SUMMARY DATA REPORT - 5

PROPAGATION OF EM SIGNALS IN UNDERGROUND METAL/NON-METAL MINES

MAGMA COPPER COMPANY- SAN MANUEL MINE

PREPARED FOR: U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
4800 FORBES AVENUE
PITTSBURGH, PENNSYLVANIA 15213

UNDER: CONTRACT J0308012

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1.0 INTRODUCTION

This report presents test results, data evaluations, and typical system performance expectations based on wireless electromagnetic propagation measurements performed in the MAGMA Copper Company's San Manuel mine near Tuscon, Arizona during March 30 through April 2 1981.

In particular, and at the Bureau's request, this work was coordinated with testing of MF prototype vehicular radios being developed by A.R.F. Products, Inc. with USBM support under Contract H0308004 as part of a system to be marketed by Mine Safety Appliance Co. This testing also employed a prototype vehicular antenna developed by Terry S. Cory, P.E. with USBM upport under previous Contract P0382223.

The work was performed under USBM contract J0308012, Propagation of EM Signals in Underground Metal/Non-metal Mines.

The authors wish to thank Mr. Hank Seany, Manager of Mines and Mr. Bob Zerga, Mine Superintendent who so kindly arranged for the visit. Particular thanks are given to Mr. Al Metcalf who arranged the logistical details of our underground work, and whos forward thinking program toward improving general mine communications at MAGMA provided the test-bed context for evaluation of the prototype equipment. The authors also wish to thank Benny Jiminez, Paul Ayala, Lorenzo De La Cruz, and Kent Billhartz for their day-by-day support of the testing. Mr. Jiminez's effort was instrumental in performing the testing, and he also provided a detailed understanding of the existing multi-level, multi-frequency trolleyphone system at MAGMA.

the authors are also indebted to Dr. Larry Stolarczyk of A.R.F. for numerous detailed consultations on MF technology, and who was present and participated in the majority of the testing.

1.1 GENERAL BACKGROUND ON COPPER MINING AT MAGMA

the San Manuel mine is the largest copper mine in the U.S., efficiently extracting copper and molybdenum sulfide from the low-grade San Manuel ore body.This ellipsoidal ore-shell body, with major workings located 2000-3000 feet mbelow the surface, has ore shell thickness varying between 100 and 1000 feet over a longitudinal extent of some 8000 feet, and with major & minor crossectional axes of about 5000 and 2500 feet respectively. The San Manuel mine operation employs in excess of 1000 men/shift with gross ore production between 60,000 and 70,000 tons/day. The mining operation employs the block caving technique; actively being implemented on three levels (2075,2375,2675 feet for haulage, and 2015,2315,2615 product/grizzly levels). The ore haulage is largely via D.C. trolley trains to four (3A,3B,3C,3D) product shafts for skipping to the surface. An additional three shafts at two locations are used to convey men, materials, and developmental rock extractions into and out of the mine. On each haulage level, the trains carry ore an average of two miles one-way from the ore raises to the dump points.

1.2 TOPOLOGICAL BRIEF OF THE HAULAGE LEVELS

The 2375 level, on which all the testing was conducted, is illustrated in

Figure 1 together with all locations on the measurement traverse. The drift crossection in the long haulage runs is essentially that of the timber ladder drift, illustrated in Figure 2; with some usage of the concrete drift (also shown in this figure). All haulage drift segments contain the D.C. trolley wire located just off the back(roof) center with the ground return wire bus also running with the "hot" trolley wire and separated about 10 inches from it. The ground wire branches to the track at periodic intervals of several hundred feet. Track construction/condition is better than normal, with a well-laid bed of wooden ties in ballast. Partcicular attention is paid to track electrical bonding; which, on the long haulage runs, is very good (electrical bonding near the grizzly ore chutes load points is poorer). also in the typical haulage drift is the audio pager phone line (generally in one of the back/rib corners) and a 2400 VAC power cable. The usual air-line/water-line large pipe bundle is typically found. The ribs and back had no metallic mesh covering; in the timbered drifts, the timbers were on both the ribs and the back spaced longitudinally on about 5-foot centers.

1.3 IDENTIFICATION OF COMMUNICATIONS REQUIREMENTS

The existing communications eminate from a dispatch locationon each level, and consist of both pager phone and trolleyphone service. Pager phones are largly MSA Pager 11's & 111's, and COMPTROL Loudmouth units. The trolleyphones are MSA 1601 units. A separate trolleyphone frequency is used on each production level; 115 KHz on the upper level, 145 KHz on the middle level, nd 190 KHz on the new lower level. There is currently a substantial amount of crosscoupling between levels of these signals; and the typical MF spectrum contains a raster of harmonics and rectified/mixed crossproducts of these fundamentals and harmonics.

Audio and radio communications on the grizzly level are currently limited to locations near certain ore passes, and are dilute.

With this as a basis, several communication-related requirements exist. These include:

- -improving the conventional trolleyphonef mode of communications to provide improved performance near the extremities of each haulage level

- -wireless communications on the haulage level to serve battery-operated service vehicles and small locomotives such that "stingers" (with attendant vehicle stopping) would not be required in order to reach the dispatcher

- -wireless communications on the grizzly levels to serve battery-operated vehicles; also, an overlay of the existing trolleyphone frequencies on these levels to provide haulage coordination and to keep product level operations from becoming muck-bound

- -portable communications for maintenance/supervisory personnel tying into either the trolleyphone channel or into a separate "command/location" channel to facilitate efficient operation

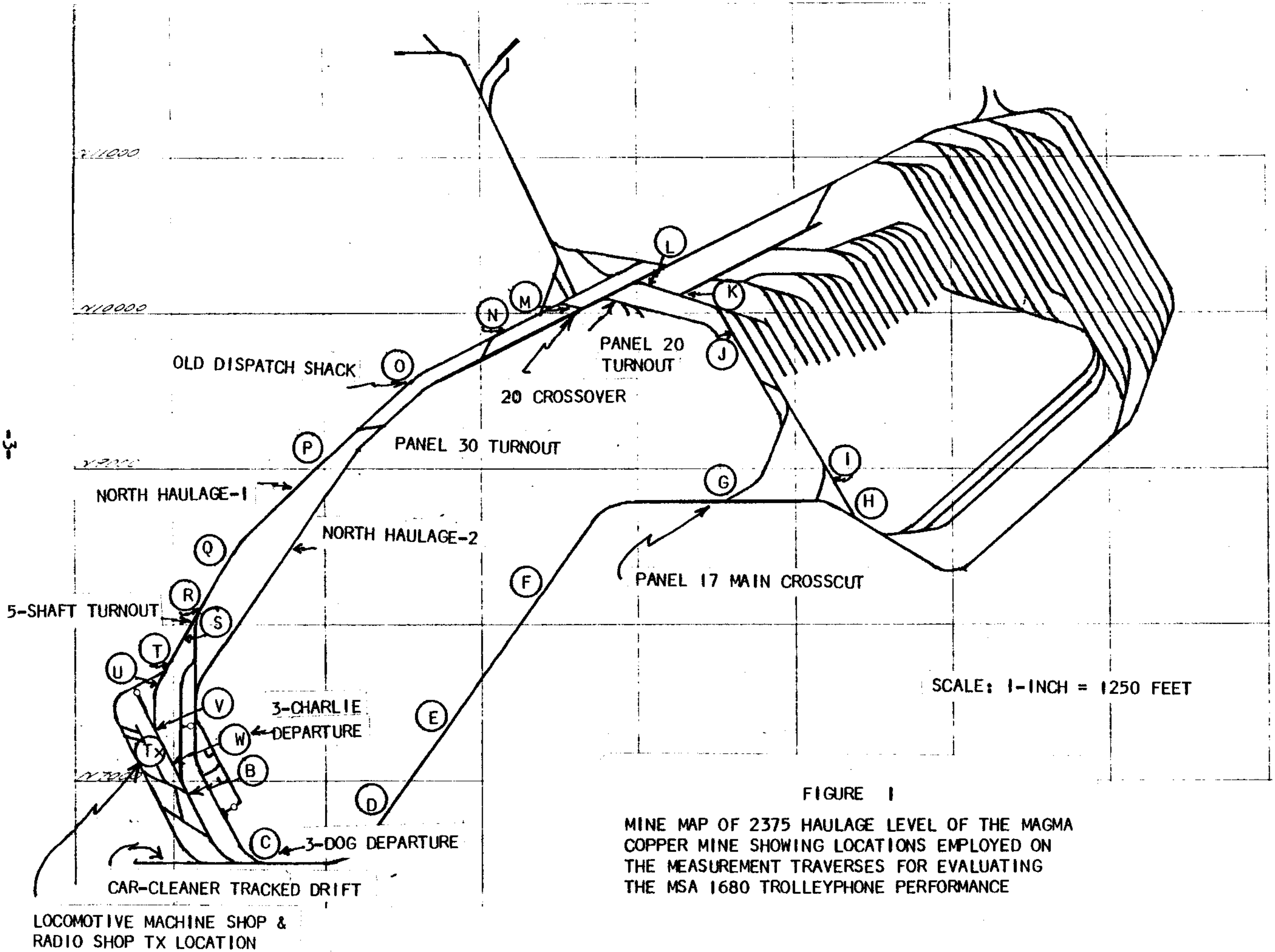
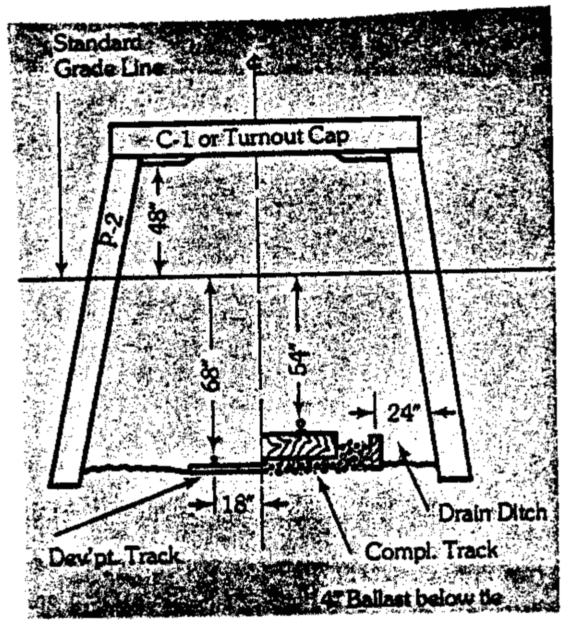


FIGURE 1

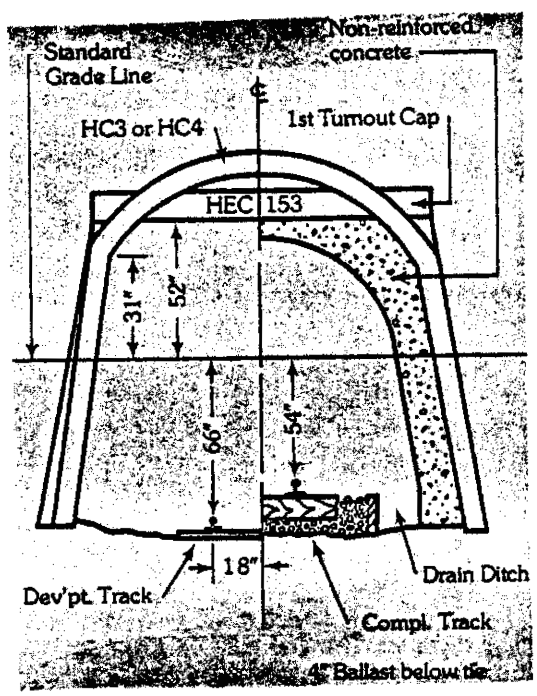
MINE MAP OF 2375 HAULAGE LEVEL OF THE MAGMA COPPER MINE SHOWING LOCATIONS EMPLOYED ON THE MEASUREMENT TRAVERSES FOR EVALUATING THE MSA 1680 TROLLEYPHONE PERFORMANCE

FIGURE 2

DRIFT CROSSECTIONAL GEOMETRIES ENCOUNTERED DURING SWEPT-FREQUENCY MEASUREMENTS IN CAR-CLEANER DRIFT



TRANSMIT LOCATION CROSSECTION FOR ALL FREQUENCY RANGES AND RECEIVE LOCATION CROSSECTION FOR VHF MEASUREMENTS



RECEIVE LOCATION CROSSECTION FOR ALL FREQUENCY RANGES EXCEPT VHF of these personnel, and to service special or emergency situations.

These requirements illustrate the merits of providing for wireless communications as a part of any large-scale trolleyphone system.

2.0 SUMMARY OF RESULTS

The work consisted both of swept-frequency signal propagation studies from 200 KHz - 1 mHz and of MF testing between a base station and a vehicle equipped with a radio at 145 KHz and 520 KHz on base-vehicle and vehicle-base linkages. These latter tests were structured to give quantitative data on a base-vehicle link @ 145 KHz and on a vehicle-base link @ 520 KHz.

All work was performed on the 2375 haulage level of the mine. The swept-frequency tests were conducted on the car-cleaner tracked drift having essentially no conductors other than the track itself. The CW tests were conducted along a 13,000-foot loop traverse beginning at and ending at the locomotive machine shop track, with the fixed test location in the radio shop adjacent to this track.

The test results fall into the following categories:

- -assessment of the viability of all MF-UHF frequencies for use in the mine on a scientific basis
- -results leading toward improved definition of proximity coupling to the track in the MF/HF range on a scientific basis
- -an assessment of the current status of the MAGMA trolleyphone system, leading toward specific suggestions for improvement
- -feasibility demonstration of the use of the new MSA/A.R.F.1680 trolleyphone in the wireless coupling mode, leading toward definition of communication possibilities achievable through the use of the new units

2.1 OVERVIEW OF RESULTS

The drift dimensions at MAGMA are sufficiently small that a fully developed waveguide mode is not achievable until the frequency is 600 MHz or higher. Moreover, te HF/VHF "null-zone" in this mine is wide and, for all practical purposes, extends from about 20 - 200 MHz. Over the VHF frequency range of 20 - 200 MHz, the useful operating range is of the order of 100 feet.

We now have sufficient data from all metal/non-metal mines to say that there is a definite optimum frequency range for close proximity coupling in tunnels. The effect is one of the normal monofilar wireless coupling excitation and excitation of the evanescent TE10 waveguide mode cancelling in so far as the magnetic flux threading a potentail monofilar conductor is concerned. This is a broad-range cancellation effect and is not just the cancellation of two small amplitude signals. The full nulling effect is expected near the waveguide cut-off frequency. The monofilar coupling mode alone is only predominant up to a frequency of about 1 MHz.

Based on the MF/HF car-cleaner track swept-frequency data, the 1/radius squared efect of a single monofilar conductor with its return path image in the rock has been validated where the coupling is roughly proportional to the distance of the conductor (or conductor ensemble) from the interface. This model also accounts for the situation where a large diameter conductor, such as a water pipe or an air line, is poor for monofilar excitation; whereas, a thin conductor encourages this excitation. For a monofilar conductor with a nearby conductor as a return path, this is not true; and for a trolley/track excitation mode, he fall-off law is nearly 1/r.

Several problems were encountered with the performance of the existing MAGMA trolleyphone system. These include:

- the harmonic and crossproduct spectra from the multiple trolleyphone signals contribute significantly to MF noise/ interference

- there is too much coupling of trolleyphone signals between levels; in some locations, the signal from an adjacent level is stronger than that for the level being observed

- there is a substantial attenuation of the base station signal power (hence,monofilar carrier current) over that expected in a typical system; this does not necessarily penalize a vehicle-base linkage path, but it definitely penalizes the base-vehicle linkage; this attenuation is of the order of 30 - 40 dB

Solution of these problems could improve the performance of the existing system configuration significantly, and could minimize the requirement for multiple J-box connections from a separate trolleyphone drive line (such as is used at MAGMA).

Testing of the MSA/A.R.F 1680 radio together with the T.S. Cory vehicular antenna prototype (furnished to USBM) demonstrated the viability of the wireless base-vehicle and vehicle-base linkages at 145 and 520 KHz out to a range in excess of 6,000 feet from the fixed transmit location. The 520 KHz tests showed that the propensity of the J-boxes to "short" the trolleyphone drive line to the track did not significantly reduce the expected performance at this frequency. The vehicle-base linkage performed better than the base-vehicle linkage, as the vehicle used a 90 uV version of the 1680 receiver that day. Using the 1 uV version, the performance would be expected to be the bilateral.

Overall, the 520 KHz performance was better than that at 145 KHz. While this would be expected vehicle-base, the 145 base-vehicle performance should have been better.

Sufficient data was gathered to determine the signal attenuation rates with distance at both 145 and 520 KHz. At 145 KHz, the rate was 4 dB/1,000 feet in the north mine(north haulage leg of the loop). At 520 KHz, the attenuation rate was 5 dB/1,000 feet in the south mine and 7 dB/1,000 feet in the north mine. At 520 KHz, the monofilar surge impedance or the trolley was determined to be 340 ohms in the south mine compared with 70 ohms in the north mine. This impedance relates to the ability of the line to carry MF current (a lower impoedance being better); and,hence, more available signal.

2.2 RECOMMENDATIONS FOR IMPROVING EXISTING MAGMA TROLLEYPHONE SYSTEM

these recommendations relate to those to upgrade the performance of the existing configuration besides the improved performance and new communications possibilities affordable through the use of the new 1680 radios.

Passband filters should be placed on each of the three base station transmitters on the three levels. This would greatly reduce the noise/interferance present, thus permitting more sensitive reception and greaer communications rage. Ideally, all units in a coupled multiple-frequency system should have such filters; but, treating the base station plus reducing the inter-level coupling should improve the performance.

