U.S. Department
of Transportation
Federal Railroad Administration

Testing a New Method of Railroad Data Transmission

Office of Research
and Development
Washington, DC 20590

DOT/FRA/ORD-80/89

February 1982

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NOTICE

Technical Report Documentation Page

1. Report No. FRA/ORD-80/89	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Testing a New Method of Railroad Data Transmission		5. Report Date November 1981
		6. Performing Organization Code
7. Author(s) J.R.Meyer, J.R.Vadeboncoeur		8. Performing Organization Report No.
9. Performing Organization Name and Address Commonwealth Research Corporation 11703 Bowman Green Drive Reston, Va. 22090		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFR53-80-C-00091
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Research and Development Washington, D.C. 20590		13. Type of Report and Period Covered Final Report November 1981
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Commonwealth Research Corporation developed the concept of an onboard diagnostic system for monitoring railroad-car fault conditions. It consists of onboard sensors and onboard radiofrequency transmitters to telemeter data to receivers monitored by train-operating personnel.

This report describes a series of tests to determine the utility of the new method of railroad data transmission in simulated operational railroad environments. These tests were conducted at the Transportation Test Center (TTC), Pueblo, Colorado.

These tests involved installing different configurations of electronic equipment and instruments on freight cars, passenger cars, and locomotives on-site at the TTC. Telemetry data were then gathered during regularly scheduled test operations of freight and passenger consists.

The tests show that the new method of railroad data telemetry provides practical means of telemetry of data associated with railcar component testing and indications of railcar fault conditions in railroad-operating environments. It was found that certain railroad track features and conditions, such as rail flaws may be detected and measured using this method.

17. Key Words railroad data transmission, railcar fault conditions, hazard detection, waveguide	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Serivce, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	36	

Form DOT F 1700.7 (8-72)

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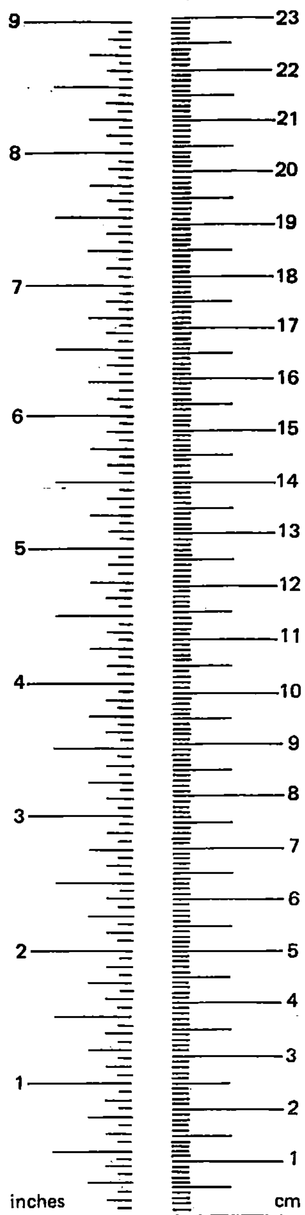
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

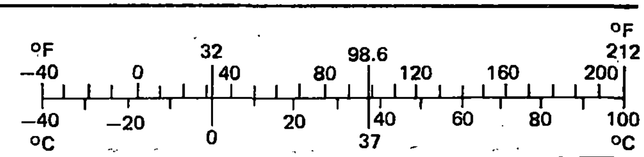
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight 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	36	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



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I. BACKGROUND

A report entitled Concept Demonstration of a New Method of Railroad Data Transmission was delivered to the Federal Railroad Administration (FRA) by Commonwealth Research Corp. (CRC) in January 1981. That report presented the results of both theoretical studies and static field tests of a newly patented method of railroad data transmission.

The method is based on the concept of using the undercarriage of railcars and the supporting track structures as an effective radiofrequency (RF) waveguide. The results of the static tests indicated that there is a high probability that the waveguide technique and modifications of that technique could be used to improve the transmission of RF and measurement data for rail passenger equipment.

To confirm these results in dynamic, simulated railroad operating environments, FRA authorized additional testing of this concept at the U.S. Department of Transportation Transportation Test Center (TTC) in Pueblo, Colorado. This report presents the results, methods, and analyses of these dynamic tests.

II. TEST OBJECTIVES

The potential advantages of this new method of railroad data telemetry are: (1) very low transmitted power, which simplifies the requirements of Federal Communications Commission (FCC) licensing; (2) elimination of interconnecting wires through the consist, which provides a convenient means of transmitting an indication of railcar-fault condition, such as a brake failure or an overheated bearing, to the on-board crew in the locomotive or caboose; (3) convenience of transmitting test data from transducers mounted on a railcar to a central monitoring point elsewhere in the train.

A set of objectives were defined by the Federal Railroad Administration (FRA) for consideration in this dynamic-testing phase. These objectives were a test of the concept under close-to-actual railroad operating conditions and an analysis of the data to determine: (1) effects of various types of track configuration and geometry (i.e., ballast, ties, switch points, grade crossings, crossovers, etc.) on received signal strength; (2) effects of train length and train velocity on received signal strength; (3) the most economical and reliable antenna configuration and location for transmitting and receiving data; (4) the extent of any interference on existing railroad equipment; and (5) design guidelines for the actual design and implementation of the system.

III. TEST EQUIPMENT

The equipment arrangement shown in Figure 1 was used to determine the relative signal strengths received during various aspects of the tests. The separation between the receiver and transmitter antennas varied between 35 and 550 feet. In some instances, the transmitter and its attached antenna were either mounted on undercar structural members or clamped to the axle, as shown in Figures 2 and 3.

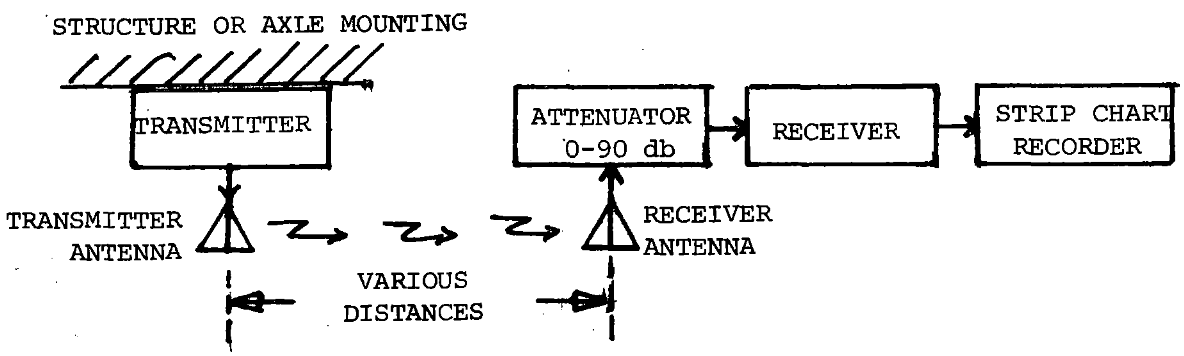


FIGURE 1. BASIC TEST EQUIPMENT ARRANGEMENT.

On the basis of the static tests results and the physical mounting requirements, the receiver antenna was mounted about 6 feet above the ground, perpendicular to the side of the car, as shown in Figures 4 and 5. The receiver, attenuator, and strip chart recorder were located inside the car, as shown in Figure 6.

Transmitter

The transmitters used for this test were two small battery-powered, crystal-controlled units operating at 154.4562 and 154.47875 MHz with output power of about 2 milliwatts. As shown in Figures 2, 3 and 7, they were contained in a small metal case with an attached "rubber ducky" antenna that can flex without either breaking or permanently deforming.

The transmitter designed and fabricated for the tests can operate continuously for up to 8 hours on a single battery charge and can withstand the substantial centrifugal forces -- moving at up to 120 miles per hour -- involved in mounting it on the axle of equipment. Since substantial shock and vibration could be experienced by the transmitter when it was

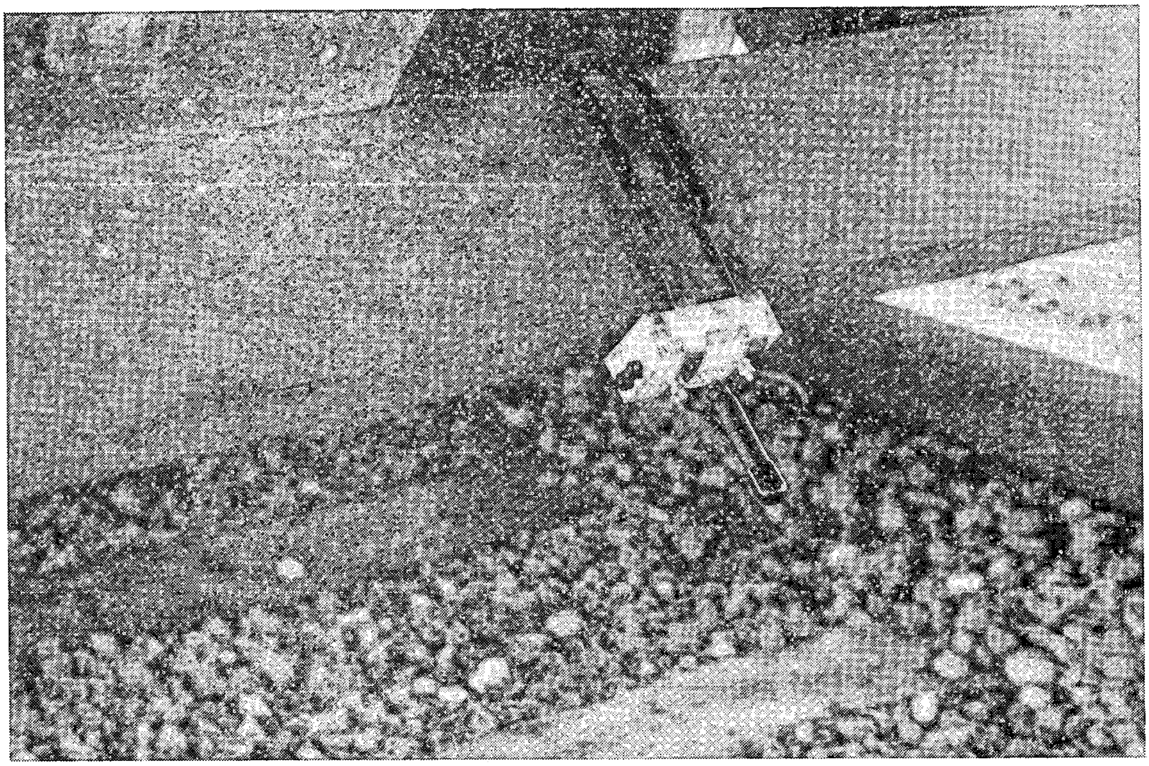


FIGURE 2. TRANSMITTER LOCATED ON AN UNDERCAR STRUCTURAL MEMBER.

