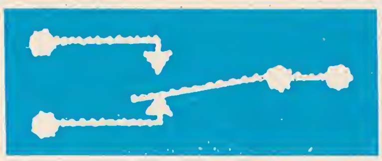
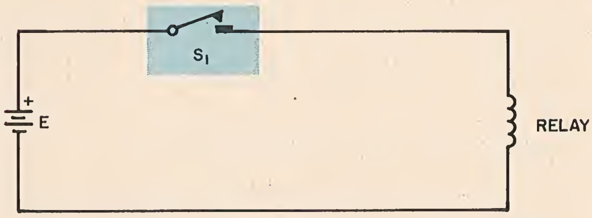


Curing interference in relay systems: Look to the source, then suppress

The erratic, broadband nature of switching transients and RFI makes them tough to handle. But a review of suppression methods shows that the problem is solved through design compromises.

THE PERFORMANCE of electronic systems is ever inhibited by transient and radio-frequency-interference (RFI) signals generated by switching circuits. These play havoc with the operation of the system and may even damage the components. Although many techniques are available to suppress the unwanted signals, each remedy involves a trade-off in some aspect of performance and a consideration of the size, weight and cost involved.

One type of suppression may mitigate the RFI, (which is sometimes referred to as electromagnetic interference, EMI) and do very little to retard the transients. Another suppressor may perform in the exact opposite manner. A third may reduce both RFI and transients, but with an accompanying decrease in switching speed.



1. **Simplified relay schematic,** showing a solenoid actuated by a toggle switch. The prime source of the RFI and transients is the switching of energy in the system.

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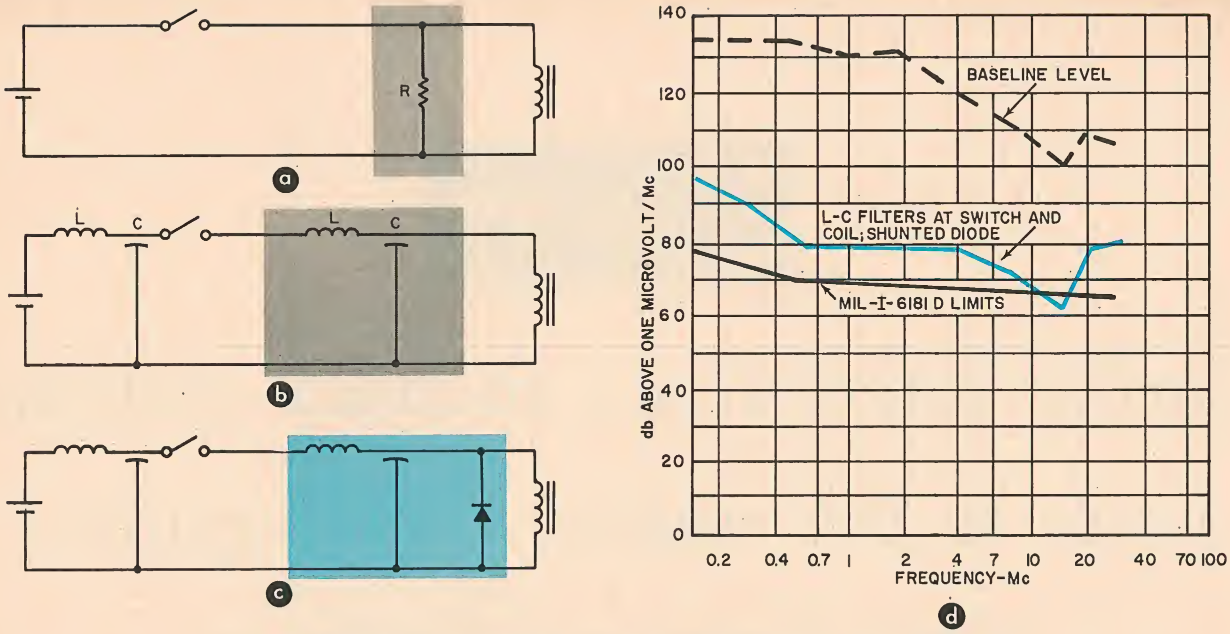
When confronted with a suppression problem then, the designer must, of necessity, choose a suppression network. His selection criteria should consider these features:

- The voltage and current levels involved.
- The suppressor's reliability.
- How well it attenuates RFI.
- How it affects noise levels.
- The suppressor's size and weight.
- How well it handles arcs and surges.
- Its influence on the switching functions, such as operate or release time.

