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CONCENTRIC-SHEAR MODE 455 KC ELECTROMECHANICAL FILTER

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Approved

Stuart Wm. Seeley

This bulletin describes an experimental 455 kc electromechanical filter of simplified design. The filter consists of four magnetostrictive ferrite disk resonators operating in the concentric shear mode. The entire filter is only 1 inch long and 5/8 inch in diameter. Broadband electrical terminations and low insertion loss make this filter ideal for application in transistorized equipment.

Introduction

The mechanical filter element is an assembly of magnetostrictive ferrite disk resonators and quarter-wave torsional couplers. A complete filter assembly removed from the case, is shown in Fig. 1. The parts are shown in more detail in Fig. 2. Separate couplers are cemented between each disk. The magnetostrictive ferrite disks are resonant in the concentric shear mode of vibration.[1] Magnetic bias is obtained from residual circular magnetism from passing a current through a hole in the center of the disk. The disk is excited in the concentric shear mode of vibration by application of the r-f field radially to the side of the disk. This makes it possible to measure the resonant frequency of each disk as well as to use the end disks of the filter for efficient electromechanical transducers. Uniform circular bias and exciting field give negligible excitation of spurious modes of vibration.

The transducers and the mechanical system have very low loss so that the important power losses occur in the coils which are coupled to the transducers. The coils are enclosed in low-loss ferrite cores, Fig. 3. These ferrite cores minimize eddy current loss in the shield can and concentrate the r-f field in the transducer disk to obtain maximum electromechanical coupling to the energized portion of the transducer. Broad-band electrical

[1] W. van B. Roberts, "Some Applications of Permanently Magnetized Ferrite Magnetostrictive Resonators", *RCA Review*, vol. 14, pp. 3-16; March 1953.

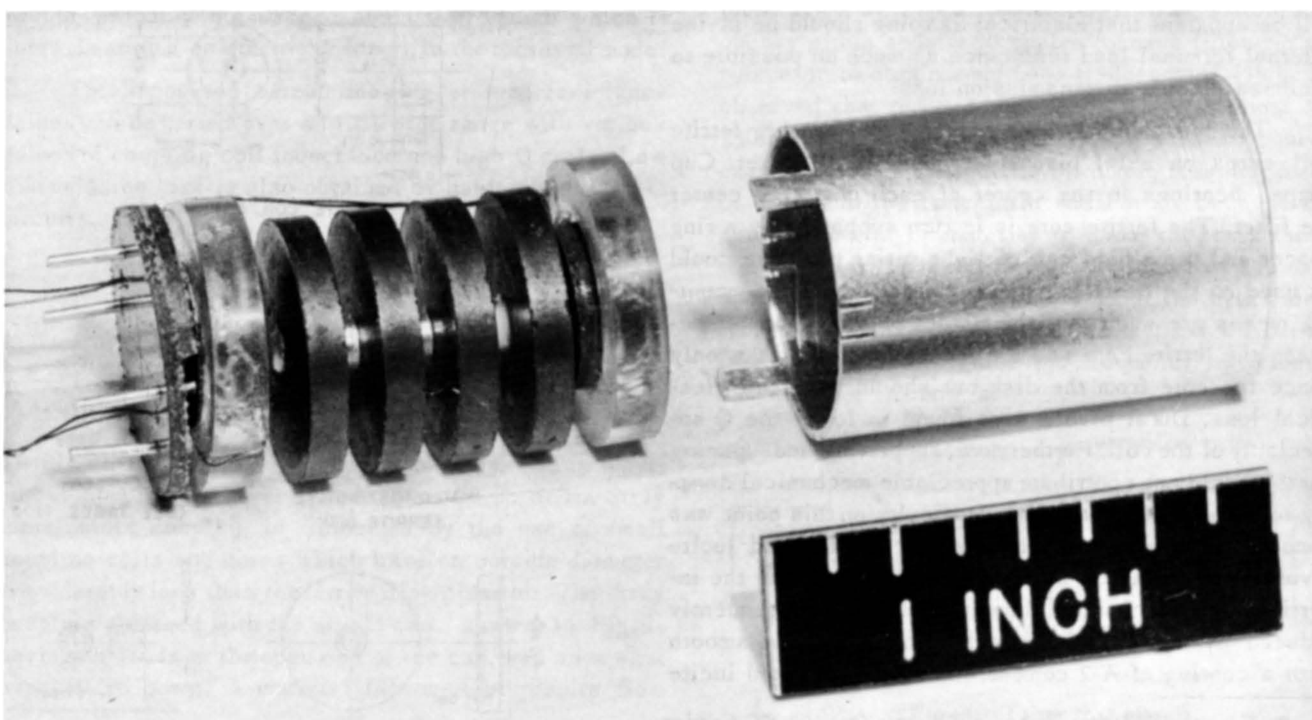

Fig. 1 – Filter assembly removed from case.

