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Urban Mass Transportation Administration

Radiated Interference in Rapid Transit Systems
Volume I: Theory and Data

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16. Abstract

This report presents a summary of the theory of generation and observation of radiated electromagnetic interference (EMI) in rail transit systems. This theory underlies the Suggested Test Procedures for radiated EMI in rail transit systems that were developed under this project and presented in a companion report. This report also presents representative radiated EMI data obtained from three different types of rail transit vehicles at two locations. The data are presented as an example of results obtained from application of the Radiated Suggested Procedures.

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PREFACE

Over the past eight years, a program has been undertaken under sponsorship of the Office of Systems Engineering, Urban Mass Transportation Administration, U.S. Dept. of Transportation, to delineate and mitigate the effects of electromagnetic interference (EMI) in rail transit operations. Cooperating in this venture have been U.S. manufacturers of rail transit propulsion and signaling equipment, rail transit system operators, members of the research and consulting community, and the technical staff of the DOT Transportation Systems Center (DOT/TSC) in Cambridge, MA. Work has proceeded under the aegis of the Rail Transit EMI/EMC Technical Working Group, and has focused on three modes of EMI: Inductive, Conductive, and Radiated.

The purpose of this report is to summarize the theory of generation and observation of radiated electromagnetic emissions in rail transit systems. Such emissions may cause electromagnetic interference (EMI). This theory underlies development and use of the Suggested Test Procedures for Radiated Emissions in rail transit systems found in Reference 2 of this report.

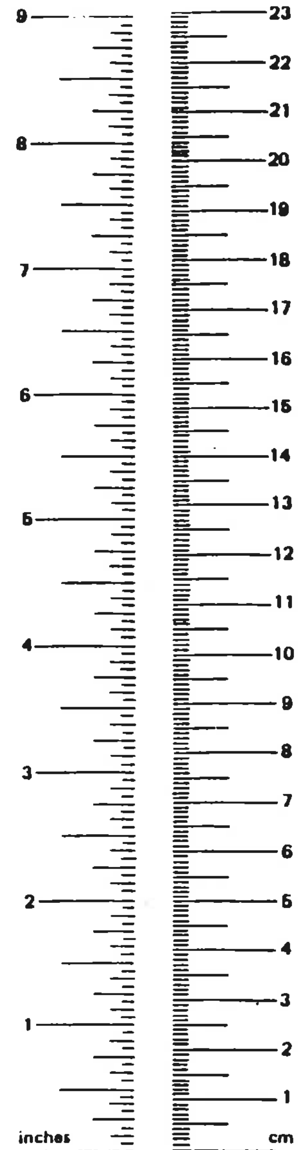
Many people contributed to the efforts to gather the data presented in this report. RF measurements at Hornell, NY were conducted by Raymond Wlodyka and Michael West of DOT/TSC, F. Ross Holmstrom of DOT/TSC and the University of Lowell, and Robert Rudich of the Garrett Corporation. Mr. West also was responsible for developing and adapting software for controlling the automated instrumentation used in these measurements, and for actual field operation of the instrumentation. Support for operation of the trains was provided by personnel from the New York City Transit Authority, Morrison & Knudsen, Inc., and Oy Strömberg AB. The measurements at the Waban Station of the Massachusetts Bay Transit Authority's Green Line were made by Louis A. Frasco of Frasco & Associates, Inc., and Charles Edelson of Comstock Engineering, Inc. Many thanks are extended to the MBTA for its kind permission to present these data in this report. And a final note of thanks must go to the sponsor of this work, Ronald Kangas of the UMTA Office of Systems Engineering, whose singlemindedness has seen UMTA's Rail Transit EMI project to a successful conclusion.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

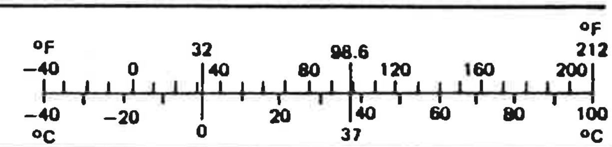
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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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EXECUTIVE SUMMARY

This report presents a summary of the theory of generation and observation of unwanted radiated electromagnetic emissions in rail transit systems. Such emissions may cause electromagnetic interference (EMI). This theory underlies the Suggested Test Procedures [Ref. 2] that were developed under UMTA sponsorship to observe and record radiated EMI in rail transit systems

This report also presents representative radiated interference data obtained from three different types of rail transit vehicles at two locations. The data were collected using the methods specified in Reference 2.

EMI data on the STARS AC Propulsion 2-car train were taken at the Morrison & Knudsen, Inc. facility in Hornell, N.Y., as was data on a DC-propelled cam-controlled 2-car rapid transit train. The Hornell data were taken by DOT, Garrett, and NYCTA personnel. Data on the MBTA's Surface Rail Car, a light-rail vehicle with chopper-controlled DC propulsion, were collected at the MBTA Waban station by MBTA contractors.

1. INTRODUCTION

The purpose of this report is to briefly outline the theory of the generation of unwanted radiated electromagnetic emissions, especially in the case of rapid transit systems, and to present representative data for radiated emissions obtained from a number of different rapid transit systems. The theory of radiated emissions presented in this report is a synopsis of more detailed discussions available in published literature [Ref. 1]. These sources provided the basis for the development of the radiated interfertence test procedures for rail transit applications that are presented in a companion report [Ref. 2].

All electronic and electrical equipment is a source of unwanted or unintended radiated electromagnetic emissions. Sometimes these emissions interfere with other electronic systems. Then and only then do they become electromagnetic interference (EMI). In decades past, the potential for EMI was relatively rare in the normal private and commercial sectors of our society. However, the past decade has seen an explosive growth in the use of new electronic systems for communications, control, computation, and entertainment. Today there is much greater prevalence of sensitive electronic systems that potentially could be adversely affected by EMI. Today there are also many new potential sources of EMI, among them many of the same electronic systems noted above. One other new class of potential EMI is that of solid-state controllers for high-power applications. To experience this type of EMI one only need listen to an AM radio in a room in which a solid-state light dimmer is used.

Radiated emissions from rapid transit rail vehicles are a potential source of EMI, since they employ many types of high-power electrical and electronic equipment. Electrical transients associated with propulsion and auxiliary power systems can cause emissions much like the unwanted electrical emanations that cause static and noise on radios and "snow" on television receivers. Radio-frequency (RF) noise, produced by many electrical devices, can be radiated through space as well as conducted along rails or wires. Experience has shown that these emissions are not likely to interfere with rail transit subsystems other than radio communications. The potential problems caused by radiated emissions from a rail transit subsystem are mostly external to the transit system. Interference with AM radio and TV reception near the right-of-way is possible. Potentially, these emanations can interfere with emergency communications such as police and fire radio networks.

New rapid transit lines in the U.S. have propulsion systems using switched thyristors to control the flow of power to the traction motors. These modern power control systems take the place of older ones using rheostats, resistor banks, and mechanically actuated electrical switches for propulsion motor control. Two types of thyristor control are in use: Chopper control of commutator-type dc motors; and inverter control of ac "squirrel-cage" induction motors.

In both types of thyristor propulsion control systems, thousands of amperes of current flowing from the third rail to the transit vehicle must be switched on and off at a rate from tens to hundreds of times per second. In dc chopper systems, third-rail current is square-wave modulated at a rate of 200 to 400 Hz, and power is controlled by varying the ratio of on-time to off-time. In ac control, three banks of thyristor switches are used to synthesize three-phase variable-frequency variable-voltage high-power signals that feed the three-phase ac induction motors.

In both of the control schemes described above, the large magnitude of repetitive current transients raises the possibility of generating radiated EMI. Radiated emissions have been detected at low levels. However to date, currently operating propulsion systems or auxiliary power systems have not interfered adversely with the operation of electronic equipment belonging to transit systems themselves, or with nearby non-transit electronic equipment used in non-transit applications. One objective of the UMTA/DOT Rail Transit EMI/EMC program is to insure that such interference does not occur in the future.

The radiated emission test procedures described in Ref. 2 are not only applicable to assessing radiated EMI levels from rail transit cars powered by new solid-state systems, but also those employing older technology. Current transients due to commutation in dc traction motors, third-rail contactor bounce, and propulsion control contactor switching are believed to be among the sources of radiated emissions observed from older types of rapid transit cars.

2. THEORY

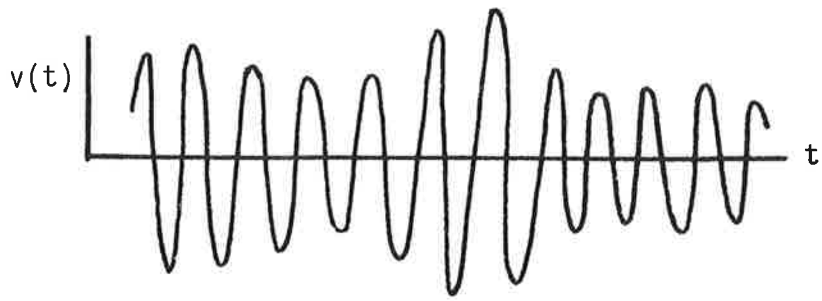
2.1 Narrow-Band vs. Broadband Emissions

Most electrical and electronic systems create detectable levels of radiated emissions. The characteristics of these emissions depend on circuit configuration, shielding if any, and the time and frequency characteristics of currents. For the purposes of characterizing EMI, emissions are divided into two categories: narrow-band, and broadband.

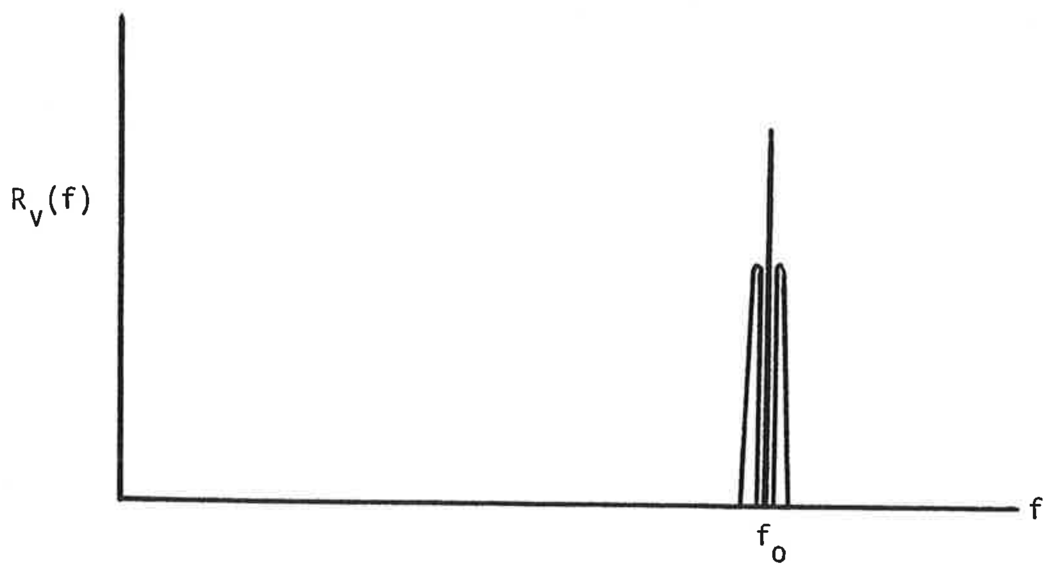
Narrow-band emissions arise from ac currents with sinusoidal or nearly sinusoidal time behavior. Typical narrow-band signals are power-frequency emanations from power lines; radio or television transmissions; undesired emissions from local oscillators in radio receivers; and undesired leakage from flexible cables carrying rf signals. These signals are called "narrow-band" because the power-density spectrum of such a signal is constrained to a window in the frequency domain whose width is much narrower than the center frequency. Figure 2.1 shows the time and frequency characteristics of a typical narrow-band signal.

Broadband emissions arise from transients in current flow. An ideal current transient is a single absolutely abrupt step change in current level in a conductor, or an extremely large single current pulse of extremely brief duration. Ideal current transients can be closely approximated by suddenly switching large currents on or off; or by electrical discharges. Such signals are called "broadband" because the energy in such a signal is spread throughout a very extensive region of the frequency domain - one in which the maximum frequency is many times larger than the minimum frequency. Figure 2.2 shows the time and frequency characteristics of a typical broadband transient signal.

A number of notorious and familiar sources of such emanations are automobile ignition systems, and electric motors of the type called "universal motors", found in small household appliances. These motors are multi-pole commutator-type motors with brushes that rapidly switch motor current from winding to winding, and create pulsed waveforms in the line current. Present-day auto ignition systems generally employ resistor-type sparkplugs or high-resistance ignition wire to damp the oscillatory current pulses that fire the sparkplugs, thus

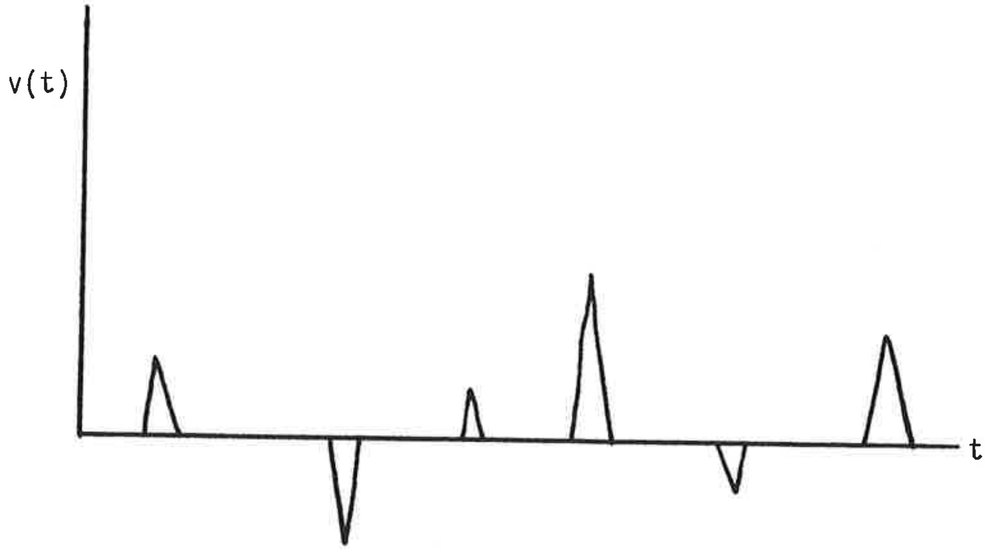


a) Time characteristics.

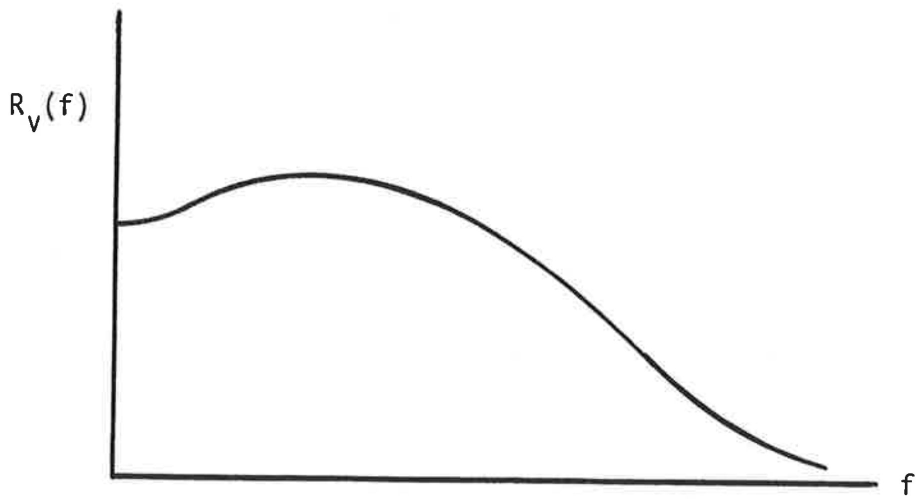


b) Frequency characteristics.

FIGURE 2.1 Time and frequency characteristics of a typical narrow-band signal. This signal is an RF carrier that is amplitude-modulated with a random baseband signal. Power spectral density $R_v(f)$ has dimensions of volts^2/Hz.



a) Train of pulses of random shape, amplitude, and frequency.



b) Power spectral density $R_v(f)$, with dimensions of volts^2/Hz.

FIGURE 2.2 Time and frequency characteristics of a train of pulses of random shape, amplitude, and repetition frequency. The power spectral density of such a signal is the Fourier Transform of its autocorrelation function. (Ref. 7) reducing EMI. Some but not all appliances using universal motors include line filters to block the current pulsations caused by the motor from circulating in the power leads, thus reducing EMI emanating from the power leads.

Other common sources of EMI are fluorescent lighting systems, in which currents turn on very abruptly each current cycle; and computers, in which all currents are abrupt pulses. Another source of EMI is the electronic dimmer for household lighting, that works by abruptly switching on the current in a lighting circuit at some adjustable point in the middle of each normal current cycle, thus causing EMI-generating transients.

One natural and sometimes important source of EMI is lightning. Some devices that do *not* cause EMI, since currents are purely sinusoidal, are ac induction motors and electrical resistance heating units, no matter how large.

Broadband emissions also can arise from repetitive sources such as square waves or trains of narrow pulses. Such waveforms can be resolved by Fourier analysis into series of harmonically related narrow-band signals; however, the series spread over very broad portions of the spectrum.

In rapid transit electrical systems, potential sources of radiated EMI are dc motors for propulsion and auxiliary power, and the choppers used in solid-state propulsion control systems. Both of these potential sources cause pulsating current through associated conductors. The amount of radiated EMI actually caused by any of these potential sources depends upon the filtering and shielding employed. Another potential cause of radiated EMI is third-rail shoe-bounce, which gives rise to transient current patterns in a car's propulsion current collection circuit.

A one-time transient signal such as a lightning burst or high-current transient will cause a single click to be heard from the speaker of an AM radio, no matter where the dial is tuned. A repetitive transient waveform, such as a high-current pulse train, or periodic non-sinusoidal current flowing in a thyristor light-dimmer circuit, will give rise to a steady buzz from the AM radio speaker. The fundamental frequency of the buzz is the repetition frequency of the transients. The received signal will sound like a buzz instead of a pure tone because many separate harmonics are received simultaneously, resulting in a complex audio waveform.

Figure 2.3 shows the time characteristics of signals at various nodes in an AM radio receiver due to reception of a repetitive train of broadband transients.

It is broadband emissions that are of greatest potential concern to rail transit operators. Manufacturers of radio communications equipment supplied to transit operators make use of well-known packaging techniques to suppress narrow-band EMI. The techniques available for suppressing broadband EMI from either non-repetitive or repetitive transients in propulsion or auxiliary power systems are much less straightforward. However, the transit operator must comply with the FCC regulations applying to industrially created EMI that say, in essence, "One must not interfere."

2.2 Near-Field vs. Far-Field Radiation [Ref. 3]

The power in continuously propagating electromagnetic waves in free space can be stated in watts per square meter of incident area. For such waves, the power density in W/m^2 is related directly to the electric and magnetic field strengths. Therefore, either E-field or H-field intensity can be used as an indication of the power density in the wave.

As a practical matter, if one moves far enough away from a point-source of radiated EMI, or from a point-source of a desired rf signal, the signal will become so weak that it will no longer be detectable. Nearby a source of EM waves, localized non-radiating E- and H-fields also are present. For physically small sources of radiation, the intensity of non-radiating fields decreases as $1/r^3$ with distance away from the source, whereas the intensity of radiating fields decreases as $1/r$. The distance at which the localized field intensity becomes less than the radiating field intensity depends on the frequency in question, and the specific physical characteristics of the source of radiation.

For an ideal Hertzian dipole radiator, comprised of a signal source driving current along a short conductor between two open capacitor plates, the distance at which $1/r^3$ attenuation gives way to $1/r$ attenuation is $(\lambda/2\pi) = 0.16$ wavelengths. The distance beyond which the radiating or "far" component of E-field becomes more intense than the localized or "near" component equals 48/f meters, where f is measured in MHz. Likewise, at a distance r away from an ideal Hertzian dipole

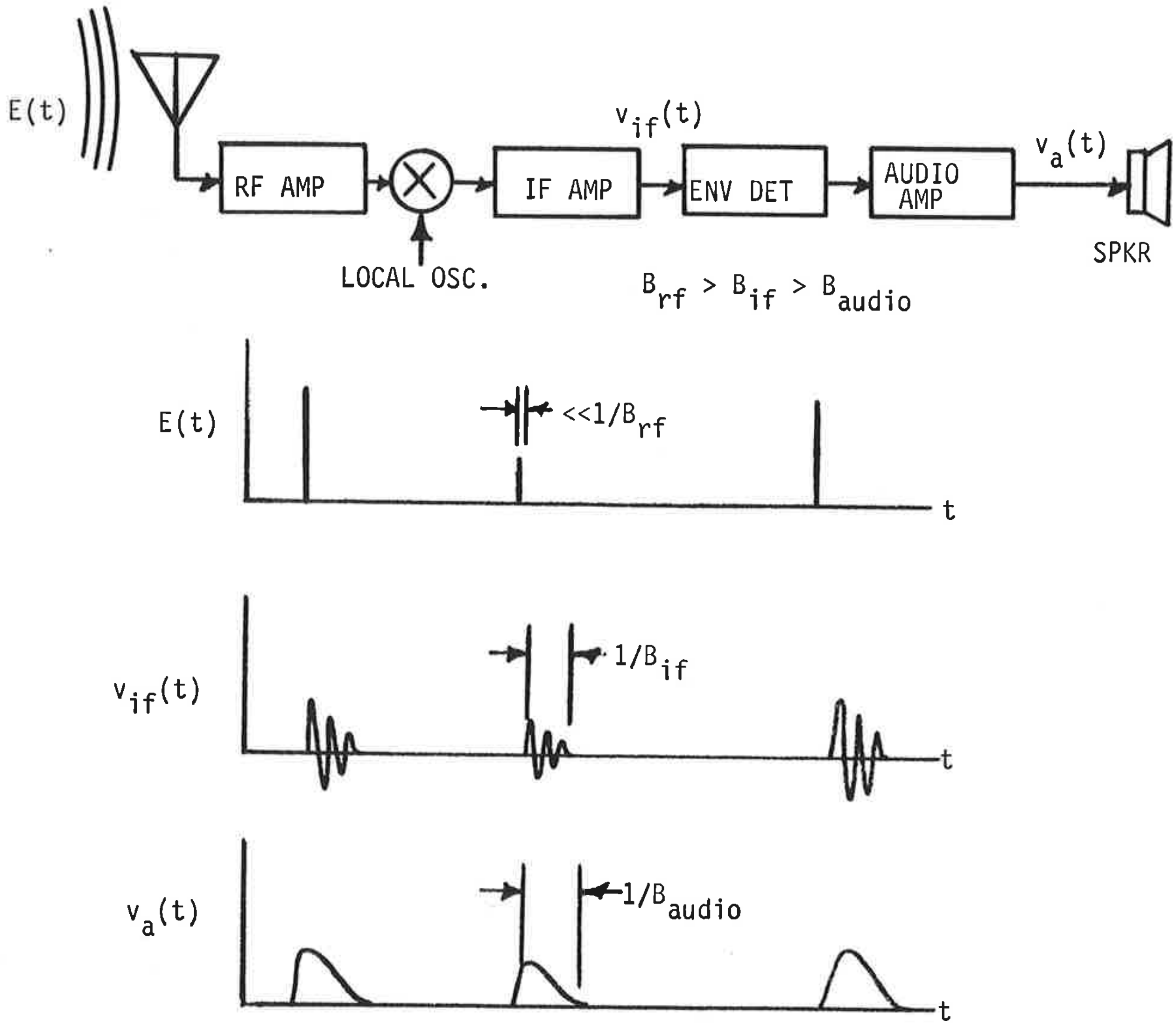


FIGURE 2.3 Time characteristics of broadband EMI signals at various nodes of an AM receiver.

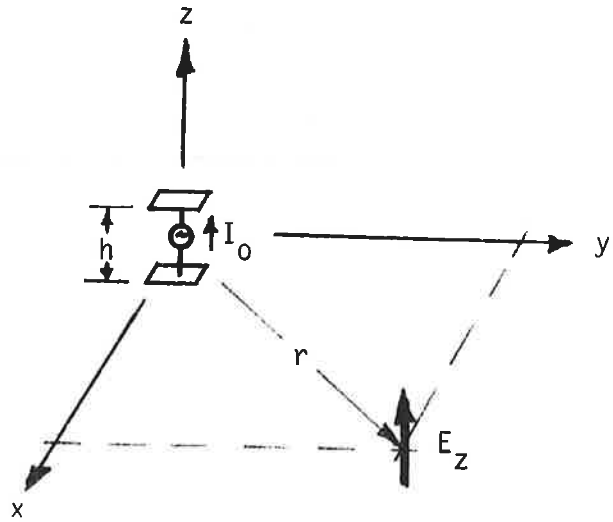
radiator, the frequency above which the far-field intensity is greater than the near field intensity is 48/r MHz. Figure 2.4 shows a plot of electric field strength vs. distance from an RF dipole radiator, with near-field and far-field regions noted.

Extrapolations based on the above relations have been used in devising the suggested test procedures set forth in Ref. 2. To deal with the uncertainty of the precise EM circuit characteristics of sources of radiated EMI, it is convenient to prescribe a standard distance at which measurements of field strength will be made, and to prescribe whether the E- or H-field component will be measured. The Suggested Test Procedure presented in Ref. 2 specifies measuring the E-field, either at 30 meters or 15 meters distance. If required, calculation of expected signal strengths at other distances then can be performed using the appropriate power law.

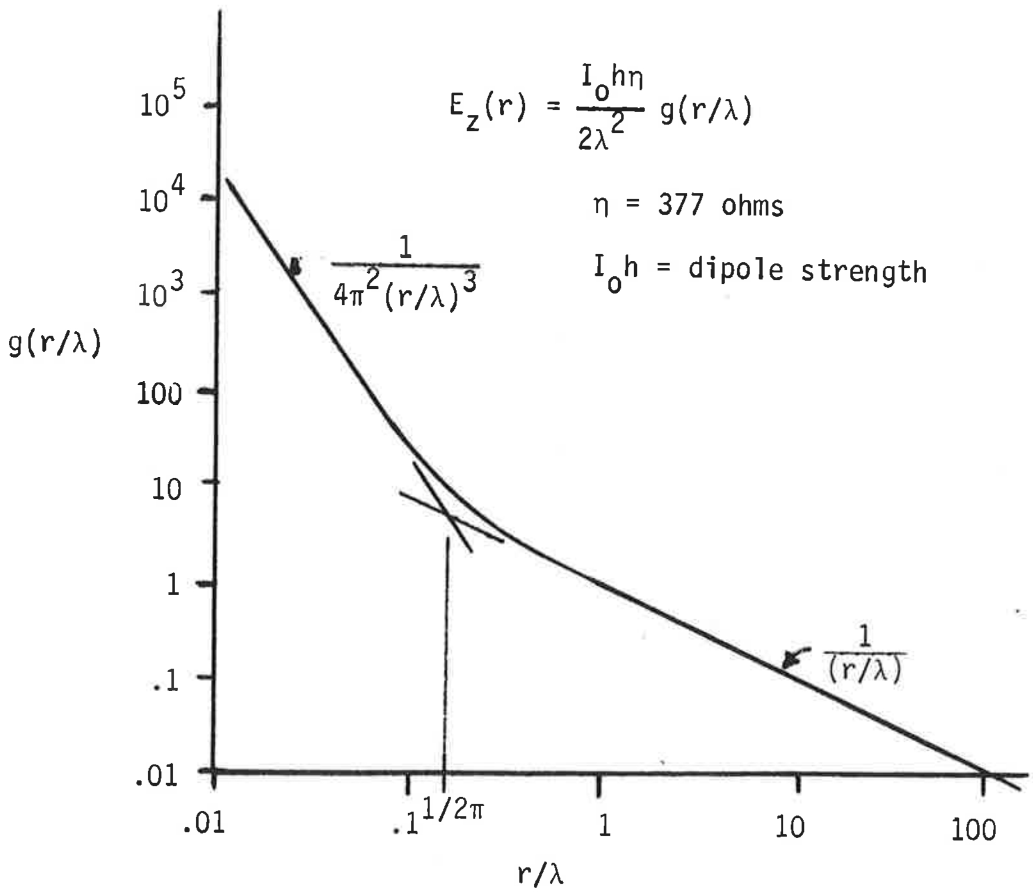
2.3 Units of Measure of Broadband Radiated Emissions [Ref. 1]

Broadband radiated emissions are caused by transients. The signal strength of a single transient is distributed in frequency in a continuous fashion. The greater the bandwidth of a filter through which the transient passes, the greater will be the peak amplitude of the signal out of the filter. For narrow-band filters, the peak amplitude attained will be directly proportional to the filter's impulse bandwidth B_{imp}. If a voltage transient is applied to the input of a narrow-band filter with bandwidth B_{imp}, center frequency f_o, and mid-band gain equal to A, and the peak instantaneous voltage attained at the output is V_{max}, then the broadband signal strength of the input transient in the vicinity of f_o, is $(V_{max}/B_{imp}A)$ volts per Hz of sensor bandwidth. Thus the dimensions of broadband noise content of the voltage transient are volts/Hz.