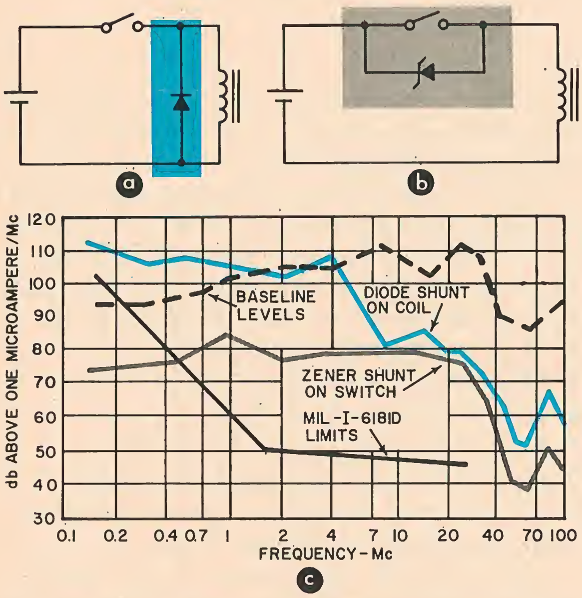
Let's examine the source of the troublesome signals and then see how they can be suppressed successfully.

Energy transfer generates RFI

The prime source of the RFI and other transients is the switching of energy in the system. A schematic of a relay solenoid actuated by a toggle switch (S) appears in Fig. 1. In closing, the switch exhibits bounce characteristics that cause the momentary de-energizing of the relay solenoid. This subsequently produces momentary oscillatory transients and switch-bounce current breaking. The latter effect is reflected as the arcing of the contacts during bounce. When S is opened, the stored energy ($1/2LI^2$) is re-



2. **Transients and switching arcs are suppressed** by the common coil-shunt resistor (a), brute-force L-section filters (b) and L-section-diode combination (c) methods. Waveforms of these methods (d) demonstrate that they fail to meet the specifications of RFI standard MIL-I-6181D.



3. **Coil transients are effectively suppressed** by a shunt diode (a), but the RFI levels remain high. A zener diode placed across the switch is more effective, as shown in the waveform of the conducted RFI levels (c).

turned to the circuit and dissipated as a loss of power in the relay core and in the switch arcing. In addition the collapsing magnetic field generates a transient or counter emf voltage expressed as

