Surface Acoustic Wave Filters

Introduction

Surface acoustic wave (SAW) filters provide excellent filtering properties at high frequencies. This makes them suitable for use in many wireless communications products such as cellular telephones, cordless telephones, TVs, VCRs, cable modems, and pagers.

How Does It Work

SAW filters use Inter Digital Transducers (IDT) as the input and output electrodes mounted on a piezoelectric substrate. An IDT is a comb structure consisting of interleaved metal electrodes, called fingers, attached to a bus bar (Figure 88).

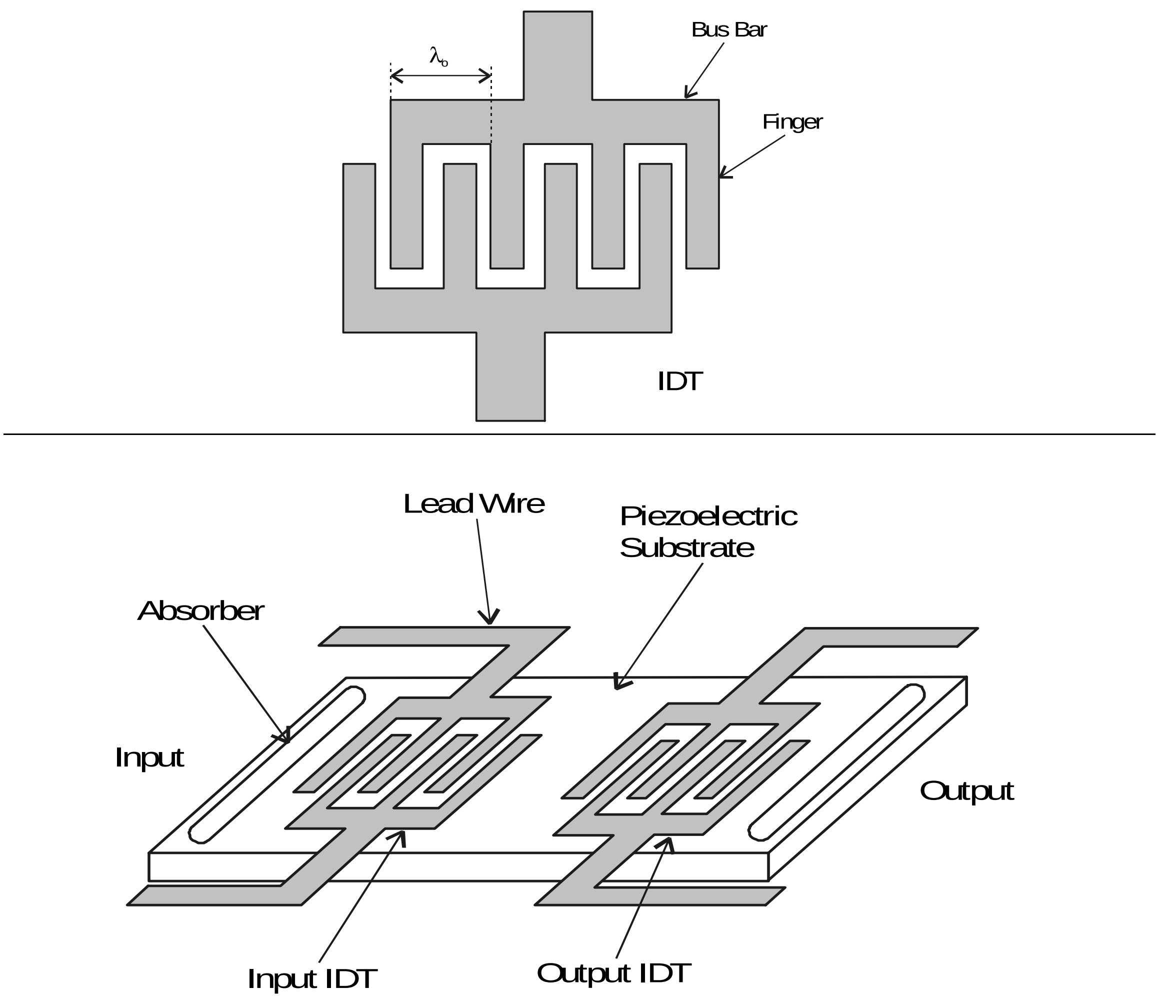

Figure 88: SAW Filter Construction

By applying a signal at the input terminal, stress is created between the electrodes by the piezoelectric effect. This stress causes the substrate to shrink and expand, forming a surface acoustic wave which propagates along the substrate to the output IDT. At the output IDT, the wave causes a potential difference between the electrodes, which is then seen as a voltage at the output terminals. The maximum amount of energy transfer occurs when the wavelength of the surface acoustic wave is the same as the distance between electrodes, λ_o. All other wavelengths are attenuated. Because of this, adjusting the pitch of the electrodes sets the center frequency of each overlapping finger section. This procedure is called variable pitch. Adjusting the finger overlap length can change the magnitude of the signal transmitted or received by each overlapping finger section. This procedure is called apodization. This is a transversal filter that enables the amplitude and GDT characteristics to be designed separately. This allows a flat passband, good selectivity, and a flat GDT to be acheived (Figure 89). A wide range of frequency characteristics can be realized just by the design of the IDT electrode pattern. Since the signal is propagated in both directions from the IDT, silicon absorbers are placed at the edges of the substrate to prevent reflections from the edge that would cause distortion.

