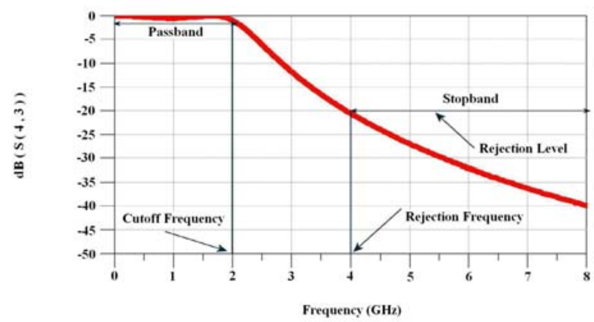
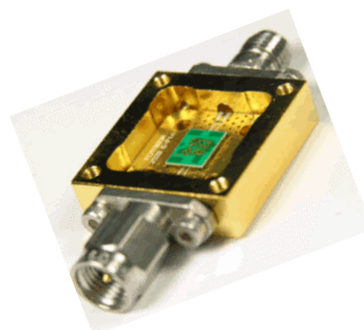




Thin Film Technology Filter Design Guide

New Table of Contents

About Thin Film Technology Corp.

Thin Film Technology Corporation is an electronic component manufacturer specializing in thin film technology. Established in 1979 in North Mankato, Minnesota, for over 30 years, Thin Film Technology has used thin film as the springboard to devise innovative component technologies to the high technology markets.

Thin film processing itself is a skilled art, and in combination with advanced manufacturing technologies, the creation of product technologies that were once only dreams can be achieved. Thin Film Technology maintains the view that thin film components do not need to be expensive. Through common sense manufacturing methods, affordable, high performance products can be obtained. Against this unique approach, Thin Film Technology sees each customer need as a challenge, one to provide only the finest in affordable performance thin film products.

The art of combination. . . the essence of Thin Film Technology. Since 1980 Thin Film Technology has been designing and manufacturing thin film components. From our ISO9001 and ISO14000 registered factory, quality products serving the computer, test equipment, telecommunication, medical, automotive and other electronic markets are shipped worldwide.

How to Use This Guide

Purpose:

The purpose of this filter selection guide is to outline predetermined filter functional responses along with frequency scaling and packaging requirements to provide a method of selection. Basic filters have multitudes of applications and uses. There are also inherent merits and trade-offs to different functional elements. A good amplitude selective filter such as a butterworth has phase dispersion that influences overshoot in the time domain. On the other hand, the flat delay response of the bessel function exhibits a gradual amplitude loss slope that contributes to jitter in the time domain. Along with selecting basic filter function attributes, certain attributes are increased by the order of the filter. For example, increasing the order of a butterworth filter increases its selectivity. Increased filter orders are accomplished by adding resonator elements that also increase physical size and material costs. The frequency at which a filter is designated is normally its 3dB roll-off point. This frequency is inversely proportional to size. This means lower frequencies are prohibitive to certain technologies based on physical size. This guide outlines the typical sizes associated with frequency scaling.

How To Use:

1. The basic filter functions are presented first for general response comparisons. Once you decide on the type of response you are interested in applying, more detailed responses are presented for comparison of attributes versus frequency for amplitude, phase, and time domain (low pass).
2. Deciding on the order of the filter required, the phase dispersion and amplitude responses can be scaled from the nominal 1GHz chart to give a good idea of the response at any frequency.
3. Once the type, function, order, and frequency of the required filter are obtained, the package requirements are grouped by charts that display element area versus frequency for each type of filter. These charts display separate slopes for each order of the specified filter type, and the area available in each package type.
4. The package types and dimensions are outlined after the package selection charts on page 17.

Low Pass Filters and their Applications

Introduction

Filters are essential to the operation of most electronic circuits. In circuit theory, a filter is an electrical network that alters the amplitude and/or phase characteristics of a signal with respect to frequency. Ideally, a filter will not add new frequencies to the input signal, nor will it change the component frequencies of that signal, but it will change the relative amplitudes of the various frequency components and/or their phase relationships.

Filters are often used in electronic systems to emphasize signals in certain frequency ranges and reject signals in other frequency ranges. To correctly specify a filter's characteristics one has to understand and specify the four corners of the filter's transfer function's plot. Without the four corners one will fall of the edge of the world. One of the four corners would be the signal magnitude of lowest interest of frequency. The second corner would be the –3dB cutoff frequency point of the signal magnitude. The third corner would be the rejection frequency and rejection magnitude of the signal and the fourth and last corner would be the out of band rejection point of maximum interested frequency. Without specifying these four corners a filter's characteristics cannot be demonstrated.

Describing all the applications of a filter in any electronics system is beyond this application note. Brief descriptions of several filter applications are discussed in the following.

Desired Signal Selection:

One of the most common applications of the filters is to select wanted signal component from the available frequency band and reject unwanted signal component from the frequency band. The addition of appropriate filters in the system will guard the interested signal component against any interference across adjacent signals. It not only distinguishes desired signal from other frequency components, but also reduces noise, which is added with the desired signal; and eliminates cross talks in between signals. The consequences of inadequate filtering translate into cross talk, signal drop out, noisy signal, and even complete transmission interruption. These phenomenon result in loss of data and interrupted network connections among users. Using correct filters can help maintain signal integrity as well combat the difficulty in transmitting and receiving a clear signal.

Duo-binary Signal Generation for Optical Communication:

In the optical communication domain, among several modulation formats, Duo-binary modulation format is a popular choice among fiber-optic communication system engineers. It is a spectrally compressed modulation format, which achieves robust chromatic dispersion tolerance while utilizing standard direct detection optical receivers. In its most common implementation, a Duo-binary signal is created using an encoder, an electrical driver amplifier, a

Mach-Zehnder modulator, and an electrical filter with a –3dB cutoff around 25-35% of data rate. Without the filter, three level Duo-binary signal creation would be impossible. The key point regarding the optical Duo-binary format is that linear phase response is needed in the electrical components in order to create the most robust transmitted eye diagram possible. This kind of linear phase response is achieved by using a Bessel Thompson filter.

Bit pattern dependent distortion minimization in Digital Communication:

In modern digital communications systems, system engineers must be aware of the impact both the magnitude and phase response of the associated components and transmission lines will have on the quality of the received bits. To minimize the bit pattern distortions phenomenon in the transmitter and receiver, a flat group delay filter can be employed. Using a flat group delay filter helps all of the frequency components comprising the transmitted pulses pass through the filter with the same time delay. It is necessary to use filters with flat group delay in order to achieve the highest eye quality in terms of overshoot/undershoot and eye symmetry. Bessel-Thompson (BT) filters can be used to filter digital signals in both transmitter and receiver applications because of their “maximally flat” group delay (i.e. highest linear phase) characteristics. BT filters achieve a significantly flatter group delay response at the expense of decreased stop band rejection.

Jitter elimination and overshoot ringing elimination:

When working in the time domain, designers face the presence of undesirable perturbations on a pulse signal, such as precursors, overshoot, and signal ringing. These perturbations extend well beyond the rise time interval and create uncertainty in the actual value of the pulse for a much longer duration. As the bandwidth increases, the signal experiences very fast rise time and fall time. This higher speed causes timing jitter resulting in a smaller signal eye opening. Faster signals also take a longer time to settle down to the final values and creates overshoot ringing, which also helps reducing signal eye opening. These phenomenon eventually reduce integrity of the signal.

One effective way to combat these undesired events is to use a optimum Gaussian low pass filter. With Gaussian wave shapes, pulse signals rise and fall smoothly and then rapidly settle to their final bit values. Also with filter frequency response, signals bandwidth is reduced, which eventually slows down the rise and fall time. Slower rise and fall time reduces the timing jitter in the signal. All oscilloscope manufacturers strive to make their oscilloscopes with responses approximating to the Gaussian filter shape.

Inter-Symbol Interference (ISI) minimization

Another important phenomenon that system engineers needs to worry about is Inter Symbol Interference (ISI). Transmitting rectangular signal pulse through a limited-bandwidth channel distorts the pulse by smearing it, where the pulse gets stretched out in time. Moreover, due to the nature of multipath propagation, the transmitted signal experiences delay spread, resulting in one symbol spreading into subsequent symbols. This spreading and smearing of the symbols carries the energy from one symbol to the next ones. This interference between adjacent symbols is called inter-symbol interference (ISI). Presence of ISI in the received signal increases the probability of signals being interpreted incorrectly. Communication system designs for both wired and wireless nearly always need to incorporate some way of controlling ISI. The addition of a low pass filter in the receiver path can help remove these defects. Raised cosine low pass filters are usually employed to reduce ISI (Inter Symbol Interference) in between bit pulse. In certain digital telecom systems, such as SDH, SONET, and Fiber Channel, system specifications mandate the use of low pass filters with –3 dB cutoff frequencies of 0.75 of the bit rate.

Aliasing Reduction

While sampling data, system engineers must pay attention to the sampling rate. Sample rates must be greater than or equal to two times the highest frequency component in the input signal. When this rule is violated, unwanted or undesirable signals appear in the frequency band of interest. This is called "aliasing." This aliasing phenomenon due to unwanted, spurious out of band signals can seriously endanger the performance of successful signal transmission. Aliasing can be reduced and eliminated by using anti-aliasing filters. Anti-aliasing filters provide a cut off frequency that removes unwanted signals (aliasing component) or at least attenuates them to the point that they do not adversely affect the system performance. Optimally designed low pass filters with high 'Q' value can be used as anti-aliasing filters to reduce the aliasing occurrence.

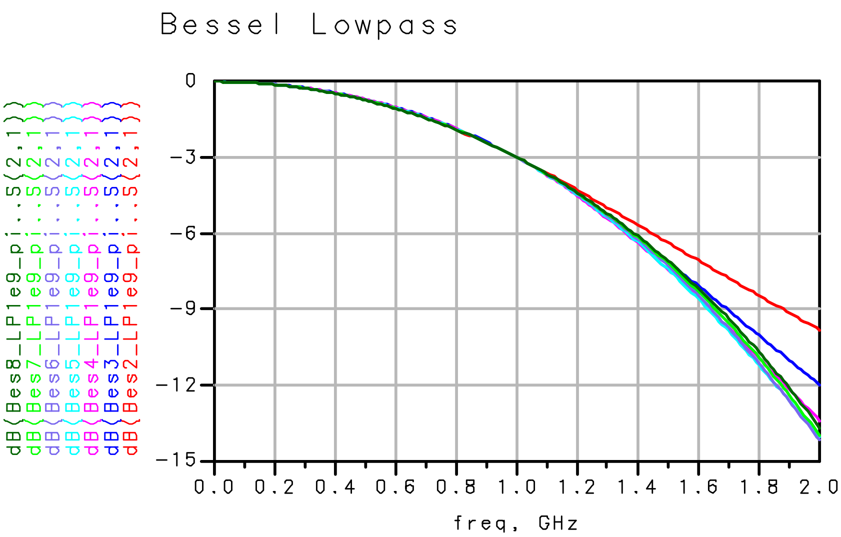
Out of Band Reflections elimination

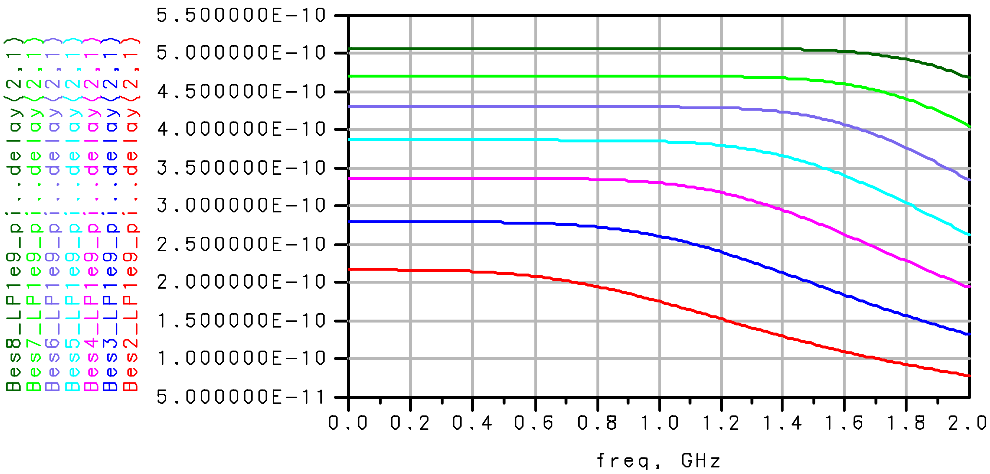
Another degradation factor for ultra high speed signal transmission is the reflections that take place outside the desired bands. Undesired interference and increased jitter can occur due to the out of band reflections. Absorptive low pass filters can eliminate out of band reflections. Using absorptive low pass filters, designers can achieve good VSWR even outside the interested frequency bands. Absorptive filters provide superior impedance matching in both the pass band and stop band. These absorb out of band reflections without the need for additional fixed attenuators.

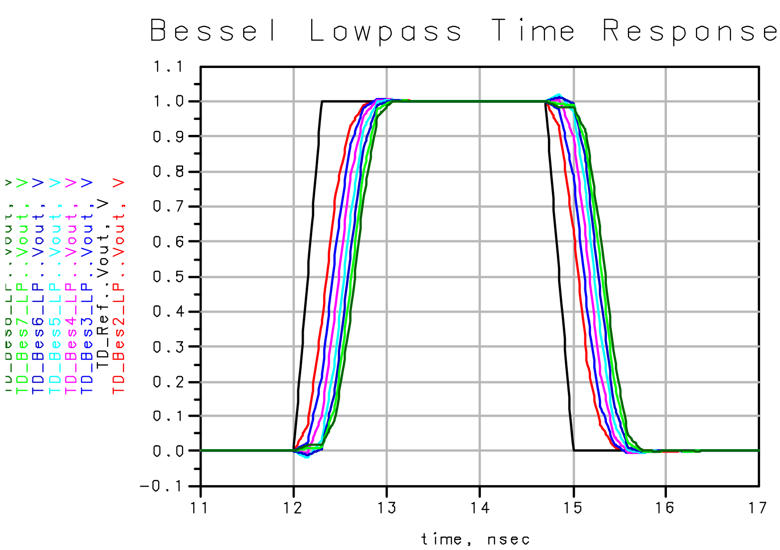
Conclusion

Several applications have been discussed in this chapter. The main application for low pass filters is to filter out undesired signal components from the band. This would clear out the signal from noise, cross talk, jitter and other undesired phenomenon. Other important applications including application in time domain as well as digital domain has also been discussed. Filters are one of the most necessary components in any sort of signal transmission. Without filters' presence in the subsystem and system level, no data transmission would be possible.

