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RADIO NOISE SURVEY PROCEDURES FOR A COMMUNICATION SITE 0.15 – 30 MHZ

by
W.R. LAUBER AND C.J. PIKE



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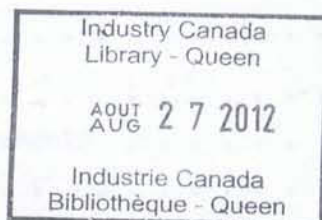
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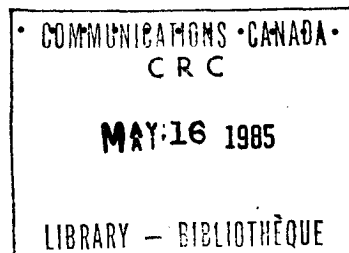
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ABSTRACT

This report gives a step-by-step plan for performing a radio noise survey at a communication site. The data obtained in the survey are used to describe the radio noise environment at the site and may be used to see if a good site is deteriorating or a bad site is improving. The general plan allows for some variation, as each site is different, but is strict enough for compatible results. The plan describes how to obtain the measurement data, how to analyze them and how to use them to evaluate the site. It also presents details for future reassessment. Finally, there is a section on how to use the basic data for communication system design and system performance prediction.

1. INTRODUCTION

1.1 BACKGROUND

The satisfactory design and operation of a radio communication system depends on consideration of all parameters affecting the operation, including: the proper choice of terminal facilities, the propagation of the signal between the terminals and the radio environment of the receiver location. Interference may be caused by signals that are intentionally radiated or by noise either of natural origin or unintentionally radiated from man-made sources. Determination of the signal environment is beyond the scope of this report. It has been long recognized that the ultimate limitation to a communication system will usually be the radio noise. Thus, it is necessary to have a knowledge of the radio noise with which the desired signal must compete at each potential receiving location so that sufficient power, or other means, may be used to override the noise.

The radio noise can be divided into two broad categories: noise internal to the receiving system and noise external to the receiving antenna (see Figure 1). The radio noise internal to the receiving system is usually the controlling noise in systems operating above 300 MHz though in a receiver with a poor noise figure, this can be the predominant noise at any frequency. This type of noise will be present due to antenna losses, transmission line losses, and noise generated in the circuits of the receiver itself. Since design considerations concerned with this type of noise are well known, it will not be given further consideration here. The second of the broad categories, external radio noise, can be divided into several subcategories with each type having its own individual characteristics. Examples of natural radio noise are: atmospheric, galactic and solar noise. Examples of man-made sources of radio noise are: automotive ignition systems, industrial scientific and medical (ISM) equipment, power lines and electrical equipment in general.

The following is a history of the radio noise degradation of a communication site. In the middle 1930's Radio Canada International (RCI) established a HF monitoring station on 18.5 acres of land in Britannia Heights (Ottawa) for: 1) technical monitoring of various broadcasting organizations transmitting to North America and 2) program monitoring for rebroadcast on the domestic network. From the middle 1960's RCI became increasingly worried about higher levels of local man-made noise and the construction of a thoroughway (Queensway) which passed within a few metres of the receiving antennas and the ever-increasing encroachment of local dwellings. When it became known in the late 1960's that the adjacent vacant land was to be developed for single family dwellings and that the City of Ottawa proposed to build a school on part of the monitoring station property, relocation became necessary. RCI subsequently found a 40 acre site 16 km out of Ottawa near Stittsville. The new site was undeveloped bush. Thus, it was necessary to construct a new building, relocate antennas and equipment and construct an access road. The total cost of the relocation as of 1972 was \$330,000.00.

Had measurements been made of the radio noise environment over the years, the data would have been very valuable. It would have been possible to calculate the rate of increase in the noise levels and predict when an intolerable level was reached. As well, it would have been possible to

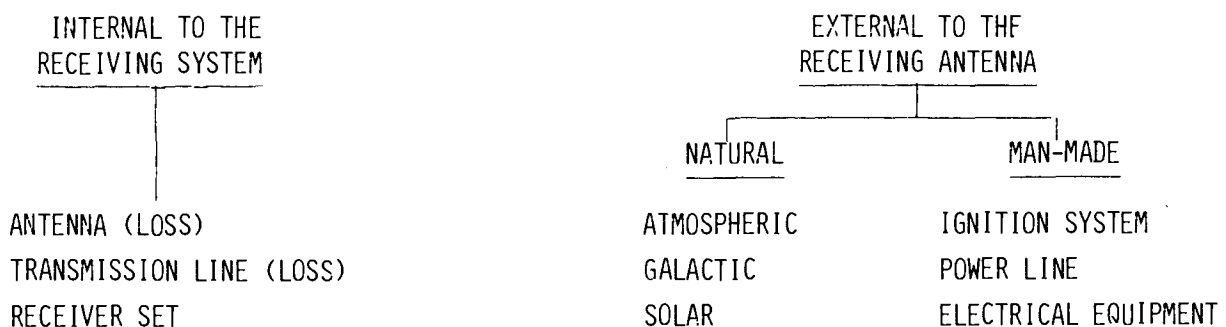


Figure 1. Categories and Examples of Radio Noise

correlate the noise levels with the performance of the communication system since the main purpose of making radio noise measurements is to use the results in the prediction of the performance of communication systems.

1.2 OBJECTIVE

The objective of this report is to provide a step-by-step measurement procedure to determine the radio noise environment of a communication site. The plan provides schedules, procedures and techniques for documenting and analysing the existing radio noise environment as well as for future reassessment. The report is written for an engineer who has been given the task of defining the radio noise environment at a communication site. The basic concepts for this work were developed internationally in the mid to late 1950's for atmospheric radio noise as discussed in URSI special report No. 7 [1]. Studies of man-made radio noise began when it was found to be contaminating some atmospheric noise records. This led to a number of studies of man-made radio noise, one in particular by Stanford Research Institute (now SRI International) for the U.S. Navy [2] upon which much of our work is based.

2. STEP BY STEP PLANS FOR A SURVEY

2.1 WHAT MEASUREMENTS TO TAKE

For a communication system the noise process of interest is the one seen by that part of the receiving system which is extracting the information from the received waveform (i.e., after the IF in a receiver). We are usually interested in a narrowband process, where the bandpass of the system is a small fraction of the received frequency. The noise process $X(t)$ at the output of a narrowband filter is given by:

$$X(t) = V(t) \cos (2\pi f t + \phi(t)) \quad (1)$$

where $V(t)$ is the envelope process
 if $\phi(t)$ is the phase process
 f is the received frequency.

An example of this is given in Figure 2. For a radio noise process in the absence of discrete signals, $\phi(t)$ is uniformly distributed. The required statistics that determine the performance of a communication system are in general, envelope statistics (the exceptions are phase-shift-keying systems), thus only the envelope process $V(t)$ is considered.

No single noise parameter will give a satisfactory measure of interference to all types of radio communication systems because the performance of a system is dependent upon the modulation scheme. However, some characteristics of the radio noise process influence the operation of any system regardless of the detection scheme. It is desirable to adopt some parameter which can be used internationally for comparing radio noise data and to which other noise parameters may be related. This basic noise parameter should be given in a form which allows it to be compared and combined with parameters

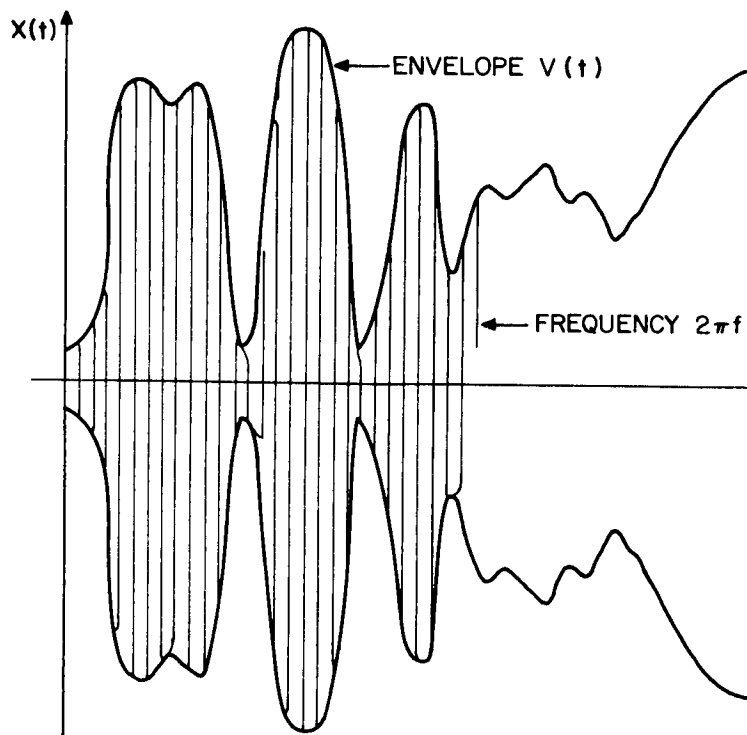


Figure 2. Typical Noise Process $X(t)$

describing other types of emissions, such as unwanted signals that cause interference. The mean noise power per unit bandwidth or power spectral density is the most basic parameter for describing broadband radio noise. The effective antenna noise figure, F_a , is the preferred way of expressing the mean noise power received from sources external to the antenna and is defined by

$$F_a = 10 \log f_a \quad (2)$$

where the effective antenna noise factor

$$f_a = p_n / kT_o b \quad (3)$$

and p_n is the received noise power, in watts, available from an equivalent loss-free antenna in a noise power bandwidth b , in hertz, k is Boltzmann's Constant 1.38×10^{-23} joules/kelvin, and T_o is the reference temperature 288K. The quantity f_a is dimensionless (the ratio of two powers) but it gives, numerically, the available power spectral density relative to kT_o and the available power relative to $kT_o b$. Thus F_a is usually defined in units of dB above kT_o or dB above $kT_o b$.

A second noise parameter termed Voltage Deviation, V_d , is related to F_a (more accurately to V_{rms} which is directly related to F_a). V_d is defined as the dB difference between the rms and the average noise envelope voltages. The value of this parameter may be used to predict the relative Amplitude

Probability Distribution (APD) of the noise which directly relates to the performance of digital communication systems (e.g., Noncoherent Frequency Shift Keying, NCFSK). From a practical point of view the higher the value of V_d the more impulsive the noise, e.g., ignition noise may have a V_d of 10-12 dB whereas receiver set noise would have a value of 1.05 dB. These two parameters have been used in radio noise measurements since the early 1950's [3] and are internationally accepted [1,4,5].

2.2 WHY TAKE THESE PARTICULAR MEASUREMENTS

There are many reasons for making the above measurements and not the standard FI meter quantities of $V_{\text{quasi peak}}$ or V_{peak} . Both of the latter were designed to detect the noise rather than measure it. They have been readily accepted because technically the state-of-the-art of commercial equipment had not advanced to make an acceptable rms meter (a meter with sufficient dynamic range) until the late 1960's although previously there was some specifically-designed laboratory equipment that could do it.

The quasi peak detector was developed in the 1930's and was related to the performance of AM broadcast listening. It is possible to correlate the quasi peak levels with the reception qualities for certain noise sources, but, there is no theoretical relationship between the performance of any other communication system and these measurements.

To estimate the value of V_{peak} one may set some probability threshold: say V_{peak} is the level exceeded 1% of the time if the whole amplitude characteristic is measured. More often it is defined as the highest level observed in a certain length of time. In either case one must state the duration of the measurement time during which the peak value was measured since theoretically there is no such thing as the "peak" value of a random noise process, i.e., there is always a finite probability that any level will be exceeded. V_{peak} is of limited use as it is not very economical to design a system based only on the worst case situation which may only occur for say a millisecond every six months.

These frequently used types of measurements (used because of the ease of measurement) which are perhaps useful in determining the degree of suppression achieved on a particular offending noise source, have little, if anything to do with how the noise affects any particular communication system.

