LADDER-TYPE BAND-PASS FILTER END SECTIONS

Filed April 20, 1967 2 Sheets-Sheet 1

FIG. 1A

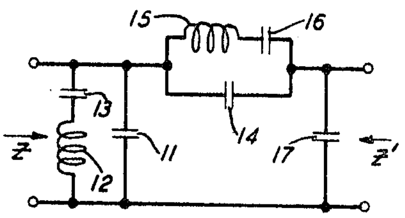

FIG. 2A

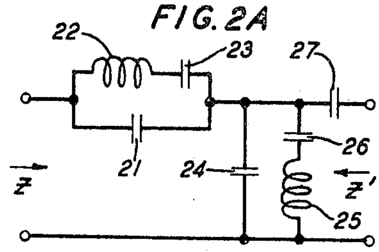

FIG. 1B

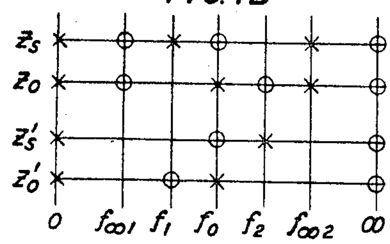

FIG. 2B

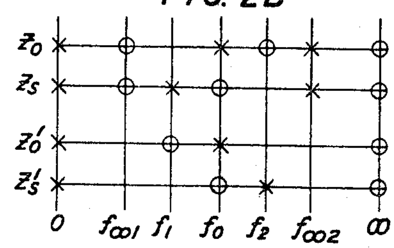

FIG. 3A

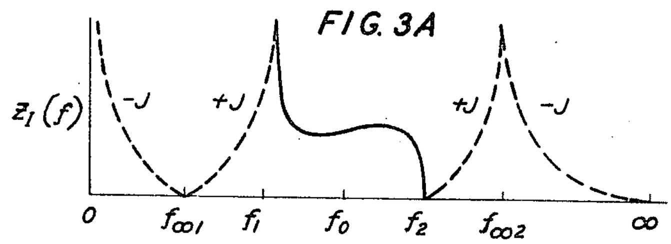

FIG. 3B

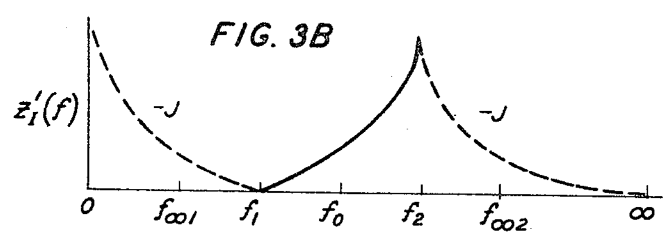

FIG. 3C

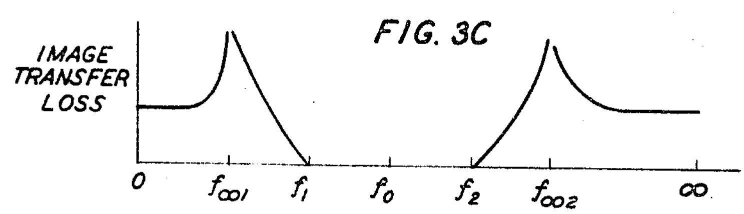

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FIG. 4

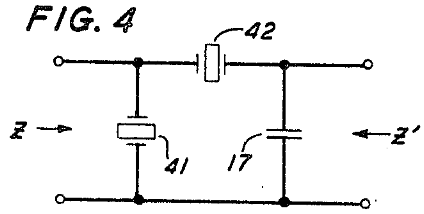


FIG. 5

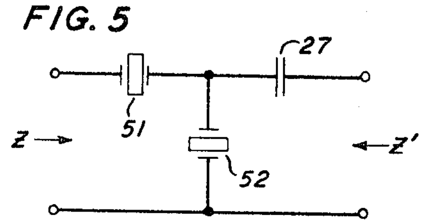


FIG. 6A

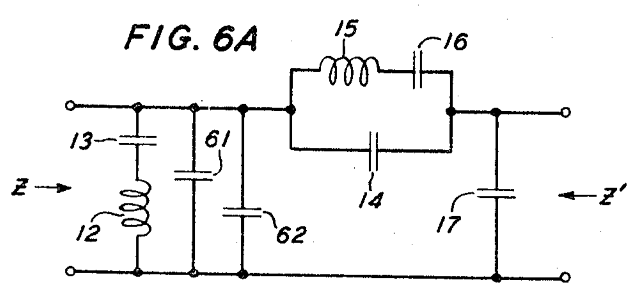


FIG. 6B

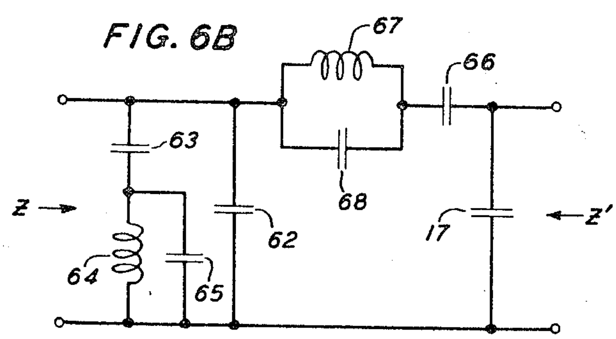
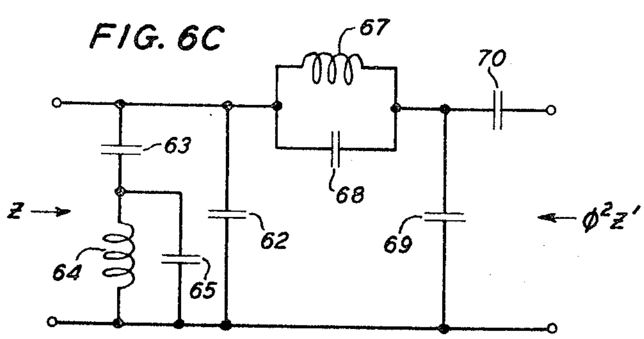


FIG. 6C



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LADDER-TYPE BAND-PASS FILTER END SECTIONS

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U.S. Cl. 333—72 7 Claims

ABSTRACT OF THE DISCLOSURE

An end section for high frequency band-pass filters minimizes ripple in the pass band response and has either a Π-type or a T-type configuration in which the outer arm on the terminating side is a capacitance shunted by the series combination of an inductance and a capacitance, the interposed inner arm is a capacitance shunted by the series combination of an inductance and a capacitance, and the outer arm on the other side is a capacitance. The impedance relationships of the three arms are defined by the pole-zero pattern of the open and short circuit impedance at both sides of the end section.

BACKGROUND OF THE INVENTION

This invention relates generally to band-pass filters and more particularly to high frequency band-pass filter end or terminating sections.

