Practical RFI Elimination Techniques for the Broadcast Engineer

By

William L. Ammons

Broadcast Electronics, Inc.

BROADCAST ELECTRONICS INC.

4100 N. 24th ST. • P.O. BOX 3606 • QUINCY, IL 62301 • PHONE 217/224-9600

a FILMWAYS company

"PRACTICAL RFI ELIMINATION TECHNIQUES FOR THE BROADCAST ENGINEER"

With the ever increasing emissions of RF, interference to broadcast station equipment is increasing. This paper will deal with three major areas of RFI (Radio Frequency Interference): sources and modes of interference, techniques used in newly designed equipment to prevent RFI, and a discussion of practical techniques a station engineer can use to minimize RFI in the station equipment.

The emphasis in this paper will be on the practical ideas and concepts that a station engineer can use to reduce interference to equipment. The first two sections of the paper will be brief overview of subject material.

A broadcast station's RFI problems are most often caused by its own transmissions, but in todays's urban environment, interference from other sources can be just as troublesome. Potential sources of interference include, but are not limited to:

1. Other broadcast station operations (AM, FM, TV, STL, etc.,).
2. Citizens band transmissions
3. Public Service and Busines Band transmissions.
4. Ham Radio
5. Digital Equipment

RF emissions, of course, vary widely in frequency and intensity from source to source. The list above is in no respect complete.

Interference to station equipment occurs primarily through two modes, Radiated and Conducted.

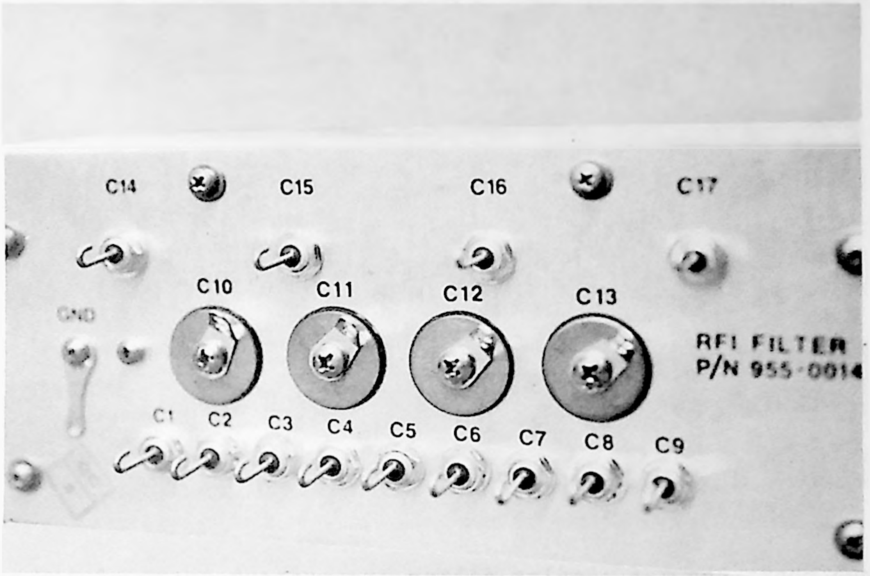
In the radiated mode interference is caused by components and circuits being directly affected by RF fields, a voltage is induced in the afflicted part and when rectified will cause interference . Interference due to this mode is usually worse in equipment with inferior shielding qualities.

RF entering the equipment via the various leads is called "Conducted RF". This form of RFI is usually the major cause of problems to broadcast equipment. RF enters the equipment indirectly thru the leads is rectified by an active stage, and interference results.

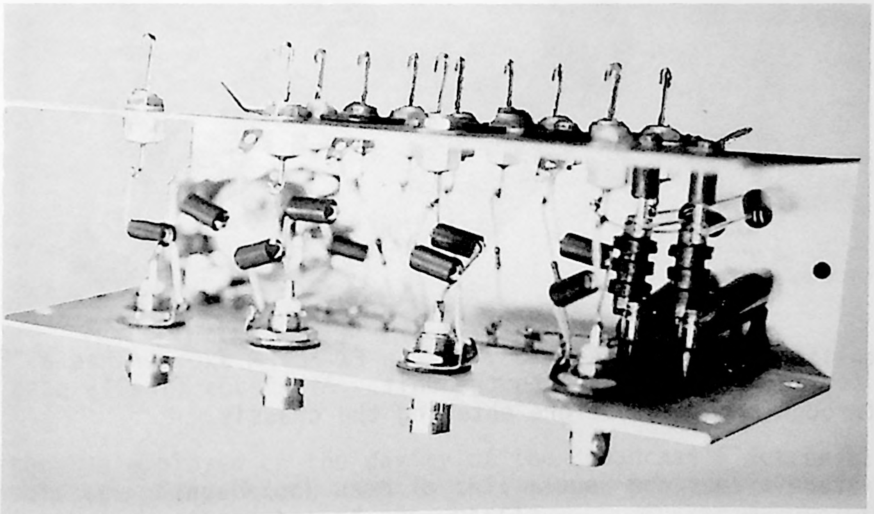
These two forms of interference will be covered in more detail in the last section of this paper.

