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FIELD STRENGTH MEASUREMENTS

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I. Introduction

An attemp has been made to make this paper useful both to those designing and maintaining field strength equipment as well as those engaged in field strength measurements. In order to avoid an unwieldy product, an attempt is made to treat the usual problems rather than to dwell too much on exceptional applications. Furthermore, it is assumed that an accuracy of approximately 1 db is the maximum accuracy desired. This permits the neglect of many second order effects which otherwise would require encumbering qualifications in many places in this report.

2. Purpose of Measurements

Measurements of field strength are generally made for one of several purposes:

(a) to determine the serviceability of the radio signal for a given service.

(b) To determine the interference producing capabilities of an emission.

(c) To measure propagation phenomena either for use in communication studies or to gain information of value to other physical studies.

(d) To determine the effectiveness of an equipment with regard to the desired signal or the effectiveness of the suppression of undesired emissions. These measurements are generally made relatively close to the equipment under test.

3. Stability of the Source

In general, measurements of desired signals are repeatable since a considerable part of the energy is radiated. On the other hand, in interference measurements the energy radiated from the source may be extremely variable as we are often dealing with leakage. If the interfering signals are by leakage from cabinet joints the tightness of these joints may vary with temperature, pressure, etc. In addition, harmonic and other spurious outputs may vary greatly with changes in load conditions which cause relative small changes in the fundamental emissions. Furthermore, many of the leakage effects at a distance may be the result of escape by several paths producing sharp nulls in the frequency and space patterns, resulting in tremendous variations in measured values. Frequency instability of spurious signals and of emission from certain ISM equipments may further complicate the measurement problem.

Special emphasis is placed on the above because the problems of repeatability of measurements have so often been confused with the accuracy of measurement.

Because of the variation of the source, the expected values of the measured field strength of harmonic and other spurious emissions may be expected to be repeatable to some fraction of the total suppression in decibels rather than to a fixed number of decibels. If the suppression of harmonics or other spurious emissions is only 30 db perhaps most measurements might be expected to fall within, say, ±3 db, but if the suppression were 100 db the probable repeatability might be expected to be ±10 db. The same repeatability problems are encountered when attempting to measure the fundamental oscillator radiation of receivers which employ methods to reduce oscillator radiation or the measurement of radiation in the null directions of highly directional antennae.

4. Kind of Antennae

For the purpose of this discussion the word "kind" will be used to differentiate between magnetic and electric radiation. If a current is flowing in a loop very small compared with a wavelength and another similar loop is placed adjacent and coaxial with it maximum voltage will be induced in the second loop. As the loops are separated by moving along the axis the voltage induced in the second one will fall off as the cube of the distance. (With loops of finite size there is some variation from the rate when the loops are not small compared to their separation.) The field involved in the foregoing discussion is termed the "induction" field. This field is generally used in the calibration of loop operated field strength meters. See Appendix A. The cube law variation under proper safeguards can also be used as an absolute standard of attenuation. See Appendix B. At distances beyond about 1/20 wavelength the rate of decrease will become substantially less until eventually the field will fall off as approximately the square of the distance.

If the loops are placed in the same plane the cube law decay will persist to approximately 1/20 wavelength and thereafter the rate of decay will markedly decrease until at approximately $\lambda/2\pi$ the voltage will vary inversely with approximately the first power of the distance. (The above assumes free space.) Beyond this distance the "radiated" field predominates over the "induction" field.

If instead of small loops small electric antennae such as very short (in wavelength) dipoles are used the same cube law variation with distance will be found as the rods are moved along a coaxial position (again having to note certain corrections in case the rod lengths are not small compared to the separation). If, however, the rods are moved parallel to each other the field first will decay at a cube law rate and then at about 1/20 wavelength the rate will decrease until at a distance of $\lambda/2\pi$ the rate of decrease will approximate the first power of the distance.

For the purposes of this paper the small loop will be defined as representing one kind of antenna - magnetic, and the very short rods as a second kind - electric. The near-in field from the loop is the induction magnetic field and the near-in field from the short dipole the induction electric field. The foregoing has considered only the exploration of the field by an antenna of the same kind. If the field is explored with an antenna of the other kind the situation will be found to be very different in the near-in region. When the rod antenna is moved along the loop axis but extends perpendicular thereto there will be found very little field. If the rod is moved in the plane of the loop the voltage induced will at first decrease approximately with the square of the distance and then at about 1/3 wavelength the decrease will approach a linear rate. The same situation will exist if the loop and dipole are changed as to which is the source and which is the receiver.