Separately designed end sections are normally used in multisection filters because image impedance tend to vary widely with frequency within the pass bands of most filter sections. In the past, half or L-type filter sections having the same pass bands as the full filter sections with which they are used have been employed as end sections to provide reasonable matches to resistive loads. Such end sections have not been completely successful, however, in minimizing pass band ripple at their terminating sides because of their inability to control their terminating side image impedances closely at both upper and lower edges of the pass band while still affording an opportunity for absorbing parasitic capacities into existing circuit components.

The principal object of the invention is to minimize the pass band ripple and simultaneously permit parastic capacity correction in a high frequency band-pass filter end section by controlling the terminating side image impedance closely at both upper and lower edges of the pass band.

Another and more particular object is to do so in as simple a manner as possible and with favorable component impedance values.

SUMMARY OF THE INVENTION

In accordance with the invention, an end or terminating band-pass filter section is given a ladder configuration with first and second outer arms and an inner arm interposed between the two outer arms and the impedance relationships of the three arms are defined by the short circuit impedance at opposite sides of the filter section having a common resonant frequency within the pass band and different antiresonant frequencies at respectively opposite edges of the pass band, the open circuit impedances at opposite sides of the filter section having a common antiresonant frequency within the pass band at the common resonant frequency at the short circuit frequencies and different resonant frequencies at respectively opposite edges of the pass band, and the open and short circuit impedances at the terminating side of the filter section having a common resonant frequency below the pass band and a common antiresonant frequency above the pass band.

