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Project NY 411 002-1
Technical Memorandum M-116

A PRACTICAL HANDBOOK FOR LOCATION AND PREVENTION OF RADIO INTERFERENCE FROM OVERHEAD POWER LINES

21 November 1956

u. s.
naval
civil
engineering
research
and
evaluation
laboratory

port hueneme,
california

OBJECT OF PROJECT

To conduct research and development studies leading to more effective methods, equipment, and facilities for the detection, location, measurement and control of electromagnetic interference sources.

OBJECT OF SUBPROJECT

To conduct studies leading to a more effective control of electromagnetic interference associated with power distribution systems.

OBJECT OF THIS REPORT

To serve power line design engineers, construction foremen, and maintenance crews as a practical guide for a better understanding of electromagnetic-interference phenomena and in the design and maintenance of interference-free power distribution systems.

RESULTS

The report achieves a brief, concise presentation of the electromagnetic interference problems associated with power distribution systems and provides a ready reference for some of the more common control methods and procedures.

U. S. Naval Civil Engineering Research and Evaluation Laboratory
Port Hueneme, California

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21 November 1956

J. C. Senn
D. B. Wright

SUMMARY

This handbook is written primarily for the use of Public Works personnel responsible for the design, construction, and maintenance of overhead power distribution systems which must be free of electromagnetic interference. It describes in non-technical terms the common causes of power line interference and lists practical measures required for the location and elimination of these causes.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

With the ever-growing use of more and more sensitive radio frequency equipment and instrumentation, it has become increasingly apparent that knowledge and techniques for reducing electromagnetic interference are needed. One of the most common sources of interference at Naval Shore Establishments is the electrical power distribution system, particularly when the system includes overhead lines. Methods of preventing or reducing interference from overhead lines are relatively simple, and are practiced, to varying degrees, quite widely by the public utility companies. The lack of a complete collection of published information on the subject has resulted in considerable confusion and sometimes in conflicting or contradictory practices. In this report, an attempt has been made to collect and describe under one cover the causes and the best methods of prevention of radio interference from overhead power lines. Such a collection of information should be of great value to Public Works design engineers, line foremen, and others who may be responsible for designing, building, and maintaining interference-free power distribution systems or sub-transmission lines.

DESCRIPTION OF INTERFERENCE

Some of the important characteristics of radio interference must be understood before its effects can be fully appreciated. Probably the most important characteristic is frequency. Any particular radio device can be tuned to a specified frequency at which it will accept a desired signal and reject any signal having a different frequency. Unfortunately, most power line interference sources are "broad band" that is, they contain signals at a large number of different frequencies. The result is that there is likely to be an interference signal at any frequency to which the receiver is tuned, and therefore the receiver cannot reject the interference signal and the wanted signal will be drowned out by "noise." Since the Navy operates various types of

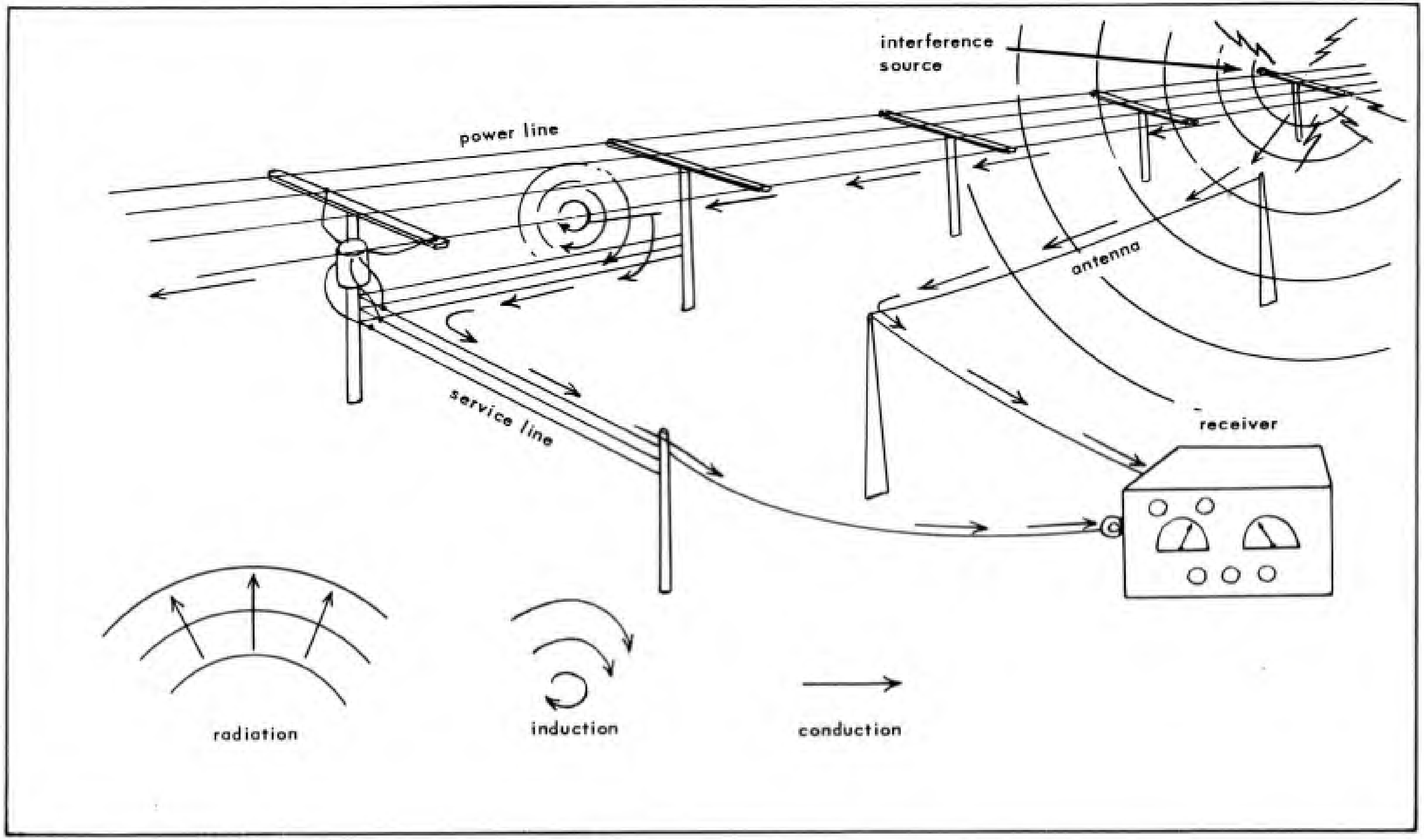


Figure 1. The mechanisms of propagation or coupling of interference from power lines.

equipment at frequencies from 14 kilocycles to 1000 megacycles or higher, it is necessary to prevent interference throughout that range.

A second important characteristic is the intensity, or field strength, of the interference signal at the antenna of the receiver. For practical purposes, the field strength is relative and important only in proportion to its relation to the field strength of the wanted signal. The ratio of the desired signal's intensity to the intensity of the interference is the "signal-to-noise ratio," or "SN ratio," and is usually expressed in decibels. The higher the SN ratio, the less effect the interference will have. The least SN ratio that is commonly acceptable is 30 decibels, a voltage ratio of approximately 32 to 1.

Another important characteristic of interference is the manner in which its energy is propagated from the source to the receiver. This energy can travel by any one or simultaneously by all of three means: conduction, induction, or radiation. The energy travels by conduction when it flows along the power line conductors, through the transformer, and into the receiver power supply or wiring. It travels by induction when the power line conductor or power supply lead carrying the interference energy is near enough to the antenna or some part of the receiver circuit to couple the interference energy into the receiver by transformer action. The third means is by radiation, in which the energy is launched into space by the overhead line or line hardware acting as a "broadcasting" antenna. In this instance, the energy can be radiated from a distant line and be reflected from a nearby fence, power line, metallic building, etc. Examples of the mechanisms of propagation are illustrated in Figure 1. Propagation by the first two methods is most important at very low frequencies because the conduction current decreases more rapidly with distance along the line as the frequency is increased. At higher frequencies, radiation becomes more efficient and is likely to be a more serious source of interference than conduction currents or induction fields. In any case, however, power line interference tends to be roughly in inverse proportion to the frequency, that is, the higher the frequency, the lower the interference level. Above a frequency of, say 25 megacycles, conducted power line interference is very likely to have its source within a distance of five to ten pole line spans of the receiver affected. On the other hand, there have been reports of objectionable radiated interference originating from sources as far as 30 miles away.

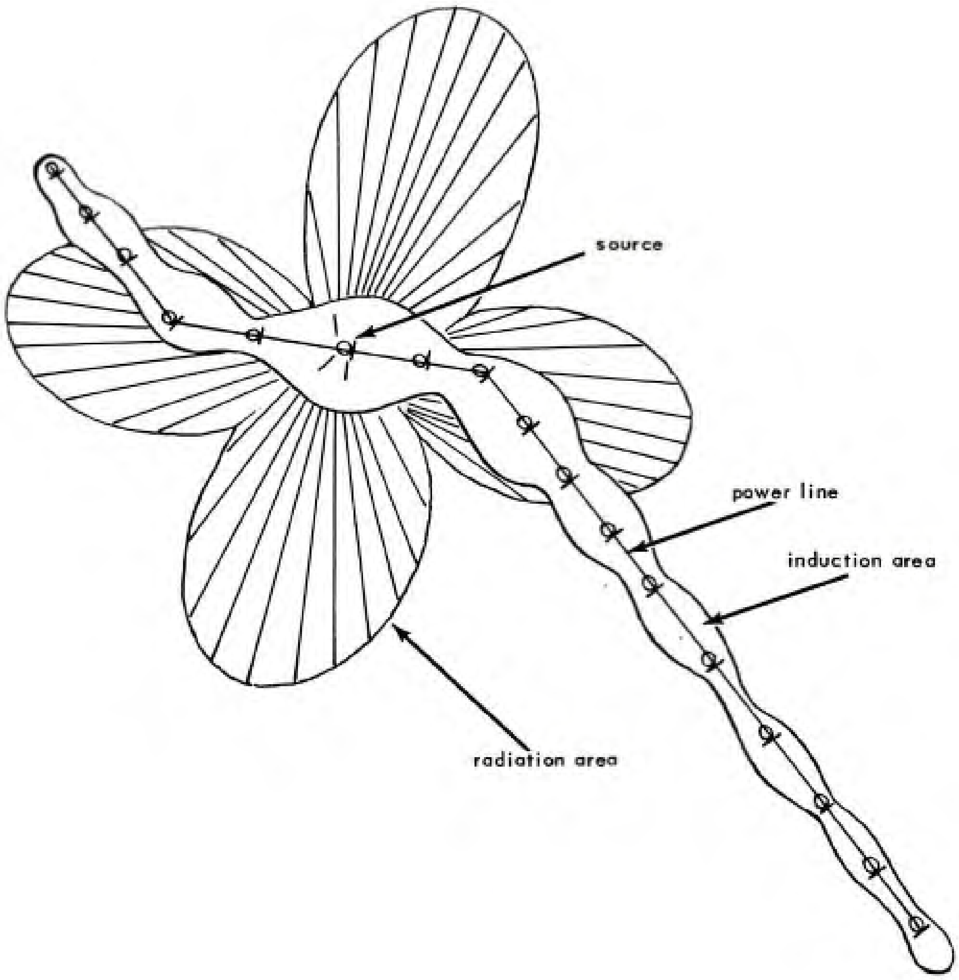


Figure 2. Relative areas affected by radiation and induction at one frequency.

