SECTION 23. FILTER CIRCUITS

HIGH-PASS CIRCUITS.

APPLICATION.

High-pass filters are universally used in circuits where it is desired to pass the higher frequencies and to attenuate the lower frequencies below a selected cutoff frequency (f_o).

CHARACTERISTICS.

Resistance-capacitance-type filters are used only for audio frequencies, whereas inductance-capacitance-type filters are used for both audio and radio frequencies, and wherever sharp cutoff is required.

The higher the frequency above cutoff, the lower the attenuation; below the cutoff frequency the attenuation increases as the frequency decreases.

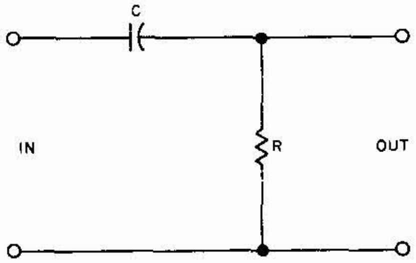
May be half-section, single-section, or multiple-section, with the multiple-section (ladder) type providing the greatest attenuation and sharpest cutoff.

May be of either the "constant $_k$" or "$_m$-derived" form, or combinations thereof.

CIRCUIT ANALYSIS.

General. A filter consists of a circuit containing a number of impedances grouped together in such a manner that it has a definite frequency response characteristic. It is designed to permit the passage (transmit) signals freely over a certain desired range of frequencies, and to attenuate (transmit poorly) over another range of frequencies. The frequency range over which the passage occurs freely is called the **pass band**, (or transmission band) and the range over which attenuation (poor transmission) occurs is called the **attenuation band.** The frequency at which the attenuation of the signal starts to increase rapidly is known as the **cutoff** frequency. The basic configurations into which the high-pass filter elements can be assembled or arranged are the **L** or **half-section,** the **T-section,** and the **pi**-section. The L-section consists of one series capacitive element and one parallel (shunt) element of either resistance or inductance, forming an inverted L (since two L-sections may be connected together to form a symmetrical T or pi-network it is referred to as a half-section). The T-section consists of two series capacitive arms and one shunt arm, resembling the letter T. The pi-section consists of one series capacitive arm with two shunt arms, resembling the Greek letter π. Several sections (or half-sections) of the same circuit configuration can be joined to improve the filter attenuation or transmission characteristic. When several sections are cascaded together, they form a **ladder** type of filter. When a filter is inserted into a circuit, it is usually terminated (matched) by a resistance of the same value at the input ends. The value of the terminating resistance is usually determined by the circuit with which the filter is used and the type of filter circuit employed. In some instances, circuit parts may be arranged basically in the form of a simple filter, even though it is not desired to provide such filter action initially. For example, the simple R-C coupling network in an audio amplifier grid circuit provides a high-pass filter effect with low-frequency cutoff, and creates a design problem because equal amplification of both the low and high frequencies is usually desired. The cutoff frequency of a filter is determined by the circuit configuration, type of filter (constant **k** or **m**-derived), and the values of the capacitors and resistors (or inductors) in the filter circuit. When the cutoff frequency is known, the values of the parts required to produce this response and the desired attenuation may be calculated mathematically by use of the proper formulas. This handbook will not be concerned with design data, but will show *the circuit configurations,* explain the circuit action, and provide information with which the technician can determine or recognize the type of filter and determine the cutoff frequency, if needed.

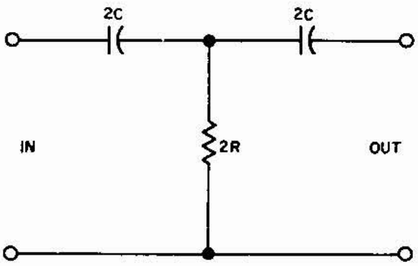
Circuit Operation. A typical *half-section R-C high-pass* filter is shown in the accompanying illustration.



Half-Section R-C High-Pass Filter

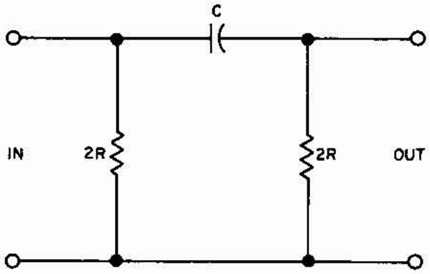
The simple high-pass filter shown in the figure is equivalent to an R-C coupling network *placed in the grid of an* amplifier stage. Note that the output voltage is taken across the resistor, and the capacitor is series-connected. The circuit is basically that of a voltage divider in which C forms the reactive arm and R the resistive arm. If the value is selected so that the capacitive reactance is equal to the resistance of resistor R at frequency f_1, then the output voltage of the network will be attenuated approximately 3 db with respect to the input voltage. This frequency is called the **theoretical cutoff frequency,** and its value is given by: $f_1 = 1/(2\pi R C)$ in cycles per second. The values of R and C are in ohms and farads (or in megohms and microfarads), and RC is the **time constant** in seconds. Thus, if the low-frequency response of an R-C-coupled amplifier is specified as having a time constant of, *for example, 2000 microseconds (which is sometimes done),* f_1 equals 80 cps (apply the values in the formula above and calculate). In the example, the theoretical cutoff frequency is approximately 80 cps, and since only a simple half-section filter is used the *cutoff is not sharp, but varies* directly with the capacitive reactance of C. However, with a sufficient number of cascaded filters of the proper value, it could be made reasonably sharp.

Consider now a T-section filter as illustrated in the accompanying figure.
This circuit arrangement forms a full-section which can be considered as two half-sections (L-sections) placed back to back with resistor R common to both.



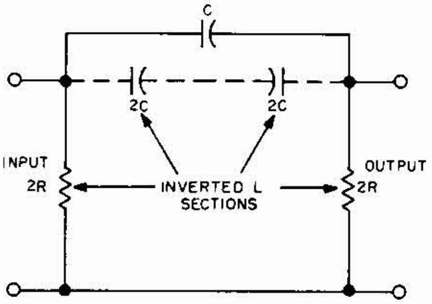
T-Section R-C High-Pass Filter

Note that in this circuit arrangement the two capacitors are connected in series; consequently, the design value of C is doubled. Likewise, the design value of R is also doubled since the two resistors are paralleled, thereby making the effective value of R that of the single L-section. The **T** arrangement provides a symmetrical input and output with the same time constant as the single section L-type filter. A typical pi-section filter network is shown in the accompanying figure.



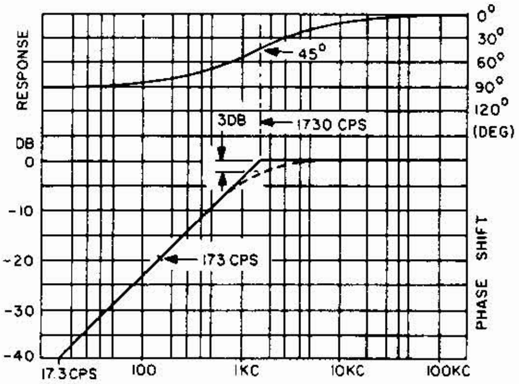
Pi-Section R-C High-Pass Filter

In this full-section arrangement the value of the resistive arms is, likewise, chosen to be double that of the half-section arrangement, and C is equal to the total value of the two series capacitors of the T-section arrangement. Development of the pi-section from two inverted L-section filters is illustrated in the following figure.
The values used are those of the basic half-section L-filter. Note that in any of the three previously shown filter arrangements the actual time constant values are identical. Therefore, the response and attenuation of each are also identical. L-sections are used where only a simple unbalanced input and output is needed. The T-and Pi-sections are used where balanced arrangements are required. Multiple-section filters are used to obtain greater phase shift and more attenuation. Thus, a two-section filter using identical values of parts will multiply the phase shift and attenuation by a factor of two. For complete design data refer to a standard text.



Development of Pi-Section Filter

In any of the filter arrangements previously discussed, the attenuation is assumed to be zero immediately above the cutoff frequency, f_0, and very large for frequencies below f_0, as shown in the following response graph.

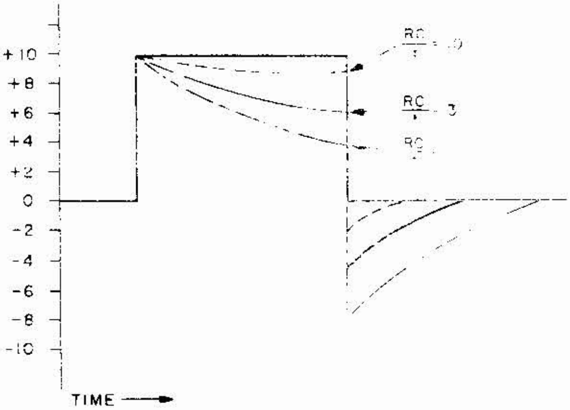


Phase and Amplitude Response Characteristics for High-Pass R-C Filter (f_0 = 1730 cps)

However, as can be seen from the chart, the attenuation (for a single-section filter) becomes relatively constant at about 12 db/octave (20 db per decade) at frequencies considerably below the cutoff frequency. The phase shift range from zero at the higher frequencies above f_0 to 45 degrees at f_0. Below the cutoff frequency the phase shift soon becomes constant at 90 degrees. The dotted line indicates how this typical Bode plot is rounded off to similate practical conditions. As a result, a 3-db difference exists between the actual and theoretical response at the cutoff frequency.

