AN OCTAVE-BAND MMIC ACTIVE FILTER*

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Abstract

The design, fabrication, and measurement of a GaAs, monolithic, active bandpass filter with a passband from 4 to 8 GHz is described. The circuit uses a set of cascaded lumped- and distributed-element L,C circuits isolated by a feedback amplifier to realize an equivalent fourth-order filter response. The final circuit was fabricated on a 3 x 2-mm GaAs substrate.

INTRODUCTION

Wide-bandwidth microwave filters have a variety of system applications, including receiver front-ends, spectrum demultiplexers, and harmonic rejectors. Traditionally, these filters have been implemented with a combination of resonator elements realized in waveguide, coax, strip, and microstrip lines. In recent years, with the rapid maturation of MMIC modeling and fabrication techniques, the miniaturization of these relatively large filter circuits has become an attractive possibility.

Previous microwave active filter realizations have been based on extensions of lower-frequency design techniques (1)–(3). For example, Sussman-Fort (3) recently proposed a design concept that uses a cascade realization of biquadratic factors. The major advantage of this approach lies in its simplicity.

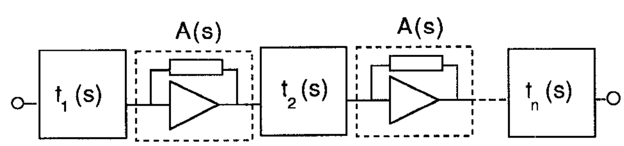
This paper describes a similar design technique in which a 4- to 8-GHz passband function is realized by cascading lower-order transfer functions isolated by active devices (see Figure 1). This leads to a frequency response that has a lower sensitivity to circuit element tolerances and a potentially higher RF circuit yield. The individual blocks are then synthesized using a combination of lumped and distributed circuit elements, and the overall circuit is realized in monolithic form.

DESIGN PROCEDURE

The first step in the proposed approach consists of synthesizing a transfer function, T(s), that meets the design specifications. In most cases, a number of different functions satisfy a given requirement. An optimum design requires a tradeoff analysis of the candidate circuits that synthesize each function. The most relevant parameters to be considered in the tradeoff are as follows:

- MMIC component realizability (including capacitance and inductance values and transmission line lengths)
- Implementation margin between the computed response and the required specification
- Frequency response sensitivity to circuit element fabrication and modeling tolerances. (This factor strongly affects the resulting RF circuit yield of the GaAs wafer.)
- Final circuit size.

Initially, all computations are performed using the lumped-element ideal circuit in order to avoid unnecessary design effort. After the preferred approach is selected, each of its elements is synthesized using a combination of distributed coupled lines, transmission lines, and thin-film capacitors. The circuit is then reoptimized to account for the effects of parasitic Ls and Cs, combined with the frequency variation of the active elements' S parameters.



$$T(s) = t_1(s) \cdot A(s) \cdot t_2(s)\ A(s) \ldots\ t_n(s)$$

Figure 1. Cascade Realization of Transfer Function T(s)

*This paper is based on work performed at COMSAT Laboratories under the sponsorship of the Naval Research Laboratory.

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Table 1. Tradeoff Analysis of Five Different Circuit Configurations

Circuit Configuration Number	L Range (nH)	C Range (pF)	Passband Margin (MHz)	Reject-Band Margin (MHz)	Out-of-Band Rejection Margin (dB)	RF Yield (%)	Estimated Size (mm)
0	0.6–2.2	0.3–10.0	121/182	146/487	2	5	4.5
1	0.16–2.3	0.41–10.0	214/143	197/86	12	9	4.5
2	0.1–3.3	0.38–10.0	428/286	157/114	12	20	4.5
3	0.4–2.7	0.18–10.0	428/128	143/142	0.8	14	4.0
4	0.6–3.0	0.07–10.0	38/85	128/102	-14	4	5.5

PROTOTYPE DESIGN

A wideband active filter with the following design goals was realized:

Passband	4–8 GHz
Rejection	> 20 dB at 3 and 9 GHz
Gain	> 10 dB
In-Band Gain Variation	< 2 dB
In-Band Noise Figure	< 5 dB

Five different transfer functions that satisfy the above design goals were generated and compared. Table 1 presents a summary of the main parameters considered in the design selection tradeoff study. All yield computations were performed using the Monte Carlo method and assumed element tolerances based on past MMIC fabrication history. Only the RF performance was considered in the yield determination, and tolerance variations were introduced only in the passive elements. This allowed immediate comparison between the passive lumped-element design (circuit configuration 0) and the different proposed cascaded designs (configurations 1, 2, 3, and 4).

The computed yields of configurations 0 and 2 are plotted in Figure 2 as a function of the number of trials. The introduction of active elements allowed a design that improved RF yield by 400 percent relative to the lumped-element filter. To obtain a meaningful comparison between the two circuits, a minimum of 200 trials must be performed.

Two extra transmission zeros were added to the transfer function to improve the out-of-band rejection above 9 GHz.

