Government
of Canada

Department of Communications

TRC-19

TELECOMMUNICATIONS REGULATION CIRCULAR

SUPPRESSION OF INDUCTIVE INTERFERENCE, CROSS-MODULATION AND SWAMPING

FEBRUARY 1, 1973

TELECOMMUNICATION REGULATORY SERVICE

Telecommunications Regulation Circulars are issued from time to time as the need arises and are intended for the guidance of those actively engaged in telecommunications in Canada. The information contained in these circulars is subject to change at any time in keeping with the development of the art of telecommunications. It is therefore suggested that interested persons should consult the nearest Superintendent of Telecommunications Regulation to ascertain whether this circular is still current.

SUPPRESSION OF INDUCTIVE INTERFERENCE, CROSS-MODULATION, INTERMODULATION AND SWAMPING.

0. INDEX

Section	Sub-Section	Paragraph	Sub-Paragraph	Subject
1.				Modulation Theory.
	1.1			Foreword.
	1.2			Description of an Electro-magnetic wave.
	1.3			Modulation and Multiplicative Processes.
	1.4			Intermodulation.
	1.5			Cross-Modulation.
	1.6			Swamping.
2.				Control of Modulation Interference.
3.				Location of Modulating Elements.
	3.0			Internal and External Modulators.
	3.1			External Modulators.
	3.2			Location of External Modulators.
	3.3			Elimination of External Modulation.
	3.4			Internal Modulation.
	3.5			Elimination of Internal Modulation Interference.
		3.5.1		Measures to Reduce Stray Fields Inside Apparatus.
			3.5.1.1	Box Chassis with bottom plate.
			3.5.1.2	Missing tube shields.
			3.5.1.3	Box Chassis lacking bottom plate.
			3.5.1.4	Apparatus using tubes but lacking shield sleeves.
			3.5.1.5	Apparatus with remote speakers.
			3.5.1.6	Interference entering via power cord.
			3.5.1.7	Interference entering via low impedance input terminals.
			3.5.1.8	Interference entering via high impedance input terminals.
			3.5.1.9	Interference entering via antenna terminals.
		3.5.2		Modifications to amplifiers to increase immunity to stray fields.
			3.5.2.1	By-passing amplifier input terminals.
			3.5.2.2	Insertion of low-pass filters into amplifiers.
	3.6			"Swamping" (Excess Signal) Interference.
	3.7			Measures to Control Interference from paging systems.
		3.7.1		Interference to Television Receivers with Antennas.
		3.7.2		Interference to Television Receivers connected to CATV systems.
		3.7.3		Interference to Citizen Band (GRS) Receivers.
4.				Components required for filter construction.
	4.1			Capacitors.
	4.2			Inductors (Chokes).
	4.3			Resonant Circuits.
	4.4			Construction Principles.
	4.5			Nonenclature.
	4.6			Connections with shielded wire.
	4.7			Quarter-Wave Stubs.

"SUPPRESSION OF INDUCTIVE INTERFERENCE,

CROSS-MODULATION, INTERMODULATION AND SWAMPING"

1. MODULATION THEORY

1.1 Foreword.

In order that the problem may be understood it is necessary to make a very brief statement on the theory of modulation of electromagnetic waves.

1.2 Description of an Electromagnetic Wave.

An electromagnetic wave can be described in the most simple sense by three parameters, i.e. "Measureable Characteristics", amplitude, frequency and phase. In a sense, the amplitude is the "Size" of a wave, usually defined in terms of current or voltage. The frequency is the number of times that the wave changes sign per second. A wide range of frequency can be encountered. In North America the power frequency is usually 60 Hertz (cycles per second); in Europe and much of Asia 50 Hz. For communications purposes, waves with frequencies between 10,000 and 40 billion Hz are used. The phase of a wave defines the times at which it momentarily has a value of zero. In principle, if a wave could be examined, one could observe these three parameters and that would be all that could be obtained from it. However if any one of these parameters be systematically varied in a manner relating to the content of a message, this message, with minor impairment, can be extracted from the received wave. In the standard broadcast band, 540 KHz to 1680 KHz, the amplitude of the wave is varied. For the FM broadcast band, 88-108 MHz, the frequency is varied. For monochrome television, amplitude is varied for the picture transmission and the frequency is varied for the sound transmission. With colour television, the monochrome picture content is transmitted by varying amplitude, the colour picture content by varying phase and frequency and by varying frequency only for sound. The above presentation of television is severely over-simplified. Modulation is an essential part of the process of conveying and receiving desired material and many cases of interference result from occurrence of inadvertent modulation processes.

1.3 Modulation and Multiplicative Processes.

Much engineering skill has been applied to the task of modulating a wave with the content of a message wave but the techniques have an essential common feature; multiplication. The two waves are fed to a device wherein they are combined in such a manner that the instantaneous mathematical values of the output wave are determined, in part by the products of instantaneous values of the individual waves. The separate waves can also be present and more complex terms as well. This multiplication process takes place whenever one or more waves pass through a non-linear circuit component.

To clarify this somewhat, it will be necessary to discuss linearity and non-linearity of electronic components. A component is described as linear if, when a varying voltage is applied and the current measured and plotted against the voltage with uniformly divided scales of current and voltage, the resulting graph is a straight line. If the line is not straight the element is called non-linear. If two voltage waves with different amplitude, frequency and phase parameters, especially frequency, be applied to a linear circuit element, the current wave flowing in that element can be described exclusively in terms of the sum of the two original waves. If the element is non-linear such will not be the case; the instantaneous values can be described only by including terms obtained by multiplying the instantaneous values of the waves. When such a wave is described in terms of individual component waves, there will be found not only waves of the original frequencies but additional waves with twice the frequency of each of the original waves and in some cases, additional components, whose frequencies are the sum or difference of the original frequencies, will be found as well. Passive elements such as resistors, capacitors and inductors are almost absolutely linear but amplifying or rectifying elements are inherently non-linear. In the case of rectifiers, the non-linearity is either acceptable or required; in amplifiers the non-linearity can be very largely compensated over a satisfactory operating range by highly developed engineering techniques. However when an amplifier is subjected to excessive input i.e. a wave of amplitude exceeding its operating range, during a part of every cycle it will be driven into non-linearity and the modulation effects can result in unwanted signals affecting its behaviour. In some cases the effect is that an amplifier ceases to amplify; such an effect is known as "Blocking". Modulation interference effects are classed into two modes, intermodulation and cross-modulation.

1.4 Intermodulation.

The general case of application of two voltage waves of different parameters, (especially frequency) to a non-linear element producing current waves which can be described in terms not only of the two original frequencies but also of the sum and differences of those frequencies has been described above. If the frequency of one wave is very much higher than that of the other and if the amplifiers concerned are constructed to respond only to a band of frequencies centred on the higher frequency, the result will be the original higher frequency and two other frequencies which are the sum and difference of the two original frequencies. These waves are usually referred to as "Side Bands". The process by which waves of new frequencies are produced when two waves enter a non-linear circuit component is known as intermodulation.

1.5 Cross-Modulation.

As mentioned above the modulated wave can be described in terms of a number of separate waves. When two modulated voltages are applied to a non-linear element it can happen that among the other waves that will be produced, there will be one in which a desired carrier and its side bands are accompanied by another wave consisting of the same desired carrier but with side bands corresponding to an unwanted modulation. Such a case is called "Cross-Modulation". It is essentially a special case of intermodulation.

1.6 Swamping.

This is not exactly a modulation process in the sense that intermodulation and cross-modulation are. It depends however on non-linearity of amplifying devices and the term applies to a case where an excessive signal drives an amplifying element into non-linearity. Swamping usually takes one of two forms:

(a) If it occurs in the R.F. or I.F. stages, the stage can be disabled for the duration of the signal. If the disabling of the amplifier is continuous the observed effect will be a cessation of sound. If such disabling is intermittent, the wanted signal may appear intermittently during the times that the interference is absent.

