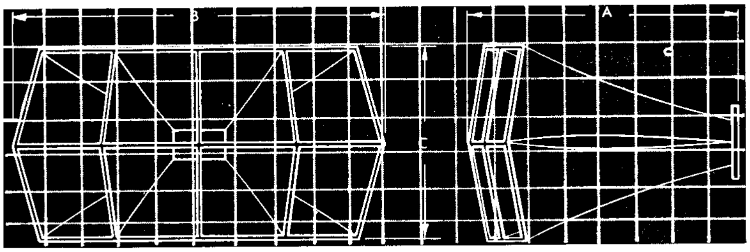

ALTEC
ENGINEERING
NOTES

TECHNICAL LETTER NO. 236

THE CONTROL OF RADIO FREQUENCY INTERFERENCE IN SOUND SYSTEMS

By
Paul Spranger

NATURE OF RFI

True RF (Broadcast) Sources

1. AM/FM broadcast (high power)
2. Television
3. Policy, fire, taxicabs, etc.
4. Amateur radio
5. Citizen's band

Steps 1 through 5 above are real sources of radio frequency interference (RFI) which produce energy that may interfere with sound equipment. All of these sources represent energy in the form of *watts per square meter* (area) or an electrical field of *volts per meter* (length). Any lead that represents some portion of a wavelength in meters is capable of absorbing energy from these sources and hence be propagated to the termination of that lead, which very often is sound equipment. The amount of power or electrical field that would be available from a half-wave dipole radiating a given power at a distance in meters from the dipole is shown on the graph in Figure 1. An example of the use of this graph is shown in Figure 1 by a heavy dotted line. We pick a distance of 1000 feet, antenna power of 10,000 watts. Follow the vertical dotted line to the solid diagonal line for 10 kilowatts. The intersection of this point and the left-hand axis of the chart shows a received power of /0.0013/ watt/meter^2. Continue up the dotted line to the intersection of the dotted diagonal line for 10 kilowatts. Read at the left-hand axis /0.70/ volt/meter.

NOTE

> This graph is very useful in determining the RF energy expected at the site from known transmitting sources when designing the system.

The major differences between the sources of RF energy listed in steps 1 through 5 would be the frequency of operation of these sources. This would determine the wavelength of the transmitted energy and hence the effective absorption of energy of the receiving wire as related to that wire in meters of length.

To determine the wavelengths involved at various frequencies, use the solid diagonal line on the graph in Figure 2. The dotted diagonal line shows the near and far field as a function of frequency; i.e., the far field radiated energy displays the polar pattern of a half-wave dipole. The example in Figure 2 shows 5 MHz, which gives a wavelength of 60 meters. If the intersection point is followed vertically to the

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wavelength in feet, we read 200 feet. If we desire the wavelength at 50 kHz (0.05 MHz), use the conversion chart which tells us to multiply f by 0.01 and λ by 100. This gives us a wavelength of 6000 meters or 20,000 feet.

Extreme high frequency represents very short wavelengths; for example, 5000 MHz would be 0.06 meter wavelength or 0.2 foot, and could readily couple to short lengths of wire. Microwave energy may have wavelengths as short as one-quarter inch, which are capable of entering metal cabinets through gaps that may look like miniature waveguides at those frequencies.

Pseudo RFI Sources

1. SCR and triac electrical control and speed control devices
2. Brush-operated motors (cash registers, office machines)
3. Relay-operated inductive loads (solenoids)
4. Computers and calculators
5. Self-induced pseudo RFI due to proximity of input/output wiring

Pseudo RFI sources are generated by many devices, such as those listed in steps 1 through 5 above. The difficult problem in dealing with such sources of RFI is that they invariably radiate at a multitude of frequencies. SCR and triac circuits are usually switched at the ac line frequency (60 Hz), but generate harmonics in the RF energy range due to the sharp rise times during switching.

Brush-operated devices are quite random in frequency generated, as they are affected by current, brush pressure, etc. As an example, Figures 3 and 4 show conducted interferences in microvolts that are generated from brush-operated motors.

The charts show that they do generate frequencies from 160 kHz up to 20 MHz with the amplitude of energy and the frequency generated to be quite variable as a function of both current and brush pressure.

NOTE

> Altec Engineering uses an electric drill to determine the susceptibility of electronic products to this type of RFI. A rule of thumb for high gain devices such as mixers is that they should not experience interference from one lab bench away from the bench being used for test.

Figure 5 shows the energy versus frequency that was present in a computer. As we all know, computers and modern electronic calculators function on an on/off characteristic which produces square waves at usually a very high clock frequency and, therefore, a large amount of harmonic energy.

Step 5 (Self-induced pseudo RFI due to proximity of input/output wiring) is a very real problem, and quite often occurs if great care is not taken in isolating input and output circuits of mixers, power amplifiers and sound systems. This type of RFI or oscillation is quite difficult to detect, as it usually occurs at a frequency in the MHz range and may not be observed with the test equipment used by contractors, technicians, etc.

DETECTION OF RFI

Any input/output lead to a device that represents an antenna at the interfering frequencies provides accessibility for RFI. The length of exposed leads, therefore, becomes more critical at extreme VHF/UHF frequencies relative to interference at lower frequencies. If RFI is of an audible nature, one can usually determine the source due to a station call announcement and, therefore, know the frequency of interference. Communication receivers can be useful in determining the exact frequency of interference from an unknown source. Once the source and location of interference has been determined, one can refer to Figure 1 (providing the transmitter antenna power is known) to determine the approximate volts per meter present at the sound equipment. This is important, as it provides a relative indication of shielding and filtering that may be required to sufficiently suppress the interference.

