

Low-loss Self-Switching Bandstop Filter

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Abstract -- A new switchable low-loss bandstop filter is presented based on an indirect switching method combined with all-pass coupled lines. The proposed design allows switching between an all-pass mode and a bandstop filter mode for On/Off operation of a bandstop response. Due to the location of the switch, which is outside of the through line, the passband insertion loss is drastically improved with this new method compared with a conventional switchable bandstop filter configuration. In addition, the method provides consistent group delay throughout the passband in both the all-pass mode and the bandstop filter mode, which is a capability that is not commonly available in conventional multi-path-type switched filter approaches. A 4-pole prototype switchable notch filter centered at 1090 MHz with 14 MHz 30-dB bandwidth was fabricated and measured for demonstration.

Index Terms -- Bandstop filter, notch filter, switchable notch filter, switchable bandstop filter

I. INTRODUCTION

Switched bandstop filters are used to achieve a reconfigurable frequency response at the front-end of an RF system that allows it to receive or reject a specific frequency band on demand. The conventional switched-bandstop-filter configuration is comprised of switches in conjunction with a bandstop filter and bypass transmission line in parallel as shown in Fig.1 (a) [1]. The switches route an RF signal to the internal direct path for the all-pass mode or to the filter path to engage the bandstop filter. In this approach, the RF signal experiences significant insertion loss from the switches in both the on and off states. The discrepancy of passband group delay is also large due to the two different signal paths between the bypass mode and bandstop mode.

An effort to minimize additional switching loss was reported through varactor-tuned intrinsically-switched bandstop filters [2]. In this approach the On/Off states of the bandstop filter are realized by tuning the center frequencies and bandwidths of bandstop resonators without external RF switches. However, long through lines are necessary to realize the desired circuit. A similar all-pass and bandstop reconfigurable response was obtained using analog tuning of shunt resonators with piezoelectric actuators and without external switching networks [3]. Due to a high-Q coaxial cavity-type resonator realized with a Substrate Integrated Cavity (SIC), a narrower bandwidth response was achieved. However, the piezoelectric actuator has hysteresis and slow tuning speed, complicating its practical applicability.

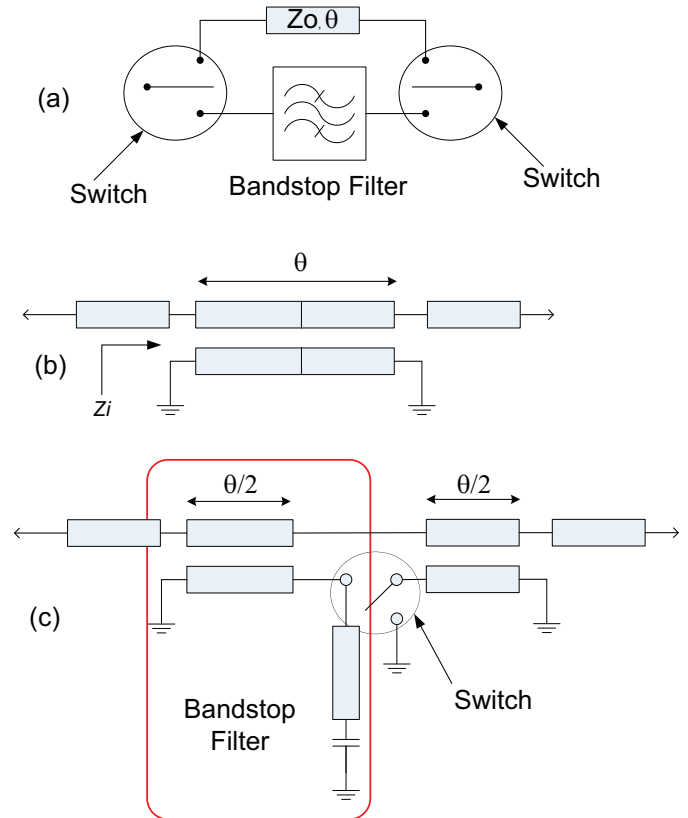


Fig.1 (a) Conventional switched bandstop filter (b) All-pass coupled line network, where $Z_i = \frac{2Z_{oe}Z_{oo}}{Z_{oe}+Z_{oo}}$ (c) Proposed all-pass network with switchable bandstop filter,

In this paper, a new method is applied to minimize additional insertion loss from switches using all-pass networks in conjunction with SPDT (Single-Pole-Double-Throw) switches. In contrast to conventional switched bandstop filters, the switches in the proposed structure are located outside of the main signal path. Therefore the transmitted signal does not go through the switching network directly, and the proposed configuration drastically reduces the insertion loss compared with conventional switchable filters. It also minimizes the discrepancy in passband group delay between all-pass mode and bandstop filter mode without supplemental lengths of transmission line, which is only possible in conventional multi-path type switchable filter designs by increasing size.

