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FINAL REPORT, EVALUATION OF RADIO INTERFERENCE PICK-UP DEVICES AND EXPLANATION OF THE METHODS AND LIMITS OF SPECIFICATION NO. MIL-I-6181B

BUREAU OF AERONAUTICS
TED Project No. ADC EL-559

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INTRODUCTION

TED Project No. ADS EL-559 was established by Bureau of Aeronautics (BUAER) letter, reference (a), for an evaluation of the relative performance characteristics of the various pickup devices used for measurement of radio interference, to provide a basis for more uniform, reliable, and generally useful specifications. The general intent of the project, described in reference (b), was to provide information and support for the working group appointed by the Interference Reduction Panel, Research and Development Board (RDB), for the revision of Specification No. JAN-I-225, reference (c).

Problem details were divided into Phases I and II as follows:

PHASE I

A comparison of the response by the loop-probe and the rod or dipole antennas to each of several types of interference sources should be made. The interference sources and radiators should be chosen so that the nearby electromagnetic fields generated vary in character, some consisting primarily of an electric component, others primarily of a magnetic component. An attempt should be made to duplicate conditions wherein it has been reported possible to have an interference source which will produce high readings on an instrument using a loop-probe pickup and negligible or low readings when using a rod or dipole antenna and vice versa. The interference sources chosen should be typical of equipment installations likely to be used in or around aircraft.

A study should be made to determine the character of the radio interference field to which typical receiver installations are most vulnerable. In particular, an attempt should be made to demonstrate that prohibitive interference may occur in a simulated typical receiver installation due to a field which produces acceptably low readings on a measuring instrument, using either a rod or dipole alone or using a loop-probe antenna alone. Conversely, an attempt should be made to show that a simulated typical receiver installation may not be affected by interference which produces prohibitive readings on measuring instruments using either a rod, dipole or loop-probe antenna alone.

Criticism has been made of the use of the loop-probe antenna in interference measurement on the basis of the close proximity of the probe to the test sample. The argument is that a strong induction field is measured which is not representative of the interference which would exist even a foot or so from the source and that measurements made some distance away give a more integrated effect of localized sources. Therefore, a study should be made to determine the relationship between the interference generated from various typical sources as measured with a small loop-probe antenna held in close proximity and that measured with a larger more sensitive magnetic loop antenna held at a distance of one or two feet. Similarly, for comparison, an attempt should be made to establish the approximate correlation, if any, between the interference measured with a small capacity-probe antenna in close proximity to the test sample and that measured with a rod or dipole antenna held at a distance of one or two feet from various sources of interference.

PHASE II

A comparative evaluation of the advantages and disadvantages of the different pickup devices from a practical usage standpoint should be made. The following factors related to pickup devices should be included in this consideration:

1. Difficulty in prescribing a precise location (distance and orientation) of the pickup antenna relative to a test sample.

2. Criticalness of location relative to test sample.

3. Effect of reflections of the interference from conducting walls and other objects on the pickup device.

4. Ease of, or necessity for, tuning over a broad frequency range.

5. Level of area interference which may be tolerated with each type of pickup device.

6. Ease of manipulation (effect of physical size and bulkiness).

7. Body capacity effects.

8. Extent of standing waves which are developed between the pickup device and the measuring instrument due to impedance mismatch.

Based on the factors above, a comparison should be made of the degree of repeatability of results which can reasonably be expected using each of the pickup devices being considered.

COMPLETED INVESTIGATIONS

The problem details of phase I were investigated and an interim report, reference (d), was issued. It contained the following conclusions and recommendations:

1. Intense radio interference fields can exist which have a large magnetic component without producing an appreciable indication on the Ferris 32A noise meter as used with the rod antenna.

2. Intense radio interference fields can impose a large interference signal on a typical receiver installation when measurements taken with a Ferris meter and a rod antenna indicate little or no interference.

3. Radio interference specification testing in the medium-high frequency (mhf) range should include tests using both the rod antenna and loop-probe. Information concerning the use of pickup devices for testing in the very-high and ultra-high frequency (vhf and uhf) ranges remains to be obtained.

4. Results obtained to date regarding possible correlation of measurements made with small loops at close proximity and larger loops at some distance away indicate that such correlation cannot be made. The major difficulty encountered in correlation of measurements made with such loops was that the gradient of the field was dependent upon the effective radius or length which in turn is dependent upon the geometry of the source of leakage.

5. Additional tests are necessary to determine if it is possible to retain use of small loop-probes at close proximity for the evaluation of radio interference leakages as affecting electronic equipment in the vicinity of the leakage.

Tests, performed to obtain information relative to Phase I, indicated the desirability of including the following additional problem details taken from the interim report:

1. The possibility that measurements made with a 3-inch loop-probe at a distance of 6 or 12 inches from the noise source (magnetic fields in the air surrounding the source or of currents induced in the ground plane) are sensitive enough to detect fields or currents so intense as to disturb a typical receiver installation.

2. The possibility that use of the 3-inch loop-probe at close proximity could be retained by taking two measurements at slightly different distances from the noise source to determine the gradient of the field.

3. If satisfactory measurements cannot be taken with the two above methods, a study should be made of larger loops and how they could be used to make satisfactory measurements.

4. When an AN/PRM-1 noise meter is available for test, its performance in making measurements of the electric and magnetic components of the induction field should be investigated.

Since the interim report was issued, a great deal of work has been done on coordination of radio interference methods and limits used by the various Government services to revise Specification No. JAN-I-225 so that it would be suitable to all the services. The magnitude and complexity of the problem was so great that successful coordination was obtained only between the Air Force and the Bureau of Aeronautics. This coordination was simplified because of the similarity of problems encountered by these services and resulted in the preparation of Specification No. MIL-I-6181B, reference (e). Analyses of the general problems involved in the over-all coordination, and methods and limits used in the new specification are considered to be the final problem details of TED Project No. ADC EL-559.

As a result of work done under this project, a large amount of information has been provided to the Research and Development Board Working Group on Revision of Specification JAN-I-225 and also the the Bureau of Aeronautics and Air Force for the revision of Specification MIL-I-6181. At the present time, full use is not being made of the various means for improving the accuracy of radio interference specification testing. Additional work should be initiated to investigate the possibilities of further minimizing the effect of the remaining sources of inaccuracy.

GENERAL DISCUSSION OF CORRELATION PROBLEMS

The original purpose of this project was to investigate the advantages and disadvantages of various pickup devices in general use to determine those best suited for radio interference measurement. After accumulation of sufficient information from laboratory tests and conferences with representatives from other interested activities, antennas were selected which integrate the field at 1 foot or more from the source, and were considered as being best suited for radio interference measurements.

Adoption of such antennas as the rod, resonant dipole, discone, and large loops, and dropping of the small sized loop and capacity pickup devices, solves the problem of over suppression of confined radio interference fields which, although highly intense over a small volume of space, attenuate rapidly with distance and do not constitute a source of interference to equipment placed a reasonable distance away. However, the use of the large antennas poses other difficulties such as high sensitivity to ambient interference, bulky size, sensitivity to reflections, differences in effective height, and need for tuning at each frequency. Also, difficulties inherent in presently available radio interference and field intensity meters include such things as variations in bandwidth, pulse response, and input impedance, in addition to the more usual difficulties of inaccurate calibration, instability, and the numerous other defects to which electronic equipment is subject. The above mentioned variables all contribute to the lack of agreement usually encountered with radio interference measurements made in different laboratories. When added to this is the fact that the various government services use different test set-ups, radio interference limits, measuring equipment, and in some cases a totally different environment, the task of making radio interference measurements uniform and reliable is seen to be extremely difficult.

After agreement on the general type of pick-up device had been reached, attention was concentrated on the elimination or control of the variables previously mentioned to make possible a coordinated government specification.

The problem may be divided into three parts as follows:

1. Radio interferences field - To control the radio interference field so that an interference source which is set up in different laboratories produces the same general field intensity and contour is of primary importance if similar measurements are to be obtained.

2. Antenna systems - The amount of energy which is transferred from the field to the input terminals of the interference meter is a function of the antenna length, impedance, location, and orientation. The energy also may vary with the type of transmission line used, if any, and the input impedance of the meter.

3. Correlation of meters - Various discrepancies arise between the final output readings obtained with the various equipments when the signal at the input terminals is the same.

Meters which are presently available for radio interference measurements in most cases give good agreement when c-w signals are being measured. Inaccuracies which arise during c-w measurements may be eliminated only by improving the meter design and therefore are not properly considered in this report. On the other hand, although widely divergent results are obtained with broadband interference measurements, they are subject to corrections which greatly improve the correlation between meters. The means for obtaining these corrections and their application and meaning constitute the final part of the problem.

In the body of the report which follows, the project problem details which were not covered by the interim report will first be dealt with and then the over-all problem involving coordination of specifications as described above will be undertaken.

PROJECT PROBLEM DETAILS

The additional problem details which were suggested in the interim report, reference (d), are discussed in the order in which they appear in the report as follows:

1. The sensitivity of a typically installed receiver to interference produced by a high current, low voltage source was in many cases much greater than that of the three-inch loop-probe, and it was impossible to make satisfactory measurements with the small loop at distances of 6 inches from the interference source.