At distance appreciably over $\lambda/2\pi$ the fields which decrease linearly with distance (in free space) are the only ones of importance. This $\lambda/2\pi$ limit is applicable to small radiators only. In the case of very large sources such as power lines the rates of decay may be considerably altered. The maximum fields in the far region are radiated in the plane of the loop antenna and normal to the axis of the electric antenna. These fields are called radiated fields. At these greater distances at locations free from local disturbing elements the "kind" of antenna is unimportant, but we still have the problem of polarization of radiated fields since the antennae in the loop case must lie in the same plane for maximum signal, no radiated signal being received if the axes of the loops are in the same line, if the loops are perpendicular to each other and the axes intersect, or under other conditions when the relative polarizations of radiation are mutually perpendicular to each other. In the electric dipole case the antennae must be parallel and positioned so that the line between their centers is normal to each antenna to get maximum radiated signals. No radiated signal is transferred when they are separated coaxially.

Either loop antennae (magnetic) or rod antennae (electric) are generally used on field strength meters below approximately 30 megacycles. The loop antennae are balanced and/or shielded to reduce electric field pickup. Present general practice is to use an unbalanced loop with an electric shield split at the top. Most loops are multiturn, although some instruments employ single turn loops or loops of several turns and impedance step-up transformers. The loop size varies from a few inches to several feet in diameter as generally used in portable equipments. Rod antennae cannot be effectively shielded from magnetic fields and are undoubtedly effected somewhat by them. One and two meter lengths are generally used for portable equipments. Generally rod antennae in this frequency range are operated in an unbalanced manner with the rest of the instrument and power supply acting as ground. In some cases additional grounding may be necessary.

Above about 30 megacycles half-wave dipoles are generally employed. They are sometimes employed in portable field strength equipment as low as 18 megacycles and for recordings of field strength at fixed locations at much lower frequencies. These antennae are in reality a combination of two kinds (magnetic and electric). Because the wavelengths are much shorter measurements are generally made at distances so that problems of kind of source and antenna dimensions relative to the distance at which the measurements are being made are unimportant. However, certain noise and interference measurement procedures are in use 1/2/in which very close spacings are used and these problems have to be faced, usually by arbitrary standards, on the placement of equipment and antenna and the type of antenna use. Even then complication arises due to the fast rate of decay of the fields in the near-in region. Measurements so made may not be representative of the actual fields at greater distances and this type of procedure should be avoided if at all possible, except where it simulates the actual physical situation encountered in practice.

All the foregoing discussion may seem unduly lengthy, but long experience has indicated that an engineer not aware of these factors soon gets himself into unforseen difficulties which can cause major errors. The above has considered the free-space situation which will in practice be further modified by the surroundings at the transmitter and field strength meter and the propagation factors involved in transmission along the earth or through the atmosphere.

5. Other Objects Near or Between Antennae

If either the field strength meter or the source is near conductors. dielectrics or magnetic materials these may affect the transmission between

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1/ MIL-I-16910 A and Amendment No. 2

2/ Proposed American Standard on Methods or Measurement of Radio Influence Voltage and Radio Influence Field (Radio Noise) - 0.015 to 25 Mc ASA Doc. C63.4.

the antennae, since these objects may pick up energy and re-radiate it, reflect it or absorb it. The intermediate objects may change not only the strength of the fields but may change the polarization or the kind of field as well. Objects near field strength meters may affect different meters differently. For example, with a loop antenna field strength set little difficulty ensues when the operator moves about the set, while the operator will considerably affect the readings of a rod antenna field strength meter. Although there is a tendency to consider only conductors, dielectrics may play a major role in affecting field strengths, especially on frequencies above some 10 megacycles. Considerable difficulty in coordinating oscillator radiation measurements from TV receivers was caused by plywood sides and other structural elements used in buildings housing the receivers under test. Conditions were found to be variable at the same location depending on whether or not the building was wet. Vertical fields at VHF and UHF frequencies may be distorted by wooden poles or other dielectric supporting members as well as by conductors. If houses are to be used over the equipment to be measured in order to obtain protection from the weather, such structures should preferably be made from low dielectric constant materials which will not absorb water. Certain plastic materials have been found to be suitable. In addition, check should be made both with and without the structure to determine its effect on the measurements. If structures are used at the field strength meter location the same precautions should be observed and the structures should be placed off the ends of the receiving antennae wherever possible.

Vertically polarized fields in the VHF and UHF region may also be greatly affected by the ground conditions. If the source antenna and the field strength measuring antenna are horizontal and close to the ground and either one is raised, the fields will tend to rise almost linearly with height until a maximum is approached and then the field will vary cyclically as the antenna is further raised. With vertically polarized antennas, however, the fields will remain substantially the same until a certain height is reached, after which the fields will increase until a maximum is reached and then there will be cyclic variations. The height range of relatively constant field will vary almost inversely with frequency and almost directly with dielectric constant. (Except where conductivity is high as in the case of sea water.) Failure to appreciate this phenomena can lead to some serious errors in evaluation. For example, if vertically polarized fields are, say at 40 megacycles over ordinary land, the fields will be fairly constant with height below 15 feet. However, measurements over water will give fields which would be relatively constant to some 60 feet.