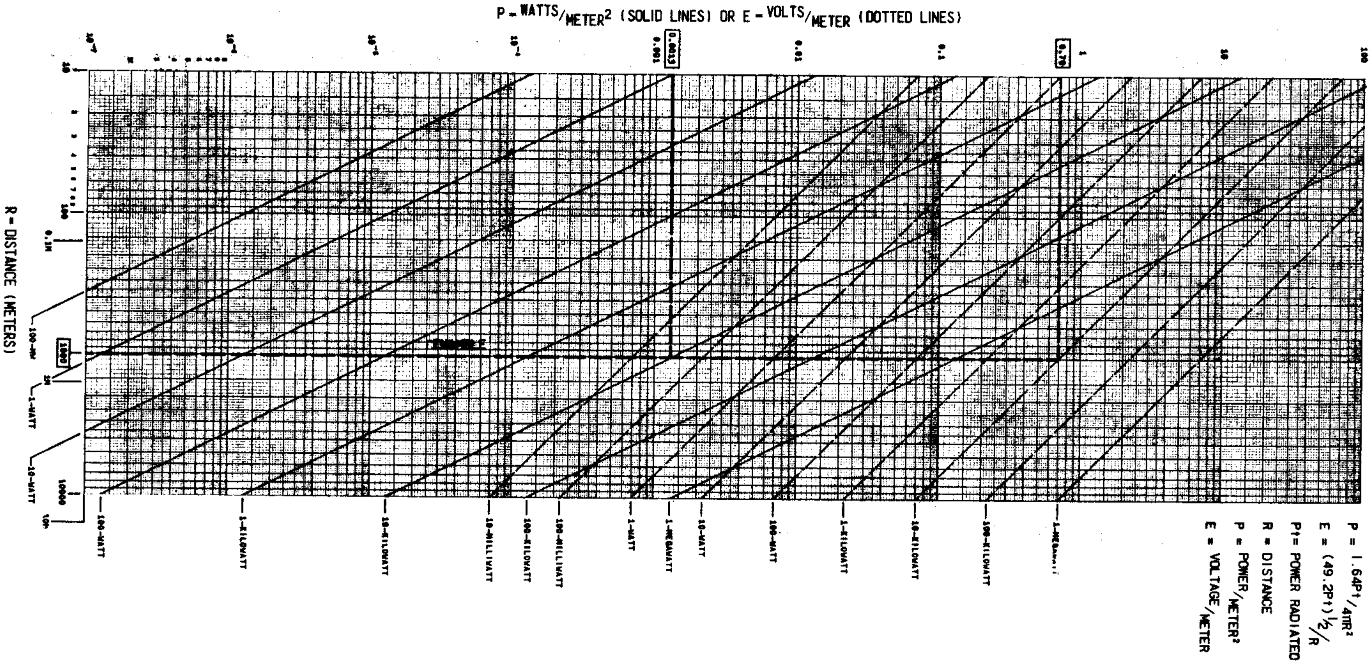
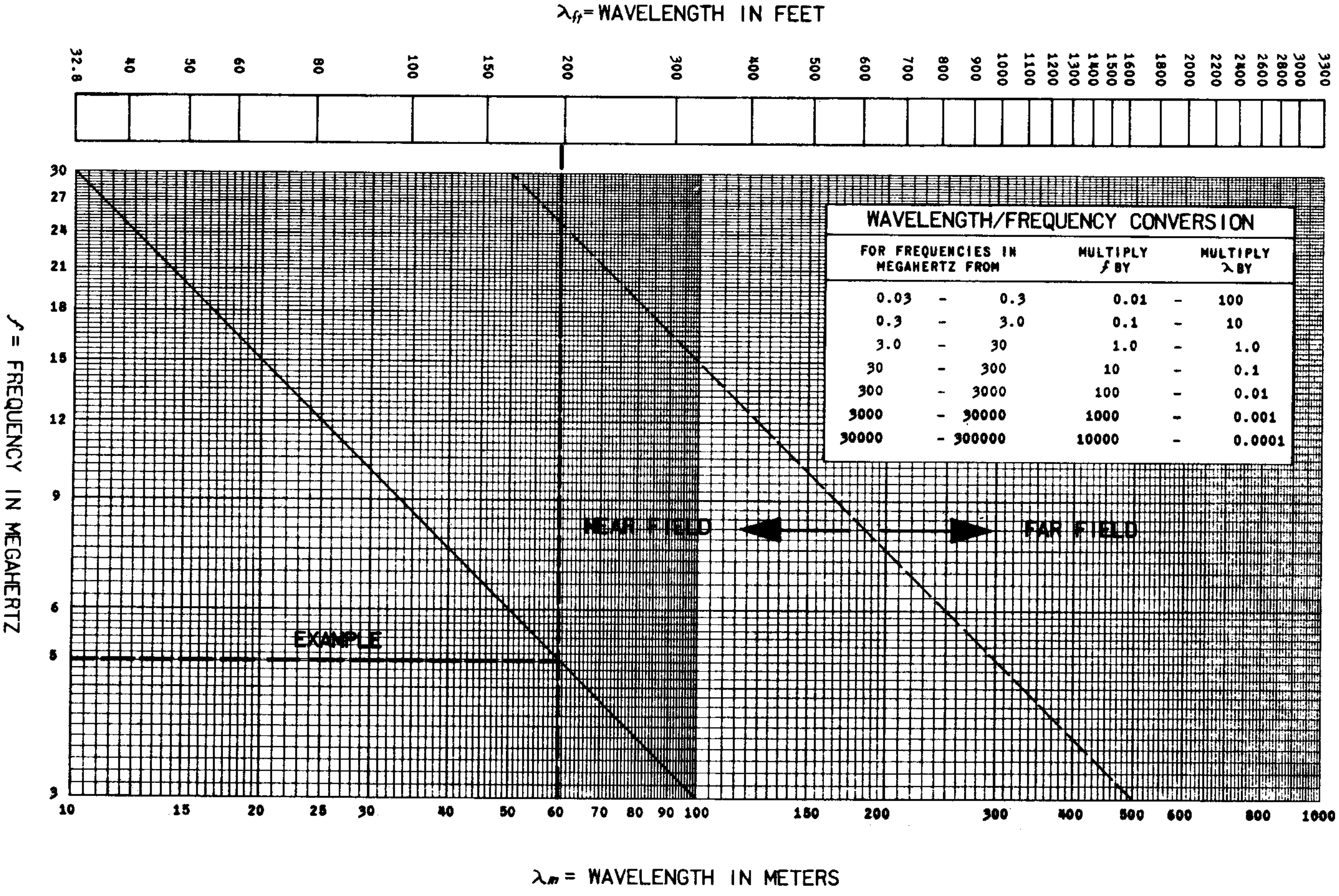


Figure 1. Power and Voltage Density at Various Distances from a Half-Wave Dipole



WAVELENGTH/FREQUENCY CONVERSION

FOR FREQUENCIES IN MEGAHERTZ FROM			MULTIPLY ƒ BY		MULTIPLY λ BY
0.03	-	0.3	0.01	-	100
0.3	-	3.0	0.1	-	10
3.0	-	30	1.0	-	1.0
30	-	300	10	-	0.1
300	-	3000	100	-	0.01
3000	-	30000	1000	-	0.001
30000	-	300000	10000	-	0.0001

