Design of Broadband, Highly Integrated, 20-30 GHz and 35-45 GHz MMIC Up-converters

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***Abstract* — The design of broadband, highly integrated up-converters is described. Two up-converters have been designed to reduce the complexity and cost of broadband millimetre wave systems by integrating a number of functions into a compact MMIC. Broadband performance was achieved for 20-30 GHz and 35-45 GHz with OIP3 exceeding 24 and 15 dBm, respectively; 2xLO leakage better than 3 dBm and excellent gain control. To our knowledge, this is the highest level of integration achieved for an up-converter at these frequencies.**

I. Introduction

Broadband wireless systems at millimetre-wave frequencies find application in Point-to-Point, Point-to-Multipoint and VSAT systems. These systems support the growing need for higher data transmission rates in consumer and professional interactive media. The MMIC chipsets for these systems form a large part of the cost. This paper presents highly integrated up-converters which effectively combine up to five chips into a single MMIC, thus considerably lowering the module complexity, cost and manufacturing variability. The MMICs integrate a LO frequency doubler, $2 \times LO$ amplifier, balanced resistive FET mixer and variable-gain RF amplifier. The 35-45 GHz up-converter also provides image rejection. The high level of integration requires comprehensive system design to ensure that each sub-circuit has adequate performance. These up-converters, used in conjunction with companion integrated, single-chip receivers, e.g. [1], and power amplifiers, e.g. [2], form a cost-effective, three-chip front-end for millimetre-wave radios.

II. System and Circuit Design

The MMIC technology is based upon a standard 0.15-µm GaAs pHEMT process from WIN Semiconductor Corp. Simulations were made with AWR's Microwave Office harmonic balance and EM simulators. The design specifications for each sub-circuit were determined by the overall system requirement and the analysis of each sub-circuit's contribution to linear and non-linear performance.

Third-order-intercept point is an important system parameter for up-converters. Integrating a number of sub-circuits requires a careful analysis of the non-linear distortion contribution of each separate stage. The distortion contribution from each RF active element adds in a voltage sense and is referred to the transmitter's input to obtain the overall system distortion.

A. Mixer Design and Performance

The mixer is the critical element in integrated up-converters. It determines the level of LO leakage and is a major contributor to the system distortion level. The mixer designs are based upon a balanced, fundamental FET resistive mixer topology [3, 4] using Lange couplers to provide good LO-to-RF rejection. The Lange couplers were designed to have equal amplitude and 180 degree phase performance to provide optimum LO rejection.

The 20-30 GHz mixer is a simple realisation of this balanced topology.

The 35-45 GHz up-converter uses a more complex form which is both balanced and provides image rejection. This is achieved by combining two balanced mixers with a third Lange coupler at the RF input and a Wilkinson divider in the LO path. Fig. 1. shows the schematic of the balanced, image reject mixer.

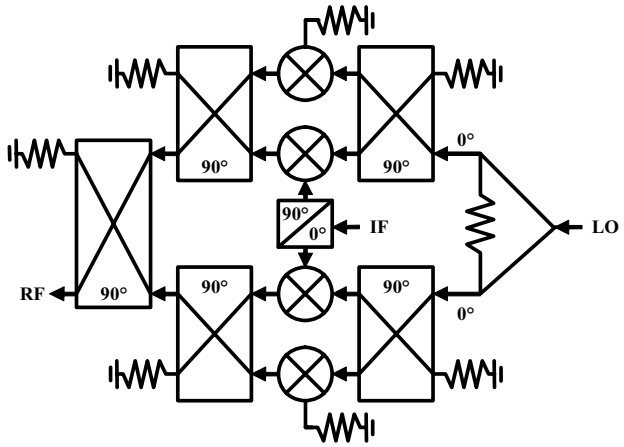

Fig. 1. Schematic of the balanced, image reject mixer

Fig. 2. shows the conversion gain and LO rejection performance of the 20-30 GHz mixer. The two nulls in LO leakage result from over-coupling the Lange couplers such that the amplitudes through the direct and coupled ports are matched at two LO frequency points, 23 and 37 GHz. This results in 35 dB LO-to-RF isolation and 8 dB conversion loss across the 20-38 GHz frequency range.