In accordance with a particular feature of the invention, the first outer arm of the filter section takes the for of a capacitance shunted by the series combination of an inductance and a capacitance, the second outer arm takes the form of a capacitance and the interposed inner arm takes the form of a capacitance shunted by the series combination of an inductance and a capacitance. The resulting end section has a minimum amount of ripple within the pass band, the terminating side image impedance is closely controlled at both upper and lower edges of the pass band, and favorable component impedance values may be employed throughout. The several circuit configurations possible are, moreover, readily realizable for small bandwidth to center frequency ratios with only capacitors and piezoelectric crystals, thus permitting the end section to be fabricated readily in integrated circuit form. For larger bandwidth to center frequency ratios, conventional lumped constant circuit components may be used.

In one important embodiment of the invention, the ladder configuration takes the form of a Π-type section and is particularly advantageous in that it is susceptible of modification to permit parasitic capacitances to be absorbed into existing circuit capacitors. In another significant embodiment, the ladder configuration takes the form of a T-type filter section in which the outer arms are series arms and the inner arm is an interposed shunt arm.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1A is a schematic diagram of an embodiment of the invention in the form of a Π-type band-pass filter end section using lumped constant inductors and capacitors.

FIG. 1B is a diagram showing the significant resonant and antiresonant frequencies of the open end short circuit impedances of the embodiment of the invention shown in FIG. 1A.

FIG. 2A is a schematic diagram of an embodiment of the invention in the form of a T-type band-pass filter end section using lumped constant inductors and capacitors.

FIG. 2B is a diagram showing the significant resonant and antiresonant frequencies of the open and short circuit impedances of the embodiment of the invention shown in FIG. 2A.

FIGS. 3A, 3B, and 3C are curves showing the manner in which the image impedances and image transfer losses of the embodiments of the invention shown in FIGS. 1A and 2A vary with frequency.

FIGS. 4 and 5 are schematic diagrams of narrow band embodiments of the invention in which the respective embodiments of FIGS. 1A and 2A are realized entirely with capacitors and piezoelectric crystals.

FIGS. 6A, 6B, and 6C are schematic diagrams showing how the embodiment of the invention illustrated in FIG. 1A may be modified to absorb all parasitic capacitances into existing circuit capacitors.

DETAILED DESCRIPTION

The embodiment of the invention illustrated in FIG. 1A is a Π-type band-pass filter end section made up of a pair of shunt arms and an interposed series arm. The shunt arm at the left or terminating side of the end section contains a capacitor **11** shunted by the series combination of an inductor **12** and a capacitor **13**. The interposed series arm includes a capacitor **14** shunted by the series combination of an inductor **15** and a capacitor **16**. The shunt arm at the right, facing the main body of the band-pass filter with which the end section is used, is merely a capacitor **17**. As shown, the impedance of the end section at the terminating side is represented by Z, while that at the other side is represented by Z′.

The relationships between the various impedance elements of the three arms in the embodiment of the invention shown in FIG. 1A are defined by the pole-zero plot shown in FIG. 1B, where Z_s and Z_o represent the short-circuit and open-circuit impedances, respectively, at the left or terminating side of the end section and Z_s' and Z_o' are the short-circuit and open-circuit impedances, respectively, at the other side. On all four lines of the figure, the abscissa is frequency, a pole or antiresonance is represented by the symbol *x*, and a zero or resonance is represented by the symbol *o*. As illustrated, all four quantities have poles at zero frequency and zeros at infinite frequency. Z_s has zero at $f_{\infty 1}$, a frequency below the pass band of the end section, and a pole at f_1, the lower edge of the pass band. Z_s also has a zero at f_0, a frequency within the pass band, and a pole at $f_{\infty 2}$, a frequency above the pass band. Z_o has a zero at $f_{\infty 1}$, a pole at f_0, a zero at f_2, the upper edge of the pass band, and a pole of $f_{\infty 2}$. Z_o' has zero at f_1 and a pole at f_0 and Z_s' has a zero at f_1 and a pole at f_0.

The embodiment of the invention illustrated in FIG. 2A is the T-type equivalent of the Π-type band-pass filter end section shown in FIG. 1A and, as shown, includes a pair of series arms and an interposed shunt arm. The series arm at the left or terminating sides of the end section contains a capacitor **21** shunted by the series combination of an inductor **22** and a capacitor **23**. The interposed shunt arm includes a capacitor **24** shunted by the series combination of an inductor **25** and a capacitor **26**. The series arm at the right, facing the main body of the band-pass filter with which the end section is used, is a capacitor **27**. As in FIG. 1A, the impedance of the end section at the terminating end is represented by Z, while that at the other end is represented by Z′.