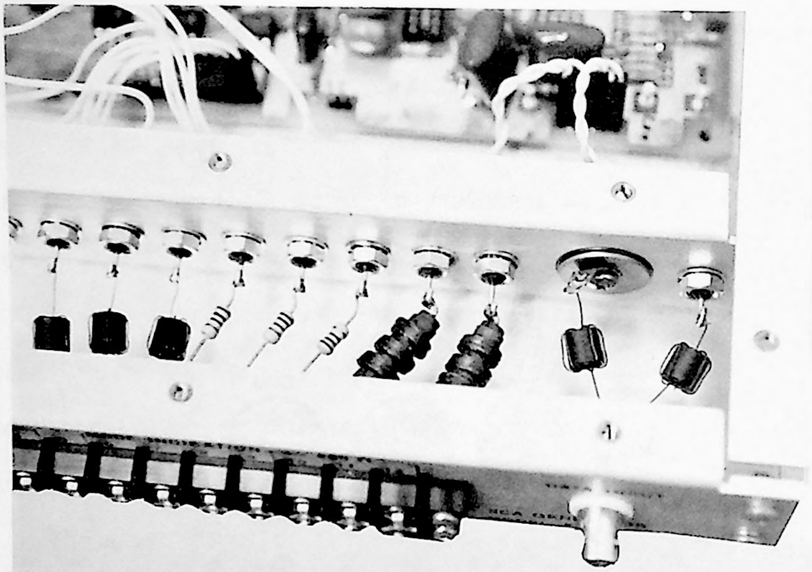
In recent years station engineers have voiced increased concern over RFI problems to their station equipment.

Some equipment designs today are now taking into account the problems that the station engineer faces from RFI. The next area of discussion will focus in on some examples of RFI prevention techniques that have been incorporated into recently designed Broadcast Electronics equipment.

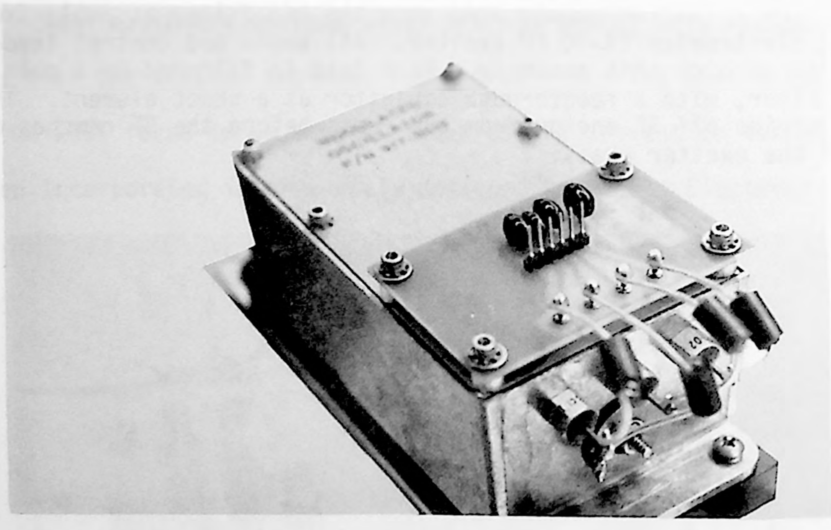


The first two photographs show the RFI filter assembly from the Broadcast Electronics FX-30 FM exciter. All audio and control leads enter the exciter through this assembly. Each lead is filtered by a multi-section filter, with a feedthrough capacitor as a shunt element. This assembly strips off RF energy from the leads before the RF reaches the main cavity of the exciter chassis.