The narrow-band filter noted above generally is the IF filter in the EMI receiver or spectrum analyzer used for measurement of broadband signal strength. In the case of rf spectrum analyzers, IF filters commonly possess "Gaussian" or bell-shaped characteristics of gain vs. frequency. For such frequency dependence, B_{imp} equals the filter's -6 dB bandwidth as determined using CW sinusoidal signals, and $B_{imp} = 1.4\, B_{res}$. [Ref. 4] Note that the resolution bandwidth B_{res} is the half-power or -3dB bandwidth.



a) Hertzian dipole



b) Variation of field strength with distance.

FIGURE 2.4. Vertical E-field strength in equatorial plane of a Hertzian dipole radiator as a function of radial distance.

The time response characteristics of a band-pass filter subjected to an impulse are dependent on the filter's impulse bandwidth B_{imp}. The impulse bandwidth of a filter actually is defined by the result of a time-domain measurement in which an extremely short-duration impulse is applied to the filter and the envelope of the output waveform vs. time is observed. By definition, the impulse time duration T_{imp} of the filter times the peak envelope amplitude equals the total area under the envelope. Then, impulse bandwidth $B_{imp} = 1/T_{imp}$. Figure 2.5 shows how T_{imp} is determined from the output waveform of a filter subjected to a short-duration impulse at the input. The definition of T_{imp} in the time domain is the dual of the definition of noise bandwidth B_{noise} of a filter in the frequency domain.

Whereas peak output amplitude in response to an input transient is proportional to B_{imp}, the time duration of the output signal is inversely proportional to B_{imp}. Thus the energy output, which is proportional to V_{max}^2 times time duration, also is proportional to B_{imp}. However, since when characterizing broadband interference it is peak output amplitude due to transients that is observed and recorded, the units of broadband signal strength are ones of signal amplitude (volts or amperes) per unit bandwidth, and not watts, volts^2, or amperes^2 per unit bandwidth.

Since E-field or H-field sensing antennas are used to observe broadband radiated emissions, and the radiated signal strengths are expressed in terms of volts/meter or amperes/meter, the corresponding units of measure for broadband radiated emissions are either (volts/meter) per MHz of receiver bandwidth, or (amperes/meter) per MHz bandwidth.

To allow for measurements of radiated EMI over broad amplitude ranges, a logarithmic scale is used, with broadband EMI given in units of dBµV/m/MHz, i.e., dB relative to 1 (microvolt/meter) per MHz. If a broadband radiated EMI signal has signal strength E_{bb} (µV/m)/MHz, then on the dB scale,

$$E_{bb,dB} = 20 \log_{10}(E_{bb}) \text{ dB}\mu\text{V/m/MHz}.$$

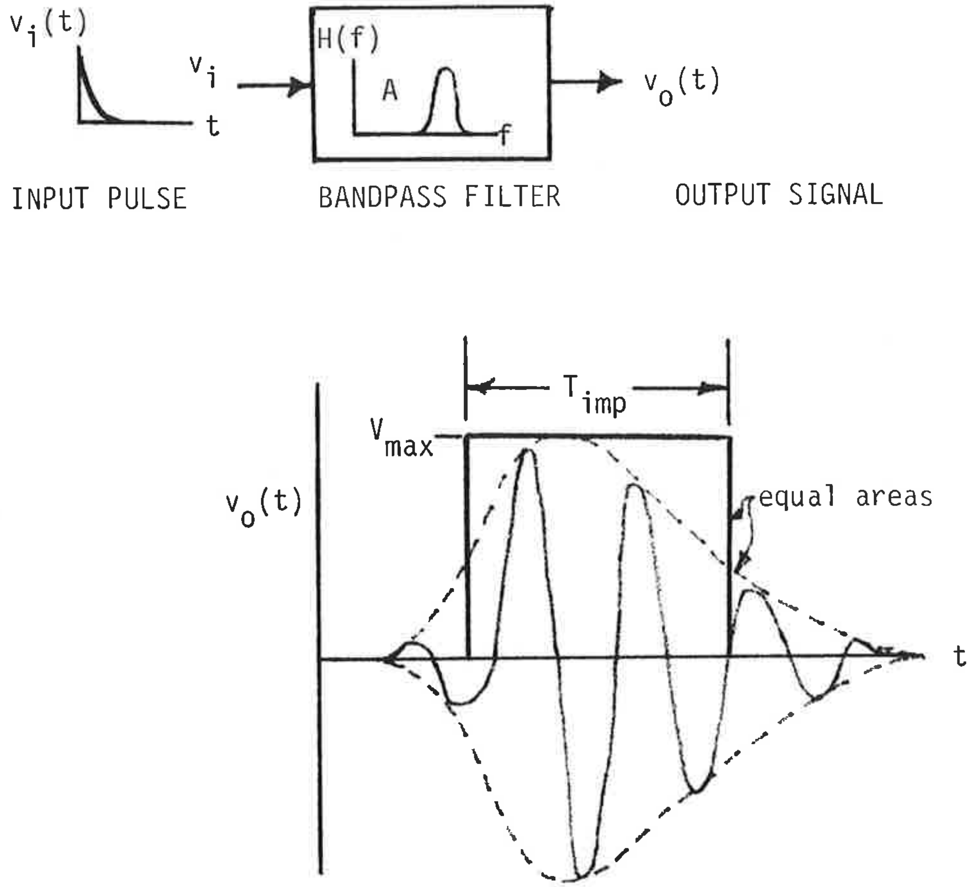


FIGURE 2.5. Determination of the impulse response time $T_{imp} = 1/B_{imp}$ for a band-pass filter. Area under square box with height V_{max} and width T_{imp} equals area under envelope.

2.4 Detection and Observation of Broadband Emissions

Broadband emissions may be observed and measured with either an EMI receiver or a swept-frequency spectrum analyzer. The more traditional instrument has been the EMI receiver. However, recent advances in the automation of electronic equipment have made the computer-controlled spectrum analyzer with graphic plotter output a very efficient instrument to use for rapid collection of broadband emission data over wide portions of the RF spectrum. [Ref's 5, 6] The theory of operation of the swept-frequency spectrum analyzer in such an application is summarized below in an example in which general symbols are used, and in which some specific numbers are applied by way of example.

2.4.1 Normal Operation of Swept-Frequency Spectrum Analyzers

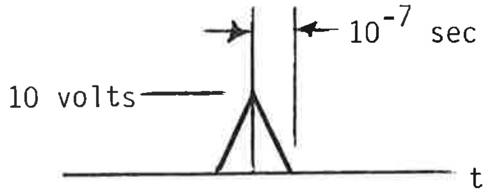
Consider the single pulse of short duration shown in Fig. 2.6(a), applied to the input of a swept-frequency spectrum analyzer. This pulse, with time behavior noted as $v_p(t)$, happens to be a triangular or Λ-pulse with half-duration $\tau = 0.1$ µsec and peak amplitude $a = 10$ volts:

$$v_p(t) = a\Lambda(t/\tau) = 10\ \Lambda(t/10^{-7}\mathrm{sec})$$

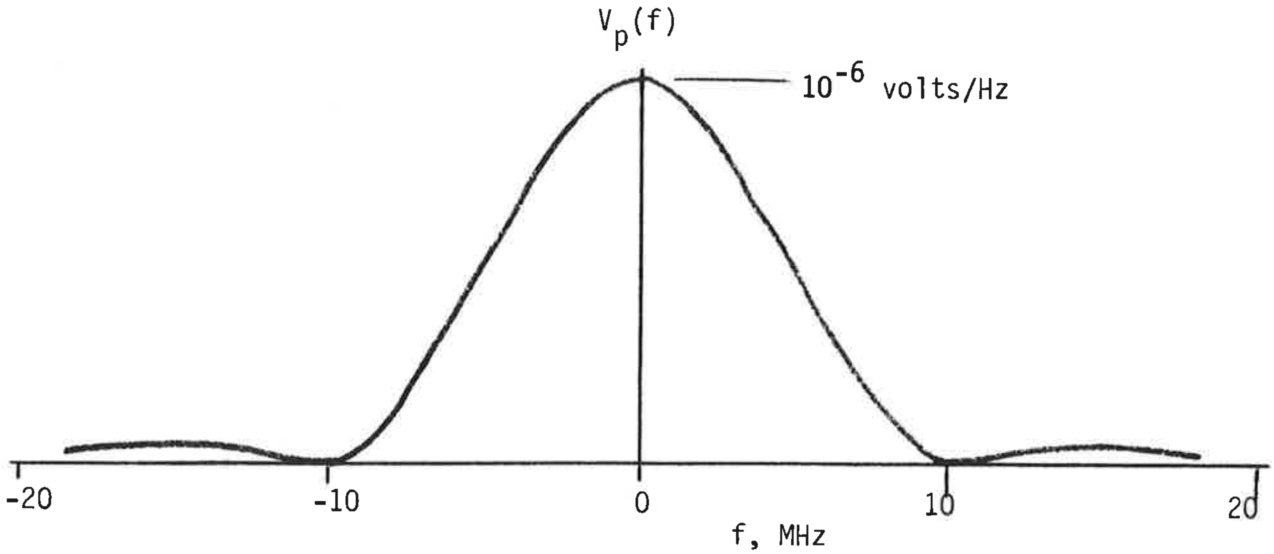
The Fourier transform of $v_p(t)$, which gives the frequency-domain characteristics of the pulse, is given by the general relation written below, which is followed by the specific result for the Λ-pulse: [See Ref. 7 for discussion and examples of the Fourier transform]

$$\begin{aligned} V_p(f) &= \int_{-\infty}^{+\infty} a\Lambda(t/\tau)\exp(-j2\pi ft)\,dt \\ &= a\tau \sin^2(\pi f\tau)/(\pi f\tau)^2 \text{ volts/Hz} \\ &= 10^{-6}\sin^2(3.14\mathrm{x}10^{-7}f)/(3.14\mathrm{x}10^{-7}f)^2 \text{ volts/Hz} \end{aligned}$$

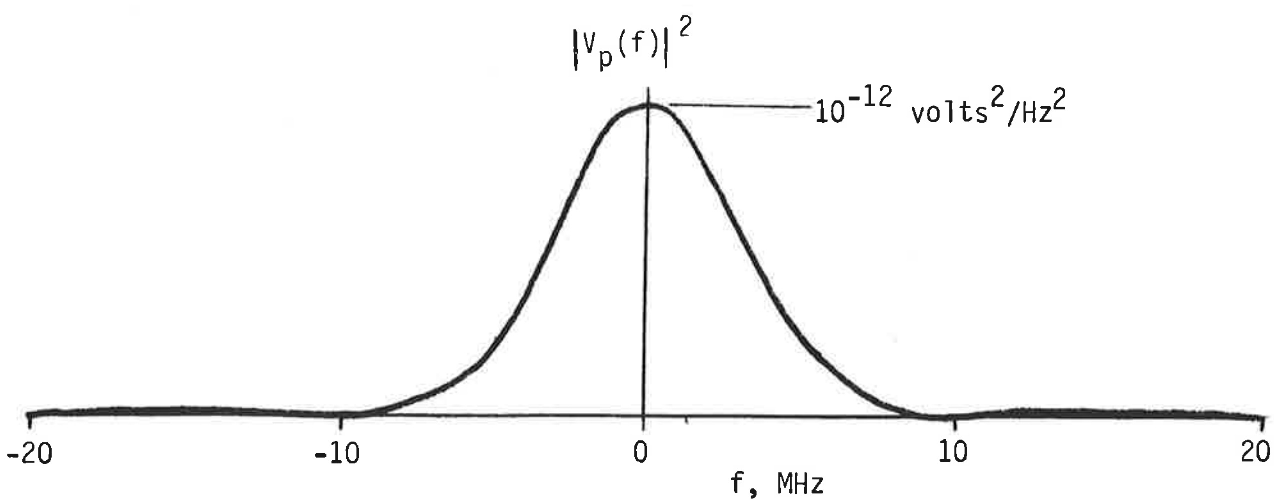
The energy density spectrum of this pulse is



a) Triangular pulse $v_p(t)$.



b) Fourier Transform of triangular pulse in (a).



c) Energy density spectrum of the triangular pulse in (a).

FIGURE 2.6. A triangular pulse and its Fourier Transform and energy density spectrum.

$$|V_p(f)|^2 = 10^{-12}\sin^4(10^{-7}\pi f)/(10^{-7}\pi f)^4 \text{ volts}^2/\text{Hz}$$

The Fourier transform and energy density spectrum of the pulse are shown in Fig's 2.6 (b) and (c).

The total energy W_p of the pulse $v_p(t)$, given in units of volts^2·sec, can be obtained either by integrating $v_p^2(t)$ over all time, or by integrating $|V_p(f)|^2$ over all frequencies:

$$W_{vp} = \int_{-\infty}^{+\infty} v_p^2(t)dt = \int_{-\infty}^{+\infty} |V_p(f)|^2 df = 6.67\text{x}10^{-6} \text{ volt}^2\text{-sec}$$

("Normalized" units of power and energy are used here, having dimensions of volts^2 and volt^2·seconds, respectively. To find actual power, divide by the resistance of the load that the voltage is applied to.)

Next consider the function $v_t(t)$, which is an infinitely long periodic train of pulses shaped just like $v_p(t)$, with duration between pulses given by T = 100 μsec:

$$v_t(t) = \sum_{n=-\infty}^{+\infty} v_p(t - nT)$$

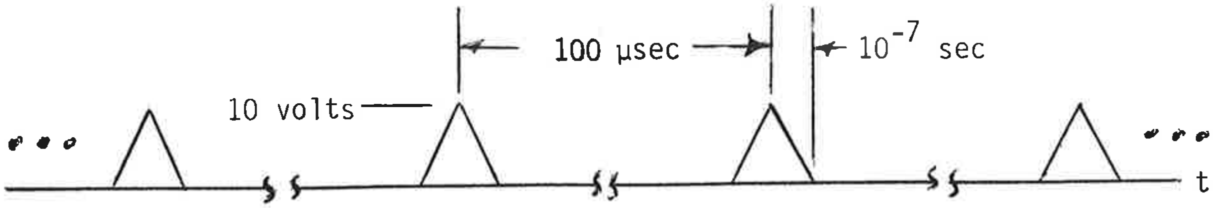
This pulse train is shown in Figure 2.7(a). The Fourier transform of $v_p(t)$ is a line spectrum, with harmonics at multiples of the fundamental frequency f_o = 1/T Hz. The amplitudes of these harmonics are weighted in a manner proportional to the frequency-depenent $V_p(f)$ function. The resulting Fourier transform of $v_t(t)$ is

$$V_t(f) = V_p(f)f_o \sum_{m=-\infty}^{+\infty} \delta(f-mf_o)$$

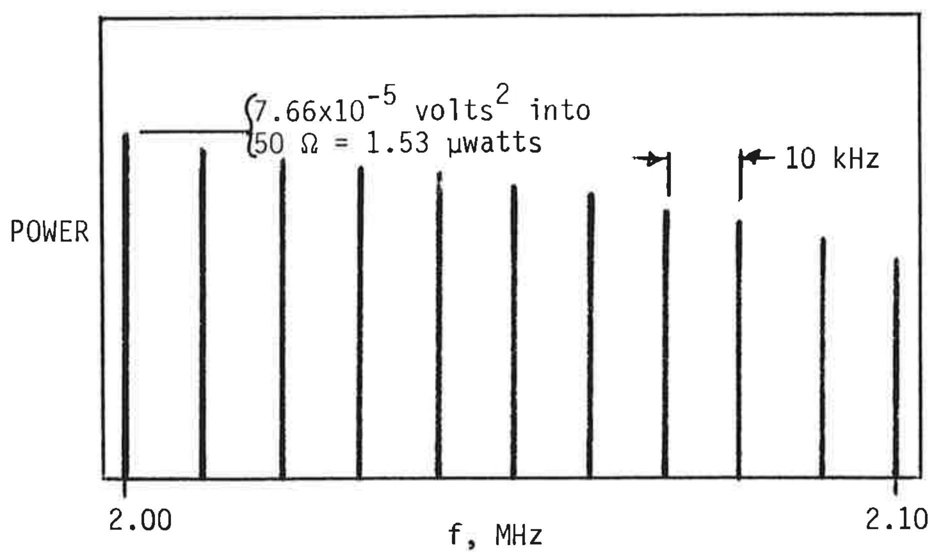
The infinitely long pulse train has infinite total energy, but finite average power. The power in each harmonic component is equal to the square of the amplitude of that component; therefore, the resulting power density spectrum $R_{vt}(f)$ for the pulse train is

$$R_{vt}(f) = |V_p(f)|^2 f_o^2 \sum_{m=-\infty}^{+\infty} \delta(f-mf_o) = f_o^2 \sum_{m=-\infty}^{+\infty} |V_p(mf_o)|^2 \delta(f-mf_o)$$

Swept-frequency spectrum analyzers respond to positive- and negative-frequency parts of signals simultaneously. Since the positive and negative-



a) A repetitive pulse train.



b) Spectrum analyzer display (linear scales are used). The upper envelope of the spectral lines has the same shape as $|V_p(f)|^2$ pictured in Fig. 2.6(c).

FIGURE 2.7. A repetitive pulse train and a portion of its power spectrum as displayed on a spectrum analyzer.

frequency power spectra are equal in amplitude, we double $|V_p(f)|^2$ but then divide by 2 again to get mean squared units of voltage instead of peak units, and obtain the observed level of signal at the m^{th} harmonic frequency mf_o equal to $f_o^2|V_p(mf_o)|^2$ volts^2. A spectrum analyzer being operated in the normally prescribed manner would display the line spectrum of the above signal, showing the power present at each harmonic frequency.

To separate out the lines, the above spectrum analyzer would have to be operated with its resolution bandwidth much narrower than the spacing between lines, i.e., with $B_{res} << f_o$. Furthermore, to assure that a harmonic component stayed within the passband of the analyzer long enough to register as the analyzer swept, the dwell time of the signal in the moving window would have to be greater than the response time of the IF filter, which is $(1/B_{res})$ seconds. Therefore, the spectrum analyzer's frequency sweep speed must be less than B_{res}^2 Hz/sec. Provided the B_{res} and sweep speed conditions are met in the first place, the spectrum analyzer will properly display the spectral characteristics of a truly periodic signal, and the displayed amplitude of each line on the CRT will be independent of B_{res} and sweep speed. To accurately observe the harmonic content of $v_t(t)$, $B_{res} << f_o$. In the example, resolution bandwidth B_{res} = 100 Hz and sweep rate = 1 kHz/sec would suffice.

Figure 2.7(b) illustrates a spectrum analyzer display from 2.0 to 2.1 MHz resulting from the application of the repetitive pulsed signal in the above example to a spectrum analyzer adjusted with the B_{res} and sweep rate noted.

2.4.2 Operation of a Spectrum Analyzer as a Broadband EMI Receiver

Now we must note that the method of operation described above is not the way spectrum analyzers are adjusted when observing broadband, i.e., transient-induced emissions. When observing broadband emissions, the response time of the spectrum analyzer's IF filter must be much shorter in duration than the time between pulses, so that the instrument responds to incoming pulses as if they were single isolated events. For this to occur, $B_{res} >> f_o$. To observe the broadband content of $v_t(t)$ in the example above, a resolution bandwidth B_{res} = 100 kHz would be acceptable. (In the case of randomly-spaced pulses, f_o should be regarded as the average pulse repetition frequency.)

In this case, since the analyzer's IF filter will respond to individual pulses as isolated events, the spectrum analyzer will not display Fourier series amplitudes. Rather, as time passes, and the beam sweeps across the CRT, and the IF center frequency sweeps, each time an input pulse hits the IF, the trace will display a pulse. The time separation of the pulses in seconds of sweep time will equal the time duration T between pulses. If one changes the sweep rate as measured in divisions/sec on CRT screen, the spacing of displayed pulses will change. Therefore, the spacing of pulses in seconds of sweep time gives the period of the pulse train. Figure 2.8 illustrates a spectrum analyzer display of broadband response to the repetitive pulsed waveform in the example above.

It is informative to consider how the narrow-band display in Fig. 2.7(b) and the broadband display in Fig. 2.8 would change if we changed the pulse rate of the repetitive signal. If the pulse rate were to double, the lines in the narrow-band display would become twice as far apart, since the lines are spaced from each other by the pulse repetition frequency. However, the lines in the broadband display would move closer together, because each line is actually a response to a single pulse, and the time between pulses determines the time separation of pulses on the display as the beam sweeps across the screen.

2.5 Application to Actual Rail Transit Operations

Experience indicates that radiated emissions from rail transit subsystems do not appear to have caused problems with on-board vehicular subsystems or wayside signaling subsystems; however, there is a potential for these emissions to interfere with licensed radio communications near wayside. The Radiated Suggested Test Procedures [Ref. 2] were created for the purpose of making measurements to determine and/or predict the potential for RF emanations from rapid transit vehicles to interfere with communications or sensitive electronic equpment.

Whereas the measurement of radiated emissions according to the suggested procedures is a straightforward matter, the interpretation of the results to determine the potential for interference must be based upon a clear understanding of the operating characteristics of the other systems involved and their possible proximity to the radiating source. The SAE has established a recommended radiated emission standard [Ref. 8], based on MIL-STD 461A, which has been superceeded by

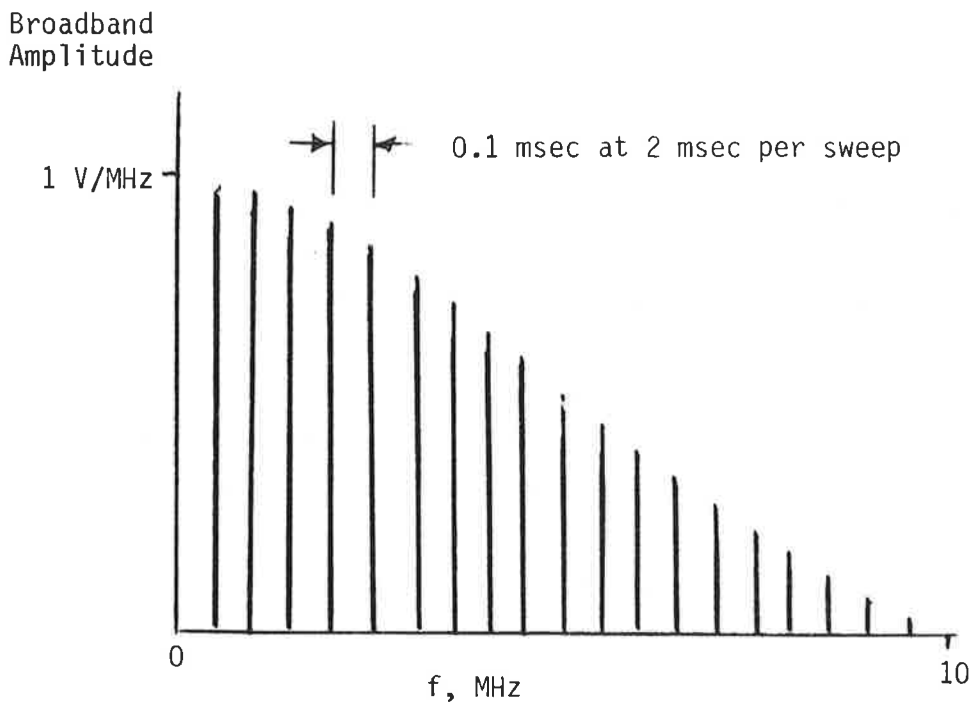


FIGURE 2.8. Spectrum analyzer display of analyzer adjusted to observe broadband content of signal in Fig. 2.7(a). Spectrum analyzer is sweeping at rate of 2 msec per sweep. Sweep range is 0 to 10 MHz.

MIL-STD 461B [Ref. 9]. (The SAE standard often is referred to as the SLRV standard, since the SLRV [Ref. 5] was one of the first vehicles to which it was applied.) However, no universally accepted standard currently exists for specifying the boundary between acceptable and unacceptable amplitude levels of broadband EMI from rapid transit equipment. As noted previously, the existing legal standard is the one promulgated by the FCC that says in effect, "Thou shalt not interfere."

It is clear that if the purpose of a test is to accurately determine the signature of radiated electromagnetic emissions from a particular vehicle, then the testing must be performed in a quiet RF environment. However, if the purpose is to determine if radiated emissions from the vehicle will interfere with existing wayside systems, then testing may be conducted in the operating environment. In that environment, emissions from the vehicle may be masked by ambient signals. Any emissions from a new vehicle that exceed a pre-existing ambient create the potential for new interference. Determination of the consequences of this interference must be made on the basis of the time and frequency characteristics of the interference, and the sensitivity and proximity of receiving devices.

3. FIELD MEASUREMENTS AND DATA

3.1 Description of Measurements

The measurements described here were performed according to the procedures outlined in "Radiated Interference in Rapid Transit Systems - Volume II: Sugested Test Procedures" [Ref. 2]. The resulting data are presented as an example of results that typically might be expected from the application of those procedures.

At the Morrison & Knudsen, Inc. rapid transit test track in Hornell, NY, measurements were made of radiated emissions from a heavy-rail 2-car rapid transit train powered by a prototype AC propulsion static inverter system developed by Oy Strömberg AB of Helsinki and the Garrett Corporation of Torrance, CA, under the UMTA STARS AC Propulsion program; and from a rapid transit train with DC propulsion controlled by switched rheostats and field winding ("cam controlled"). Both of these trains were property of the NYCTA, a collaborator in the STARS AC Propulsion program. The Hornell data were taken by DOT, Garrett, and NYCTA personnel.

At the Waban Station of the MBTA Green Line measurements were made of emissions from a DC chopper-controlled light rail vehicle -the Surface Rail Car (SRC). The MBTA data were taken by Frasco & Associates, Inc., of Belmont, MA, under contractual provisions noted in Appendix B.

Equipment used at both sites consisted of:

- Hewlett-Packard Model 8568A spectrum analyzer with HP Model 9826 controller and HP Model 2671G graphics printer
- Antennas: 14 kHz - 30 MHz rod antenna; 30-200 MHz biconical antenna; 200 MHz - 1 GHz log periodic antenna
- Antenna tripod
- Filters and attenuators; power isolation transformers; connectors and cables
- The UMTA EMI test insturmentation van

The spectrum analyzer was controlled by the controller using software developed specifically for RF EMI measurements by John Adams of NBS, Boulder, CO, and Michael D. West of DOT Transportation Systems Center, Cambridge, MA. The controller was programmed to plot the SAE ARP 1393 limit, shown as either a dashed or solid line, on the broadband data graphs.