The relationships between the various impedance elements of the three arms in the T-type filter section shown in FIG. 2A are defined by the pole-zero plot shown in FIG. 2B, where the symbol meaning is the same as in FIG. 1B. As illustrated in FIG. 2B, all four quantities have poles at zero frequency and zeroes at infinite frequency. Z_o has zero at $f_{\infty 1}$, a pole at f_0, a zero at f_2, and a pole at $f_{\infty 2}$. Z_s has a zero at $f_{\infty 1}$, a pole at f_1, a zero at f_0, and a pole at $F_{\infty 2}$. Z_o' has zero at f_1 and a pole at f_0 and Z_s' has a zero at f_0 and a pole at f_2.

The embodiments of the invention illustrated in FIGS. 1A and 2A have the same image impedances at both sides and have the same image transfer loss. Comparison of their pole-zero plots shows that, in both, the short-cricuit impedances at opposite sides of the end section have a common zero or resonant frequency at f_0 and different poles or antiresonant frequencies at f_1 and f_2, the opposite edges of the pass band. Similarly, in both, the open circuit impedances at opposite sides of the end section have a common pole or antiresonant frequency at f_0 and different zeroes or resonant frequencies at f_1 and f_2. Finally, in both, the open and short circuit impedances at the left-hand or terminating side of the end section have a common zero or resonant frequency at $f_{\infty 1}$ and a common pole or antiresonant frequency at $f_{\infty 2}$.

The image impedance at the left or terminating sides of the embodiments of the invention shown in FIGS. 1A and 2A is shown in FIG. 3A. As shown, this image impedance, represented by Z_I, is a negative reactance between zero frequency and $f_{\infty 1}$ and descends in magnitude from infinity to zero. There is a positive reactance between $f_{\infty 1}$ and f_1 and increases in magnitude from zero to infinity. Z_I is resistive between $f_1$and f_2 and descends rapidly in magnitude above f_1 from infinity to a value which holds with relatively little deviation through f_0 to a frequency approaching f_2. From that point, Z_I drops rapidly to zero. Z_I is a positive reactance and goes from zero to infinity in magnitude from f_2 and $f_{\infty 2}$. Z_I is a negative reactance above $f_{\infty 2}$ and decreases in magnitude from infinity and approaches zero at infinitely high frequencies.

The effect of the present invention in minimizing pass band ripple at the terminating side of the end sections shown in FIG. 1A and FIG. 2A is clearly illustrated in FIG. 3A. The degree to which the magnitude of Z_I is flat with frequency from a frequency just above f_1 to a frequency just below f_2 depends primarily upon the location of $f_{\infty 1}$ and $f_{\infty 2}$ with respect to f_1 and f_2. In this manner, the invention affords close control of the image impedance at the terminating side of the end sections at both edges of the pass band rather than at only one as afforded by much of the prior art. At the same time, the invention permits ready attainment of this result with a relatively simple circuit configuration and with relatively favorable component impedance values.

The image impedance at the other sides of the embodiments of the invention shown in FIGS. 1A and 2A is illustrated in FIG. 3B. As shown, this image impedance, represented by Z_I', is a negative reactance between zero frequency and f_1 and descends in magnitude from infinity to zero. It is resistive between f_1 and f_2 and increases from zero to infinity. Above f_2, Z_I' is a negative reactance dropping from infinity at f_2 until it approaches zero at infinitely high frequencies. This characteristic produces an exact match to the image impedances of most full band-pass filter sections with which the end sections are likely to be used.

The manner in which the image transfer loss of the embodiments of the invention shown in FIGS. 1A and 2A varies with frequency is illustrated in FIG. 3C. As shown, there are loss peaks at $f_{\infty 1}$ and $f_{\infty 2}$. There is minimum loss in the pass band from f_1 to f_2.

Although band-pass filter end sections embodying the invention are shown in FIGS. 1A and 2A as they may be realized for broad band applications with lumped constant inductors and capacitors, they may be realized with capacitors and piezoelectric crystals as well for high frequency applications requiring relatively narrow pass bands. Such end sections are particularly well suited for fabrication in integrated circuit form.

