Electronic TUBES

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HARMONIKER

Effective and Economical Harmonic Attenuator to Defeat TVI

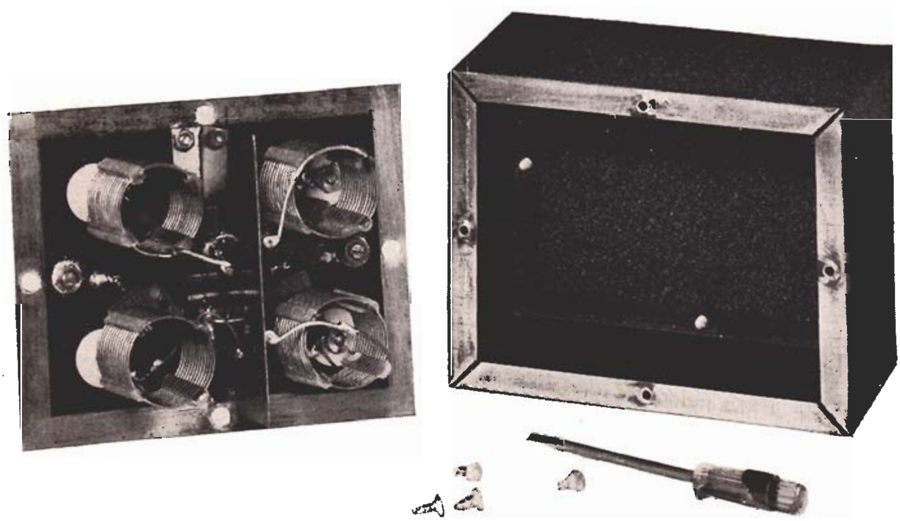


Fig. 1. Exposed View of Eighty Meter, 300 Ohm Harmoniker

The Harmoniker is a harmonic attenuating filter, designed to work on any one amateur band, and designed to attenuate greatly *all* harmonics of any signal transmitted in that particular band. It is placed between the final output circuit and the antenna feed line. The Harmoniker is sufficiently effective that, properly constructed and intelligently installed, it should enable the average amateur effectively to eliminate all TVI caused by harmonic radiation from the antenna and antenna feed line.

Attenuating all harmonics in a filter of this sort means that individual harmonic traps normally installed in the plate leads of the final are unnecessary. Elimination of separate plate traps is extremely desirable because normally a set of them is required for each TV channel. If harmonic radiation from the feeder and the antenna proper is minimized, by use of the Harmoniker, to the point where it will not cause TVI it is then only necessary to ensure that radiation directly from an unshielded transmitter is not causing trouble. This aspect of TVI will not be covered, since the Harmoniker acts only to attenuate harmonics which might otherwise be radiated from the antenna system. However, in most cases the major source of TVI is harmonic radiation from the antenna system.

Whether or not you are troubled with TVI, the use of such a filter in your antenna system will reduce the harmonic output of your station (transmitter and antenna) to a marked degree and may save you the woes of a warning ticket from the FCC for excessive harmonics.

GENERAL FEATURES

The Harmoniker is a half-wave filter with special properties that make it an ideal harmonic attenuator for amateur transmitters. For example, it is effective over the entire width of any one amateur band. This means that it is not necessary to stay on one particular frequency—you can use your VFO to its full extent.

Note that the Harmoniker is not the type of low-pass filter which will pass any frequency up to some given point, for example, 30 megacycles, and attenuate only higher frequencies. With a filter of this sort no low order harmonic attenuation is achieved when operating in the lower frequency bands.

No appreciable amount of power is lost in the Harmoniker. Generally speaking, inserting this filter between the final output tank and the antenna feeders will occasion a loss of only 0.1 DB—that is, only 1/60 of an S unit.