The effect of a high-pass filter on the response of a rectangular pulse is indicative of the action produced by this type of filter. Since the output voltage of the high-pass filter is taken from across the resistor which is in series with the capacitor and the input circuit, it is evident that before the pulse is applied, there is no charge in the capacitor and no current in the circuit. Therefore, no voltage output is obtained. Upon application of the rectangular pulse, the initial current is equal to E/R. Since the output voltage is equal to the current times the resistance, the output voltage also rises instantaneously to E. Thus the rise time in this circuit is maintained without any change. However, as the capacitor charges, the current through the resistance decreases; hence, the output voltage decreases. Eventually, the capacitor charges to the input voltage and the output voltage drops to zero.

The following figure shows the over-all response of a high-pass filter to a rectangular pulse of 15 microseconds duration with different time constant values (R times C).



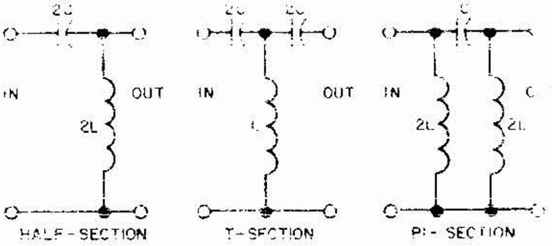
Typical Pulse Response Variation with Time Constant or Pulse Width Changes

From the previous paragraph it is clear that the rise time is unaffected, as shown in the figure. When the time constant is long with respect to the pulse duration, little effect on the pulse shape is obtained. For example, with a time constant of 150 microseconds in the filter, and a pulse of 15 microseconds time duration applied to the filter input, the output voltage will drop to only 0.9 of the input voltage, as shown by the dotted line in the figure (for an RC/t ratio of 10). On the other hand, when the pulse duration is equal to the time constant, the capacitor charges to approximately 63% of its full value and the current flow through the resistor is such as to produce an output voltage of only 0.37 that of the input (RC/t = 1 in the figure).

When the input voltage drops to zero at the end of the pulse duration period, the output voltage of the filter is equal to the voltage across the capacitor. For instance, in the previous example of the large time constant ratio of 10, the output voltage dropped to only 0.9 of the input. Therefore, a charge of 0.1E must exist on the capacitor at the end of the pulse. The capacitor voltage is negative with respect to the input voltage since it opposes the input voltage. Therefore, when the input voltage drops to zero, the output voltage drops to -0.1E, and the capacitor then discharges to zero volts. It is evident, then, that the greater the voltage drop across the capacitor at the end of the duration period of the pulse, the greater will be the negative voltage at the output of the circuit when the input pulse falls to zero.

Since R-C filters respond to the time constant of the circuit, it is evident that while filters of many sections can be used, the simple equivalent time constant of the entire network will basically determine the filter characteristics, and that really sharp cutoff cannot be obtained. With the use of L-C filter circuits, however, it is possible to produce the desired pass band with a much sharper cutoff and attenuation characteristics. Since both inductance and capacitance are used, a single-section L-C filter is capable of a 180-degree phase shift.

High-pass filter circuits using inductance and capacitance follow the same type of circuit configuration as do R-C filters, as shown in the following figure.

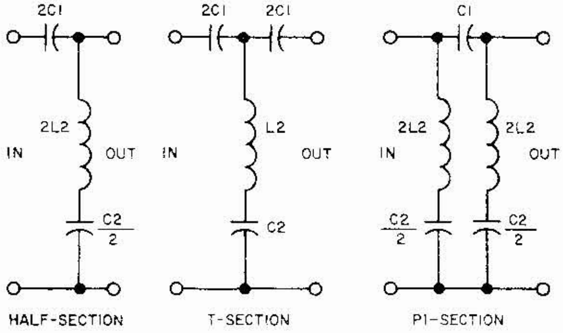


High-Pass L-C Filter Circuits

Basic filter theory stipulates that where reactances of the same sign (either all capacitance or all inductance) are used, the characteristic impedance presented by the filter to the input or output circuit is a reactance. On the other hand, where reactances of opposite sign are used (such as capacitance and inductance), the characteristic impedance becomes resistive over one range and reactive over another range. Thus the design and matching of filters becomes an engineering problem, and is treated on an ideal theoretical basis. This means that while a filter may be considered to have infinite rejection beyond a particular cutoff frequency, in practice the result may not be as great as predicted. Likewise, the cut-off frequency may not be as critical or as sharp as the design figures indicate.

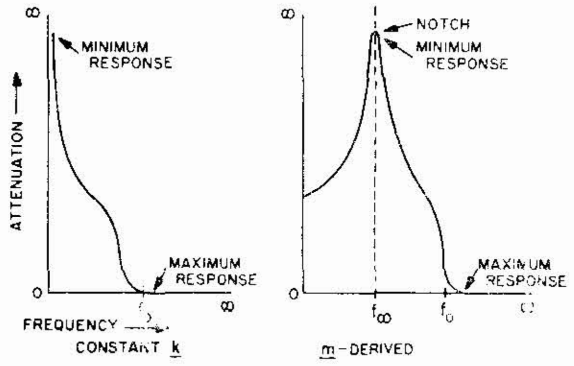
All the previously discussed filter arrangements are of the **constant k** type, which has a gradual rather than a sharp cutoff frequency. In this simple type of filter the series filter arm impedance, Z_1, and the shunt filter arm impedance, Z_2, are so related that their product is a constant at all frequencies ($Z_1 \times Z_2 = k^2$). Therefore, it derives its name from this relationship. This constant, in turn, is also equal to R^2, since Z_1 and Z_2 are reciprocal reactances (X_C and X_L, respectively), and $k^2 = L/C$. Thus, the formula for determining the cutoff frequency becomes: $f_c = 1/4\pi\sqrt{LC}$, where L and C are in henrys and farads, respectively.

A more complex form of high-pass filter circuit is the **m-derived** type. In this type the cutoff frequency is sharper and the total attenuation of the unwanted frequencies greater. Typical circuits of the series-connected, m-derived type are shown in the following illustration.



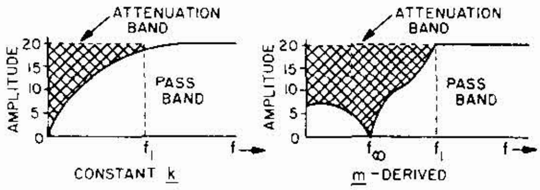
Series m-Derived High-Pass Filters

As can be seen from the illustration, a series-connected L-C network (L_2 C_2) is placed across the output or across the mid-termination of the filter circuit. As designed, this network is made series-resonant at a frequency below the usual cutoff frequency. For the high-pass filter this resonant frequency, called the **frequency of infinite attenuation** (f_∞), is selected at a value of about 0.8 f_0. Since f_∞ is resonant and is series-connected across the input or output, it represents a short circuit across the filter for the resonant frequency (with a pass band determined by the Q and resistance of the circuits). Therefore, the normally sloping attenuation characteristic which approximates 12 db/octave for the constant **k** filter is "notched" off. In effect, the m-derived filter is sharply separated from the frequencies below f_∞, and thereby provides sharper and better cutoff of the lower frequencies. The action described can be visualized clearly when the attenuation (response) characteristics for the two types of filters are compared, as shown in the following figure.



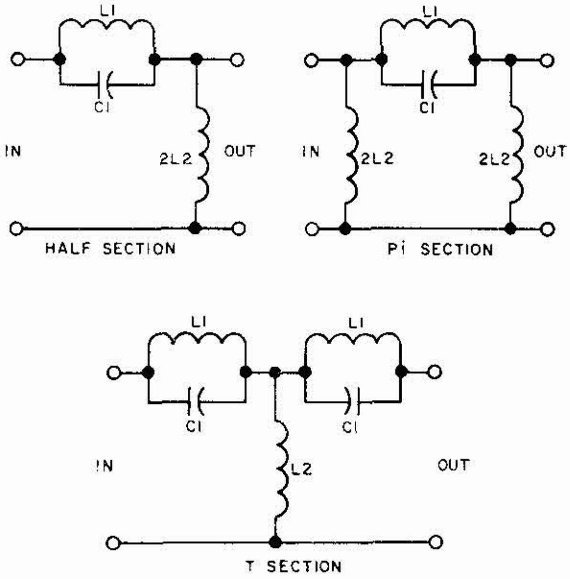
Comparison of Filter Attenuation Characteristics

While a constant attenuation is shown for the constant **k** type, with a reduced value of attenuation below f_∞ for the m-derived type, the sharpness of the m-derived cutoff at f_∞ (assuming zero circuit resistance at resonance) provides better high-pass performance, as illustrated below.



Comparison of Transmission Characteristics

The shunt-connected type of m-derived filter is shown in the following figure.



Shunt m-Derived High-Pass Filters

In the shunt-type filter, the high-pass action occurs by passage of the signal through the filter via capacitor C1 for those frequencies above f_∞, and by attenuation of the signal due to the action of the parallel resonant circuit of L_1C_1 at the infinite attenuation frequency, f_∞. In addition, since the inductive reactance of L_2 increases with frequency, the lower frequencies below f_0 are shunted across the output and lost. Since the parallel-resonant circuit of L_1C_1 represents a high impedance at resonance, frequencies around f_∞ (depending upon the circuit Q) are greatly attenuated and are prevented from passing through the filter. This type of operation is mostly used for the band-rejection type of filter, to be discussed later in this section.