2. Sensitivity of the 3-inch loop was too low to give satisfactory measurements of the field gradient. Removal of the loop from the immediate vicinity of the signal source reduced pick-up to such an extent that signals from sources of moderate intensity could not be detected.

3. Satisfactory methods have been found for taking measurements of radio interference with large loop antennas, but the required equipment is not generally available. In addition, an interim agreement has been reached among the interested services to shelve such measurements until greater familiarity is obtained with the latest proposals on measurements taken with rod and dipole antennas. If the number of cases of low impedance interference sources which are met with in actual practice warrant the use of loop antennas for their detection and measurement, the incorporation of these antenna into specifications will then be undertaken.

4. The AN/PRM-1 noise meter has been tested and found satisfactory for measuring the electric and magnetic components of the induction field. This meter makes possible greatly increased accuracy of radio interference measurements and represents a marked improvement over previous commercially available meters.

The problem details of Phase II involve the comparative evaluation of the advantages and disadvantages of the various pick-up devices from a practical standpoint. Since a final decision has been reached for purposes of inter-service specification correlation in favor of the larger size pick-up devices, an extensive evaluation is no longer required. However, with respect to practical measurements, the loop-probe was much easier to use and provided better repeatability of measurements. Its major disadvantage lies in the fact that it was highly sensitive to fields confined to a small volume which therefore did not constitute a potential source of interference to electronic equipment.

METHODS FOR IMPROVING THE ACCURACY OF RADIO INTERFERENCE MEASUREMENTS

THE RADIO INTERFERENCE FIELD

Control of the radio interference field so that an interference source which is set up in different laboratories produces the same general field intensity and contour is required if accurate and repeatable measurements are to be obtained. Comparatively simple procedures are required for equipments which may be tested in open space far from other noise sources and reflecting surfaces. The majority of such equipments are vehicles; the general procedure followed in the latest specifications is to provide diagrams indicating the exact location and orientation of the radio interference pick-up antenna with respect to each particular type of vehicle. While this method is satisfactory for self-contained, wheeled and motorized equipment, it is not at all satisfactory for testing complex airborne equipment which may require several different sources of power and a large amount of supplemental laboratory gear for correct operation.

In most cases, when equipment is to be installed in aircraft it is tested in the laboratory or the place of manufacture. Radio interference levels in such areas are almost always too high to permit accurate measurements without a shielded enclosure. Aircraft radio interference specifications, such as reference (e), permit the use of shielded rooms and provide diagrams to show the desired location of the equipment under test and to show the position and orientation of the pick-up antenna. Circuit diagrams are also provided showing installation details of standard impedance networks in all power leads. This permits accurate and repeatable measurements of conducted interference to be made and also controls the amount of radiated interference in such leads. In this manner, the field intensity, its contour, and consequently its effect on the pick-up antenna is controlled as much as possible; however, it must be realized that variables which prevent agreement of inter-laboratory measurements still exist. These variables include such things as differences in shielded room dimensions, location of metallic bodies within the room, and the location and number of observers. In the higher frequency ranges, very small changes in physical relationships can produce large changes in measurements. This effect is minimized by recording only the maximum readings obtained when the observer moves about in the shielded enclosure.

From the foregoing discussion it is obvious that the methods used for obtaining repeatable signals from the radio interference field are not all that can be desired and further effort should be expended on their improvement in the future.

ANTENNA SYSTEMS FOR RADIO INTERFERENCE MEASUREMENTS

In the frequency range 0.15 to 20 mc, radiating elements, pick-up antennas and distances, generally used for radiated radio interference measurements, are small compared to wavelength. The amount of energy transferred from field to antenna depends on the nature of the signal source and the type of receiving antenna used. For instance, if the radiating interference source is a single, small closed loop of wire, a great deal of current can flow without developing much voltage across the loop. Consequently, a large magnetic component is developed in the induction field in conjunction with a comparatively small electric component. To extract a large amount of energy from such a field, a similar loop antenna, correctly matched to a receiver, should be used as the pick-up device to provide what may be compared to a good impedance match in ordinary circuit theory. If a short rod antenna, sensitive to the electric component of the field, were used as the pick-up device very little energy transfer would result and a situation comparable to a condition of impedance mismatch would exist. When a short rod antenna is the signal source, a large voltage can be developed on the rod, but with very little current flow. Consequently, the field developed is composed of a large electric component and a small magnetic component. In this case, another rod used as a pick-up device would indicate the presence of an intense field, whereas, a loop antenna would give very little indication. Typical radio interference sources in aircraft include the extreme cases described and all other variations. In general, the ratio of the electric to the magnetic components surrounding an unshielded lead will vary directly as the impedance of the load terminating the lead, and the apparent impedance presented to the various pick-up antennas will vary in the same manner. This statement applies to radial and tangential field components as contrasted with the more usual concept of wave impedance encountered in shielding theory, which applies only to the components tangential to the line of propagation.

Although it would be desirable to require the measurement of both the electric and magnetic components of the interference field, it is felt at the present time that such requirements would make specification testing excessively complex. Experience has indicated that aircraft electronic equipments, which operate in the lower frequency ranges (0.15 to 20 mc), are more sensitive to the electric field because of the unshielded high impedance antenna lead-in, which has been in general use. Present practice is to control the electric field by radio interference measurements. This is done by utilizing a 41-inch rod antenna and treating any difficulties arising from equipments generating strong magnetic fields as special cases which require particular attention when the equipment is installed in the plane. Reference (e) requires that all equipment used with antennas be designed for use with a shielded antenna lead. If and when the unshielded antenna lead is completely eliminated from use in aircraft, a review of present methods and limits in the frequency range 0.15 to 20 mc will be required. Radio interference meters using the 41-inch rod antenna are so constructed and calibrated that they read directly the microvolts which are induced in the antenna by the interference field.

A different situation exists for measurements made in the vhf and uhf ranges. Standing waves are usually present and interference fields, preponderantly electric or magnetic in nature, are seldom found at distances of 1 foot or greater. In addition, the antennas which are used are sensitive to a wide range of field impedances. For instance, a resonant dipole antenna has good sensitivity to low impedance (magnetic) fields near its center and high impedance (electric) fields near its ends. Other antennas, such as the discone, have a completely different distribution of impedance, polarization, physical size, and contour. Obviously, comparison of the effect of a given interference field upon the dipole and the same field on a discone can only be made in a very general manner. For this reason, in reference (e) radio interference limits are derived expressly for each particular antenna that is to be used, and exact correlation between different types of antennas is not expected. Practically all radio interference and field intensity instruments used in this frequency range are equipped with dipole antennas, and because it is the simplest antenna, with respect to determination of effective height and impedance, it has been taken as the standard antenna for the setting of radio interference limits. This means that if limits are to be derived for another type of antenna, comparative readings should be made with the new antenna placed in a radio interference field previously calibrated with a resonant dipole. Care must be taken that the antennas be located the same distance from the source and that the distance is that called for in the specification to be used. The antenna should also be oriented in the manner in which they are to be used, and the intensity of the field should be adjusted to induce a voltage in the dipole equal to the specification limit for which the correlation is made. If the polarization of the antennas being compared is different, the polarization of the radiating source should be arranged to be midway. The correlation should be made with different sources of signal and an average taken of the results.

Assuming that limits have been derived in terms of microvolts induced in a dipole antenna, it now becomes necessary to relate the limit to an actual reading observed on an interference meter coupled to the antenna. The portion of the antenna induced voltage appearing across the input impedance of the meter is a function of the antenna impedance and the input impedance, assuming that any cable used is correctly terminated at the receiver. Since commercially available meters have different input impedances, the input voltage which corresponds to a given limit in microvolts induced in the antenna will be different for the various meters. For this reason, standard limits which apply to all meters may only be expressed in terms of voltage induced in the antenna. However, the limits may be broken down into input microvolt limits derived expressly for each type of meter, as in reference (e). The means for obtaining the limits of reference (e) and specific examples of the computations involved are given in the section on, "Derivation of Specification No. MIL-I-6181B Limits."

CORRELATION OF METERS

While minor discrepancies are found in the correlation of c-w measurements made with the various types of field intensity meters, results are generally satisfactory and far exceed the accuracy of correlation of broadband interference measurements. Consideration is given here only to the causes of inaccuracy in broadband correlations.

Differences in Bandwidth

For the purposes of reference (e) and this report, a broadband interference is considered to be impulsive in nature, and the energy which such interference injects into the input circuits of a receiver is directly proportional to the receivers average bandwidth. This is not strictly true for such types of interference as commutator noise or fluorescent lights; however, tests such as described in reference (f) indicate that reasonably good correlation is obtained using this assumption. Impulse type interference sources emit energy which is spread over a comparatively large frequency spectrum, and the receiver samples a portion of this spectrum in the vicinity of the frequency to which it is tuned.