ELECTRICAL CIRCUIT

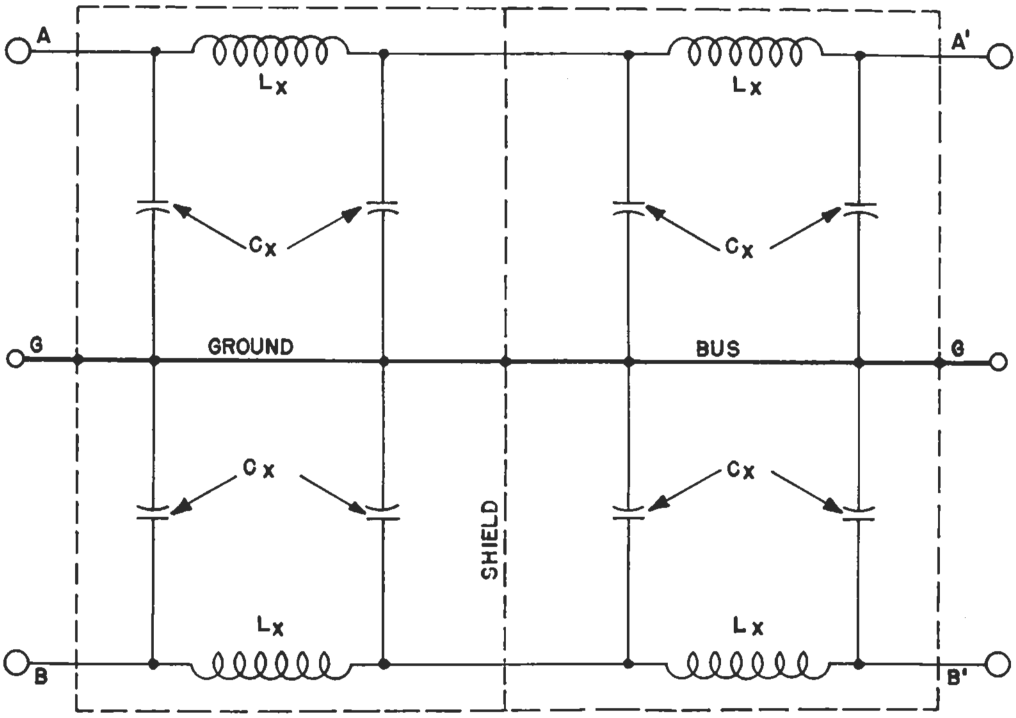


Fig. 2. Circuit Diagram of Harmoniker

CIRCUIT CONSTANTS

100 Ohm Harmoniker

80 meters: L_x=2.1 uH (12T #3014 Miniductor)
C_x=840 mmf, 500 volt mica

40 meters: L_x=1.1 uH (13T #3006 Miniductor)
C_x=450 mmf, 500 volt mica

20 meters: L_x=0.55 uH (10T #3002 Miniductor)
C_x=220 mmf, 500 volt mica

15 meters: L_x=0.37 uH (7T #3005 Miniductor)
C_x=150 mmf, 500 volt mica

10-11 meters: L_x=0.28 uH (7T #3001 Miniductor)
C_x=110 mmf, 500 volt mica

6 meters: L_x=0.155 uH (4T #3001 Miniductor)
C_x=60 mmf, 500 volt mica

300 Ohm Harmoniker

80 meters: L_x=6.3 uH (*21T #3015 Miniductor)
C_x=280 mmf, 1000 volt mica

40 meters: L_x=3.3 uH (*18T #3011 Miniductor)
C_x=150 mmf, 1000 volt mica

20 meters: L_x=1.65 uH (15T #3010 Miniductor)
C_x=73 mmf, 1000 volt mica

15 meters: L_x=1.11 uH (13T #3006 Miniductor)
C_x=50 mmf, 1000 volt mica

10-11 meters: L_x=0.84 uH (15T #3002 Miniductor)
C_x=37 mmf, 1000 volt mica

6 meters: L_x=0.46 uH (9T #3002 Miniductor)
C_x=20 mmf, 1000 volt mica

** Two complete coils can be obtained from one B & W Miniductor. (In all other cases only one coil is obtained from one Miniductor.)*

Probably the most important feature of this filter is that the harmonic attenuation is obtained over a wide range of impedances. That is, the Harmoniker will work with a wide variety of transmission lines almost without regard to their impedance—be they 70 ohm, 300 ohm, etc. Further, the Harmoniker can be installed between transmitter and transmission line without changing any coupling adjustments or tuning. It's as though the filter weren't there as far as your fundamental frequency is concerned, but it does keep the harmonics out of the antenna system.

