

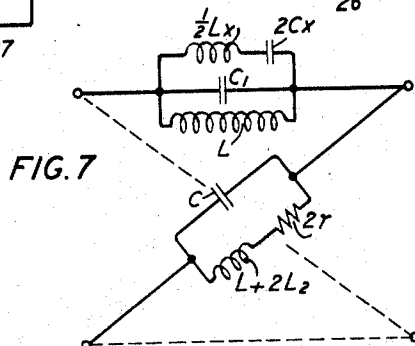
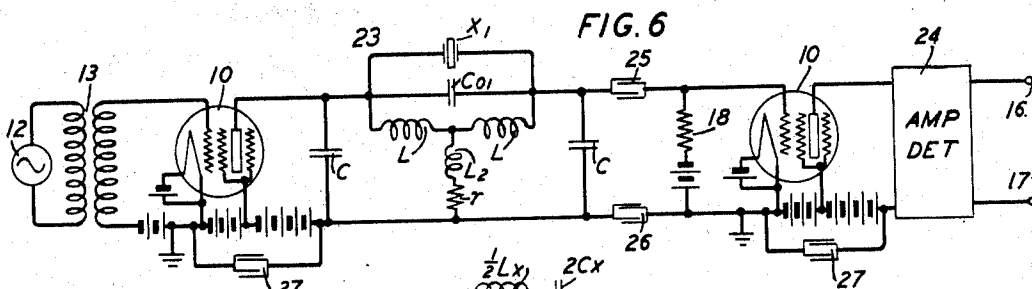
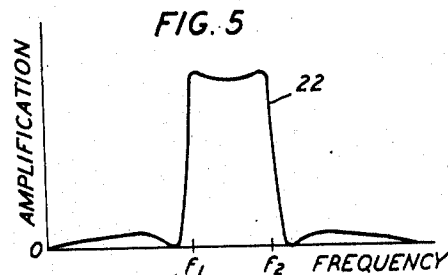
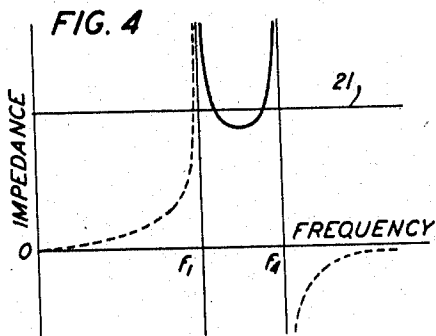
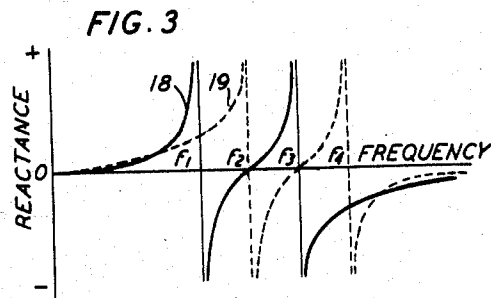
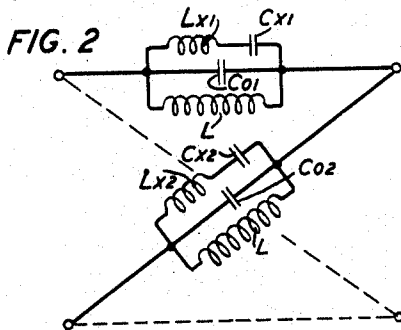
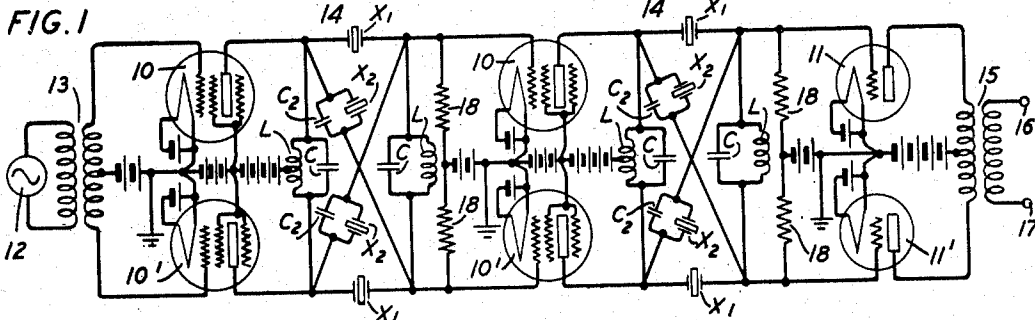
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HIGH FREQUENCY AMPLIFIER