(b) If it occurs in the audio frequency stages, the modulation of the interference signal may dominate the device's output.

2. CONTROL OF MODULATION INTERFERENCE

Such interference can be controlled only by keeping unwanted signals out of amplifiers. Once the intermodulation process has caused signals of unwanted modulation to accompany those with wanted modulation in the same frequency band, it is inherently impossible to remove them. In case of two speech signals sometimes the ear can listen to one instead of the other but in an apparatus, except in cases of extremely sophisticated signalling systems and circuit design, nothing can be done at this point. This bulletin is therefore concerned with methods of preventing unwanted modulated signals entering amplifiers. Most interference cases arise because the steps necessary to do this have not been taken during manufacture. It must be remembered that domestic equipment has been made at various times, especially before use of high power transmitting equipment in residential areas started to become common. To a degree this problem may not have existed at the time of manufacture. Thus shielding or filtering necessary to control it was left out of the sets because it was in most cases unnecessary and in all cases would be somewhat expensive. Its unnecessary introduction would cost the manufacturer competitive advantage and loss of business. It must be noted that the fault usually lies in the equipment suffering interference, not in the equipment causing it. In most cases such equipment is operating within its licence. If it is suspected that a source of interference is operating other than as licenced, the case should be referred to the Department of Communications.

In the following paragraphs, modifications to domestic electronic equipment to render it less susceptible to interference will be described. Because most such equipments use voltages which are dangerous to human life it is recommended that "Mods" be incorporated by qualified technicians. A further reason for this is the increasing use of printed wiring and "Miniaturised" circuitry which accompanies the growth in use of solid state electronic devices. Such equipment is far more susceptible to damage than tube-using equipment with "wired" wiring.

3. LOCATION OF MODULATION ELEMENTS.

The non-linear element causing modulation interference can be either without or within the equipment affected. They are described as external and internal modulation respectively.

3.1 External Modulators.

The most common sort of external modulating element consists of a corroded joint between two pieces of metal, especially two pieces of dissimilar metal. This is most likely to occur if one of the pieces of metal is copper or copper alloy such as bronze or brass. Copper forms two oxides of which one, cuprous oxide, along with copper or another metal, can be used to constuct a rectifier. At one time copper-oxide rectifiers were quite important commercially. If such a joint occurs in an element of sufficient length to intercept a moderate signal strength it can intermodulate two signals and reradiate them and any set picking up these reradiated signals is liable to suffer interference. Any corroded metal joint can cause such interference because, although the non-linear element so-formed would be of quality far lower than acceptable for construction of apparatus, its effect in producing interference can still be too great to be tolerable. Thus metal joints in clothes lines constructed with wire can be trouble-sources or the metal flashing on a roof, a connection to a ground terminal, a T.V. receiving antenna mast, accidental contact between metal parts in a house, especially if this is intermittent, accidental contact between a metal-foil vapour barrier and other metal parts of a house, wire mesh beneath stucco, fire escapes, telephone lightning arrestors. When an equipment suffers interference from such a mechanism it is because the interfering signal has been rendered, to the apparatus, essentially indistinguishable from the desired signal and the only remedy is to locate and eliminate the defect. Location is described in paragraph 3.2, its elimination in paragraph 3.3.

3.2 Location of Elements Causing External Modulation.

The effect of an external modulator is not significantly different from that of an internal modulator in the results that it produces so observation of the characteristics of the interference is not helpful in determining whether it is internal or external or if it is external, locating it. However it may be observed that in a certain room, an equipment cannot be used but that it can be used elsewhere. In such a case, it would be worthwhile to try to determine whether or not the interference source is internal or external to that set. The easiest way to investigate this is by use of a portable receiver capable of operating in the same frequency band as the set observed to be affected. Normally, the interference, if the source is a cross-modulator, will be louder, the closer one can move to it. Shaking a floor or guy wires or ground wires of a T.V. antenna may be observed to make the cross-modulation come and go. In some cases the cross-modulator may actually be a rectifier of another A.C. powered device requiring direct current for its operation. In such a case the interference would be eliminated if this set were not operating. Fluorescent lamps have been known to cause cross-modulation on account of a non-linearity of the discharge.

3.3 Elimination of External Modulation.

If some junction or article has been identified as the source of external modulation a number of remedies may be applicable.

(1) If it is a joint which should normally be conductive it should be either tightened securely or soldered.

(2) If the metal parts are not normally required to be in contact, they can be either permanently separated such as by introducing insulating material or they could be securely connected, if it is optional whether they be connected or not. The principle here is that either complete insulation or complete conduction will equally well eliminate an external modulator.

(3) If the external modulator is a rectifier in some other apparatus it can be bypassed with a small capacitor, of the order of .05 microfarad. If this is not sufficient an additonal .001 microfarad R.F. capacitor should be added. The point to be observed here is that the capacitive reactance of a capacitor does not continuously decrease as the frequency increases; at some frequency a capacitor becomes resonant and develops inductive reactance at all higher frequencies. This effect in a given capacitor can be countered by shunting it with another much smaller unit in which this change from capacitive to inductive reactance takes place only at a much higher frequency.

3.4 Internal Modulation.

Internal modulation unlike external modulation, cannot usually be remedied by elimination of a non-linear element, because, almost always, it is a component necessary to the set, the interference resulting from unwanted signals reaching it. A possible rare exception is an imperfect solder joint, easily repaired by momentarily melting it with a soldering iron and letting it freeze. The remedy, then is to:

a) prevent the unwanted signals from entering the equipment and/or

b) prevent such signals within the set from reaching non-linear elements.

In practice, simple prevention is impossible but by reasonable effort, access by unwanted signals to the non-linear elements of a domestic electronic apparatus can be reduced to a level far below the as-manufactured condition and usually to the point where it is negligible.

3.5 Elimination of Internal Modulation Interference.

3.5.1 Measures to reduce stray fields inside set.

3.5.1.1 Loose Enclosure.

If a set has a box chassis with a bottom plate, clean and tighten all connections between them.

3.5.1.2 Missing tube shields.

If a set uses tubes, check that shields are used on all sockets capable of accepting them.

3.5.1.3 Chassis lacking bottom plate.

If a set has a box chassis but no bottom plate; add a bottom plate, taking care (a) to avoid creating a shock hazard and (b) to allow ventilation; most tube sets produce heat which if not removed by air currents can cause damage. Wire screen is almost as effective as solid sheet but impairs ventilation much less.

3.5.1.4 Apparatus using tubes but lacking shield sleeves.

If the early stages of a tube-using apparatus lack sleeves for mounting tube shields, a temporary installation of tube shields should be tried (improvising a connection to the chassis) to see if they will help. As a last resort, since replacing a socket can be troublesome, sockets for the initial stages could be replaced with sockets with tube-shield sleeves, or the sleeves and shields could be added.

3.5.1.5 Apparatus with remote speakers.

The most common entry point of strong radio or radar signals into an amplifier system is via the loudspeaker leads. This is because most good quality amplifiers have a feedback loop which couples a portion of the audio output signal back to the earlier stages to provide some degeneration for imporved frequency response. Thus any signals picked up on the loudspeaker leads will find an easy path of entry to the early stages of the amplifier which are the most sensitive. Interference is then amplified along with the desired signals.

Recommended cures for the above are:

3.5.1.5 (i) Replace the speaker leads with shielded wire, grounding the outside metallic braid to the amplifier chassis. (See sub-section 4.6.)

3.5.1.5 (ii) By-pass the loudspeaker leads to the amplifier chassis using 0.01 mfd to 0.03 uF disc ceramic capacitors. See sub-section 4.1. Keep all leads as short as possible. See Fig. 3.5.1.5 (ii).