V_{rms} is more useful for a number of reasons. Firstly, it is directly related to the effective antenna noise factor (f_a) which is used by a system designer to estimate the required receiver noise figure for the system (see Appendix C). Secondly, the performance of most communications systems is determined to be a function of the signal-to-noise ratio (SNR). This is defined as the ratio of the average signal power to the average noise power in a given bandwidth. Thus we need V_{rms} measurements which we directly relate to the average noise power and are bandwidth convertible. Thirdly, since the average power of broadband noise varies directly with receiver bandwidth, then it is possible to compare measurements made with different equipments, i.e., we do not all have to use the same receiver bandwidth to make our measurements. Finally, it is known that from measurements of V_{rms} and V_d one can predict the Amplitude Probability Distribution (APD) of the noise

with mathematical models. From the APD one can directly predict the performance (bit error rate and character error rate) of a NCFSK (teletype) system. The theory was developed for atmospheric noise but we believe it is also applicable to man-made noise.

2.3 WHERE TO TAKE THE MEASUREMENTS

The three fundamental domains of measurements, as outlined in Figure 3, are the antenna farm, surrounding area and the communication building. The primary measurements are taken in the antenna farm. These give a representative sample of the actual environment that the communication antennas are operating in. They should be taken at distances greater than 10 metres from the communication antennas to avoid interaction. Outside the antenna farm one must check for specific sources of man-made radio noise in the surrounding area (5 to 10 km). The noise levels from such possible sources as powerlines, power plants and vehicles should be measured. Likewise, radio noise sources in the communication building should be identified and traced. Photographs of frequency sweeps for service antennas serve as a check for interference and operation. For example, if the spectrum sweeps of two identical antennas looking in the same direction are seriously different, you should suspect problems from the antenna with the lowest levels.

If you suspect that the antenna farm is degraded by man-made noise you should check this by making measurements at a local site (within 50 km) that is remote from any possible source of man-made noise. A photograph of each measurement location should be taken and the location marked on a map for future reference.

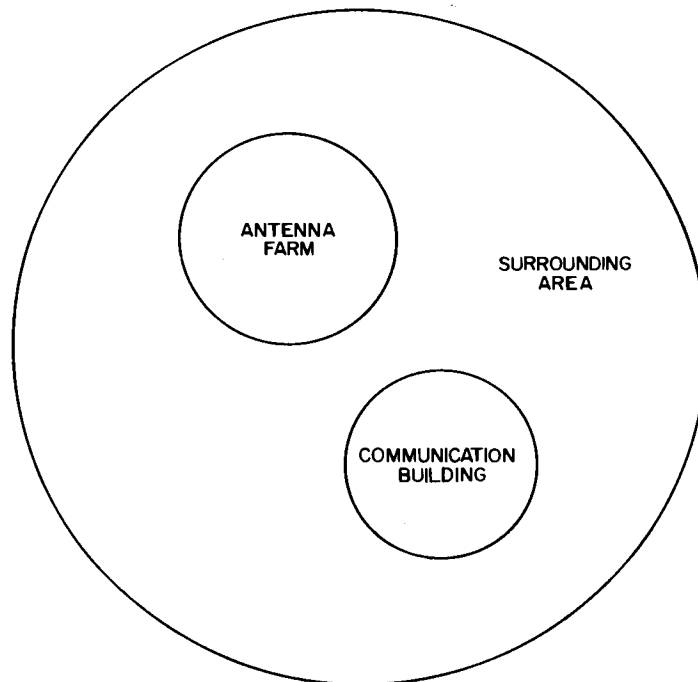


Figure 3. Three Measurement Domains

2.4 WHEN TO TAKE THE MEASUREMENTS

The dominant source of natural noise at HF is atmospheric noise which is propagated from the three main thunderstorm areas of the world, i.e., South America, Africa and South-East Asia. The received noise follows a well known diurnal trend because of source generation and propagation. It is lowest in the morning and highest in the evening. Figures 4, 5 and 6 show the two extremes of predicted atmospheric noise for three seasons in Ottawa. There may be as much as a 20 dB difference in the noise level between the two time periods, especially at low frequencies, 2.5 MHz. There is a third line on these figures referred to as the QRSL. This stands for "Quiet Rural Site Line" and will be discussed in Section 4. To date no one known to the authors has been able to measure levels of atmospheric noise much below this line in the morning time period.

HF predictions of atmospheric noise [4] divide the day into 6, four-hour periods. We chose to take the site survey noise measurements in the 0800-1200 LST (Local Standard Time) period and in the 2000-2400 LST period. This latter period will result in predominantly atmospheric levels which will be used later in the overall site evaluation. The morning period was chosen for the site measurements because it has the lowest predicted levels of natural noise especially at frequencies below 10 MHz. Any locally generated man-made noise will easily be seen in this time period. The afternoon is also a good time to discriminate against distant thunderstorms, however, locally generated thunderstorms usually build up in the afternoon especially at southern latitudes in Canada. These locally generated atmospherics will bias the afternoon measurements.

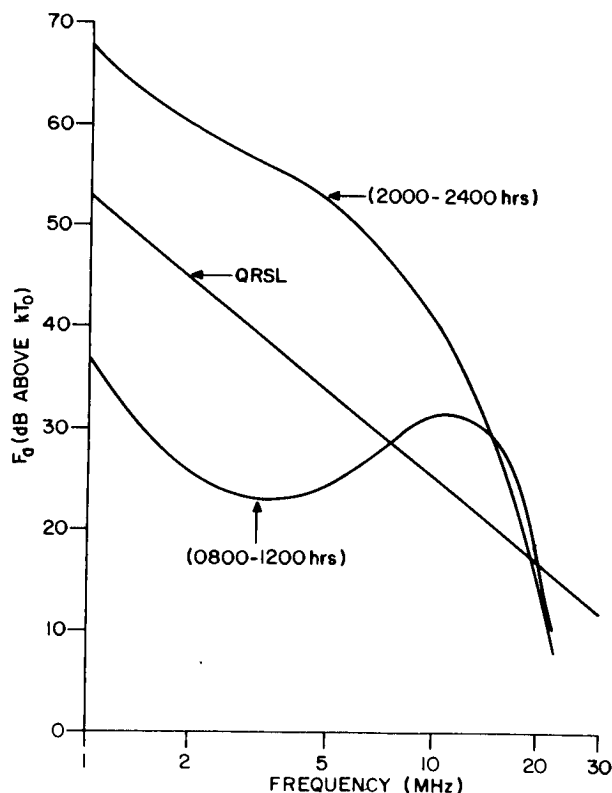


Figure 4. CCIR Natural Noise Predictions, Ottawa, Spring

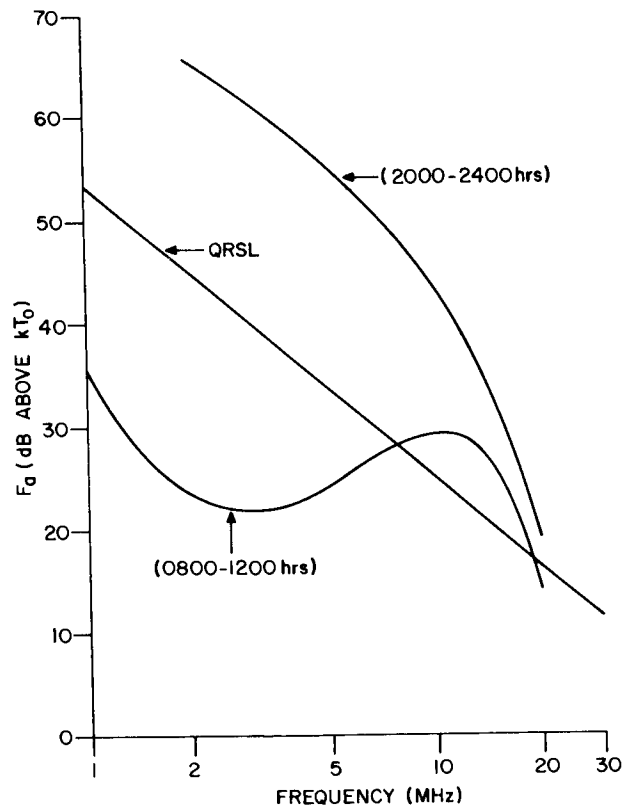


Figure 5. CCIR Natural Noise Predictions, Ottawa, Summer

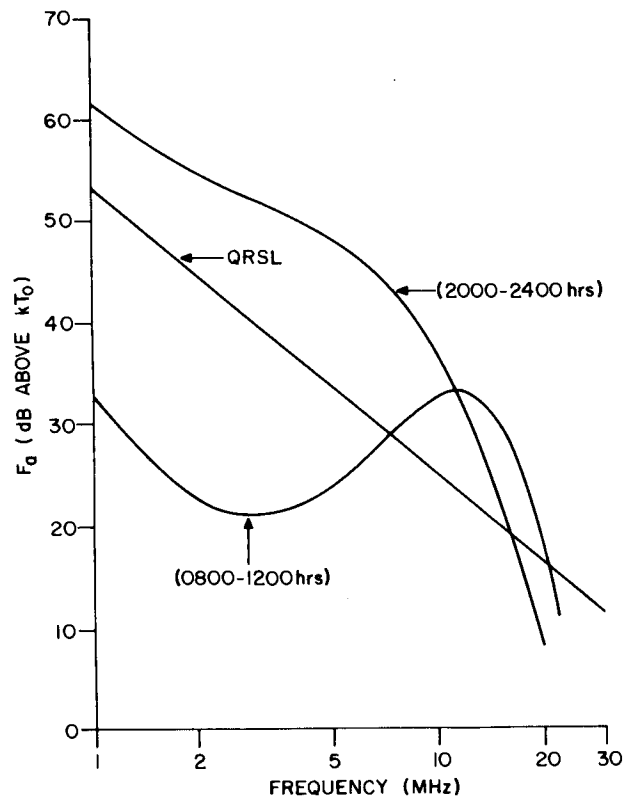


Figure 6. CCIR Natural Noise Predictions, Ottawa, Winter

In general, measurements should be taken at least half an hour after sunrise or sunset to ensure good day or night readings, respectively. Do not take measurements when you can see lightning and hear thunder so local storms do not effect the results. Even the CCIR Report 322 data [4] has the local storm effects edited out.

2.5 EQUIPMENT

The equipment used for the noise measurements consists of a 9-foot vertical whip with its associated coupler and ground plane attached to the roof of a vehicle and a Singer NM-26T Electromagnetic Noise Meter (see Figure 7.) To date, this is the only commercially available receiver* that has been used to measure the two noise parameters V_{rms} and V_d . At quiet sites the Comdel HDR 102 low noise preamplifier has been used to increase the sensitivity of the receiving system. The preamplifier must have a high dynamic range, low noise figure (2.5 dB max.), power gain of about 9 to 12 dB and input and output impedances of 50 ohms. The 9-foot vertical whip is used because it has more sensitivity than either the 41-inch whip or the loop antenna (see Table 1). It is very important to use an omni-directional antenna when one does not know the whereabouts of the noise sources. The antenna is attached to the roof of a vehicle for a good ground plane. This increases the system sensitivity by 2 to 3 dB over that obtainable by having the 2x2 foot ground plane on the ground [6]. The vehicle has not been found to degrade the antenna pattern, i.e., the antenna looks like a short vertical rod over an infinite perfectly conducting ground plane. Also for practical purposes it is necessary to have the equipment in a vehicle, especially during rain, cold or snow, to have an all-weather measurement system.

2.6 HOW TO TAKE THE MEASUREMENTS

A complete set of blank forms (Noise Data, Calibration Data and Summary Noise Data sheets) used in the survey is given in Appendix D. Six nominal frequencies are used to cover the HF band (5, 7, 10, 15, 20 and 25 MHz) and six for lower frequencies (.17, .3, .5, 1, 1.8, and 2.5 MHz). Measurements are taken at signal-free spots near these nominal frequencies. These twelve measurement frequencies were chosen so that the data will appear at evenly spaced intervals on a log-frequency plot. A measurement consists of 11 samples of V_{rms} and V_d using the MEDIUM time constants (or the shortest time constants that give readings with small variations, 1-2 dB swings between readings) taken at 15-second intervals. A survey should last for 10 to 14 days; ten days bare minimum and fourteen days recommended. Take measurements at each frequency both in the 0800 to 1200 hr and 2000 to 2400 LST time periods as mentioned previously. This 14 day schedule prevents two to three days of local atmospherics and six to seven days of possible HF blackout from adversely affecting the results. From this it is possible to obtain an accurate estimate of the day-to-day variation of the noise. The reason for

* The Singer NM-25T field intensity meter can be modified with a separate unit called the "RMS and V_d Converter" which is manufactured in Ottawa by Richard Brancker Research Ltd. to measure the parameters V_{rms} and V_d . Recently Fairchild Electrometrics have produced a converter for their EMC-25 field intensity meter that will allow for these measurements but to date no test data have been produced using this meter.

taking 11 samples 15 seconds apart is that it is a compromise between getting enough data and finding a signal-free frequency for at least 3 minutes. A detailed outline is given in Appendix A of the Noise Measurement Procedure which includes the operation of the equipment and the completion of the data sheets.