The attenuation afforded to harmonics is as follows: second harmonic—31 db (1260 to one in power); third harmonic—48 db (63,000 to one in power); fourth harmonic—59 db (almost one million to one in power); fifth harmonic—67 db; sixth harmonic—75 db; seventh harmonic—79 db; eighth harmonic—84 db. For each additional harmonic, the attenuation becomes greater and greater, increasing at the rate of approximately 30 db per octave.

DESIGN DETAILS

It is hoped that the Harmoniker will be used by the beginning amateur as well as the old timer. Harmonics can and do emanate from practically any type of transmitter, whether it be a ten watt or a thousand watt job. In order that the beginning amateur may take advantage of the Harmoniker's properties without wading through a technical discussion, this section will be treated in simple terms. The more technical-minded are referred to "Design Theory" at the end of this article.

Acting as a half-wave filter, the Harmoniker has many of the properties of a half-wave transmission line. For example, any half-wave filter can be used at any impedance, since the input impedance of the filter with load is the same as that of the load itself. The same is true of a half-wave transmission line. (On the other hand, the Harmoniker attenuates harmonics while the half-wave transmission line will not.)

In a general manner of speaking, then, the Harmoniker may be placed between the transmitter and the transmission line in any amateur installation, regardless of the impedance of the transmission line itself. While this is true, there are several things to be noted. If the transmission line had not been matched, standing waves would have been present. If the Harmoniker were inserted in this line these standing waves would still be present and this condition might result in overloaded filter elements. Therefore, the Harmoniker should normally be used only with transmission lines that are relatively free from standing waves.

Aside from the transmitter power, one other thing can affect the voltage across the circuit elements of the Harmoniker. Refer to the circuit diagram, Fig. 2. It will be seen that there are four end condensers, (two on the input side, two on the output side) and four center condensers. Assume that a Harmoniker was designed for a 300 ohm load. If this filter were used with a 300 ohm matched transmission line, the voltages on the eight condensers would be equal. However, if this same unit were used with a 600 ohm load, the voltage on the end condensers would be greater than the voltage on the center condensers. If the unit were used on a 150 ohm load, the reverse would be true.

These voltage relationships (caused by standing waves in the filter itself) will be treated in more detail later on, but are mentioned here to show why it was found desirable to design two different Harmonikers—a low and a high impedance unit—for each band. Having two designs available, you can select the one which most closely fits your requirements, and avoid the necessity of using condensers with a high voltage rating.

If the impedance of your transmission line is between 50 and 150 ohms, you would use the low-impedance Harmoniker which is designed for 100 ohm work. Similarly, you would use the high-impedance Harmoniker, which is designed for 300 ohm work, if your transmission line impedance is between 150 and 600 ohms.

The circuit diagram also shows three input terminals and three output terminals. The input and output connections are A—B and A′—B′, respectively, for balanced lines (such as twin-lead and open wire line). The connections to be used are A—G and A′—G′, respectively, when unbalanced lines such as coaxial cable are used.

Because only half of the Harmoniker is being used when an unbalanced line is employed, the 100 ohm unit automatically becomes a 50 ohm unit for coaxial cable use. Thus an exact design is available for the popular 50 ohm RG8/U coax. If the Harmoniker is to be employed entirely for unbalanced feeder use, then only one-half of the unit need be constructed. Everything below the ground bus may be omitted. However, if the complete unit is built, it may be used for unbalanced feeder work if a shorting connection is made between terminals G and B (or G′ and B′) and connections made to A—G and A′—G′. *Make only one shorting connection.*

SELECTION OF PROPER UNIT

For 50, 72 or 95 ohm coaxial cable, use the design data for the 100 ohm Harmoniker. Make only half the unit, that is, use two coils, L_x, and four condensers, C_x.