Vertical E-field was measured over 7 frequency bands from 111 kHz to30 MHz using a vertical rod antenna. Horizonal E-field was measured from 20 to 200 MHz using a biconical antenna oriented with antenna centerline parallel to the tracks. Horizontal E-field was measured from 200 to 500 MHz using a log periodic antenna pointing at the track. The choice of polarizations matches the polarizations used by commercial radio and TV, with vertical polarization being used in the standard broadcast AM band, and horizontal polarization being used in the TV and commercial FM bands.

The data presented here represent a small sample of that collected at either test site. More than 100 individual train runs were made at the Boston site alone, each one yielding a data plot. The sample spectral plots presented below were chosen to illustrate results typical of the two diverse environments.

3.2 Hornell Data

The distance from the track centerline to antenna tripod was 15 meters (50 feet). Data were taken for the following six cases:

- Ambient conditions with ac power to the dc substation turned off
- Ambient conditions with ac power to the substation on, but dc power to the third rail turned off
- Ambient conditions with third rail power on
- AC train accelerating past the antenna position from stop, with a speed of approx. 30 mph when train's nose was opposite antenna
- AC train accelerating from initial stopped position with train's nose opposite antenna
- DC train accelerating past the antenna position from stop, with a speed of approx. 30 mph when train's nose was opposite antenna

The Hornell data are presented in Appendix A. Table A-1 lists the pages in Appendix A on which data for specific cases and frequency ranges are found.

3.3 MBTA Data

The distance from the track centerline to antenna tripod was 30 meters (100 feet). Data were taken for the following two cases:

- Ambient conditions with third rail power on
- Train accelerating from initial stopped position with train's nose opposite antenna

The MBTA data are presented in Appendix B. Table B-1 lists the pages in Appendix B on which data for specific cases and frequency ranges are found.

3.4 Discussion of Data

Inspection of Ambient data from Hornell and the MBTA shows that in the first two frequency ranges spanning 111 to 528 kHz, the Hornell ambient broadband level with substation off is approx. 6 db quieter than at the MBTA. However, the Hornell ambient level rises appreciably when the substation is turned on, and more still when power is applied to the third rail. When the Hornell data were taken, the spectrum analyzer's sweep generally was triggered by the power line, thus allowing observation of ambient broadband signals that are repetitive at a harmonic of 60 Hz. The broad pulses in the Hornell ambient data with substation or third rail on are actually superpositions of multiple approximately periodic pulses recurring at the 360 Hz substation ripple frequency.

Across the 550 kHz-1.6 MHz commercial AM band, the MBTA ambient is dominated by radio stations, whereas only a few stations show up at Hornell.

From 1.6 MHz to 20 MHz, the ambient broadband levels at Hornell are more a function of time of day and corresponding meteorological conditions. The ambient data for substation on but third rail off happened to be taken near 6 PM on a day with heavy late-afternoon thunderstorm activity. Therefore, broadband levels for this case exceed both the substation-off and third-rail-on levels, which were observed at times earlier in the respective days. In this frequency range, the MBTA ambient data tend to fall between the quieter and noisier Hornell plots.Between 20 and 500 MHz, little broadband noise detectable above the instrumentation noise floor is seen in any ambient plot from either location.

The ambient plots contain a number of weak narrow-band radio signals that might be mistaken for broadband pulses. One way to spot these signals in the data presented here is to see if they appear on more than one trace taken at the same location. The strong narrow-band radio and TV signals stand out unambiguously. Ideally, narrow-band signals should all be spotted and marked as data are being taken, as is suggested in the test procedures of Ref. 2.

The Hornell broadband emissions from both AC and DC trains are easily observable and measureable above the ambients from 111 kHz to approx. 20 MHz. At some frequencies the AC train is slightly noisier, and at others the DC train is. By and large they appear comparable. Above 20 MHz, broadband emissions from eithere train are no longer observable above the instrumentation noise floor.

It is interesting to note that the MBTA ambient data tend to fall below the SAE ARP 1393 limits completely across the spectrum, and the data for the MBTA's SRC, where visible above the ambient, also tends to fall below the limit, or at worst nudge it at isolated frequencies.

The MBTA broadband emissions from the SRC are essentially not differentiable from the ambient at frequencies below 13 MHz. However, from 13 to 370 MHz, the SRC car's emissions can be detected above ambient. This behavior differs from either of the Hornell cars, whose emissions were plainly visible below 20 MHz but not above. The MBTA data were obtained by taking car data immediately after ambient data in each frequency band, and therefore broadband pulses seen in the car data cannot be explained away as an ambient that worsened.

Since the purpose of this report is to demonstrate what broadband data look like, no further analysis of the data will be made. The data presented demonstrate that ambient conditions change from place to place and time to time. The data also demonstrate that other parts of the rail transit power system can have a profound effect on ambient levels. Finally, the data show that different types of rapid transit cars have different identifiable broadband emission characteristics.

4. SUMMARY

The Radiated Suggested Test Procedures [Ref. 2] are designed to aid the skilled pratitioner in acquiring data that can be related to the operational concerns of rapid transit systems. The data and the graphical results are subject to interpretation, based upon the prior experience of the practitioner. By applying standardized procedures to the collection and reduction of the data, the interpretation of the data will be more straightforward.

The test procedures applied above are based on adaptations and extensions of well-known standardized techniques previously specified by the U.S. Department of Defense, the Society of Automotive Engineers, and other standards-setting bodies. The procedures that have been demonstrated here are aimed at performing measurements and producing data in a standardized manner that can be applied efficiently and effectively to assess the radiated emission characteristics of rail transit vehicles. If RF emissions are discovered that exceed specified limits, other types of tests performed in the field or in the laboratory may be called for to identify the offending sources.

Ultimately, it is the responsibility of the authority ordering the tests, whether that be transit operator, prime contractor, equipment manufacturer, or whoever, to define the purpose of the tests, select the proper location, and determine what data are necessary and sufficient to meet the stated objectives.

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2. "Radiated Interference in Rapid Transit Systems - Volume II: Suggested Test Procedures", DOT Report No. UMTA-MA-06-0153-85-11, U.S. Dept. of Transportation, Transportation Systems Center, Cambridge, MA 02142, June 1987.

3. Simon Ramo & John R. Whinnery, Fields and Waves in Modern Radio, Wiley, New York, 1953, pp 496-499.

4. "Application Note 142: EMI Measurement Procedure", Hewlett-Packard Corporation, Palo Alto, CA, 1972.

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7. Ronald N. Bracewell, The Fourier Transform and its Applications, Second Edition, McGraw-Hill, New York, 1978.

8. "SAE Recommended Practice ARP 1393: Electromagnetic Compatibility and Interference Control for Rapid Transit Vehicles", Society of Automotive Engineers, Inc., 3 May 1976.

9. "Military Standard: Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference - MIL-STD 461B", U.S. Department of Defense, Washington, DC, 1 April 1980.

APPENDIX A

RADIATED EMISSION DATA FROM TESTS OF THE STARS AC-PROPULSION RAPID TRANSIT TRAIN AND A CAM-CONTROLLED DC-PROPELLED TRAIN

Tests were performed at the Morrison-Knudsen rapid transit car facility in Hornell, N.Y. in June 1986. The test track was approx. 350 meters (1150 ft) in length, and allowed maximum speeds of approx. 35 mph. Third rail power was provided by a three-phase full-wave (6-pulses per 60-Hz cycle) solid-state rectifier, with a fundamental ripple frequency of 360 Hz. Receiving antennas were positioned 15 meters (50 ft) from the centerline of the test track. Vertical E-field was observed from 115 kHz to 30 MHz using a whip antenna with a multi-band balun. Horizontal E-field was observed from 20 to 200 MHz using a biconical antenna, and from 200 to 500 MHz using a log-periodic antenna.

On each data page, operational test data are recorded at the top, followed by a computer-generated display of broadband signal strength in dBµV/m/MHz. The bottom figure is of signal strength at the spectrum analyzer input in units of dbmW. Spectrum analyzer input signal data are used in conjunction with spectrum analyzer input impedance and impulse bandwidth and antenna factor, to obtain broadband signal strength. The following table lists data pages for Hornell measurements.

Table A-1: Page Index of Broadband Emission Data from Hornell, NY

	Frequencies								
Measurement	111-263 kHz	243-528 kHz	484k-1.159 MHz	1.128-2.411 MHz	2.269-6.704 MHz	6.467-12.66 MHz	12.39-30.0 MHz	20-200 MHz	200-500 MHz
Ambient with rectifier substation off	A-2	A-8	A-14	A-20	A-26	A-32	A-38	-----	-----
Ambient with substa. on but third rail power off	A-3	A-9	A-15	A-21	A-27	A-33	A-39	A-44	A-48
Ambient with third rail power on	A-4	A-10	A-16	A-22	A-28	A-34	A-40	A-45	A-49
AC train max. accel.; approx.30 mph when nose opp. antenna.	A-5	A-11	A-17	A-23	A-29	A-35	A-41	A-46	A-50
AC train max. accel. from stop with nose opp. antenna.	A-6	A-12	A-18	A-24	A-30	A-36	A-42	-----	-----
DC train max. accel.; approx. 30 mph when nose opp. ant	A-7	A-13	A-19	A-25	A-31	A-37	A-43	A-47	-----

HORNELL - SUBSTATION OFF AMBIENT: 111-263 kHz

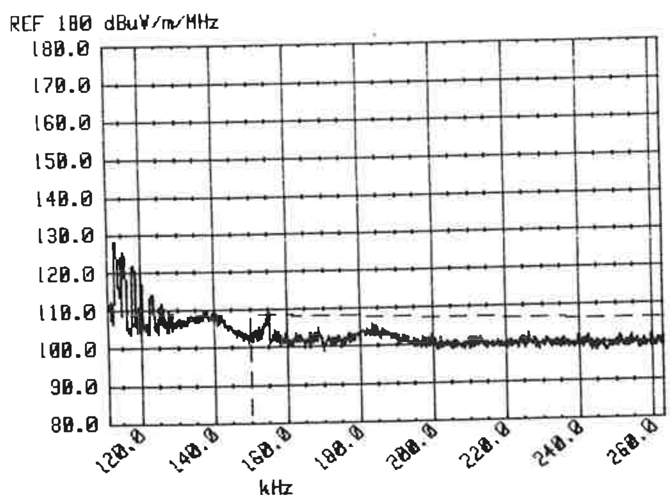
RUN #54 - STORED IN FILE....AC4 RECORD # 28
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:15:50

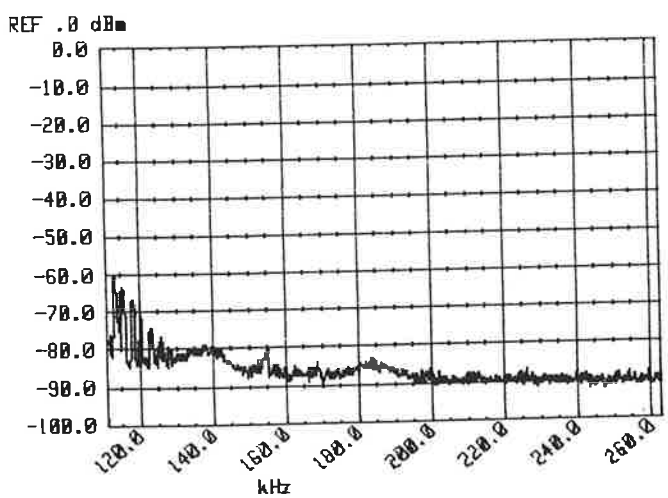
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





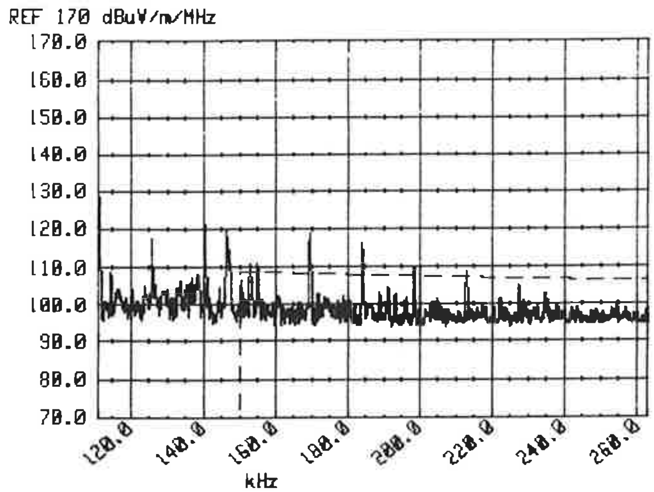
HORNELL - THIRD RAIL OFF AMBIENT: 111-263 kHz

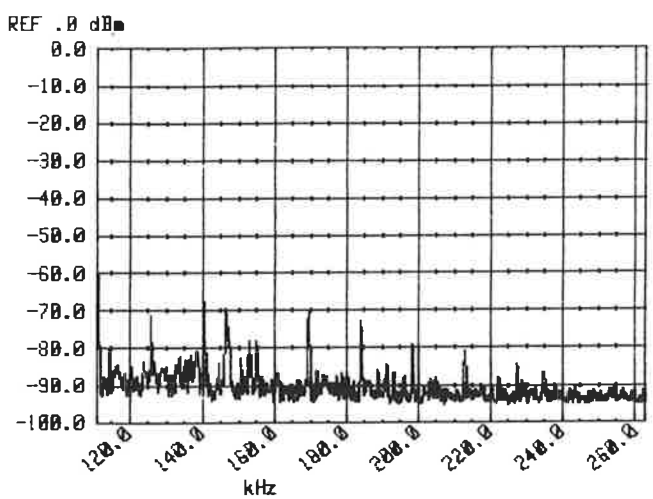
RUN #2 - STORED IN FILE....AC1 RECORD # 3
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 17:32:58

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:SAME AS RUN#1 EXCEPT BALUN SWITCHER WAS TURNED OFF
TRACE WAS OBTAINED IN CLEAR WRITE SAMPLING MODE.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





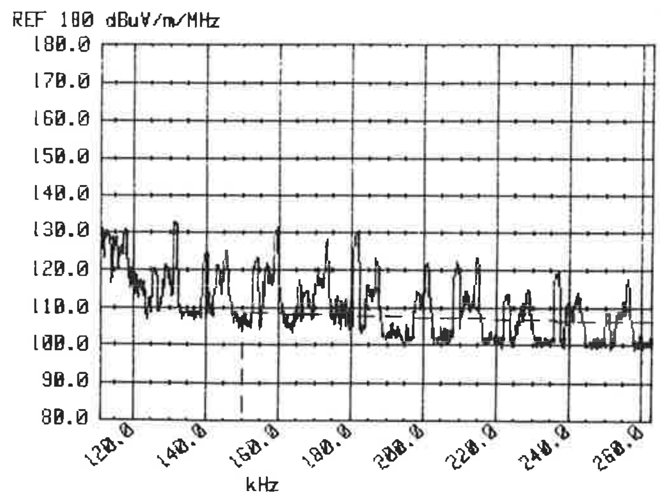
HORNELL - THIRD RAIL ON AMBIENT: 111-263 kHz

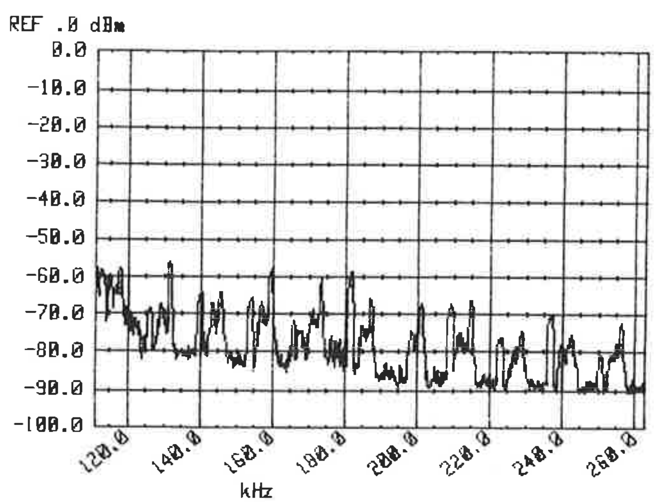
RUN #18 - STORED IN FILE....AC1 RECORD # 18
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:35:34

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





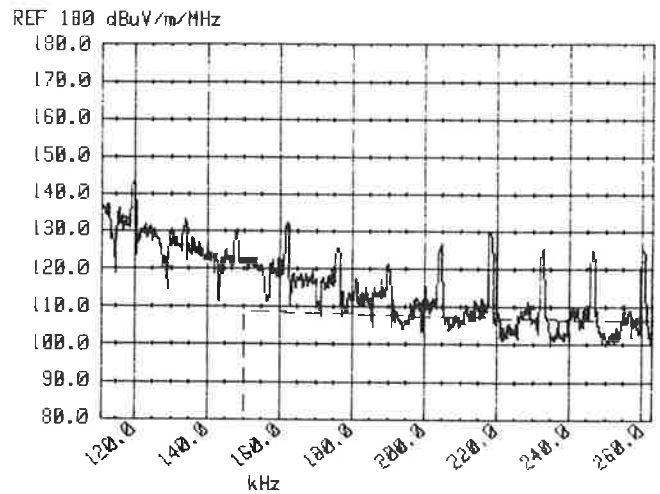
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 111-263 kHz

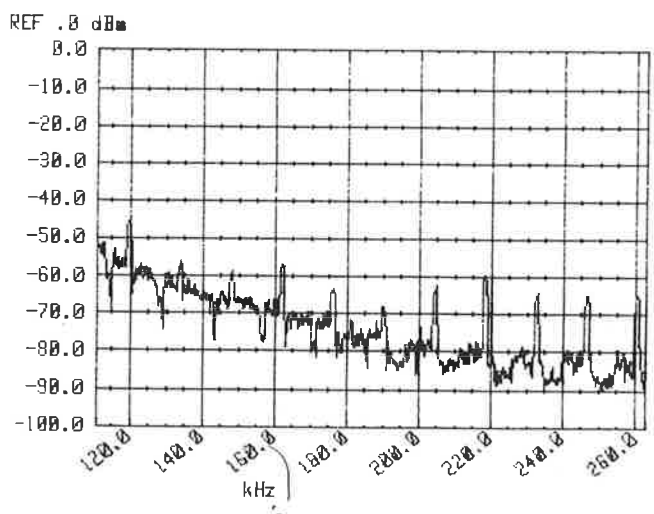
RUN #51 - STORED IN FILE....AC3 RECORD # 1
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:08:26

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





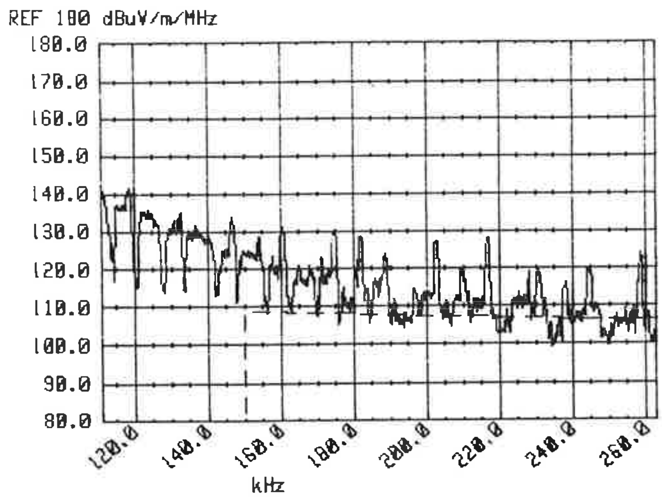
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 111-263 kHz

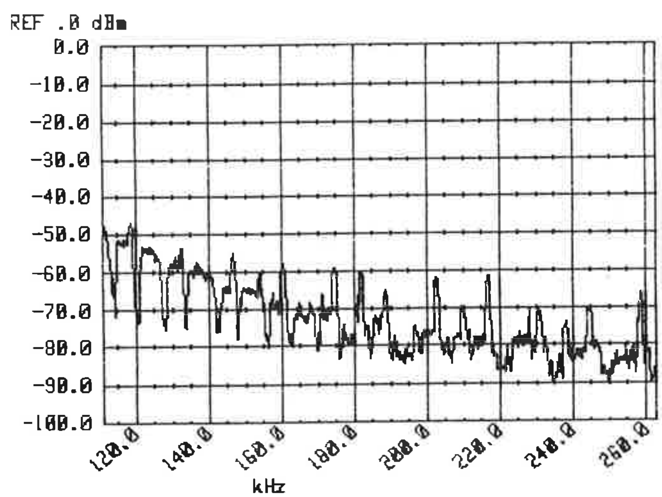
RUN #45 - STORED IN FILE....AC4 RECORD # 19
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:26:45

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





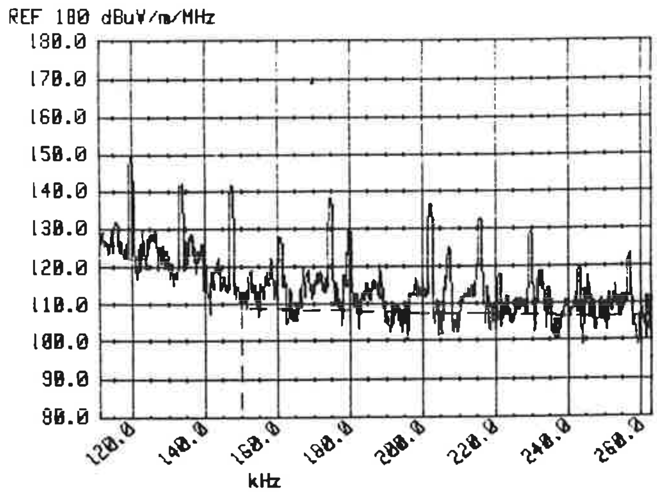
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 111-263 kHz

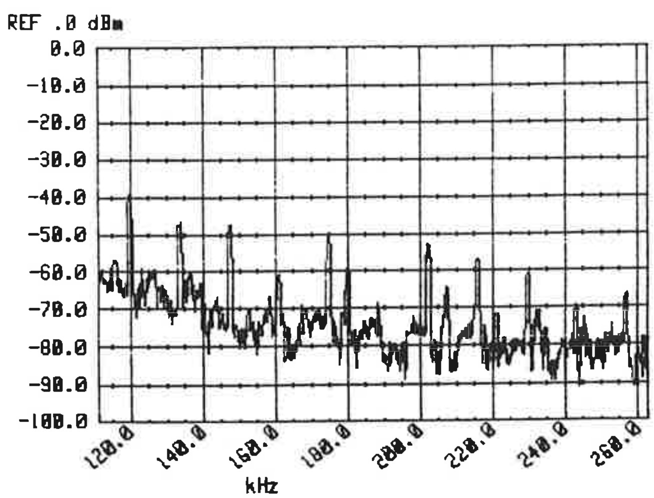
RUN #77 - STORED IN FILE....AC5 RECORD # 8
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:15:58

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





HORNELL - SUBSTATION OFF AMBIENT: 243-528 kHz

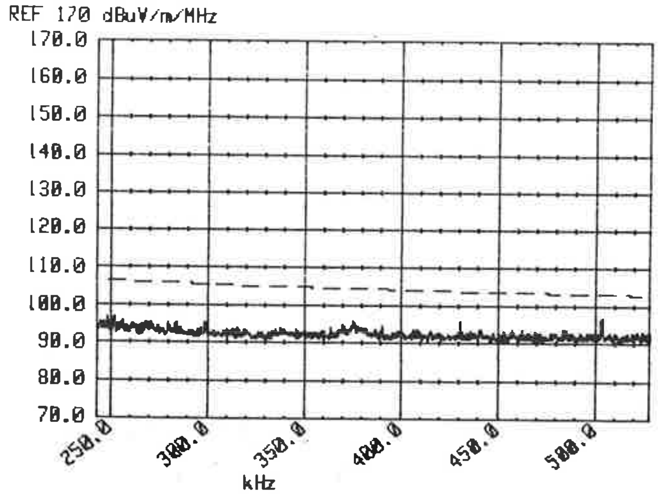
RUN #55 - STORED IN FILE....AC4 RECORD # 29
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:17:00

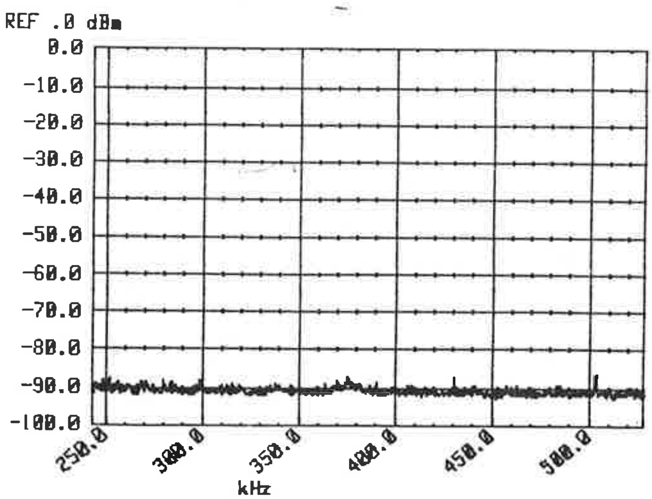
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





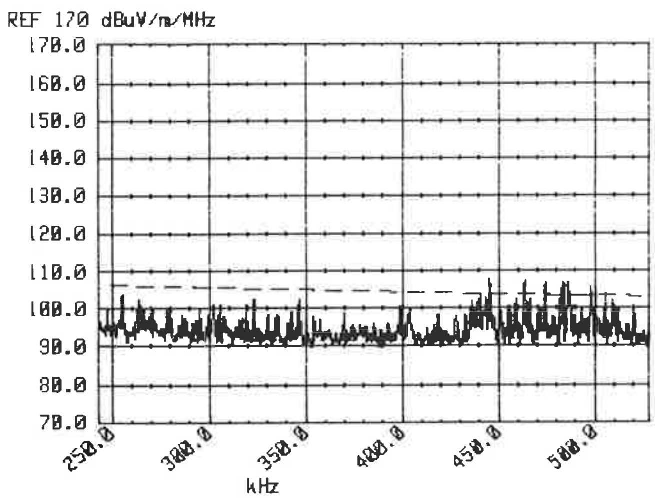
HORNELL - THIRD RAIL OFF AMBIENT: 243-528 kHz

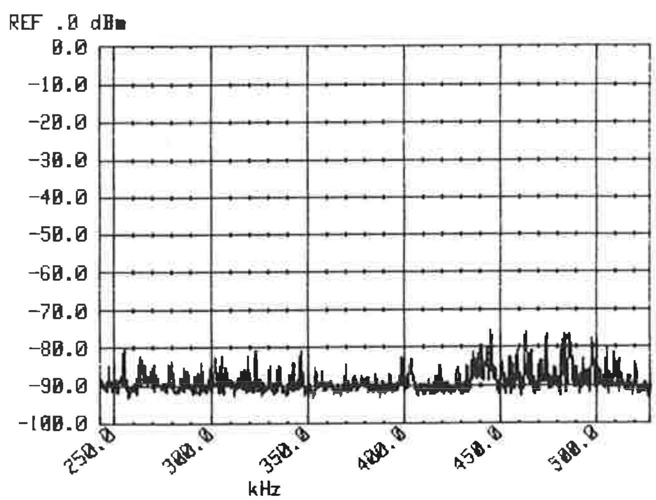
RUN #4 - STORED IN FILE....AC1 RECORD # 5
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 17:52:17

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASURMENT. 360 HZ HARMONICS HAVE ALMOST
DISAPPEARED.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





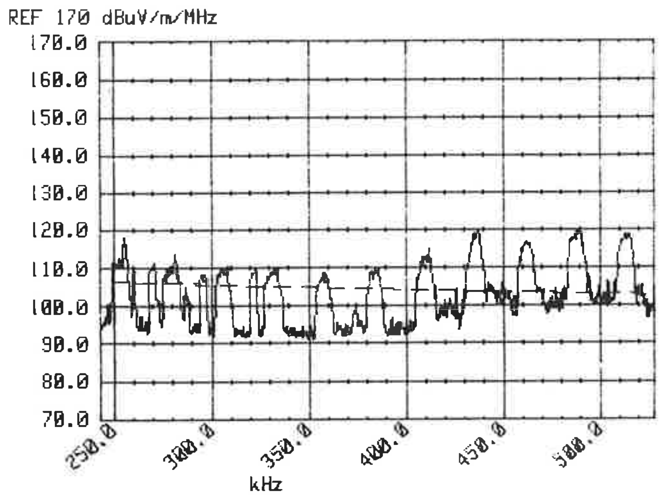
HORNELL - THIRD RAIL ON AMBIENT: 243-528 kHz

