Varactor-Tuned Bandstop Filters with Tunable Center Frequency and Bandwidth

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Introduction

Tunable bandstop filters are useful in adaptive receiver front-ends, where they are used to excise co-site and foreign interferers. In situations where the characteristics of an interferer are unknown, in addition to center frequency tuning a bandwidth tuning capability is also attractive. While the engineering of the bandwidth versus tuned center frequency response has been demonstrated [1], to date very little work has been done on the development of tunable bandstop filters which provide independent control of both center frequency and bandwidth.

This paper presents a new tunable bandstop resonator architecture which allows for both center frequency and bandwidth tuning. It consists of a varactor-loaded transmission line resonator with odd symmetry about one axis coupled twice to a through line. No tuning elements are placed in the signal through path. It is based upon a recently developed proposed bandstop resonator coupling topology [2] where the bandwidth is determined not only from the strength of the couplings but also from the electrical length of the associated through line. Bandwidth tuning is achieved by differentially two varactors attached at opposite ends of the resonator, and center frequency tuning is achieved by tuning both varactors simultaneously.

Basic Concept

Shown in Fig. 1a is a highpass prototype of a conventional 1st-degree bandstop section, comprised of a resonator coupled to a transmission line. The coupling is modelled with an admittance inverter K. Applying even/odd mode analysis, the bandwidth of this section can be shown to be proportional to K^2.

Shown in Fig. 1b is a highpass prototype of an alternative 1st-degree bandstop section [1], comprised of a resonator coupled to a transmission line twice across an electrical length θ. Coupling the resonator to the transmission line twice effectively forms two signal paths, and depending on the value of θ either destructive or constructive interference can result. Also note that the two couplings K may be opposite in sign, depending on the coupling mechanism and topology of the resonator used. Using even/odd-mode analysis the 3-dB bandwidth of this section can be shown to be:

Case 1 (couplings K are the same sign):

$$BW = 4K^2 \cos^2\frac{\theta}{2} \tag{1}$$

Case 2 (couplings K have opposite sign):

$$BW = 4K^2 \sin^2\frac{\theta}{2} \tag{2}$$

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Assume for the moment that both couplings K have the same sign, and so the bandwidth is given by (1). Eq. 1 is a maximum when θ is an integer multiple of 360°:

$$\theta = 2\pi n, \quad n = \{0,1,2\ ...\} \tag{3}$$

Under this condition the phase difference between the two signal paths is 180° and maximum destructive interference occurs, resulting in maximum stopband bandwidth for a given coupling K. Eq. 1 is zero (and thus the coupling to the resonator is effectively cancelled) when θ is an odd multiple of 180°:

$$\theta = \pi n, \quad n = \{1,3,5\ ...\} \tag{4}$$

Under this condition the two paths are in phase and maximum constructive interference occurs. When the couplings K are of opposite sign, the bandwidth is given by (2) and condition (3) results in minimum and (4) results in a maximum.

It has just been shown that the bandwidth of the bandstop resonator topology of Fig. 1b is dependent not only on the strength of the couplings K but also on the transmission line electrical length θ. Therefore the bandwidth can be tuned by changing θ, which could readily be achieved with the use of a phase shifter. A more elegant solution, which avoids placing tuning elements in the through path, is to indirectly tune θ using the tuning elements already being used to tune the center frequency of the filter. This can be achieved by coupling the resonator to the transmission line in such a way that the reference planes for the two couplings shift in opposite directions when tuning elements attached to opposite ends of the resonator are differentially tuned.

Shown in Fig 2a is a half-wavelength resonator coupled to a through line, with the center of the coupled-line section determined by electrical lengths θ_1 and θ_2 (θ_1+θ_2=180°). Both the resonator and the through line are assumed to be lossless TEM transmission lines. Also shown in Fig. 2a are the travelling-wave phase relationships when port 1 is excited. These phase relationships show that the location of the coupling reference plane (an RF short) is dependent on θ_1 and θ_2, and in the case of Fig. 2a the coupling reference plane shifts to the right when the ratio of θ_1/θ_2 is increased. In practice θ_1 and θ_2 can be effectively controlled with varactors attached to the ends of the resonator.