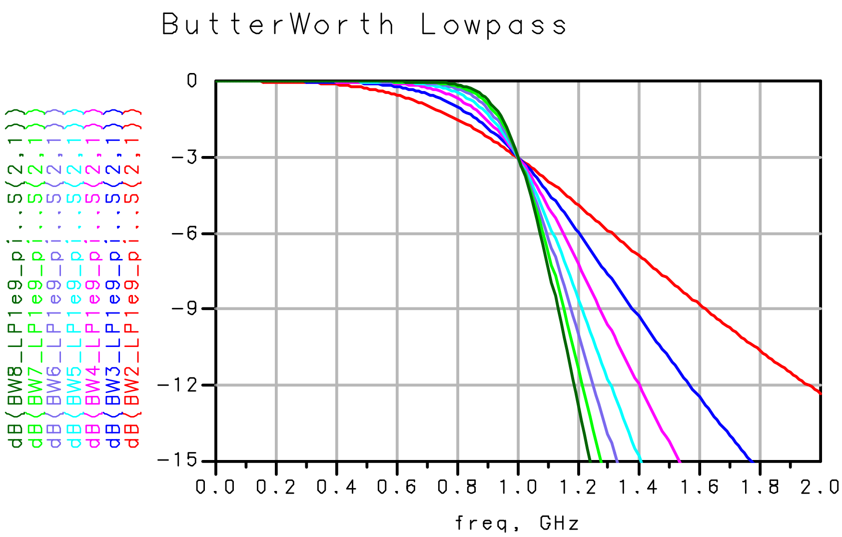
Bessel Low Pass Filter Plots

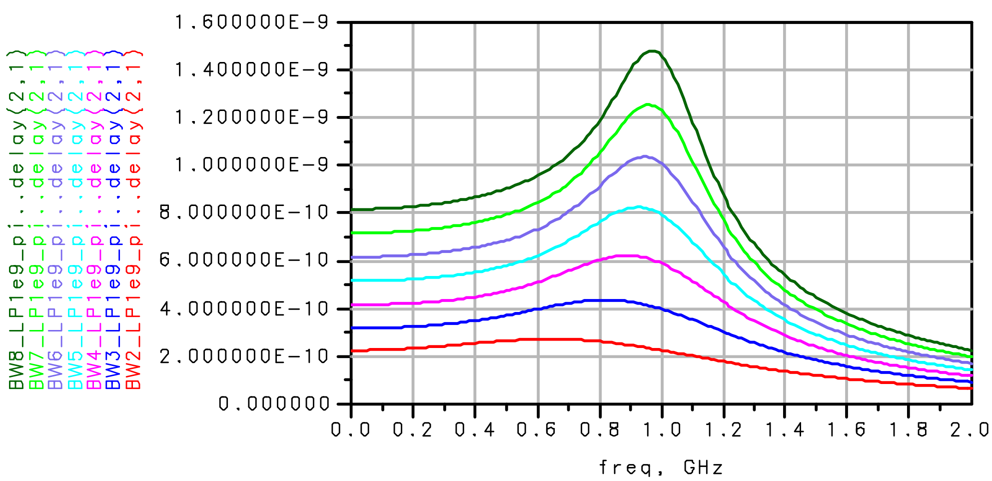


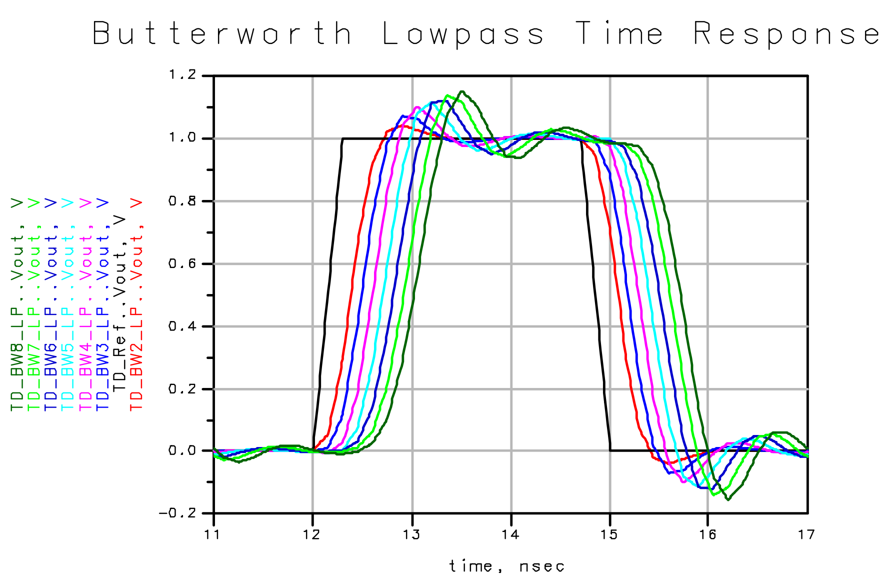




Butterworth Low Pass Filter Plots

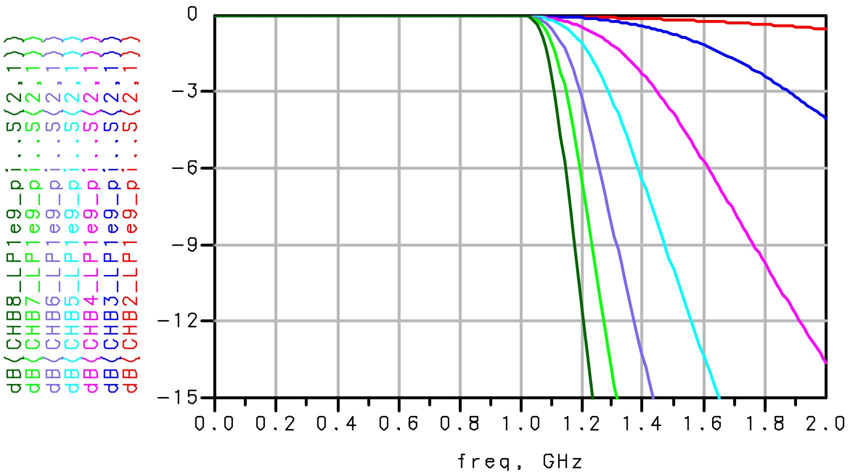


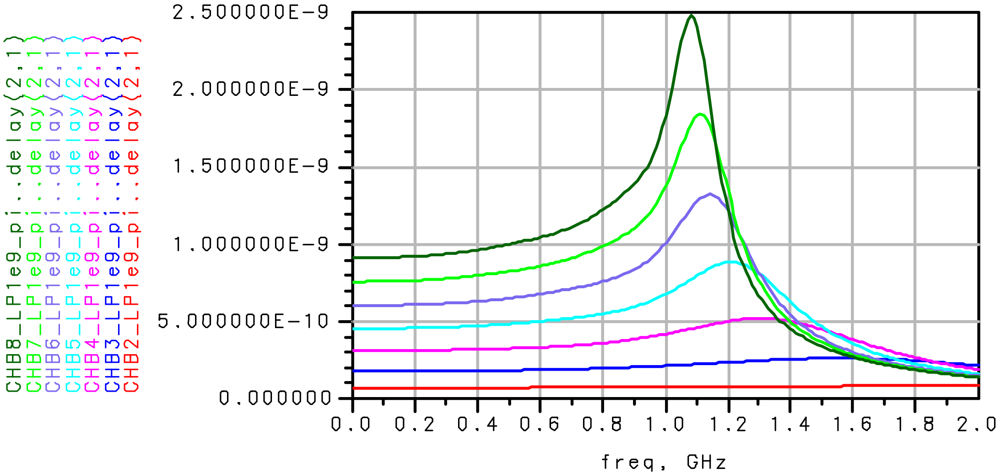




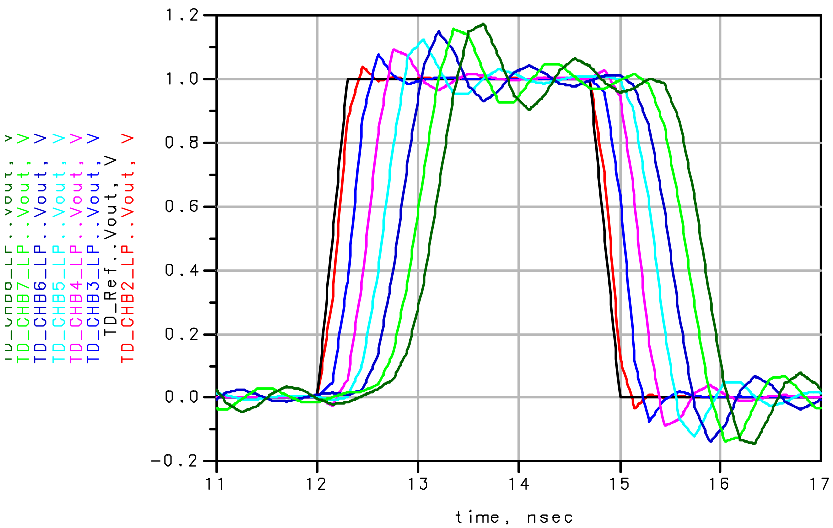
Chebychev Low Pass Filter Plots

Chebychev Lowpass

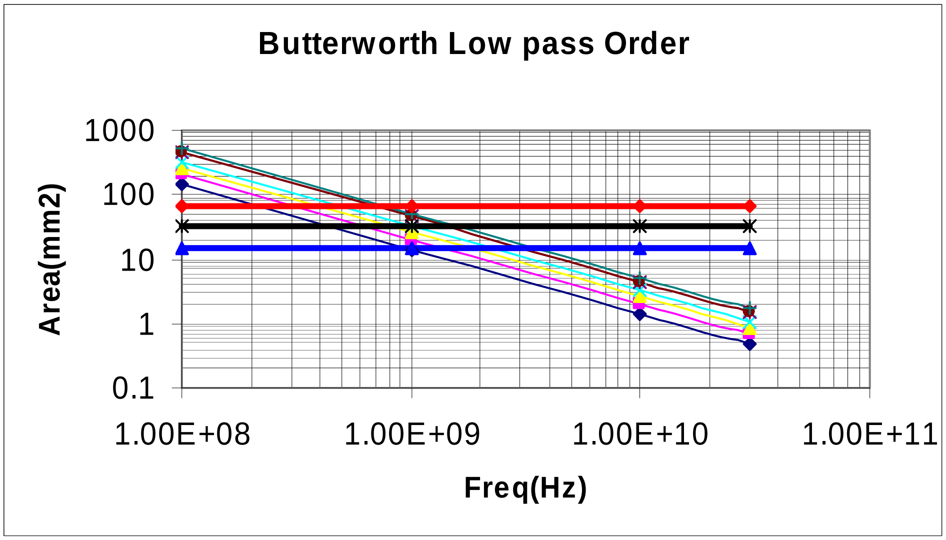


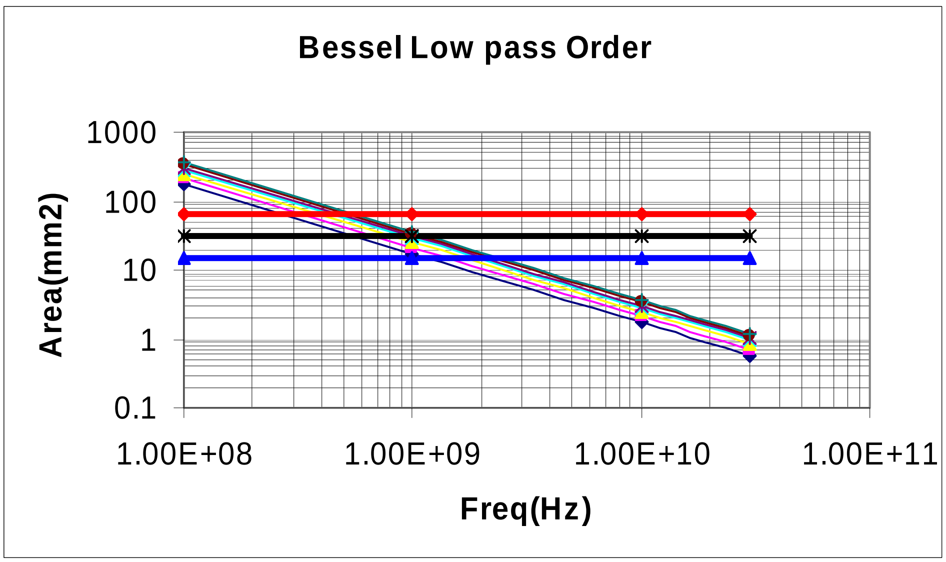


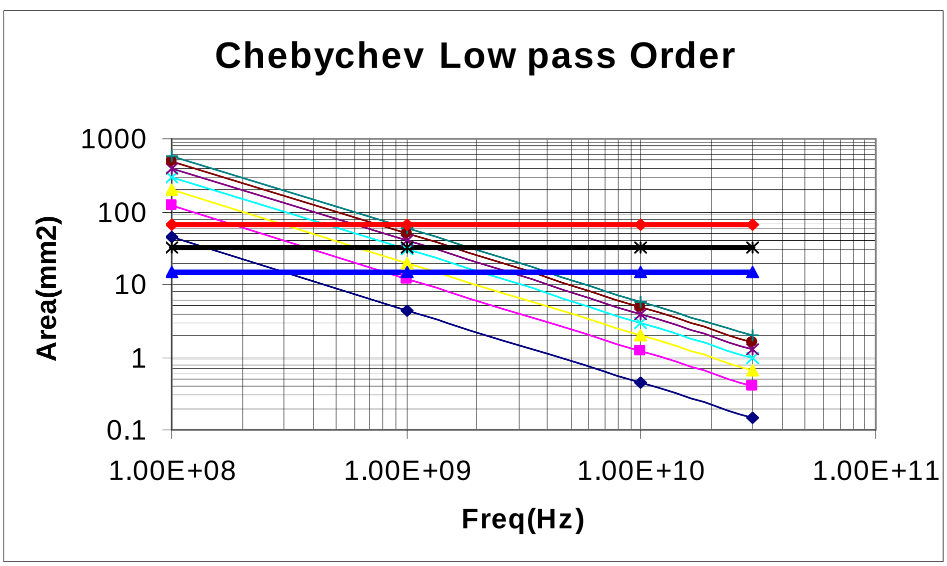
Chebychev Lowpass Time Response

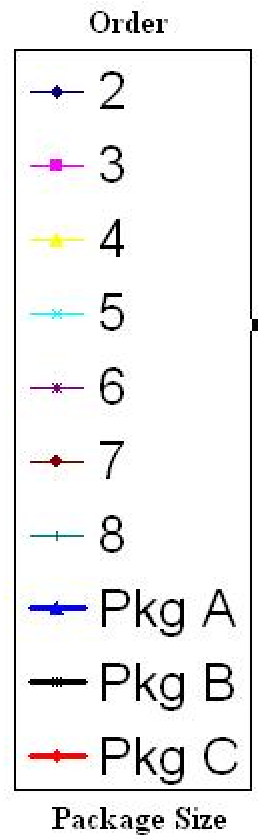


Low Pass Filter Package Selection Charts



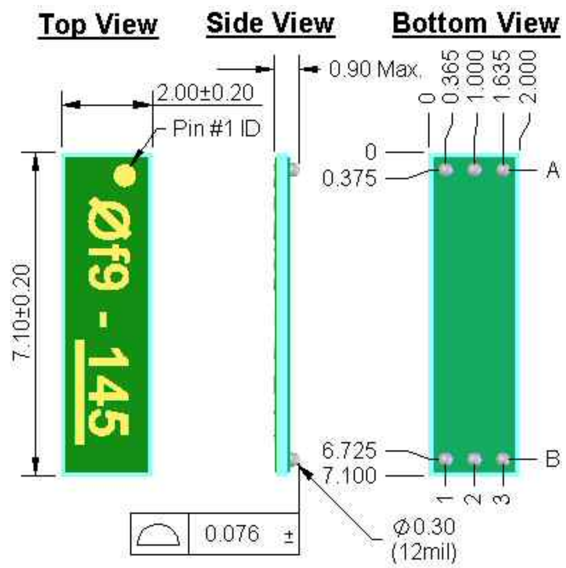






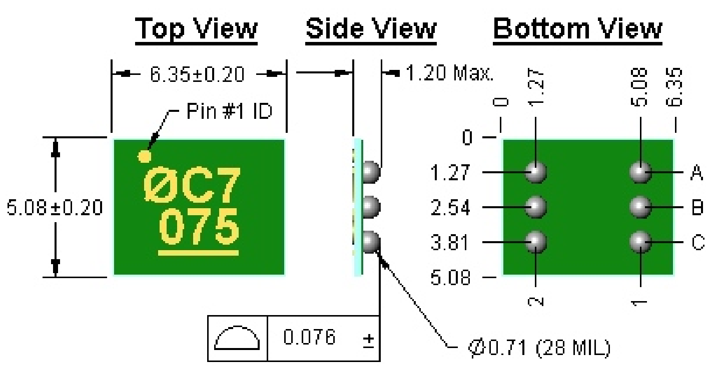
TFT Standard Low Pass Filter Packages & Footprints

Package A (7.1 x 2.0mm—6 pin BGA)

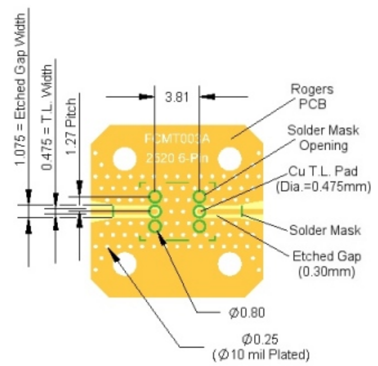


Contact factory for proper footprint and DXF output.

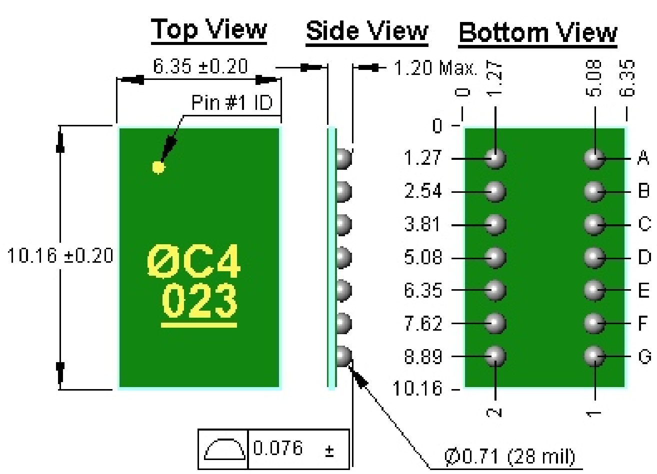
Package B (6.35 x 5.08mm—6 pin BGA)



Contact factory for DXF output of this footprint



Package C (10.16 x 6.35mm—14 pin BGA)



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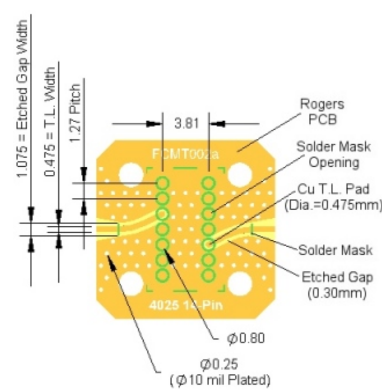


Band Pass Filters and their Applications

Introduction

Band Pass Filters are essential to almost all signal processing circuits. They are used in electronic systems to pass certain components of the signals entire spectrum. They pass certain desired frequencies of the signal spectrum, while rejecting and attenuating the undesired frequency components of the signal spectrum. An ideal band pass filter should have a completely flat pass band and should completely attenuate all frequency spectrums outside of the pass band. However, in practical terms, filters cannot completely attenuate all frequencies outside the desired frequency range. There is region outside of the intended pass band where frequencies are attenuated, but not rejected. This is known as the roll-off frequency. Generally, filter designs attempt to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. The cutoff frequency of the band pass filter is the boundary where the undesired frequency component is attenuated. It is the edge of the filter frequency response range. The bandwidth of the filter is the difference between the upper and lower cutoff frequencies.

Describing all the applications of the Band pass filter is beyond the scope of this application note. Brief descriptions of several filter applications are discussed in the following.

Desired Signal Selection:

The most important applications of the Band Pass filters is to pass the desired signal components from the available frequency spectrum and reject unwanted signal components. In a data transmission system, desired data is embedded in the specific frequency. Band pass filters can be used to successfully collect the data from the entire frequency spectrum. The filter is used to pass only the desired portion of the spectrum, where the data is embedded; and to attenuate the other frequencies. To the receivers point of view, the frequency spectrum that does not have the embedded data is undesired information. Thus, by running the signal through the appropriate filter, the undesired portion of the frequency is rejected, leaving only the frequency where data is embedded.

The consequences of inadequate filtering translate into cross talk, signal drop out, noisy signals, and even complete transmission interruption. These phenomenon result in loss of data and interrupted network connections among users. Using the correct filters can help maintain the signal integrity as well as to combat the difficulty in transmitting and receiving a clear signal.

Reducing Inter Symbol Interference (ISI)