II. FILTER DESIGN

An all-pass network using parallel transmission lines is shown in Fig.1 (b). A through line is parallel coupled with a transmission line in which both end sections are terminated with grounds. In this configuration, the magnetic and electric couplings are balanced along the coupled lines and all frequencies pass through the through line without any interruptions over ideally infinite bandwidth [4]. If the coupled line section is split into two symmetric sections and a shunt series bandstop resonator is added in the middle of the grounded coupled line as shown in Fig.1 (c), the all-pass response from the modified coupled line is still maintained due to the balanced couplings from the symmetric structure. However, if the balanced couplings between coupled lines are broken by a switch located in the middle of the grounded coupled lines, the circuit is no longer an all-pass network. Then the coupled line section loaded with a shunt series resonator behaves as a bandstop filter as shown in Fig.1 (c). For this purpose a SPDT switch is inserted in the middle of the all-pass coupled line sections, and a bandstop resonator is attached in the middle of the coupled line sections in shunt. When the switch is set to connect the two coupled line sections, the all-pass state results as shown in Fig. 2 (a), and a bandstop filter response does not appear as long as the coupling from both coupled line sections cancels. The shunt series resonator connected in the middle of all-pass coupled line has an actual resonance around 1398 MHz in this example. However the bandstop resonance is completely suppressed by coupling cancellation of all-pass coupled line network...

However, when the switch is in the bandstop mode as shown in Fig.2 (b), then the coupling balance between the two coupled line sections is broken, and the coupled line resonator behaves as a bandstop resonator. In the bandstop mode, the right-hand side coupled line section individually has an all-pass-mode coupled-line configuration because the switch connects its left side to ground, and it is used as part of the required phase shift between resonators for impedance matching in high-order bandstop filter design. In this example the resonant frequency of the resonator shifts from 1398 MHz (allpass state) to 1000 MHz (bandstop state). This approach therefore allows for a relatively small shift in resonant frequency between the on and off states, which in turn minimizes the resonator Q_u degradation caused by switch loss.

Besides low passband insertion loss and high resonator Q_u , another advantage of this approach is less discrepancy of the passband group delay between all-pass mode and bandstop filter mode. In the case of conventional switched bandstop filter design, there are often different path lengths for each switching mode to minimize size. The group delay responses are therefore different for each mode. However, in the proposed switchable notch filter, only one path exists between

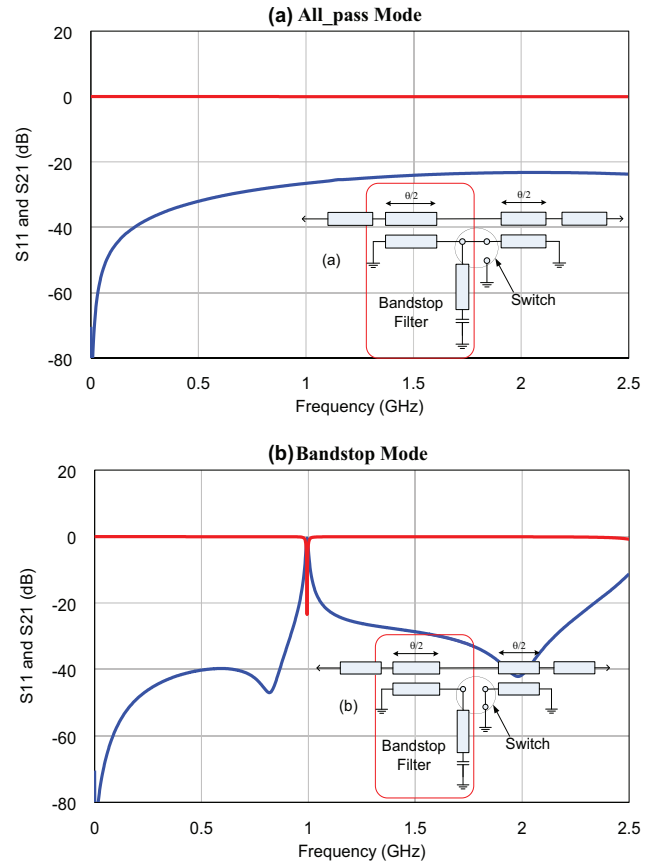


Fig.2 Switchable bandstop filter response (a) All-pass mode, (b) bandstop mode

all-pass and notch filter modes, which results in the same delay for two different modes in system design.