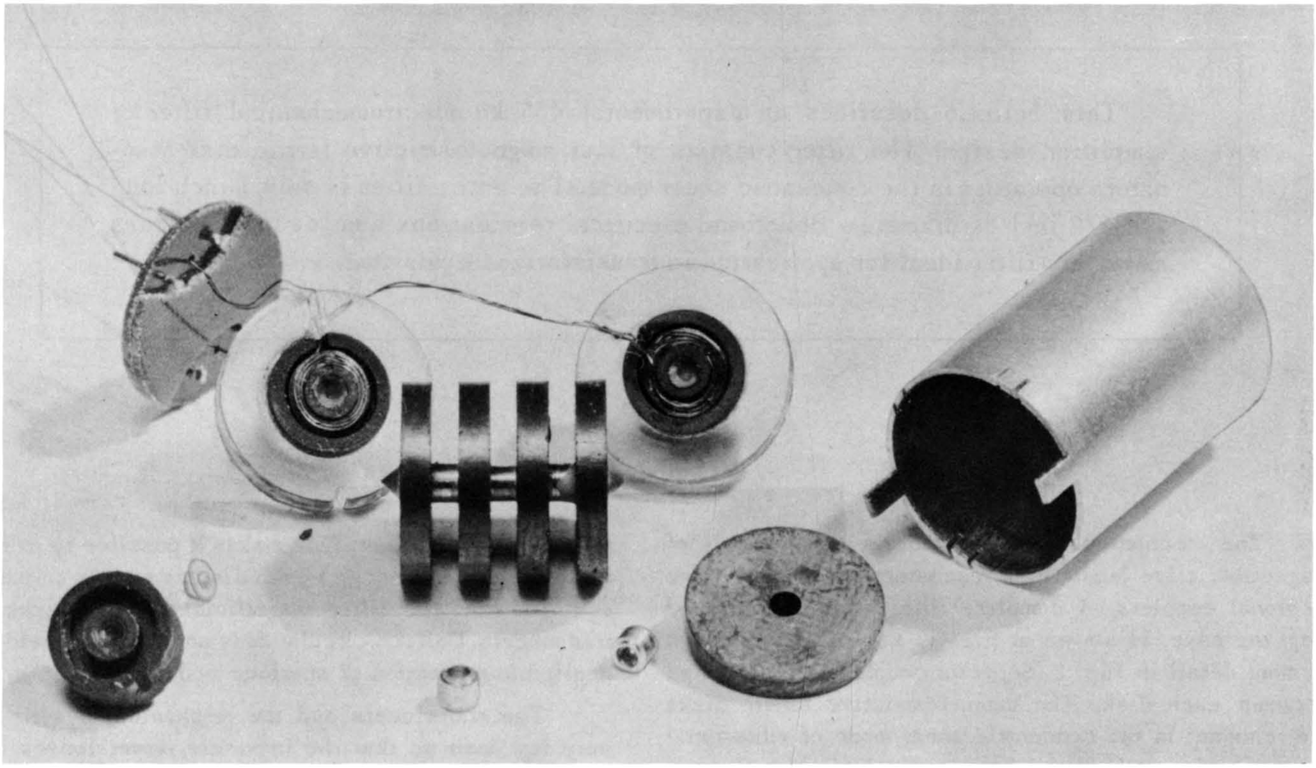

Fig. 2 – Filter subassemblies and parts.

termination is possible when the electromechanical coupling coefficient is relatively large, and the magnetostrictively energized portion of the end resonator, also a transducer in this case, is relatively small.[2] It will be apparent that electrical damping should be in the external terminal load resistance as much as possible to minimize electrical transmission loss.

