A Monolithic Double-balanced Upconverter for millimeter-wave Point-to-Multipoint Distribution Systems

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***Abstract* - The design and performance of a monolithic double-balanced upconverter for mm-wave point-to-multipoint distribution systems are presented. Individual building blocks including the LO / RF balun, IF balun, LO / RF power amplifier, and the double-balanced mixer are also fabricated and tested. The complete upconverter, measuring 3x3.2mm, upconverts the 3 - 5GHz IF to 40.5 - 43.5GHz band with 20 dBm output power.**

I. INTRODUCTION

Double-balanced mixers (DBMs) provide inherent port isolations, LO AM noise rejection, even-order mixing product suppression and high dynamic range. These desirable mixer properties are often exploited to realise high performance receivers with low intermodulation distortion [1-10]. These properties, however, are equally desirable in transmitter applications for upconverting signals with low spurious output. In this paper, the DBM is employed to develop a high power level upconverter for point-to-multipoint distribution systems.

II. CIRCUIT STRUCTURES

A. Double-Balanced Mixer

Fig. 1 shows the building blocks of a DBM. It consists of an arrangement of four mixing elements with LO, RF and IF baluns. Schottky diodes have been the primary device employed for the mixing elements [1-4]. Due to their highly non-linear characteristics, they inherently exhibit poor intermodulation and spurious response properties. Moreover, in the monolithic realm, they are usually implemented using some derivative of the MESFET structure. This often results in sub-optimum diodes with inferior mixer performance in comparison with mixers using discrete diodes.

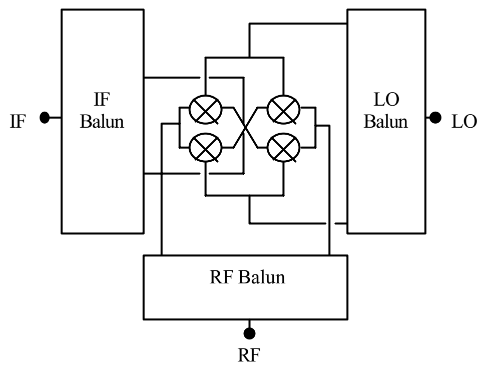

Fig. 1: Double-balanced mixer block diagram

Dual-gate FETs, which provide separate gates for the LO and RF have also been used to realise monolithic DBMs [10]. However, dual-gate FET mixer designs usually require accurate non-linear models, which are often highly complex and not readily available. They are also subject to instability problems.

Resistive FET mixers, which exhibit inherently low intermodulation properties have recently been employed in DBMs [5-9]. Other advantages of the resistive FET mixer include low DC power consumption and guaranteed stability. Monolithic resistive DBMs operating up to Ku-band have been reported [6, 8]. The mm-wave resistive DBM presented here employs 0.25 μm AlGaAs/InGaAs PHEMTs.

Besides the mixing elements, the other aspect of DBM design is the LO, RF and IF baluns. Many previous monolithic designs have employed active baluns for the LO and lumped element baluns for the low frequency IF. Although active baluns reduce the LO power requirements by offering gain, they are often sensitive to the operating conditions, require several DC bias connections and have poor noise and linearity performance. In the design presented here, an alternative approach using a passive LO balun in conjunction with an amplifier is employed.

B. Upconverter

Fig. 2 shows the block diagram and primary specifications of the upconverter. A single power amplifier is designed to cover both the LO and RF bands. Instead of lumped element components, the IF balun employs a dual spiral transformer. This results in a more robust and compact design with low component count.

