Investigation of Passive Bandpass Filters Using MMIC Technology

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Abstract— **It is a unique concept to dedicate a MMIC processing run solely for passive filter components. After going through preliminary design procedures, key parameters such as tap position, resonator length and coupling gaps may be studied in a controlled experiment to ascertain the optimal design. The MMIC fabrication process allows the design engineer the luxury of numerous filter designs within a single iteration and is extremely cost effective when compared with an equal number of hybrid MIC designs. MMIC filters are extremely small, highly reliable, and utilized existing processing technology. Passive filters are important when prime power consumption is limited as in advanced phased arrays for air and space applications. Ku-band MMIC parallel coupled, elliptical, and interdigital designs are investigated. The interdigital type yielded state-of-the-art performance and required the least substrate area.**

I. Introduction

THERE are many advantages in filter design using established GaAs monolithic microwave integrated circuit (MMIC) foundry layout and fabrication processes. Yield for a passive MMIC filter run is close to 100% and RF performance is extremely repeatable. MMIC filter performance is not comparable to standard hybrid and waveguide technology due to the low Q. However, depending on system requirements, MMIC filters may be a viable option to allow for a complete module to be fabricated on a single chip thus leading the way towards high-volume components at an affordable cost. This is extremely crucial for advanced phased arrays which can easily possess over a thousand elements.

A GaAs wafer can be divided into individual rectangular sections which are called reticles. Each reticle can be different or individual ones may be repeated. For our case study we utilized six different reticles and repeated them over a 3-inch GaAs wafer. (Note that all the filter designs are different within each reticle.) Our reticle size was 360 mils × 360 mils. For a 3-inch wafer we had 38 complete reticles. Within the six reticles we incorporated a variety of different filter structures that included 4 elliptical, 12 parallel coupled, and 38 interdigital filter designs. After step-and-repeat of the six baseline reticles across the entire wafer we had a total of 20 elliptical, 87 parallel coupled, and 244 interdigital filters (see Fig. 1).

It is a unique concept to dedicate a MMIC processing run for just passive filter components. Most MMIC filters do not have geometries less than 0.5 microns; therefore, common photolithographic techniques which are compatible with MESFET technology are suitable. The mask set required to fabricate the filters is usually 5 layers versus 10 to 14 for active circuits, thus the processing is simple and quick. If one had to fabricate over 50 filters in hybrid form and incorporate ground vias in certain designs then a single MMIC run is significantly cost effective in terms of time, labor, and material.

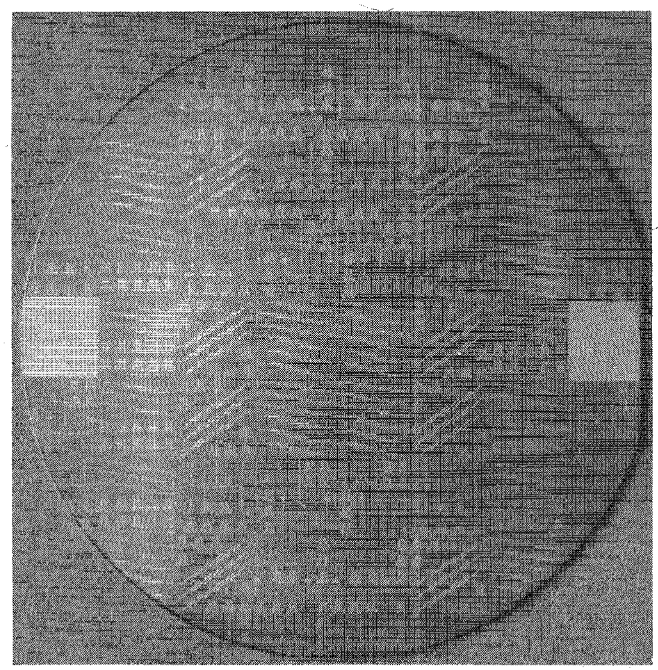

Fig. 1. 3-inch GaAs MMIC passive filter wafer (4 mils thick). This wafer contains over 350 filters composed of Ku- and K-band interdigital, parallel coupled and elliptical designs. Expensive fixturing and labor was eliminated by using on-wafer probing. (Due to limited length of the letter, only the Ku-band results are discussed.)