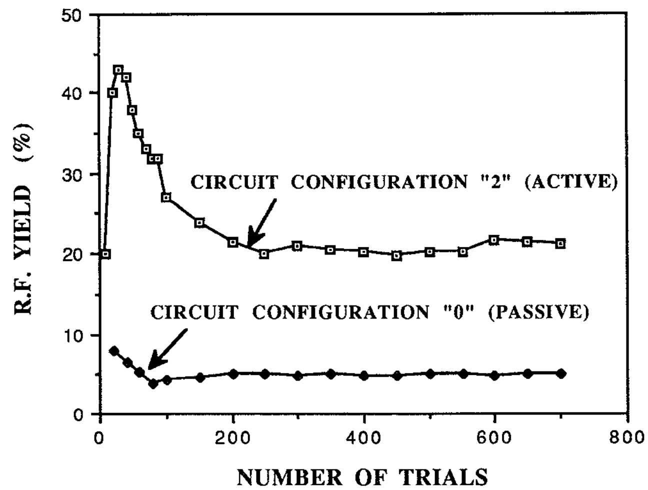

Figure 2. Computed RF Yield Comparison for Circuit Configuration 0 (Passive, Lumped-Element Realization) and Configuration 2 (Active Realization)

MMIC FABRICATION

Circuit configuration 2 was selected for the practical implementation. Its lumped circuit form is shown in Figure 3, and a photograph of its distributed MMIC realization is presented in Figure 4. The inductors were synthesized with different combinations of coupled high-impedance transmission line sections. The capacitors were fabricated from 2,000-Å silicon nitrate films. The FETs are standard, low-current, 0.5-µm gate length devices on GaAs substrate. Figure 5 shows the filter assembled in a carrier between two 50-Ω lines in alumina substrate that interface with a coaxial test fixture.

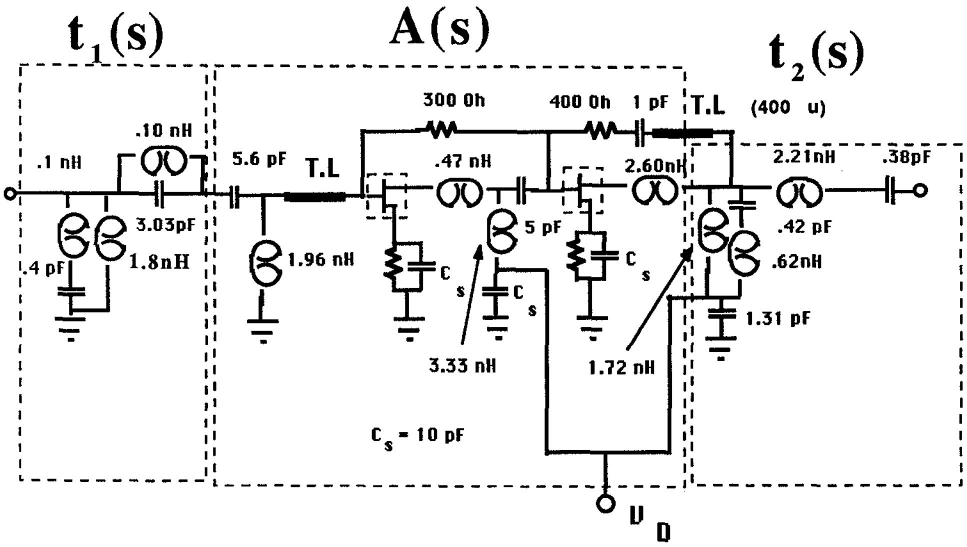

Figure 3. Circuit Configuration 2

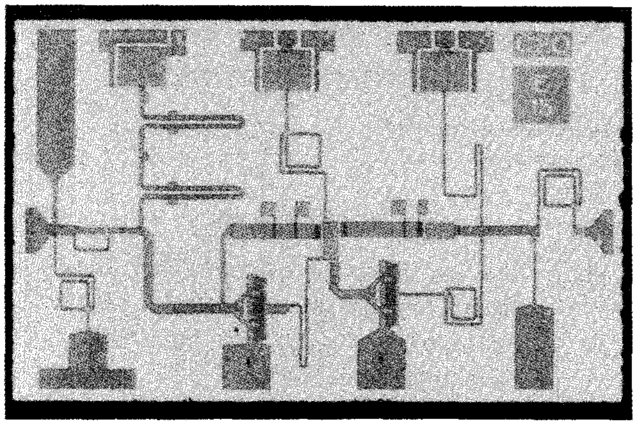

Figure 4. MMIC Realization of Circuit Configuration 2

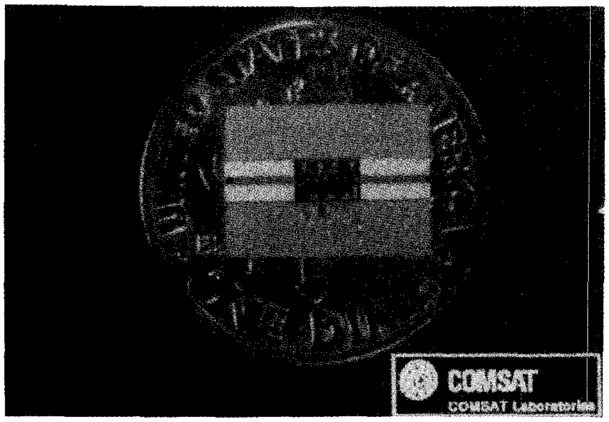

Figure 5. MMIC Filter Assembled for Test

MEASURED PERFORMANCE

Figure 6 shows a comparison of the computer-simulated results and the measured data from the first fabricated wafer. No circuit adjustment was necessary to obtain these results. The measured noise figure of four random units (selected only on the basis of a pass/fail DC test) is shown in Figure 7.