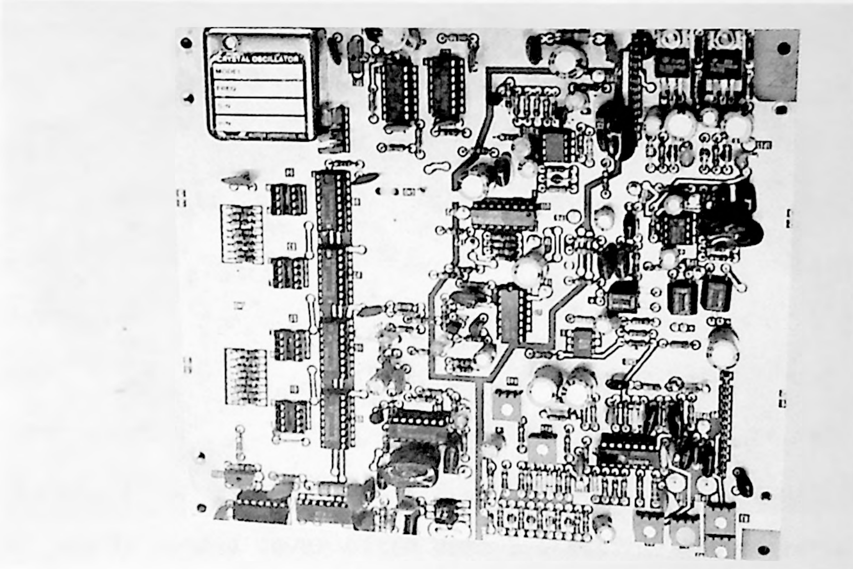




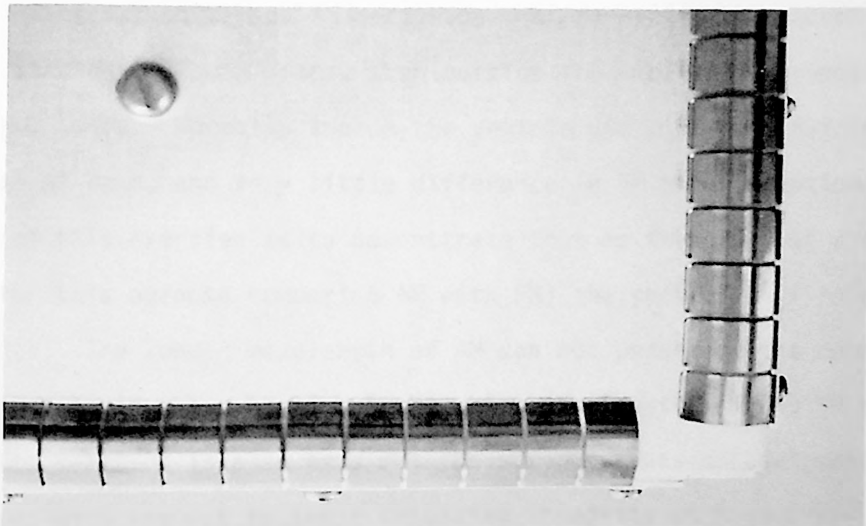
The above photo shows a similar filter arrangement on the Broadcast Electronics FC-30 SCA Generator.



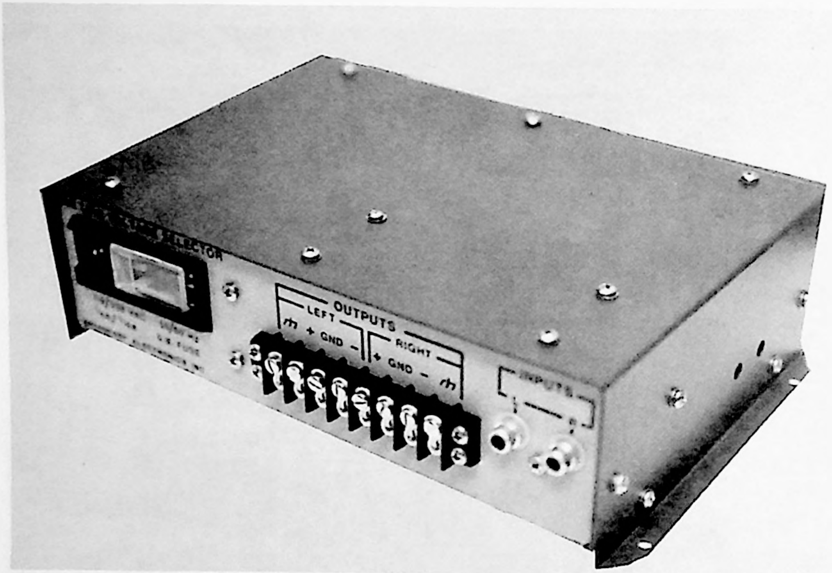
The modulated oscillator assembly in the FX-30 FM exciter has a "PI" section filter for each lead going into the unit. All leads finally pass through a feedthrough capacitor before entering the chassis.



Extensive ground plane was used on this PC assembly from the FX-30. Ground plane on a PC board can add excellent shielding and grounding qualities to a design. Note the ground plane is broken in several places to eliminate ground loops.



Fingerstock is employed on the cavity of the Broadcast Electronics FM-30 FM transmitter. Fingerstock used in this manner provides a positive RF connection between the door and the chassis.



The Broadcast Electronics EP-1 phono preamp has extensive RF shielding to minimize both conducted and radiated interference. Note the number of, and close spacing of screws used to bond the cover to the chassis. Internal tooth lock washers bite through the paint and provide a good electrical bond between chassis members. Both the power line and audio connections are RF filtered by multi-section networks.