The inter-level coupling should be reduced. This involves "sniffing out" the hard-wired coupling routes between levels which are generating the problem, and then placing tuned traps on the "culprit" conductors to minimize this coupling.

There is a 30 - 40 dB loss in current between that expected to flow in the trolley line and that flowing into a low impedance load on the RF coax in the locomotive shop radio shack. This loss is 37.5 dB at 520 KHz and is expected to be roughly the same at 145 KHz. The maximum base station current from the directly-driven coax that flows in the trolley wire for 20-watt output capability is only 3 - milliamperes @ 145 KHz. This is way too low. This problem is indicative of a chronic problem in many trolleyphone systems. in these systems, the base station is constant-voltage coupled between the trolley wire (or DC bus) and the rail. For a high-impednace system, this inputs very little power (hence current) to the line. While a trolleyphone system can work on a purely voltage detection basis, the operating range is influenced by the increased noise susceptability, the effects of other vehicles (varying loadsd), and the requirement for a high-voltage non-sensitive receiver front end. The MAGMA system works this way too, even though the base station feeds a coax. By the time the coax/phone wire reaches the main J-box, both conductors are at the same potential, and the return path is already via the track/DC ground bus.

This classic way of operating is an extension of a low-frequency (DC) concept; and, in general, provides way less than optimum performance from the system.

The trolleyphone operation cab be improved by current-feeding (constant current transformation) the trolley line as a monofilar conductor. This will permit the natural impednace of the trolley system to boost the RF voltage at locations (if any) where this impedance becomes high. It will also guarentee near-optimum operation in the base-vehicle or base-portable wireless communication modes, if these are implemented, as the magnetic field strength present in the haulage drift is proportional to the level of monofilar current flowing.

2.3 *COMMUNICATIONS SYSTEM POSSIBILITIES*

In addition to permitting integrated wireless/direct-coupled trolleyphone operation on each haulage level, the inclusion of wireless radios with sensitive receivers will permit the coupling of RF carrier current to any conductors already passing between haulage and grizzly levels. This will permit the extension of communications to the grizzlt levels. Frequencies in the 500 - 1000 KHz range will be best for this, and operation may be netted directly with a lower frequency trolleyphone linkage using a repeater as a frequency translation device. A limited amount of dedicated wiring may be requred to extend operation over an area on the grizzly level.

To affect quality wireless operation at the far ore-loading extemities of each haulage level, one or more repeaters may be necessary. This is because of the extensive signal division due to the large number of parallel tracked drifts in these loading areas. This necessity should be assessed following the recommended conversion of the base station coupling to a constant-current basis.

In conjunction with the possible inclusion of wireless portable operation at MAGMA, base-portable one-way paging should be implemented on a tone basis, if necessary, to obtain the maximum range extension away from drifts with carrier current carrying conductors. In this mode, the paged party can proceed to to a location in close proximity to these conductors to enable a quality portable-base path. The use of repeaters in this type mine is envisioned to improve the coupling into conductors, or for use in a line amplifier mode to extend the range along conductors rather than as a stand-alone wireless-wireless operating means for area coverage.

3.0 EXPERIMENTAL APPROACH

The in-mine testing was all performed on the 2375 haulage level. A chronological summary of the testing is as follows:

Tuesday, March 31-

Swept-frequency tests over the MF,HF,VHF, AND UHF bands were performed on the car-cleaner track. This drift contained essentially no conductors, save for the track. The transmit location was set up in a timbered section of the drift. The receive location was set up 243 feet away in a concrete drift section. MF and HF data were taken for all three principal polarizations of the loop antennas. The HMD orientations were set up in the drift center with the antenna 1.1 meters above the track. The transmit VMD orientation loop plane was positioned 1 foot(0.3 meters) above the rails. This geometry is illustrated in Figure 4. The receive VMD was alternatively positioned 1 foot, 4 feet, and 8 feet above the rails.

The normal deployment of the VHF and UHF antennas in both vertical and horizontal polarizations was made in the drift center. No signal was received at VHF, so the receive location was moved closer to the transmitter into a timbered drift section 111 feet from the transmitter.

Also, on Tuesday, a 1680 radio was installed on a trolley-operated locomotive for long-term qualitative testing by mine personnel in comparison with the 1601. This radio employed a 145 khz passband filter to minimize receiver desensitization.

Wednesday, April 1-

A 1680 base station radio was set up in the locomotive machine shop radio shack; another 1680 radio with a 1 uV front end and a 145 khz passband filter was set up on a battery powed locomotive together with the prototype vehicular antenna. The spectrum analyzer was set up in a man car pulled by thelocomotive to permit quantitative signal and noise measurements on the base-vehicle linkage. A retuned Collins portable antenna was used with the spectrum analyzer. Talking tests were conducted around the loop traverse via anel 17, as illustrated on the mine map of Figure 1. Quantitative tests were performed at the test locations given in Table 6.

Thursday, April 2-

The Collins 0.2 uV-front-end base transceiver and MSA 1680 vehicular radio were set up at 520 KHz similarly as for the Wednesday tests, except that the vehicular radio had a 90 uV front end and was used without a passband filter. The vehicular antenna tuning was changed with an interchangable 520 Khz head replacing the 145 KHz head used on Wednesday. This time, the spectrum analyzer was set up in the radio shack to permit quantitative testing on the vehice-base linkage. The spectrum analyzer was coupled to one of the coaxial leads feeding the Collins base station transceiver with a Stoddard current probe. The fixed location of the spectrum analyzer permitted a more fine-grained assessment of signal levels than did its usage on the man car of the previous day. Talking tests were again performed around the panel 17 loop traverse, and quantitative tests were performed at the test locations given in Table 7.

In the afternoon, a debriefing on all tests was conducted with mine personnel; and comments were solicited regarding the mechanical embodiment of the vehicular antenna.

Due to the small drift crossectional size and the relative rib/back "roughness" created by the timbers, X-band microwave usage was deemed not to be appropriate for this type mine, and the CW tests were not performed.

4.0 DATA REDUCTION AND ANALYSIS FACTORS

The swept-frequency MF and HF data were reduced employing correction factors for the measurement system only, to facilitate the augmented data presentation for these ranges. The VHF and UHF data were reduced employing correction factors normalizing the results to a 1-watt transmitter into practical man-pack type antennas. This latter characterization permits the results to be used directly in the assessment of practical system performance possibilities. These correction factors are given in Table 1 and are to be added directly in dB to the data in dBm from the oscillographs. Derivation of these correction factors will be left to the final report on this contract.

To permit quantitative assessment of the 2nd and 3rd days testing, CW correction factors were derived for the retuned Collins portable antenna at 145 KHz and for the Stoddard current probe at 520 KHz. These correction factors are also given in Table 1.

To facilitate range identification of locations along the measurement traverse, distances along this traverse to these locations measures both along north mine and south mine loop legs are given in Table 2.

TABLE I

FIELD STRENGTH DATA CORRECTION FACTORS

FREQUENCY(MHZ)		SWEPT FREQ(DB)	CW(DB)
0.20	NOTE: MF & HF SWEPT	69.5	
0.25	FACTORS ARE THOSE	69.7	
0.35	FOR TEST SYSTEM	69.4	
0.45	ONLY AND ARE NOT	68.5	
0.55	NORMALIZED FOR	67.0	
0.65	PRACTICAL SYSTEMS	65.1	
0.75		63.3	
0.85		60.7	
0.95		59.0	
CF FOR PORTABLE ANT @ 145 KHZ TO CURRENT IS			74.0
CF FOR CURRENT PROBE @ 520 KHZ TO CURRENT IS			61.4
2.0		62.0	
4.4		52.4	
7.9		51.6	
11.2		50.7	
14.4		50.0	
18.0		49.7	
20		104.7	
30		103.1	
40		107.2	
50		108.7	
60		103.1	
70		102.7	
80		102.6	
90		105.1	
100		111.5	
110		110.8	
120		114.2	
130		113.8	
140		110.8	
150		112.3	
160		111.7	
170		111.6	
180		115.1	
190		116.5	
200		116.5	
200		108.5	
300		117.1	
400		122.9	
500		123.3	
600		128.7	
700		130.5	
800		133.5	
900		135.6	
1000		132.8	

TABLE 2

DISTANCES TO LOCATIONS ALONG THE MEASUREMENT TRAVERSE ON THE 2375 HAULAGE LEVEL

LOCATION	LOOP DISTANCES STARTING ON SOUTH HAULAGE (FEET)	LOOP DISTANCES STARTING ON NORTH HAULAGE (FEET)
B	480	13,676
C	1,180	12,976
D	2,180	11,976
E	2,788	11,368
F	3,880	10,276
G	5,320	8,836
H	6,220	7,936
I	6,500	7,656
J	7,892	6,264
K1	8,124	6,032
K2	8,212	5,944
L	8,660	5,496
M	9,180	4,976
N	9,564	4,592
O	10,324	3,832
P	11,132	3,024
Q	12,124	2,032
R	12,364	1,792
S	12,524	1,632
T	12,692	1,464
U	12,892	1,264
V	13,244	912
W	13,516	640
B	13,676	480

5.0 DATA PRESENTATION & ANALYSIS

The MF and HF data reduction has permittedthe validation of the coupling model for a monofilar conductor having its return path being in the conducting surface immediatedly adjacent to the conductor. The model for this analysis is illustrated in Figure 3. To enable comparisons, the monofilar track current was computed from this model for the test geometry of the track. Each rail of the track was considered to be a separate additive monofilar conductor, so defined. The computed results are shown in Figure 4. There is little difference in the model (except for coupling range) between the VMD and coplanar HMD loop orientations. The measured HMD and VMD data were reduced and are given in Tables 3 and 4. This data was expressed in the form of monofilar mode current in the track, and is given in Figure 5. As can be seen from the figure, the agreement for all three VMD ranges converging on a common track current is very good.

in Figure 5, the computed results for the test system show a general increase in coupling with increase in frequency. This is what would be expected for monofilar mode excitation in a non-constrained(tunnel/drift) geometry. All metal/non-metal mines so far have exhibited the rapid fall-off of of current or field strength through the HF region(except for the case where the current is excited and retrieved probe-probe); a condition which is not physically realizable with simple monofilar mode coupling excitation alone. The cause for this effect has now been identified by the authors to be the interaction between the normalmonofilar mode excitation and that of the evanescent TE10 waveguide mode. This effect is illustrated in Figure 6. The TE10 mode uniformly distributes the horizontal H field vertically over the entry/drift crossection. The direction of this flux is so as to directly cancel the monofilar mode excitation. This is not a narrowband effect; but, is broad in spectrum. Essentially perfect cancellation will occur near the waveguide cutt-off frequency.

Thus, the MF range has been shown to provide optimum close proximity coupling to conductors in constrained tunnels; a fortuitous event to add to te list of conductor-free and remote coupling optima already associated with mf propagation in coal mines.

The reduced swept-frequency VHF data and UHF data are given respectively in Tables 5 & 6 and in Figures 7 & 8. This data shows VHF transmission to be essentially non-existent with a range of only 100 feet or so; and with a UHF fully developed waveguide mode being limited to frequencies above about 600 MHz for this type mine.

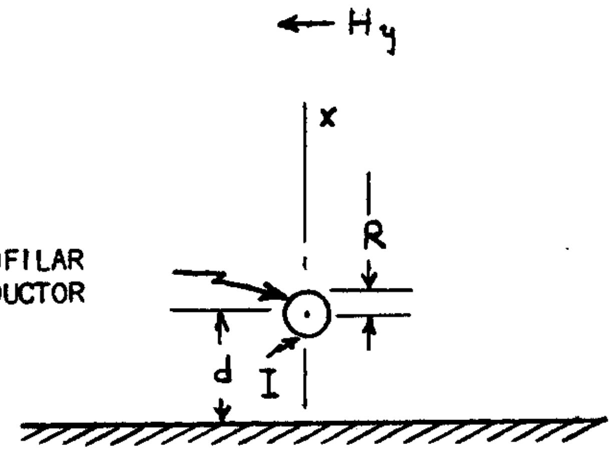
The reduced CW range test data using the 1680 prototype radio and the prototype vehicular antenna are given in Tables 7 & 8 respectively for 145 and 520 KHz. The range attenuation effects are most graphically displayed in Figure 9 on a linear range basis, normalized to monofilar mode current. A similar graph for 520 KHz only, plotted on semi-log paper, is given in Figure 10. This graph is also normalized with respect to monofilar mode current in the trolley wire. The left-hand ordinate gives the monofilar mode current actually experienced in the radio shack. The right-hand ordinate gives the expected actual trolley monofilar mode current. These levels, differing by 37.5 dB, were determined by comparing noise spectra at 520 KHz as received in the shack and as alternatively received in the man-car. The expected 520 KHz trolley current agrees with the measured 145 KHz current in the trolley wire, which verifies the conversion factor.

The trolley monofilar mode current levels are notably less than those expected for a directly driven trolly wire from a base station. It is significant to note that a 1-watt portable with a loop antenna in close proximity to the wire can excite as much current as the directly driven trolley with 20-watt capability. This is because the base station drives the trolley on a constant-voltage basis; a chronic generic problem with the configuration of most conventional trolleyphone systems.

From the data, it was possible to define the trolley monofilar line driving point and surge impedance levels. These are shown in Figure 11. Note that the north mine levels are significantly lower than those in the south mine. This is due to the two(north haulage-1 and north haulage-2) routes, and crossovers to the panel areas close to the transmitter which do not occur on the south route.

FIGURE 3

MONOFILAR TRACK COUPLING MODEL GEOMETRY



$$H_y = \frac{I}{2\pi}\left[\frac{\sqrt{d^2 - R^2}}{x^2\left[1 - (d^2 - R^2)/x^2\right]}\right]$$

FOR CAR-CLEANER TRACK DRIFT RECEPTION:

FOR VMD 1-FOOT = 0.3 M SPACING

H_y(DB) = I (DB) - 17.0

4-FOOT = 1.22 M SPACING

H_y(DB) = I (DB) - 32.5

8-FOOT = 2.44 M SPACING

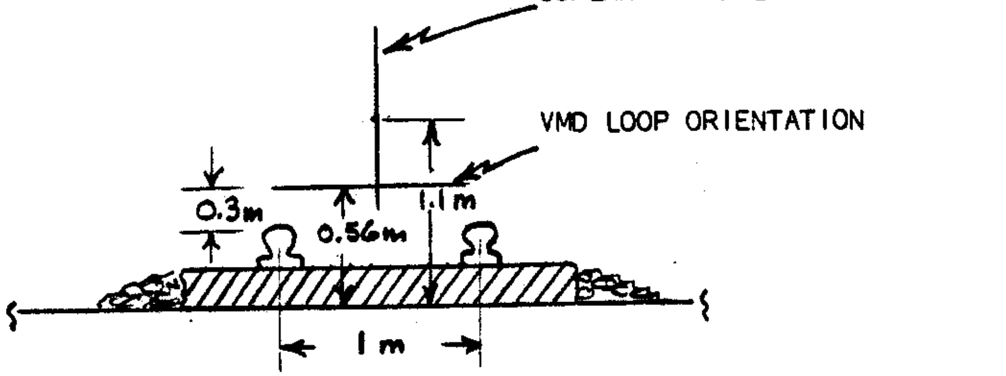
H_y(DB) = I (DB) - 43.8

FOR HMD 1.1 M SPACING

H_y(DB) = I (DB) - 29.2

FIGURE 4

COMPUTED MF/HF MONOFILAR MODE TRACK COUPLING CORRESPONDING TO CAR-CLEANER DRIFT MEASUREMENTS



FREQ(MHZ)	TEST SET INA $AMP \times M^2 \times TURNS$	TRACK CURRENT(2 COND.) DB ABOVE 1 uAMPERE
0.20	0.183	34.0
0.25	0.206	37.0
0.35	0.231	40.9
0.45	0.274	44.6
0.55	0.435	50.3
0.65	0.730	56.3
0.75	0.410	52.5
0.85	0.231	48.6
0.95	0.164	46.6
2.0	0.326	59.0
4.4	0.410	67.9
7.9	0.291	70.0
11.2	0.231	71.0
14.4	0.130	68.2
18.0	0.103	68.1

NOTES:

SURGE IMPEDANCE OF 100 OHMS / RAIL ASSUMED TO GROUND
IMAGE RETURN PATH IS IN GROUND(ROCK)
TRACK CURRENT IS TOTAL OF TWO LOOP VALUES

EQUIVALENT H FIELD IS 29.2 DB BELOW CURRENT FOR SHOWN EXCITAION LOCATIONS (WHICH ARE ROUGHLY EQUIVALENT FOR BOTH ORIENTATIONS)

TABLE 3

REDUCED MAGNETIC FIELD STRENGTH AND COUPLED CURRENT DATA TAKEN ON A SWEPT-FREQUENCY BASIS IN THE CAR-CLEANER TRACK DRIFT WHICH CONTAINED NO OTHER SIGNIFICANT CONDUCTORS @MF

		TX & RX ANTS COPLANAR HMD 1.1M ABOVE TRACK CENTER	
FREQUENCY (MHZ)	DBM	H(DB ABOVE 1uA/M)	I(DB ABOVE 1uA)
0.20	-62.0	+ 7.5	+42.7
0.25	-56.5	+13.2	+48.4
0.35	-52.5	+16.9	+52.1
0.45	-51.0	+17.5	+52.7
0.55	-50.5	+16.5	+51.7
0.65	-49.5	+15.6	+50.8
0.75	-50.5	+12.8	+48.0
0.85	-56.0	+ 4.7	+39.9
0.95	-58.0	+ 1.0	+36.2

