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A Novel MMIC Active Filter with Lumped and Transversal Elements

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A novel active filter structure has been developed and demonstrated as an MMIC. This filter structure makes use of both lumped elements and active transversal elements. The combination of lumped and transversal elements provides performance superior to a filter made of lumped elements alone, and is much smaller than a filter made of transversal elements alone. This miniature MMIC filter has a passband of 9.8-11.1 GHz with 2 dB loss, and better than 30 dB rejection 1.1 GHz from either passband edge. This level of performance could not have been achieved on a conventional 4 mil thick GaAs MMIC with only passive lumped elements.

Introduction

Microwave filters are generally realized with networks of distributed elements that can be quite large, or with discrete lumped elements which require custom tuning. For many applications, the size of distributed element filters is excessive. The cost of lumped element filters can be prohibitive. MMIC filters would offer the possibility of both small size and low cost.

The development of MMIC filters has received little emphasis. In general MMIC filters are made with lumped element equivalents, and are avoided unless they are required as part of another function which is implemented on MMIC [1]. This is primarily attributable to the poor performance that may be expected of conventional MMIC filters. Inductors on MMICs are of relatively poor performance. Regardless whether they are spirals or high impedance line sections, they suffer from low Q and low self-resonant frequencies. Spiral inductors typically have a Q of 30 at 10 GHz. Self resonant frequency varies with inductor size, the largest inductor that can practically be made with a self-resonant frequency below 18 GHz is on the order of 2 nH. Because of these limitations in inductor performance, filters with sharp cut-off characteristics cannot be realized. Somewhat better performance may be achieved if the substrate is thicker than the conventional 4 mils. Nonetheless, adequate filter response is generally unachievable.

The use of MMIC compatible transversal and recursive filters has been reported. The size of a conventional transversal filter is excessive for a pure MMIC implementation. This has been circumvented by using an off-chip delay line [2]. The size of the complete filter assembly is still quite large. Novel topologies of transversal and recursive filters have also been shown [3]. These filters are smaller than conventional implementations, and could conceivably be implemented as MMICs, although as very large ones.

The filter reported in this paper uses lumped elements to achieve a basic band-pass filter response. Transversal elements are used sharpen the band-pass characteristic. Active elements are included to overcome the high loss of MMIC lumped elements. Inductors have been realized with high impedance transmission lines; spiral inductors may be substituted without significant effect on performance.

Lumped and Transversal Element Filter Circuits

A typical microwave transversal filter structure is shown in Figure 1. In such a filter, multiple amplitude elements (transversal elements) are combined 180° out of phase. The phase delay is provided by 90° line lengths on the input and output sides [4][5]. By appropriate selection of the number of transversal elements, and by tailoring their amplitudes, a wide range of passband characteristics may be realized. In order to achieve the same level of performance as is demonstrated by

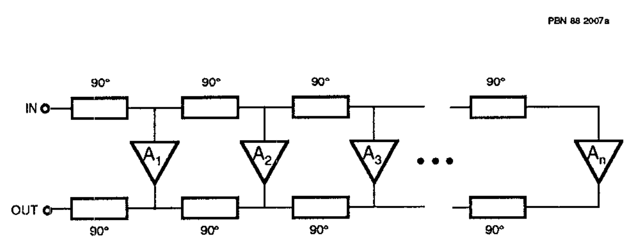

Figure 1. Conventional Microwave Transversal Filter Structure.

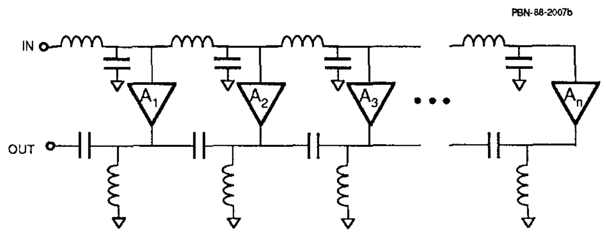

Figure 2. Lumped and Transversal Element Filter Structure.

filter presented in this paper, on the order of 25 transversal elements and 12.5 wavelengths of transmission line would be required. The size of a such a filter would be inappropriate for MMIC implementation .

The structure of the lumped and transversal element filter presented in this paper is shown in Figure 2. The 90° line sections from Figure 1 have been replaced by lumped element filter equivalents. These filter sections have 90° delay or advance near cut-off. Transversal filtering is possible by appropriate tailoring of the amplitude elements.