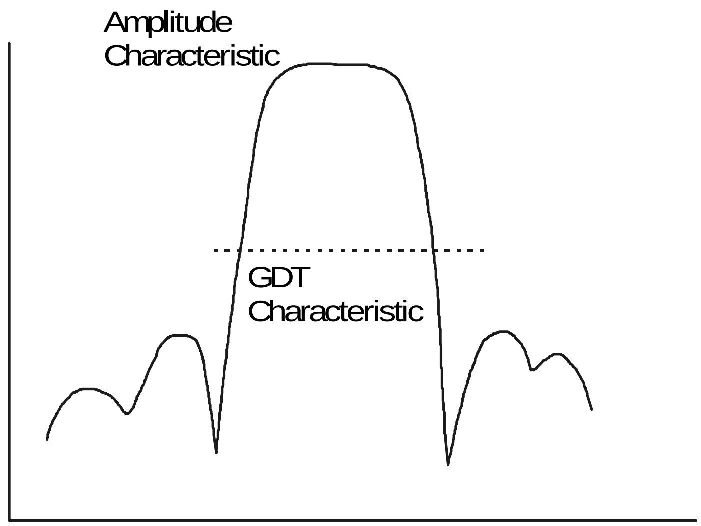

Figure 89: SAW Filter Characteristics

Causes of Signal Distortion

There are two main causes of distortion in SAW filters. The first is called direct breakthrough. This is when the signal is powerful enough to be picked up at the output without having traveled through the piezoelectric material. The signal is seen at the output attenuated but unfiltered before the filtered signal is seen. The other type of distortion is called triple transit echo (TTE). This is a result of the signal bouncing between the two IDTs. If the signal takes time τ to be seen at the output then the TTE signal will be seen 2τ after the main signal. Figure 90 illustrates the signal paths and Figure 91 shows the input and output as a function of time.

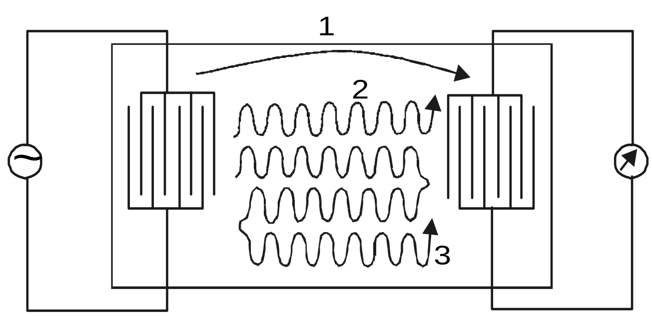

Figure 90: SAW Filter Signal Paths

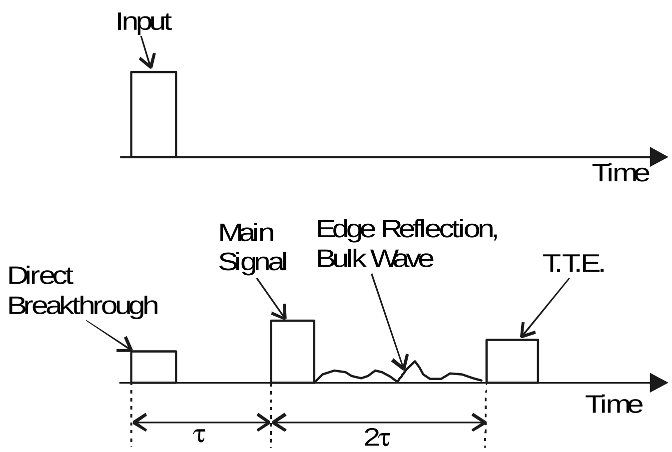

Figure 91: SAW Filter Signal Timing

TTE tends to cause a ripple in both the amplitude characteristic and in the GDT, which can cause errors in digital systems, and in the amplitude characteristic, which results in signal distortion. In TVs, because of the delay, this can cause a ghost image to the right of the main image. Direct breakthrough also causes ripples in the GDT and amplitude characteristics as well as deterioration in attenuation level outside the pass band. Signals that should not pass could then cause interference later in the circuit. In TVs, this can cause a ghost image to the left of the main signal.
In order to minimize the signal attenuation in the filter it is desirable to minimize the insertion loss in the filter. The insertion loss is not the same as the power loss. We distinguish between power loss and insertion loss in the following way: insertion loss is the ratio of output voltage when the filter is shorted to the maximum output voltage when the filter is inserted; power loss is the ratio of the available power of the source to the power supplied to the load. Numerically,