The third area of discussion in this paper will deal with some practical applications, that a station engineer can use to minizize RFI to station equipment. We noted earlier that there were two principle forms of RFI to equipment (Radiated and Conducted). First, we will deal with some concepts and "cures" for radiated RFI problems.

Radiated RFI is usually more pronounced in equipment that has poor shielding qualities. Loose fitting covers, doors or removeable panels may provide a single point low ohmic contact to the chassis of a given piece of equipment, but have little shielding ability at 100 megaHertz. A given piece of equipment may also work fine at AM broadcast frequencies but, in a strong RF field at 100 megaHertz, be susceptible to interference. A loose fitting or poorly bonded cover often does a beautiful job of reradiating RF into a chassis. At VHF frequencies fasteners on a cover or panel may be a quarter wave length apart, again seriously diminishing the shielding of the equipment. A practical demonstration of shielding effectiveness versus frequency is to take a battery powered AM-FM radio inside a car or van and compare AM reception versus FM reception. After noting the reception of the various stations on both bands, step outside the vehicle and compare reception on the two bands. Normally inside the vehicle you will note fairly poor reception AM band, and very little difference in FM band reception. The purpose of this exercise is to demonstrate that as frequency of a RF source rises (for this purpose comparing AM with FM) the shielding of an enclosure diminishes. The longer wavelength of AM can not penetrate the comparatively small openings in the vehicle but the short wavelengths of the FM broadcast can. This relation is also true for the various types of equipment found at a station, with respect to their shielding integrity at high (VHF-UHF) frequencies.

There are some steps that an engineer can take to minimize radiated interference by improving the RF integrity of a given piece of equipment. Listed below are some general concepts that an engineer can take to improve the shielding of the equipment.

1. Use internal tooth lock washers under screw heads and nuts that join chassis members together. This type of washer bites through paint and coatings to provide positive contact with the bare metal. Scraping paint off where fasteners are used will also help.

2. Reduce the distance between the fasteners that bond chassis members together. Refer to the photograph of the Phono preamp on page 6. Note the short spacing between screws. This is done to ensure good cover bonding even at VHF frequencies.

3. Add shielding strips such as fingerstock and mesh gasket material to removeable covers and panels.

4. Short, Wide, bonding straps between the chassis and swing out doors etc. can make a big difference in the RF integrity at VHF and UHF.

5. For small projects, a very RF tight box may be constructed out of blank double sided PC board material. Solder all edges carefully, and the enclosure will be an effective RF shield.

Conducted RF enter equipment via various leads (power line, inputs, outputs, etc.), and causes interference by directly feeding RF to active circuits or reradiating RF inside the chassis. For example, at FM broadcast frequencies, the 36 inch leads from a turntable to a phono preamp often act as a quarter wave antenna, doing a fine job of delivering RF into the preamp.

A common symptom of conducted RFI is changing levels of interference to a piece of equipment as the leads are moved about.

Conducted RFI in existing equipment can often be minimized by the implementation of the following concepts. The most effective and practical method of minimizing conducted RFI, is the filtering of all leads entering the equipment. We looked earlier at some photographs on page 3 and 4, showing some filter networks in equipment. In many cases RF filtering may be added to existing equipment by an engineer.

Several basic filters make up the majority of decoupling networks used to curb conducted RFI.

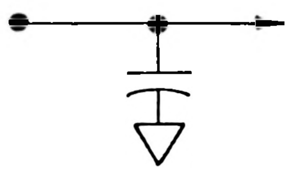


Fig. 1

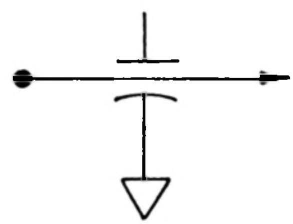


Fig. 2

A single element shunt capacitor filter (Fig. 1) will do a fair job of decoupling a line of RF if the reactance of the capacitor is low at the frequency of the interfering signal. The capacitor leads, as in all cases where the capacitor is used as a shunt element, must be kept short as possible. For effective operation into the UHF bands, a feedthrough capacitor should be used (Fig. 2). A series inductor as a single element filter is not recommended as it may just reradiate RF into the chassis.

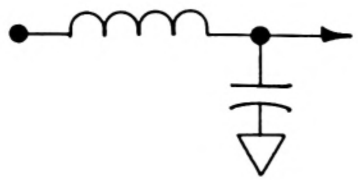


Fig. 3

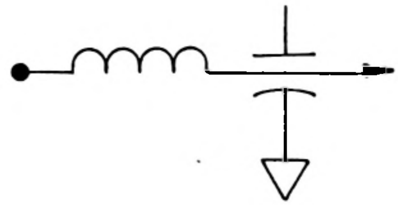


Fig. 4

A two element filter network formed by a series inductor and a shunt capacitor (Fig. 3) can exhibit good RF decoupling characteristics over a wide bandwidth. With the use of a 1000 pF feedthrough capacitor and ferrite choke, over 60 dB of attenuation at FM broadcast frequencies can be obtained (Fig. 4).