Recently a number of impulse generators which simulate impulse interference have been developed especially for improving the accuracy of measurements of broadband radio interference. A good example is the Purdue Impulse Generator. It was developed at Purdue University under the auspices of the Signal Corps and is now available commercially as Impulse Generator IG-102, manufactured by Empire Devices Incorporated, Bayside, New York. The output of the IG-102 consists of repetitive impulses, similar to impulses obtained from ignition interference, having a maximum amplitude of approximately 180 volts and a duration of 0.0005 microseconds. The repetition rate may be varied between 2.5 and 2500 IPS. In contrast to ignition interference, which has a large energy content in the mhf and lower ranges with a rapid decrease in the vhf range, the energy content of the signal generator impulse is constant from audio frequencies up to 1000 mc. This means that if the signal were applied to the input terminals of a constant bandwidth receiver, the same amplitude output signal would result regardless of what frequency the receiver was tuned to between audio frequencies and 1000 mc, assuming of course that all other possible variables such as input impedance and gain were held constant. A simplified idea of what takes place may be obtained by considering the events which would occur if the receiver were a single stage r-f amplifier resonant at some frequency below 1000 mc. (To avoid confusion, the signal emitted by interference sources or generators will be referred to as impulses, and the resulting receiver output signal will be referred to as pulses.) The duration of the impulse being only 0.0005 microseconds would, in general, be only a small fraction of the time required for a single cycle of oscillation of the amplifier. Its application would have the effect of suddenly charging the condenser of the tuned r-f circuit to a value depending directly on the energy available in the charging pulse. The circuit will now proceed to oscillate back and forth until all the electrical energy has dissipated in the resistance of the circuit. For a given amount of reactance, if the resistance is high, the Q is low and the energy will be dissipated in a comparatively short interval; whereas, if the resistance is low, the Q is high and the circuit will oscillate for a comparatively long period of time. Since the bandwidth of the circuit is inversely proportional to the Q, obviously the duration of the oscillations will become greater for decreases in bandwidth and vice versa. If the initial pulse is now considered from the viewpoint of its component Fourier harmonic frequencies, it can be shown that the only portion of the pulse energy which contributes to the oscillations is contained in those harmonics which lie within the pass band of the amplifier.

Increasing or decreasing the bandwidth will include a larger or smaller number of Fourier harmonics. This increase or decrease in the available energy content results in a corresponding increase or decrease in the peak amplitude of the amplifier output signal. If the signal is now fed to a suitable detector which reproduces the envelope of the r-f oscillations, the output pulse has a peak amplitude directly proportional and a duration inversely proportional to the amplifier bandwidth. The duration and shape of the pulse are a direct result of how long the oscillations last in the r-f amplifier, and they have no relationship to the duration and shape of the original interference impulse which injected the energy into the amplifier. The output pulse obtained with ignition interference would be the same size and shape as that obtained with the IG-102 Impulse Generator or any other source of impulse noise provided only that the source injects the same initial amount of energy into the r-f amplifier. Thus the original interference impulse may be any of an infinite variety of shapes and amplitudes and still have the same ability to cause radio interference at a particular frequency.

The preceding discussion assumes that the bandwidth of the measuring instrument in cycles per second is larger than the impulse repetition rate in impulses per second for the following reasons:

Assuming a bandwidth of 5 kc, which is of the order of noise meter bandwidths in the 0.15 to 20 mc range, the output pulse duration would be approximately 1/5000 second. Therefore, the effects of each individual impulse will disappear in 1/5000 second and the receiver will be in a quiescent state before the reception of each succeeding impulse; provided the repetition rate is less than 5000 per second. This means that each impulse is treated individually, and if they are all the same amplitude the output pulses will also maintain a constant amplitude. However, if the repetition rate were raised to greater than 5000 per second, succeeding impulses would strike the receiver while it still was in oscillation and the output pulse amplitude would become random.

These events describe what essentially occurs when impulse interference is picked up by a radio receiver or interference meter. Measurements may be made by the substitution method by using such meters as the PRM-14 which has a small impulse generator incorporated within itself. This permits easy measurement of broadband interference, but requires knowledge of the bandwidth to allow c-w measurements to be made. On the other hand, if the instrument is similar to the PRM-1 which utilizes the internal random noise generator, then c-w measurements are made directly but the broadband measurements require knowledge of the bandwidth. An external impulse generator is highly useful in plotting the noise-bandwidth in this case. By definition, the rms sine wave input microvolts required to produce a sine wave second detector peak amplitude equal to that produced by an impulse signal is equal to the intensity of the impulse in microvolts per unit bandwidth times the bandwidth of the receiver in the same units. For example, if a

10-microvolt per kilocycle bandwidth signal were applied to a meter having a bandwidth of 2 kilocycles, a pulse would appear at the second detector with a peak amplitude equal to that of the sine wave which would appear at the second detector if a 20 microvolt rms sine wave were applied. Bandwidths may be measured approximately with sine wave signal generators by determining the frequencies at which the voltage at the second detector is down 6 db on each side of the center frequency. Present practice is to measure the bandwidths of the most accurate meters available with impulse generators, and then make comparative measurements of interference sources to obtain correction factors for the less accurate meters. A description of the procedures is given in the following section.

DERIVATION OF SPECIFICATION NO. MIL-I-6181B LIMITS

ROD ANTENNA LIMITS

Standard broadband radio interference limits for use with the 41-inch rod antenna as derived in reference (e) are shown in figure 1.

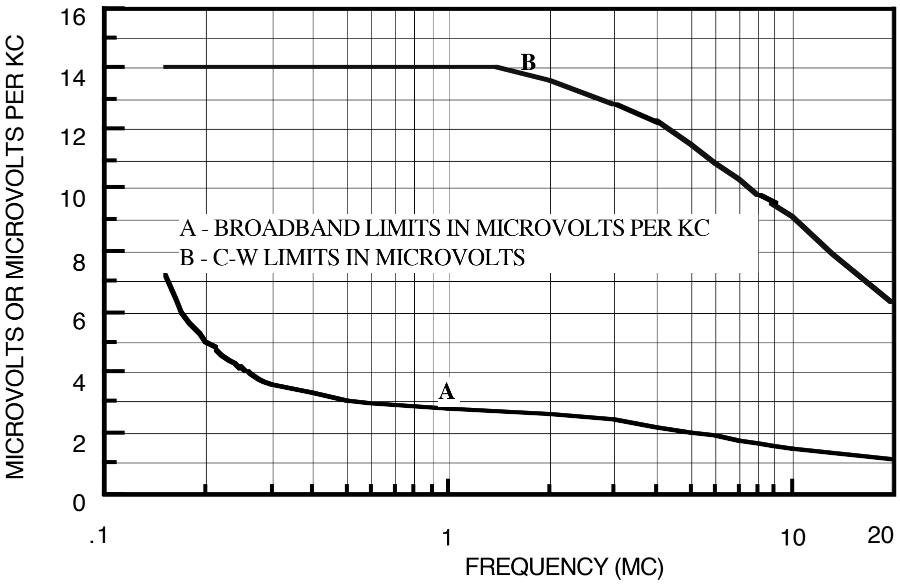


FIGURE 1 - Standard Limits for Signals Induced in a 41-Inch Rod Antenna

These limits were decided upon as a result of tests made on a BC-384Q receiver installed in a shielded room. A 24-inch lead-in and a 12-foot straight wire antenna outside the shielded room were used to simulate an aircraft set-up. Various types of radio interference sources such as d-c motors, poorly shielded dynamotor cables, an adjustable output ignition source, etc., were installed at a distance of 1 foot from the lead-in. At those frequencies where interference sources happened to produce an interference signal which was slightly above the background of the BC-348Q, a measurement was made with an AN/PRM-1 in conjunction with its rod antenna. The rod was located 1 foot from the noise source, and the resultant measurement was taken as an approximation of the desired radio interference limit. Results of the tests are shown in Figure 2. Figure 3 also gives background readings of the AN/PRM-1 which represent the lowest limits which were measurable with that meter.