The mechanical filter is supported by the ferrite coil cores on axial pivots attached to the filter. Cup shaped bearings in the center of each coil core center the filter. The ferrite core is in turn supported by a ring spacer and the shield can. A light spring pressure could be used on the bearings. The requirements of the mounting means are such that the pivots or other support between the ferrite core and the filter disk should not only space the core from the disk but should have low electrical loss. Dural pivots were found to lower the Q appreciably of the coil. Furthermore, supporting and spacing parts should not contribute appreciable mechanical damping to the end resonator disk. Difficulty on this point was encountered when pressure was put on rounded lucite pivots which resulted in a 5 to 10 db increase in the insertion loss. Mechanical damping has been subsequently reduced by making the pivot bearings hard and smooth with a coating of A-2 cement,[3] and using pointed lucite pivots. Satisfactory terminations have been obtained without particularly careful control of the spacing. Spacing between the ferrite core and the disk apparently should

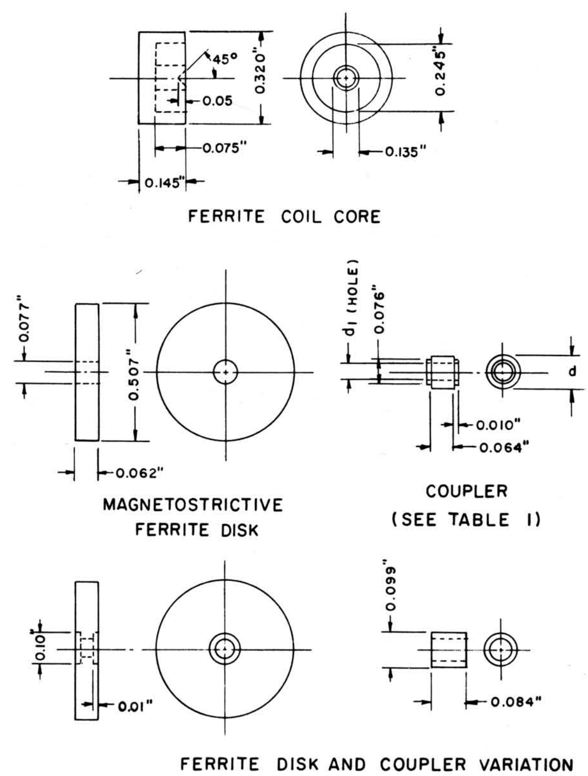

Fig. 3 – Mechanical filter details.

[2] R. W. George, "Electromechanical Filter for 100 KC Carrier and Sideband Selection", *Proc. IRE*, vol. 44, No. 1, Jan. 1956.

[3] Armstrong Products Co., Argonne Road, Warsaw, Indiana.

be as small as practical, perhaps on the order of 0.01 to 0.02 inch.

Design

It should be possible to calculate the filter dimensions to give the required bandwidth on the basis of the kinetic energy of the resonators and the couplers. However, it has been found easier to make the filters and measure the bandwidth.

An attempt has been made to use coupling coefficients of the Campbell type.[4] This was tried by using couplers all alike with end disks 1/2 the thickness of the interior disks. Useable filters were obtained which were promising; however, the attenuation on the low frequency side of the passband was sloppy and included unexpected spurious responses. Filters made using identical disks with somewhat larger end couplers eliminated these difficulties. The spurious responses of these filters were generally at least 60 db down over the frequency range of 160 kc to 1,600 kc. One unexplained response about 50 db down has been found in some filters around 700 kc.

The couplers are naturally more delicate and the assembly with cement requires more care with narrower band filters. For narrow bandwidth of somewhat less than 2 kc, it might be better to use thicker resonator disks to increase the required mass of the couplers. The thickness should probably not exceed about 0.075 inch which is approximately a quarter-wave-length in the torsional mode.

The input and output damping or load resistance values can be varied over a fairly wide range with various values of coupling coil inductance and high Q coils. Low transmission loss is also obtained by having high Q, L-C circuits.

Stray Input-Output Coupling

The experimental filters were first tested in a completely closed shield with leads at each end. Stray input-output coupling was very small, over 60 db down. Stray input-output coupling is minimized by the use of small coupling coils and cores which have an outside diameter considerably less than the ferrite disk diameter. The stray coupling obtained with the shield can, shown in Fig. 1, having all leads at the open end of the can, was somewhat over 40 db down. A material improvement results from closing the open end of the can. The ferrite coil cores may be increased in size somewhat to increase the coupling which might be required for very wide band filters, or, to make more space for more efficient or higher impedance coils.

