Novel Millimeter Wave Active MMIC Triplers

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ABSTRACT

A novel millimeter wave MMIC active balanced tripler with input driver amplifier has been developed using GaAs PHEMT 0.25 micron technology. Frequency conversion is realized using the high third harmonic currents of an overdriven class A amplifier with output short circuits at the fundamental and higher order harmonics with optimum load conductance at the third harmonic. Q-and W-band MMIC triplers were developed and exhibited +12 and +5 dBm peak output powers respectively. A MMIC W-band receiver was fabricated using the Q-band active multiplier to drive a subharmonic mixer with 5-dB overall conversion gain.

INTRODUCTION

Frequency multipliers are used extensively for transmitters and receiving chains in modern systems [1-4]. The active multiplier has the advantage over the varactor diode type for lower conversion loss and significant wider bandwidth. Active multipliers have generally been configured as X2 and provide good performance [5-6]. Many system configurations require X3 multipliers and developments have been reported using varactor based MMICs [7]. X3 multiplication has been reported for active X3 multipliers operating at pinchoff [8], where the odd harmonic currents are relatively low. A need exists for an X3 multiplier with higher output third harmonic currents and higher output power that can be integrated with other MMIC functions.

ACTIVE X3 MULTIPLIER

The operation of a typical active multiplier requires operating the transistor class C in order to enhance the third harmonic currents. Figure 1 illustrates the Fourier currents versus conduction angle for a transistor with constant transconductance. As can be seen from this figure, the optimum conduction angle is 80 degrees with a normalized third harmonic current (A3) of 0.185. This current is normalized to Imax = 1A, where Imax is the peak to peak current. Operation in this mode requires a high breakdown voltage device, and exhibits high harmonic currents and high conversion loss.

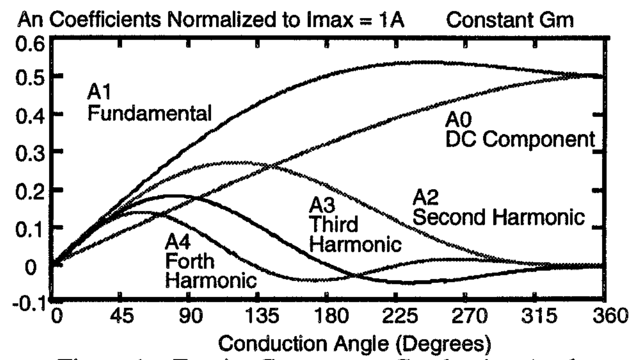

Figure 1. Fourier Currents vs. Conduction Angle

A new method of generating third harmonic power for the millimeter wave frequencies is required. Biasing the transistor class A results in high gain at the fundamental and when overdriven, results in significant odd order harmonics, like the desired third harmonic. Figure 2 illustrates the Fourier currents for a constant transconductance device as well as the relative power at the third harmonic compared to that obtained at the fundamental frequency as a function of the overdrive angle. This angle represents the number of degrees that the transistor is overdriven through one cycle. It can be seen that for an overdrive angle of 270 degrees, the power at the third harmonic is 5.6 dB below that of the fundamental.

For efficient operation in this mode, a short circuit is required across the output of the transistor at all frequencies except for the third harmonic. Significant currents are at the fundamental with low currents a the fifth harmonic. Even order harmonics are low. Under these conditions, the load conductance (GL) to be presented to the transistor at the third harmonic is:

GL = 2A3 (Vmax - Vmin)/Imax, where:

Vmax = maximum load voltage
Vmin = transistor's knee voltage
Imax = peak-to-peak transistor current

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Over Drive Angle (oa) (Degrees)	A1	A3	Relative Power P3rd/Pfund (A3/A1) Ratio (dB)
0	0.5	0	0
45	0.508	0	0
90	0.528	-0.012	0.022 (-16.43 dB)
135	0.553	-0.036	0.065 (-11.86 dB)
180	0.579	-0.075	0.13 (-8.88 dB)
225	0.602	-0.122	0.203 (-6.4 dB)
270	0.621	-0.167	0.27 (-5.63 dB)
315	0.633	-0.2	0.315 (-5 dB)
360	0.637	-0.212	0.333 (-4.77dB)

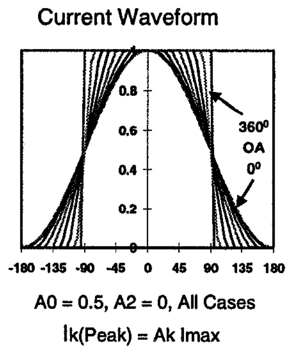

Figure 2. Third Harmonic/Fundamental Power and Current vs. Overdrive Angle

The RF power (P) generated at the third harmonic with this load conductance is:

P = 2A3 (Imax) (Vmax - Vmin)/8

The DC power required (Pdc) is:

Pdc = 0.5 A0 (Vmax - Vmin) Imax F, where:

A0 is the dc Fourier normalized current (0.5)
F = 1 + 2 Vmin/(Vmax - Vmin)

The efficiency, P/Pdc, (η) is:

η = A3/(2A0F)

For full overdrive, with Vmin = 0, the theoretical efficiency is 0.167 for third harmonic power generation.

CIRCUIT DESCRIPTION

Q-band Balanced Tripler

The active balanced tripler circuit schematic is shown in figure 3. A balanced multiplier has the advantages of 3 dB more output power, and also increased suppression of other harmonics.

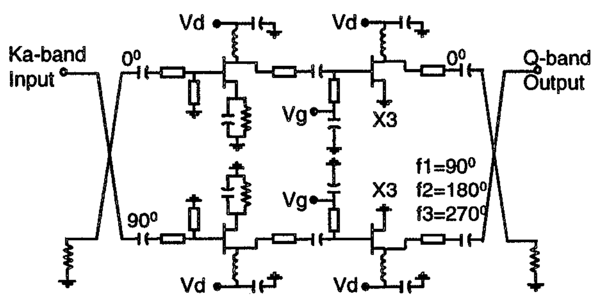

Figure 3. Schematic of Balanced Tripler

As shown in figure 3, the input Ku-band signal is amplified in the first stage and feeds the tripler FETs 90 degrees out of phase. The fundamental leakage remains 90 degrees out of phase. The second and third harmonic are 180 degrees and 270 degrees out of phase respectively. When combined in the output coupler only the third harmonic signals are in phase. The fundamental harmonic is 180 degrees out of phase and cancels at the output.

The multiplier FET is a common source 200 μm device, with a gate length of 0.25 μm. The FET is biased at 1/2 Idss with a drain voltage of 5.0 volts. The output match presents a short circuit at the fundamental and the second harmonic. The matching network at the third harmonic a high pass type. The input to the multiplier has a lowpass matching at the fundamental frequency.

An output power of +18 dBm at Q-band was desired and the theoretical drive required was +23.6 dBm, or 5.6 dB conversion loss. The input buffer amplifier drives the multiplier FET, and reduces phase ripple at the multiplier input. The buffer amplifier is self-biased, and wideband matching was used at the input and output.

After completing the electrical design, two buffer amplifier/multipliers were laid out on the MMIC chip. A Lange coupler centered at Ku band was put at the input, and a Q-band Lange coupler was put at the output. The couplers give better than 15 dB return loss at the input and output which lowers ripple over wideband operation. Figure 4 shows the MMIC Q-band multiplier photograph. The chip size is 60x60 mils.

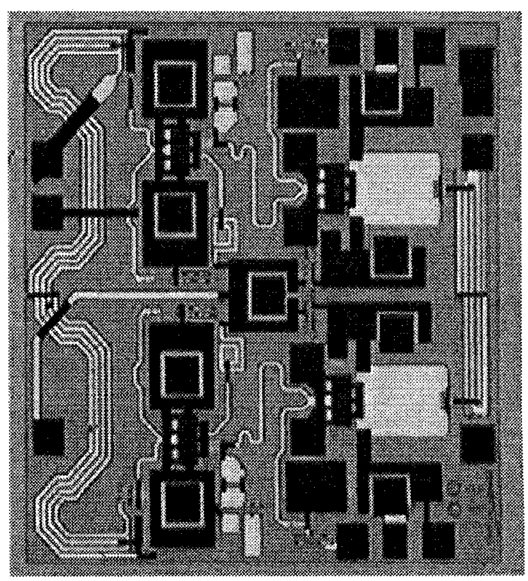

Figure 4. Q-band Tripler

W-band Multiplier

A tripler was also designed to multiply from Ka band to W-band. The same topology was used for the W-band

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as for the Q-band except the circuit was not balanced. Figure 5 shows the MMIC W-band tripler photograph. The chip size is 60x60 mils.