In the **m**-derived filter, **m** is a design constant from which the filter gets its name. This constant basically represents a coupling factor, and appears in all the design formulas. It is some value less than 1, usually 0.6. Thus, the frequency of infinite attenuation is; $f_\infty = f_n\sqrt{1-m^2}$, which for a cutoff frequency of 7000 kc and an **m** of 0.6 is, by substituting values, $7000 \times \sqrt{1-0.36} = 7000 \times 0.8$, or 56000 kc. The cutoff frequency for the **m**-derived high-pass filter is: $f_n = 1 / (\pi\sqrt{LC})$.

In this case the value of **m** determines the final values of L and C. When the cutoff frequency and the frequency of infinite attenuation are known, **m** can be determined from the formula:

$$m = \sqrt{1 - \left(\frac{f_\infty}{f_n}\right)^2}$$

If the frequency values in the example above are substituted in this formula, it will be seen that **m** is 0.6, as selected above. When **m** is equal to 1, the **m**-derived filter and the constant **k** filter are identical. Values of **m** smaller than 0.6 move f_∞ closer to f_n (sharpen the cutoff), and values greater than 0.6 move f_∞ farther from f_n (broaden the cutoff).

In the schematic illustrations of the filter sections shown previously, various values of L and C are indicated. These indicators merely show that the design values of L and C as chosen are either that of the original value, or are multiplied by (or divided by) 2 to produce the proper total value for use in the configuration illustrated. This change of value is necessitated by the requirements for proper matching, and for the connection of cascaded filter sections to produce the desired performance. For example, when connecting two pi-sections together, the input and output inductors parallel the output and input inductors, respectively, of the next or preceding section. Since inductors in parallel have half the value of the original inductance, these networks normally use a value of 2L where more than a single section is to be connected in a ladder-type network. For further information, the interested reader is referred to standard textbooks on filter design.

FAILURE ANALYSIS.

Generally speaking, either the filter performs as designed or it does not. Any open or short-circuited condition of the individual parts can lead to one of three possibilities: the open part may cause a no-output condition; the short-circuited part may cause a no-output or a reduced-output condition; or the defective part may be located in a position in the circuit that markedly affects the filter cutoff frequency, pass band, or attenuation characteristics. Usually, all three of these last mentioned conditions are affected to some extent. Therefore, it becomes rather difficult to determine whether the filter is faulty and to spot the defective part with simple servicing techniques. In most instances, a check for continuity with an ohmmeter will indicate any open-circuited parts. In the case of the capacitors in the network, they can be checked with an in-circuit type of capacitance tester for the proper capacitance. Any short-circuited capacitor should be found during the resistance and continuity check. Where a low-frequency inductor is under suspicion, the resistance may be used as a guide; but when the resistance is so low that it is less than an ohm (as in high-frequency coils), the suspected coil must be disconnected and checked in an inductance bridge.

If a filter is suspected of operating improperly and the cutoff frequency is known (if not, it can be calculated approximately by using the formulas referenced in the preceding discussion of circuit operation), a pass band check can be made with an oscilloscope (and an r-f probe) and a signal generator. With the signal generator modulated and simulating the input signal, the output of the filter is observed on the oscilloscope (use the vertical height of the modulation supplied by the r-f probe as an indication of relative amplitude). For a high-pass filter, the height of the pattern should decrease rapidly as the cutoff frequency is passed (while reducing frequency), and the pattern should stay at approximately the same height for frequencies above cutoff. If such indications are obtained, the filter is probably operative, and some other portion of the associated circuit is at fault. If these indications are not obtained, the filter is definitely at fault, and each part must be individually checked for the proper value. Where a spare filter is available, it is usually easier to make a quick substitution of the entire filter to determine whether the performance changes; a change indicates a defective filter.

LOW-PASS CIRCUITS.

APPLICATION.

Low-pass filters are used in circuits where it is desired to pass only the lower frequencies and to attenuate any frequencies above a selected cut-off frequency.

CHARACTERISTICS.

Resistance-capacitance (RC) type filters are generally used for audio frequency applications, whereas inductance-capacitance (LC) types of filters are used for both audio and radio frequencies, particularly for wherever sharp cutoff is required.

The lower the frequency below cut off, the lower is the attenuation; above the cut-off frequency the attenuation increases as the frequency increases.

May consist of half-sections, single sections, or multiple sections, with the multiple-section type providing the greatest attenuation and the sharpest cutoff.

May be of either the "constant **k**" or "m-derived" form, or any combination thereof.

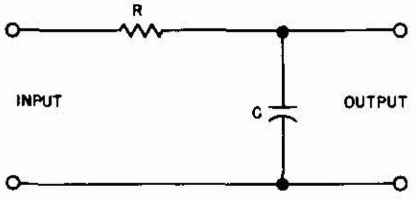
CIRCUIT ANALYSIS.

General. The low-pass filter circuit consists of resistance or inductance together with capacitance combined and connected in such a manner that they have a definite frequency response characteristic. The low-pass filter is designed to permit the passage of low frequency signals over a desired range of frequencies, and to attenuate the higher frequencies above this range. The frequency range over which the passage occurs is called the **pass band**, the range over which attenuation or poor transmission occurs is called the **attenuation band.** The frequency at which the attenuation of a signal starts to increase rapidly is known as the **cutoff frequency.** The basic configurations into which the low-pass filter elements can be assembled or arranged are the "L" or half-section, the "T" or full section, and the Pi type.

The L-section filter consists of one series resistor or inductor, and one parallel component of either resistance or capacitance. The T-type filter consists of two series inductors and one shunt resistance or capacitance. The Pi-type consists of one series inductor and two resistive or capacitive shunts, resembling the Greek letter π (pi) from whence it takes its name. Several sections (or half sections) of the same circuit configuration can be joined to improve the attenuation or transmission characteristics of the filter. When several sections are cascaded together, they form a **ladder** type of filter. When a filter is inserted into a circuit *it is usually terminated (matched) by a resistance or impedance* of the same value at the input end. The value of the terminating resistance or impedance is usually determined by the circuit with which the filter is used and the type of filter circuit employed.

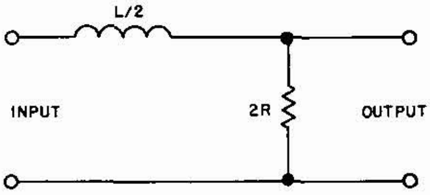
The cutoff frequency of a filter is determined by the circuit configuration, type of filter (constant **k** or **m**-derived), and the values of the inductors and resistors (or capacitors) in the filter circuit. When the cutoff frequency is known, the value of the parts necessary to produce this response and the desired attenuation may be calculated mathematically by the use of the proper formulas. This Handbook will not be concerned with design data, but will show the circuit *configuration, explain circuit action,* and provide information with which the technician can determine or recognize the type of filter and determine the cutoff frequency, if needed.

Circuit Operation. A typical half-section R-C low-pass filter is shown in the accompanying illustration.



Half-Section R-C Low Pass Filter

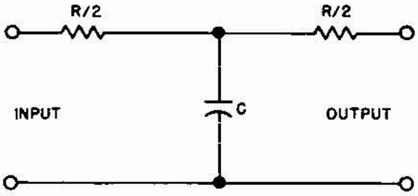
Note that the output is taken across the capacitor and the resistor is connected in series. The circuit is basically that of a voltage divider in which C forms the reactive part, and R the resistive arm. If the values are selected so that the capacitive reactance of C is equal to the resistance of R at frequency f_o, then the output voltage of the voltage divider network will be attenuated approximately 3 db with respect to that of the input voltage. This frequency is called the theoretical **cutoff frequency,** and its value is given by : $f_o = 1/2\,\pi\,RC$ in Hertz. The values of R and C are in ohms and farads (or in megohms and microfarads), and RC is the time constant in seconds. A similar half-section low-pass filter arrangement using inductance and resistance (R-L) is shown in the accompanying illustration.



Half-Section R-L Low Pass Filter

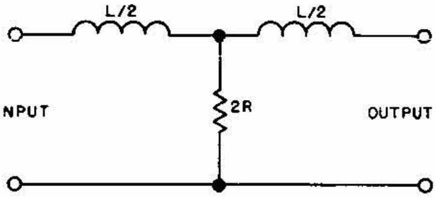
Note that in this instance the output is taken across the resistor and that the reactance is connected in series. The circuit also is a voltage divider in which L forms the reactive arm, and R the resistive arm. If the values are selected so that the inductive reactance of L is equal to the resistance of R at f_o, then the output voltage of the voltage divider will be attenuated approximately 3 db with respect to the input voltage. The theoretical frequency in this instance is found by the formula: $f_o = 2\,\pi\,RL$, in Hertz, with R and L in ohms and farads, and RL is the time constant in seconds.

Consider now a T-section filter as illustrated in the accompanying figure. This circuit arrangement forms a full section which can be considered as two half-sections (L sections) placed back to back.



T-Section R-C Low-Pass Filter

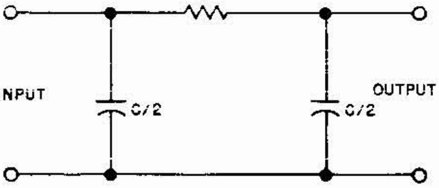
Note that in this circuit arrangement the two resistors are connected in series; consequently the design value of R is halved. Likewise, the design value of C is halved, since the two capacitors are paralleled thereby making the effective capacitance equal to the value of a single half section. The T-arrangement provides a symmetrical input and output with the same time constant as the single-section L-type figure. A typical T network using RL components is shown in the accompanying illustration.



