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# Radio-Interference Control as Applied to Business Machines*

**Abstract: This paper discusses certain known characteristics and sources of radio interference and methods used to reduce the interference levels present in business machines. Particular attention is given to electromechanical machines ranging from a simple card perforator, operated by an electrical contact and an electromagnet, to electronic data-processing machines. The sources of interference in these machines are found in a wide variety of components and circuit configurations, such as electrical contacts, gas tubes, unterminated transmission lines and motors.**

**Some of the problems encountered in reducing this interference to a satisfactory level are described. Testing methods are also considered. A description is given of the development of a universal line filter which has been most successful in reducing noise transmission over power cables.**

**The development of reinforced plastic machine covers presents a special problem in radio-interference control. A discussion is given of experimental solutions to this problem through the use of such techniques as copper screening, copper spray, and imbedded metallic foils.**

## Introduction

Radio interference is defined as any electrical disturbance which causes undesirable response or malfunctioning of electronic communications or measuring equipment, including radio, radar, sonar, loran, shoran, television, and various other devices for electronic detection and recognition.

Electronic accounting machines and data-processing equipment contain varied complex circuitry and components, many of which could be prolific sources of rf energy. Unwanted radio-frequency disturbances may be caused by obvious arc-producing sources such as dc motors, circuit breakers, switches, relays, thermostats, and brushes. Usually, but not always, distinguishable arcs will be accompanied by broad-band rf disturbances. In addition to these obvious rf generators, considerable rf interference can be traced to thermal agitation in resistors, shot noise, partition effect, flicker effect in vacuum tubes, fluorescent and mercury-arc lamps, cold solder joints, and momentary contact between charged metals.

The Armed Services have issued specifications with rigid limits for radio interference, and particular requirements for electric office machines, printing and lithographic equipment. Compliance with these specifications very often requires special testing techniques, careful circuit analysis, and many times requires stringent corrective procedures and installation of suppression devices.

The intent of this paper is to present some typical examples of radio-interference problems in business machines with suggestions for equipment design and methods for radio-interference correction.

## Analysis of radio-interference problems

Among the many machines capable of producing rf energy are computers, electric typewriters, accounting and data-processing machines, proof machines, time equipment, punches, verifiers and sorters.

Within these machines are found such potential radio-interference generating devices as dc motors, commutators, emitters, clutch magnets, solenoids, relays, switches, tubes, transmitters, amplifiers and associated electronic circuitry, and fluorescent and mercury-arc lamps, functional corona, high-voltage supplies and the like. Each of these machines presents varied interference problems. In order to meet radio-interference requirements, methods for control must constantly be evaluated in the

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laboratories for engineering, manufacturing and assembly departments.

Very few disturbances contain all their energy at a single frequency, but most interference consists of short pulses of energy where there are some characteristic time intervals associated with the generation of the interference, such as build-up time or duration of the pulse. A qualitative analysis of pulse characteristics shows:

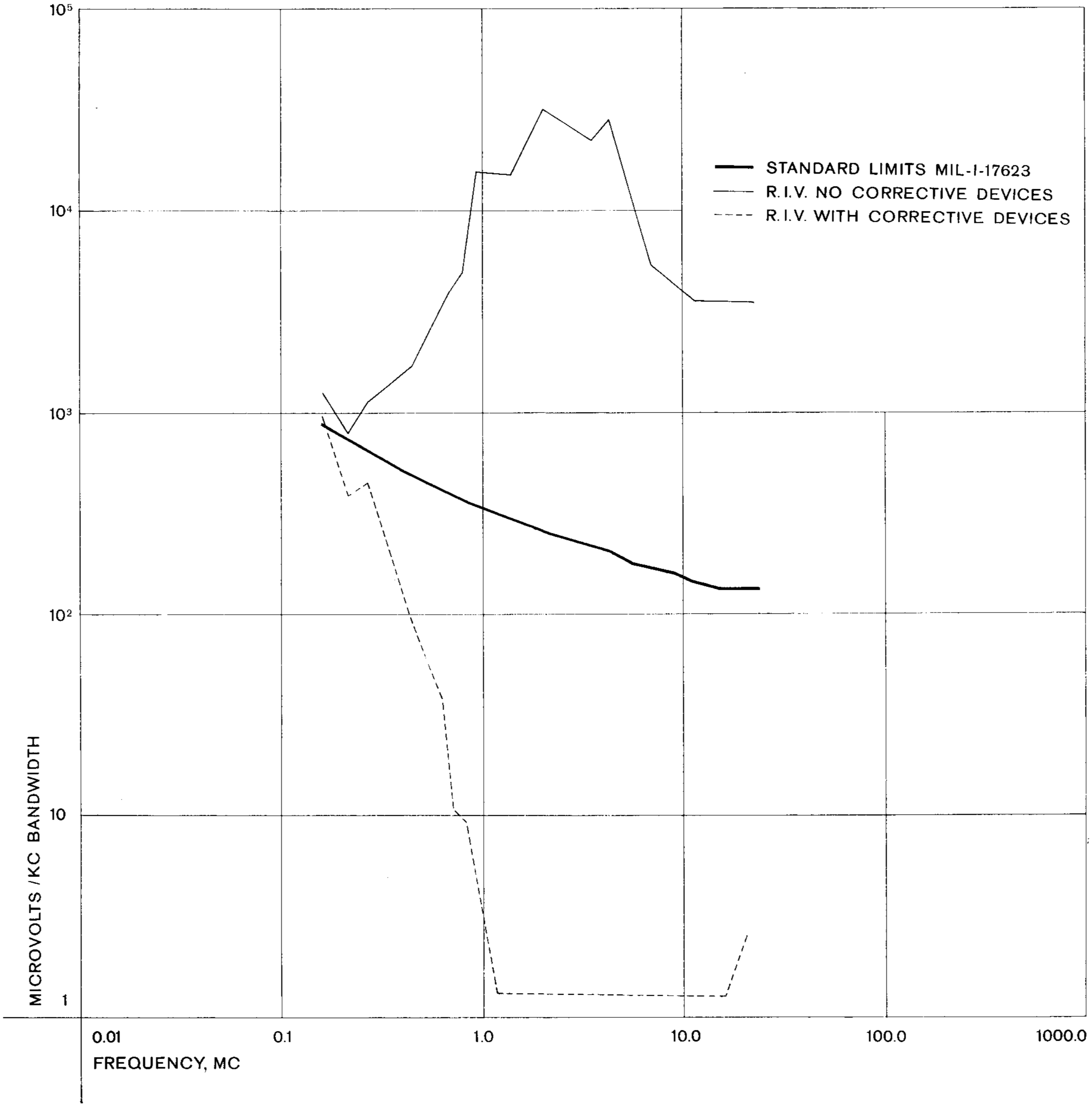
*a. Reciprocal spreading.* For a pulse of finite duration, the spread of frequencies is roughly inversely proportioned to its duration.

