# 25.5 to 76.5GHz Active Frequency Tripler for Automotive Radar Applications

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*Abstract* — **This paper discusses the development of a 25.5 GHz to 76.5 GHz single stage active frequency tripler for automotive radar applications. With an input drive level of 17 dBm at f/3, the frequency triplers tested demonstrated an output power level of 0 dBm from 73 to 82 GHz. The frequency tripler was subsequently cascaded with a 25.5 GHz VCO to demonstrate a 76.5 GHz VCO.**

## I. INTRODUCTION

For automotive radar sensor applications such as active cruise control, collision avoidance, or backup aid radar sensors, low cost W-band voltage controlled oscillators (VCO) with a moderate tuning range and low phase noise are needed in a FM CW system. Typically a tuning range of 1GHz from 76-77 GHz with a phase noise of –80 dBc at a 100 kHz offset is required for a VCO used in a FM CW automotive application.

First generation automotive sensors currently use waveguide based Gunn diode VCOs [1]. Alternatives to a Gunn diode VCO include GaAs pHEMT VCOs operating directly at 77 GHz or a lower frequency VCO that is multiplied in frequency to the automotive band. To achieve low phase noise with a fundamental frequency GaAs pHEMT design, an external phase lock loop is typically required for frequency stabilization. Another approach is to cascade a lower frequency VCO with low phase noise (e.g. a HBT VCO) with a frequency multiplier.

This paper details the development of a 25.5 GHz to 76.5 GHz frequency tripler that can easily be cascaded with a low phase noise VCO or DRO operating at 25.5 GHz. A demonstration of a cascaded GaAs MMIC VCO/buffer amplifier with a frequency tripler is also described.

## II. CIRCUIT DESIGN AND FABRICATION

This W-band frequency tripler was designed as a single stage active frequency tripler operating in a class A mode [2] with low drain bias. When overdriven, this mode has high gain in the fundamental and odd order harmonics. The input circuit is impedance matched to fo at 25.5 GHz while the output circuit is impedance matched to 3fo at 76.5 GHz. The input circuit has a shunt LC notch filter to provide a short circuit at 3fo while a shunt LC notch filter was also added to the output circuit to short circuit any signal output at fo. A λ/4 open circuit stub to suppress fo was not used since it would also suppress the desired 3fo output. An additional λ/4 open circuit stub minimizes the 2$^{nd}$ harmonic on the output circuit. A 4x50 um FET cell is used for the active device. The typical operating bias for the frequency tripler shown in Fig. 1 is 1.5-2.0 volts drain bias and 15-25 mA of drain current.

The predicted performance of the W-band frequency tripler is shown in Fig. 2. In the figure, the fundamental, 2$^{nd}$ harmonic, and desired 3$^{rd}$ harmonic output levels are shown versus drive levels of 15-20 dBm. The input frequency is on the x-axis. The design was centered for operation at 25.5 GHz. This plot shows that the 25.5 GHz fundamental is attenuated by at least 39 dB and the 2$^{nd}$ harmonic is attenuated by 33 dB. The desired 3$^{rd}$ harmonic output level is predicted to be approximately –2 dBm with a 17 dBm drive level. Thus the conversion loss was predicted to be 19 dB for this design. The nonlinear analysis shown was performed using a Materka model of the 200 um FET used in the design.

The W-band frequency tripler was fabricated using TriQuint's 0.25 um dual-recess pHEMT device process. This process was selected for the design to allow for possible integration with a VCO/buffer amplifier for a single MMIC solution. This design also uses TriQuint's 3MI metal interconnect process to reduce the circuit size.

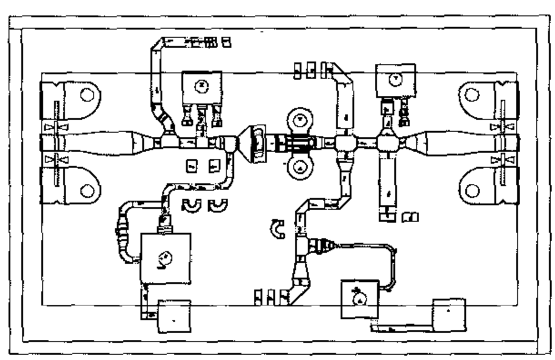


Fig. 1. Frequency Tripler Layout. Die size is 0.87 mm x 1.54 mm.

