K-Band MMIC Active Band-Pass Filters

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***Abstract*—Two K-band active band-pass filters using 0.15-μm GaAs pHEMT technology, with one fixed-frequency and the other tunable, are designed, fabricated, and tested. The fixed-frequency filter has its central frequency at 22.6 GHz, with 900-MHz bandwidth (4%). The tunable filter can be tuned from 19.5 to 21.5 GHz with the same bandwidth. Both circuits have a common size of 1 mm $\times$ 1 mm. To our knowledge, the tunable filter is the highest frequency tunable active filter ever reported.**

***Index Terms*—Active band-pass filter, K-band, pHEMT.**

I. Introduction

OWING to the improvement of design and process technology, the use of microwave monolithic integrated circuit (MMIC) technology to realize microwave filters would clearly be advantageous because of the potentially great performance-to-size ratio and the compatibility of such networks with other MMIC circuits. A passive filter implemented by quarter-wavelength or half-wave length transmission line resonators is usually bulky while most of the reported microwave or millimeter-wave active filters [1]–[13] were realized with smaller sizes. Also, passive filters often need bond wire or flip-chip connected to the MMIC circuits and thus increases the difficulty in the circuit integration. Moreover, active filters can achieve a much narrower bandwidth than the passive ones without suffering for high insertion loss since the active device can compensate the loss for other passive elements or even provide gain in spite of the filter bandwidth of the filter. However, the main challenge in the active filter design is the process variation in the active device. Hence, it would be useful to design an active tunable microwave or millimeter-wave filter to achieve a prescribed filter response by intrinsic or auxiliary tuning mechanism.

In this paper, a fixed-frequency and a tunable K-band active band-pass filter are presented. The fixed-frequency filter has the operating frequency centered at 22.6 GHz, with 900-MHz bandwidth, while the tunable filter can be tuned from 19.5 to 21.5 GHz. Table I summarizes the reported tunable active filter designs, respectively. It is observed that the tunable design in our study has the highest operating frequency among the reported tunable active filters with a compact size.

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II. K-Band MMIC Active Filter Implementations

The active filters are usually designed based on recursive or negative resistance compensation approaches. Recursive active filters usually exhibit poor return losses from the published measured results [4], [5] as well as simulations, and thus easily cause instability. On the other hand, the negative resistance can be used to compensate the losses from other passive elements to enhance the Q-factor of the total passive network. Active filters designed using this approach are more stable and have good rejection ratio. Besides, the Q-enhanced resonator, which is achieved by the negative resistance compensation, following after the amplifier could result in high gain active filter [10].

Both the K-band second-order fixed frequency and varactor-tuned active band-pass filters are implemented using the WIN's standard 6-in 0.15-μm GaAs-based power pHEMT MMIC process with the same circuit architecture. Fig. 1 presents the schematic diagram of the fixed-frequency filter. The negative resistance generators not only provide the negative resistances but also serve as inductors. A high-impedance transmission line serves as the feedback inductor, and a feedback capacitor is connected between gate and source. These two feedback elements make the input impedance negative. The other two high-impedance transmission lines provide the necessary inductance looking into the negative resistance generator. A capacitor C_f is required for negative resistance tuning. A 3-nH RF choke inductor is used to provide a dc ground to the source terminal. The only difference between the fixed-frequency and tunable filter designs is that the radial stubs are replaced by reverse biased Schottky diodes as varactors for frequency tuning.

The common gate HEMT device used in the designs is two-finger with 50-μm total gate width. It has f_{T} of 85 GHz, $f_{\max}$ of 120 GHz, peak G_{m} of 495 mS/mm, and maximum I_{d} of 650 mA/mm. From the simulation, the real part of the negative resistance goes from 3 to -1.5 V at 23 GHz when V_{ds} varies from 0.9 to 1.5 V, while the imaginary part almost remains constant. The impedance of the imaginary part increases with frequency and thus the negative resistance generator looks like a shunt inductor with a variable resistor. In this design, the inductance is about 0.35 nH. The benefit in the filter design provided by the constant imaginary part is that the center frequency and the bandwidth may be kept the same while the negative resistance varies.

The capacitors were realized with the radial stubs, inter-digital capacitors and microstrip-line gaps. These elements were all EM simulated by the full wave solver HFSS. The chip photographs of both fixed-frequency and tunable active filters are shown in Fig. 2, with a common chip size of 1 mm $\times$ 1 mm.