For 95 ohm twin conductor cable, 72 ohm twin-lead, twisted pair, or any other balanced line whose impedance is not over 150 ohms, use the design data for the

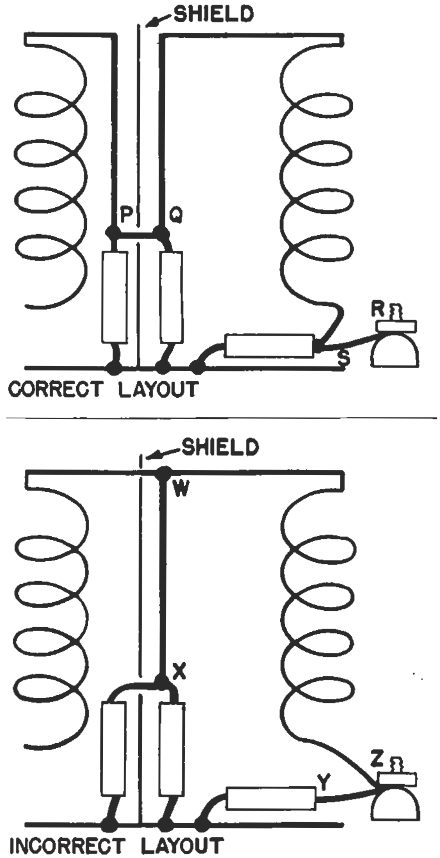


Fig. 3. Sketch of Correct and Incorrect Layout

100 ohm Harmoniker and build the entire unit as shown. Make connections to A—B and A′—B′ and run a short ground connection to either terminal G or G′.

For 300 ohm twin-lead or open-wire transmission lines with impedances up to 600 ohms, use the 300 ohm Harmoniker and connect to A—B and A′—B′, again grounding either G or G′.

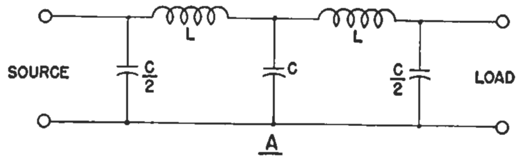
The more advanced amateur may design his Harmoniker to the exact impedance of his transmission line if he so desires. Full information on how this may be done will be found under "Design Theory."

POWER CAPABILITY

The data given under "Circuit Constants" is for a Harmoniker which is rated nominally for one kilowatt peak level. When only one-half of this unit is used, as is the case when coaxial cable is employed, the unit will operate at 500 watt peak level.

Therefore, if a higher peak level is required, it will be necessary to use condensers with a higher voltage rating. It is also possible that the coils may overheat, but this may be experienced in only a few high-power amateur installations.

The voltage rating for condensers C_x specified under "Circuit Constants" will be adequate for a one-kilowatt (output) CW, NBFM, SSB, etc. transmitter, or for a 250 watt AM transmitter, assuming that both sections of the filter are used, as is the case with a balanced feed line. If coaxial cable is employed and only one-half of the unit is in use, the power rating is 500 watts for CW, etc. and 125 watts for AM phone.



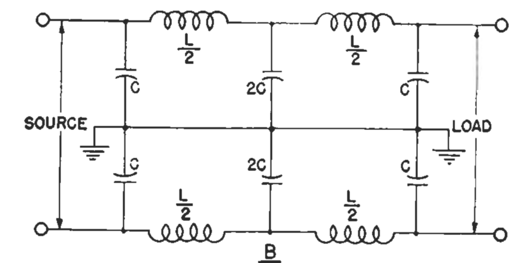


Fig. 4A. Unbalanced Pi Filter; Fig. 4B. Balanced Pi Filter

The Harmoniker may be used with a one-kilowatt AM rig (balanced line feed) if condensers with twice the specified voltage rating are substituted. Similarly, twice the voltage rating is required if a one-kilowatt CW rig feeds an unbalanced line (half the unit in use). It will be necessary to use condensers with four times the voltage rating if a one-kilowatt AM rig is used with unbalanced feeders.

HARMONIKER CONSTRUCTION

The Harmoniker shown in the photographs is a 100 ohm, 3.5–4.0 mc unit. It is built into a 3 by 4 by 5 inch metal box. This size box is adequate for all Harmoniker designs with the possible exception of the 300 ohm unit for 80 and 40 meters. The coils for these two units are rather large, and might require a larger box.

Fig. 1 indicates how the components are mounted on one removable plate of the box. Four feed-through insulators are used for terminals A, A′, B and B′. These are mounted on the 4 by 5 inch plate one inch each side of center and one inch in from the ends of the plate. Two metal binding posts are used for terminals G and G′. A heavy ground bus wire is run between terminals G and G′.