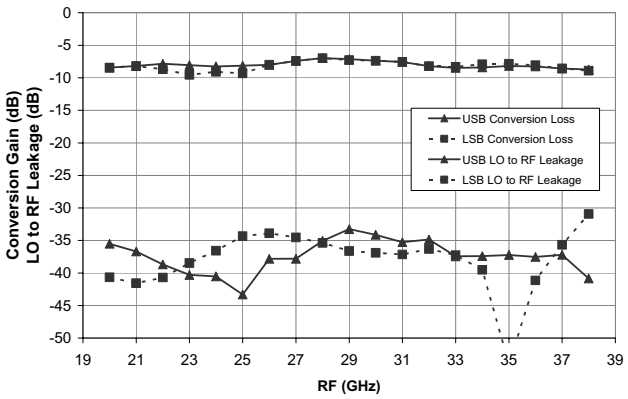

Fig. 2. 20-38 GHz Mixer up-conversion gain and LO-to-RF isolation

Fig. 3. shows the conversion gain and image rejection of the 35-45 GHz mixer. The mixer provides better than 20 dBc image rejection and 11 to 13 dB conversion loss. Fig. 4. shows the LO leakage of the 35-45 GHz mixer. The null in LO to RF leakage occurs at 41 GHz, the point at which the Lange couplers have equal direct and coupled path amplitudes. The mixer is well suited to the RF frequency band of 37 to 40 GHz for which the integrated up-converter was designed.

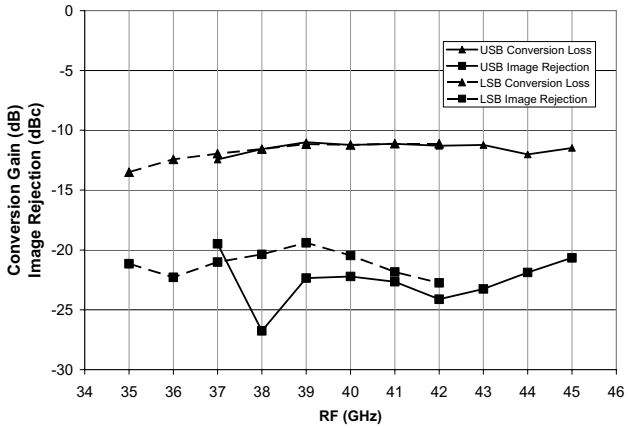

Fig. 3. 35-45 GHz mixer up-conversion gain and image rejection

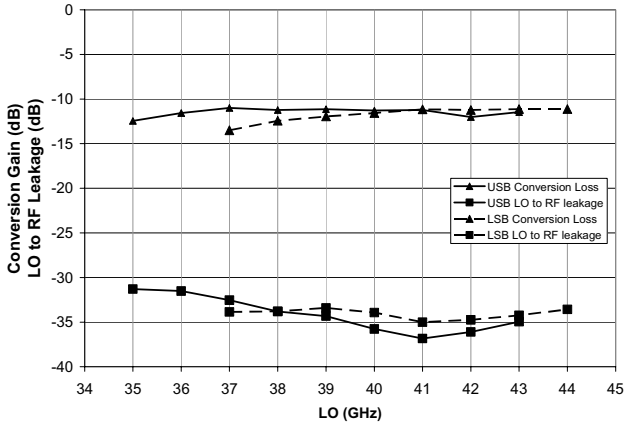

Fig. 4. 35-45 GHz mixer up-conversion gain and LO-to-RF isolation

B. 20-30 GHz up-converter

The 20-30 GHz up-converter was designed to provide a broadband integrated solution for transmitter applications. Fig. 5. displays the block diagram of the 20-30 GHz up-converter. It integrates five functions into a single chip with area of 6.4 mm^2 and is shown in Fig. 6.