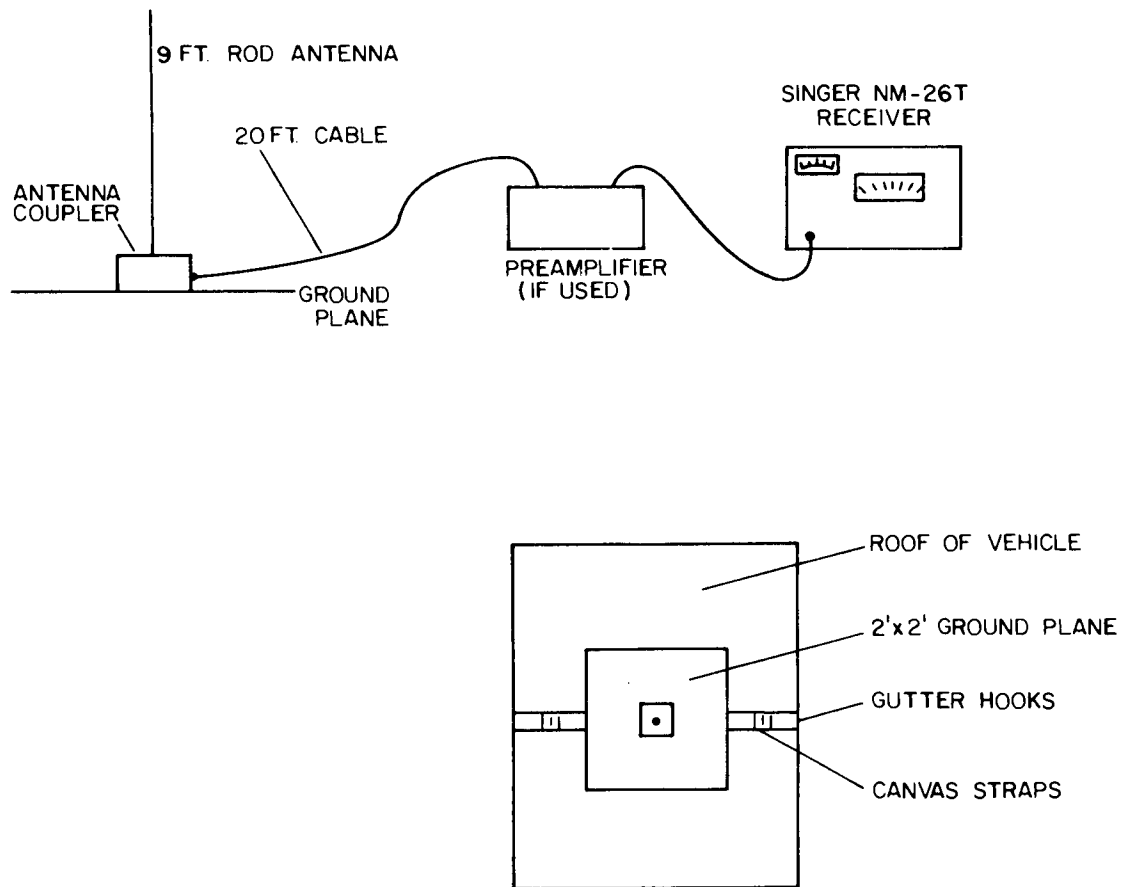


Figure 7. Measurement Equipment

Table 1. Antenna Factors (Coupler Insertion Loss, dB)

FREQUENCY (MHz)	9-FOOT ROD	41-INCH ROD	LOOP
1	23.0	31.6	50.8
2.5	16.8	24.0	44.6
5	14.9	21.0	41.1
10	10.0	18.9	37.8
15	10.9	20.2	37.6
20	7.0	15.0	31.5
25	7.0	16.1	31.8
30	7.8	16.8	32.0

2.7 CCIR PREDICTIONS

Before going to a site one should have a good estimate of the levels of natural noise (atmospheric and galactic) at the site. CCIR Report 322 [4] shows the predicted levels of natural noise for any site in the world for Spring (March, April, May), Summer (June, July, August) Autumn (September, October, November) and Winter (December, January, February) in six time periods (0000 to 0400, 0400 to 0800, 0800 to 1200, 1200 to 1600, 1600 to 2000 and 2000 to 2400 hours Local Standard Time) and as a function of frequency. To facilitate the use of this data, the Communications Research Centre (CRC) has a computer program to which one simply provides the input of the longitude and latitude of the site and the program produces a printout of this prediction. These predictions are available at CRC. Call one of the authors (W.R. Lauber). Plots of these predictions should be prepared and taken on the survey. They may be used to determine whether or not the site is natural noise limited. The night-time (2000 to 2400 hrs) predictions have proven quite accurate (within ± 6 dB). If the measured night-time values are much higher than these predictions there could be an interference problem at the site that should be checked into before you leave. Much lower values especially at frequencies below 10 MHz could signal an ionospheric disturbance or blackout.

Great care should be exercised when using the CCIR predictions for the 0800 to 1600 hour time period especially at frequencies below 10 MHz. To date neither ourselves nor any other group known to the authors have been able to measure levels as low as the predictions when they drop below the Quiet Rural Site Line (see Section 4, equation 11).

2.8 PLANNING AND SCHEDULING

The time of the year should be chosen so that conditions (weather, insects, etc.), communication site activity (in some cases directly relates to survey assistance, lodging and vehicle) and vacations, will not conflict with the survey. The personnel at the communication site can usually furnish a general assessment of the problems that are being experienced with radio interference, previous survey data and a layout of the area. With as much background information as possible, a plan listing major concerns should be established keeping in mind that the antenna farm, surrounding area and communication building are the three basic areas to look at. Where possible a measurement plan should be defined (i.e., frequencies, number of readings and special instructions should be given to the survey team to further quantify the nature of the measurements). See Figure 8 for a typical Measurement Plan. A schedule is drawn up to allocate the defined tasks evenly among the members of the survey team, to give a time slot for each task, and to determine the necessary man-power. It has been noted from past surveys that a minimum of three people are required for a two week outing (see Figure 9 for a typical Schedule). It should be stressed that experience is required in taking the data, because without any radio background it is very difficult to find a true signal-free frequency, to really understand the radio noise environment and to assess the quality of the site.

Task Number	Task	Time Allotment		Description
		Days	Hours per Task	
1	Antenna Farm and Quiet Site	14	3 1/2	Standard set of 11 readings of V_{rms} and V_d at 15 sec. intervals for 12 frequencies (.17, .3, .5, 1, 1.8, 2.5, 5, 7, 10, 15, 20 and 25 MHz).
2	Area survey	3	3 1/2	Standard set of measurements at three other evenly spaced locations in the area.
3	Powerline Profile	3	3 1/2	Take a representative sample of V_{rms} and V_d (depending on the spread of the readings) at 15, 30, 45, 60 metres from the powerline.
4	Vehicle Ignition	2	3 1/2	Measurements of V_{rms} and V_d at 3 and 10 metres from various vehicles at 15, 20, 25 and 30 MHz.
5	Emergency Lighting	1	3 1/2	Spectrum analyzer displays from 1 KHz to 50 MHz on battery and ground leads with current probe.
6	Battery Charger	1	3 1/2	Same procedure as Number 5.
7	Study	8	3 1/2	Familiarization of measurement team with the site to be investigated.
8	Open	8 at 3 1/2		To complete any unfinished tasks.

Figure 8. Measurement Plan

DATE	MON	TUE	WED	THU	FRI	SAT	SUN	MON	TUE	WED	THU	FRI	SAT	SUN	MON	TUE
NAME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
M	Establish lodging and vehicle	7	1	1	7	-	1	1	1	8	1	8	1	1	1	Prepare to leave
John A		2	2	3	3	-	-	4	4	7	2	3	-	-	8	
N		1	1	-	1	1	-	-	1	1	-	1	1	-	1	
M		1	7	1	1	1	-	1	1	1	8	1	-	1	1	
Howard A		2	2	3	3	-	-	4	4	8	5	7	-	-	8	
N		-	1	1	-	1	1	1	-	1	1	-	1	1	1	
M		1	1	7	1	1	1	7	7	1	1	1	1	-	8	
Murray A		2	2	3	3	-	-	4	4	6	2	3	-	-	8	
N		1	-	1	1	-	1	1	1	-	1	1	-	1	1	
M - Morning 0800-1130 A - Afternoon 1230-1600 N - Night 1900-2230 Numbers - are task numbers from the Measurement Plan (see Figure 9)																
Overtime: John - 10 @ 1 1/2x + 2 @ 2x Howard - 9 @ 1 1/2x + 3 @ 2x Murray - 9 @ 1 1/2x + 3 @ 2x																
Note: After hours and Saturday work calculated at 1 1/2 x hourly rate. Sunday calculated as 2 x hourly rate.																

Figure 9. Measurement Schedule

2.9 F_a CALCULATIONS

The effective antenna noise figure, F_a , is the preferred way of expressing the mean noise power received from sources external to the antenna and is defined by:

$$F_a = 10 \log f_a \quad (4)$$

where

$$f_a = p_n / kT_o b \quad (5)$$

and p_n is the received noise power, in watts, available from an equivalent loss-free antenna (i.e., power available after correction for antenna losses) in a noise power bandwidth b , in hertz, k is Boltzmann's constant 1.38×10^{-23} joules/kelvin, and T_o is the reference temperature, 288K. The quantity f_a is dimensionless (the ratio of two powers) but it gives, numerically, the available power spectral density relative to kT_o and the available power relative to $kT_o b$. Thus F_a is usually defined in units of dB above kT_o or dB above $kT_o b$.

For a short vertical antenna over a perfect ground and a reference temperature $T_o = 288$ K (15°C)

$$F_a = E_n - 20 \log F + 95.5 - 10 \log b \quad (6)$$

where E_n is the measured rms field strength of the vertical component of the noise field from a short vertical monopole over a perfect ground (in dB above 1 $\mu\text{V/m}$) for a noise power bandwidth b . F is the received frequency (MHz). Appendix B shows the derivation of this equation along with the assumptions used.

From the measurements

$$E_n = MR + MC + AF + CL \quad (7)$$

where MR is the rms meter reading (dB above 1 μV),

MC is the meter correction figure (dB),

CL is the antenna cable loss (dB) and

AF is the antenna figure which is made up of two parts $AF = CF - EH$ where CF is the coupler insertion loss factor (dB) and EH is the antenna effective height (dB above 1 metre).

Combining 6 and 7 we have

$$F_a = MR + K_f - G \quad (8)$$

where G is the gain of the low noise preamplifier, if used, and

K_f is a combined factor having a different value for each frequency

$$K_f = 95.5 - 10 \log b - 20 \log F + MC + CF - EH + CL \quad (9)$$

The effective power, bandwidth b , of the Singer NM-26T receiver is approximately 4 kHz. See Table 1 of discussion by Hagn and Shepherd of "A Field Comparison of RI and TVI Instrumentation" [7].

The meter correction figure, MC , is determined by reading the rms meter after calibration when a known signal (CW) from a signal generator is used as input. This gives a measure of the measurement accuracy for the receiver.

The coupler insertion loss figure, CF , is determined from a set of calibration curves supplied with each antenna coupler.

The effective height of a vertical monopole less than $\lambda/10$ in physical height above an infinite, perfectly conducting ground plane is equal to one-half the physical height. For the 9-foot rod the effective height figure, EH is

$$EH = 20 \log (9/2 \times 0.3048) = 2.7 \text{ dB above 1 metre}$$

The antenna cable losses, CL , are calculated for the cable, usually 20 feet of RG-58, connecting the antenna coupler to the receiver.

