Wide-Passband Filters With In-Band Tunable Notches for Agile Multi-Interference Suppression in Broad-Band Antenna Systems

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***Abstract*— Sharp-rejection and low-loss planar wide-band bandpass filters with embedded in-band frequency-agile notches, that are useful for dynamic multi-interference mitigation in broad-band antenna systems, are presented. The proposed RF filter concept consists of in-series-cascaded transversal signal-interference filtering cells with an embedded tunable quasi-absorptive-type notch in the transmission range of each of them. Each of these cells is made up of three signal-propagation paths in which one of them is reused by both filtering functionalities. This leads to smaller footprint as opposed to conventional solutions based on in-series cascades of separate filtering units. Furthermore, the in-band tunable notches can be spectrally merged so that the number of active rejection bands in the passband is dynamically controlled. For experimental-demonstration purposes, a 2-GHz two-stage microstrip prototype with two independently-tunable quasi-absorptive-type notches is developed and characterized.**

***Index Terms*— Bandpass filter, bandstop filter, broad-band receiver, interference, notch filter, reconfigurable filter, tunable filter, wide-band antenna, wide-band filter.**

I. Introduction

Interference mitigation has become an important challenge in broad-band RF receivers for advanced high-data-rate wireless technologies and wide-band radar applications [1]. Due the large portions of the electromagnetic (EM) spectrum to be simultaneously acquired by their broad-band antennas, they are heavily exposed to unwanted interfering signals coming from other co-existing services.

The aforementioned scenario is illustrated in Fig. 1, in which a plurality of out-of-system interferers are captured by the wide-band antenna along with the desired signal. The incorporation of a tunable multi-notched-band filter into the receiver chain is then crucial to dynamically eliminate them so that they do not saturate the entire receiver. Current trends towards hardware minimization have revealed the need for co-integrating different RF-analog-processing actions into the same component. In that sense, this reconfigurable multi-notch filter could be co-synthesized either with the broad-band antenna or the pre-selection wide-passband filter in a dual-function circuit.

Regarding wide-band antennas with embedded tunable suppressed bands, different design techniques have been proposed in the last few years [2], [3]. However, they are limited by a poor-to-moderate power-rejection level for the notched bands as well as the number of notches that can be produced. Furthermore, the effect of the embedded ib-band stopbands over desired close-to-notch signals is not visible in these studies.

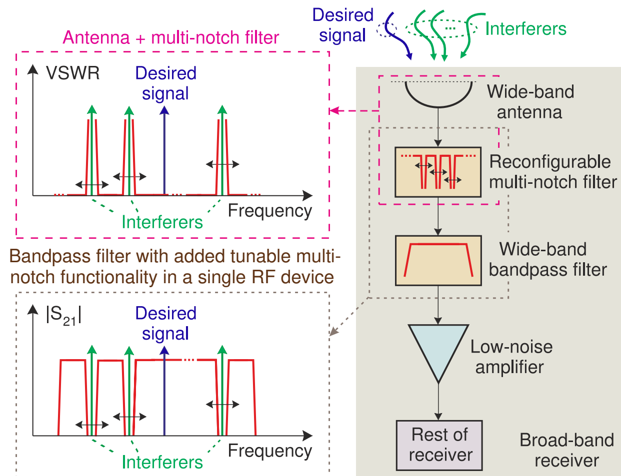


Fig. 1. Block diagram and operational principle of a broad-band receiver with incorporated reconfigurable-multi-notch RF filtering functionality for dynamic multi-interference mitigation ($|S_{21}|$: power transmission response; VSWR: voltage standing wave ratio). Note that the devised reconfigurable RF filtering solution incorporates both functionalities at the same filter volume.

In relation to wide-band bandpass filters with inserted in-band notches, most of the previous contributions have primordially focused on spectrally-static-notch realizations [4], [5]. It should be noted that only a very few co-integrated broad-passband/notched-band filtering devices with reconfigurable in-band stopbands have been reported [6], [7]. However, they exhibit some drawbacks, such as limited power-rejection depths for the tunable notches, narrow notch-tuning range, and deteriorated selectivity in the upper-stopband region in [7].