$$Voltage\ \ loss = 20\log\left(\frac{V_S}{V_L}\right)$$

$$Insertion\ Loss = Voltage\ Loss - 20\log\left(\frac{R_S + R_L}{R_L}\right)$$

$$Power\ Loss = Voltage\ Loss + 10\log\left(\frac{R_L}{4R_S}\right)$$

Where:
V_S = source voltage
V_L = load voltage
R_S = source resistance
R_L = load resistance

Common practice to reduce insertion loss is to conjugately match the input and output impedances. SAW filters have a capacitive component in input and output impedance, which can be cancelled by adding inductors. The purely resistive components of the filter impedance can be matched with R_S and R_L. However, the TTE level and power loss are inversely related: when the power loss is reduced the TTE increases. As a result, it is necessary to greatly mismatch the filter. For practical uses a –40dB suppression of TTE is required which requires a theoretical power loss larger than 16dB. Adding a safety margin, the actual power loss should be greater than 18dB.
The level of direct breakthrough has three main causes. The first is electrostatic causes like stray capacitances. The second is electromagnetic inductions due to the currents passing through the printed pattern. To limit these effects, the printed input and output patterns should be made small and short and the VIF stage should be shielded from the other stages. The last cause is ground loops. There are a number of places on the board where the earth grounds are mutually connected. These should be cut where possible to limit the number of loops.

Applications

Television, Cable, and VCR

The most common use of SAW filters is in television receivers. A television signal has three parts: a sound signal, a picture signal, and a color or chroma signal. These three signals are placed in a 6MHz frequency band called a channel. Within the 6MHz band, the video carrier is centered at 1.25MHz from the low end and the sound carrier is centered at 250kHz from the upper end. This leaves a 1.5MHz guard between the adjacent channels to prevent interference. The chroma carrier is centered at 3.58MHz from the video carrier. Figure 92 illustrates the television signal.

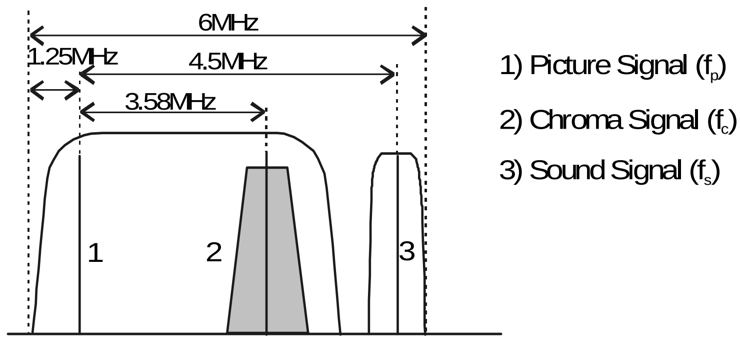

Figure 92: TV Channel Spectrum Description (NTSC-M)

Television receivers all have the same basic parts. The first part is an antenna or, in the case of cable television, a cable. The antenna receives all channels simultaneously, spread across the frequency spectrum.

The next part is a tuner that selects the desired channel by using a local oscillator to bring the channel frequencies down to the IF frequencies. The IF frequencies are the frequencies that the rest of the receiver is tuned to and uses to produce the picture and sound. The oscillator frequency is adjusted by the user and forms a reference signal. All of the signals from the antenna are subtracted from the reference signal and the desired channel is reduced to the IF frequencies and reversed. For example, channel 6 lies in the range from 82 to 88 MHz. As stated before, the video carrier is 1.25MHz above the low end, which is 83.25MHz, and the sound carrier is 4.5MHz above this, or 87.75MHz (Figure 93a). The standard IF frequencies in the U.S.A. are 45.75MHz for the picture and 41.25MHz for the sound. By tuning the oscillator to 129.00MHz, the channel 6 video carrier becomes 129 – 83.25 = 45.75 and the sound carrier becomes 129 – 87.75 = 41.25. This reduces the signal to the IF frequencies and inverts the signal, the video signal is now higher than the sound signal (Figure 93b). All of the frequencies in the antenna are treated in this manner and then sent to the next stage.