Figure 2. Wavelength/Frequency Conversion

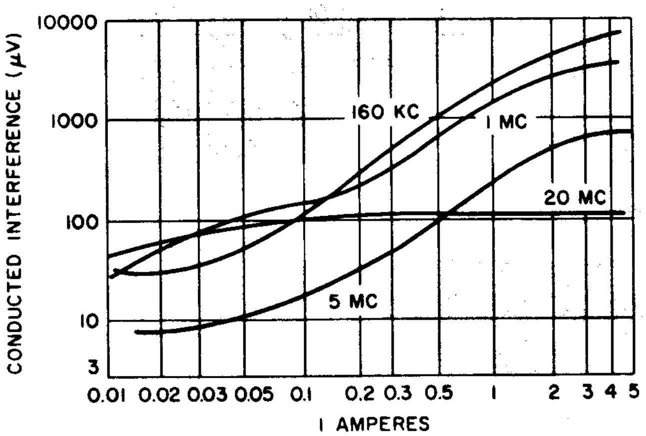


Figure 3. Effect of Brush Current on Generated Interference

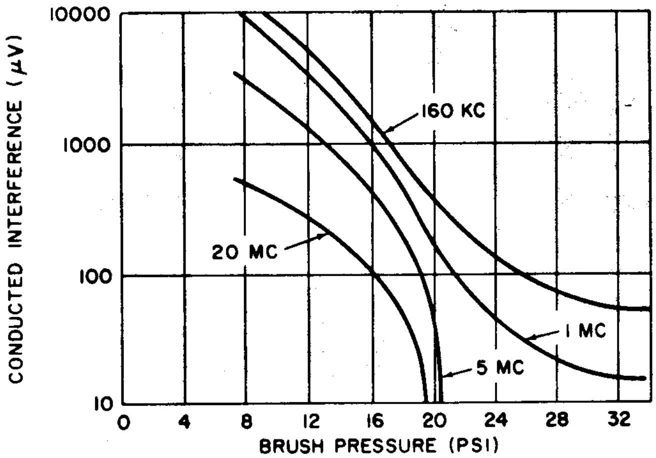


Figure 4. Effect of Brush Pressure on Generated Interference

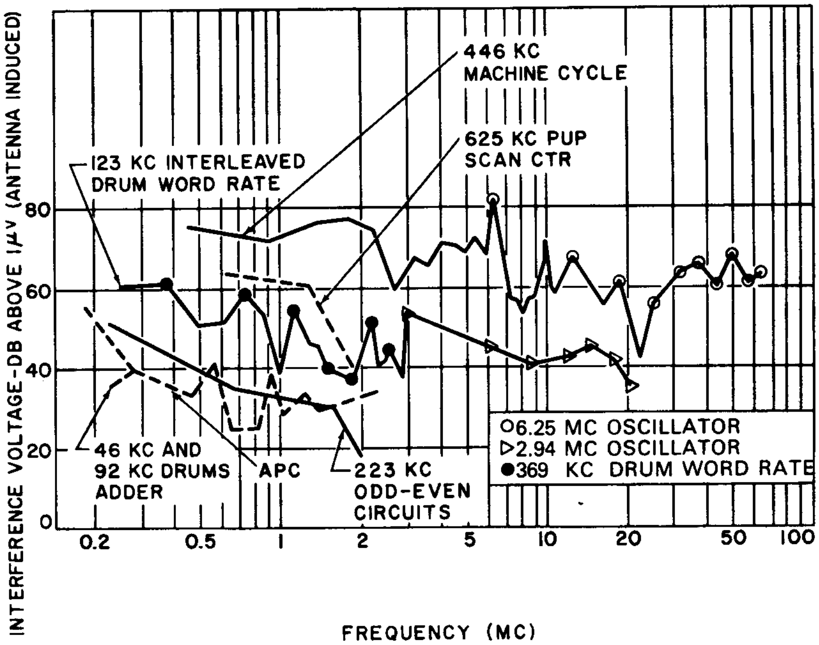


Figure 5. Composite CW Radiated Interference Spectra (From Harder and Powers, Sixth Armour Conference)

NOTE

An RF field strength meter could be used for the above test.

Next, we should attempt to isolate where the RF energy is entering the piece of sound equipment. We can determine this by disconnecting all leads, except for the outputs, and then listen to see if RF is still present. If RF is still present, it may be necessary to utilize headphones with shielded leads to eliminate or reduce RF energy from being picked up by the output leads. Continue to reconnect all circuits to the unit and determine which circuit is picking up the RFI.

NOTE

Altec Engineering uses a 5-watt CB transmitter for RFI susceptibility testing. Mixers and amplifiers are connected to loads with inputs connected to normal microphone leads. The CB transmitter will produce about 1 volt/meter at a 10-meter distance.

ELIMINATION (Examination of Methods Employed for Suppression of Various Forms of RFI and to Minimize Pickup of RFI by Externals Leads)

Balanced Input/Output Wiring

The use of balanced lines in all input and output leads can materially minimize the pickup of unwanted energy normally experienced by a single-ended connection. Figure 6 shows two cabinets connected by a common circuit ground and a single signal lead.

Figure 7 shows the effective impedances that are present in such a circuit which would allow currents to be developed from any source, and in particular RFI that would cause signals to appear as sources to the respective cabinets. To effectively eliminate this type of problem, a balanced line is used between cabinet "A" and cabinet "B" (Figure 8), with transformers at each end, and for the transition from single-ended to balanced.

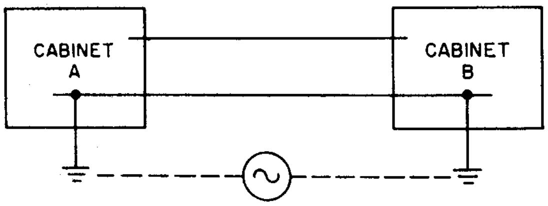


Figure 6. A Potential Difference Exists Between the Two Cabinets Which May Introduce Interference

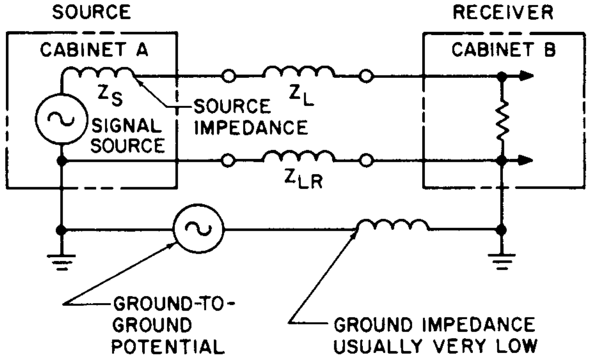


Figure 7. Schematic Diagram Illustrating a Potential Difference Between the Same Ground in a System

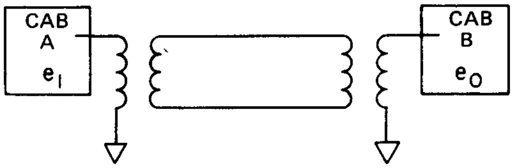


Figure 8. A Balanced Line for Reducing Susceptibility to Interference

Additional suppression of unwanted energy can be achieved by twisting the balanced pair and also by shielding. Attenuation of balanced twisted pairs achieves up to 80 dB of unwanted signal attenuation. Greater than 60 dB is definitely realizable.

Shielded Input and Output Leads

Shielding input and output leads is considered an accepted practice to minimize or eliminate unwanted signals (RFI) in communication or sound equipment. It is in general taken for granted that any form of shielding may adequately perform this function. However, shielding comes in all sizes and configurations with resultant differences in the ability to properly attenuate unwanted signals. These unwanted signals, and especially RFI, may be present in several forms; that is, an electrical field and also a magnetic field. Table I shows the shielding effectiveness at 5 MHz of various materials and constructions. The table shows a large variety of attenuation from a minimum of 9 dB up to 89 dB. From it we can see that we should be very critical of the type of shielded cable that is employed to perform this function.