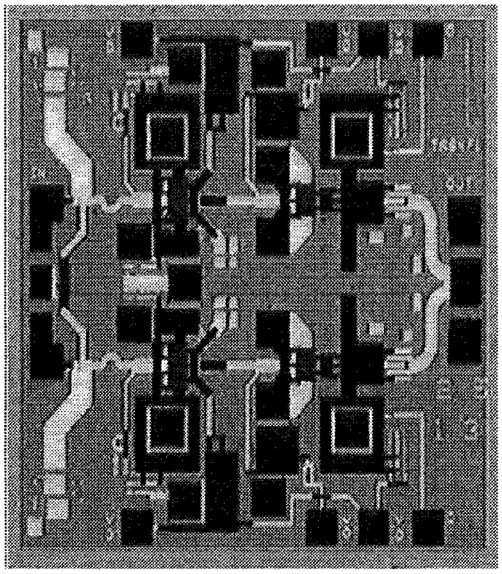

Figure 5. W-band Tripler

MEASURED MMIC PERFORMANCE

Figure 6 shows the output power of the Q-band tripler versus output frequency. Also shown is the fundamental and second harmonic leakage. The output power peaks at +12.5 dBm with fundamental suppression of 40 dB below the desired third harmonic output. This is equivalent to 60 dB of fundamental suppression showing the cancellation of the fundamental at the tripler output. The second harmonic suppression is 20 dB below the third harmonic output. The driver amplifiers compressed lower than expected giving a lower than desired output power. The operational bandwidth was over 9 GHz which is usable for many wideband millimeter wave applications.

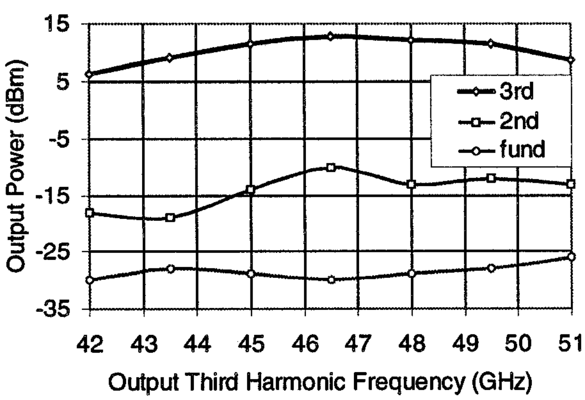

Figure 6. Output of Q-band Tripler

Figure 7 shows the output power for the W-band active X3. The peak power occurs at 99.5 GHz at +5.5 dBm.

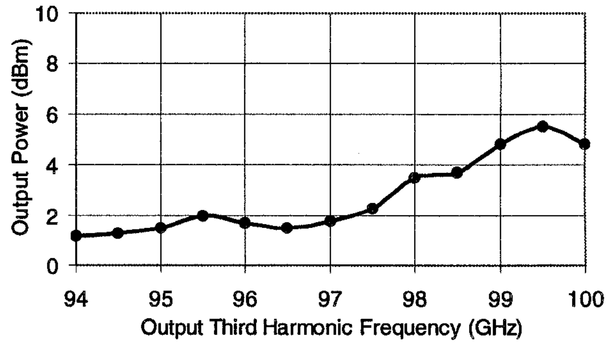

Figure 7. Output of W-band Tripler

APPLICATIONS OF MULTIPLIERS

MMIC multipliers offer a low cost simple approach to working at millimeter wave frequencies. By using multipliers at the input to devices, the need for special packaging and special connectors is minimized. Figure 8 shows the block diagram of a millimeter-wave W-band receiver where the MMIC Q-band tripler is used to drive the LO port of a W-band subharmonic mixer. The LO signal is input at Ku frequencies and is tripled to Q-band. The subharmonic mixer internally generates a W-band signal to mix with the W-band input.

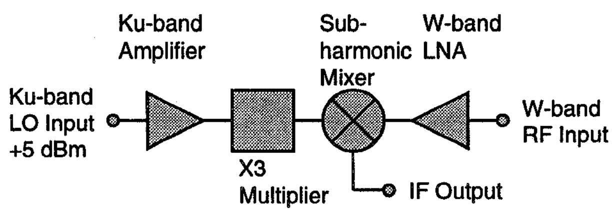

Figure 8. Block Diagram of W-band Receiver with Q-band Tripler

Figures 9 shows the performance of the receiver. The IF is at 20 MHz and the conversion gain shows the wideband response of the Q-band tripler driving the mixer LO port. Figure 10 is a photo of the receiver.