T-Section R-L Low-Pass Filter

In this instance, since the inductors are in series, only half the inductance is used in each and, since the resistors are effectively in parallel, the half-section resistance value is multiplied by 2. The T section supplies a symmetrical input and output with a time constant equal to that of the single half-section.

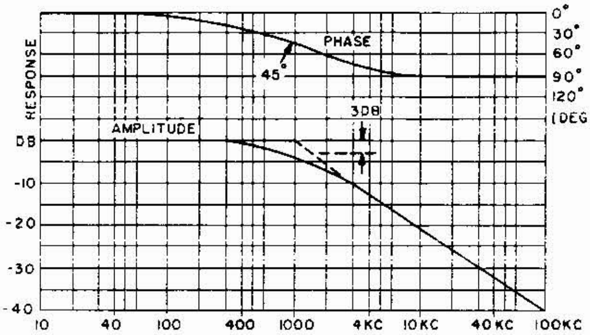
A typical pi-section filter network is shown in the accompanying diagram.



Pi-Section R-C Low Pass Filter

In this full section arrangement the value of the resistive arm is equal to the value of two half sections, while the value of the capacitor is half the total value. Note that in any of the previously discussed filter arrangements the actual time constant values are identical. Therefore, the response and attenuation of each are also identical. L-sections are used where only a simple unbalanced input and output is needed. The T- and Pi-sections are used where balanced arrangements are required. Multiple section filters are used to obtain greater phase shift and more attenuation. Thus, a two-section filter using identical values of parts will multiply the phase shift and attenuation by a factor of two. For complete design data refer to a standard text.

In any of the filter arrangements previously discussed the attenuation is assumed to be zero immediately below the cutoff frequency, f_0, and very large for frequencies above f_0, as shown in the following response graph.

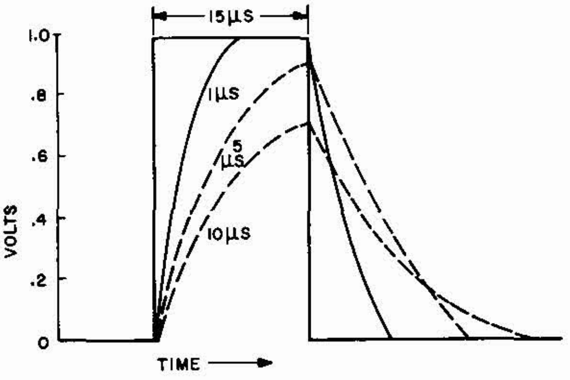


Phase and Amplitude Response Characteristics for Low Pass Filter (f_0=1,000 Hz)

However, as can be seen from the chart, the attenuation (for a single-section filter) becomes relatively constant at 12 db/octave (20 db per decade) at frequencies considerably above cutoff. The phase shift ranges from zero at the lower frequencies below cutoff to 45 degrees at f_0. Above the cutoff frequency the phase shift soon becomes constant at 90 degrees. The dotted line indicates how this typical Bode plot is rounded off to simulate practical conditions. As a result, a 3 db difference exists between the actual and theoretical response at the cutoff frequency.

The effect of a low-pass filter on the response of a rectangular pulse is indicative of the action produced by this type of filter. Since the output voltage is taken from across the capacitor, which is in series with the resistor and the the input circuit, it is evident before the pulse is applied, there is no charge in the capacitor and no current in the circuit. Therefore, no voltage output is obtained. Upon application of the rectangular pulse the initial current is equal to E/R. Since the capacitor cannot change its charge instantly, the high charging current drops the voltage across the resistance and the output voltage rises exponentially as the capacitor charges. Thus, as the capacitor charges the current through the resistor decreases, while the voltage across the capacitor increases correspondingly. Eventually the capacitor charges to the full input voltage and the output voltage is at a maximum. The output voltage stays at this value for the remainder of the pulse. At the end of the pulse the capacitor discharges, also exponentially, and the output voltage eventually decreases to zero.

The following figure shows the overall response of a low-pass filter to a rectangular pulse of 15 microseconds duration with different time constant values (R times C). From the previous explanation, it is clear that both the rise and fall times of the pulse are greatly affected. The effect is least for a small time constant. For example, consider the response of an RC circuit with a time constant of 1 microsecond to a rectangular pulse of 15 microseconds duration.

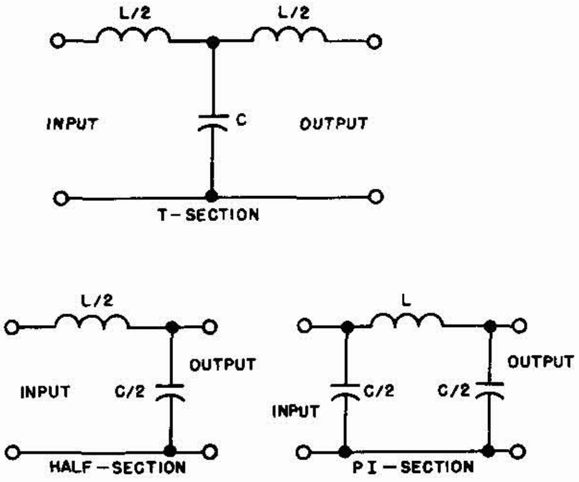


Typical Pulse Response Variation with Time Constant or Pulse Width Changes

Since the rise time is taken between the 10% and 90% amplitude limits of the pulse, we see from a universal time constant table that the leading edge reaches its maximum of 90% amplitude in 2.2 microseconds and remains approximately at this value for the remaining 12.7 microseconds (7 time constants are required to reach full amplitude). When the pulse ends, the decay time follows the same curve and the capacitor is 90% discharged in 2.2 microseconds, and completely discharged before the beginning of the next pulse. Consider now the response curve for a 5 microsecond time constant. In this case the leading edge of the pulse rises to 90% of maximum in two time constants, the pulse is terminated and decays to zero in the next two time constants. Because of the increase of time constant the capacitor charges to only 90% of the maximum and the output voltage is 10% less than for the 1 microsecond condition. For the extremely long time constant of 10 microseconds it takes the entire pulse duration of 15 microseconds for the pulse to reach approximately 78% amplitude. Thus the longer the time constant the lower is the output amplitude and the more distorted is the pulse.

Since RC filters respond to the time constant of the circuit, it is evident that while filters of many sections can be used, the simple equivalent time constant of the circuit basically determines the filter characteristics, and that really sharp cutoff cannot be obtained. With the use of L-C filter circuits however, it is possible to produce the desired pass band with much sharper cutoff and attenuation characteristics. Since both inductance and capacitance are used, a single-section L-C filter is capable of a 180 degree phase shift.

Low pass filter circuits using inductance and capacitance follow the same type of circuit configuration as do R-C filters as shown in the accompanying figure.



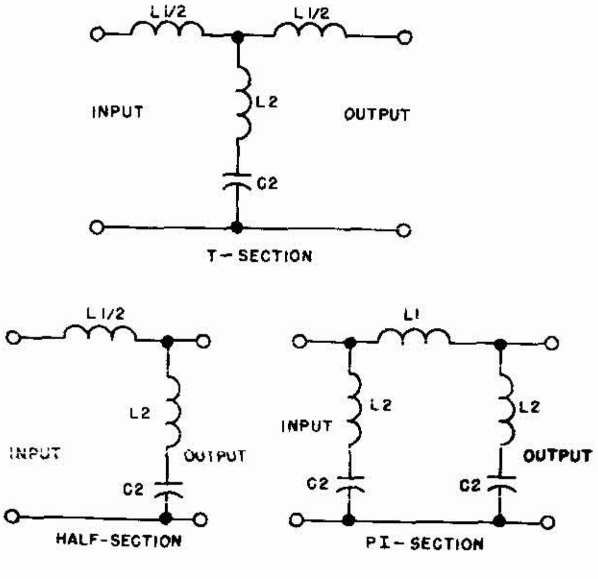
Low-Pass L-C Filter Circuits

In the L-type low-pass filter using L-C components the high frequencies applied to the input are offered a relatively high inductive reactance by series inductor L, and a low capacitive reactance through the shunt path to ground provided by capacitor C. Therefore, the high frequency signals are attenuated by L and effectively shunted to ground by C if they pass the inductor. On the other hand, the low frequencies are offered little opposition by L and high opposition by C. Therefore, the lower frequencies pass from input to output with little attenuation. The T-type filter operates identically with the half section filter, but provides a symmetrical input and output configuration with the same time constant as a single section L-type filter. The pi-type filter is actually formed from two inverted L-type filters and provides slightly better cutoff and attenuation. In this case the high frequencies are first offered a low impedance path to ground by the first filter capacitor with high attenuation offered by the series inductor. Any remaining high frequency signals are then effectively shunted to ground by the low impedance of the second (output) capacitor. The basic L-type filter is used where only a simple unbalanced input and output are required. The T- and Pi-types of filter are used where balanced arrangements are necessary.

Basic filter theory stipulates that where reactances of the same sign (either all capacitance or all inductance) are used, the characteristic filter impedance presented by the filter to the input or the output circuit is a reactance. On the other hand, where reactances of opposite sign are used (such as capacitance and inductance), the characteristic impedance becomes resistive over one range and reactive over another range. Thus the design and matching of filters becomes an engineering problem, and is treated on an ideal theoretical basis. This means that while a filter may be considered to have infinite rejection beyond a particular cutoff frequency, in practice the result may not be great as predicted. Likewise, the critical cutoff frequency may not be as sharp or as critical as the design figures indicate.