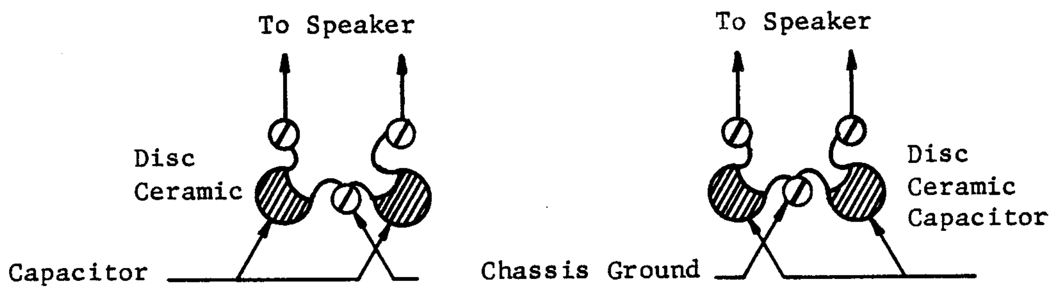
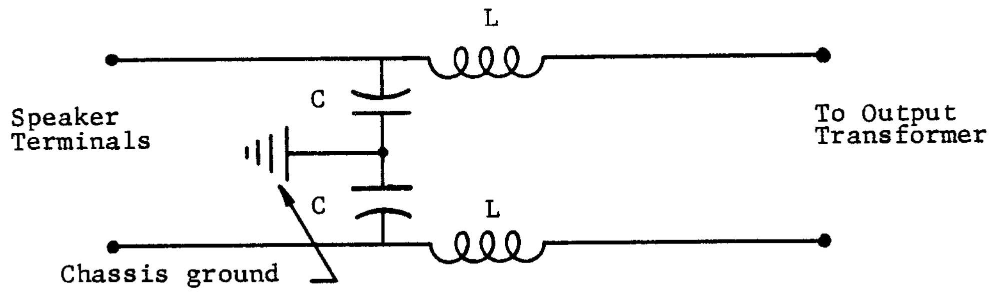


Fig. 3.5.1.5 (ii)

R.F. By-Passing speaker leads

3.5.1.5 (iii) <u>Insertion of Low-Pass Filters into speaker leads</u>.

Another method used by some manufacturers and applicable to more difficult cases consists of a filter network installed under the amplifier chassis between the speaker terminals and the output transformer. This filter consists of two capacitors as in Fig. 3.5.1.5 (ii) above plus two small radio frequency chokes. See sub-section 4.2. Keep all leads as short as possible.



L Radio Frequency choke, 1.3 microhenry choke 2.0 Ampere current capacity
C .01-03 uF . ceramic 500 volt

Fig. 3.5.1.5 (iii) Insertion of Low-pass filters into speaker leads.

With the low impedance of the loudspeakers the above components will not affect frequency response of the amplifier.

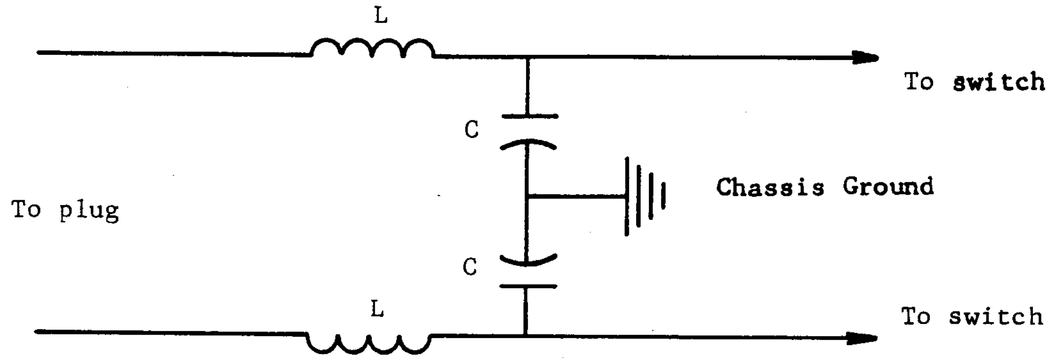
3.5.1.6 <u>Interference entering via power cord</u>.

In many instances strong signals gain entry via the power cord. This can be prevented by:

(a) installing 0.01 to 0.03 uF disc ceramic capacitors, 500 volt rating, from each side of the AC line to chassis ground where the line enters the chassis. Capacitance greater than 0.03 uF should not be used because such would increase shock hazard with transformerless apparatus.

(b) installing a 0.01 uF disc ceramic capacitor across the high voltage power supply output filter capacitor.

(c) in extreme cases a filter network similar to that in paragraph 3.5.1.5(iii) may be necessary as shown below. See section 4 for details on selection of components.



L. R.F. Choke, insulated, 1.7 micro henry, current capacity 2.5 amperes

C Capacitor, .01 to .03 uF 500 volt

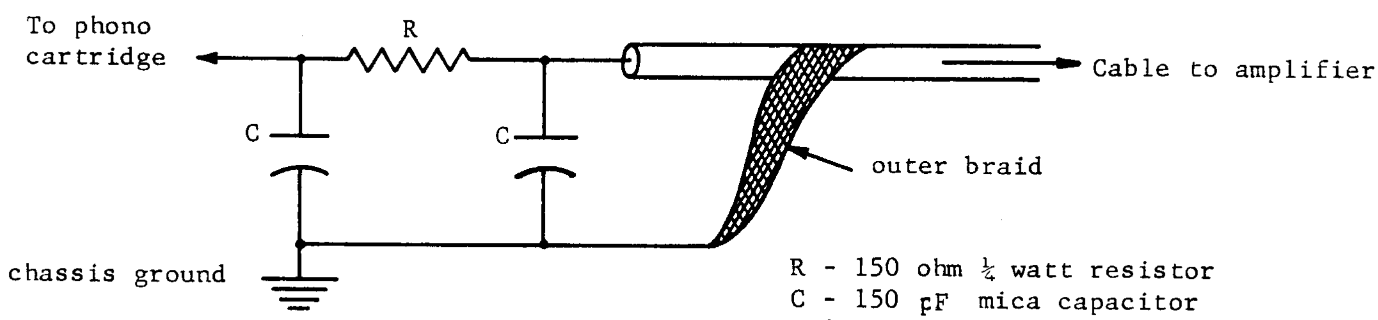
Fig. 3.5.1.6

Insertion of Low-pass filter into power cord.

3.5.1.7 Interference entering via low impedance input terminals, e.g. dynamic microphone input. The measures described under 3.5.1.4 (iii) apply.

3.5.1.8 Interference entering via low impedance input terminals e.g. piezo-electric microphone input or record pick-up.

Some turntable phone arms use a short length of unshielded wire from the cartridge to terminals in the base of the turntable chassis where it connects to a shielded cable running to the amplifier input. This is an ideal entry point for strong radio or radar signals. Where possible this unshielded wire should be replaced by special light weight shielded wire made specially for this purpose. If the added weight of this shielded wire upsets the phono arm tracking force, the only alternative is to insert a filter at the tie point referred to above. This consists of two mica capacitors and one resistor. In the case of stereophonic pick-ups a filter will be required in each lead.



R - 150 ohm ¼ watt resistor
C - 150 pF mica capacitor
Tolerance - immaterial

Fig. 3.5.1.8

Insertion of Low-pass filter into phonograph cartridge or microphone terminals.

3.5.1.9 Interference entering via antenna terminals.

The essence of this method is to place additonal selectivity ahead of the antenna terminals.

On some AM/FM stereophonic receivers, FM receivers, TV sets and combination units, strong radio or radar signals may gain entry into the chassis via the antenna circuit and eventually find their way into the audio circuitry to produce interference.

Disconnecting the antenna lead will prove whether or not it is the pick-up source. If this is found to be the case, the cure is to filter these signals out before they enter the chassis as follows:

(a) If the interfering signal is below 50 MHz., connect a high pass filter in the antenna lead. Several models are commercially available.

(b) Connect parallel traps in the antenna feed line, these being tuned to the frequency of the interfering signal.