A class of microwave planar multi-stage wide-band bandpass filters with embedded in-band tunable quasi-absorptive-type notches is described in this paper. The devised RF filter configuration allows for dynamic multi-interference mitigation in wide-band antenna systems. It features high rejection depths for its independently-tunable notches. Furthermore, as added flexibility capability when compared to related prior-art components, it enables notch spectral-merging to shape equi-riple-type wider stopbands and readily control the number of active notches.

II. Theoretical Foundations

The circuit architecture and operational principles of the proposed RF wide-band bandpass filter concept with embedded spectrally-agile in-band notches are shown in Fig. 2. It consists of the in-series cascade connection of several transversal signal-interference filtering sections [8]. Each of these filtering sections comprises three electrical paths that are combined and operate as follows: i) transmission-line-type paths 1 and 2 allow to synthesize a wide-passband filtering response, and ii) path 3—made up of lossy resonators that are coupled between them—and path 1 introduce an in-band quasi-absorptive-type notch. Thus, path 1 is reused by both filtering functionalities so that circuit-size and insertion-loss advantages in relation to a conventional in-series cascade approach of a separate wide-passband transversal filtering section—as for example the one in [9]—and a notch filtering unit is attained. The transfer function of each transversal filtering section is then determined by the aggregation of the wide-band bandpass and notch filtering actions. By making tunable the notches of the filtering sections—in the multi-stage arrangement in Fig. 2—by means of controllable resonators in path 3, a high-selectivity broad-passband filter with multiple in-band spectrally-agile notches can be synthesized. Moreover, as also illustrated in Fig. 2, the produced in-band adaptive notches can be further exploited to transform the overall wide-band transmission range into a multi-band bandpass one with/without embedded stopbands. These reconfigurable eliminated bands can also be used to control the bandwidths of the shaped passbands by modifying their cut-off frequencies.

As supporting examples, Fig. 3 represents the theoretical power transmission and reflection parameters for two states of a three-stage design that is based on the RF filter concept in Fig. 2—i.e., three in-band notches are generated—. The values for its design parameters for paths 1 and 2 in all the filtering cells and the inter-cascading lines are as follows ($Z_0 = 50\ \Omega$ is the reference impedance and $f_d = 1$ GHz is the design frequency): $Z_1 = 2.16Z_0$, $Z_2 = 1.9468Z_0$, $Z_c = 0.95Z_0$, $\theta_1(f_d) = 90^o$, $\theta_2(f_d) = 450^o$, and $\theta_c(f_d) = 90^o$. Path 3 is realized with quarter-wavelength transmission-line impedance inverters at f_d of line impedances $Z_{3A} = 1.1828Z_0$ and $Z_{3B} = 2.792Z_0$ along with the following values for the natural frequencies—f_{res1}, f_{res2}, and f_{res3}—and quality factors—Q_1, Q_2, and Q_3—for the lossy resonators in its transversal filtering sections—1, 2, and 3, respectively—:

- Fig. 3(a): $f_{res1} = 0.8969f_d$, $f_{res2} = f_d$, $f_{res3} = 1.1053f_d$, $Q_1 = 97.92$, $Q_2 = 72.48$, and $Q_3 = 80.33$.