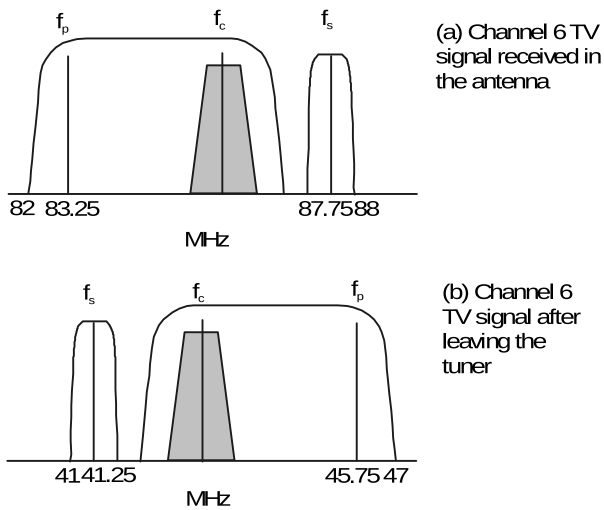

Figure 93: TV Channel Conversion

The third stage is a SAW filter. This filter selects the signals only in the IF frequencies. All others are rejected. To continue the example above, the tuner has reduced the channel 6 signals to the IF frequencies. Since the SAW filters only pass the IF frequencies, only the channel 6 signals are sent on to the rest of the receiver. This stage begins what is called the tuned part of the receiver. The rest of the receiver is adjusted so that only the signals in the IF frequencies are seen or manipulated and the operator does not have to adjust anything else.

The next part is an amplifier that increases the signal strength. The amount of energy received at the antenna is very small and even more is lost in the previous stages. This stage boosts the strength to a point that the following stages can more effectively use.

The next stage is an IF detector that strips away the carrier signals reducing the signals to the baseband (0 – 6MHz) and inverting them using the same method as the tuner.

Next the signal is split two ways. One part is passed through a filter that selects only the sound information. This information is passed to an amplifier and then to a FM detector where the signal is demodulated. From here the signal goes to the speaker on the TV. The other part is passed through a trap that selects only the picture and chroma information. This information is sent to an amplifier and then to the picture tube circuitry.

This is the basic idea behind the receiver, though there are a few different kinds with slightly different designs.

Figure 94 shows a diagram of a basic receiver and the resulting signal after each section.

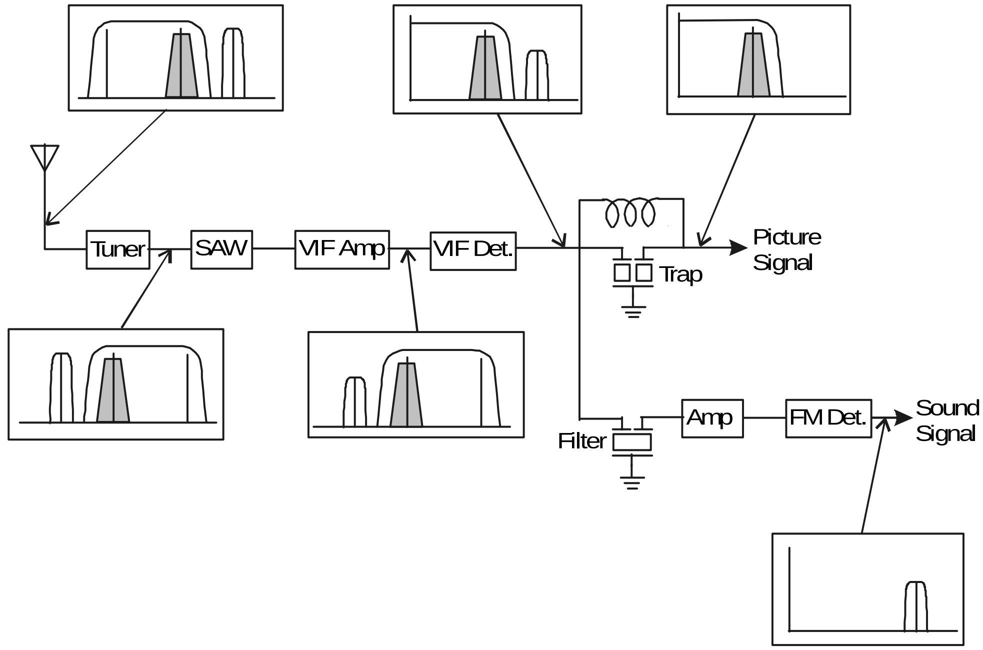

Figure 94: TV Signal In A Receiver

Types of TV, VCR, and Cable Receiver

There are three main kinds of receiver used in television, cable, and VCRs. The first is the inter-carrier system (Figure 95). This system is the basic system described above. This is the cheapest and simplest system but suffers from "buzz" which results from the picture signal breaking into the sound signal.