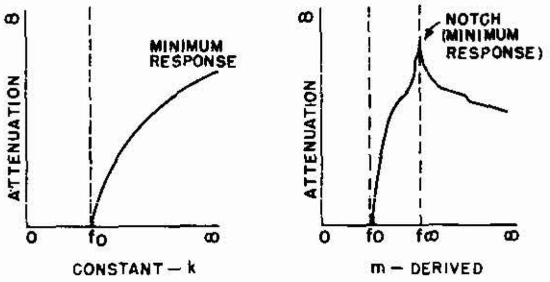
All the previously discussed filter arrangements are of the **constant k** type, which has a gradual rather than a sharp cutoff frequency. In this simple type of filter the series filter arm impedance, Z1 and the shunt filter arm impedance, Z2, are so related that their product is a constant at all frequencies ($Z1 \times Z2 = k^2$). Therefore, it derives its name from this relationship. This constant, in turn, is also equal to R^2, since Z1 and Z2 are reciprocal reactances (X_L and X_C, respectively), and $R^2 = L/C$. Thus the formula for determining the cutoff frequency becomes: $f_0 = 1/\pi$ LC, where L and C are in henrys and farads, respectively.

A more complex form of low-pass filter circuit is the **m-derived** type. In this type of filter the cutoff frequency is sharper, and the total attenuation of the unwanted frequencies is greater. Typical circuits of the series-connected m-derived type are shown in the accompanying illustration.



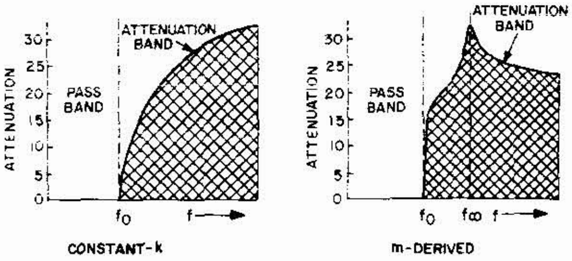
Series m-Derived Low-Pass Filters

As can be seen from the illustration, a series-connected L-C network (L2C2) is placed across the output or across the mid-termination of the filter network. As designed, this network is made series-resonant at a frequency above the usual cutoff frequency. For the low-pass fister this resonant frequency, called the **frequency of infinite attenuation** (f_∞) is selected at a value of about 1.25 f_0. Since f_∞ is resonant and is series connected across the input or the output it represents a short circuit across the filter for the resonant frequency (with a pass band determined by the Q and resistance of the circuits). Therefore, the normally sloping attenuation characteristic which approximates 12 db/octave for the constant k filter is "notched" off. In effect, the m-derived filter is sharply separated from the frequencies above f_∞ and therefore, provides sharper and better cutoff of the higher frequencies. The action described can be visualized more clearly when the attenuation (response) characteristics for the two types of filters are compared as shown in the following figure.



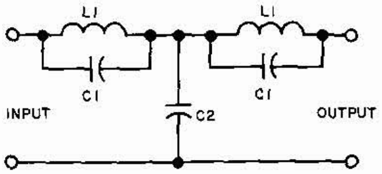
Comparison of Filter Attenuation Characteristics

While a constant attenuation is shown for the constant k type, with a reduced value of attenuation below f_∞ for the m-derived type, the sharpness of m-derived cutoff at f_∞ (assuming zero circuit resistance at resonance) provides better low-pass performance, as illustrated below.

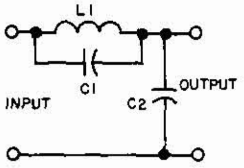


Comparison of Transmission Characteristics

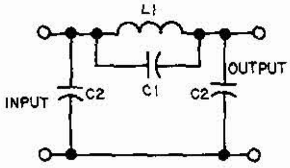
The shunt-connected type of m-derived filter is shown in the following figure.



T-SECTION



HALF-SECTION



PI-SECTION

Shunt m-Derived High Pass Filters

In the shunt-type filter the low-pass action occurs by the shunting of the high frequencies to ground via capacitor C2 for those frequencies above f_∞, and by attenuation of the signal due to the action of the parallel resonant circuit of L1-C1 at the infinite attenuation frequency f_∞. Since the capacitive reactance of C2 decreases with frequency the higher frequencies above f_0 are shunted to ground and lost. Since the parallel-resonant circuit of L1C1 represents a high impedance at resonance, frequencies around f_∞ (depending upon the circuit Q) are greatly attenuated and are prevented from passing through the filter. This type of action is mostly used for the band rejection type of filter to be discussed later in this section.

In the m-derived filter, m is a design constant from which the filter gets its name. This constant basically represents a coupling factor, and appears in all the design formulas. It is some value less than 1, usually 0.6. Thus the frequency of attenuation if $f_\infty = f_0/\sqrt{1-m^2}$, which for a cutoff frequency of 1000 cycles and an m of 0.6, is by substituting values, $1000/\sqrt{1-0.36} = 1000/.8$, or 1250 cycles per second. The cutoff frequency for the m-derived filter is $f_0 = 1/(\pi\sqrt{LC})$.

If the frequency values in the example above are substituted in this formula, it will be seen that m is equal to 0.6 as selected above. When m is equal to 1, both the constant k and the m-derived filters are identical. Values of m smaller than 0.6 move f_∞ closer to f_0 (sharpen the cutoff), while values greater than 0.6 move f_∞ farther from f_0 (broaden the cutoff).

In the schematic illustrations of the filters shown previously, various values of L and C are indicated. These indicators merely show that the design values of L and C are shown to be multiplied or divided by 2 to produce the proper value for the configuration illustrated. This change of value is necessitated by the requirements for proper matching, and for the connection of cascaded filter sections to produce the desired performance. For example, when connecting two pi-sections together the input and output capacitors parallel the input and output capacitors, respectively of the next or preceding section. Since capacitors in parallel have twice the value of the original capacitance, these networks normally use a value of C/2 where more than a single section is to be connected in a ladder type network. For further information, the interested reader is referred to standard textbooks on filter design.

FAILURE ANALYSIS.

Generally speaking, either the filter performs as designed or it does not. Any open or short circuited condition of the individual parts can lead to one of three possibilities: the open part may cause a no-output condition; the short-circuited part may cause either a no-output or a reduced-output condition; or the part may be located in a portion of the circuit that markedly affects the filter cutoff frequency, pass band, or attenuation characteristics. Usually all three of these last mentioned conditions are affected to some extent. Therefore, it becomes rather difficult to determine whether the filter is faulty and to spot the defective part with simple servicing techniques. In most instances, a check for continuity with an ohmmeter will indicate any open-circuited parts. In the case of the capacitors in the network, they can be checked with an in-circuit type of capacitance tester for the proper capacitance. Any short-circuited capacitor should be found during the resistance and continuity check. Where a low frequency inductor is under suspicion, the d-c resistance may be used as a guide; but where the resistance is so low that it is less than one ohm (as in high frequency coils) the suspected coil must be disconnected and checked with an inductance bridge.

If a filter is suspected of operating improperly and the the cutoff frequency is known (if not, it can be calculated approximately by using the formulas referenced in the preceding discussion of circuit operation), and a pass-band check can be made with an oscilloscope and a signal generator. With the signal generator modulated and simulating the input signal, the output of the filter is observed on the oscilloscope. For a low pass filter the height of the pattern should decrease rapidly as the cutoff frequency is passed (while increasing the frequency), and the pattern should stay at approximately the same height for frequencies below cutoff. If such indications are obtained the filter is most probably operative, and some other portion of the associated circuit is at fault. If these indications are not obtained, the filter is definitely at fault, and each part must be checked individually for proper value.

BAND-PASS CIRCUITS.

APPLICATION.

Band-pass filter circuits are used to allow frequencies within a certain frequency band to be passed or transmitted with minimum attenuation and to block all frequencies above and below this frequency band.

CHARACTERISTICS.

Uses L-C type filters.

Frequencies between lower and upper cutoff frequencies are passed with little attenuation; frequencies above and below these values are attenuated.

Series and parallel resonant circuits combined with a series or shunting inductance or capacitor are used to develop each configuration.

Attenuation and cutoff varies with the number of elements used (the greater the number of elements, the greater is the attenuation and the sharper the cutoff).

CIRCUIT ANALYSIS.

General. The band-pass filter circuit consists of inductive and capacitive components combined and connected in such a manner that they have definite frequency response characteristics. The band-pass filter is designed to permit the passage of frequencies within a desired range or band width, and to attenuate any frequencies not in this range. The range of frequencies which is capable of being passed is referred to as the **pass-band**, the range of frequencies above and below the pass band, where attenuation or poor transmission occurs is called the **attenuation band.** The frequency at which the attenuation of a signal starts to increase rapidly is known as the **cutoff frequency.** The basic configurations into which the band-pass filter elements can be assembled or arranged are the **"L"** or **half-section**, the **"T"** or **full-section**, and the **pi** section.

The L-section filter consists of one inductive component, capacitive component, or one combination of inductive and capacitive components in series with the input and output, together with one inductive component, capacitive components, or combination of inductive and capacitive components shunting the input and output. The T-type filter consists of two series (inductive and/or capacitive) component groups separated by one component group shunting the input and output. The pi-type consists of one series component group between two component groups shunting the input and output. Serveral sections or half-sections can be joined to improve the attenuation or transmission characteristics of the filter. When several sections are cascaded together, they form a **ladder** type of filter. When a filter is inserted into a circuit it is usually terminated (matched) by a resistance or impedance of the same value at the input end. The value of the terminating resistance or impedance is usually determined by the circuit with which the filter is used and the type of filter circuit employed.