	RX ANT VMD SPACED AS GIVEN ABOVE RAIL TOP								
	1-FT	4-FT	8-FT	1-FT		4-FT		8-FT	
FREQ (MHZ)	DBM	DBM	DBM	H(DB)	I(DB)	H(DB)	I(DB)	H(DB)	I(DB) ABOVE 1uA OR 1uA/M
0.20	-53.5	-	-	+16.0	+33.0	-	-	-	-
0.25	-48.0	-	-	+21.7	+38.7	-	-	-	-
0.35	-42.0	-56.0	-71.0	+27.7	+44.4	+13.4	+45.9	- 1.6	+42.2
0.45	-37.0	-51.0	-68.0	+31.5	+48.5	+17.5	+50.0	- 0.1	+43.7
0.55	-30.0	-43.5	-58.0	+37.0	+54.0	+23.5	+56.0	+ 9.0	+52.8
0.65	-27.0	-37.0	-52.5	+38.1	+55.1	+28.5	+61.0	+12.6	+56.4
0.75	-28.0	-39.5	-55.0	+35.3	+52.3	+24.2	+56.7	+ 8.3	+52.1
0.85	-36.0	-49.0	-62.0	+24.7	+41.7	+12.1	+44.6	- 1.3	+42.5
0.95	-43.0	-56.0	-69.0	+16.0	+33.0	+ 3.2	+37.5	-10.0	+33.8

TABLE 4

REDUCED MAGNETIC FIELD STRENGTH AND COUPLED CURRENT DATA TAKEN ON A SWEPT-FREQUENCY BASIS IN THE CAR-CLEANER TRACK DRIFT WHICH CONTAINED NO OTHER SIGNIFICANT CONDUCTORS @ HF

		TX & RX ANTS COPLANAR HMD 1.1M ABOVE TRACK CENTER	
FREQUENCY(MHZ)	DBM	H(DB ABOVE 1uA/M)	I(DB ABOVE 1uA)
2.0	-58.0	+ 4.0	+39.2
4.4	-42.0	+10.4	+45.6
7.9	-37.0	+14.6	+49.8
11.2	-56.0	- 5.3	+29.9
14.4	-60.0	-10.0	+25.2
18.0	-	-	-

	RX ANT VMD SPACED AS GIVEN ABOVE RAIL TOPS								
	1-FT	4-FT	8-FT	1-FT		4-FT		8-FT	
FREQ(MHZ)	DBM	DBM	DBM	H(DB)	I(DB)	H(DB)	I(DB)	H(DB)	I(DB)
2.0	-26.0	-42.0	-62.0	+36.0	+53.0	+20.0	+52.5	0.0	+43.8
4.4	-33.0	-46.5	-62.0	+19.4	+36.4	+ 5.9	+38.4	-9.6	+34.2
7.9	-50.0	-57.0	-	+ 1.6	+18.6	- 8.1	+27.1	-	-
11.2	-	-	-	-	-	-	-	-	-

H in DB ABOVE 1uA/M

I in DB ABOVE 1uA

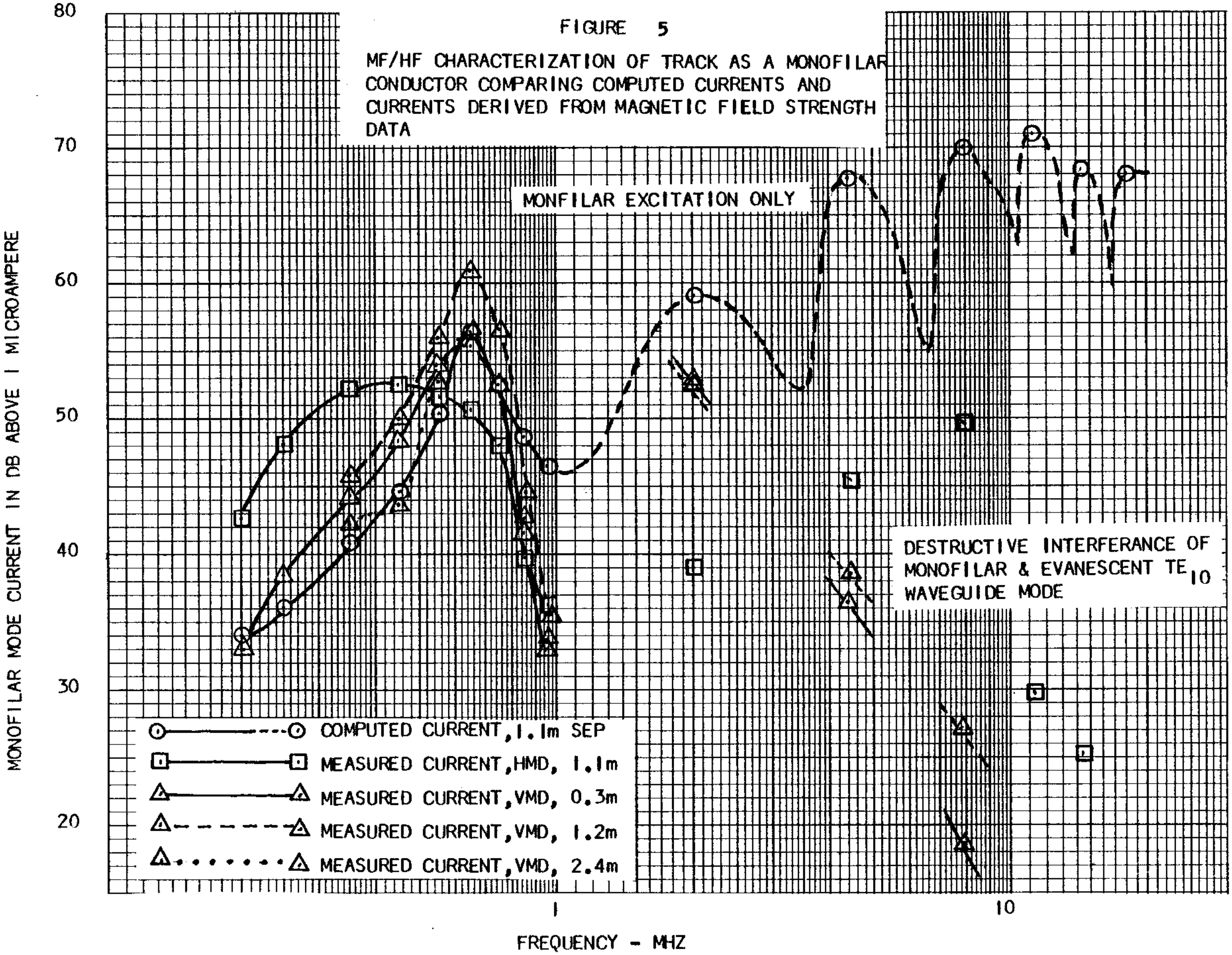


FIGURE 5

MF/HF CHARACTERIZATION OF TRACK AS A MONOFILAR CONDUCTOR COMPARING COMPUTED CURRENTS AND CURRENTS DERIVED FROM MAGNETIC FIELD STRENGTH DATA

FIGURE 6

GEOMETRY SHOWING THE DESTRUCTIVE CANCELLATION OF MAGNETIC FIELD COMPONENTS FROM A TRANSMITTING LOOP ANTENNA IN NORMAL MONOFILAR MODE EXCITATION AND TE_{10} WAVEGUIDE MODE EXCITATION

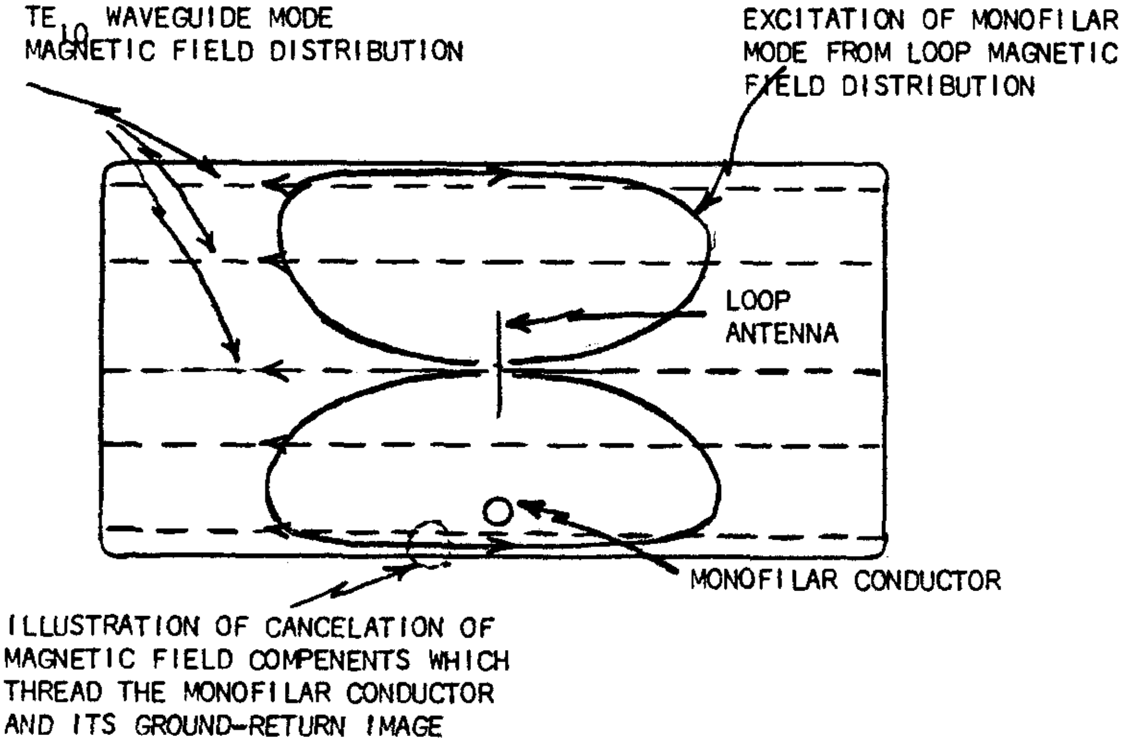


TABLE 5

REDUCED VHF ELECTRIC FIELD STRENGTH DATA TAKEN ON A SWEPT-FREQUENCY BASIS ON A 111 FOOT PATH IN THE CAR-CLEANER TRACKED DRIFT

FREQ(MHZ)	HORIZONTAL POLARIZATION DBM	HORIZONTAL POLARIZATION E(DB ABOVE 1uV/M)	VERTICAL POLARIZATION DBM	VERTICAL POLARIZATION E(DB ABOVE 1uV/M)
40	-	-	-	-
50	-	-	-	-
60	-	-	-52.0	+51.1
70	-	-	-	-
80	-	-	-52.0	+50.6
90	-	-	-52.0	+53.1
100	-56.0	+55.5	-50.0	+61.5
110	-54.0	+56.8	-53.0	+57.8
120	-	-	-54.0	+60.2
130	-60.0	+53.8	-	-
140	-51.0	+59.8	-54.0	+56.8
150	-53.0	+59.3	-58.0	+54.3
160	-56.0	+55.7	-58.0	+53.7
170	-54.0	+57.6	-50.0	+61.6
180	-56.0	+59.1	-52.0	+63.1
190	-58.0	+58.5	-53.5	+63.0
200	-60.0	+56.5	-48.0	+68.5

TABLE 6

REDUCED UHF ELECTRIC FIELD STRENGTH DATA TAKEN ON A SWEPT-FREQUENCY BASIS ON A 243 FOOT PATH IN THE CAR-CLEANER TRACKED DRIFT

	HORIZONTAL POLARIZATION		VERTICAL POLARIZATION	
FREQ(MHZ)	DBM	E(DB ABOVE 1uV/M)	DBM	E(DB ABOVE 1uV/M)
200	-	-	-	-
300	-50.0	+67.1	-	-
400	-36.0	+86.9	-60.0	+62.9
500	-33.0	+90.3	-46.0	+77.3
600	-31.0	+97.7	-40.0	+88.7
700	-31.0	+99.5	-42.0	+88.5
800	-35.0	+98.5	-42.0	+91.5
900	-36.5	+99.1	-44.0	+91.6
1000	-40.0	+92.8	-46.0	+86.8