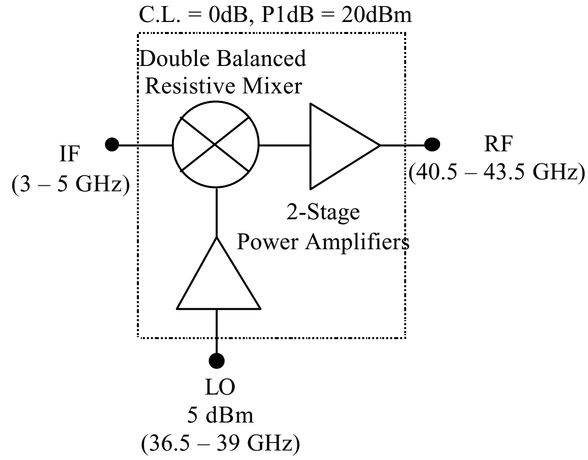

Fig. 2: Upconverter block diagram

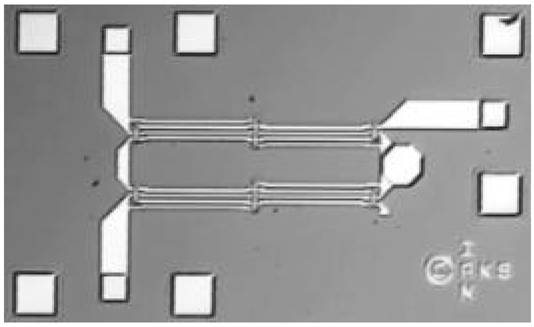

Fig. 3: LO / RF balun MMIC (0.8 x1.4 mm)

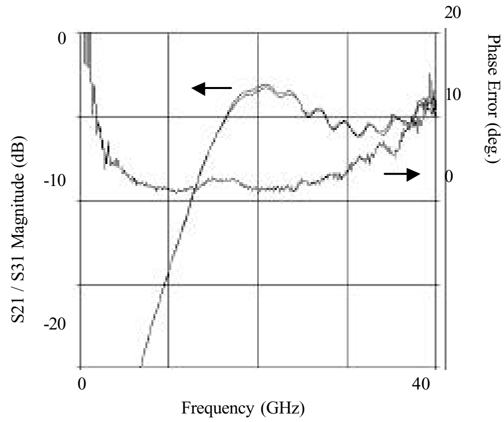

Fig. 4: LO / RF balun performance

Fig. 4 shows the performance of the LO / RF balun. Both the balun *S21* and *S31* exhibit an average value of 4.5 dB with a ripple of ± 1.5dB. Despite the ripples in the performance, the amplitude and phase imbalances between the two outputs are less than 0.5dB and 10° over the 20 to 40GHz range.

III. MMIC REALISATIONS AND PERFORMANCES

The development of the upconverter adopts a modular approach in which individual building blocks are fabricated and tested to ensure first-pass success. The fabricated circuits include the LO / RF balun, IF balun, DBM, LO / RF power amplifier, and the complete upconverter. The MMICs are fabricated by Marconi Caswell Ltd. using the standard H40 foundry process which employs 0.25µm gate length AlGaAs/InGaAs PHEMTs on a 100µm thick GaAs substrate.

A. LO / RF Balun

The LO / RF balun is realised by combining two interdigital Lange couplers, as shown in Fig. 3. To realise the tight coupling for broadband operation and matched odd- and even- mode phase velocities, narrow line widths and gaps are required. However, compromises have to be made to stay within the foundry process limitations for reasonable yield. The widths and gaps of the interdigital fingers are designed to be 9µm and 6µm respectively. The lengths of the couplers are 700µm for operation centered at 38 GHz.

B. IF Balun

For the lower frequency IF balun, a pair of spiral transformers is used in placed of the interdigital couplers. Fig. 5 shows a photograph of the fabricated MMIC which consists of two oppositely wound twin-coil transformers connected in series. The input coil is terminated with an open-circuit while the output coils are terminated in a short-circuit. Each twin-coil transformer operates as a quadrature coupler with a center frequency roughly corresponding to an unwound length of a quarter wavelength. In the present design, the operating bandwidth is designed to be between 3 to 5 GHz. The spiral transformers have 4.5 turns with track width and gap of 12µm and 8µm, respectively. These dimensions are well within the fabrication limits of the foundry.