Shown in Fig. 3 is a fabricated 4-pole prototype Chebyshev notch filter design using the proposed configuration for the following specifications.

- Center Frequency = 1090 MHz
- 3-dB passband = 80 MHz
- 30-dB Rejection bandwidth = 14 MHz
- 4th-order Chebyshev response

An initial 4-pole prototype Chebyshev bandstop filter is realized in distributed form through appropriate circuit transformations and approximations as described below.

Design Procedures:

1. A prototype 4-pole distributed Chebyshev bandstop filter is realized with 4-transmission zeros and 5 unit elements. Series parallel stub resonators are coupled through unit-element transmission lines. [Fig.3 (a)]

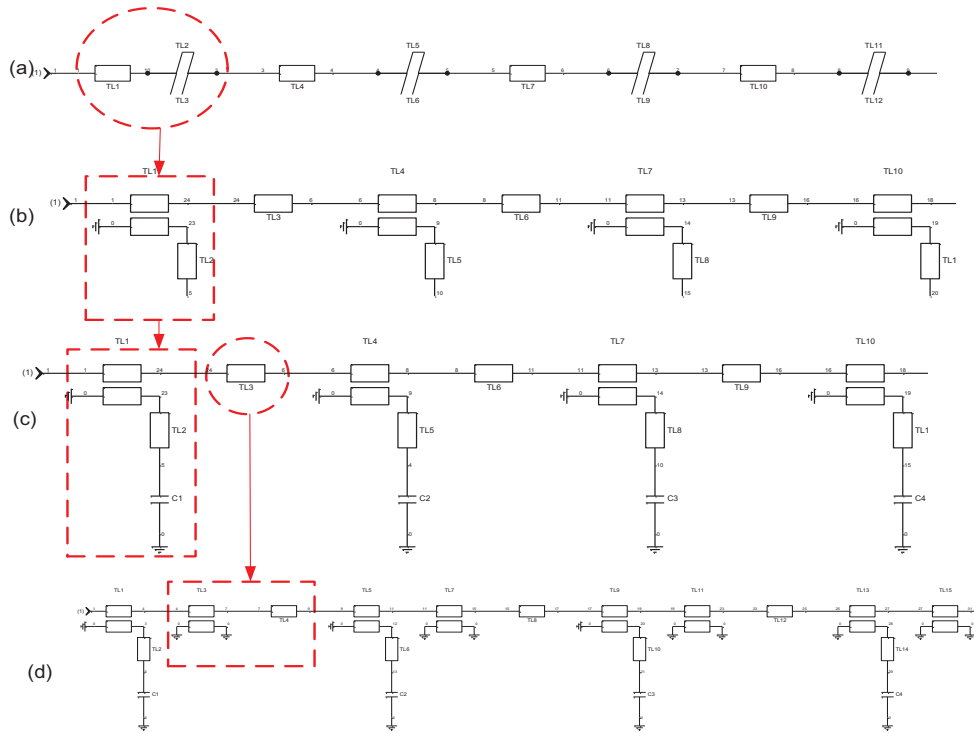


Fig. 3 Circuit Transformations for bandstop filter: (a) 4-pole prototype distributed Chebyshev bandstop filter, (b) After Ikeno coupled line transformation from transmission line with series resonator to grounded coupled line with shunt open stub, (c) After replacing shunt open stub with open stub with loaded capacitor to reduce the shunt open stub length, (d) After transformation from transmission line to all-pass grounded coupled line, final circuit for bandstop-mode operation.

2. Series parallel stub is transformed into grounded parallel coupled line with an open shunt stub by Ikeno coupled line transformation [5]. [Fig.3(b)]
3. Shunt open stub is replaced with a shunt transmission line with a loading capacitor to reduce the shunt open stub length. [Fig.3(c)]
4. Interconnecting transmission line is transformed into an all-pass double-grounded coupled line and additional transmission line. [Fig.3(d)]. This is the final circuit for bandstop-mode operation.