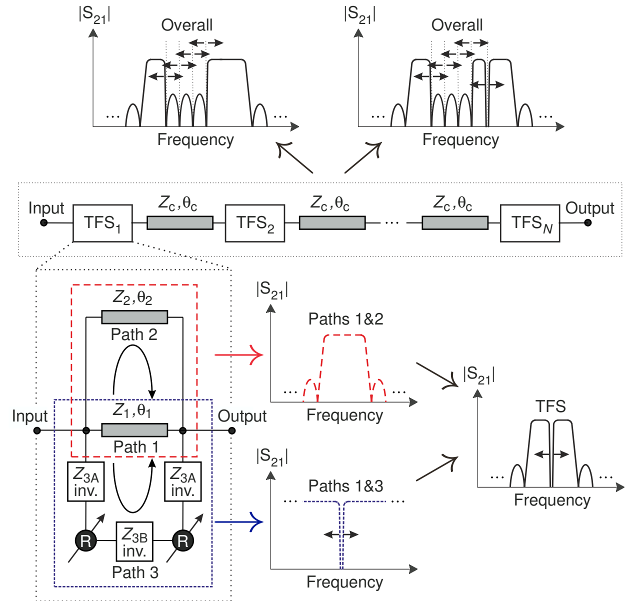


Fig. 2. Circuit detail and operational principles of the proposed multi-stage wide-band bandpass filter with embedded tunable in-band notches ("TFS": transversal filtering section; "R": resonator; Z: characteristic impedance; θ: electrical length).

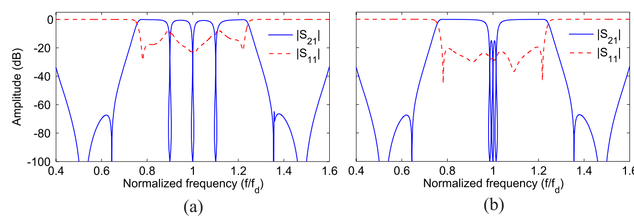


Fig. 3. Theoretical power transmission ($|S_{21}|$) and reflection ($|S_{11}|$) responses for two different states of a three-stage design based on the RF filter concept in Fig. 2. (a) Response with spectrally-separated in-band notches. (b) Response with the three in-band notches shaping a three-transmission-zero stopband.

- Fig. 3(c): $f_{res1} = 0.9858f_d$, $f_{res2} = f_d$, $f_{res3} = 1.0144f_d$, $Q_1 = 73.73$, $Q_2 = 72.5$, and $Q_3 = 71.64$.

As demonstrated in Fig. 3, by properly adjusting the resonant frequencies and the quality factors of the lossy resonators inserted into the transversal filtering sections, in-band notches with theoretically-infinite attenuation are created. They can be positioned throughout the entire passband range of the filter either at separated frequencies—Fig. 3(a)—or close to each other to shape multi-transmission-zero wider stopbands—Fig. 3(b)—.

III. Experimental Results

To verify the proposed signal-interference broad-passband filter concept with controllable in-band quasi-absorptive-type notches, a two-stage microstrip prototype with 2-GHz center frequency and 40% relative bandwidth was developed and tested. Its layout and photograph are shown in Fig. 4. For its manufacturing, a Rogers 4003C microstrip substrate with the following characteristics was utilized: relative dielectric permittivity 3.55, dielectric thickness 1.524 mm, metal thickness 35 μm, and dielectric loss tangent 0.0027. As can be seen in Fig. 4, the transmission-line-type paths of its constituent transversal filtering section—referred to as paths 1 and 2 in Fig. 2—were implemented as microstrip lines whose lengths and characteristic impedances were selected as detailed in the design process in [9] to conform the desired overall passband. The remaining electrical path—denoted as path 3 in Fig. 2—was realized through two inter-coupled capacitive-loaded resonators that interact with path 1—mechanically-adjustable capacitors from Johanson Corp. were employed into these resonators whose ground connections were implemented through 1-mm-diameter metallic via holes—.

The simulated and measured power transmission and reflection parameters of the constructed filter prototype for one example state are plotted in Fig. 5. The independent-reconfiguration capabilities of the in-band quasi-absorptive-type notches are validated in Fig. 6. Fig. 6(a) demonstrates how the lower notch is spectrally controlled—27-to-46-dB isolation in the range 1.81-1.97 GHz—so that a two-transmission-zero stopband is shaped when the tuned notches are placed in a close proximity to each other. Fig. 6(b) shows upper-notch tuning—44-to-17-dB isolation in the range 1.8-2.16 GHz—along with its spectral merging with the lower one.