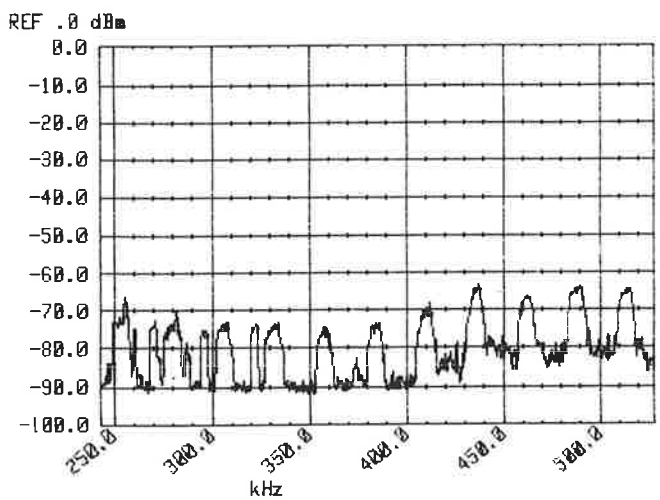
RUN #19 - STORED IN FILE....AC1 RECORD # 19
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:43:45

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





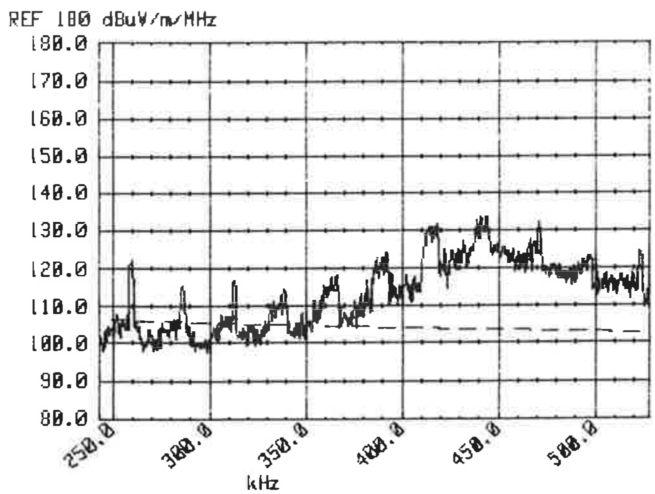
HORNELL- AC TRAIN MAX. ACCEL. PAST ANTENNA: 243-528 kHz

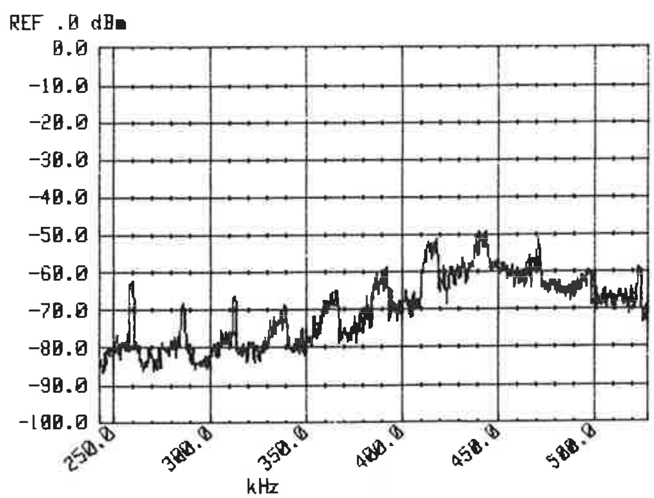
RUN #52 - STORED IN FILE....AC3 RECORD # 2
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:16:16

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





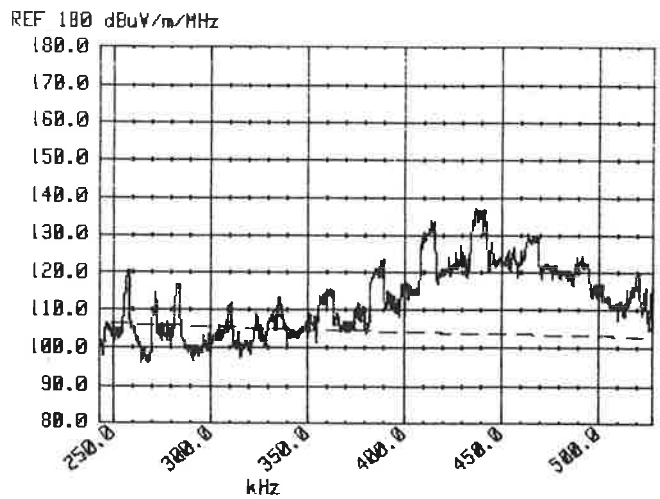
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 243-528 kHz

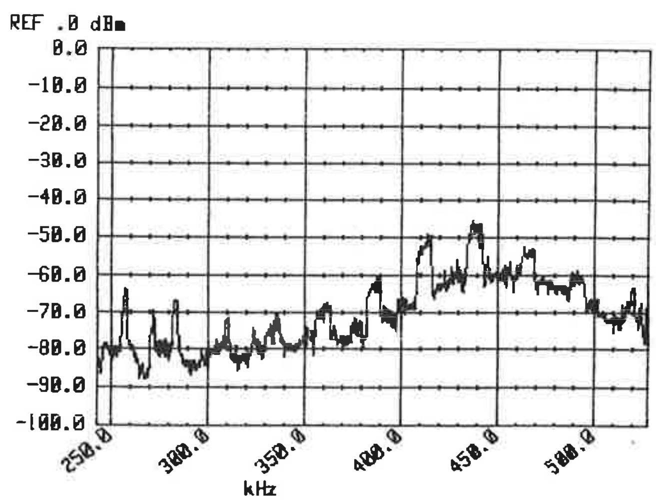
RUN #46 - STORED IN FILE....AC4 RECORD # 20
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:28:37

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





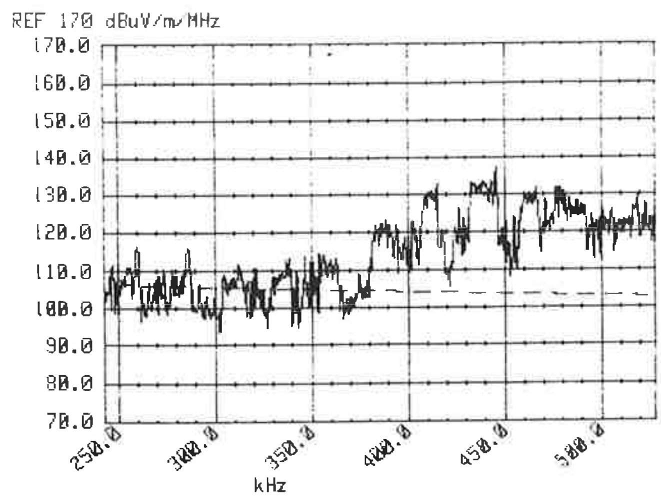
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 243-528 kHz

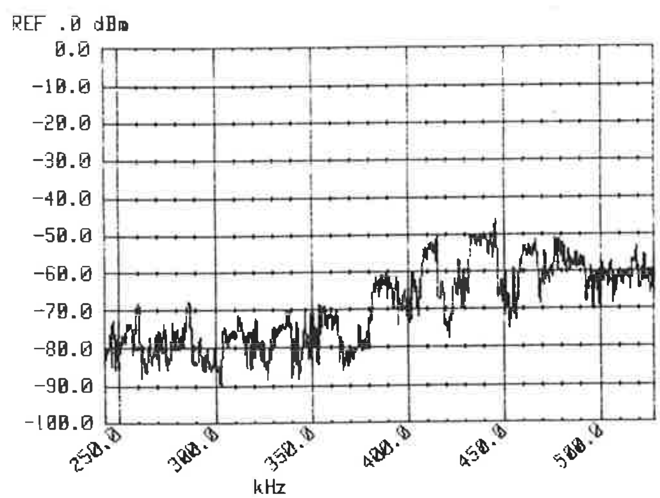
RUN #78 - STORED IN FILE....AC5 RECORD # 9
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:18:07

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
. STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





HORNELL - SUBSTATION OFF AMBIENT: 484 kHz-1.159 MHz

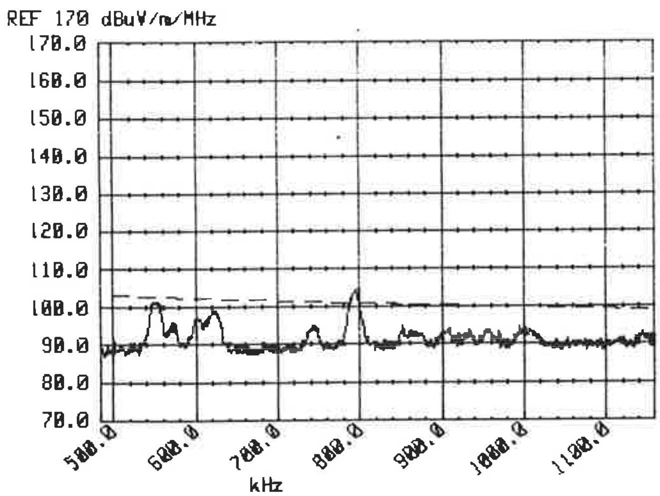
RUN #56 - STORED IN FILE....AC4 RECORD # 30
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:17:37

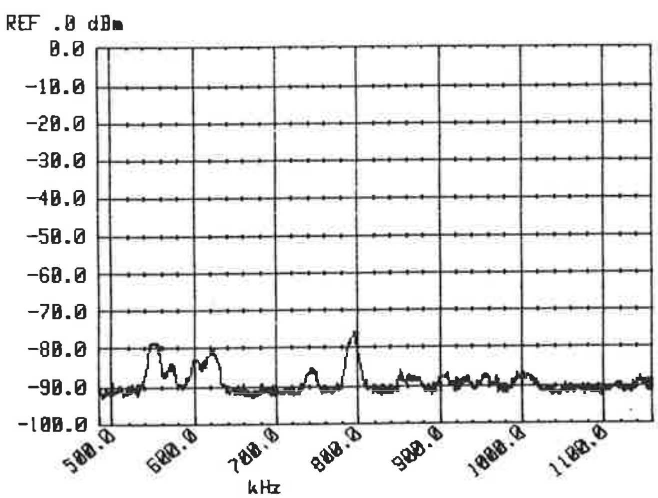
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





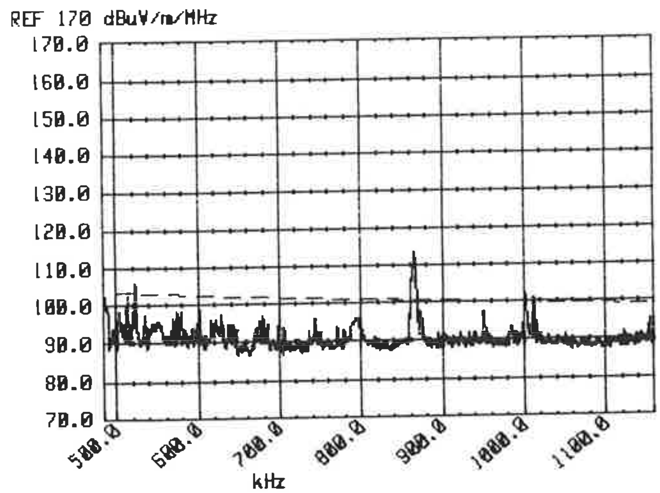
HORNELL - THIRD RAIL OFF AMBIENT: 484 kHz-1.159 MHz

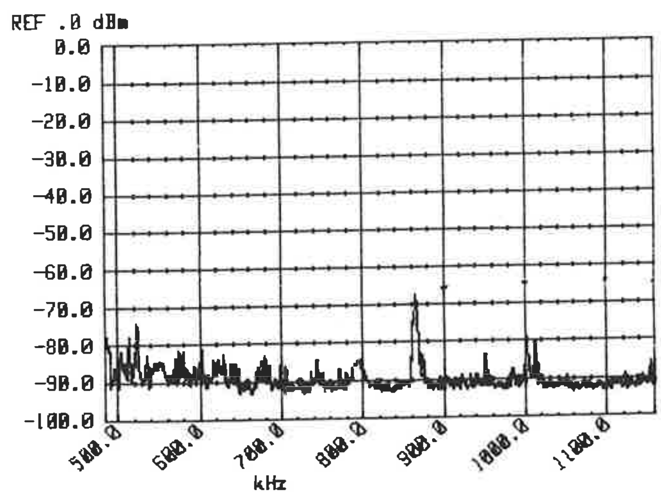
RUN #6 - STORED IN FILE....AC1 RECORD # 6
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 17:57:15

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





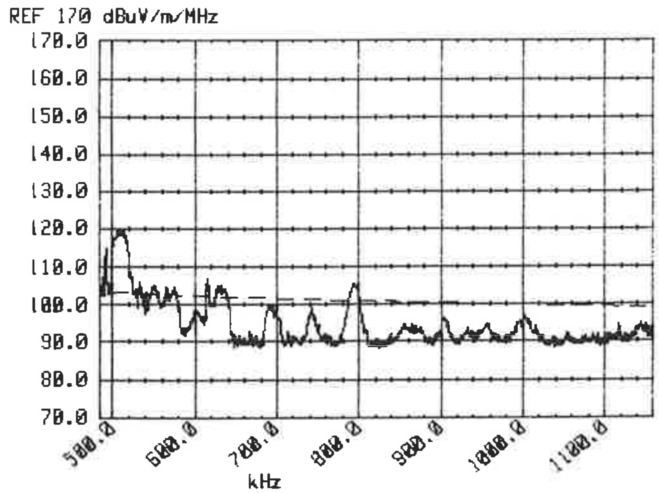
HORNELL - THIRD RAIL ON AMBIENT: 484 kHz- 1.159 MHz

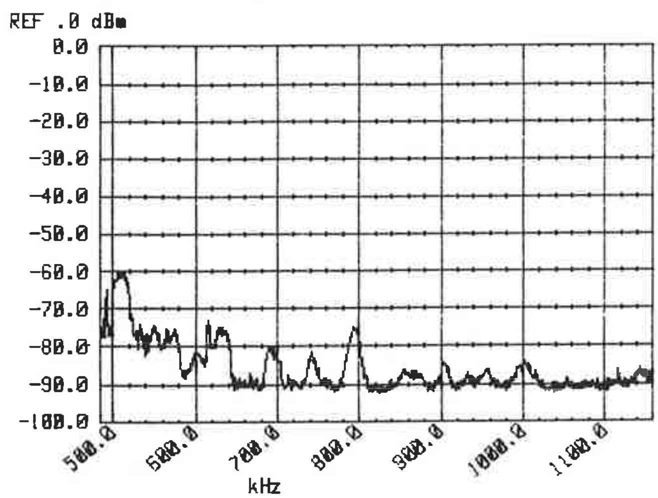
RUN #20 - STORED IN FILE....AC1 RECORD # 20
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:47:20

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





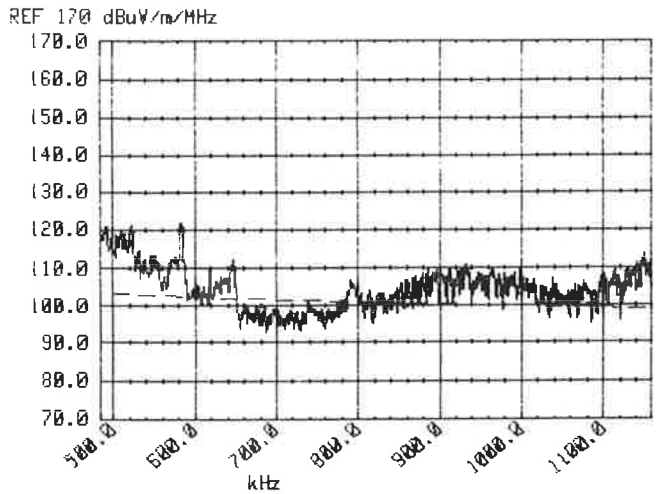
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 484 kHz-1.159 MHz

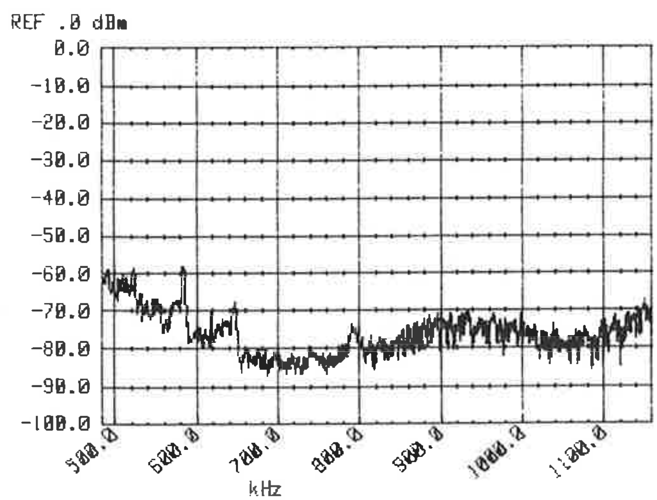
RUN #53 - STORED IN FILE....AC3 RECORD # 3
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:22:13

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





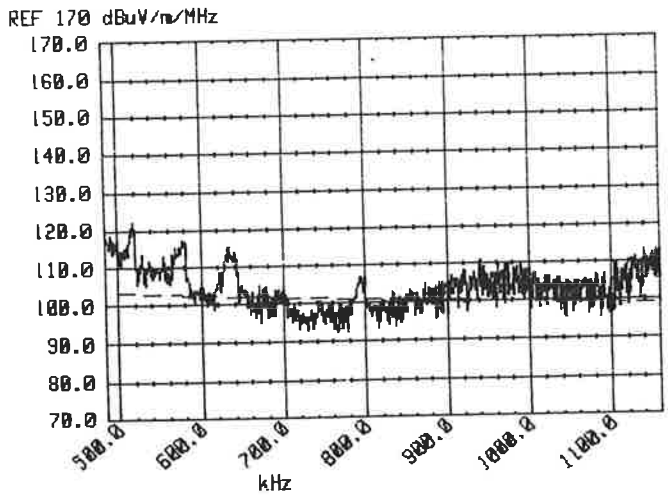
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 484 kHz-1.159 MHz

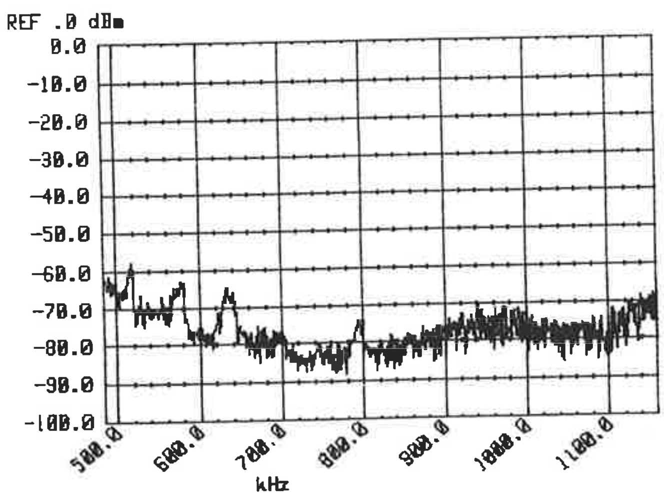
RUN #47 - STORED IN FILE....AC4 RECORD # 21
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:30:37

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





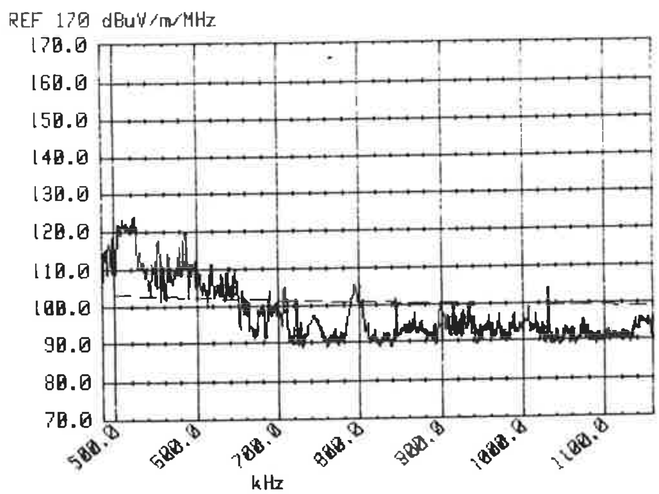
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 484 kHz-1.159 MHz

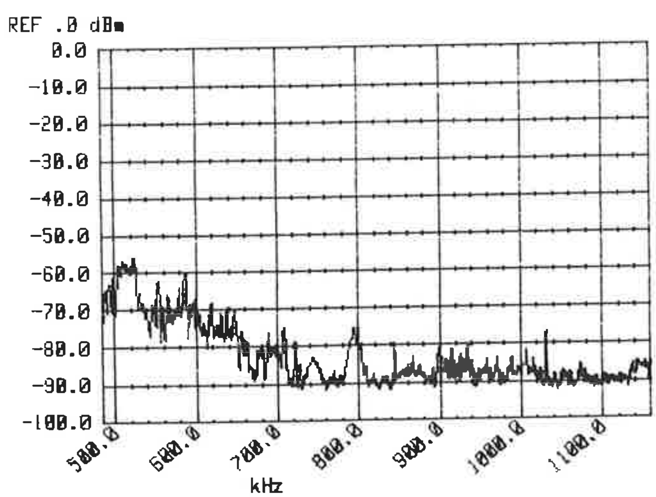
RUN #79 - STORED IN FILE....AC5 RECORD # 10
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:20:34

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
. STANDING START. SYNC MODE FOR ALL IN THIS SERIES.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





<u>HORNELL - SUBSTATION OFF AMBIENT: 1.128-2.411 MHz</u>

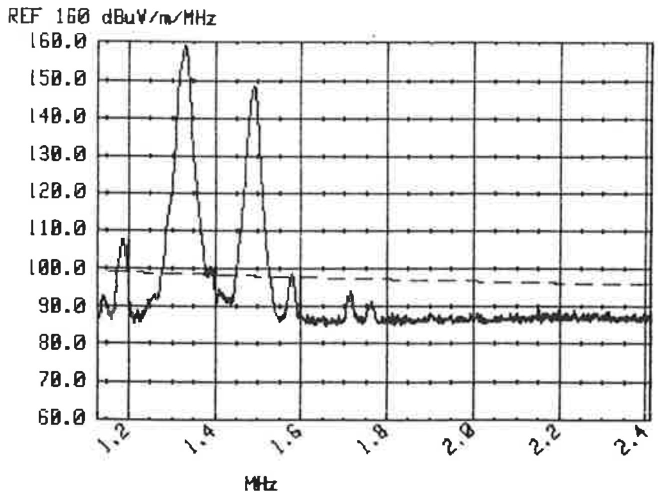
RUN #57 - STORED IN FILE....AC4 RECORD # 31
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:18:21

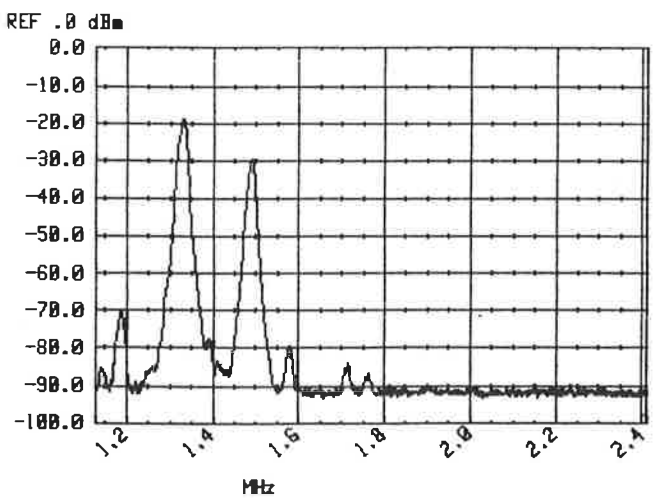
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





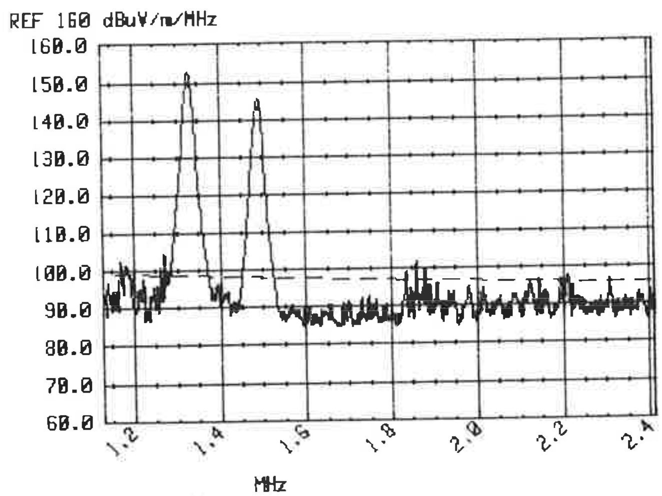
HORNELL - THIRD RAIL OFF AMBIENT: 1.128-2.411 MHz

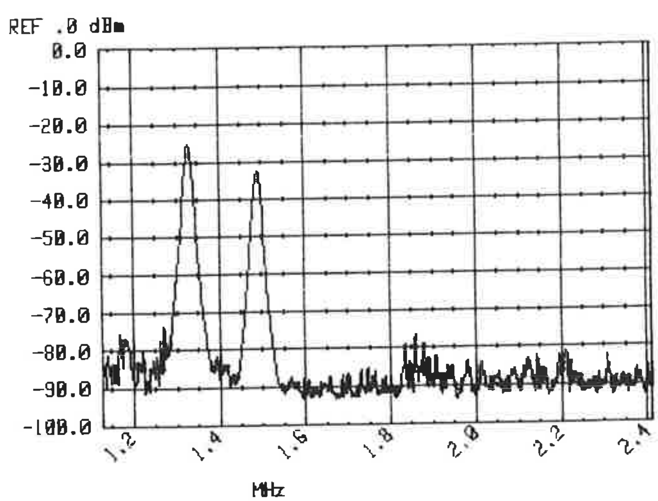
RUN #7 - STORED IN FILE....AC1 RECORD # 7
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 18:04:38

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





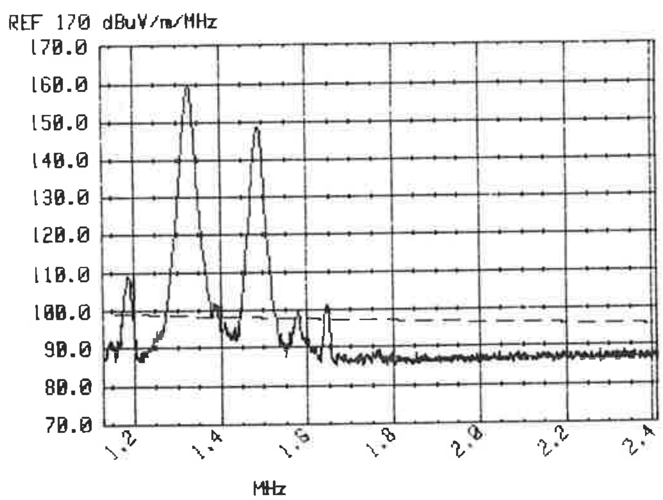
HORNELL - THIRD RAIL ON AMBIENT: 1.128-2.411 MHz