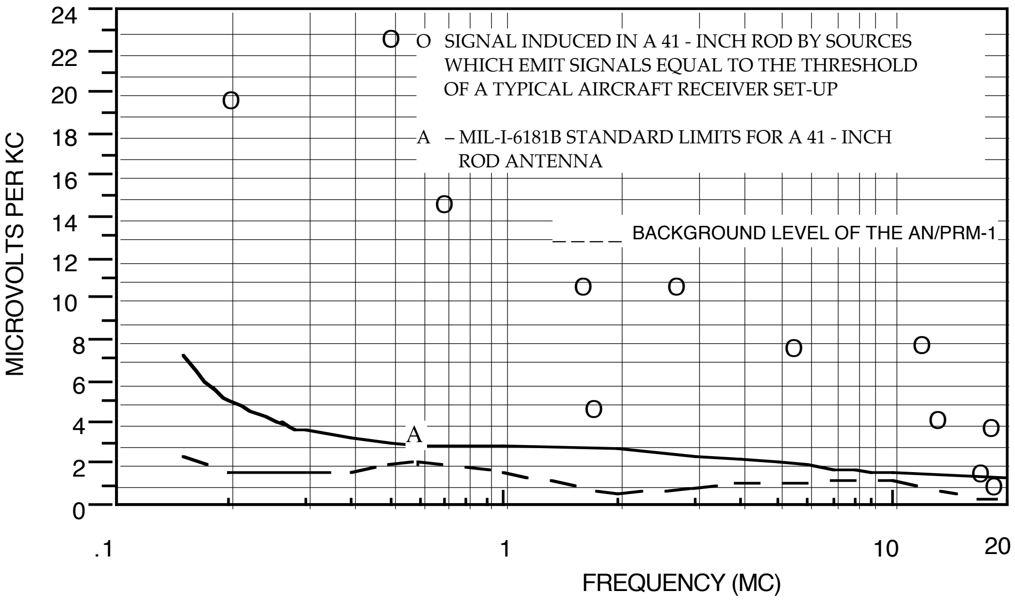


FIGURE 2 - Test Results for Determining Broadband Electric Field Limits

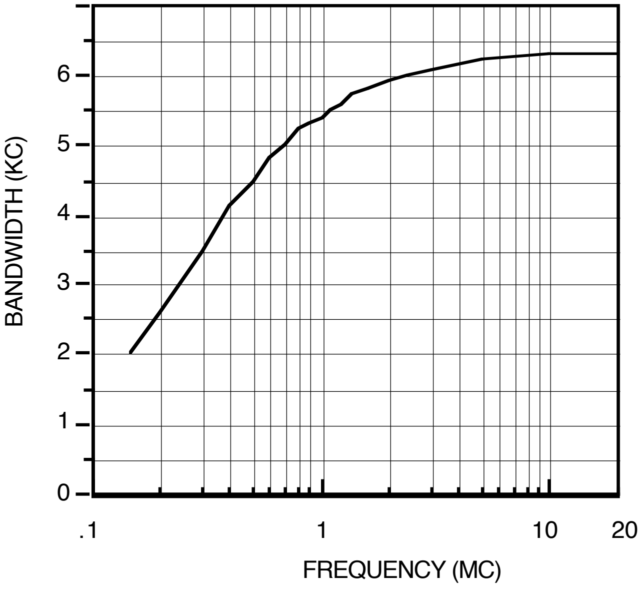


FIGURE 3 - Average AN/PRM-1 Bandwidth Curve

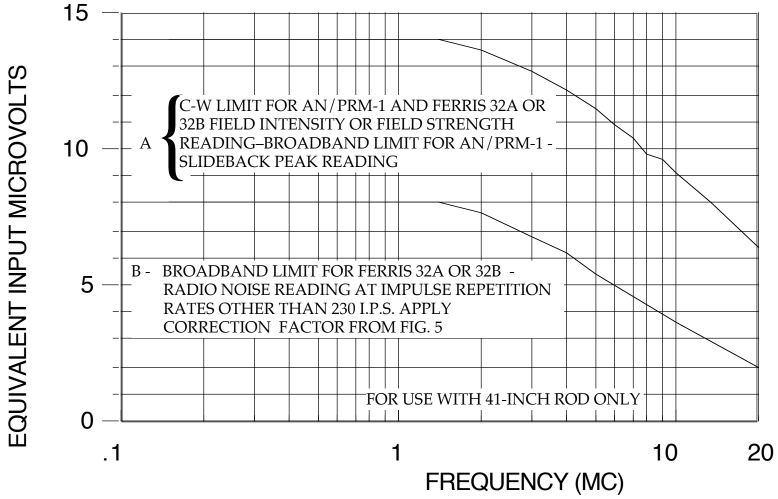


FIGURE 4 - Simplified Limits for the AN/PRM-1 and Ferris Meter

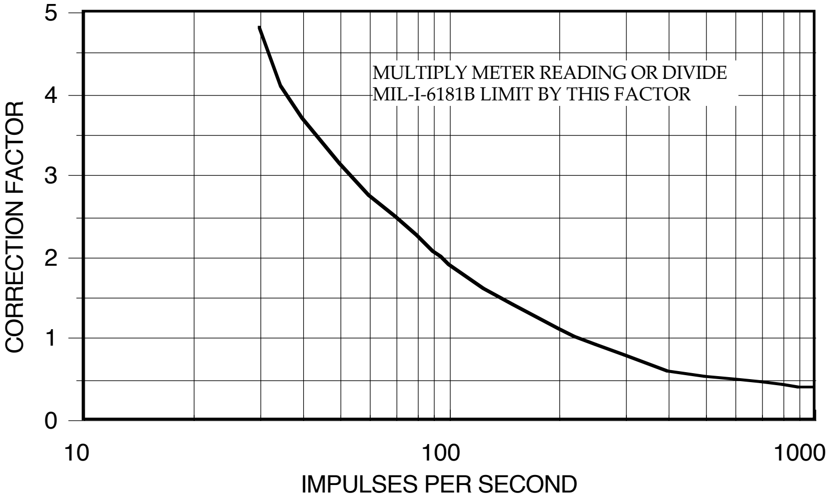


FIGURE 5 - Ferris Meter Impulse Repetition Rate Correction Factor

Reports have been received that some of the meters have an unusually high background level, but this can generally be corrected by selecting a 1R5 mixer tube with low noise characteristics. Figure 3 gives the bandwidth of the AN/PRM-1 as measured with the IG-102 impulse generator. The input microvolt limits of Figure 4 (curve A) which apply specifically to the AN/PRM-1 can be found by multiplying the standard limits of Figure 1 (curve A) by the bandwidths of Figure 3. This simple relationship is due to the meter being calibrated so that the microvolts induced in the 41-inch rod antenna are read directly by the meter. Figure 4 also gives c-w limits for the AN/PRM-1. These limits are numerically equal to the broadband input microvolt limits; the only difference is that they are to be read in the "Field Intensity" position rather than in the "Peak" position.

The c-w limits were agreed upon as representing desirable limits for c-w signals in aircraft and also as providing some simplification in representation of the limits. Curve B of Figure 4 gives the broadband input microvolt limits for Ferris Meter 32A or 32B. These limits were found by setting up a field with an adjustable noise source so that the standard limits of reference (d) were produced as measured with the AN/PRM-1; the AN/PRM-1 was then replaced by the Ferris Meter and the reading obtained was recorded as the Ferris Meter broadband limit. Unfortunately, peak measurements cannot be made with with the Ferris Meter so that the limit obtained this way is only good for the pulse repetition rate at which the test was made. For this reason, figure 5 is provided so that corrections may be made for various pulse repetition rates. If the repetition rate is unknown, estimates may be made through oscilloscopic observation, listening tests, etc.; but this becomes particularly difficult when the interference consists of signals from two or more sources.

Evidently, in a great many cases the use of a meter incapable of peak measurements will involve expenditure of a great deal of extra work and time. Since no problem of correlation exists for c-w measurements, the c-w limit for the AN/PRM-1 applies equally to the Ferris Meter. In addition, the standard limit curve for c-w microvolts induced in a 41-inch rod antenna, curve B figure 1, is exactly the same as the specified limit of curve A figure 4, because the meters are calibrated with a dummy antenna to read the antenna induced microvolts.

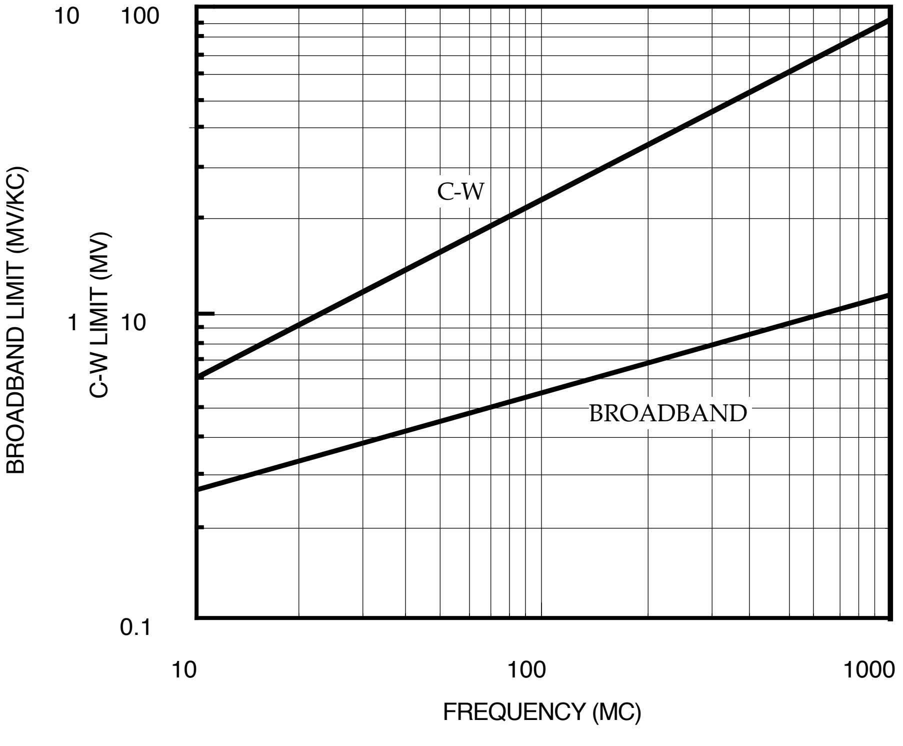


FIGURE 6 - Standard Limits for Signals Induced in a Resonant Dipole Antenna

DIPOLE ANTENNA LIMITS

Standard broadband radio interference limits as derived for the dipole antenna are shown in Figure 6. These limits represent the maximum allowable open circuit voltages which may be induced in a resonant dipole by any broadband radio interference source under test. The actual levels shown were determined by adjusting an interference source to provide a level of interference just equal to the old limits of Specification No. MIL-I-6181, as read on the least sensitive meter in use, and then measuring the interference with a meter known bandwidth and capable of peak measurements. The voltages measured across the input terminals of the meter were used to calculate the antenna induced voltage with the following formula:

$$\text{Antenna Induced Voltage (uv/kc or uv)} = \text{Input terminal Voltage (uv/kc or uv)} \times \left(1 + \frac{72}{\text{meter input impedance}}\right)$$

This formula may be used for either broadband or c-w calculations. Input terminal voltage in equivalent microvolts input is equal to the actual meter reading times whatever factors (if any) required by the instrument handbook to find the voltage across the input terminals. This result may now be converted to input terminal voltage in terms of uv/kc by dividing by the bandwidth if the meter reading was a slide-back peak measurement. Examples of actual calculations for the Measurements 58, TS-587, and AN/URM-17 are given in this report under the section, "Broadband and C-W Calculations For Dipole Antennas." Methods used for calculation with the AN/URM-38 are contained in reference (g). Although broadband interference measurements are not required in reference (e) above 150 megacycles, complete information is provided at the higher frequencies for possible future reference. At the present time, simplified limits are given for each meter in general use. It is felt that in the future when improved equipments are in extensive use and there is better understanding of the methods described herein, the radio interference limits should be stated only in terms of the standard limits for each acceptable antenna; then, no mention need be made in specifications of particular meters or their limits.

