AN MMIC TWIN-TEE ACTIVE BANDPASS FILTER

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ABSTRACT

The design and performance of an MMIC active bandpass filter based on a twin-tee notch circuit are described. Design goals included a center frequency of 2 GHz and a Q that could be varied to well over 100. The device was fabricated in GaAs using 150 um transistors. Die size is approximately 1 square mm, and power dissipation is approximately 180 mW. Although Q values meet expectations, the measured center frequency is low.

I. INTRODUCTION

The large gain-bandwidth product of GaAsFET transistors has led to a number of efforts to realize active filters in monolithic integrated form at microwave frequencies. Motivation for these efforts has been miniaturization. It is anticipated that size reduction on the order of 20 to 1 could be obtained for an active bandpass filter at 2 GHz compared to its passive element counterpart. A variety of techniques have been suggested or employed. These include, but are not limited to, negative resistance cancellation of loss in inductors and transmission line segments [1], replacement of passive inductors with active simulations [2], and circuit methods that utilize positive feedback for Q enhancement [3]. Given the large number of circuit approaches that could possibly be applied to this task, it is not surprising that the field is still in a state of flux and that standard means for realizing microwave active filters have not yet evolved.

It should be emphasized that, although they do promise order of magnitude size reduction, active filters bring with them their own set of problems, some of which can be limiting in applications. Among these are restricted dynamic range and signal distortion, high noise figure, and, possibly, markedly higher Q and center frequency sensitivity to temperature and bias potentials. In this paper, we report results obtained with another effort at MMIC active filter realization, namely that based on the low-frequency technique of negative feedback amplification with a notch network in the feedback path.

The availability of high-gain, controlled phase-shift amplifiers at low frequencies has led to the development of active filters that use negative feedback to obtain a bandpass characteristic. Negative feedback circuits have allowed attainment of stable, high-Q transfer functions, although several operational amplifiers are typically required [4]. One of the simplest of the negative feedback circuits uses a notch circuit in the feedback path as shown in Fig. 1. Conceptually, at the frequency where transmission through the notch is zero, there is no negative feedback and the circuit gain is that of the open-loop amplifier. At frequencies off the notch zero of transmission, the feedback is negative and the circuit gain is reduced from the open-loop value. Analysis shows that the Q depends on the open-loop gain of the amplifier and is given by:

$$Q = (K+1)/4,$$

where K is the amplifier open-loop gain.

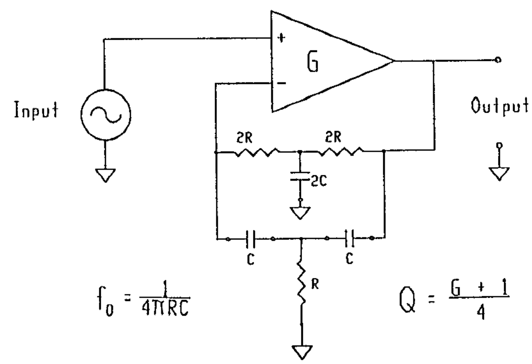

Fig. 1 Negative feedback circuit using a notch circuit in the feedback path.

It has not been, as yet, possible to obtain the high gain with controlled phase shift characteristic at microwave frequencies that is typical of low-frequency operational amplifiers. The maximum voltage gain of a GaAsFET amplifying stage is limited by the product of transconductance and drain-source resistance and is on the order of 10-12. A cascade of these can be envisioned, but the accompanying phase shift becomes excessive for negative feedback if the cascade consists of too many stages; three stages seems to be a practical limit.

II. MMIC FILTER DESIGN

The circuit that was implemented is shown in Fig. 2. Initially, the overall circuit design was simulated using SPICE [5,6]. A small-signal model was developed for the GaAsFET that accurately reflected its small-signal characteristics under different bias conditions. This model was used to obtain approximate design values for each circuit element. The model was also used to study the sensitivity of circuit Q to variations in bias voltage. Simulation indicated that a large range of Q values could be obtained by varying the bias voltages.

