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RADIO FREQUENCY SHIELDING OF CABLES

by

C W Harrison

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CHARLES W. HARRISON, JR.

RADIO-FREQUENCY SHIELDING OF CABLES*

THE AUTHOR

was born in Virginia. He attended the U. S. Coast Guard Academy, New London, Conn., and received the B.S.E. and E.E. degrees in 1939 and 1940, respectively, from the University of Virginia, Charlottesville. He received the M.S. degree in communication engineering in 1942 from Harvard University, Cambridge, Mass., and under the sponsorship of the ONR, received the M.E. and Ph.D. degrees in applied physics from Harvard in 1952 and 1954, respectively. He completed the Navy course in radar engineering at the Massachusetts Institute of Technology, Cambridge in 1942, and subsequently was engaged in lecturing to officers of the Armed Forces assigned to the radar schools at Harvard and Princeton University, Princeton, N.J., for several years. He has had four tours of duty in the Electronics Design and Development Division, Bureau of Ships; two at the U. S. Naval Research Laboratory; one at the Signal Corps Engineering Laboratories (Evans Signal Laboratory); one at the Philadelphia Naval Ship Yard; one as Electronics Officer, Staff of Commander Operational Development Force; and one on the Staff of the Chief, Armed Forces Special Weapons Project. He left active service as a Commander in the regular Navy in 1957 to join the Scientific Staff of the Sandia Laboratory, Albuquerque, New Mexico. Dr. Harrison is a member of the Research Society of America, the American Scientific Affiliation, URSI, and Sigma Xi. He is a registered professional engineer in Virginia, the District of Columbia, and Massachusetts.

INTRODUCTION

THE GENERAL problem discussed in this technical memorandum can be summarized in the following way:

An end-capped sectionalized metallic cylinder contains one or more sensitive heating elements (resistors) which are connected by suitable multiconductor cabling to an external switch and DC power source. It is required that as little RF power as possible be dissipated in the load resistors. Very intense electromagnetic fields extending in frequency from below VLF through the microwave spectrum may exist in the vicinity of the cylinder and the cabling. Generally speaking, it is not feasible to

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shield the cable leads extending from the external source to the metal cylinder, but some form of shielding of the interior cables is permissible if it can be shown to be efficacious. Shielding integrity of the metallic cylinder cannot be guaranteed, and, on occasion, access doors to the cylinder may be opened for the purpose of making circuit adjustments. Various cable shielding arrangements are to be examined qualitatively for their effectiveness at all radio frequencies encountered and recommendations made concerning techniques and procedures to be employed that would be of value in minimizing radio-frequency pickup of the wiring.

The response of electric and magnetic probes within an imperfectly conducting cylinder of small radius compared to the wavelength having "shielding integrity" has been calculated [1, 2]. It is anticipated that these reports will prove to be useful adjuncts to the present memorandum concerning the minimization of radio-frequency pickup of cabling through the use of shields and other means.

FUNDAMENTAL CIRCUITS

Figure 1 illustrates a loop antenna with load resistance R_L constructed of a section of highly conducting coaxial cable. If the loop is linked by a magnetic field, i.e., a differential electric field exists between the "sides" of the structure, a voltage will be induced in the outer sheath of the cable, which appears as the voltage V across the gap shown in the drawing. This voltage is in effect applied to the sending end of a coaxial cable which is terminated in the resistance R_L. Thus the circuit portrayed by Figure 1 is a receiving antenna system and serves to demonstrate that a shield containing a break (gap) is not necessarily effective as a shield at radio frequencies.

The question may now be asked as to what steps may be taken to minimize the radio-frequency power in the resistance R_L. One obvious solution is to reduce the area enclosed by the loop by allowing the outer conductor of the coaxial transmission line to make continuous electrical contact along the

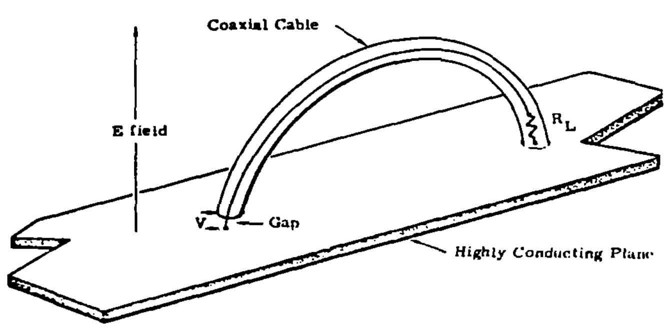

Figure 1. Coaxial Cable Loop Antenna with Load

Figure 1. Coaxial Cable Loop Antenna with Load.