AMOUNT OF SUPPRESSION REQUIRED

In practice it is impossible to eliminate radio interference entirely; therefore, it must be known what is an acceptable level of interference. A good starting point for determining this acceptable level is the required signal-to-noise ratio of the receiving equipment which will be affected. It has been pointed out that an SN ratio of 30 decibels is generally accepted, but it is possible that a particular set will require a higher SN ratio. In some instances, certain sensitive relays, such as those used in computers, could be operated by low level interference signals, so the interference would have to be kept below the sensitivity level of such relays. It would then be necessary to know what the highest interference levels likely to be found on a power line are, how these levels are affected by distance and frequency, and how these can be reduced to tolerable values.

It has been determined that power line interference depends to a small extent on the voltage of the power line, being slightly higher as the voltage is increased if there is no corona. When the lines commonly used on a Naval Shore Station are properly designed and built, corona discharge is not likely to be found. Radiated interference is inversely proportional to the square of the distance from the line, thus if the interference level is 1000 microvolts per meter at a distance of 100 feet from the line, it will be approximately 10 microvolts per meter at 1000 feet from the line, at a given frequency. Radiated interference does not follow the line for great distances, but will cover a broad area to the sides of the line. Conducted interference also decreases with distance, but in a more complex way; the logarithm of the maximum value of conducted interference voltage is inversely proportional to the distance along the line at a given frequency. The voltage actually has a periodic series of maximum and minimum values due to standing waves along the line, but the natural logarithm of the voltage at each maximum point will be in inverse proportion to the distance. For low frequencies, the proportion is very small, and the reduction in interference with distance will be only one or two decibels per thousand feet of line. Conducted and induced interference affect only a narrow area to the sides of the line, but may follow the line for many miles. The consequences of the above characteristics of radiated and conducted interference are illustrated in Figure 2. The induction field is a direct result of the conducted current; therefore, the area affected by the induction field alternately increases and decreases in width because of the standing waves in the conducted current.

The logarithmic decay of the conducted current results in successively narrower maximum widths of the affected area as the distance from the source is increased.

If there are local impedance changes on the line, there will also be sharp changes in the width of the area affected by the induction field, but the area will always be centered about the main line and taps. Figure 2 also illustrates in a rough way the area affected by direct radiation from the interference source. Since the radiation field does not depend for its support on the line conductors, it will tend to affect a much broader area. It must be pointed out here that the illustration is an attempt to show not the absolute effect, but only the areas in which each type of propagation is predominant. There is actually no real limit to either area. Both effects are always present, but the radiation field is very small in comparison to the induction field near the line and large in comparison to the induction field at greater distances from the line. For other frequencies, a different standing wave condition and a different number of radiation lobes can result, but the same rough relationship of the affected areas will hold.

The maximum level of conducted interference on a power line due to faulty construction or operation is not likely to exceed 400,000 microvolts at a frequency of 20 kilocycles. This value is approximately 30 to 79 times[1] the value in microvolts per meter that can be measured by a receiver directly under the line; therefore, the maximum interference directly under the line will have a peak value of from 1300 to 5070 microvolts per meter at most. These values will be roughly in inverse proportion to the frequency, and in inverse proportion to the square of the distance from the line. Generally, for normally-operating lines, the interference levels will be considerably lower than those quoted above. Based on Canadian and Federal Communications Commission regulations, Foust and Frick[2] have recommended a value of 50 microvolts per meter as the maximum acceptable radio interference voltage to be measured directly under a line at midspan. This assumes that the receiver is at a reasonable and normal distance from the line so that the maximum interference voltage at the antenna will be 50/3.2 or 15.6 microvolts per meter. Although this level is above the limits set in Navy Radio Interference Specifications[3], it is impossible in practice to measure levels much lower than this on any shore station because of atmospheric and other ambient noise, and because of internal noise in the measuring equipment.

SOURCES AND CORRECTIONS FOR POWER LINE RADIO INTERFERENCE

For convenience, the sources of power line radio interference can be divided into the following six classes:

I. Conductors
II. Insulators
III. Hardware
IV. Switchgear and line apparatus
V. Utility equipment
VI. Foreign lines and equipment

In the discussion to follow, each class will be defined, the mechanism by which the interference is introduced into the line will be described, and practical methods for reducing interference from that source will be described. Table I in the Appendix briefly lists sources and corrections for classes I to IV for easy reference.

I. Conductors. This class includes the line wire, the tie wire, or the clamp used to secure the conductor to the insulator, bond wires, ground wires, and connectors.

Two mechanisms of interference production are involved. The first is the intermittent spark discharge due to a localized excessive voltage stress. The second is a localized corona discharge due to ionization of the air in the vicinity of the conductor. Voltage overstress and spark discharge occur when the conductor is partially insulated by corrosion products, "weatherproof" insulation, or a very small air-gap to some other metal part on the pole. As the line voltage increases during a quarter cycle, it reaches a value that will cause the insulation to break down momentarily and discharge through the capacitance of the insulator. Such a discharge can take place once during each half cycle of the 60-cycle voltage, or it may occur several times during each half cycle, resulting in 120 or more sharp pulses each second. Such a series of pulses are shown for one cycle of the power line voltage in Figure 3. Since the discharge current rises very suddenly in each pulse, the pulse will contain a large number of harmonic frequencies, and radio interference currents result. These currents are coupled into the line conductors which will conduct and radiate the energy.

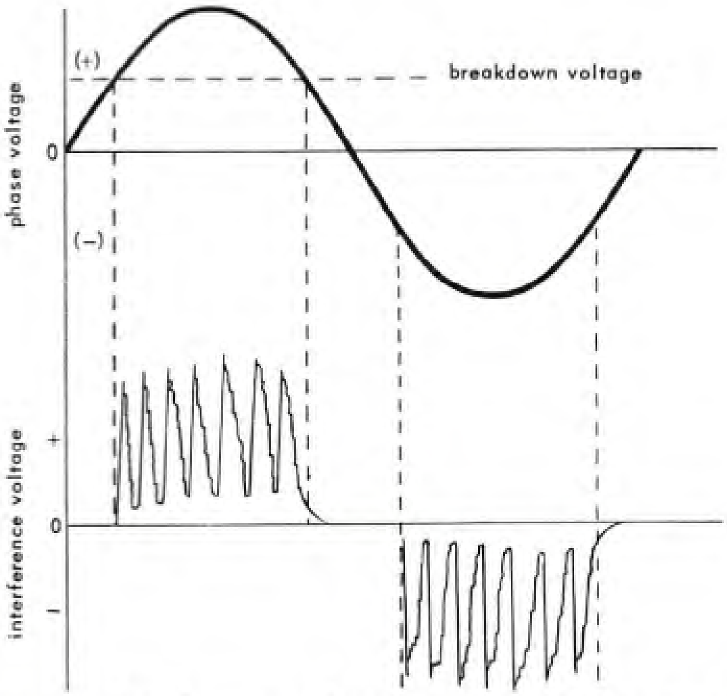
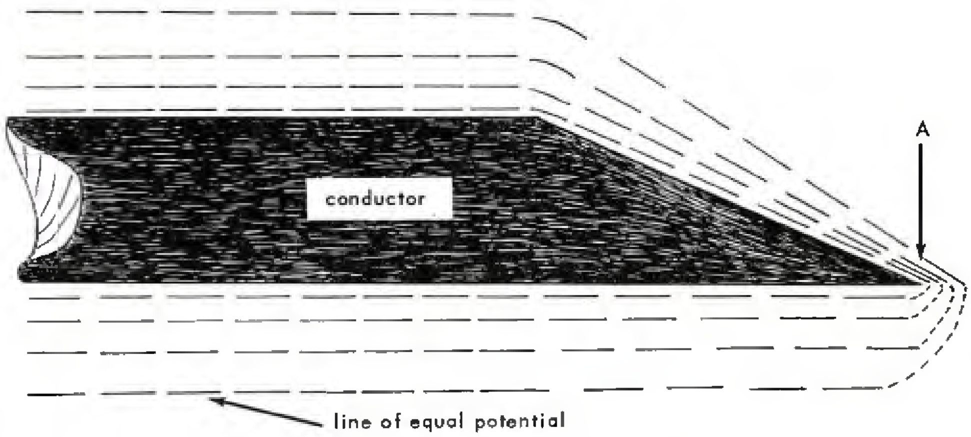


Figure 3. Interference pulses caused by insulation breakdown. Each pulse contains a large number of harmonic frequencies.