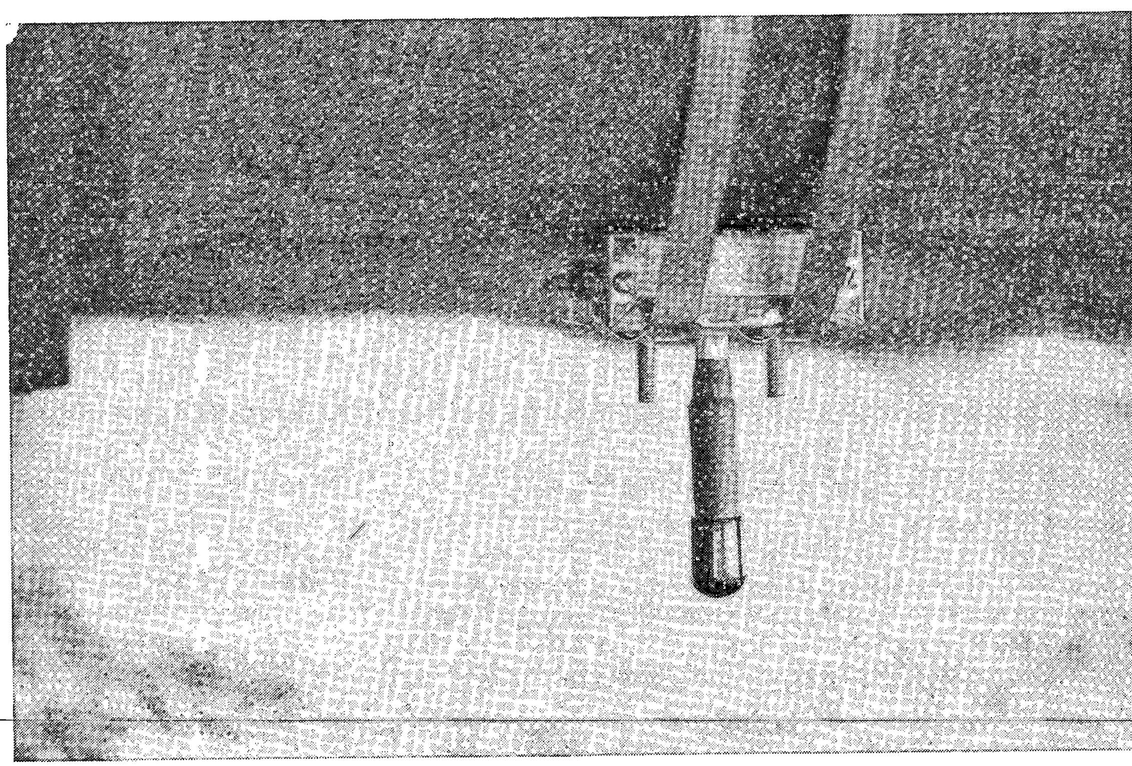


FIGURE 3. TRANSMITTER LOCATED ON AN AXLE.

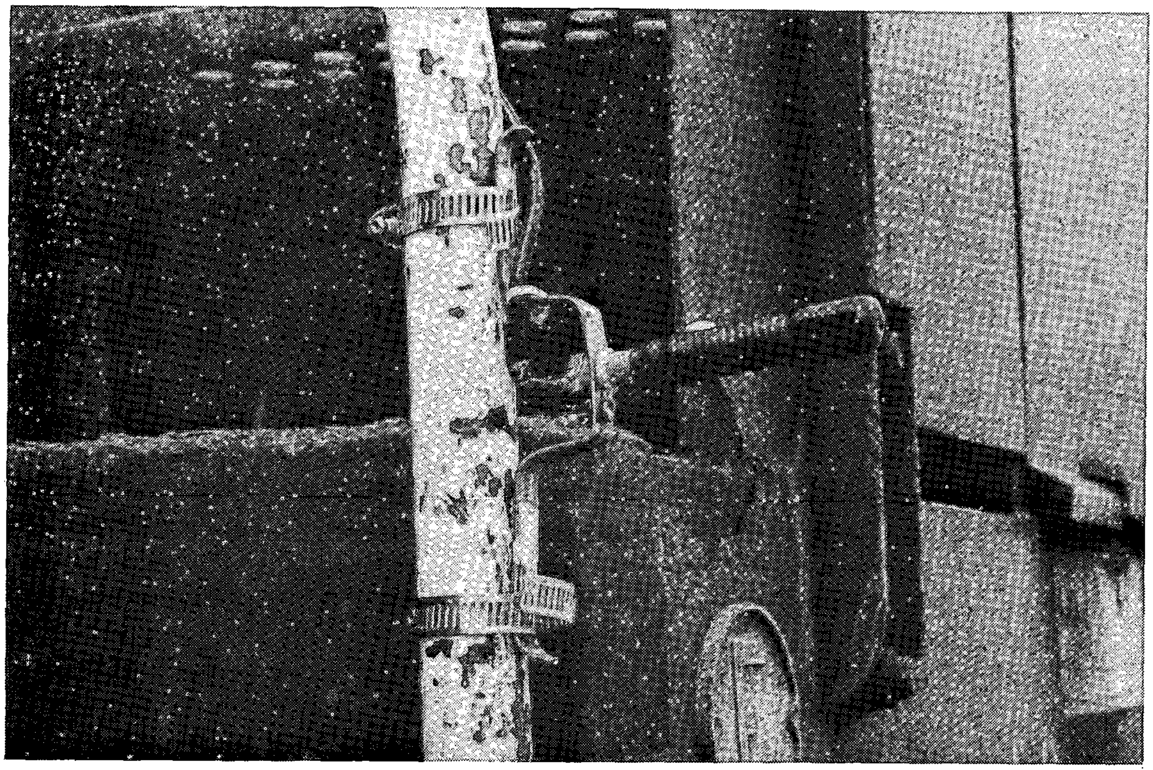


FIGURE 4. RECEIVER ANTENNA MOUNTED ON HAND RAIL OF LOCOMOTIVE.

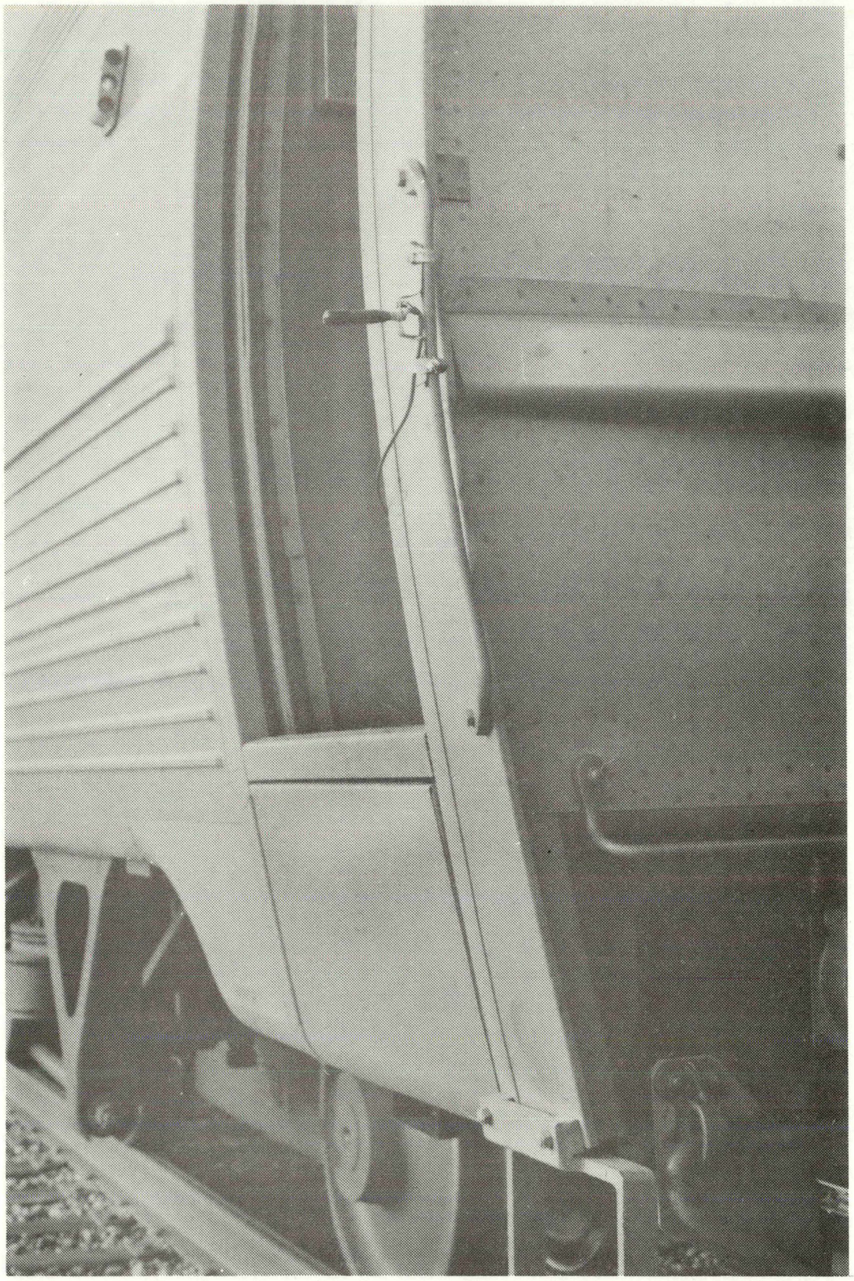


FIGURE 5. RECEIVER ANTENNA MOUNTED ON HANDRAIL OF AN AMTRAK COACH.

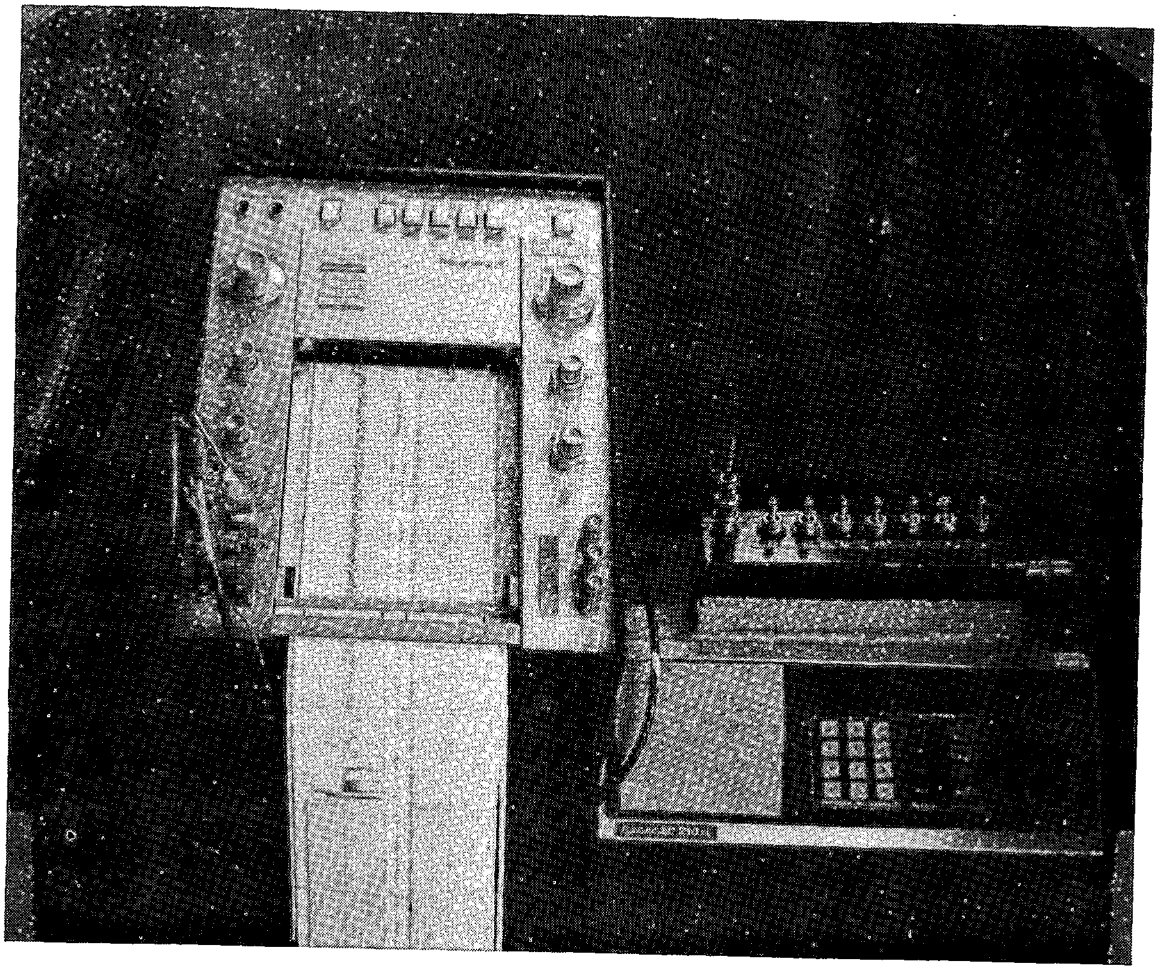


FIGURE 6. RECEIVER, SWITCHABLE ATTENUATOR, AND STRIP CHART RECORDER.

