June 17, 1941. N. M. RUST 2,245,722

COUPLING NETWORK

Filed April 12, 1939

Fig. 1

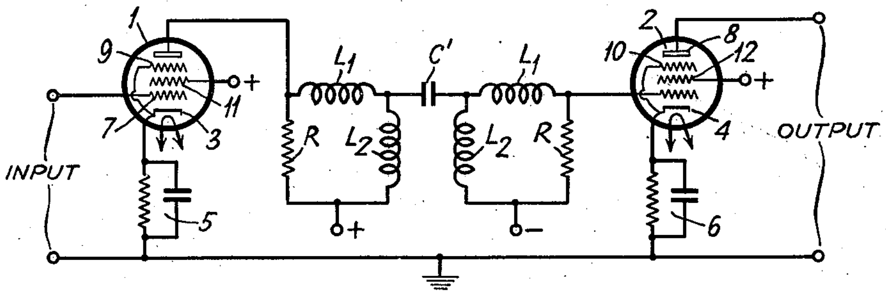
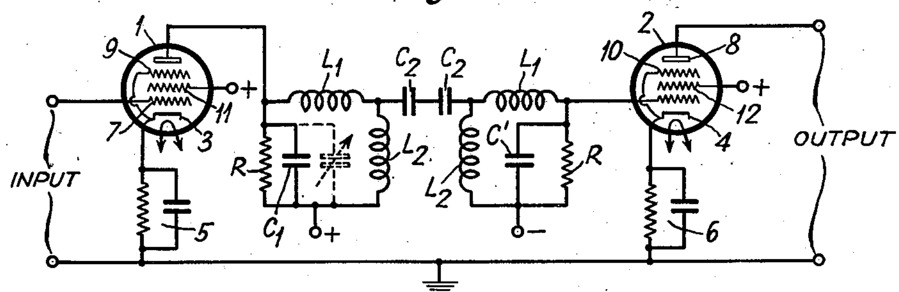


Fig. 1a



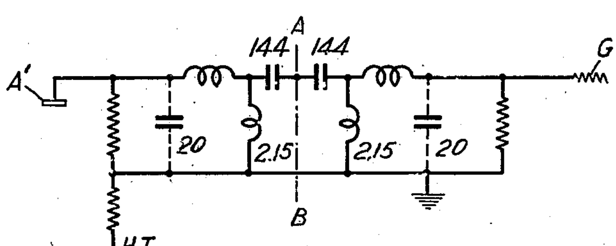


Fig. 2a

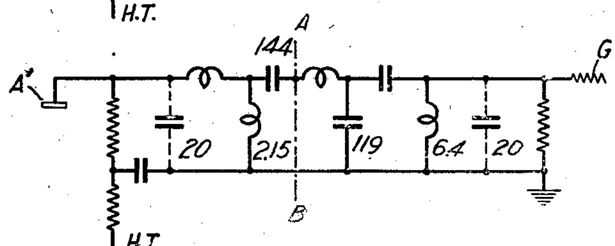


Fig. 2b

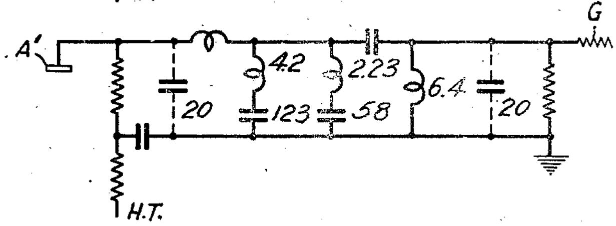


Fig. 2c

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Patented June 17, 1941

2,245,722

UNITED STATES PATENT OFFICE

2,245,722

COUPLING NETWORK

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Application April 12, 1939, Serial No. 267,384
In Great Britain April 14, 1938

3 Claims. (Cl. 179—171)

This invention relates to electrical networks suitable for use as inter-stage coupling networks in electron-discharge tube amplifiers and has for its main object to provide improved amplifiers of substantially uniform response over a wide frequency range, adapted for use at high frequencies, and of relatively high amplification having regard to the performance in other respects. The invention is of wide application but two important applications are (1) to video signal amplifiers in high fidelity television apparatus and (2) to high frequency amplifiers.

