100	....do	8
458.150	....do	8
458.200	....do	8
458.250	....do	8
458.300	....do	8
458.350	....do	8
458.400	....do	8
458.450	....do	8
458.500	....do	8
458.550	....do	8
458.600	....do	8
458.650	....do	8
458.700	....do	8
458.750	....do	8
458.800	....do	8
458.850	....do	8
458.900	....do	8
458.950	....do	8
470-512	Base or mobile	9
806-821	Mobile	10
851-866	Base or mobile	10
952 and above	Operational fixed	11
1427-1435	Operational fixed, base or mobile	12
2450-2500	Base or mobile	13
10,550 to 10,680	....do	....

(c) Explanation of assignment limitations appearing in the frequency table of paragraph (b) of this section:

(1) This frequency is shared with tne Special Emergency Radio Service.

(2) This frequency will be assigned only in accordance with a geographical assignment plan and is reserved primarily for assignment to Highway Maintenance systems operated by states. The use of this frequency by other Highway maintenance licensees will be authorized only where such use is necessary to coordinate activities with the particular state to which the frequency is assigned. Any request for such use must be supported by a statement from the state concerned.

(3) The frequencies available for use at operational fixed stations in the band 72-76 MHz are listed in § 90.257(a)(1). These frequencies are shared wiht other services and are available only in accordance with the provisions of § 90.257.

(4) This frequency is not available for assignment to stations in the Highway Maintenance Radio Service located in Puerto Rico and the Virgin Islands.

(5) This frequency is reserved for assignment for use in highway maintenance systems operated by licenses other than States.

(6) This frequency is only assigned to Highway Maintenance stations licensed for its use prior to April 28, 1952. Such use may continue on a secondary basis to any government or non-government radio operation.

(7) The frequencies available for use at fixed stations in this band, and the requirements for assignment are set forth in § 90.261. Operation on these frequencies is secondary to stations in the Industrial and Land Transportation Radio Services where they are assigned for land mobile operations.

(8) This frequency is available in this service on a shared basis with all other Public-Safety Radio Services.

(9) Subpart L contains rules for assignment of frequencies in the 470-512 MHz band.

(10) Subpart M contains rules for assignment of frequencies in the 806-821 and 851-886 MHz bands.

(11) Assignment of frequencies for operational-fixed stations in the bands 952 and above is governed by Part 94 of this Chapter.

(12) This frequency band is available to stations in this service subject to the provisions of § 90.259.

(13) Available only on a shared basis with stations in other services, and subject to no protection from interference due to the operation of industrial, scientific, or medical (ISM) devices.

(14) This frequency may not be assigned with 100 miles of New Orleans (coordinates 29-56-53 N and 90-04-10 W).

(d) Additional frequencies available. In addition to the frequencies shown in the frequency table of this section, the following frequencies are available in this service. (See also § 90.253.)

(1) The frequencies 27.235, 27.245, 27.255, 27.265, and 27.275 MHz are available in accordance with § 90.255.

(2) The frequency bands 31.99 to 32.00 MHz, 33.00 to 33.01 MHz, 33.99 to 34.00 MHz, 37.93 to 38.00 MHz, 39.00 to 39.01 MHz, 39.99 to 40.00 MHz and 42.00 to 42.01 MHz are available for assignment for developmental operation subject to the provisions of Subpart P.

(3) Frequencies in the band 73.0-74.6 MHz may be assigned to stations authorized their use on or before December 1, 1981, but no new stations will be authorized in this band, nor will expansion of existing systems be permitted. (See also § 90.257.)

(e) Limitation on number of frequencies assignable. Normally only two frequencies or pairs of frequencies in the paired frequency mode of operation, will be assigned for mobile service operations by a single applicant in a given area. The assignment of an additional frequency or pair of frequencies will be made only upon a satisfactory showing of need, except that:

(1) Additional frequencies above 25 MHz may be assigned in connection with the operation of mobile repeaters in accordance with § 90.247, notwithstanding this limitation.

(2) Frequencies in the 25-50 MHz, 150-170 MHz and 450-512 MHZ bands, and the frequency bands 903-904 MHz, 904-912 MHz, 918-926 MHz and 926-927 MHz may be assigned for the operation of Automatic Vehicle Monitoring (AVM) systems in accordance with § 90.239, notwithstanding this limitation.