L & C to be chosen in accordance with sub-section 4.

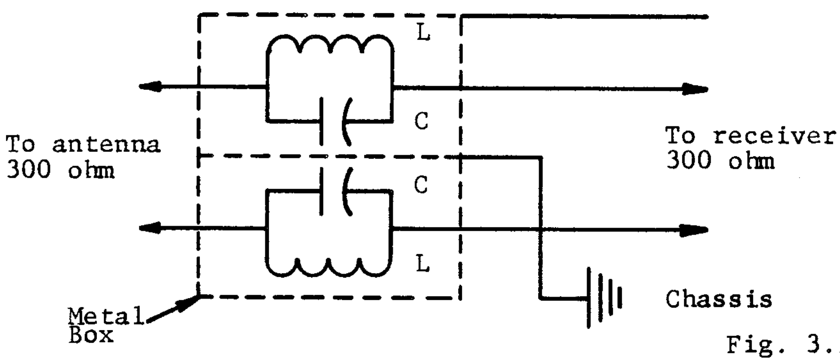


Fig. 3.5.1.9
Insertion of parallel trap in antenna leads

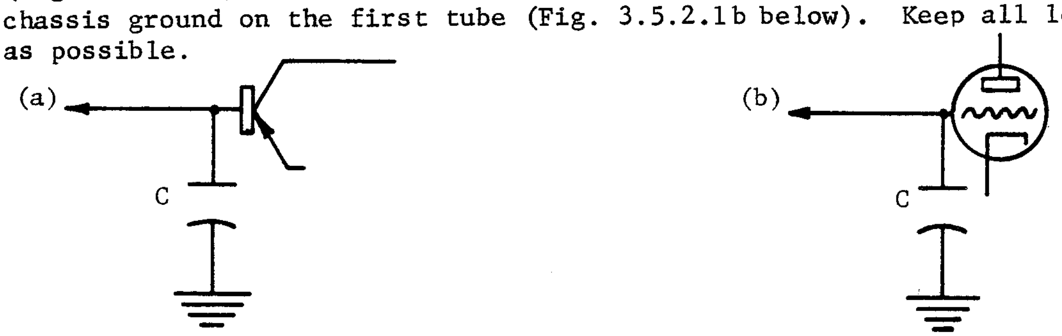
(c) Connect a quarter wave stub tuned to the frequency of the interfering signal across the antenna terminals. Construction and installation of quarter-wave stubs is described in sub-section 4.7.

3.5.2 Modification to Circuitry to Reduce Interference.

The measures discussed in 3.5.1 are essentially peripheral in that they do not involve the internal circuitry of the equipment, only its enclosure, input leads and output leads. They therefore can be applied with minimum danger to the equipment. However, they may not always be adequate. The following measures should give additional interference abatement in such cases.

3.5.2.1 By-passing amplifiers input.

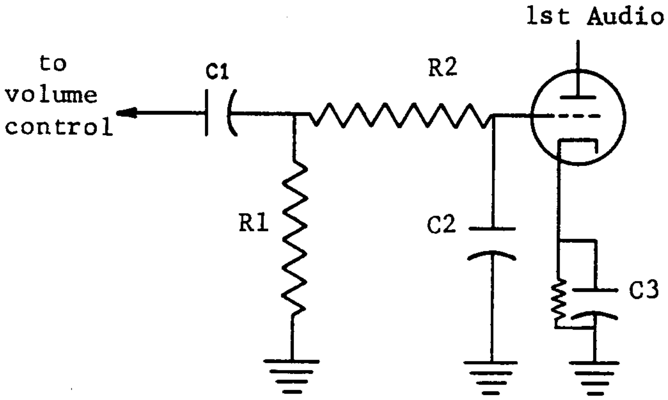
If the interference persists after applying the above cures, (sub-section 3.5.2) it may be necessary to apply filtering across the input of the first transistor stage (or grid of the first vacuum tube). This consists of a 100 to 250 pF. capacitor connected from the base of the transistor to chassis ground (Fig. 3.5.2.1a), or in the case of a vacuum tube amplifier, from the grid to chassis ground on the first tube (Fig. 3.5.2.1b below). Keep all leads as short as possible.



C - mica capacitor
C - 100-200 pF

Fig. 3.5.2.1 (a) (b) By-passing Amplifier

Tube type radio and television sets, particularly the AC/DC variety, often use grid leak biasing on the first audio amplifier stage. The grid resistor in such cases is generally in the order of 5 to 10 megohms which places the grid so high above ground it is very prone to overloading by strong radio or radar signals. A suggested modification is shown below.

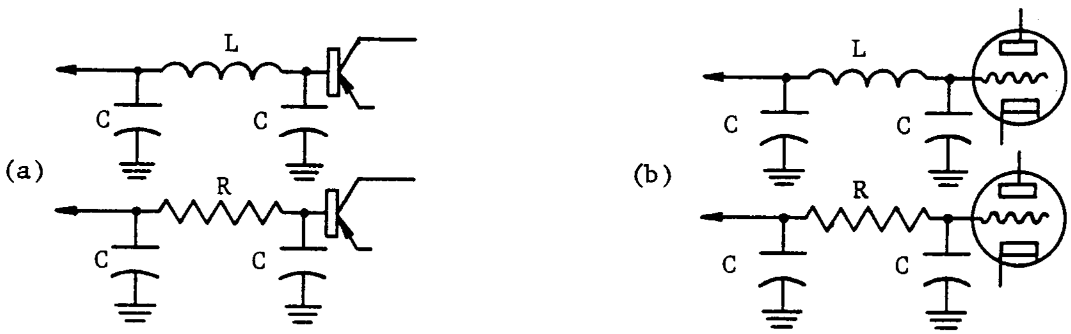


C1 - 0.01 uF paper or ceramic capacitor
C2 - 100 to 250 pF mica capacitor
C3 - 0.001 mfd ceramic capacitor on AC/DC sets
R1 - 2 megohm ¼ watt resistor
R2 - 50,000 to 75,000 ohm resistor

Fig. 3.5.2.1 (c) R.F. By-Passing grid-leak.

3.5.2.2 <u>Insertion of Low-Pass Filter into Amplifier</u>.

In extreme cases a small radio frequency choke or a 50,000 - 75,000 ohm resistor and a second condenser may be required as follows. The effect is to insert a Low-pass filter.



C - 100 - 250 pF mica capacitor
R - 50,000 to 75,000 ohm ¼ watt resistor
L - Radio Frequency Choke, 1 microhenry.

Fig. 3.5.2.2 Insertion of Low-Pass Filter into amplifier.

3.6 <u>"Swamping" (Excessive Signal) Interference</u>.

The remedies for swamping interference are essentially the same as those for other types namely:

(i) as far as possible exclude the unwanted wave from the equipment affected by building shielding into the cabinet.

(ii) if measure (i) is inadequate, add by-pass capacitors to external leads.

(iii) if measures (i) and (ii) are inadequate, insert low-pass or band-pass filtering into external leads.

(iv) if measures (i), (ii), (iii), are inadequate, selectively by-pass amplifier inputs.

(v) measures (i-iv) are listed in order of increasing difficulty, danger to the operator, and of required expertise to avoid damage to equipment.

Basically the approach to curing this type of interference is to find out how the signal is being picked up or where it is gaining entry into the amplifier and then eliminate its pick-up or entry by the addition of shielding or filters as outlined above. An open-minded and objective approach is necessary; stray fields can enter an equipment in peculiar ways. Sets have been encountered where the interfering signal was fairly weak but on placing one's hand near or on the volume control, the interference increased greatly in level. Investigation revealed that the volume control shaft was insulated from the ground and was actually serving as the pick-up point. The cure here is to replace the volume control with one whose shaft is grounded.