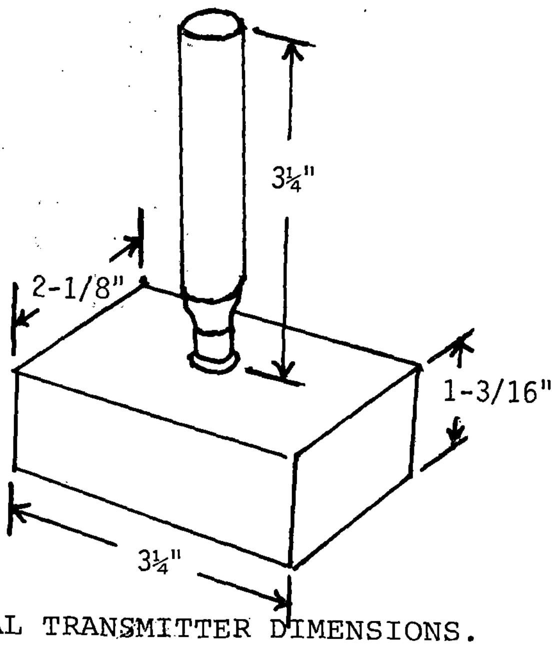


FIGURE 7. TYPICAL TRANSMITTER DIMENSIONS.

directly affixed to the railcar axle, the transmitter components were encased in silicon rubber to assure reliable functioning during the tests.

During the tests, minimal vibration or centrifical force-related problems were encountered with the two test transmitters. For long-term use, additional hardening would probably be necessary to reduce further the long-term fatigue that might result from the shock and vibration felt on the undercar structures.

The transmitter was mounted either on the axles or on the frame members of the railway equipment by stainless steel straps similar to those used for hose clamps (see Figures 2, 3, and 7). These stainless steel straps are ruggedly constructed and appeared to be completely satisfactory for the mounting of the lightweight transmitters.

Receiver

Since more than one transmitter might be operating at one time on adjacent frequencies, it was necessary to distinguish between the transmitters. The crystal-controlled transmitters used for the tests have good stability. However, because of the inherent drift involved in most tunable VHF receivers and spectrum analyzers, it was necessary to use a crystal-controlled receiver, such as the commercially available frequency synthesized scanners that monitor VHF and UHF frequencies. In this particular test, a Bearcat 210 XL scanner was modified to fulfill the receiver function.

After the first test, it was determined that the best method of using this type of receiver was to connect the strip chart recorder into the internal squelch signal strength line so that the actual received signal strength could be monitored without its amplitude being affected by the automatic gain control circuitry. The output of the receiver was fed in to a strip chart recorder with a frequency response characteristic of approximately 100 Hz. Additional filtering was provided on the output line in order to reduce this frequency response to prevent excess cluttering caused by receiver and types of noise.

IV. TEST METHODS

The first step in preparing for the tests involved mounting the transmitters. In accordance with the test requirements, these were attached either to an undercar structural member or on an axle. Once the transmitter was installed, its power switch was turned on, and a battery-powered digital frequency counter was used to determine proper on-frequency transmitter operation. Next, the serial numbers of the cars between the transmitter and the receiver were recorded. This allowed a determination of the distance between the transmitter and receiver antennas by checking the individual car dimensions on file at the Transportation Test Center (TTC).

Once the receiver antenna, power, and recorder connections were made, the receiver was calibrated by tuning to the transmitter frequency with the maximum signal strength and then keying this frequency into the receiver's memory.

Next, a variable attenuator was switched through its entire range (0 to 90 db) with the strip chart recorder attached to the receiver's internal squelch signal strength line. Because of the limited dynamic range of the squelch signal strength line, it was necessary to set the attenuator in the middle of the range of anticipated signal strengths during the actual running tests. In some cases, this had to be further adjusted, while the train was moving to prevent saturation or "bottoming-out" of the squelch signal strength voltage on different track sections.

The strip chart recorder equipped with an event marker plotted an exact recording of the passing of physical features such as mileposts and section markers. This permitted good correlation between the received signal strength and the physical position on the track.

V. TEST RESULTS

Three sets of tests were conducted at the Transportation Test Center (TTC). The first set involved high-speed electrified passenger equipment on the 15-mile Railroad Test Track. However, because that equipment was unavailable on later dates, the second and third tests used freight car equipment on the 4.8-mile long loop used for Facility For Accelerated Service Testing (FAST).

First Test Set

During the first 1-day test, a single transmitter was mounted about 275 feet from the receiver, first on an undercar valve body of passenger car #21018, then on the axle, as shown in Figure 8.

This test was conducted to examine the audio output signal amplitude from the receiver. The transmitter was designed to have a low-level tone modulation (5 percent) for identification, so that the receiver would provide an audio output. This audio signal was rectified and used to feed the strip chart recorder, thus providing an indication of signal amplitude.

It should be pointed out that the Automatic Gain Control (AGC) of this receiver was not disabled for this test series. Thus, a considerable amount of amplitude variation did not show because of the AGC circuitry. During the last part of the test compensation was made by connecting the transmitter to the axle and reducing the attenuation to zero. With the transmitter in this location, the rotation of the axle caused the transmitter signal strength to change much more quickly than could normally be corrected by the AGC system.

This test series resulted in the strip of data shown in Figure 10. The strip of data, while considerably cluttered with noise, seemed to correspond to some of the physical features found on that section of track.

The results of this part of the test were rather uneventful. The receiver AGC fully compensated for changes in path loss so that the received signal stayed fairly constant. One interesting event did occur. The background noise, or interference, on two occasions exhibited a "zero-beating" characteristic, as shown in Figure 9. The source of this interference and the train operation feature that may have produced it was not determined.

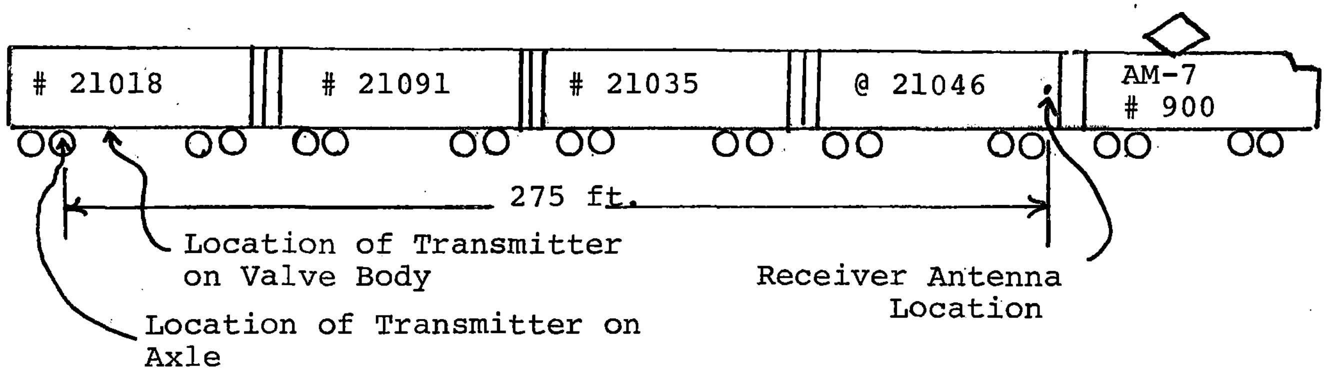


FIGURE 8. EQUIPMENT LOCATION DURING THE FIRST TEST USING PASSENGER EQUIPMENT.

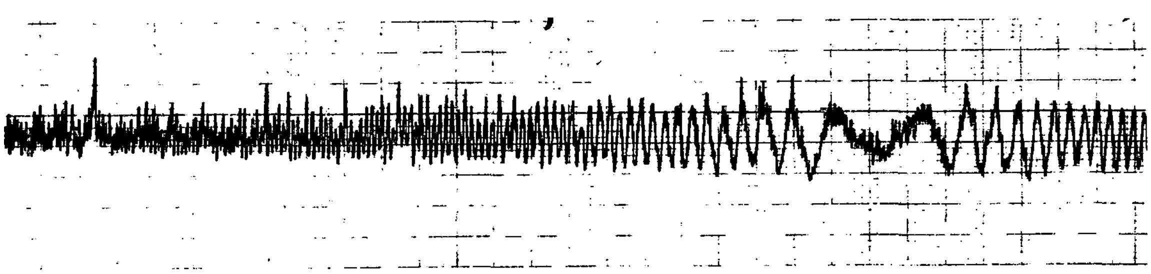


FIGURE 9. APPARENT ZERO-BEATING OF THE RECEIVER INTERFERENCE NOISE SIGNAL.

The tests conducted when the transmitter was connected to the axle did produce interesting results that hinted at some additional uses of this data transmission method. This part of the test also showed that some changes were necessary in the procedure. The transmitter was very lightly modulated (about 5 percent) since the amplitude modulation was intended to be used only for identification purposes, and it was desirable to minimize any modulation sidebands. However, with the loss of the received signal for only a short time, the squelch would not immediately cut out the background noise, which would then come through very strongly for a short period. To overcome this problem, the attenuation was reduced to zero so that the AGC and squelch controls were continuously saturated.

Figure 10, a typical portion of the tape recorded on this run, shows use of the audio output as the signal source for the strip chart recorder. The event markers were inserted on the tape upon passing each 1,000-foot roadside marker. The number on the marker was then recorded manually at approximately the same position on the chart. As can be seen in Figure 10, the signal base line held fairly constant with additional noise or signal loss, resulting in an upward deflection caused by noise; but, in others, it appeared to be caused by physical features on and around the track.

Figure 11 shows the change in the base line level as the train slowed to a stop. Each signal cycle at the right side of the figure represents one rotation of the axle. The vertical "spikes" were caused by noise probably related to the catenary system. Later tests indicated that these speed-related cycles represented about a 9-db shift in signal strength.

Obtained from two consecutive runs, the chart strips in Figures 12, 13, and 14A exhibit similar patterns. Figure 14A is of particular interest since the pattern shown between mileposts 22 and 23 seems to be caused by the rail flaw shown in Figure 14B. Unfortunately, no further tests on this section of track were possible, so verifying data could not be collected.

Conclusions from First Test Set

Conclusions drawn from this test period were: (1) fixed position-mounted transmitters produce reliable signals regardless of track configuration, if the receiver has an adequate gain margin and has a fast-acting AGC system; (2) the signal strength from transmitters mounted on the axle seems to show a 9-db shift depending on antenna position; (3) if the AGC system of

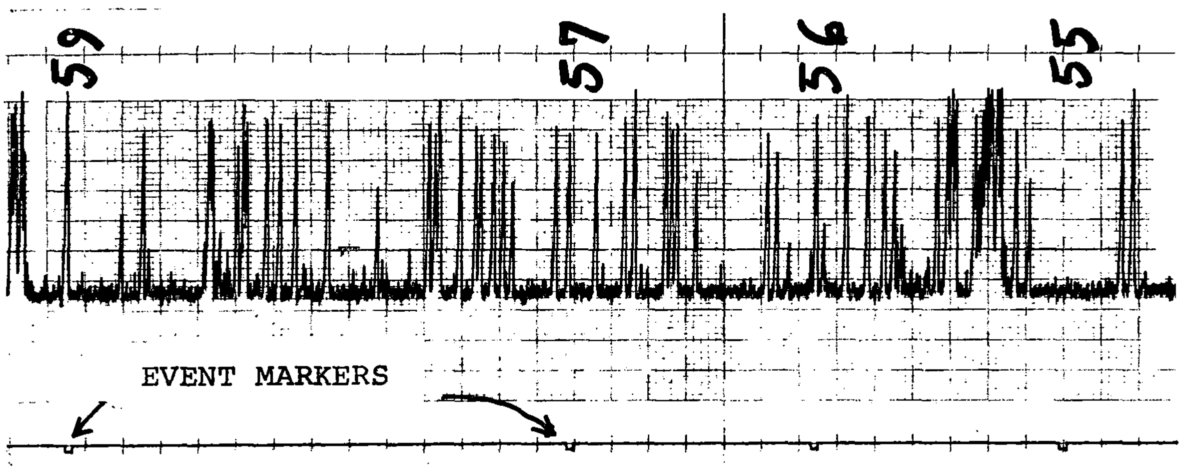


FIGURE 10. TYPICAL RECORDING FROM FIRST RUN USING 0 db ATTENUATION AND 5 MM/SEC CHART SPEED.