*b. Slope of wave fronts.* The more rapidly pulse amplitude builds up or falls off, the greater is the proportion of high-frequency energy.

The energy spectrum is therefore a useful tool in the analysis of interference.

The important sources of interference are convection currents (those traveling through a gaseous medium) or conduction currents (those passing through a solid conductor). Considering the basic equation $I = E/Z$, in which the current $I$ is considered the effect produced by the electromotive force $E$ against the impedance $Z$, we

*Figure 1* **Line-conducted radio-interference voltages on a typical electromechanical machine.**



see there are two basic processes by which interference may originate from varying current (and its associated magnetic and electric fields). One source is the generation of varying emf and the other is variation of impedance.

- *Interference tests*

In 1935, the homemade screen room used generally for interference tests was adequate, according to the standards of those days. As the specifications grew more meaningful and as instrumentation progressed, lower ambient interference areas were constructed to obtain more accurate data. At the present time, seven screen rooms are used. A unique installation in one of our new laboratories consists of a 20 × 22 ft interference-shielded enclosure inside an acoustical reverberation room, designed to accommodate business machines. Filtered service has been provided for equipment demanding up to 25 kva capacity.

The screen does not interfere with the acoustical properties of the larger volume of the reverberation room, which has a ceiling height of 14 ft, as compared to 8½ ft for the screen room. The reverberation room was designed to provide 45-db attenuation.

- *Frequency spectra of two machines*

*Typical electromechanical machine:* To illustrate a pattern of correction, Fig. 1 displays an energy spectrum of the conducted* radio-interference voltage as a function of frequency, encountered in a typical electromechanical machine.

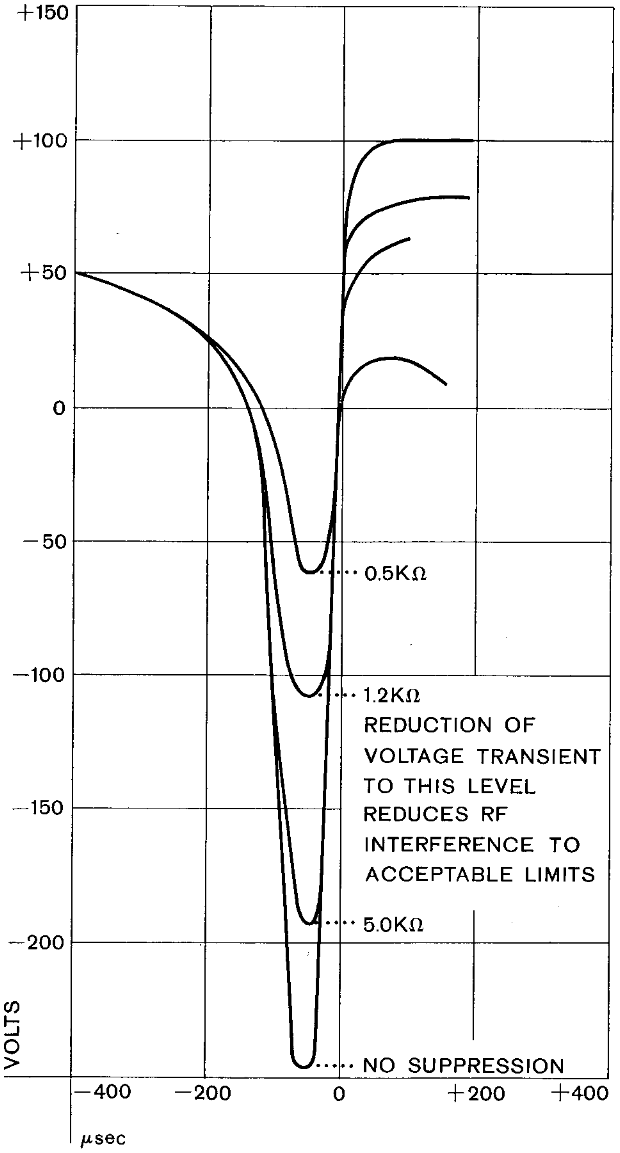
This particular machine had a 115-volt, 60-cycle, single-phase input. Punched cards are fed from the hopper and each card cycle occurs in 600 milliseconds.