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HIGH FREQUENCY AMPLIFIER

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This invention relates to band selective amplifiers for use at high frequencies and more particularly to amplifiers employing vacuum tubes of the screen-grid type having high internal impedance.

The principal object of the invention is to improve the efficiency of high frequency amplifiers using screen grid tubes while at the same time maintaining a sharply defined band transmission characteristic.

The high internal impedance, ranging from 200,000 to 500,000 ohms, which is characteristic of screen-grid amplifying tubes makes it difficult to couple such tubes in tandem through high frequency band selective circuits of the ordinary type without a large loss of amplification. The reason for this is that high frequency band selective circuits using ordinary electrical elements can not be constructed with characteristic impedances of more than about 40,000 ohms in the transmission range. When higher impedances are attempted the effect of dissipation in the inductance coils greatly reduces the efficiency of transmission in the selected band and also practically destroys the band selectivity. When impedances of the order of 40,000 ohms or less are used, the great disparity of the tube and the circuit impedances results in a large part of the possible amplification being dissipated in the internal resistance of the tube.

In the amplifier circuits of the invention, these losses are avoided by the use of certain types of piezo-electric crystal band-pass filters as the coupling circuits between successive tubes. In the preferred forms, the impedance branches of the filters comprise piezo-electric quartz crystals shunted by inductances, the latter being so proportioned and so disposed in the circuit that their dissipation is without effect upon the filter characteristics. I have found that filters of this type can be built to transmit bands of frequencies of widths as great as 10,000 cycles per second at mean frequencies of over 100,000 cycles per second and may have characteristic impedances which closely match the internal impedance of typical screen-grid amplifier tubes. The combination of these filters with screen-grid amplifier tubes, therefore, permits the maximum possible amplification to be obtained while at the same time great sharpness of selectivity is maintained.

The invention will be more fully understood from the following detailed description and from the appended drawing of which;

Fig. 1 shows one form of the invention;

Figs. 2 to 5, inclusive, are diagrams and curves explanatory of the circuit of Fig. 1;

Fig. 6 illustrates a modified form of the invention, and

Fig. 7 is a diagram explanatory of Fig. 6.

The amplifier of Fig. 1 is of the push-pull, or balanced, type each of the first two stages comprising a pair of similar screen-grid tubes 10, 10' with their cathodes connected together and to ground and the third stage comprising a pair of three electrode tubes 11, 11' similarly connected. For the sake of simplicity, the circuits for heating the cathodes are omitted and the sources of potential for energizing the grids and the plates are indicated schematically as batteries. It will be understood, however, that any of the usual arrangements may be used for these purposes.

The successive pairs of tubes are coupled in tandem through similar lattice type filters 14 which will be described in detail later. The grids of the first stage tubes are connected through a transformer 13 to a wave source 12 and the plates of the last stage tubes are connected through a transformer 15 to output terminals 16 and 17. Resistances 18 connecting the grids and the cathodes of the second and third stage tubes provide proper resistive termination for the filter for which purpose they should have values equal to the plate circuit resistance of the preceding tube. In most cases, however, they may be omitted without serious effect upon the amplifier characteristic.

The filters 14 are of the symmetrical lattice type, the line branches comprising piezo-electric quartz crystals X_1 and the lattice branches comprising crystals X_2 shunted by capacities C_2 . At each end of the lattice a shunt inductance L and a shunt capacity C are connected which cooperate with the crystal branches to determine the transmission characteristic of the filter as hereinafter described. The inductance at the input end of the filter also serves as a plate current supply path for the tubes connected thereto, a tap at the midpoint being provided for connection to the plate current source.