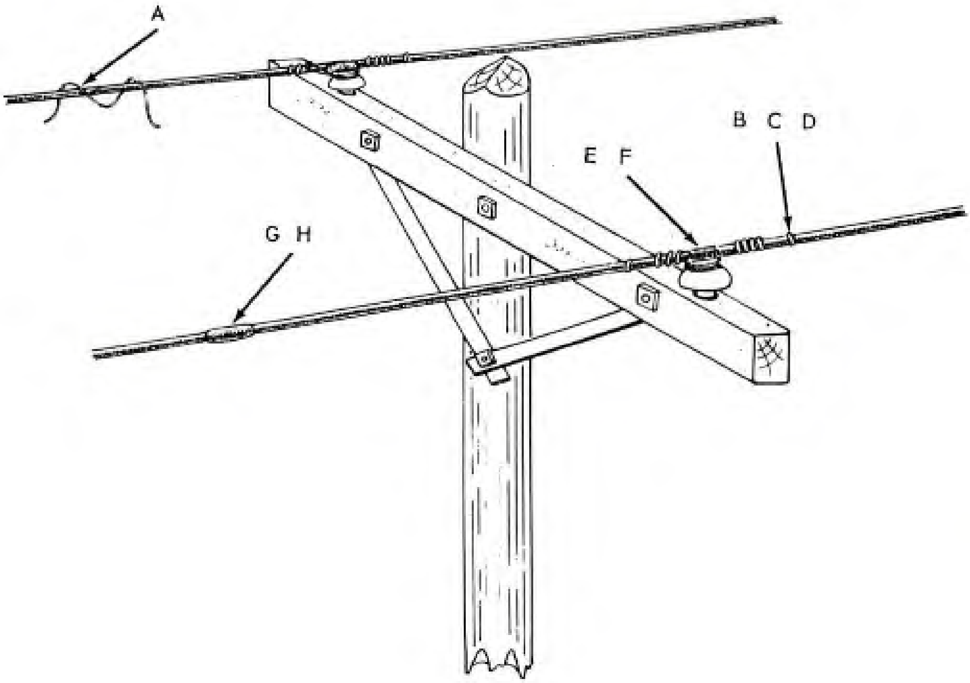


Note: The lines of equal potential are crowded at A, resulting in a greater voltage difference per unit distance across the air which may cause the air to ionize.

Figure 4. Voltage overstress at a sharp point on a conductor.

Corona discharge results when the voltage gradient at a conductor surface is made too large by the existence of a sharp point or edge on the conductor or tie wire.

Figure 4 illustrates the manner in which an excessive voltage gradient can be developed near a conductor. This illustration can be considered as a cross-section of a sharp-pointed conductor and the electric field which surrounds it. Each broken line represents the edge of an imaginary cylinder around the conductor. The voltage from "ground" is the same at any point on a given cylinder. The voltage between any pair of cylinders, or equipotential surfaces, is the same as between any other pair. The voltage stress on the air, then, will depend on the spacing of these equipotential surfaces. At the point of the conductor in Figure 4, the surfaces are crowded very close together; therefore, the number of surfaces per inch of air is much larger than the number along the straight section of conductor. The result is that the air is stressed by a larger voltage per inch or voltage gradient. Electrons in the air are accelerated by this voltage gradient with sufficient violence to ionize the air near the conductor. The ions are themselves accelerated and cause other ions to be formed. Since ions are charged particles, their motion through the air constitutes an electrical current flow from the air into the conductor. Again, the sharp breakdown during each half cycle results in current pulses rich in radio frequency harmonics and radio interference is generated. Another troublesome type of conductor interference is known as external cross-modulation, which is most often the result of a corroded connection. If the line conductor should pick up two or more fairly strong radio frequency fields, a corroded joint in the conductor will cause non-linear rectification of the two currents. The resulting phenomenon is the same as takes place in the mixer stage of a superheterodyne receiver: a large number of "beat" frequencies are set up and conducted or radiated by the line. The corrosion that causes this effect can occur, especially in coastal or industrial areas, when a splice is made by twisting or serving the two conductors instead of using a more positive mechanical splice. When conductors of dissimilar metals must be joined, corrosion will always occur unless special connectors designed specifically for that particular combination of metals are used. Examples of such connections are: aluminum primary to copper transformer leads, aluminum primary to copper primary conductors, copper ground wire to iron transformer case, copper ground wire to exposed steel core of ground rod, etc. External cross-modulation also can occur at corroded- or dissimilar-metal junctions on metal building materials, fences, etc.



A - Keep conductor clear of bits of wire, kite strings, etc.

B - Keep ends of tie wires away from insulator.

C - Use only bare soft tie wire.

D - Avoid sharp points and protruding ends on tie wire.

E - Make sure tie wire is tight.

F - Strip insulation from conductor and make close contact with the insulator.

G - Use only approved pressure connectors, automatic splice or sleeves for splice.

H - Use special bimetal connector to connect dissimilar metal conductors.

Figure 5. Corrections for common sources of conductor interference.

The remedies for conductor interference are relatively simple. Figure 5 illustrates some common practices required for the prevention of conductor interference. These are:

1. Insure good contact at line splices by using pressure sleeves or automatic splices, never twisted wire splices.

2. Always use a bare, annealed copper tie wire or pressure clamp.

3. Install tie wires so that they cannot become loosened by wind or temperature changes.

4. Use approved corrosion-resisting spring-loaded hot line clamps and make certain they are tight. These should be checked for corrosion and loosening whenever routine maintenance checks are made.

5. Insure that ground wires, bond wires, and all staples (including parts hidden in the wood) are at least 1-1/2" from any ungrounded metal parts such as transformer brackets, crossarm braces, and through-bolts.

6. Clamp bond wires or ground wires only against other metal parts. Wood will shrink and loosen the ground wire. The wire should be clamped against a washer or locknut. (see III, "Hardware").

7. Make sure that all conductors not in use on the line are securely grounded at frequent intervals along the line. This is required for safety, and is necessary to prevent radio interference.

8. Remove all sharp points from tie wires or conductor "serves," and seal split-bolt connectors in an approved sealing compound or insulating tape. Form a loop or eye at the end of any projecting end of wire.

9. On insulated line conductors, strip the insulation from the wire where contact is made with the insulator.

10. Keep lines cleared of "trash" such as kite strings, bits of wire, etc.

11. Always use special connectors designed for the purpose if dissimilar metals must be connected together.

II. Insulators. This class is self-explanatory. The mechanism by which insulators produce radio interference is the same as for conductors, i.e., creation of current pulses by momentary breakdown due to overstress. The overstress can occur in one or more ways. One is by way of leakage paths created by dirt or salt, and moisture on the surface of the insulator. A second is through hairline cracks in the insulator glaze. Another type of intermittent discharge occurs when the insulator does not fit tightly on the insulator pin and the air space between pin and insulator breaks down. Occasionally, the insulators used are not properly selected for the line voltage and for local weather conditions such as fog or salt spray. Also, in some instances, a grounded neutral wire has been installed on a bare metal neutral bracket without an insulator. When this bracket becomes corroded, an intermittent discharge to the ground wire occurs.

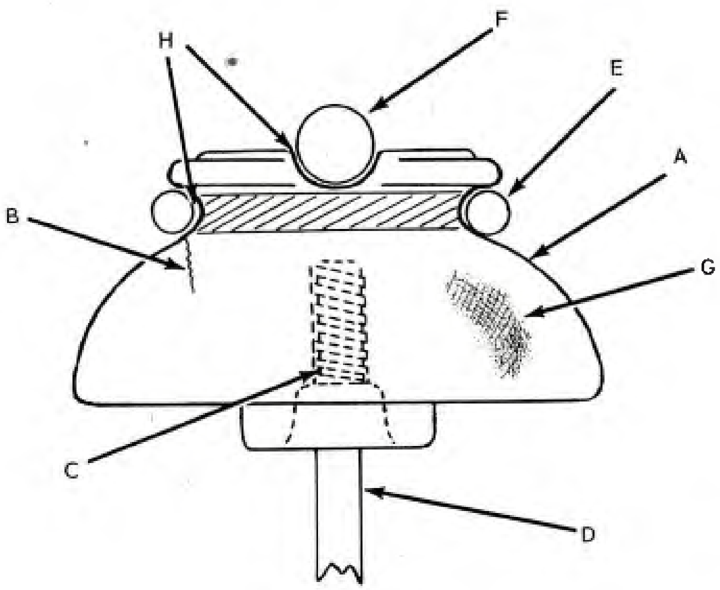
Some special techniques and materials for the reduction of insulator interference can be described at this point. It has been found that normal insulators produce high interference levels because of the uneven distribution of voltage stress. This stress can be "graded" by the use of a special semiconducting glaze formed just below the surface of the conventional glaze during manufacture. This special glaze is inexpensive, does not appreciably alter the insulating quality of the insulator, and reduces the insulator interference to a negligible fraction of the usual value. Such insulators are available, when specified, from all the major insulator manufacturers under various designations, such as "silentype," "radio-freed," "radio-proofed," etc. It must be remembered when specifying this type of insulator that its use will prevent only the interference which was formerly caused by normally operating insulators, and will not necessarily have any effect on other types of insulator interference. In order to qualify for the "interference-free" designation, each insulator must be tested by the manufacturer against a specification which requires a maximum radio influence voltage (on the line) of 50 microvolts for all insulators rated 79 kilovolts or less.

Another special material available from insulator manufacturers is conducting paint, which is useful for grading the voltage stress in the conductor and tie-wire grooves. The paint is simply brushed into the grooves and allowed to dry before the conductor is installed. Sometimes, conduction paint is used as an expedient to paint the outside surface of conventional insulators or to apply under the metal cap used on some insulators. This treatment of conventional insulators is effective, though not as permanent as might be desired. It can be used to extend the useful life of old insulators which otherwise might have to be replaced by interference-free types.

For the higher voltage ratings, clamp-top insulators are available in interference-free design. The clamp provides a more intimate and more positive conductor contact than the tie top, is simpler to install, and prevents conductor slippage, loosening, and abrasion.

In many areas, heavy surface contamination of insulators is caused by salt spray, dust, industrial fumes, concrete dust, etc. This contamination ordinarily is not harmful if heavy rains are frequent enough to keep the insulators washed. However, if light rains or fog are common, the contaminants collect moisture and cause not only radio interference, but also crossarm charring, pole-top fires, and insulator flashovers. Many utility companies make regular circuits of their lines, washing all the high voltage insulators with a high pressure stream of water from a fire hose on a truck. This operation can be performed under proper, experienced supervision without interrupting service. The hose nozzle must be securely grounded for the operator's protection, and the operator should be provided with a well-insulated platform on the truck. It is usually most convenient to arrange a contract agreement between the Naval activity and the local utility company which provides that the utility furnish a truck and crew at regular intervals for insulator washing. Since the time required at each pole is only a few seconds, this is not an expensive procedure.