This machine features a control panel which can be wired to permit an almost unlimited number of machine functions. Various machine functions were run through the machine to determine the highest levels of radio interference. These levels were determined by means of various loop probes associated with the radio-interference field-intensity instruments at different frequencies. The results of this preliminary survey were only an indication of the magnitude of the problem. These results confirmed the conditions representing normal maximum loading, under which the final measurements were made. Recommendations were then based on the final measurements.

After test conditions had been established, sequential steps for the first complete set of both conducted and radiated measurements were made to determine the radio-interference voltage levels without corrective devices and their relation to the requirements.

A study of the interference showed that during this operation, the machine in question was a source of both a high and a moderate induction field. Both the electric and magnetic components of the induction field were sensed by the pickup antennae. Sensing of the electric components indicated that a high-voltage condition existed; sensing of the magnetic components proved that a high current flow was present on the machine surfaces. These conditions would be resolved separately. Figure 1 shows that the highest interference voltage was between 1.8 and 3.6 mc. The ratio between the peak voltage and the limit curve was about 120:1 or approximately 41 db. Investigation of the machine circuitry disclosed that this interference was being produced by transient negative voltage peaks as high as 250 volts, incurred when certain magnet armatures opened, as shown in Fig. 2. Further tests revealed that six circuit breakers were responsible for the rather high interference between 10 and 20 mc.

*Figure 2* **Reduction of voltage transients in magnets with shunt resistors.**



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*"Conducted" refers to power-line conduction of rf currents which affect other equipment.

The magnets and circuit-breaker contacts produced both conducted and radiated interference over this range of frequencies. The calibrated dipole antenna also disclosed leakage of radiated energy between 30 and 150 mc, as shown in Fig. 3.

Radiated radio-interference-level difference of approximately 28 db, between 10 and 20 mc, was caused by the make and break of six different circuit-breaker cam contacts. The over-all conducted radio-interference voltage appears to be quite broadband, with peaks up to 20,000 microvolts per kilocycle band width, as shown on Fig. 1.

Various possible approaches for reducing the radio interference generated by the machine would include installation of a main-line filter, RC networks, shunt resistors and other point-suppression devices. Analysis of the energy spectra, Figs. 1 and 3, indicated a need for such an approach and showed the attenuation requirements.

The energy spectrum, Fig. 1, indicates that a filter designed to provide 40-db attenuation would be quite adequate to reduce conducted interference to acceptable limits. It had been our experience with impulse-type loads that a conventional pi-filter would not be successful at the lower frequencies. A very low shunt impedance is required to obtain low levels of interference at 0.150-0.400 mc. The use of a pi-type filter creates the possibility of a resonant condition at these frequencies with resultant high shunt impedance and a subsequent loss of attenuation.

The resonance problems inherent in the pi-type filter had led us to design a filter with a dual L-type network employing air-core inductances and feed-through-type capacitors. Later, more success was evident with inductances using Permaloy toroidal cores for the chokes. Use of these cores enables higher relative attenuation in the same physical space.

Extra care must be exercised to provide an electrically clean metal surface upon which to mount the filter to provide one large ground surface rather than several to eliminate circulating rf currents at the various bonds. All paint, grease and matter foreign to the mounting area must be removed. The filter is secured with four mounting screws, with lock washers inserted under both the screw heads and the nuts. For highest efficiency this filter is installed with particular attention to good shielding between the input terminals and circuitry and the output of the filter.

Installation of this filter reduced the interference voltage to below acceptable limits up to 10 mc. For adequate suppression above that frequency, however, the interference emanating from the continuously running circuit-breaker cams was reduced by resistive-capacitance networks shunted across the contact points. The network values used in this instance were 0.1 $\mu$f capacitance in series with 100 ohms resistance.

The energy-spectra curve, Fig. 3, disclosed leakage of radiated energy between 30.0-150.0 mc.

Within the magnet assembly there were many magnets, any one of which could be energized, depending on the operation. Investigation revealed no common point that could be suppressed and be effective for all of them, so it became necessary to apply some simple, inexpensive means of source suppression for each magnet. With the aid of an oscilloscope, the transients produced by the operation of the magnets were recorded. Then began a methodical progression of installing suppression devices to determine which would be most effective.

Lack of space was a problem. In this instance, there were a number of banks of magnets with only slightly over ¼-in clearance between banks. Also, the unit was constructed so that it could be opened for service. This design requirement imposed a mounting problem.

The interference was reduced to acceptable levels by installing a 1200-ohm, one-watt resistor shunting each magnet coil. It was noted during test that the use of smaller values as low as 500 ohms reduced the transient voltage to even lower levels. However, this lower value could be detrimental to the existing circuits because of the delay in drop-out time of the magnets.

Reduction of the resistance values also resulted in lesser rf interference levels as indicated in Fig. 2. Increased heat dissipation would make it necessary to increase the wattage rating, which would require a larger physical size for the resistor.

These measurements also pointed up the need for improved shielding. A very important part of developing interference-free equipment lies in the use of well grounded shields which provide adequate enclosure. An electrically tight enclosure is impossible with our type of equipment; but some modifications to the existing covers and screening of some of the functional open areas reduced interference. To reduce the rf energy present on the covers, as well as leakage through the seams and openings, it is necessary to provide good electrical bonding between the covers and the grounded machine frame. For a low rf impedance path to ground, care is taken to remove all paint and foreign matter on the area under all cover screw heads. Star washers are also placed under the screw heads and tightened to insure good contact with the metal base. Spot checks at various frequencies show the results of the improved bonding. These measures tend to reduce the interference levels, but still were not adequate to comply with the specification limits. A survey with the rf loop probes indicated that the rf energy was leaking from the openings in the covers such as at the control and indicator panels. To reduce the leakage at the control-panel cover, a copper mesh screen, large enough to completely cover the opening in the area occupied by the handle, is secured by screws and star washers to the clean inside surface of the cover. The indicator panel is treated in a like manner.