conducting ground plane. The magnetic field linking the loop is then greatly reduced and the induced voltage will be very small except at the very highest frequencies. A second solution is to close the gap, thus short-circuiting the voltage V. If it is not feasible to eliminate the gap, as is sometimes the case in practice, one or more of the following steps should prove efficacious:

(a) A coaxial line filter having DC continuity may be installed in series with the cable having a cutoff frequency below the lowest frequency of the fields likely to activate the circuit. (The filter should be checked experimentally to insure no high-frequency pass bands.)
(b) The coaxial transmission line may be filled with a lossy dielectric.
(c) The inside surface of the outer sheath and the surface of the inner conductor may be coated with a lossy conductor. High-frequency currents will be forced to flow in the lossy conductor, through the operation of the phenomenon of "skin effect," and the signal will sustain increased attenuation over that available from the uncoated cable.
(d) Combinations of (a), (b) and (c).

The schemes suggested in (b) and (c) for reducing radio-frequency power in the load resistance require the use of rather long cables in terms of the wavelength, i.e., progressively longer cables are required as the frequency is decreased to achieve sufficient attenuation of the signal. In scheme (c) the thickness of the lossy metal coating must increase as the frequency decreases.

It is evident that a series resonant circuit connected across the gap will not suffice because wide-band signal attenuation is required.

Even with a closed gap there is the possibility that at very low frequencies a substantial voltage will be induced into the center conductor. This is because the penetration of the fields into the metal shield increases at decreasing frequency. One can even envision cases in which the "skin depth" will actually exceed the thickness of the sheath. It is to be emphasized that shielding at very low radio frequencies is extremely difficult to execute. One possible escape is to construct the outer sheath of the coaxial cable of ferromagnetic material—the thicker the better—and accept the increased resistance of the line to the flow of DC current.

In many present-day coaxial cables the outer sheath is fabricated of copper braid. For this type of line, short-circuiting the gap does not guarantee freedom from radio-frequency pickup. It is a well-known fact that extremely high-frequency fields will pass through braid "shielding" (but with some attenuation). On the other hand, if the outer sheath of the coaxial cable consists of a copper tube and the gap is short-circuited, one is assured that no appreciable high-frequency radio energy will reach the load resistor R_L at all frequencies for which the thickness of the copper sheath is many skin depths.

Figure 2 illustrates a sleeve-stub receiving antenna system. The electric field E causes a voltage V to be developed across the sending end of a coaxial cable terminated in R_L. The question of concern is how to minimize the radio-frequency pickup of the circuit. It is evident that if one ignores impedance matching, the antenna becomes progressively more effective as the frequency of the incident electric field is raised. (It is assumed that the dimensions of the sleeve-stub antenna are very small in terms of the wavelength in the VLF region.) By decreasing the dimension l, the length of the exposed inner conductor, or by extending the outer sheath of the coaxial cable, the frequency at which RF pickup becomes troublesome is increased. Even if the length of the exposed inner conductor l is decreased to zero, the coaxial cable will behave like an antenna at sufficiently high frequencies; a circular diffraction antenna without baffle (or open-ended coaxial antenna) having been evolved [3]. To prevent pickup at high frequencies when there is no exposed inner conductor, a highly conducting end cap should be used. Great care must be exercised to insure that the cap makes contact with the outer surface of the sheath all the way around its periphery. Again, the use of lossy dielectric, lossy metallic coatings, etc., in the coaxial line may prove effective at the higher frequencies to prevent RF from reaching the load resistor. At the lower frequencies the coaxial cable must be surrounded with, or be constructed of, ferromagnetic material if the most effective shielding is to be obtained.