At the present time whenever an amplifier of substantially uniform response over a wide frequency range and/or for amplifying very high frequencies is required, it is customary to resort to resistance-capacity coupling between the stages. This type of coupling, however, has serious defects and limitations as follows:

1. With increase in the frequency the effect of stray capacities (effectively in shunt across the anode and grid resistances) becomes increasingly important and this puts a limit upon the performance at high frequencies, the limit depending upon the relationship between the values of the stray capacities and the values of the resistances.

2. With decrease in the frequency the impedance of the coupling condenser becomes increasingly important and imposes a low frequency limitation which is governed by the relationship between the value of the coupling condenser and the values of the resistances.

The present invention seeks to reduce or avoid these limitations and defects.

According to this invention an electrical network, suitable for use as an inter-stage coupling network in an electron discharge tube amplifier, is a four terminal network having an input terminal and an output terminal effectively common and comprises two resistances one between the input terminals and the other between the output terminals, an inductance in shunt across each resistance and a coupling condenser connected between a tapping point on one inductance and a tapping point on the other. As will be appreciated each of the inductances thus comprises in effect, a series coil (on one side of the tapping point thereon) and a shunt coil (on the other) and the provision of these coils enables the above mentioned defects to be largely overcome thus permitting the use of higher resistance values than would be possible were the coils not provided and therefore higher amplification. It is broadly true to say that the series coils, in conjunction with the stray capacities (in effect across the resistances) increase the response at higher frequencies, while the shunt coils compensate for low frequency losses due to the high impedance of the coupling condenser at low frequencies. The values of the series coils should be properly selected with regard to the stray capacities and the values of the shunt coils should be selected in relation to the coupling condenser with regard to the upper and lower frequency limits required. A convenient design technique will be described later herein.

The invention is illustrated in and further explained in connection with the accompanying drawing, wherein Fig. 1 illustrates diagrammatically one embodiment of the invention as applied to an amplifier for long and medium broadcast wave bands, Fig. 1*a* is the electrically equivalent circuit of Fig. 1, and Figs. 2*a*, 2*b* and 2*c* illustrate the design development of a coupling network according to the invention.

Referring now to Fig. 1, the amplifier comprises two pentodes **1**, **2** each having its cathode **3** or **4** earthed through the usual capacity shunted bias resistance combination **5** or **6**. Input is applied between the first grid **7** of the pentode **1** and earth and output is taken from between the anode **8** of the pentode **2** and earth. The suppressor grids **9** and **10** are connected to their respective cathodes and the screen grids **11** and **12** are positively biased as in the customary way. The network between the two stages is in accordance with this invention and, in describing the network, reference letters which identify individual elements and also represent their values, will be used in order to facilitate understanding of the design description to be given later. The coupling network comprises an inductance L1 in series with a condenser C′ in series with another inductance L1 in series in the order stated between the anode of the first valve and the first grid of the second. The positive terminal of a source of anode potential is connected to the anode of the first pentode through a resistance R and is also connected to the anode side of the condenser C′ through an inductance L2. A source of grid bias is connected to the first grid of the second pentode through a resistance R and also to the grid side of the condenser C′ through a second inductance L2. The condenser C′ may, for theoretical purpose, be regarded as consisting of two condensers C2 in series each equal to 2C′ and the stray capacities may be regarded as consisting of two condensers C1 connected across the respective resistances R at the anode of the first valve and the control grid of the second. This is shown by Figure 1*a* which is the electrically equivalent circuit of Figure 1. In some cases a small "trimmer" condenser (shown in broken lines in Figure 1*a*) may be used to supplement one of the condensers C1 but this will usually not be required.

This network may be regarded as a back-to-back compound line impedance transformer made up of two similar compound sections terminated (by resistances R) at both ends. Since a pentode is a high impedance valve a separate anode resistance R is connected between the anode of the first valve and the source of anode potential but if the first valve were a triode or other valve of internal impedance R the separate anode resistance could be omitted. Similarly, as regards the grid termination, if the operating frequency were so high that the grid impedance was (due to electron transit time effects) low enough, a separate grid terminating resistance R could be dispensed with.