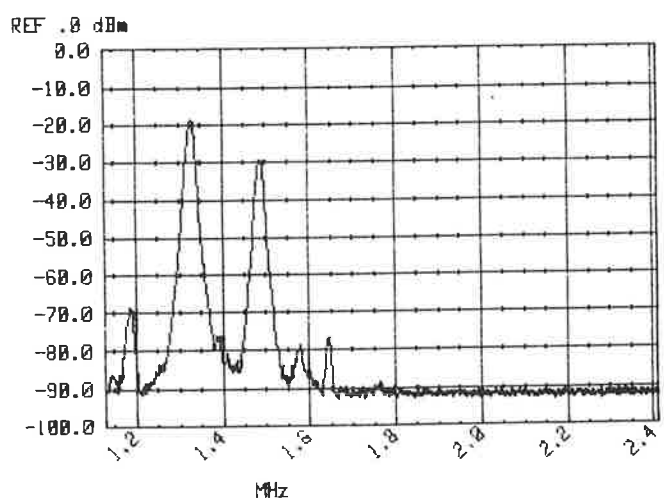
RUN #21 - STORED IN FILE....AC1 RECORD # 21
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:50:12

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





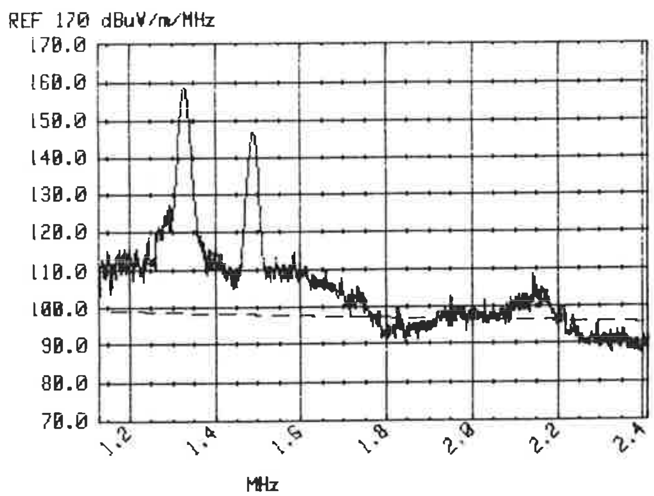
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 1.128-2.411 MHz

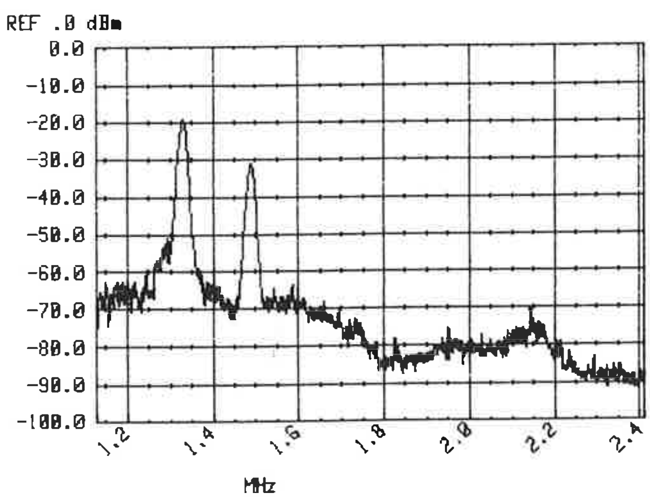
RUN #54 - STORED IN FILE....AC3 RECORD # 4
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:28:01

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





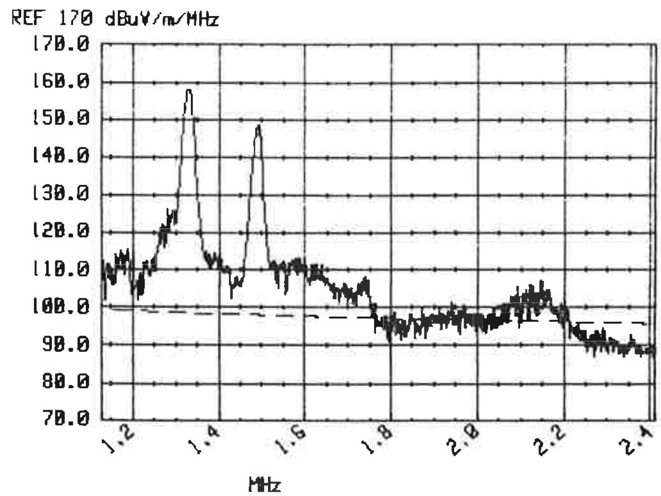
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 1.128-2.411 MHz

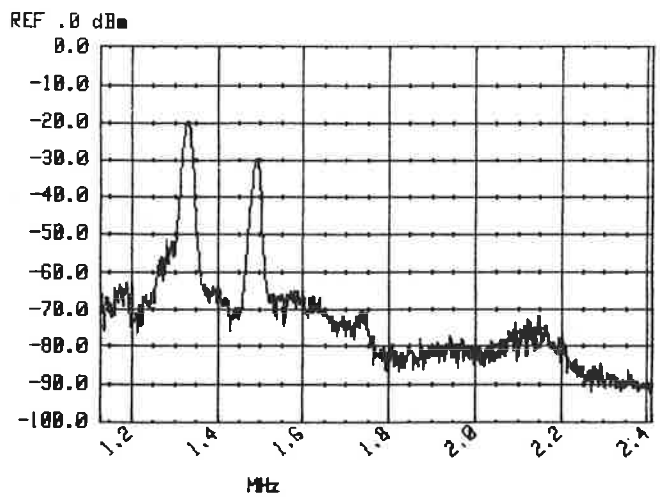
RUN #48 - STORED IN FILE....AC4 RECORD # 22
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:32:47

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





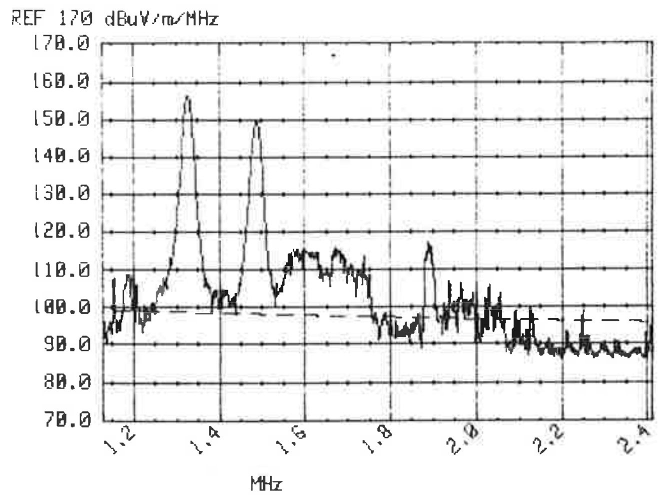
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 1.128-2.411 MHz

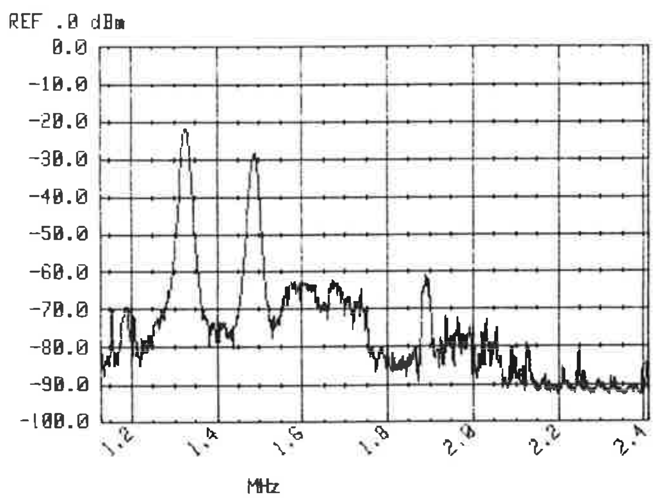
RUN #80 - STORED IN FILE....AC5 RECORD # 11
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:22:15

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





HORNELL - SUBSTATION OFF AMBIENT: 2.269-6.704 MHz

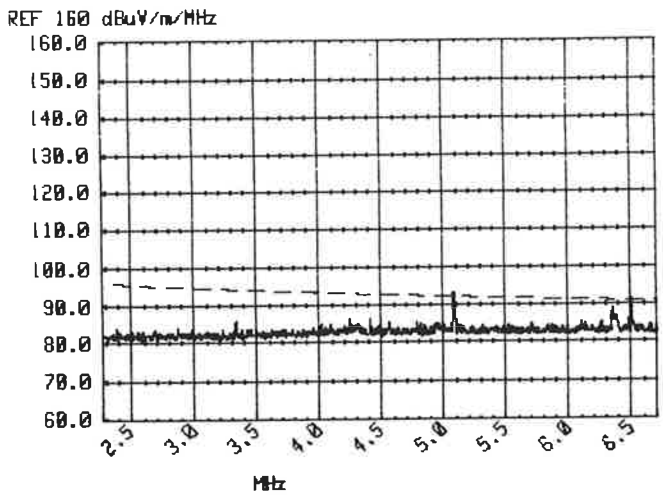
RUN #58 - STORED IN FILE....AC4 RECORD # 32
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:18:56

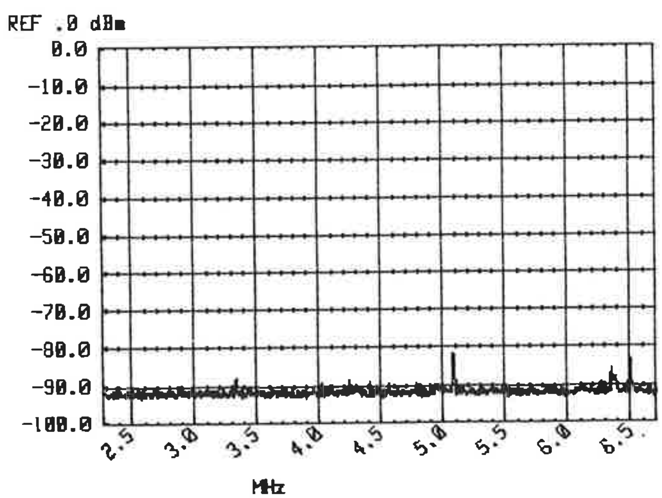
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





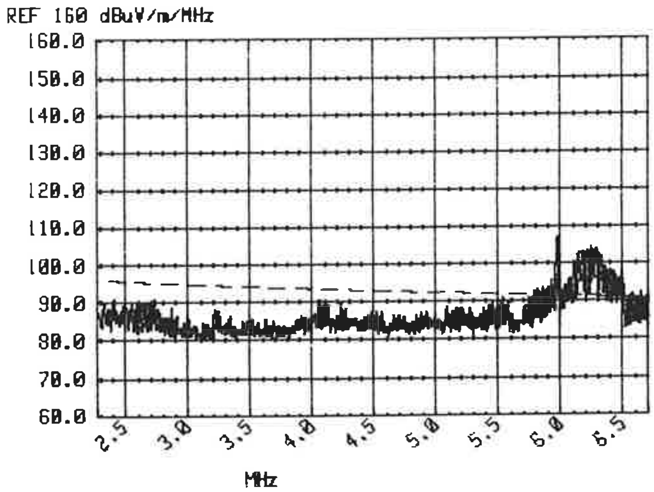
HORNELL - THIRD RAIL OFF AMBIENT: 2.269-6.704 MHz

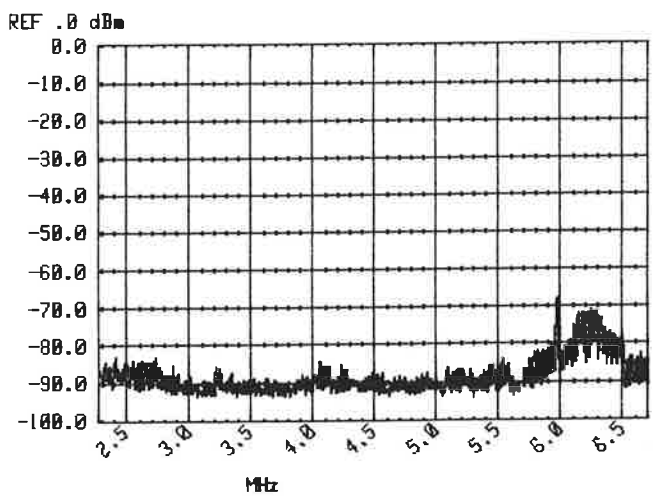
RUN #8 - STORED IN FILE....AC1 RECORD # 8
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 18:08:07

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





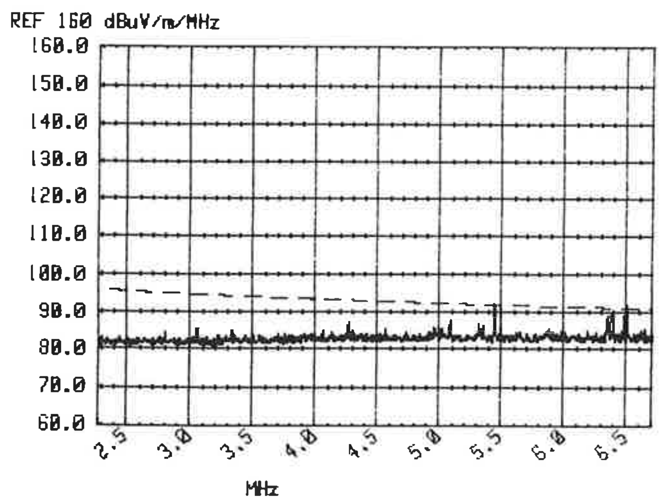
HORNELL - THIRD RAIL ON AMBIENT: 2.269-6.704 MHz

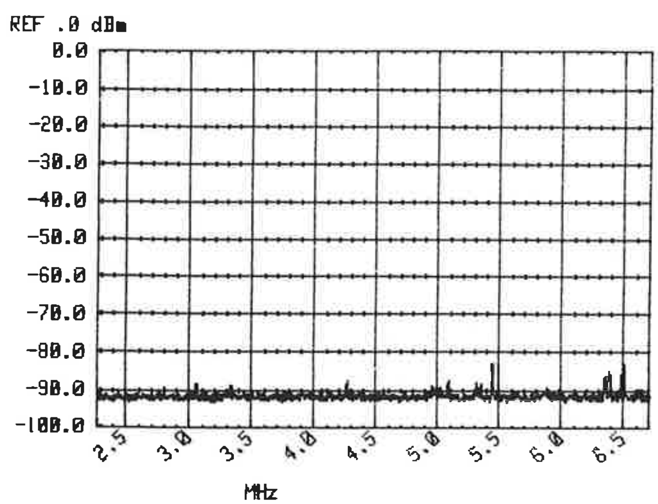
RUN #22 - STORED IN FILE....AC1 RECORD # 22
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:52:23

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





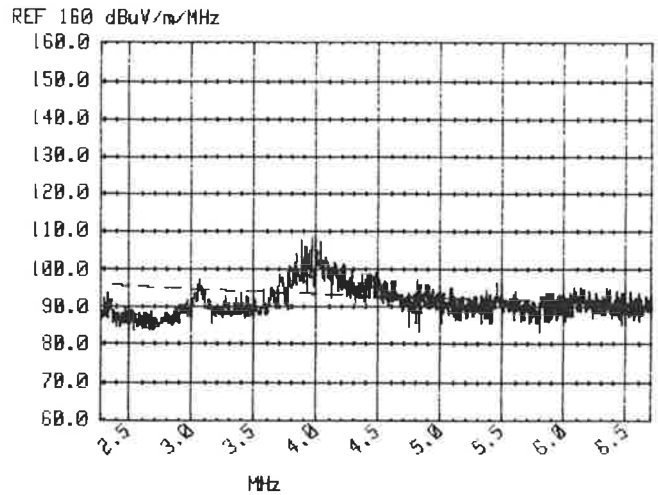
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 2.269-6.704 MHz

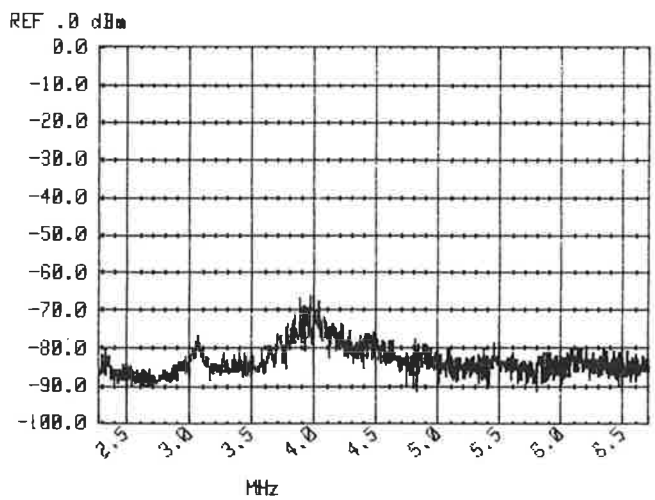
RUN #55 - STORED IN FILE....AC3 RECORD # 5
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:32:06

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





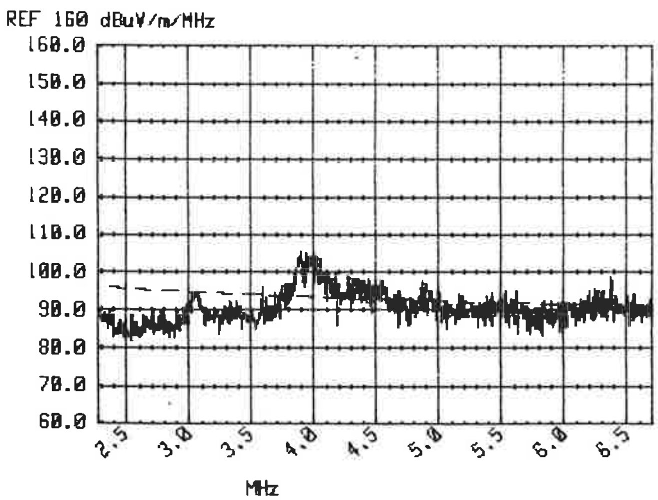
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 2.269-6.704 MHz

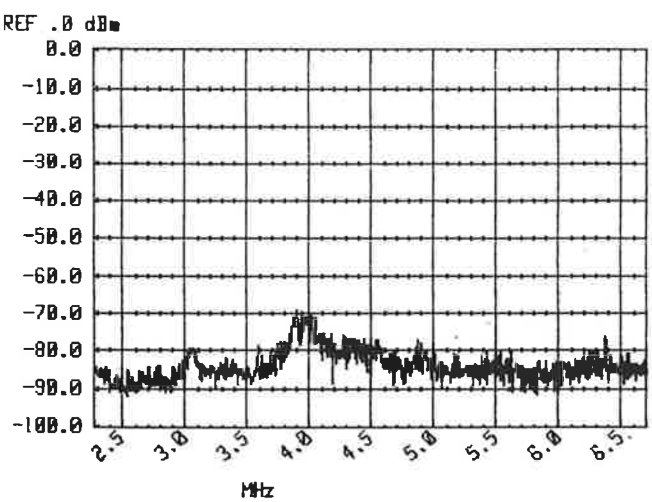
RUN #49 - STORED IN FILE....AC4 RECORD # 23
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:35:24

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





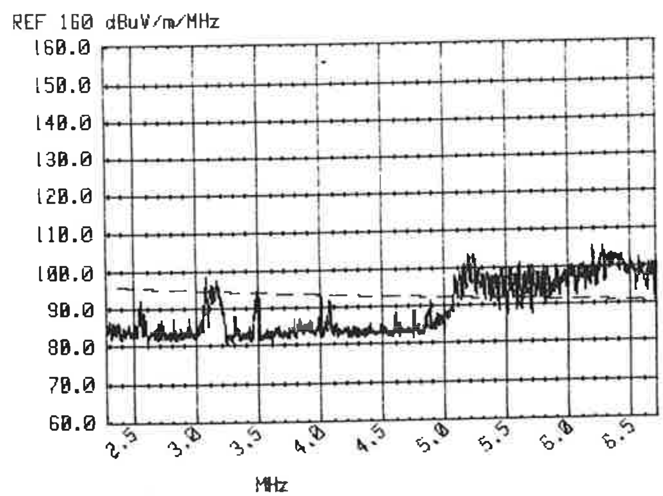
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 2.269-6.704 MHz

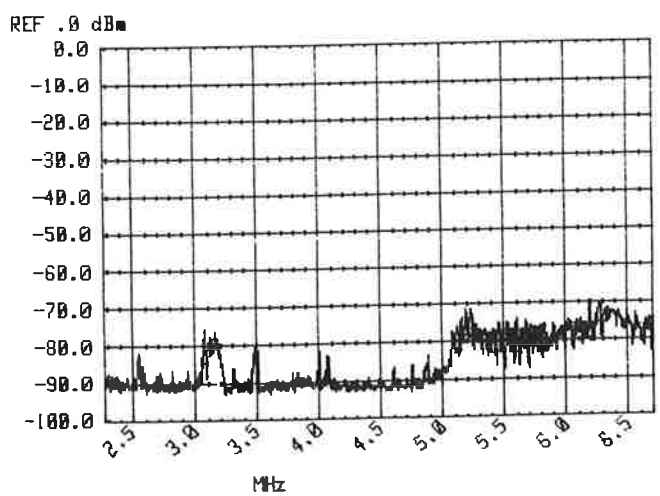
RUN #81 - STORED IN FILE....AC5 RECORD # 12
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:23:46

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





HORNELL - SUBSTATION OFF AMBIENT: 6.467-12.660 MHz

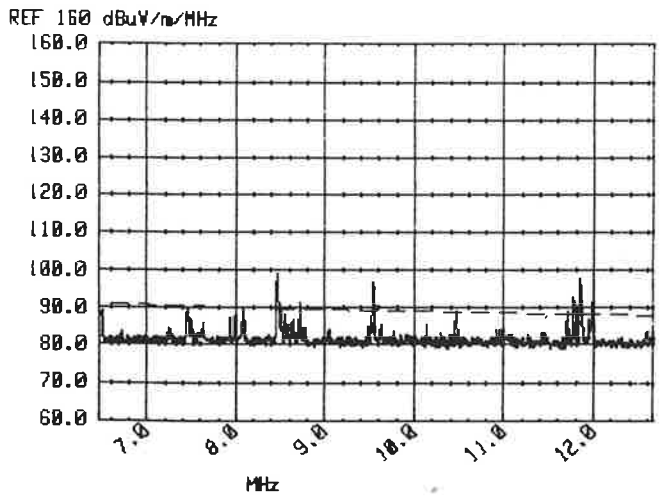
RUN #59 - STORED IN FILE....AC4 RECORD # 33
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:19:30

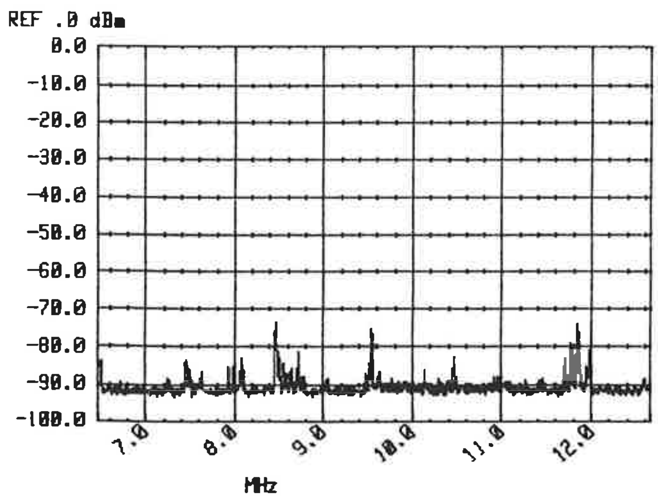
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





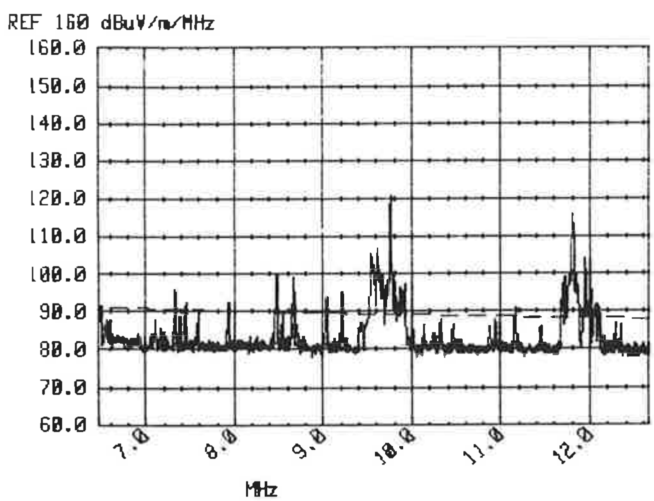
HORNELL - THIRD RAIL OFF AMBIENT: 6.467-12.660 MHz

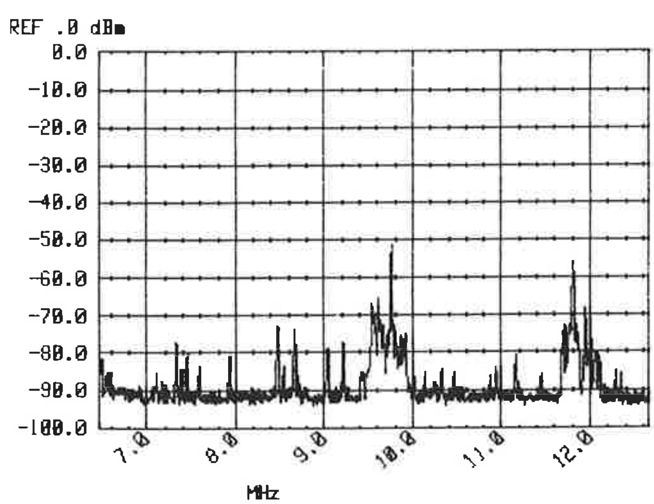
RUN #9 - STORED IN FILE....AC1 RECORD # 9
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 18:16:24

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





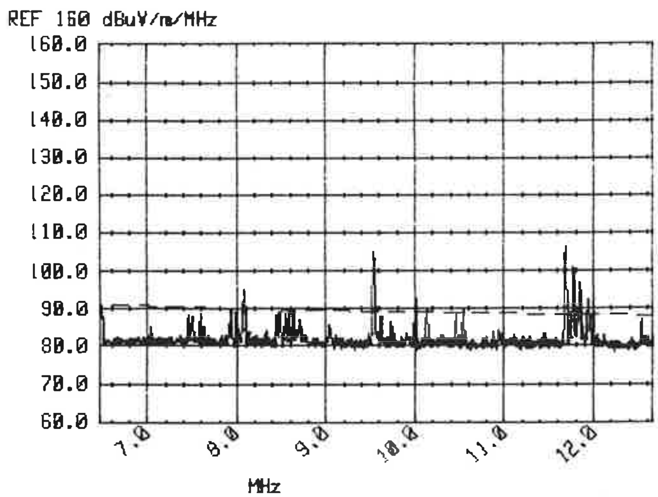
HORNELL - THIRD RAIL ON AMBIENT: 6.467-12.660 MHz

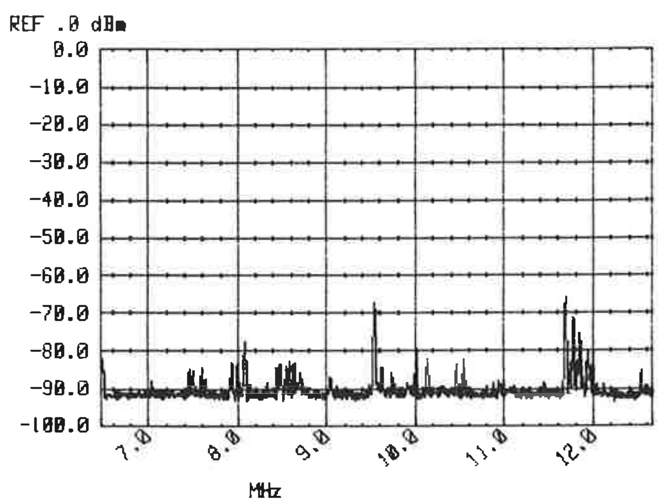
RUN #23 - STORED IN FILE....AC1 RECORD # 23
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:54:25