The values for K_f for each frequency may be simply computed using equation 9. For example, if $b = 4000$ Hz, $F = 2.5$ MHz, $MC = +0.5$ dB, $CF = 16.8$ dB, $EH = 2.7$ dB, $CL = 0.13$ dB,

$$\text{then } K_{2.5} = 95.50 - 36.02 - 7.96 + 0.50 + 16.80 - 2.70 + 0.13 = 66.3$$

The values of K_f are rounded off to the nearest 0.1 dB to be consistent with the meter readings, i.e. the meter scale of the NM-26T may be read to the nearest 0.1 dB. After the F_a values have been computed they are rounded off to the nearest dB since that is the accuracy of the meter.

2.10 EQUIPMENT TESTS

Some receivers come with different calibration (CAL) points for each band, usually only about 0.25 dB apart. To make it easier for the operator and to obtain repeatable results, the idea of using only one CAL point has been adopted. Measure the CAL point at each nominal measurement frequency by injecting a known signal level into the receiver. From these, select a value representative of the set of 12 CAL points, preferably at an even dB value (say 9 or 10 etc., not 10.25 or 9.5). This will be the CAL point for the receiver. Next use a Dymo or some other type of marker to mark the CAL level on the receiver. Using this CAL point and a known signal, determine the errors caused by using this CAL point. These errors must be added to the final measurements as the Meter Correction Figure (MC).*

* If 10 is used and the true value is 10.25 then 0.25 dB must be added to each measurement, i.e., $MC = +0.25$ dB. However, if 10 dB is used and the true value is 9.5 then 0.5 dB must be subtracted from each measurement, i.e., $MC = -0.5$ dB.

It is necessary to determine the minimum discernable signal or system sensitivity. This is found at each frequency by terminating the receiver (or preamp) with a 50 ohm load and reading the V_{rms} meter. These values are then used to calculate the minimum measurable noise levels, F_{amin} . It is also useful to measure the noise figure of the receiver and preamp receiver system at the various frequencies.

The preamp gain should be checked at the nominal frequencies. We have had some mismatch problems with the Comdel preamp. These were found by measuring a transmitted signal with and without the preamp in the system. As well as determining the preamp gain, this test takes into account all system mismatch losses.

Finally, although the effective height figure of 2.7 dB above one metre has been used in most of our noise calculations, it is very useful to measure this with the particular vehicle configuration that you are using [6]. This is done by the following: (1) establish a stable field using a signal generator and a vertically polarized antenna located 300 metres or more from the receiving set up. (2) Measure the field with a calibrated loop on the vehicle where the 9 foot rod antenna will be located (take several measurements to ensure a uniform field). (3) Measure the received voltage on the rod antenna through the coupler. (4) The effective height figure, EH, can then be calculated from the following:

$$EH = MR_{loop} + AF_{loop} - (MR_{rod} + CF_{rod}) \quad (10)$$

where MR_{loop} , MR_{rod} are the received voltages of the loop and rod respectively, AF_{loop} is the loop antenna figure from a chart and CF_{rod} is the 9 foot rod coupler figure from a chart all in dB.

The value of 2.7 dB above one metre was derived from theory for a short vertical rod (Equation B6 in Appendix B). The following table shows that this value is accurate to within 2 dB for the frequencies covered in this survey; i.e., up to 25 MHz. Measurements that we have taken with the antenna mounted on the roof of a vehicle have confirmed the value of 2.7 dB above one metre within ± 2 dB.

Frequency (MHz)	EH (dB above one metre)
2.5	2.7
5.0	2.7
10.0	3.0
20.0	3.8
25.0	4.5

2.11 PRELIMINARY ANALYSIS OF DATA IN THE FIELD

Prepare a CALIBRATION DATA sheet as shown in Figure 10 to compute the K_f factors to be used to convert the Meter Readings (MR) to F_a . The K_f fac-

tors given assume that the meter readings are at least 6 dB above the set noise level. Appendix A page 32 describes the procedure to be used when the meter readings are near set noise, i.e., they are to be corrected, if possible before adding to the K_f factors. Compute the F_a values from the median MR for each frequency and day and transfer them to the SUMMARY NOISE DATA Sheet (see Figure 11) and plot the daily F_a values on a scatter plot as shown in Figure 12. (This shows the scatter plot for the first four days). The daily F_a data should cluster within 3 to 4 dB except at points where you expect atmospheric noise (10,15 and 20 MHz daytime). If the scatter plot starts to show some very noisy days and some very quiet ones, i.e., two clusters, then one should try to identify the source of the man-made noise before you leave the site. Also if you have atmospheric noise at frequencies around 1 and 2 MHz in the day and the levels seem higher than usual then you should suspect local atmospheric activity within a few hundred km of the site. It is possible in some seasons (especially Summer) for this to occur on two or three days of your survey. Since the measurements are taken over 14 days, the local atmospherics will not greatly affect the overall assessment of the site.

The first day's measurements are very important. If the levels are low and quiet (only natural noise evident by aural monitoring) then you could have a 'good' site. However, if the levels are high and noisy (man-made noise evident by aural monitoring) then you may have to try to locate the source of noise and advise communication personnel. Also on the first day it will take about 50% longer to do the measurements as you try to find quiet frequencies and set up a routine procedure.

3. ANALYSIS OF F_a AND V_d DATA

On return from a survey, it is necessary to analyse the measurement data and present them in a useful manner for use now and in the future. This section will mainly be concerned with the antenna farm data but the methods should be used with all the data. The summary noise data sheets contain F_a day, F_a night, V_d day and V_d night data. Calculate the median and standard deviation for each set at each frequency. The median gives the best estimate for a typical value of the noise parameter because it is not biased by one or two high or low values as the mean or average value is. The standard deviation gives an idea of the day to day variation of the noise.

There are a number of ways of plotting the data for presentation in a report. Figures 13, 14 and 15 show three possible ways of using the data of Figure 11: scatter plot, median plus maximum to minimum, and median $\pm \sigma$ (standard deviation). Each method has its advantages and disadvantages. The first method (Figure 13) shows a point for each day and frequency. Multiple points are hard to plot, but they do give a good look at the statistical variation of the data. The median point may be plotted as a large or a distinct point e.g., an "x". (The median point will be used in all evaluation techniques discussed in the next section.)

The second method (Figure 14) shows the median and the extreme values measured which show something of the true spread of the data e.g., if the median is in the centre of the two extremes, this means that the measured values were uniformly spread between the highest and lowest values. However,

CALIBRATION DATALOCATION OTTAWA CRC QUIET SITEDATE MAY 1975PREAMPLIFIER COMDEL SN: 201RECEIVER NM-26T SN: 0550ANTENNA/COUPLER 9-FT. ROD SN: 106

$$K_f^* = 95.5 - 10 \log b - 20 \log F + MC + CF - EH + CL$$

FREQ. (MHz)	MC (dB)	CF (dB)	EH (dB)	CL (dB)	K_f (-20 dB ATTEN.)	K_f (0 dB ATTEN.)	PREAMP GAIN (G) (dB)	$K_f - G$ (-20 dB ATTEN.)
0.17	+0.5	28.8	2.7	0.01	81.5	101.5	9.0	72.5
0.3	+0.5	26.5	2.7	0.02	74.3	94.3	9.0	65.3
0.5	+0.2	25.5	2.7	0.04	68.5	88.5	9.0	57.5
1.0	+0.2	23.0	2.7	0.07	60.1	80.1	9.0	51.1
1.8	0.0	19.6	2.7	0.11	51.4	71.4	9.0	42.4
2.5	0.0	16.8	2.7	0.13	45.8	65.8	9.0	36.8
5.0	0.0	14.8	2.7	0.19	37.8	57.8	9.0	28.8
7.0	-0.2	14.5	2.7	0.22	34.4	54.4	9.0	25.4
10	0.0	10.1	2.7	0.28	27.2	47.2	9.0	18.2
15	+0.3	10.8	2.7	0.35	24.7	44.7	9.0	15.7
20	-0.2	7.1	2.7	0.42	18.1	38.1	9.0	9.1
25	-0.4	7.0	2.7	0.48	15.9	35.9	9.0	6.9

KEY:

MC - METER CORRECTION

CF - COUPLER INSERTION LOSS FIGURE

EH - EFFECTIVE HEIGHT

CL - CABLE LOSS

* K_f ONLY FOR A SHORT VERTICAL ROD ANTENNA.

Figure 10. Calibration Sheet

SUMMARY NOISE DATA

LOCATION ANTENNA FARM PARAMETER F_a TIME 0800-1200 EST DATE MAY 1975

DATE FREQ (MHz)	1	2	3	4	5	6	7	8	9	10	11	12	13		MEDIAN	SIGMA		COMMENTS
0.17	-	-	-	-	-	-	-	-	NO	DATA	-	-	-					BAND AT 0.17 MHz TOO CROWDED WITH BEACONS
0.3	70	72	75	73	72	78	75	77	73	70	71	79	72		73	3.0		LOCAL ATMOSPHERIC ON MAY 12 SOME POWERLINE NOISE ON MAY 6,7 AND 8
0.5	62	65	68	66	64	73	74	71	64	66	66	78	65		66	4.7		
1.0	53	59	54	57	55	61	62	55	57	65	57	70	65		57	4.8		
1.8	49	51	47	50	52	53	55	56	50	52	55	70	53		52	5.6		
2.5	42	43	42	43	44	48	47	49	44	43	43	55	43		43	3.8		
5.0	34	35	36	35	36	42	40	41	36	40	37	49	37		37	4.1		
7.0	29	31	30	30	32	36	34	35	32	31	32	44	31		32	3.9		
10	30	32	31	29	36	38	37	37	31	30	34	46	31		32	4.7		
15	27	33	29	30	34	41	36	39	40	32	42	45	32		34	4.8		
20	22	23	22	25	23	25	24	27	23	23	22	27	22		23	1.8		
25	19	20	18	20	21	19	19	20	20	20	19	21	20		20	0.9		

Figure 11. Summary Noise Data Sheet (F_a)

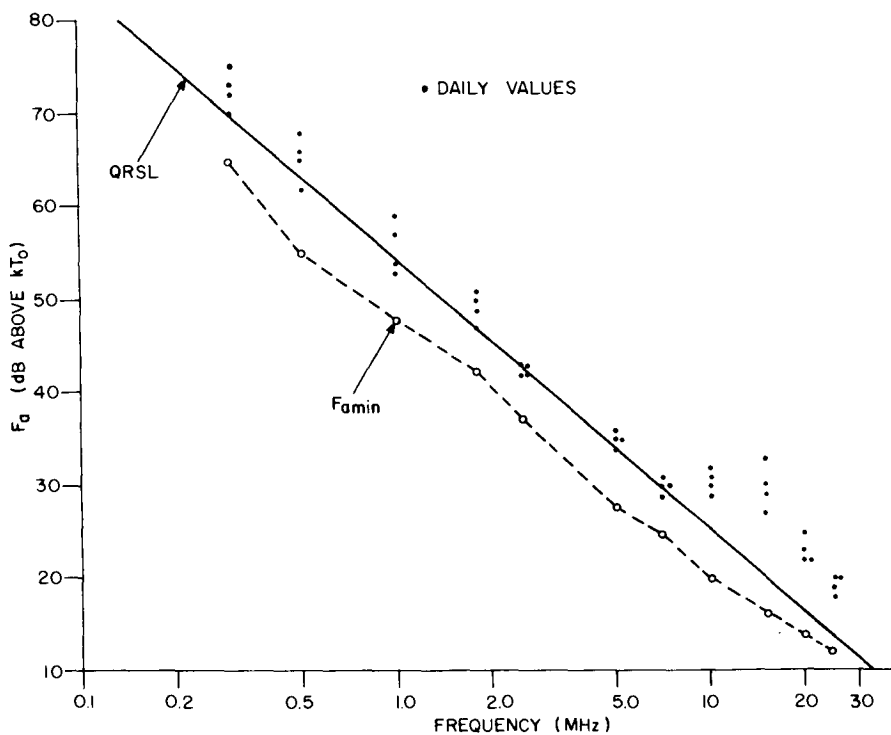


Figure 12. Sample Scatter Plot (4 Days)