III. MEASURED RESULTS

Fig.4 shows the photo of the fabricated 4-pole switched band stop Filter. The length of coupled-line section is 27 degrees-long in the final circuit and the shunt-series bandstop resonator is 38 degrees-long with a loading capacitor to extend the upper spurious-free passband from the reentrant harmonics. The filter is fabricated on Rogers RO4003C ($\epsilon_r=3.38$, thickness=0.060") as a microstrip line implementation. Peregrine Semiconductor switches (PE42422) are used for the RF switches in each resonator. Switch insertion loss is 0.25 dB typical at 1000 MHz and switching time is 4 μ s maximum. The circuits were fabricated using an LPKF Laser milling machine and ground through holes were plated using LPKF ProConduct paste.

Lengths of transmission line are added between bandstop resonator sections so that the total length between resonators, including the lengths of the double-grounded coupled line sections, was approximately 90 degrees for inter-resonator

coupling. The measured data is shown in Fig. 5 for both the all-pass mode and the bandstop mode. The insertion loss at all-pass mode is about 0.32 dB at 1090 MHz. A conventional switched bandstop filter would have > 0.5 dB of insertional loss from the signal-routing switches alone. The rejection at the center of frequency of 1090 MHz at bandstop-mode is about 33 dB. A comparison between simulated and measured data is shown in Fig. 6. The insertion loss is slightly higher than expected due to radiation, ground via plating, and connectors. If the circuit is realized with a higher-Q planar structure such as suspended strip line, deeper and sharper notch responses could be available. A comparison of the group delay between the all-pass and bandstop modes is shown in Fig. 7. There is a negligible difference in group delay over the passband between two modes as expected.

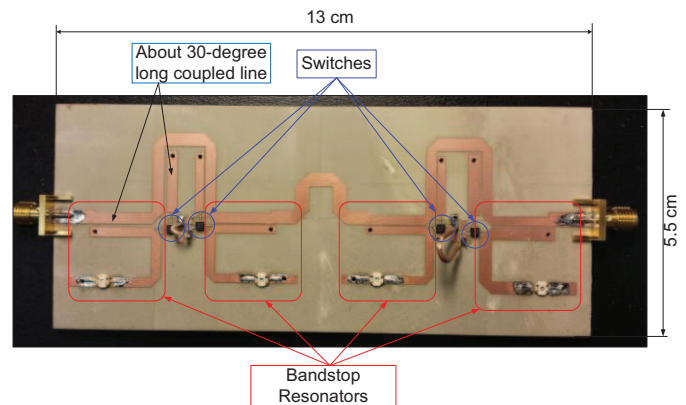


Fig. 4 Fabricated 4-pole self-switched bandstop filter (5.5 cm (w) x 13 cm (L))

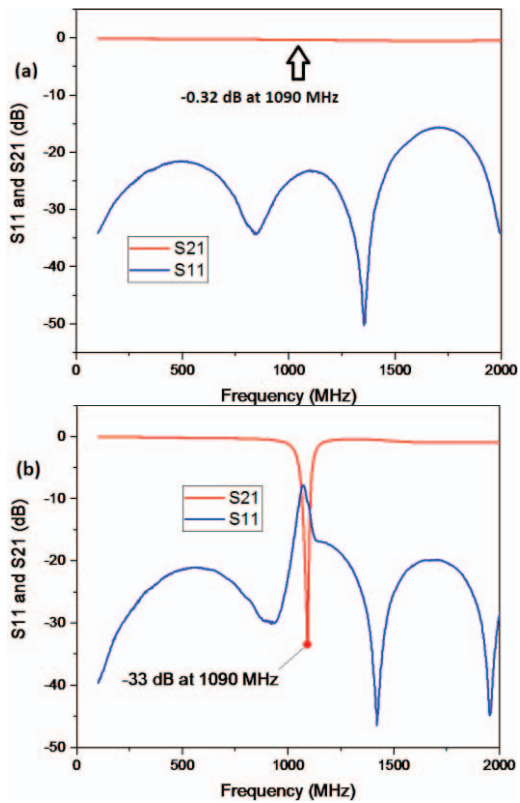


Fig.5 Measured data of 4-pole bandstop filter (a) all-pass mode (b) Bandstop mode.