Pulsed c-w signals, as emitted by radar transmitters, are not considered to be broadband interference, and limits for this type of signal should be equal to or closely associated with the c-w limits; however, the peak measurements should be made to eliminate pulse repetition rate as a variable. It will be observed that all calculations assume a dipole antenna impedance of 72 ohms, which will result in inaccuracies when the dipole impedance departs from this value. However, this will result mainly in an inaccurate calculation of the antenna induced microvolts but will have a much smaller affect on the actual correlation of meters. In other words, the relative ability of the various meters to impose the same restrictions in the radio interference specification testing of electrical or electronic equipment will remain essentially the same. Variations of antenna impedance between 20 and 100 ohms produce maximum inaccuracies in meter correlation of less than 10 percent.

BROADBAND AND C-W CALCULATIONS FOR DIPOLE ANTENNAS

TS-587 Broadband Calculations

Let us assume that broadband radio interference tests have been made using the high frequency tuning head (RF-37/U) with the following conditions and results:

Frequency	150	mc
Actual Meter Reading (Peak)	47	uv
HF Microvolt Calibration (Enc. A, TS-587 Handbook)	2	
Bandwidth in Kilocycles (Figure 7)	306	kc
Input Impedance	95	ohms

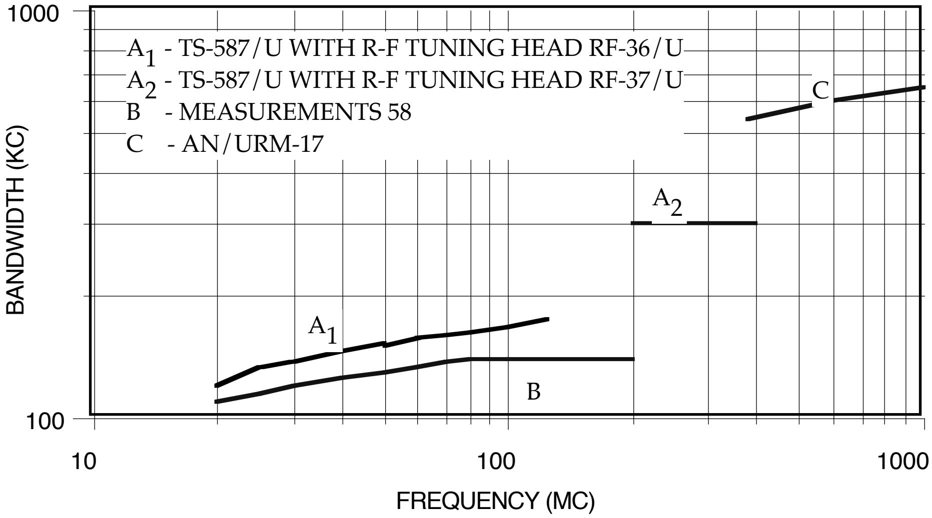
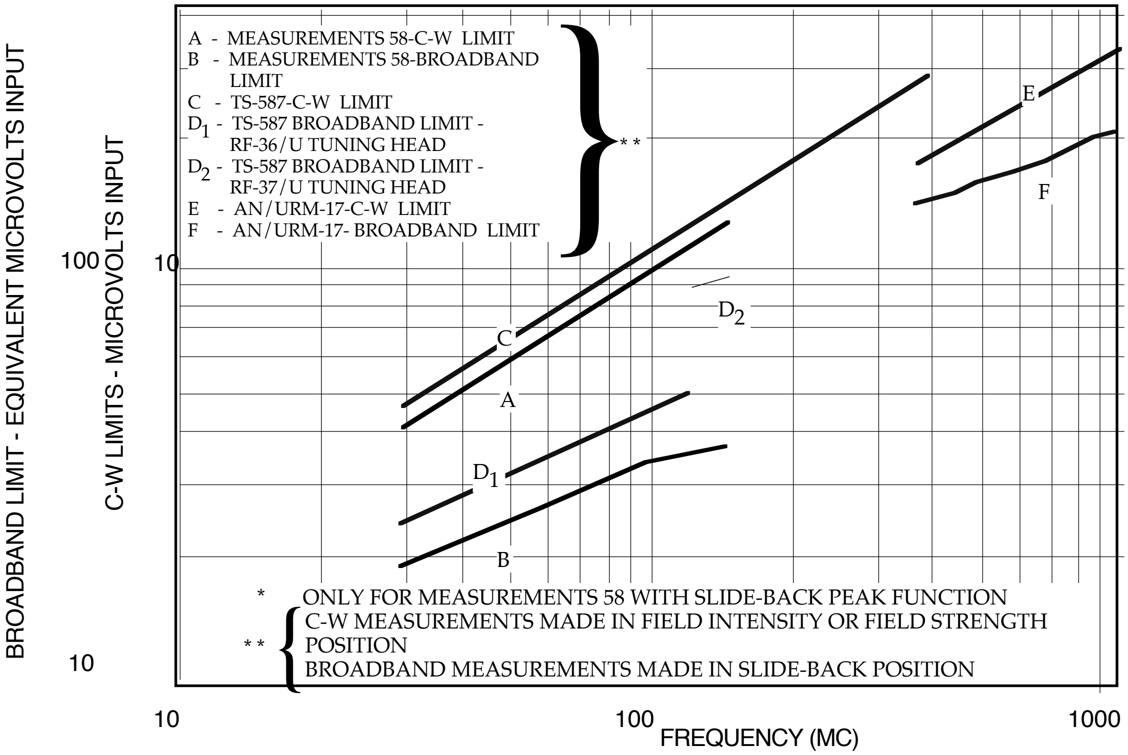


FIGURE 7 - Average Bandwidth Curves for the TS-587, Measurements 58, and AN/URM-17



* ONLY FOR MEASUREMENTS 58 WITH SLIDE-BACK PEAK FUNCTION

* * C-W MEASUREMENTS MADE IN FIELD INTENSITY OR FIELD STRENGTH POSITION
BROADBAND MEASUREMENTS MADE IN SLIDE-BACK POSITION

FIGURE 8 - Simplified Limits for the TS-587, Measurements 58*, and AN/URM-17

The HF microvolt calibration is a correction factor which changes the actual meter reading into the corrected microvolts existing across the input terminals of the receiver. The peak microvolts may be changed to microvolts per kilocycle by dividing by the bandwidth. Therefore:

Equivalent Input Microvolts = 47 x 2 = 94

and

$$\text{Antenna Induced Voltage (uv/kc)} = \frac{94}{306} \times \left(1 + \frac{72}{95}\right) = 0.54$$

The intensity of the interference is found to be just equal to the limits of reference (f) in either the input microvolt limit for the TS-587 (curve A, figure 8) or the antenna induced microvolt limit of figure 6. If measurements are now made with another TS-587 having a totally different and unknown bandwidth, the results will be incorrect to an extent depending on the amount of divergence (from the bandwidth of figure 7). While this is admittedly incorrect, it is the method now used with reference (e) and represents a substantial improvement in accuracy over methods previously used in which no correction at all was made for bandwidth. The reason for using this system was to provide a simple limit for each meter used by personnel unfamiliar with the technical difficulties. Future specifications should give broadband radio interference limits only in terms of the standard limits, as in figure 6, so that the measurements will require the knowledge of bandwidth and that the maximum possible accuracy of measurement may be attained.

TS-587 C-W Calculations

Conditions and results of test are assumed as follows:

Frequency	150	mc
Actual Meter Reading (Field Strength Position)	6.5	uv
HF Microvolt Calibration (Encl. A, TS-587 Handbook)	2	
Input Impedance	95	ohms

Input Microvolts = 2 x 6.5 = 13

and

$$\text{Antenna Induced Voltage (cw uv)} = 13 \times \left(1 + \frac{72}{95}\right) = 22.9$$

In the above case note that the signal intensity is slightly less than the c-w limits of figure 6 and curve C, figure 8. Also, if the antenna induced microvolts were divided by the antenna effective height or $\frac{\lambda}{\pi}$, it would be converted into microvolts per meter and would give the same answer that would be obtained if the input terminal microvolts had been multiplied correctly by the factor of Figure 4 and 5 in the TS-587 handbook. This, of course, applies only to the frequency range in which the dipole is resonant.