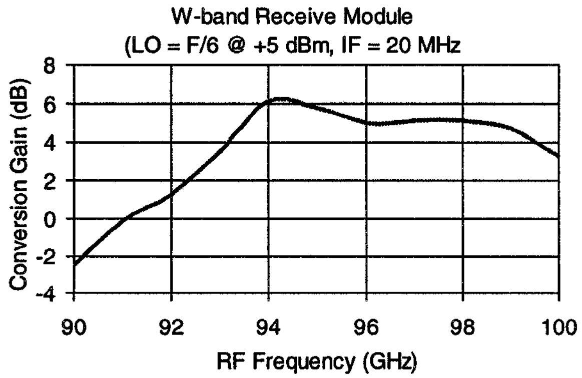

Figure 9. Measured Performance W-band Receiver with Q-band Tripler

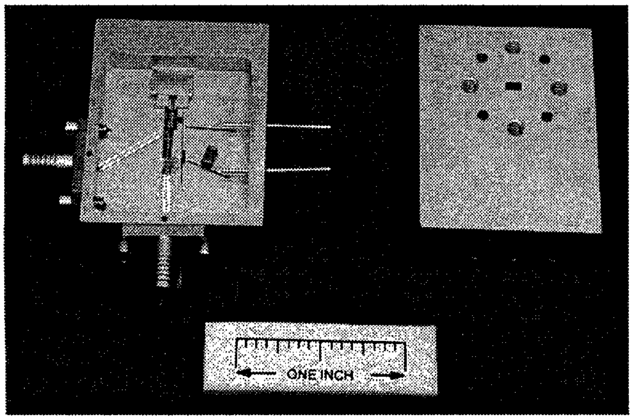

Figure 10. Photograph of W-band Receiver with Q-band Tripler

CONCLUSIONS

A novel multiplier that uses class A overdriven operation has resulted in good tripler operation in the millimeter wave. Both Q- and W-band MMICs with integral driver amplifier were developed and fabricated with peak output powers of 12- and 5-dBm power levels. A MMIC receiver using the Q-band tripler to drive a subharmonic mixer achieved an overall 5-dB conversion gain.

REFERENCES

[1] Peter Stenger, Michael Sarantos, Edward Niehenke, Howard Fudem, Christopher Schwerdt, Fred Kuss, David Strack, George Henry, and John Masti, "A Miniature, MMIC One Watt W-band Solid State Transmitter,"1997 IEEE MTT-S International Microwave Symposium Digest, pp. 431-434.

[2] E. W. Lin, Y. Kok, S. Dow, H. Wang, T. T. Chung, S. Lau, D. Okamuro, B. R. Allen, "An Advanced Single-Chip Ka-Band Transceiver," 1996 IEEE MTT-S International Microwave Symposium Digest, pp. 513-515.

[3] U. Guttich, J. –M. Dieudonne, A Klaasen, H. Sledzik, K. –E. Schmegner, U. Goebel, M. Bobeim, "A Low Noise Heterodyne 89 Ghz MMIC Module for the Multifrequency Imaging Microwave Radiometer (MMIR)," 1996 IEEE MTT-S International Microwave Symposium Digest, pp. 21-24.

[4] M. Sholley, R Alvarez, T. Leary, D. Renkowitz, S. Schell, L. Wendel, D. Cisneros, W. Brunner, B. Osgood, C. Gage, J. Alley, T. Cazares, P. Yocum, "W-band Collision Avoidance Radar for Light Rail Applications," 1996 IEEE MTT-S International Microwave Symposium Digest, pp. 321-324.

[5] Mohammed Abdo-Tuko, Ralf Bertenburg, "A Balanced Ka-Band GaAs FET MMIC Frequency Doubler," IEEE Trans. Microwave and Guided Wave Letters, vol. 4, July 1994, pp. 217-219.

[6] Long Tran, Michael Delaney, Russ Isobe, Derick Jang, Julia Brown, "Frequency Translation MMICs Using InP HEMT Technology, 1996 IEEE MTT-S International Microwave Symposium Digest, pp. 261-264.

[7] M. Cohn, R. G. Freitag, H. G. Henry, J. E. Degenford, and D. A. Blackwell, "A 94 Ghz MMIC Tripler Using Anti-Parallel Diode Arrays for Idler Separation," 1994 IEEE MTT-S International Microwave Symposium Digest, pp. 736-766.

[8] Ofira Von Stein, Jim Sherman, "Odd Order MESFET Multipliers with Broadband, Efficient, Low Spurious Response," 1996 IEEE MTT-S International Microwave Symposium Digest, pp.667-670.