The filter is equivalent in its transmission properties to the symmetrical lattice shown schematically in Fig. 2 in which the line branches comprise the parallel combination of inductance L , capacity C_{01} , and a resonant circuit made up of inductance L_{x1} and capacity C_{x1} . The lattice branches comprise a similar combinations of inductance L , capacity C_{02} and resonant combination L_{x2} , C_{x2} . In this equivalent circuit, the crys-

tals X_1 have been replaced by the resonant circuit L_{x1} , C_{x1} , and a shunt capacity which together with the external capacity C makes up the shunt capacity C_{o1} . A similar substitution has also been made for the crystals in the line branches.

The electrical equivalent of the crystal described above has been found to represent the properties of the crystal very accurately over a frequency range up to and well above the first natural resonance of the crystal. For filter purposes the crystals should preferably be of quartz in the form of a rectangular plate cut with its plane perpendicular to the electrical axis and its greater length along the mechanical axis. The electrodes should be applied to faces perpendicular to the electrical axis and the crystal should be mounted so that it is free to vibrate freely by expansion and contraction along the mechanical axis.

For this form of crystal the equivalent electrical coefficients are given in terms of the crystal dimensions by the following formulae:

$$L_x = \frac{106.1lt}{w} \text{ henries}$$

$$C_x = \frac{.322w/10^{-14}}{t} \text{ farads}$$

$$C_e = \frac{40.2w/10^{-14}}{t} \text{ farads}$$

in which L_x and C_x are respectively the inductance and capacity of the resonant combination, C_e is the electrode capacity, and l , w , and t , are the crystal dimensions, in centimeters, along the mechanical, optical, and electrical axes respectively.

The general form of the frequency characteristics of the branch impedances is shown by the curves of Fig. 3 of which curve 18 represents the reactance of the line branches and curve 19 that of the lattice branches. The frequencies of resonance and anti-resonance are designated f_1 , f_2 , f_3 and f_4 and the condition for the existence of a single continuous transmission band is indicated by the coincidence at frequency f_2 of a resonance of the one impedance with an anti-resonance of the other and a similar coincidence at frequency f_3 . The frequency f_2 corresponds to the resonance frequency of crystal X_1 and frequency f_3 to the resonance of crystal X_2 .

The values of the impedance elements of the circuit of Fig. 2 are readily found in terms of the inductance L and the critical frequencies f_1 to f_4 by means of the theorem described in an article by R. M. Foster entitled "A reactance theorem" Bell System Technical Journal, Vol. III, No. 2, April 1924. For the case illustrated the values are as follows:

$$\frac{1}{C_{o1}} = L \frac{\omega_1^2 \omega_3^2}{\omega_2^2}$$

$$\frac{1}{C_{x1}} = L \frac{\omega_1^2 \omega_2^2 \omega_3^2}{(\omega_2^2 - \omega_1^2)(\omega_3^2 - \omega_2^2)}$$

$$L_{x1} = L \frac{\omega_1^2 \omega_3^2}{(\omega_2^2 - \omega_1^2)(\omega_3^2 - \omega_2^2)}$$

$$\frac{1}{C_{o2}} = L \frac{\omega_2^2 \omega_4^2}{\omega_3^2}$$

$$\frac{1}{C_{x2}} = L \frac{\omega_2^2 \omega_3^2 \omega_4^2}{(\omega_3^2 - \omega_2^2)(\omega_4^2 - \omega_3^2)}$$

$$L_{x2} = L \frac{\omega_2^2 \omega_4^2}{(\omega_3^2 - \omega_2^2)(\omega_4^2 - \omega_3^2)}$$

where ω denotes 2π times frequency.

The characteristic impedance K of the filter is given by the equation

$$K = \frac{\omega}{\sqrt{C_{o1}C_{o2}(\omega_2^2 - \omega_1^2)(\omega_4^2 - \omega_3^2)}} \quad (3)$$

its value being real, or resistive, at frequencies between the band limits ω_1 and ω_4 and imaginary, or reactive, elsewhere. At the band limits the characteristic impedance is infinite and at the near band frequency it has a minimum value K_m given by

$$K_m = \frac{1}{\sqrt{C_{o1}C_{o2}(\omega_4 - \omega_1)}} \quad (4)$$

The variation of the characteristic impedance with frequency is shown in Fig. 4, the dotted portion of the curve representing reactive values and the solid portion resistive values. The horizontal line 21 represents a typical value of the impedances between which the filter should operate, this value preferably being about 20 per cent greater than the minimum value of the characteristic impedance given by Equation 4.