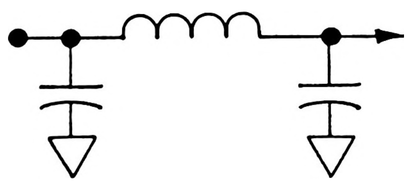


Fig. 5

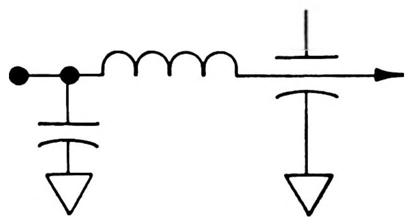


Fig. 6

A three element "PI" filter, when components are properly selected, can provide 40 dB of RF attenuation over a wide bandwidth (Fig. 5). As with the other two filters above, for good effectiveness at VHF and UHF frequencies, the third element should be a feedthrough capacitor (Fig. 6).

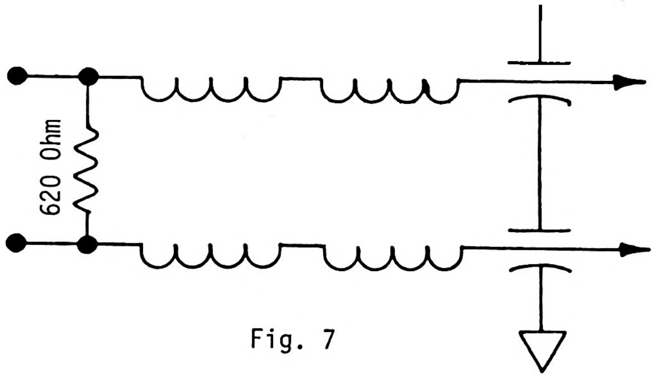


Fig. 7

Figure 7 is an example of a wideband filter used on a balanced audio line. Two inductors are used in series to insure high series impedance over a wide bandwidth. Low-impedance feedthrough capacitors insure effective operation into the UHF bands. The 620 ohm resistor was placed in front of the inductors to insure that they do not saturate under high frequency, high level audio signals.

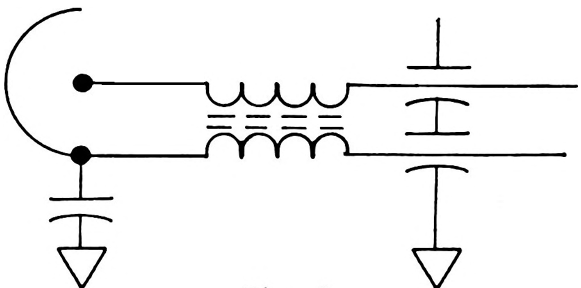


Fig. 8

The filter network above (Fig. 8) is a wideband network used on the input to a phono preamp. A shunt C shorts RF energy traveling on the lead outer conductor to the chassis. A bi-filar wound torrid choke effectively filters out differential mode RF. Because of the high impedance of the preamp, a 50 pF feedthrough was used to filter the signal lead.

The capacitors and inductors used to form filter networks, often behave in opposite ways from what we desire. For example, at 100 mHz some capacitors will act as inductors, and some inductors will act as capacitors. The impedance of seven inductors and five capacitors were measured from 500 kHz to 110 mHz on an RF vector impedance meter. The results were tabulated and are found on pages 13 and 14.

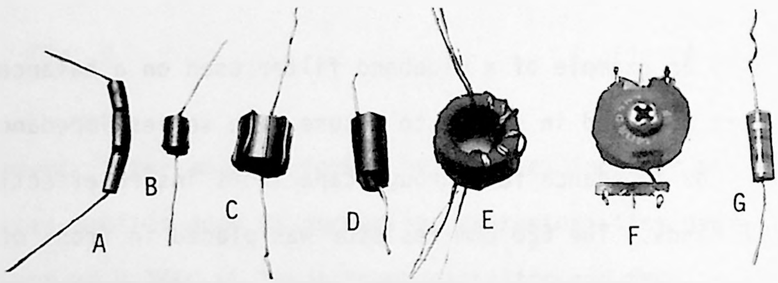


Fig. 9 - Seven chokes listed in table 1.

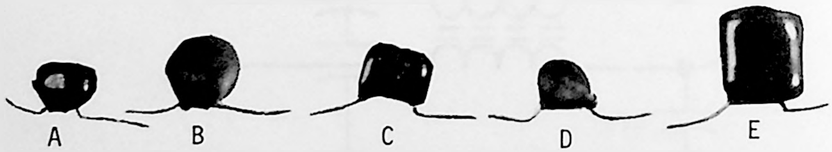


Fig. 10. - Five capacitors listed in table 2.