As part of the design process coplanar probe pads are incorporated into the input and output of each filter. Now it is possible to RF characterize each filter using on-wafer probe techniques. It is no longer necessary to cut and mount each filter in its own fixture. This saves a significant amount of labor and material which translates to program cost saving.

The MMIC fabrication process allows the design engineer the luxury of a multitude of designs within one iteration. Thus, after going through analytic design procedures similar to those to be described in Section II, key parameters such as tap position, resonator length, and coupling gaps may be studied in a controlled experiment to ascertain the optimal structure.

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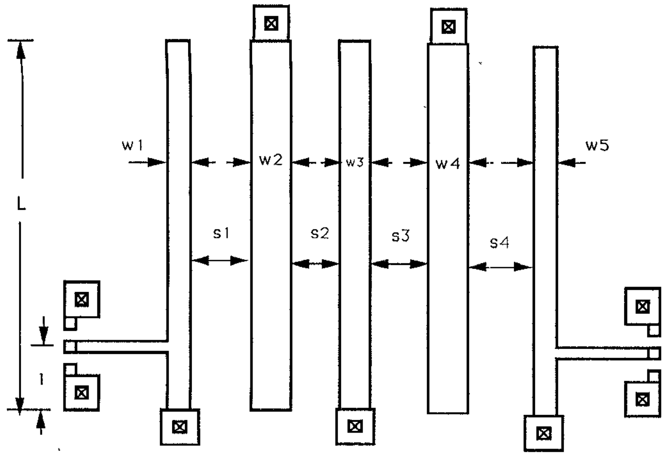

Fig. 2. Ku-band (17 GHz) five-pole interdigital filter layout. Overall component size is 40 mils × 60 mils. $w1 = w5 = 3.5$ mils, $w2 = w4 = 2.67$ mils, $w3 = 2.71$ mils, $s1 = s4 = 3.1$ mils, $s2 = s3 = 3.3$ mils. x's represent ground via holes.

II. Passive MMIC Filter Trade-Off and Analysis

A plethora of published literature addresses the design and analysis of passive filters. Our goal was to implement 17 GHz MMIC filters which had less than 2.5-dB insertion loss, provide at least 20-dB attenuation 1 GHz from the passband, require a minimum of substrate area, and did not require any prime power.

We examined parallel coupled, elliptical, and interdigital passive bandpass filters. Throughout this paper we are addressing microstrip filter technology. Other technologies such as coplanar waveguide are viable alternatives; however, for the system modules to be designed, microstrip is the most mature in terms of available CAD tools and MMIC foundry cell libraries.

Elliptical filters have the potential for extremely fast rolloff around the passband and have a low insertion loss [1]. However their out-of-passband response is extremely poor. Furthermore the physical implementation of them in distributed form requires a significant amount of substrate area. We decided to implement this filter primarily due to its low loss characteristic.

Parallel coupled filters are a common topology implemented in planar format [2]. The insertion loss was predicted to be at least 4 dB in the passband. However, in comparison to the elliptical filter, they required less substrate area and have spurious bands only at 2 fo, 3 fo, etc., of the passband.

The most interesting topology to implement in MMIC form are interdigital filters. To the best of the authors' knowledge this paper is the first publication of these filters fabricated using MMIC technology. In order to implement these filters, the transmission line resonators must be terminated with short circuits. For high-frequency microwave and millimeter-wave microstrip implementation this can be a formidable task. GaAs MMIC technology already includes via hole elements as well as a variety of capacitor technologies (interdigital [3] and metal-insulator-metal [MIM]) useful for combline filters as part of the established foundry circuit fabrication process. Thus, the physical implementation of these filters are no longer a challenge as in hybrid MIC technology.