TABLE I
COMPARISON OF THE PREVIOUSLY REPORTED TUNABLE FILTER DESIGN AND THIS WORK

Reference	Technology	Chip Size (mm^2)	Tuning Range (GHz)	Bandwidth (GHz), (%)	Design Features
[5]	GaAs HEMT	2 x 2	9.6~9.9	0.4 (4%)	Recursive
[9]	0.5-μm GaAs MESFET	3 x 2	1.6~2.9	0.12 (4.5%)	Negative Resistance
[10]	0.15-μm AlGaAs/In GaAs HJFET	1.5 x 1.7	1.85~2.15	0.3 (15%)	Negative Resistance
[13]	0.2-μm GaAs pHEMT	3.4 x 5.5	7.6~8.6	0.2 (2.5%)	Recursive
This Work	**0.15-mm GaAs pHEMT**	**1 x 1**	**19.5–21.5**	**0.9 (4%)**	**Negative Resistance**

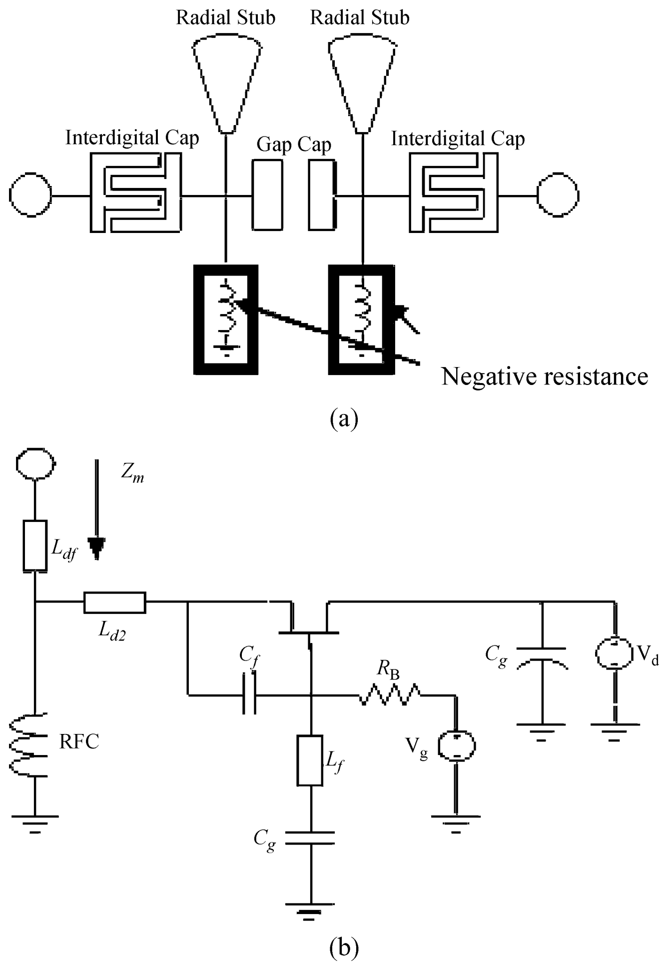

Fig. 1. (a) Schematic of the fixed frequency active filter. The tunable active filter use varactors as tunable capacitors to replace the radio stubs. (b) Schematic of the negative resistance generator.