$$E = -L \frac{di}{dt} \text{ volts} \qquad (1)$$

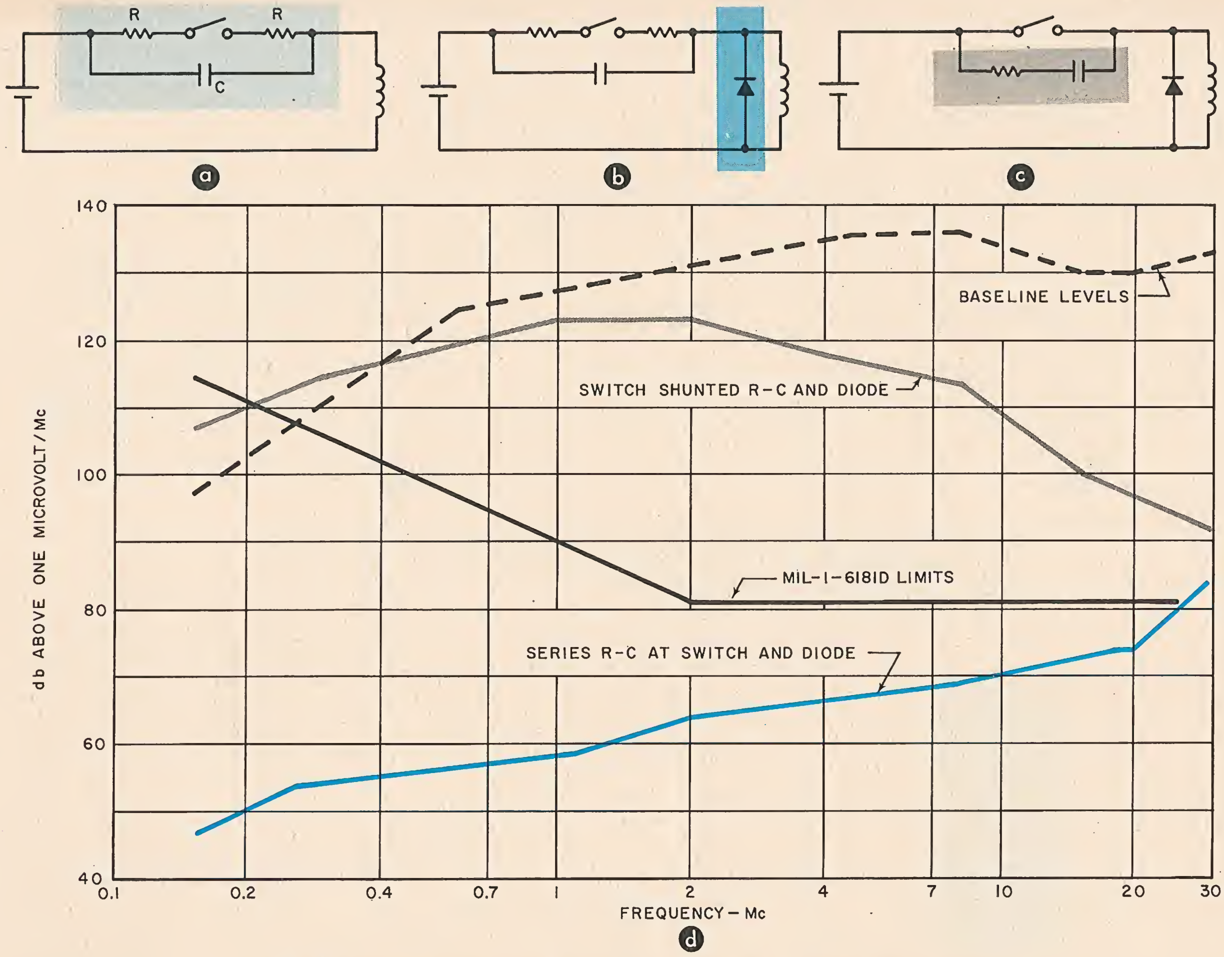
As S opens, an arc appears, due to the breaking current. This arc is quenched as the switch further opens. The arc is restruck as the relay voltage transient increases, due to the changes in coil current. The process continues until the coil current reaches zero. It may be noted in an oscilloscope trace of the coil voltage waveform that the transients do not exhibit a normal exponential rise. They take the form of a series of sawtooth waveforms and are a reflection of the switch arcing condition.

The general description of the RFI that is generated is that it is broadband in frequency and impulsive in nature. It may be conducted back into the power supply, coupled into the ac power circuits or radiated from the line, the solenoid and the switch. When the current abruptly decreases after the switch opens, the changing magnetic field resulting from the varying current is capable of inducing large impulse currents into adjacent wiring sections. The low impedance nature of this field may enable it to deeply penetrate even shielded wiring.[1]

Evolution of suppression methods

The techniques for suppressing solenoid transients and switch arcs have been developed over the years. An early RFI study showed that the coil transient could be greatly reduced by a coil shunting resistor (Fig. 2a). The magnitude of this shunt resistor is kept within four times the coil resistance

1. Techniques for measuring RFI levels may be found in military specifications such as Mil-I-6181D, Mil-I-16910C and Mil-I-11748B.



4. **RC network suppresses the RFI** but does not reduce the transients (a). Addition of diode (b) further improves the RFI suppression. Shunt-RC network combats the switch transients but does not limit the RFI (c). The effectiveness of the series-RC-network-diode combination is exhibited in the RFI level waveforms (d).