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Subpart H - Policies Governing the Assignment of Frequencies

§ 90.171 Scope.

This subpart contains detailed information concerning the policies under which the Commission assigns frequencies for the use of licenses under this part, frequency coordination procedures, and procedures under which licensees may cooperatively share radio facilities.

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§ 90.173 Policies governing the assignment of frequencies.

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(f) In the 150-170 MHz band, no application will be granted which proposes a base station located less than 16 km (10 mi.) from an existing base station on a frequency 15 kHz removed. In the Taxicab Radio Service, the minimum separation is 12 km (7 mi.).

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Subpart J - Non-Voice and Other Specialized Operations

§ 90.231 Scope.

This subpart sets forth requirements and standards for licensing and operation of non-voice and other specialized radio used (other than radiolocation). Such uses include secondary signaling, telemetry, radioteleprinter, radiofacsimile, automatic vehicle monitoring (AVM), radio call box, relay, vehicular repeater, and control station operations.

§ 90.233 Secondary base/mobile nonvoice signaling operations.

On a secondary basis to voice operations, the use of A2, A9, F2, F9 (audiofrequency toneshift or tone phase shift) or F9Y emission may be authorized to base/mobile operations in accordance with the following limitations and requirements:

(a) Authorizations are limited to mobile service frequencies below 950 MHz.

(b) Maximum duration of a transmission for each distinct non-voice message, including automatic repeats of the message, may not exceed 2 seconds. There must be a break in the carrier between each such transmission.

(c) Required station identification for non-voice operations must be made by F3 or A3 emission and may be given by the base station for a base/mobile system.

(d) Secondary non-voice operations under this section may not be authorized for tone paging, telemetry, radiolocation, AVM, radioteleprinter, radiofacsimile, or radio call box operations. These operations are authorized under other sections of this part.

§ 90.235 Secondary fixed tone signaling and alarm operations.

In the Local Government, Police, Fire, Highway Maintenance, Forestry Conservation, Power, and Petroleum Radio Radio Services, fixed operations may be authorized for tone or impulse signaling on mobile service frequencies above 25 MHz within the area normally covered by the licensee's mobile system on a secondary basis to the primary mobile service operation of any other licensee for the purposes described in paragraphs (a) and (b):

(a) In the Public Safety Radio Services, the only purposes for which such secondary signaling may be used are:

(1) Indication of equipment malfunction.

(2) Actuation of a device to indicate the presence of an intruder, fire, or other hazardous condition on the property under the protection of the licensee.

(3) Indication of an abnormal condition in facilities under the jurisdiction of the licensee that, if not promptly reported, would result in danger to human life.

(4) Transmissions that may be necessary to verify status of equipment; adjust operating conditions; correct any abnormal condition; or to activate devices that alert the public to a condition affecting the imminent safety of life or property.

(5) Confirmation of status, when an operation or correction has been accomplished, or when an alerting device has been activated.

(b) In the Power and Petroleum Radio Services, the only purposes for which such secondary signaling may be used are:

(1) Indication of failure of equipment or service used in the facilities of the licensee.

(2) Indication of an abnormal condition in the production, transmission, collection, distribution, refining, or transporting facilities of the licensee, which if not promptly corrected would result in failure of the equipment affected.

(3) Transmission from the point where alarms or other operational data are received as may be necessary to verify status of equipment or processes; verify or adjust operating conditions; restore lost service; place standby equipment in operation; or to correct any abnormal conditions which would otherwise result in the immediate or continued failure in the licensee's operations.

(4) Confirmation of status or operating conditions, or that an operation or correction intended to be accomplished in subparagraph (3) of this paragraph has occurred.

(c) All such secondary signaling shall be subject to the following technical requirements:

(1) The bandwidth shall not exceed that authorized to the licensee for the primary operations on the frequency concerned.

(2) The output power shall not exceed 30 watts (at the remote site).

(3) A1, A2, A9, F1, F2, and F9 emission may be authorized. In the Police Radio Service A3 or F3 emission may also be authorized.