The insulator surface contaminants peculiar to some areas cannot be removed easily by a high-pressure water stream. In this case, silicone materials, such as "Insulcone," are available from the insulator manufacturers for applying to the insulator surfaces. After the silicone is applied to the clean insulator surface, most contaminants will adhere only very lightly and can be easily washed away by a stream of water.



A - Specify radio-free insulators.

B - Check for hairline cracks.

C - Avoid air pockets between pin and insulator.

D - Use only metal pins.

E - Avoid using tie wire too large for groove.

F - See that conductor is bare, clean, and in intimate contact (see H).

G - Do not allow insulator to become too dirty or coated with salt, smoke, etc.

H - Use conduction paint if necessary in tie wire and conductor grooves to insure good contact.

Note: Use fog-type insulators in areas where fog is common.

Figure 6. Insulator interference corrections.

The remedies for insulator interference are almost self-evident, but they are illustrated in Figure 6 and listed briefly below for the sake of completeness:

1. On all new construction, specify "radio-freed" or "radio-interference-proofed" insulators. Whenever an insulator is replaced, make this same specification.

2. In locations where fog, salt spray, dust, or industrial fumes, and smoke are common, schedule the regular washing of primary insulators with a high pressure water spray.

3. Before installation carefully inspect all insulators for cracks, and handle insulators carefully.

4. Use only tight-fitting metal insulator pins. An asphalt emulsion has been used inside insulators to reduce radio interference, but this is not a permanent solution.

5. When designing lines for an area known to have regular fog or salt spray conditions, specify "fog type" insulators. The use of insulators of higher voltage rating has not been found effective in reducing interference under these conditions, though they may be used to raise flashover levels.

6. Always install grounded neutral wires on insulators. A secondary spool insulator is sufficient for this purpose.

7. Use tie wires of proper size for the tie-wire groove. Oversize tie wires will cause spalling or cracking of the insulator.

8. Prevent kinks, dirt, corrosion, or rough spots on tie wires or the conductors at the point of insulator contact. If necessary to insure intimate contact, apply "conduction" paint to tie-wire and conductor grooves.

9. On voltages of 23 kv and above, consider the use of clamp-top, rather than tie-top, insulators for more positive conductor contact.

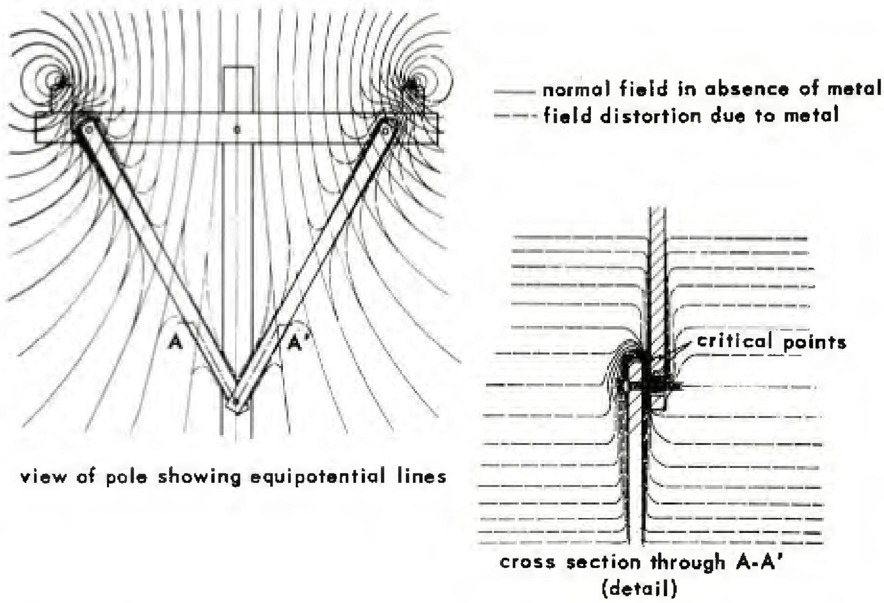


Figure 7. Model power pole illustrating electrostatic field distortion leading to production of power line interference.

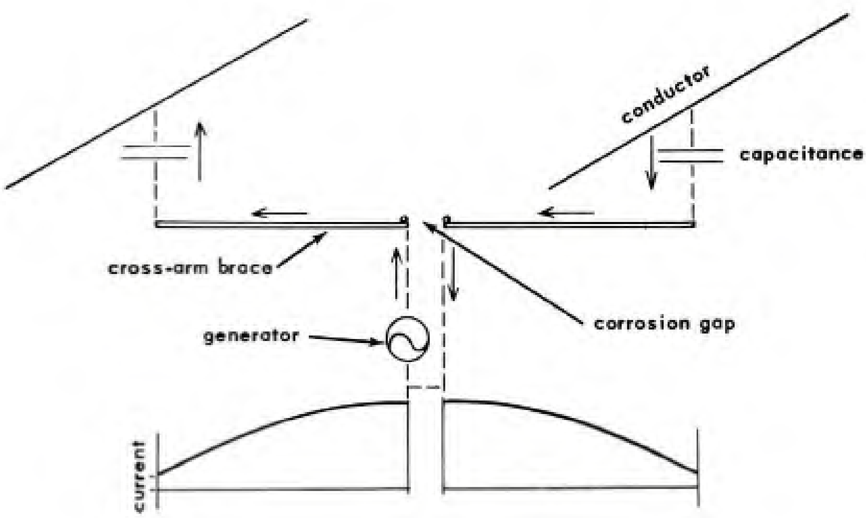


Figure 8. Antenna effect of cross-arm braces.

III. Hardware. This class includes the most frequent, the worst, and often the most baffling of all the sources of radio interference on overhead power lines. The class is made up of all bolts, metal brackets, cross-arm braces, washers, guy wires, clamps, insulator hardware, and staples. The mechanism of interference production is almost always the intermittent discharge through poor insulation, whether the insulation be a small air gap or a corrosion film. The pole line hardware is located in the powerful alternating electric field set up by the line conductors. It also may be in a magnetic field due to the load current in the conductors. Any piece of metal in the electric field forces the field to distort to form lines of equal potential along the metal. When two such pieces of metal are brought very near to each other, there may be a large difference of potential between them, as illustrated in Figure 7. If the two pieces are insulated from each other by a corrosion film or a small air gap, an abrupt insulation breakdown and discharge can occur one or more times on each half cycle, resulting in the previously described harmonic-rich pulse. Figure 8 shows how the pieces of hardware will form a highly efficient dipole antenna at certain frequencies,depending on the size of the pieces. In addition, the interference will be capacitively coupled into the overhead lines which form a good horizontal antenna and which conduct the interference into sensitive areas. The conditions for hardware interference are set up whenever two pieces of hardware either are not securely bonded to each other or are permanently separated by an air gap of at least 1-1/2 inches or a path along the wood of at least 2 inches. The remedies for hardware interference are always, (a) separation, or (b) secure bonding, and (c) tightness to prevent intermittent contact. Following is a list of typical corrections and precautions for hardware interference:

1. Maintain at least 2-inch clearance through wood, or 1-1/2 inch clearance through air from metal insulator pins to any other metal parts such as cross-arm braces, through-bolts, square washers, moulding staples, conduit, etc.

2. Maintain at least 2-inch clearance through wood, or 1-1/2 inch clearance from lightning arrestor and fuse block brackets to any other hardware, including guy wires and guy plates.

3. Maintain at least 2-inch clearance through wood, or 1-1/2 inch clearance through air from any part of a transformer case or bracket to ground wires, staples, or other hardware.

4. Maintain at least 2-inch clearance through wood, or 1-1/2 inch clearance through air from any guy wire or guy plate to any other hardware, including other guys on the same pole.

5. Install only one guy wire on a single guy plate.

6. Maintain tension in all guy wires.

7. Maintain clearance between guy wires and energized conductors, even if the guy wire is fitted with strain insulators.

8. Use only as many guy wires as necessary. Use bridle guys if necessary to give support at more than one point.

9. Maintain at least 2-inch clearance through wood, or 1-1/2 inch clearance through air from street lamp brackets and metal conduit to any other hardware.

10. Use only clean, uncorroded insulator pins. Specify approved corrosion-resistant or "double-galvanized" pins and hardware where necessary.

11. Permanently bond cross-arm braces together on circuits above 5 kv.

12. Where local electrical safety codes permit, bond metal insulator pins or suspension insulator hardware securely together on circuits above 5 kv.

13. If possible, avoid using suspension insulators on slack conductor spans.

14. If suspension insulators must be used on slack spans, use a heavy spring clip or other suitable device to maintain a pressure contact between the metal parts. Temporary relief can be obtained by greasing clevis and pin or ball and socket joint with a grease containing graphite.

15. Maintain tightness of all through-bolts, lags, and nuts. Specify "static-proof" hardware of corrosion-resisting materials to avoid loosening due to wood shrinkage.

Figure 9 is a composite illustration of some of the most common corrections required for hardware interference.

Figure 10 illustrates some typical "static-proof" hardware which provides secure bonding of metal parts and will not loosen due to wood shrinkage. In Figure 10A, a washer-head through-bolt and washer-head nut are shown. Since the washer is an integral part of the bolt or nut, there can be no loose washers making intermittent contact. Loosening of the washer-head nut on the bolt is prevented by using the lock nut shown in Figure 10B. Washer-head nuts should also be used on double-arm bolts. These bolts are available without heads and with threads along their entire length. When assembled with washer-head nuts and lock nuts, such a double arm bolt assembly becomes a single, permanently bonded unit. The spring washer in Figure 10C is used in place of an ordinary round washer, and is most useful in maintaining tightness of insulator pins in wood cross-arm pin holes. The tapped washer in Figure 10D gives the reduction in pressure afforded by a conventional square washer, but has the advantage of being bonded to the bolt by the threads, thus eliminating intermittent contact.

The washer-head lag screw in Figure 10E provides a secure bond at the contacting surfaces between cross arm braces and avoids the necessity of holding the braces against wood subject to shrinkage. The screw is used in place of a conventional lag screw, but the braces are not held between the screw head and the wood. Instead, the braces are clamped securely between the washer head and the nut. The drive-grip lag screw in Figure 10F has serrations on the shank near the head which prevent loosening due to vibration. This type of screw, however, does not provide a secure bond with other hardware.