As an alternate choice, certain electrically conducting glass and plastic panels which have been investigated could be used where it is necessary to have visual indication.

Figure 3 shows levels of radiated interference before and after R.I.V. suppression devices were added, as compared to the levels called for in the specifications.

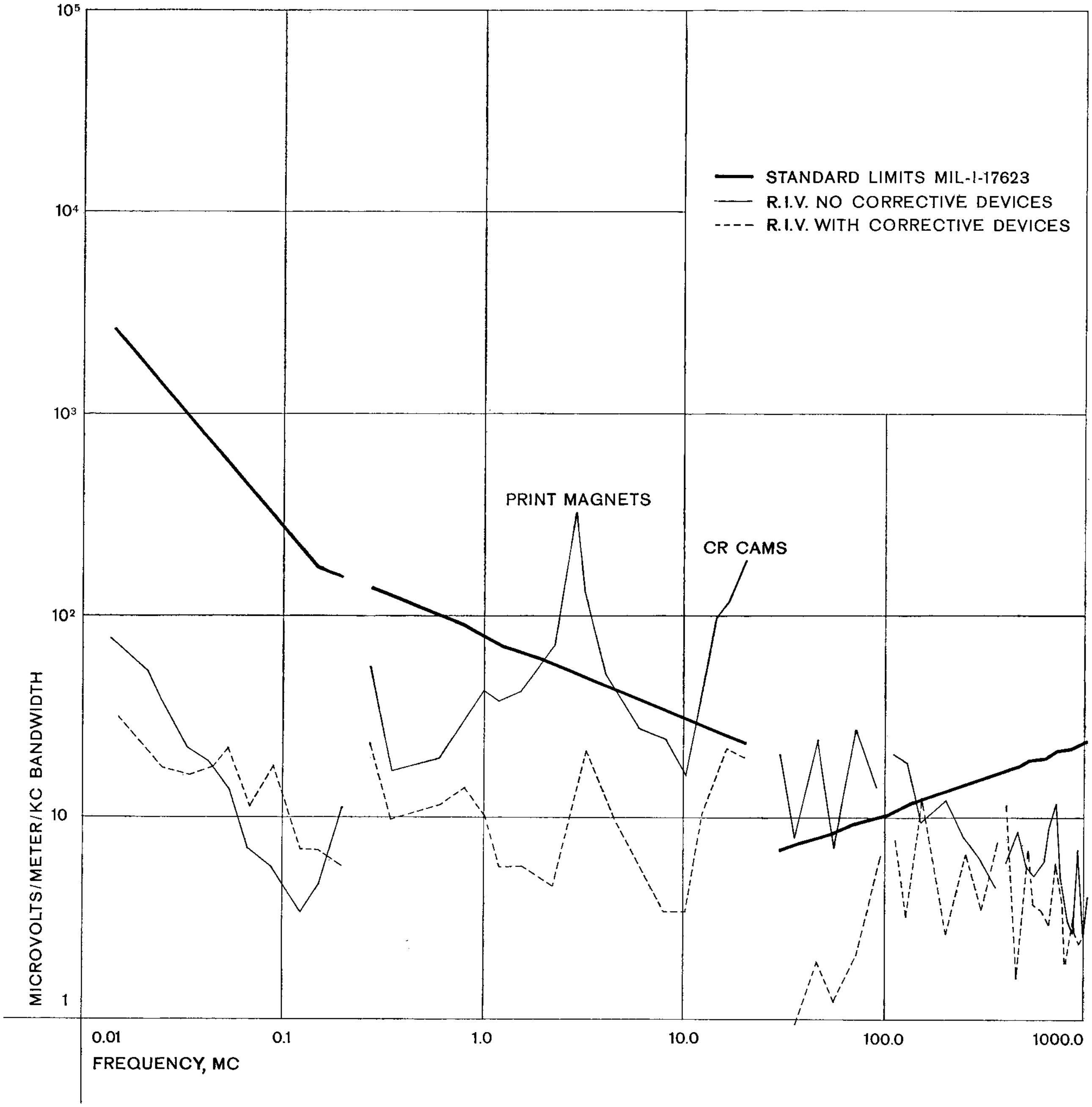
*Pilot model:* In an evaluation of a pilot model of an experimental-model machine, the equipment was thoroughly tested to determine the sources of interference and magnitude of the rf energy.

The interference conducted on the power lines was found to be far in excess of the radiated interference. Tests were made to determine the amount of conducted interference created by various components of the machine. In the range of 0.150 through 20.0 mc, the highest conducted interference originated in a continuous-running cam unit. This level of interference existed with various machine features not operating.

Between 0.150 and 1.50 mc, both the commutators on an ac-dc series-wound motor and mercury-arc lamps in the model created conducted interference in excess of specification limits.

The interference voltage in excess of limits between 12 and 20 mc was also caused by continuous-running cams. That above the limits between 55 and 90 mc was traced to faulty operation of a particular group of contacts.