Magnetostrictive Ferrite Resonator Disks

The disk resonators were made of nickel-iron ferrite containing very little cobalt impurity.[5] The resonant frequency of the disk is principally a function of diameter. The hole in the center which is necessary in order to magnetize the disk, contributes a minor modification of the resonant frequency. Non-uniformity in the thickness of a disk results in variations of resonant frequency. Experience with small lots of 25 to 50 disks pressed by hand indicates that the 455 kc disks might be expected to have resonant frequency variations of less than plus or minus 500 cycles when produced under more uniform production conditions.

The resonant frequency of the disks is modified by the assembly with the couplers so that the mid-band frequency of the filter is somewhat different. This frequency difference should be fairly constant under production conditions for a given type of filter.

The disks used in the experimental filter had a diameter of from about 0.507 to 0.509 inch and a hole diameter of 0.077 inch. Nominal thickness was about 0.062 inch. They were selected or tuned to be matched in frequency within about ± 50 cycles for each filter. No attempt was made to obtain a mid-band frequency of 455 kc. It was observed that the mid-band frequency was about 1100 to 1300 cycles lower than the disk resonant frequency in each case. It is difficult to lower the resonant frequency of a disk in the concentric shear mode because this requires removal of material to make the disk thinner in the region of the nodal ring zone which has a diameter of about 0.7 times the disk diameter. If the disks are to be tuned, it is more practical to make them a little low in frequency and then raise the frequency by grinding the outside edge or corners.

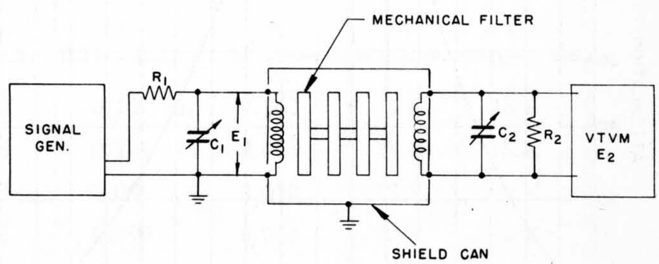

Fig. 4 – Filter test circuit.

[4] W. van B. Roberts and L. L. Burns, "Mechanical Filters for Radio Frequencies", *RCA Review*, vol. 10, pp. 348-365, Sept. 1949.

[5] R. L. Harvey, "Ferrites and Their Properties at Radio Frequencies", *Proc. NEC*, vol. 9, pp. 287-298, February 1954.

No study was made of frequency-temperature coefficient and constancy of electromechanical coupling coefficient. Improvement of these factors may preferably be made under production conditions. Relatively high coercive force is also desirable to minimize the possibility of loss of residual magnetic bias.

The ferrite disks can be tested under standardized conditions which give relative indications of electromechanical coupling coefficient and coercive force rather than absolute values. Sample checks of these factors and the frequency-temperature coefficient should be adequate. The physical soundness and resonant frequency of each disk to be used must be determined. The resonant frequency is probably most easily measured by the use of a simple bridge circuit which should be adaptable to automation.

Physical faults such as voids and cracks not only reduce the electromechanical coupling coefficient and residual magnetic bias, but also result in spurious resonant frequency responses. The main resonant frequency is usually altered considerably and is accompanied by lower bridge unbalance output at resonance. Satisfactory disks will generally be selected when the r-f input to the bridge is varied over narrow limits of frequency, say ±500 cycles or ± 1000 cycles of the normal resonant frequency, and, if selection or rejection is based on standardized values of bridge unbalance output at resonance. This test should be made with a standardized method of magnetizing and with the disks all at the same temperature.

The assembled mechanical portion of the filter should be re-magnetized by the standard current to insure against loss of bias due to shock or exposure to strong magnetic fields while handling and assembling the disks. It may also be desirable to *age* the filter at an elevated temperature to stabilize the residual bias if operating temperatures are expected to be higher than usual.

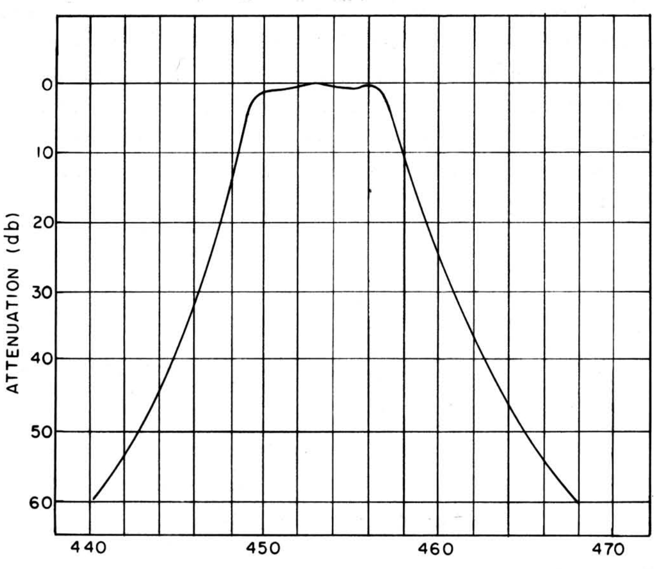

Fig. 5 – Filter No. 8.