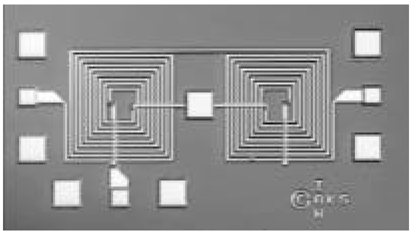

Fig. 5: IF balun MMIC (0.7 x1.5 mm)

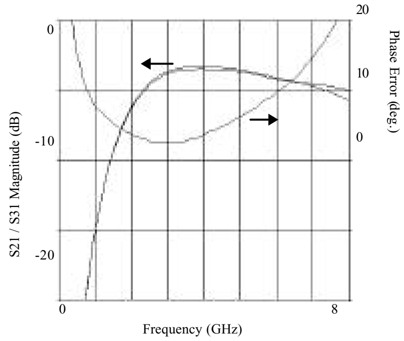

Fig. 6 IF balun performance

As shown in Fig. 6, the *S21* and *S31* of the IF balun tracks each other closely up to 6GHz. The insertion loss at the centre frequency is less than 0.5dB at mid-band. The amplitude and phase imbalances are respectively within 0.2dB and 10° from 2 to 6 GHz.

C. Double-balanced Mixer

Fig. 7 shows the photograph of the resistive DBM, consisting of four PHEMTs, LO/RF and IF baluns. Reverse gate bias for the PHEMTs are applied to the LO balun through a mesa resistor. Particular attention was devoted to the layout of the circuit in order to maintain symmetry and to minimise transmission line crossings in the circuit; these introduce parasitics and may degrade the performance of the mixer. Most of the cross-overs and discontinuities were placed in the IF path as the IF is low enough that these are acceptable.

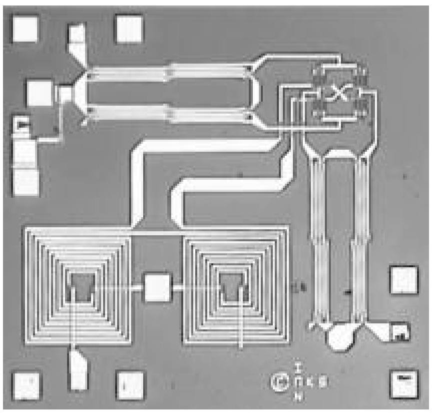

Fig. 7: Double-balanced mixer MMIC (1.6 x 1.7mm)

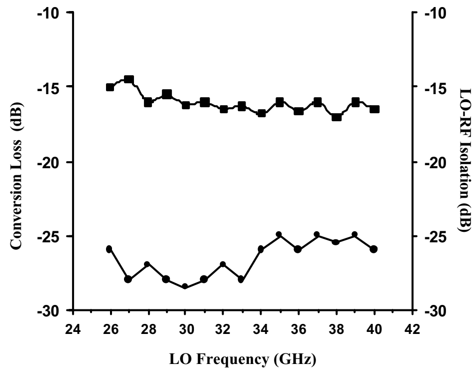

Fig. 8 Double-balanced resistive mixer performance

Having verified the operating frequency ranges and performances of the LO / RF and IF baluns, the upconverter performance of the double-balanced mixer was measured. A fixed IF of 4 GHz at 0dBm was applied to the mixer, while the LO was swept from 26 to 40 GHz. Across the frequency band, a conversion loss of 16 ± 1 dB was obtained with over 25 dB of LO-RF isolation, as shown in Fig. 8. The high conversion loss was due to the insufficient LO power level applied, which was 10dBm. Unfortunately, this was the maximum LO power available for the measurement. With 10dBm LO power, an input IP3 of 18dBm was obtained from two-tone intermodulation measurements with 0 dBm IF power.