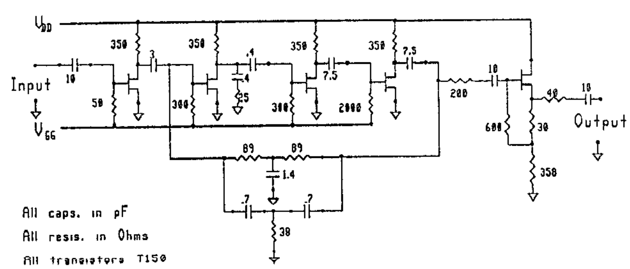

Fig. 2. The twin-tee active bandpass filter circuit.

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An initial layout was performed based on the results of the SPICE simulation. This layout was then simulated using Touchstone [7]. These simulations used the bias conditions derived from the SPICE simulations of the circuit. Each trace, capacitor, thin-film resistor, etc., was modeled as an appropriate distributed element. The additional delay introduced did cause the center frequency to move down in frequency, and this result was expected. Circuit values were modified to move the center frequency back to the target value of 2 GHz.

The final circuit layout is shown in Fig. 3. The layout is approximately 1 mm by 1 mm, including the bonding pads.

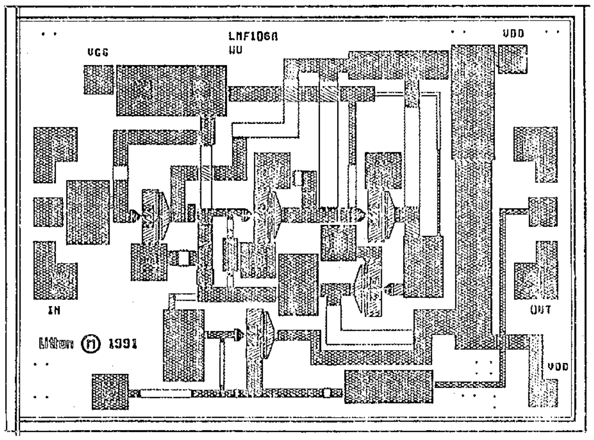
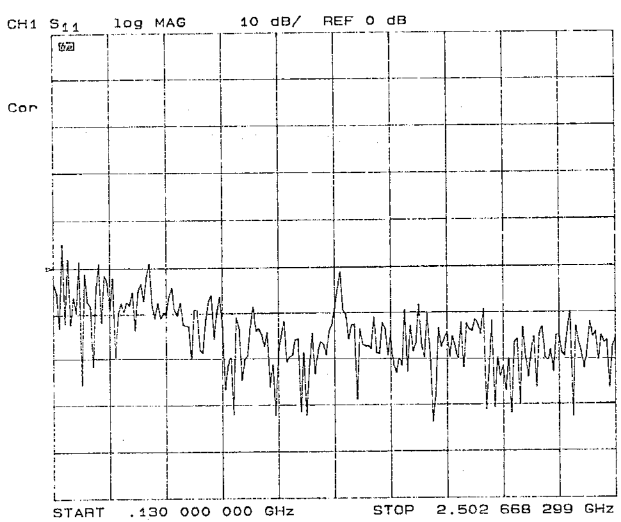


Fig. 3. The final circuit layout.

III. RESULTS

The four S-parameters for a given bias condition are shown in Fig. 4. These measurements were taken with an input power of -65 dBm. The center frequency and Q, as given by S21, are approximately 1.32 GHz and 100, respectively. The values of S11, S12, and S22 were deemed acceptable for this type of filter.