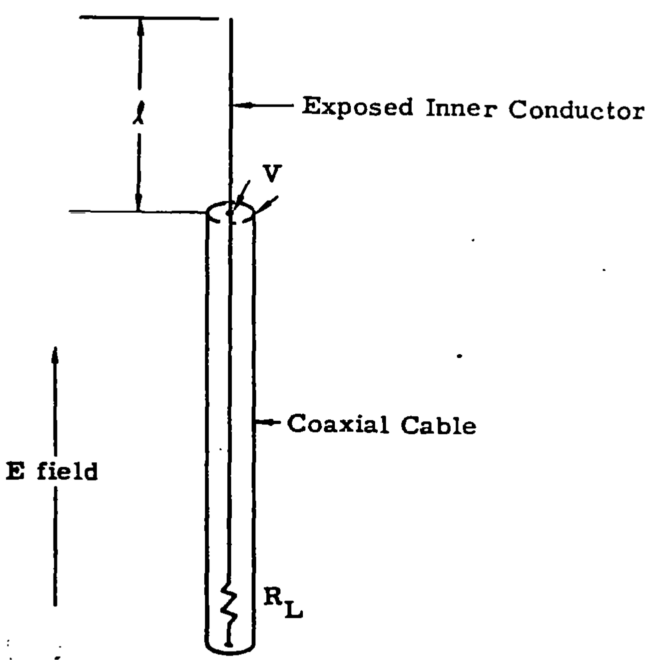

Figure 2. Sleeve-Stub Antenna Receiving System.

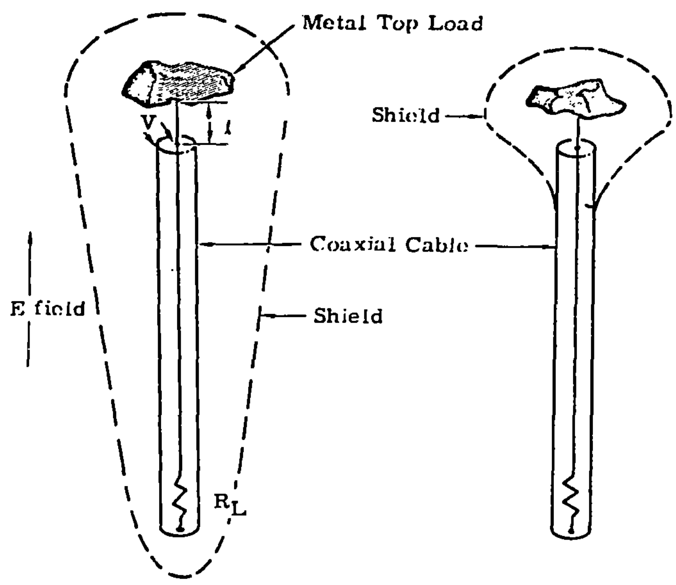

Figure 3. Top-Loaded Sleeve-Stub Antenna Receiving System.

Figure 3 shows a top-loaded sleeve-stub receiving antenna system. The operation of this circuit is the same as that set forth for the circuit without top load (Figure 2), except that for receiving systems of the same dimensions the RF pickup of the top-loaded structure is usually significant to somewhat lower frequencies than for a structure without top loading. In order to minimize the radio-frequency power in the load R_L, a closed highly conducting metal shield of suitable thickness should enclose the top load in any form suggested by the dotted lines.

Figure 4 portrays a resistance-loaded electric dipole. Even though the dimension $2l$ is quite small compared to the wavelength, a very substantial RF signal may be delivered to the load R_L. To minimize RF pickup requires the use of a highly conducting shield completely enclosing the dipole, as indicated by the dotted lines.

Figure 5 represents a circuit consisting of a battery connected to a resistor by a balanced line consisting of a shielded twisted pair. One can say cor-

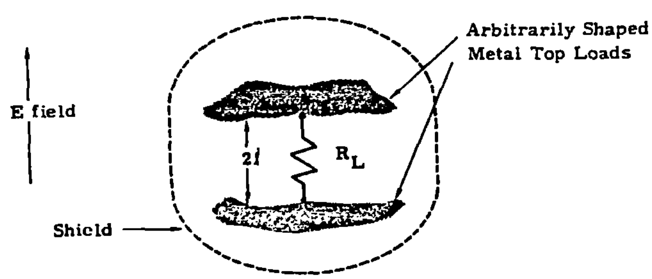

Figure 4. Resistance-Loaded Electric Dipole.

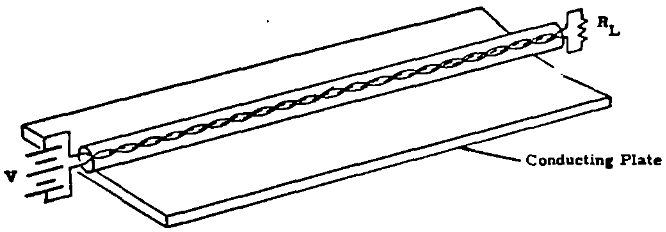

Figure 5. Voltage Source Connected to a Load Resistance by a Shielded Twisted Pair Balanced Line.

