Piezoelectric Filters

Introduction

As you may know, we are constantly surrounded by all sorts of radio frequencies. From audio range frequencies that we can hear to very high frequencies that are visible as light, our electronics and we are constantly being immersed in these frequencies. It is the job of a band pass filter to pick out only the range of frequencies desired for the intended application.

Ideally, when an inputted signal (say from an antenna) goes through a band pass filter, all frequencies that are within the bandwidth ("pass-band") of the filter will be allowed to pass through the filter. Those frequencies above or below the pass-band region (in the "stop-band") will be attenuated (or rejected) at some fixed value (determined by the filter) and thus will not be seen at the output of the filter. Figure 29 visualizes the effect of an ideal band-pass filter.

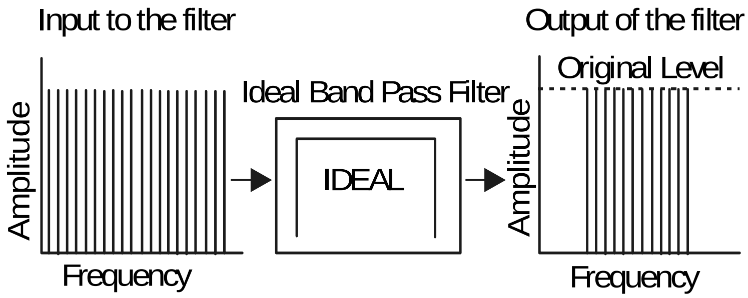


Figure 29: Ideal Band Pass Filter

As you can see in Figure 29, all frequencies are allowed to enter the filter but only those frequencies within the pass-band are allowed to exit the filter unattenuated (or unaffected).

One would expect that the band of frequencies passed by the filter would leave the filter unaffected, but this is not the case for a practical band-pass filter. There are many parasitic losses associated with a practical band-pass filter, such as insertion loss, ripple, and non-ideal roll off. Figure 30 visualizes the effect of a practical band-pass filter on a signal.

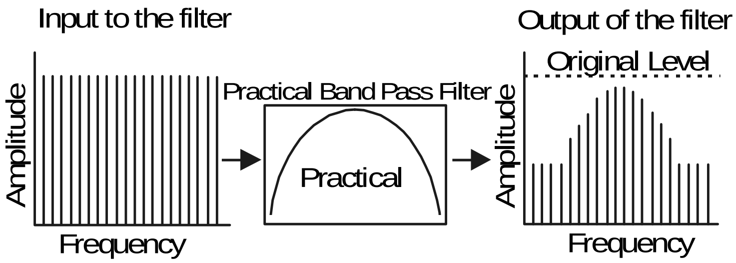


Figure 30: Practical Band Pass Filter

As you can see from comparing Figure 29 to Figure 30, the output of the filter is quite different. First you will notice that the signal level of the output signal in Figure 30 is less than the original signal level. This is due to the inherent loss (or insertion loss) of the filter. You will also notice that the sides of the pass-band in Figure 30 are not vertically straight, as in Figure 29. Practical filters, as in Figure 30, can not achieve such performance. The response will always look rounded. Very selective filters will have roll off approaching that of an ideal filter, but will trade off performance in other key filter performance parameters.

One very important parasitic effect not shown in Figure 30 is Group Delay Time (GDT). The next section will cover this important effect.

Group Delay Time (GDT)

For this discussion we are only concerned with the effect of GDT on the frequencies being allowed to pass through the band pass filter. We are looking at this characteristic specifically since it is the hardest to understand.

In a practical band-pass filter, the filter actually causes the passed frequencies to be delayed slightly in time as they pass through. The delay time is not constant across the pass-band and the frequencies end up being delayed by differing amounts of time. Frequencies occurring close to the center frequency of the filter are delayed the least while frequencies closer to the edges of the pass-band are delayed more. This delay effect is referred to as Group Delay Time (GDT). Since the frequencies are effected in time, the phase of the frequencies in relation to each other is changed. Hence, the term phase delay is sometimes used as a synonym to GDT. Figure 31 visualizes this delay effect.