3.7 Measures to Prevent Interference from Paging Systems.

These measures could be included under sub-section 3.5 and 3.6 but with rapid growth of such systems and the detailed nature of the solution, applicable to the band being used, it is considered advantageous to place them in a single sub-section. The following examples illustrate the problem and the nature of remedial measures.

3.7.1 Interference to Television Receivers with Antennas.

Television receivers; various effects being noted ranging from modulation of the video signal by paging tones to complete blanking of both sound and video signals.

As this interference was entering the receiver via the antenna, a 300 ohm balanced high pass filter was used. In its original form the filter cut off at approximately 54 MHz with 4 dB insertion loss in the video band channel 2. By adjusting the inductance of the centre series circuit (as shown by Fig. 3.7.1) the insertion loss was improved and with a cut-off frequency of 50 MHz this filter proved satisfactory.

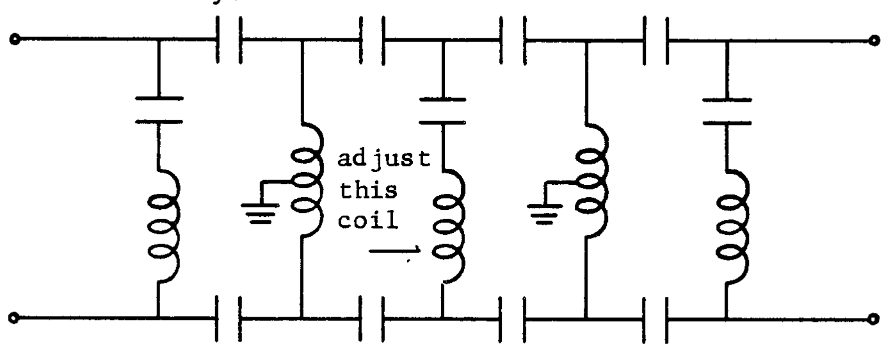


Fig. 3.7.1

3.7.2 Interference to Television Receivers connected to CATV systems.

Over 200 television receivers in an apartment block, fed by low impedance co-axial systems were suffering interference.

Solution

a 75 ohm unbalanced high-pass filter is required. Since there does not seem to be a suitable commercial product, a design is given. See Fig. 3.7.2.

This filter has a pass-band from 44 MHz to 1000 MHz and more than 60 dB attenuation below 40 MHz.

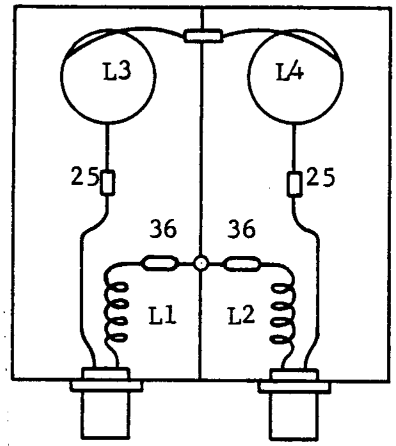
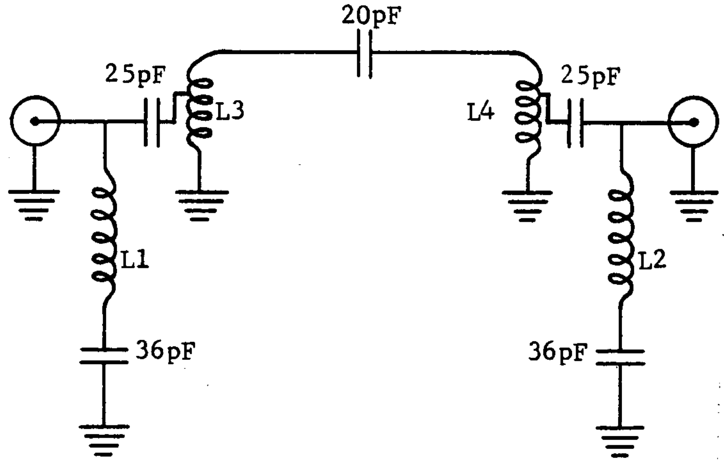


Fig. 3.7.2 (a) Mechanical Assembly



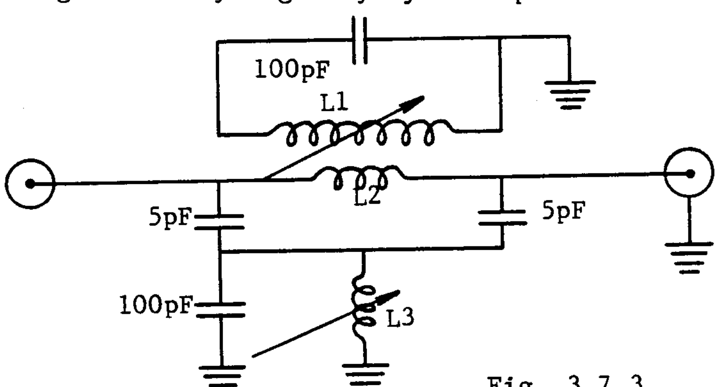
Schematic Diagram

Fig. 3.7.2 (b)

L1 and L2,10 turns No. 22 enamelled wire, 1/4 inch diameter form. L3 and L4, 4 turns of 14 wire 1/4 inch diameter, tapped 1/2 turn from end of coil at high R.F. potential, coil spaced 8 turns per inch. Capacitor tolerance 5%.

3.7.3 Interference to Citizen Band Receivers.

Interference was found to be entering a Citizen-Band receiver via the antenna, therefore a trap was required that was capable of withstanding the high output voltage of the transmitter. Commercial trap seems to be available, but the design Fig. 3.7.3 by Page Boy system operator is considered by them to be superior.



L1 and L3-8 turns No. 22 AWG magnet wire wound on 3/8" Ceramic Form Diameter of Coil 1/2"

L2 - Single Turn Loop of Polythene Covered Wire Inductively Coupled to L1. All Capacitors 100 Volts Working, 5% tolerance, Mica.

Fig. 3.7.3

4. Components Required for Filter Construction.

The components required for construction of filters tend to be somewhat specialized and they cannot always be bought "over the counter". It is hoped that these notes may be helpful.

4.1 Capacitors.

A capacitor is a device in which energy is stored by subjecting an insulating material to an electric field. Formerly, such a device was called a "Condenser" and they are still widely known by this name. However, the name "Capacitor" has been adopted to avoid confusion; every steam power plant has one or more condensers wherein steam is condensed to water. With steadily growing use of electronic control devices in such places, confusion could arise with the older name and the new name permits a desirable symmetry of nomenclature, i.e. a Resistor is characterized by Resistance, and Inductor by Inductance and a Capacitor by Capacitance.

The insulator is usually in the form of a sheet to which metal electrodes are applied. The following combinations are common.

Electrode Material	Insulator	Capacitance Range	See Remark
Aluminum Silver-plated brass	Air	1 - 1000 pF	1
Silver or Nickel-plated Spring brass	Air, mica	1 - 1000 pF	2
Sprayed Zinc	Paper, Synthetics	1000 pF to 10uF	3
Aluminum Foil Deposited Silver	Mica	5 pF to .016 uF	4
Deposited Silver	Ceramic	100 pF to 2.2 uF	5
Aluminum, Electrolyte	Aluminum-Oxide	1 - 70,000 uF	6
Tantalum, Electrolyte	Tantalum Oxide	1 - 50 uF	6

Capacitors are also characterized by maximum rated voltage for which they are suitable. A rating of 100 volts is acceptable unless otherwise stated.

REMARKS.

1. The metal-plated air-insulated capacitor is quite stable and if one set of plates be mounted on a shaft, a capacitance variable over a range 30:1 is readily obtained. Such capacitors are therefore commonly used as the variable elements of tuners, especially in the AM broadcast band.

The same construction is used also for high quality variable capacitors intended for occasional adjustment, to compensate drift in other circuit elements.

This type of capacitor could be used for constructing a tuned circuit (para. 4.3) but it is much larger and more expensive than the compression trimmer described below and would usually require more care in mounting.