Appropriate filter placement in the system will guard the desired signal component against any interference across adjacent signals. The filter will attenuate all of the frequency components, including adjacent signals, while accepting the desired signal portions. As a result, it will diminish the vast majority of the interference due to adjacent signals. Band pass filters will also help to bring Inter Modulation Distortion (IMD) and Cross Modulation

Distortion (CMD) problems due to modulation under control

Cross Talk Reduction:

In signal transmission, “Cross Talk” refers to the phenomenon where the transmitted signal in one channel or frequency creates and undesired effect in another channel or frequency. It is due to the coupling of one circuit to another. This phenomenon takes place where the signal content leaks (bleeds) from one channel to the other adjacent channels. Cross talk is often described as co-channel interference and adjacent channel interference. Appropriate band pass filtering around the desired frequency stops the other frequency components from entering into the desired frequency component.

Noise reduction:

As the signal moves through the circuit subassemblies, active components add noise to the signal. Usually, the frequency of the added noise signals from active components is of a higher frequency than the intended signal. Another noise source to the signal is from the power supply. The noise frequency of the power supply’s added noise is usually lower than the intended signal frequency. Correct placement of properly designed band pass filters will eliminate the noise from both sources. It will attenuate the low frequency power supply noise and the high frequency active component noise from the desired frequency component.

Phase shifter:

Another application of the band pass filter is delay filter. Band pass filters can also be used as delay line. It is sometimes used due to it’s smaller package size and impedance matching properties. By using the correct amount of delay, the signal can be shifted for the intended amount of phase shift. As a result the band pass filter can be used as Phase Shifter.

Feed Forward Error Correction:

One important criterion to have error free data transfer is to have a precise error correction system in the receiver design. More often than not, the noise is added while the signal passes through the active components. The feed forward error correction process is a very popular way to reduce the added noise in the signal. In this technique, the original signal is delay subtracted from the added noise signal. Then the resultant component is the added noise from the active component. Band pass filters are used to delay the signal for certain wavelengths. This is another application of using band pass filters as a delay filter. Band pass filters are used instead of delay lines due to their smaller package sizes and impedance matching properties.

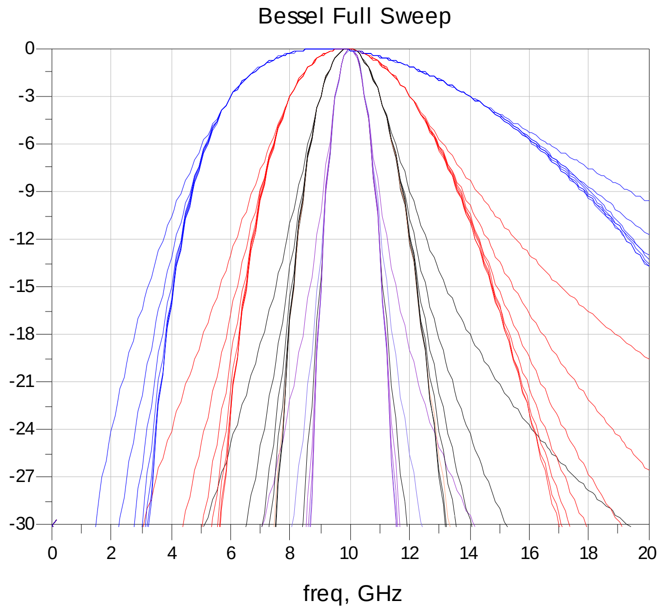
Channelization:

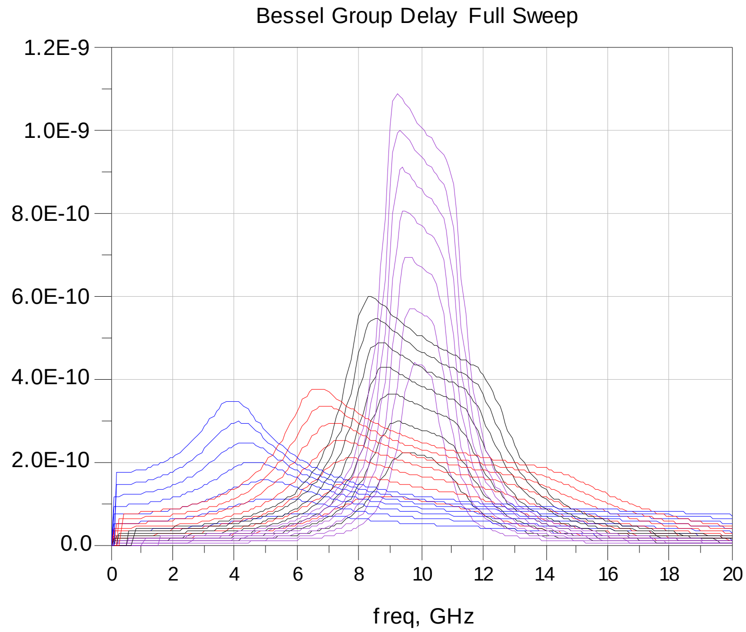
Channelization is another application for band pass filters. It diverts the incoming signal into different channels. Using band pass filters with properly designed signal cutoff frequencies, different channels can be isolated. The signal can then be divided for different channels.

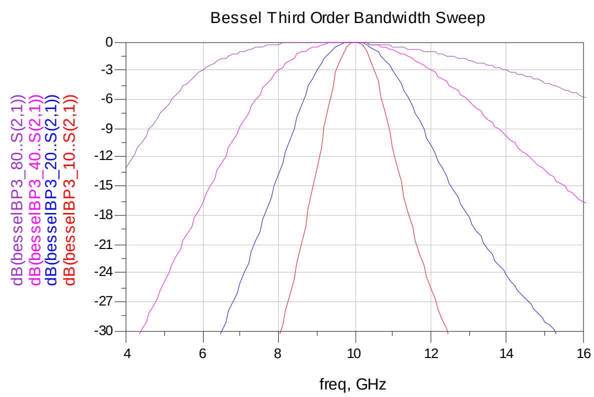
Conclusion:

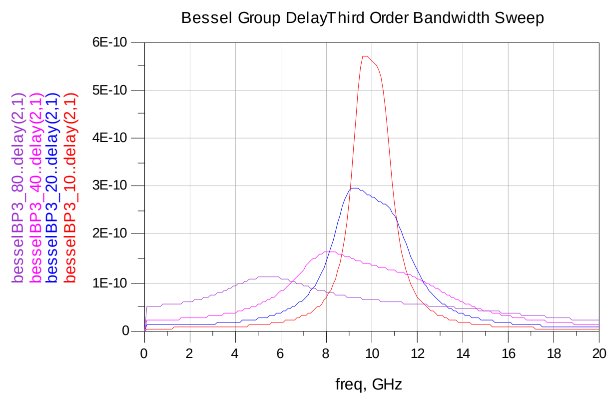
Several application of the band pass filter are described in this document. Aside from these common applications, band pass filters can be used for many other applications of signal processing. Among them diplexers and triplexers are some of the more common applications. However, the most important application of the band pass filter is the selection of desired signal component from the entire frequency spectrum.