At all frequencies the effects of overhead wires, cables or other conductors must be considered. Generally all field strength antenna should be removed therefrom by at least several times the height of the disturbing media in areas of good ground conductivity and further in areas of poor ground conductivity. When measuring field strengths with a loop antenna the effect of such disturbing influences can often be detected by the direction of arrival of the wave or b poor loop nulls. Further checks involve the rate of change of the field as the overhead structures are approached. If an attempt is being made to evaluate the null of a directional

system, especial precautions will need be taken, since a long power line or telephone line may conduct energy into the area of the null region where measurements are being made.

At frequencies above a few megacycles disturbing effects from underground cables generally do not have to be considered but at frequencies much below 2 megacycles such cables can cause appreciable errors in field strength measurements made near them even when the cables are buried a number of feet. Very long underground cables (or cables connecting to overhead lines) are to be especially avoided. Fortunately, the disturbing fields are generally the induction fields and the effect of the cables can be determined by measuring at a number of locations at different distances away from the cables. In regions of very poor ground conductivity these cables can be very troublesome and the effects may be complicated by directional patterns. Actually wires buried a distance underground in areas of fair to poor conductivity have been found useful as directional Beverage antennae.

6. Polarization Effects

The preceding discussions have touched on some polarization effects. At low frequencies vertically polarized signals are the one almost exclusively of interest except for sky-wave reception where horizontal polarization may be used. So far as ground-wave propagation is concerned the polarization continues as radiated, except for minor wave-front tilt. However, for ionospheric reflections the received signal is a mixture of vertical and horizontal polarization except for certain critical frequencies and distances. For this reason the loop field strength meter will not have its usual direction indication characteristics on sky-wave signals since end-on it receives the vertical signal and broadside the horizontally polarized signal.

Above about 30 megacycles the location of antennae for most services will be an appreciable fraction of a wavelength or more above the earth and both polarizations are useful. Tropospheric signals at long distances as well as those signals propagated near the ground generally retain their original polarization as differentiated from signals reflected by the ionosphere.

Conductors near the transmitter or receiver not wholly horizontal or vertical may pick up one polarization and re-radiate a component of the other. Many sources themselves may contain both components. Harmonic and spurious radiation may be polarized differently from the fundamental.

7. Units of Measurement

The unit of measurement commonly used is the microvolt per meter, millivolt per meter or volt per meter. This unit is only rigorously applicable to the electric component of fields but is generally also used

for expressing measurements of magnetic fields or the magnetic component of radiated fields. For radiation fields in free space the energies in the two fields are equal and the indicated microvolts per meter for either measurement is the same. The type of antenna used should be stated in reporting measurements.

In case the emissions being measured are broader than the bandwidth of the field strength set, consideration must be given to the effect of field strength meter bandwidth on the intercepted signal. For impulse noise with widely spaced impulses and having a uniform distribution throughout the part of the spectrum under consideration the peak voltage will be a direct linear function of bandwidth and this leads to the unit of microvolts per meter per kilocycle. (Or microvolts per meter in a kilocycle band.) Other types of noise or signals may or may not be dependent on bandwidth as well as detector law and time constants.

8. Field Strength Meter Circuitry

The signal delivered to the field strength set may vary from a fraction of a microvolt to a number of volts. If this range of voltages were applied directly to a mixer and attenuation applied later in the meter there would be severe problems of non-linearity. In addition there would normally be other signals present which would lead to cross-modulation difficulties or desensitization. For this reason practically all meters employ an attenuator at the received frequency as well as at later places in the receiver chain. In some sets, antennae of different sizes may be used to obtain more or less sensitivity as desired. In addition, field strength meters generally employ at least one tuned circuit (in the case of loop sets the loop itself) before the first tube. This tuned circuit or circuits reduces the problem of cross-modulation and overloading which would be present if signals throughout the spectrum were applied to the first tube. These precautions are especially important for noise meters for use on broadband low duty cycle noise such as ignition noise.

The radio frequency attenuator generally takes the form of a switched compensated capacity divider for frequencies up to about 25 megacycles. (In some cases as high as 135 megacycles.) Above about 15 megacycles matched resistive type coaxial attenuators (or compensated resistive attenuators) are commonly used. There are few field strength sets as such available above 1 KMC although one company has a series of sets up to 10 KMC. Although not used in any present set the waveguide attenuator similar to the HP-382 should be ideal since it has practically zero insertion loss and is continuously variable. Such a device if available at lower frequencies would solve many problems by permitting the rest of the measuring set to be used only as an indicator at a constant level, avoiding non-linearity and overload problems.