Shown in Fig. 2b is the proposed tunable bandstop resonator architecture with bandwidth tuning capability. It consists of a resonator coupled twice with parallel coupled-line sections to a transmission line across an electrical length θ_0, and so effectively implements the coupling topology of Fig. 1b. Also note that parallel-line couplings possess an odd symmetry about the center line. Because of this, differentially tuning the varactors C_1 and C_2 shifts the reference planes of the two couplings in opposite directions along the transmission line, thus allowing the electrical length between the two couplings to in effect be controlled. In other words, by coupling a resonator to transmission line in this fashion it is possible to control the equivalent electrical length θ of Fig. 1b (and thus the bandwidth) using just the tuning elements attached to the resonator. Shown in Fig. 2c and Fig. 2d are simulated responses of the proposed bandstop resonator for various center frequency and bandwidth states, including the intrinsic “off” state where the stopband bandwidth goes to zero. Note that in the "off" state the resonator is still resonating at 1 GHz, but the bandstop response is completely suppressed.

Results

Shown in Fig. 3a is a microstrip prototype of a tunable 2nd-order absorptive notch filter using the resonator topology shown in Fig. 2b. As done in [3], a small amount of coupling is intentionally introduced between the two resonators. This coupling serves to improve the normally dissipative-loss limited notch depth by creating destructive interference. The circuit was fabricated on *Rogers Duroid* RO4003 (ε_r=3.38, thickness=60 mils) using a milling machine. The varactors are *Aeroflex/Metelics* MGV-125-24-E25 (GaAs hyper-abrupt junction, C_j=0.35-7.3 pF). Shown in Fig. 3b and Fig. 3c are the measured results. The center frequency is tunable from 1.2 GHz to 1.6 GHz and the bandwidth is tunable from 70 MHz to 140 MHz (this prototype was not designed to be intrinsically switchable).

Conclusions

A new tunable bandstop resonator architecture has been presented which, for the first time, allows for both center frequency and bandwidth tuning using only tuning elements attached to the resonator. A 2nd-order microstrip prototype notch filter demonstrating the concept was successfully designed, built, and measured.

References:

[1] A. I. Abunjaileh and I. C. Hunter, "Tunable combline bandstop filter with constant bandwidth," *IEEE International Symposium on Microwave Theory and Techniques*, pp. 1349 – 1352, June 2009

[2] A. C. Guyette, "Design of fixed- and varactor-tuned bandstop filters with spurious suppression," submitted to the *40th European Microwave Conference 2010*

[3] D. R. Jachowski and A. C. Guyette, "Sub-octave-tunable notch filter," *IEEE International Symposium on Electromagnetic Compatibility*, pp. 99-102, Aug. 2009.

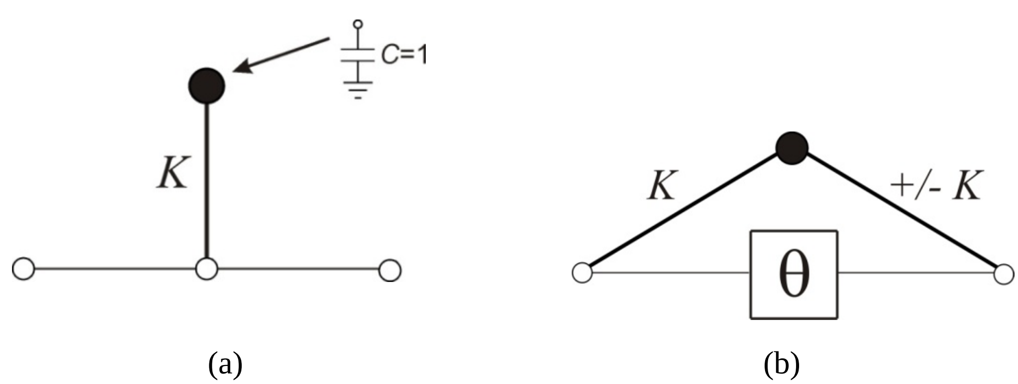


Fig. 1 1st-degree highpass prototype sections comprised of shunt capacitors and couplings *K*. (a) Conventional. (b) Alternative [2].