(4) For systems authorized in the Public Safety Services after June 20, 1975, to be used for the purposes outlined in paragraph (a) of this section, the maximum duration of any one nonvoice signal may not exceed 2 seconds and shall not be transmitted more than three times. The maximum duration of any one voice alarm shall not exceed 6 seconds and shall not be transmitted more than three times. For systems authorized prior to this date, any one alarm or warning may be transmitted a maximum of five times and each transmission shall not exceed 6 seconds; such system to include existing facilities and additional facilities which may be authorized as a clear and direct expansion of the existing system.

(5) For systems authorized in the Petroleum Radio Service after June 1, 1976, each transmission for any one alarm, warning corrective action, or requirement, positive confirmation, checkback, or other purpose set forth in paragraph (b) of this section, shall be limited to a maximum duration of 2 seconds and shall not be repeated more than three times. For systems authorized prior to June 1, 1976, any one alarm or warning may be transmitted a maximum of five times and each transmission may not exceed 6 seconds; such systems to include existing facilities and additional facilities which may be authorized as a clear and direct expansion of the existing system.

(6) For systems authorized in the Power Radio Service after June 1, 1976, each transmission for any one alarm, warning corrective action, or requirement, positive confirmation, checkback, or other purpose set forth in paragraph (b) of this section, shall be limited to a maximum duration of 2 seconds and shall not be repeated more than five times. For systems authorized prior to June 1, 1976, any one alarm or warning may be transmitted a maximum of five times and each transmission may not exceed 6 seconds; such systems to include existing facilities and additional facilities which may be authorized as a clear and direct expansion of the existing system.

(7) Systems employing automatic interrgation shall be limited to nonvoice techniques and shall not be activated for this purpose more than 10 seconds out of any 60-second period. This 10 second timeframe includes both transmit and response times.

(8) Frequency loading resulting from the use of secondary signaling will bot be considered in whole or in part as a justification for authorizing additional frequencies in the licensee's mobile system.

(9) A mobile service frequency may not be used exclusively for secondary signaling.

(10) Automatic means shall be provided to deactivate the transmitter in the event the carrier remains on for a period in excess of 3 minutes.

(11) Operational fixed stations authorized pursuant to the provisions of this paragraph are exempt from the requirements of §§ 90.137(b), 90.425 and 90.429.

(12) Base, mobile relay, or mobile stations may transmit secondary tone or impulse signals to receives at fixed locations subject to the conditions, and for the purposes set forth in this section.

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§ 90.469 Unattended operation.

(a) Subject to the provisions of §§ 90.243, 90.245, and 90.247, mobile relay, fixed relay, and mobile repeater stations are authorized for unattended operation; and the transmitter control point requirements set out at §§ 90.463 through 90.465 shall not apply.

(b) Self-activated transmitters may be authorized for unattended operation where they are activated by either electrical or mechanical devices, provided the licensee adopts reasonable means to guard against malfunctions and harmful interference to other users.

Appendix C. INPUT/OUTPUT DESCRIPTION RAMP CONTROLLER

DESCRIPTION OF EXTERNAL INPUTS

TITLE	REFERENCE	FUNCTION PERFORMED
LEVEL IN 0 LEVEL IN 1 LEVEL IN 2	P1-34 P1-35 P1-36	Binary encoded inputs from remote computer to force segmenter level
CLOCK IN	P1-33	Input signal from 24 hour time clock that is used in conjunction with mode selector to determine controller operation
QUEUE IN DEMAND IN MERGE IN FREEWAY IN	P1-23 P1-25 P1-27 P1-29	Inputs from vehicle presence detectors
ON LINE CONTROL	P1-30	Control input from remote computer
MANUAL PB	P1-48	Input from manual push button for signal advance
AUTO/MANUAL	P1-49	Control input to select manual mode operation when true
BY-PASS DEMAND IN SPARE IN 1 SPARE IN 2 SPARE IN 3 SPARE IN 4	P1-32 P1-19 P1-31 P1-46 P1-47	Reserved for future expansion

NOTES:

1. All inputs use ground true logic for state condition.
2. Binary encoding for segment levels are as follows:

SEGMENT	LINE 2	LINE 1	LINE 0	
A	0	0	0	
B	0	0	1	
C	0	1	0	0=FALSE
D	0	1	1	1=TRUE
E	1	X	X	X=DONT CARE

DESCRIPTION OF EXTERNAL OUTPUTS

TITLE	REFERENCE	FUNCTION PERFORMED
PERCENT 0 PERCENT 1 PERCENT 2 PERCENT 3 PERCENT 4 PERCENT 5 PERCENT 6	P1- 8 P1- 9 P1-10 P1-11 P1-12 P1-13 P1-14	Binary encoded output of freeway occupancy percentage (0 to 100%)
LEVEL OUT 0 LEVEL OUT 1 LEVEL OUT 2	P1-15 P1-16 P1-17	Binary encoded output of segment level to remote computer
QUEUE OUT DEMAND OUT MERGE OUT FREEWAY OUT	P1-22 P1-24 P1-26 P1-28	Output of vehicle presence detectors to remote computer
GREEN CONFIRM	P1-40	Green signal confirm output to remote computer
VOLUME 0 VOLUME 1 VOLUME 2 VOLUME 3 VOLUME 4 VOLUME 5 VOLUME 6	P1-20 P1-21 P1-54 P1-37 P1-42 P1-44 P1-38	Binary encoded output of freeway volume to remote computer
FLASH SIG 0 FLASH SIG 1	P1-45 P1-50	Output signal drivers for the advance warning flashers
GREEN SIG AMBER SIG RED SIG	P1-51 P1-52 P1-53	Output drivers for the ramp metering control signal lights
BY PASS DEMAND OUT BY PASS GREEN BY PASS AMBER BY PASS RED SPARE OUT 1	P1-18 P1-39 P1-41 P1-43 P1-55	Reserved for future expansion

APPENDIX D. LOG OF RF TEST - TIME PERIODS

TUESDAY AM Approx. 7:00 AM - 8:50 AM. Clear - Cool - Approx. 43°F. All stations performed normally. Checked District 2 printer by Telephone at 8:00 AM - operational.

TUESDAY AM NOON 11-1. Clear - Warm. All stations O.K. Checked printer O.K.

TUESDAY PM Started 3:15. Accident IB caused queuing on OB lanes. Upstream ramps came on because of clock and occupancy reading. Had to stop approx. 3:30 - 3:45. Restarted approx. 6:00 PM. Clear - 63°F. Observed at transmitter site downstream queuing was not evident at 30% occupancy (1 min average) outside lane flowing 1850-1900. All overloading at University and upstream of this point due to 3 lanes to two (2) lanes drop. University has rather large, long acceleration lane. Completely dark at 7:00 PM. Slave 2 (Forest Park) bits 1 and 3 sometimes do not get changed to new state until the 2nd transmission. Do not know what is causing problem. This type of problem has been reported at all 3 stations. (Investigate this phenomenon with Larry Burgess (SECODE)). Hope printer has plenty of tape.

WEDNESDAY AM Started 6:15 AM. Dark - Cloudy - 53°F. Summit and Forest Park controllers consistently are changing on 2nd transmission - do not know why this is happening. No outright failures have been evident. All independent outdoor advertising signs are off. Approx. 7:45 - Had to stop transmitting for 3 to 4 minutes while printer tape supply was replaced. Approx. 8:25 - Study Ended.

WEDNESDAY NOON Started 11:00 AM. Cloudy - 65°F - Slight wind. All stations appear O.K. Noticed distinctive bit changing at Summit where all bits change on 2nd transmission. Not always predictable. Remainder of study went without incident.

WEDNESDAY PM Start approx. 3:05 PM. Cloudy - Slight wind. Sent 4 sets. Stopped approx. 4:15. Back on at 5:40 PM. Sundown 6:15. All signs on by 6:30. No problems of skipping occurred.

THURSDAY AM Started approx. 6:35 AM. 50°F - Fog. Problem of 2nd tone @ Summit and Forest Park. Voice radio communications bad between same and Montgromery (transmitter site). Lights on Summit 6:53. 7:00 Forest Park - Lots of interference with Walkie-Talkies throughout the period. Many 2nd tones. Problem at University with 2 bits forced on after data sets 5, 1, 2, and parts of 3, 6, 7 have only 2 bit changes. Good.

THURSDAY NOON Started approx. 11:20 AM. Hot - Sunny - 71°F - Clear. Same 2nd tones at University, Forest Park and Summit. It seemed to improve with time. At 1:23 the study ended. It was discovered that the volume of the RF Received could control tone decoding.