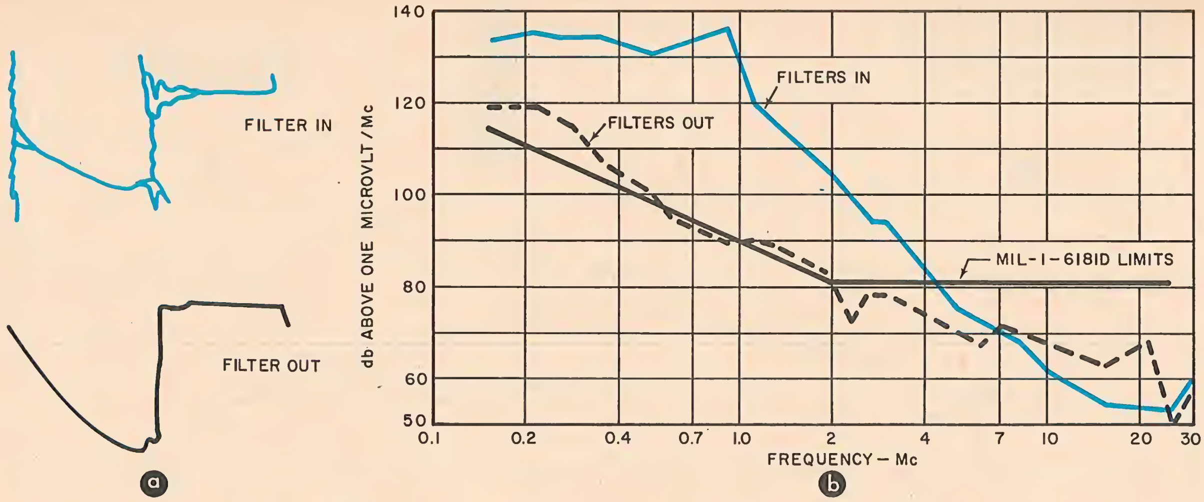
value. This method, however, has the inherent disadvantage of additional power dissipation. Moreover it is very basic and can only meet a non-stringent RFI suppression need.

The typical brute-force method of using L-section filters to suppress coil- and switch-generated RFI is shown in Fig. 2b. This network, while effectively suppressing the RFI, does not solve the problem of the coil-generated transients. It has the added disadvantage of weight and size.