TABLE I

Choke Impedance versus Frequency (in Ohms) *

FREQUENCY IN MEGAHERTZ	A		B		C		D		E		F		G	
.5	7	+85°	23	+85°	210	+80°	12	+85°	15	+90°	9.6k	+85°	7	+85°
1	14	+85°	48	+85°	400	+78°	24	+87°	26	+90°	54k	+15°	14	+85°
1.5	22	+80°	74	+85°	600	+73°	36	+87°	38	+90°	16k	-70°	21	+85°
2	29	+72°	100	+72°	780	+70°	48	+87°	50	+90°	11k	-80°	28	+87°
5	56	+55°	180	+70°	1.60k	+55°	125	+87°	130	+90°	3.30k	-90°	68	+88°
10	80	+47°	250	+35°	2.60k	+40°	270	+74°	280	+90°	1.45k	-90°	135	+90°
20	115	+38°	350	+33°	3.60k	+42°	490	+53°	700	+70°	260	+0°	275	+90°
30	137	+33°	410	+30°	4.05k	-43°	640	+40°	1.0k	+40°	1.80k	-85°	425	+90°
40	152	+30°	460	+26°	3.80k	-54°	770	+28°	1.15k	+38°	840	-90°	600	+90°
50	162	+26°	500	+22°	3.20k	-62°	870	+16°	1.30k	+28°	600	-90°	800	+90°
60	170	+24°	510	+20°	2.80k	-67°	940	+6°	1.43k	+18°	480	-90°	1.10k	+90°
70	175	+22°	540	+18°	2.45k	-70°	980	-6°	1.55k	+10°	400	-90°	1.50k	+90°
80	180	+20°	555	+15°	2.15k	-72°	960	-15°	1.6k	0°	340	-85°	2.10k	+90°
90	185	+20°	560	+14°	1.95k	-75°	960	-25°	1.65k	-12°	300	-90°	3.40k	+85°
100	185	+20°	560	+13°	1.75k	-75°	880	-30°	1.55k	-28°	260	-85°	6.00k	+80°
110	190	+20°	580	+12°	1.65k	-75°	840	-38°	1.50k	-25°	240	-85°	18k	+40°

KEY TO CHOKE DATA:

- A - 3 - .125 dia. Ferrite Beads on #22 gage wire, Fair-Rite Type #2643000301
- B - .125 dia. Ferrite Bead w/2T #32 wire,Fair-Rite Type #2643000301
- C - 7 Turns #32 wire on .291 dia. Ferrite Bead, Fair-Rite Type #2643000801
- D - Choke, Ferroxcube UK200-20/4B Ferrite Choke
- E - 6 Turns #32 Tri-Filar wound on .500 dia. Torrid Ferrite Core, Fair-Rite Type #5961001103
- F - Pot Core Ferroxcube, 3B7 Core, 30 Turns Bi-Filar Wound
- G - 2.2 uh molded choke, J.W. Miller #9250-222

*Measured on Hewlett Packard 4815A RF Vector Impedance Meter

TABLE 2

Capacitor Impedance Versus Frequency (in Ohms)*

FREQUENCY IN MEGAHERTZ	A		B		C		D		E	
.5	840	-90°	370	-90°	32	-90°	36	-90°	3.0	-90°
1.0	420	-90°	185	-90°	16	-90°	18	-85°	1.6	-70°
1.5	280	-90°	125	-90°	11	-90°	13	-85°	1.2	-58°
2.0	210	-90°	91	-90°	8	-90°	10	-85°	1.0	-45°
5.0	81	-90°	37	-90°	3	-80°	4.0	-75°	1.0	+0°
10.0	41	-90°	18	-90°	1.0	-50°	2.0	-58°	1.0	+37°
20	19	-90°	8.0	-90°	1.0	+54°	1.0	+ 0°	1.0	+60°
30	12	-90°	4.4	-85°	2.2	+70°	1.4	+45°	2.2	+70°
40	7.5	-90°	2.2	-75°	3.0	+78°	2.0	+60°	3.0	+72°
50	4.8	-80°	1.0	-40°	4.0	+82°	2.8	+70°	3.6	+80°
60	2.6	-70°	1.0	+45°	5.0	+82°	3.4	+75°	4.2	+80°
70	1.2	-35°	2.0	+70°	5.8	+84°	4.0	+80°	5.0	+80°
80	1.0	+37°	3.0	+80°	6.7	+86°	4.8	+80°	5.6	+84°
90	2.2	+70°	4.0	+80°	7.7	+86°	5.5	+80°	6.4	+84°
100	3.2	+78°	4.6	+85°	8.4	+90°	6.0	+82°	7.0	+84°
110	4.4	+82°	5.4	+85°	9.5	+90°	6.7	+85°	7.6	+86°