*Figure 3* **Voltages from radiated interference, typical electromechanical machine.**



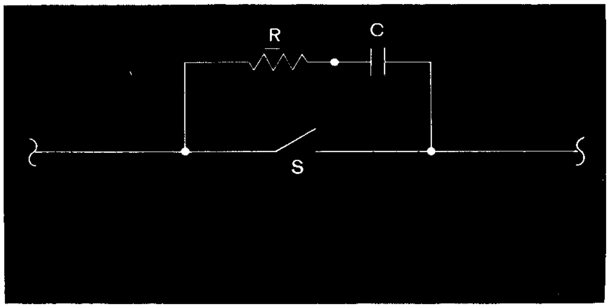


*Fig. 4a*

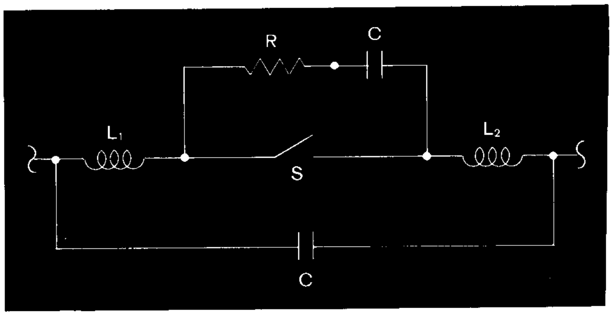
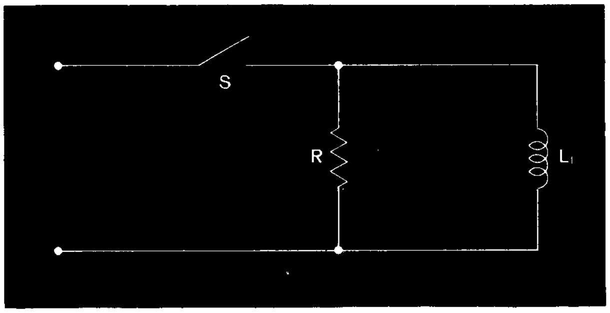


*Fig. 4b*

*Figure 4* **Methods for reduction of interference.**

a) *RC filter.*
b) *Series inductance — shunt capacitor, with RC combination.*
c) *Shielded enclosure and feed-through capacitors.*
d) *Series resistors with shunt capacitor.*
e) *Resistance-shunted inductance.*
f) *Rectifier for switch in inductive circuits.*
g) *Double pi-filter.*

*Fig. 4e*



After the curve of insertion loss versus frequency was plotted, it was possible to recommend specifications for a line filter which would have suitable attenuation to suppress most of the conducted rf energy on the power lines. The requirements for this machine were 120 v, 25 amp, 60 cps, with attenuation characteristics of 32 db at 0.15 mc with a linear rise to 43 db through 10 mc. Beyond 10 mc attenuation could fall off.

The following recommendations should be followed for these conditions:

1. Install resistance-capacitance networks to shunt offending cams.
2. Correct mechanical operation contacts.
3. Install feed-through-type capacitors to ac-dc series-wound motor, between brushes and motor housing.
4. Isolate ac from dc wiring.
5. Provide better fitting covers with smaller openings for viewing internal operations.
6. Insure clean metal-to-metal contact or bonding of components.
7. Install a close-fitting metal cover over the control-panel wiring.
8. Limit the capacitance between the machine frame and line to 0.1 $\mu$f to limit the leakage current from machine frame to earth ground to 5 ma.

### Filter design requirements

LC filters may either be used at the source to prevent the transmission of interference or at the receiver to prevent its reception, but generally it is better to have LC filters built in at the source than at the receiver. For suppression purposes a low-pass filter is usually preferred over other types, with a cutoff frequency near 10 kc. The filter will then have a small insertion loss at dc and at power frequencies and will attenuate all rf currents.

Three conditions limit the value of capacitance used in a suppression circuit. The first is inductance, which usually increases with the size of the capacitor, and since the resonant frequency is raised by decreasing the inductance, it follows that a smaller capacitance increases the high-frequency effectiveness. Secondly, in ac circuits the amount of power current drawn by the capacitor limits its size. Current drain should be negligible. The third consideration is the adverse effect a capacitor may have on life of contact or breaker points. The internal inductance of the rolled section of a bypass capacitor is fixed, but the external inductance of the capacitor lead can be lessened by reducing this lead length. However. even with leads only ¼-in. long, a bypass capacitor becomes ineffective at frequencies much over 5 mc.

The feed-through-type capacitor differs from the conventional capacitor in that all ground leads have been eliminated, and its internal inductance reduced, thereby raising its resonant frequency considerably. It consists of a feed-through bus that passes through the center of the capacitor section which is rolled in the extended-foil manner. Alternate foils on each side of the feed-through bus are soldered together, one set soldered to the bus and the other set to the housing. The feed-through capacitor is most effective when mounted through a shield wall with thorough circumferential contact. This minimizes the inductances and the resistance from the housing to