FIGURE 7

SWEPT-FREQUENCY VHF REDUCED DATA TAKEN IN CAR-CLEANER TRACKED DRIFT AT A RANGE OF 111 FEET FROM THE TRANSMITTER

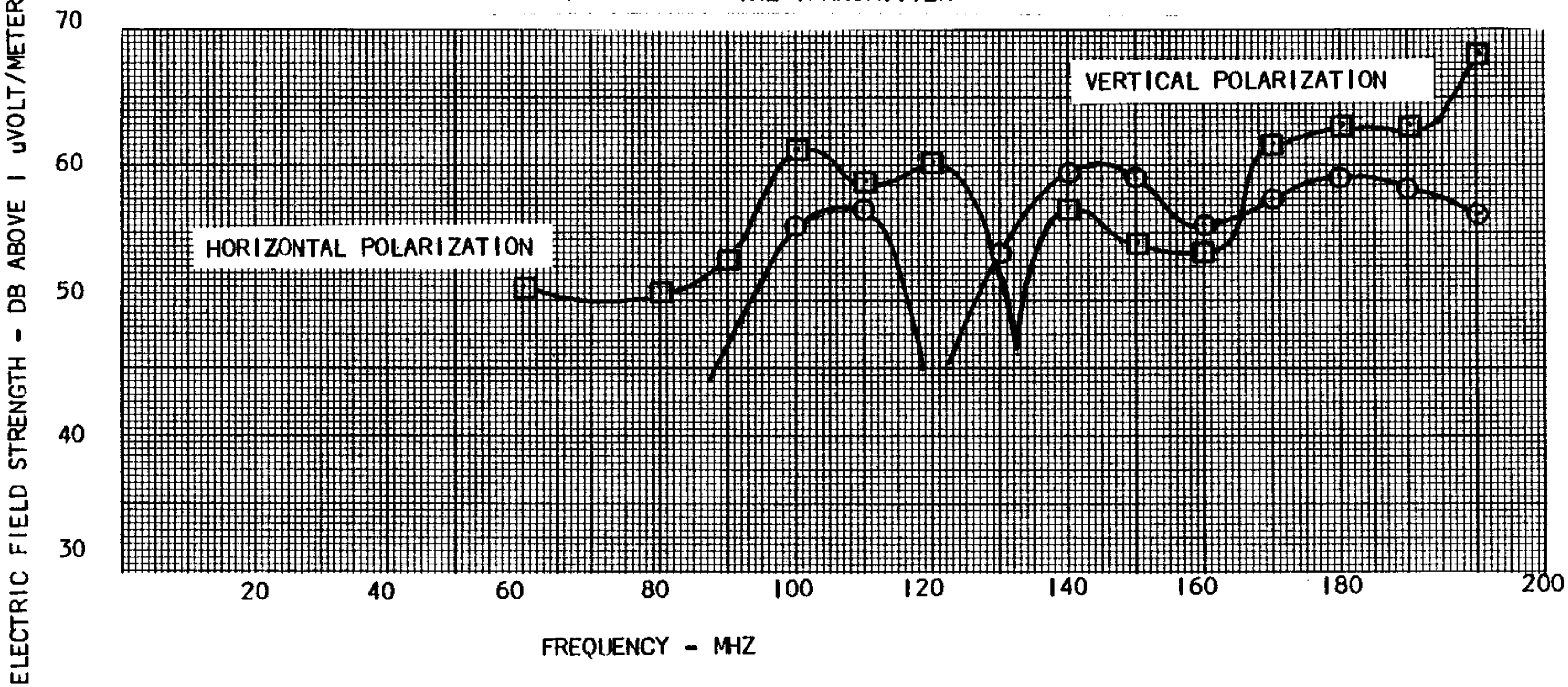


FIGURE 8

SWEPT-FREQUENCY UHF REDUCED DATA TAKEN IN CAR-CLEANER TRACKED DRIFT AT A RANGE OF 243 FEET FROM THE TRANSMITTER

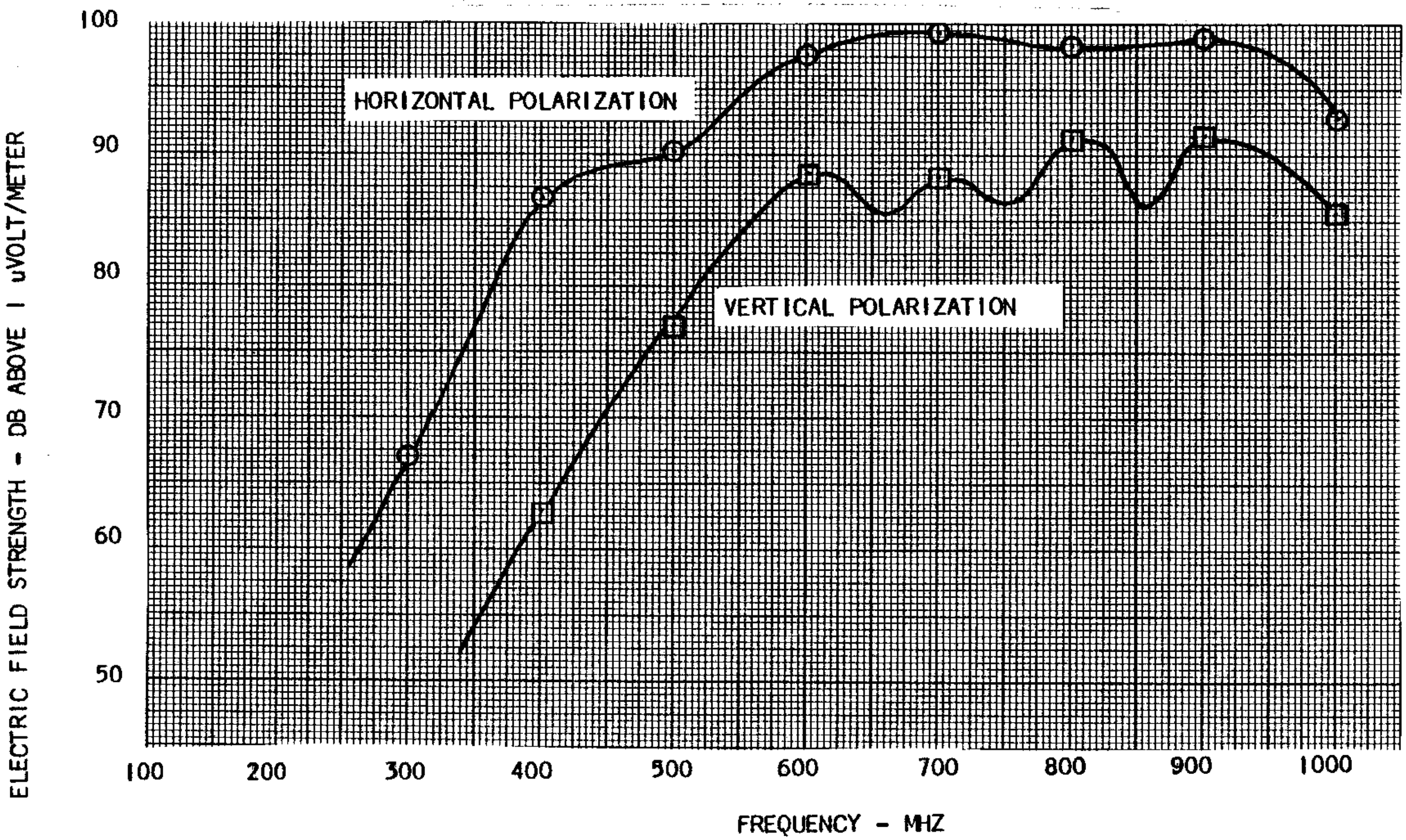


TABLE 7

REDUCED DATA FROM 145 KHZ TROLLEYPHONE TESTS ON THE BASE-VEHICLE LINKAGE ALONG THE MEASUREMENT TRAVERSE

LOCATION	DBM	MONOFILAR CURRENT DB ABOVE 1uAMPERE
G	- 5.0	+69.0
K	-25.0	+49.0
M	-20.0	+54.0
O	-16.0	+58.0
Q	- 8.0	+66.0

TABLE 8

REDUCED DATA FROM 520 KHZ TROLLEYPHONE TESTS ON THE VEHICLE-BASE LINKAGE ALONG THE MEASUREMENT TRAVERSE

LOCATION	DBM	MONOFILAR CURRENT DB ABOVE I uAMPERE	
A	-39.0	+22.4	CORRECTED FOR PREAMP
B	-39.0	+22.4	" " "
C	-47.0	+14.4	" " "
C	-54.0	+ 7.4	" " "
D	-57.0	+ 4.4	" " "
E	-53.0	+ 8.4	" " "
F	-59.0	+ 2.4	" " "
G	-69.0	- 8.1	" " "
H	-66.0	- 4.6	" " "
I	-64.0	- 2.6	
J	-73.0	-11.6	
K	-67.0	- 5.6	
L	-54.0	+ 7.4	
M	-35.0	+26.4	
N	-60.0	+ 1.4	
O	-49.0	+12.4	
P	-45.0	+16.4	
Q	-43.0	+18.4	
R	-38.0 PORT -45.0 VEHIC	+23.4	
S	-30.0 PORT -28.0 VEHIC	+31.4	
T	-32.0	+29.4	
U	-35.0	+26.4	
V	-30.0 PORT -43.0 VEHIC	+18.4	
W	-50.0	+11.4	

NOTE: THESE CURRENT VALUES AS RECEIVED IN THE RADIO SHOP ARE INCREASED BY 37.5 DB TO GIVE ACTUAL MONOFILAR CURRENT ON THE TROLLEY SYSTEM

FIGURE 9

REDUCED DATA EXPRESSED AS MONOFILAR MODE CURRENT FROM TROLLEYPHONE TESTING ON BASE-VEHICLE AND VEHICLE-BASE PATHS AT 145KHZ AND 520 KHZ RESPECTIVELY

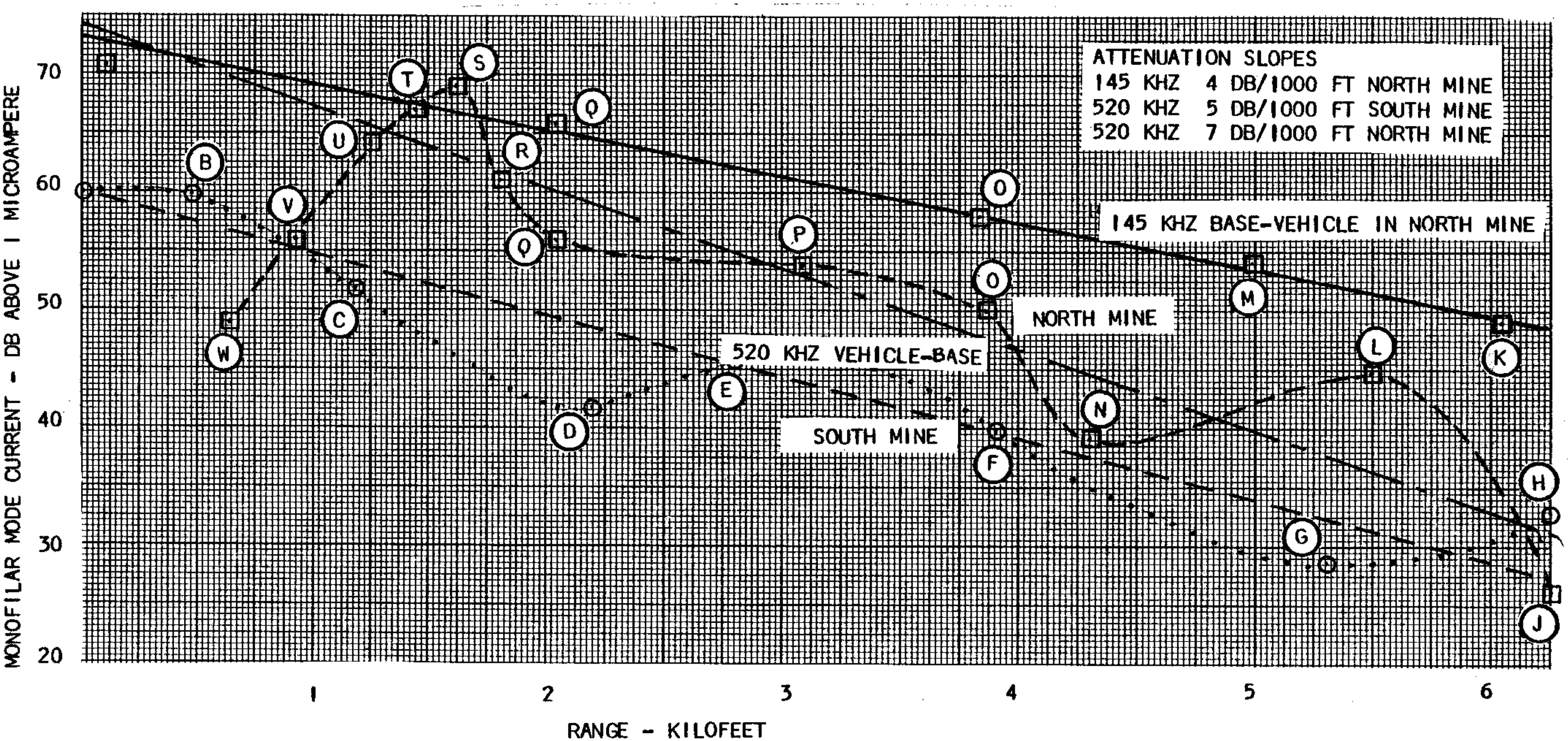


FIGURE 10

REDUCED DATA EXPRESSED AS MONOFILAR MODE CURRENT LEVELS ON VEHICLE-BASE PATH AT 520 KHZ DIFFERENTIATING BETWEEN CURRENT RECEIVED IN RADIO SHOP AND THAT EXPECTED ON THE TROLLEY CONDUCTOR SYSTEM

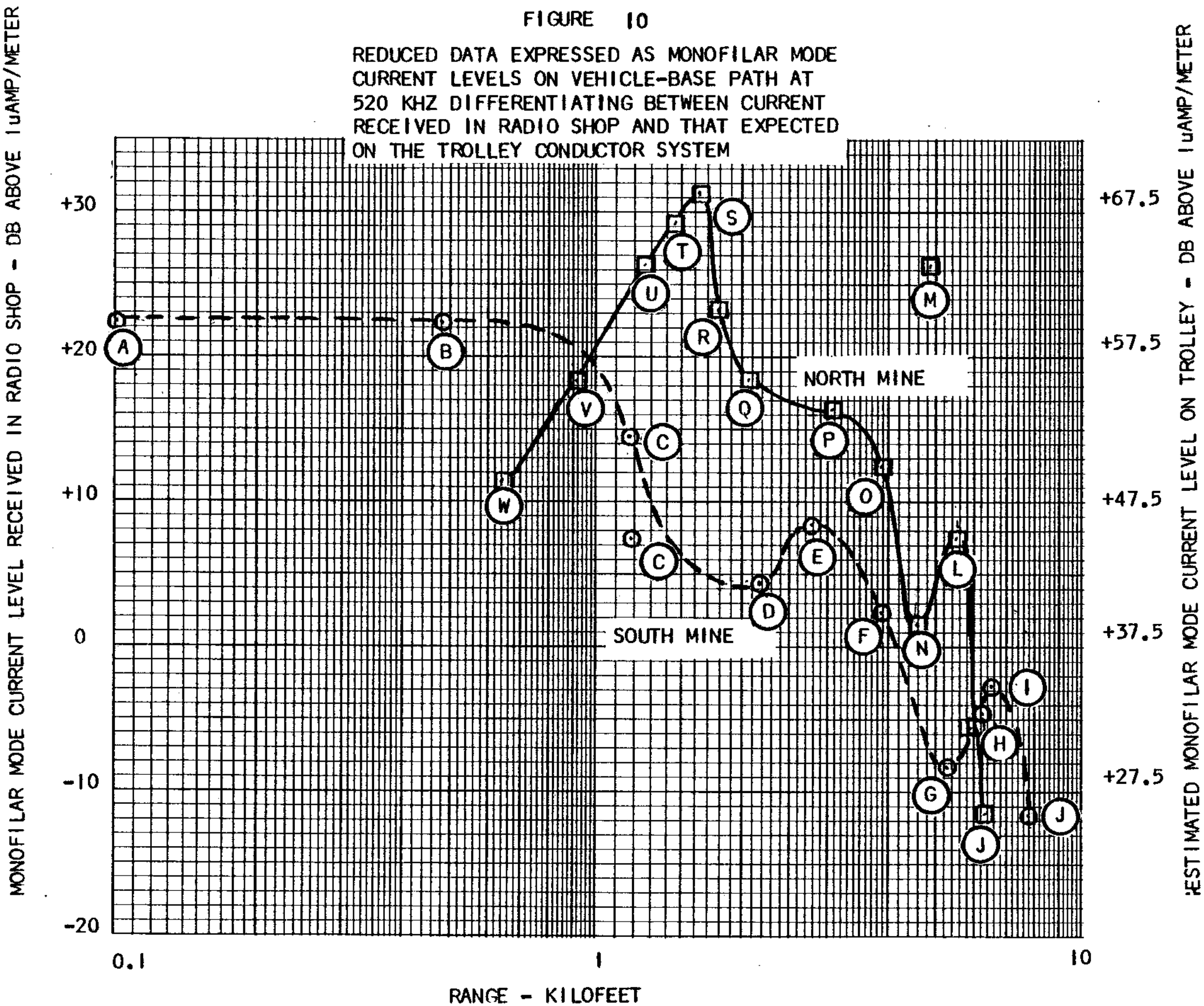


FIGURE 11

MONOFILAR LINE SURGE AND DRIVING POINT
IMPEDANCE DATA DERIVED FROM THE TROLLEYPHONE
TEST DATA AND ESTIMATED CONDUCTOR CURRENTS

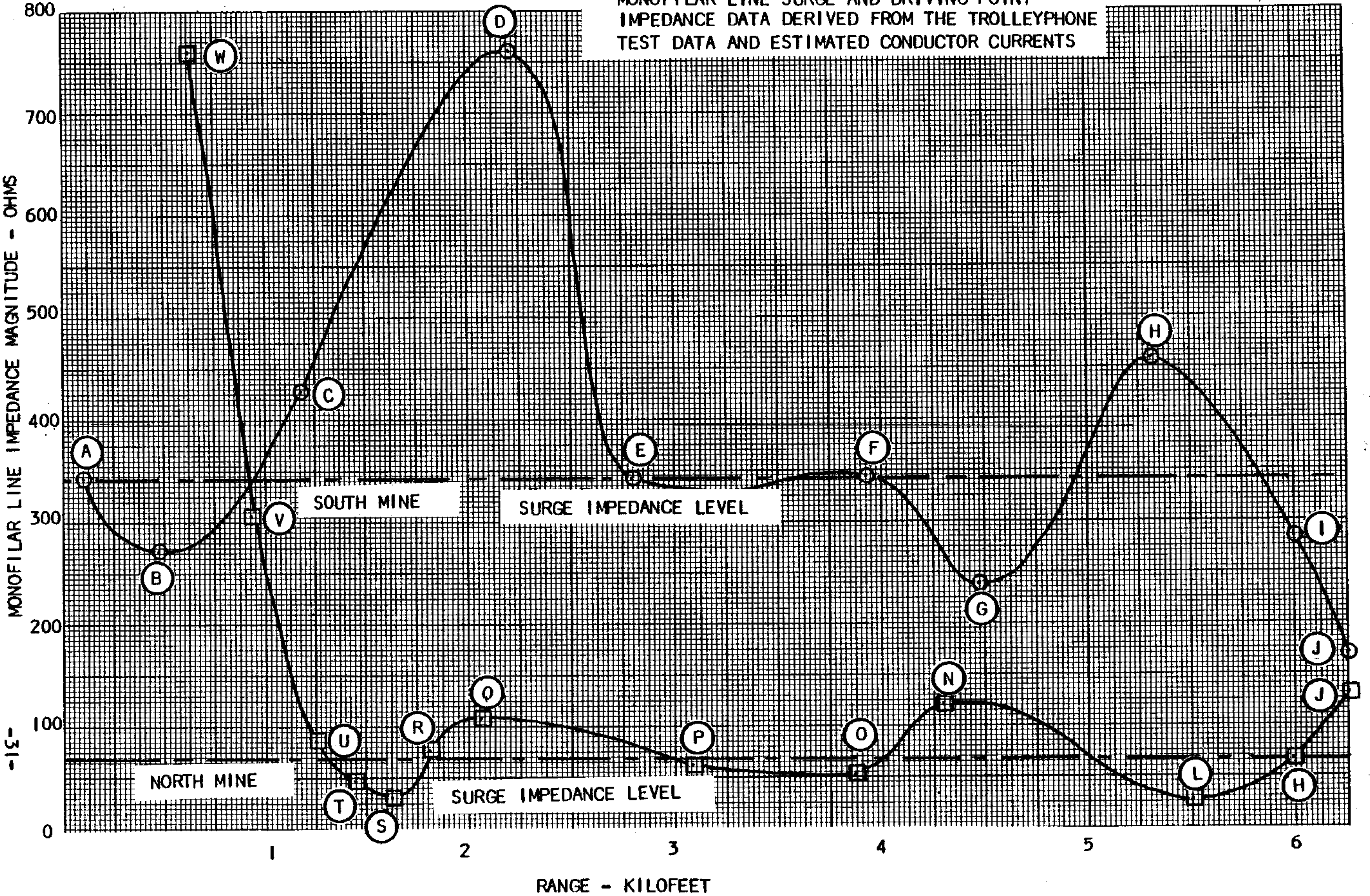
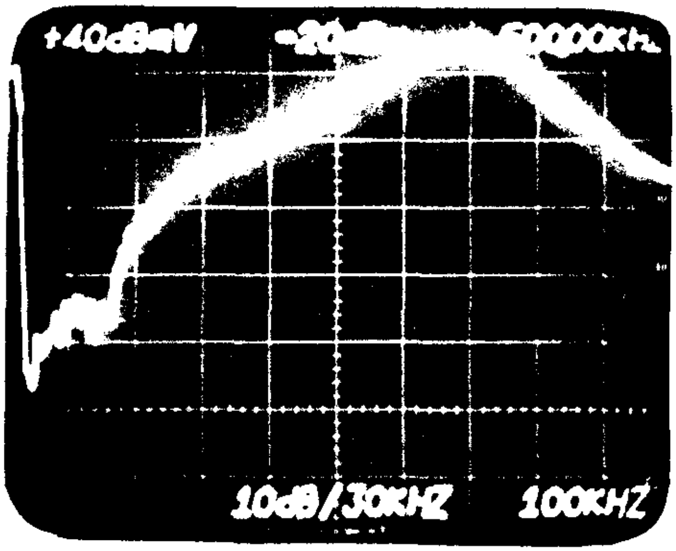
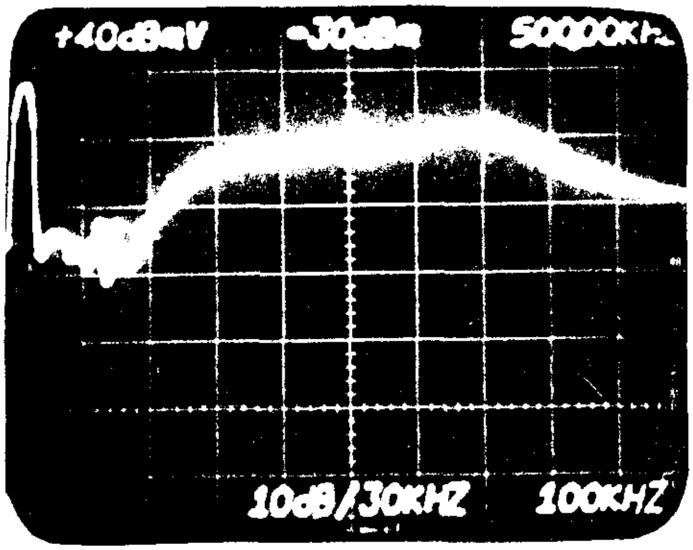