From the foregoing formulae it will be seen that by choosing different values of the critical frequencies f_2 and f_3 a large number of networks may be computed all of which have the same transmission band and the same characteristic impedance at the mean frequency of the band, but have different values of the component impedance elements. The particular values chosen for these frequencies determine to a large extent the attenuation characteristic of the filter at frequencies outside the band and also the phase characteristic within the band. A simple rule for the allocation of the frequencies is to make their values form a geometric series, that is, such that the ratio of each frequency to the next higher frequency is the same in each case. Under this condition a high level of attenuation is maintained at all frequencies outside the band when the shunting inductances are equal. The geometric spacing of the frequencies also corresponds to the condition that the shunt inductances provide the proper amounts of reactance to neutralize the total shunt capacities of the respective branches at the resonance frequencies of the crystals.

In practice, slight deviations from the geometric spacing of the frequencies do not affect the attenuation level outside the band to any great extent and, accordingly, other frequency allocations may be used. When the band width is narrow, of the order of 10 per cent of the mean band frequency, the geometric arrangement will not differ noticeably from a simple uniform spacing of the frequencies at equal intervals. Another rule for the spacing of the frequencies to maintain a high attenuation level and a linear phase characteristic is described in U. S. Patent 1,828,454 to H. W. Bode.

The value of the shunt inductances may be determined from the desired characteristic impedance using an alternative form of Equation 4 as follows:

$$K_m = \frac{\omega_1 \omega_4 L}{\omega_4 - \omega_1} \quad (5)$$

the value of K_m being chosen with respect to the terminal impedances between which the filter is to work in the manner already indicated. Having thus determined the value of the shunt inductance the remaining quantities follow from Equation 2.

Since the crystal capacities are very small and

since the additional shunting capacities may be quite small also, it follows from Equation 4 that the mean frequency impedance of the filter may be made very large. In practice, however, it is

necessary to take into account the fact that the inductance coil has some shunt capacity which will appear as part of the effective capacity shunting the crystal thereby reducing the value of the characteristic impedance. In addition the electrode capacities of the connected vacuum tubes will also be effectively in shunt to the crystal. With suitable coil construction the total external capacity may be kept down to about twenty micromicrofarads which is small enough to permit impedances of several hundred thousand ohms to be obtained.

The magnitudes of the quantities involved will be illustrated by the following example of a filter designed to couple vacuum tubes having plate resistances of 500,000 ohms and to pass a band of frequencies extending from 1200 to 1212 kilocycles per second. In this case the resonance frequencies were chosen as follows: $f_1=1,200,000$ c. p. s., $f_2=1,202,610$ c. p. s., $f_3=1,209,425$ c. p. s., $f_4=1,212,000$ c. p. s., and the mean frequency characteristic impedance was taken as 400,000 ohms.

The values of the elements in the equivalent circuit of Fig. 2, as obtained from Equations 2 and 5 are as follows:

$$\begin{aligned} L &= 0.52 \times 10^{-3} \text{ henries} \\ C_{01} &= 32.9 \times 10^{-12} \text{ farads} \\ C_{02} &= 33.35 \times 10^{-12} \text{ farads} \\ C_{X1} &= 1.468 \times 10^{-15} \text{ farads} \\ C_{X2} &= 1.459 \times 10^{-15} \text{ farads} \\ L_{X1} &= 11.91 \text{ henries} \\ L_{X2} &= 11.90 \text{ henries} \end{aligned}$$

Choosing a thickness of .05 centimeter for each crystal the following values of the crystal dimensions and of the elements of filter as arranged in Fig. 1 are obtained.