Measurements 58 Broadband Calculations

Conditions and results of test are assumed as follows:

Frequency	150	mc
Actual Meter Reading (Slide Back Peak Position)	19	uv
Actual Meter Reading (Quasi-Peak)	4.3	uv
Bandwidth in Kilocycles (Figure 7)	140	kc
Scale Factor	2	
Impulse Rate of Interference	1000	pps
Input Impedance	72	ohms

The quasi-peak reading is obtained with the panel switch set to the "Peak" position, but this does not give a true peak reading. The peak reading refers to measurements made with a slide-back peak reading function which may be added to the Measurements 58 and which gives the same reading for all repetition rates. Some meters do not have sufficient gain on the high frequency bands and require a scale multiplying factor. Calculations for meters having a slide-back peak reading function are made as follows:

Equivalent Input Microvolts = 19 x 2 = 38

and

$$\text{Antenna Induced Voltage (uv/kc)} = \frac{38}{140} \times \left(1 + \frac{72}{72}\right) = 0.54$$

It is observed that the interference, as calculated, is equal to the broadband limits of figure 6 and curve 6, figure 8. The calculations as shown apply only to those Measurements 58 meters which are calibrated to read the input microvolts. There is some confusion here because in the past these meters have been calibrated to read the signal existing across the meter input terminals, but at present they are calibrated to read the antenna induced voltage. If the network used for calibration contains an 83-ohm resistor, the meter is calibrated to read input microvolts; whereas, if it contains a 50-ohm resistor the meter will read antenna induced microvolts. Results which are calculated as above must further be divided by a factor of 2 for meters which read antenna induced microvolts.

<u>Calculations for Meters Which do not Have the Slide-Back Peak Function</u>

The pulse repetition rate correction factor is 0.7, as obtained from figure 9.

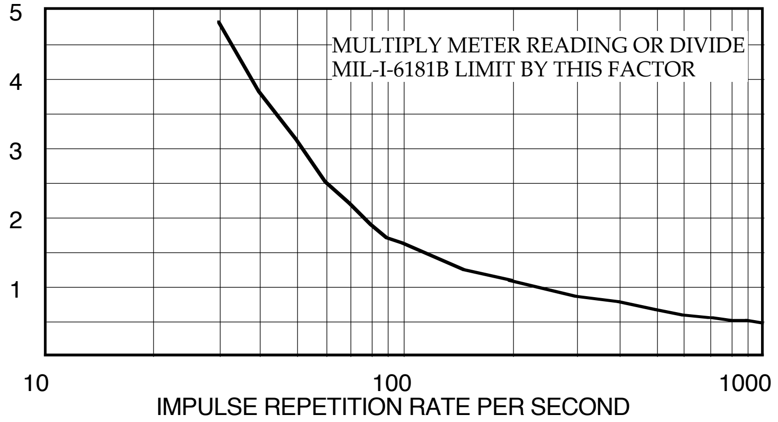


FIGURE 9 - Measurements 58 Impulse Repetition Rate Correction Factor

Equivalent Input Microvolts = 4.3 x 2 x 0.7 = 6

Comparison with the limits of curve A_2, figure 10 shows this result to be equal to that limit. This last system of measurement is the least reliable and should not be used if a slide-back peak measurement can be made with the instrument. Under some conditions of test, the determination of the repetition rate of the interference may be very difficult.

In reference (e) the legend of the pulse repetition rate curve calls for division of the limit by the factor rather than multiplication of the measurement. This is to determine if the background of the instrument is to be the limit. This condition occurs when both the pulse repetition rate and limit of Curve A_2, figure 10 are low.

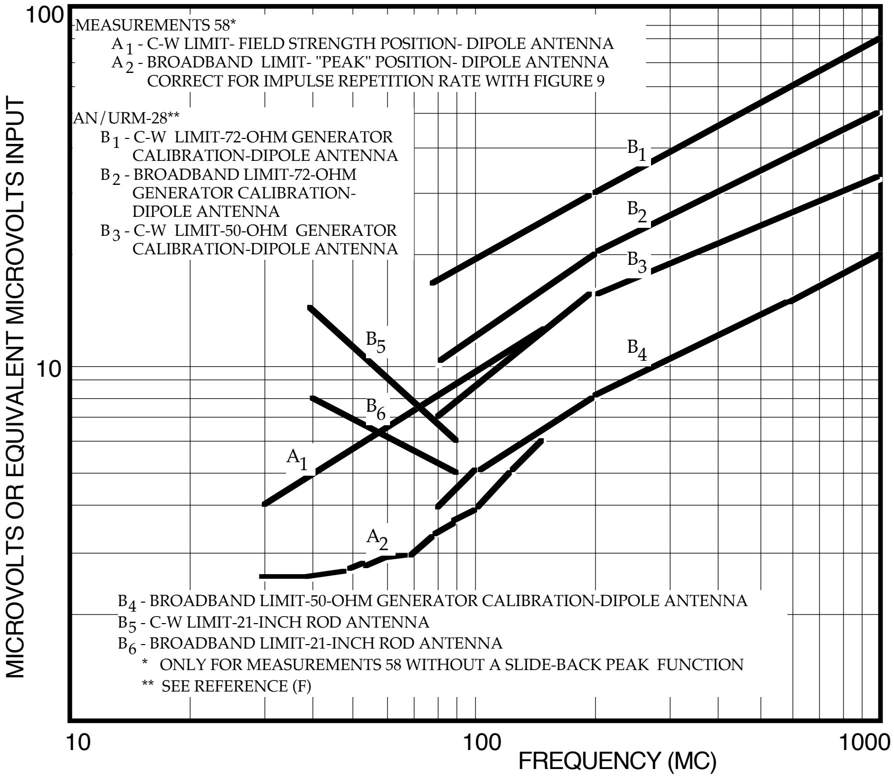


FIGURE 10 - Simplified Limits for the Measurements 58* and AN/URM-28

Measurements 58 C-W Calculations

Condition and results of test are assumed as follows:

Frequency	150	mc
Actual Meter Reading (Average Position)	6	uv
Scale Factor	2	
Input Impedance	72	ohms

For meters which are calibrated in terms of input microvolts:

Input Microvolts = 6 x 2 = 12

and

Antenna Induced Voltage (cw uv) = $12 \times \left(1 + \frac{72}{72}\right) = 24$

Comparison with the limits shown in figures 6 and 10 shows that the interference was just below the limit as presented in either curve. Figure 10 is not the same as the input microvolt limit contained in reference (e), because the limit curve presented in the specification is an approximation which is supposed to represent all limits for the Measurements 58 and URM-28. Also, until the present, broadband simplified limits, given in curve B, figure 8, have not been provided in specifications for Measurements 58 meters equipped with a peak reading function. To eliminate as many variables as possible and avoid confusion, the limits given in the specification for these meters should be changed to those given in figures 8 and 10.

If the Measurements 58 were calibrated in terms of antenna induced microvolts, the results of either calculation given in the "Measurements 58 C-W Calculation" section would have to be divided by a factor of 2.

AN/URM-28 Calculations

A complete description of the methods of measurement and calculation used with the AN/URM-28 is given in reference (g). This report also contains data on a preferable method for calibrating the AN/URM-28 from a 72-ohm signal generator and for making measurements between 40 and 90 mc with a 21-inch rod antenna. Radio interference limits which should be used in conjunction with all antennas and calibration methods are given by curves B_1 to B_6 of figure 10. Use of the 21-inch rod with the AN/URM-28 has been introduced because the dipole antenna AT-275/URM-38 covers only the frequency range between 80 and 1000 mc.

URM-17 Broadband Calculations

Broadband radio interference measurements are not required in reference (e) above 150 mc, but the calculations are given here for possible future reference. The dipole antenna used with the AN/URM-17 is physically small and appreciably thick compared to its length, causing a significant increase in the antenna impedance and also a decrease in the physical length when it is at resonance. In other words, the antenna impedance becomes greater than 72 ohms, and the effective height becomes less than $\frac{\lambda}{\pi}$. This is apparent in the factors of chart 1 and figures 7 to 12 of the AN/URM-17 calibration curves and handbook, respectively. The dipole antenna used with the AN/URM-28 is similar in physical dimensions to antenna of the AN/URM-17 and should be subject to the same variations. At 400 megacycles the inaccuracy is small, but at 1000 megacycles it becomes of the order of 20 percent. To compensate for these changes and obtain agreement between the AN/URM-17 and other meters using dipole antennas a change in the equation is required. Up to this time the equation was used to relate the induced microvolts to the input microvolts. To maintain the simplest equation, all of the change will be assumed to result from an increase in antenna impedance so that:

Between 400 and 1000 mc, dipole antenna impedance = $Za = 102 - \frac{6000}{F}$

where

F is the frequency in megacycles.