The inter-section shield is 2¾ by 3¼ inches. It may be made from almost any material, although brass was used in the unit pictured, for easy soldering. Fig. 1 indicates how the shield is fastened to the mounting plate. Note that the paint has been scraped from the entire edge of the box and the edge of the mounting plate. Similarly, the paint must be removed at the point where terminals G and G′ are attached, and where the inter-section shield is fastened to the mounting plate.

Fig. 3 shows the correct way to wire the Harmoniker circuit. It is necessary to make connections to the condensers as close to their molded case as possible. The objective is minimum lead inductance. Toward this end use large diameter wire—No. 12 is suitable. Note that the leads from one end of the coils are brought separately to the condensers, as at points P and Q. *Do not* use a common lead, such as W to X. Also, connect the other end of the coil directly to the condenser, at point S, and *do not* connect it as shown to point Z.

It is not advisable to wind your own coils unless equipment is available to check the inductance accurately. The use of Barber and Williamson Miniductors, as specified, will insure correct inductance. Mount the coils as shown in the photographs. The number of turns specified refers to the actual number of turns on the coils, but leave enough extra wire on each end to make connections. This extra lead length has been taken into account. The actual inductance specified, which may be used if you wind your own coils, refers to the total inductance of the coil and its leads. It is important that the coil specifications be followed closely, or the unit will not be "tuned" for the proper frequency.

The condensers used should be mica condensers. It will be worthwhile to go to a little trouble to get condensers which are as close to the specified capacitance as possible. Inasmuch as the capacitance specified can not be obtained, in most cases, with one condenser, it will probably be necessary to parallel condensers in order to get the required capacitance.

Probably the easiest way to obtain the proper condensers is to purchase mica condensers with a plus or minus 5 percent tolerance. As a double check, these could be compared with each other on an inexpensive capacitance bridge, and any condenser returned which was found to be of a substantially different capacitance from the group average.

It would also be possible to use mica trimming condensers of the proper voltage rating. These should be set to the proper capacitance on a capacitance bridge which could be trusted within 5 percent. The disadvantage here is that the Harmoniker would probably not fit in a 3 by 4 by 5 inch box if adjustable condensers were used.

The more care that is taken to ensure that the specified value of capacitance is obtained, the better the results.

The two center condensers in each half of the circuit may be replaced by a single condenser if so desired. This single condenser, having a capacitance twice the value of C_x, may be placed on either side of the inter-section shield. Caution should be exercised to maintain a low lead inductance. Because this is difficult with some of the larger size condensers, two identical condensers were used in the original unit.

INSTALLATION AND OPERATION

Inasmuch as harmonics are not attenuated until they encounter the Harmoniker, mount the unit as close to the output stage as possible. If the transmitter is completely shielded (as it should be to eliminate the last vestige of TVI) the Harmoniker could well be mounted on the outside of the shield, with short connections made to the output stage. Care must be taken with the leads which connect the transmitter to the Harmoniker, because these leads can radiate harmonics under certain conditions.

In general it will be unnecessary to change your present output coupling system. However, if you are using link coupling with the center of the link grounded, ***remove this ground connection.*** The Harmoniker (used as a balanced filter) does this job for you automatically and far better than any arrangement on the pickup coil.

One must be certain to use the Harmoniker only with a reasonably "flat" line, that is, one which has a low standing-wave ratio. This is particularly necessary when operating at power levels which may produce voltages across the condensers close to their maximum ratings. If the unit is placed in a line with a high SWR, the reward will undoubtedly be a few blown condensers in the Harmoniker.

Of course, the Harmoniker may be used in a line with a high standing-wave ratio (tuned line) if the impedance at that particular point is known, so that the Harmoniker may be designed accordingly.

No d-c voltage should be allowed to appear across the condensers in the Harmoniker.

Be certain to connect terminal G or G′ by means of a short heavy conductor directly to the chassis or frame of the transmitter.

Never try to use a Harmoniker on a band for which it is not intended. For example, if one kilowatt of power on ten meters was fed into a twenty meter Harmoniker, the result would be 999 watts dissipated in the Harmoniker and one watt fed through to the antenna for perhaps a fraction of a second. A further result would be that you would no longer have that twenty meter Harmoniker.