Another effective shielding method, more often employed in output circuits, is the use of semi-rigid electrical conduit. This is very effective to both electrical fields and magnetic fields. Figure 9 shows the effectiveness of various materials used to shield magnetic fields.

Figure 9 shows that curve "G" copper tape and steel braid provides the greatest attenuation of a magnetic field. Figure 10 shows the attenuation of electrical fields as a function of various materials.

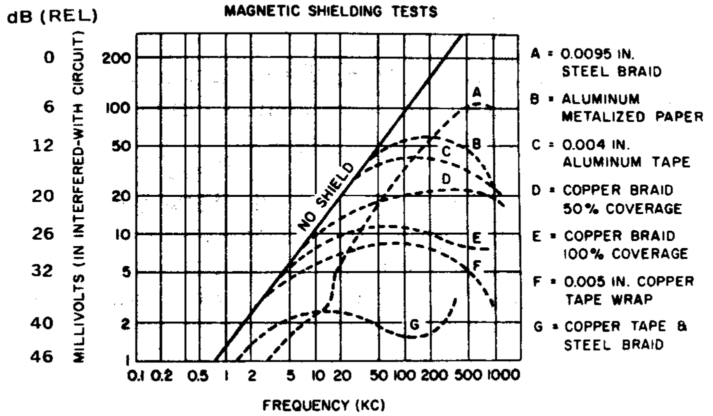


Figure 9. Induction Due to Magnetic Field
(From Gooding and Slade, op cit.)

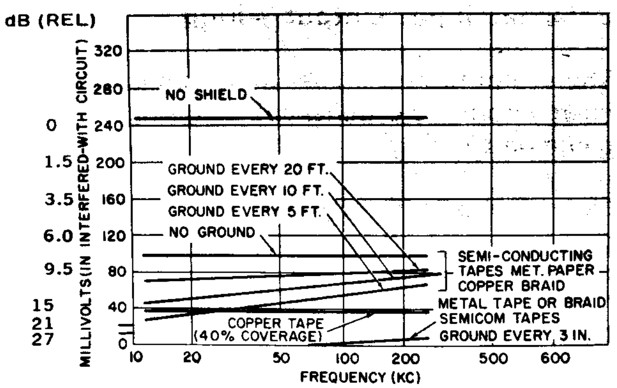


Figure 10. Induction Due to Electric Field
(From Gooding and Slade, "Shielding of Communication Cable")

For example, we see that semiconducting tape material gives approximately 9.5 dB of attenuation, which agrees with the figures of Table I. Another interesting point to note in Figure 10 is that greatly improved attenuation is achieved by grounding any of the shielding material every 3 inches. Here again it would be good practice to ensure solid grounding of shield leads at both ends and as many grounds along the length of the shield as is practical to minimize the effective antenna length of the shielded cable. If a long length of shielded cable cannot be grounded at sufficiently short intervals, and still shows some evidence of RF pickup due to a very strong RF field in the particular area, additional attenuation can be achieved by bypassing the leads directly to the shield at both input and output connections of the cable (see Figure 11).

Table I. Shielding Effectiveness — Various Materials and Constructions

Shield description	Relative shield effectiveness K_s* at 5 MHz	dB
No. 36 AWG tinned copper braid, 50% coverage	2.9×10^{-3}	50.7
No. 36 AWG tinned copper braid, 75% coverage	1.06×10^{-3}	59.5
No. 36 AWG tinned copper braid, 85% coverage	0.850×10^{-3}	61.4
No. 36 AWG tinned copper braid, 95% coverage	0.636×10^{-3}	64.0
No. 36 AWG tinned copper served shield, 100% coverage	7.65×10^{-3}	42.3
Flat wire braid - 0.002 in. thick, 48% coverage	11.90×10^{-3}	38.5
No. 36 AWG tinned copper braid, 85% coverage (2 conductors twisted together - overall shield)	0.0352×10^{-3}	89.0
Extruded semiconductive thermoplastic (with no drain wire)	No apparent shielding	
Extruded semiconductive thermoplastic (with drain wire)	No apparent shielding	
Double-faced aluminum on Mylar backing. Spirally wrapped tape - 50% overlap	5.2×10^{-3}	45.7
1/4-in. Alcoa aluminum foil 0.005 in. thick	24.0×10^{-3}	32.4
Impregnated semiconductive cloth tape (no drain wire)	0.353 (very poor shield)	9.0
Semiconductive black cloth tape with No. 30 drain wire	0.900 (no shield effectiveness)	.915
Semiconductive yarn, 40-denier, with no drain wire	0.350 (very poor shield)	9.0
Semiconductive yarn, 40-denier, with No. 30 drain wire	0.291 (very poor shield)	10.7

*K_s is the shielding-effectiveness factor derived from using cylindrical testers to obtain an absolute measurement of the shielding effectiveness. Therefore, 0 = perfect shielding and 1 = no shielding.

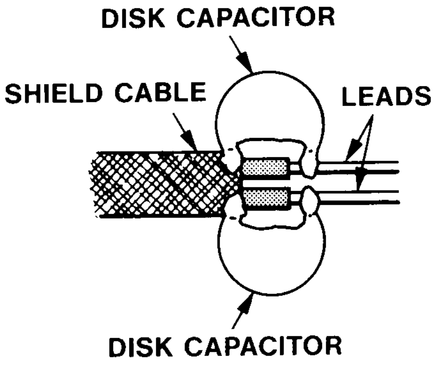


Figure 11.

Care should be taken to use small-value ceramic capacitors, and to keep the capacitor lead length as short as practical. Consider the impedance of the circuit, and select the capacity reactance to be 5 or 10 times greater at the high band limit, say 20 kHz.

RFI Filtering Circuits Where Leads Enter the Device

If RFI is still present from leads that enter the device, steps must be taken to suppress this RFI at the point of entry into the device. If the RFI is not excessive, it may be attenuated by using several forms of capacitors. These are schematically shown in Figure 12 and are:

1. A capacitor with a lead-in wire
2. A feed-through capacitor
3. An "L" capacitor which displaces the characteristics of a distributed low-pass filter

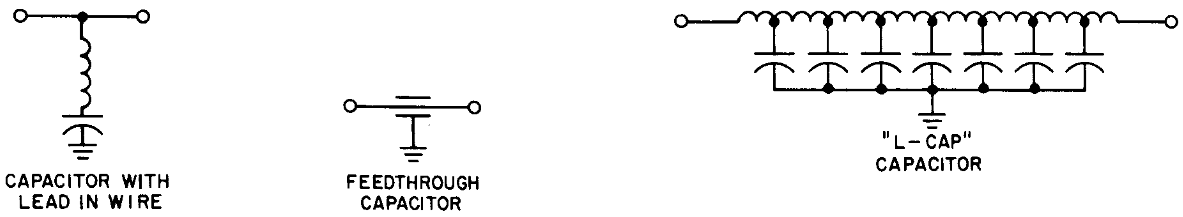


Figure 12. Electrical Circuit Equivalents for Capacitor Suppression Devices

If the RFI is of a known fixed frequency such as a TV or broadcast station, a capacitor may be used very effectively.