KEY TO CAPACITOR DATA:

A - 390 pF Mica, 100 Vdc

B - .001 uF, Ceramic Disc, 1 kVdc

C - .01 uF polycarbonate, Radial, 50 Vdc

D - .01 uF Ceramic Disc, 25 Vdc

E - .1 Mylar, Radial , 50 Vdc

*Measured on Hewlett Packard 4815A RF Vector Impedance Meter

Table 1 on page 13 reveals the impedance versus frequency of seven selected inductors/chokes. The impedance is given in ohms and phase angle for each frequency.

Note first the impedance of choke A versus frequency. This type of choke is often assumed to minimize RFI, however it has an impedance of only 14 ohms at 1 mHz and 185 ohms at 100 mHz. By taking one of the ferrite beads used to make up choke A, and winding 2 turns of #32 magnet wire through it (refer to choke B), impedance over the measured range was nearly 3 times higher than choke A. This type of choke is useful to several hundred megaHertz and is easily constructed as the photograph on page 12 shows.

Choke C is constructed in the same manner as choke B, but uses a larger ferrite bead with 7 turns of #32 magnet wire through it. Its impedance at 1 mHz is nearly 10 times that of choke B. Maximum impedance of this choke is at 25 mHz, at parallel resonance. This choke provides useful performance to several hundred megaHertz.

Choke D is a commercially available ferrite choke, useful out to several hundred mHz. Its construction is similar to chokes A and B. Choke E is a tri-filar wound choke on a torid ferrite core. This choke features good broadband performance to differential mode RF. A choke wound in this manner is much more immune to AC field pickup than the other chokes discussed so far.

A bi-filar wound pot core (choke F) exhibits a high impedance at AM broadcast frequencies (56k Ohms at 1.2 mHz). Being bi-filar wound makes this choke useful on balanced audio lines. This choke is mainly effective below 10 mHz and has several series resonant modes above 15 mHz.

An effective choke for FM broadcast frequencies is choke G, exhibiting an impedance of 18k Ohms at 110 mHz. However, at AM broadcast frequencies, this choke has the same impedance as choke A.

After studying the table it is apparent that some chokes are better than others for a given frequency. Table 2 gives the frequency versus impedance values for some small value capacitors frequently used for RF bypassing. (page 14)

The first capacitor is a 390 pF mica, 100 volt (capacitor A). One can see that it is not too effective for use at 1 mHz, but a series resonant frequency of 75 mHz makes it useful as a shunt element in VHF RF filter. Capacitor B is series resonant at 55 mHz and is a good choice for low VHF frequency bypassing. Capacitor C, although 10 times as large a value as B, is not as good a bypass capacitor at 100 mHz. Its impedance at that frequency is an inductive 8.4 ohms compared 4.6 ohms inductive for capacitor B. At 1 mHz capacitor C however exhibits an impedance more than 10 times lower than capacitor B.

Construction of a capacitor can also affect its impedance at high frequencies. Capacitor C and D both have a value of 0.01 uF and are both radial type constructions. Capacitor C is a polycarbonate and capacitor D is a ceramic disc. In this case the ceramic capacitor has slightly better characteristics at VHF.

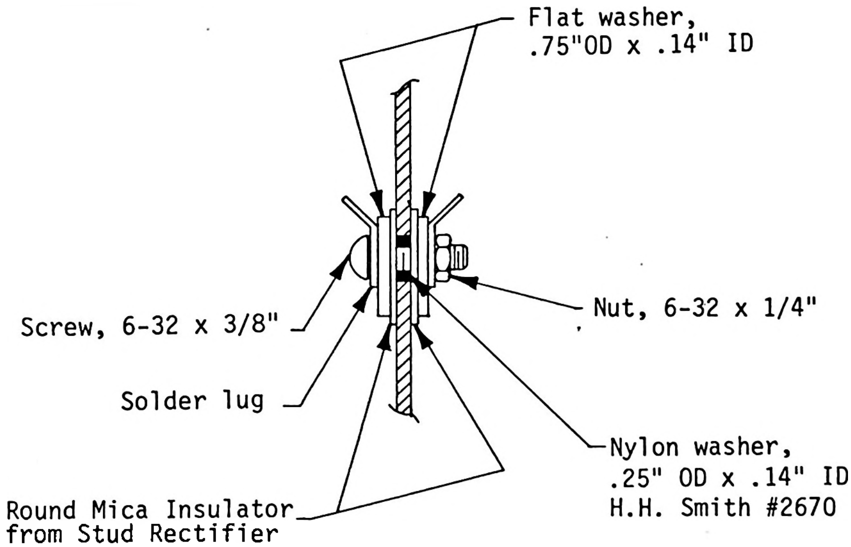
Capacitor E is 10 times the value of capacitors C and D, and at 1 mHz exhibits roughly 10 times lower impedance than C or D. It has the lowest series resonant frequency of any of the capacitors tested and is an effective bypass up to about 50 mHz.