A prediction of the output power at the fundamental, 2nd harmonic, and 3rd harmonic versus input power at 25.5 GHz is shown in Fig. 3. As the input power is varied from 0 to 20 dBm, it is seen that the optimum drive level and minimum conversion loss for the frequency tripler is approximately 14 dBm. At very low drive levels, < 2 dBm, the fundamental and 2nd harmonic levels are linear and above 2 dBm it can be observed that more power is transferred into the 3rd harmonic. For a drive level of 6 to 12 dBm, the 3rd harmonic is linear and begins to saturate above 12 dBm. Above 14 dBm, the output level saturates and increases 2-3 dB for a 6 dB change input level.

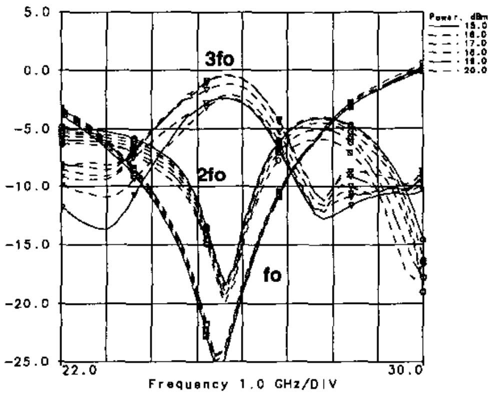



Fig. 2. Predicted Output Power Versus Frequency and RF Drive Level

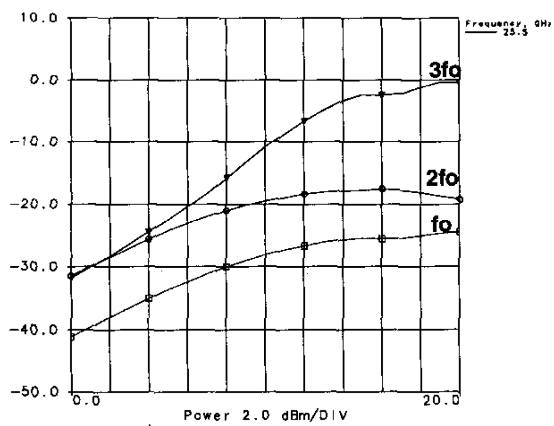



Fig. 3. Predicted Harmonic Levels Versus Input Power

## III. FREQUENCY TRIPLER RF PERFORMANCE

Several frequency triplers were assembled on carrier plates and tested. The input signal was provided with a coax 2.4 mm GSG (ground-signal-ground) probe and the output was measured using a W-band waveguide GSG probe. The output signal level and frequency was measured on a spectrum analyzer using a harmonic mixer that was calibrated to a W-band power meter. All the circuits tested were unconditionally stable and were measured over an output frequency range of 70-84 GHz with an input signal of 17 dBm at f/3 as shown in Fig. 4. For the baseline circuits tested, the average measured output power varied from approximately –4 dBm to –2.5 dBm over the 75 to 84 GHz frequency range. The measured conversion loss in this frequency range was 19.5 dB to 21.5 dB and compares favorably with the expected conversion loss of 19 dB. The best conversion loss (19.5 dB) occurs in a 3 GHz range from 81 to 84 GHz. Thus, the frequency tripler as built appears to be tuned higher than the desired 76-77 GHz band.

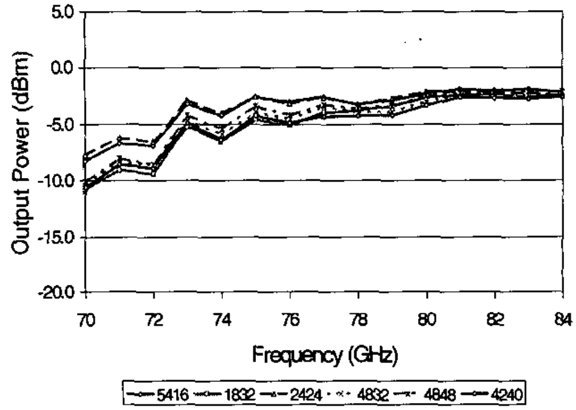



Fig. 4. Measured Output Power Versus Frequency

Fig. 5 is a plot of the measured output power versus input power for a typical baseline frequency tripler at 77 GHz. The data compares well with the predicted result of Figure 3 and shows similar saturation at a –3dBm level. For instance at a 14 dBm input level the predicted and measured output level are –4 dBm and –5 dBm while at other levels the agreement is even closer.