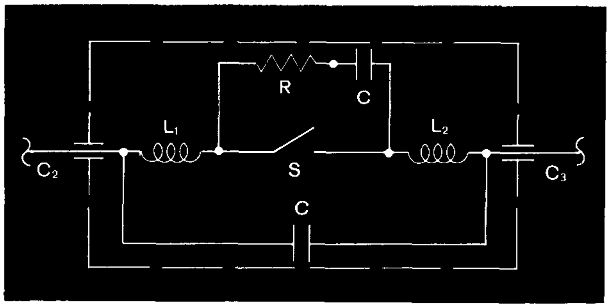


*Fig. 4c*

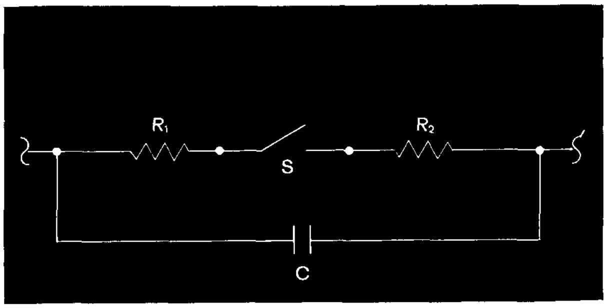


*Fig. 4d*

*Fig. 4f*

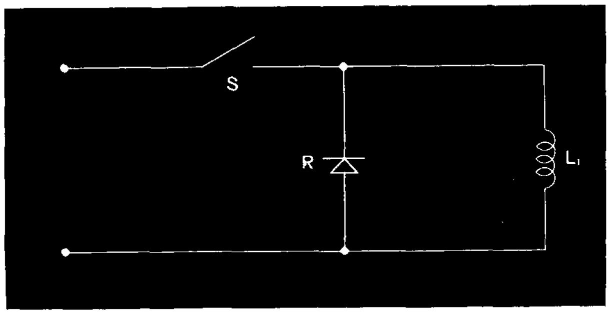
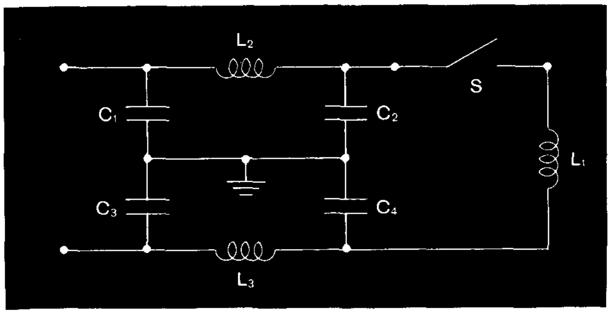


*Fig. 4g*



ground and also provides excellent shielding between the input and output terminals of the capacitor. This type of capacitor is far superior to any other single-element suppression device.

Other methods for reduction of interference are:

1. Conventional resistance-capacitance filter across switch, Fig. 4a.
2. Series inductance and shunt capacitance in combination with resistance capacitance, Fig. 4b. This type of low-pass filter is quite effective in attenuating steep wave transients developed by a switch but because of the distributed capacitance across the inductance and of the capacitor leads, will not always completely suppress the surge.
3. Shielded enclosure and feed-through capacitors, Fig. 4c. This method raises the resonant frequency by reducing the inherent inductance from line to ground and is a more effective bypass unit.
4. Filter with series resistors and shunt capacitors, Fig. 4d. Provided a slight voltage drop can be tolerated, resistances can be used in place of inductances. This allows for a longer rise time during the make, and longer fall time at break. Leads should be short.
5. High resistance for switch in an inductive circuit, Fig. 4e. A high resistance may be placed across an inductance to provide a path for the currents caused by the collapsing magnetic field when the switch is opened.
6. Rectifier for switch in an inductive dc circuit, Fig. 4f. An alternate path for currents caused by a collapsing magnetic field can be provided by placing a selenium rectifier across the inductance. When the switch is closed, the rectifier resistance will be very high and the source current will flow through the inductance, when switch opens, however, the reversed current from self-induced voltage will be passed by the low-resistance rectifier and will be dissipated.
7. Conventional double pi-filter, Fig. 4g. This type of filter may be used to suppress interference to some extent in an inductive circuit. Its effectiveness is determined by the nature of the interference and the insertion loss of the filter.
8. Filter as in Fig. 4g, with shielded leads and switch. This arrangement would be ideal for most any type of interference and very effective, although it is quite expensive.
9. Negative-voltage-characteristic resistors for Fig. 4e. A resistor having a negative voltage coefficient of resistance may be used where the resistance decreases as the applied voltage increases. This means that as the inductive field collapses, the current from the high-voltage surge will flow through the resistance which, being low at this time, will dissipate the energy. In normal operation of the device the resistance will be relatively high and thus there will be no appreciable dissipation through the resistor. This method has its drawbacks, however, in that this type resistor also has a negative temperature coefficient and if used in a circuit with many high current surges through it, or used in too high an ambient, the resistance will drop to a low point and will draw excessive current in the circuit.