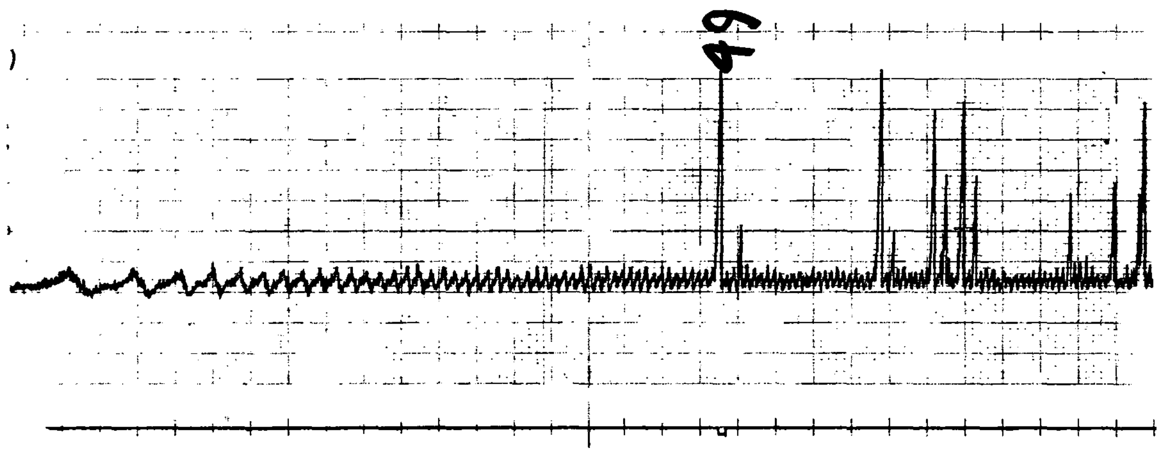


FIGURE 11. SIGNAL PATTERN PRODUCED AS TRAIN SLOWED TO STOP.

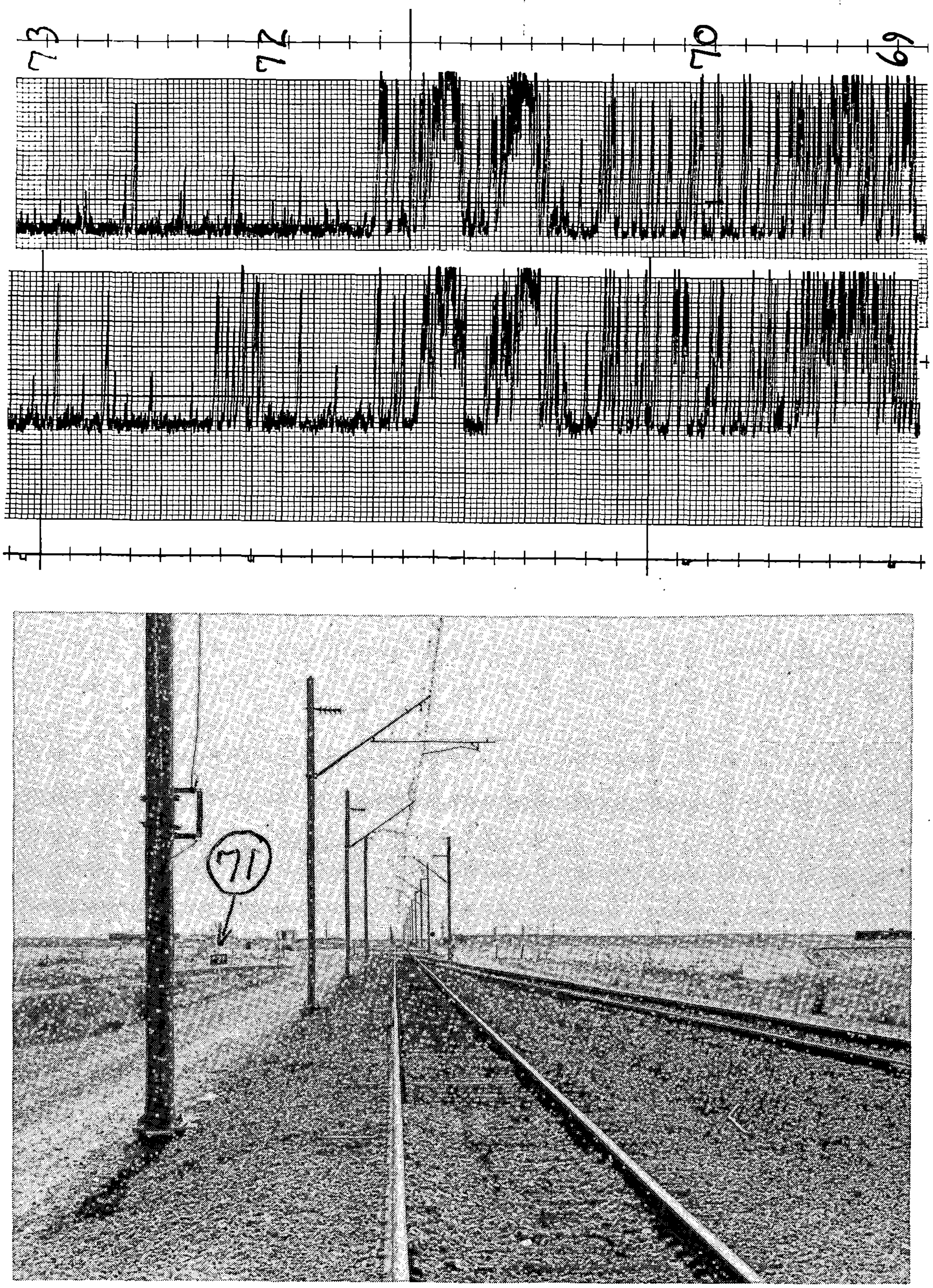


FIGURE 12. CHART RECORDINGS AND PHOTO OF AREA AROUND POST 71 (0 db ATTENUATION, 5 MM/SEC). THE DOUBLE HUMP SIGNAL APPARENTLY CAUSED BY THE TRACK TURN OUT.

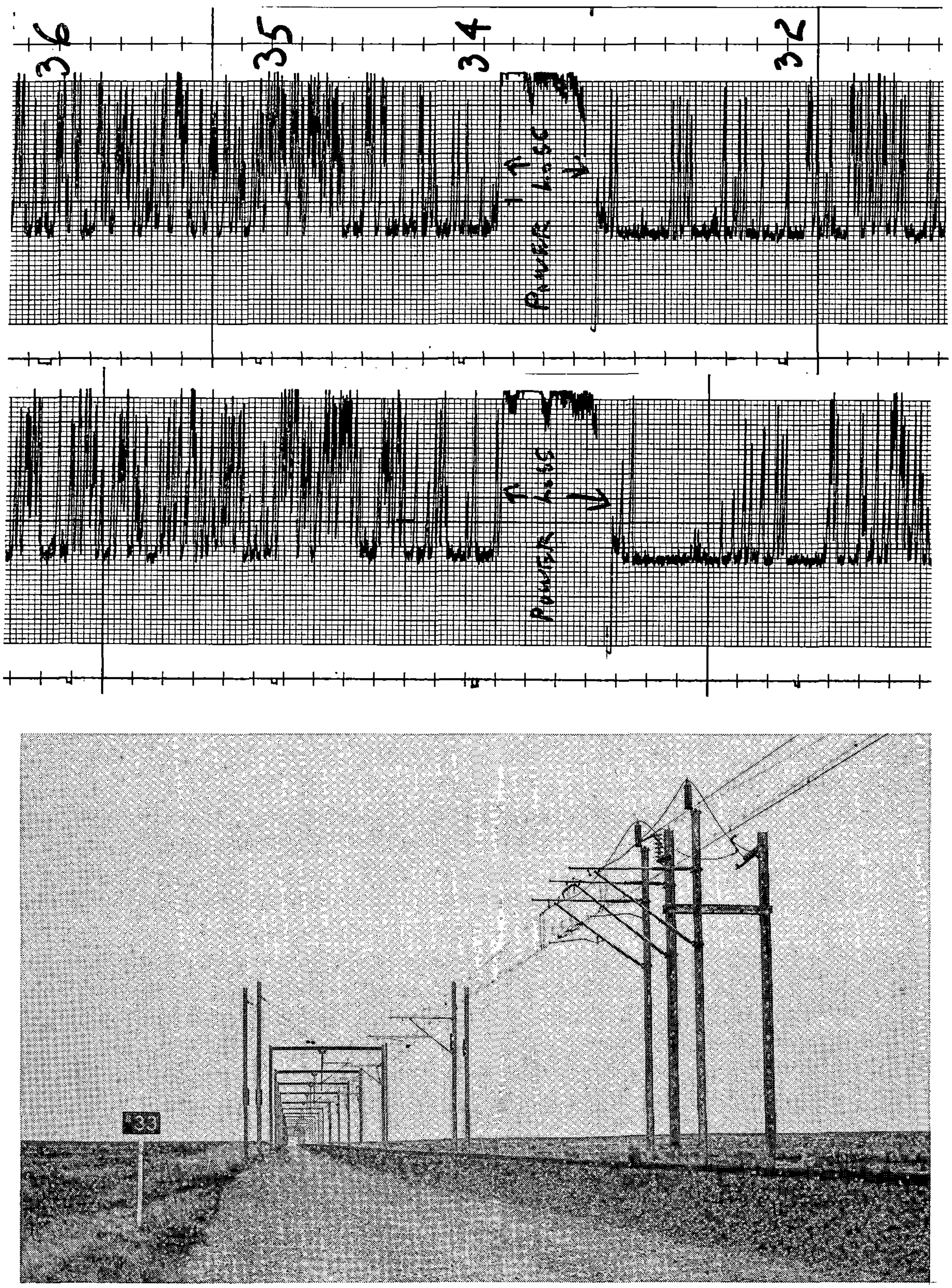


FIGURE 13. CHART RECORDING AND PHOTO AT POST 33 SHOWING CHANGE IN SIGNAL BASELINE APPARENTLY DUE TO CATENARY POLES ON BOTH SIDES OF TRACK. (0 db, 5 MM/SEC)