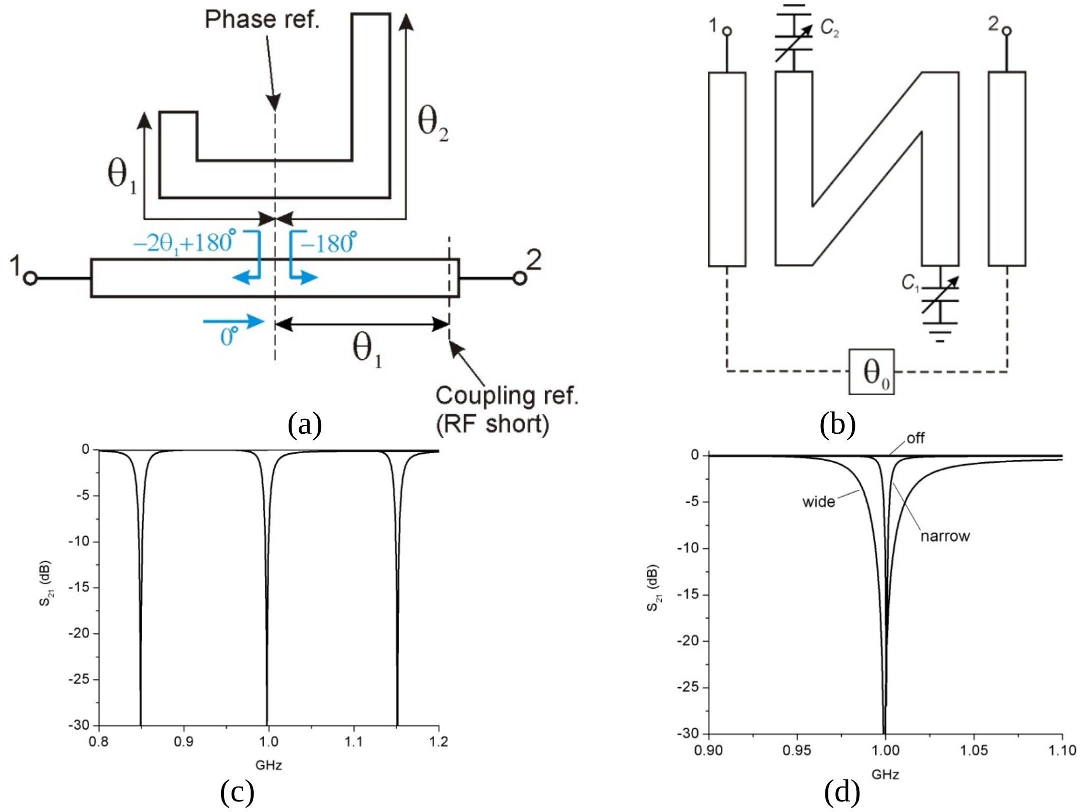
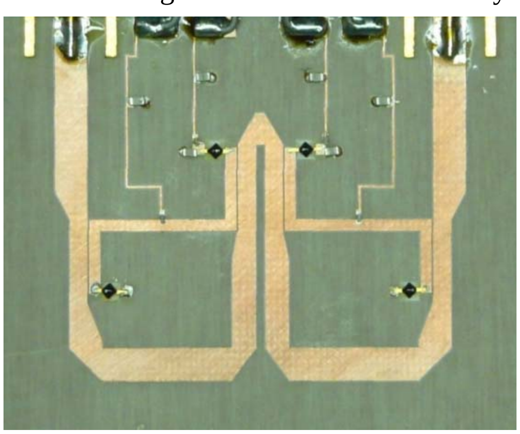


Fig. 2 (a) Coupling reference plane shifting concept (b) Tunable-bandwidth bandstop resonator topology, consisting of a resonator coupled twice to a transmission line (c) *AWR Microwave Office* simulation showing center frequency tuning, (d) *AWR Microwave Office* simulation showing bandwidth tuning and intrinsic switching obtained from differentially tuning varactors C_1 and C_2.



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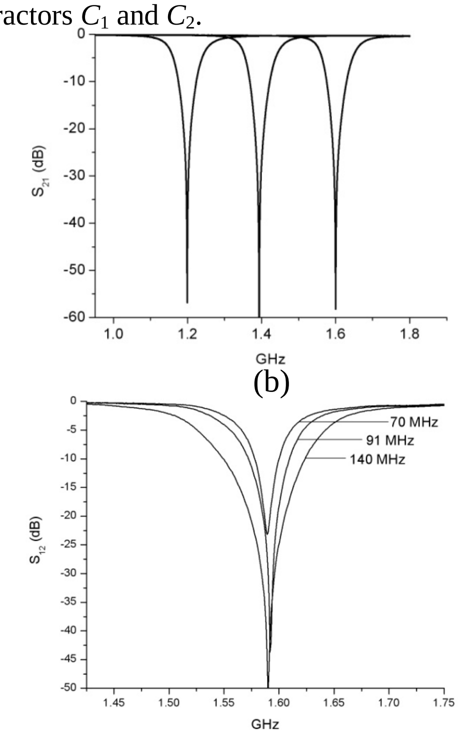

Fig. 3 Tunable 2nd-order absorptive notch filter with both center frequency and bandwidth tuning (a) microstrip circuit, (b) measured results showing center frequency tuning with the bandwidth set to 100 MHz, (c) measured results showing bandwidth tuning obtained by differentially tuning varactors.