TVI ELIMINATION

Interference to television reception caused by amateur transmitters is generally due to one or more of four effects—radiation of harmonics from the transmitter itself; radiation of harmonics from the antenna system; overload of the TV receiver by the fundamental; and overload of the video circuit in the receiver from radiation on the 160 and 80 meter bands.

The last two effects, overload of the TV receiver by your fundamental frequency or signals getting into the video amplifier, are most easily eliminated by placing suitable filters, traps or shields directly on the receiver. At any rate, these effects will be noted only when the TV receiver is very close to the transmitting location.

Radiation of harmonics from the transmitter (oscillator stage, buffer stages, power supply leads, final stage, etc.) is another cause of TVI. The approach to cure this effect is complete shielding of the transmitter and bypassing of power supply leads, etc.

The third, and probably the most prevalent cause of TVI is radiation of harmonics from the antenna system. It should be possible to eliminate this condition by use of the Harmoniker. In especially severe TVI cases, and of course when you are certain of the cause, two Harmonikers may be used in series if one proves to be insufficient.

When attempting to clear up TVI for the first time, here is a suggested approach.

If you are operating on 7, 14 or 28 megacycles, determine whether the TVI is caused by fundamental or harmonic radiation. To do this, transmit carrier and examine the TV tube screen when the TV receiver is tuned to a TV signal. If the screen becomes blank, or the picture "washes out" then fundamental radiation is undoubtedly causing your trouble. If a herringbone pattern appears, the trouble is most likely due to harmonic radiation. With modulation, horizontal bars will appear on the screen and may obscure the herringbone pattern, so do not use a modulated carrier for this preliminary test. Of course, if you have a SSB transmitter, it will be necessary to transmit a single frequency (carrier or a sideband tone) to generate an equivalent signal.

When operating on the 160 and 80 meter bands the checks mentioned above will not be conclusive, because 1.75 to 4 megacycle energy may get into the video amplifier of the receiver. Therefore, to determine what causes the TVI in this case, another method is suggested. Change the frequency of the transmitter and watch the herringbone pattern on the screen. A change of frequency from one end of the band to the other will not change the spacing of the pattern appreciably if the interference is from the fundamental but the pattern will change substantially if the interference is caused by harmonic radiation.

Once you have determined the cause of TVI, the method of attack is obvious. The least likely causes, namely overloading the receiver, are best cured at the receiver, as mentioned before.

Radiation direct from the transmitter requires shielding of the transmitter and proper bypassing of power supply and other leads.

Interference caused by harmonic radiation from the antenna system is a joy to cure. Merely install a Harmoniker and relax to enjoy your future QSO's.

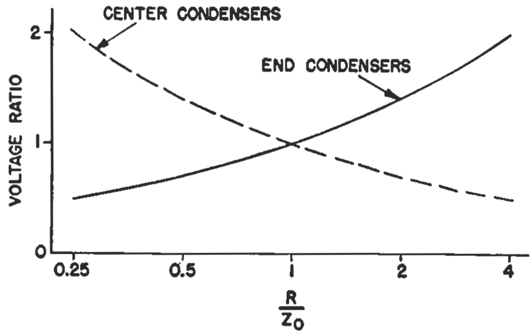


Fig. 5. Curve Illustrating Voltage Change on Harmoniker Condensers for Various Mismatch Ratios

DESIGN THEORY

As is well known, an integral number of half wavelength sections of lossless transmission line of any impedance may be placed between a source of power and a load and the operation of the system will be the same as though the load were connected directly at the source. The half-wave filter is similar to one half-wave section of transmission line in this respect. The important point of dissimilarity is that a half-wave line will not attenuate harmonics, while the half-wave filter, on the other hand, attenuates all harmonics, the attenuation increasing with the order of the harmonic.

A half-wave filter looks like a low-pass filter of two sections. These sections may be either T or pi sections but only the pi type of filter will be discussed. Fig. 4A shows an unbalanced pi filter and Fig. 4B shows a balanced pi filter. These filters become half-wave filters when the load voltage is 180 degrees out of phase with the input (source) voltage. The formulae for the inductance and capacitance required to make half-wave pi-section filters (see Figs. 4A and 4B) are:

$$L = \frac{Z_o}{2\pi f_o}, \text{ and}$$

$$C = \frac{1}{\pi Z_o f_o}$$

where Z_o is the load impedance (resistance) which gives a standing wave ratio of one-to-one in the filter at the frequency f_o. The units are henrys, farads and cycles per second.

