Tunable, Substrate Integrated, High Q Filter Cascade for High Isolation

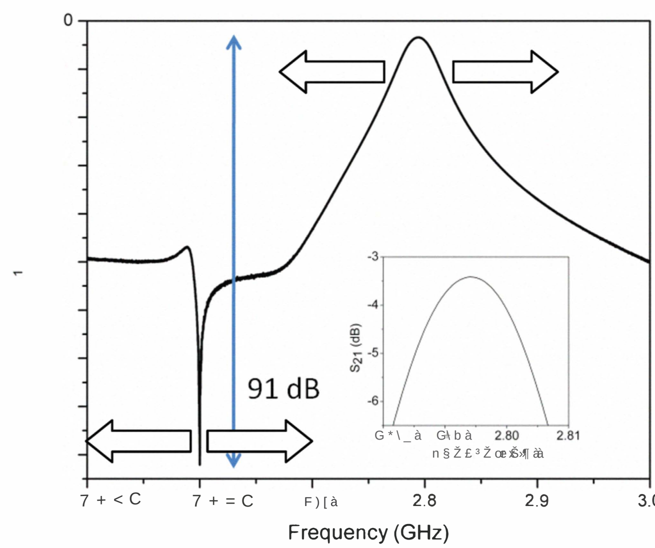

Fig. 2. Measured results of > 90dB isolation with the combination of tunable bandpass and bandstop filters.

magnetic field of the first mode of the resonator. In the bandstop case, a shunt feed is used. A semi-circular slot is incorporated in the ground plane of a microstrip line. Other than the slot in the ground plane, the microstrip line is a through line. This slot couples the magnetic field of the microstrip mode with the magnetic field of the first mode of the resonator. Effectively, the slot is only a substantial mismatch to the feed line when the resonator is at resonance. Therefore, the shunt-feed bandstop case passes the off resonance spectral content of the signal, while the series-feed bandpass case attenuates the off resonance content of the signal.

The concept is shown in Fig. 2, which is a plot of measured results from cascading a tunable two pole bandpass filter with a tunable two pole bandstop filter to achieve greater than 90 dB of isolation between two frequency bands of interest.

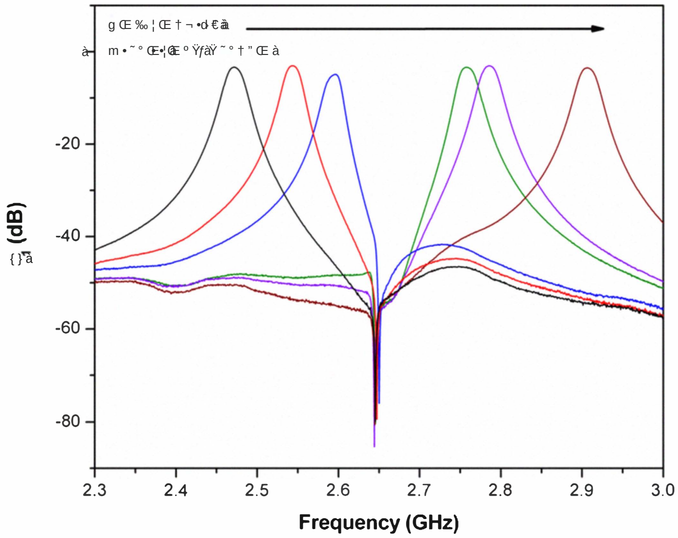

Fig. 4. Bandpass filter being tuned around a bandstop filter, useful in a situation with a constant interferer.