Data On Experimental Filters

The circuit shown in Fig. 4 was used in testing these filters. Some variation in coil-core spacing to the filter resulted in unequal values of R_1 and R_2, and C_1 and C_2. Tuning capacity was on the order of 500 $\mu\mu f$ when using 75 turn coils. Tests were made with an output voltage, E_2, of about 0.1 volt, however, the filters operate satisfactorily with output voltages of up to 10 volts or more. Response curves for 4 filters are shown in Figs. 5 to 8. The shape factor is on the order of 3 to 3.5.

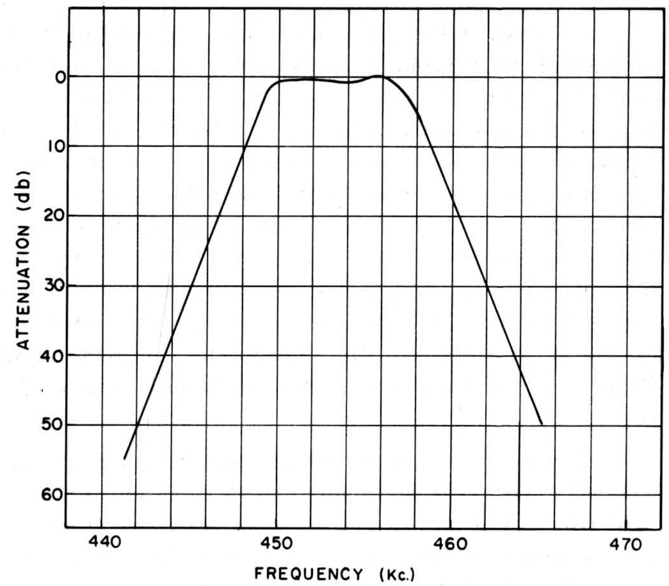

Fig. 6 – Filter No. 9.

Electrical insertion loss is estimated at less than 6 db. This was based on the power input to the filter at the terminals where E_1 is measured, and the output power in R_2. E_1 varies considerably with frequency in the pass-band with the result that this method of measurement is not very satisfactory.

The coils were layer or random wound with about 75 turns of No. 36 enamel wire. It should be possible to make better coils. The coil space in the ferrite cores could also be made somewhat deeper and/or larger in diameter. The overall diameter of the core, Fig. 3, might be increased to as much as 0.4 inch without making the broadband termination too critical or without resulting in a serious increase in stray input-output coupling. These and other variations in construction may be desirable for production or circuit application reasons and will have to be tried under production conduction conditions to determine the effects.

Mechanically perfect joints between resonators and couplers are desired. Satisfactory results were obtained with Armstrong cement No. A-2. There should be a number of other cements which would be suitable for this purpose.

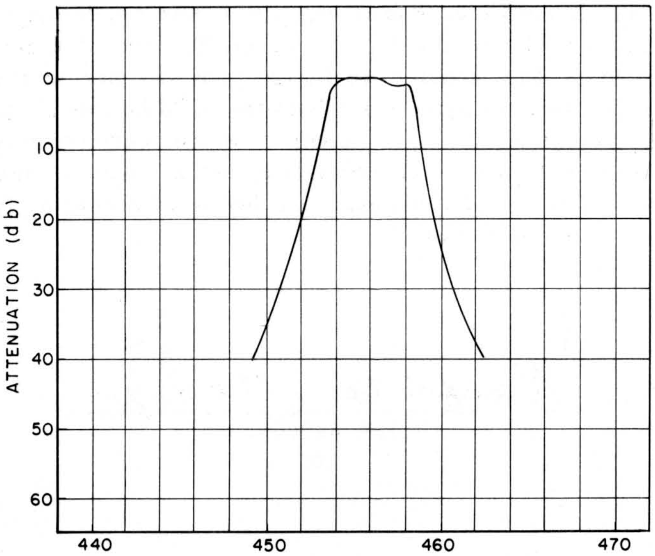

Fig. 7 – Filter No. 10.