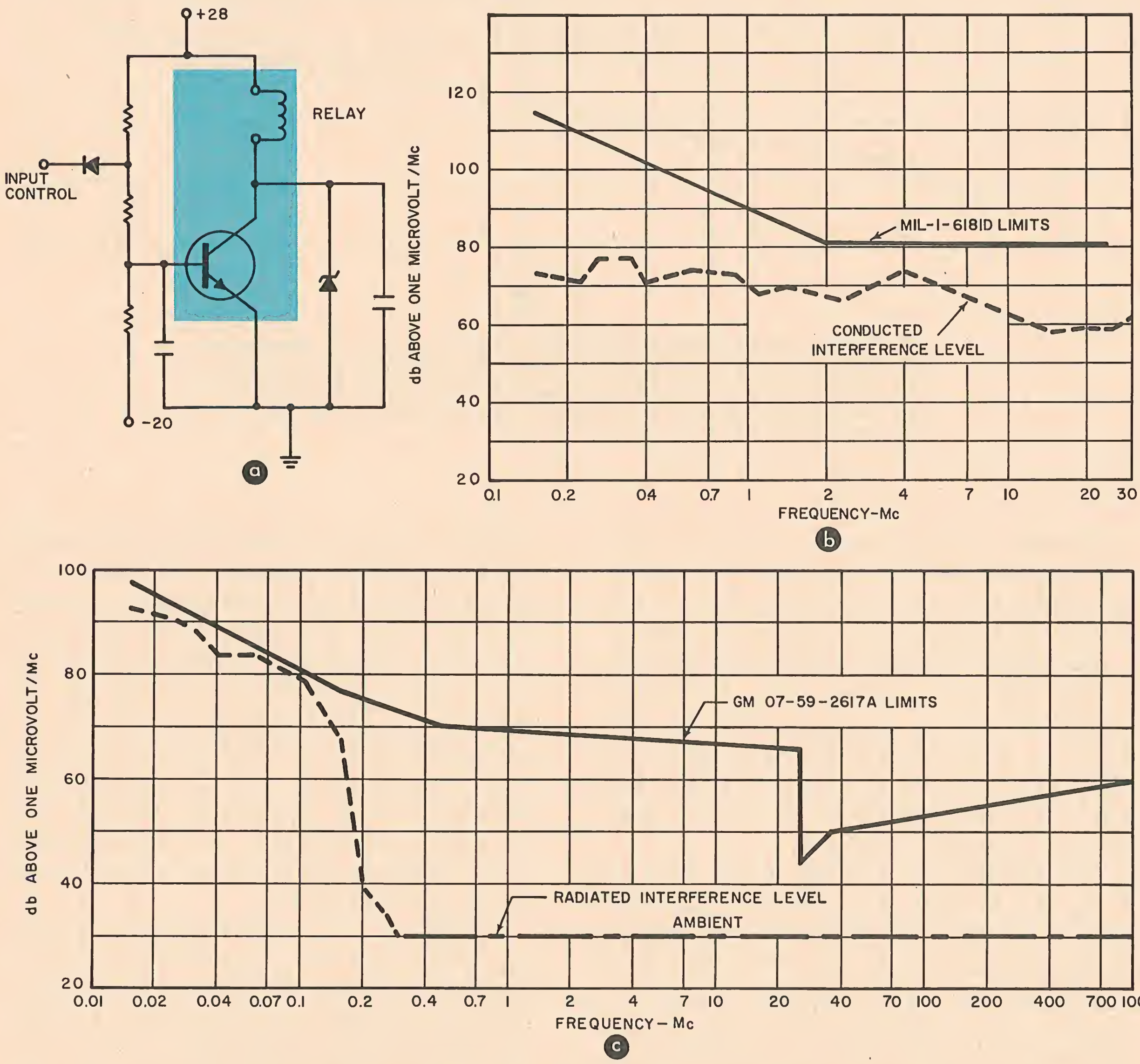
The addition of a diode across the coil (Fig. 2c), to limit the transient amplitude, reduces the transient markedly, but, because of its placement, does not sufficiently reduce the RFI. Thus, further filtering is needed to suppress the conducted RFI and shielded wiring is required to reduce the radiated RFI. Data taken (Fig. 2d) show that without shielded wiring for this network configuration, the radiated RFI levels exceed Mil-I-6181D limits.

The use of a diode alone to limit the coil transient (Fig. 3a) has become quite standard for reliability purposes. Its effect is to dissipate quickly the inductor-stored energy into the diode and load circuitry and to present no excessive voltage at the switch with which to develop or sustain an arc. However, the RFI-suppression quality of this approach is poor, and it may cause the generated, conducted and radiated interference to increase at some frequencies. Data in Fig. 3c show the increase in RFI-conducted levels resulting from use of just a diode across the relay coil.

The use of a zener diode across the actuating switch (Fig. 3b) is a superior advance to that of the diode coil shunt. This method achieved an average of 20 to 30-db of radiated magnetic-field suppression over the frequency range 0.150 Mc to 100 Mc. An additional plot of the data for the zener suppression is included in Fig. 3c. It clearly shows a more effective suppression of the conducted RFI. However, this method, while a great



5. **Current waveforms** of stepping switch-coil (a) show that transistor-driven solenoids have cleaner waveforms and reduced interference levels when filters are not employed (b).



6. **Typical transistor relay driver** (a) is logic-operated. Conducted interference level (b) at the high side of the coil shows that even without an rf filter, the RFI level is within specifications. Radiated interference level (c) was also within specs, although shielded wiring was not used.

improvement over the more conventional approaches described earlier, does not provide the total RFI suppression normally required in today's specifications.

A series-shunt RC network (Fig. 4a) that effectively suppressed the switch-generated RFI was then developed. While this network is not intended to reduce the coil transients to supply-line voltage levels, it does resolve the RFI part of the problem. In addition its use in this combination is current-limited, because of the resistor voltage drop and the power dissipation requirements. However, it is suitable only for relays drawing less than 100 ma of current. It is also attractive because the series-RC network has been reduced to an integrated circuit that approximates a postage stamp in size.