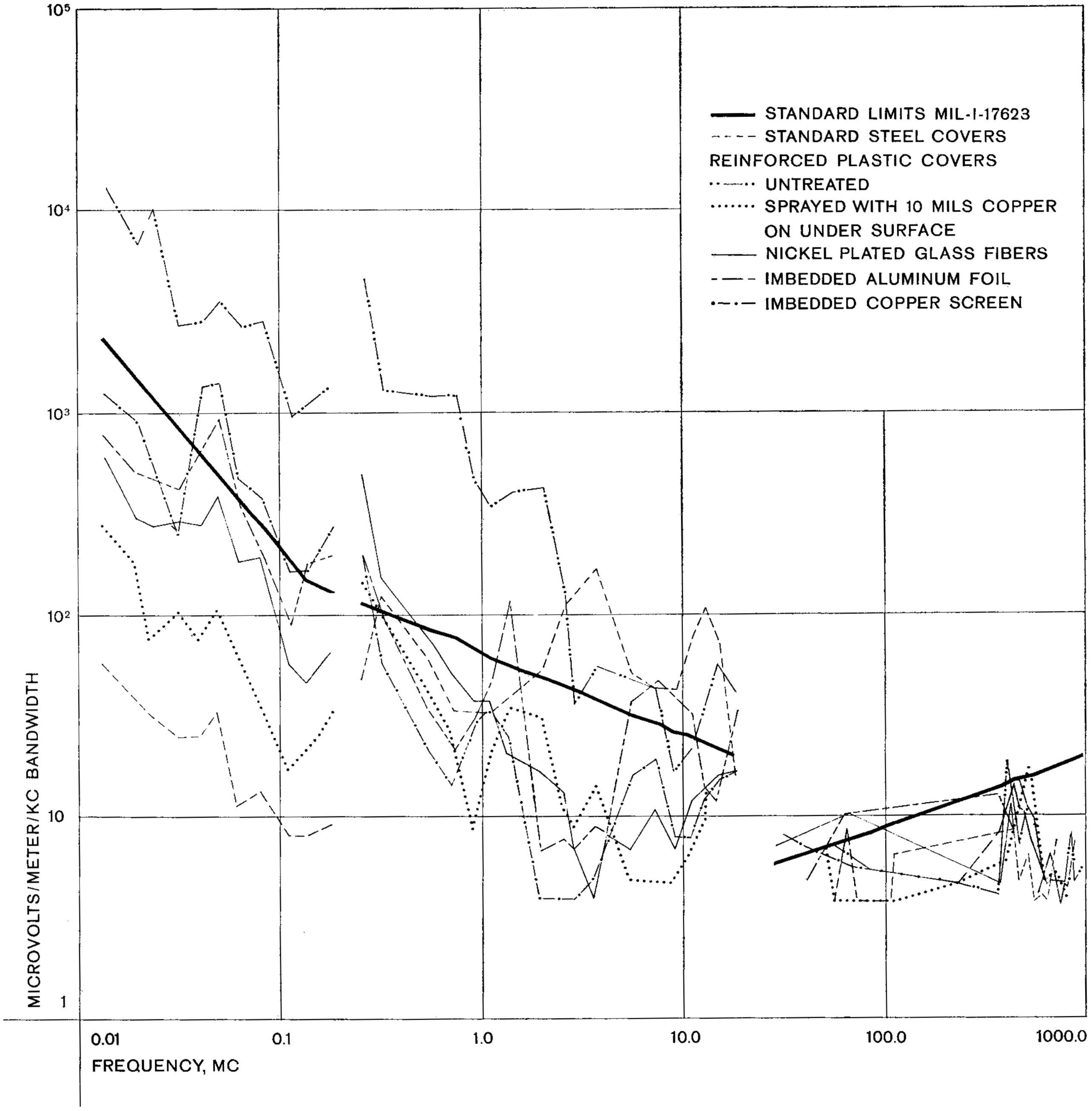
### Shielding requirements

In considering the use of plastic covers, it is recognized that for good radio-interference control, the shielding effect of the covers should be at least as good as that of conventional steel covers. For test purposes a high-usage machine was chosen to evaluate various shielding media in reinforced plastic, for comparison with standard steel covers.

In the choice of materials for this test, it was felt that copper would ultimately be most effective because preliminary testing indicated the presence of a strong electric field and relatively small magnetic-field disturbances. Copper has often been recommended for such applications because of its high conductivity and excellent reflective characteristics. As shown in Fig. 5, this choice was justified by the results obtained from both copper spray and copper screen.

In these tests, two types of reinforced plastic covers

*Figure 5* **Voltage readings from radiated interference, typical electromechanical machine with tube-controlled reading circuits.**



exhibited greater shielding effectiveness than the steel covers. Listed below, in order of decreasing shielding effectiveness, are the various types of covers tested.

1. Reinforced plastic with 10 mils of copper sprayed to the under surface.
2. Reinforced plastic with imbedded copper screening.
3. Standard steel covers.
4. Reinforced plastic with nickel-plated glass fibers.
5. Reinforced plastic with imbedded, perforated aluminum foil.
6. Untreated reinforced plastic.

The relative values of each of these types of shielding media are shown graphically in Fig. 5.

The shielding effectiveness to the electric field using reinforced plastic covers sprayed with 10 mils of copper averaged 25 db between 0.015 and 20.0 mc, and averaged 8 db to the magnetic field between 30 and 1000 mc.

Aluminum foil imbedded in the plastic covers was ineffective primarily because the foil, being only two or three mils thick, could not be soldered or bonded effectively.

A plastic material reinforced with nickel-plated glass fibers, although expensive, would be well suited because of its physical properties. For this application the fibers were chopped into two-inch lengths and glued to a plate of perforated metal. The fibers were then sprayed with resin and cured. The resultant nickel-plate mat weighed only 1 oz/ sq ft and the total weight of the glass mat only 3 oz/ sq ft. Again the deterrent factor was a means of devising a practical method of bonding the nickel to the machine frame for a low-impedance connection to ground.

The ultimate in shielding effectiveness requires a cover design with as few open seams and with as few joints as possible. It is also necessary to provide good clean metal-to-metal contact over the entire circumferential surface. This becomes a perplexing problem when machines must be opened periodically for servicing. The re-bonding problem apparently requires costly extraneous devices, such as electrically conductive gaskets or serrated spring-type fingers.

Figure 5 shows that a standard steel shield affords excellent shielding effectiveness at the lower frequencies (0.014 up to 0.33 mc), and from 0.47 through 1.9 mc. From 1.9 through 18.0 mc, and from 30.0 through 1000.0 mc, standard steel covers present little impedance to the generated interference, excepting at a few points in the uhf bands. In fact, the readings very nearly approach those taken with all the machine covers removed.

The untreated reinforced plastic covers, because of the absence of metal in shielding, proved to be quite ineffective up to 20.0 mc, as would be expected. Between 30 and 1000 mc the interference level paralleled that of the machine with standard metal covers.

The reinforced plastic, sprayed with 10 mils of copper on the under surface, exhibited very good shielding effectiveness. The measured interference exceeded the specification limits at only two frequencies over the entire frequency range of 0.015 to 1000 mc.