For the background on these formulae the reader is referred to *Communication Engineering*, by W. L. Everitt, 1st Edition, 1932, pages 178–181, McGraw-Hill Publishing Co., New York. In other words, this information has been available for some time. The Harmoniker now is a reality because W2KUJ realized how important the practical application of this information could be in an attack on all harmonic radiation.

The half-wave filter is quite forgiving of impedance mismatch. The attenuation of harmonics is virtually unaffected by mismatch, and the very low insertion loss at the fundamental frequency increases but very little with mismatch ratio. It is only when the filter is used at high power levels that one must be concerned about serious mismatch since the circuit elements of the filter have maximum current and voltage ratings.

The curve of Fig. 5 illustrates what happens when the resistive load into which the filter operates departs from the design impedance of the filter when operating at a given output power. The subscript zero indicates the conditions at the design impedance. The symbol

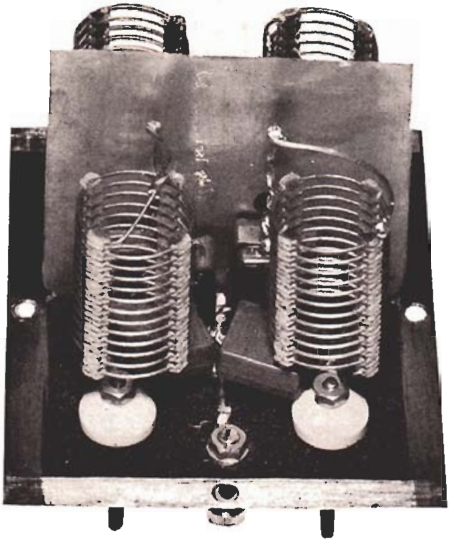


Fig. 6. Detailed View of Eighty Meter, 300 Ohm Harmoniker Showing Placement of Parts and Wiring Details

R/Z_0 is the ratio of the load resistance (into which the filter actually works) to the design Z_0 of the filter. The voltage ratio is the ratio of the voltage on either the center or end condensers to their voltage (E_0) when working in a filter where R/Z_0 is equal to unity.

In all cases $E_0 = \sqrt{PZ_0}$ where P is the output power in watts. Note that when R is greater than Z_0 the voltage ratio increases for the end condensers. In general, the voltage across the end condensers is:

$$E_e = E_0\sqrt{R/Z_0}$$

and the voltage across the center condensers is:

$$E_c = E_0\sqrt{Z_0/R}$$

These formulae hold only for the unbalanced filter. For the balanced filter, the voltage across any one condenser will be one-half that given by these formulae. The curve of Fig. 5 holds for either the balanced or unbalanced case.

When designing your own Harmoniker, care should be taken to use condensers with a sufficiently high voltage rating. To ensure this, make calculations as follows. First determine the E_0 voltage from the formula involving power and the design impedance of the filter impedance. This impedance should be the same as the load impedance for most economical design. (For a balanced filter, divide this value of voltage by two.) Next, refer to Fig. 5 to find the multiplying factor for mismatch (unless you choose a Z_0 equal to R). The value you now have is the RMS voltage across any condenser in the filter, unless you intend to use the filter in an AM phone rig, in which case multiply the voltage by two. The peak voltage will now be 1.414 times the RMS value. Choose condensers having at least this voltage rating—or higher.

The power lost in the filter increases when R and Z_0 are not equal. In general this increase is small. For example, the power loss is 25 per cent greater when R/Z_0 is equal to 0.5 (or 2) than it is when R is equal to Z_0.

If you use CW, NBFM or SSB the peak output power is the value you should use for P in calculations. It is safe to use a value for P that is 0.8 times the DC *peak input*. In any case, the objective is to prevent damage to the condensers because of overvoltage.

Fig. 7. View of Completed Harmoniker Showing Input and Output Terminals

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—*Lighthouse Larry*

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