The addition of the diode across the relay coil (Fig. 4b) again improves the RFI suppression and increases circuit reliability by protecting the network capacitor from relay transient levels. The simple shunt-RC network (Fig. 4c), while helpful in combating switch transients, is ineffective in suppressing the generated, broadband RFI, even when placed in combination with the relay-shunt diode. A comparison of the shunt-RC-diode combination with the series-RC-diode combination to suppress conducted RFI appears in Fig. 4d. Note the improvement for the series network configuration—60 db at 150 Kc.

Transistors can suppress RFI

The use of transistor circuits for switching has led to a more intensive investigation of their RFI suppression possibilities when the transistors are used as solenoid drivers.[2] In 1962 the author participated in RFI suppression for Avco's SEK 17-4 R/v checkout equipment. Within the equipment, 18 solenoid-actuated stepping switches and 11 relays formed the basic broadband RFI problem. No special deviations were granted, or requested, for conducted and radiated RFI for transients over the frequency range 30 cps to 10 Gc.

In the initial design of this equipment, L-section, low-pass RF filters were used between the 28-volt supply and the stepping switch solenoid to reduce to low levels any interference conducted back to the power supply. The stepping-switch circuits used as the solenoid driver were logic-operated and employed a transistor-SCR switching combination. The predictable transients generated by these filters are noted in the comparison of the solenoid current waveforms (both with and without filters) in Fig. 5a. The difference in conducted RFI levels under the same conditions, taken at the coil high side, is shown in Fig. 5b. Note the clean current waveform and the reduced interference without the filter. In addition, radiated interference levels from this source, taken on an open breadboard basis over the frequency range 10 Kc-1000 Mc, were 20 to 50 db below specification limits over the major portion of the range.

The typical relay driver used is shown in Fig. 6a and was logic-operated. The zener diode is used to protect the transistor against the coil transients, and the capacitors are used for wave-shaping. Figures 6b and 6c show the high-side coil-conducted and radiated interference levels, respectively, for this configuration without the use of an RF filter.

Final tests for the equipment breadboard showed that radiated and conducted levels over applicable portions of the band (30 cps-1000 Mc) were well within the specification limits of GM-07-59-2617A, with one exception. At 300 Mc the radiated level was 6-db above limits. This was attributed to the ac ON toggle switch. The test results were obtained without either outside shielding or the use of a single RF filter for any dc or ac power lines.