2. In this capacitor, one electrode or set of electrodes is made of spring bronze nickel-plated. The electrodes, separated by mica insulators, are interleaved and a screw, insulated from the electrodes, can be tightened so as to bring the spring electrodes solidly in contact with the mica separating them from the other electrodes. The capacitance can thus be varied. The range of adjustment varies with the number of plates and the voltage rating but for a common unit rated at 175 D.C. working, the following apply:

Plates	Capacitance pF
1 - 1 1/4	1.5 - 15
1 - 1 3/4	2.7 - 30
2	5 - 80
3	9 -180
4	25 -280
5	50 -380
6	80 -480

These capacitors are compact (typically 3/4" x 5/8" x 3/8"), light enough in weight that, if it is inconvenient to attach them to a panel, they can be supported by the terminals. The principal problem of using them may be the extent to which their capacitance can be disturbed by the presence of a screw-driver and in tuning out an unwanted signal it may be necessary to make repeated small adjustments, removing the screw-driver after each and observing whether the last adjustment improved the performance.

3. Capacitors made in this way are commonly used for blocking passage of direct current while passing alternating current. They are reasonably stable and can be made suitable for voltage from 100 VDC to 2000 VDC. They are primarily useful at frequencies up to a few hundred kHz. Their restricted frequency range and fairly large physical size render them unsuitable for the purposes of this circular.

4. Capacitors made in this way are called silver-mica or foil-mica capacitors. They are compact, light, stable and inexpensive. Usually, units made for 500 volts DC are light enough to be supported by their leads. Their frequency range extends from DC to several hundred MHz. The above advantages have given rise to extensive use for military quality-oriented equipment so that high quality is almost universal. Manufacturing tolerances are 1%, 2%, 5%, 10% and 20%. On the presumption that the smaller tolerances are available only to bulk purchasers, recommendations for choice of capacitance made in this circular are based on the premise that units of 10% tolerance are available. Mica capacitors are suitable for any fixed-capacitor application cited in this bulletin but for by-pass applications, ceramic insulated units will be less bulky and possibly easier to install, especially if a transistor amplifier is to be by-passed.

5. Such units are made by coating a thin plate of ceramic material (typically Barium Titanate, or another composition with a solution containing silver). The plate is heated and the solution decomposes leaving a thin tightly-adhering layer of silver. This is done for both sides. Leads are attached and a plastic encapsulation applied. Such capacitors are suitable to use over a wide range of frequencies but their manufacturing tolerance is high and their capacitance also varies widely depending on temperature. Typical tolerances are +80% -20% so they are unsuitable for use as tuning elements. However, their small size makes them eminently suitable for addition into crowded space such as, for example, by-passing the input to a transistor amplifier.

6. Capacitors made in this way are called Electrolytic since they contain electrolyte. The metal is also specified because in most ways, Tantalum electrolytic capacitors are greatly superior to Aluminum capacitors. Most electrolytic capacitors are usable only if polarized with a DC voltage exceeding any AC voltage present.

Their frequency range is much lower than that of other types, their capacitance is usually quite high (the reason why they are used,) much too high for any purpose relevant to this circular and imprecise. For this reason, they are limited to low frequency by-pass, especially rectifier filters. They are wholly unuseable for interference control as described in this circular.

4.2 Inductors.

An inductor is a component in which energy is stored in a magnetic field. It can also be called a "Coil", after the form of the wire winding or "Choke" because many inductors are used in a rectifier to pass the direct current but to "choke" off alternating current.

An inductor typically consists of a wire winding, usually enamelled copper (Magnet wire) placed on a "core". The core is characterized by a number known as permeability, the ratio by which the inductance of the inductor is greater than that obtainable with magnetically neutral material. Generally cores or core materials with permeability different from 1.00 suitable for purposes relevant to this bulletin are available only to manufacturers and they will not be considered further.

An inductor is primarily characterized by its "inductance", stated in Henries, after Henry, an early researcher, or more usually in millihenries or microhenries. Since an inductor contains a winding of conductive material it is also characterized by an unwanted resistance and for the same reason, it will have a current capacity limited by heating. In some cases, it will be found that an inductor of the inductance value required for a given application is commercially available. In such a case one should check the current capacity, especially if an inductor is to be inserted in series with a power cord.

4.2.1 Making Inductors.

Often, the most convenient way to obtain an inductor is to make it. This is especially so if there are two convenient terminals already present to which it can be attached electrically and mechanically.

4.2.1.1 1.3 Microhenry unsupported inductor, low precision, current capacity 1.5 amperes.

Wrap 24 turns of No. 18 solid enamelled wire on a 1/4 inch diameter form, with adjacent turns touching. Any round or approximately-round object such as a pencil of approximate diameter 1/4 inch will do. A narrow strip of cellulose tape laid along the winding to make it more rigid will make it easier to handle but this is only a convenience. The winding will expand enough to slip easily off the form.

4.2.1.2 1.6 Microhenry unsupported inductor, low precision, current capacity 2.5 amperes.

Make as per 4.2.1.1 above but use a 3/8" diameter form and No. 16 solid enamelled wire. A layer of electric tape (preferably PVC tape) should be placed over the coil to prevent accidental contact between the coil and more delicate circuit elements.

4.2.1.3 1.0 Microhenry inductor, moderate precision current capacity 1 ampere.

See Fig. 4.3.1 and 4.3.2, determine the required inductive reactance. Obtain a 2 watt resistor, of resistance at least 500 times the reactance.

The resistor is to be used as a precise stable coil form with lead wires. The wattage rating defines the exterior dimensions as length 11/16", diameter 5/16." The resistance, if chosen as above, is irrelevant because it will be shunted by a much smaller reactance. Then, with No. 20 enamelled wire, close-wound, on the resistor and the ends soldered to the leads, inductors of the following values can be made with fair precision;

TABLE 4.3.2.3(i)

Number of Turns.	Inductance Microhenries.
20	1.52
18	1.34
16	1.17
14	1.00

A strip of tape will hold the winding temporarily in place - a small drop of cement at each end (nail polish will do) will hold them permanently. Care must be taken not to use too much lest the insulation on the wire be dissolved permitting an inter-turn short which will alter the inductance unacceptably.

4.2.1.4 General case, inductance of moderate precision.

If a precise inductor capable of carrying a current greater than 1.6 amperes must be made, or if No. 20 wire or a form of 5/16" diameter is not available, the following formula may be used:

$$L = \frac{n^2 a^2}{9a + 10b} \text{ in microhenries}$$

n = number of turns

a = the radius of a turn, centre of form to centre of wire in inches

b = n x the turn-spacing, inches.

To use the formula - first choose a form diameter and a wire size. "a" is then half their sum. Assume a number of turns - n. and work out the formula. If the inductance is too large, reduce "n" and work out the formula again. It must be remembered that in the formula, both numerator and denominator are changed with "n". Wire sizes are given below:

TABLE 4.3.2.3(ii)

Wire size AWG	Current Amp.	Diameter, Inches.
20	1.6	.0334
18	2.0	.0418
16	2.5	.0524
14	3.1	.0659

4.3 Resonant Circuit Construction.

An inductor free of resistance draws a current wave which lags the voltage by 90 degrees, i.e. it is a quarter cycle later than the voltage. A capacitor draws a current which leads the voltage by a quarter cycle.

A current leading by a quarter cycle is equivalent to a negative current, of the same value lagging by a quarter cycle. Thus, in principle, for any frequency, for any inductor, a capacitor can be found such that, when connected in parallel, the lagging current of the inductor is equal in magnitude to the leading current of the capacitor and the two currents add to zero. The combination will then conduct very little current. This effect is called "parallel resonance". By similar reasoning it can be shown that the same elements, connected in series, will carry a current of the same frequency but the voltage across the inductor and capacitor cancel. This is called "Series resonance". In practice, capacitors almost absolutely free of resistance are readily obtainable but all inductors have significant resistance. However, for many purposes the above description is adequate.

