Tunable Reflectionless Microstrip Bandpass Filters

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***Abstract*— A class of frequency-reconfigurable reflectionless microstrip bandpass filters is reported. This RF/microwave device is based on a complementary-duplexer architecture made up of a bandpass-type and a bandstop-type channel with resistive termination. Whereas the bandpass channel defines the transmission profile of the overall filter, the input-signal energy that is not transmitted by this channel is absorbed by the bandstop branch. In this manner, a reflectionless behavior at the filter input is achieved. The theoretical foundations of the devised input-reflectionless bandpass filter and synthesis examples for single/multi-stage designs are presented. Furthermore, for experimental-validation purposes, a two-stage prototype that can be tuned within the 0.8–1.1-GHz range is manufactured and tested.**

***Index Terms*— Absorptive filter, adaptive filter, bandpass filter, duplexer, filter cascade, microstrip filter, planar filter, reconfigurable filter, reflectionless filter, tunable filter.**

I. Introduction

The design of reflectionless or absorptive RF/microwave filters is currently gaining considerable attention. Contrary to most of classic filter schemes, the input-signal energy that is not transmitted to the output is dissipated in the filter volume instead of being reflected at its input. As a result, undesired power reflections that can deteriorate the operation of sensitive RF blocks in the RF front-end chain and reduce the overall linearity and efficiency of the transceiver are suppressed.

Whereas frequency reconfiguration is a very desired feature in modern RF/microwave devices for flexible next-generation RF transceiver development, only a limited number of spectrally-adaptive reflectionless filters have been reported. Moreover, most of them exhibit a bandstop-type response, such as the ones in [1]–[5] for microstrip, lumped-element, cavity-resonator, and hybrid acoustic-wave-lumped-element technologies. On the other hand, the availability of reflectionless bandpass filters is even more scarce and restricted to spectrally-static designs. This is the case of the filters in [6]–[9], whose circuit topologies could hardly be adapted to tunable realizations while maintaining the reflectionless property.

In this paper, a type of frequency-tunable reflectionless bandpass filter is proposed using as a basis the filter concept in [10]. It is based on a duplexer arrangement with complementary-transfer-function bandpass and bandstop channels. In this manner, a reflectionless behavior can be attained at its input terminal. Furthermore, by synchronously tuning the resonators of the duplexer branches, its transfer function can be reconfigured while preserving the input-reflectionless characteristic. The RF operational principles of the engineered input-reflectionless bandpass filter approach are described in Section II. As proof-of-concept demonstrator, a two-stage microstrip prototype with frequency control in the range 0.8–1.1 GHz is manufactured and measured in Section III.

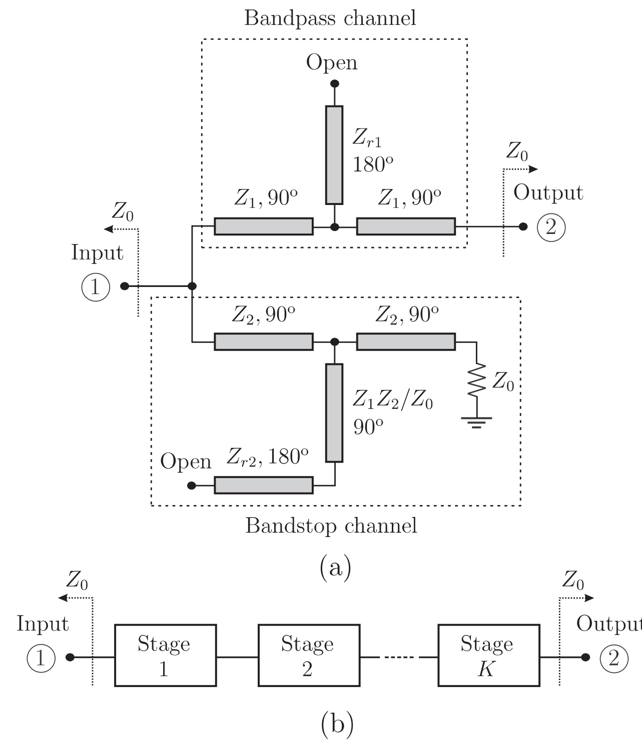

Fig. 1. (a) Circuit detail of the proposed reflectionless bandpass filter based on a complementary-duplexer architecture: first-order case (Z_1, Z_2, Z_{r1}, and Z_{r2} denote characteristic impedances of transmission-line segments—Z_0 is the reference impedance—and all their electrical-length values are expressed at the center frequency of the filter). (b) In-series-cascade K-stage scheme for filter designs with increased stopband attenuation.