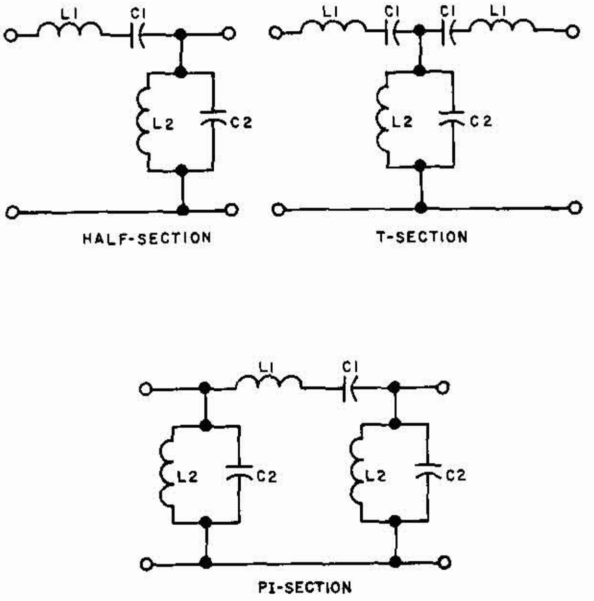
The cutoff frequency of a filter is determined by the circuit configuration, type of filter **(constant k or m derived),** and the values of the inductors and capacitors in the filter circuit. When the cutoff frequency is known, the value of the parts necessary to produce this response and the desired attenuation may be calculated mathematically by the use of the proper formulas. This Handbook will not be concerned with design data, but will show the circuit configuration, explain circuit action, and provide information with which the technician can determine or recognize the type of filter and in most cases, determine the cutoff frequencies if needed.

Circuit Operation. A typical half-section band-pass filter is shown in the accompanying illustration. This is a **constant k** type band-pass filter. The pass-band of frequencies is offered a low impedance by the series resonant circuit, and a high impedance by the parallel resonant circuit which shunts the input and output. The resonant circuits are tuned to frequencies within the pass-band. All frequencies on either side of the pass-band are offered a higher impedance by the series resonant circuit and a decreased impedance by the shunting resonant circuit; therefore, the frequencies outside of the pass-band are attenuated and the frequencies within the pass-band are transferred with little or no attenuation. The T-type filter operates identically to the half-section or L-section filter, but provides a symmetrical input and output configuration. The pi-type filter is actually formed from two series connected inverted L-type half-section filters and provides slightly better cutoff and attenuation than the single half-section. In this case, the attenuation-band of frequencies is offered a low impedance path to ground by the first shunting parallel resonant circuit and a high impedance by the series resonant circuit. Any remaining attenuation-band frequency signals are shunted to ground by the low impedance of the second parallel resonant circuit. The basic L half-section filter is used where only a simple unbalanced input and output are required. The T- and pi-section filters are used where balanced arrangements are necessary.

The design and matching of filters becomes an engineering problem, and is treated on an ideal theoretical basis. This means that while a filter may be considered to have infinite rejection beyond a particular cutoff frequency, in practice the result may not be as great as predicted. Likewise, the critical cutoff frequency may not be as sharp or as critical as the design figures indicate.

All of the previously discussed filter arrangements are of the **constant k** type, which has fairly sharp cutoff frequencies, even in its simplest form. In **constant k** type filters the product of the impedance in series with the input and output, and the impedance shunting the input and output is constant regardless of the frequency (Z series $\cdot$ Z shunt $= k^2$). Therefore, it derives its name from this relationship. This constant, in turn, is also equal to R^2 (R is the value of the terminating resistance). To determine the bandwidth of the pass-band ($f_2 - f_1$) of an L-section **k** type filter, the formula $f_2 - f_1 = R/L$, may be used. To determine the value of the center frequency of the pass-band (f_c), the formula $f_c = C_1R^2/L$, may be used.

A more complex form of band-pass filter circuit is the **m-derived** type. An **m**-derived type of filter may be composed of various numbers of inductive and capacitive components in series or parallel connection within a section of of the filter. An L-section **m**-derived filter for example, may contain three, four, five, or six elements within two possible

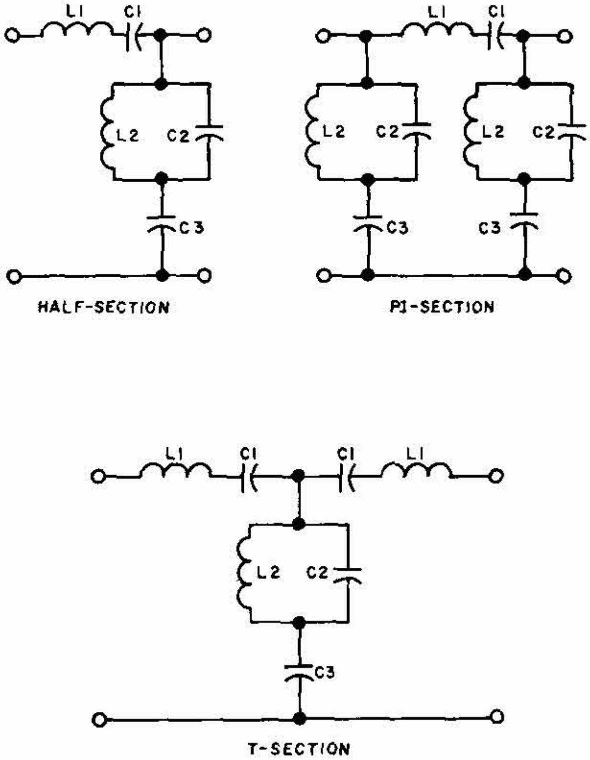


Constant k Band-Pass Filters

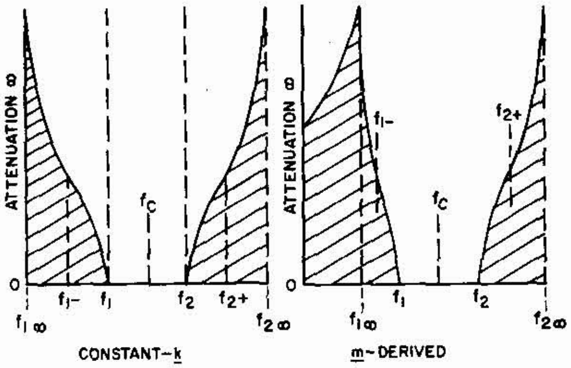
series configurations and two possible shunt configurations. In order to obtain the same degree of sharpness in attenuation at both upper and lower cutoff frequencies as is obtained in a **constant k** type filter an **m**-derived filter of at least 5 elements would be required. Typical circuits of one series connected **m**-derived type 5-element, band-pass filter are shown in the accompanying illustration.

These **m**-derived type of filters offer low series impedance, and high shunt impedance to the pass-band frequencies, since the series and shunt resonant circuits are tuned to the frequencies within the pass-band. All frequencies on either side of the pass-band are offered a greater impedance by the series resonant circuit and a decreased impedance by the shunting resonant circuit. Capacitor C3 is of such a value that frequencies below the pass-band are attenuated to a greater degree. Thus frequencies outside the pass-band are attenuated and the frequencies within the pass-band are not attenuated.

In the band-pass filter f1∞ represents the **lower frequency of infinite attenuation** and f2∞ represents the **higher frequency of infinite attenuation.** At f1 and f2 the filter effectively appears as a short circuit across the output. The 5 element series arrangement of **m**-derived filter (the 5th element is a capacitor) has a low frequency minimum response notch at f1∞, and therefore, provides sharper and better cutoff of the lower frequencies. The action described can be visualized more clearly when attenuation (response) curves for the **constant k** and the **m-derived** filters are compared as shown in the accompanying diagrams. The response of the 5 element shunt arrangement **m**-derived filter is the same as the 5 element series arrangement **m**-derived filter if the fifth element of the shunt arrangement is an inductance and the fifth element of the series arrangement is a capacitor.



Series m-Derived, 5-Element Band-Pass Filter

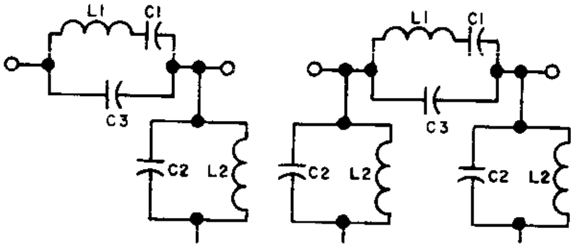


CONSTANT-k m-DERIVED

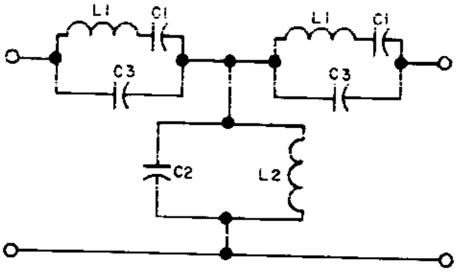
Comparison of Filter Attenuation Characteristics

The **constant k** type filter shows equal attenuation above $f2$ and below $f1$ (the cutoff frequencies). A steep increase in attenuation is apparent between frequencies $f2$ to $f2+$ and to $f1-$, however once frequencies $f2+$ and $f1-$ are reached, the attenuation curve becomes more gradual until $f1\infty$ and $f2\infty$ are reached. In this case frequencies $f1\infty$ and $f2\infty$ exist at the lowest possible and highest possible frequencies. A similar attenuation slope occurs between $f2$ and higher frequencies of the five element, m-derived, band-pass filter. A different slope, with a sharp minimum notch however, exists between frequency $f1$ and the lower frequencies in the m-derived filter. Frequency $f1\infty$ does not occur at the lowest possible frequency, but at some intermediate frequency above zero. Thus, the slope between $f1$ and $f1\infty$ produces a much steeper attenuation curve than the **constant k** filter for the lower frequencies, even though there is still a gradual widening of the slope between $f1-$ and $f1\infty$. Between $f1\infty$ and the lowest possible frequency the attenuation decreases slightly.