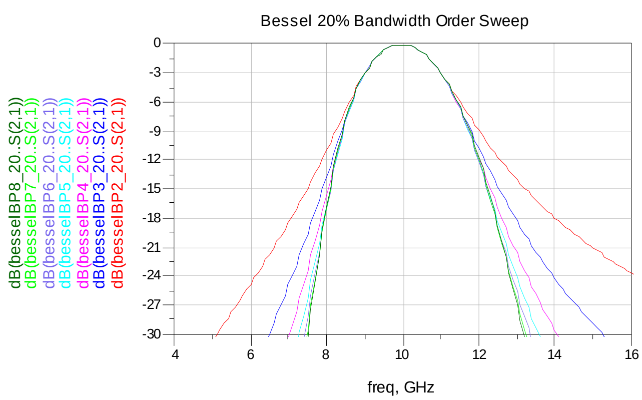
Bessel Band Pass Filter Plots

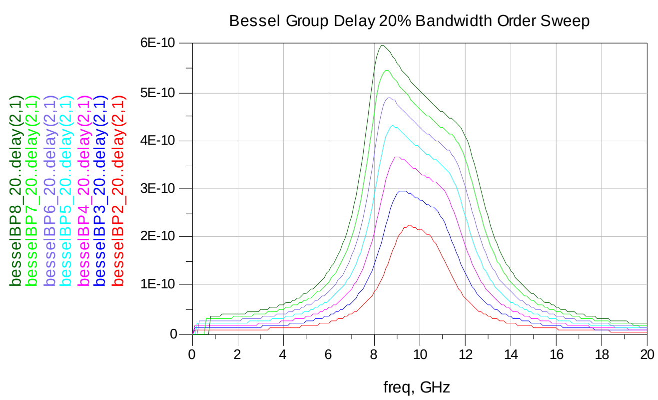




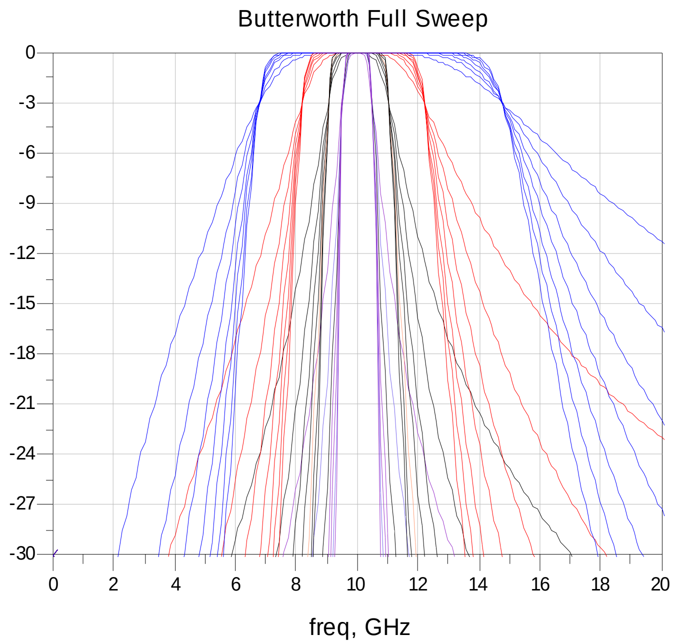


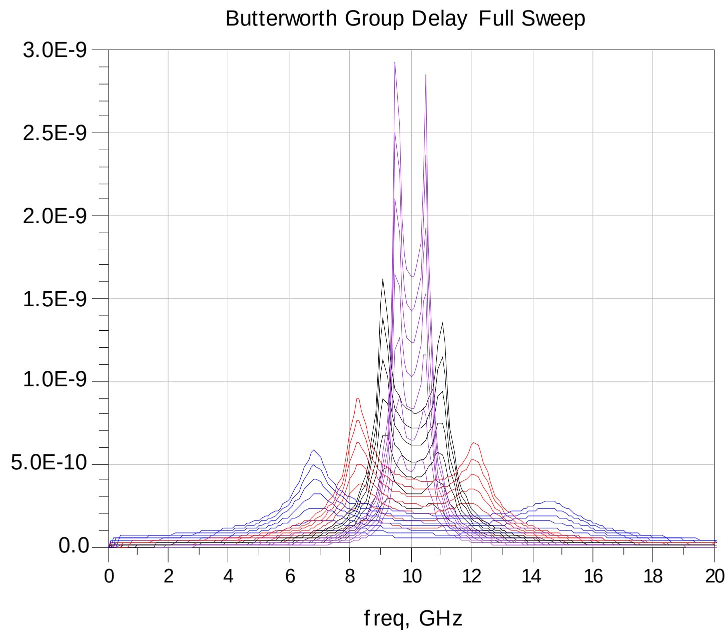


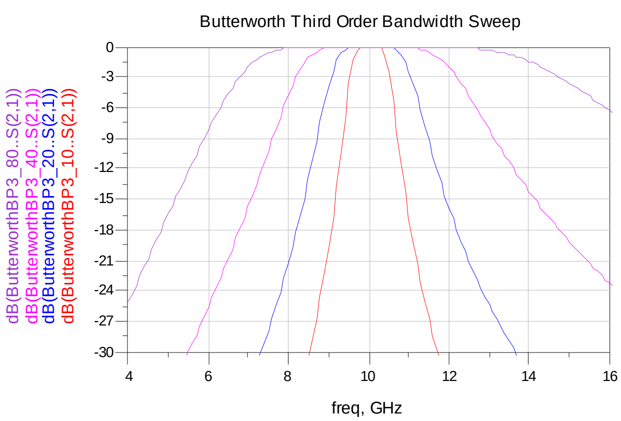


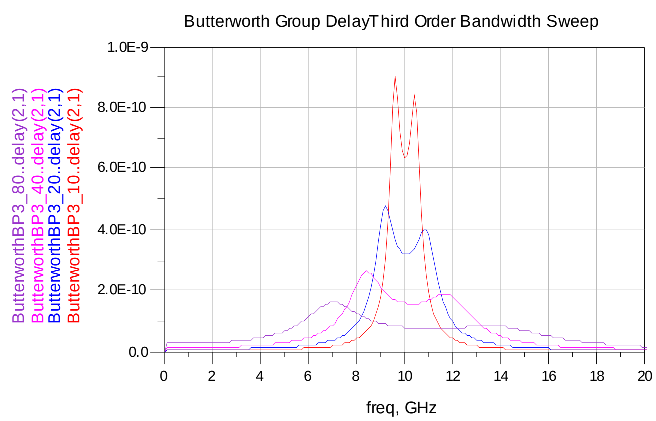


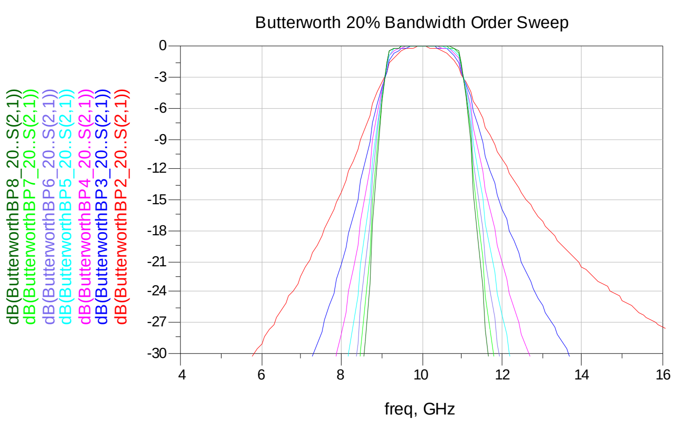
Butterworth Band Pass Filter Plots

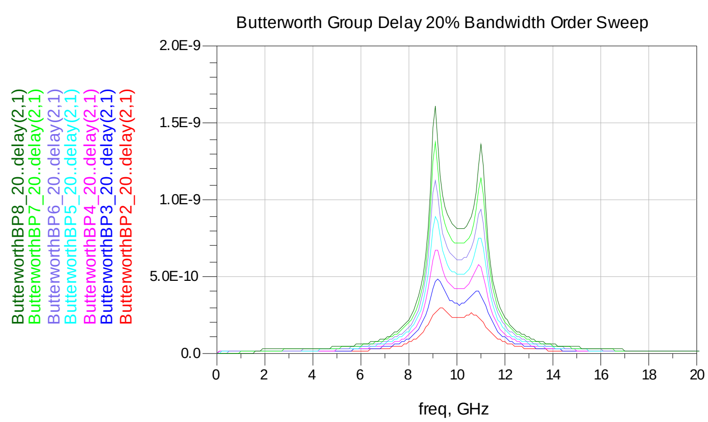




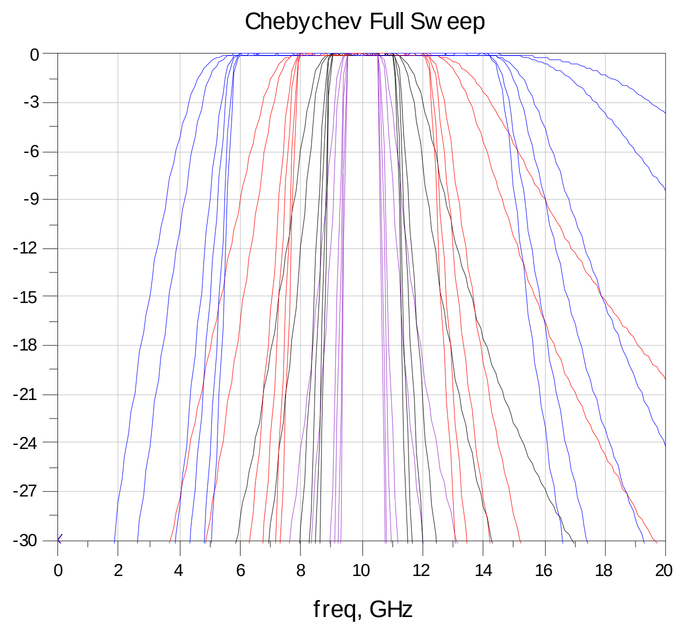


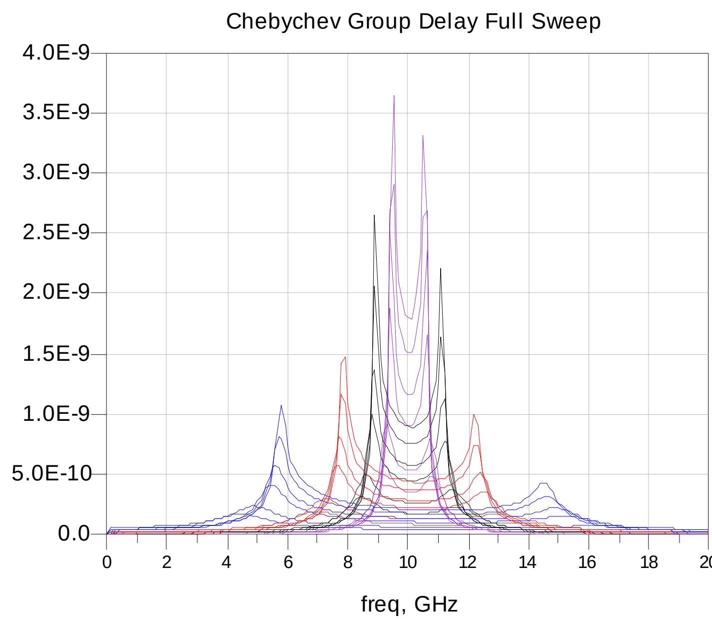


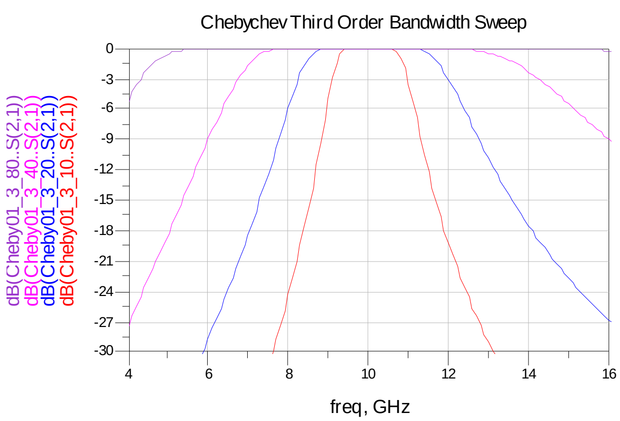


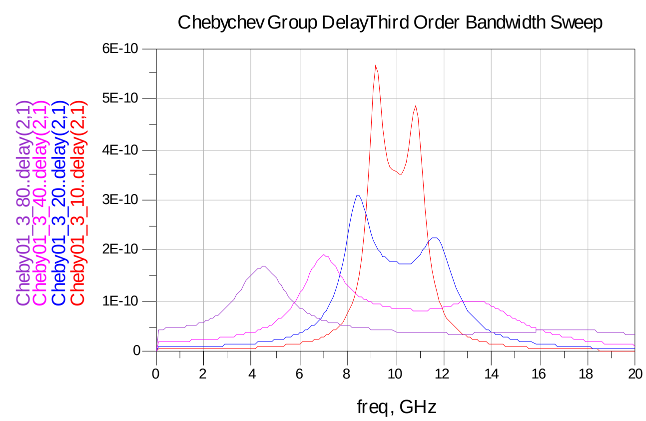


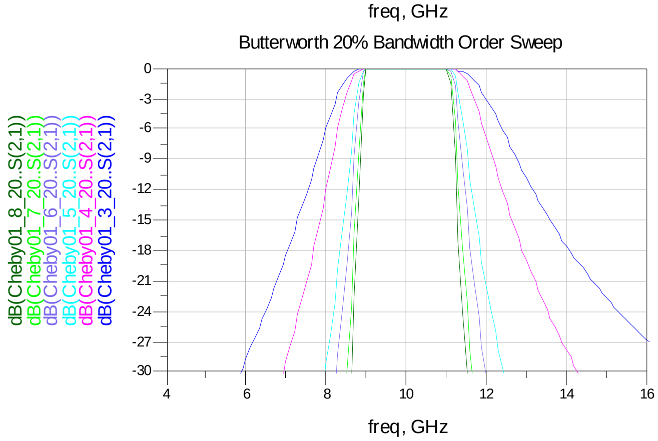
Chebyshev Band Pass Filter Plots

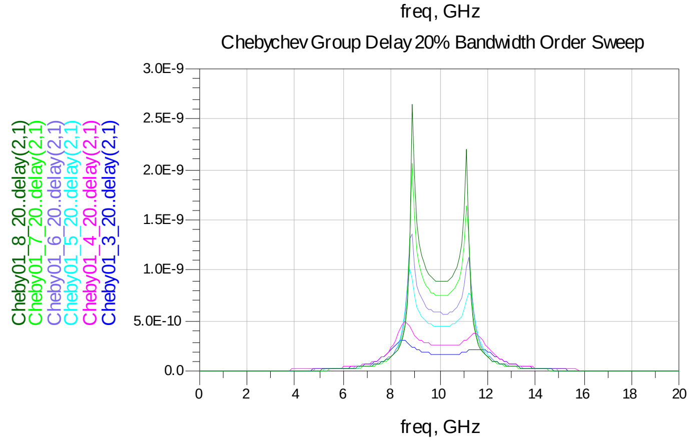






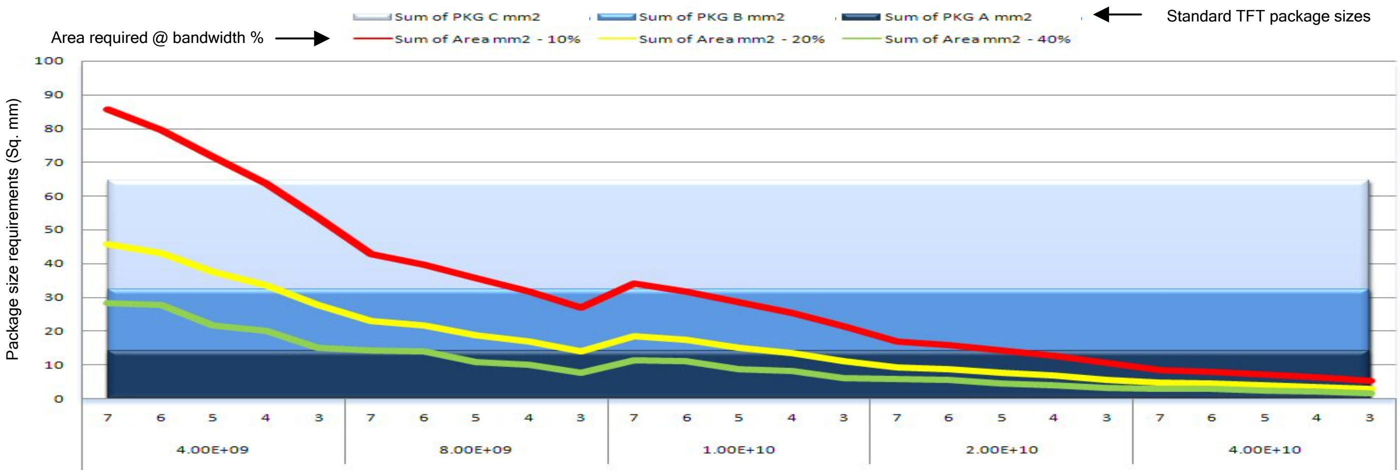






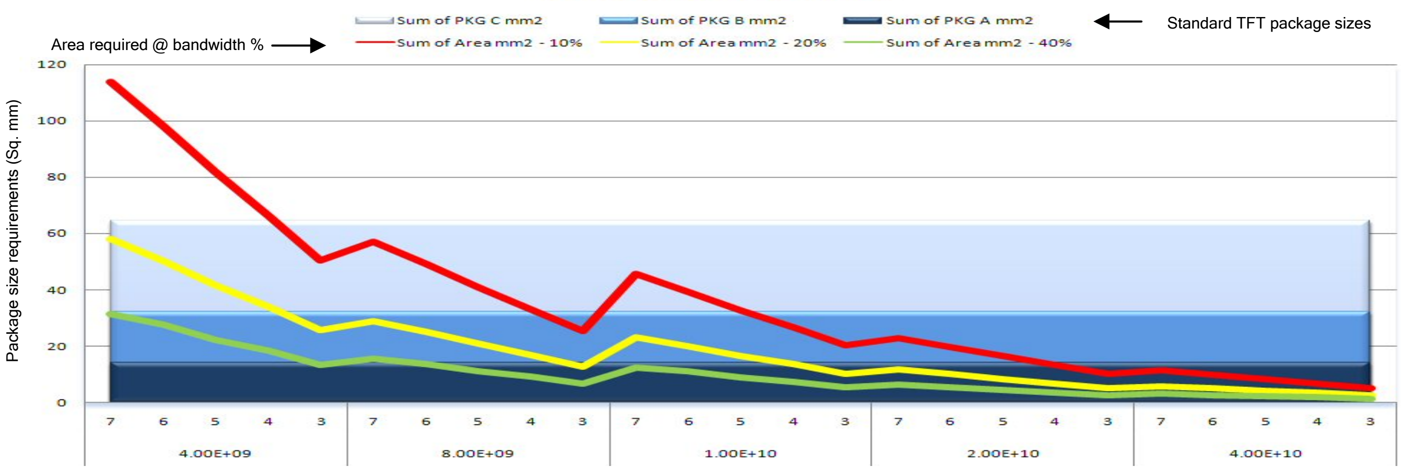
Band Pass Filter Package Selection Charts

Band Pass Filter Area - Bessel Filter



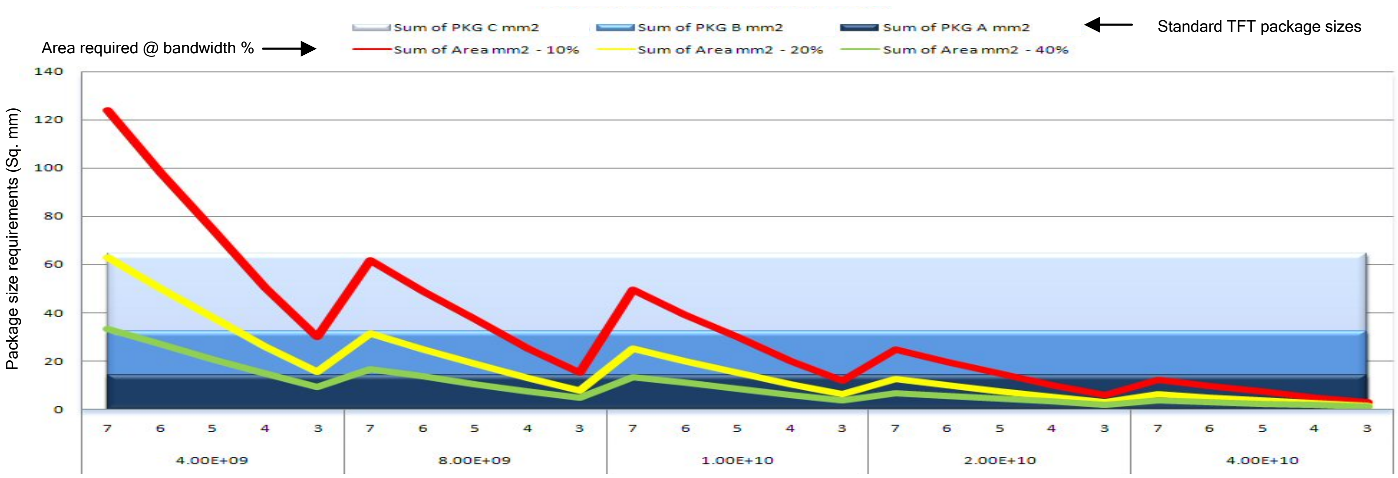
"X" axis scale shows cutoff frequency and number of orders

Band Pass Filter Area - Butterworth Filter



"X" axis scale shows cutoff frequency and number of orders

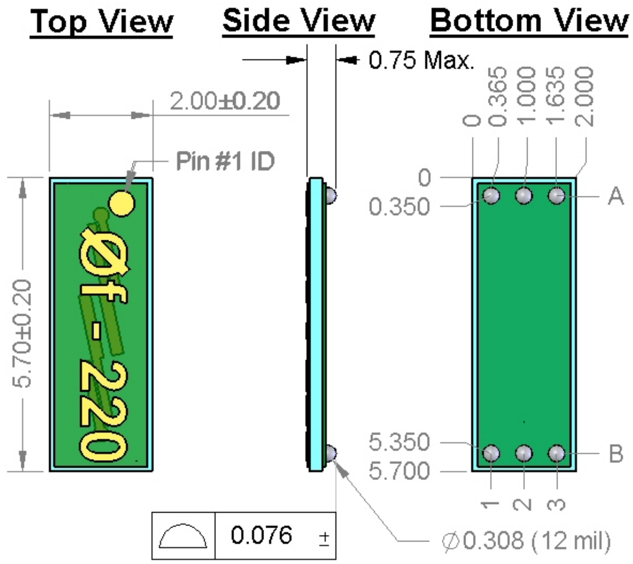
Band Pass Filter Area - Chebyshev Filter



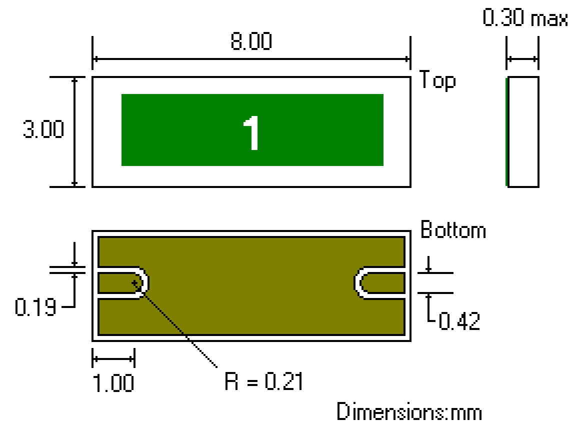
"X" axis scale shows cutoff frequency and number of orders

TFT Standard Band Pass Filter Packages & Footprints

Package A1 (5.7 x 2.0mm—6 pin BGA)

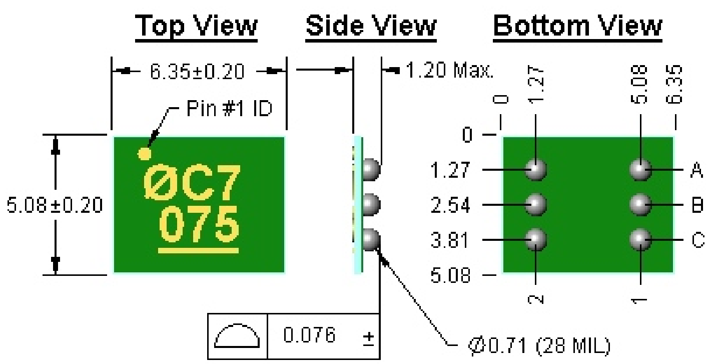


Package A2 (8.0 x 3.0mm Gnd-Sgn-Gnd LGA)

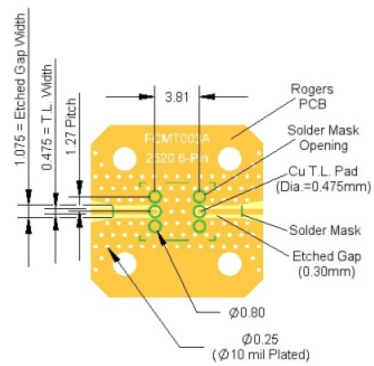


Contact factory for proper footprint and DXF output.

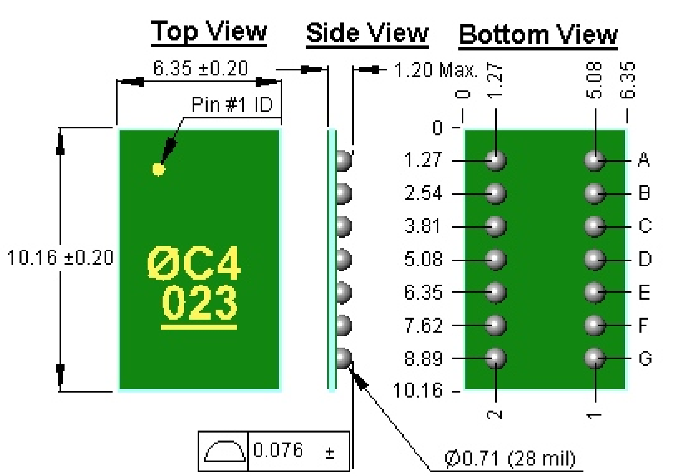
Package B (6.35 x 5.08mm—6 pin BGA)



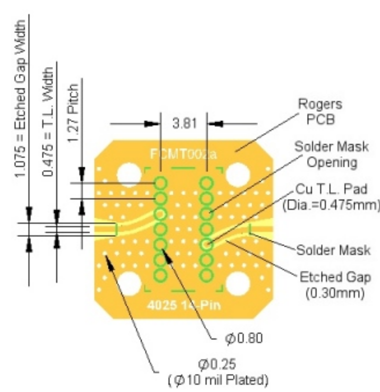
Contact factory for DXF output of this footprint



Package C (10.16 x 6.35mm—14 pin BGA)



Contact factory for DXF output of this footprint