The first tuned circuit and radio frequency attenuator are generally followed by a mixer or a radio frequency amplifier state and then a mixer. The mixer stage is generally followed immediately by an intermediate

frequency attenuator. This attenuator is often mechanically coupled to the radio frequency attenuator so that the radio frequency attenuator operates on the higher voltage ranges and then the intermediate frequency attenuator operates on the lower voltage ranges. The intermediate frequency attenuators may be stepped resistive networks, stepped capacity dividers, tapped induction networks, or continuously variable waveguide below cut-off attenuators. In some meters the attenuator action, at either radio frequency or intermediate frequency is obtained not by an attenuator but by changing the gain of the amplifiers by change of bias. It is a good practice to make provision for disengaging the radio frequency and intermediate frequency attenuators so that they may be checked one against the other.

A possible source of error is the lack of standard methods of marking the attenuator ranges. While most field strength meters have their attenuators and indicating meters so arranged so that the product of the attenuator readings, meter readings and a factor or factors gives the actual field strength, some meters are calibrated as is usually the practice for voltmeters. In this practice the attenuator marking indicates the range in use. Thus, if the attenuator reads 10 millivolts and the indicating meter reads 5 on a scale of from 1 to 10, the field strength is 5 millivolts and not 50 millivolts.

The intermediate frequency amplifier of a field strength meter drives a detector and metering circuit or circuits. In present day meters the time constants of these circuits are so arranged as to read one or more of the following:

(a) Slide-back aural peak.

(b) Metered peak.

(c) Quasi-peak (Several different types)

(d) Average of the absolute value of voltage

These various detectors will be discussed further in Appendix C.

One field strength meter of early design used a square law detector and the meter indication was proportional to power, but no commercial field strength meter is known to now be in general use giving an indication proportional to power. This is probably reasonable since most communication receivers use a linear detector rather than a square law detector.

Many field strength meters have provision for an automatic-gain-control voltage to be fed back to give the indicating meter an appropriately logarithmic scale. Some instruments employ a shaped pole piece meter to obtain this type of scale.

Most field strength meters use varying deflection of the indicating meter to interpolate between decade or smaller attenuator steps. One U. S. set, the RCA 308 A and B, has a continuously variable intermediate frequency attenuator and uses a fixed meter reading. The use of the meter scale for interpolation involves certain errors due to non-linearities, and indicating meters having scales covering more than one decade must generally have careful maintenance if reasonable accuracies are to be maintained. The precaution of checking the meter scale against the step attenuator should always be taken when making measurements since otherwise non-linearities may cause very large errors. Offsetting the difficulty of maintaining meter linearity in meters having several decades on the meter is the convenience in use in the measurement of varying signals. Meters with several decades range are indicated for the measurement of varying or fading signals, especially where high accuracies may not be required, as in the measurement of power line noise.

9. Meter Self-Calibration Procedures

A few meters have depended solely on their constructional stability without self-calibration provisions. Some check may be obtained in these meters by noting the tube noise indication. This approach is not too satisfactory at the present state of the art unless signal generators are available for frequent checking. In general, self-calibration is provided by one of the following methods:

(a) Continuously variable-frequency calibration oscillator with thermo-couple amplitude check. This probably has the best long term stability.

(b) Continuously variable-frequency calibration oscillator with crystal-diode, tube diode or grid current indicator. The latter is generally not too desirable because of the certain errors often introduced.

(c) Fixed-frequency calibration oscillator for setting field strength meter sensitivity at at least one place in each band. This method has the difficulty that changes in alignment can cause serious errors at other frequencies unless some further check is employed such as use of an impulse generator for extrapolation to other frequencies.

(d) Noise diode. (Especially for noise meter) This is a compact type of calibrator but is not wholly satisfactory as presently used in meters for other than noise measurements or rough measurements both because of its own accuracy problems and the effect of bandwidth. The observed instabilities may be more related to the portable nature of the equipment in which this method is used rather than the fundamental inherent errors of a noise diode.

(e) Impulse generator. (Especially for noise meters.) This type of source is probably preferable for impulse noise measurements but has some drawbacks such as bandwidth changes affecting measurements of continuous wave and signals other than impulse noise. Here again the judgments in evaluation are at least partially related to particular arrangements presently used in meters.

(f) Built-in signal generator and signal generator attenuator. This is probably the best method but generally results in increased cost and weight, especially since very good shielding and filtering are required.

The self-calibration facilities are generally satisfactory over limited periods of time and the instruments should be periodically checked against external standards. It is well to make daily checks until the stability of the particular instrument is determined. These checks should be made at various levels to check attenuators as well as signal sources and should include checks of the interpolation meter linearity. During these checks it is generally well to check the alignment with a sweep oscillator at several levels. Mis-alignment may cause operating difficulties, affect attenuator ratios, affect response on broad-band signals, cause regenerative effects resulting in bandwidth changes with signal level. Occasionally the regenerative effects may be due to the feeding back of an intermediate frequency harmonic to earlier stages and may result in rather sharp change in sensitivity as the frequency is changed. Similar abnormal effects have been noted in sets in which there is unwanted coupling between the calibrating oscillator and the rest of the set. Any sudden change in set sensitivity as the frequency is changed should lead to an investigation as to cause. In particular sets several sharp humps in sensitivity were found apparently due to the case acting as a cavity. These changes in sensitivity were reduced by placing space cloth (resistive loss) pads within the case.