Different suppressors often combined

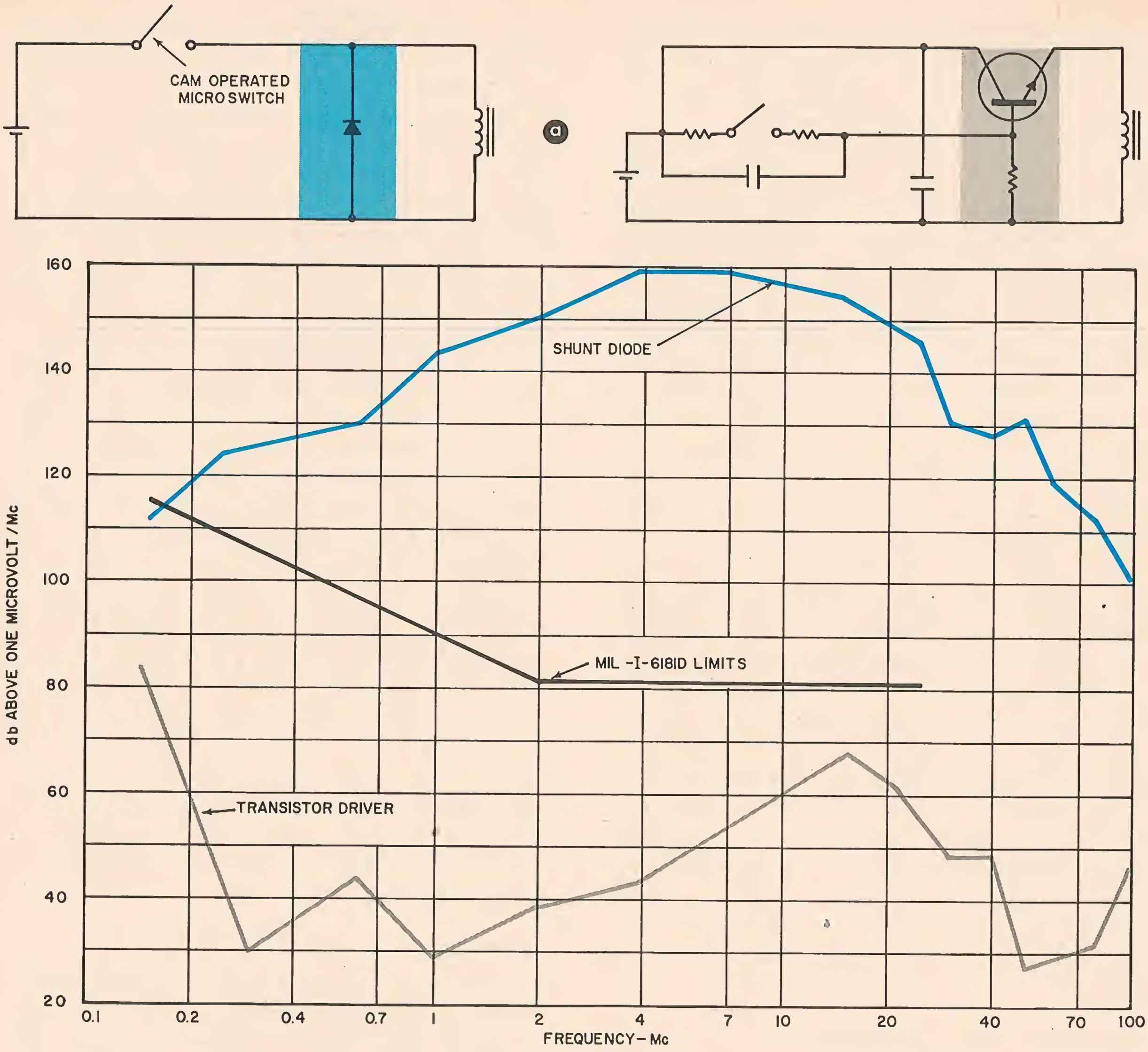
In those cases where the solenoid driver is not logic-operated and a switch is used to apply the driver input, effective RFI suppression can be achieved by a combination of methods. The series RC network (integrated circuit) can be put to use as part of the switch-driver combination to make an RFI-free circuit.[3]

The test circuits used appear in Fig. 7a. A microswitch, actuated by a cam, energizes the relay directly in one case, and a series-RC-network-suppressed switch, controlling a transistor driver, does the job in the other. The comparative results of conducted RFI for the two configurations is shown in Fig. 7b. Note the marked differences in the levels.

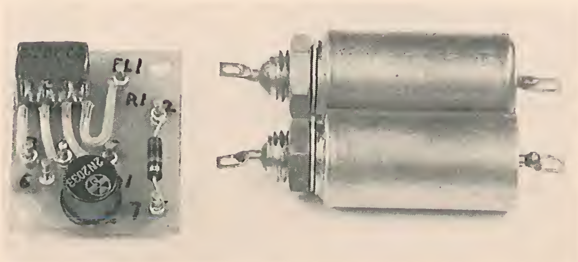
The advantages of the series-RC and driver combination are many. The current through the microswitch for the switch-relay circuit is 0.5 amp; for the switch-driver circuit, the current is only about 5.0 ma. In the case of the simple cam-operated microswitch, two low-pass RF filters (LC type) would be required to suppress the switch and relay broadband RFI. In the other networks, no filters are required, other than the RC

2. Pecota's Study at Sperry Gyroscope, IRE Convention Record, Vol. 6, Part 8, 1958.

3. As reported by Busch and Albin (surprs) at the 1965 Relay Conference, Stillwater, Okla.



7. **Shunt-diode suppressor** (top) falls far short of combination transistor driver-series-RC-network suppressor (bottom) in reducing interference in non-logic-operated solenoids (a). Test results of conducted RFI levels (b) show the marked superiority of the combination suppressor method.