Thin Film Technology Coupled Line Structure Band Pass Filters

Current Offerings:

Thin Film Technology Corp. introduces band pass filters for Point-to-point WiMax applications for wireless communication systems. These band pass filters illustrate excellent performance with low insertion loss, and minimal pass band ripple. They provide outstanding rejection of undesired signals for systems operating in WiMax applications. This filter is extremely compact and is offered in a surface mount package.

Construction:

Our Band Pass Filters are fabricated on low loss, high purity alumina substrates with a coplanar micro-strip design that is capable of supporting frequencies up to 50GHz. The footprint is a Ground-Signal-Ground configuration with gold metallization in a Land Grid Array (LGA) package. The filters are covered with a protective passivation material to eliminate environmental influence.

Measurement:

All of our filters are 100% performance checked as a final step in our production processing. The filters are measured with high speed Ground-Signal-Ground probes using a 40 GHz Hp 8722D network analyzer. The probes are calibrated on calibration substrates designed for the probes. Figure 1 and 2 demonstrates the measurement techniques and the measurement results of the filter respectively.

Figure 1 - measurement setup with G-S-G probes

Filters have also been measured on a Rogers test board, while enclosed in a wave-guide. Figure 3 and 4 demonstrate measurement techniques and result of the filter respectively. Five different filters are measured to realize the variation between product to product. Mounting the filters to the test boards takes into account the effects of the filter footprint which accounts for the difference of the two measurement plots (Figs 2 & 4).