NOTE

> The schematic shows the capacitor with a series inductor which is representative of the lead length inductance of the capacitor. This inductance and the capacitor form a series tune circuit and provide essentially a short circuit at resonance. Figure 13 shows paper tubular capacitors and the frequency of resonance versus lead length.

Here we show a desired attenuation frequency of 3 MHz where (4) 0.25 µf with a 0.1-inch lead length; (3) 0.1 µf with a 0.6-inch lead length; (2) 0.05 µf with a 1.2-inch lead length; (1) 0.01 µf will resonate with a 6-inch lead length. Obviously, the 0.25 µf would be impractical because of the 0.1-inch lead length. Also, from a circuit impedance standpoint, it would present an excessive reactance at high end audio frequencies. Figures 14 through 16 show the self-resonant characteristics of mica, ceramic and ceramic standoff capacitors.

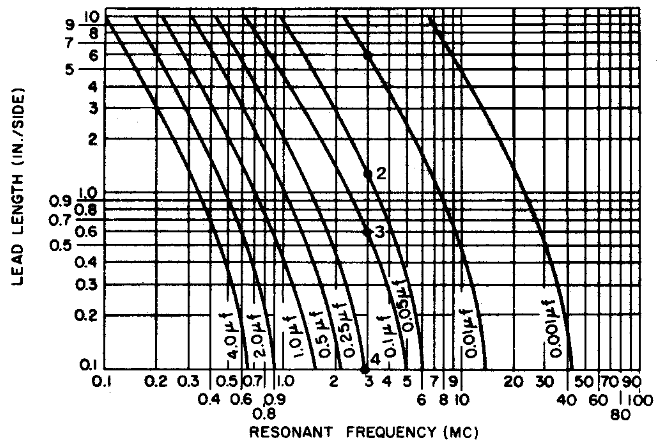


Figure 13. Resonant Frequency as a Function of Lead Length for Paper Tubular Capacitors

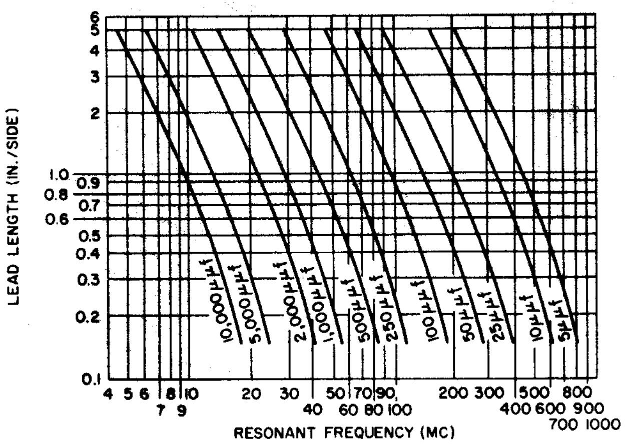


Figure 14. Resonant Frequency as a Function of Lead Length for Mica Capacitors

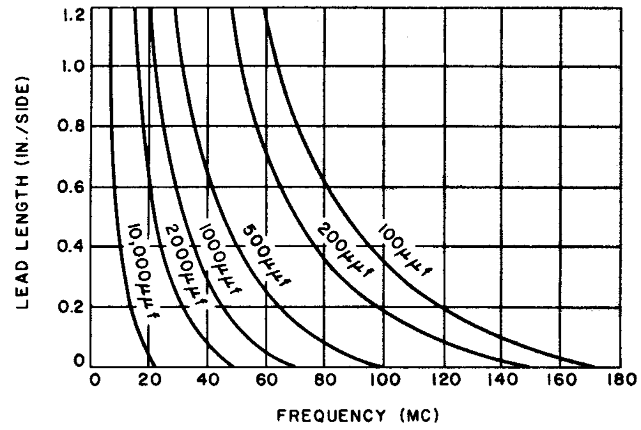


Figure 15. Resonant Frequency as a Function of Lead Length for Disc Ceramic Capacitors

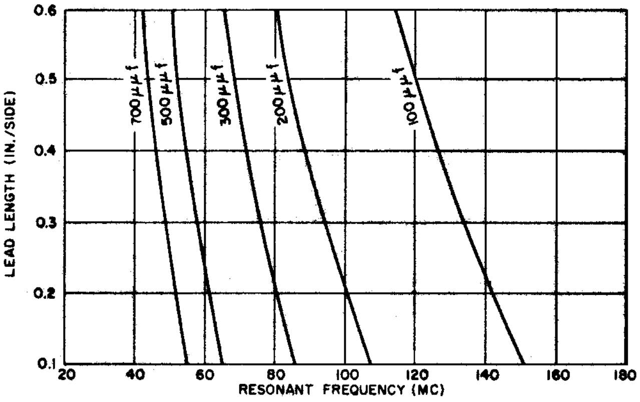


Figure 16. Resonant Frequency as a Function of Lead Length for the Standoff Type Ceramic Capacitor

Figure 17 shows the self-resonance of a 0.05 μf capacitor which achieves maximum attenuation of 40 dB at approximately 5 MHz.

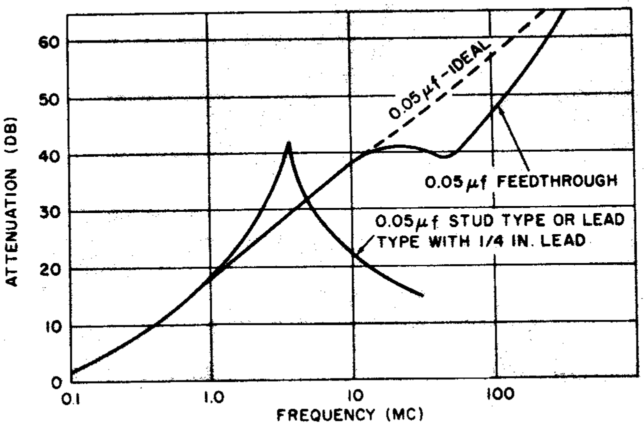


Figure 17. Insertion Loss of a Feedthrough Capacitor Compared with an Ideal and a Lead Type Capacitor. (From Proceedings of the Second Conference on Radio Interference Reduction, Armour Research Foundation)