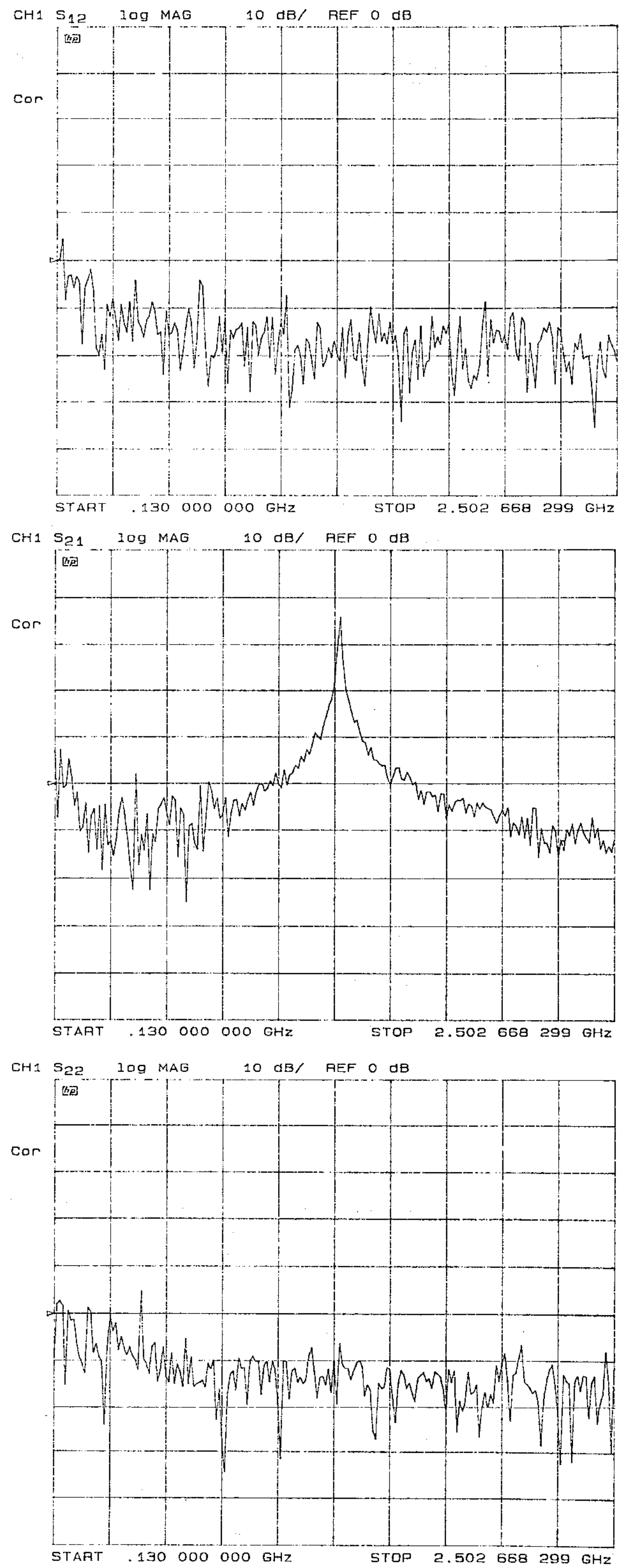


Fig. 4. The four S-parameter measurements with an input power of -65 dBm, Vdd = 5.985 V, Vgg = -0.785 V: a) S11; b) S12; c) S21; d) S22.

Fig. 5 shows the variability of Q available by varying the bias voltage Vgg. It will be noted that the center frequency does change slightly as the Q is varied over its entire range.