It is therefore possible by connecting a suitable inductor-capacitor parallel combination in the antenna leads, to prevent the resonant frequency being passed to the receiver. The following describes the selection of a suitable inductor and capacitor to reject a known frequency. The procedure follows:

(1) Determine the frequency to be rejected.

(2) Draw on Fig. 4.3.1 a vertical line at that frequency, between the lines AA and BB, slanting downward to the right. These lines mark the upper and lower limits of easily available variable capacitors.

(3) Observe the range of inductance values represented by lines standing diagonally upward to the right.

(4) Choose an inductance value in the range observed in Step 3 for which construction data are given in sub-section 4.2.

(5) Identify the capacitance line intersecting the frequency line and the inductance line corresponding to the inductance chosen in Step 4.

(6) Note the reactance corresponding to this intersection.

(7) Dividing by 10, 100, 1000 as necessary, draw on Fig. 4.3.2:

(a) a line corresponding to the frequency to be rejected.

(b) a line corresponding to the reactance chosen in Step 6.

(c) a line corresponding to the inductance chosen in Step 4.

The three lines should intersect at a common point; minor care must be taken in Step (c).

(8) Note the capacitance line which passes through the intersection of lines 7(a) and 7(b). This should be approximately equal to the value given in Step (5) but will be much more accurate. Let this value be C.

The capacitance C should then be made up of 2 units, a fixed mica capacitor, 10% tolerance of capacitance .8C and variable capacitor (Trimmer) of maximum capacitance .3C, connected in parallel.

e.g., suppose a capacitance of 30 pF is required. It will be made up of a fixed mica capacitor of 24 pF, 10% tolerance and a trimmer with a maximum capacitance 9 pF. Then, if the exact capacitance required to tune the combination is 30 pF, depending on the departure of the fixed capacitor from its exact value, the capacitance could be distributed as follows:

Fixed Capacitor, low limit 21.6 pF, Variable Capacitor 8.4 pF.
Fixed Capacitor, nominal 24 pF, Variable Capacitor 6 pF.
Fixed Capacitor, high limit 26.4 pF, Variable Capacitor 3.6 pF.

The choice of components should therefore provide for departure of either the inductor or the fixed capacitor from nominal. Some "trading" on the fixed and variable capacitors may be necessary if very small values are needed.