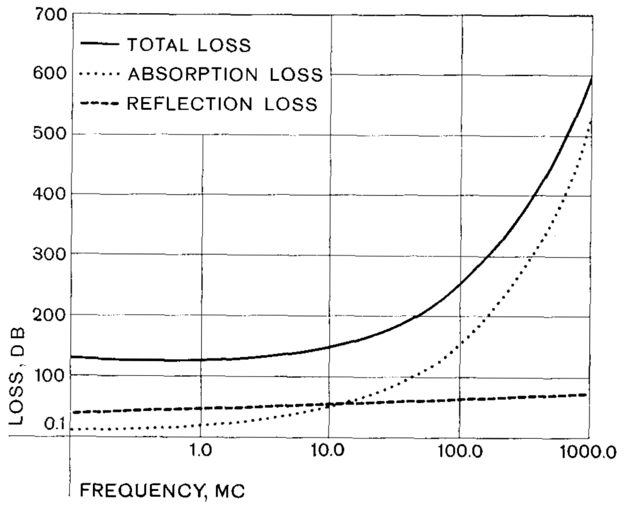


*Figure 6a* **Absorption, reflection and total losses in five-mil copper sheet.**

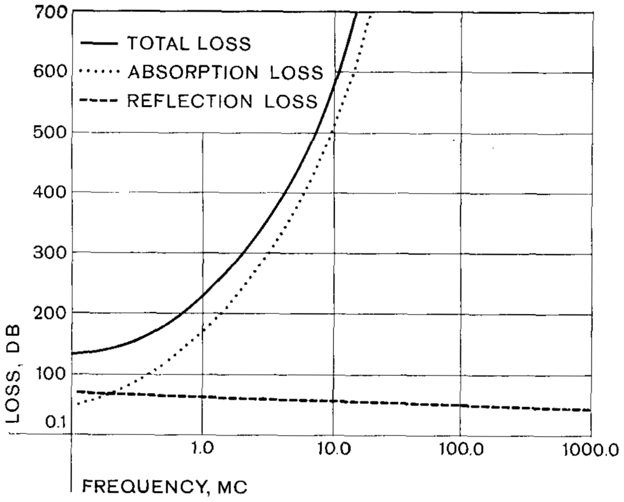
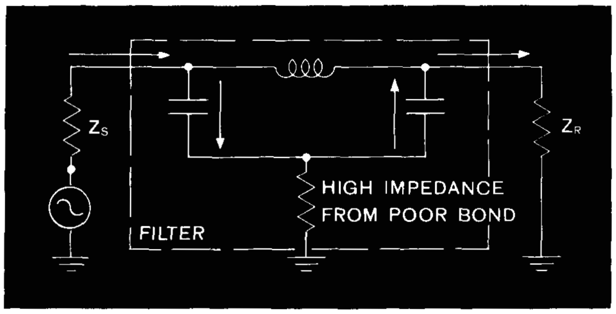


*Figure 6b* **Losses in five-mil sheet of magnetic material with relative conductivity 0.1, relative permeability 1000.**

*Figure 7* **Poor filter efficiency due to high-impedance ground connection.**



## Conclusions

Shielding effectiveness is due primarily to: (1) reflection losses and (2) attenuation losses. The reflection loss depends upon the degree of impedance mismatch between the air medium and the metal sheet. Attenuation losses are due to absorption in the shield. The amount of leakage of radiated energy is approximately proportional to the size of openings and joints. It is desirable to use several small holes instead of one large hole if the design of the machine permits. Holes for ventilation should be covered with fine-mesh copper screening which should be soldered in a continuous line around the edge of the opening.

Since increasing the shield conductivity generally increases both the reflection and the absorption effectiveness, the shielding material should always have as high a conductivity as possible. Increasing the relative permeability, i.e., using magnetic materials, increases the absorption effectiveness but decreases the reflection effectiveness. The thicker the magnetic material, the higher the absorption loss.

Figures 6a and 6b illustrate losses in magnetic and non-magnetic shielding materials.

It is frequently found that the most troublesome type of interference is conducted over the machine line cords. Although radiated interference energy attenuates or diminishes as the square of the distance from the source in free space, the energy conducted over the wiring is not dissipated at such a rapid rate.

Filter networks are used in line connections to divert energy at the interference frequencies, and components have low resistance for minimum effect on performance of the machine at its normal operating frequency. The case of the filter should be a good radio-frequency connection to the frame of the machine. Figure 7 shows a filter inserted into a machine line connection and illustrates poor filter efficiency due to a high-impedance ground connection.

Wiring on the input side of the filter should be isolated from the output wiring. If shielded cable or conduit is necessary to achieve this isolation, it is important that the shield or conduit be bonded at all points of entry or exit. Because of the inherently high capacitance of such shielding, it is recommended that use of shielding wire, cable or conduit be avoided wherever possible. Instead, the filter may be mounted on the inner surface of an outside panel of the machine, or, preferably, on the machine frame inside an outside panel and bringing the input wiring directly into an opening in the filter case through the panel.

Radio interference should be carefully considered in the basic design of all equipment, major units, assemblies, and systems. Electric and electronic equipment must operate satisfactorily not only alone, but also in conjunction with other such equipment which may be placed nearby. This requires that the operation of all such equipment should not be adversely affected by radio-interference voltages and fields reaching it from external sources, and also requires that such equipment should not itself be a source of radio interference which might adversely affect the operation of other nearby equipment. Therefore, design should be such that the least practical amount of radio interference is inherently generated and propagated before major units for interference reduction are applied. Major units and techniques that must be used, such as filtering, shielding and bonding, should be used efficiently in order to minimize space and weight penalties. All possible advantages should be taken of the use of radio-interference source reduction directly at the interference source.

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