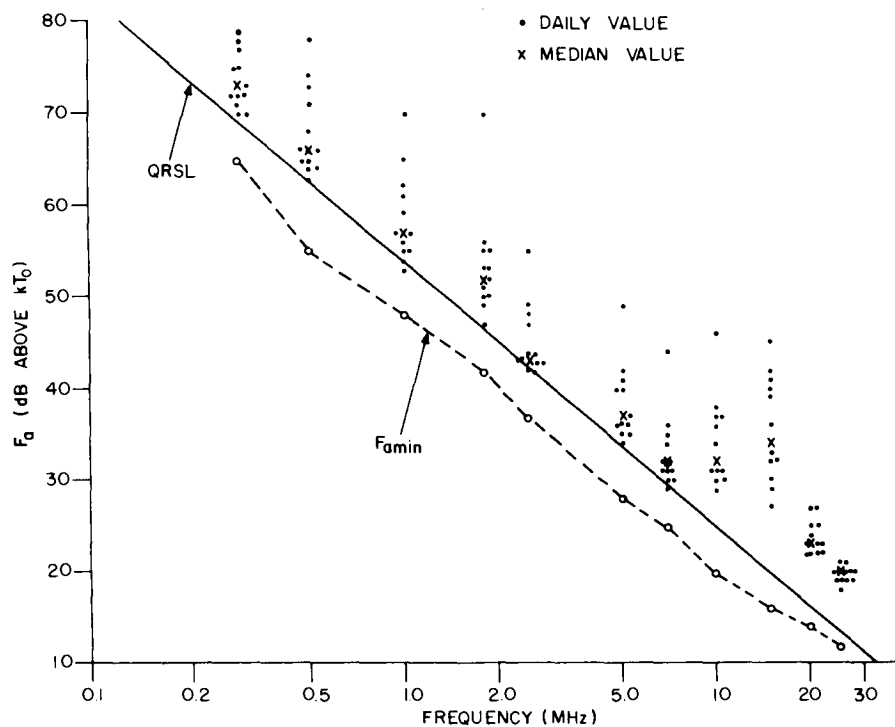


Figure 13. Sample Analysis Scatter Plot

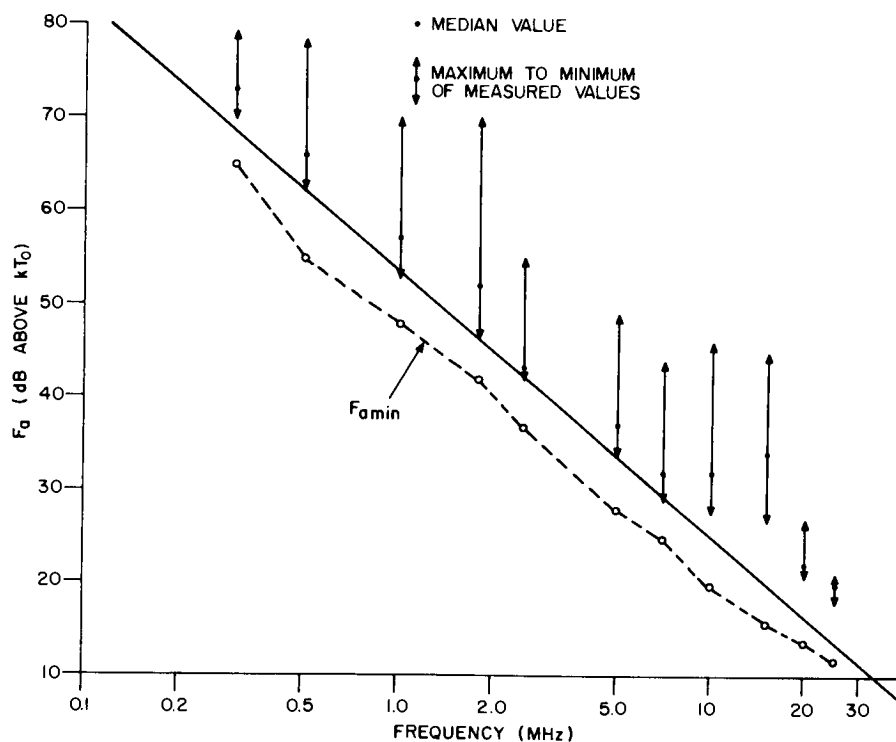


Figure 14. Sample Median Plus Maximum to Minimum Plot

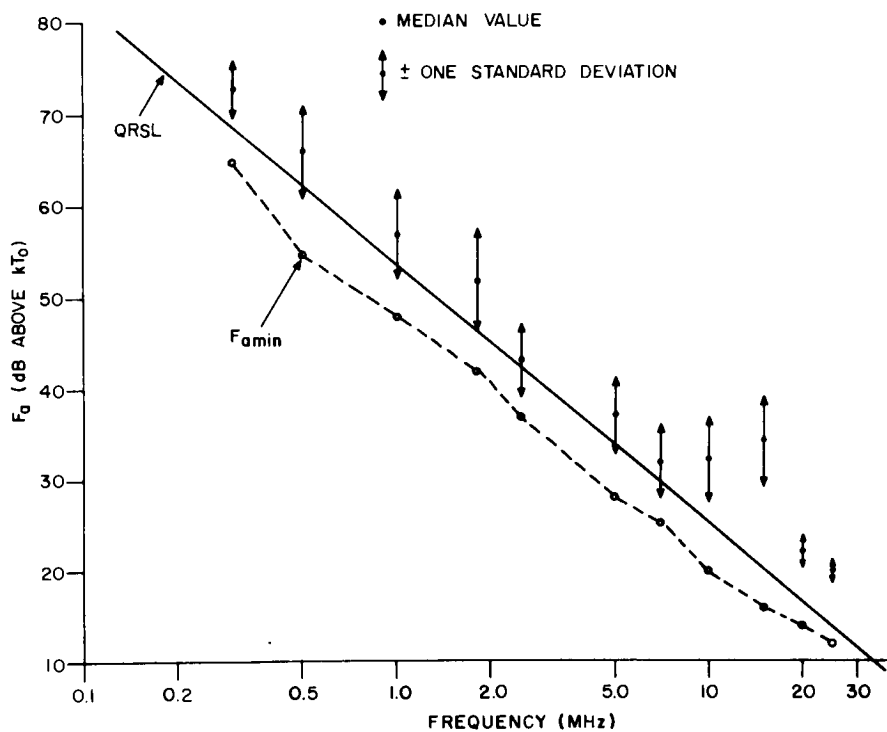


Figure 15. Sample Median and Standard Deviation Plot

if the median is near the bottom of the extremes, this means that most of the measured values were at the bottom with at least one day being significantly higher.

The third method (Figure 15) gives the median and an equal spread about the median based on the standard deviation. This equal spread may not be realistic as discussed in connection with method two. All of the above methods have their merit, no one is preferred over the other. Use the method that best explains the data for your requirements.

In addition to the measurement data, two lines should be shown on each F_a graph and one other for the V_d graphs. For the V_d graphs the $V_d = 1.05$ line should be used as a reference line. On the F_a graphs, the F_{amin} data measured in the equipment tests should be plotted to show the minimum measurable data. The CCIR natural noise prediction should be shown on all F_a nighttime plots and the Quiet Rural Site Line (defined in Section 4) should be shown on all F_a daytime plots. These are the reference lines used for each of these sets of data.

Another possible analysis technique involves computing the median and ratios of upper and lower deciles from the measurement data. The latter two quantities are defined as, D_u , the estimate of the ratio in dB of the upper decile (value exceeded 10% of the time) to the median and, D_l , the estimate of the ratio of the median to lower decile (value exceeded 90% of the time). Some recent and ongoing work by Hagn and Sailors [8] has shown that it is possible to use these values (median, D_u , and D_l) to derive models which describe the probability distribution of the noise levels. Note the values of D_u and D_l are computed from all the individual measurements at a particular frequency and time of day. It is possible to compute these by hand but a calculator or small computer is very handy. There are 154 measurements to use for each frequency (11 measurements / day x 14 days). The distribution of F_a levels is required to compute the distribution of signal to noise ratios for the probability of successful communication. There is space available in the final column on the Summary Noise Data Sheet for listing the D_u and D_l values. Again one can plot the median and the D_u to D_l range as a function of frequency.

4. SITE EVALUATION

In order to evaluate a site there must be a reference or standard for a "good" site. In the frequency range of interest (0.15 to 30 MHz) there is such a reference. It is referred to as the expected values of man-made noise at a quiet receiving location (Quiet Rural Site Line, QRSL, for short). "These values are typical of the lowest values at sites chosen to ensure a minimum amount of man-made noise and much lower values will seldom be found at sites which are not several kilometres from powerlines and electrical equipment." [4] The equation of this line as a function of frequency is:

$$F_a = -28.6 \log F + 53.6 \quad (11)$$

where F is the received frequency (MHz). From experience, we have found that

an rms difference of three to four dB between the measured F_{am} 's, (median values of F_a) and the QRSL defines a "good" site [9], i.e., one that has no man-made radio noise degradation and is thus natural noise limited. For a site degraded by man-made radio noise this rms difference is much larger.

A second criterion for a "good" site is that there should be about a 20 dB increase in noise level (F_{am}) at 2.5 MHz at night compared to the day for the spring, summer and autumn seasons (March to November, inclusive) [9]. If this difference is substantially less than 20 dB, say 12-14 dB, then there is a strong possibility that the site is degraded by some sort of powerline noise which is the dominant source of man-made radio noise at frequencies below 10 MHz. This criterion is good for mid-latitudes in Canada. At high latitudes (those higher than 62°N) this criterion is not valid as day-night differences of only 3-4 dB have been measured at good sites [10].

A third possible criterion of site degradation is that the median values of the V_d measurements, V_{dm} , are greater than 2.5 dB for the day-time measurements. The reasons for this are: firstly, noise with high V_d values are impulsive and will severely degrade most communication systems and secondly, high V_d values are generally characteristic of high noise levels. This latter would be confirmed by the F_a measurements.

5. FUTURE REASSESSMENT

Once a particular site has been surveyed any future reassessment depends primarily on the extent of development (housing or industry) around the site. For a remote site which is 5 to 10 km away from any development the noise levels should remain fairly constant and we suggest a full scale reassessment every three to five years. Reported problems should be dealt with when they occur. However, if development starts at or near a site one should reassess the site every year. These data were lacking in the relocation of the CBC site mentioned in the introduction and for the DND site at Albro Lake near Halifax which was moved to Mill Cove in 1966.

Figure 16 shows a hypothetical history of site degradation by the increase in levels of man-made radio noise. This site started off as a quiet site and then some development started near the site. Powerline noise from a broken insulator significantly raised the noise level. When this was fixed the level dropped but because of the continuing development an intolerable noise level was reached within a few years. The intolerable level in this example was defined to occur when the day-time level was the same as the night-time level at 2.5 MHz.

This type of information can be used to predict when a site will have to be relocated well in advance of the actual move if a monotonically increasing trend is seen to be developing. A particular site that is of concern to us is CFS Leitrim. In 1974 a survey of this site was carried out. At that time the site was fairly quiet with an intermittent source of powerline noise degrading it somewhat. In 1977 after the survey was carried out at this site and because of increasing housing development to the north and west the noise levels were found to be much higher. This is the first site at which we hope to be able to obtain a real quantitative history of site degradation by man-made radio noise.