FIG. 4 illustrates an embodiment of the invention which is an all crystal and capacitor equivalent of the Π-type end section shown in FIG. 1A. Since the lumped constant equivalent circuit of a piezoelectric crystal is simply a capacitor shunted by the series combination of an inductor and another capacitor, the left or terminating side shunt arm in FIG. 4 is a piezoelectric crystal **41** and the interposed series arm is a piezoelectric crystal **42**. The shunt arm on the other side is, as before, simply a capacitor **17**. The relationships between the impedances in the various arms of the embodiment of the invention shown in FIG. 4 are defined by the pole-zero plot illustrated in FIG. 1B.

FIG. 5 illustrates an embodiment of the invention which is an all crystal and capacitor equivalent of the T-type end section shown in FIG. 2A. The left or terminating side series arm in FIG. 5 is a piezoelectric crystal **51** and the interposed shunt arm is a piezoelectric crystal **52**. The series arm on the other side is, as in FIG. 2A, simply a capacitor **27**. The relationships between the impedances of the various arms of the embodiment of the invention shown in FIG. 5 are given by the pole-zero plot of FIG. 2B.

A significant additional advantage of the embodiment of the invention illustrated in FIG. 1A is that the schematic diagram is susceptible of modification to absorb parasitic capacities into the capacities of actual circuit capacitors. The manner in which this may be done is shown in FIGS. 6A, 6B, and 6C. These figures represent three successive steps of modification and involve only simple Norton transforms.

In FIG. 6A, capacitors **11** in FIG. 1A has been replaced by two parallel capacitors **61** and **62**. Nothing else has been changed. FIG. 6B shows the next step in the modifications, where each capacitor shunted by the series combination of an inductor and a capacitor has been replaced by a capacitor in series with the parallel combination of an inductor and a capacitor. Thus, the combination of capacitor **61** shunted by the series combination of inductor **12** and capacitor **13** has been replaced by the combination of capacitor **63** in series with the parallel combination of inductor **64** and capacitor **65**. Similarly, the combination of capacitor **14** shunted by the series combination of inductor **15** and capacitor **16** has been replaced by the combination of capacitor **66** in series with the parallel combination of inductor **67** and capacitor **68**. The final step in the transformation is shown in FIG. 6C, where the combination made up of shunt capacitor **17** to the right of series capacitor **66** has been replaced by the combination made up of a shunt capacitor **69** to the left of a series capacitor **70**. The impedance level at the right-hand side of the filter section is changed only by a scaling factor Φ^2.

As can be seen from an inspection of FIG. 6C, each important parasitic capacity of the end section as transformed appears in parallel with an actual circuit capacitor. The capacitive values of the circuit capacitors may, therefore, be fixed so that the final desired capacity values are provided by their own capacities in combination with the parasitic capacities. A higher order of accuracy in filter design than heretofore is thereby made possible.

I claim:

1. A band-pass ladder-type filter section having first and second outer arms, an inner arm interposed between said first and second outer arms, a single pass band, and single loss peaks both above and below said pass band in frequency wherein said first outer arm comprises a capacitance shunted by the series combination of an inductance and a capacitance, said second outer arm comprises a capacitance, said interposed inner arm comprises a capacitance shunted by the series combination of an inductance and a capacitance, the short circuit impedances at opposite ends of said filter section have a common resonant frequency within said pass band and different antiresonant frequencies defining respectively opposite edges of said pass band, the open circuit impedances at opposite ends of said filter section have a common antiresonant frequency within said pass band at the

common resonant frequency of the short circuit impedances and different resonant frequencies defining respectively opposite edges of said pass band, and the open and short circuit impedances at the end of said filter section formed by said first outer arms have a common frequency below said pass band and a common antiresonant frequency above said pass band.

2. A band-pass filter section in accordance with claim **1** which is a Π-type filter section and in which said outer arms are shunt arms and said inner arm is an interposed series arm.

3. A band-pass Π-type filter section in accordance with claim **2** in which the elements of said first shunt arm and said interposed series arm are lumped constant inductors and capacitors.

4. A band-pass Π-type filter section in accordance with claim **2** in which said shunt arm and said interposed series arm both comprise piezoelectric crystals.

5. A band-pass filter section in accordance with claim **1** which is a T-type filter section and in which said outer arms are series arms and said inner arm is an interposed shunt arm.

6. A band-pass T-type filter section in accordance with claim **5** in which the elements of said first series arm and said interposed shunt arm are lumped constant inductors and capacitors.

7. A band-pass T-type filter section in accordance with claim **5** in which said first series arm and said interposed shunt arm both comprise piezoelectric crystals.

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U.S. Cl. X.R.

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