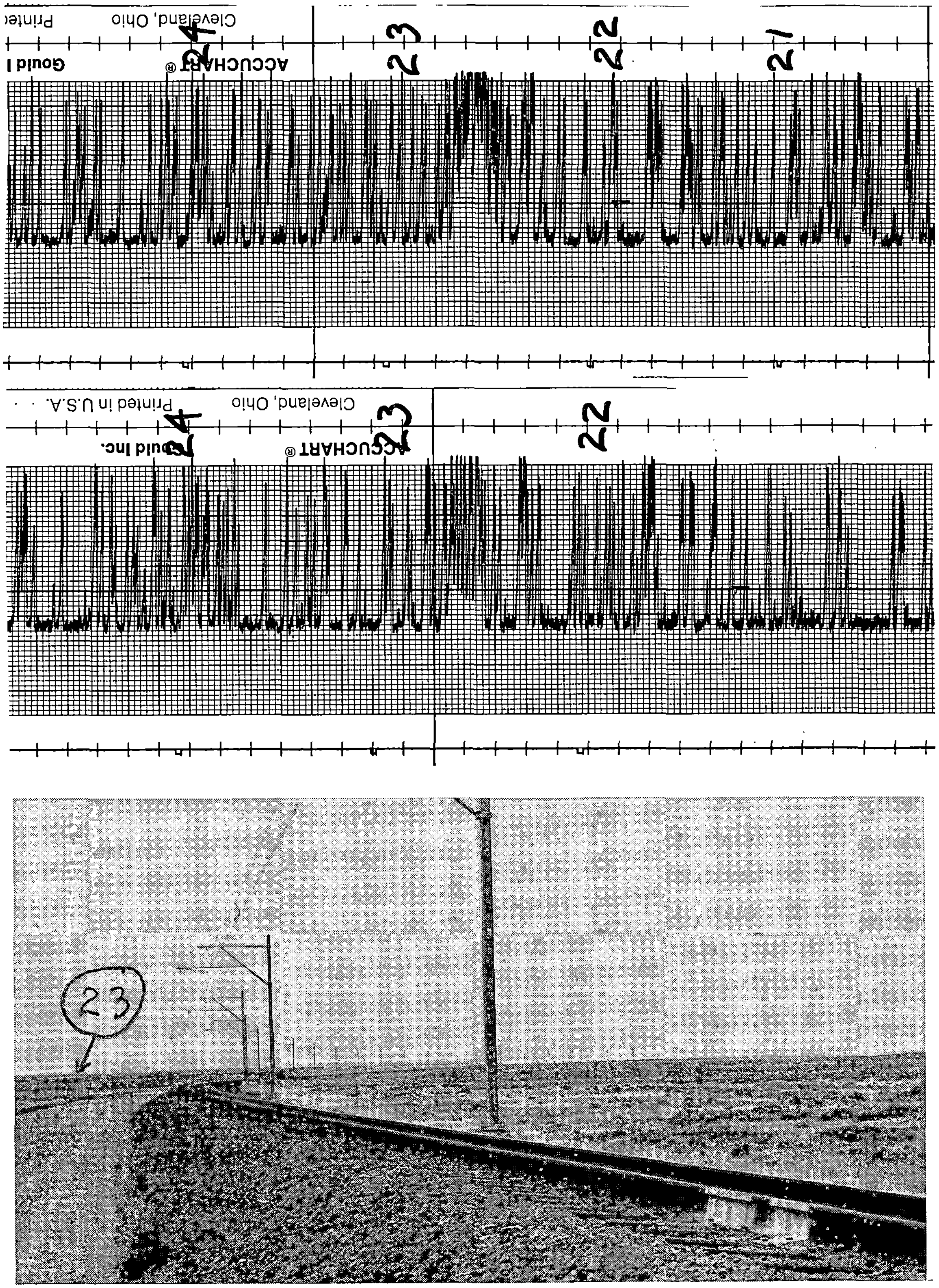


FIGURE 14A. CHART RECORDINGS AND PHOTO OF AREA BETWEEN POSTS 22 AND 23 SHOWING APPARENT INDICATION OF RAIL FLAW. (SEE FIGURE 14B FOR CLOSE-UP PHOTO) (0 db, 5 MM/SEC)

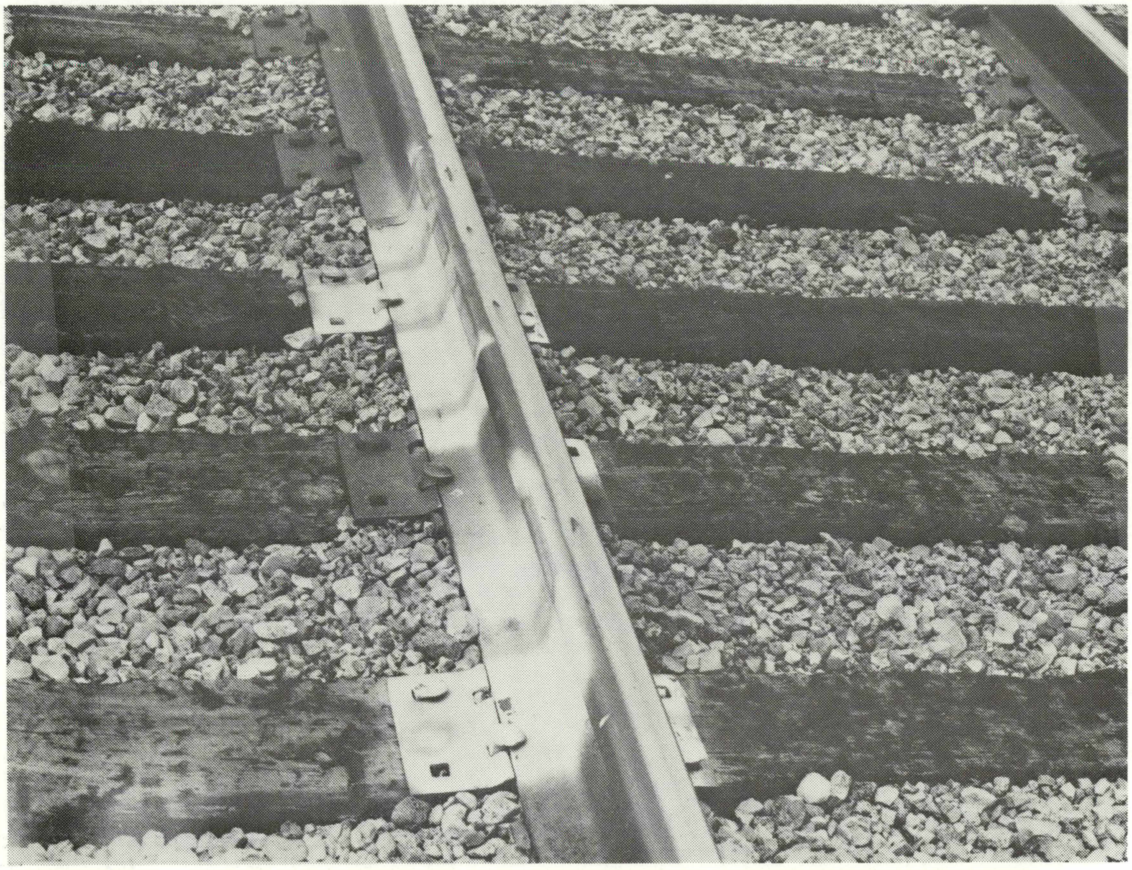


FIGURE 14B. RAIL FLAW BETWEEN POLES 22 AND 23.

the receiver is disabled or saturated with a strong signal, then track and surrounding area physical features will appear as amplitude changes in the output signal.

The next series of tests took these findings into consideration, and the test equipment was modified to monitor the strength of the received signal instead of the audio output.

Second Test Set

The second set of tests at the TTC were conducted on May 28 and 29, 1981. These tests utilized the FAST track equipment since operations of the high-speed passenger equipment had ceased. To operate the test equipment in a FAST locomotive, a converter was required to convert the normal train electrical power to 110 v AC. In the first day of FAST tests, the set-up was the same as the first test set and proved relatively uneventful. The results were similar to those encountered on the passenger equipment.

The next day, the receiver was modified to monitor the squelch level voltage. Also, a second transmitter was added, as shown in Figure 15. Then, tests were conducted with both the transmitters attached to the axles, as was done with the

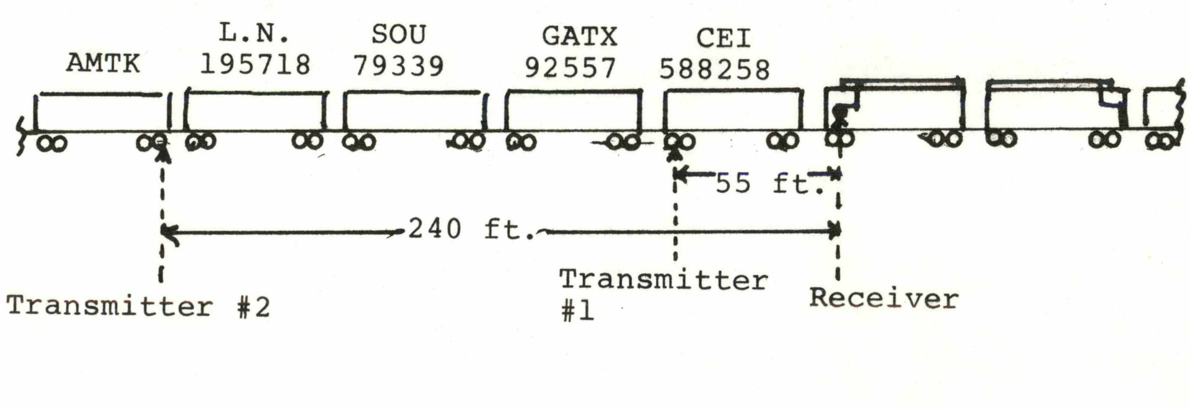


FIGURE 15. FIRST SERIES OF TESTS USING FAST EQUIPMENT.

passenger equipment. The results continued to show that reliable transmission could be maintained to a receiver in the cab, from a transmitter on a rotating axle, even with a substantial amount of attenuation inserted in the receiver antenna line. Results also continued to show that the signal strength varied in repeatable and predictable fashion, depending upon the particular section of track.

[Transmitter No. 2 developed an intermittent operating difficulty that prevented its further use for this run; and, only transmitter No. 1 was used.]

Figures 16 and 17 present the results of different runs with the recorder set at various speeds in order to magnify the horizontal axis. The effects of the rotation of the axle can be seen in Figure 17.

Since the signal modulation associated with the rotation of the axle obscured data that might otherwise be available by looking at the amplitudes of the signal, it was decided that the final test set should be conducted using transmitters mounted both on the axle and in a fixed position on the car body.

Third Test Set

The third test set was conducted on June 11 and 12, 1981. On the first day, the tests compared the signals from the rotating and the stationary transmitters at approximately the same distances from the receiver and determined any differences in received signal strength. The equipment arrangement for these tests is shown in Figure 18. Transmitter No. 1 was located on the forward axle to the rearmost truck of a railcar, four cars back from the locomotive (a distance of approximately 240 feet). Transmitter No. 2 was located in a fixed position underneath the car at approximately 235 feet. The positioning of transmitters No. 2 and No. 1 is shown in Figures 2 and 3, respectively.

The receiver antenna was installed on the handrail of the locomotive, as shown in Figure 4. The receiver equipment was arranged in a manner similar to that shown in Figure 6. For the preliminary setup, the receiver was tuned to the frequency that provided the maximum amplitude from each transmitter. That frequency was then placed onto the receiver memory so that it could be easily tuned from one frequency to the other. Since the receiver was crystal controlled, the stability was quite good and retuning was not required once the frequency of maximum signal amplitude was determined.

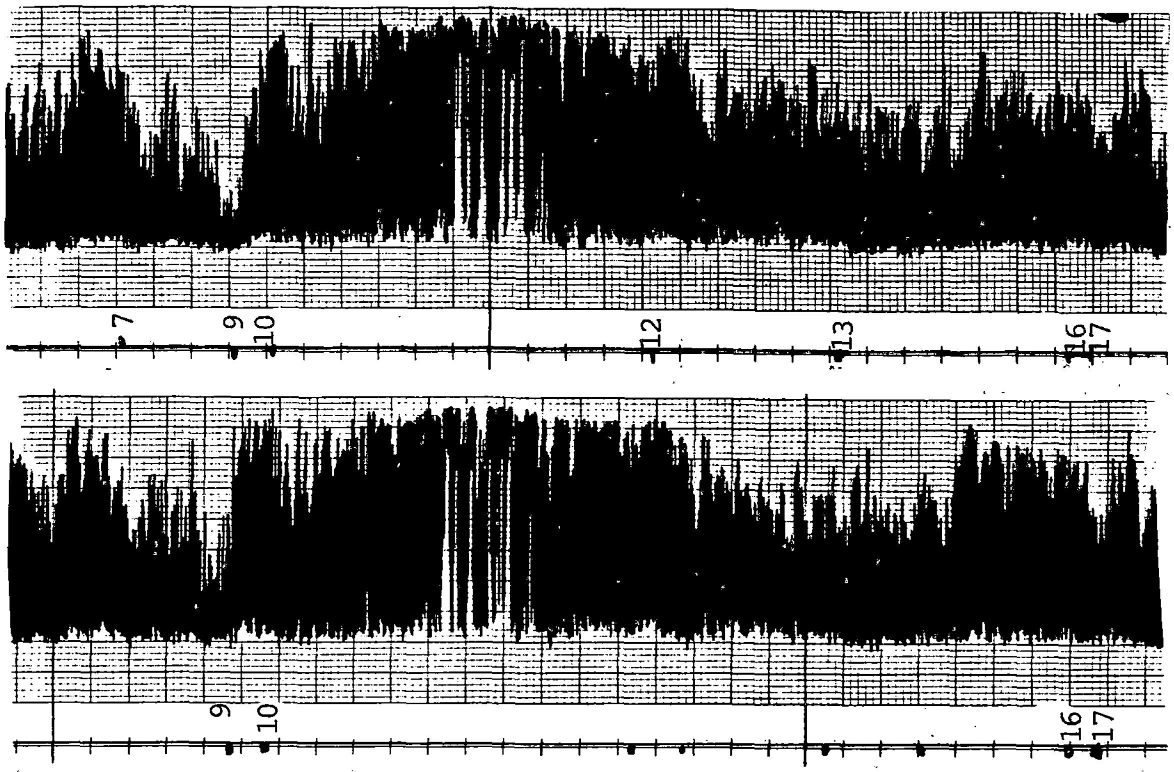


FIGURE 16. PORTIONS OF CHART RECORDINGS OF SIGNAL RECEIVER FROM TRANSMITTER #1 ON TWO CONSECUTIVE ROUND TRIPS.