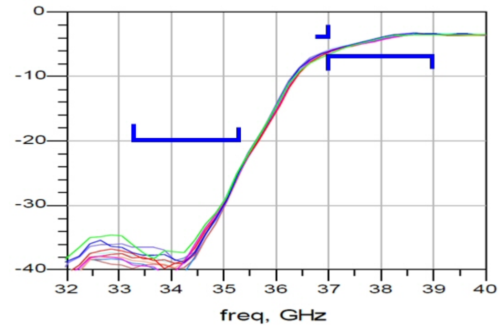


Figure 2 - measurement result of a BPF with a pass band of 38.3-40.0 GHz using G-S-G probes (showing to 40GHz due to limitation of VNA)

TFT has the capability to incorporate the footprint into the filter design in order to eliminate any negative performance effects after mounting. Refer to the Application Notes section of our website for more information.

Figure 3 - Filters soldered in a wave-guide test board

Conclusion:

The band pass filters discussed in this section are related to WiMax applications with pass band frequencies between 35-40 GHz. TFT also has the capability to design and manufacture BPF's for other applications in frequency ranges from 1 to 40 GHz and in different package sizes as well. Contact us for all of your band pass filter needs.

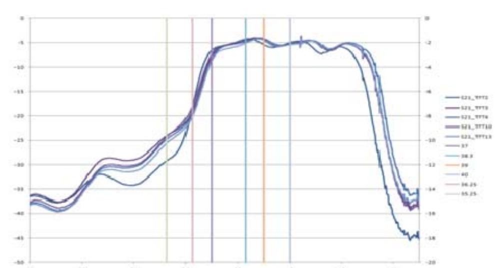


Figure 4 - measurement result of a BPF with a pass band of 38.3-40.0 GHz mounted to the wave-guide test board

TFT Radio Frequency Resonator Style Band Pass Filters

Current Offering

Thin Film Technology Corp. manufactures a full line of passive electronic components from precision resistors to electrical filters. As a part of the electrical filter offerings, TFT offers band pass filters (BPF) for Radio Frequency applications. Our Radio frequency band pass filters are generally used in wireless applications. Frequency ranges for the Radio Frequency Band Pass Filters starts from 800 MHz to 2.5 GHz. Filters in the frequency range of 2.5 GHz to 4.0 GHz are currently in development.

These are all Resonator type filters, which provide excellent performance with low insertion loss and high stability. We currently offer three kinds of filters based on the number of filter poles. Filters are with two and three poles are designed to work with Wireless devices, while four pole filters are designed for Base station communication applications.

Construction:

Our radio frequency band pass filters are made with 3 mm square dielectric coaxial resonators. The number of filter poles dictates the number of resonator stages. Resonators are constructed on the circuit boards with the signal and ground path connected to the board. Two pole filters are 8.0 mm long, 7.0 mm wide and 3.7 mm in height. Three pole filters are 13.5 mm long, 10.0 mm wide and 3.7 mm in height. Four pole filters are 12.0 mm long, 13.5 mm wide and 3.8 mm in height.

Measurement:

Our band pass filters are measured using a Vector Network Analyzer (VNA). The VNA is calibrated prior to each use to provide a high standard of measurement. All of our filters are 100% performance checked as a final step in our production process.

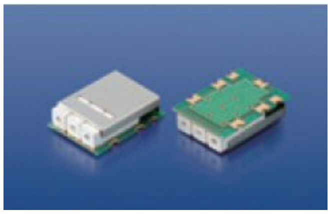
2-Pole Resonator Filter:

Picture of 2-pole resonator filter

Plots of typical 2-pole, 800MHz filter with 20MHz BW

TFT Radio Frequency Resonator Style Band Pass Filters

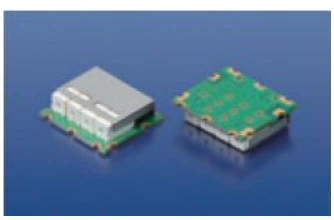
3-Pole Resonator Filter:



Picture of 3-pole resonator filter

Plots of typical 3pole, 800MHz filter with 13MHz BW

4-Pole Resonator Filter:



Picture of 4-pole resonator filter

Plots of typical 4pole, 800MHz filter with 13MHz BW

Filter Design Space:

Our current resonator type band pass filters are from 850 MHz to 2.50 GHz frequency range. However, we have the capability to manufacture band pass filters with different frequency ranges and electrical specifications for various applications. Resonator filter's working bandwidth and frequency range depend on the length and diameter of the dielectric resonator. The resonator size also dictates the filter component size. The bandwidth of our filter is 20% of the filter cutoff frequency. For 800 MHz cutoff frequency, the bandwidth is 10 to 20 MHz and for 2.3 GHz cutoff frequency the bandwidth is 80 to 100 MHz

Conclusion:

Thin Film Technology Corp.'s Radio Frequency band pass filters that are discussed in this section are suitable for wireless application of the frequency range of 850 MHz to 2.5 GHz. TFT also manufactures coupled line structure band pass filters for 35 to 40 GHz for high frequency WiMax applications. As a manufacturer of passive electronic components, TFT has the capability to simulate, design and manufacture BPF's for other frequency ranges from 800 MHz to 40 GHz with different bandwidth ranges. Please contact us for all of your band pass filter requirements.

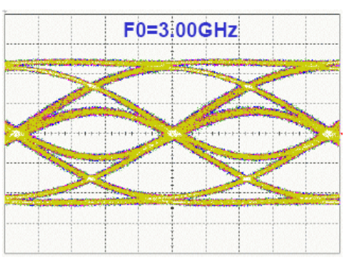
Thin Film Technology Filter Technology and Capabilities

Overview:

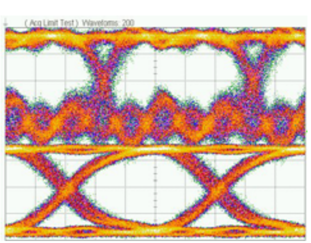
Thin Film Technology (TFT) is a high-speed passive component manufacturer who will provide you with custom electrical filter designs for your optical system designs. In addition to the custom filter design work, we also carry a standard set of enhanced duo-binary electrical filters for your immediate needs.

Custom Electrical Filter Design:

Thin Film Technology will work with you to provide a fast electrical filter network design for your front or back end optical application. One of our specialties is the concept and design of an "Enhanced Bessel" Filter for Duo-binary modulation type schemes for the front end of the optical system. Optical Duo-binary systems with conventional electric components (NRZ Driver) require a low drive voltage modulator and an electrical filter that exhibits good return loss and group delay performance.

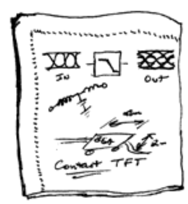


At the back end of the electro-optical system there is an issue of tuning the receiver sensitivity to optimize for the spectral content of the data. TFT also provides the electrical filtering solutions to help minimize the high frequency noise content after the trans-impedance amplifier to improve the eye opening.



With both the front end and back end designs, the return loss and group delay become as important in the electrical filter design as the cutoff frequency. These objectives have both been achieved with "Enhanced Passive Bessel" filters that provide the end user the opportunity to optimize the performance of the optical long-haul system.

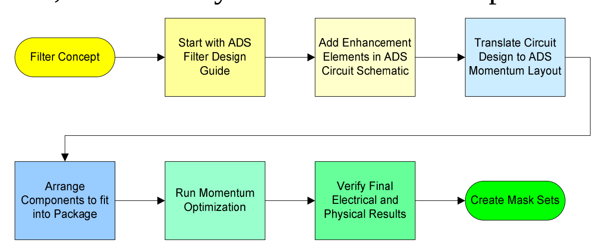
Design Conception



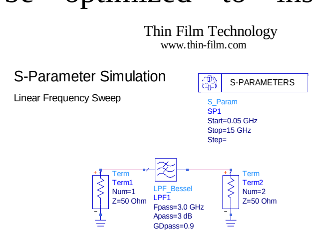
Designing your custom filter starts by taking your concept design and reviewing the desired filter parameters. The electrical and physical design concepts are reviewed in order to insure manufacturability of the electrical filter. Once the preliminary specifications are approved, the design process begins.

Simulation Services:

Using Agilent's Advanced Design System RF Electronic Design Software, commonly known as ADS, we take your desired filter parameters



(both electrical and mechanical) and input it into the simulation software. The circuit design can be optimized to insure it will meet the specifications approved earlier. The circuit design is transferred to the ADS Momentum simulator. This layout

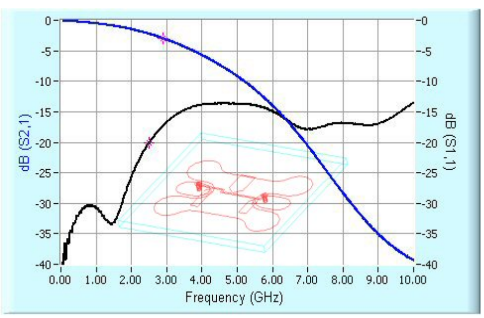


simulator accounts for element interaction of the physical layout and can be used to further optimize the design. If needed, the ADS simulation software allows us to test and recommend the circuit layout surrounding the filter to insure proper functioning when the physical device is realized.

Thin Film Technology is currently working with another simulation environment from VPI Systems called VPItransmissionMaker. This simulation software provides a method to verify the full optical path, as described in the paper titled "High Speed Optical Designs Need High Speed Design Tools". This would allow TFT to provide further services in the electrical filter design process.

Component Manufacturing:

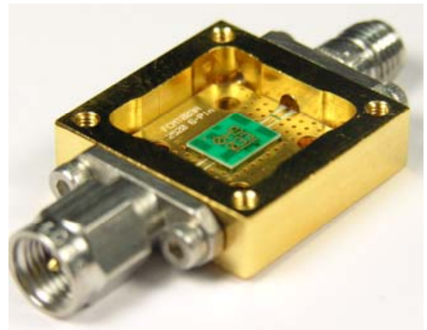
Once the electrical and physical results from the ADS circuit simulations are verified, the design can now be sent to mask directly from the



simulation setup. The prototypes are produced in our state of the art fabrication facility. Once the electrical filter parts are physically complete, the prototypes are characterized on the bench using a Vector Network Analyzer. The S-Parameter data file is saved for verification and reference. Using the ADS simulation software, this frequency domain data can also be analyzed in the time domain to insure eye diagram results.

Bench Test Components:

The manufactured prototypes can also be put onto our in-house designed and produced evaluation board and coaxial measurement module (CMM) providing SMA connections to



the device for bench top testing and customer qualification of the design. Not sure which filter will provide the best results? Thin Film Technology will provide a set of these CMM's for testing on your bench allowing you a flexible means of interchanging different filter components to determine how the overall response will be.

Conclusion:

Thin Film Technology will provide you with standard or custom Enhanced Electrical Bessel Filter components for both the front end and back end electrical subsystems in an optical system design. TFT utilizes thin film processes for high performance electrical filter components. We will simulate, design and manufacture the custom filter component for your optical system. Fast optical designs are realized using high performance service for your design support including fast turn custom prototypes to full production capacity, start to finish.

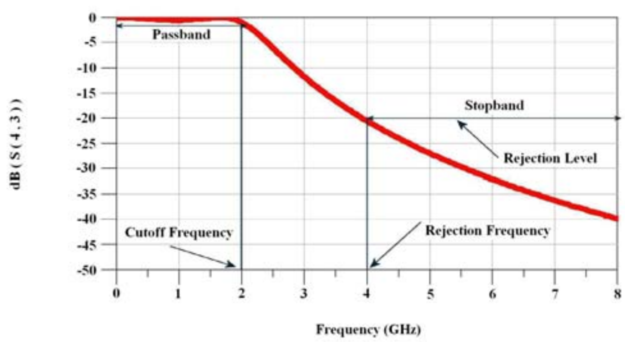
Filter Specification Requirements

Introduction

Incorrect specification or over specification for a filter can increase the design and manufacturing cost. Sometimes tradeoffs become enormous while manufacturing over specified filters. For example, over specifying requirements for a Low pass filter like low insertion loss accompanied with very sharp roll off and flat group delay response for higher than cut off frequency increases the complexity and size of the component. This not only adds to the cost of the design but also adds extra manufacturing efforts in the build and test cycles. Another example is out of band absorption for absorptive low pass filters. Over specification of absorption for bands more than five times the cutoff frequency can lead to additional design as well as tuning efforts in the test and integration stages of the process. Similar occurrences can happen with tighter VSWR requirements. The discussion below focuses on filter specification parameters and tradeoffs in order to assist the System Engineers in understanding, and consequently specifying requirements. Realistic as well as more effective filter specifications reduces cost and delivery impacts in the form of delays and costly overruns.

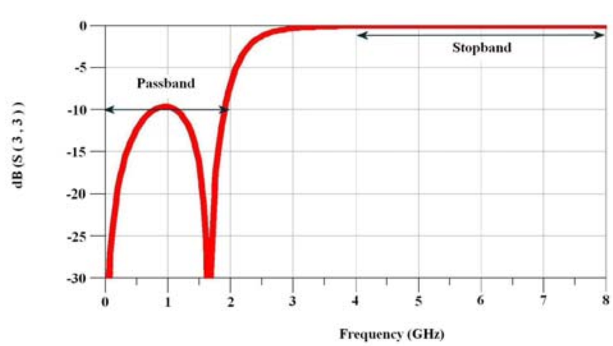
Electrical parameters consideration and requirement:

1. Cutoff Frequency - Cut-Off frequency (Fc) is the transition point from the passband to the start of the stop band in a low pass filter. That transition point is normally the 3dB point.
2. Rejection Frequency – Specific frequency or frequencies where the signal is attenuated at some specified value or set of values. The region outside the desired passband is sometime defined as the rejection frequency or frequencies, and the attenuation as the rejection.
3. Rejection Level in dB - Usually defined as the level of suppression for a filter to suppress transmission of signal energy in the rejection frequency bands, and is normally expressed in dB.
4. Insertion Loss (IL): Insertion loss is another important characteristic to consider in selecting a filter. It is the loss presented to the signal as it travels in the desired signal path. Generally, it is desirable to keep insertion loss to a minimum. In the real world, however, a certain amount of insertion loss must be accepted to achieve the desired or required degree of selectivity. Fortunately, insertion loss doesn't always harm the system performance. In many cases, several decibels of insertion loss might be tolerated before system performance begins to degrade. The plot illustrates insertion loss response of a 2.0



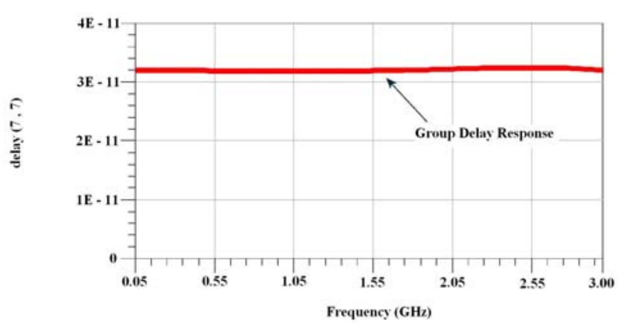
GHz Chebyshev low pass filter. It demonstrates the filter’s pass band, stop band, cutoff frequency, rejection frequency, and rejection level in dB.