For crystal X_1

$$\begin{aligned} l &= 0.224 \text{ centimeter;} \\ w &= 0.11 \text{ centimeter;} \\ t &= 0.05 \text{ centimeter;} \end{aligned}$$

for crystal X_2

$$\begin{aligned} l &= 0.223 \text{ centimeter;} \\ w &= 0.11 \text{ centimeter;} \\ t &= 0.05 \text{ centimeter.} \end{aligned}$$

The capacity C in shunt to the external inductance L has the value 32.7 micro microfarads, and C_2 in shunt to crystal X_2 is 0.45 micro microfarads. The capacity C will, of course, include the shunt capacity of the inductance and also the tube capacity, which may amount to a total of about twenty micro microfarads. The use of small variable air condensers in shunt to the coils permits the capacity value to be adjusted to the correct value taking into account these extraneous capacities.

The particular example described above is suitable for use in an intermediate frequency amplifier of a short wave double detection radio receiver. As the frequency is lowered it becomes necessary to use thinner crystals in order that the requisite crystal capacity, determined mainly, by the band width and the characteristic impedance, can be obtained. It is practicable, however, to use crystals as thin as one-tenth of a millimeter and by increasing the mean frequency characteristic impedance to about 400,000 ohms it becomes possible to construct filters of the type

described above to pass a band of 10,000 cycles per second at a mean frequency of about 200,000 cycles per second. Narrower bands can be obtained at still lower frequencies.

The spacing of the resonance and anti-resonance frequencies in the example given above departs somewhat from the geometrical or even spacing hereinbefore mentioned. This particular frequency spacing was chosen to produce a crossing of the reactance characteristics at frequencies outside the band and close to the band limits in the manner indicated in Fig. 3, such crossings corresponding to frequencies of infinite attenuation.

The type of amplification characteristic obtained as the result of this is illustrated by curve 22 of Fig. 5. The attenuation peaks of the filter cause the amplification to fall sharply to zero just outside the band limits and the substantial equality of the two branch impedances maintains the attenuation high at all other frequencies outside the band. The two crests of the amplification characteristic occur at the frequencies within the band at which the filter impedance exactly matches the terminal impedances.

An adaptation of the invention to amplifiers of the unbalanced type is shown in Fig. 6 in which a pair of screen grid tubes 10, 10, are coupled by means of an unbalanced high impedance band filter 23. As in Fig. 1, 12 denotes a source of high frequency waves and 13 a transformer coupling the source to the input terminals of the first stage tube. The output of the second tube is connected to an amplifier detector 24 which may be of conventional form or which may include additional stages similar to those illustrated in detail.

The coupling filter in this case is of the bridged-T type comprising a T-network of equal inductances L and shunt inductance L_2 , a bridging arm including a piezo-electric crystal X_1 with a shunt capacity C_{01} , preferably variable, and external shunt capacities C . A small resistance r is included in series with inductance L_2 for the purpose of balancing the dissipation in the filter.

The plate current of the first tube is fed through the inductances L_2 and L and to prevent the plate voltage reaching the electrodes of the second tube blocking condensers 25 and 26 are inserted in the circuit. Additional condensers 27 are connected in shunt to the plate current sources to provide low impedance paths for the high frequency currents.

The filter is equivalent in its transmission properties to the symmetrical lattice filter shown schematically in Fig. 7. The line branches of this filter, of which only one is shown, consists of three parallel branches namely, an inductance L corresponding to the series inductance of the T in Fig. 6, a resonant circuit consisting of an inductance $\frac{1}{2}L_X$ and a capacity $2C_X$ corresponding to the resonance of the crystal X_1 , and a shunt capacity C_1 which is equal to the capacity C plus twice the capacity C_{01} plus twice the crystal electrode capacity. The line branches will thus be seen to include an impedance equal to half the impedance of crystal X_1 together with the other elements mentioned. The lattice branches each include only a simple anti-resonant circuit composed of capacities C in parallel with an inductance of value $L+2L_2$ and a resistance $2r$.