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





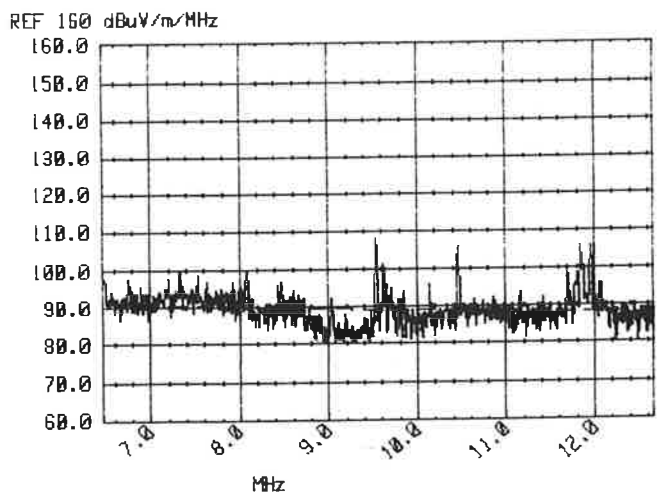
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 6.467-12.660 MHz

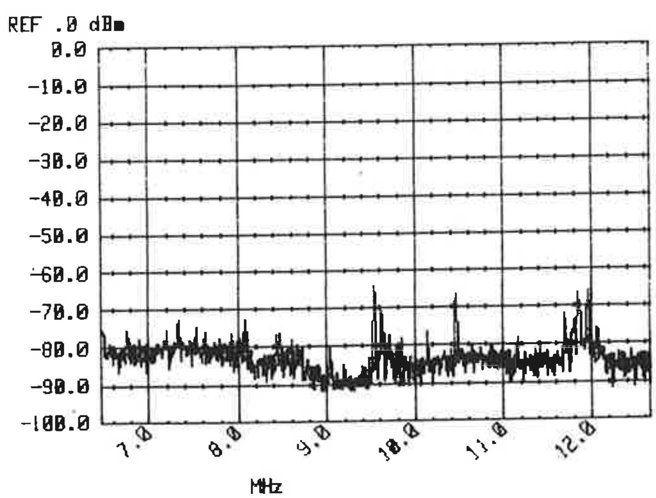
RUN #56 - STORED IN FILE....AC3 RECORD # 6
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:36:52

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





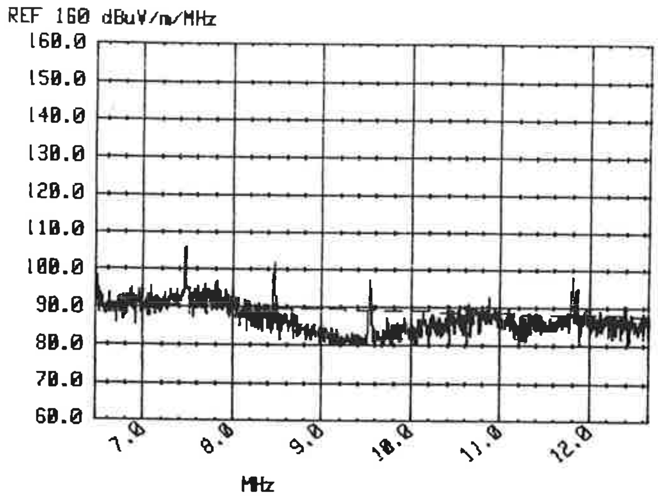
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 6.467-12.660 MHz

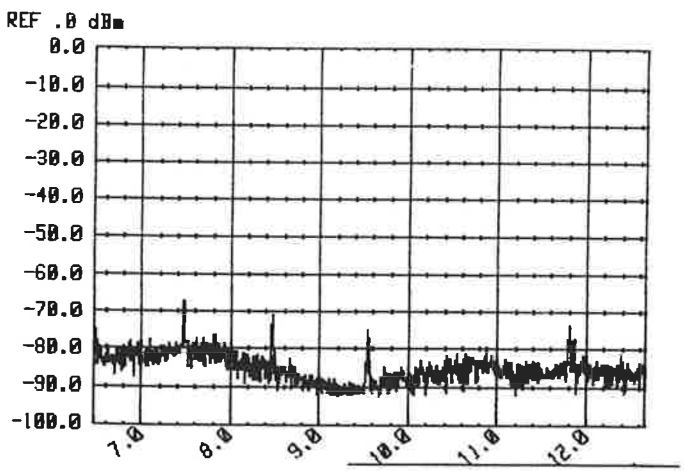
RUN #50 - STORED IN FILE....AC4 RECORD # 24
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:38:01

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





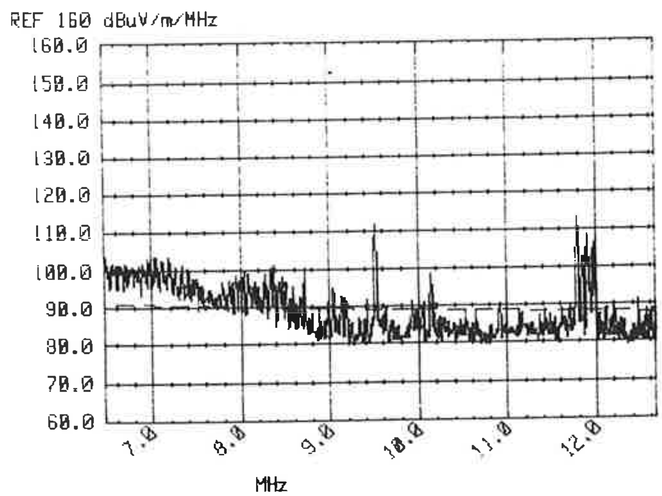
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 6.467-12.660 MHz

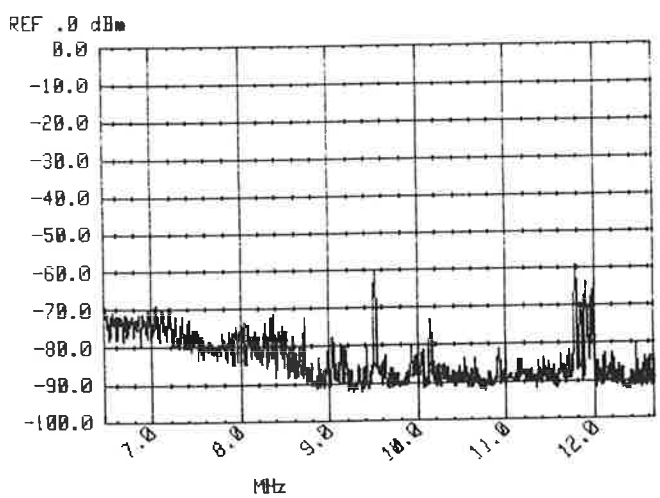
RUN #82 - STORED IN FILE....AC5 RECORD # 13
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:25:33

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz   STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





HORNELL - SUBSTATION OFF AMBIENT: 12.39-30.0 MHz

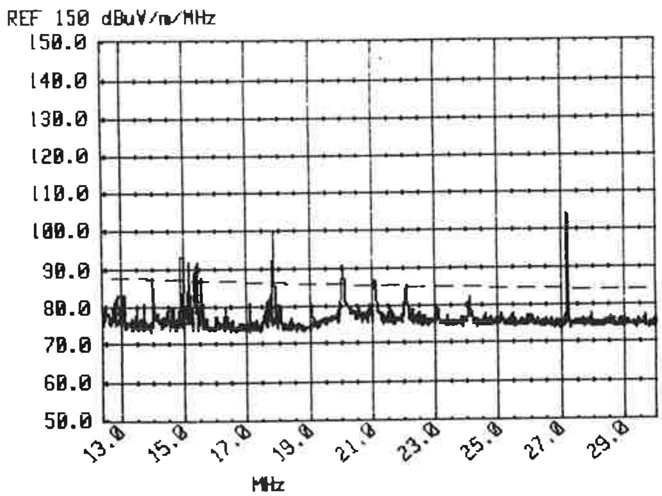
RUN #60 - STORED IN FILE....AC4 RECORD # 34
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 12:20:39

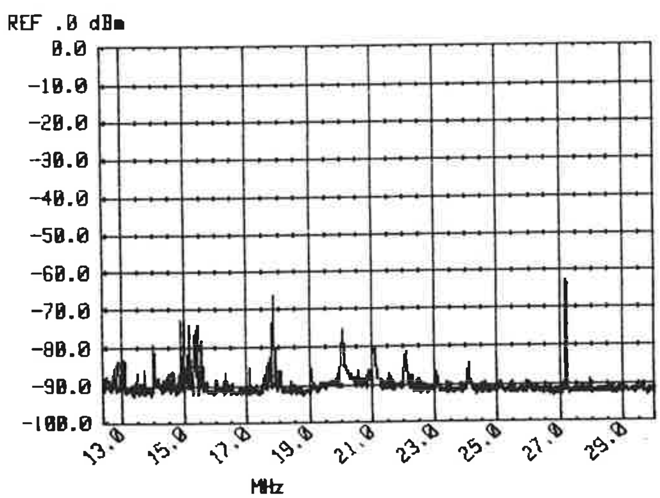
ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT WITH SUBSTATION POWER OFF.
TRAIN FAR AWAY.

TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





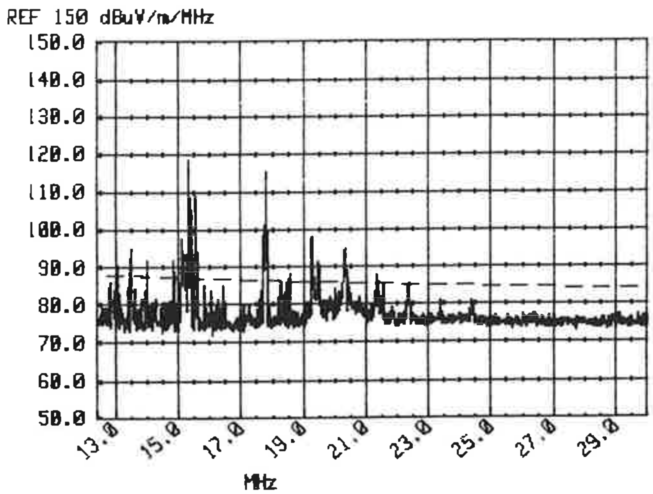
HORNELL - THIRD RAIL OFF AMBIENT: 12.39-30.0 MHz

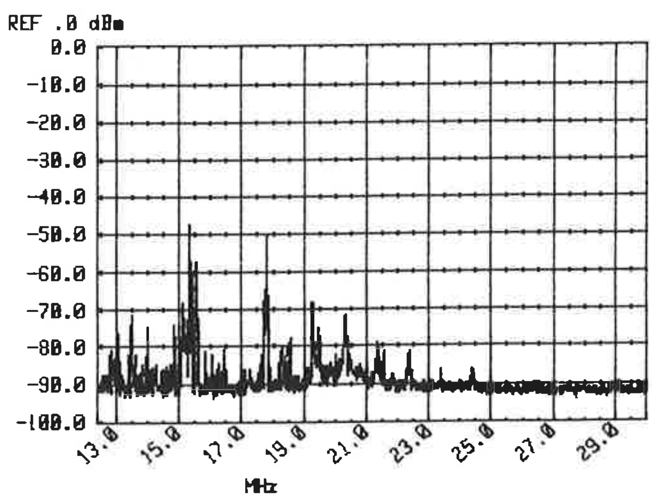
RUN #10 - STORED IN FILE....AC1 RECORD # 10
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 18:21:02

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





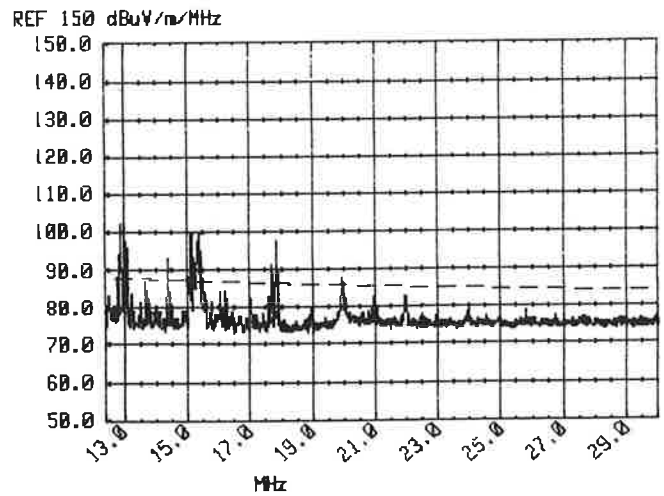
HORNELL - THIRD RAIL ON AMBIENT: 12.39-30.0 MHz

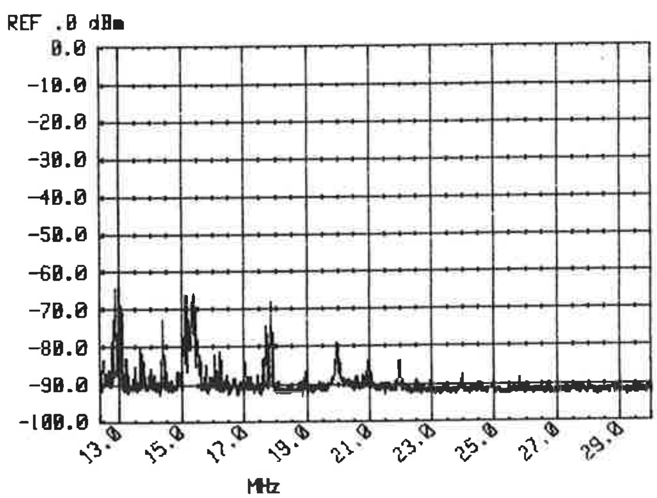
RUN #24 - STORED IN FILE....AC1 RECORD # 24
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 10:56:58

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





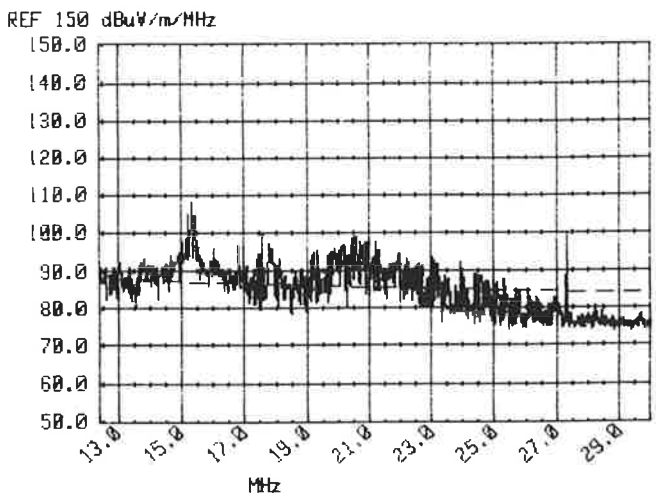
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 12.39-30.0 MHz

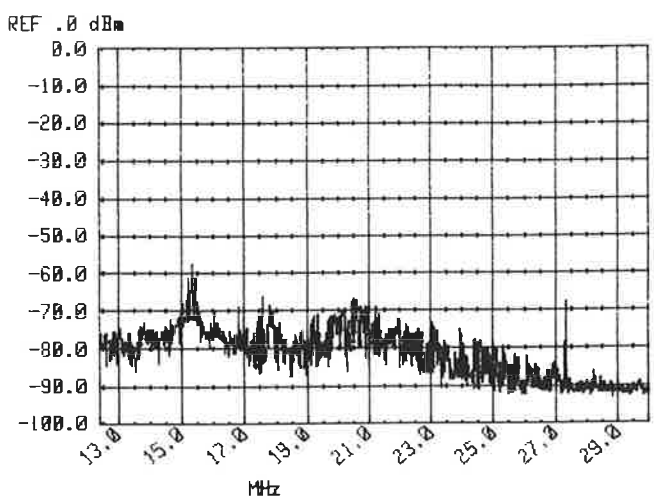
RUN #57 - STORED IN FILE....AC3 RECORD # 7
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:39:39

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





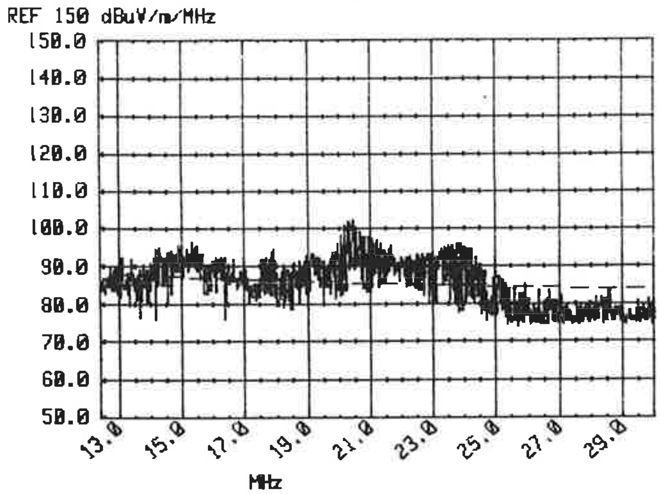
HORNELL - AC TRAIN MAX. ACCEL. FROM ANTENNA: 12.39-30.0 MHz

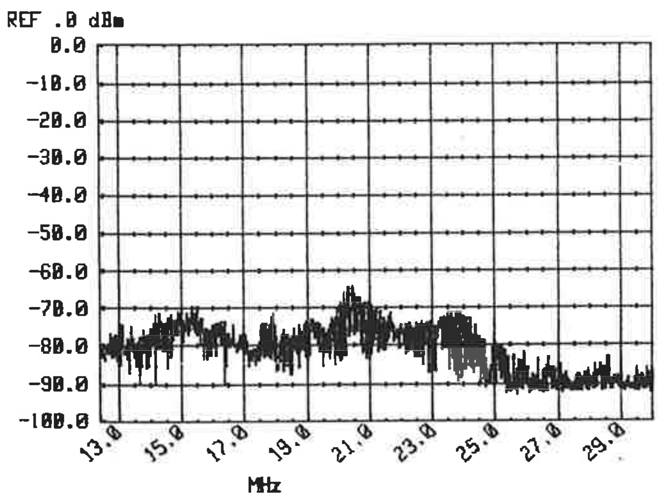
RUN #51 - STORED IN FILE....AC4 RECORD # 25
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 18 Jun 1986 10:39:12

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:ACCEL FROM STANDING START WITH NOSE AT ANTENNA.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





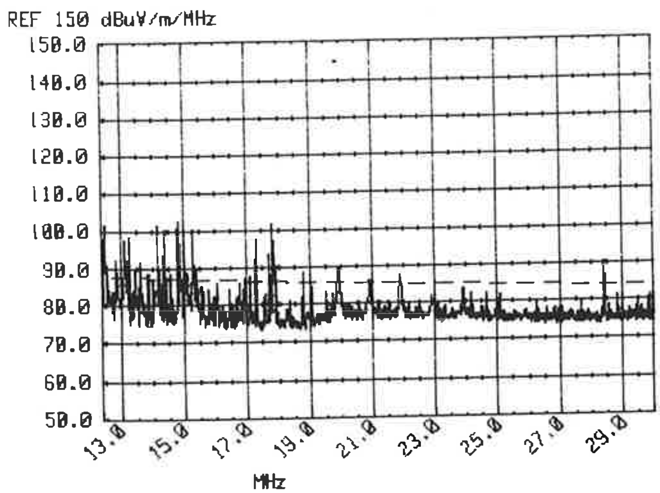
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 12.39-30.0 MHz

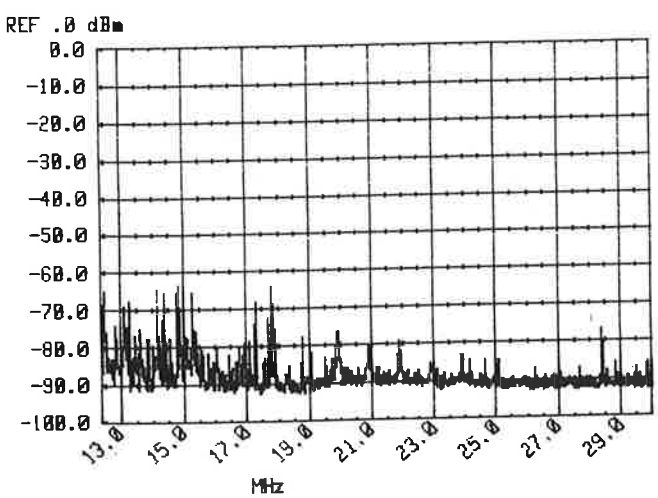
RUN #83 - STORED IN FILE....AC5 RECORD # 14
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:28:16

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





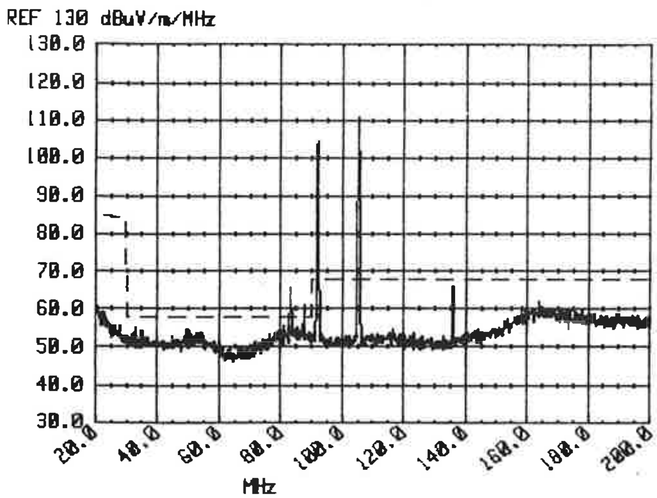
HORNELL - THIRD RAIL OFF AMBIENT: 20.0-200.0 MHz

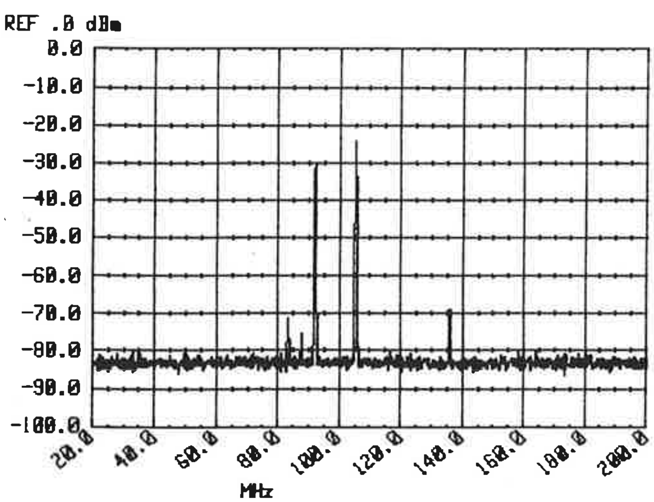
RUN #11 - STORED IN FILE....AC1 RECORD # 11
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 18:41:16

ANTENNA - BICONICAL MODEL BIA-25 S/N 1120
Antenna orientation:Paral GROUND. Paral E.U.T.

START 20.0 MHzSTOP 200.0 MHz
RES BW 100 kHz VBW 30 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





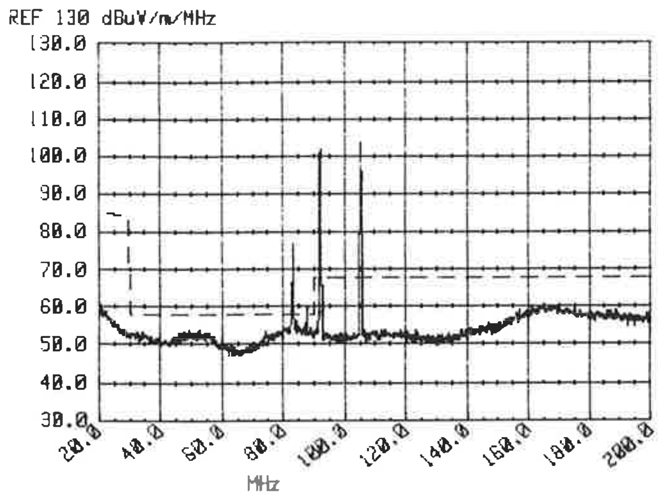
HORNELL - THIRD RAIL ON AMBIENT: 20.0-200.0 MHz

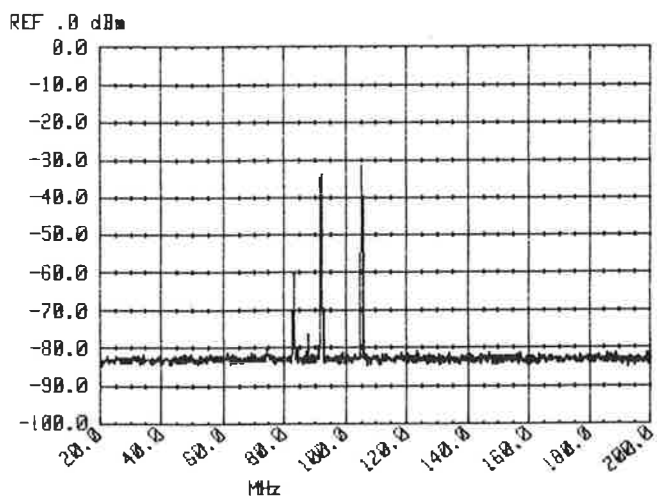
RUN #25 - STORED IN FILE....AC1 RECORD # 25
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 11:00:32

ANTENNA - BICONICAL MODEL BIA-25 S/N 1120
Antenna orientation:Paral GROUND. Paral E.U.T.

START 20.0 MHzSTOP 200.0 MHz
RES BW 100 kHz VBW 30 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





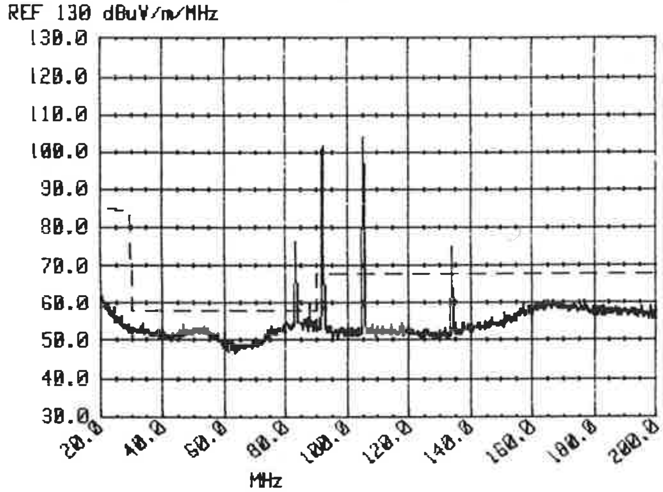
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 20.0-200.0 MHz

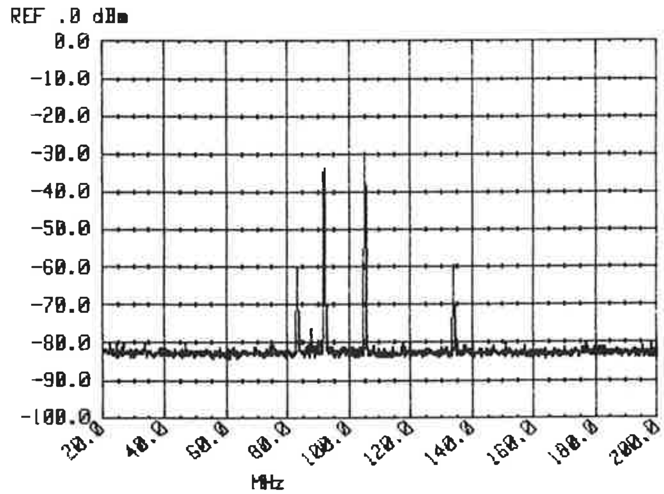
RUN #58 - STORED IN FILE....AC3 RECORD # 8
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:45:02

ANTENNA - BICONICAL MODEL BIA-25 S/N 1120
Antenna orientation:Paral GROUND. Paral E.U.T.