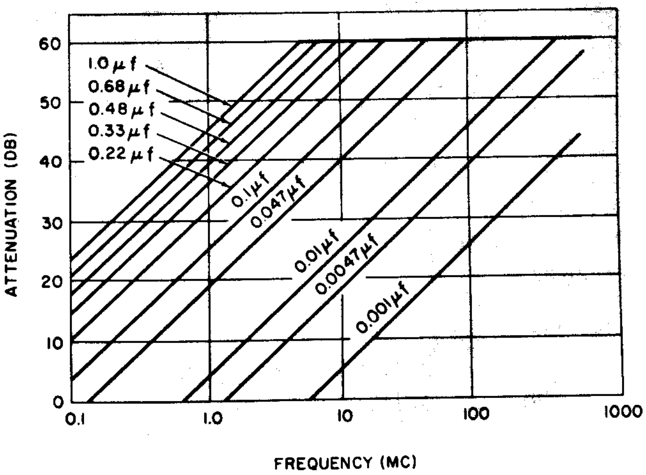


Figure 18. Insertion Loss Curves of a Feedthrough Capacitor

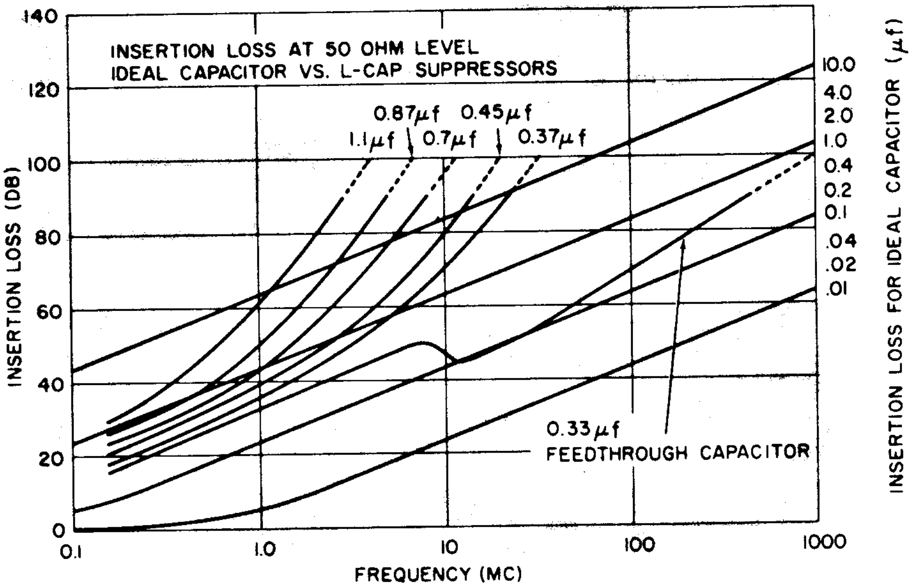
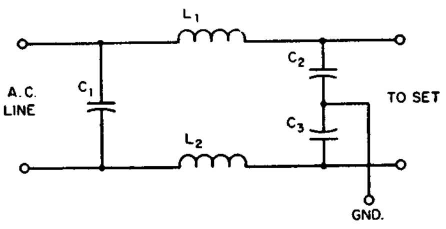


Figure 19. Insertion Loss Curves of an Ideal and L-Cap Capacitor at 50-ohm Level (From Proceedings — Second Armour Conference)

If additional attenuation is required, brute force filters should be used, particularly in output circuitry and ac lines. Figure 20 shows typical filters for these applications. Note that all leads connected from inductors to capacitors, and capacitors to grounds, should be kept as short as possible.



The values of C1, C2 and C3 are not generally critical; capacitances from .001 to .01 μF can be used. L1 and L2 can be a 2-inch winding of No. 18 enameled wire on a half-inch diameter form.

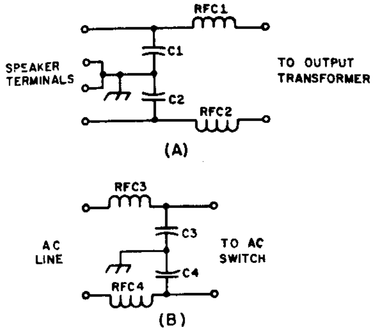


Figure 20. "Brute-force" ac Line Filter

For different values of capacitors, the nomograph of Figure 21 may be used to calculate air core inductors. The nomograph was derived from the following equation. Use Figure 22 to determine the distributed capacity of the single coil.

$$L = \frac{0.5d^2 1^2 T^2}{9d + 201}$$

where L is the inductance in microhenries,
d is the average coil diameter in inches,
1 is the length of the winding in inches,
T is the number of turns per inch.