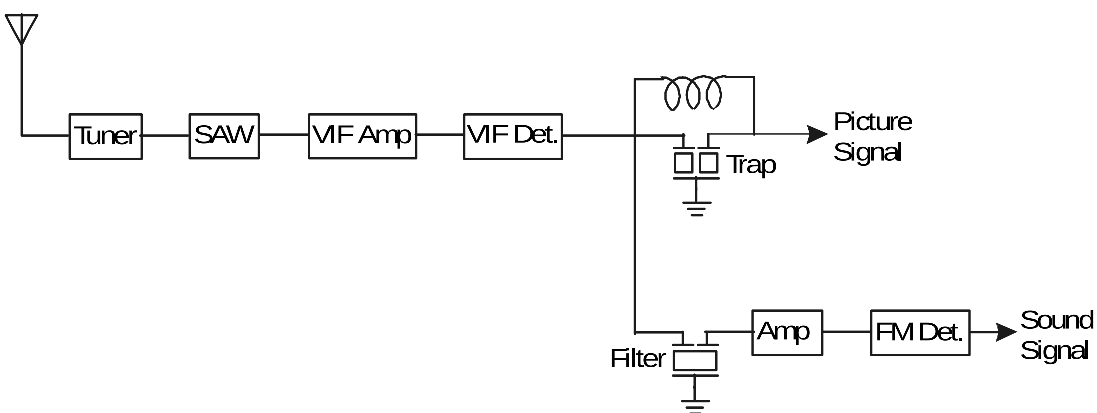

Figure 95: Inter-Carrier System

The second kind of receiver is called the quasi-parallel system (Figure 96). This system has two SAW filters after the tuner: one to select the picture and chroma IFs and one to select the sound and picture IFs. The picture and chroma signals go through the amp, VIF detector, and trap as before. The sound and picture signals go through an amplifier and then to an SIF detector where the picture signal is used as a reference to strip away the sound carrier signal. A filter then removes the picture signal, an amplifier increases the signal strength, and a FM detector demodulates the signal. This system has better signal separation than the inter-carrier system.

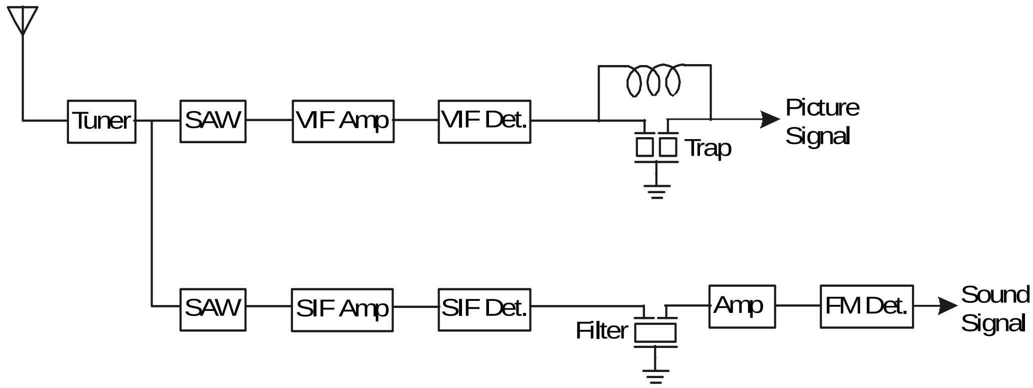

Figure 96: Quasi-Parallel System

The last receiver is called the split-carrier system (Figure 97). It is similar to the quasi-parallel system except that the SIF detector is replaced by an oscillator that converts the sound signal down to the sound IF frequency. Because of this the picture signal is not needed as a reference so the SAW filter selects only the sound IF. This system has the best signal selection and the most complicated design.