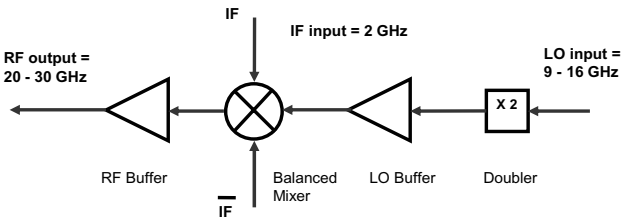

Fig. 5. Schematic of 20-30 GHz up-converter function blocks

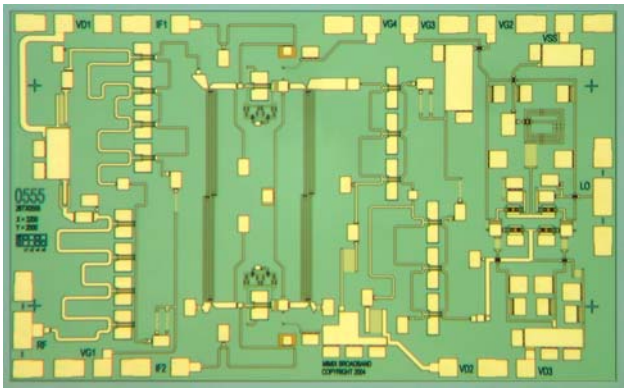

Fig. 6. Photograph of 20-30 GHz up-converter MMIC

The LO input is on the right side of the chip and feeds a broadband frequency doubler. This doubler has been designed using an active differential balun that drives a pair of common-drain pHEMTs which act as a rectifier with good fundamental suppression [5]. This on-chip doubler reduces the frequency of the required off-chip LO source to microwave frequencies which can be supplied by a single chip oscillator with pre-scalar, e.g. [6]

A distributed amplifier buffers the doubled LO signal and provides 15 dBm to the balanced resistive mixer.

The IF signal is fed through an external 180 degree hybrid into north and south ports of the balanced mixer. The RF signal feeds the variable-gain distributed amplifier which provides -6 to +19 dB gain and OIP3 = 27 dBm at maximum gain.

C. 35-45 GHz up-converter

The 35-45 GHz up-converter was designed to provide a broadband integrated solution for transmitter applications. Fig. 7. displays the block diagram of the 35-45 GHz up-converter. It integrates five functions into a single chip with area of 6.72 mm^2 and is shown in Fig. 8.

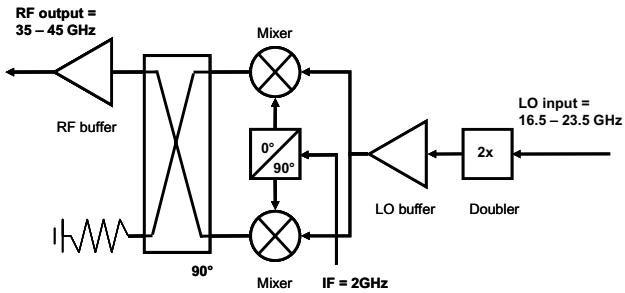

Fig 7. Schematic of 35-45 GHz up-converter functional blocks

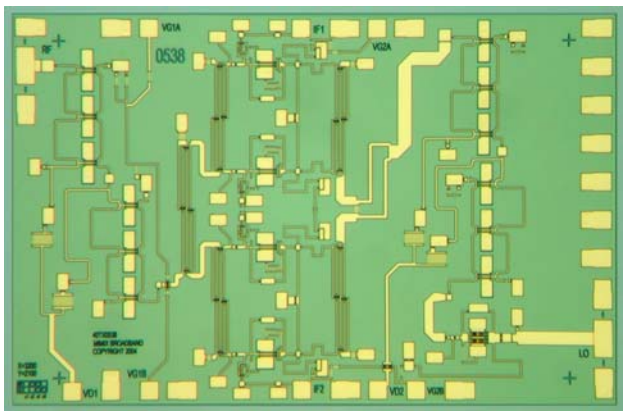

Fig 8. Photograph of 35-45 GHz up-converter MMIC

The LO input is on the right side of the chip. The extended 50-Ω line on the LO path is to accommodate the size of other circuits placed on the same engineering mask-set. It can be easily reduced, leading to a total chip size of 6.0 mm^2.