The modified equation for frequencies between 400 and 1000 mc then becomes:

$$\text{Antenna Induced Voltage (uv/kc or cw)} = \text{Input Terminal Voltage (uv/kc or cw)} \times \left(1 + \frac{102 - \frac{6000}{F}}{\text{Meter Input Impedance}}\right)$$

Use of the above formula permits determination of input microvolt limits from the standard limits of figure 6 for any receiver using a dipole of the same general physical dimensions as that of the URM-17.

Calculations for broadband interference with measurements and test conditions assumed are as follows:

Frequency	400	mc
Actual Meter Reading (Slide back peak position)*	470	uv
Bandwidth in Kilocycles (Figure 7)	540	kc
Calibration Factor (Chart 2 - URM-17 correction factors)	0.32	
Input Impedance	50	ohms

* This reading includes the attenuator factor (X10)

Equivalent Input Microvolts = 470 x 0.32 = 150

$$\text{Antenna Induced Voltage (uv/kc)} = \frac{150}{340} \times \left(1 + \frac{102 - \frac{6000}{400}}{50}\right) = 0.76$$

If these results are compared with figure 6 and curve F, figure 8, note that the interference would be just equal to the limits as expressed by either curve.

Similarly, calculations may be made for c-w interference with measurements and test conditions assumed as follows:

Frequency	400	mc
Actual Meter Reading (Field Intensity Position)*	57	uv
Calibration Factor (Chart 2 - URM-17 Correction Factors)	0.32	
Input Impedance	50	ohms

* This reading includes the attenuator factor (X10)

Input Microvolts = 57 x 0.32 = 18.2

$$\text{Antenna Induced Voltage (cw)} = 18.2 \times \left(1 + \frac{102 - \frac{6000}{400}}{50}\right) = 50$$

Comparing the results with figure 6 and curve E, figure 8, the c-w interference is just at the acceptable level as expressed by either curve. It is observed that figure 8 and the c-w input microvolt limit of Specification No. MIL-I-6181B are in slight disagreement. The cause of this is that the original input limits were derived by using the calibration factors supplied with an AN/URM-17. Subsequent checks with another AN/URM-17 gave somewhat different results, probably due to differences in input impedance. Since the limits of figure 8 are more accurate, the specification limits should be changed to agree with it.

If the meter reading of 57 had been used to obtain the field strength surrounding the dipole, it would have been multiplied by the factor of Chart 1 (URM-17 Correction Factors) which in this particular case is 3.6. This results in a field strength calculation of 205 microvolts per meter. If a good dipole antenna, that is, one that has insignificant diameter as compared to its length, were now placed in this field, the voltage induced in it may be calculated with the usual effective height of $\frac{\lambda}{\pi}$. This gives a result of 49 microvolts which is in agreement with the original limit of 50 microvolts induced in an accurate dipole antenna, as given in figure 6. Therefore, in the frequency range 400 to 1000 mc, a given radio interference field, which induces a voltage in an accurate dipole antenna equal to the standard radio interference limits, will induce a slightly different voltage in an AN/URM-17 dipole; however, the differences appearing in measurements made with the AN/URM-17 and physically similar antennas could readily be accounted for by the methods previously described.

MISCELLANEOUS INFORMATION

The information contained in this section may not be of immediate use, but may be of future importance for planning further revision of specifications.

MAGNETIC FIELD RADIO INTERFERENCE LIMITS

When tests were made to determine limits for use with the 41-inch rod antenna, similar tests were also made to determine limits that would be desirable for use with a shielded loop antenna. The procedure followed was to install a BC-348 receiver in a shielded room in a manner typical of aircraft installations, cause interference to be induced in it from various sources of magnetic interference located at a distance of one foot, and then measure the magnetic field intensity with the PRM-1 in conjunction with its loop antenna. The possibility of electric field pick-up by the receiver was eliminated by checking the interference source for electric field emission with the 41-inch rod antenna. It was a comparatively simple problem to create radio interference sources with almost all the energy residing in the magnetic field by partially shielding a high current source. Results of the tests are shown in figure 11. This figure also shows proposed broadband radio interference limits as measured with an 8-inch 2-turn loop antenna. Standard limits for loop antennas of similar size, but having a different number of turns, would be related to figure 11 directly as the number of turns divided by two, The limits are given in terms of microvolts per meter instead of microvolts induced in the loop because of inherent difficulties in the present method of calibration and use of the AN/PRM-1 as described in the following paragraphs.

The methods for dealing with magnetic field measurements have been kept as simple and straightforward as possible by following the procedures described in the PRM-1 handbook; however, the situation is not at all satisfactory. Calibration of loop antenna measurements in terms of microvolts per meter can be considered correct only for measurements in the radiated field, where the ratio of the electric field intensity in microvolts per meter in magnetic field intensity in microamperes per meter is a constant equal to the intrinsic impedance of free space (377 ohms). The use of such a calibration means that an attempt is being made to measure the electric field with an indication which is proportional to the magnetic field. In the case of radio interference measurements, which are almost always made close to the source with wave impedances other than that of free space, the intensity of both field components must be determined separately because neither can be calculated from the knowledge of the other. Use of the PRM-1 loop calibrations results in an erroneous indication of a large electric component in induction fields which are almost entirely magnetic.

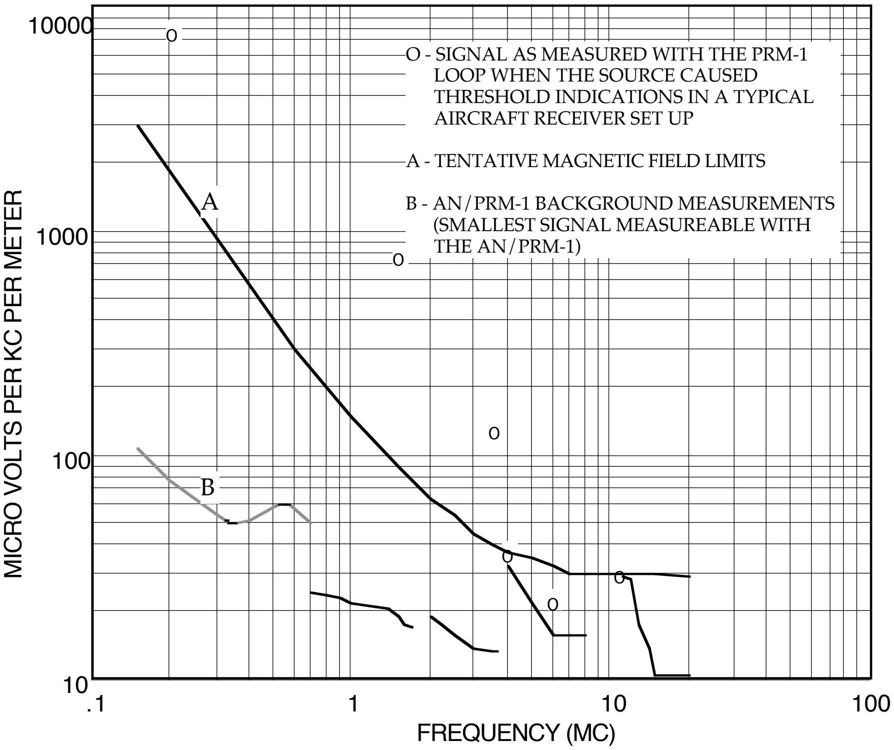


FIGURE 11 - Test Results For Determining Broadband Magnetic Field Limits

It appears that PRM-1 Charts 3 and 4 should be changed to give the results of loop field strength measurements in terms of microamperes per meter, which then would be of satisfactory accuracy regardless of the distance from the source at which measurements are made. This may be accomplished by dividing the correction factor at the bottom of each chart by 377. The proposed limits of figure 11 may be changed to standard limits in terms of loop induced microvolts by multiplying the limit at each frequency by 0.00145F (effective height of the loop) where F is the frequency in megacycles.

DISCONE ANTENNA MEASUREMENTS

During the week of 30 November 1953, personnel from the Signal Corps and Rome Air Development Center visited NADEVCEN to establish correlations between resonant dipole measurements and discone measurements of broadband radio interference. While the tests were in progress, a number of unusual occurrences indicated the presence of variables in the correlations which had not previously been foreseen, especially with respect to tests made inside a shielded room. The discrepancies were ascribed to the sensitivity of the receivers to interference components lying outside the receiver pass-band which were presented to the receiver input terminals with particular efficiency by the wide-band characteristics of the discone antenna. Attempts to prove that this was the case, using broad band generators which differed in their energy content in the higher frequency range (above 100 mc), were unsuccessful. Later study of the recorded results of the correlation tests gave additional support to the first assumption.

Since two separate and complete tests were run with an accurate broadband impulse generator and short dipole as the source of signal, it was possible to obtain a rough comparison of the relative abilities of the resonant dipole and discone for obtaining consistent results. At any particular frequency, if two measurements were made at different decibel output levels of the signal source, it would appear that the two measurements made with the dipole or the discone should differ by the same number of decibels as observed between the impulse generator readings. This is not strictly correct, because a number of variables were present such as differences in the position of and distances between the radiating and receiving antennas, number of observers present, etc.