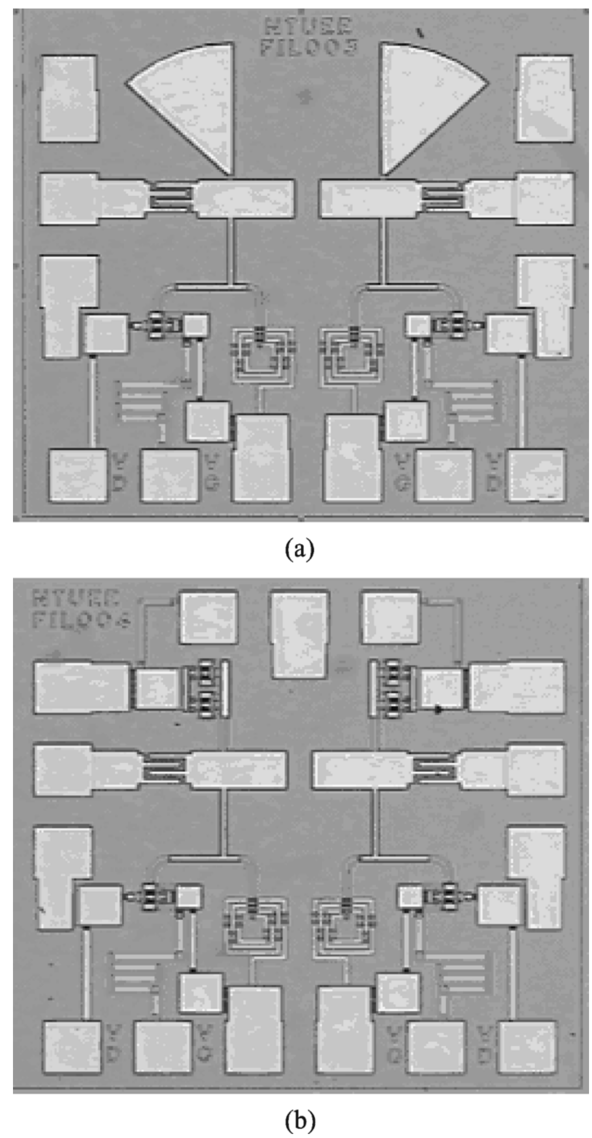

Fig. 2. Chip micrograph of the (a) fixed frequency active filter and (b) tunable active filter, with a common size of 1×1 mm^2.

III. MEASUREMENT RESULTS

The chips are measured via on-wafer probing. Fig. 3 presents the simulation and the measurement results of the insertion gain and input return loss for the fixed-frequency active filter with the HEMT devices turned on. It can be found that the loss compensation mechanism can be brought up by activating the HEMT device. The bandwidth is about 900 MHz centered at 22.6 GHz with the input return loss better than 8 dB across the pass band. The input return loss is better than those of the recursive filters, as can be observed in [4] and [5]. The supply voltage is at $V_g = 0$ V and $V_d = 1.2$ V with a total supply current of 42 mA and dc power consumption of 50 mW. The simulation results agree with the measurement results reasonably.

Fig. 4 presents the simulation and the measured insertion losses of the varactor-tuned active filter under different varactor voltages from 15 to 27 GHz. The transistors in negative resistance generators are biased at $V_g = 0$ V and $V_d = 1.2$ V. By controlling the varactor voltage (V_{tune}) from -3 to -5 V, the

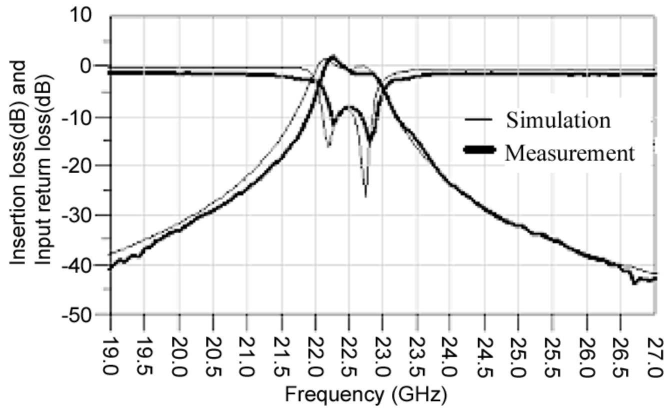

Fig. 3. Simulation and measured insertion loss and input return loss of the fixed-frequency active band-pass filter when HEMT is on.

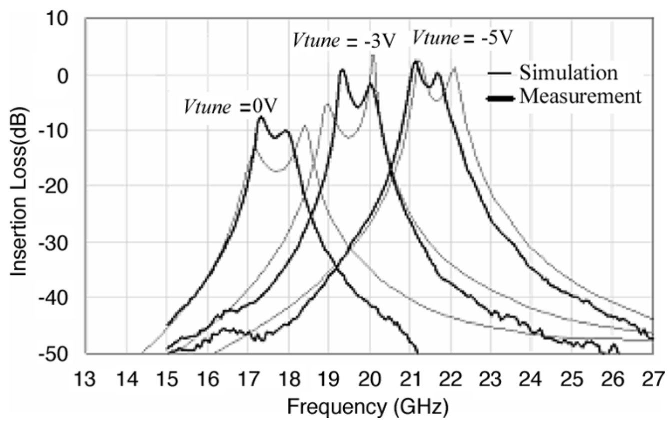

Fig. 4. Simulation and measured insertion losses of the varactor-tuned active filter under different varactor voltages.

center frequency varies from 19.5 to 21.5 GHz. In fact, the filter characteristics can be observed even from 17.2 GHz when the varactor voltage is 0 V. However, the low reverse-biased varactor voltage contributes to a high capacitance and results in a high insertion loss. The discrepancies between measurement and simulation at lower frequencies may be due to varactor model inaccuracy near low reverse bias condition.