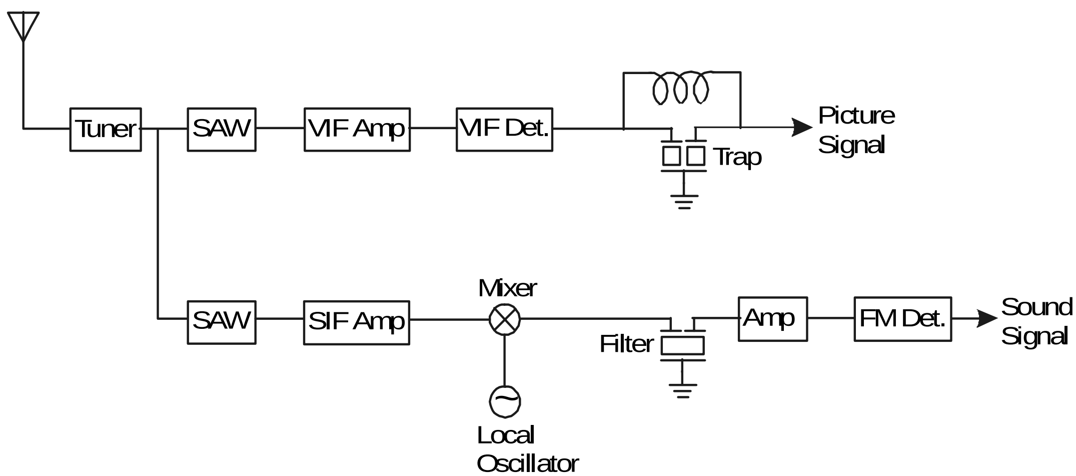

Figure 97: Split-Carrier System

Connection of the SAW Filter to Other Stages

The most common way of compensating for the high insertion loss of the SAW filter is by inserting an amplifier. Where the amplifier is inserted and how the stages are connected becomes important to reducing losses and distortion. When the amplifier is placed before the filter, it is called a preamplifier system. Input impedance matching is accomplished by R_C in Figure 98. The parallel inductor cancels the capacitive component of the filter input impedance. Increasing the value of R_C will increase the gain of the amplifier but will also increase TTE. The output impedance match is accomplished by R_3. Here, a higher value for R_3 results in a lower TTE, but as stated before, R_C should equal R_3 for minimum power loss. The values of R_C and R_3 must be determined by compromising between gain and TTE suppression. Because the signal is amplified to high levels, intermodulation distortion becomes a concern. A common way to prevent this is to insert a negative feedback resistor on the emitter.

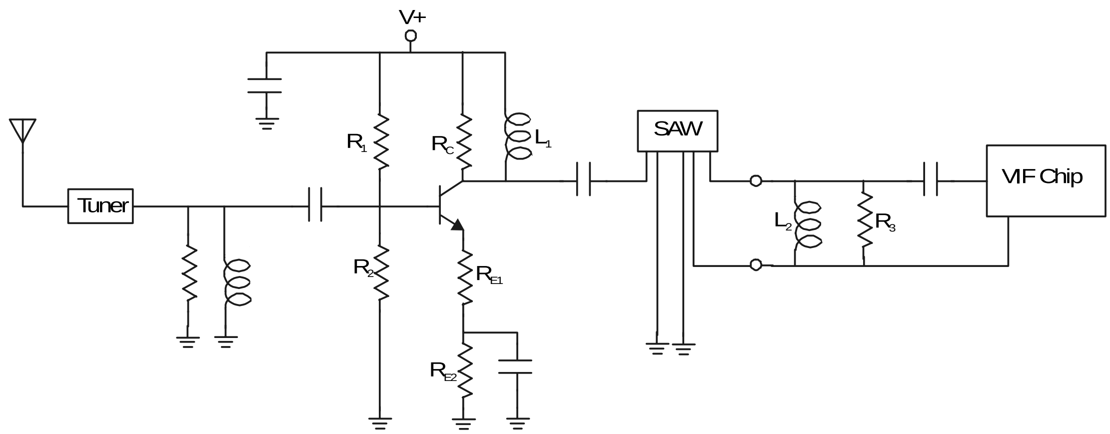

Figure 98: Pre-amplifier Matching Circuit

The preamplifier system is suited for high impedance SAW filters. For low impedance filters, the resistor values would have to be small to suppress TTE. If R_C is too small, then the collector current is limited by the maximum collector dissipation of the transistor and the gain suffers. In order to use a low impedance filter an impedance conversion circuit is required (Figure 99). The capacitance of the SAW filter corresponds to C_2 in the conversion circuit, the coil corresponds to L_1, and capacitors added in place of the circles in Figure 98 correspond to C_1. The transformation ratio is given by $C_1 : (C_1 + C_2)$ and the impedance ratio is given by $C_1^2 : (C_1 + C_2)^2$. An arbitrary impedance transformation can be set by picking a convenient value of C_1. The impedance at the input of the filter can be increased by stepping down and at the output the impedance can be increased by stepping up. In this way, a low impedance filter can be used with the same peripheral circuit.