D. LO / RF Power Amplifier

Fig. 9 shows a photograph of the LO/RF power amplifier. It is a two-stage power amplifier employing three 4x60 PHEMTs. The output matching network transforms the 50 Ω load to the optimal load impedances of the output stage. The interstage and input matching networks provide an overall flat gain response with good input return loss over the required bandwidth. These design objectives were achieved in the fabricated MMIC, as shown in the measured results of Figs. 10 and 11.

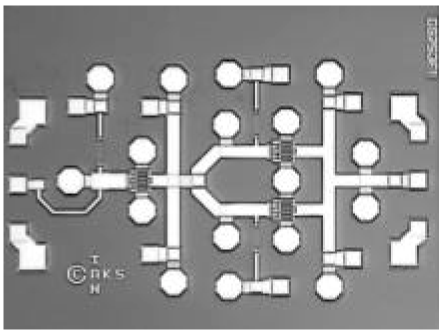

Fig. 9: LO/RF power amplifier MMIC (1 x1.7 mm)

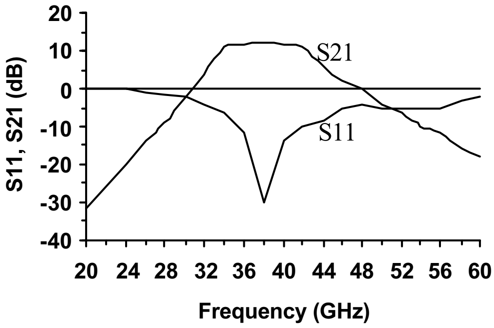

Fig. 10 LO/RF power amplifier small-signal performance

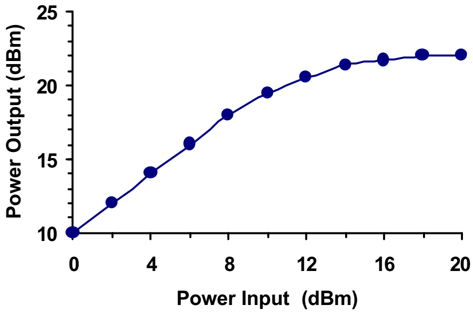

Fig. 11: LO/RF power amplifier output power

performance

Fig. 10 shows a flat gain response of 10dB from 33.5 to 43.5 GHz with better than 10dB input return loss. The output P1dB obtained from Fig. 11 is better than 20dBm.

E. Complete Upconverter

By incorporating all the building blocks together on a single MMIC, the complete upconverter shown in Fig. 12, measuring 3x3.2 mm, is realised. With the addition of the LO and RF power amplifiers, the upconverter achieved 0dB conversion loss with 5dBm LO input power.

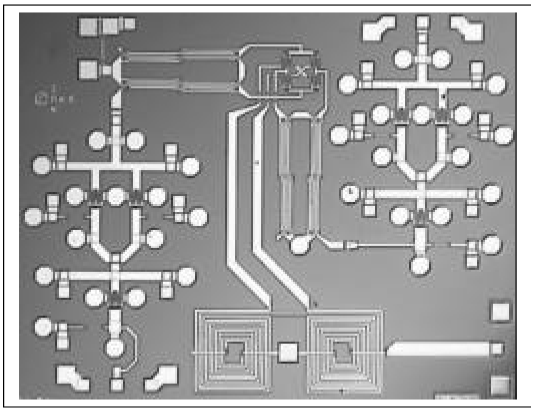

Fig. 12: Complete upconverter MMIC (3 x 3.2 mm)

IV. CONCLUSIONS

A millimeter-wave double-balanced upconverter has been developed. Resistive PHEMTs, which exhibit low intermodulation are employed as the mixing elements. The LO/RF and IF baluns utilise compact passive coupling structures with good amplitude and phase balance, which are critical to the mixer performance. Power amplifiers are included for the LO and RF ports to achieve low input LO input drive and high output power requirements. The performances of the various building blocks have been individually verified to ensure the successful application of the upconverter for millimeter-wave point-to-multi-point distribution systems.

V. REFERENCES

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