The shunt-connected type of five element m-derived band-pass filter is shown in the accompanying illustration. This shunt connected filter uses three capacitors and two inductors to comprise the five necessary components as does the series-connected m-derived filter just described.



HALF-SECTION PI-SECTION



T-SECTION

Shunt m-Derived Band-Pass Filter

In this 5 element shunt m-derived band-pass filter L1 and C1 form a series resonant circuit at the pass-band frequencies and L2-C2 form a parallel resonant circuit. The series resonant circuit is aided by capacitor C3 in offering a low series impedance to the pass-band, and the parallel resonant circuit offers a high impedance to the pass-band. This shunt arrangement has an attenuation curve just opposite to that of the series arrangement previously discussed, where $f2\infty$ is a frequency less than a maximum frequency and $f1\infty$ is at the lowest possible frequency. By using a series arrangement with three inductive components and two capacitive components the same attenuation curve is obtained.

In the m-derived filter, m is a design constant from which the filter gets its name. This constant basically represents a coupling factor, and appears in all of the design formulas. In the case of the band-pass filter there are two m factors. These m factors have a value of 1, or less and are assigned designations $m1$ and $m2$. The values of $m1$ and $m2$ can be computed by complex formulas based on the quantities of the lower cutoff angular frequency ($f1$), the upper cutoff angular frequency ($f2$), and the upper and lower frequencies of peak attenuation ($f2\infty$ and $f1\infty$). These design formulas are beyond the scope of this book.

FAILURE ANALYSIS.

Any open or short-circuited condition of the individual parts can lead to one of three possibilities: the open part may cause a no-output condition; the short-circuited part may cause either a no-output or a reduced-output condition; or the part may be located in a portion of the circuit that markedly affects the filter cutoff frequency, pass band, or attenuation characteristics. Usually all three of these last mentioned conditions are affected to some extent. Therefore, it becomes rather difficult to determine whether the filter is faulty and to locate the defective component with simple servicing techniques. Capacitors can be checked with an in-circuit capacitance checker for the proper capacitance. Short-circuited capacitors usually can be detected by checking the capacitors with an ohmmeter. The d-c resistance of the inductors is checked with an ohmmeter to determine if they are the proper value; but where the resistance is so low that it is less than one ohm (as in high frequency coils) the suspected coil must be disconnected and checked with an inductance bridge.

If the cutoff frequencies of a filter suspected of operating improperly are known a pass-band check can be made with an oscilloscope and a signal generator. With the signal generator modulated and simulating the input signal, the output is observed on the oscilloscope. For a band-pass filter the height of the pattern should increase rapidly as the beginning of the pass-band is reached, and the height of the pattern should decrease rapidly at the end of the pass-band as the second cutoff frequency is passed. The pattern should remain at relatively the same amplitude for the complete pass-band. If such indications are obtained the filter is most probably operative, and some other portion of the associated circuit is at fault. If these indications are not obtained, the filter is definitely at fault, and each part must be checked individually for proper value.

BAND-REJECTION CIRCUITS.

APPLICATION.

Band-rejection, or band-stop, filters are used in circuits where it is desired to reject or block a band of frequencies from being passed, and to allow all frequencies above and below this band to be passed with little or no attenuation.

CHARACTERISTICS.

Uses L-C type filters for sharp cutoff.

Frequencies between lower and upper cutoff frequencies are attenuated; frequencies lower and greater than these values are passed with little attenuation.

May be either constant **k** or **m**-derived types.

Attenuation and cutoff varies with the number of elements used (the greater the number of elements, the greater is the attenuation and the sharper the cutoff).

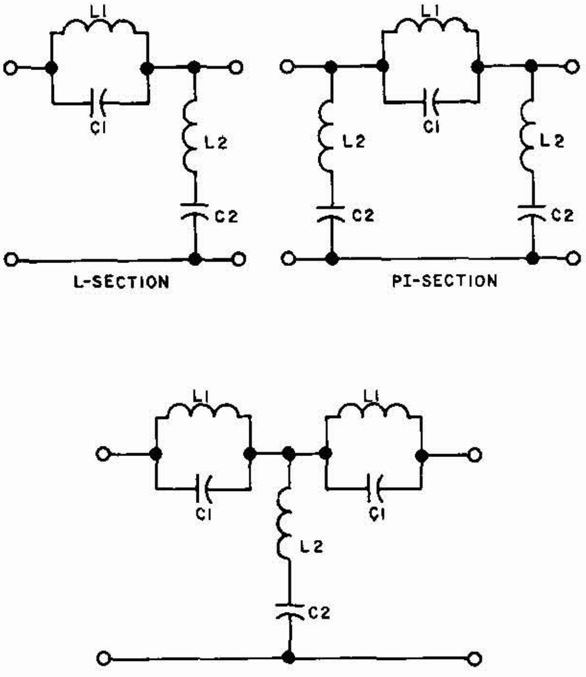
CIRCUIT ANALYSIS.

General. The band-stop filter circuit consists of inductive and capacitive networks combined and connected in such a manner that they have a definite frequency response characteristic. The band-stop filter is designed to attenuate a specific frequency band and permit the passage of all frequencies not within this specific band. The frequency range over which attenuation or poor transmission occurs is called the **attenuation band;** the frequency range over which the passage of signal readily occurs is called the **pass-band.** The lowest frequency at which the attenuation of a signal starts to increase rapidly is known as the **lower cutoff frequency** (f1); and the highest frequency at which the attenuation of a signal starts to increase rapidly is known as the **upper cutoff frequency** (f2). The basic configurations into which the band-elimination filter elements can be arranged or assembled are the L or half-section, the T-section, and the Pi-section.

The L-section filter consists of one parallel combination of inductance and capacitance in series with the input and one series combination of inductance and capacitance shunting the input. The T-type filter consists of two parallel combinations of inductance and capacitance in series with the input separated by one shunting combination of inductance and capacitance. The P-type filter consists of two series combinations of inductance and capacitance shunting the input and output separated by one parallel combination of inductance and capacitance connected in series with the input. Several sections (or half sections) of the same circuit configuration can be joined to improve the attenuation or transmission characteristics of the filter. When several sections are cascaded together, they form a **ladder** type of filter. When a filter is inserted into a circuit it is usually terminated (matched) by a resistance or impedance of the same value at the input end. The value of the terminating resistance or impedance is usually determined by the circuit with which the filter is used and the type of filter circuit employed.

The cutoff frequencies of a filter are determined by the circuit configuration, type of filter (constant **k** or **m**-derived), and the values of the inductors and capacitors in the filter circuit. When the cutoff frequencies are known, the value of the parts necessary to produce this response and desired attenuation may be calculated mathematically by the use of the proper formulas. This Handbook will not be concerned with design data, but will show the circuit configuration, explain circuit action, and provide information with which the technician can determine or recognize the type of filter and determine the cutoff frequencies, if needed.

Circuit Operation. Band-elimination filter circuits are shown in the accompanying illustration in L-section, T-section, and Pi-section arrangements.



Band-Rejection k-Type Filter

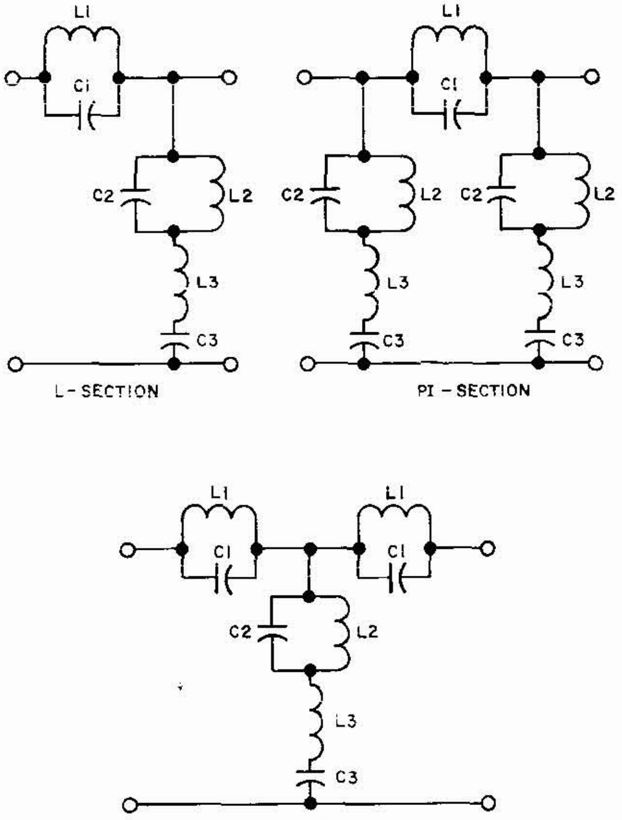
In the L-section band-rejection filter any frequencies not within a selected band are offered low series impedance by L1 and C1 and offered a high shunting impedance by L2 and C2. For this reason those frequencies not within the band are easily passed from input to output with little or no attenuation. Those frequencies within the selected band are those frequencies to which L1 and C1 are resonant and L2 and C2 are resonant. The parallel resonant circuit of L1 and C1 offers a large series impedance to the frequencies within the rejection band and thus tends to block passage of these frequencies through the filter. The series resonant circuit of L2 and C2 offers *almost no impedance to the frequencies within the rejection band*, thus any signals in the rejection-band which may have passed through L1 and C1 are shunted across the output. Therefore, those frequencies within this band are greatly attenuated. The T-section series resonant circuits offer minimum impedance because *at resonance the inductive* reactance (XL) equals the capacitive reactance (XC); and in a series circuit the impedance (Z) is equal to the formula