Run interference into the ground . . . Transistor-driver suppressor network (left) is more effective then heavy and bulky, conventional brute-force filter suppressor (right).

network shown for the switch. This network (described earlier) consists of two 30-ohm resistors, which also provide the proper bias for transistor saturation, and a 0.47 μf capacitor element.

The other advantages of this design are size and weight. A comparison of the sizes of the filters and the switch-transistor driver makes clear the substantial improvement in the driver case. This underlines the fact that the engineer need not use bulky suppression networks for limiting interference in small solid-state systems (see photograph).

All of the methods used to suppress RFI in relays extend the release, or drop-out, time of the relays. A method for calculating relay drop-out time is given by Donohoo (see bibliography). In the transistor driver circuit approach, both zener and conventional diodes placed across the coil will reduce the drop-out time. This method is basically similar to the use of back-to-back zener diodes for relay-transient suppression (as shown by

Jordan and others). The problem with the use of the single diode is that its action continues the flow of current through the coil and prevents drop-out from occurring immediately after the circuit's supply energy has been cut off. The zener diode placed back-to-back with the ordinary diode precludes this holding action.

In virtually all of the methods to suppress interference, a key point in design is involved: The most effective suppression is obtained when the network is placed at the source of the interference, rather than at a so-called "critical" output point. This results in improved system reliability and the greatest economy in size, weight and cost. ■ ■

Bibliography

(This list represents only a sampling of the many papers and articles on interference suppression in switching circuits.)

Albin, A. L., and Busch, E., "Miniaturized Components for RFI Suppression in Photo-Optical Control Systems," Tenth National Technical Symposium, Society of Photo-Optical Instrumentation Engineers, August, 1965.

Albin, A. L., and Busch, E., "Miniaturized Components for Relay Interference Reduction," Thirteenth Annual Relay Conference, April, 1965.

Budzilovich, P. N., "Three Component Arc Suppression Network," *Electronics*, September, 1960.

Burruano, S. J., "EMI Control Plan for SEK 17-4 R/V Checkout Systems," Report #626-1, 1962.

Burruano, S. J., "Summary of SEK 17-4 Unit RFI Tests," Report #626-2, June, 1962.

Burruano, S. J., and Busch, E., "Electromagnetic Interference Compatability Plan for KA-60 Camera System," June, 1964.

Chase, L. G., "Electrical Transient Interference in a Missile Weapon System," Electro-Magnetic Compatibility Lecture Series, ASD, AFSC, WPAFB, Ohio, 1961.

Deuber, B., "Development of RFI Shielding Urged at Circuit Design Stage," *Electronic News*, May 18, 1964.

Donohoo, D. J., "Minimizing Inductive Kick and Fall Time," *EEE*, September, 1965.

ELECTRONIC DESIGN Special Report on Radio Frequency Interference, Vol. 10, No. 20, Sept. 27, 1962.

"Finding RC Values for Contact Protection in Mercury Wetted Relays," Electronic Capabilities Econogram, February, 1965.

Goldblum, R. D., "Measuring Dc Relay Coil Transients," *Electronic Industries*, April, 1965.

Haber, E. and Jambor, L. D., "Shortcut to Design of Diode-Resistor Suppression Networks," ELECTRONIC DESIGN, Oct. 25, 1965.

Hermann, K., "Selecting Transistors for Coil Drivers," *Electro-Technology*, December, 1962.

Jarva, W., "Suppression of Inductive-Loaded Contacts with Zener Diodes," Filtron Report TM-1103-1, 8 August, 1961.

Jiu, R., "Relay Contact Bounce Measurements," *Electronics*, August, 1955.

Jordan, J. S., "Suppressing Relay Coil Transients," *Electronic Industries*, April, 1965.

Pecota, W., "Small Lightweight RF Interference Suppressors Using Transistors," (Sperry Gyroscope) IRE Convention Record, Vol. 6, Part 8, 1958.

"Transistorized Relay Circuits," Aerovox Research Worker, May-June 1959.

Voell, R. F., "Methods for Elimination of Surge Voltages Produced by Inductive Interruptions," Convair Application and Techniques Bulletin #7, 1957.