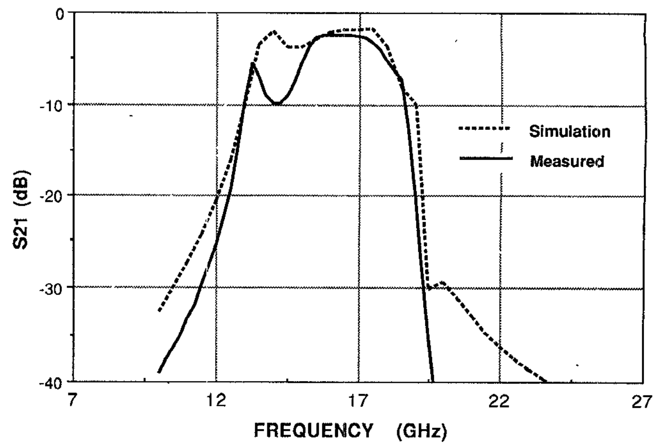

Fig. 3. Simulation and experimental results for the insertion loss of a five-pole MMIC Ku-band interdigital filter.

Probably the greatest challenge to implement interdigital filters is in the design. The variables to consider are resonator length, width, and variable gap spacing between elements. Ultimately, one would like to use an EM simulator to obtain extremely accurate results. Unfortunately an EM simulator was not available. Therefore, we utilized a multiconductor transmission line analysis that is commercially available based on a moment method approach [4]. Although this program provides a quasi-TEM analysis, it does allow the designer a method to gain insight into the filter performance. We performed a preliminary design following the procedure described in [2]. Once the capacitance matrix was determined we went to the moment method analysis to study the structure performance and optimize it. The optimum simulated structure had 1.5-dB insertion loss in the passband. This filter required the least area (a factor of 16 and 6 times smaller than the elliptical and parallel coupled structures, respectively) and the first spurious band is at 3 fo. Fig. 2 shows the layout of the interdigital filter in which resonator lengths are all equal but their width, gap spacing and tap position are all variables. The resonator length L is the physical length; however, in the computer analysis we included the fringing capacitance.

Common to all the filter designs was the requirement to efficiently couple to the structure. For the parallel coupled filter we designed the outer elements such that the filter would be directly matched to a 50-ohm system. Interdigital capacitors and coupled lines were utilized to match the elliptical filters. For the interdigital design a tapped line approach was used to minimize the filter size. Many variations of a design are easily implemented in MMIC form; thus, a controlled experiment was utilized to determine the optimal tap position.

III. Experimental Results

Excellent performance was achieved for MMIC Ku-band interdigital bandpass filters. The insertion loss was less than 2.5 dB (see Fig. 3) and the return loss was better than 12 dB across the band of interest.

Results for the parallel coupled filters were comparable with the CAD simulations. The insertion loss was at least 5 dB across the passband. The elliptical filter exhibited over 8 dB insertion loss. We attribute a majority of this latter value to difficulty in matching this circuit to a 50 ohm system.

IV. CONSLUSION

We have taken advantage of existing GaAs MMIC processing technology to rapidly and economically design a multitude of filter designs in a single iteration. GaAs foundries have established design rules and technology to fabricate lumped element components, via hole ground, and various transmission line structures. By careful use of controlled experiments an optimal design can be easily obtained. With the use of on-wafer RF characterization an entire 3-inch GaAs Filter wafer with over 300 different designs can be measured in 3 days. We eliminate the necessity of having to design and fabricate fixtures which become expensive as one goes higher in frequency.

For system applications where substrate area is limited, high reliability required, limited prime power, and excellent RF performance required monolithic interdigital filters are an excellent solution. In this letter, we presented a unique design approach and state-of-the-art results for MMIC Ku-band passive bandpass filters using an interdigital topology. In addition we have compared them to conventional elliptical and parallel coupled designs.

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