$$\sqrt{R^2 + (XL - XC)}.$$

The impedance then, is simply equal to $\sqrt{R^2}$ or R, the d-c resistance of the coil. A parallel circuit offers maximum impedance at resonance. The impedance in a parallel resonant circuit can be expressed as $Z = XC^2/R = XL^2/R$, (XC being equal to XL at resonance). By using $Z = XL^2/R$ the formula $Z = XLQ$ can be derived, since $Q = XL/R$. The Q of any circuit is maximum at resonance; therefore, the impedance of a parallel resonant circuit is maximum at resonance. The T-section filter operates identically to the L-section filter, but provides a symmetrical input and output configuration with approximately the same cut off and attenuation as a single L-section filter. The pi-section filter is actually formed from two inverted L-section filters and provides slightly better cutoff and attenuation. In this case, frequencies within the rejection-band are first offered a low impedance by the first series resonant circuit shunting the input. Any remaining signal within the rejection-band that is not shunted across the input is then attenuated by *the remainder of the filter in the same manner that an* L-section filter attenuates the undesired frequency band. The basic L-section filter is used where only a simple unbalanced input and output are required. The T- and Pi sections are used where balanced arrangements are necessary.

All the previously discussed filter arrangements are of the **constant k** type. In this simple type of filter the series impedance arm, Z1, and the shunt filter arm impedance, Z2, are so related that their product is a constant at all frequencies ($Z1 \times Z2 = \mathbf{k}^2$). Therefore, it derives its name from this relationship. This constant, in turn, is also equal to R^2 the squared value of the terminating resistance. In these series constant **k** type band-rejection filters the center frequency, fc, is equal to $1/2\pi\sqrt{L_1C_1}$. Once the center frequency is obtained the bandwidth can be computed by the formula $f2-f1 = fc/Q$, where Q represents the amount of selectivity of a circuit. This value of Q equals the inductive reactance of L1 divided by the value of the d-c resistance of the inductor ($Q = XL1/R$).

A more complex form of band-rejection filter circuit is the **m-derived** type. In this type of filter the cutoff frequencies (f1 and f2) are much sharper, and the total attenuation of the unwanted frequencies is greater. Typical circuits of the series-connected **m-derived** filters are shown in the accompanying illustration.



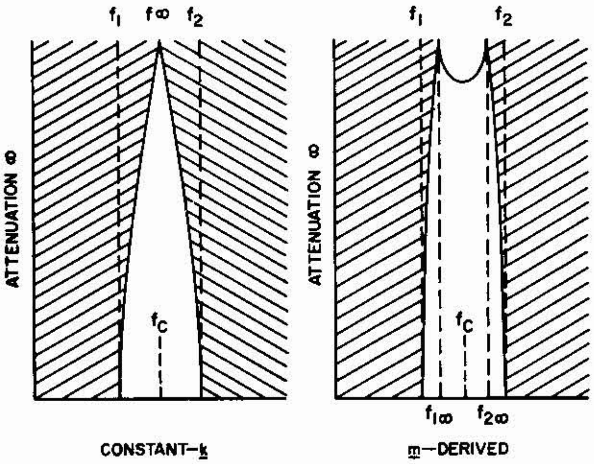
L-SECTION

PI - SECTION

T- SECTION

Series m-Derived Band-Stop Filters

These **m**-derived type of filters offer high series impedance, and low shunt impedance to the rejection-band frequencies, since the series and shunt resonant circuits are tuned to the frequencies within this band. All frequencies on either side of the rejection band are offered less impedance by the parallel circuit (L1 and C1) in series with the input and output and greater impedance by the series circuit shunting the input and output. Inductance L2 and capacitance C2 form a parallel circuit, which is in series with L3 and C3. The values of L2 and C2 are chosen such that at some frequency, which corresponds to the **lower frequency of infinite attenuation** (f1∞), their combined reactance will form a series resonant circuit with the reactances of L3 and C3. Another series resonant circuit will be formed from these same components at the **higher frequency of infinite attenuation** (f2∞). At the frequencies where these resonant points occur the attenuation curve indicates sharp peaks or notches. These resonant points are not as broad as the band-width to which L1 and C1 are tuned to resonance. Therefore, the frequencies between f1∞ and f2∞, although being attenuated, are attenuated less than f1∞ and f2∞. The action described can be visualized more clearly when attenuation (response) curves for the constant **k** and **m**-derived filters are compared as shown in the accompanying illustration.



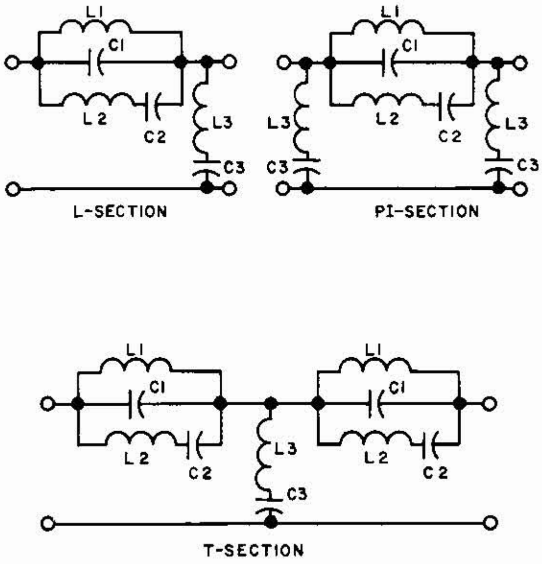
Constant-k **m-Derived**
Comparison of Filter Attenuation Characteristics

The constant-**k** attenuation curve shows gradual attenuation of signal from frequencies f1 and f2 to the center frequency fc. The attenuation on both sides is equal, causing the resulting attenuation curve to look like an inverted cone. The frequencies of infinite attenuation intersect at fc, and thus occur at a single frequency.

The **m**-derived attenuation curve shows a much steeper and sharper attenuation at frequencies f1 and f2. Furthermore, the attenuation slopes from f1 and f2 do not intersect at the center frequency, but reach frequencies of infinite attenuation on both sides of the center frequency represented by f1∞ and f2∞. From these frequencies of infinite attenuation the attenuation decreases nonlinearly toward the center frequency. This **m**-derived attenuation curve is representative of both series **m**-derived and shunt **m**-derived band-rejection filters.

The shunt **m**-derived band-rejection filter is shown in the accompanying illustration. It is composed of a parallel-series network in series with the input and output, and a series network shunting the input and output.

In the shunt **m**-derived band-stop filter inductor L2 and capacitor C2 are added to a constant-**k** configuration band-stop filter. L2 and C2 are of such a value that they in conjunction with L1 and C1 form a parallel resonant circuit at frequencies f1∞ and f2∞. This causes the attenuation to increase above the normal attenuation between the cutoff frequencies f1 and f2 caused by the parallel resonant circuit of L1 and C1 and the series resonant circuit C3 and L3. After f1∞ and f2∞ the attenuation decreases toward the center frequency, since L2 and C2 in conjunction with L1 and C1 are tuned very sharply to and the two frequencies f1∞ and f2∞.



Shunt m-Derived Band-Elimination Filter

In the **m**-derived filter, **m** is a design constant from which the filter gets its name. This constant basically represents a coupling factor, and appears in all design formulas. The **m** factor has a value of 1 or less. The value of **m** can be found by the following formula:

$$m = \sqrt{1 - (f2\infty - f1\infty)^2 / (f2 - f1)^2}$$

FAILURE ANALYSIS.

Any open or short circuited condition of the individual parts can lead to one of three possibilities: the open part may cause a no-output or a reduced output condition; the short-circuited part may cause either a no-output or a reduced output condition; or the part may be located in a portion of the circuit that markedly affects the filter cutoff frequencies, attenuation band, or attenuation characteristics. Usually all three of these last mentioned conditions are affected to some extent. Therefore, it becomes rather difficult to determine whether the filter is faulty and to locate the defective component with simple servicing techniques. Capacitors can be checked with an in-circuit capacitance checker for the proper capacitance. Short circuited capacitors usually can be detected by checking the capacitors with an ohmmeter. The d-c resistance of the inductors is checked with an ohmmeter to determine if they are the proper value; but where the resistance is so low that it is less than one ohm (as in high frequency coils) the suspected coil must be disconnected and checked with an inductance bridge.

If the cutoff frequencies of a filter suspected of operating improperly are known, a rejection-band check can be made with an oscilloscope and a signal generator. With the signal generator modulated and simulating the input signal, the output is observed on the oscilloscope. For a band-elimination filter the height of the pattern should decrease rapidly as the beginning of the rejection-band is reached, and the height of the pattern should increase rapidly at the end of the rejection-band as the second cutoff frequency is passed, in the case of the **m**-derived filter, or begin increasing immediately after the center frequency is passed in the case of the constant **k** filter. If such indications are obtained the filter is operative, and some other portion of the associated circuit is at fault. If these indications are not obtained, the filter is at fault, and each part must be checked individually for proper value.