CONCLUSIONS

A new design philosophy for the realization of wideband MMIC active filters has been proposed and tested. The design employs low-order filter sections isolated by active elements that decrease circuit response sensitivity to passive element tolerances. Only one fabrication cycle was necessary to realize an excellent filter response of one octave bandwidth (4 to 8 GHz). Reproducibility of results among randomly tested units validates the approach for MMIC applications.

ACKNOWLEDGMENTS

The authors wish to acknowledge useful technical discussions with D. Webb, G. Tait, C. Rauscher, and C. Krowne from the Naval Research Laboratory, Washington, D.C. They are also indebted to their COMSAT colleagues T. Duong, R. Mott, R. Gupta, B. Geller, and L. Holdeman for helpful suggestions and successful fabrication of the MMIC wafer.

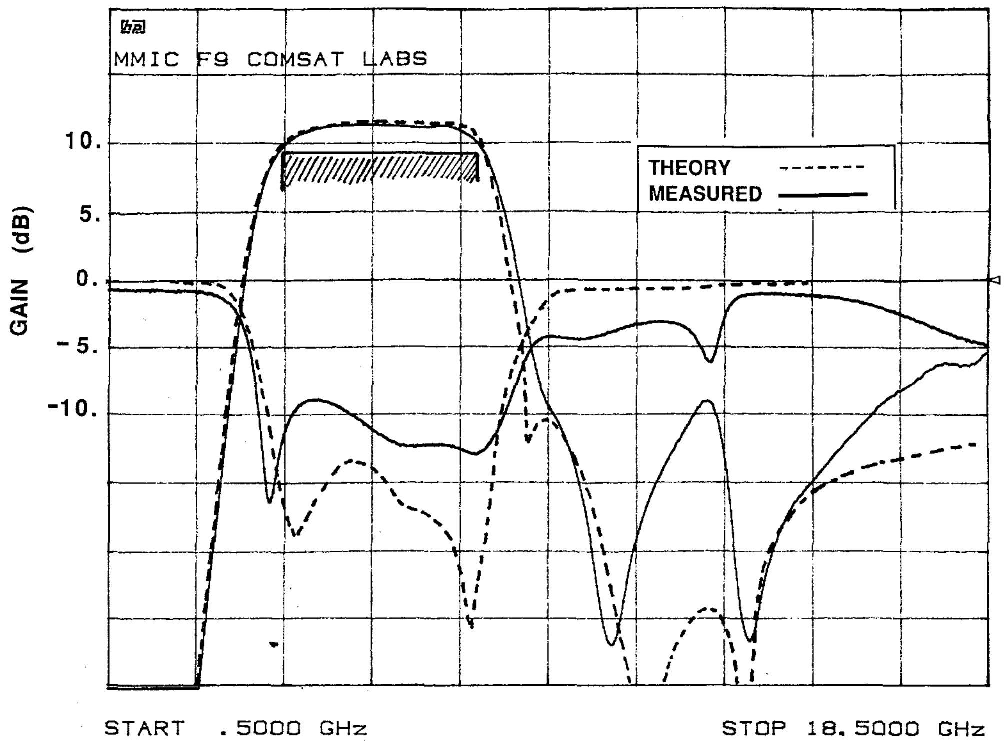

Figure 6. MMIC Filter Measured and Computed Transmission and Return Losses

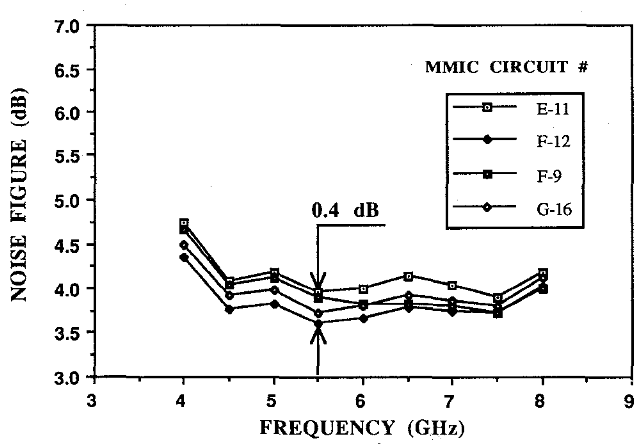

Figure 7. Measured In-Band Noise Figure of Four Random Filter Circuits

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