There are so many things that may happen that the user of field strength sets should maintain constant vigilance for unusual conditions. The state of art is not such that the meters can be regarded as reliable as the usual DC or AC voltmeter or ammeter.

10. Power Supplies

Some field strength meters operate directly from dry batteries. Some of these instruments provide rheostats to adjust the voltage to a specified value. Others provide means of adjusting the gain to compensate for voltage changes. Some sets operate from 6 to 12 volt storage batteries and employ vibrators for the plate supply, which usually is regulated in some manner. With low voltage one must be careful that the gaseous regulator tubes do not extinguish as the signal level is changed or rather large errors may ensue. Low or high battery voltage may also cause errors due

to changes in filament or cathode temperatures especially in sets using grid or diode tube calibration circuits. If variations are encountered with battery voltage and accurate measurements are desired, it may be necessary to provide a correction factor for battery voltage. Many of the VHF, UHF and microwave sets are designed for AC operation. Here again, the line voltage may affect the accuracy, especially if some tube or other component is somewhat weak. If possible the correct voltage should be supplied by use of a regulator free from harmonic distortion since a regulator with harmonic distortion does not regulate both the heater and plate supplies correctly.

11. Special Checks

(a) Some meters employ antenna cable having 2 balanced conductors. It is a good precaution to check the continuity of these cables before and after each set of measurements by use of an ohmmeter since failures frequently occur. The same procedure is good even with other cables because in field use hidden troubles develop.

(b) Always check attenuators one against the other if possible and also the indicating meter linearity against attenuator scale. Although it is convenient to have radio frequency and intermediate frequency attenuators controlled by one knob this prevents checking one against the other except by cross-reference to the meter scale.

(c) In measurements of harmonic or spurious emissions, it is always important to be sure that the harmonics or spurious indications are not being generated in the field strength meter. If an antenna resonating knob is provided, it should resonate at the usual position or an image response or a direct intermediate frequency response may be indicated. The use of a radio frequency attenuator step should cause the proper decrease in measured level. If the decrease is much greater look for harmonics being generated in the front end due to overload or cross-modulation products. If a resonant dipole is ued as an antenna and one is measuring the second harmonic of a station increasing the antenna length 2 times should reduce the received signal. If it increases it then a harmonic is probably being generated in the field strength set itself. When trying to measure harmonic or spurious frequencies above the fundamental down 50 or more db from the fundamental a set of high-pass filters is very helpful. Likewise when measuring spurious emissions below the fundamental frequency the use of low-pass filters is helpful.

12. Special Considerations Relating to Noise Meters

(a) The Journey of the Impulse Through the Set and its Modifications.

Ignition and similar interference will generally have a spectrum such that the energy per cycle is practically constant through the bandwidth of even the relatively broad circuits in the field strength set early stages. As the pulse journeys through the set each encounter with selective circuits tends to lengthen the pulse and to reduce its amplitude. If no gain (or loss) were involved and the impedance level were constant the average value of the excursion of the pulse in either positive or negative direction would tend to remain constant. The peak value would first be restricted to some extent by the bandwidth of the pick-up antenna and then further modified by any radio frequency tuned circuits before the first tube. If we do not have such tuned circuits the peak value of the pulse may overload the first tube. The first tube gives some gain but the next circuits tend to reduce the peak value. In good design of noise meter we must avoid too much gain before selectivity.

(b) Detector characteristic

When the signal reaches the detector we may

(i) Bias the detector back until the tips of the peak of the impulse as it appears at the detector can just be heard or in the case of impulse of varying height, until the desired repetition rate is obtained.

(ii) Apply the modified impulse to a detector of a desired response and obtain a meter indication dependent to some degree on the time-constant of the metering circuit and the variation of the pulse height and repetition rate.

13. Meter Functions Used for Measurements of Various Type Emissions

(a) The position marked "field intensity", "field strength" or "average" usually employs a detector responding to the average of the voltage (absolute value regardless of sign) and is calibrated to read the RMS value of voltage for the case of an unmodulated continuous-wave emission: (A0 or F0). With the use of an antenna factor the value is expressed in either volts (or submultiples) per meter or watts (or submultiples) per square meter. Below 300 mc/s the field strength is generally expressed in microvolts per

meter and above 3000 megacycles in watts per square meter, while in between either term may be used.

The same position is generally preferred for many modulated emissions including classical A3 modulation and classical F3 modulation. The position is also usually used for A1 or A2 emission where the key-down position can be maintained during measurement. In all the above cases it is necessary that the field strength meter bandwidth be greater than that of the emission unless appropriate corrections are made.