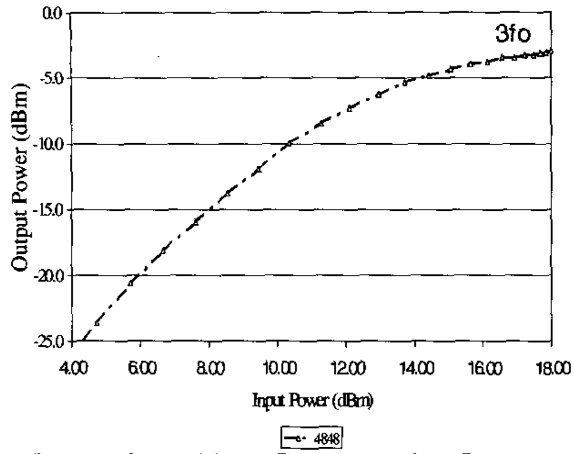



Fig. 5. Measured Output Power Versus Input Power

With subsequent minor tuning, the frequency tripler output power was increased to the 0 dBm level thus reducing the conversion loss to 17 dB. The tuned output power in Fig. 6 is flat with approximately +/- 0.5 dB variation over the 73-82 GHz frequency range.

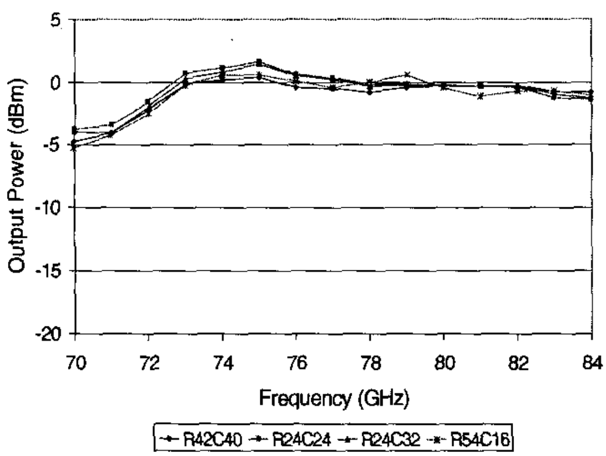



Fig. 6. Tuned Tripler Output Power Versus Frequency, Pin=17dBm

## IV. CASCADED VCO-FREQUENCY TRIPLER PERFORMANCE

Fig. 7 shows a carrier plate layout of a 25.5 GHz VCO cascaded with a frequency tripler to demonstrate an alternate means of developing a 76-77 GHz VCO with moderate tuning bandwidth. The 25.5 GHz VCO was designed as a negative resistance oscillator using a 200 um pHEMT device with a gate resonator terminated by a 120 um GaAs Schottky diode. A two stage buffer amplifier was included with the VCO and provided sufficient isolation to limit frequency pulling to less that 2 MHz for any load VSWR. The two stages were comprised of a 200 um FET cell driving a 400 um output FET cell to achieve a 15 dBm output power level.