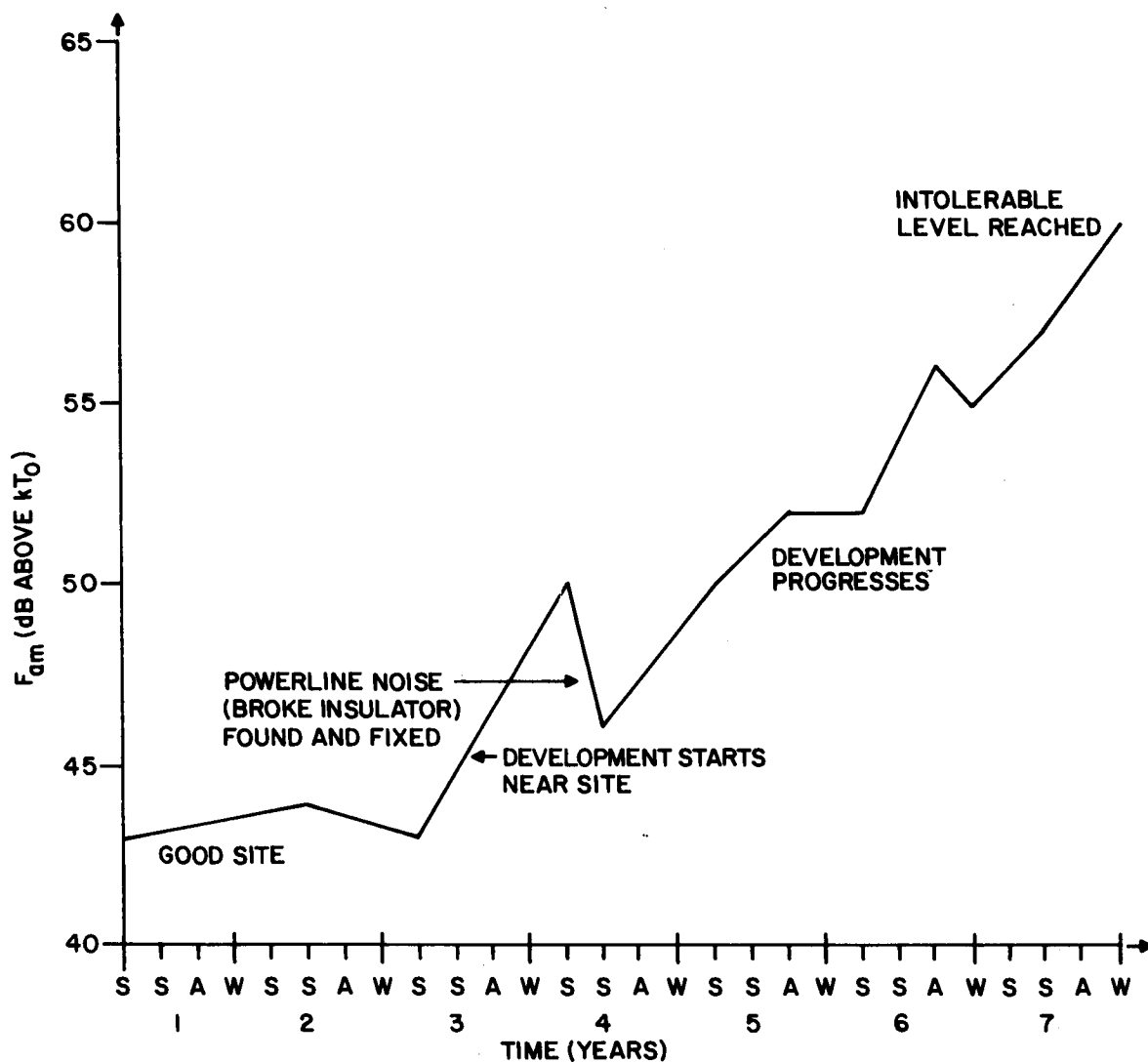


Figure 16. Hypothetical History of Site Degradation (2.5 MHz)

6. SUGGESTIONS TO MAINTAIN OR IMPROVE SITE PERFORMANCE

Most communication centres cannot withstand a major overhaul to eliminate in-house interference, so they must control the influx of new interfering equipment and suppress or replace existing offending systems. A comprehensive overview of electrical noise is given in the Donald R.J. White series [11] which shows how to identify, measure and suppress electromagnetic interference so that various systems will function in a compatible environment. Section 3 of this series is particularly helpful, especially the chapters on grounding and shielding since poor grounding techniques are major sources of interference problems. The MIL STD 461 procedure of noise measure-

ments, as simply outlined in the Hewlett Packard note [12], (a spectrum analyzer approach), may be used as a screening tool before equipment is installed in the communication area so that corrective action may be taken beforehand, if required. New installations of a larger scale should be carefully planned and supervised to ensure compatibility of new and existing equipment.

Sources of interference in the area surrounding the communication centre should be identified, documented and suppressed where possible. In this manner interfering systems may be brought to the attention of the proper authorities such as the local power companies for broken insulators on power-lines. Noise suppression kits should be installed on vehicles (where applicable) that travel in the surrounding area and traffic should be kept to a minimum. To ensure optimum antenna efficiency and minimum interference from other systems a regular maintenance schedule should be established.

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A P P E N D I X A

Measurement Procedure

The following is the recommended measurement procedure to be followed for each set of measurements.

A.1 PREPARATION OF NOISE DATA SHEETS (SEE FIGURE A1):

- *Location* - note briefly the location of the measurements.
- *Equipment* - note serial number of equipment and type of antenna.
- *Weather* - note whether sunny, cloudy, raining or snowing, rain or snow within preceding 12 hours, thunderstorm within 6 hours, or occurrence of northern lights.
- *Sheet* - use sequential sheet numbers for the whole survey.
- *Date* - note the date.
- *Time* - note the local time and zone (e.g., Eastern Standard Time) at the beginning of the measurements or the beginning of that sheet if more than one is used for this measurement set.

A.2 PREPARATION OF EQUIPMENT

- Assemble the 9-foot rod antenna, coupler, 20 foot antenna cable and ground plane and attach to roof of vehicle.
- Unpack NM-26T receiver but do not connect antenna.
- Turn POWER switch to ON.
- Turn FUNCTION switch to FI (Field Intensity) and check battery voltage.
NOTE: This receiver is powered by NiCad batteries which perform best if worked very hard. They should last 4 to 5 days on one charge (specified to run 40 hours when new). Do not recharge until necessary. Charging of the batteries after each set of measurements will severely shorten the life of the battery pack.
- Turn POWER switch of preamp package to ON and check battery voltage.

NOISE DATA

LOCATION CRC-HFDF - ANTENNA FARM
 ANTENNA 9-FT. ROD SN: 106
 RECEIVER NM-26T SN: 550
 WEATHER COOL OVERCAST

SHEET 3
 DATE 4 May 1977
 TIME 1015 EST

1. FREQ. <u>2.5</u>		2. FREQ. <u>5.0</u>		3. FREQ. <u>10</u>	
	Vrms	Vd		Vrms	Vd
-20			-20		
ATTN	10.0	1.2		15.0	2.5
	10.5	1.2		15.5	2.5
	10.0	1.5		15.0	3.0
	10.0	1.5		16.0	3.0
	10.5	1.2		17.0	2.5
	10.0	1.2		16.0	3.0
	9.5	1.2		15.0	3.0
	10.0	1.2		17.0	3.5
	10.0	1.2		16.0	3.5
	9.5	1.2		17.0	3.5
	9.5	1.2		16.0	3.0
MEDIAN	10.0	1.2		16.0	3.0

4. FREQ. <u>15</u>		5. FREQ. <u>20</u>		6. FREQ. <u>25</u>	
	Vrms	Vd		Vrms	Vd
-20			-20		
ATTN	18.0	1.5		7.5	1.0
	17.0	1.5		7.0	1.0
	18.0	1.5		7.0	1.0
	18.0	2.0		6.5	1.0
	19.0	2.0		7.0	1.0
	19.0	2.0		7.0	1.0
	19.0	2.0		6.5	1.0
	19.0	2.0		7.0	1.0
	19.0	2.0		6.5	1.0
	19.0	2.0		7.0	1.0
	19.0	2.0		7.0	1.0
MEDIAN	19.0	2.0		7.0	1.0

LINE	PREAMP	NOISE CHARACTERISTIC (S-soft, M-moderate, L-loud)								COMMENTS
		GAL	ATM	BUR	PWR	SRG	CLK	IGN	HSH	
1.	COMDEL 201								S	VERY QUIET
2.	COMDEL 201								S	VERY QUIET
3.	-----		M							ATMOSPHERICS
4.	-----		S							ATMOSPHERICS
5.	-----	X								GALACTIC
6.	-----	X								GALACTIC

Figure A1. Completed Noise Data Sheet

A.3 CALIBRATE V_d METER

- Turn FUNCTION switch to NOISE.
- Terminate receiver in 50Ω load.
- Turn ATTENUATOR switch to -20 dB (x.1).
- Turn Red CAL pot. for maximum RMS meter deflection.
- Set Meter time constant toggle switches located below RMS meter to "SHORT".
- Set V_d meter to read 1.0 dB with the V_d zero pot (in the laboratory a CW signal is used to set V_d meter to read 0.0 dB but in the field you should use the set noise of the receiver which is $V_d = 1.05$ or 1.0 dB on the meter).

A.4 TUNE TO DESIRED FREQUENCY

- Connect the antenna to the RF INPUT.
- Connect headphones.
- Select the appropriate frequency band and set the band switches on both the antenna coupler and the receiver.
- Search for a signal-free frequency* within ± 0.5 MHz of nominal frequency for frequencies above 2.5 MHz. Search within ± 100 kHz for the lower frequencies.

The Department of Communications has a book entitled "Table of Frequency Allocations 10 kHz to 275 GHz" [13].

While it is very possible that these allocations will be modified at the World Administrative Radio Conference (WARC) in 1979, this book is useful in finding a quiet frequency. One should stay away from the Broadcast bands as they are always busy. However, parts of the aeronautical mobile bands will usually be signal free for the three minute period required to take a noise measurement.

Check that it is signal-free by using BFO. Monitor noise with headphone to assure there is no signal contamination being measured. If utterly impossible to find a signal-free frequency, null the RMS meter and note lowest minimum reading with signal. Note the actual frequency used (this will be used on other days).

* Twelve measurement frequencies from 0.15 to 25 MHz are to be chosen so that the data will appear at evenly spaced intervals on a log-frequency plot, e.g., $0.17, 0.3, 0.5, 1.0, 1.8, 2.5, 5, 7, 10, 15, 20$ and 25 MHz.

A.5 CALIBRATE V_{rms} METER AND TAKE V_{rms} AND V_d READINGS

- Obtain calibration figure from Dymo tape or tag on front of receiver and switch FUNCTION switch to CAL.
- Adjust the red CAL pot. until the desired calibration figure is achieved on the RMS meter.
- Return FUNCTION switch to NOISE.
- Take 11 pairs of readings of V_{rms} and V_d at 15 second intervals and record them on the NOISE DATA sheet.

A large, (± 10 dB), swing of the RMS meter may be damped by selecting longer time constants for RMS and V_d meters by using the toggle switches on the front panel (MED Medium) has been found adequate for most types of noise encountered to date).

If the RMS meter reading is constantly above 23 dB, switch ATTENUATOR to 0 dB or +20 dB or until reading falls below 23 dB.

The set noise level for this receiver is near -23 dB V, therefore, if RMS meter reading is below 4 to 5 dB, with the attenuator in the most sensitive position; i.e., -20 dB, insert preamp between antenna and receiver. (Connect antenna to INPUT (left) terminal and OUTPUT (right) terminal to receiver.) If reading is still in the range 0 to 3 dB V above set noise, note under NOISE CHARACTERISTIC on data sheet "near set noise"* and only take 3 readings. Note use of preamp. on Noise Data Sheet.

- Set meter time constant switches to "SHORT".
- Repeat Sections D and E for all frequencies.
- At the end of each measurement (3 minutes) calculate and record the median value of V_{rms} and V_d . The median is the sixth value when the data of eleven readings is sorted from lowest to highest or vice versa. If only 3 readings were taken, the median would be the second reading when ordered.

A.6 COMPLETION OF MEASUREMENTS

- After all readings have been completed, make a note of the propagation conditions by consulting operations personnel. They will be able to report if an HF blackout is in progress.
- Check battery voltage of receiver by turning FUNCTION switch to FI.

* If reading is 6 dB above set noise do not adjust, if reading is 5 dB above set noise, decrease measurement by 1 dB, if reading is 4 dB above set noise decrease measurement by 2 dB, and if reading is 3 dB above set noise decrease by 3 dB and declare "below set noise".

A.7 NOISE CHARACTERISTIC

The major sources of radio noise at these frequencies are: 1) Atmospheric, 2) Galactic, 3) Powerline and 4) Vehicle ignition noise. Aural descriptions are given for the various types of noise as listed on the "NOISE DATA SHEET". It is important to be able to recognize the source type if you are trying to eliminate a certain type of man-made noise from a site. A general rule for the noise characteristic is: If you are sure of the source then mark it down, if you are not sure of the source then try to describe the aural sound.

Galactic noise (GAL) is the result of a large number of distant sources in the galaxy which has a hollow high-pitched hiss characteristic normally heard above 20 MHz.