FIGURE 12

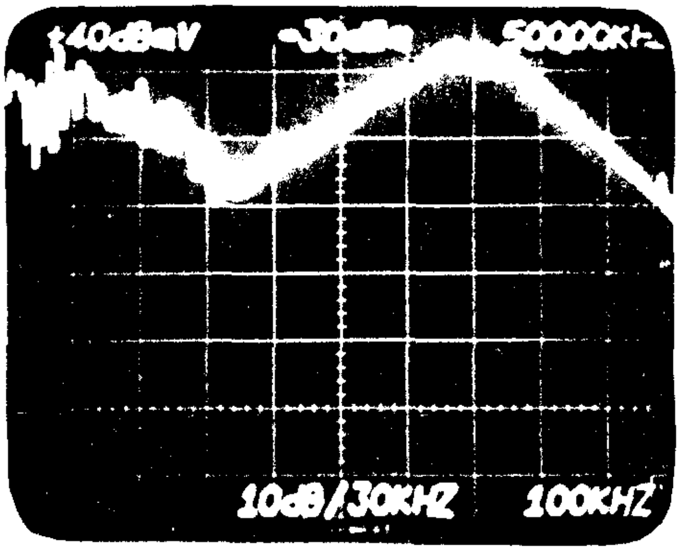
ORIGINAL OSCILLOGRAPHS OF MF SWEPT-FREQUENCY
DATA TAKEN ON CAR-CLEANER TRACK DRIFT



TX & RX ANTS VMD, RX @ 1-FT, TX @ 1-FT



TX & RX ANTS COPLANAR HMD 1.1 M ABOVE TRACK



TX & RX ANTS VMD, RX @ 4-FT, TX @ 1-FT

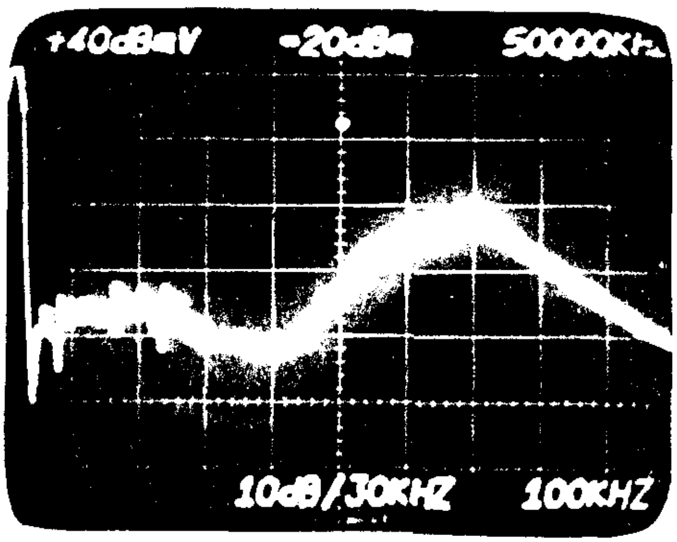
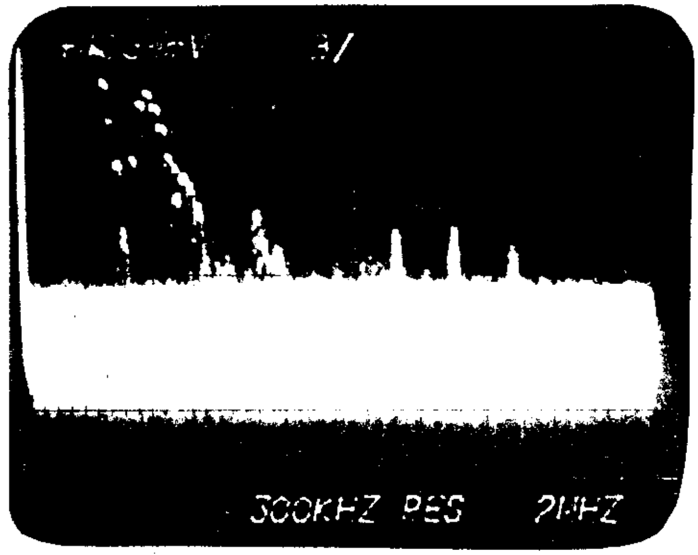
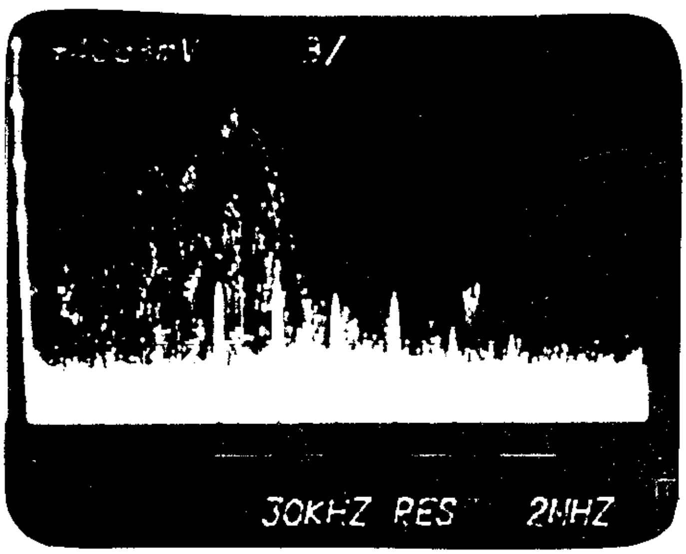


FIGURE 13

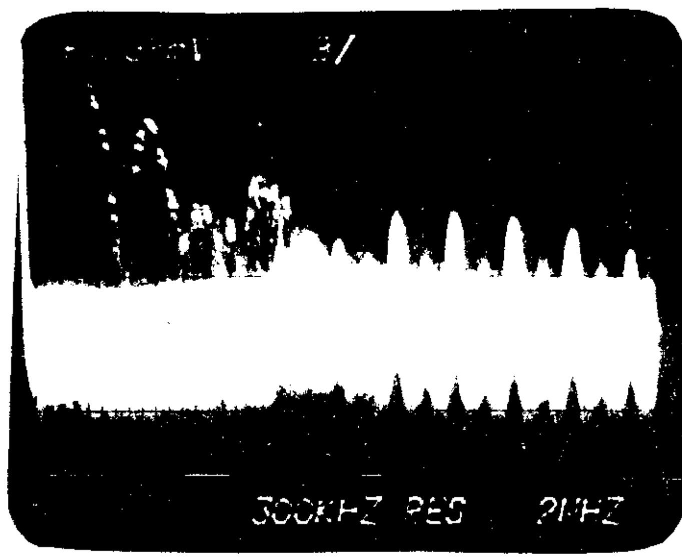
ORIGINAL OSCILLOGRAPHS OF HF SWEPT-FREQUENCY
DATA TAKEN ON CAR-CLEANER TRACK DRIFT



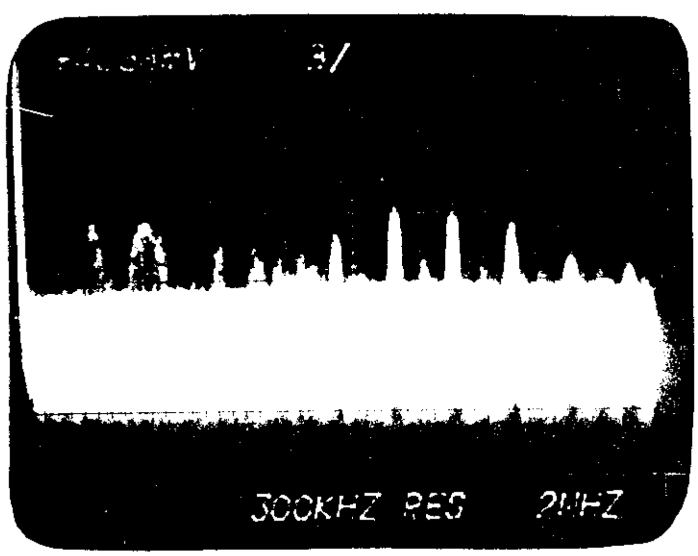
TX & RX ANTS VMD, RX @ 1-FT, TX @ 1-FT



TX & RX ANTS COPLANAR HMD 1.1 M ABOVE TRACK



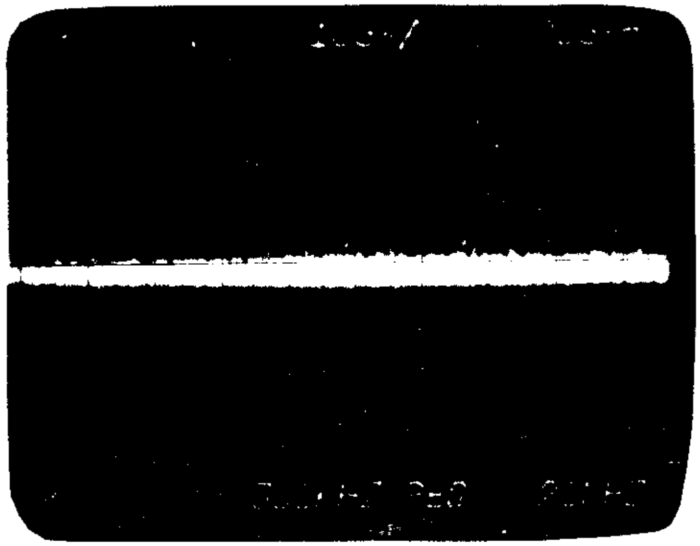
TX & RX ANTS VMD, RX @ 4-FT, TX @ 1-FT



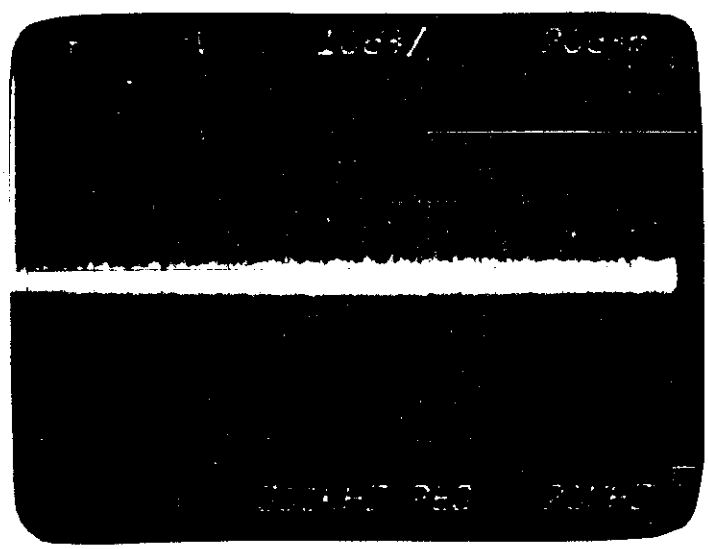
TX & RX ANTS VMD, RX @ 8-FT, TX @ 1-FT

FIGURE 14

ORIGINAL OSCILLOGRAPHS OF VHF SWEPT-FREQUENCY DATA TAKEN IN THE CAR-CLEANER TRACKED DRIFT



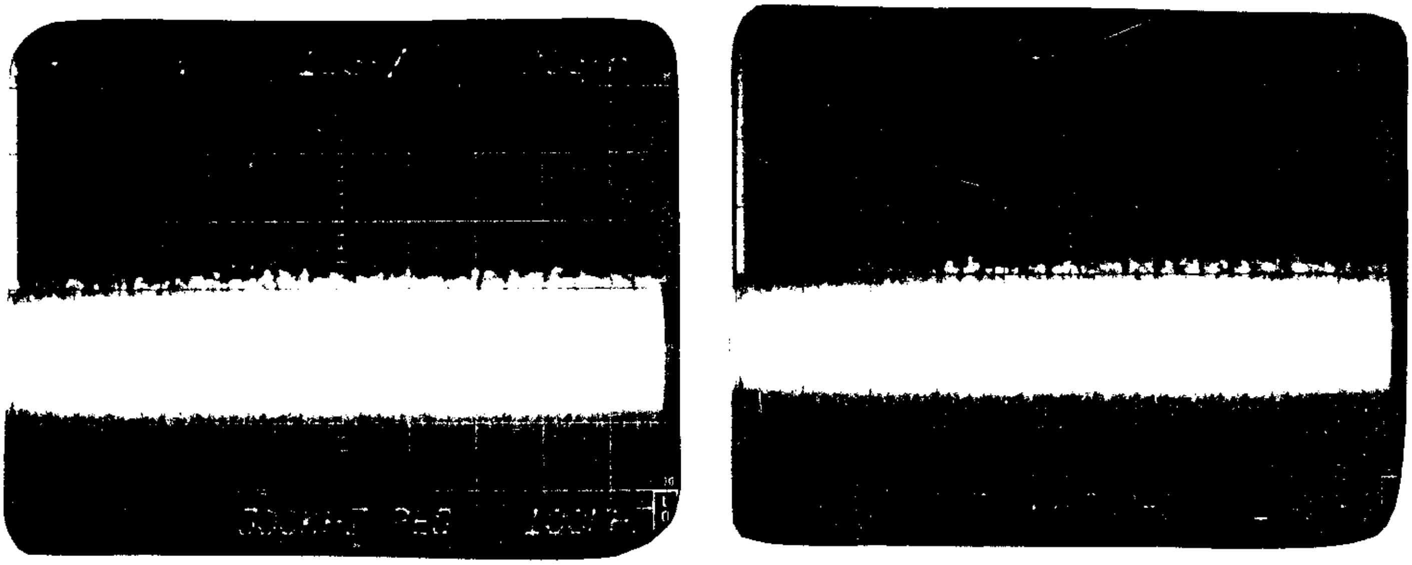
HORIZONTAL POLARIZATION



VERTICAL POLARIZATION

FIGURE 15

ORIGINAL OSCILLOGRAPHS OF UHF SWEPT-FREQUENCY DATA TAKEN IN THE CAR-CLEANER TRACKED DRIFT

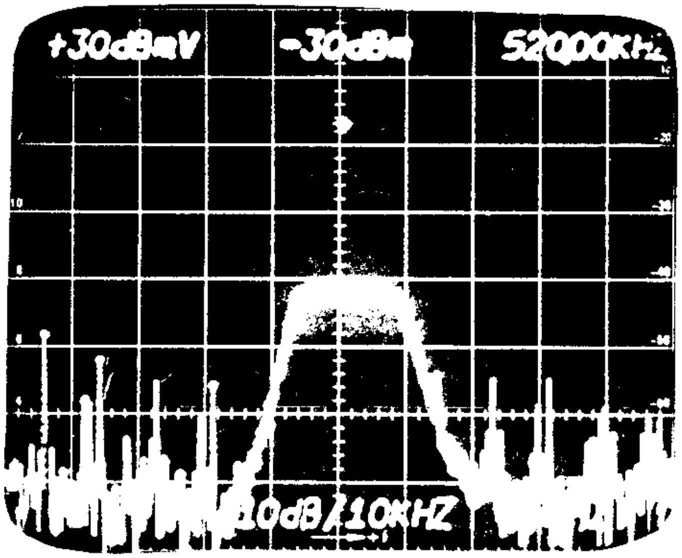


HORIZONTAL POLARIZATION

VERTICAL POLARIZATION

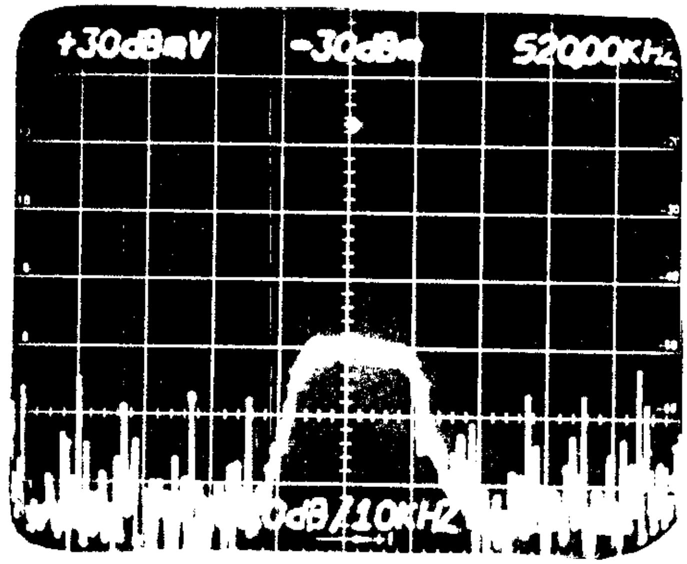
FIGURE 16(A)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-
PHONE TESTING, VEHICLE-BASE