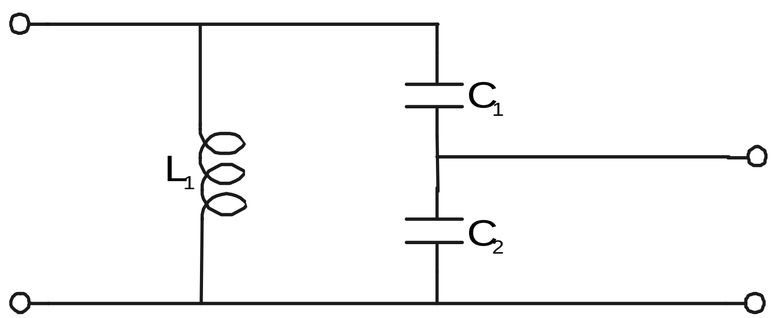

Figure 99: Impedance Conversion Circuit

The system that places the amplifier after the filter is called a postamplifier system. Figure 100 shows an example of a postamplifier system. The input impedance will have a value around 50Ω to 100Ω while the output of the tuner is nominally 75Ω. Since the input of the SAW is not 75Ω the output circuit of the tuner can be affected. If the impedance is higher than 75Ω, then the Q of the IF output circuit becomes high and the bandwidth becomes narrower. To prevent this, a Q damping resistor should be placed in parallel with the input terminals of the SAW filter. Because of the low signal level after the filter there could be deterioration of the noise figure. For this reason, it is desirable to use a high gain tuner. In order to prevent deterioration of the Signal to Noise ratio the tuner should be able to handle a high signal level before AGC begins to operate.

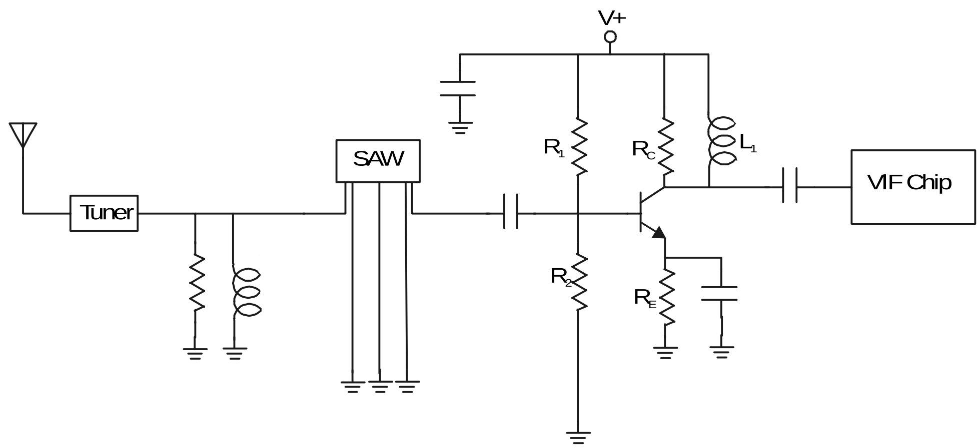

Figure 100: Post-amplifier Matching Circuit For Low Impedance

The postamplifier design is best used with low impedance filters because the filter termination is limited to a low impedance. To use high impedance filters with this design a tuning coil must be placed in series with the filter input as shown in Figure 101. This will allow a close match at the input that will reduce loss. The large mismatch at the output will cause a high loss that will suppress TTE. In this way, a high impedance filter can be used with the same peripheral circuit.

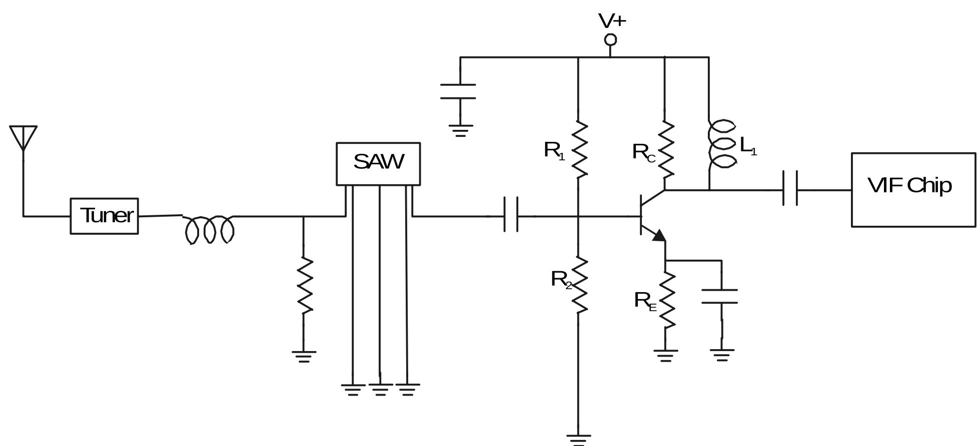

Figure 101: Post-amplifier Matching Circuit For High Impedance

If the gain of the VIF chip can be increased then the amplifier becomes unnecessary. The tuner becomes the signal source for the SAW with a fixed impedance of 75Ω and the VIF chip becomes the load with an impedance between 1kΩ and 3kΩ. Since the source and load have fixed impedances it is necessary to include matching circuits in either the input or the output. For a high impedance filter, a parallel coil can practically match the output of the filter to the input of the chip, or a series coil matches the input of the filter to the output of the tuner as described previously. In the case of a low impedance, the input of the filter is matched to the output of the tuner by a parallel coil, or the output of the filter is matched to the input of the chip by the transformation circuit described above. Both circuits can attain an insertion loss of approximately 10 - 18dB making the amplifier unnecessary. Figure 102 shows diagrams for both types of filter.