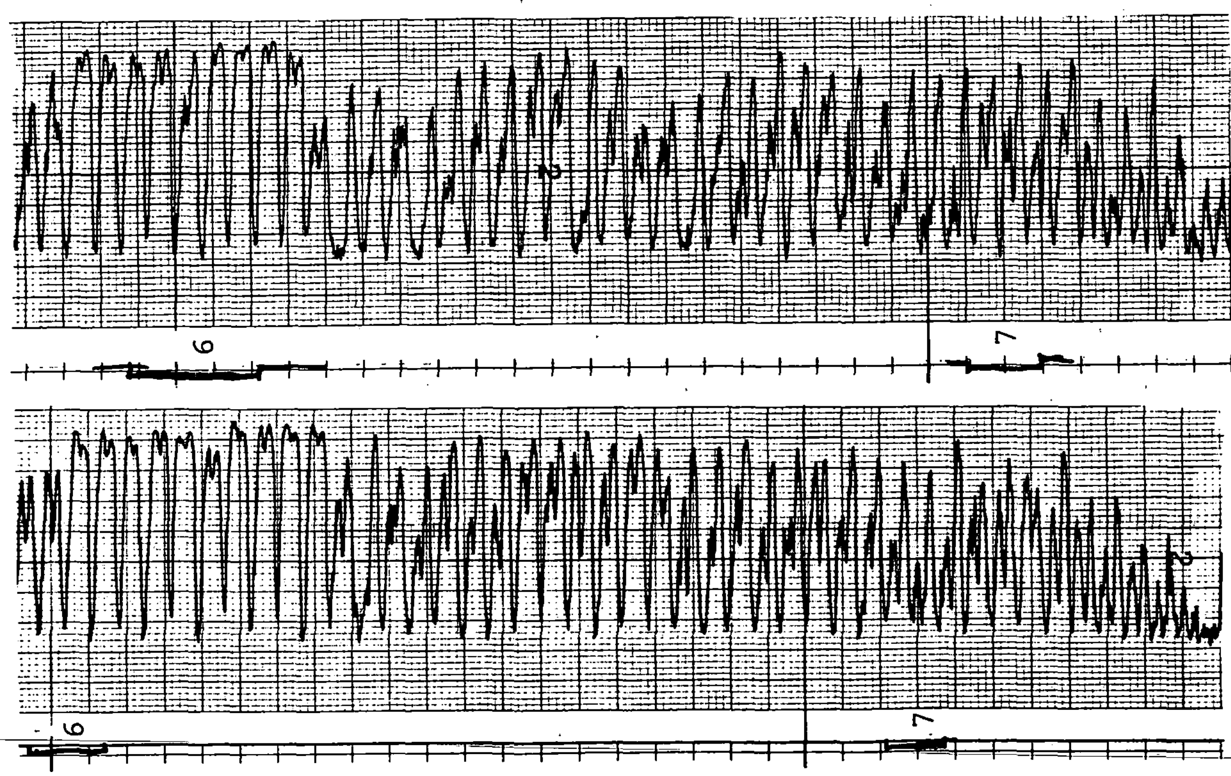


FIGURE 17. PORTION OF CHART RECORDING FROM SECTION 6 ON TWO CONSECUTIVE RUNS. (CHART SPEED 25 MM/SEC)

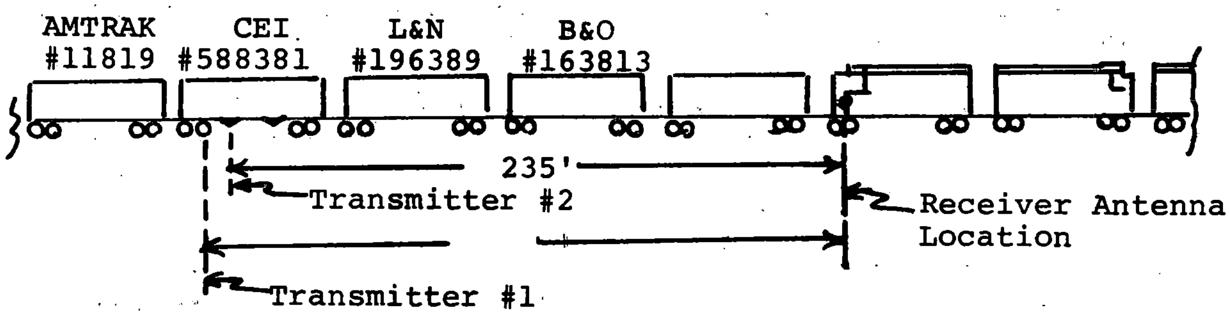


FIGURE 18. TEST SET UP FOR THE FIRST DAY OF THE FINAL TEST SERIES.

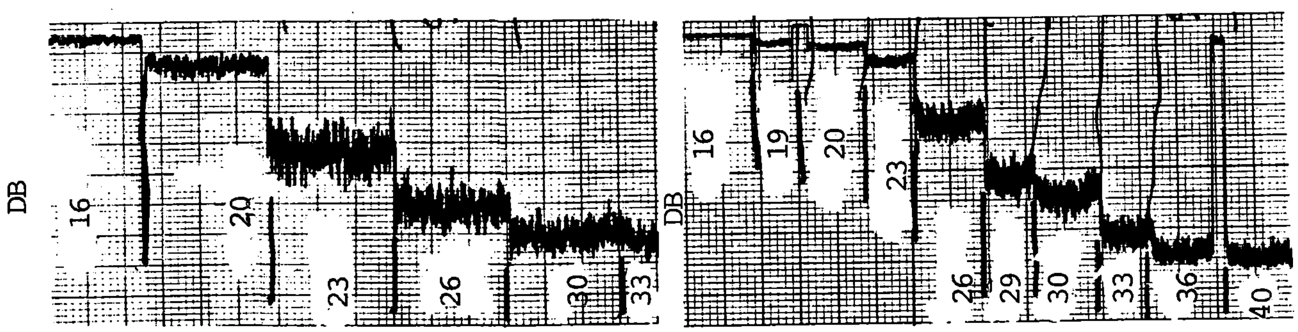


FIGURE 19. ATTENUATION CALIBRATION CURVES FOR FIRST RUN OF FINAL TEST SERIES SHOWING RECEIVER SQUELCH SIGNAL VOLTAGE.

The next step was to switch through the attenuation ranges for each of the transmitter frequencies. These results are shown in Figure 19 -- the successive degrees of attenuation were switched into the receiver antenna line to force it from minimum to maximum signal strength. This range of attenuations then serves as a basis for providing calibrations to the actual strip chart recordings shown in Figure 20.

During these tests, the attenuation was varied to obtain an optimum range of signals for the receiver. This was required because of the limited dynamic range of the receiver squelch signal voltage system.

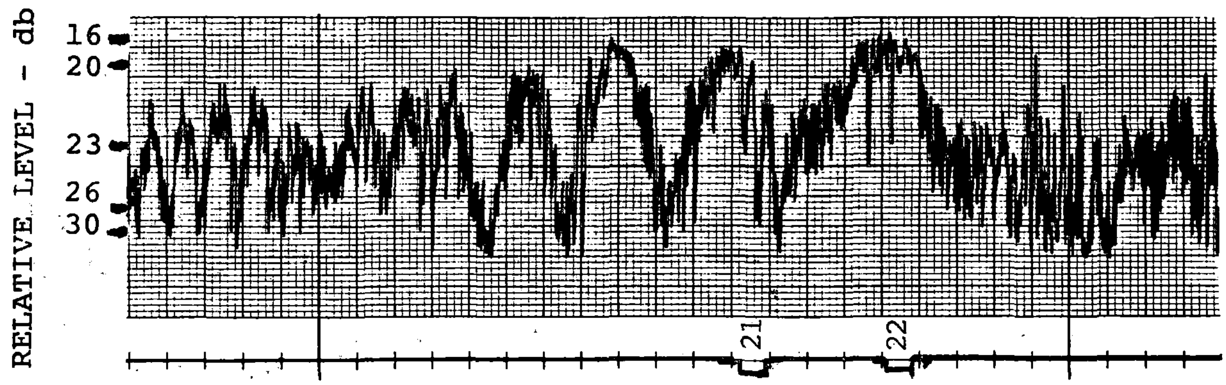
The results of these tests showed that a rotating antenna on the axle had signal fluctuations from a 9 to 12 db range, which were similar to the results of an earlier test using the passenger equipment.

As shown in Figure 20, the signal fluctuations of both the fixed and the rotating antennas exhibit approximately the same patterns at the same locations. Obviously, the amount of clutter on the trace from the fixed-position antenna indicates that if variations of signal transmission strengths are of prime importance then a fixed rather than a rotating antenna would provide a more thorough picture of the changes in signal strength.

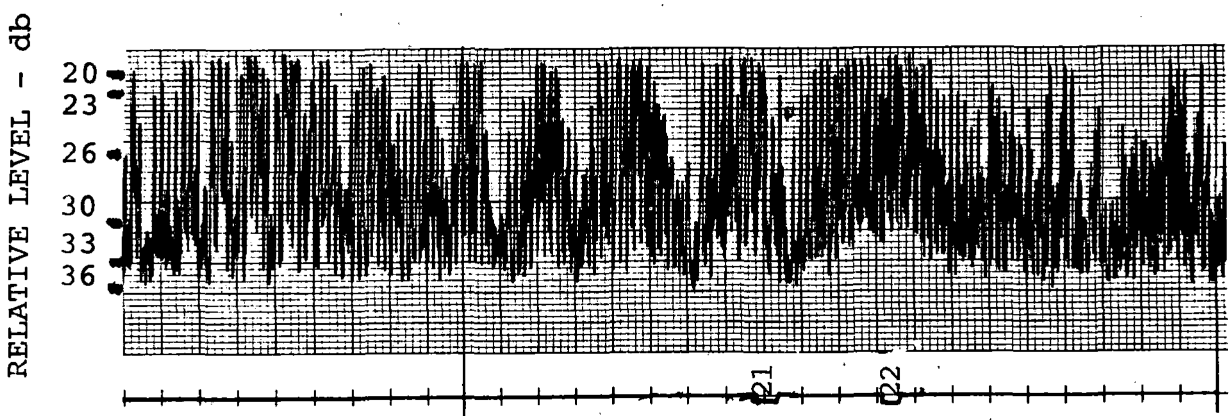
The last day's test further explored the signal variations that could be expected with the transmitters in fixed locations and at various distances from the receiver. In the previous day's test, the transmitter was installed four cars away from the receiver. In this test, one transmitter was located 11 cars in back of the receiver; the other transmitter was located on the car preceding the receiver. As shown in Figure 21, the distance was 35 feet for transmitter No. 1 and 550 feet for transmitter No. 2.

In making the calibrations, the chart in Figure 22 was established for the relative attenuation for transmitter No. 2.