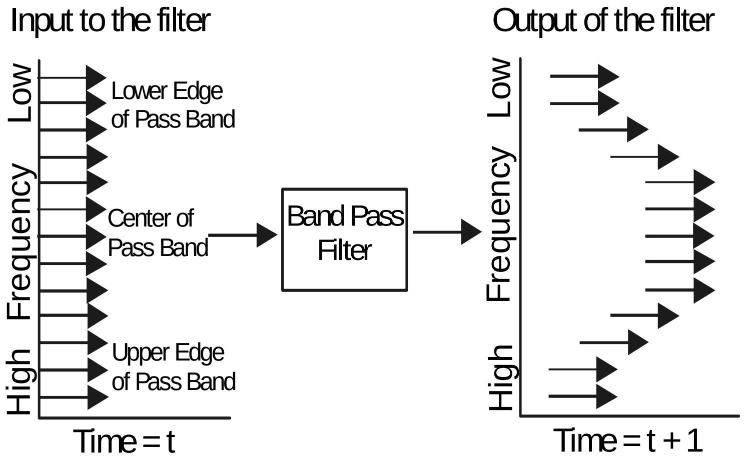


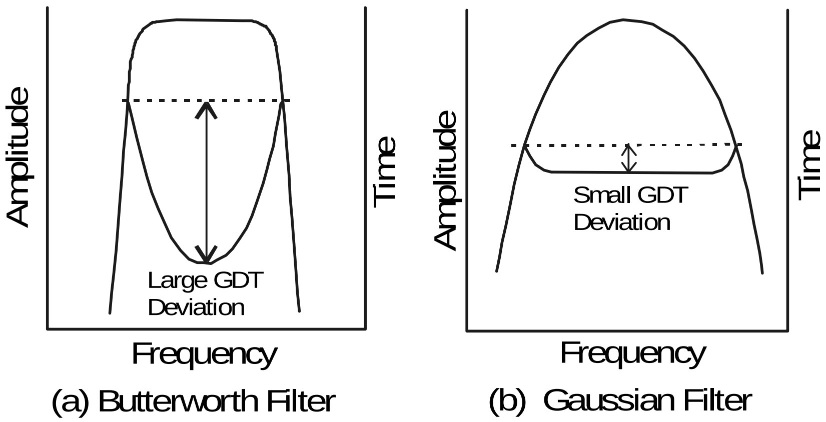
Figure 31: Group Time Delay

In Figure 31, we see a series of frequencies (we will only look at frequencies occurring within the pass-band of the filter, even though other frequencies are entering the filter as well) just prior to entering the filter. The frequencies are all aligned at the same point in time. Think of this like a horse race and each arrow (representing a frequency) is a horse. At time “t”, all of the horses are at the starting gate. The race starts and the horses / frequencies enter the filter. At the end of the race (time now equals “t+1”, or some time in the future), as shown at the “output of the filter” in Figure 31 above, the horses / frequencies that traveled near the center of the filter’s pass band leave the filter first. Those horses / frequencies near the upper and lower edges of the filter’s pass-band are delayed compared to the horses / frequencies at the center. The horses / frequencies at the pass-band edges have been delayed in time. This means that the filter imparts some time delay to frequencies in the pass-band. This effect can be considered a form of distortion since the filter is modifying the frequencies it should pass. Ideally, the filter should not effect the signal in the pass band at all.

In purely analog systems, this GDT is not too devastating. GDT generally causes distortion of the signal but usually not to the point of adversely effecting the analog system.

In a digital system, however, GDT can be devastating if the delay is too great. The heart of a digital system is the square wave (pulse). The square wave is composed of many sine waves of various frequencies (harmonics). The higher and lower sine wave frequencies form the squared off shoulders and the steep transition point. The frequencies most important to a square wave’s shape are the frequencies usually effected the most by the GDT effect. This effect can degrade the square wave to a point where it loses all meaning to a digital system. For a digital system engineer, this means that his Bit Error Rate (BER) will suffer.

A band pass filter’s characteristics have a significant effect on the magnitude of GDT deviation that occurs between the delay times of each frequency in the pass-band. A band-pass filter with a Butterworth type response has poor GDT performance but has good selectivity and a flat pass-band. The Butterworth response is characterized by a flat pass-band with relatively sharp roll-off (Figure 32a).



(a) Butterworth Filter (b) Gaussian Filter

Figure 32: Types of Band Pass Filter

The GDT of this type of filter is characterized by a large deviation time between the frequencies around the center frequency and the frequencies at the pass-band edges.