Assume the above described amplifier to be required to operate over a frequency range of 150 k. c.–1500 k. c. the log. mid-band frequency (Fo) being thus 474 k. c. The recommended method of design is as follows: Taking the first section comprising L1 C1 C2 and L2 and writing ja for L1; jb for C1;

$$-j\frac{a}{c}$$

for C2; and $-jbc$ for L2 and assuming that C1 is 20 micro-micro-farads we have

$$b=20\times10^{-12}\times2\pi\times474\times10^{3}=.0000596$$

Take the upper limiting frequency (Fc2) as 1530 k. c. and the lower (Fc1) as 144 k. c.

Then

$$\frac{Fc1}{Fo}=3.3\gamma=10\therefore ab=.1$$

and

$$C=\frac{1}{.9}=1.111$$

Match the sections at

$$\frac{F}{Fo}=3.05 \quad B=6$$

(matching frequencies 155 k. c. and 1450 k. c.)

$$a=\frac{ab}{b}=\frac{.1}{.0000596}=1675$$

$$L_1=\frac{a}{2\pi Fo}=\frac{1675}{2\pi\times.474}=563 \text{ micro-henries.}$$

$$A=\frac{a}{bc}=2.53\times10^{7}$$

Zob (the characteristic impedance looking in to jb) =

$$\sqrt{AB}=\sqrt{2.53\times10^{7}\times6}=12{,}300 \text{ ohms}$$

$$\therefore R=12{,}300 \text{ ohms}$$

$$\frac{a}{c}=1510\therefore C2=.000222$$

$$bc=.0000596\times1.11\therefore L2=5{,}050 \text{ microhenries.}$$

It may be shown that at the matching frequencies of 155 and 1450 k. c. and at the mid-band frequency (474 k. c.) the gain is quite close to that given by a straight resistance-capacity coupling network with anode and grid resistances each equal to 12300 ohms but without loss due to stray capacity. The deviation in gain between the limits should, at its worst, not exceed about 2 decibels. Some difficulty may, no doubt, be experienced in realising the inductance L2 at 5050 micro-henries but departure from the theoretical as respects the value of this component is not seriously disadvantageous and results only in a little asymmetry in the gain-frequency characteristic. Care should be taken to avoid self-capacity in L1 and to reduce it as far as conveniently practicable in L2.

In the above described method of design the significance of the symbols employed is at follows:

a=impedance of series arm at log mid band frequency
b=admittance of shunt arm at log mid band frequency
c=internal impedance ratio

and the formulae used are as follows:

$$C=\frac{1}{1-ab}$$

$$A=\frac{ac}{b}=\frac{a}{bc}=Zoa.Zob=Z_0^2$$

where Zoa is the image impedance from the low impedance end of the section, and Zob is the image impedance from the high impedance end of the section and Zo is the geometric mean impedance.

$$B=\frac{C}{1-ab\gamma}=\frac{Zob}{Zoa}$$

$$\text{Tanh }\theta=\sqrt{\frac{-ab\delta}{1-ab\gamma}}$$

where

$$\delta=\left(\frac{F}{Fo}-\frac{Fo}{F}\right)^2$$

$$\gamma=\left(\frac{F}{Fo}\right)^2+\left(\frac{Fo}{F}\right)^2-1$$

$$Zoa=\sqrt{\frac{A}{B}}$$

$$Zob=\sqrt{AB}$$

at Fc

$$ab\gamma=1$$

or

$$\gamma=\frac{1}{ab}$$

A television I. F. amplifier for one video side band was constructed to the same circuit as above described. The single side band range was 1.5 megacycles, the mid-band frequency being 5.3 megacycles so that the band was 5.3±.75 megacycles. The valves were pentodes with a mutual conductance of 3 milli-amperes per volt and the following component values were used:

L1=56 micro-henries each
R=7000 ohms each
L2=4.5 micro-henries each
C′=.03108 micro-farads

The gain realised was over 10 per stage.