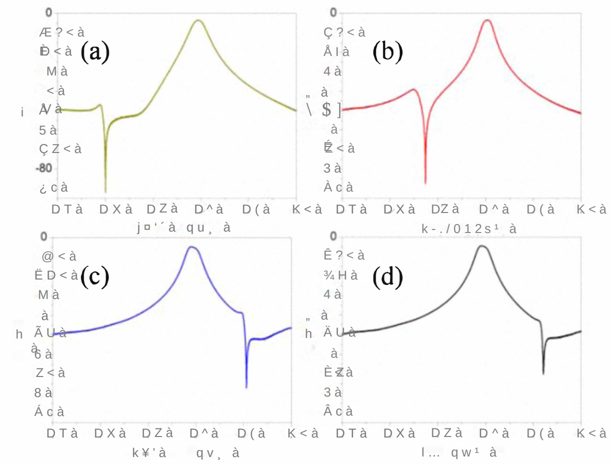

Fig. 5. Bandstop filter being tuned around a bandpass filter, useful in a situation with a hopping interferer. BS filter piezo voltage is decreased from (a) to (d).

response of the filter away from the notch frequency degrades with increasing loading because of worsening return loss, so the value of 66 ohms was chosen as a tradeoff between the out of band reflection and the bandwidth adjustability. A Microsemi MV20001-150A varactor with low absolute capacitance and high capacitance tuning range (0.15 pF-0.5 pF) was used.

III. Bandpass/Bandstop Cascade

When a bandstop filter is placed in cascade with a bandpass filter and the two filters are tuned to different frequencies, the bandpass out of band response presents an impedance to the bandstop input port that is different from the characteristic impedance of the system at the operating frequency of the bandstop filter. Therefore, the inter-filter transmission line affects the bandstop filter frequency response, and the response is far from a superposition of the individual filter S-parameter responses. Specifically, the length of the inter-filter transmission line changes the depth of the null produced in the frequency response. For high isolation, the phase of the output reflection coefficient of the bandpass filter and that of the input reflection coefficient of the bandstop filter should be examined and corrected for at the center frequency of the bandstop filter (assuming the bandpass filter precedes the bandstop filter in the system).

The inter-filter transmission line results in modified phase of the output reflection coefficient of the bandpass filter, and it was found that the null depth achieves a maximum, which is the best case, when the phase difference between the modified reflection coefficient of the bandpass filter at the bandstop filter center frequency and input reflection coefficient of the bandstop filter is 180 degrees. The minimum null depth was found when the phase difference was 90 degrees.

A low loss phase shifter could be used to ensure the optimal phase between the filters. However, one of the aims of the present work is to show that significant performance benefits can be realized without varying the phase of the connection. Accordingly, all measurements shown are taken with the same physical length connecting the bandpass and bandstop filters.

Because of the effect of out-of-band bandpass port impedance on the subsequent notch filter, the filter cascade isolation performance is best when the bandpass and bandstop filters are tuned in close proximity to each other. This is a favorable effect as the cascade's performance is most important when the two filters are tuned near one another. When an interferer is spectrally far from the pass band of the bandpass filter, the bandpass filter will provide high levels of isolation by itself. When an interferer is near the pass band of the bandpass filter, the cascade effect produces high levels of isolation that would otherwise be difficult to achieve for a static bandpass filter.

IV. Measured Results

Measured results showing the bandpass filter being tuned about a stationary bandstop filter are shown in Fig. 4. This would represent the case where the receive band is searching for a signal in the presence of a fixed interferer. Measured results showing the bandstop filter being tuned about a fixed bandpass filter are shown in Fig. 5, representing the case when an interferer is hopping through the spectrum around a fixed receive band. These plots show that isolation of 70-90 dB is possible between two spectrally close frequencies of interest over the 2.3 to 3.0 GHz band. Fig. 6 compares the cascaded result to the response of a simple two pole bandpass filter, showing the deep notch in the spectrum comes at the expense of 0.7 dB extra insertion loss in the pass band. The total pass band insertion loss of the four resonator chain increases to -3.4 dB. Fig. 7(a) shows that the bandpass and bandstop filters can be tuned within 55 MHz of one another around 2.63 GHz (2.1%). In Fig. 7(a), the bandpass filter is tuned to 2.595 GHz and the bandstop filter is tuned to 2.650 GHz. The bandpass filter insertion loss increases from -3.4 dB to -4.9 dB at this 2.1% spacing and degrades further at lower spacings. Using