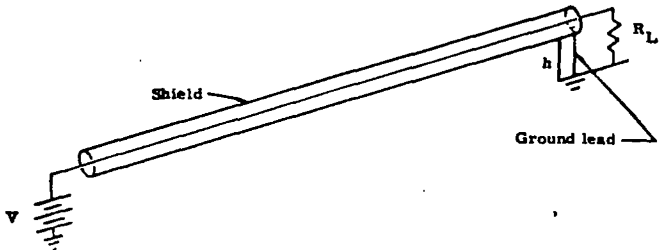

Figure 6. Circuit Employing Conventional Shielding.

rectly that as long as the line is truly balanced the RF power in the load R_L will be extremely minute if the voltage induced in the terminal "loops" by the RF field is insignificant. It is a well-known fact that if terminal effects are ignored, a line consisting of a twisted pair has lower RF pickup capability than an identical line without the twists. Furthermore, the pickup capability is further reduced drastically by positioning the line in contact with a highly conducting plane. This is brought about by image effects. The optimum arrangement, assuming that the entire circuit cannot be surrounded by a closed shield, is to encase the twisted pair in a highly conducting tube and require contact along the length of the tube with a large conducting plane.

Figure 6 portrays a circuit employing what may be described as conventional shielding, such as braid over a conducting wire. The return path is "ground." At audio frequencies this arrangement is moderately satisfactory but, as the frequency of the incident radiation increases, the length of ground lead may become significant compared to the wavelength. When this occurs, the shield and the ground lead form an inverted L-receiving antenna. The top load of the antenna, i.e., the shield, oscillates at an RF rate with respect to ground and thus serves no purpose as a shield. This circuit illustrates the importance of employing ground leads of zero length when this is physically possible.

A metallic cylinder with closed ends is illustrated by Figure 7. It consists of several cylindrical sections screwed together, or otherwise secured by the use of bolts around the periphery of two butting flanges. The cylinder contains an access door, which when open forms a slot in the shield.

If the radius of the cylinder is small in terms of the wavelength of the incident electric field, and "shielding integrity" is maintained, i.e., the access

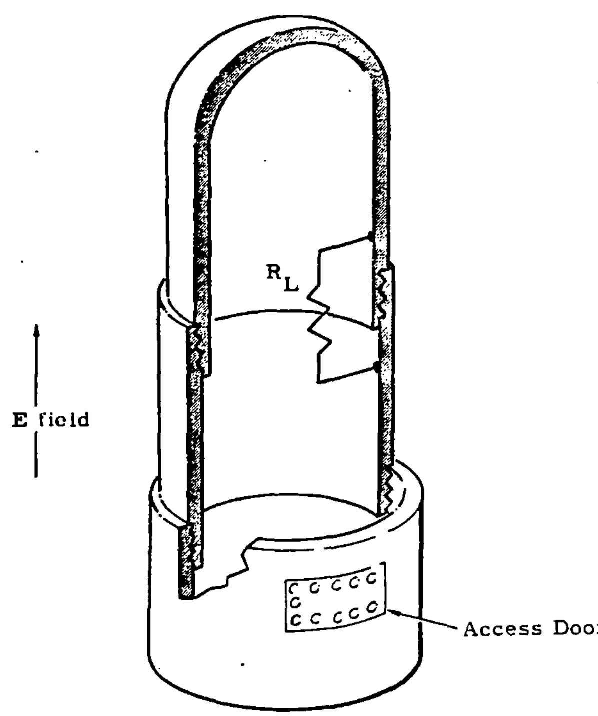

Figure 7. Sectionalized End-Capped Metallic Cylinder with an Access Door (slot).

door is closed and makes good contact with the cylinder around its perimeter, and the several sections provide continuity at high frequencies without potential drop, one can calculate the electric field inside the cylinder in terms of the incident field or in terms of the actual field existing on the outside surface of the cylinder [2]. At low radio frequencies this field may be substantial in cylinders fabricated of rather thin-walled copper or aluminum. A reduction in the field is accomplished by constructing the cylinder of ferromagnetic material. At high frequencies, when the wall thickness corresponds to several skin depths, the field inside the cylinder will be very small.

If the sections of the cylinder do not fit together so as to insure an essentially zero resistance contact at the lower frequencies, a substantial voltage may be developed across R_L, if it is effectively connected between two sections as shown in the drawing. At progressively higher frequencies the capacitive reactance between the threads decreases, so that the voltage across R_L decreases.