IV. <u>Switchgear and Other Line Apparatus.</u> This class covers air switches, oil switches, automatic reclosers, regulators, fuses, and power factor correction capacitors. In most instances, interference in this class is the result of faulty design by the manufacturer, or of improper installation or use on the line. Fortunately, the manufacturers have recognized and solved most of the design problems related to interference so this class is a relatively infrequent interference source. The mechanisms of interference production are the corona discharge and the intermittent insulation breakdown previously described, caused by sharp points or edges on conducting surfaces, by improper spacing, or

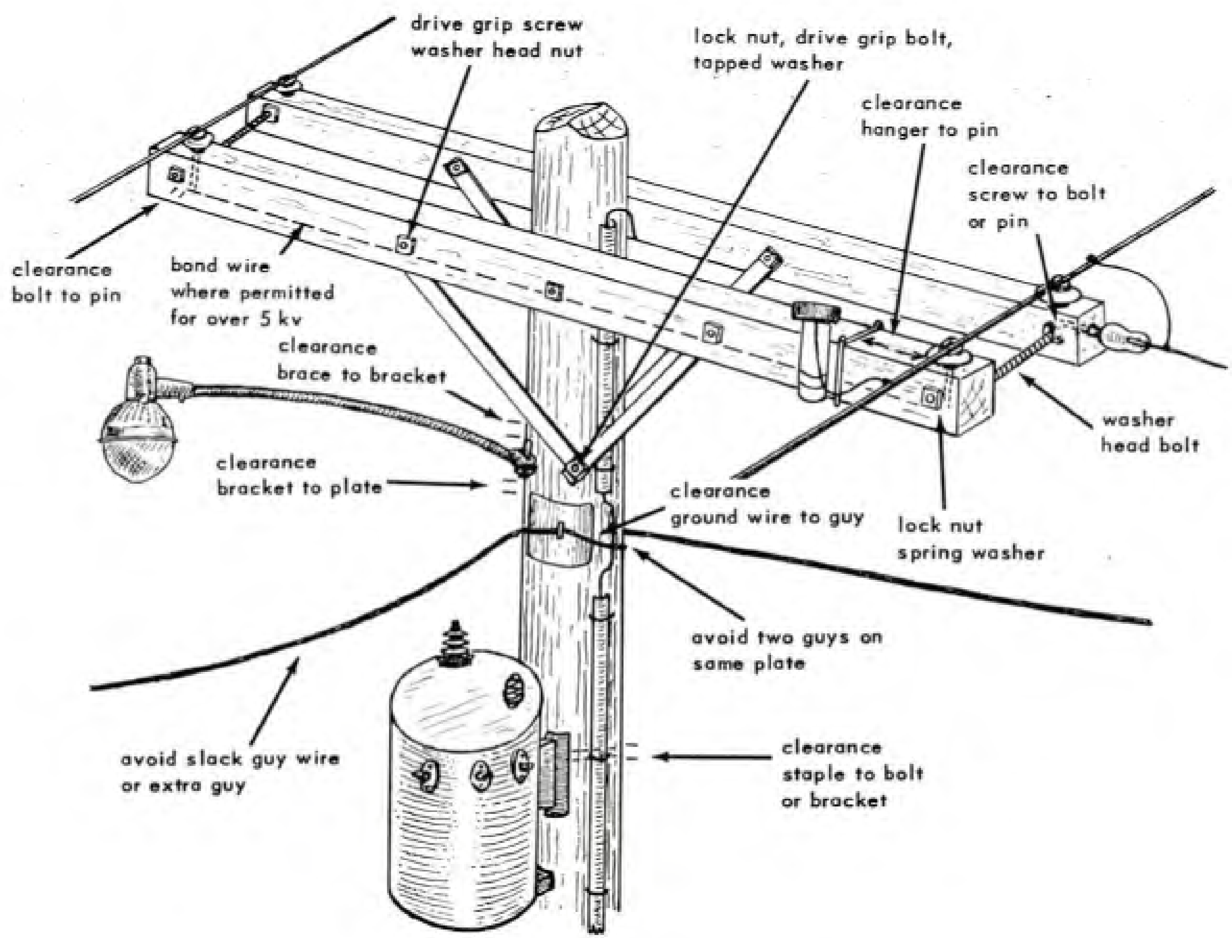
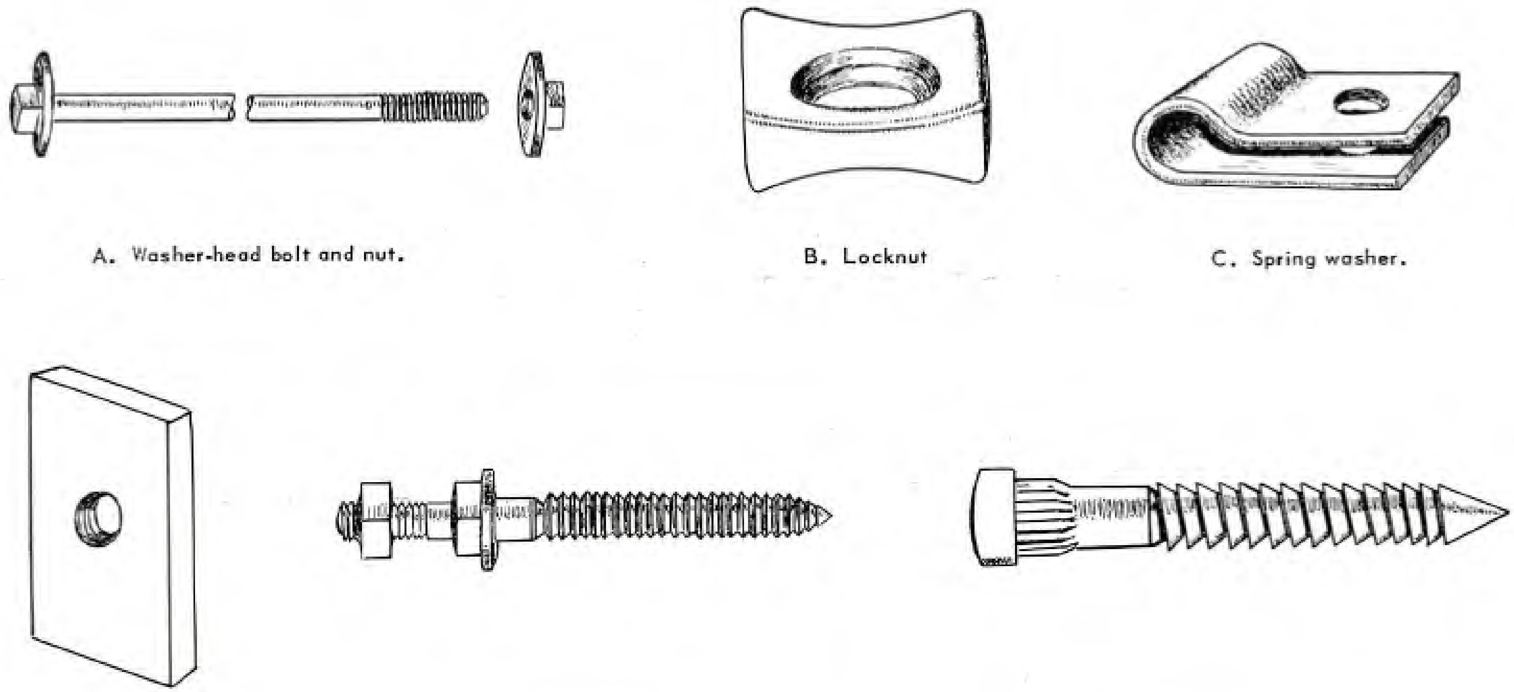


Figure 9. Hardware corrections (clearances) for eliminating interference.



A. Washer-head bolt and nut.
B. Locknut
C. Spring washer.
D. Tapped washer.
E. Washer-head lag screw.
F. Drive grip lag screw.

Figure 10. Some typical "static-proof" hardware.

by air space in insulators, respectively. Following is a list of typical corrections for line apparatus interference.

1. Specify approved corrosion-resistant fuses. Insure that all fuse ferrules make secure contact in the clips. During routine maintenance, inspect fuse ferrules for corrosion or looseness.

2. Maintain at least 2-inch space through wood and 1-1/2 inch space through air from metal conduit and straps on the pole to any ungrounded hardware.

3. Periodically check the load and condition of oil in transformers, perhaps at one-year intervals. Radio interference due to failing transformer insulation is a sure indication of almost immediate disaster.

4. Maintain clearance of at least 2 inches on wood or 1-1/2 inches through air from non-energized metal parts of any switch to any other hardware. Bonding can not be substituted for proper clearance on a switch.

5. Avoid sharp points or protruding strands of wire on the high-voltage leads to transformers, switches, capacitors, and all other apparatus. If a protruding wire must be left, form an eye in the end of it to prevent corona.

6. Use switches of correct voltage rating.

7. In mounting high-voltage apparatus, avoid forming sharp corners or edges on any metal part, whether it is to be energized or not.

8. In order to avoid an interference-producing air space in bushings on oil switches or other apparatus, specify that the apparatus be equipped with interference-free bushings. These are normally supplied on most apparatus. An air space in a high voltage bushing not only causes interference, but will eventually cause the bushing to fail, sometimes with explosive violence.

9. Specify, or have installed, suppressors on contact-making voltmeters or relays for use with automatic voltage regulators.

10. Replace leaky or noisy lightning arrestors immediately.

V. Utility Equipment. This class includes all devices that take their power from the line and are normally operated at low voltage. Potentially, this is the most prolific source of power line interference, and includes almost every possible mechanism of interference production. It is beyond the scope of this report to describe the many suppression techniques required for utility equipment. More important to this discussion is the manner in which such interference can affect sensitive equipment by way of the power line. Interference from utility equipment can be coupled into the power line by any of the three possible ways, namely, by conduction, induction, or radiation. Once it has entered the power line, it can be propagated by any of the same ways to receivers at a great distance from the original source. When such interference is detected, it must be traced to its source and the user of the equipment must be requested to cooperate in applying the appropriate corrective measures. Since the power line engineer or line foreman is not ordinarily responsible for suppression of utility equipment, corrective measures will not be listed, but the following typical utility equipment interference sources are tabulated as a guide to interference location. The list is not intended to be a complete one, but is typical of sources found on or near Navy Shore Stations.