Atmospherics (ATM) are caused by distant thunderstorms, sounds like sporadic crashes of electrical disturbances with many overlapping strokes.

Bursts (BUR) are high levels of noise for a short duration of time without any particular regular pattern.

Powerline (PWR) noise has a characteristic sound that may range from a hum to a crackle or an intermittent buzz.

Surges (SRG) are rapid increases and decreases in noise level that sound wave-like in character.

Clicks (CLK) are impulsive noises without a regular pattern sounding like a house light switch being turned ON and/or OFF.

Ignition noise (IGN) is a low hum mixed with an impulsive noise whose repetition rate is dependent on the speed of the vehicle - each pulse resulting from the firing of one spark plug.

Hash (HSH) is a complete mixture of sounds not resembling any particular type of transmission or noise.

A P P E N D I X B

Theory of F_a Equation

The noise power received by an antenna may be expressed in terms of an effective antenna noise factor f_a defined by:

$$f_a = p_n / kT_o b \quad (B1)$$

where p_n is the received noise power available from an equivalent loss-free antenna (watts) i.e., the power available after correction for antenna losses.

k is Boltzmann's constant (1.38×10^{-23} joules/kelvin)

T_o is the reference temperature (K)

b is the effective receiver noise power bandwidth (Hz)

From (B1), f_a is a dimensionless factor, thus, one can define the quantity

$$F_a = 10 \log f_a \text{ (dB above } kT_o b \text{)} \quad (B2)$$

which is the noise power per unit bandwidth in dB relative to kT_o (effective antenna noise figure).

Taking $10 \log$ of (B1), one obtains

$$F_a = P_n - 10 \log kT_o - 10 \log b \quad (B3)$$

Here F_a is in dB, and accordingly each term of the right hand side of (B3) may be considered to have units of decibels, and where P_n is the mean noise power in dB above 1 watt. (dB (1W)).

If $T_o = 288$ K (approximately 15°C)

$$10 \log kT_o = -204 \text{ dB (1W)} \quad (B4)$$

NOTE: In practice, the reference level kT (where T is the ambient temperature) will be used for calibration in place of the level kT_o , however $T - T_o$ will not likely exceed 30K so that no more than a 0.4 dB error will be introduced by using T in place of T_o .

From antenna theory [14] the total power in watts extracted from a radio wave by a lossless antenna and delivered to the receiver assuming a perfect impedance match is given by

$$p = \frac{e^2 h_e^2}{4r_a} \text{ (watts)} \quad (B5)$$

where

e is the incident rms field strength (volts/metre)

h_e is the effective antenna height (metres)

r_a is the radiation resistance (ohms)

For a "short" antenna, the charge distribution is essentially constant, thus the current distribution is linear [15]. Also the effective height for a straight vertical antenna over a perfect ground is given by [16].

$$h_e = \frac{\lambda}{\pi \sin \frac{2\pi h}{\lambda}} \sin^2 (\pi h/\lambda) \text{ for } h \leq \lambda/4 \text{ (metres)} \quad (B6)$$

where h , is actual height

If $h = \lambda/4$, $h_e = 0.64h$

If $h = \lambda/8$, $h_e = 0.53h$

If $h = \lambda/10$, $h_e = 0.52h$

Therefore, for a "short" antenna $h_e \approx h/2$ (metres).

For an antenna with a linear current distribution over a perfect ground and $h_e \approx h/2$, r_a is given by [17]

$$r_a = 40 \pi^2 \frac{h^2}{\lambda^2} \text{ (ohms)} \quad (B7)$$

Substituting equation (B7) into equation (B5) and replacing λ by $300/F$ where F is the received frequency in MHz,

$$p_n = \frac{e^2 h^2}{4(2)^2} \times \frac{300^2}{F^2} \times \frac{1}{40\pi^2 h^2} \quad (B8)$$

$$p_n = \frac{14.3e^2}{F^2}$$

Transforming into decibel units:

$$P_n = E_n - 20 \log F + 11.5 \quad (B9)$$

substituting (B9) and (B4) into (B3) and converting E_n from V/m to $\mu\text{V/m}$

$$F_a = E_n - 120 - 20 \log F + 11.5 + 204 - 10 \log b \quad (B10)$$

$$F_a = E_n - 20 \log F + 95.5 - 10 \log b \quad (B11)$$

where

F_a is the effective noise figure of an equivalent lossless antenna
(dB above kT_o),

E_n is the measured rms field strength of the vertical component of the
noise field from a short vertical monopole over a perfect ground (dB
above 1 $\mu\text{V/m}$) in bandwidth b ,

F is the frequency (MHz),

b is the effective receiver noise power bandwidth (Hz).

A P P E N D I X C

Use of the F_a and V_d Data for System Design and Performance Predictions

C.1 USE OF F_a DATA FOR SYSTEM DESIGN

As well as being an internationally accepted way of presenting radio noise data in absolute terms which may be compared with anyone else's measurements regardless of equipment bandwidth, F_a may be used practically in system design work.

The effective antenna noise factor, f_a , is related to the system overall operating noise factor f by the following equation [18]

$$f = f_a - 1 + f_c f_t f_r \quad (C1)$$

where f_c is the noise factor associated with the antenna circuit losses,

f_t is the noise factor associated with the transmission line losses,

f_r is the noise factor of the receiver.

To use this relationship in determining the required receiver noise figure for a system consider the following example. If we assume that there are no antenna or transmission line losses i.e., $f_c = f_t = 1$, the above equation becomes:

$$f = f_a - 1 + f_r \quad (C2)$$

We also assume that the minimum measured external noise $F_a = 20$ dB above kT_{ob} (i.e., $f_a = 100$) for the system bandwidth considered. Thus, for a perfect receiver (i.e., $f_r = 1$) the system noise figure, F^* is 20 dB. Let the criterion for f_r be that its value is such that it will only increase F by 1 dB. Equation (C2) gives a value of $f_r = 27$ ($F_r = 14.3$ dB) for an overall system noise figure, F , of 21 dB ($f = 126$). Any lower receiver noise figure cannot decrease F by more than 1 dB, i.e., a practical system in which the receiver noise figure is 8 dB, will be external noise limited i.e., better than necessary.

If we assume antenna losses of 3 dB and transmission losses of 3 dB i.e., $f_c = f_t = 2$, the equation becomes:

$$f = f_a - 1 + 4 f_r \quad (C3)$$

* F is equal to $10 \log f$.

In this case, for F not to be raised by more than 1 dB (to 21 dB), F_r must not be higher than 8.3 dB ($f_r = 6.8$) for external noise to act as a limiting factor in the communication system design.

C.2 USING F_a AND V_d DATA FOR SYSTEM PERFORMANCE PREDICTIONS

A method of estimating the average power and average envelope voltage of the radio noise environment as a function of location, time and frequency has been presented in this report. Also, the foregoing section told how to find the noise figure required for operating in a given noise level. A method of using this information to provide an estimate of the performance of a communication system operating in the measured radio noise environment is now considered. Spaulding and Disney give a good discussion of this [18]. Further, there are a number of examples of system performance prediction from radio noise measurements in the literature [18, 19, 20, 21, 22].

Since F_a and V_d measurements alone cannot provide sufficient information of a noise process for communication system design work, mathematical modelling must be used. To date, most modelling work has been done for atmospheric noise which is the dominant noise source in the frequency range 30 kHz to 30 MHz. One of the many mathematical models developed for atmospheric noise is called the "Log-Normal" model. As well as modelling atmospheric noise it has been used to model some man-made radio noise [23]. This model will be used here because it has been widely used and accepted and because the model parameters are easily related to the measured quantities V_{rms} and V_d .

A simple example of the use of V_{rms} and V_d data to predict the performance of a noncoherent frequency shift keying (NCFSK) (teletype) system is presented here. Montgomery [19] has shown that the probability of a bit error for this type of signal is given by one-half the probability that the instantaneous noise envelope exceeds the signal level.

In this example, the measured value of V_d was 6.0 dB in the bandwidth of the communication system. This corresponds to a moderately impulsive radio environment. The signal-to-noise ratio (SNR) will be used in the performance prediction. The Log-Normal model for this value of V_d produces the relative Amplitude Probability Distribution (APD) of the envelope of the noise shown by the "MAN-MADE" curve in Figure C1. The APD shows the percent of time each level on the ordinate is exceeded. For example, the V_{rms} level is exceeded about 11% of the time. An 18 dB SNR produces a level exceeded 0.2% of the time. Therefore, the probability of a bit error (p_e) in this case is $1/2 (0.002) = 0.001$ (or 10^{-3}). Similarly, other error rates may be read off the graph.

A second line on the figure marked "GAUSSIAN" is the envelope distribution for gaussian noise with the same V_{rms} value as the other distribution. For the same performance as above, i.e., $p_e = 10^{-3}$, the required SNR for the gaussian noise is 8.0 dB.

This example shows two things, first the system performance, and second, the magnitude of the error that may occur if one assumes a gaussian

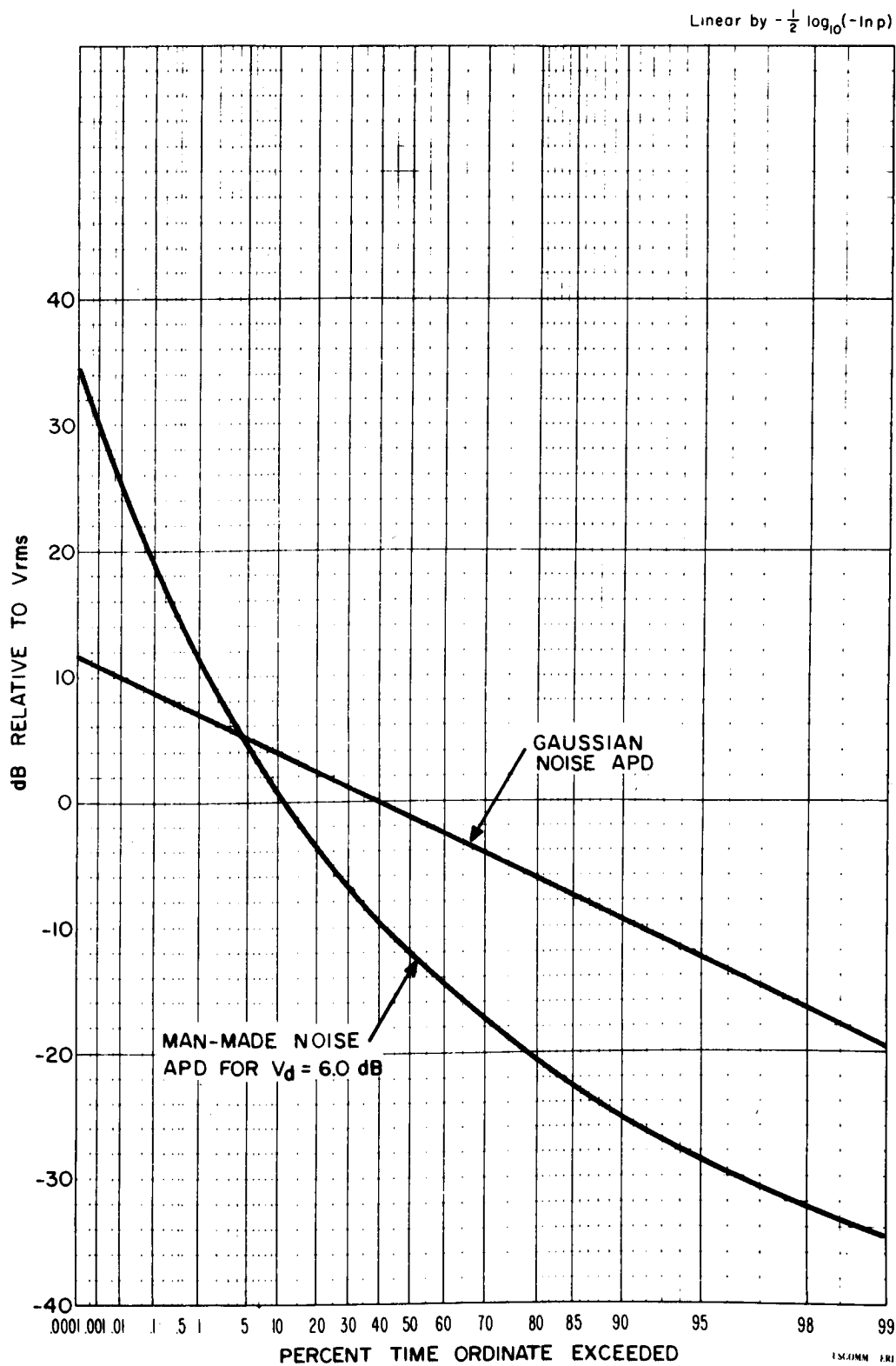


Figure C1. Relative Amplitude Probability Distribution

radio noise environment whereas the real noise environment is moderately impulsive.