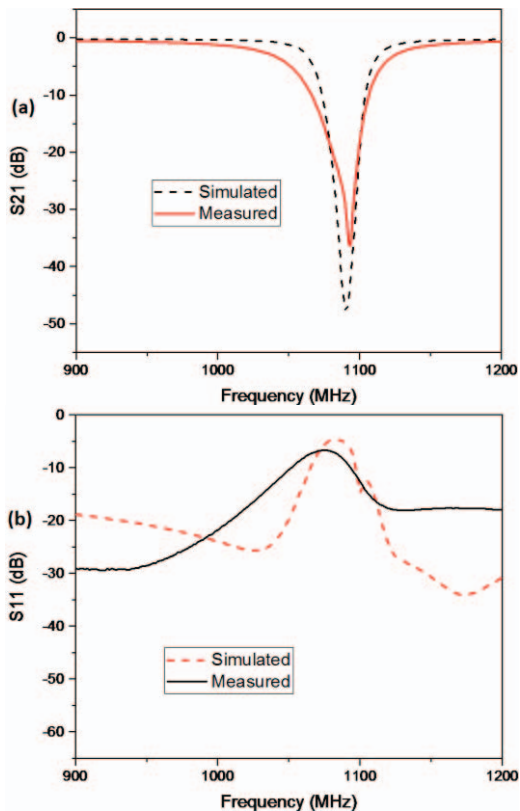


Fig.6 Simulated and Measured data of 4-pole bandstop filter (a) Insertion loss (b) Return loss (solid line measured, dotted line simulated).

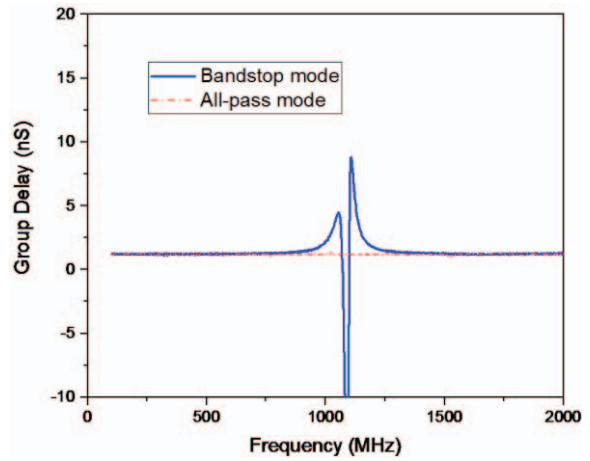


Fig.7 Group delay comparison between all-pass mode and bandstop mode (solid line: bandstop mode, Dotted line: all-pass mode).

IV. CONCLUSION

In this paper, a low-loss switched notch filter is presented with low RF-switch-related passband insertion loss and minimal group delay deviation between all-pass mode and notch filter mode. In the proposed method, RF switches are not located in the direct path of the main signal, and so switch loss is minimized. The proposed structure will be useful for applications that require low insertion loss and consistent group delay over the passband between switched states.

ACKNOWLEDGEMENT

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REFERENCES

- [1] J. D. Rhodes, "Switched Bandstop Filters," *Int. Journal of Circuit Theory and Applications*, vol. 22, pp. 107-120, 1994.
- [2] Guyette, A.C., "Intrinsically Switched Varactor-Tuned Filters and Filter Banks", *Microwave Theory and Techniques, IEEE Transactions on Year: 2012, Volume: 60, Issue: 4 Pages: 1044 - 1056*
- [3] Naglich, Eric J.; Juseop Lee; Peroulis, D.; Chappell, W.J. "Switchless Tunable Bandstop-to-All-Pass Reconfigurable Filter", *Microwave Theory and Techniques, IEEE Transactions on Year: 2012, Volume: 60, Issue: 5 Pages: 1258 - 1265*
- [4] L. Young, G. L. Matthaei, and E. M. T. Jones, "Microwave Microwave Filters, Impedance-matching networks, and Coupling Structures, Artech House, 1980, pp.233
- [5] J. A. G. Malherbe, "Microwave Transmission Line Filters", Artech House, 1980
- [6] Naglich, E.J.; Guyette, A.C.; Peroulis, D."High-Q intrinsically-switched quasi-absorptive tunable bandstop filter with electrically-short resonators", *Microwave Symposium (IMS), 2014 IEEE MTT-S International*