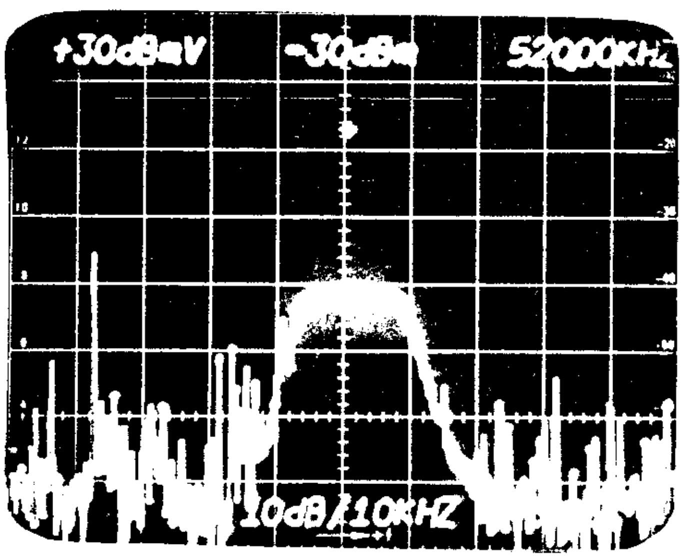
LOCATION A

XMIT FROM LOCO MACHINE SHOP, 20W IN VEHIC ANT



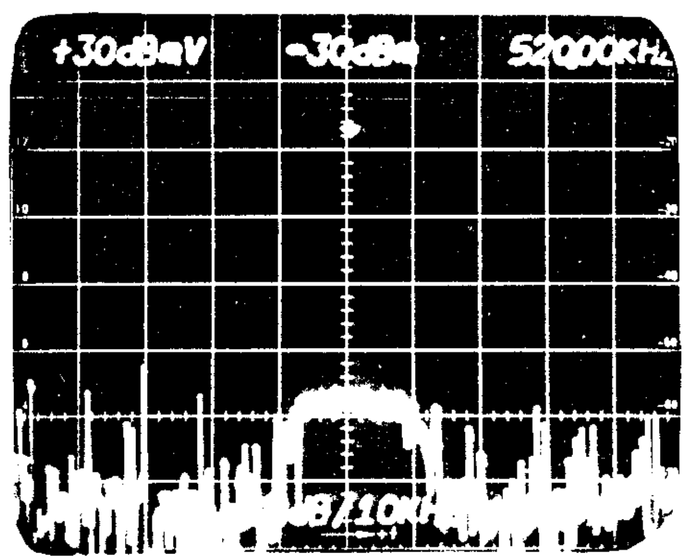
LOCATION C

C1,CAR-CLEANER TURNOUT;3-DOG DEPARTURE
SAME LEVEL



LOCATION B

FIRST TURNOUT



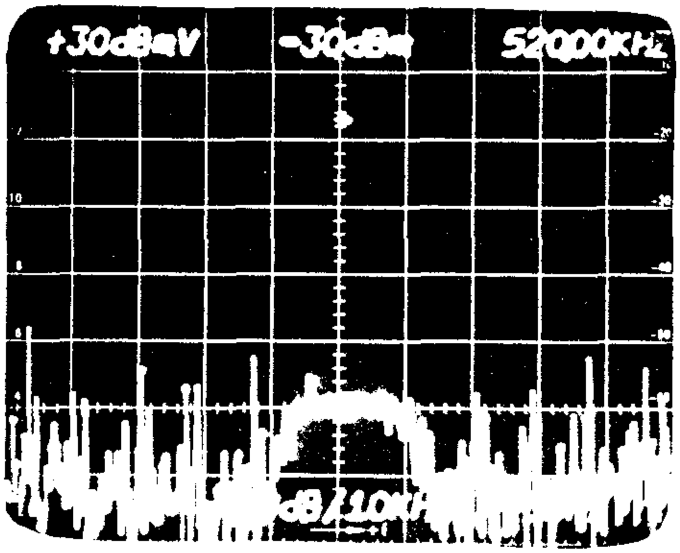
LOCATION C

C2,AFTER 3-DOG DEP; MOBILE CANNOT HEAR
BASE

NOTE: RECEIVE PREAMP NOT USED AT THESE LOCATIONS

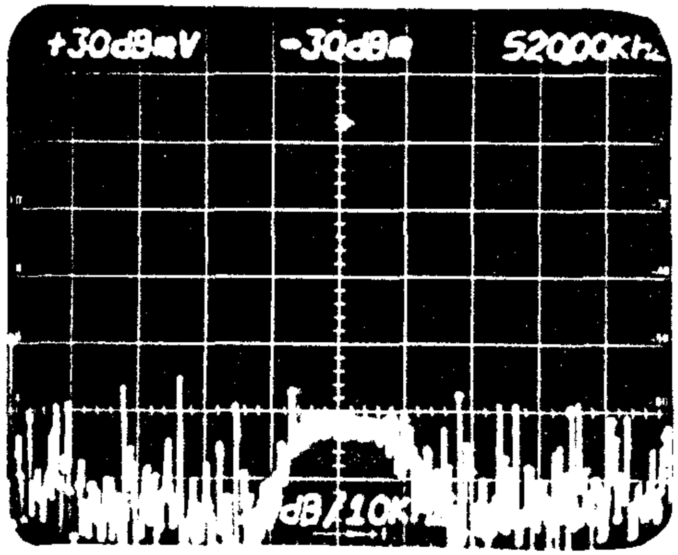
FIGURE 16(B)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-PHONE TESTING,VEHICLE-BASE



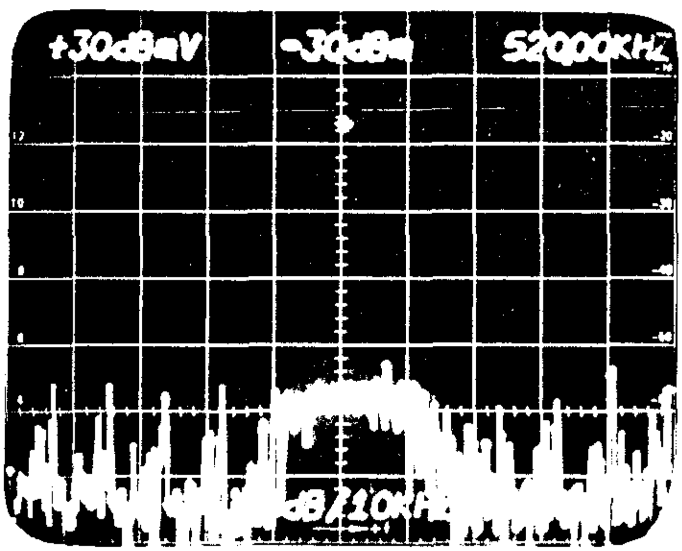
LOCATION D

ABOUT 500 FT ALONG SOUTH HAULAGE PAST 3-DOG DEPARTURE



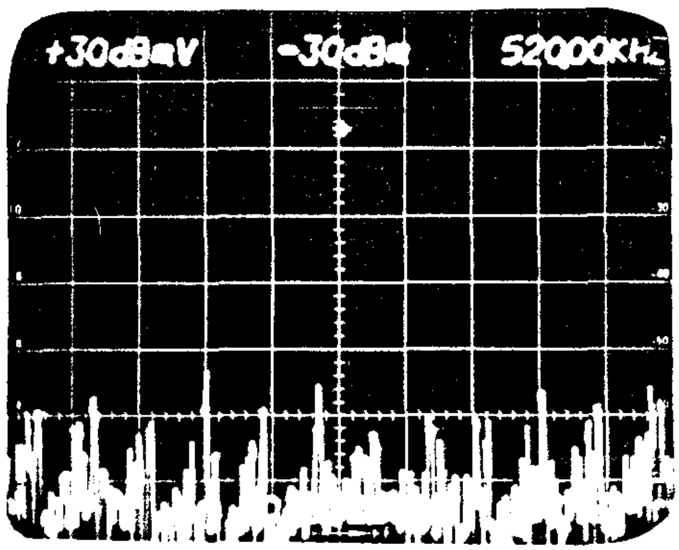
LOCATION F

MIDWAY BETWEEN 3-DOG DEP & 17 SOUTH



LOCATION E

ABOUT 1000 FT ALONG SOUTH HAULAGE PAST 3-DOG DEPARTURE



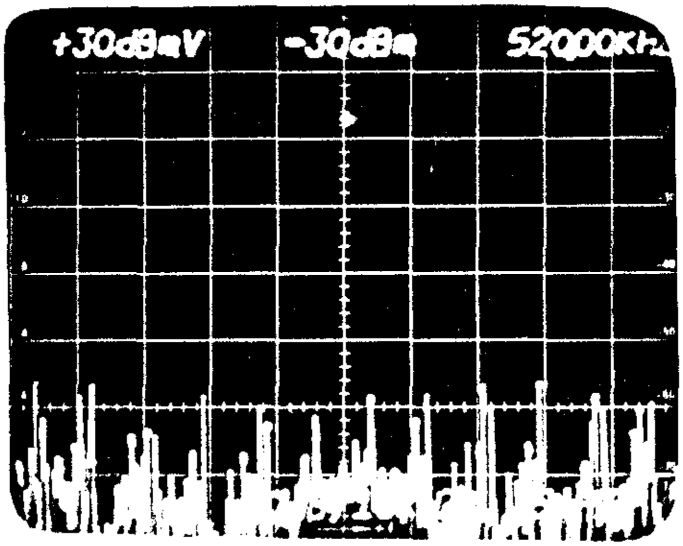
LOCATION G

G1, PANEL 17, MAIN CROSSCUT

NOTE: RECEIVE PREAMP NOT USED AT THESE LOCATIONS

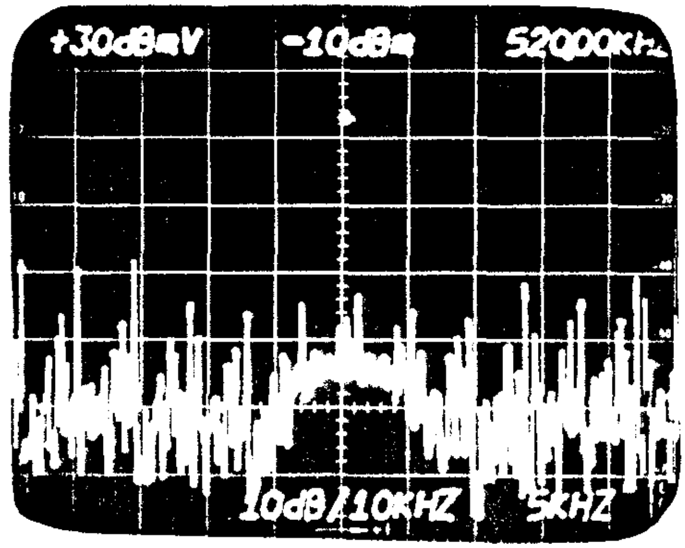
FIGURE 16(C)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-
PHONE TESTING, VEHICLE-BASE



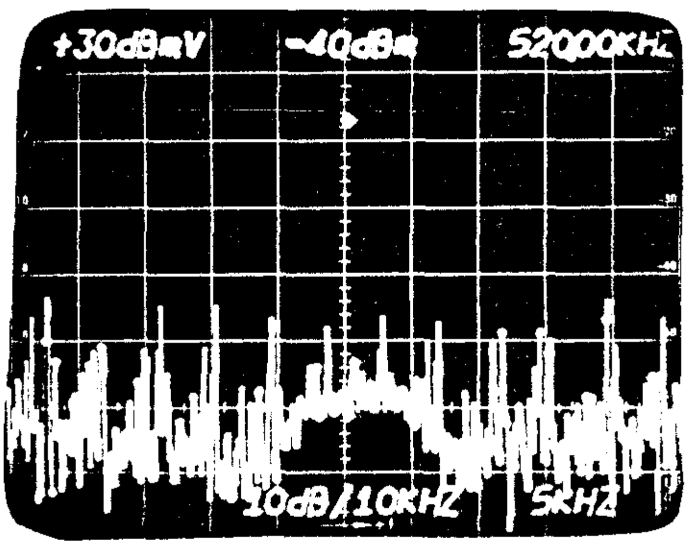
LOCATION G

G2, 17 SOUTH, NOISY



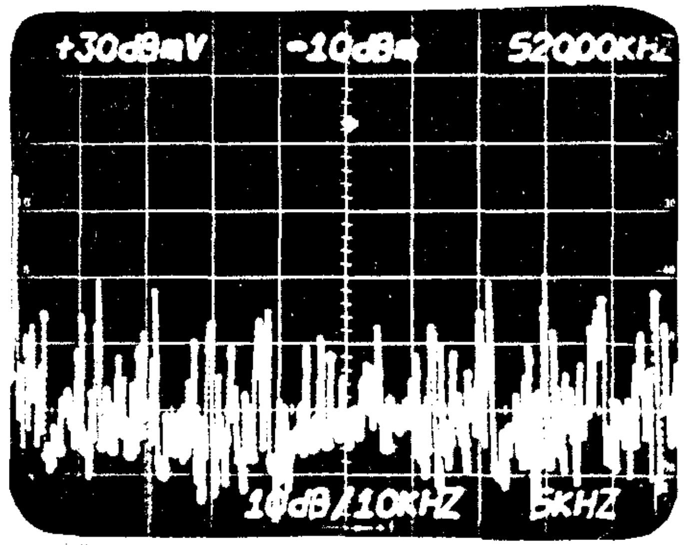
LOCATION I

PANEL 17



LOCATION H

PANEL 17, MAIN CROSSCUT



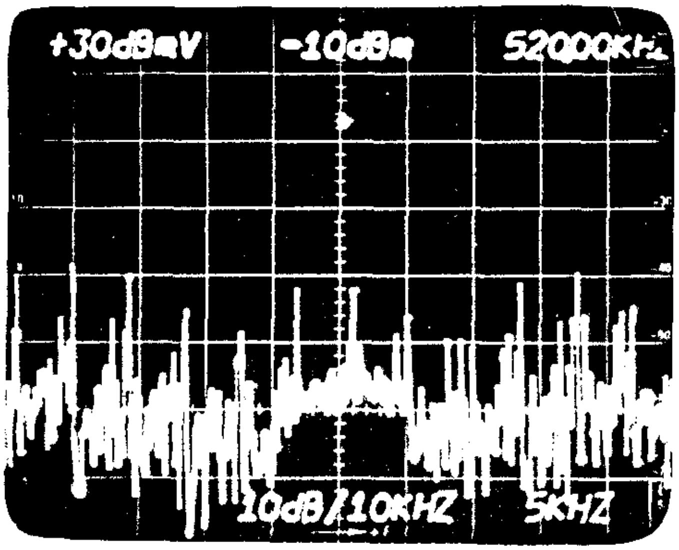
LOCATION J

PANEL 17 NORTH

NOTE: RECEIVE PREAMP NOT USED AT LOCATIONS G & H; ALL LOCATIONS THEREAFTER USED THE PREAMP WITH 33 DB GAIN

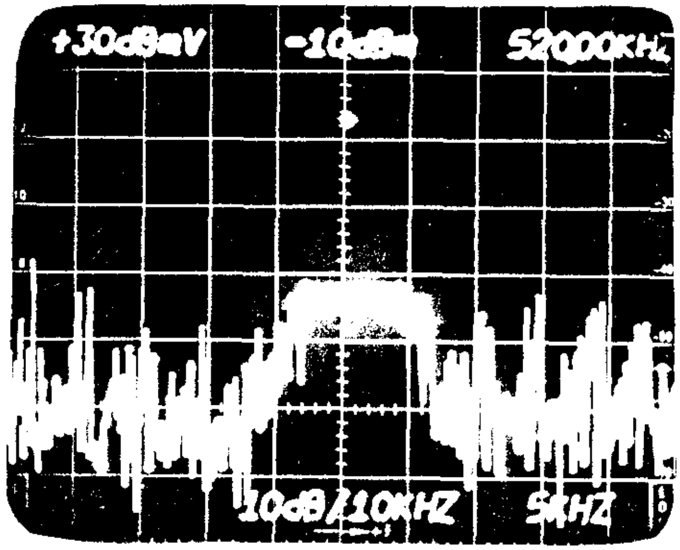
FIGURE 16 (D)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-
PHONE TESTING, VEHICLE-BASE