If all but the last gain element (A_n) are ignored, then the circuit is simply a low pass filter in cascade with a gain element (A_n) in cascade with an high pass filter. This results in a band pass filter characteristic. The additional amplitude (transversal) elements (A_1 through A_{n-1}) may then be tailored to improve the band-pass characteristic.

In a conventional transversal filter, a large number of elements are needed just to provide a basic band-pass shape. In the filter in Figure 2, the basic band-pass shape is provided by the lumped elements, replacing a very large number of transversal elements. Transversal elements are added to refine the band-pass characteristic. Very few transversal elements need be added to provide a sharp band-pass characteristic.

The schematic of the 9.8-11.1 GHz band-pass filter is shown in Figure 3. The basic structure of Figure 2 is used. This filter can accommodate up to five transversal elements, but only three are needed to achieve adequate performance. Each lumped element filter is terminated by a 50 Ω resistor. This ensures that both the lumped element filters are properly matched, and that the last FET (FET3) is unconditionally stable. The other FETs (FET1 and FET2) are very small, and are also unconditionally stable.

MMIC Fabrication

The filter was fabricated as an MMIC and is shown in Figure 4. The inductive elements are made with high impedance transmission line sections. The capacitors are made with 2000 Å of silicon nitride. The transversal elements are standard low current, ion implanted FETs with 0.5 µm gates and 3 x 10^{17} cm^{-3} doping. All bias circuitry is included on chip. A common bias is used for all drains. The gates are individually biased through 2 kΩ resistors, although they can be biased by a common voltage. The wafer was thinned to 4 mils and 20 x 100 µm vias holes were etched. The complete MMIC measures 70 x 75 mils (1.8 x 1.9 mm) including some area taken up by test patterns. Chip size could be further reduced by replacing some high impedance line sections with spiral inductors.

Measured Performance

The measured performance of the filter is shown in Figure 5. Passband loss is 2 dB, with 1 dB ripple. For a strict-

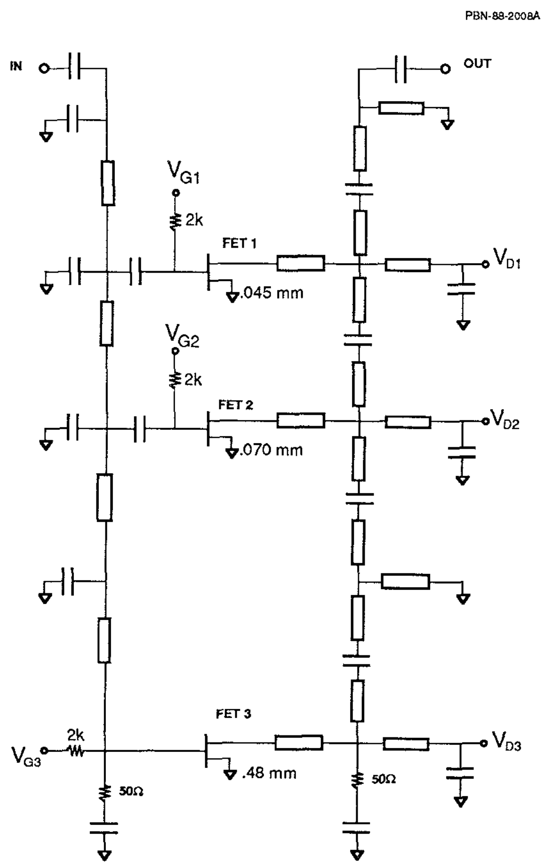

Figure 3. Schematic for the 9.8-11.1 GHz Active Band-Pass Filter MMIC.

ly passive lumped element filter, the passband loss would be on the order of 9 dB. The active transversal elements reduce the loss by approximately 7 dB. Greater than 30 dB rejection is achieved 1.0 GHz from the lower passband edge, 1.1 GHz from the upper passband edge. Modeling shows that with a conventional lumped element filter such rejection could at best have been achieved 2.2 GHz from the passband edges. Return loss is 5 dB or better within the passband, and approaches 0 db outside of the passband as would be expected from a lumped element filter. The FETs in the filter are biased at 3 volts on the drain, and -0.8 volts on the all gates (~ 40% I_{dss}).