The measured noise figure of the tunable active filter is 17 dB at 21.2 GHz. The high noise figure is mainly because it has very low gain (or even loss) in this design. However, connecting a high gain LNA in front of the active filter can possibly minimize the increase of the overall system noise, as pointed out in [11]. The output power at the 1-dB compression is -20 dBm when the input is -19 dBm at the center frequency of 21.2 GHz, which is also relatively low due to the low drain bias condition.

IV. Conclusion

Fixed-frequency and tunable K-band active filters were implemented based on the negative resistance compensation method using 0.15-μm GaAs pHEMT MMIC process. The fixed frequency filter has a central frequency of 22.6 GHz with 900-MHz bandwidth (4%). The tunable filter can be tuned from 19.5 to 21.5 GHz with 900-MHz bandwidth, which is the highest frequency tunable active filter reported to date.

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References

[1] L. Billonnet, B. Jarry, and P. Guillon, "Theoretical and experimental analysis of microwave tunable recursive active filters using power dividers," in *IEEE MTT-S Int. Symp. Dig.*, vol. 1, Jun. 1993, pp. 185–188.

[2] M. Delmond, L. Billonnet, B. Jarry, and P. Guillon, "Optimization of noise performance for various topologies of microwave active recursive filters," in *IEEE MTT-S Int. Symp. Dig.*, vol. 3, Jun. 1998, pp. 1173–1176.

[3] H. Ezzedine, W. Mozannar, L. Billonnet, B. Jerry, and P. Guillon, "Low noise first-order active recursive filter," in *IEEE Radio Frequency Integrated Circuit (RFIC) Symp. Dig.*, 1999, pp. 171–174.

[4] C.-H. Lee, S. Han, and J. Laskar, "GaAs MESFET duel-gate mixer with active filter design for Ku-band applications," in *IEEE Radio Frequency Integrated Circuit (RFIC) Symp. Dig.*, 1999, pp. 203–206.

[5] M. Delmond, L. Billonnet, B. Jarry, and P. Guillon, "Microwave tunable active filter design in MMIC technology using recursive concepts," in *IEEE Microwave Millimeter-Wave Monolithic Circuits Symp. Dig.*, May 1995, pp. 105–108.

[6] J. Tissier, W. Mouzannar, L. Billonnet, B. Jarry, and P. Guillon, "Novel alternative design methods based upon combined amplification, matching and filtering approaches in MMIC technology," in *IEEE MTT-S Int. Symp. Dig.*, vol. 1, 2000, pp. 409–412.

[7] Y.-H. Cho, S.-C. Hong, and Y.-S. Kwon, "A low-power monolithic GaAs FET based on negative resistance technique," *IEEE Microwave Guided Wave Lett.*, vol. 8, no. 4, pp. 161–163, Apr. 1998.

[8] B. Hopf, I. Wolff, and M. Guglielmi, "Coplanar MMIC active bandpass filters using negative resistance circuits," in *IEEE MTT-S Int. Symp. Dig.*, vol. 2, May 1994, pp. 1183–1185.

[9] U. Karacaoglu and I. D. Robertson, "MMIC active bandpass filters using varactor-tuned negative resistance elements," *IEEE Trans. Microw. Theory Techn.*, vol. 43, no. 12, pp. 2926–2932, Dec. 1995.

[10] H.-H. Wu and Y.-J. Chan, "Tunable high-Q MMIC active filter by negative resistance compensation," in *Gallium Arsenide Integrated Circuit (GaAs IC) Symp. Dig.*, Oct. 1, 1997, pp. 252–255.

[11] M. Ito, K. Maruhashi, S. Kishimoto, and K. Ohata, "60-GHz band coplanar MMIC active filters," *IEEE Trans. Microw. Theory Techn.*, vol. 52, no. 3, pp. 743–750, Mar. 2004.

[12] M. Delmond, L. Billonnet, B. Jarry, and P. Guillon, "High-order monolithic active recursive filter based upon multicellular approach," in *IEEE MTT-S Int. Symp. Dig.*, vol. 2, Jun. 1996, pp. 17–21.

[13] R. Malmqvist, C. Samuelsson, T. Nilsson, I. Ferrer, and M. Alfredson, "7.6–8.6-GHz tunable active GaAs pHEMT MMIC filter for agile compact on-chip X-band radar receiver front ends," in *Proc. Asia-Pacific Microwave Conf.*, vol. 3, Nov. 2003, pp. 1680–1683.