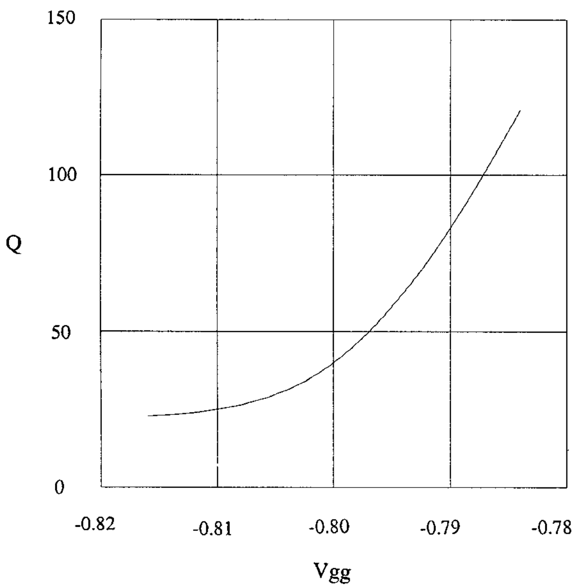
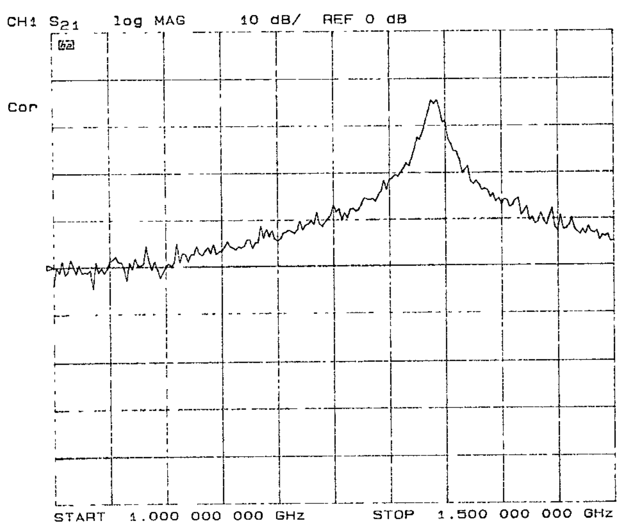


Fig. 5. Circuit Q versus bias voltage Vgg, Vdd = 5.985 V.

Fig. 6 shows S21 for several different values of input power. The output is compressed for larger input powers, and the 3 dB compression point is measured to occur at -35 dBm.



