

Pole/Zero Filter Design

Introduction

Today's crowded communication bands and increasing use of closely located receivers and transmitters require RF System designers to pay more attention than ever before to their equipment's generation and rejection of potentially interfering in-band signals and noise. The receiver must operate in the presence of large interfering signals on adjacent channels. Likewise, transmit noise and spurious requirements can come to within 10dB of thermal noise in some systems at frequencies only a few percent removed from the carrier. To meet these requirements, narrowband tunable bandpass filters are generally utilized. Filters of the fixed tuned variety are readily available to cover those applications where system complexity does not dictate tunability. Switching a bank of fixed tuned filters can be an effective method for imitating a tunable filter when size and cost are not issues, but this approach becomes physically impractical as the number of filters goes up and entails thoughtful design of the switching circuitry.

Low loss, high performance, narrow-band tunable RF filters are utilized in much present day RF equipment. Applications include: receive preselection and IF filters, receive and transmit LO phase noise improvement, transmit interstage filtering, and sometimes even filtering of the transmit output stage. Pole/Zero's line of narrowband tunable filters allows the system designer or project engineer to take the time consuming and costly task of filter development out of the development cost.

Tuning Components

Changing the resonant frequency of a tuned circuit can be done by varying either its inductance or capacitance. Because of their smaller size and higher Q, capacitors are generally chosen as the tuning element. One way to accomplish this is by allowing the capacitance to be a bank of switched discrete capacitors. Far from ideal, the PIN diode remains the choice RF switching component when medium to high in-band RF power handling, 1 to 100 watts or greater, is required. Once a high cost component, diode manufacturers now offer high performance parts in low cost SMD packages. Some JFETs are available that exhibit usable RF switch characteristics, but RF power handling can only approach the 1 watt level. Varactor diodes remain the choice tuning element for RF power handling to 20mW.

Selecting the Right Tunable Filter

Selecting the right filter for the job requires the designer to consider a number of aspects. These relate to technical performance, size/weight, and cost. On the technical side, the filter performance characteristics can be summarized:

- Insertion Loss
- Bandwidth/Selectivity
- RF Power Handling
- Intercept Point (IP3)
- Tuning Range
- Tuning Speed
- Power Consumption

Additionally, the size, and weight of the filter must be considered, especially for portables and airborne equipment. And as always, cost is a major driver in engineering decisions.

Insertion Loss and Bandwidth/Selectivity

An unfortunate rule of nature dictates that a filter's insertion loss and bandwidth are inversely related; the narrower the bandwidth of a filter of a given technology, the higher its loss. The bandwidth-loss relationships are measured by a filter designer using the property called "unloaded Q". This property measures the Q of an unloaded resonant circuit. Q is mathematically defined for a resonant circuit by the equation:

$$Q = \omega \cdot R \cdot C \text{ or } Q = R/(\omega \cdot L)$$

It is readily obvious that the higher the value of R, which for an unloaded resonator represents the lossy component, the higher the value for Q. The insertion loss of a 2-pole Butterworth filter is given by the equation:

$$IL = 20 \cdot \log[Q/(Q - 1.414/BW3dB)]$$

Again, the only way to improve a filter's IL, for a given technology and bandwidth, is to increase the Q of its resonant circuits. Generally, this means larger size and/or increased DC power consumption, and higher cost, due to higher quality components.

RF Power Handling

This parameter can be the most important one in selecting a tunable filter. As opposed to fixed tuned filters that consist of passive components, tunable filters contain active components, which have limited linearity. The 1dB compression point of a filter is the RF signal level where IL increases by 1dB. For a tunable filter, this occurs when the RF signal's peak voltage imposed across an active tuning component, whether PIN diode or varactor, approaches the DC bias voltage applied. For PIN diodes, power handling can be improved with increased reverse bias, however care must be taken to ensure the sum of the bias voltage and the peak RF voltage do not exceed the breakdown voltage of the parts. Insufficient forward bias current can also limit power handling but is usually of secondary importance.

Intercept Point (IP3)

Third order intercept point is a figure of merit for linearity and is closely related to the 1dB compression of the filter. When two large "interfering" signals (F1 and F2) are applied to a filter, two new signals are generated which appear one on either side of the interferers and spaced from them by F1 - F2. If these interfering signals occur within the filter's passband, the distortion products can be large and easily fall right on top of a desired signal. In a tunable filter, this distortion is caused by the non-linearity of the active components when large RF voltages are imposed on them. Inband IP3 is generally 10 to 15dB higher than the 1dB compression level of a filter. The amplitude of the distortion products decreases as the interfering signals are moved out of the passband and on to the filter skirts. Note that even though the filter being specified may not have to handle high RF levels, the requirement for IP3 may drive its size, weight, and cost due to the relationship between RF power handling and IP3.

Tuning Range

The narrower the tuning range required of the filter, the higher the performance. If your tuning range can be reduced, or two half-band filters can be utilized, usually at least one other technical parameter can be significantly improved.

Power Consumption

PIN diodes require DC power when forward biased. Generally, by increasing the forward bias of a diode, unloaded Q is increased and thus IL improved.

Standard Filter Designs

Pole/Zero's standard MINI-POLE, MAXI-POLE, and POWER-POLE bandpass filters are 2-pole, constant Q designs and are aligned to provide a close approximation to a Butterworth response. Filter tuning ranges are available based on popular communication bands covering 1.5MHz to 1GHz. Units are available with standard 3dB bandwidths from 1.8 to 20%. Figure 1 shows a simplified Block Diagram of a filter module.

Tuning is accomplished via a PIN diode switched binary capacitor array placed in parallel with a high Q inductor or resonator. A single +5vdc input provides the current for diode forward biasing and an additional input voltage between +30 and +100vdc is required for diode reverse biasing. An internal DC-DC converter running off the +5vdc supply for generating the high bias is an option on the MAXI-POLE, and is standard on the POWER-POLE.

The tuning arrays are driven by a decoder/driver that contains all of the necessary circuitry to receive digital tuning commands, translate them to the internal filter tuning codes, and drive the PIN diodes with the proper bias. The entire tuning process is accomplished in under 10 microseconds for most bands. The standard input format is a parallel 8 bit binary word allowing each filter 251 tune positions (the last 5 tune words are reserved for special functions), linearly spaced over it's RF tuning range.

For lower RF power handling requirements, small size, or battery operated equipment, Pole/Zero's "MICRO-POLE" offers designers an off-the-shelf DIGITALLY TUNED filter solution. With insertion loss and selectivity performance similar to the "MINI" series, the "MICRO-POLE" requires a single +3 to +5vdc input at less than 1 mA current. Tuning is controlled via an 8 bit binary sequence similar to that described above. This series is packaged as a SMD module with dimensions of 0.5" x 1.0" x 1.5". This latest addition to the P/Z family of tunable filters offers communication engineers the final building block for low power front-end receiver design. As easy to specify as 50mW MMIC amplifiers or mixers, the "MICRO-POLE" provides a small, low-cost, low-power solution for RF receiver front ends.

Customized units are always available as well as Pole Zero's series of tunable Notch Filters and Filter/Amp cascades.