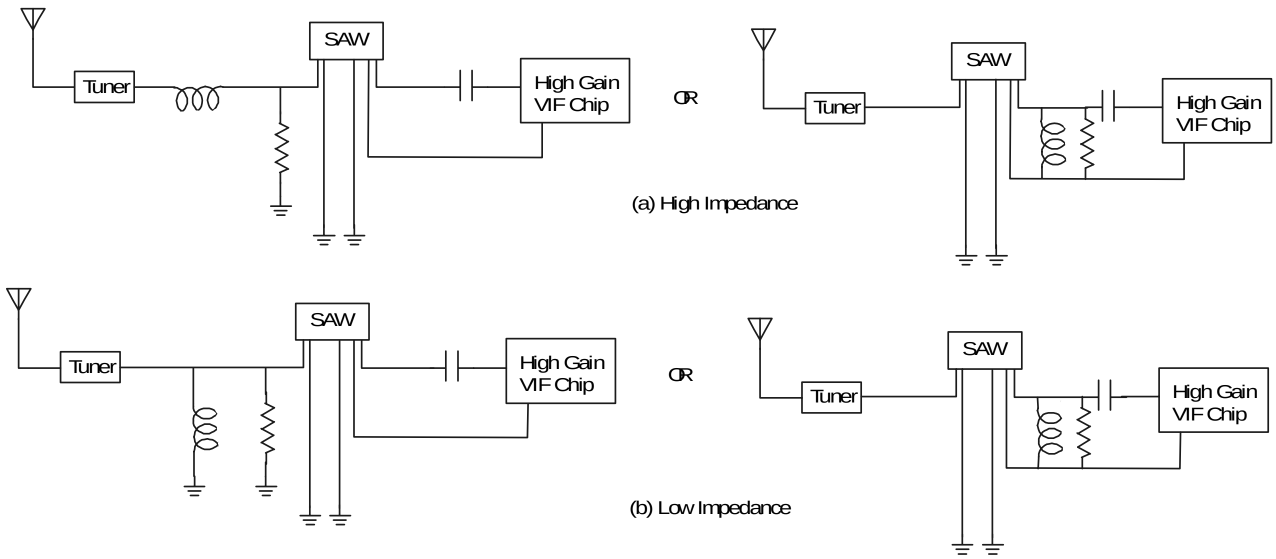

Figure 102: No Amplifier Matching Circuits

Murata offers a characterization service, free of charge, which will provide a matching circuit for the SAW filter. The customer must provide samples of the IC they intend to use and Murata will provide the output circuit and frequency correlation data. It is recommended that the customer provide a sample of their PC board so that both impedance matching and breakthrough suppression can be evaluated. This ensures the best possible performance of the filter.

Parts

Figure 103 shows the basic part numbering structure Murata uses for its SAW filters.

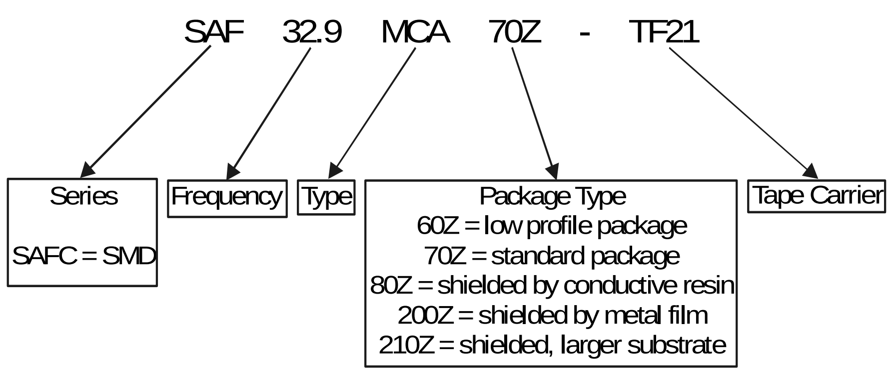

Figure 103: SAW Filter Part Numbering System

The 80Z and 200Z packages can be supplied in ammo-pack packaging. A SAW filter data book, listing the filters and the system each filter applies to is available upon request.