The LO is frequency doubled by a highly compact, passive frequency doubler [7]. A distributed amplifier buffers the 2 × LO signal and provides up to 15 dBm of LO power to two balanced mixers through a Wilkinson power divider.

The IF input power is fed through an external 90-degree hybrid into the north and south ports of the image-reject, balanced mixer.

The two balanced mixers combine the RF output through a Lange coupler which will allow the unwanted image signal to be rejected. The wanted sideband is amplified by a variable-gain distributed amplifier which provides -13 to +17 dB gain and OIP3 = 25 dBm at maximum gain.

III. Measured Performance

RF performance was measured on-wafer. Table I summarises the performance of both up-converters and Figs. 9. to 15. display measured results.

TABLE I – TYPICAL PERFORMANCE PARAMETERS.

Parameter	units	20-30 UC	35-45 UC
RF	GHz	20 - 30	37 - 40
LO	GHz	9 - 16	17.5 – 21
IF	GHz	2	2
LO input power	dBm	0	4
Conversion Gain	dB	9	2 - 5
Image Rejection	dBc	0	15
OIP3	dBm	24	15
IIP3	dBm	15	10
Gain Control Range	dB	20	30
2 × LO Leakage	dBm	0, < 3 max	< 0

A. Measured performance of 20-30 GHz up-converter

IF input power was fed into the north input with the south IF input terminated in 50 Ohms. A 3-dB improvement in conversion gain and intermodulation performance is obtained by feeding the IF input through a 180 degree hybrid into both inputs of the balanced mixer.

The conversion gain, which is about 8 dB, and a measure of the 2 × LO leakage are shown in Fig. 9. as a function of the LO frequency. The suppression of 2 × LO below the RF output level depends on the chosen IF level. The OIP3 is approximately 25 dBm and the IIP3 exceeds 15 dBm at maximum gain (Fig. 10.). This measurement was taken with a 0 dBm LO power level and IF signal carrier levels of -10 dBm/tone with video averaging used to lower the average noise floor of the spectrum analyser display. Fig. 11. shows that 25 dB of dynamic range is obtained by varying the gate bias of the up-converter's RF buffer amplifier.

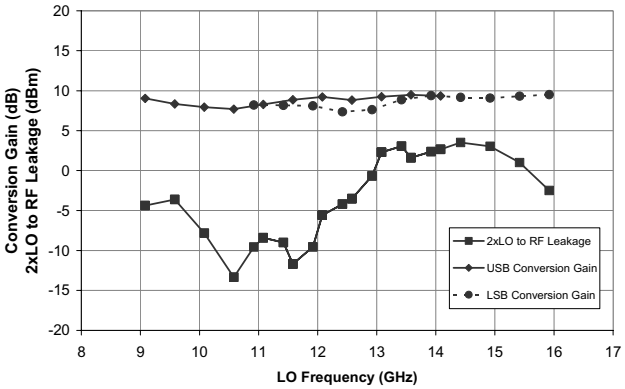

Fig. 9. 20-30 GHz up-converter upper and lower sideband conversion gain and 2 × LO-to-RF leakage