Earlier in the text it was recommended that feedthrough capacitors be used in applications that require effective RF filtering out to VHF. From the data presented in Table 2, it was shown that all of the capacitors tested lose effectiveness beyond about 80 mHz. A good 1000 pF feedthrough capacitor however, may measure 2 ohms -85° at 100 mHz and be an effective bypass to 1 gHz. Refer to some applications of feedthrough capacitors on pages 3 and 4.

FIG. 9

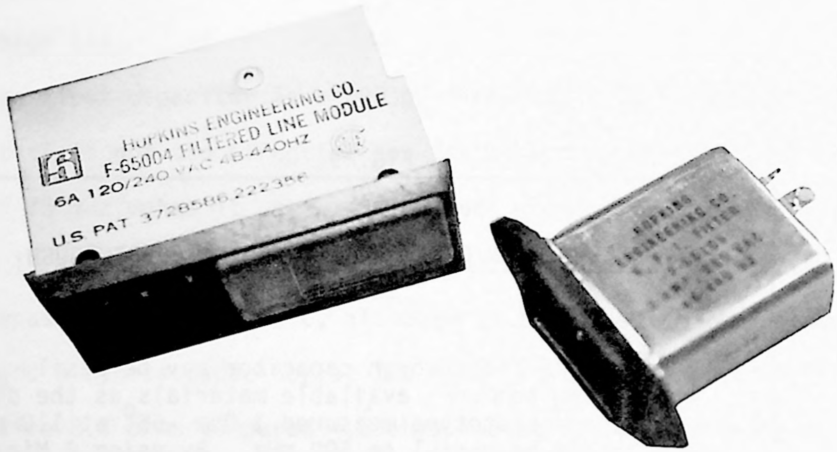
CONSTRUCTION OF AN EASY TO BUILD FEEDTHROUGH CAPACITOR

A 230 pF feedthrough capacitor may be easily built from commonly available materials as the diagram shows. The prototype measured 1 Ohm -65° at 110 mHz and should be useful to 500 mHz. By using 2 Mica insulators on each side, the capacitance will roughly halve.



COMMERCIAL RF FILTERS FOR POWER LINES

The photograph shows two commercial power line RF filters. Most filters of this type will provide good RF attenuation to VHF. They are inexpensive and can be chassis mounted to existing equipment. These filters are more effective than RF filters with wire leads at VHF.



In our discussion of controlling conducted RFI we have looked at some simple filter networks and performance of some capacitors and chokes at various frequencies.

By integrating the data from tables 1 and 2 to the examples of filter networks presented, one can derive an effective RF filter for most frequencies.

For example, a piece of equipment is operated in a strong channel 2 (51.25 - 55.75 mHz) RF environment, and the station engineer wishes to reduce conducted RF into that equipment. A good choice of components for a two element filter (Fig. 3), might be choke C listed in Table 1 (series element), and capacitor B listed in Table 2 (shunt element).

These components were chosen due to the choke (C), having a high impedance at channel 2, and the capacitor (B) being nearly series resonance (A short) at that frequency. Another example would be component choice for RF filtering at FM frequencies. A good choice for a series element would be choke G (table 1) and capacitor A (Table 2). In this case an even more effective shunt element would be the feedthrough capacitor described in Figure 9.

It is beyond the scope of this paper to cover all aspects of controlling RFI, either conducted or radiated. This paper was presented to show some concepts of RFI elimination which have not often been discussed.

At this point a summary is in order.

1. There are two modes of RFI to equipment, conducted and radiated, and in most cases the interference caused by both can be minimized.

2. We looked at some pictorial examples of equipment which have integral RF shielding or filter networks. These pictures, it is hoped, will help an engineer implement ideas in the station equipment.

3. Conducted RF can be controlled with several basic filter networks.

4. Components do not behave at RF frequencies as reactance formulas would derive. At RF, components exhibit resonances and can act as capacitive or inductive elements.

5. Referring to data in Table 1, it was shown that some chokes are nearly transparent (a short) to RF at some frequencies.

6. The data presented in table 2 shows that the most effective capacitor to bypass a given frequency is a capacitor which series resonates as a shunt element at or near that given frequency.

7. When constructing RF filter networks, the shunt element should exhibit a low impedance. It is very important that the leads of the capacitor be as short as possible for best performance.

It is the authors sincere hope, that some or all of the information presented here will help solve the problems you may encounter with RFI.