The values of the equivalent lattice elements may be computed in the same manner as in the case of the filter of Fig. 2, the resistance $2r$ be-

ing neglected in this part of the design computation. In general, the filter is subject to the same kind of limitations as to band width and impedance as that of Fig. 1 but since the crystal X_1 in the bridged-T arrangement of Fig. 6 has twice the impedance of the crystal equivalent in the lattice it can be constructed with smaller capacities without the minimum thickness limit being exceeded. Consequently, filters of this type can be built for lower frequencies than those of Fig. 1 and filter amplifiers of the type shown in Fig. 6 can be constructed to pass bands of about 10,000 cycles per second at mean frequencies down to about 100,000 cycles per second.

The value of the resistance r in the shunt branch of the filter may be determined as follows: Each of the shunt coils of the equivalent lattice of Fig. 7 will have a certain resistance the effect of which is to diminish the sharpness of selectivity of the filter and to introduce irregularities into its transmission characteristic. If the resistance of inductance L is designated r_1 and that of coil L_2 as r_2 , the total resistances of the inductive branches of the line and the lattice arms of the filter of Fig. 7 will be respectively r_1 and $r_1 + 2(r_2 + r)$. At the frequencies of the transmission band and over a considerable range on each side thereof these resistances may be replaced by shunt resistances of values

$$\frac{r_1}{\omega^2 L^2} \text{ and } \frac{r_1 + 2(r_2 + r)}{\omega^2 (L + 2L_2)^2}$$

respectively, which will be equal when

$$\frac{2(r_2 + r)}{r_1} - 1 = \left(\frac{L + 2L_2}{L} \right)^2 \quad (6)$$

When the resistance r is proportioned in accordance with this formula, the dissipative effects are the same as would be produced by connecting equal high resistances across the input and the output terminals of the filter and removing all dissipation from within the filter. This effect manifestly will appear as a constant loss at all frequencies and will not affect the selectivity.

In Fig. 6 the T-network of inductances L and L_2 is made up of three physical inductances. It is, of course, obvious that the shunt inductance L_2 may be replaced by mutual inductance between the two series coils in accordance with well known principles.

What is claimed is:

1. In combination, a thermionic amplifier having an anode, a cathode, a control grid, and a screen grid, and a band pass wave filter connected to the output terminals thereof, said wave filter including a piezo-electric crystal and additional reactances proportioned with respect thereto to provide a single transmission band between

preassigned frequencies, and having a characteristic impedance within said band substantially equal to the internal space resistance of said amplifier.

2. An amplifier for signal modulated high frequency waves comprising in combination a screen grid vacuum tube, a band-pass wave filter having its input terminals connected to the anode and cathode respectively of said vacuum tube, and a utilization circuit connected to the output terminals of said filter, said filter including in at least one of its branches a piezo-electric crystal and having an inductance effectively in shunt to said crystal, said crystal and said inductance being proportioned with respect to the other elements of said filter to provide a single transmission band between preassigned frequencies and a characteristic impedance within said band substantially equal to the internal space path resistance of said vacuum tube.

3. An amplifier for signal modulated high frequency currents comprising in combination a pair of thermionic space discharge tubes each having a cathode, an anode, a control grid, and a screen grid, and a band-pass filter having its input terminals connected to the anode and cathode of one of said tubes and its output terminals to the cathode and control electrode of the second of said tubes, said filter comprising a plurality of impedance branches at least one of which includes a piezo-electric crystal, and an inductance effectively in shunt to said crystal, said crystal and said inductance being proportioned with respect to the other elements of said filter to provide a single pass-band between preassigned frequencies and a characteristic impedance substantially equal to the internal space path resistance of said vacuum tubes.

4. In combination with an amplifying stage comprising a screen grid vacuum tube, a band-pass wave filter having its input terminals connected to the output terminals of said amplifying stage, said filter comprising a plurality of impedance branches each including a piezo-electric crystal and arranged to form a symmetrical lattice network, an inductance effectively shunting each of said crystals proportioned to cooperate therewith to provide a single transmission band between preassigned frequencies and to make the characteristic impedance of said filter substantially equal to the internal space path impedance of said amplifying stage at the frequencies of the transmission band.

5. A combination in accordance with claim 4 in which the shunting inductances of the filter comprise equal inductances connected respectively between the input and the output terminals of the lattice.

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