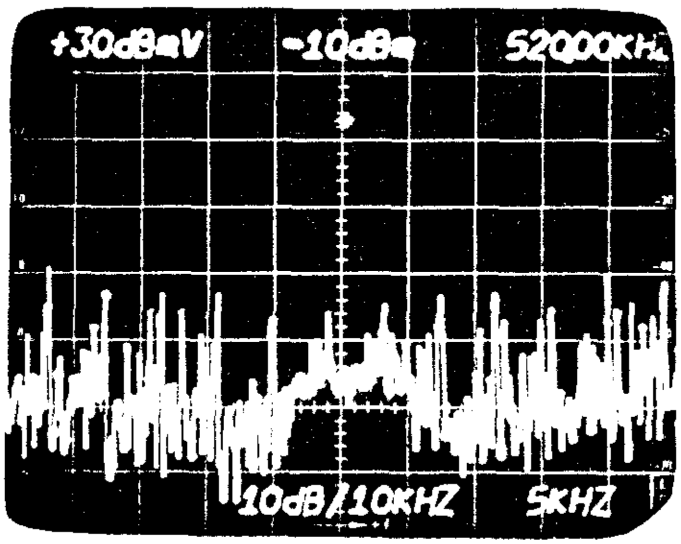
LOCATION K

K1, PANEL 17 MAIN



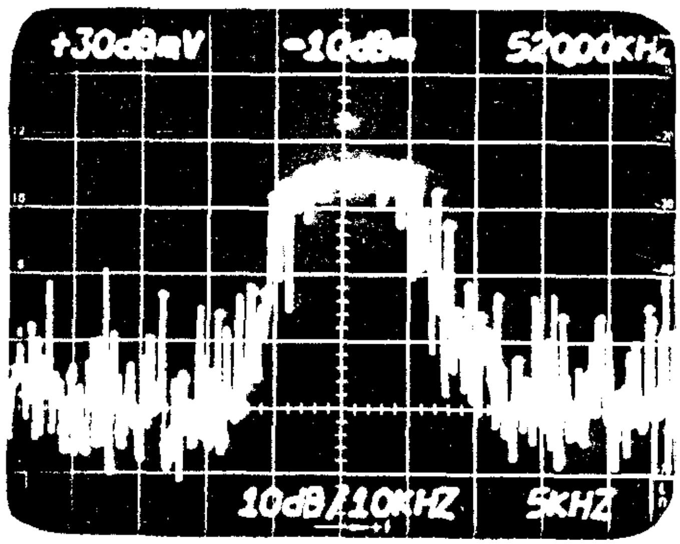
LOCATION L

TOWARD 20 CROSSOVER



LOCATION K

K2, MAIN LINE 17 NORTH/2 HAULAGE

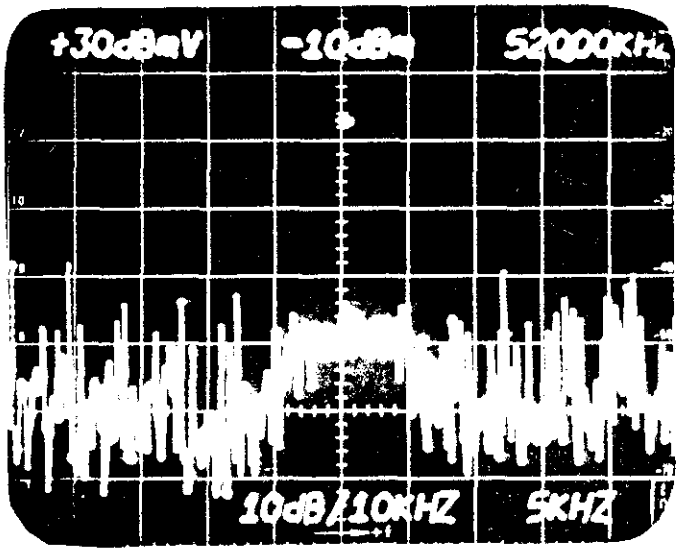


LOCATION M

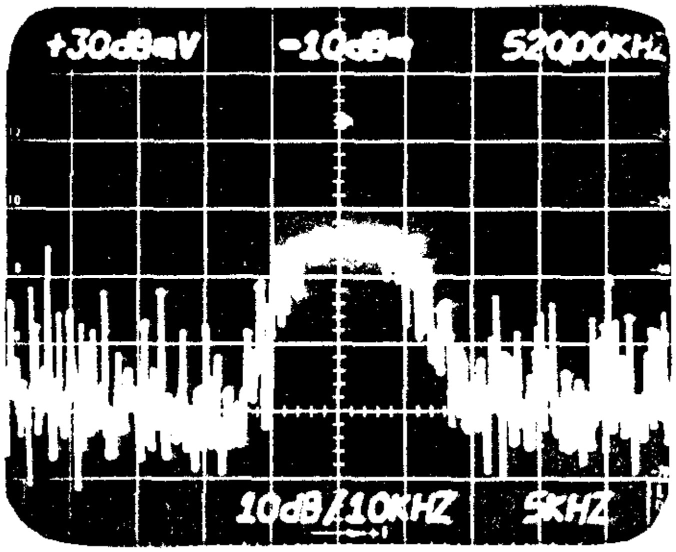
NORTH HAULAGE-1, CHANGED ANT LOCATION

FIGURE 16 (E)

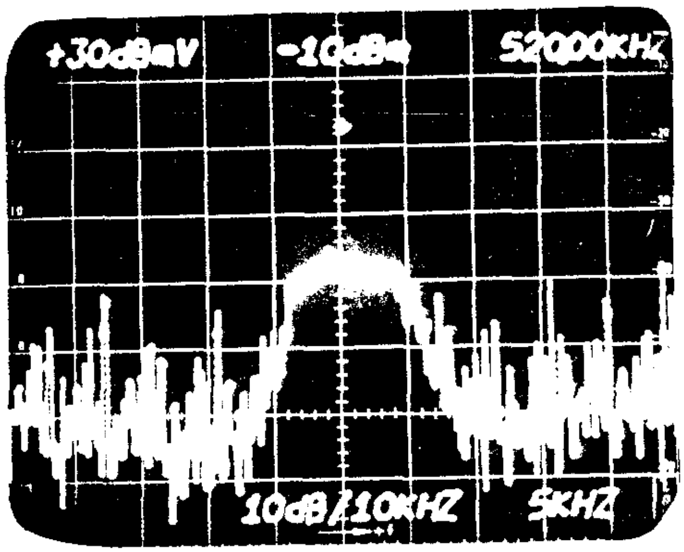
ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-
PHONE TESTING. VEHICLE-BASE



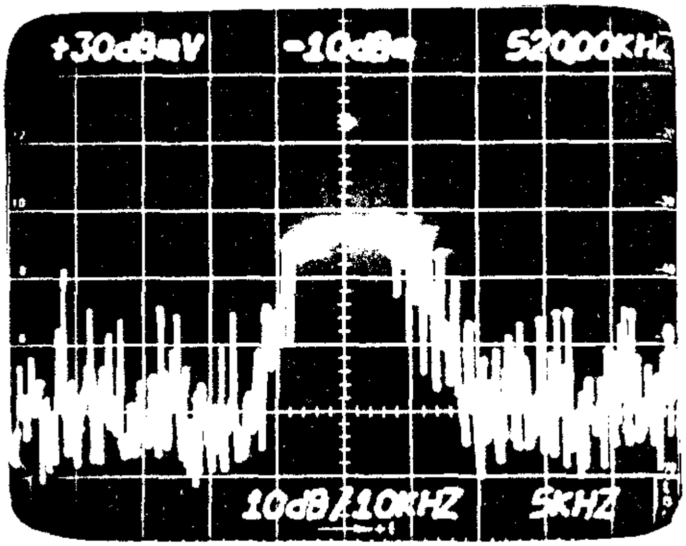
LOCATION N
JUST AFTER 20, SEVERAL HUNDRED FEET



LOCATION P
100 FT PAST 30 CROSSOVER



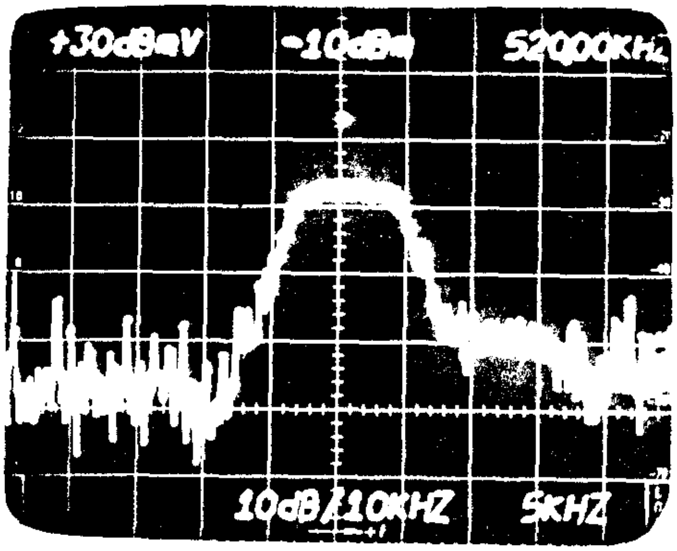
LOCATION O
OLD DISPATCH SHACK



LOCATION O

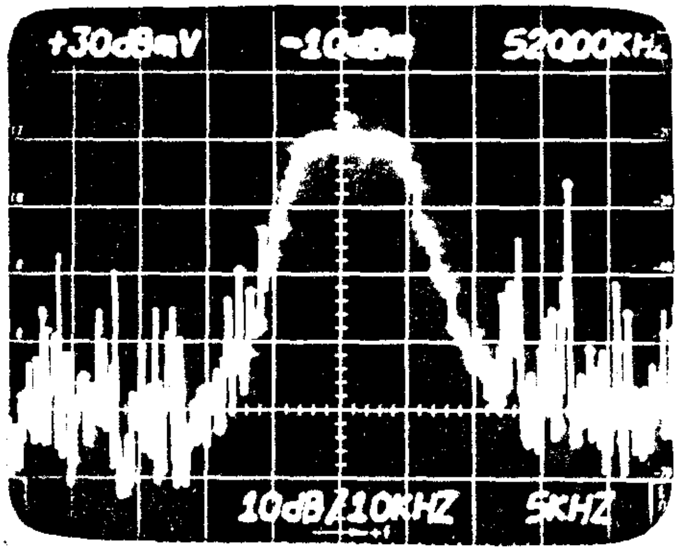
FIGURE 16 (F)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-
PHONE TESTING, VEHICLE-BASE



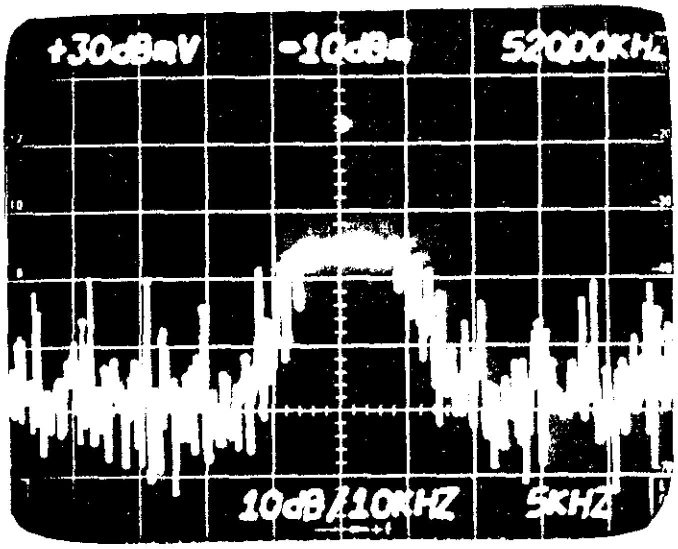
LOCATION R

R1,5-SHAFT TURNOUT,PORTABLE(1-2 FT FROM WIRE)



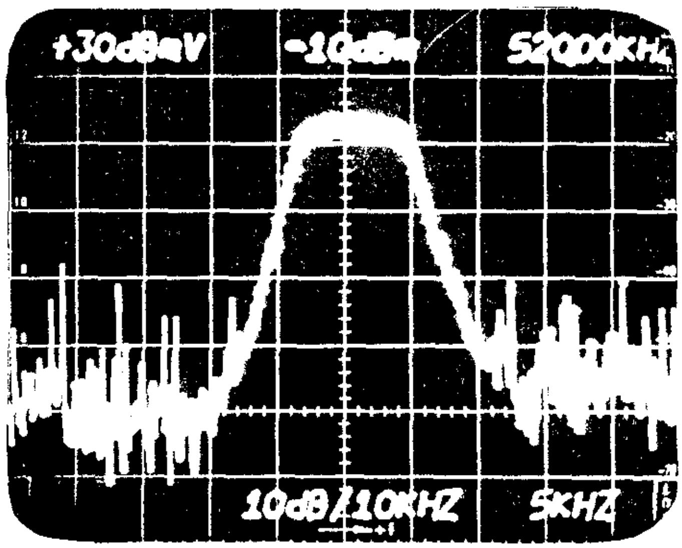
LOCATION S

S1,AIR DOORS,PORTABLE(1-2 FT FROM WIRE)



LOCATION R

R2,5-SHAFT TURNOUT,VEHICLE

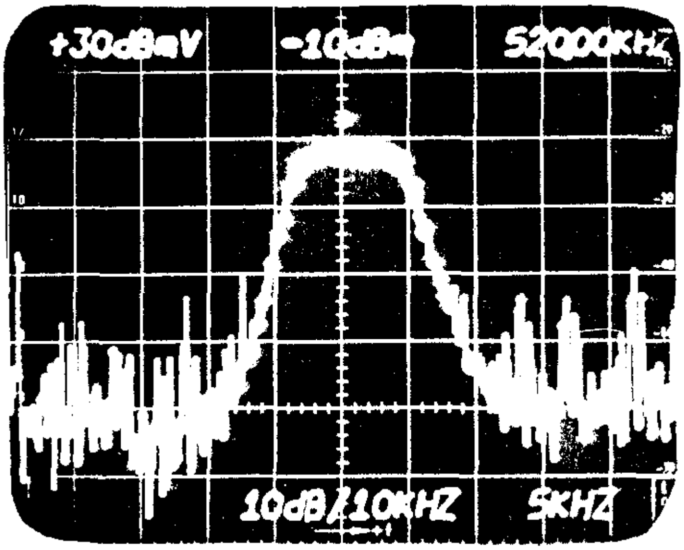


LOCATION S

S2,AIR DOORS, VEHICULAR

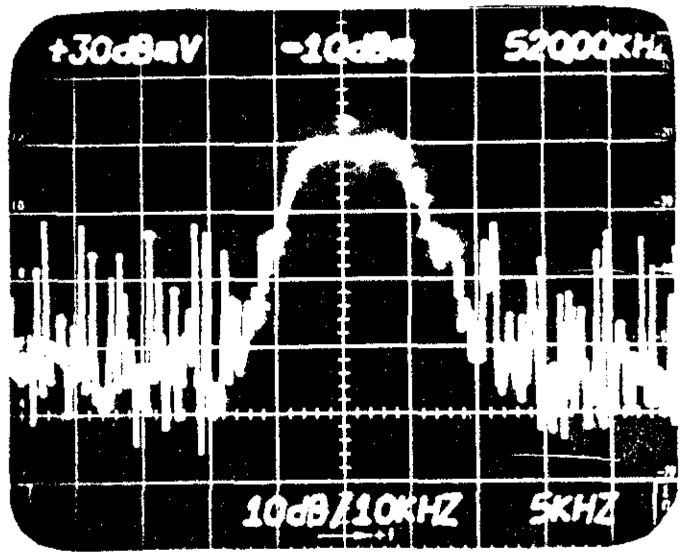
FIGURE 16(G)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-PHONE TESTING, VEHICLE-BASE



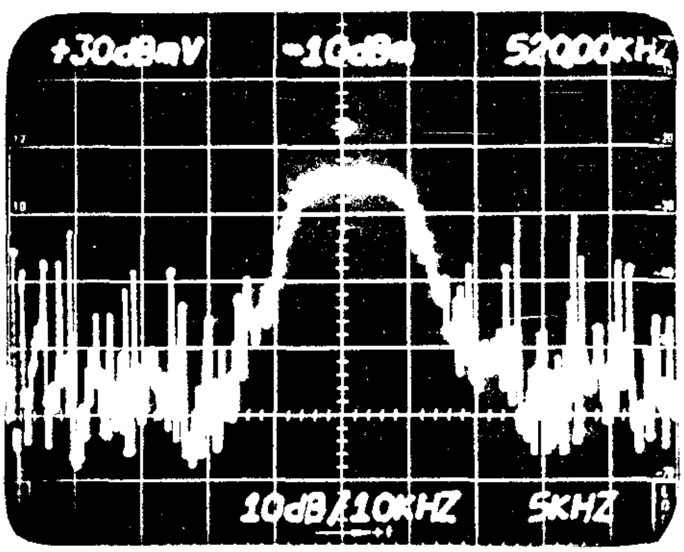
LOCATION T

BETWEEN AIR DOORS



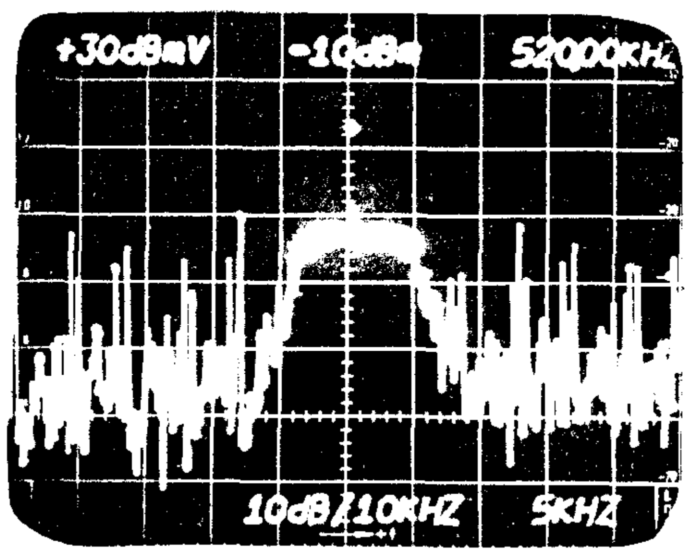
LOCATION V

V1,2ND SET OF AIR DOORS,PORTABLE(1-2 FT,WIRE)



LOCATION U

AFTER AIR DOORS

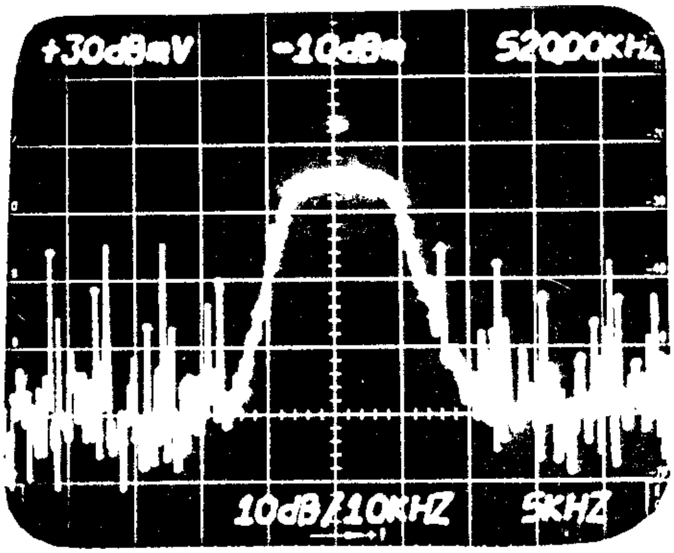


LOCATION V

V2,2ND SET OF AIR DOORS, VEHICULAR

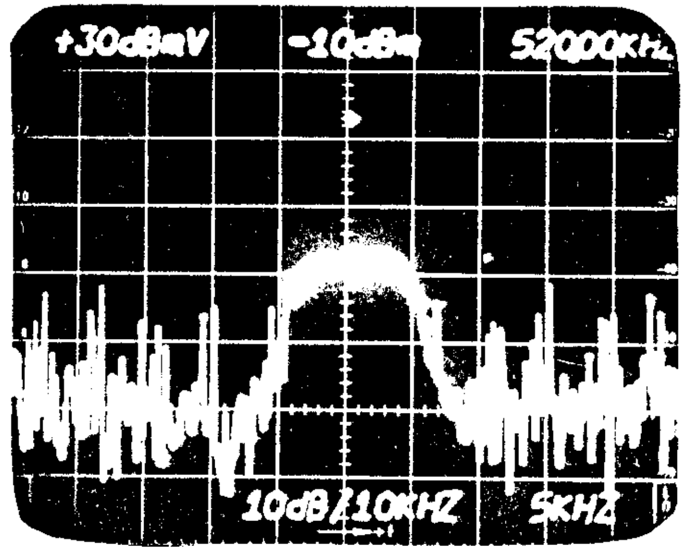
FIGURE 16(H)