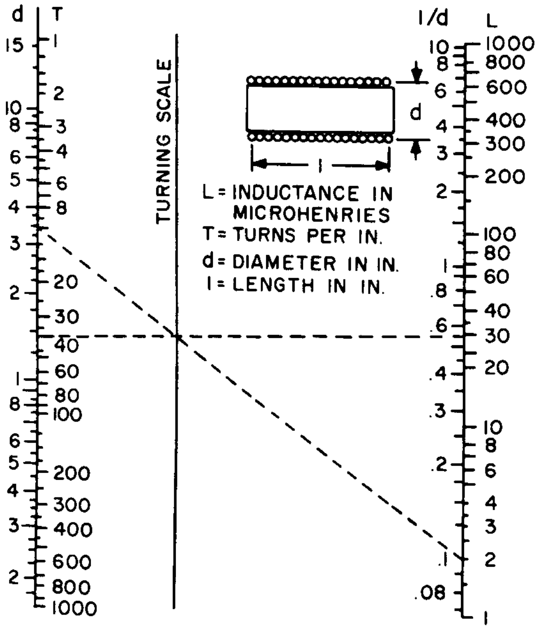


Figure 21. Nomograph for Single-Layer Coil Design

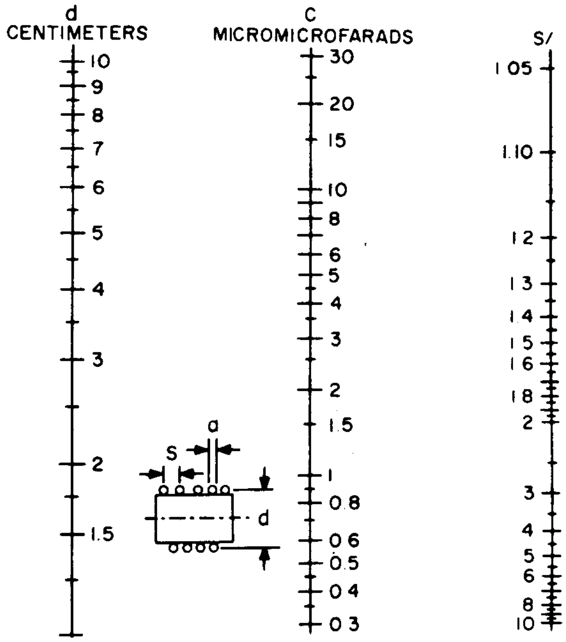
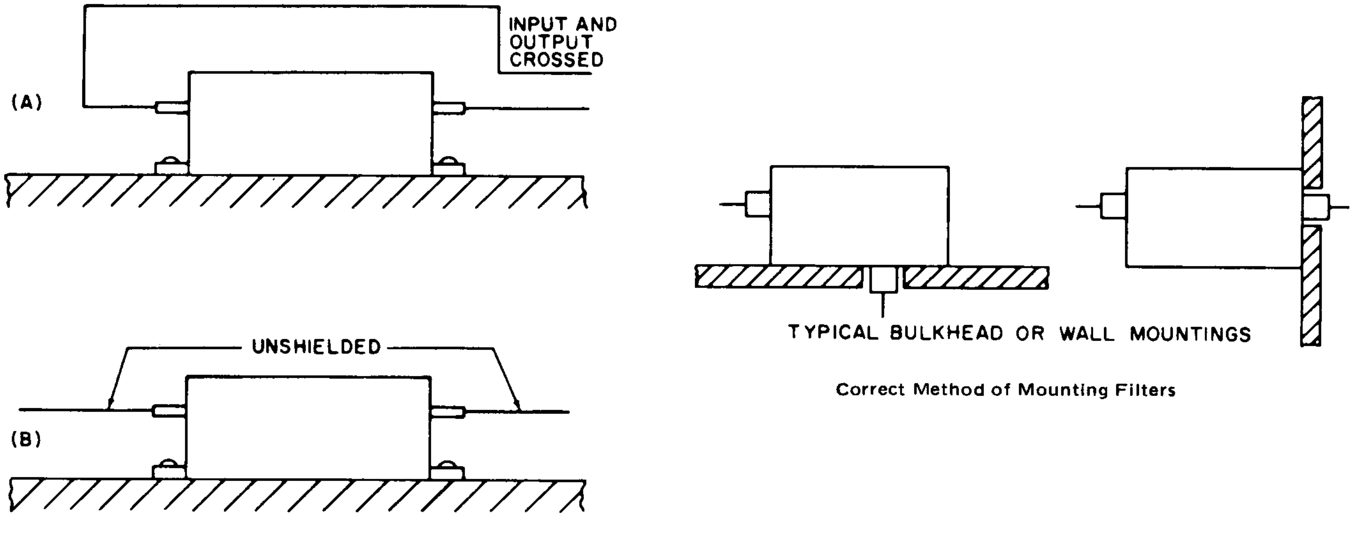


Figure 22. Nomograph for Determining the Distributed Capacitance of Single-Layer Coils

If the brute force filter is sufficiently exposed to be susceptible to RFI, the filter should be completely enclosed using capacitor feed-through to the filter box and mounted as shown in Figure 23.



Incorrect Method of Mounting Filters

Correct Method of Mounting Filters

Figure 23.

Earth Ground to Equipment (not Third Wire AC Lead)

Earth ground to communication and sound equipment must employ a solid ground, (low resistance) particularly to prevent the cabinet and associated equipment from being an antenna subject to RFI pickup. The third wire in an ac lead; i.e., ground wire, is not recommended as a method of obtaining a good earth ground. This lead should be disconnected and not used. Figures 24 and 25 illustrate typical electronic equipment grounding practice.

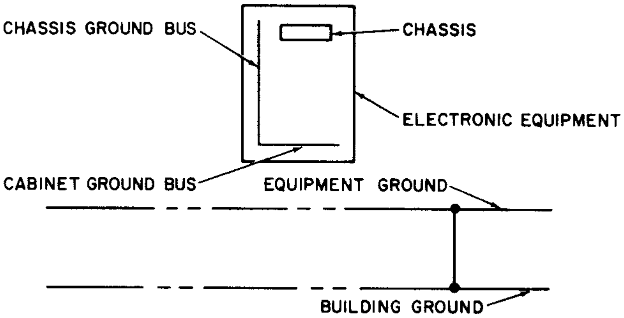


Figure 24. Typical Grounding Connections for Electronic Equipment

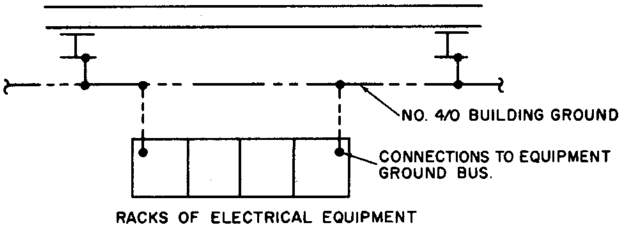


Figure 25. Typical Grounding for an Electronic Equipment Installation

Figures 26 through 31 show additional grounding techniques that will ensure low-resistance grounds. The Cadweld connections are weld-type connections made by the Cadweld Co. Refer to an electrical supply catalog for specific information.

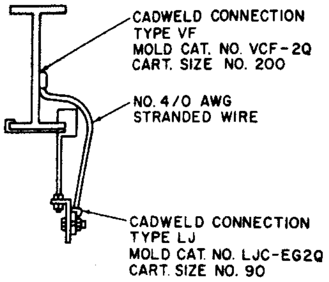


Figure 26. Recommended Beam Support for Ground Bus

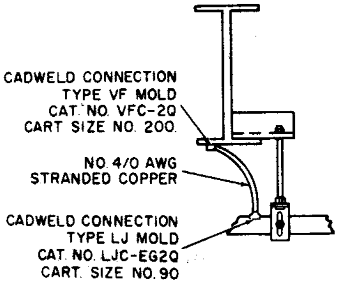


Figure 27. Recommended Typical Hanger Installation

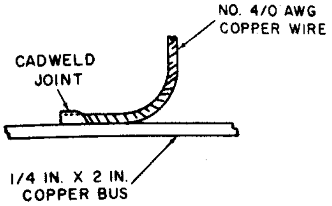


Figure 28. Recommended Terminal Connection

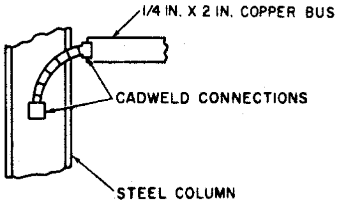


Figure 29. Preferred Column Connection

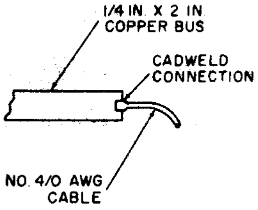


Figure 30. Preferred Connection of Bus Bar to the End of a Bus Bar

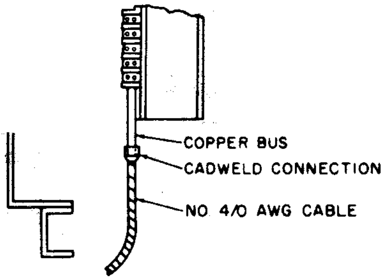


Figure 31. Preferred Connection of a Bus Bar to a Console

The final point in obtaining a good earth ground is to ensure the method of obtaining a ground to earth is adequate. Tables II, III and IV show effects of soil conditions on resistivity of the soil, and Figures 32 and 33 show the effects of treating the soil with salt. Figures 34 and 35 show the resistivity obtained with different sizes of ground rods and rod depths.

Table II. The Resistivity of Different Soils[1]

SOIL	RESISTANCE (OHMS) 5/8 IN. X 5 FT. RODS			RESISTIVITY (OHMS PER CM³)		
	Avg.	Min.	Max.	Avg.	Min.	Max.
Fills Ashes, cinders, brine waste	14	3.5	41	2,370	590	7,000
Clay, shale, gumbo, loam	24	2	98	4,060	340	16,300
Same—with varying proportion of sand and gravel	93	6	800	15,800	1,020	135,000
Gravel, sand, stones, with little clay or loam	554	35	2,700	94,000	59,000	458,000

[1] Bureau of Standards. Technical Report No. 108.