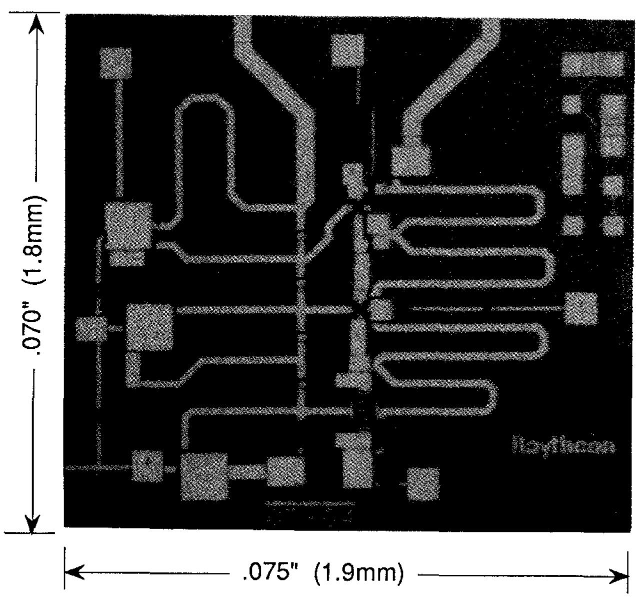

Figure 4. Photograph of the 9.8-11.1 GHz Band-Pass Filter MMIC.

Performance is essentially unaffected for drain voltages from 2.5 to 7 volts. Current consumption is 42 ma, so at 3 volts, power consumption is only 126 mW.

In order to confirm the contributions of the transversal elements, separate biases were provided to each FET, allowing their gains to be removed. This was done by reducing drain bias to 0 volts, and gate voltage to beyond pinch-off (-4 volts). This allows most of the effect from any given FET to be removed. But since a substantial capacitive path still exists from gate to drain (~ 0.3 pf/mm), a very slight effect from any FET still exists. The results of this experiment are shown in Figure 6. The curve labeled "all FETs" is the same as S_{21} in Figure 5. The other two curves indicate the performance when FET1 is turned off, and when both FETs 1 and 2 are turned off. FETs 1 and 2 do not contribute much gain, so the passband loss does not change significantly. The cut-off frequencies are not significantly changed, near in rejection degrades substantially. Modeling shows that if FETs 1 and 2 could be completely removed, rejection would degrade further.

Summary

A novel filter structure has been described using a combination of lumped and transversal elements. The resulting filter yields performance superior to what can be achieved with lumped elements alone, and in a much smaller size than could be realized with transversal elements alone. A 9.8-11.1 GHz MMIC band-pass filter was fabricated to demonstrate the concept.

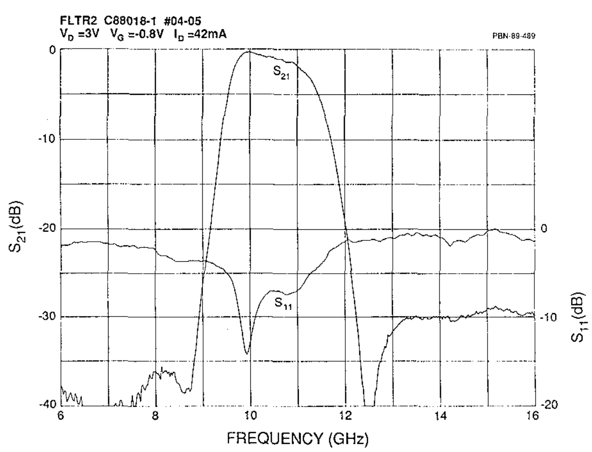

Figure 5. Measured Performance of the 9.8-11.1 GHz Band-Pass Filter MMIC.

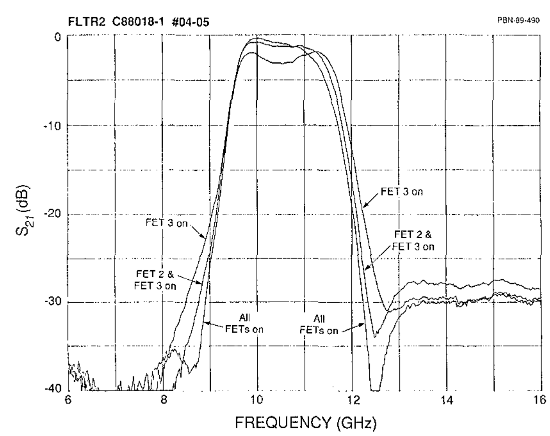

Figure 6. Measured Performance of the 9.9-11.1 GHz Band-Pass Filter in Normal Operation, and When Some FETs Are Turned Off.

Although only a passband filter was shown, the concept can readily be extended to include low pass filters, high pass filters, and diplexers. Similar circuitry can be envisioned to include recursive elements.

Acknowledgement

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