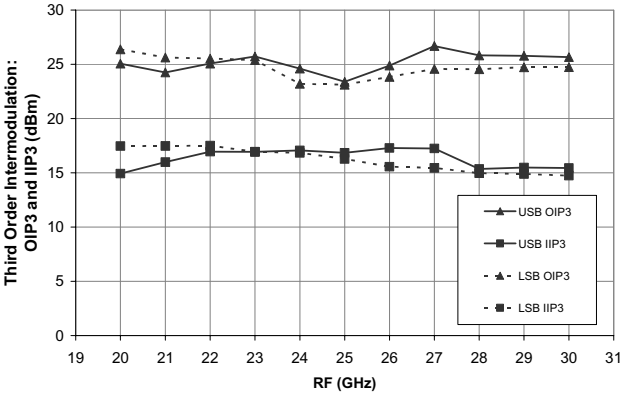

Fig. 10. 20-30 GHz up-converter OIP3 and IIP3 performance

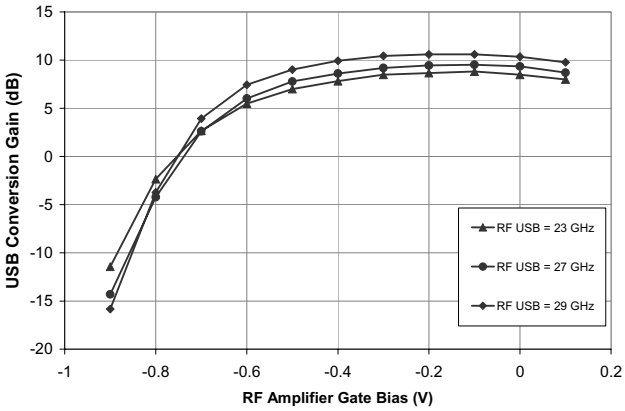

Fig. 11. 20-30 GHz up-converter upper sideband conversion gain as a function of the RF buffer amplifier bias

B. 35-45 GHz up-converter

RF performance was measured from 35 to 45 GHz in both USB and LSB modes. The IF input power was fed into both IF inputs using 3-dB, 90° hybrid.

The conversion gain is approximately 5 dB for both sidebands across the 37 to 40 GHz range and greater than 2 dB for USB from 35 to 45 GHz. The image rejection exceeds 15 dB for both sidebands across 35 to 45 GHz and 25 dB for USB over the 37 to 40 GHz range. Fig. 12. shows both conversion gain and image rejection data and Fig. 13. shows the 2 × LO leakage. For most 37 to 40 GHz applications the IIP3 exceeds 15 dBm. Over the full 35 to 45 GHz band, the up-converter USB OIP3 also exceeds 15 dBm. Fig. 14. shows the OIP3 and IIP3 performance for both sidebands at maximum gain. Fig. 15. shows that 30 dB of dynamic range is obtained by varying the gate bias of the up-converter's RF buffer amplifier.