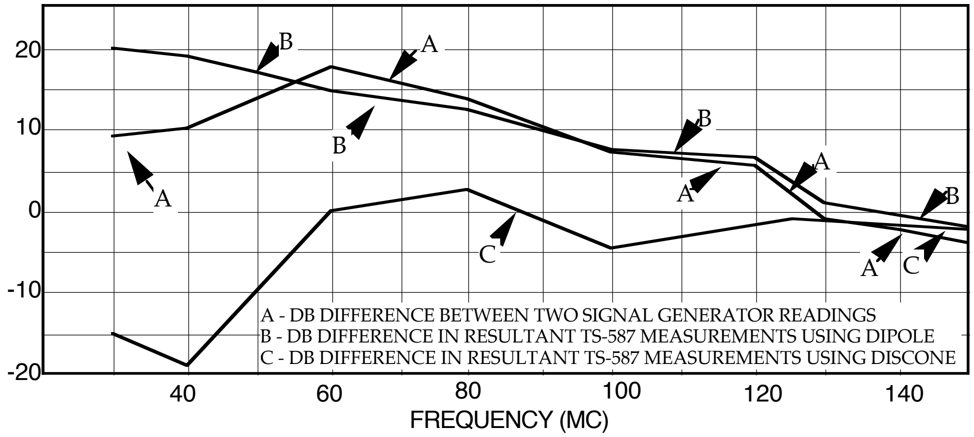


FIGURE 12 - Comparison of the Repeatability of Dipole and Discone Antenna Measurements as made with the TS-587

Figure 12 shows the difference in decibels of the measurements made with the dipole and discone in conjunction with the TS-587, and the difference in decibels of the signal generator output level. If no variables were present, all three curves would coincide. It is observed that the discone measurements indicate the presence of variables which are far greater than those encountered with the resonant dipole, especially at 40 mc. As a result of this observation, tests were made at 40 mc of discone pick-up with all variables held constant, except the intensity of the field. The surprising result was that the pick-up was a nonlinear function of the field intensity as shown in figure 13. In other words, the correlation between the discone and dipole could differ by at least 10 db depending on the signal level used. The other curves of figure 13 show the changes in output obtained with changes in the source when the impulse noise signal was fed to the receiver from a resonant dipole, by direct connection to the generator, and when fed from the discone with a sine wave generator as the source of signal.

Since all the curves have much the same slope, except the discone curve in conjunction with broadband interference, the unusual rate of change in receiver indication appears to be a function of interference components outside the receiver pass band and the frequency response in the discone. This indicates that accurate broadband measurements would require that only receivers having much better "front-end" rejection than the TS-587 be used with the discone antenna. Further investigations of this problem are to be made.

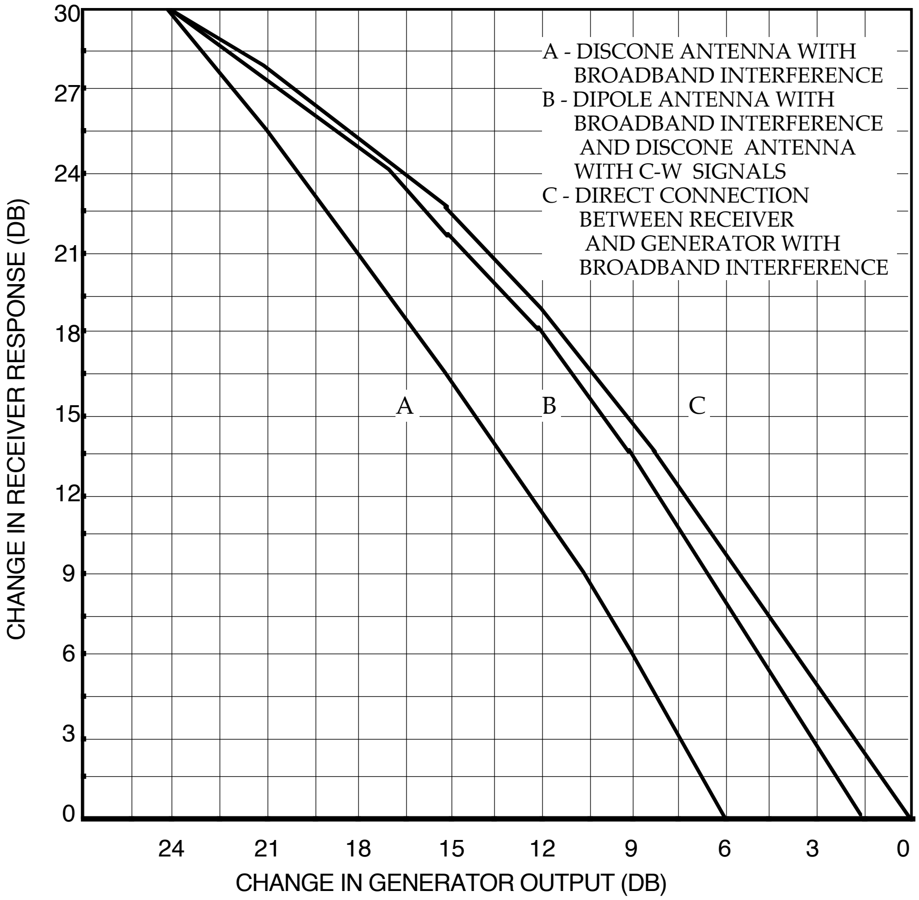


FIGURE 13 - Effect of the Discone Antenna on the Linearity of Response of the TS-587

CONCLUSIONS AND RECOMMENDATIONS

The methods for minimizing inaccuracies in radiated radio interference measurements, as described in this report, have been adopted largely in government specifications of recent issue, as in reference (e). However, even reference (e) does not make full use of the maximum accuracy attainable because of the approximate limit curves for the AN/URM-28 and Measurements 58, and because of the general assumption that all meters of a given type have the same bandwidth. It has been found that variations in bandwidth of the order of 2 to 1 are quite common. Therefore, it is recommended that specification measurement of broadband interference to the standard limits of figures 1 and 6 be allowed for those who are interested in maximum accuracy, and in the future, that the simplified broadband specification limits be expressed in terms of input microvolts per kilocycle bandwidth. These limits may be found for each peak reading meter simply by dividing the broadband limits of figures 4 and 8 by the corresponding bandwidths of figures 3 and 7. Also, it is recommended that the new limits, expressed in curve B, figure 8, and all the curves of figure 10 be incorporated in reference (e) as soon as possible, and that the present combined input microvolt limit curve for the Measurements 58 and AN/URM-28 of reference (e) be deleted. The URM-17 c-w limit curve of figure 3, reference (e), also should be changed to agree with figure 8, curve E.

The adoption of additions and corrections, previously described, would leave variations in the field contour and intensity as the most important source of discrepancies between measurements made in different laboratories.

It is recommended that further work be initiated for better control of the field and/or improved pick-up devices to obtain greater repeatability of measurements.

It is recommended that continuous observations be made of interference sources, encountered in aircraft between 0.15 and 20 mc, to ascertain whether magnetic sources of interference constitute a problem of sufficient importance to require incorporation of magnetic field measurements into radio interference specifications.

It is recommended that further work be initiated to investigate the performance and means of adapting (if required) the new radio interference meters (NF-105 and NF-114) for Bureau of Aeronautical specification testing.

A major source of difficulty in obtaining accurate and useful radio interference measurements has been the lack of understanding of basic principles involved in the methods of reference (e). Therefore, it is recommended that the information contained in the report pertaining to calculation of limits, correlating of meters, and control of the radio interference field be given wide distribution to individuals concerned with the measurement of radio interference.

Radio interference and field intensity meters such as contracted for by government agencies have the primary function of making measurements almost exclusively in the induction field. The present practice of converting loop antenna measurements into an expression of the electric field intensity is accurate only for the radiated field. It is recommended that in the future the noise and field intensity meter manufacturers be required to present loop antenna calibrations in terms of the magnetic field intensity in amperes per meter so that such measurements will also be meaningful in the induction field.

The discone antenna has been found to introduce new variables into the measurement of radiated radio interference with the TS-587. It appears almost certain that even greater inaccuracies will be obtained with meters having poorer "front-end" rejection. Therefore, it is recommended that the discone antenna not be used for Bureau of Aeronautics specification testing unless means are found to eliminate the additional inaccuracies caused by its broadband, and any other, characteristics.

REFERENCES

(a) BUAER ltr Aer-EL-52 ser 22336 of 23 Mar 1950
(b) BUAER ltr Aer-EL-4181 ser 117085 of 10 Oct 1951
(c) Spec No. JAN-I-225" Interference Measurements, Radio, Methods of, 150 Kilocycles to 20 Megacycles (For Components and Complete Assemblies)"
(d) Report No. ADC-EL-T12-50 Phase I, "Study of the Pick-up Characteristics of the Three- Inch Loop Probe, Rod and Dipole Antennas a Used for Evaluating Radio Interference for Specification Testing"
(e) Spec No. MIL-I-6181B, "Interference Limits, Tests and Design Requirements, Aircraft Electrical and Electronic Equipment"
(f) University of Pennsylvania Report, "Investigation of the Measurement of Noise" - Progress Report No. 22, Contract NObsr 49128, Index NE-120 803 with Bureau of Ships, United States Navy
(g) Report No. NADC-EL-5366 - Calibration and Test Procedures for Use with Radio Interference Measuring Set AN/URM-28

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