The "average" position of some meters may read the peak value on signals having high repetition rates for pulses at the peak value such as TV visual signals having positive synchronizing signals. This difficulty is avoided in some noise meter designs by making the detector charge time constant less than 0.2 of the bandwidth of the meter.

The "quasi-peak" position is generally used for types of emission which are keyed or pulsed or for which there is a variation of the average value to voltage with modulation, as for example, A1, A2 or reduced carrier transmissions. The quasi-peak position is also used for some noise measurements. If the emissions under measurement have a bandwidth greater than that of the measuring set the bandwidth of the field strength set should be stated.

High duty cycle pulsed transmission will usually be measured in the quasi-peak position. Very low duty cycle pulse transmission or interfering pulses will normally be measured in the peak position. If the bandwidth of the meter is greater than the emission then the value will still be expressed in peak volts (or submultiple thereof) per meter or peak watts per meter. If the bandwidth of the emission is greater than the field strength set, then either an appropriate correction should be made or the results expressed in volts (or submultiple thereof) per meter in a kilocycle bandwidth or watts per square meter in a kilocycle bandwidth.

While measurements made at one bandwidth can be corrected to another bandwidth for certain simple type of signals, this is not the general situation, especially where the signal may be a composite of several types of noise or of desired and interference components of a signal. The same difficulties are inherent in the correction of signals or noise measured with given detector time constants to that which would have obtained if other time constants were used.

In many measurements, both the set bandwidth and the detector time constants are involved, and correction becomes very questionable.

A study question was proposed by Commission I at URSI (Boulder 1957) concerning the standardization of measurement parameters into discrete families of bandwidth, time constants and detector laws. CISPR as well as various national standardization groups also has certain specifications and proposed specifications with regard to the measurement parameters and equipments. A discussion of the problem is included as Appendix C. Until further standardization is made the various emissions should be reported as follows unless otherwise indicated in the submission of the data.

A0 - Average
A1 - Quasi-peak (or average if key held down)
A2 - Average (for keyed modulation)
    - Average (with key down for total emission keyed)
A3 - Average (also for single side band if carrier not reduced.)
A3a - A3b - Quasi-peak
A4 - Average
A5 - Average (for negative sync)
    - Quasi-peak or peak (for positive sync)
A9 - Average
A9c - Quasi-peak

F0, F1, F2, F3, F4, F5, F9 - Average. Care must be exercised that the bandwidth of the field strength meter is adequate. Otherwise measurements may have to be made by use of quasi-peak means.

P0 and other pulsed emissions - Quasi-peak or peak as indicated in particular report.

The above quasi-peak measurements may be made with any of the various quasi-peak standards now in use but the particular one used should be specified. For most of the emissions above little or no difference will be involved. The major differences with the various quasi-peak time constants are encountered in interference measurements on low duty cycle emissions. In all quasi-peak and peak measurements care must be exercised to insure that extraneous disturbances such as ignition or switching transients are not affecting the results.

APPENDIX A

CALIBRATION OF FIELD STRENGTH METERS EMPLOYING LOOP ANTENNAS

A field strength meter employing loop antennas may be calibrated by a standard field technique, in which the field strength may be computed from the measured current flowing in a loop of known dimensions at a certain distance from the loop antenna of the instrument which is to be calibrated. For this purpose it is preferred to place the sending and receiving loops so that they are coaxial (rather than co-planar), for simplicity of computation and freedom from the radiated field components. (It will be noted that for maximum received signal the receiving loop is positioned differently by 90 degrees from the position it would have for maximum reception of a radiated field. This is because the calibration is carried out using the induction field originating at the sending loop rather than the radiation field.)

The distance between the sending and receiving loops is limited in practice to the region between about 5 and 15 loop diameters, when the loop diameters are comparable. Large spacings reduce errors in measurement of the distance and reduce the error made in approximating the position of the electrical center of thickness of the receiving loop. Large spacings also reduce the effects caused by the proximity of the instrument case to the receiving loop. On the other hand, large spacings may introduce a possibility of errors caused by the reception of radiation field components from the equipment supplying radio frequency current to the sending loop, which decay with distance at a slower rate than does the desired induction field component from the sending loop.

The sending loop is preferably made of one circular turn of small-diameter wire, supported by a groove in the edge of a disc of insulating material. The small diameter simplifies measurement of the distance between the loops and also the specification of the sending loop diameter. The use of only one turn reduces the difference of current along the wire loop due to standing waves or capacity between turns. A circular loop is preferred because the computations are much simpler than those for other shapes.

