Advanced Microwave Filtering Devices Based on Signal-Interference Techniques

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***Abstract*—This report is intended to summarize the key research achievements resulting from the work carried out under the IEEE MTT-S Graduate Fellowship program 2015–period between March 2014 and March 2015–. The aim of this research project is the development of new advanced microwave filtering devices based on transversal signal-interference principles. In accordance with the project objectives, the miniaturization of planar signal-interference filters has been addressed through capacitive-loading size-reduction techniques. Furthermore, a new family of bandpass filters (BPFs) based on the hybridization of microstrip and surface-acoustic-wave (SAW) technologies have been devised. These filters extend the applicability of signal-interference circuits to narrow-band specifications. Lastly, the design of multi-functional microwave devices inspired on signal-interference techniques has been demonstrated. In particular, Wilkinson-type power dividers and impedance transformers simultaneously exhibiting single/multi-band filtering capabilities have been conceived. Note that all this work has resulted in two publications in international journals and five international conference papers during the period under consideration.**

***Index Terms*—Bandpass filter (BPF), impedance transformer, microwave filter, miniaturized filter, multi-function circuit, planar filter, signal-interference filter, surface-acoustic-wave (SAW) filter, Wilkinson-type power divider.**

I. Introduction

High-frequency filters are essential devices in RF/microwave transceivers. Among the wide range of devised planar filtering structures reported in the technical literature, signal-interference filters have recently grown in popularity due to their remarkable filtering characteristics. For example, sharp-rejection passbands with broad attenuated bands or multi-band operation with an arbitrary number of passbands. They have also been used in reconfigurable-bandwidth bandpass filter (BPFs) and varactor-tuned bandstop filter design with extended upper stopband.

However, the rapid evolution of wireless communication systems requires an even more efficient use of the spectrum, establishing a set of shortcomings that are difficult to overcome by conventional signal-interference filters. Some of these constraints have already been identified and addressed under this research work and during the concerned period. They are i) the large area occupied by traditional signal-interference filters in the lower part of the RF spectrum, ii) their inability to perform narrow-band bandpass filtering actions, and iii) the exploitation of signal-interference structures in multi-functional microwave devices.

In this project, signal-interference filters have been miniaturized by means of capacitive-loading techniques, applicable to any class of transversal filtering section (TFS). Secondly, novel narrow-band signal-interference BPFs exploiting mixed-technology surface-acoustic-wave-(SAW)/microstrip TFSs have been reported. Finally, dual-function microwave components have been developed through the incorporation of transversal signal-interference networks into other types of microwave devices. By doing so, single and multi-band filtering capabilities have been added to the processing action inherent to the original circuit.

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II. Project Outcome

A. Capacitively-Loaded Miniaturized Signal-Interference Filters

As is well known, physical size is a major concern in modern circuits. Due to the nature of classic signal-interference filters–constituted by transmission lines whose electrical lengths are integer multiples of 90º at the design frequency–, its physical size becomes especially bulky at the lower part of the RF spectrum. Since this type of circuits do not contain coupled-line stages, their size has been reduced by partitioning their constituent transmission-line segments into quarter-wavelength sub-segments and, subsequently, applying capacitive-loading and line-meandering techniques. In this manner, a capacitively-loaded multi-cell equivalent circuit has been devised, which is applicable to any type of signal-interference TFS and any class of transfer function.

For illustrative purposes, a single-band signal-interference BPF which exploits capacitive-loading and line-meandering techniques has been built and tested in [1]. It shows a ≈75% size reduction when compared to its fully-distributed-element counterpart. Moreover, this miniaturization philosophy has been applied to more challenging designs, such as dual-band and reconfigurable-bandwidth single-band BPF prototypes, resulting in more than 50% size reduction in both cases [2].

B. Hybrid SAW/Microstrip Signal-Interference Filters

With the aim of extending the suitability of signal-interference filters to narrow-band designs–firstly engineered for moderate-to-ultra-wide-band specifications–, SAW devices have been embedded into the branches of multi-path signal-interference planar TFSs. The inclusion of these high-*Q* elements allows to notably shortening the transmission lines of the TFS, with a subsequent size reduction and decrease of the insertion loss when compared to its fully-planar counterpart.

According to the latter, three different approaches have been presented [3]-[5]. They are as follows:

1) In the first approach, a one-port or two-port SAW resonator is incorporated into one of the branches of the signal-interference TFS, as in-band node, so that the high-*Q* properties of the SAW resonator are substantially transferred to the overall transfer function [3].
2) The second approach takes benefit from the ultra-abrupt slope existing between the resonance and the anti-resonance frequencies of the one-port SAW resonator itself, which is incorporated in both arms of a bi-path signal-interference TFS to conform one of the passband edges–resonator acting as non-resonant node– [4].
3) In the third realization, the inherent bandwidth of an embedded RF SAW BPF is broadened owing to constructive signal-energy interactions taking place in the signal-interference TFS [4], [5].

Note that 3-dB relative bandwidths of approximately 0.5% for multi-stage BPFs shaped by TFSs with embedded SAW resonators and of 6-10% for multi-stage BPFs formed by TFSs which include RF SAW BPFs have been attained.

C. Multi-Functional Signal-Interference Filtering Devices

Traditionally, the design of RF/microwave chains has been conceived as the series-cascaded connection of several microwave components that are independently designed and, subsequently, need for matching networks. However, over the last few years, a new approach based on the co-design of microwave components capable of featuring simultaneously several processing actions has become an attractive alternative. This is due to advantages in terms of reduced complexity, smaller size, and lower insertion loss. Following this trend, dual-function circuits have been conceived here by embedding signal-interference transversal networks into conventional microwave components.

Firstly, Wilkinson-type power dividers exhibiting single and multi-band filtering capabilities have been devised. To experimentally validate this concept, a triple-band and a quad-band power divider have been manufactured and measured. Besides, such a topology has been extended to lumped-element realizations and included as a part of more complex circuits, in particular, as power divider/combiner of a channelized active BPF [6]. Lastly, impedance-transformers, for any arbitrary pair of real impedances, showing single/multi-band filtering have been devised by substituting the lines of quarter-wavelength transformers by transversal signal-interference cells. For demonstration, single-band and dual-band prototypes have been reported [7].

III. Professional Career Plan

The MTT-S Graduate Fellowship Program has provided the research activities I have been developed with recognition, giving a boost to my professional career. It also allowed me to attend *IEEE MTT-S IMS* for the first time and do research with financial support.

Upon graduation, I wish to find a job in the industry within the field of RF/microwave technologies. I would like to exploit my skills in a company which considers research and development as an essential strategic element for its growth.

IV. IMS Impression

Attending *2015 IEEE MTT-S International Microwave Symposium*, held in Phoenix, was a great and very valuable experience. During the event, I had the chance to attend sessions of top-level personalities in the world of microwave engineering and do networking. Besides, I took part in a workshop on *Nanopackaging: Multifunctional Nanomaterials and Devices Towards 3D System Miniaturization*.

Since I also participated as a student volunteer, I could learn more about the conference organization. Moreover, I met other Ph.D. candidates all over the world with similar backgrounds, with whom I shared knowledge, concerns, and experiences.

V. Acknowledgment

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