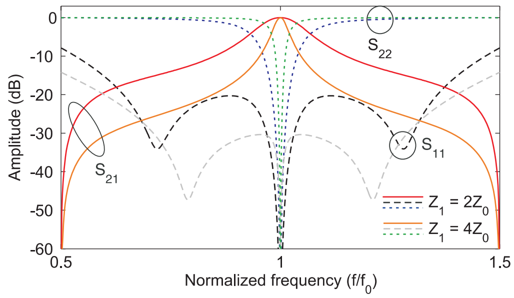

Fig. 2. Theoretical synthesis examples of the reflectionless bandpass filter in Fig. 1(a) in terms of S parameters: bandwidth control by means of Z_1 ($Z_2 = Z_{r1} = Z_{r2} = Z_0$ where Z_0 is the reference impedance).

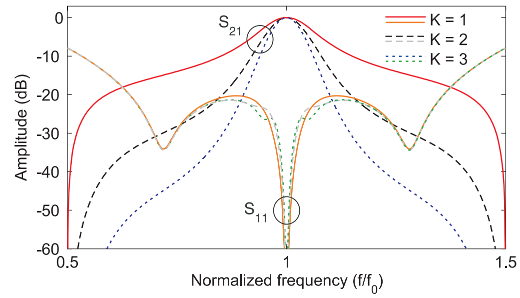

Fig. 3. Theoretical synthesis examples of the reflectionless bandpass filter in Fig. 1(a) and (b) in terms of S parameters: single- and multi-stage designs ($Z_1 = 2Z_0, Z_2 = Z_{r1} = Z_{r2} = Z_0$ where Z_0 is the reference impedance).

II. Theoretical Foundations

The circuit detail of the proposed reflectionless bandpass filter is shown in Fig. 1(a). It is based on a duplexer network composed of first-order bandpass- and bandstop-type channels with complementary filtering responses. These channels are designed by selecting its characteristic-impedance variables as detailed in Fig. 1(a) so that they have complementary transfer functions. Note that the quarter-wavelength transmission-line segments at the filter center frequency correspond to distributed impedance inverters and the open-ended half-wavelength ones are resonators. The operational principle of this device is as follows:

- Its power-transmission profile is determined by the bandpass-filtering channel, whose input/output ports are selected as those of the overall filter configuration.
- The input-signal energy that is not transmitted to the output terminal is almost dissipated by the reference-impedance resistor that loads the bandstop-type branch. In this manner, an input-reflectionless behavior is achieved in the complete filtering network.

For illustration purposes, theoretical synthesized examples in terms of S-parameters of the reflectionless bandpass filter architecture in Fig. 1(a) are depicted in Fig. 2. As can be seen, a narrower passband-width is obtained as the Z_1 value is increased. Note also that the input-reflectionless behavior is not perfect due to the frequency dependance of the transmission-line-based impedance inverters.

Finally, it should be remarked upon that the proposed input-reflectionless bandpass filter concept can be generalized to higher-selectivity designs by using higher-order channels in its complementary duplexer. Moreover, as shown in Fig. 1(b), several replicas of the first-order input-absorptive bandpass filter in Fig. 1(a) can be directly cascaded in series to increase the out-of-band attenuation. This is proven in Fig. 3, in which theoretical synthesized power transmission and input-reflection responses of single-, two-, and three-stage designs are drawn. As observed, in these multi-section filter schemes, the input-reflection profile is determined by its first constituent stage.

III. Experimental Results

To confirm the practical viability of the proposed input-reflectionless bandpass filter concept, a 50-Ω-referred two-stage tunable microstrip prototype was developed and measured. It was designed to exhibit a 3-dB relative bandwidth of 9% at 1 GHz and a tuning range of 0.8–1.1-GHz. Note that this input-absorptive filter principle can also be applied to other technologies and extended to other types of transfer function [10].

The layout and a photograph of the built prototype are shown in Fig. 4. Frequency agility was added through mechanically-adjustable capacitors (1–5-pF thin-trim trimmer capacitors from Johanson Corp. grounded at one edge with 1-mm-diameter metallic via holes). They were added at the end of the resonators in the bandpass and bandstop channels of each stage. For circuit manufacturing, an RO4003 microstrip substrate with the following parameters was used: relative dielectric permittivity $\varepsilon_r = 3.38$, dielectric thickness $H = 1.52$ mm, metal thickness $t = 17.8$ μm, and dielectric loss tangent $\tan\delta_D = 0.0027$.