The loop current may be measured by an ordinary small radio-frequency ammeter. The ammeter is placed in the loop in a position which makes the internal radio-frequency circuit of the ammeter a continuation of the arc of the loop. The ammeter should be of a type known to have negligible frequency errors up to the highest frequency of interest, or its calibration curve should be taken into account. Ammeters with full-scale ranges of 0.12, 0.25 and 0.50 amperes have been used successfully in calibration work. These instruments are found to be sensitive to changes in ambient temperature, so it is therefore necessary to perform a calibration of the ammeter at the time it is to be used, or to rely on a temperature correction curve obtained by such a calibration. This calibration is preferably carried out by comparison with a laboratory type current-measuring instrument of the dynaometer type at a low frequency, such as 60 cycles. It is inadvisable to make this calibration by using direct current unless it is known that the RF ammeter is of a type which indicates direct current correctly.

The location of the apparatus for performing calibrations of loop-type field strength meters should be one which is a considerable distance from metallic masses or conductors which might tend to distort the distribution of field. As a test of the adequacy of a test location, the results obtained there may be compared with results obtained when the apparatus is temporarily moved outdoors well away from any other influence.

The field strength at the plane of the receiving loop may be computed from the following formula[1] (valid for $d > 7r_1$ and $d > 7r_2$):

$$(E) = \frac{60\pi r_1^2 \; I}{(d^2 + r_1^2 + r_2^2)^{3/2}} \cdot \sqrt{1 + \left(\frac{2\pi d}{\lambda}\right)^2}$$

where E = equivalent free-space electric field strength in RMS volts per meter.
r_1 = radius of transmitting loop, meters.
r_2 = radius of receiving loop, meters. If receiving loop is rectangular, use radius of circle of equivalent area.
d = axial spacing meters, between coaxial loops.
I = transmitting loop current, RMS amperes.
λ = free-space wavelength, meters.

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[1] Frank M. Greene, "Calibration of Commercial Radio Field Strength Meters at the National Bureau of Standards," NBS Circular 517, December 1951.

APPENDIX B

A SIMPLE RF STANDARD OF ATTENUATION

Various attenuation standards have been described in the literature. Some of the most satisfactory of these are based upon the attenuation of an electromagnetic wave along a waveguide at a wavelength much longer than the critical wavelength. The attenuation per unit distance in such a waveguide may be computed from the measured cross-sectional dimensions of the guide, with proper allowance for the depth of penetration of the waves into the guide walls. The construction of an accurate attenuation device according to this principle requires precise machine work and careful dimensional measurements.

A simpler attenuation standard may be made by eliminating the wave-guide walls altogether. The transmitting and receiving elements of the attenuator may be small coaxial loops. It may be shown that, if the diameters and thicknesses of the loops are very small in relation to the distance separating them, or in relation to the wavelength, the received voltage varies according to the inverse cube power of the distance. Therefore the use of such an attenuator requires careful attention to only one critical dimension, the distance between the loops. Furthermore the attenuator is capable of self-checking, as will be shown in the following. Let the received voltage at loop spacing d_1 be e_1, and the received voltage at spacing d_2 be e_2. According to the theoretical attenuation law:

$$A = \frac{e_1}{e_2} = \left(\frac{d_2}{d_1}\right)^3$$

where A is the voltage attenuation ratio.

The attenuation ratio A may be repeatedly determined at a number of combinations of distances d_1 and d_2 so chosen as to keep $\left(\frac{d_2}{d_1}\right)^3$ constant.

In practice it has been found that an inverse cube law attenuation standard of this type can be made simply by the use of two unshielded loops each made of a number of turns of small diameter wire filling a groove 1/16 inch wide in a 1 inch diameter insulating cylinder ½ inch long.

For improved sensitivity each loop is made resonant to the operating frequency in the neighborhood of 1 megacycle, by use of parallel capacitances. The conductors leading to the loops are shielded and the resonating capacitors are placed at points near the terminals of these cables instead of near the loops. The insulating cylinders on which the loops are wound are supported in an insulating cylinder about 36 inches long. One loop is fixed in position, while the other is free to move and is moved by an attached insulating rod extending longitudinally through the outer cylinder.

The rod may carry a pointer or distance scale as desired.

It is found, by the self-check method described, that the inverse cube law variation with distance is closely maintained up to about 8 inches and out to 36 inches or more, at 1 megacycle. It may be expected that deficiencies in shielding of the apparatus at either end of the system will place a practical upper limit on distance, as will the proximity of metallic objects near the path between the loops. At high frequencies or long distances radiation effects may become important. For these reasons it is proposed that an attenuation standard having these dimensions is limited to differential attenuations of the order of 30 db and frequencies up to about 5 megacycles. At low frequencies the initial attenuation may be prohibitive.