1. DC motors in general
2. Commutator motors of all types
3. Motor-generator sets
4. Electric office machines
5. Electric motor-driven household appliances
6. Laundry equipment
7. Floor waxers and sanders
8. Electric razors
9. Machine drive belts
10. Welders
11. Gaseous rectifiers
12. Spark-ignition oil burners
13. Radar equipment
14. Communications transmitters
15. Radio and television receivers
16. Teletype machines
17. Inter-com systems
18. Phonographs
19. Railway signals
20. Traffic lights

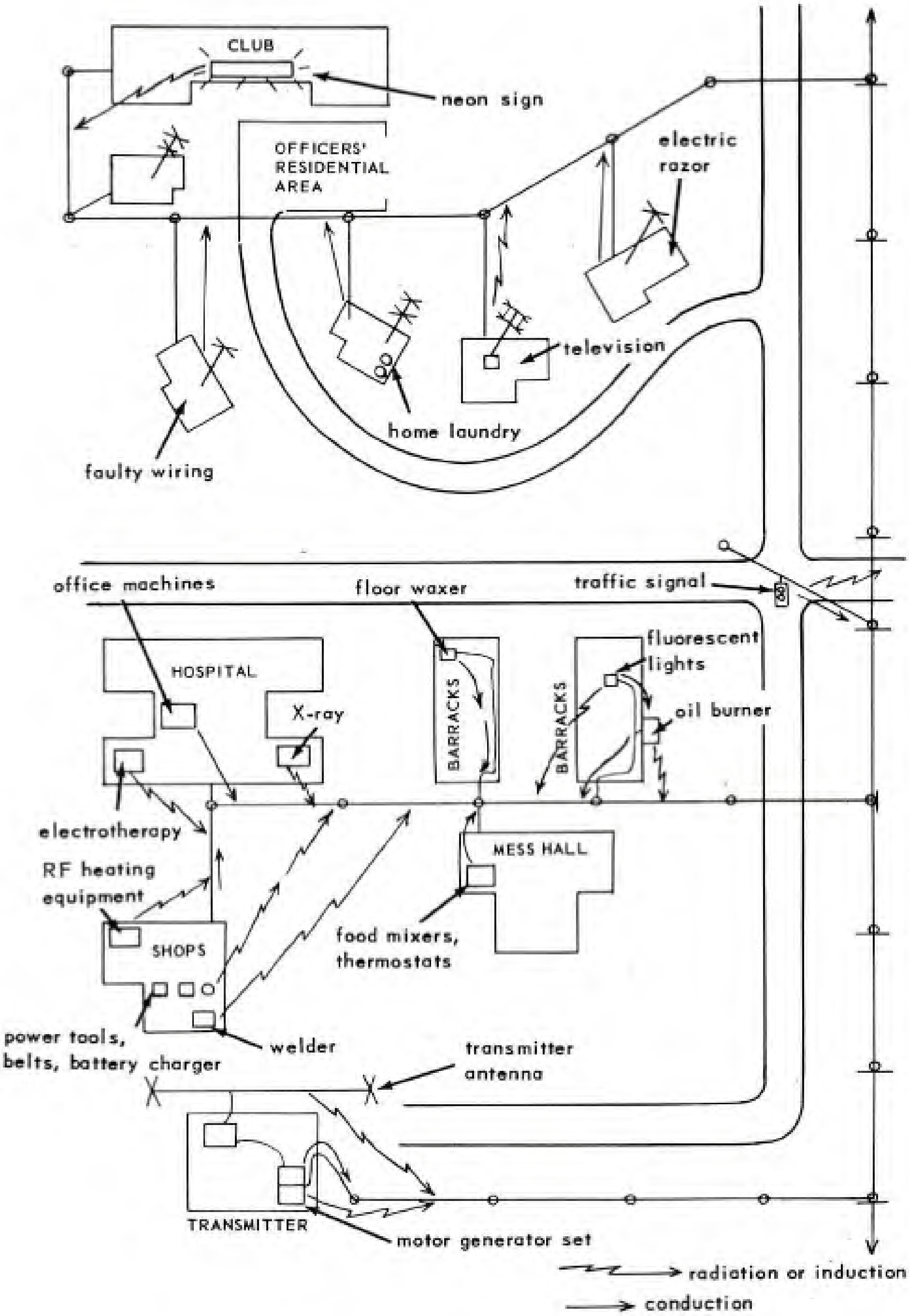


Figure 11. Utility equipment interference.

21. Neon or flasher signs
22. Call systems (doorbells, buzzers, etc.)
23. Induction heating equipment
24. Radio frequency heating equipment
25. Medical diathermy equipment
26. X-ray machines
27. Pasteurizers
28. Ultra-violet lamps
29. Relays
30. Thermostats (blankets, heaters, aquariums, etc.)
31. Electric fences
32. Fluorescent lamps
33. Faulty building wiring
34. Faulty leads to utility equipment
35. Electric heaters
36. Battery chargers
37. Salt spray test equipment

Figure 11 illustrates some of the common utility equipment sources that are found on Navy Shore Stations.

VI. Foreign Lines and Equipment. For the purpose of this discussion, "foreign" lines and equipment will be defined as lines and equipment not intentionally coupled to the Navy power distribution system. These will include power and communications lines not under the control of the Navy which may or may not be coupled to the system through transformers. As is the case with utility equipment, the production of radio interference in this class can occur in many possible ways. This type of interference is not the responsibility of the distribution engineer, and requires the cooperation of those who are responsible. Coupling of "foreign" interference can take place through radiation or induction, but not through conduction. Once on the power line, however, the interference can be coupled into sensitive equipment at great distances from the source by all three of the possible propagation mechanisms.

As a guide to location of foreign sources of interference, some common foreign sources are listed below:

1. All types of automotive equipment having gasoline engines.

2. All types of automotive equipment having a battery-operated starting system with a dc generator and voltage regulator.

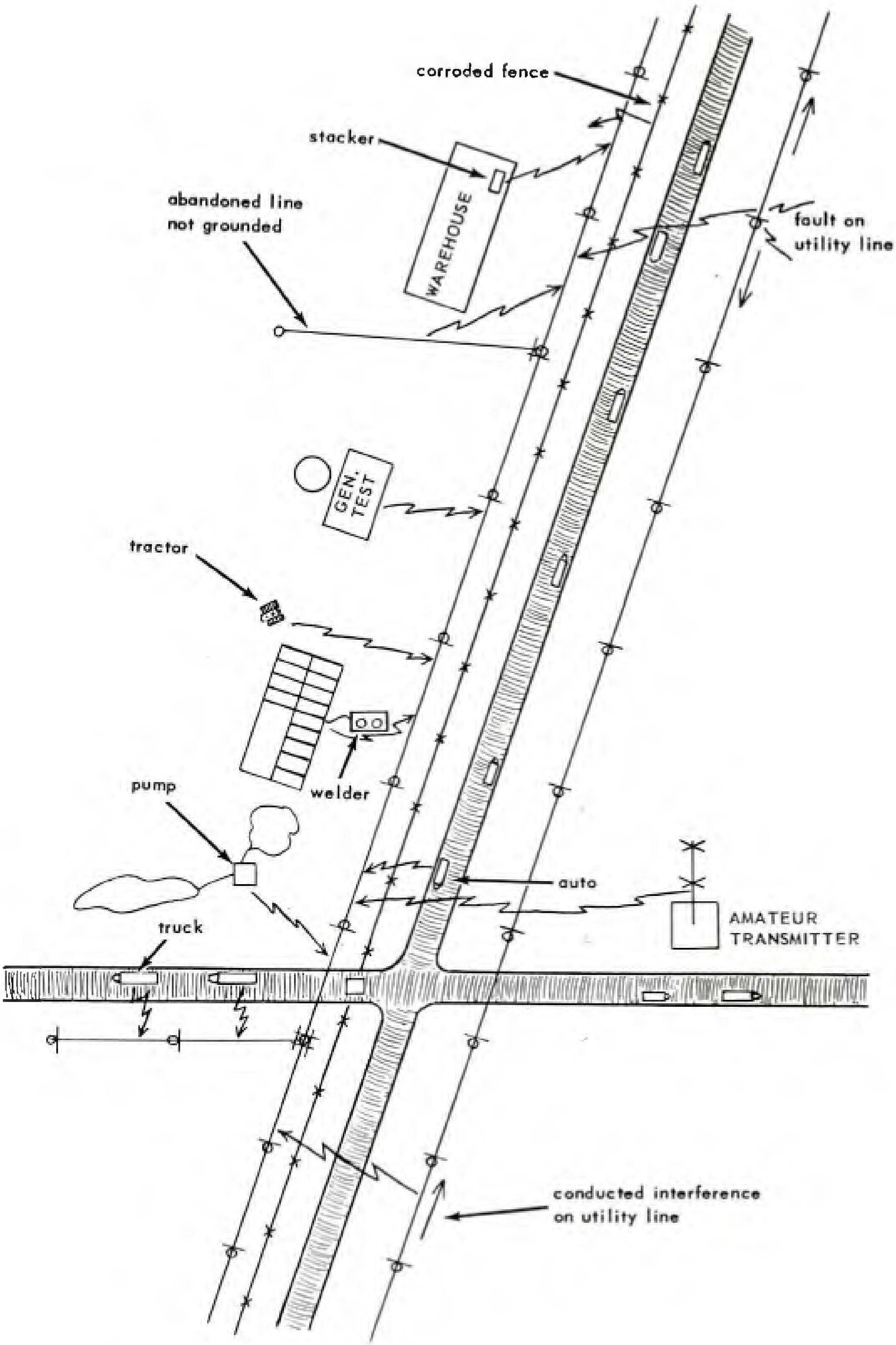


Figure 12. Foreign sources of interference.

3. Self-starting diesel engine-generator sets or construction equipment.

4. Gasoline engine-generator sets or construction equipment.

5. Welders

6. Portable gasoline engine-driven equipment.

7. All types of materials-handling equipment.

8. Ungrounded or corroded metal fences.

9. Amateur radio transmitters and other civilian transmitters.

10. Static discharge from nearby isolated supporting guys, abandoned antennas, or metal building members.

11. Interference on foreign power and communications lines due to any of the causes listed in classes I through V.

12. Generator load banks.

Figure 12 illustrates some of the more common foreign interference sources affecting a Naval Shore Station.