The simulated (with the software package Advanced Design Systems from Keysight) and measured (with an Agilent E8361A network analyzer) S-parameters of the fabricated prototype for one example state are compared in Fig. 5. As can be seen, a fairly-close agreement between simulations and measurements was obtained. Its main measured characteristics are as follows: center frequency of 0.98 GHz, 3-dB absolute bandwidth of 86 MHz—i.e., equal to 8.8% in relative terms—, minimum in-band power insertion-loss level of 0.91 dB, and minimum input-power-matching levels of 16.5 dB and 10 dB within the 3-dB bandwidth and 0.55-1.45-GHz spectral range, respectively.

The measured reconfiguration capabilities of this circuit are illustrated in Fig. 6. In particular, for a center-frequency tuning from 0.88 to 1.07 GHz, the measured minimum in-band insertion-loss level and 3-dB absolute bandwidth are respectively in the intervals 0.5–0.8 dB and 123–133 MHz (i.e., 8.4%–9.8%). Note that the input-reflectionless

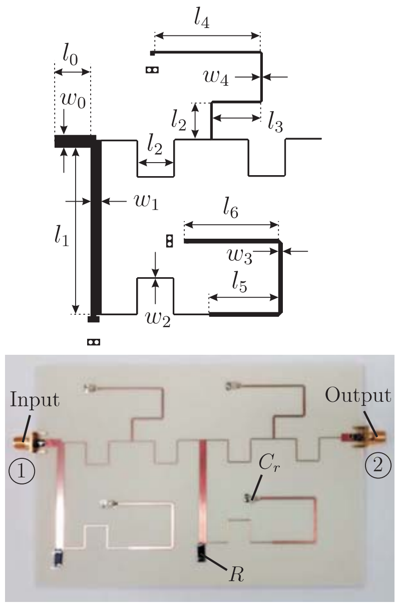

Fig. 4. Layout—half part—and photograph of the manufactured reflectionless tunable microstrip bandpass filter prototype (dimensions in mm: $w_0 = 3.42$, $w_1 = 2.97$, $w_2 = 0.3$, $w_3 = 1.12$, $w_4 = 0.56$, $l_0 = 10$, $l_1 = 40.4$, $l_2 = 10$, $l_3 = 13.4$, $l_4 = 29.4$, $l_5 = 19.2$, and $l_6 = 26.2$; components: $C_r = $ 1–5 pF and $R = 45.9\ \Omega$).

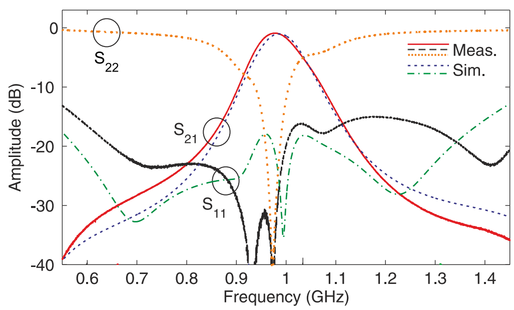

Fig. 5. Simulated and measured power transmission ($|S_{21}|$) and input-reflection ($|S_{11}|$) parameters and measured power output-reflection ($|S_{22}|$) parameter of the manufactured reflectionless tunable microstrip bandpass filter prototype for one example state (estimated quality factor $Q = 100$ at 1 GHz for all variable capacitors).

behavior is preserved in all these states, hence validating the proposed tunable absorptive RF filter design principle.

IV. Conclusion

A frequency-adaptive input-reflectionless RF bandpass filter approach based on a complementary duplexer has been presented. Its class of transfer function is determined by its bandpass-type channel, whereas the resistor that loads its bandstop-type channel dissipates the non-transmitted input-signal energy. Thus, a reflectionless behavior at the filter input port that is reasonable maintained with the tuning of its resonators is attained. The RF operational principles of the proposed input-reflectionless

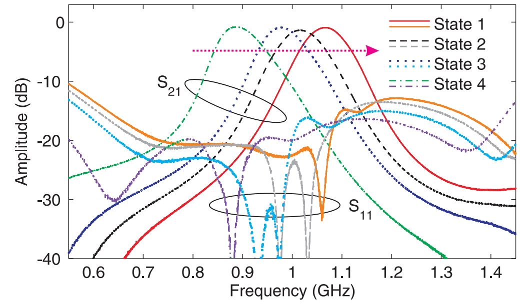

Fig. 6. Measured center-frequency tuning capabilities in terms of power transmission ($|S_{21}|$) and input-reflection ($|S_{11}|$) parameters of the manufactured reflectionless tunable microstrip bandpass filter prototype.

bandpass filter have been described. Moreover, filter design examples with increased stopband attenuation using in-series-cascade multi-stage schemes have been shown. For practical verification, a 0.8–1.1-GHz frequency-tunable two-stage prototype has been manufactured and measured.

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