A band-pass filter with a Gaussian type response has good GDT performance, but only moderate selectivity (Figure 32b). The Gaussian response is characterized by a rounded pass-band with moderate roll-off. The GDT of this type of filter is characterized by a small deviation time between the frequencies around the center frequency and the frequencies at the pass-band edges.

One important point to make is this: if all frequencies in the pass-band were delayed by the same amount of time, the overall negative effect to the system (analog or digital) is diminished.

GDT Specification

In the specification for a filter that has controlled GDT characteristics, Murata specifies GDT deviation as opposed to absolute GDT. Absolute GDT references all measurements from the time a signal is inserted into the filter. GDT deviation refers to the time difference from the first frequency out of the filter to the last frequency out of the filter, for a given signal. GDT deviation is a better measurement since the most important information is how the frequencies deviate from each other in time. In all GDT measurements, the unit of measure is time (usually in nanoseconds or microseconds) over a given bandwidth. Here is an example of a GDT spec: 25µS max over ±30kHz (referenced to f_o).

Other Band Pass Filter Characteristics

Figure 33 shows the response plot of the output from a band pass filter. The various band pass characteristics of interest are labeled and numbered. The explanation for each of these characteristics is shown in the table.

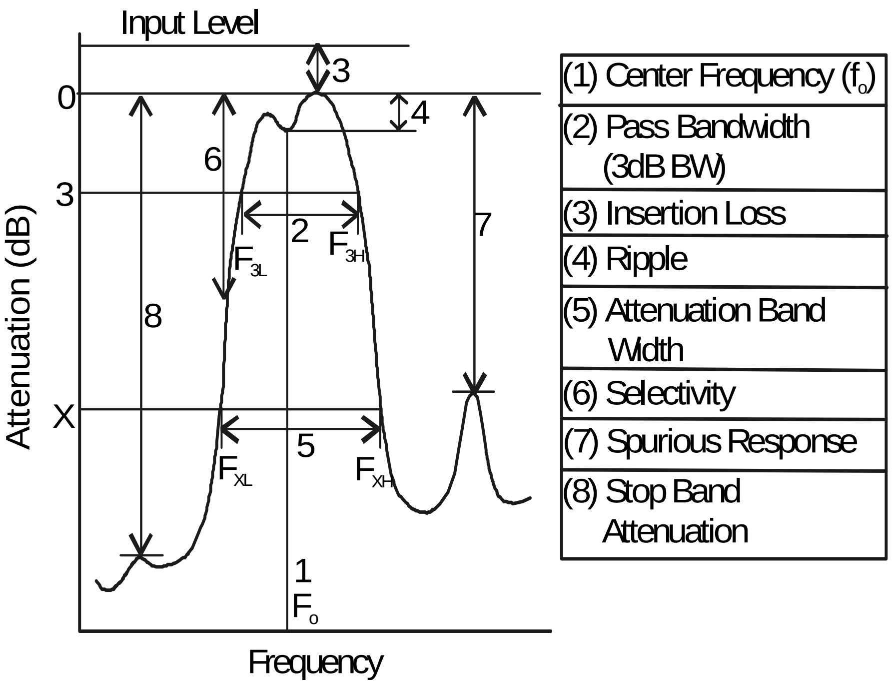


Figure 33: Band Pass Filter Characteristics

- Center Frequency

The frequency in the center of the pass band. To calculate the center frequency, use the following equation (some symbol notation is from Figure 33):

$$F_o = \frac{F_{3L} - F_{3H}}{2}$$

Example: F_o = 455kHz

- Pass-Bandwidth

This is the difference between the two frequencies (F_{3L} and F_{3H}) that intersect a horizontal line 3dB down from the point of minimum loss. Depending on the filter type, some filters specify the 6dB bandwidth instead of the 3dB bandwidth. In this case, the horizontal line used to intersect the frequency plot is 6dB down from the point of minimum loss.
Example: 3dB B.W. = 60kHz total or ±30kHz (referenced to f_o).
6dB B.W. = 64kHz total or ±32kHz (referenced to f_o).

- Insertion Loss

The minimum loss for a given input signal associated with the given filter. It is expressed as the input/output ratio at the point of minimum loss. The insertion loss for some filter products is expressed as the input/output ratio at the center frequency.
Example: I.L. = 5dB max.