Assume now that "shielding integrity" is maintained between sections of the cylinder, but that the access door is opened. At radio frequencies in the vicinity of the middle of the spectrum there will be virtually no field in the cavity because the slot is below cutoff, the thickness of the wall is many skin depths, and the size of the cylinder is such that no cavity modes (resonances) are possible. However, as the frequency is increased, RF energy will be admitted to the cavity through the phenomenon of cavity resonance.

It would appear that the difficulty can be "postponed" to higher frequences by reducing the dimensions of the access door and by compartmentalization of the cylinder. The idea is to keep the slot below cutoff as high in the RF spectrum as possible and substitute for a large cavity resonator a number of smaller ones. The compartmentalization of the cyclinder must be executed with care, allowing no "floating" contacts between baffle plates and the inside surface of the cylinder, etc.

Another way of reducing the field within the cylinder is to fill it with a broadband RF absorbing material. This treatment is likely to be effective only at frequencies in the microwave region.

It is evident that reduction of the field within the cylinder is essential since all exposed wiring will pick up RF in proportion to the existing field strength.

COMPOSITE CIRCUIT

Figure 8 represents a composite circuit which violates most of the rules of shielding. Steps to be taken to reduce RF pickup by the cables will be enumerated.

Assume at the outset that it is not feasible to shield the cabling completely. Where the external shield ends, one should be sure to group as closely as possible the wires going to the battery and ground so that a loop antenna is not formed. Each conductor in this bundle should be surrounded by dielectric of high loss at radio frequencies. (This treatment should extend the full length of the cable, i,e., from the battery to the load resistor R_L.) The entire cable should be run as close to a large highly conducting plane as possible. The greater the ratio of the lengths of shielded to unshielded cable the better. It should be grounded to the conducting plane all along its length. The lower end of the external shield should be faired out and thoroughly grounded to the external surface of the metallic cylinder. Similiar treatment should be accorded the upper end of the internal shield. Thus gaps in the shield where the cable passes through the wall of the cylindrical case are eliminated. Preferably the internal shield should close over the load resistance. If this is not possible to execute, the longer the internal shield the better. Lengthening the shield for a given length of inner conductor pushes to higher frequencies the frequency at which pickup of RF energy entering the cylinder via the access door becomes significant. Note that a balanced circuit, as shown, is preferable, from the point of view of shielding, to an unbalanced one in which the return path is "ground." The installation of a baffle plate between the access door and the load, as illustrated, will eliminate the pickup of RF entering the cylinder through the access door. The internal shield should be run as close to the inside surface of the metallic cylinder as possible and should make contact with it. If contact cannot be maintained, the shield should be grounded to the inside surface of the case at frequent points along its length, using grounding leads that are as short as possible. The loop formed in the conductors at the load resistance should have as small an area as possible. If an absolutely noninductive capacitor is available, it may be connected directly in parallel with R_L to reduce the RF drop across the load.

The best internal shielding consists of conduit. If the load resistance, R_L, is located in a box, the box should be constructed of highly conducting material (or at least be metal plated) and the conduit carefully sealed electrically to the box. The conduit must make perfect contact around its circumference with the cylindrical case at the exit hole. Cable having a braided shield, although undesirable, would probably be required outside the cylinder. The upper end of this shielded cable might be run into a metal junction box, where installation of an RF filter for each circuit involved has been made. In this way the RF pickup of the unshielded portion of cable might be reduced to acceptable values before it is transmitted through the cable to the load resistance.

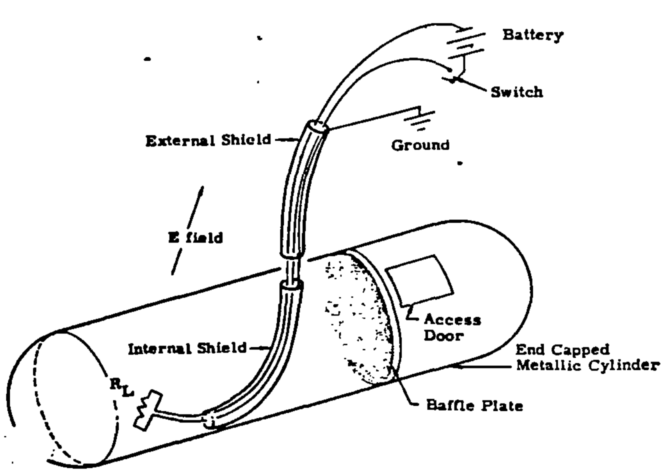

Figure 8. Composite Circuit.

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