5. Return Loss: The return loss is a measure of the filter performance. It is an indicator of how close the input and output impedance of the



filters are matched. Return loss affects the ripple of the filter in the passband. The plot illustrates return loss response of a 2.0 GHz Chebyshev low pass filter. It demonstrates the filter's pass band, and stop band characteristics.

6. Input Power Level: The power measured at the input terminal of a filter when the output is properly terminated.
7. Out of band absorption: Out of band absorption is impedance matching in the stop band region. It is done by adding resistive elements in the filter structure.
8. Group Delay: Group delay is the rate of phase change due to frequency. Phase distortion due to frequency change can be measured with linearity of the group delay response. The plot illustrates group delay response of a 2.0 GHz



Bessel low pass filter. It demonstrates flat group delay response, which is one of the Bessel filter's characteristics.

Mechanical parameters consideration and requirement:

1. I/O path – BGA, LGA, Wirebond or other.
2. Package Style – SMT (Surface Mount Technology), Module, or other packaging requirements
3. Size Restrictions – Real estate considerations such as tight circuit board requirements, height, width, length, and weight restrictions
4. Quantity – Can assist in establishing pricing break points, design techniques, as well as addressing scheduling considerations
5. Additional Requirements - Indoor or outdoor use, or other unique requirements, and other environmental considerations

Tradeoffs

Several tradeoffs should be considered while specifying the filter. Over specification on rejection level increases the complexity of the design. Another important parameter here is how far out the rejection must extend, and how far out the stopband must span. For example, two times the cutoff frequency is more realistic and achievable with lower design and manufacturing costs. Out of band signal absorption can be another example to be careful of. Absorption of bands in four or five times of the cutoff frequency can greatly complicate the design.

Packaging consideration:

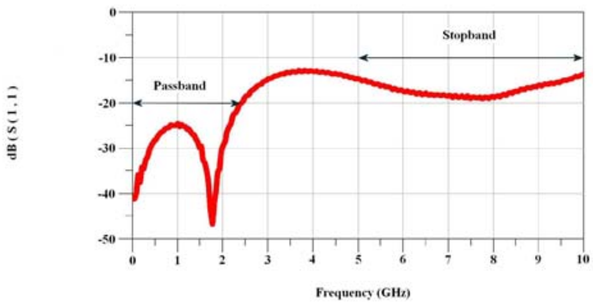
Packaging considerations and options can also impact the manufacturing costs . The size of the filter impacts the costs the most. It is important to realize that the tighter the specification, the greater the size and the higher the cost of the filter. For example, if a filter is desired with low insertion loss and very sharp roll off for the rejection band, it requires more orders to be realized; which increases the size and in turn increases the costs of the filter. Filters with more reactive elements require larger package sizes. Also, high power filters require a larger package so that the components are correctly placed for the even distribution of the electrical current. Also, when products can be supplied in tape and reel carriers which can use pick and place tooling, manufacturing costs are reduced, resulting in a less expensive part.

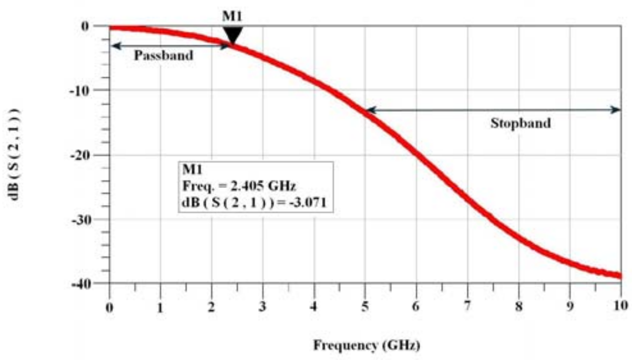
Absorptive Functionality for Filters

Absorptive Filter:

Absorptive filters are required when the component needs to absorb undesired signal energy. Usually components pass energy in the pass band and reflect energy in the stop band. Pass band refers to the frequency of interest. However, there are some circumstances when the energy needs to be substantially absorbed in the stop band. Specially, when return loss from one component can damage the functionality of another component. Another reason for signal absorption in the stop band is for signal interference suppression in receivers of frequency agile communication systems. To accomplish these objectives, the component needs to absorb the energy in the stop band. Return loss needs to be very low for a specific frequency range in the stop band. To achieve low return loss characteristics, absorptive filters are used instead of ordinary reflective filters. Absorptive filters are designed by using resistors along with inductors and capacitors. These filters function by matching the source resistance into the resonator resistances (resonator impedances at resonance) at stop band frequencies, so that signal power is dissipated in, rather than reflected from the resonators.

Thin Film Technology is very capable of manufacturing absorptive filters. TFT utilizes thin film processing for high performance electrical filter components. TFT uses resistive material for resistor, distributed capacitor, and inductor in conjunction with capacitance and inductance to produce the absorptive filter. The attached plots illustrate the insertion loss and return loss characteristics of TFT manufactured 2.5 GHz absorptive low pass filters. As the return loss (S11) plots demonstrates, even though the filter's cut off frequency is 2.5 GHz, the filter's return loss is lower than –10 dB up to 5.0 GHz. Moreover, return loss is lower than –15 dB up to the cutoff frequency. TFT's absorptive filter's specification calls for return loss characteristics to be less than –15dB up to the cut off frequency and less than –10 dB up to two times the cutoff frequency.

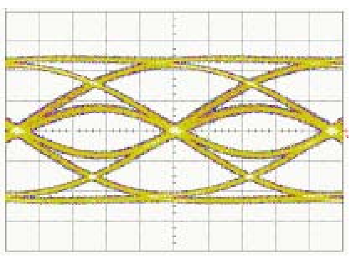




Thin Film Technology Enhanced Filters for Optical Markets

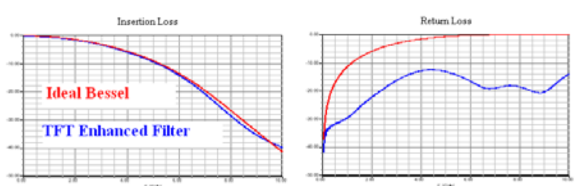
Overview:

Many new enabling optical modulation techniques rely on critical electrical filtering at both the front and back end of the electro-optical system. At the front end there are many emerging modulation techniques being developed. Optical Duo-binary systems with conventional electric components (NRZ Driver) require a low drive voltage modulator and an electrical filter exhibiting good return loss and group delay performance. At the back end there is an issue of tuning the receiver sensitivity to optimize for the spectral content of the data. These objectives have been achieved with “Enhanced Passive Bessel" filters.



Enhanced Electrical Filters:

Because of the multi-level nature of the modulation techniques, high power microwave amplifiers are required to push the MZ modulators to 2pi levels. These Amplifiers are very sensitive to



component return loss and interconnect design. Typically these designs are aided by linear circuit simulation and large signal s-parameters. Critical passive electrical filter design is required to insure that all parameters of the filter are met. TFT utilizes thin film processes for high performance electrical filter components.

Enhanced Electrical Filters:

Using Agilent's Advanced Design System RF Electronic Design Software (ADS), the filter design can be customized to further enhance the return loss response, group delay flatness, and the interconnect design. TFT can work with you to provide an optimized design to insure it will meet the critical parameter specifications within your system design. As speeds of these systems increase, the design guidelines used with the current material sets don't work without careful consideration of return loss, insertion loss and frequency content. Let us increase your success rate without effecting the time to market by providing the necessary custom filter design.

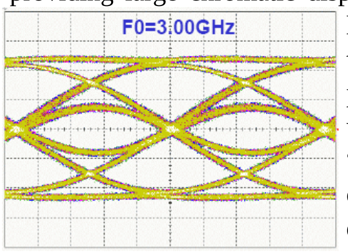
Enhanced Electrical Filters:

Thin Film Technology Corporation can provide you with standard or custom Enhanced Electrical Bessel Filter components for both the front end and back end electrical subsystems in an optical system design. These filters provide an enhanced return loss design feature to help eliminate problems associated with reflected signals. We can simulate, design and manufacture a custom electrical filter component for your optical system. Fast optical designs are realized using high performance service for your design support including fast turn custom prototypes to full production capacity start to finish.

High Speed 10Gbps Optical Design

Abstract:

Duo-binary modulation is a scheme for transmitting R bits/sec using less than R/2 Hz of bandwidth. For 10 Gbps data streams, Duo-binary signals are generated by a 2.8 or 3.0 GHz 4th Order Bessel filter that combines the functions of the FIR filtered and the analog filtered signal, deliberately distorting the pattern into a signal containing three values (1, 0, and -1). The bandwidth limiting of the optical Duo-binary signal (half of bandwidth of conventional NRZ signal) results in a narrow multiplexed transmitted optical signal where the wavelength spacing between channels is shortened providing large chromatic dispersion tolerance to achieve long-distance optical transmission. This article presents the advantages of using TFT's high order "enhanced Bessel" filters to optimize Duo-binary optical data transmission.



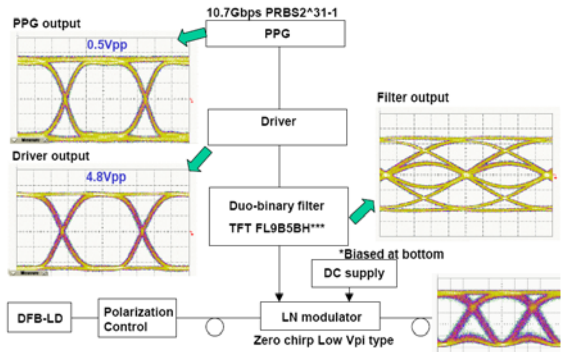
Thin Film Technology's 3.0 GHz "Enhanced Bessel" filter producing the Duo-binary eye pattern.

Introduction:

Many new enabling optical modulation techniques rely on critical electrical filtering at both ends of the E-O & O-E system. At the front end there are many emerging modulation techniques being developed. Optical Duo-binary systems with conventional electric components (NRZ Driver) require a low drive voltage modulator and an electrical filter with a sharp cut-off. New modulators have been developed, such as the Sumitomo Low Drive Voltage Modulator.www.socnb.com/division/hproduct_e/opto.html.

Sumitomo's Low Drive Voltage Modulator

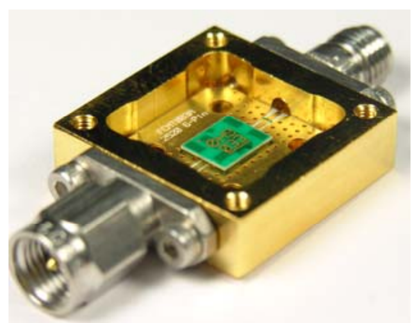
For Duo-binary modulation, Bessel filters are the filters of choice due to their time domain characteristics. Adding additional orders to the filters creates an "Enhanced Bessel" filter that provides the end user the opportunity to optimize the performance of the optical long-haul system.



Front End Electro-Optical System

This paper will show the performance of a 200km loaded electro-optical system by using a Sumitomo low drive voltage modulator combined with the Thin Film Technology (TFT) absorptive "Enhanced Bessel" filter. The critical control of the many characteristics of the filter is achievable by use of the thin film design structure.

Thin Film Technology Filters:



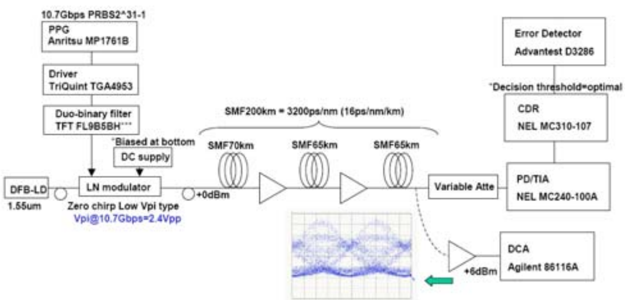
Thin Film Technology's 3.0 GHz "Enhanced Bessel" filter producing the Duo-binary eye pattern.

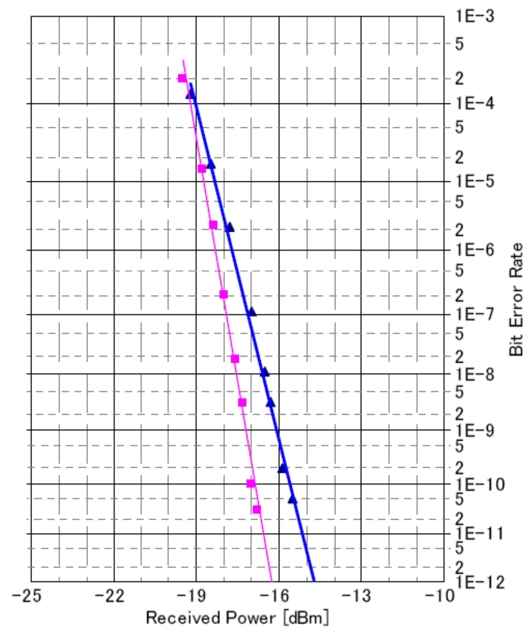
Because of the multi-level nature of the modulation techniques, high power microwave amplifiers are required to push the MZ modulators. These Amplifiers are very sensitive to component return loss, group delay flatness, and interconnect design. To accommodate these sensitive requirements, TFT simulates ("High Speed Optical Designs Need High Speed Design Tools"), designs, & manufactures high order absorptive "Enhanced Bessel" filters by utilizing thin film processes to control and optimize the performance of the filter, as described in the paper titled: "Thin Film Technology Custom Electrical Filter Designs".