START 20.0 MHzSTOP 200.0 MHz
RES BW 100 kHz VBW 30 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





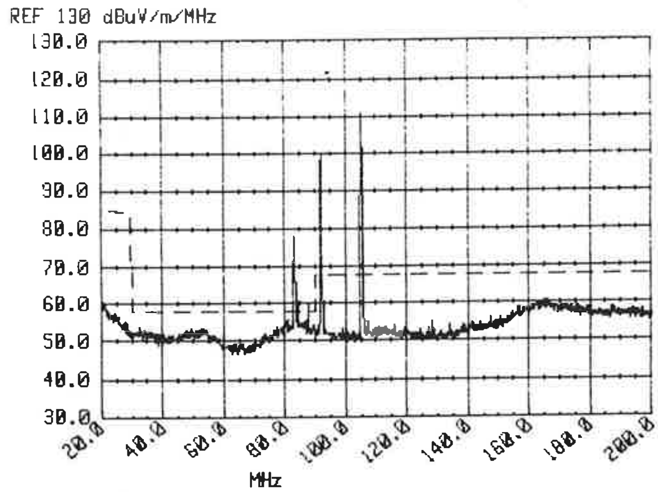
HORNELL - DC TRAIN MAX. ACCEL. PAST ANTENNA: 20.0-200.0 MHz

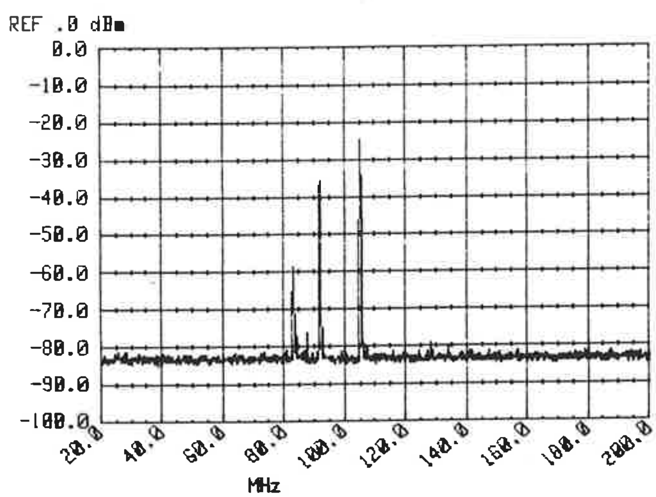
RUN #84 - STORED IN FILE....AC5 RECORD # 15
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 19 Jun 1986 09:35:56

ANTENNA - BICONICAL MODEL BIA-25 S/N 1120
Antenna orientation:Paral GROUND, Paral E.U.T.

START 20.0 MHzSTOP 200.0 MHz
RES BW 100 kHz VBW 30 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCEL OF G.E. CARS TOWARDS PLANT FROM
STANDING START.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





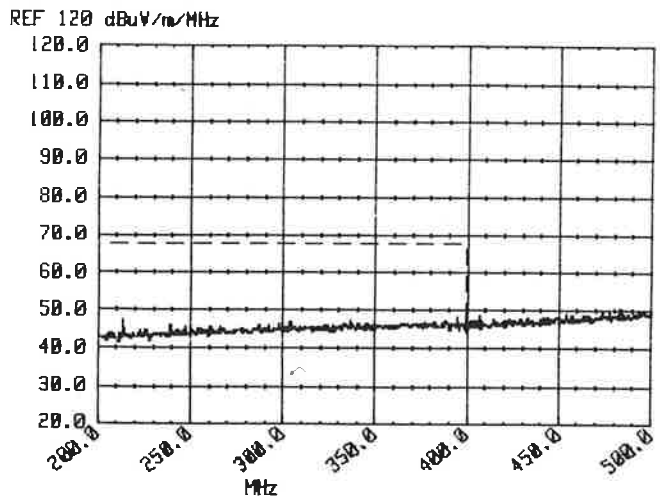
HORNELL - THIRD RAIL OFF AMBIENT: 200-500 MHz

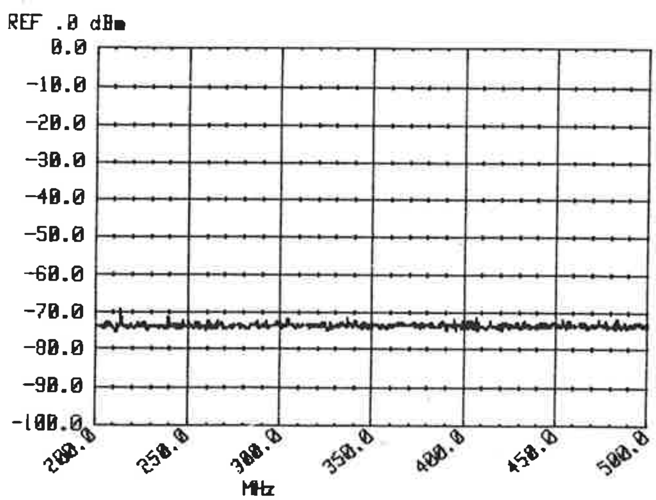
RUN #13 - STORED IN FILE....AC1 RECORD # 13
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 16 Jun 1986 18:51:08

ANTENNA - LOG-PERIODIC MODEL LPA-25 S/N 1077
Antenna orientation:PLANE Paral GROUND. AXIS Perp E.U.T.

START 200.0 MHz STOP 500.0 MHz
RES BW 1 MHz VBW 300 kHz SWP 20 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT MEASUREMENT.
NO THIRD RAIL VOLTAGE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 1 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





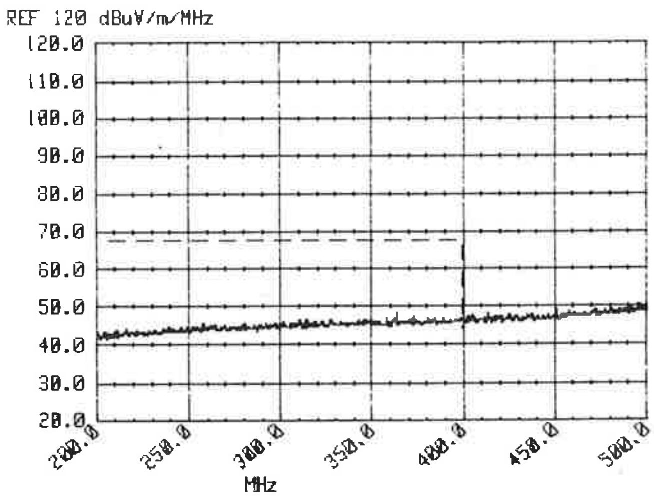
HORNELL - THIRD RAIL ON AMBIENT: 200-500 MHz

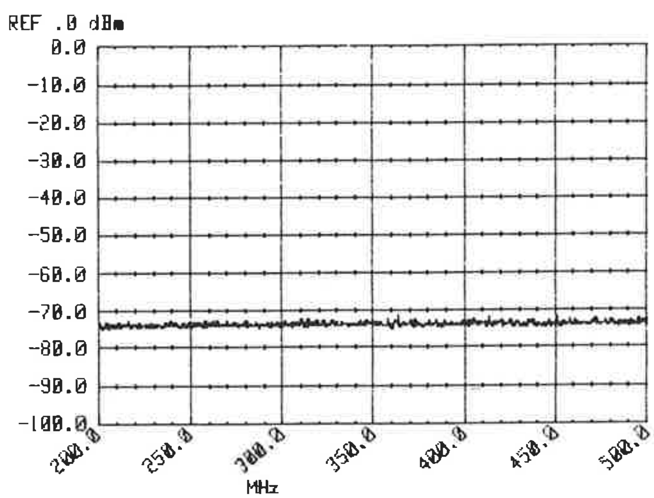
RUN #27 - STORED IN FILE....AC1 RECORD # 27
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 11:11:51

ANTENNA - LOG-PERIODIC MODEL LPA-25 S/N 1077
Antenna orientation:PLANE Paral GROUND, AXIS Perp E.U.T.

START 200.0 MHz STOP 500.0 MHz
RES BW 1 MHz VBW 300 kHz SWP 20 msec ATTEN 10 dB
NO FILTERS USED

REMARKS: TRACE WAS TAKEN IN LINE SYNC MODE.
AMBIENT MEASUREMENT. THIRD RAIL ON.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





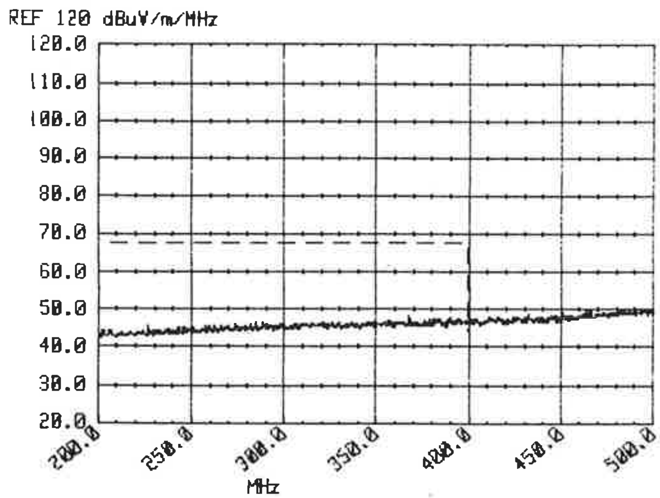
HORNELL - AC TRAIN MAX. ACCEL. PAST ANTENNA: 200-500 MHz

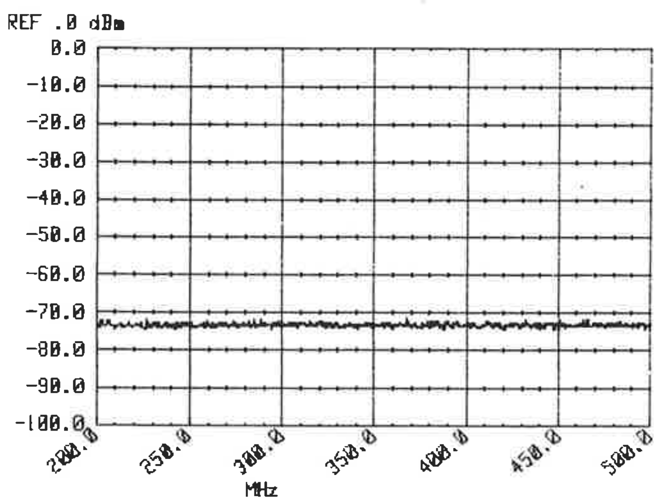
RUN #60 - STORED IN FILE....AC3 RECORD # 10
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 17 Jun 1986 16:51:55

ANTENNA - LOG-PERIODIC MODEL LPA-25 S/N 1077
Antenna orientation:PLANE Paral GROUND. AXIS Perp E.U.T.

START 200.0 MHz STOP 500.0 MHz
RES BW 1 MHz VBW 300 kHz SWP 20 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:TRAIN ACCELERATING TOWARDS PLANT FROM STOP.
LINE SYNC MODE.
TRACE WAS OBTAINED IN PEAK HOLD FOR 3 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





APPENDIX B

RADIATED EMISSION DATA FROM THE MBTA SURFACE RAIL CAR

Tests on the Surface Rail Car (SRC), an articulated light-rail vehicle employing chopper-controlled dc propulsion, were performed in May and June 1986 at the Massachusetts Bay Transit Authority's Waban Station on the Green Line. The data presented here are used through the courtesy of the MBTA. The tests were performed by Frasco & Associates, Belmont, MA, under contract to the the MBTA's vehicle supplier, Kinki Sharyo. Data were taken by Louis A. Frasco of Frasco & Associates, and Charles Edelson of Comstock Engineering, Inc. Only a small representative sample of the data recorded in those tests is presented here. Receiving antennas were positioned 30 meters (100 ft) from the centerline of the test track. . Vertical E-field was observed from 115 kHz to 30 MHz using a whip antenna with a multi-band balun. Horizontal E-field was observed from 20 to 200 MH using a biconical antenna, and from 200 to 500 MHz using a log-periodic antenna.

On each data page, operational test data are recorded at the top, followed by a computer-generated display of broadband signal strength in dBμV/m/MHz. The bottom figure is of signal strength at the spectrum analyzer input in units of dbmW. Spectrum analyzer input signal data are used in conjunction with spectrum analyzer input impedance and impulse bandwidth and antenna factor, to obtain broadband signal strength. The following table lists data pages for MBTA measurements.

Table B-1: Page Index of Broadband Emission Data from the MBTA

	Frequencies								
Measurement	111-263 kHz	243-528 kHz	484k-1.159 MHz	1.128-2.411 MHz	2.269-6.704 MHz	6.467-12.66 MHz	12.39-30.0 MHz	20-200 MHz	200-500 MHz
Ambient with third rail on	B-2	B-4	B-6	B-8	B-10	B-12	B-14	B-16	B-18
Max. accel. from standing start	B-3	B-5	B-7	B-9	B-11	B-13	B-15	B-17	B-19

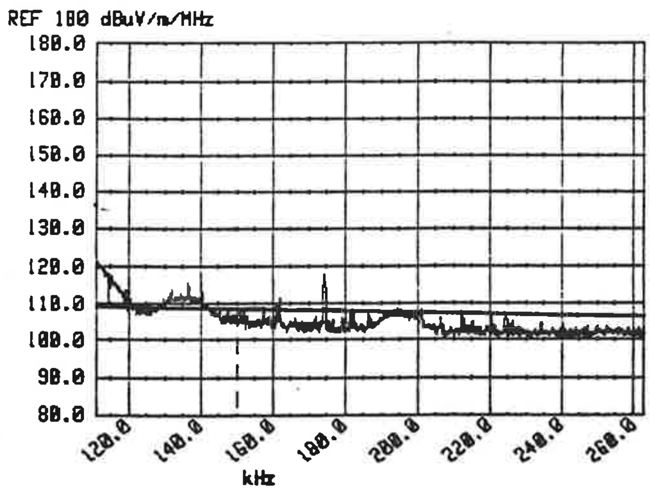
MBTA AMBIENT: 111-263 kHz

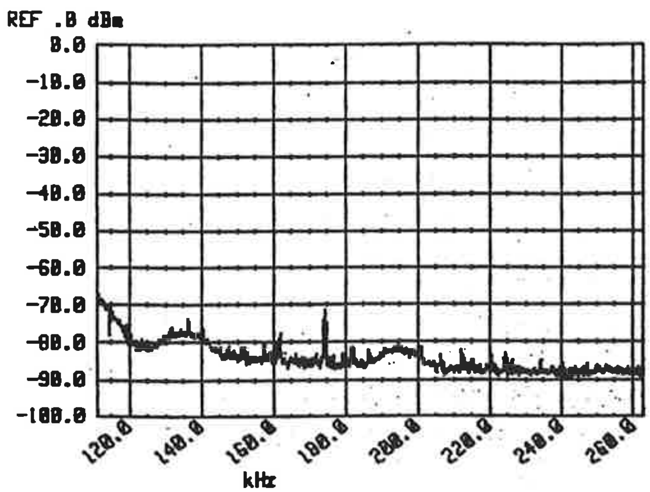
RUN #18 - STORED IN FILE....DS5 RECORD # 18
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:23:27

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 4
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





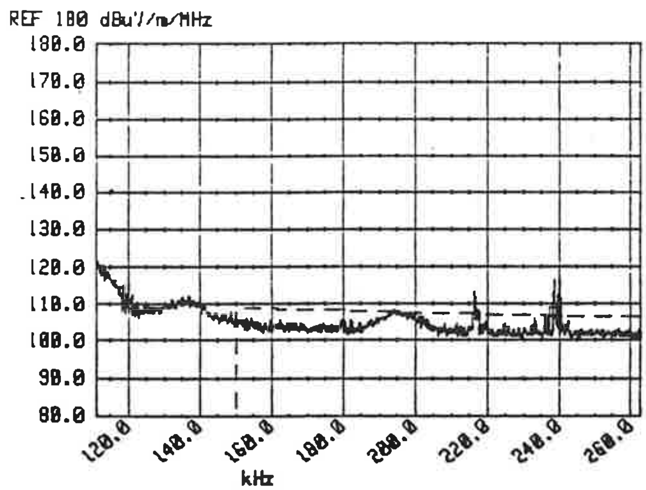
MBTA SRC - MAX. ACCEL.: 111-263 kHz

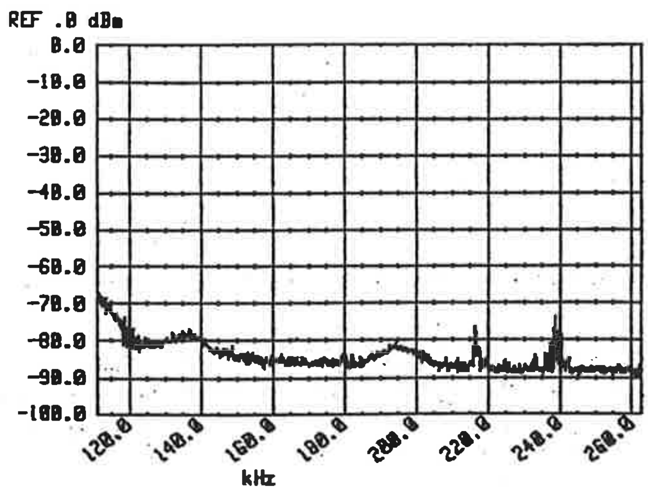
RUN #20 - STORED IN FILE....DS5 RECORD # 20
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:26:19

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 4
Antenna orientation:Perp GROUND.

START 111.0 kHz STOP 263.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





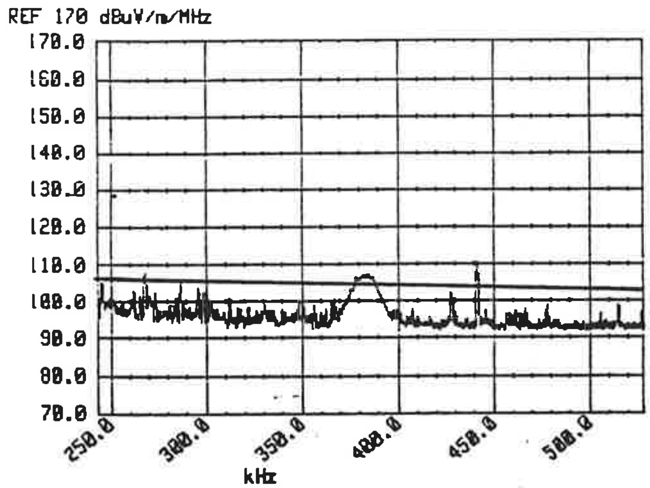
MBTA AMBIENT: 243-528 kHz

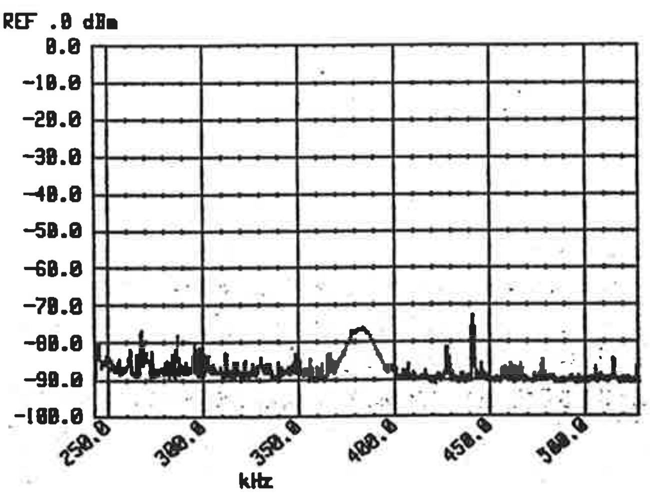
RUN #23 - STORED IN FILE....DS5 RECORD # 23
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:29:41

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 5
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





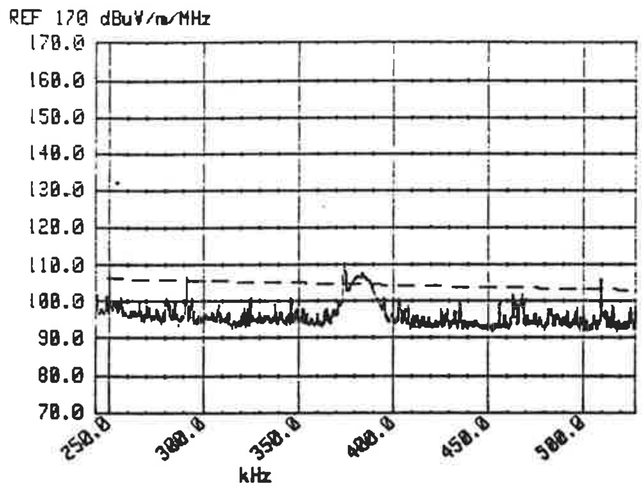
MBTA SRC - MAX. ACCEL.: 243-528 kHz

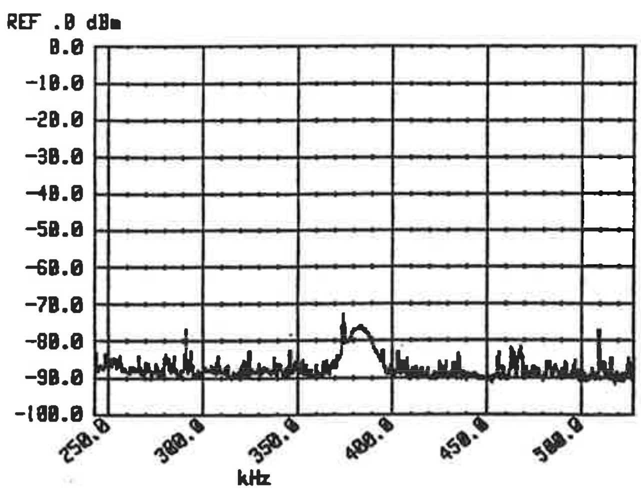
RUN #25 - STORED IN FILE....DS5 RECORD # 25
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:32:43

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 5
Antenna orientation:Perp GROUND.

START 243.0 kHz STOP 528.0 kHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





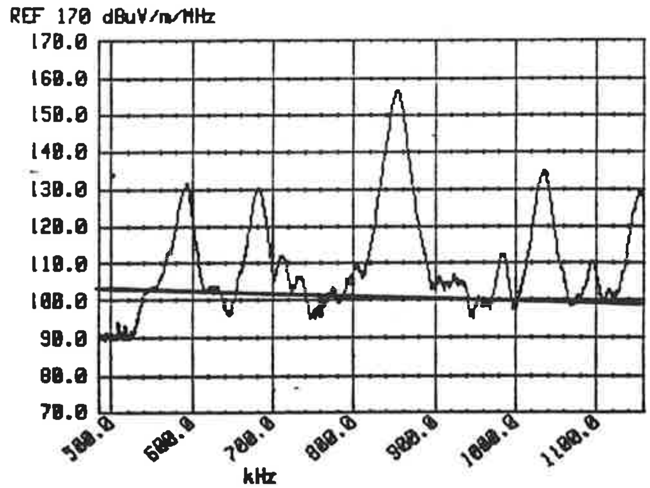
MBTA AMBIENT: 484 kHz-1.159 MHz

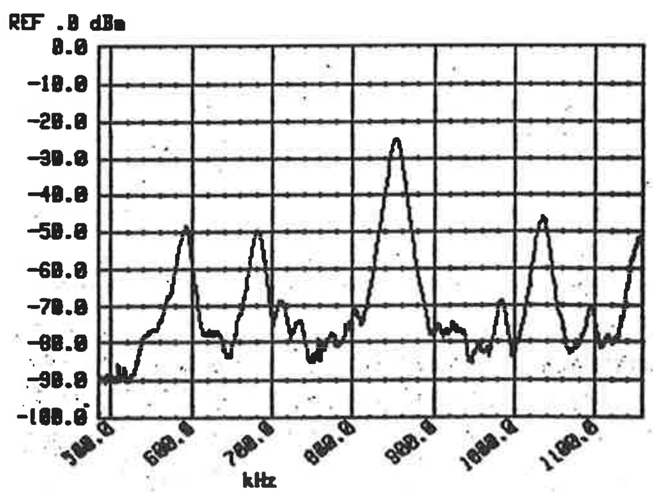
RUN #46 - STORED IN FILE....DS4 RECORD # 46
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 15:28:22

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 6
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





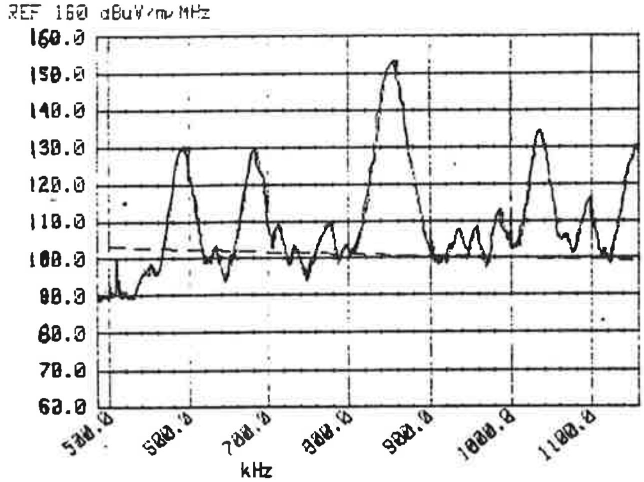
MBTA SRC - MAX. ACCEL.: 484 kHz-1.159 MHz

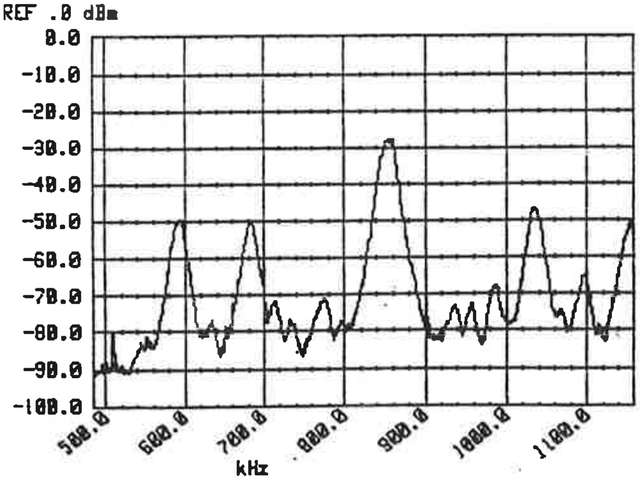
RUN #44 - STORED IN FILE....DS5 RECORD = 44
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:45:57

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 484.0 kHz STOP 1.1590 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





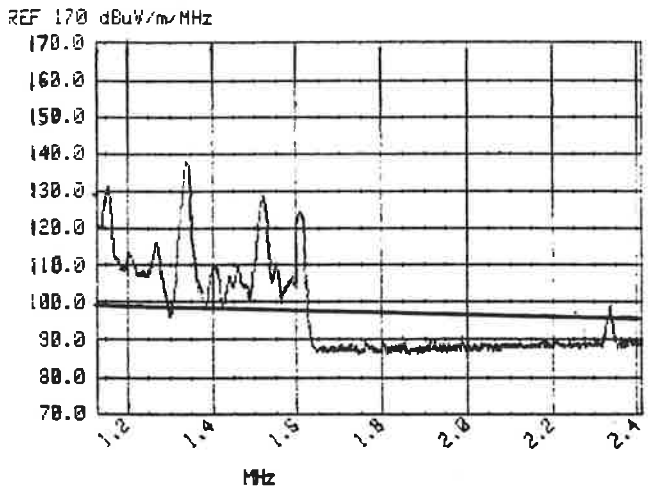
MBTA AMBIENT: 1.128-2.411 MHz

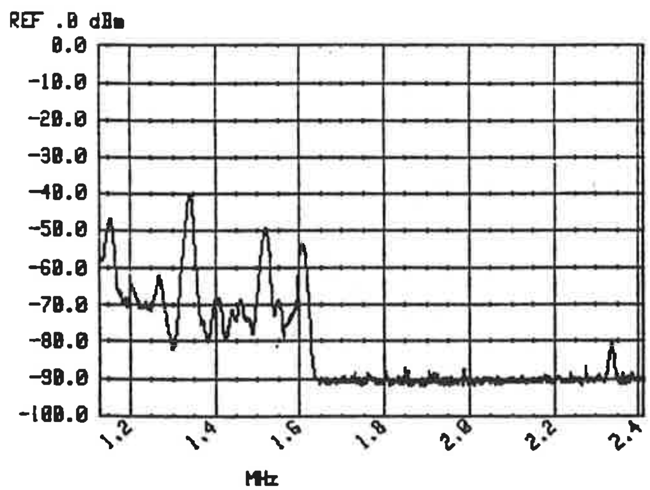
RUN #33 - STORED IN FILE....DS5 RECORD # 33
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:44:49

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 7
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





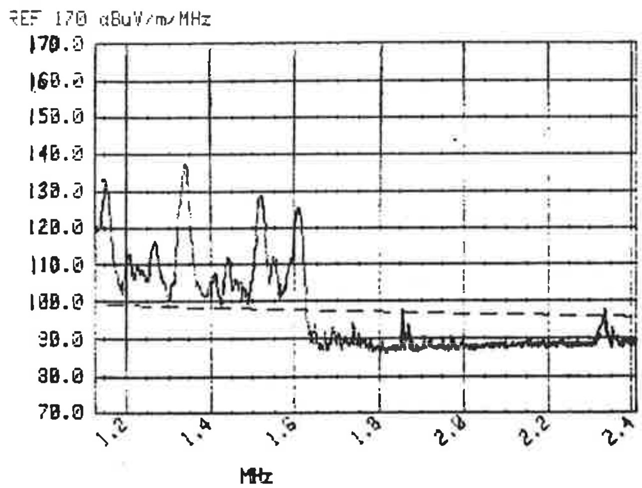
MBTA SRC - MAX. ACCEL.: 1.128-2.411 MHz

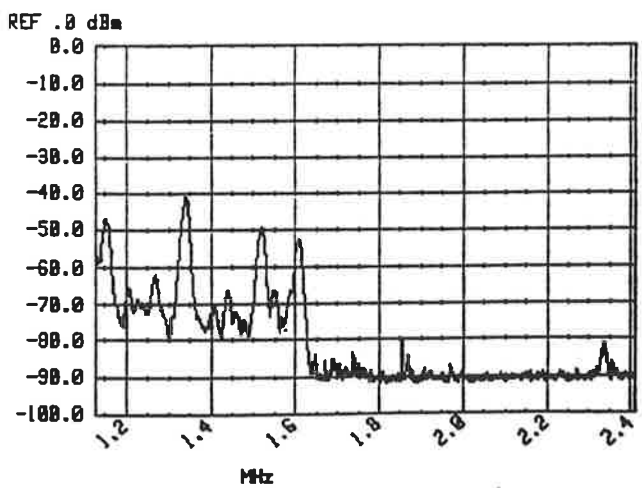
RUN #35 - STORED IN FILE....DS5 RECORD # 35
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:47:20

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 7
Antenna orientation:Perp GROUND.