LOCATION OF POWER LINE RADIO INTERFERENCE

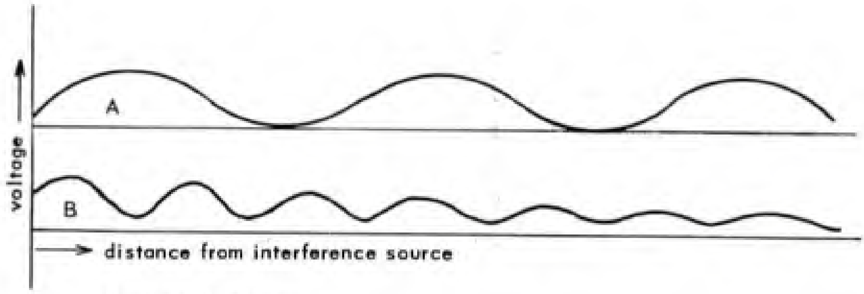
Once a distribution system has been designed and built with careful attention to the details of preventing interference on the lines and apparatus, it is a relatively simple and routine matter to maintain the interference-free conditions. Practically all the requirements for interference-free operation are also requirements for safety, efficiency, and economy. On the best of systems, however, unforeseen effects of nature or accidents will create sources of radio interference. Unfortunately, locating an unknown source of interference is not so simple as correcting it. No simple set of steps can be listed which will guarantee the location of a source in a few minutes. However, some information can be given which will be of great help in finding the source.

Only a few basic tools are required for interference location. The most important is a radio receiver equipped with a directional antenna, a signal strength meter, and a speaker or headphones. Several such "interference locators" are available commercially, but almost any "all-band" broadcast receiver, with minor modifications, will do as well. An ordinary automobile radio equipped with a frequency converter is also suitable. The second important item is an ordinary sledge hammer, which is used to tap a suspected pole in order to note the effect of vibration on the interference level. Also quite useful is a lineman's "hot-stick," equipped with a small neon tube near one end.

The directional antenna is useful in determining whether the interference source is actually on the power line. If the source is not on the line, the antenna will indicate the general location of the source, and will usually indicate the specific equipment causing the interference. A visual inspection of the offending equipment will then, in many cases, reveal the actual cause. If not, a low-sensitivity probe of one or two turns of shielded wire can be substituted for the loop antenna to pinpoint the source.

If the source is determined to be on the power line, the antenna will not indicate in which direction the source can be found. It will then be necessary to travel along the line and associated taps, noting the direction of travel in which the interference increases. The receiver should be tuned to increasingly high frequencies as the search area is narrowed down, because the interference signal level changes faster with distance at higher frequencies, making it easier to determine the right direction. It must be remembered that the interference field intensity has periodic peaks and dips along the power line; therefore, it must not be assumed that the source is necessarily located where the first maximum signal is found. It is the relative intensity of the successive peaks that determine the location. As one travels toward the source, the signal will rise and fall repeatedly, but each peak will be larger than the previous one. Figure 13 illustrates this periodic variation in field intensity, under a power line, for two different frequencies.

There are further complications, however, because any change of impedance on the line will create a new standing wave. Such an impedance discontinuity may cause either an increase or a decrease in the interference voltage, depending on the impedance relationship and



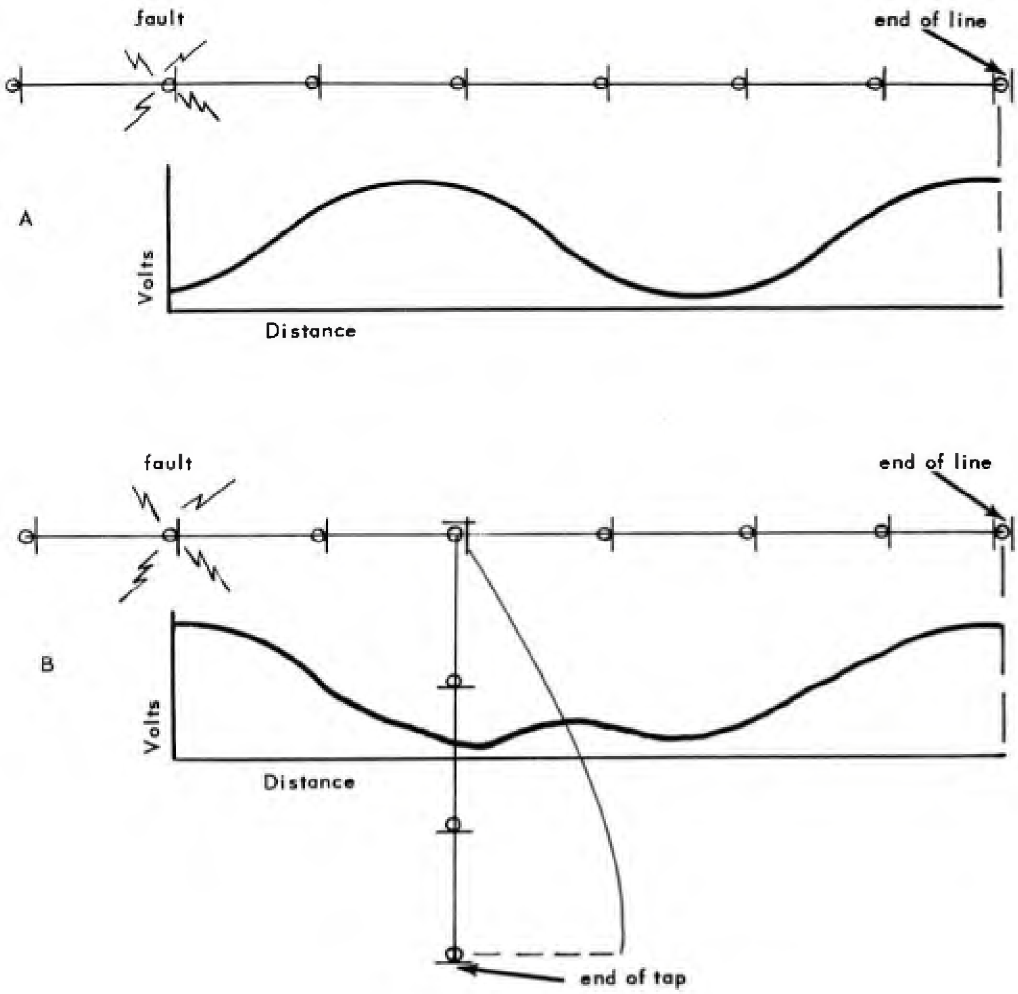
A - Low frequency.

B - High frequency.

Note that the peaks are higher near the source, but the source may not be exactly at the location of the highest peak, since the exact location depends on the loading of the line.

Figure 13. Radio frequency voltage standing waves under a power line.

the frequency to which the receiver is tuned. The most common forms of impedance discontinuity on a power line are caused by "taps" on the primary, transformers, underbuilt secondary circuits or communication lines, service connections, changes in line height or spacing, changes in the number of primary conductors, and deadends. The effect of a tap on the field distribution is shown in Figure 14. Another complication is the normal rise of the interference voltage that occurs at any frequency at the end of a line if the line is not terminated in a low impedance. This is, of course, a special case of impedance discontinuity. A baffling effect sometimes occurs as follows: the receiver indicates a rise in interference level as a certain area is approached from either direction, but a sharp drop is found near the suspected pole. This takes place when a source on the line is feeding interference into the line in both directions, with the result that the impedance to the interference source is low at that point.



A - Radio frequency voltage distribution on line without taps.

B - Radio frequency voltage distribution at same frequency on same line with a tap connected.

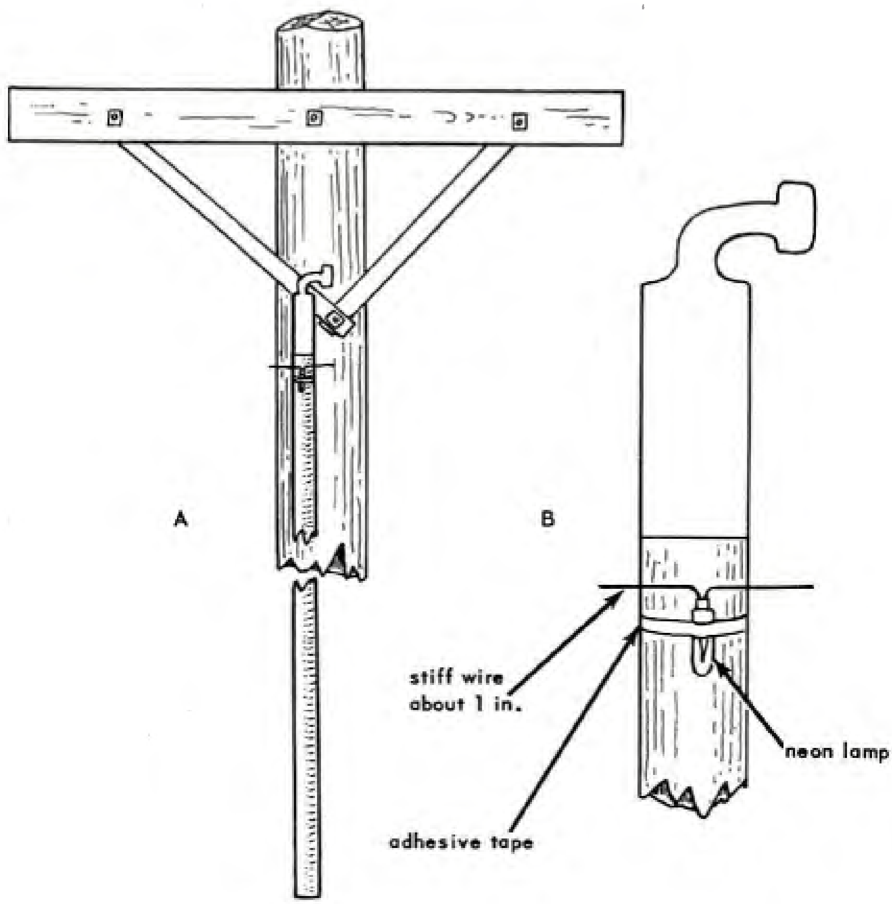
Figure 14. Effect of a tap in field distribution.