Repeated attempts to establish a similar curve for transmitter No. 1 proved futile. Later experiments indicated that transmitter No. 1 was too close to the receiver and its signal leaked directly into the receiver, bypassing the antenna and the attenuator. It was found that the signal level recorded for transmitter No. 1 would change substantially depending upon the position of the operator in the cab and the positions of the car door or windows. Repeated efforts to eliminate this problem were unsuccessful. Thus, the data from transmitter No. 1 were discarded since there was no reliable way of measuring its signal strength.



TRANSMITTER #1 (FIXED POSITION) WITH 23 db ATTENUATION IN SERIES WITH ANTENNA



TRANSMITTER #2 (AXLE MOUNTED) WITH 33 db IN SERIES WITH RECEIVER ANTENNA

FIGURE 20. RECORDINGS FROM BOTH FIXED AND ROTATING ANTENNAS APPROXIMATELY 240 FEET FROM THE RECEIVING ANTENNA.

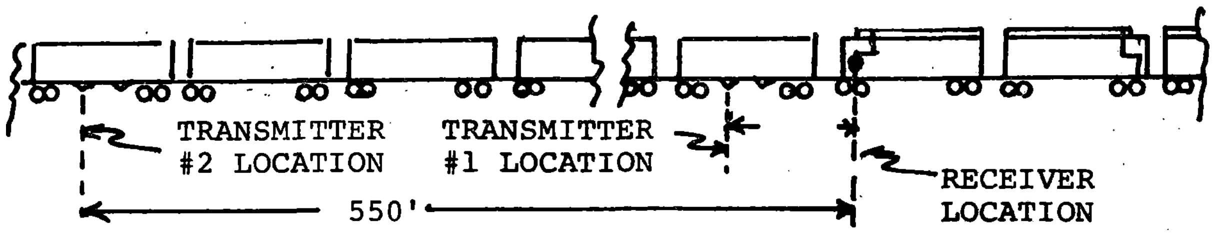


FIGURE 21. TEST SET UP FOR THE FINAL DAY OF THE LAST SET OF TESTS.

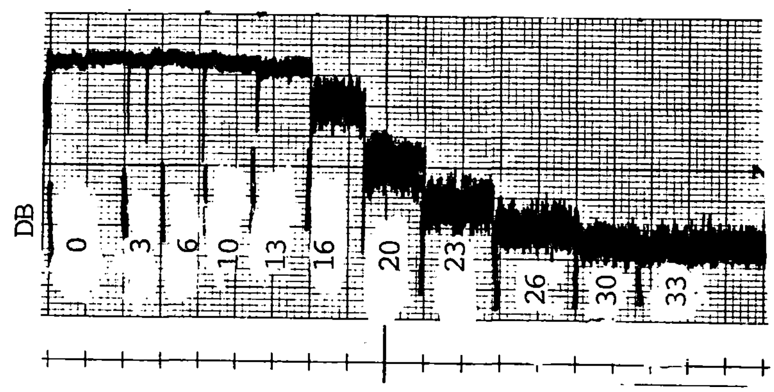


FIGURE 22. ATTENUATION CALIBRATION CURVES OF TRANSMITTER #2 FOR TEST SET UP SHOWN IN FIGURE 21.

Figure 23 shows three consecutive runs recorded at a trace speed of 25 mm/minute with a 20-db series attenuation display. These results exhibit a repeatable pattern that has superimposed on it a small noise level. The only way to eliminate this noise is to apply large filter capacitors to the recorder input, however, the capacitors also eliminated some of the desirable data. It was decided to record both the desirable data and the small noise level. It should be pointed out that when the trace was at the far left of the strip, as shown in Figure 23, the receiver squelch control voltage was basically in saturation and a stronger signal would provide no additional deflection. Thus, the areas where the signal amplitude is above 13 db should be considered as nonvalid for comparison purposes.

As Figure 23 shows, there was a repeatable signal profile on consecutive runs as a result of changes in signal strength from transmitter No. 2. The key question is: What profile of the track or track conditions led to these amplitude shifts? In an attempt to find an answer, Figure 24 was assembled using the same basic data as shown in Figure 23 except at a faster chart speed so that a more detailed analysis could be conducted.

Figure 24 presents some of the key geometric aspects of the track that may have a relevant effect on the received strength of the transmitter signal. The results of the data are very repeatable; however, reviews of both strip charts in Figure 24, available data on the fast track conditions, and a series of photographs taken of the track fail to reveal the significant correlation between established geometric aspects and the signal strength that had appeared during the first set of tests.

Perhaps unidentified FAST track features or distant signal reflections are primary causes of these signal changes. In general, the concrete ties and continuously welded rails (most of Section 17) tend to provide a stronger signal; while, in general, the curves (Section 3) tend to provide a weaker signal. Also, areas of insulated joints Sections 5, 11, and 17 seem to strongly affect the signal strength. In reviewing Figure 24, it should be noted that the transmitter was approximately 550 feet from the receiver position. As a result, the data shown in Figure 24 may be skewed by as much as 550 feet, depending upon the way a particular physical feature affects the received signal strength.

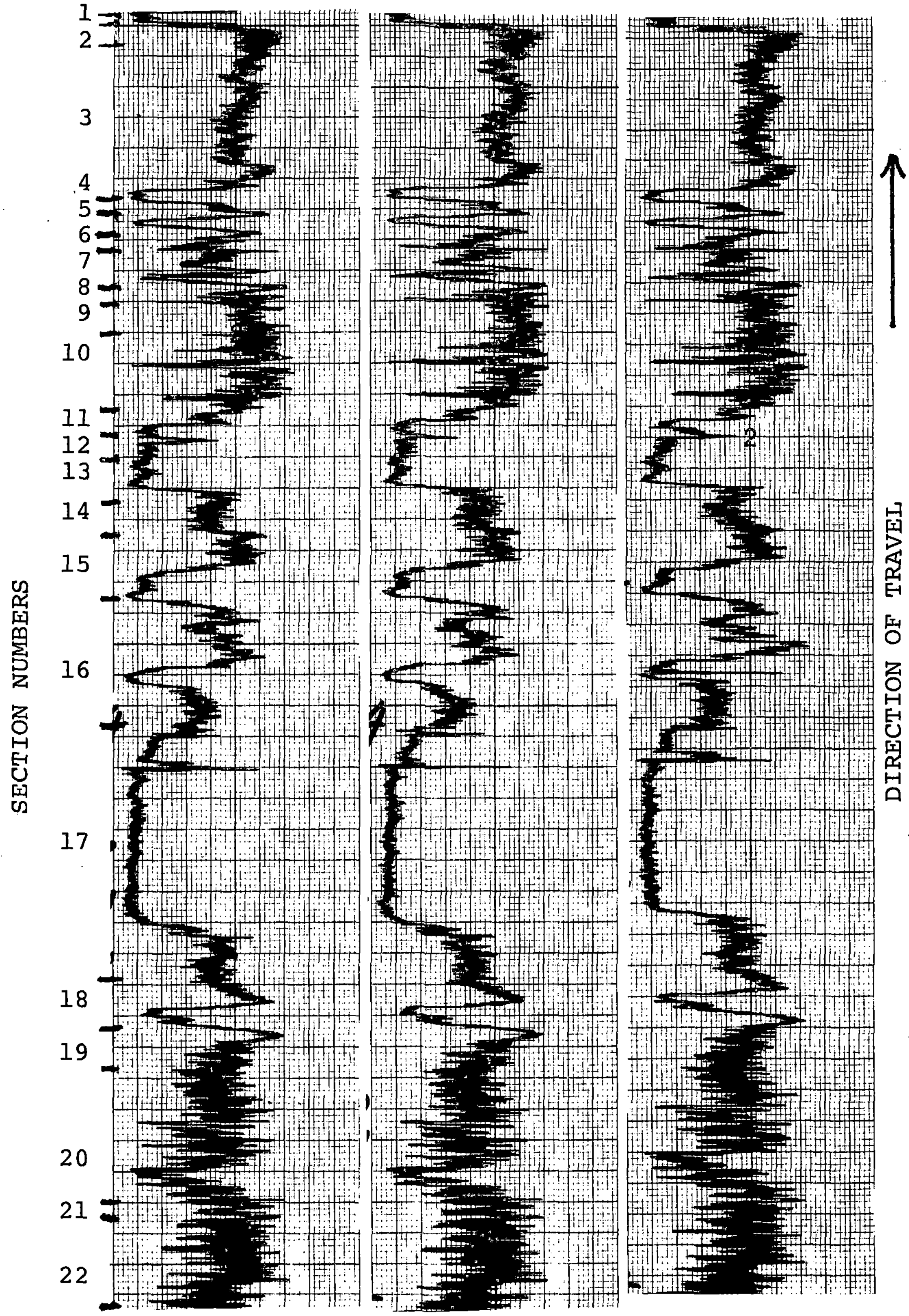


FIGURE 23. RECORDINGS FROM THREE CONSECUTIVE RUNS IN CLOCKWISE DIRECTION WITH 25 MM/MIN CHART SPEED AND 20 db SERIES ATTENUATION.

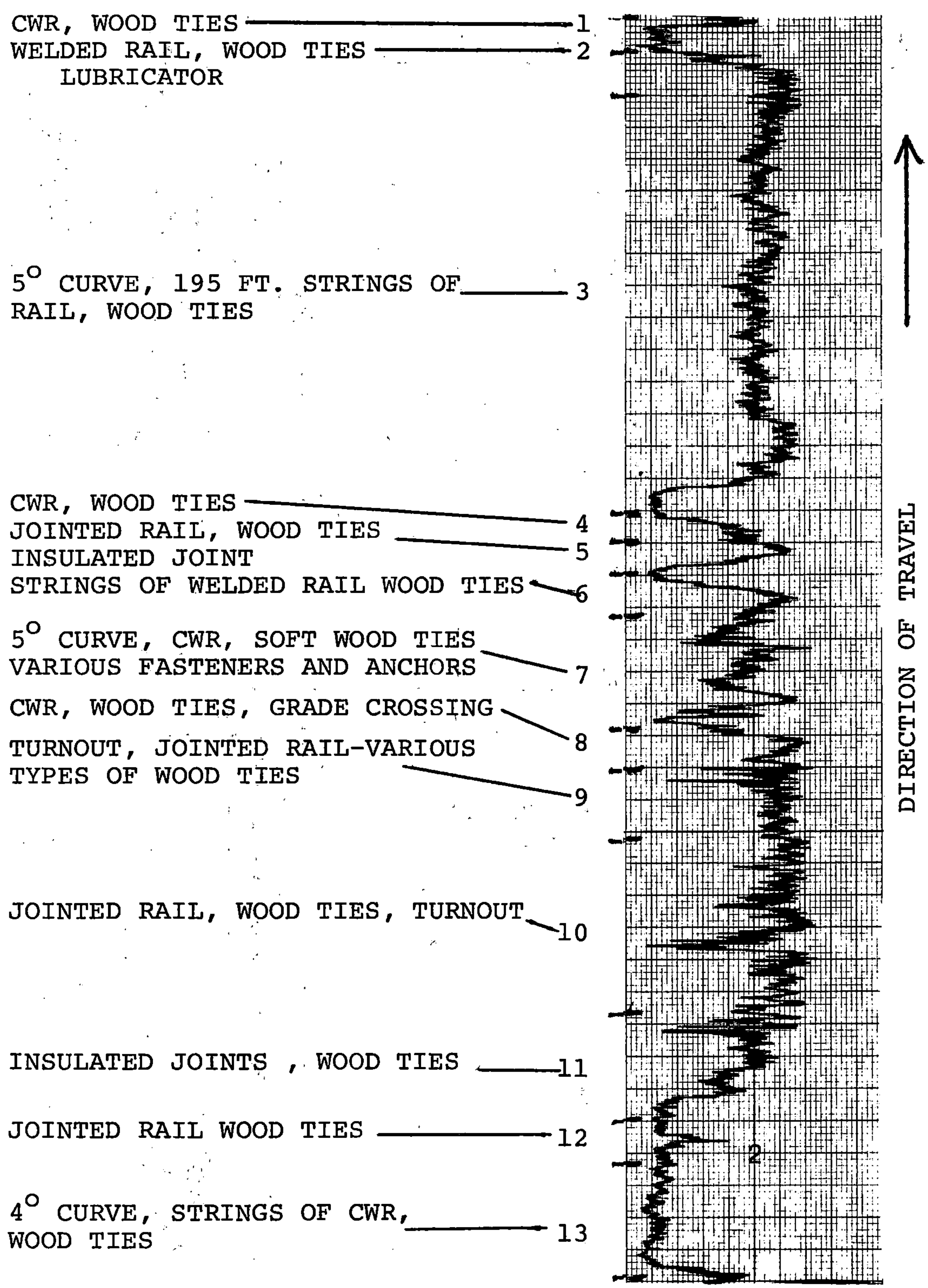


FIGURE 24. CHART RECORDING FROM FINAL RUN TAKEN WITH CHART SPEED OF 5 MM/SEC. IMPORTANT TRACK AND GEOGRAPHIC FEATURES ARE INDICATED.