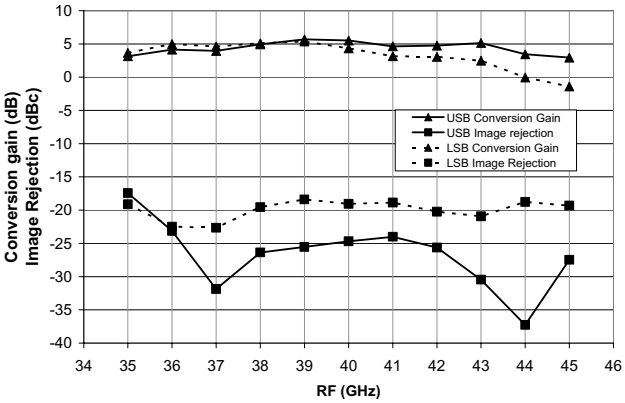

Fig. 12. 35-45 GHz up-conversion gain and image rejection

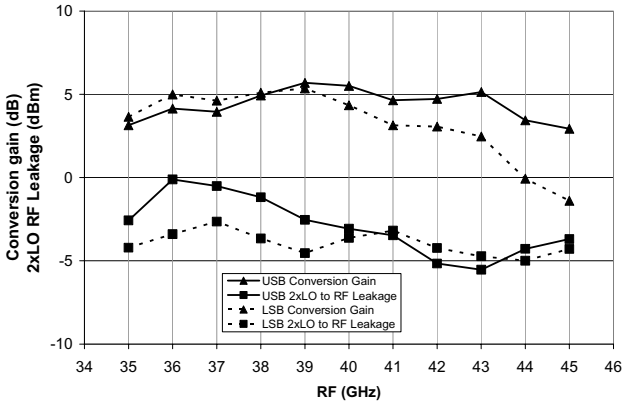

Fig. 13. 35-45 GHz up-conversion gain and 2 × LO-to-RF leakage

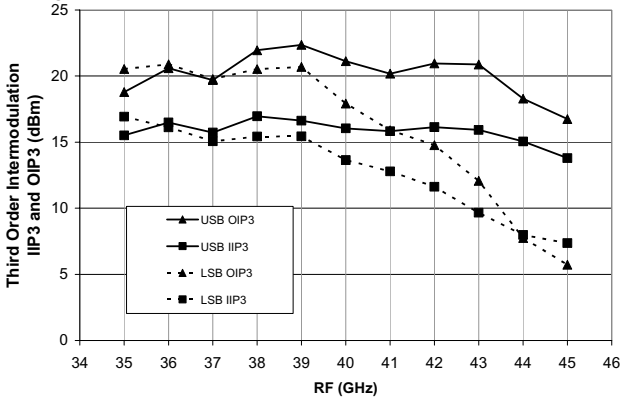

Fig. 14. 35-45 GHz up-converter OIP3 and IIP3 performance

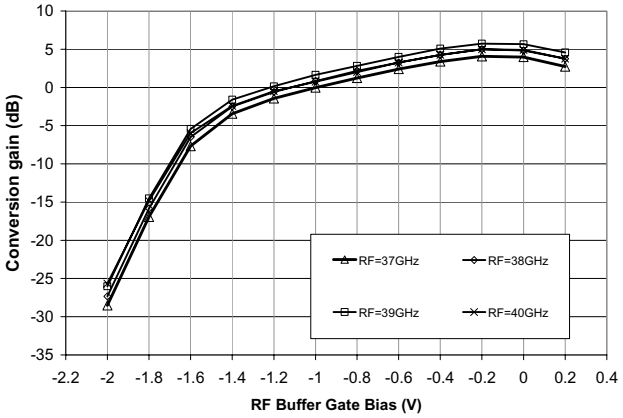

Fig. 15. 35-45 GHz up-converter - USB conversion gain as a function of the RF buffer amplifier bias

IV. Conclusion

This paper presents the design and measured performance of highly integrated up-converters which combine five functions into single MMICs – one for the 20-30 GHz band and one for the 35-45 GHz band. These MMICs display broadband performance with OIP3 exceeding 24 and 15 dBm, respectively, 2 × LO leakage better than 3 dBm and excellent gain control. The high level of integration results in simple, cost-effective solutions for broadband wireless systems.

Acknowledgement

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References

[1] XR1004 Product datasheet, Mimix Broadband Inc. Houston. 2005.

[2] A. Bessemoulin, S. Mahon, A. Dadello, G. McCulloch, and J. Harvey, "Compact and Broadband Microstrip Power Amplifier MMIC with 400-mW Output Power using 0.15-µm GaAs PHEMTs" to be published in GAAS® 2005, Paris 2005.

[3] K. Yhland, *Resistive FET Mixers*, Chalmers University of Technology, Sweden, 1999.

[4] S. Maas, *Microwave Mixers,* 2nd ed, Artech House, Inc., 1993.

[5] F. Raay, G. Kompa, "Design and Stability Test of a 2-40 GHz Frequency Doubler with Active Balun," *IEEE MTT-S Digest*, vol. 3, pp. 1573-1576, June 2000.

[6] 14OSC0501 Product datasheet, Mimix Broadband Inc. Houston. 2005.

[7] M. Jonsson, H. Zirath, K. Yhland, "A New FET Frequency Multiplier," *IEEE MTT-S Digest*, vol. 3, pp. 1427-1430, June 1998.