In some cases it may be required for the attenuation outside the pass range and adjacent the cut off frequencies to increase as rapidly as possible, e. g. to eliminate a strong interfering signal adjacent the desired frequency spectrum. This may be achieved by so designing the shunt arms of the network (other than shunt arms representing shunt capacities due to valves and strays) to be series resonant at the unwanted frequency or frequencies or, in general, at frequencies just outside the cut-off frequencies. In such a case the values of the inductance and capacity in each series-resonant shunt arm is so chosen that the net reactance at the log-mid-frequency are as required by the above described design principles. Figures 2*a*, 2*b* and 2*c* illustrate the design development of such a network with series resonant shunt arms from what may be termed the "prototype" network, Figure 2*a* showing the prototype, Figure 2*b* an equivalent circuit and Figure 2*c* the final network. For the sake of simplicity in description actual values of inductance, capacity and resistance are indicated in these figures in micro-henries, micro-micro-farads and ohms respectively.

It will be understood, however, that these figures are given only for the particular filter chosen by way of example.

The prototype filter of Figure 2*a* has a log mid-frequency of 10 megacycles and a band width of ± 2 megacycles. The shunt capacities of 20 $\mu\mu$fds. include valve capacities and "strays."

It will be seen that the two halves of the filter are symmetrical about the line AB each half constituting a "compound" section, the two sections being "back-to-back."

Now if the shunt arms—each of 2.15 micro-henries—are to be replaced by series resonant arms, one of which is to be tuned above the upper cut-off frequency, (say to 14 Mc) and the other below the lower cut-off frequency, (say 7 Mc) then at the log mid-frequency of 10 Mc, the 14 Mc arm will appear as a capacity reactance, whilst the 7 Mc arm will appear as an inductive reactance. The equivalent prototype structure therefore assumes the form shown in Figure 2*b*, where the sign of each reactance to the right of line AB is changed from the corresponding one in Figure 2*a* but retains the same numerical value. Here the shunt inductance of 6.4 μH. is of such reactance at 10 Mc, that taken in parallel with the 20 $\mu\mu$f. capacity due to the valve and strays, the resultant reactance will be equal to that of 20 $\mu\mu$f., but of opposite sign (i. e. positive).

In Figure 2*c* the shunt arm comprising 4.2 μH. in series with 123 $\mu\mu$f. is resonant at 7 Mc, and at 10 Mc its reactance is equal to that of a 2.15 μH. inductance. Similarly, for the other series resonant arm, comprising 2.23 μH. in series with 58 $\mu\mu$f., the resonant frequency is 14 Mc, and at 10 Mc its reactance corresponds to a capacity of 119 $\mu\mu$f.

It will be noticed that the two series reactances given by the two 144 $\mu\mu$f. condensers in Figure 2*a* have been replaced in Figure 2*b* by two equal and opposite reactances and therefore cancel out, so that no corresponding reactance is shown in Figure 2*c*.

In Figures 2*a*, 2*b* and 2*c* A′ represents the anode of valve **1** and G the control grid of valve **2**.

I claim:

1. A coupling network between a pair of vacuum tubes for extending the frequency range in which uniform amplification is obtained over that obtainable with the conventional resistance-capacity coupling network, comprising a resistance connected in the anode circuit of the first tube, a second resistance connected in the grid circuit of the second tube, a first inductance, a coupling capacity and a second inductance connected between the anode side of the first resistance and the grid side of the second resistance, and a pair of additional inductances, one connected between the low potential end of the first resistance and the junction between the first inductance and the coupling condenser, and the other connected between the low potential end of the second resistance and the junction between the second inductance and the coupling condenser.

2. A coupling network as defined in claim 1 wherein the first and second inductances in combination respectively with the stray capacities of the plate and grid resistances have the effect of increasing the response at the high frequency end of the range and the additional inductances have the effect of increasing the response at the low frequency end.

3. In a resistance-capacity coupled amplifier, an interstage coupling network comprising in combination, an output anode resistor, an input grid resistor, an inductance connected in shunt across each of said resistors, and a coupling condenser connected between an intermediate point on one of the inductances and an intermediate point on the other inductance, said inductances being subdivided by said points of connection that the portions which together with the coupling condenser are serially connected between the high potential ends of the anode and grid resistors combine with the stray capacities effectively in shunt across the anode and grid resistors to increase the response at high frequencies, and the remaining inductance portions have such values relative to the coupling condenser as to increase the response at low frequencies.

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