ORIGINAL OSCILLOGRAPHS FROM 520 KHZ TROLLEY-
PHONE TESTING, VEHICLE-BASE



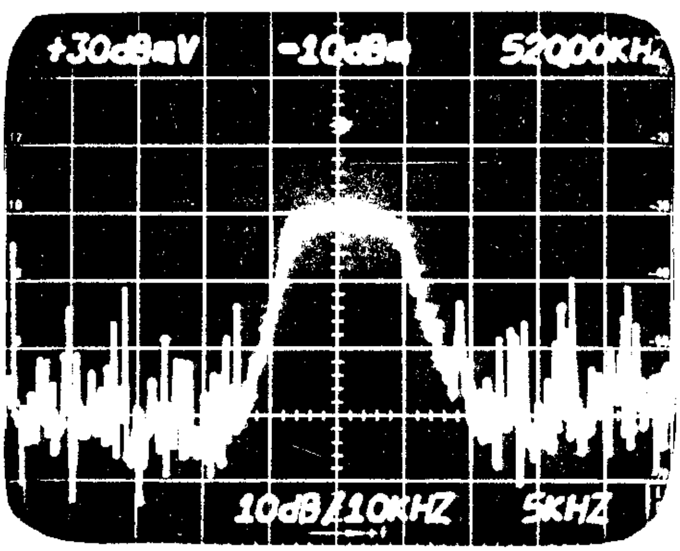
LOCATION W

W1,PORTABLE,3-CHARLIE DEPARTURE,VERT LOOP



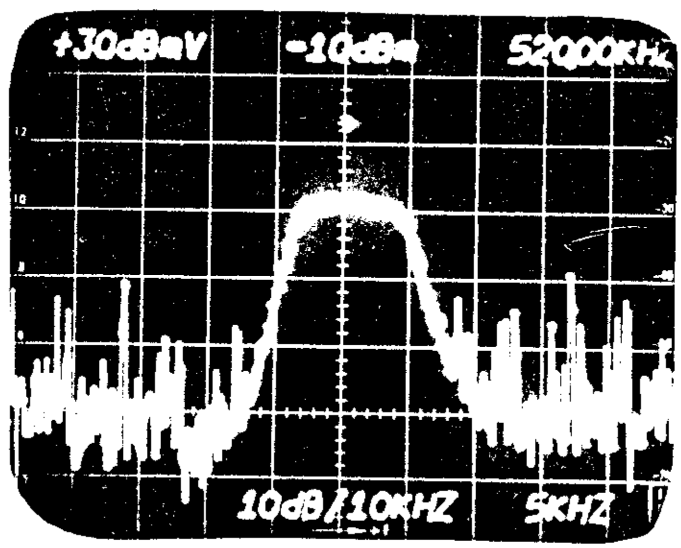
LOCATION W

W3,3-CHARLIE DEPARTURE,VEHICULAR



LOCATION W

W2,3-CHARLIE DEPARTURE,PORTABLE(1-2 FT,WIRE)
HORIZONTAL LOOP

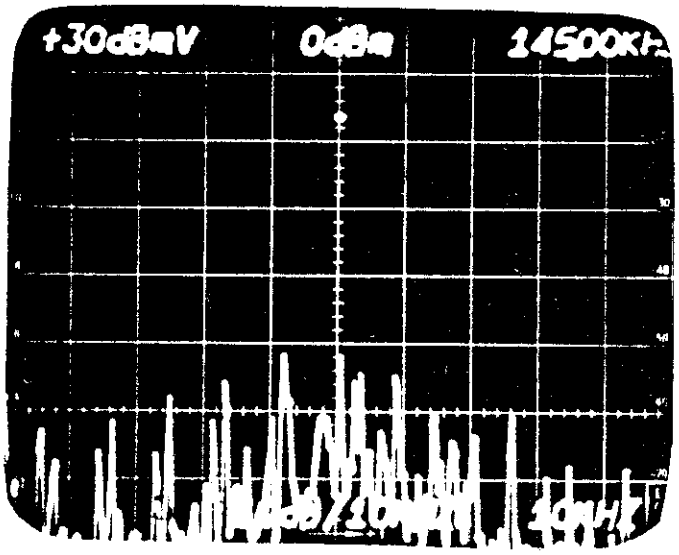


LOCATION X

PORTABLE,OUTSIDE LOCO SHOP,1-2 FT FROM WIRE

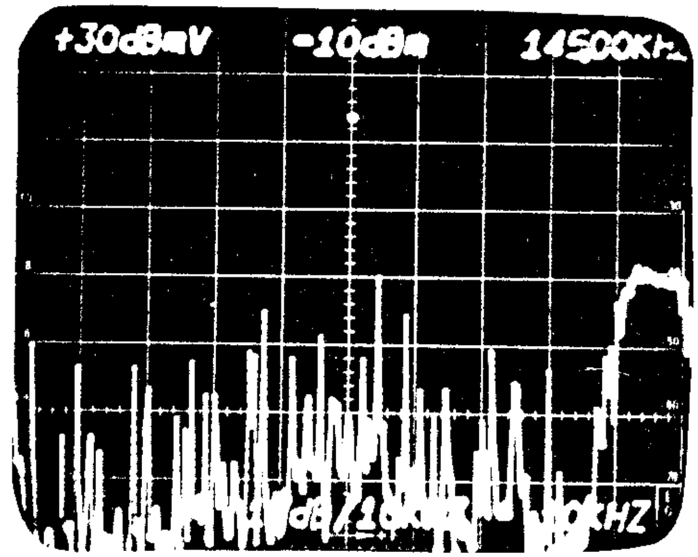
FIGURE 17(A)

ORIGINAL OSCILLOGRAPHS FROM 145 KHZ TROLLEY-
PHONE TESTING, BASE-VEHICLE



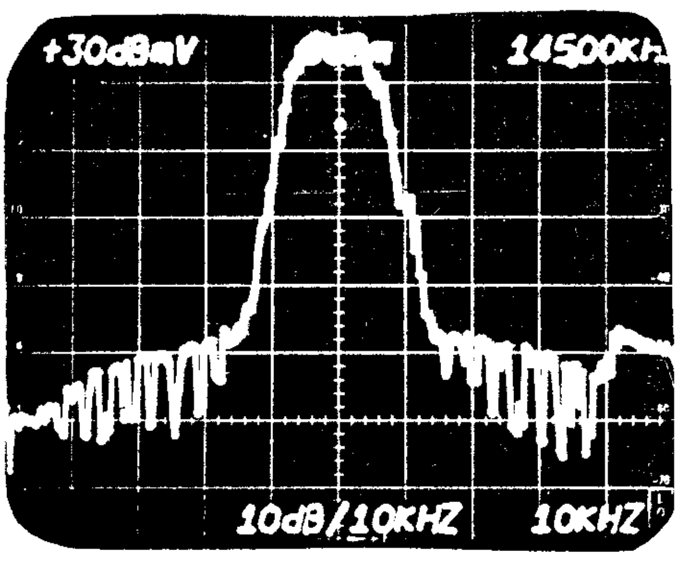
LOCATION G

G1,NOISE, 17 SOUTH, 2-METERS FROM WIRE



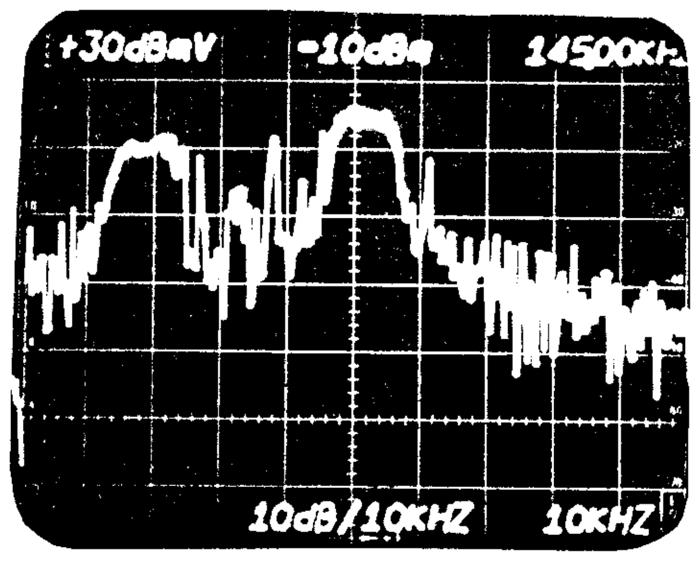
LOCATION K

K1,NOISE PLUS 190 KHZ, 17 SOUTH END



LOCATION G

G2,17 SOUTH

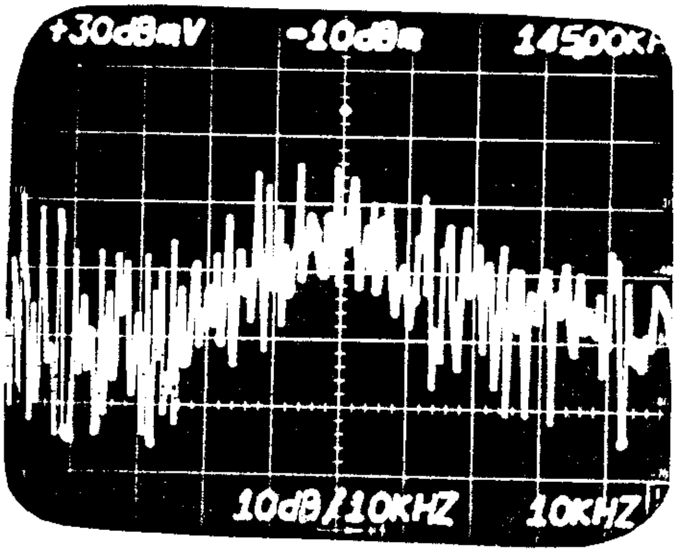


LOCATION K

K2,AFTER 17-NORTH SWITCH

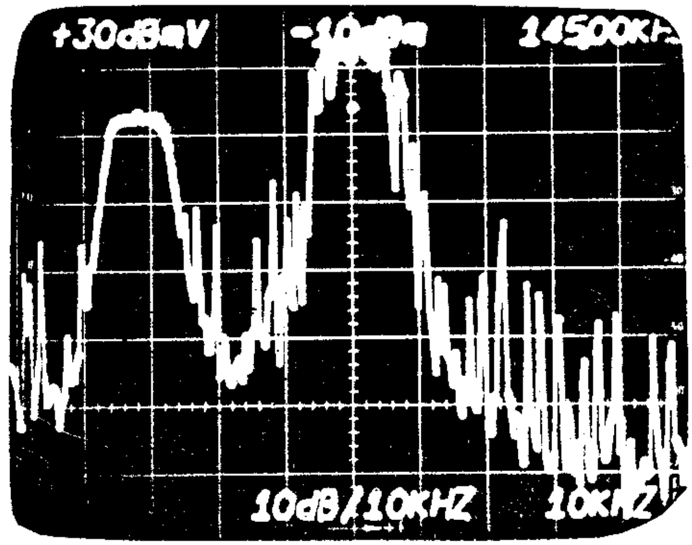
FIGURE 17(B)

ORIGINAL OSCILLOGRAPHS FROM 145 KHZ TROLLEY-
PHONE TESTING, BASE-VEHICLE

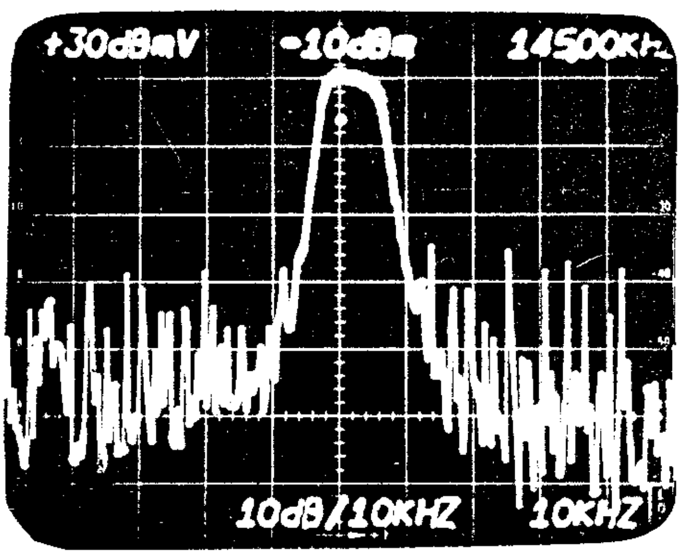


LOCATION M

M1,NOISE, NORTH HAULAGE-1

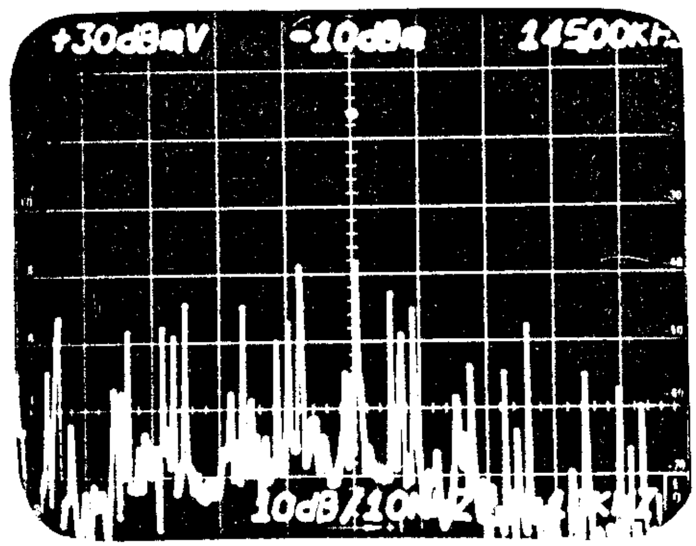


LOCATION O



LOCATION M

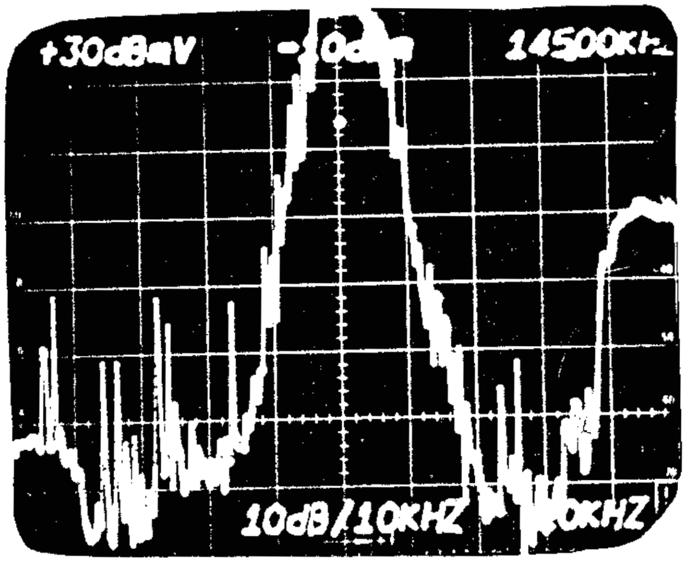
M2,NORTH HAULAGE-1



LOCATION Q

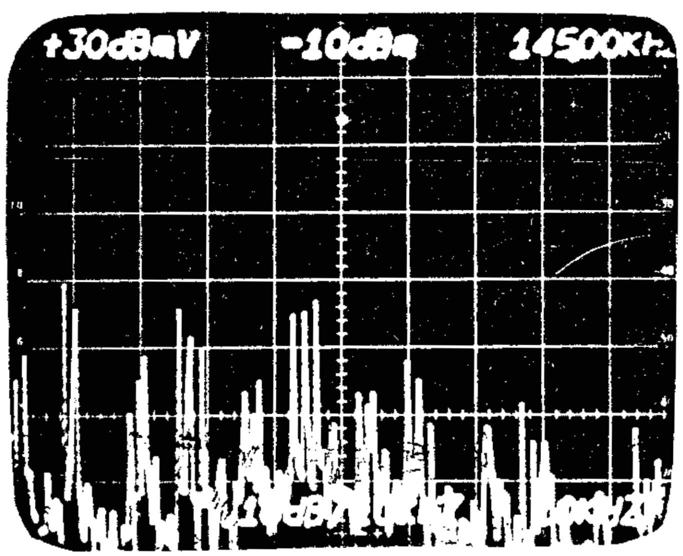
Q1,NOISE, NEAR 5-SHAFT TURNOUT

FIGURE 17(C)
ORIGINAL OSCILLOGRAPHS FROM 145 KHZ TROLLEY-
PHONE TESTING, BASE-VEHICLE



LOCATION Q

Q2, NEAR 5-SHAFT TURNOUT



LOCATION X

OUTSIDE LOCO SHOP