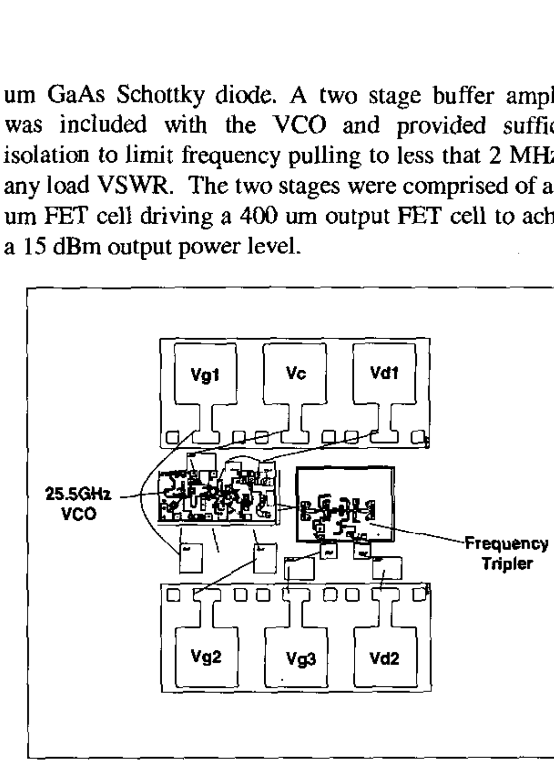
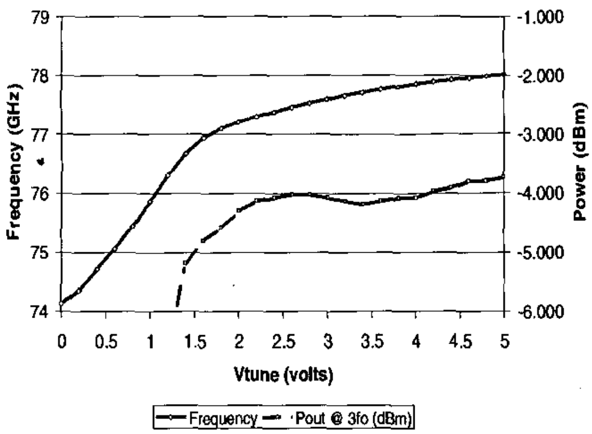



Fig. 7. Cascaded 25.5-76.5GHz VCO-Amplfier-Tripler

Tuning bandwidth of the VCO as designed was on the order of 1 GHz and the measured phase noise was –84 dBc to –92 dBc at a 1 MHz offset. Drain bias for the VCO-buffer amplifier and frequency tripler was set to 1.5 volts and drain current for the cascade was measured at 130 mA. Bias to the varactor diode was varied over a 0-5 volt range. Individual VCO-buffer amplifiers were measured to have an output power of 14-15 dBm and thus provided a sufficient drive level for the cascaded circuit.

The performance of the cascaded VCO-buffer amplifier-frequency tripler is shown in Fig. 8. This figure shows the output frequency and output power of the cascaded circuit versus control voltage. The VCO was designed to operate linearly with a control voltage range of 1.5-5.0 volts. In the 0-1.5 volt range the output frequency is nonlinear due to the rapid change in capacitance as the varactor diode transitions into pinchoff in this range. The output power as noted varies from –4.2 to –3.8 dBm over the 2.0-5.0 volt range and the output frequency varies linearly from 77.2-78 GHz at a rate of 267 MHz/volt. This output level was expected based on the 19 dB conversion loss of the baseline frequency tripler. Below 2.0 volts the output level decreases by 2.0 dB. This is caused by the tripler conversion loss increasing by the same amount as the VCO is tuned across the 74-76 GHz frequency range. With tuning of the frequency tripler as noted above, the output power would be flat down to the lower 74 GHz band edge.

Fig. 8. Cascaded VCO-Tripler Performance




Design changes to the frequency tripler have been identified and with a second design iteration, a cascaded output level of >0 dBm should be possible. In any future re-design of this frequency tripler, the device size may need to be increased somewhat to provide even higher drive power to a W-band medium power amplifier. Adding a W-band medium power amplifier would then provide sufficient output power for a Gunn diode VCO replacement.

## V. CONCLUSION

Today's automotive radar sensors currently use Gunn diode oscillators for transmit at 76-77 GHz. The GaAs MMICs described here were developed to demonstrate potential alternatives for W-band frequency generation. This paper has presented results of a successful frequency tripler with a 9 GHz operational bandwidth that could be used in automotive radar sensor applications. A demonstration of a cascaded W-band VCO-frequency tripler with a 800 MHz linear tuning range was also described, and has the potential to be further developed into a low cost replacement for a Gunn diode VCO.


## ACKNOWLEDGEMENT

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