High Speed 10Gbps Optical Design

Test Setup:

The following 10 Gbps, 200km optical design demonstration was assembled. This demo used the TFT high order absorptive Enhanced Bessel filters.



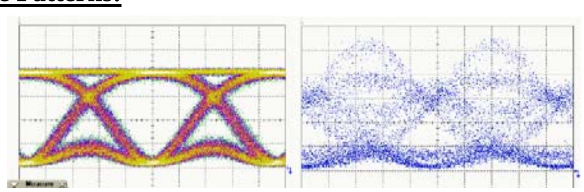


Back-to-Back = Magenta and After 3200ps/nm = Blue

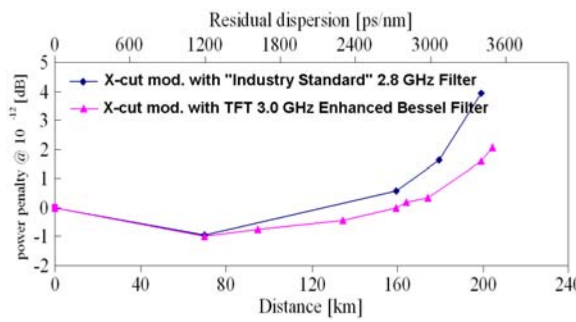
Measured Results:

From the above 10 Gbps optical demonstration setup that included the Sumitomo low drive voltage modulator, three TFT 9th order "Enhanced Bessel" filters were tested, 2.75, 3.0, and 3.25 GHz. Testing on the above setup showed the FL9B 3.0Ghz filter to have the optimum results. The following plots show the performance results that were achieved:

Eye Patterns:



Back-to-Back and After 3200ps/nm



Power Penalty Comparison to a "Industry Std." Filter

BER Waterfall Curves:

Bit Error Rate	*Received Power*		*Power Penalty*
	B-to-B	**3200ps/nm**	
10^{-9}	-17.2 dBm	-16.1 dBm	1.1 dB
10^{-12}	-16.4 dBm	-14.9 dBm	1.5 dB

Conclusion:

This high speed 10 Gbps optical demonstration shows the benefits of combining TFT's "Enhanced Bessel" filters, which exhibit exceptional time domain characteristics and low return loss, with the Sumitomo low drive voltage modulator for Duo-binary data transmission to provide better BER curves on the system output side. By utilizing thin films to realize high performance electrical filter components, TFT can simulate, design, and manufacture the custom filter component for your optical system by providing high performance service for your design support including fast turn custom prototypes to full production capacity start to finish.

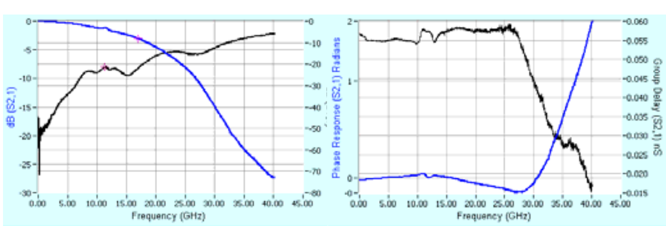
Enhanced Bessel Filters for 40Gbps Systems

Overview:

Thin Film Technology (TFT) is a high-speed passive component manufacturer who can provide you with enhanced Bessel filters for your optical system designs. TFT utilizes thin film processes for high performance electrical filters that are used in the transmitter and receiver of high-speed electro-optical systems. Thin Film Technology Corporation can provide you with standard or custom "Enhanced Electrical Bessel" Filter components for both the front end and back end electrical subsystems in an optical system design. These filters provide an enhanced return loss and tight group delay design characteristics to help eliminate problems associated with reflected signals. Thin Film Technology can simulate, design, and manufacture a custom electrical filter component suitable for your optical system. Fast optical designs are realized using high performance service for your design support including fast turn custom prototypes to full production capacity start to finish. In addition to the custom filter design work, we also carry a standard set of 10 and 40 Gbps enhanced duo-binary electrical filters for your immediate needs.

Enhanced Bessel Filter for 40Gb/s:

TFT has been providing Bessel filters to the optical industry for maximum flat group delay performance and enhanced return loss. TFT's enhanced Bessel Filters are 9th order low pass filters that matches the S_{21} parameter and group delay characteristics of an ideal 5th order Bessel filter, but provide improved return loss characteristics. Insertion loss specification of the filter is +/- 5% of the cutoff frequency. Forward and reverse return loss specification is –13 dB up to the cutoff frequency in a surface mountable BGA package and is –12 dB up to 30 GHz in a wire-bondable package. Typical Group Delay is 10ps up to 1.5 times cutoff frequency.

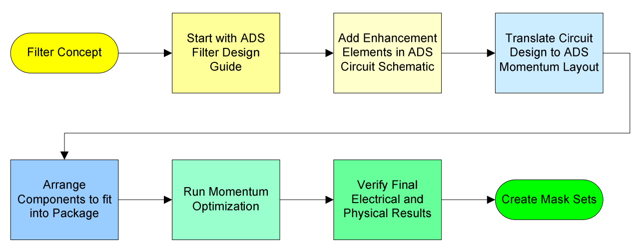


Typical S_{21} and S_{11}; Phase and Group Delay performance of TFT's 40Gbps Enhanced Bessel Filter.

For 40 Gbps Duobinary systems, TFT manufactures a wide range of 9th order Enhanced Bessel filters having -3dB cut-off frequencies from 12GHz to 18GHz. We provide filters in Ball Grid Array (BGA) packages as well as in wire-bondable packages.

Simulation Services:

Using Agilent's Advanced Design System RF Electronic Design Software, commonly known as ADS, Thin Film Technology will work with you to take your desired filter parameters (both electrical and mechanical) and input it into the simulation software.

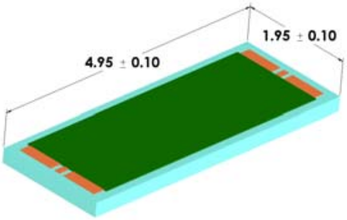


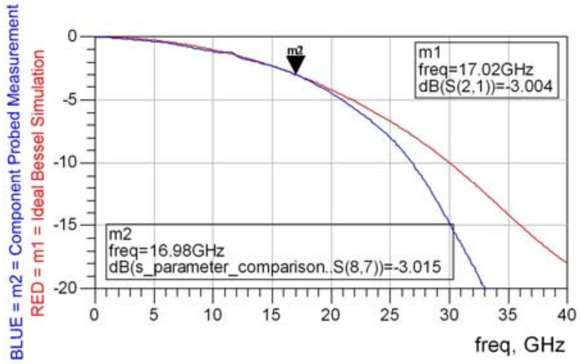
The circuit design can be optimized to insure it will meet the specifications approved earlier. The circuit design is transferred to the ADS Momentum simulator. This layout simulator accounts for element interaction of the physical layout and can be used to further optimize the design. If needed, the ADS simulation software allows us to test and recommend circuit layout surrounding the filter to insure proper functioning when the physical device is realized.

Enhanced Bessel Filters for 40Gbps Systems

Wire-bondable Packaged Filter:

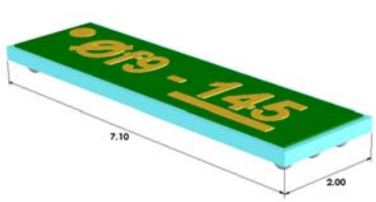
To maximize signal integrity performance, TFT offers filters in 1.95mm x 4.95mm package with gold plated pads for wire bondable packages. The benefit of the wire-bondable package is the extension in the "footprint" bandwidth which minimizes the influence to the enhanced Bessel filter's performance. The below plot demonstrates the insertion loss performance of a TFT 15 GHz 9th order enhanced Bessel wire-bondable filter package in comparison to the ideal 5th order Bessel function. The probed part matches simulation through 20 GHz.BGA



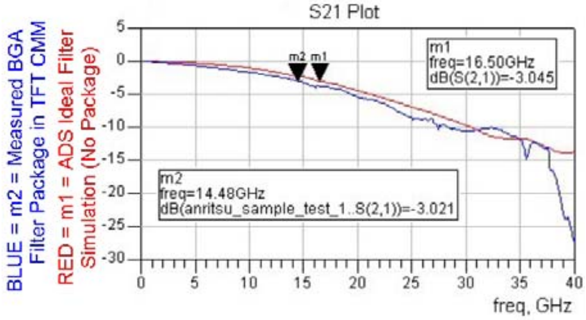


BGA Packaged Filter:

For lower cost and easy handling capability TFT provide filters in 2.0 x 7.1mm BGA package. A thru trace in this 6-pin BGA package, with the footprint, exhibits a component bandwidth of 30 GHz.



The 30 GHz package bandwidth in series with the filter's bandwidth (cut-off) will result in an overall filter package bandwidth lower than the ideal filter design, as shown in the plot below (for more information on this topic, please see the TFT 40 Gbps filter package application note). The below S_{21} plot shows the simulated and measured (in TFT's CMM) performance of BGA packaged 14.5 GHz 9th order enhanced Bessel filter.



Closing:

Thin Film Technology can provide you with standard or custom Enhanced Electrical Bessel Filter components for both the front end and back end electrical subsystems in a 10 and 40 Gbps optical system design. The "Enhanced Bessel" filters, which exhibit exceptional time domain characteristics and low return loss, are realized using high performance service for your design support including fast turn custom prototypes to full production capacity start to finish. TFT utilizes simulation techniques and also capitalizes on the advantages of thin film construction to realize these high performance electrical filter components. We can conceptualize, synthesize, and realize FAST!

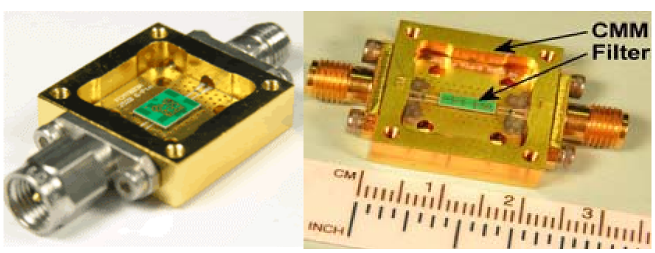
TFT Coaxial Modules in Reality Aided Design

Introduction:

There are many microwave devices that are not considered to be easily mounted in planar circuit assemblies. Passive filters for optical modulators are one of these. It was long considered that you could not cut a surface mount device into a multi-GHz path. These parts needed to be coaxial modules or Gold wire bonded to achieve the performance required by the 10 Gbps plus applications.

As a very high-speed digital component company, Thin Film Technology has developed an open source coaxial measurement module (CMM) that brings the reality of surface mount 10 and 40Gbps path components into the open. By leaving the module open it is easy to see that the filter function is provided by a single surface mount component within a very realizable planar environment.

TFT's Coaxial Measurement Module:



These modules have 20GHz bandwidths and beyond. When designing high-speed signal integrity components, TFT considers the footprint to be part of the component. The component's footprint is mated to a footprint on the Rogers printed circuit board contained in the CMM. The component, footprint, PCB coupon, and module now provide the full working environment for the component.

TFT's CMMs typically demonstrate a family of components such as low pass filters, high pass equalizers, and attenuators for use in tuning a systems performance on the designer's test bench before translating the component and footprint directly into the end design.

Advantage to the End User:

The ability to tune the system on the bench utilizing the component and its footprint is what we call Reality Aided Design (RAD). The RAD process allows us to see the impact of the component tolerances and optimize the design for best performance with the confidence from using real devices and assembly processes. The ability to directly transfer the component and associated footprint out of the CMM onto a production board allows the designer to fully characterize the component in the real world environment prior to final production assembly.

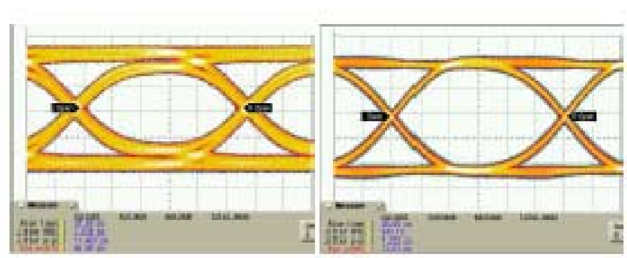


Figure 18: Comparison of the data eye at the output of the ATE test fixture with and without equalization using the Rogers 4350 dielectric materials with a PRBS 31 data pattern at 12.8 Gbps.

Thin Film Technology Engineering Services

General

Thin Film Technology brings its engineering service to the customer in many facets including filter component recommendations, demonstrating how to use filters in their specific applications, as well as full design simulation and prototype development. Simplifying the specification, development and testing of these types of devices is what we bring to our customers. Engineering from concept through realization is made practical and economical by the use of simulated measurement models, yield analysis, and real bench testing.

Test Bench Tools and Services

Thin Film Technology has a full line of coaxial bench tools to aid in your design, simulation, test, measurement, and calibration. Besides the complete line of high performance passive electronic SMT components, we have these components realized into coaxial measurement modules (CMM) to facilitate their capabilities on the bench. This allows for component level tuning to find the optimum solution. We will also help in refining the existing capabilities to put you in front of your competition with specific custom component and implementation technology.

Product Lines

- Enhanced Bessel Filters
- Equalizer (high pass filters)
- Performance chip resistors and networks
- Miniature High Speed Inductors
- Delay lines
- Low pass Filters
- Band pass Filters
- High speed Attenuators
- Power Splitters
- Antennas
- Integrated Passive Devices (IPD's)

Engineering and Design Services

- Design
- Simulation
- Modeling
- Prototyping
- Network Analysis
- Jitter analysis
- Failure analysis
- Environmental testing
- Custom microwave fixturing
- Microwave probing

Shared Risk Approach

- Free upfront technical proposals
- complete non-disclosure protection

- Engineering Rate — $/hr (consult factory)
- Technician Rate — $/hr (consult factory)
- Simulation Rate — $/hr (consult factory)
- Test Bench Rate — $/hr (consult factory)
- Prototype lot run — $ (consult factory)
- Design iterations with lot run — $ (consult factory)

Coaxial Measurement Modules
(20GHz)

- Individual components (2 week Lead time)
- Part family Kit 2/Ea (4 week lead time)
- Calibration Grade Kit - 3/Ea + Traceable engineering DATA (6week lead time)
- Your design - Custom Module footprint (4 weeks extra)

Consult factory for current pricing

Your Notes

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