APPENDIX C

DETECTOR TIME CONSTANT AND BANDWIDTH CONSIDERATIONS

For most types of interference, the average of the absolute value of the voltage is probably the best measure of the intolerable interference limit. For emissions having a relatively high duty cycle this average value can be measured with most field strength sets. For low duty cycle emission, however, overload generally prevents this type of measurement with present equipments. This equipment difficulty has probably tended to make quasi-peak measurements be used. The original quasi-peak constants of 10 millisecond charge and 160 millisecond discharge even permitted some overload problems for very low duty cycle pulses and probably lead to the present 1 and 600 millisecond constants (US) or 1 and 160 (CISPR). However, in many applications the use of a charge time as short as 1 millisecond results in short pulses of high peak value being weighted far too heavily in the indicated value as compared to their interference probabilities. Under many conditions, it is impossible to measure the desired interference because of atmospheric, switching, or other transients which give large quasi-peak readings. In view of the advantages of measuring average of the voltage, methods of reducing present instrumentation problems have been investigated. If the bandwidth of the measuring equipment is sufficiently reduced, then the duty cycle of the pulses as appearing at the detector will be increased. If sufficiently narrow bandwidths are employed, then the overload problems of present equipments are avoided. Another advantage of the narrow bandwidth is the increased possibility of measuring the interference through radio signals present on the air. For example, when attempting to measure interference from the pulse circuits of radar transmitter, it is often difficult to find frequencies in the region 5 to 25 megacycles which are clear enough of station signals to measure the interference when using present equipment having a bandwidth of some 6 kc.

If measurements are made on impulse emission and the bandwidth is kept wide enough to prevent overlap at the detector, then the average value of voltage will be independent of bandwidth. In addition, continuous wave and many types of modulated signals will not be affected by the bandwidth or by the modulation provided the bandwidth is sufficient to pass the modulation sidebands. Signals having a varying value of the average voltage with different modulations will, of course, show change. Random noise will increase with the square root of bandwidth.

For signals, the average value of which vary with modulation, for example, suppressed carrier telephone transmissions, the most appropriate method of measurement is probably a quasi-peak arrangement which is an approach similar to the VU meter used in audio work.

Pulsed signals, such as those encountered in radar, may be measured by peak methods, but the results may have to be altered to evaluate their interfering effects because of the difference in repetition rates. Pulse signals which are modulated in amplitude, width of pulses or frequency of pulses may better be measured for most purposes in a quasi-peak or averaging circuit.

The partioular parameters of signals or interfering emission which should be measured depends on the purpose of the measurements and the conditions under which measurements must be made. If we are interested only in comparing the ratio of two signals identical except in amplitude and under interference-free conditions, it probably makes little difference what detector constants are employed, except that we may still have to consider overload problems. However, if we are comparing emission having a different waveform, then the choice of detection constants may greatly affect our ratio. If we are attempting to compare the interference effects the several emissions may have on some radio service, the detector constants may greatly affect the result.

The presence of other emissions may also affect our choice of detector and bandwidth constants. If we are endeavoring to measure ignition or similar [illegible] emission, we may find that broad bandwidth and peak detector circuits are preferable. However, if we have some very strong local signals present we might prefer a narrower bandwidth. On the other hand, if we were trying to measure a CW signal in the presence of ignition interference, a narrow bandwidth and an averaging detector circuit would be preferable. However, for measuring a signal such as FM, too narrow a bandwidth might not be desirable. For measuring a keyed telegraph signal, a quasi-peak circuit has advantages. However, if the charge time is made too small, the desired telegraph signal might be obscured by ignition or atmospheric interference.

The above considerations are not academic but involve very real practical problems. From these considerations, it appears rather evident that any single measurement standard isnot feasible. On the other hand, correction of one set of measurements made with one set of parameters for comparison with a set made with another group of parameters is rather difficult, especially where the emission under measurement is not one type but a mixture of types, such as impulse and random white noise.

It is therefore considered proper that several discrete families of parameters be provided to assure reasonable flexibility, but at the same time to facilitate direct comparison of measurements by different organizations. For certain studies, measurements need be made only under one condition. However, where interference capabilities are of interest, or emissions of different types are to be compared, measurements should be made using several sets of the discrete parameters in order to provide a more complete description of the emission.

In order that measurements made by different investigators may be compared, it is proposed that certain parameters be standardized and that whenever possible all data be taken at one or more of the discrete bandwidths and time constants. Measuring equipments for any particular frequency range should provide a choice of several of these values. Suggested standard values are shown below:

Bandwidths (kilocycles)

.20	63
0.63	200
2.0	630
6.3	2000
20	6300

Time Constants - Average Measurements (a)
(Average of voltage over period specified in seconds)

.001
.01
0.1
1.0
10
100 (b)

(a) The initial r.f. by-pass capacity in the detector circuit must be small enough to avoid peak responses rather than average.

Time Constants - Quasi Peak Measurements (Seconds)

Charge	Discharge
.001	0.160
.001	0.600
.010	0.160
.010	0.600
.100	1.60
1.00	6.00
1.00	100 (b)
10.0	100 (b)

(b) These values are included primarily for use in continuous recordings of radio signals or atmospherics.

The foregoing value of bandwidths have been chosen with a view of obtaining approximate coincidence with presently-available equipments where possible without sacrificing a reasonable uniformly-stepped set of values.