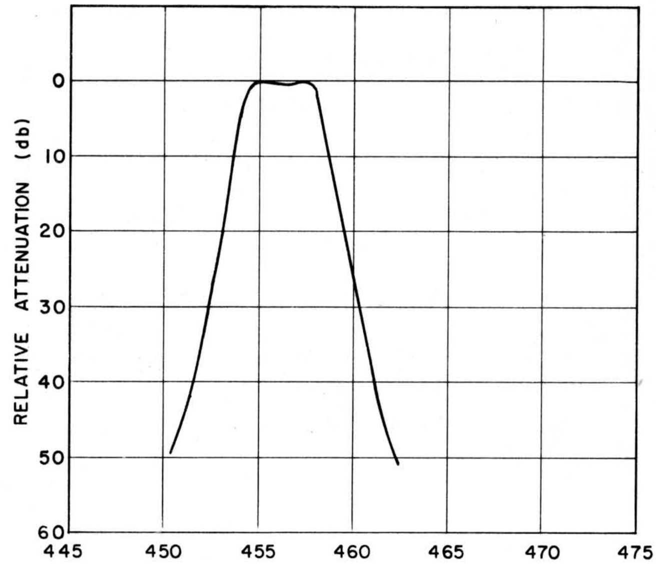

Fig. 8 – Filter No. 11.

The use of quarter-wave couplers permits the use of the largest possible diameter which will give the desired coupling coefficient. The couplers should be made of material having low mechanical losses. This material should also have a reasonably low frequency-temperature coefficient if the ferrite resonator disks have a very low frequency-temperature coefficient. Bandwidths obtained with various parts dimensions are shown in Table I and Fig. 3.

Pivots or other supporting-spacing means which are in the flux path of the coils should have low electrical loss as well as good mechanical characteristics. Pivots should be either loose or cemented in the filter element in such a way as to minimize mechanical losses. Cemented pivots may appreciably detune the end resonator and therefore should have small mass. Another mounting arrangement which was tried was a loose fitting bakelite shaft through the filter. Small washers at each end spaced the filter with respect to the coil cores. This method of mounting is satisfactory if very little or no pressure is put on the spacers so that the filter element is positioned with substantially no binding.

A variation in disk and coupler shapes is shown at the bottom of Fig. 3 which might be more suitable for production. A recess on each side of the disk centers the coupler and pivot-bearing assembly. The couplers are

TABLE I

Data On Experimental Filters

Filter Number	Bandwidth (cps)	Couplers: Interior d	Couplers: Interior d_1	Couplers: End d	Couplers: End d_1	R_1	R_2
8	8260	0.095 in.	0.062	0.100 in.	0.062	9 K	18 K
9	9500	0.095	0.058	0.100	0.058	18 K	18 K
10	5340	0.090	0.058	0.095	0.058	18 K	9 K
11	4000	0.086	0.066	0.090	0.066	50 K	4 K*
12	17000	0.107	0.058	0.115	0.058	40 K	18 K

*Across a tap on the output coil. Or this tap can be connected directly to a transistor circuit.

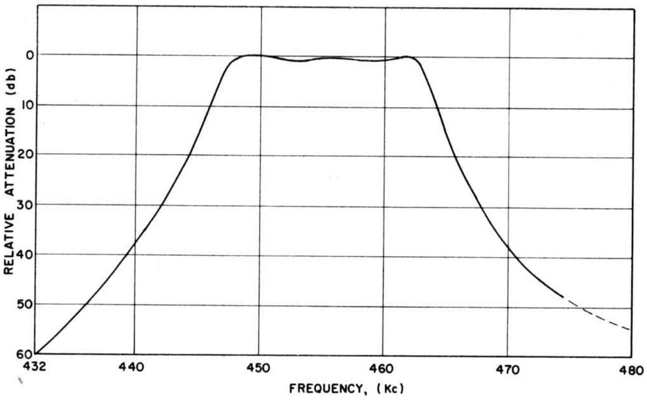

Fig. 9 – Filter No. 12

simply cut-off pieces of tubing with a permissible length variation of perhaps 2 or 3 percent. The outer diameter would be kept constant to fit the recessed hole in the ferrite disk, while the inner diameter would be chosen to give the desired coupling coefficient. The couplers may be made of a variety of materials including possibly some ceramics. The dimensions given herein of course apply only to the use of dural.

Ralph W. George

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