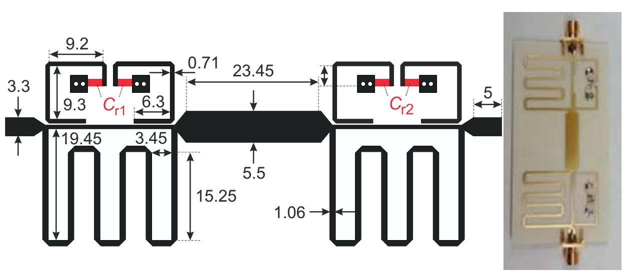


Fig. 4. Layout and photograph of the manufactured prototype (dimensions, in mm, are indicated).

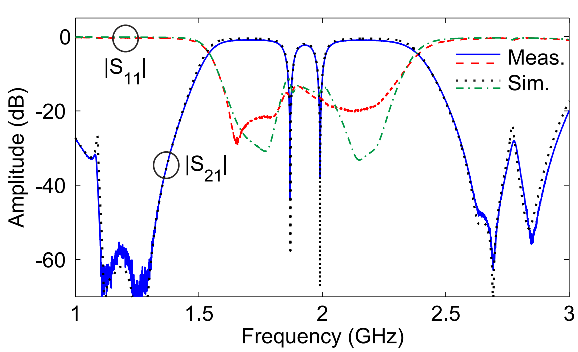
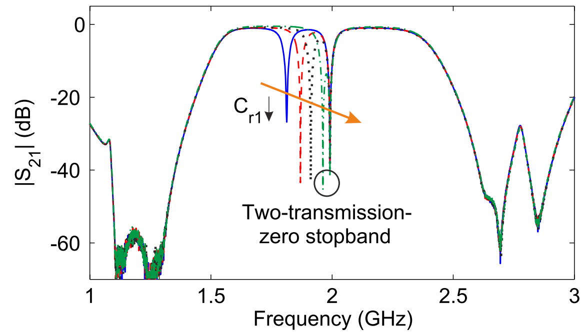


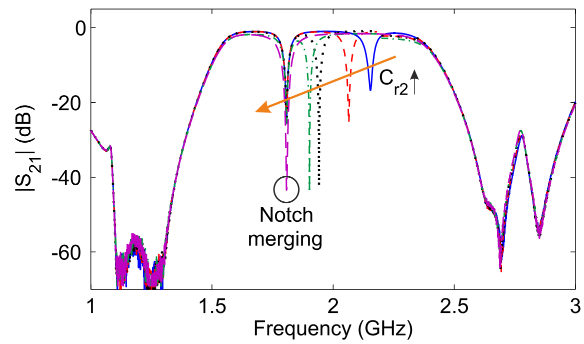
Fig. 5. Simulated and measured power transmission ($|S_{21}|$) and reflection ($|S_{11}|$) of the manufactured prototype for one state.

IV. Conclusion

A type of microwave transversal signal-interference planar filter with co-integrated broad-band bandpass and in-band-tunable-quasi-absorptive-notch filtering capabilities



(a)



(b)

Fig. 6. Measured reconfiguration capabilities of the manufactured prototype in terms of power transmission response ($|S_{21}|$). (a) Frequency tuning of the lower in-band notch and shaping of a two-transmission-zero stopband when it comes to a close proximity to the upper in-band notch. (b) Frequency tuning of the upper in-band notch and spectral merging with the lower one.

has been described. Its building filtering section consists of a three-path circuit structure in which one of these electrical paths is reused by both filtering functionalities under the feedforward signal-combination formalism. Thus, smaller size and lower insertion loss than in a conventional approach based on in-series-cascaded wide-passband and tunable-notch filtering units is achieved. For practical-verification purposes, a 2-GHz two-stage microstrip prototype with two embedded tunable quasi-absorptive-type notches was manufactured and tested.

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