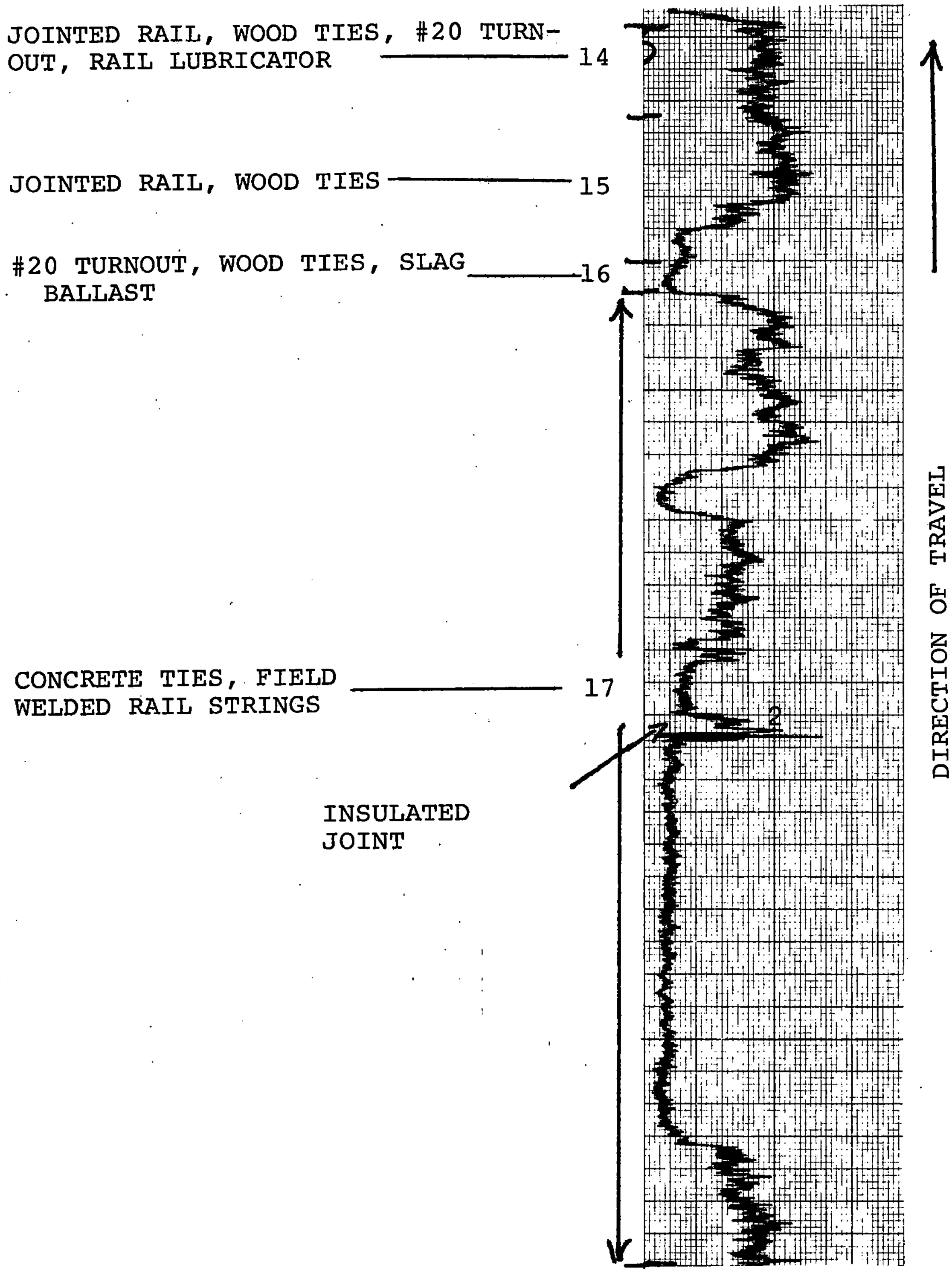


FIGURE 24. (continued)

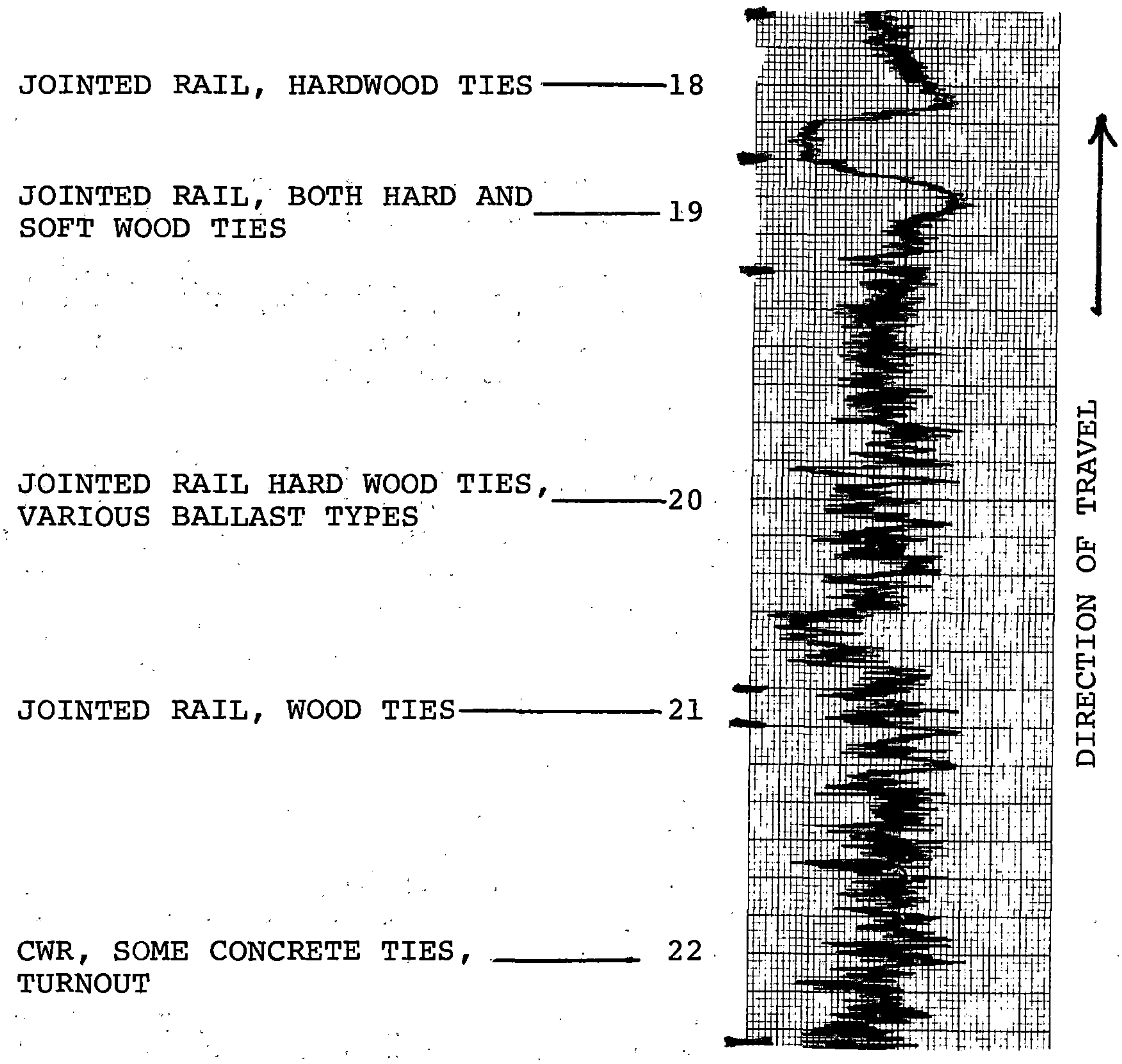


FIGURE 24. (continued)

Conclusion

In accordance with the test objectives stated in Section II, answers to specific questions can be given, as follows.

1. Effects of various types of track configuration and geometry on signal strength. The signal seemed to fluctuate over a range of up to 15 to 20 db. However, there was not conclusive identification of specific features or feature combinations that caused these changes.

2. The effect of train length and velocity on signal strength. Velocity seemed to have no affect on signal strength. The effect of distance on strength can be derived by comparing Figures 18 and 19 with Figures 21 and 22. These show approximately a 5-db decrease in signal strength with the same transmitter in the same location on an identical car with a distance increased from 235 feet to 550 feet. With a free-space attenuation formula of:

$$10 \ \mathrm{LOG}_{10} \ 1/(D_1/D_2)^2$$

the free space attenuation increase should be about 7.4 db. Thus, the "waveguide" signal loss seems to be less than would be found in free space.

3. The most economical and reliable antenna configuration and location for transmitting and receiving. The small, flexible "rubber ducky" antennas shown in Figures 2, 3, 4, 5, and 7 worked well and had a high resistance to physical abuse. The receiver antenna mounting method shown in Figures 4 and 5 proved satisfactory. The transmitter antenna placement in either a fixed or a rotating situation works satisfactorily as long as the antenna is located in the "waveguide." A fixed-location antenna has the advantage of a stable signal and less physical stress on the transmitter.

4. The extent of any interference effect on existing railroad equipment. No interference with railroad equipment was noticed, and none is anticipated because of the low-power levels. This method may be susceptable to interference caused by electric locomotive equipment operating from a catenary. But this could be reduced or eliminated by an improved receiver design (narrower bandwidth and improved shielding).

5. Design guidelines for actual design and implementation of the system. These are: (1) transmitter power output equivalent to free-space needs for an equal distance will be more than adequate; (2) the use of a "rubber ducky" type of antenna is recommended to get a one-quarter wavelength antenna at 150-160 MHz in a small, rugged package; (3) stainless steel hose clamps are adequate for attaching the transmitter to either the axles or the car body; (4) for axle mounting of the transmitters, G forces of up to 150G must be allowed (Silicone problem); (5) a crystal-controlled transmitter frequency in the range of 150-160 MHz would seem to be best for the "waveguide" effect (there are several low-power telemetry channels in this band that would work well -- if the FCC approves); (6) receiver antenna placement is not critical although it should be perpendicular to the general plane of the mounting surface; (7) receiver bandwidth should be as narrow as possible to eliminate interference, especially from catenary-powered trains; (8) if the transmitter is axle mounted, the receiver AGC system should have a fast enough response time to cover at least two cycles of the 10-db signal level change per axle rotation.

Further Recommendations

During these tests, several equipment and methodology problems were encountered that prevented the full identification of the effects of various track conditions on received signal strengths. If further tests are conducted, the following changes should be incorporated.

(1) The receiver should be able to provide signal level indications over a minimum 20-db dynamic range.

(2) The receiver antenna cable, attenuator, and receiver should be capable of withstanding strong, "on frequency" local signals without noticably affecting the indicated antenna signal strength.

(3) A single channel strip-chart recorder with an event marker and a 20 to 100 Hz bandwidth should be adequate, unless a second channel could be used as a speed recorder to allow the precise location of position, for comparison with recorder signal variations. (A time base and event marker at signposts do not adequately account for speed changes caused by grade variations.)