Table III. The Effect of Moisture Content on the Resistivity of Soil[1]

MOISTURE CONTENT (PERCENT BY WEIGHT)	RESISTIVITY (OHMS PER CM CUBE)	
	TOP SOIL	SANDY LOAM
0	> 1,000 X 10^6	> 1,000 X 10^6
2.5	250,000	150,000
5	165,000	43,000
10	53,000	18,500
15	19,000	10,500
20	12,000	6,300
30	6,400	4,200

[1] P. J. Higgins. "An Investigation of Earthing Resistances." *IEE Journal*, Vol. 68, p. 136.

Table IV. The Effect of Temperature on the Resistivity of Soil

Sandy Loam: 15.2% Moisture

Temperature		Resistivity
°C	°F	(Ohms/cm³)
20	68	7,200
10	50	9,900
0 (water)	32	13,800
0 (ice)		30,000
− 5	23	79,000
−15	14	330,000

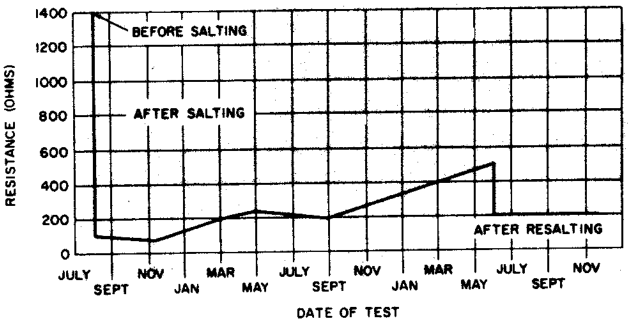


Figure 32. Changes in Resistance of a Ground Connection in Response to Presence of Salt Over a Considerable Period

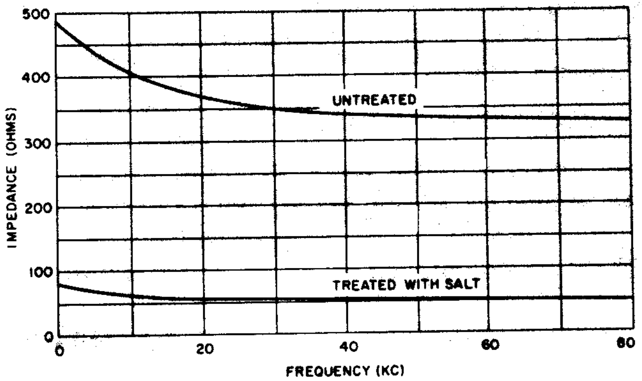


Figure 33. Relation Between Impedance to Ground and Frequency for a 1-Inch Pipe Electrode (driven depth: 21.5 feet)

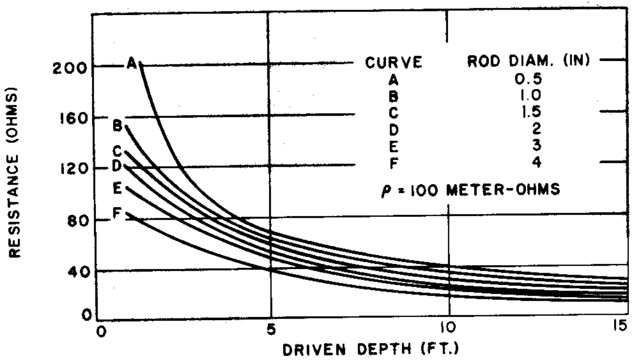


Figure 34. Theoretical Variation of Resistance with Depth for Round Electrodes of Various Diameters

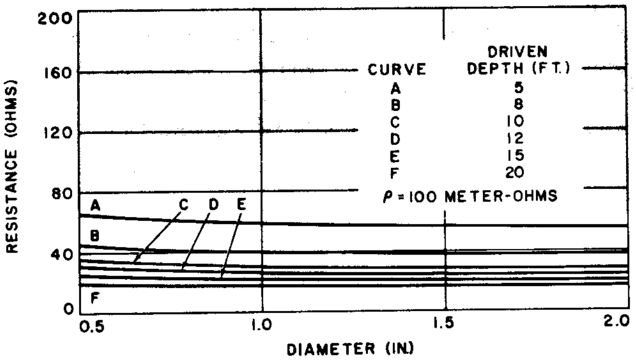


Figure 35. Theoretical Variation of Resistance With Diameter for Round Electrodes at Various Depths

AC Line Isolation Transformer

If the ac line is a source of RF pickup being introduced into the device, a method to reduce this is to employ a remote line-isolation transformer which incorporates an electrostatic shield that should be ground to a good earth connection; then use a twisted shielded pair from the isolation transformer to the device. This will minimize the effects of the ac line acting like an antenna for RFI pickup.

CONCLUSION

The foregoing information should allow proper solutions to correcting electrical and RFI interference problems from all sources. Altec, in turn, on all new products (in particular mixers and so forth), has incorporated RF filtering on input leads and ac lines by incorporating ferrite beads and bypass capacitors.

RFI elimination from large sound system installations must be treated as a total system problem. An example of a complex system interference problem and some of the solutions was the Ballistic Missile Early Warning System (BMEWS).

It was reported that a typical site consisted of many radar and support buildings interconnected by shielded passageways. These passageways (shielded for the protection of personnel from radiation) were approximately 10–12 feet wide, with an average length of 650 feet between adjacent buildings, and sometimes joined together to form a continuous, mile-long passageway. All of the power lines, telephone lines, data cables and waveguides carrying RF power from the high-powered transmitters to the antennas were installed in these tunnels. The design objective was to minimize the internal, mutual interference effects in such a passageway. To accomplish this, the following criteria were established:

1. The power leads were twisted.
2. Inherent shielding of armor trays and structure was utilized.
3. The affected communication lines were always balanced, twisted pairs.

The estimated effect of these criteria were:

1. Twisted power leads, –26 dB
2. Inherent shielding, –6 dB
3. Balanced, twisted pairs, –80 dB

These criteria proved effective, and it is a matter of record that the BMEWS sites are operational.

Further consideration of the preceding examples makes clear that as systems grow in size, so does the interference problem. The major problem lies within large systems. When cabling these systems, certain rules have wide application. Low-level, medium-level and high-level signal-carrying wires should be isolated and grouped together to form cables. Low-level is defined as circuits carrying signals with a magnitude of less than 1000 microvolts; medium-level, from 1000 microvolts to 3–5 volts; high-level, all ac power circuits and radar pulse circuits. These different levels, having been grouped according to signal level, should be physically separated from one another by as much distance as is practical; shielding and shading from separate wireways should be employed. If these wireways are connected with a good low-impedance path-to-site ground, their shielding effectiveness will substantially reduce interference between the various levels of signal.