START 1.128 MHz STOP 2.411 MHz
RES BW 10 kHz VBW 10 kHz SWP 30 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





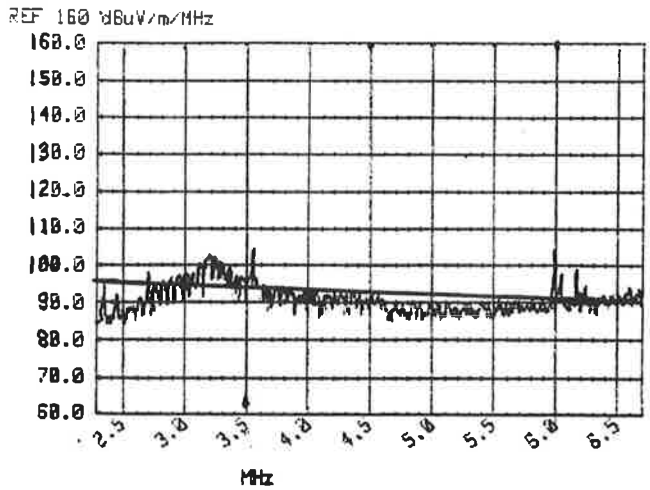
MBTA AMBIENT: 2.269-6.704 MHz

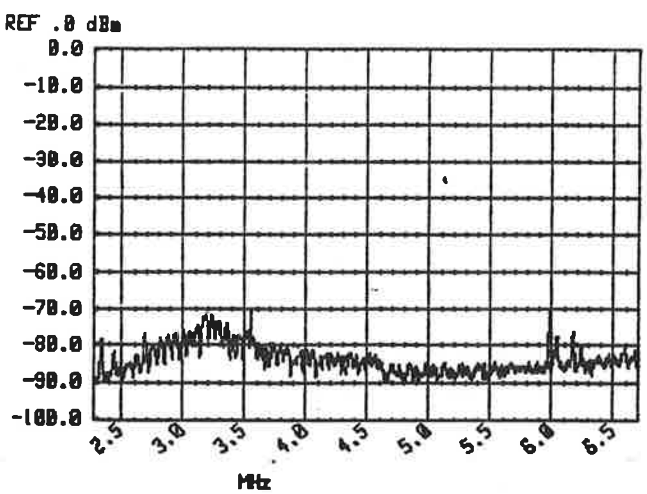
RUN #38 - STORED IN FILE....DS5 RECORD # 38
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:50:49

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 8
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 8
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





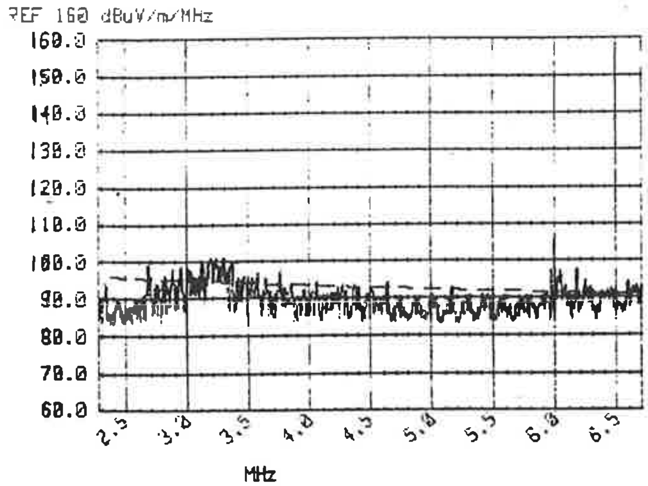
MBTA SRC - MAX. ACCEL.: 2.269-6.704 MHz

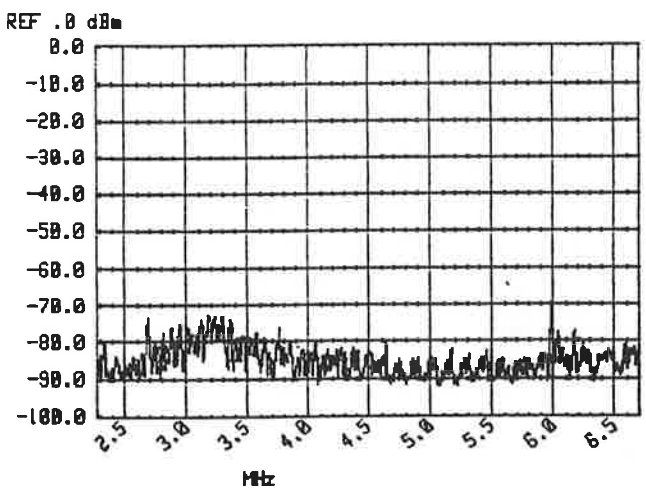
RUN #40 - STORED IN FILE....DS5 RECORD # 40
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 5 Jun 1986 02:54:12

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 6
Antenna orientation:Perp GROUND.

START 2.269 MHz STOP 6.704 MHz
RES BW 10 kHz VBW 10 kHz SWP 100 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START
-TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





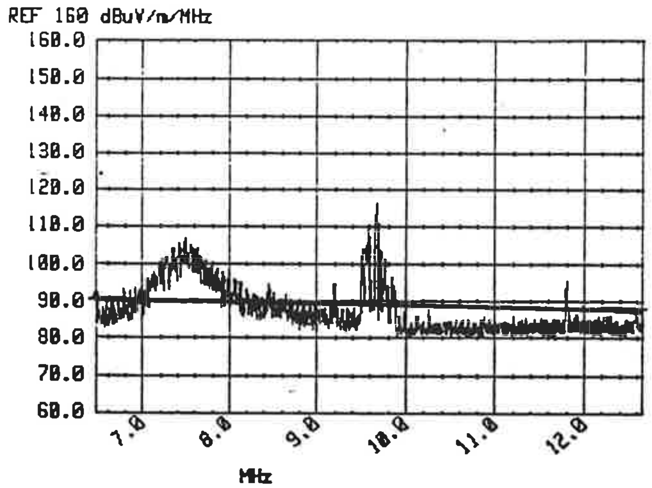
MBTA AMBIENT - 6.467-12.660 MHz

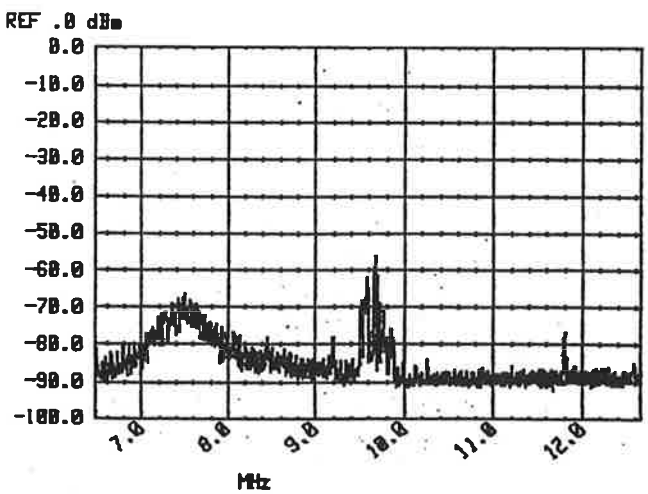
RUN #19 - STORED IN FILE....DS4 RECORD # 19
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 13:41:16

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 9
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





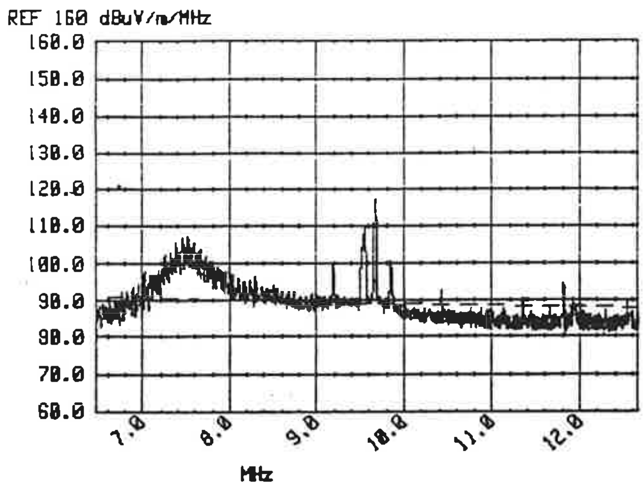
MBTA SRC - MAX. ACCEL.: 6.467-12.660 MHz

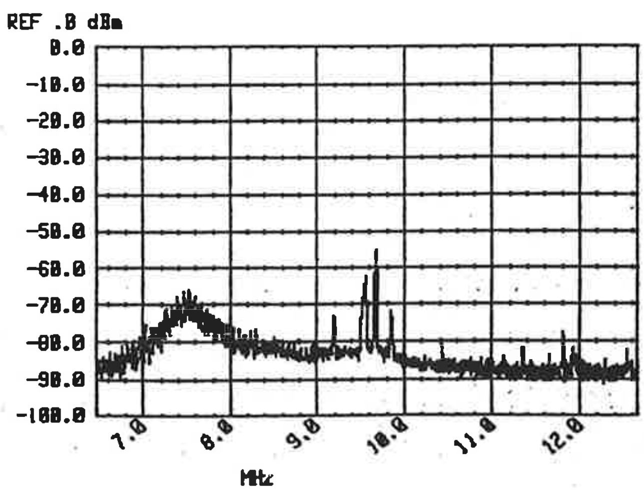
RUN #23 - STORED IN FILE....DS4 RECORD # 23
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 14:44:33

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 9
Antenna orientation:Perp GROUND.

START 6.467 MHz STOP 12.660 MHz
RES BW 10 kHz VBW 10 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:17 MPH COAST THEN MAX POWER, SRC
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





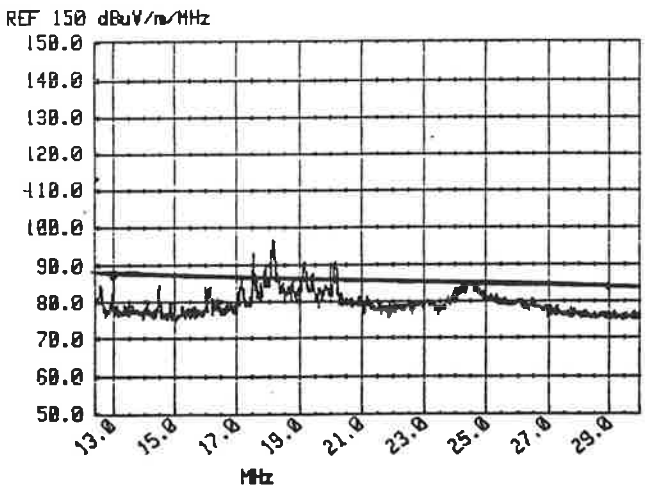
MBTA AMBIENT: 12.39-30.0 MHz

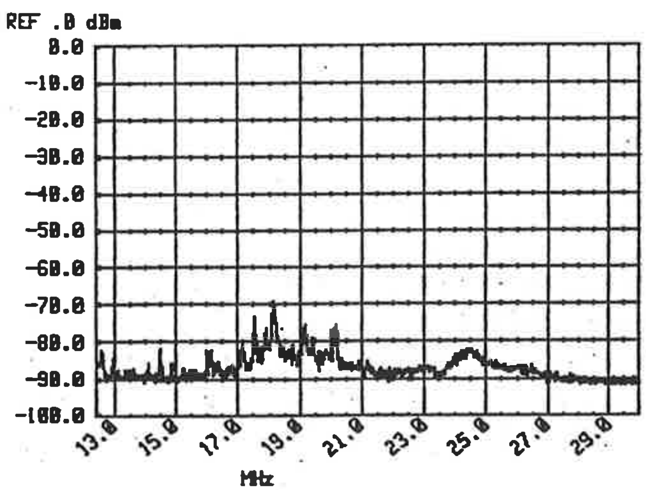
RUN #29 - STORED IN FILE....DS4 RECORD # 29
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 14:51:20

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BALUN 10
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





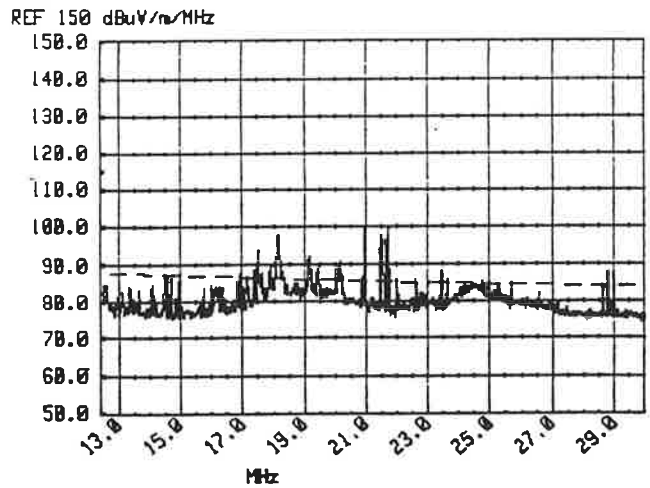
MBTA SRC - MAX. ACCEL.: 12.39-30.0 MHz

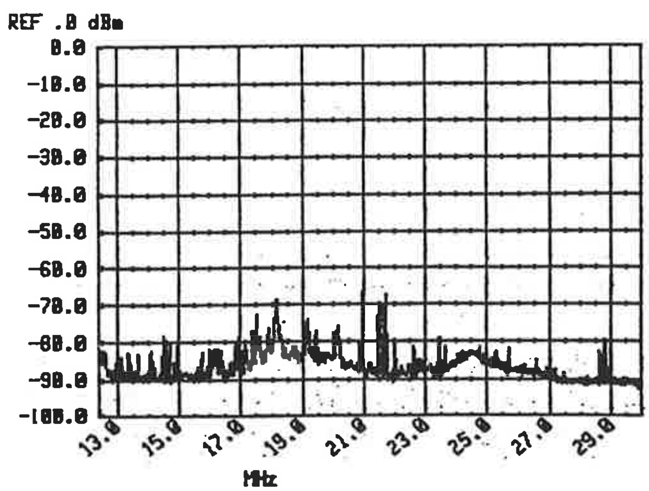
RUN #25 - STORED IN FILE....DS4 RECORD # 25
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 14:47:10

ANTENNA - VERTICAL RVR-25 S/N 565 - BALUN POSITION= 10
Antenna orientation:Perp GROUND.

START 12.39 MHz STOP 30.00 MHz
RES BW 10 kHz VBW 10 kHz SWP 500 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STOP, SRC
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





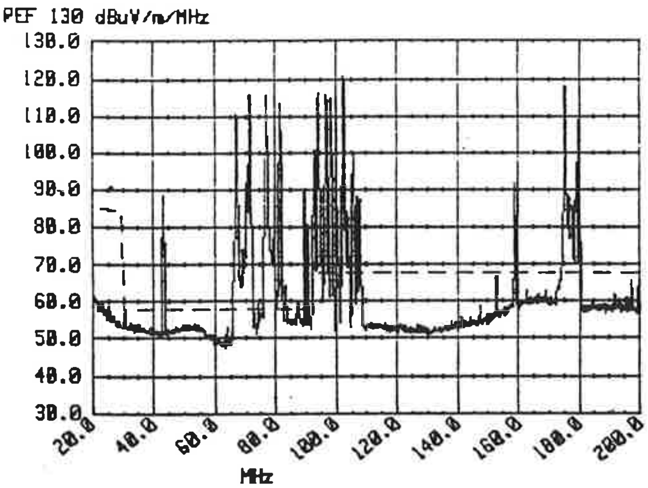
MBTA AMBIENT: 20.0-200.0 MHz

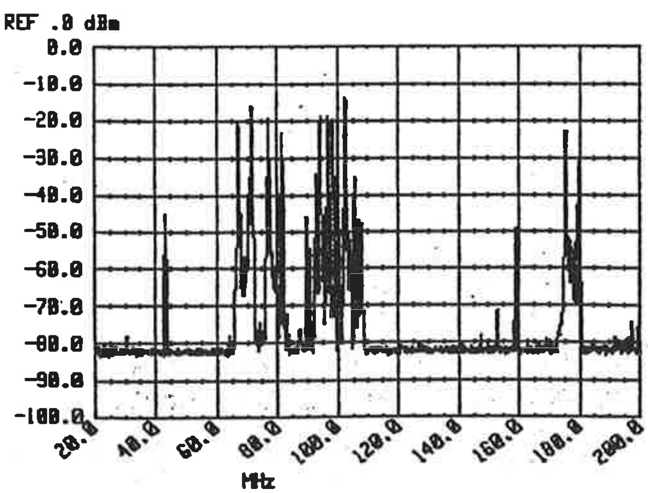
RUN #34 - STORED IN FILE....DS4 RECORD # 34
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 14:58:46

ANTENNA - BICONICAL MODEL BIA-25 S/N 1120
Antenna orientation:Paral GROUND. Paral E.U.T.

START 20.0 MHzSTOP 200.0 MHz
RES BW 100 kHz VBW 30 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT BUT VEHICLE PULLED IN TO AREA
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





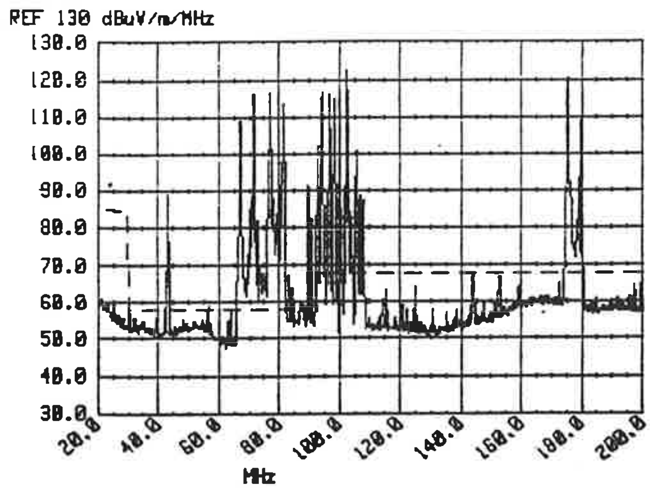
MBTA SRC - MAX. ACCEL.: 20.0-200.0 MHz

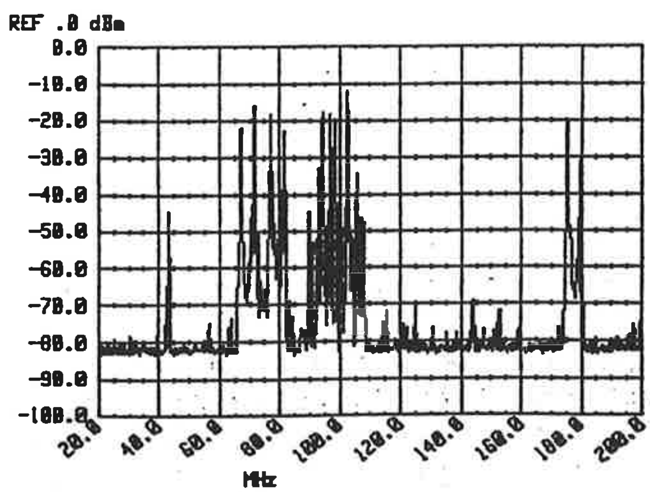
RUN #30 - STORED IN FILE....DS4 RECORD # 30
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 14:54:09

ANTENNA - BICONICAL MODEL BIA-25 S/N 1120
Antenna orientation:Paral GROUND. Paral E.U.T.

START 20.0 MHzSTOP 200.0 MHz
RES BW 100 kHz VBW 30 kHz SWP 150 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START. SRC
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





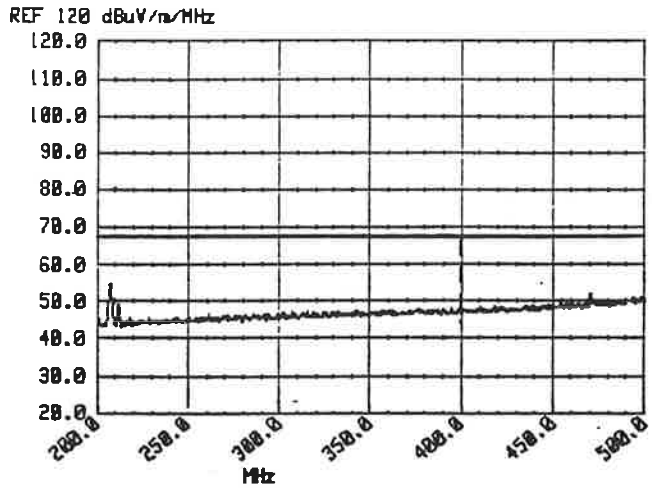
MBTA AMBIENT: 200-500 MHz

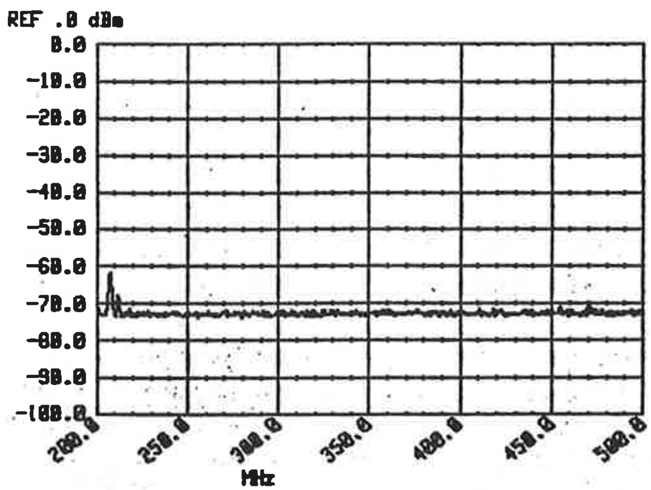
RUN #36 - STORED IN FILE....DS4 RECORD # 36
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 15:02:20

ANTENNA - LOG-PERIODIC MODEL LPA-25 S/N 1077
Antenna orientation:PLANE Paral GROUND. AXIS Perp E.U.T.

START 200.0 MHz STOP 500.0 MHz
RES BW 1 MHz VBW 300 kHz SWP 20 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:AMBIENT
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





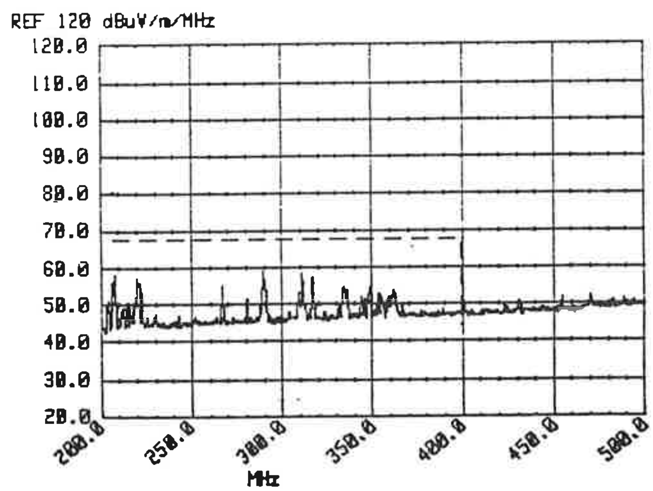
MBTA SRC - MAX. ACCEL.: 200-500 MHz

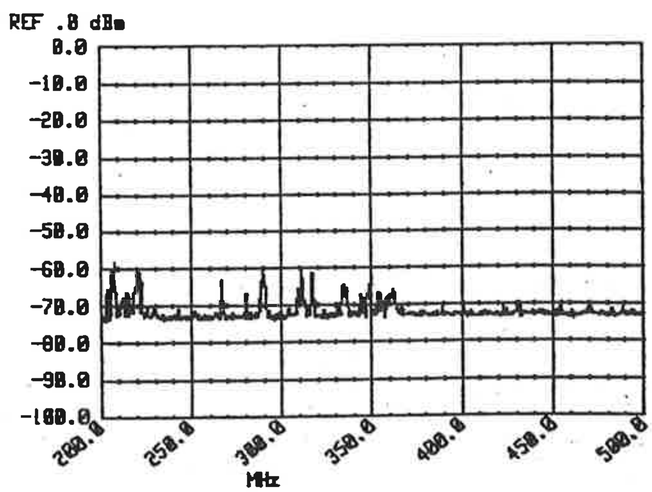
RUN #37 - STORED IN FILE....DS4 RECORD # 37
DATA FROM SPECTRUM ANALYZER (dBm) CORRECTED TO dBuV/m/MHz
TRACE TAKEN 29 May 1986 15:03:24

ANTENNA - LOG-PERIODIC MODEL LPA-25 S/N 1077
Antenna orientation:PLANE Paral GROUND. AXIS Perp E.U.T

START 200.0 MHz STOP 500.0 MHz
RES BW 1 MHz VBW 300 kHz SWP 20 msec ATTEN 10 dB
NO FILTERS USED

REMARKS:MAX ACCELL FROM STANDING START, SRC
TRACE WAS OBTAINED IN PEAK HOLD FOR 8 SECONDS.
BROAD BAND CORRECTION FACTORS WERE APPLIED ACROSS SPAN





* GOVERNMENT PRINTING OFFICE: 1988 - 501099 / 80007