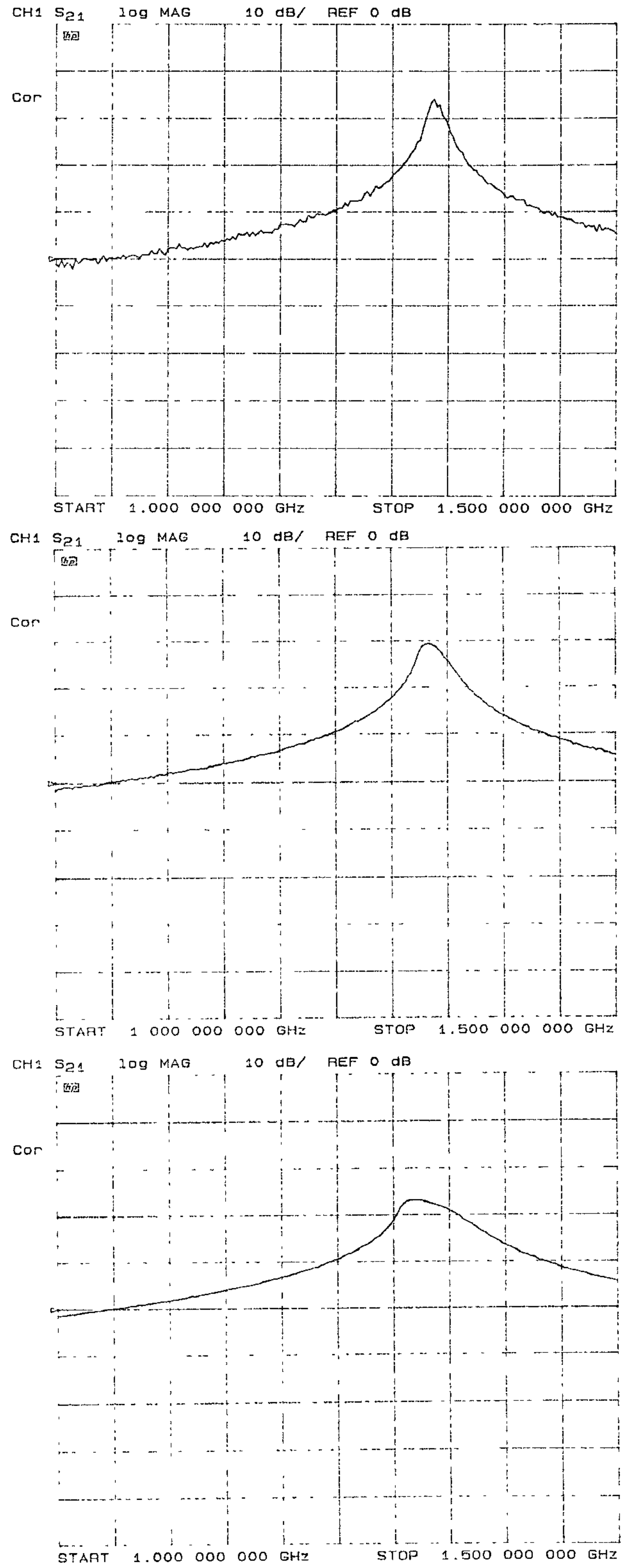


Fig. 6. S21 for different powers, Vdd = 5.981 V, Vgg = -0.782 V: a) -65 dBm; b) -55 dBm; c) -45 dBm; d) -35 dBm.

Fig. 7 shows a plot of measured noise figure versus frequency. The noise figure remains fairly constant on each side of the center frequency, although it is slightly worse above the center frequency. The average value of the noise figure is approximately 17 dB.

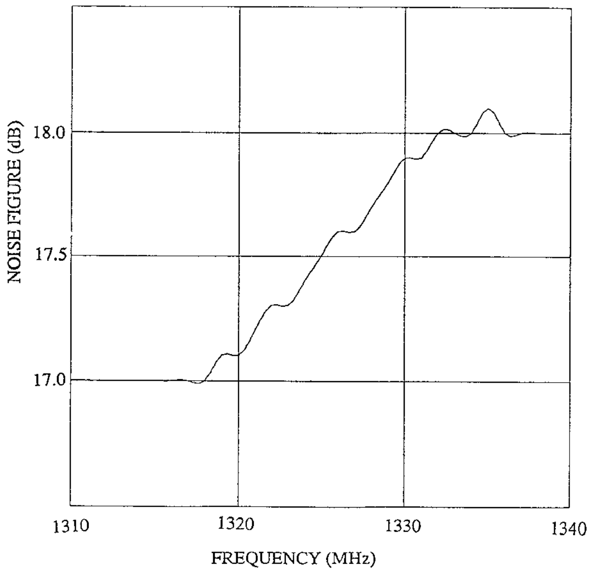


Fig. 7. Circuit noise figure versus frequency.

The active filter stage requires approximately 6 V and 30 mA from the positive supply and about -0.8 V negative bias for typical bias conditions. Total power consumption is approximately 180 mW.

IV. CONCLUSIONS

Measured performance of this circuit was reasonably close to predicted results derived from simulation with the exception of the center frequency. The design value was 2 GHz, while the measured value in the actual circuit was 1.35 GHz. Speculation as to the cause of the difference centers on the capacitance values of the twin-tee circuit; however, this has yet to be definitely proven as the reason for the low center frequency.

It is clear that the circuit suffers from several deficiencies that prevent it from immediately being of practical use. These include a high noise figure, small dynamic range, and high Q sensitivity to bias conditions. It is anticipated that there would also be a substantial Q sensitivity to temperature. Some optimization could be done to reduce the noise figure, primarily through the use of a grounded gate input stage and adjustment of resistor values in the circuit. Dynamic range would also be improved if the noise figure were reduced. Another improvement in dynamic range could be obtained by taking a careful look at the output stage, perhaps resorting to a series connection of transistors to increase the available output swing. Finally, there appears to be no ready way to substantially reduce the Q sensitivity to bias conditions. The fact that Q can be varied with bias might, however, be used to advantage in some applications. Ultimately, to make such a circuit usable might require that two such circuits reside on the same chip, side by side, with one serving as a 'master' circuit and one serving as a 'slave'. The master would be continually under automatic adjustment to set the bias conditions to the desired value, while the slave circuit would have the same bias as the master circuit and, presumably, would then have the same Q and center frequency.

ACKNOWLEDGEMENT

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