There is presently much work being done in the area of voice communication systems. Few voice systems are judged or designed by the intelligibility of speech, instead system performance is usually specified in terms of signal to noise ratio of the received signal. The most common procedure for determining the performance (intelligibility) of a voice channel is by having a trained team to subjectively score the percentage of intelligent speech in a message. Although these methods are repeatable they are very expensive and time consuming. What is needed is an inexpensive and efficient objective evaluation of speech intelligibility that is comparable to the subjective methods. Hartman and a group at the Institute for Telecommunication Science (ITS) laboratories in Boulder Colorado have developed and are testing an objective performance criterion based on linear predictive coding techniques for voice systems [24]. SRI International has recently designed a general radio system performance model for voice and other communication systems, however, the actual definition of successful communication has been left to the user [25]. An important part of this model is the use of the median F_a value and D_u and D_l to define the variation of the noise levels in the short-term. Akima and Spaulding of the ITS laboratories are also presently doing work in the area of simulation models to determine the performance of both voice and digital communication systems [26].

A P P E N D I X D

Blank Forms Required for Survey

1. NOISE DATA Sheet
2. CALIBRATION DATA Sheet
3. SUMMARY NOISE DATA Sheet
4. SEMILOG GRAPH Paper

NOISE DATA

LOCATION _____ SHEET _____
 ANTENNA _____ DATE _____
 RECEIVER _____ TIME _____
 WEATHER _____

	1. FREQ. _____		2. FREQ. _____		3. FREQ. _____	
	Vrms	Vd	Vrms	Vd	Vrms	Vd
ATTN						
MEDIAN						

	4. FREQ. _____		5. FREQ. _____		6. FREQ. _____	
	Vrms	Vd	Vrms	Vd	Vrms	Vd
ATTN						
MEDIAN						

FREQ	PREAMP	NOISE CHARACTERISTIC (S-soft, M-moderate, L-loud)								COMMENTS
		GAL	ATM	BUR	PWR	SRG	CLK	IGN	HSH	
1.										
2.										
3.										
4.										
5.										
6.										

Figure D1. Noise Data

SUMMARY NOISE DATA

LOCATION _____ PARAMETER _____ TIME _____ DATE _____

DATE FREQ (MHZ)															MEDIAN	SIGMA	COMMENTS

Figure D3. Summary Noise Date

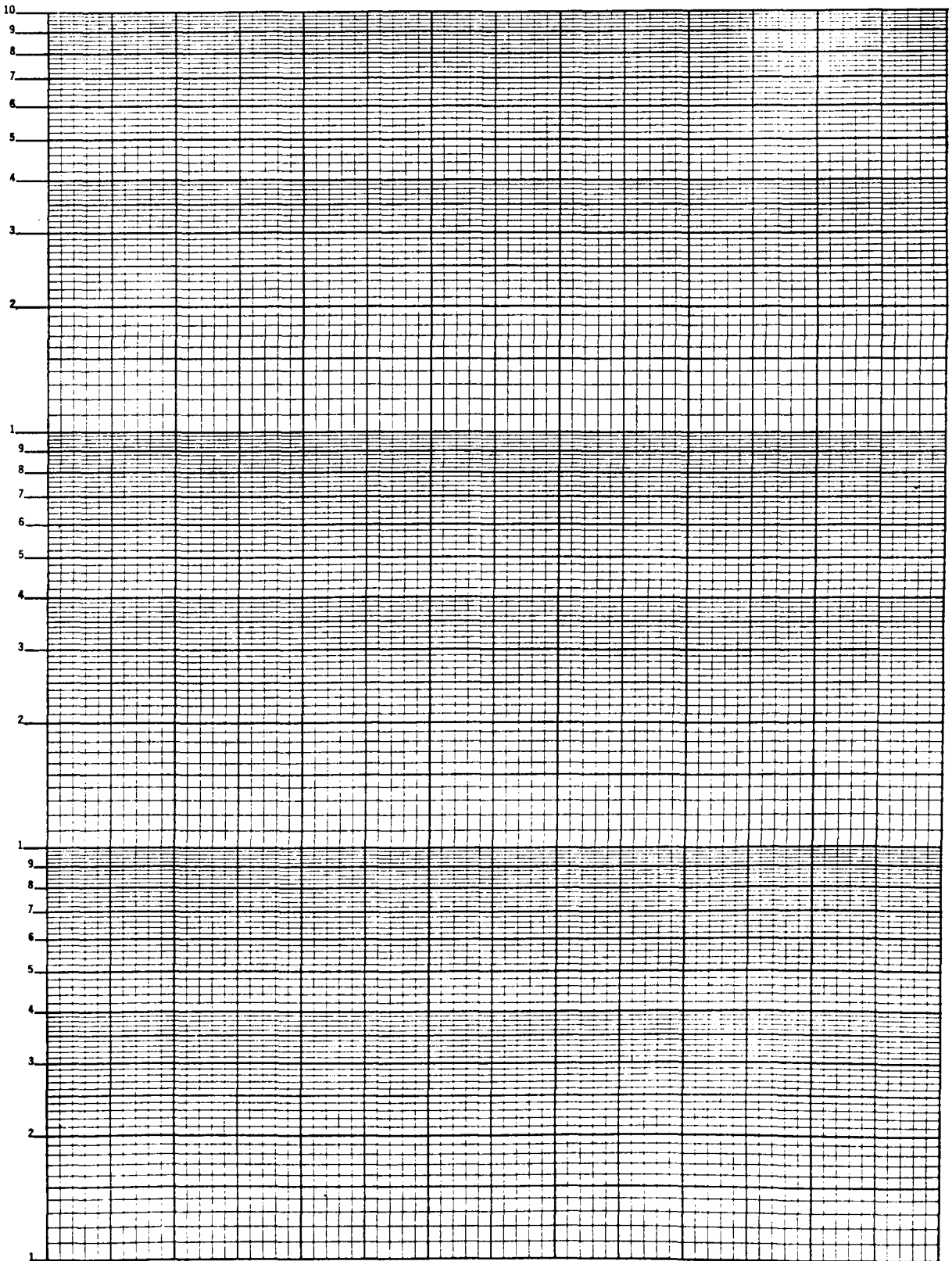


Figure D4. Semilog Graph Paper

CRC DOCUMENT CONTROL DATA

1. ORIGINATOR: Department of Communications/Communications Research Centre
2. DOCUMENT NO: CRC Report No. 1325
3. DOCUMENT DATE: August 1979
4. DOCUMENT TITLE: Radio Noise Survey Procedures for a Communication Site 0.15 - 30 MHz
5. AUTHOR(s): W.R. Lauber and C.J. Pike
6. KEYWORDS: (1) HF
(2) Site
(3) Survey
7. SUBJECT CATEGORY (FIELD & GROUP: COSATI)
- 17 Navigation, Communications, Detection, and Countermeasures
17 02 Communications
8. ABSTRACT:
- This report gives a step-by-step plan for performing a radio noise survey at a communication site. The data obtained in the survey are used to describe the radio noise environment at the site and may be used to see if a good site is deteriorating or a bad site is improving. The general plan allows for some variation, as each site is different, but is strict enough for compatible results. The plan describes how to obtain the measurement data, how to analyze them and how to use them to evaluate the site. It also presents details for future assessment. Finally, there is a section on how to use the basic data for communication system design and system performance prediction.
9. CITATION: _____

EXECUTIVE SUMMARY

DOCUMENT NO: CRC Report No. 1325

TITLE: Radio Noise Survey Procedures for a Communication Site 0.15 – 30 MHz

AUTHOR(S): W.R. Lauber and C.J. Pike

DATE: August 1979

CRC has been making HF radio noise surveys of a number of communication sites across Canada since 1973. In 1977, DND decided to set up a team to perform this task at their sites. CRC assisted in training this team of technicians and an engineer in the background and techniques required for a site survey. This report is based on our experience and the notes used to train this team.

This report describes the step-by-step procedures to determine the radio noise environment of a communication site. The report is written at an engineering level with sufficient references to explain the background of the procedures set forth. The plan describes what measurements to take and where, when and how to take them. The recommended equipment to be used is described as well as the calibration procedures required to ensure the gathering of accurate data. Sections are also included on the analysis of the data, site evaluation, future reassessment and suggestions to maintain and improve site performance. Four appendices are provided to give (1) a detailed measurement procedure (written at a technician level), (2) the theoretical derivation of the F_a equation including the assumptions used, (3) typical uses of the noise measurement data for communication system design and performance predictions and (4) blank forms required for a survey.

There has been interest shown by DND and others for a unified test procedure for radio noise surveys at communication sites. Also, the IEEE EMC radio environments technical committee has used parts of this material in its draft standard on "Recommended Procedures for Measuring the Radio Environment (10 kHz – 10 GHz)".

We are presently modifying these techniques for use at VHF/UHF where, almost always, man-made radio noise dominates the natural noise background of the radio environment. To date, there are no unified procedures to determine the VHF/UHF radio noise environment.

SOMMAIRE À L'INTENTION DE LA DIRECTION

N° DU DOCUMENT: Rapport du CRC N° 1325

TITRE: Procédures sur les bruits radioélectriques dans la bande de 0,15 à 30 MHz pour un emplacement de télécommunications

AUTEUR(S): W.R. Lauber et C.J. Pike

DATE: Août 1979

Depuis 1973, le CRC effectue des sondages sur les bruits radioélectriques HF à un certain nombre d'emplacements de télécommunications au Canada. En 1977, la DN a décidé de mettre sur pied une équipe chargée de s'acquitter de cette tâche à ses emplacements. Le CRC a participé à la formation de cette équipe composée de techniciens et d'un ingénieur et l'a aidé à apprendre les notions et les techniques nécessaires pour mener un sondage à un emplacement. Le présent rapport se fonde sur notre expérience et sur les notes que nous avons employées pour assurer la formation de cette équipe.

Le présent rapport décrit la marche à suivre pour déterminer les bruits radioélectriques présents à un emplacement de télécommunications. Rédigé à l'intention d'ingénieurs, il comporte suffisamment de renvois pour expliquer l'historique des procédures qui y sont décrites. Le plan décrit les mesures à prendre, l'endroit où les prendre, leur fréquence et la façon de les prendre; il décrit aussi le matériel dont l'utilisation est recommandée, de même que les modalités d'étalonnage destinées à assurer la cueillette de données justes. Le rapport comprend également l'analyse des données, l'évaluation de l'emplacement, la réévaluation future et des propositions visant le maintien et l'amélioration de la situation constatée à l'emplacement. Les quatre annexes comprennent: (1) une méthode de mesure détaillée, rédigée à l'intention de techniciens; (2) la dérivation théorique de l'équation F_a , y compris les hypothèses adoptées; (3) les utilisations typiques des données de mesure des bruits en vue de la conception des systèmes de télécommunications et de la prévision de leur performance et (4) un spécimen des formulaires qui seront utilisés au cours des sondages.

La DN et d'autres organismes se sont dits intéressés à ce qu'il y ait une seule méthode d'essai pour les sondages sur les bruits radioélectriques aux emplacements de télécommunications. En outre, le comité technique de l'A.I.I.E.E. sur le milieu radioélectrique et la compatibilité électromagnétique a utilisé des parties du document dans son projet de norme, intitulé "Recommended Procedures for Measuring the Radio Environment (10 kHz - 10 GHz)".

Nous modifions présentement ces techniques en vue de leur utilisation dans les bandes VHF et UHF, où les bruits radioélectriques d'origine humaine dominent presque toujours les bruits naturels du milieu radioélectrique. Jusqu'à maintenant, il n'existe aucune méthode unique visant à déterminer les bruits radioélectriques dans les bandes VHF et UHF.

LAUBER, W.R.
--Radio noise survey procedures
for a communication site...

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