When receiver output readings are being recorded in an effort to find the proper direction in which to carry the search, care should be taken to insure that all readings are taken at the same distance from the line. If the line does not follow a road at a uniform distance, it may be desirable to take all readings directly under the line. The location of the peaks can usually be made from a vehicle on the road, however.

The complications described above are so common that, with the exception of cases of obvious malfunctions or damage, the interference source cannot be located without the survey of a large area. A careful visual observation of the line during the search is extremely important. Such observation will often reveal a piece of rusty wire hanging on a line conductor, a loose piece of hardware, a charred cross arm due to a faulty insulator, a nearby arc welder, and so on. Some interference sources produce an audible sound, such as the buzzing sound of a leaking insulator or the snapping of hardware sparks.

When the search has narrowed down to a small area, the sledge hammer and hot line stick can be brought into play. The hammer is used to tap the pole, very gently at first, and the receiver will indicate any change in interference due to vibration. An immediate change is a good indication of hardware noise on the pole being struck, while a delayed change may mean that the vibration has travelled along the line conductors to disturb offending hardware on a neighboring pole. An estimate of the distance to the correct pole can be made by noting the amount of the time delay. It is very important that the pole not be struck with great force, since this may temporarily clear the fault without revealing its cause, and will require duplication of the search at a later date.

The hot line stick is used to gently probe the hardware, ground and bond wires, tie wires, insulators, and so on, while the receiver output is carefully noted. When the offending item is moved slightly, the interference will change or stop, and the cause can be identified. If a small neon bulb is taped on the hot stick near one end, it will serve as an indicator for radio interference fields. The use of the hot stick and neon probe is illustrated in Figure 15. The leads of the neon bulb are bent in opposite directions perpendicular to the stick to form a miniature dipole antenna. When this short dipole is within a few inches of a source of interference, the bulb will glow, and the glow can be seen from the ground.



A - Probing hardware with lineman's hot stick.

B - Use of neon tube on hot stick as interference indicator.

Figure 15. Hot stick probe.

An important clue to identifying a source of interference is the sound it produces in the receiver speaker or phones. Identification by sound requires a great deal of experience and observation for good results, for it is entirely a subjective measurement. Certain types of interference sounds can be described, but the descriptions should not be taken too literally, as the descriptive terms are of necessity extremely loose, due to the lack of any purely objective definition. A few of the common sources are described below in terms of their sound, but the individual operator should be able to make a description, in his own terms, of many others as he gains experience.

1. Commutator motors - "high-pitched, tearing"
2. Corona - "hissing"
3. Insulators - "rasping" or "buzzing"
4. Hardware, corroded - "staccato," irregular
5. Loose hardware - "popping"
6. Fluorescent lamps - "high pitched and rough hum"
7. Traffic lights - regular "clicks" or "pops"
8. Ungrounded conductor with static discharge - irregular bursts of low-pitched "static"
9. Spark ignition - sharp, regular "staccato"
10. Welding arc - "frying"

MAINTENANCE OF RADIO INTERFERENCE CONTROL

The maintenance of overhead lines in radio interference-free condition is of extreme importance for several reasons. The first is the necessity for maintaining good communications, accuracy of radio instrumentation, and uninterrupted control of sensitive relays. Occurrence of radio interference originating on the line itself is often a warning that serious trouble is developing in the power system. Investigation should be made of every source of interference, as soon as it develops, to stop the interference and to forestall a possible power failure. Each additional source of interference that develops multiplies the difficulty of locating any other source; therefore, there is no economy in delaying the location and correction of a source of interference in order to handle several faults at once. If several interference faults are allowed to develop, the addition of unsuppressed equipment to or near the distribution system is likely to go unnoticed, and the control of such equipment will become extremely difficult.

To prevent the development of interference, line crews should be trained to watch for the potential causes of interference. They should be furnished with receivers to listen for interference during all routine maintenance and line patrols, to preclude the need for many difficult searches. A good source of practical information on radio interference for distribution system engineers and line foremen is the publication "Radio Interference from Electrical Apparatus and Systems" by H. O. Merriman, available for one dollar from the Canadian Department of Transport, Air Services Branch, Telecommunications Division. For those interested in more detail or a theoretical approach, a bibliography of recent literature is included in this report.

FIELD SURVEYS

While it is considered beyond the intended scope of this report to discuss in detail the technical aspects of radio interference measurement, the following general information on this subject will be useful to distribution system engineers.

For location of sources of radio interference on power lines it is necessary to have only the very simple equipment previously described. The usual receiver is not in any sense a measuring instrument, but rather a useful indicator. To determine the actual value of an interference signal it is necessary to use highly complex, delicate, and sensitive instruments. These instruments, which are listed and described in some detail in Specification MIL-I-16910A, cover the frequency range from 15 kc to 1000 mc, requiring four complete receivers with individual power supplies, antennas, cables, and other accessories. The instruments all require frequent calibration, and must be moved about only with great care. Only one of the four is truly portable, and all are poorly suited for location work. In spite of the above disadvantages, however, this equipment is the most accurate available for making field surveys. At frequencies of 25 megacycles and below, interference can be measured in terms of its magnetic field by use of a loop antenna. At all frequencies, measurements can be made on the electric field using a whip or a dipole antenna. Weighting circuits, made up of appropriate condensers and resistors are used to give an indication of the interference field in terms of "peak," "quasi-peak," or "field intensity" values. The peak value is an approximation of the actual maximum amplitude of individual pulses. The quasi-peak circuit stores up several successive peaks for a short time, and the reading will depend on how fast the peaks occur. The field-intensity circuit stores up the impulses for an even longer time and indicates the average value of the interference. The most useful reading for survey purposes appears to be the peak value, although the quasi-peak reading is favored by some authorities as a better indication of the nuisance value of the interference.

When a field survey is made, the usual practice is to set up each receiver directly under the power line at the middle of a span so that future surveys can be made under the same conditions. The ac generator used to supply instrument power must be very carefully shielded and equipped with the proper radio interference filters. Readings should not be taken while a vehicle is passing near, nor should test locations be too near metal fences, trees, or buildings, since these objects can act as reflectors of radio interference.

The cost of interference-measuring instruments is very high, and calibration is expensive and time-consuming. Since a field survey of any particular station is needed only occasionally, it is generally advisable to have the survey made by a local private contractor. Several electronic firms have the necessary instruments and experienced engineers needed for such surveys, and will furnish their services at reasonable cost.

APPENDIX

TABLE 1. Sources and corrections for four classes of equipment.

Source	Correction
Class I: Conductors	
a. splice corrodes on similar metals	pressure sleeve, automatic splice
b. splice or connection corrodes, dissimilar metals	special connector
c. tie wire insulated	bare tie wire
d. tie wire kinked, dirty, or rough	smooth, clean annealed tie wire
e. tie wire loose	use secure "long tie"
f. projecting tie-wire end	keep end away from insulator, form an eye at end
g. loose or corroded hot line clamp	spring-loaded corrosion-resisting clamp. Keep clamp tight.
h. ground wire, bond wire, or staples too near ungrounded hardware	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
i. bond wire or ground wire clamped against wood	clamp between nut and washer
j. non-energized conductor not grounded	ground at frequent intervals
k. insulated conductor on insulator	strip insulation off at contact with insulator

Source	Correction
Class I: Conductors (contd.)	
l. "trash" on conductors (bits of wire, kite strings, etc.)	keep conductors cleared
Class II: Insulators	
a. "noisy" insulators	on new construction, specify interference-free insulators, replace old insulators with same
b. dirty insulators	regular washing with high pressure water stream
c. cracked insulators	handle carefully, inspect for cracks
d. loose insulators	make sure insulators fit pins tightly; do not use wood pins
e. heavy fog	specify fog-type insulators
f. grounded neutral on metal bracket	install grounded neutral wire on insulators
g. tie wire too large for groove	use smaller tie wire
h. poor conductor to insulator or tie wire to insulator contact	apply conduction paint to insulator grooves
i. insecure conductor to insulator contact, conductor abrasion	specify clamp-top insulators for 23 kv and above
Class III: Hardware	
a. insulator pins too near other hardware	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood

Source	Correction
Class III: Hardware (contd.)	
b. arrestor, fuse brackets too near other hardware	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
c. transformer case too near hardware or ground wire	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
d. guy wires too close to each other or to pole hardware	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
e. more than one guy wire on a guy plate	use separate plates for each guy
f. slack guy wire	maintain tension
g. insulated guy wire too near conductor	maintain tension and clearance
h. unnecessary guy wire	remove excess guys, or use bridle guy
i. street lamp bracket too near other hardware or metal conduit	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
j. insulator pins corroded	specify corrosion resisting pins
k. cross-arm braces corroded or loose	use "static-proof" lag screws or bond braces permanently
l. electrostatic discharge from insulator pins or suspension insulator hardware	bond insulator pins or suspension hardware together on circuits above 5 kv, if local safety codes permit
m. poor contact between metal parts of suspension insulators	avoid use of suspension insulators in slack spans; use spring clip to maintain tight contact or use conductive grease in joints

Source	Correction
Class III: Hardware (contd.)	
n. hardware loose due to wood shrinkage or wind movement	specify "static-proof" hardware
Class IV: Switchgear and Line Apparatus	
a. Corroded or loose fuse	specify fuses with corrosion-resisting ferrules, make sure fuses fit tightly in clips
b. metal service conduit too near ungrounded hardware	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
c. transformer insulation failure	make periodic load checks and check oil level and condition on transformers
d. switch parts too near hardware	maintain 1-1/2 in. clearance in air, 2-in. clearance in wood
e. corona from high-voltage leads	avoid protruding ends of wire; form eye in end of any such wire
f. corona from switch	specify switch of proper voltage rating; avoid sharp edges or points on switch hardware
g. noisy apparatus bushings	specify interference free bushings
h. noisy contact-making voltmeter or relay on voltage regulator	specify or have installed suppressors
i. noisy lightning arrestors	replace arrestors

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A PRACTICAL HANDBOOK FOR LOCATION AND PREVENTION OF RADIO INTERFERENCE FROM OVERHEAD POWER LINES, by J.C. Senn and D.B. Wright. 1 November 1956. 47 pp. illus.
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1. Radio interference - Countermeasures
I. Senn, J.C.
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