- Ripple

If there are peaks and valleys in the pass band, the ripple is expressed as the difference between the maximum peak and the minimum valley.
Example: Ripple = 1dB max.

- Attenuation Bandwidth

Attenuation bandwidth is the bandwidth of the pass-band at a specified level of attenuation. This is similar to the 3dB or 6dB bandwidth except that the attenuation level used is significantly higher, usually 20dB or larger. In Figure 33, it is the difference between F_{XL} and F_{XH} where “X” is the attenuation level.

Example: 40dB B.W. = 100kHz total or ±50kHz (referenced to f_o).

- Stop Band Attenuation

Stop band attenuation is the maximum level of strength allowed for frequencies outside of the pass-band.
Example: Attenuation 455 ±100kHz = 35dB min.

- Spurious Response

The spurious response is the difference in decibels (dB) between the insertion loss and the spurious response in the stop band (area not in the specified pass-band).
Example: Spurious Response = 25dB min.

- Input / Output Impedance

The input and output impedances are the impedance values that the filter should be electrically matched to at the filter's input and output, respectively.
Example: I/O impedance = 1KΩ

- Selectivity

The selectivity is the ability of a band pass filter to pass signals in a given frequency bandwidth and reject (or attenuate) all frequencies outside of the given bandwidth. A highly selective filter has an abrupt transition between the pass-band region and the stop band region. This is expressed as the shape factor, which is the attenuation bandwidth, divided by the pass bandwidth. The filter becomes more selective as the resulting value approaches one.

Connecting Filters In Series

It is sometimes helpful to increase outband attenuation by connecting filters in series. If the input and output impedances of the filters are equal, then the filters may be connected directly to each other. If they have different impedances, a matching circuit may be necessary.
The main advantage to connecting filters in series is that there is a much better spurious response attenuation and outband attenuation. Some disadvantages are that insertion loss, GDT, and ripple are all additive. The differences between worst case and best case for each specification can cause a wide variation in these specifications when they are added. For example, if the insertion loss of a filter is specified to be between 3 and 6dB, then when they are added the insertion loss will be between 6 and 12dB.
The main disadvantage is that the center frequency variations part to part can decrease the absolute bandwidth of the combination of filters. As can be seen in Figure 34, if the center frequencies are slightly off, then the absolute bandwidth will be between the lower end of the filter that is centered higher and the upper end of the filter that is centered lower.

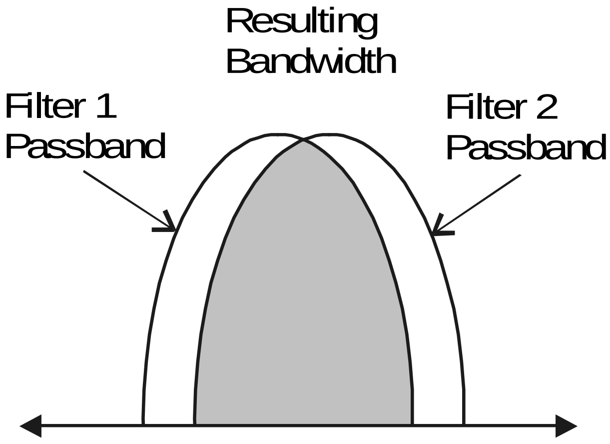


Figure 34: Resulting Bandwidth When Cascading Filters

The resulting center frequency will be somewhere between the two filters. For some applications this is not a large problem and is cheaper than buying filters with more elements.

PZT Band Pass Filters

Filter types available

The PZT group of Murata only offers band pass filters. We offer band pass filters with the following center frequencies:

- 450kHz or 455kHz
- 10.7MHz and 4.5 to 6.5MHz (Sound IF applications for video)

Note: Murata's PZT group also makes band pass filters from 3.58MHz to 6.5MHz, but these filters are typically for video / TV applications only. We can also offer VIFSAW filters, which are band pass filters too, but are also for video / TV applications specifically. There is a specific application manual for these video products, but the concepts for band pass filters apply to these products as well.

Most filters are available in both leaded and surface mount (SMD) packages. Certain specialty filters are only available in leaded packages.
The next section will display the variety of Murata filters available at 450/455kHz and 10.7MHz, and each filter's basic electrical specifications