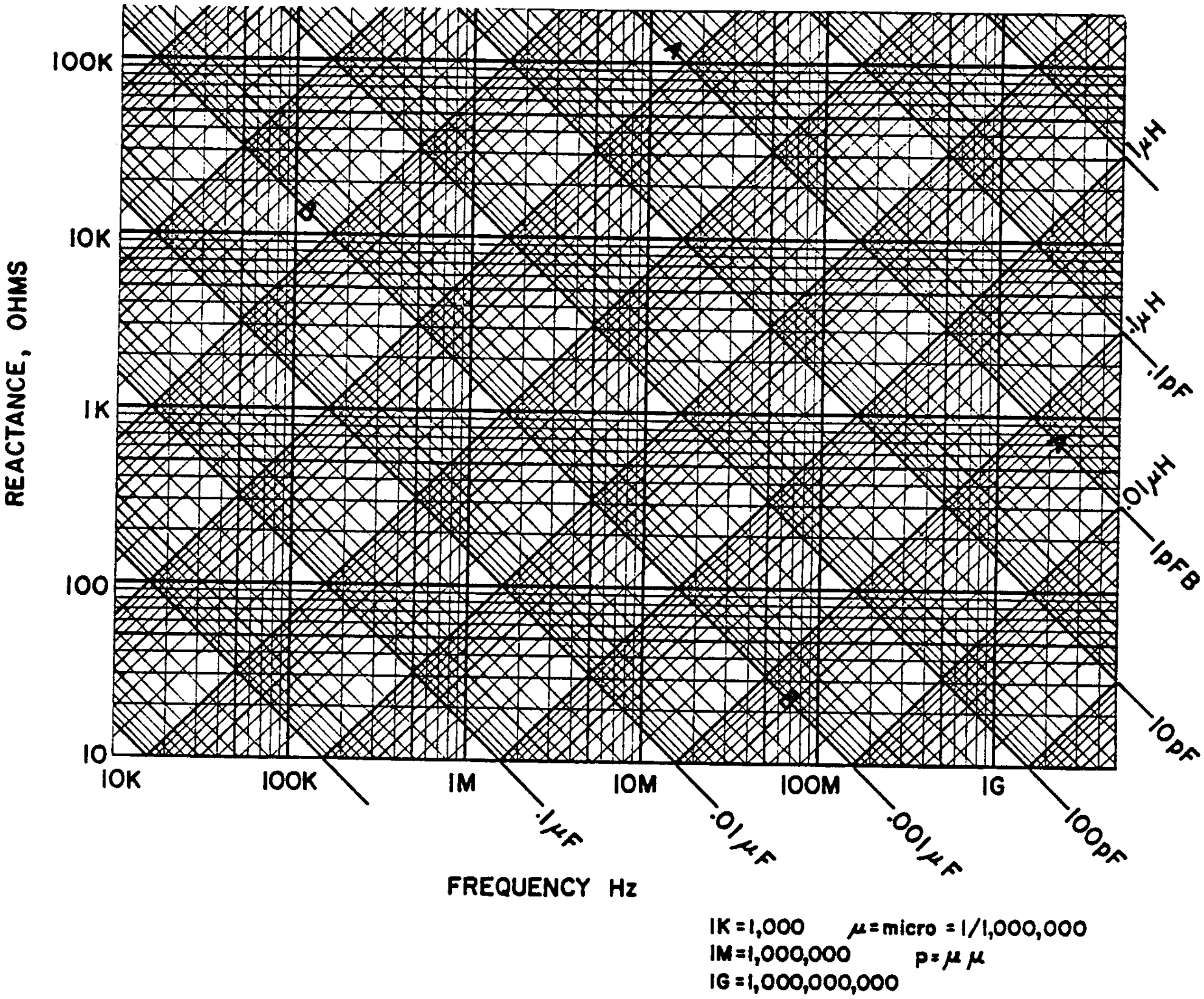


Fig. 4.3.1
Reactance Frequency Chart. Coarse

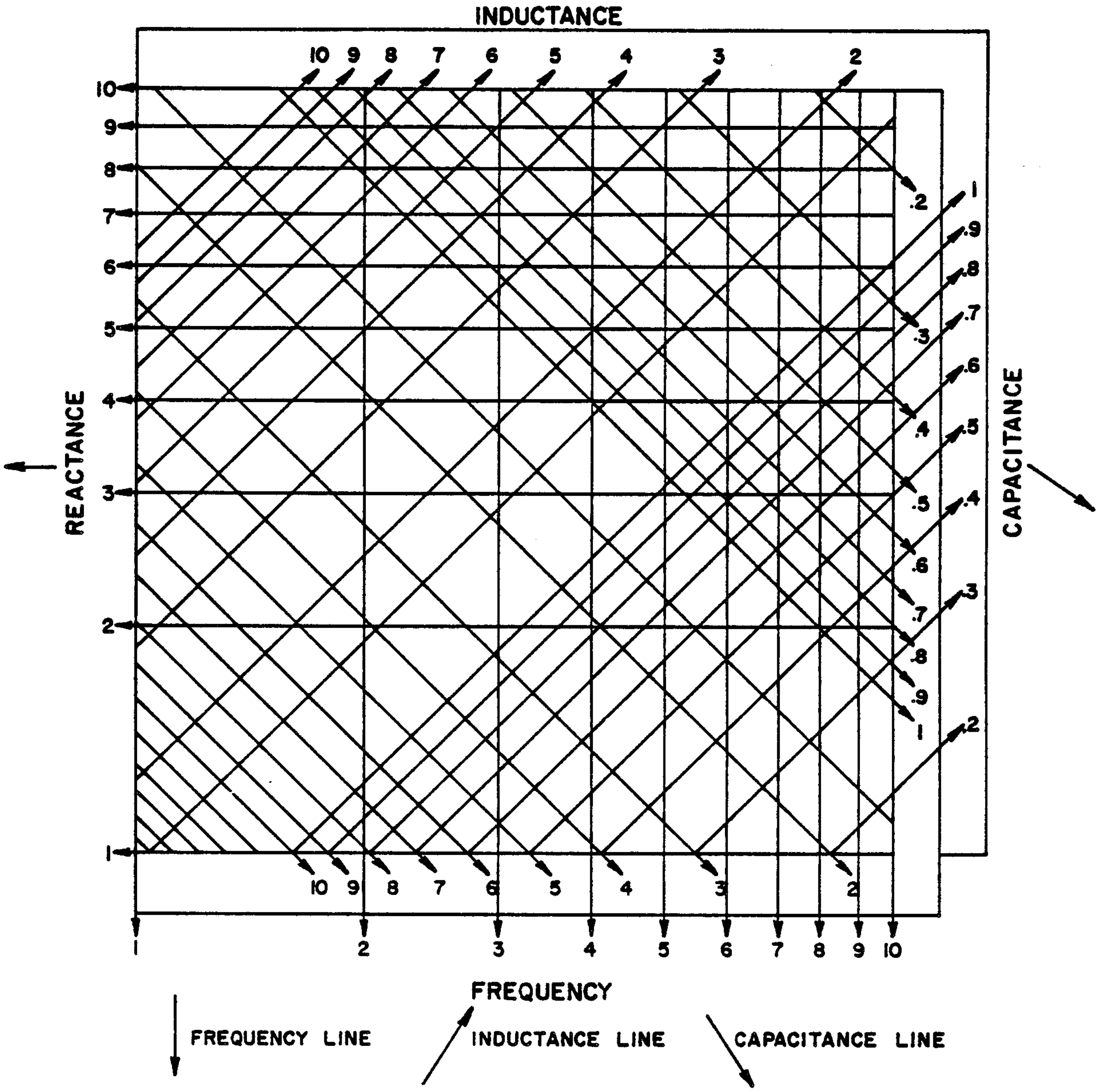


Fig. 4.3.2
Reactance Frequency Chart. Fine

4.4 Construction Principles.

It is recommended that all alterations to domestic electronic equipment be made by qualified technicians, for safety to both personnel and apparatus. If this is not convenient, the following should be observed.

(1) Only rosin flux ("Radio") solder may be used. Acid-core solder or soldering paste, unless guaranteed free of zinc chloride, must not be used. Such materials leave a residue of zinc chloride which promotes corrosion and conducts current with possible severe damage. If there is doubt about a soldering flux being free of zinc chloride, a bit, or slight smear on the finger tip, can be touched to the tongue. If there is any sharp taste, the material must not be used. It is advisable not to use a soldering iron which has been used with zinc chloride, but if necessary, this is permissible after careful cleaning with a rag after the tip is hot, with care also to avoid fire.

(2) Magnet wire comes with several different insulation materials roughly identifiable by colour. The most common is a dark brown colour; it is readily scraped off with a knife or sand paper. It can be dissolved with paint remover. The most common alternative is much more reddish and transparent - sometimes wire with this insulation appears bare. This material is much more difficult to remove and care must be taken that the coil not be damaged by the force required to grip it.

4.5 Nomenclature.

Electronics is characterized by use of a very wide range of numbers. The custom has therefore been developed of having names for units and a set of multiplicative adjectives which combine to give units from 1 million times larger to 1 million - million times smaller. The units are:

Characteristics	Symbol	Units	Symbol
Resistance or Reactance	R	Ohm	
Capacitance	C	Farad	F
Inductance	L	Henry	H
Frequency	f	Hertz (cycle per second)	Hz
Voltage	E or V	Volt	V
Current	I	Ampere	A
Power	W	Watt	W

Multiplicative Adjective	Multiplies by	Symbol
Kilo	1,000	K
Mega	1,000,000	M
Giga	1 thousand million	G
milli	1/1,000	m
micro	1/1,000,000	u or m*
pica or micro-micro	1/1,000,000,000,000	p or mm

* used exclusively with microfarad. Capacitances greater than .1 Farad are practically never used.

4.6 Connecting Shielded Wire

Shielded wire consists of an inner conductor, made up of a number of strands for flexibility, insulated and covered with a sheath of fine braided tinned copper wire. A braided cotton or extruded plastic sheath is often added. The sheath covers approximately 98% of the inner wire so that it cannot "see" electric fields outside the sheath because they terminate (for the most part) there. Use of such wire is an effective remedy for interference, but in making connections care must be taken that the sheath not touch the inner conductor. Many co-axial connectors are constructed so that this is done very simply and with no loss of shielding, but in some cases, the shielded wire must be converted to simple 2-conductor cable. To do this, it is necessary only to remove, or push back the protective covering and about 2 inches from the end, with a plastic knitting needle, tooth pick or any pointed tool unlikely to pierce the inner insulation, tease the shielding wires apart to leave a small hole. Bend the cable double at this point with the hole showing. The inner conductor can then be pulled out and straightened. Pulling the sheath through the fingers will greatly reduce its size so that it can be inserted into a terminal for soldering. This operation will be found quite simple when tried with a piece of shielded wire.

4.7 Quarter-Wave Stubs

A piece of transmission line of length equal to one-quarter of the wavelength of a wave of a given frequency propagated along a line of the same construction displays what might at first sight seem surprising characteristics; if one end is shorted, the other end presents an open circuit to voltages at that frequency, and if the end is opened, it presents a short to voltage of that frequency. This property is quite frequency-selective and it can be used to eliminate an interfering signal from a television receiver by shorting it out. Such short lengths of transmission line, used as filter elements, are called "stubs". To eliminate an interfering signal by a stub, proceed as follows:

(a) identify the channel to be eliminated;
(b) from Table 4.7. a) determine the length of line to cut;
(c) cut a piece of cable, length equal to that given in step (b);
(d) remove the insulation from a length of the cut piece given in Table 4.7. a) (length to strip);
(e) bend the stripped conductors so that they lie parallel at 3/4 of their original spacing. (This preserves a parameter known as characteristic impedance, which depends on cable insulation and spacing.)
(f) connect the stub to the receiver antenna terminals, placing it as closely as possible to the position it will occupy, preferably not in contact with a metal surface. The stub should not be held in the hand because the conductivity of the hand will alter the stub's characteristic;
(g) determine the position at which the best cancellation of the unwanted channel is obtained;
(h) cut the bare wire extending beyond the antenna terminals to one-half of its length;
(i) repeat steps (g) and (h) until the unused bare wire is about 1/2" long;
(j) bend the unused bare wire around the terminal screws and tighten.

This trial and error process is unavoidable because the velocity of propagation along the lead-in is significantly different from its free-space value and this difference is strongly affected by manufacturing details such as thickness and formulation of insulation. The finished stub should not be rolled up on itself but may be draped against insulating materials and fastened with cellulose tape.

Table 4.7. a) Nominal Length for Open Quarter-Wave Stub to Trap Out the Unwanted Television Channel

Channel	Nominal Length, inches	Length to cut	Length to strip
2	46.5	47	2
3	42	43	1 7/8
4	38.2	39	1 3/4
5	33.2	34	1 3/4
6	30.8	31 1/2	1 3/8
7	14.5	14 7/8	9/16
8	14.0	14 3/8	9/16
9	13.6	13 7/8	9/16
10	13.1	13 3/8	9/16
11	12.7	13	9/16
12	12.35	12 9/16	9/16
13	12.0	12 3/8	9/16

G.H. Stewart

for W.J. Wilson,
Director-General,
Telecommunications
Regulation Branch.