Development of 30 and 20 GHz MMIC mixers for miniaturized personal communications systems

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Abstract

Several MMIC downconverters have been developed for use in experimental 30/20 GHz Satellite Personal Communications Terminals. The non-linear PHEMT and diode models are described and the design and performance of the downconverters are discussed. The design and performance a 30 GHz single-balanced PHEMT diode upconverter is also reported. The 20/4 GHz downconverter has a conversion loss of 1.5 dB at 20 GHz while the 30/4 GHz version was found to have 3.0 dB loss at 30 GHz. Both mixers showed spurious suppression better than 40 dB and required 3.5 dBm of LO power. The DC-50 MHz/30 GHz single balanced PHEMT diode upconverter, using a miniature distributed 180° hybrid, was found to have 10 dB conversion loss between 10 and 50 MHz. The RF-LO isolation was 22 dB.

Introduction

Personal communications systems operating in the 30/20 GHz frequency range are currently being studied at the Communications Research Centre and will require small, low cost, RF components capable of being manufactured in large quantities. Technologies such as MMICs offer potential solutions to large volume requirements and this paper addresses the non-linear modelling, design and performance of 20/4 GHz and 30/4 GHz MMIC downconverters and a baseband/30 GHz MMIC upconverter for use in such communications systems. The DC-50 MHz/30 GHz upconverter uses diodes and a miniature distributed 180° hybrid in a single-balanced circuit topology and was developed specifically for use in the transmit section of a prototype satellite personal communications terminal.

Non -linear models

A. *PHEMT model*

A 150 x 0.25 μm pi-type PHEMT was characterized on an RF waferprober by collecting small signal S-parameter and DC data at multiple bias points. The parameters for a non-linear Materka model [1] were then extracted from the 20 S-parameter and I-V data sets, over the 0.5 to 30 GHz range, using a commercial non-linear parameter extractor, HarPE™. The S-parameters and DC data were simultaneously fitted to the model.

An in-house software program, implementing the Fukui DC FET parameter extraction technique [2], was used to measure and compute Rs, Rg, Rd, Is, N, and V_{to}, in order to facilitate the fitting of the DC I-V data to the model. These DC parameters were used as starting values for the optimizer. The modified Materka model, as used in Microwave Harmonica™, is shown in Fig. 1 together with the extracted parameters in Table 1.

B. *PHEMT diode model*

Schottky diodes are frequently not offered by MMIC foundries for RF applications because of their relatively low cut-off frequency characteristics. However, our requirement demanded development of a MMIC diode upconverter and, in order to assess the RF performance of such devices, we constructed several diodes from PHEMT layouts by connecting their drain and source terminals together and measured their DC and RF characteristics. Based on the results, a single finger, 0.1 x 40 μm, diode was selected for our application and a non-linear model was extracted from the wafer probed, small signal S-parameters (0.5 - 30Ghz) and DC I-V data at several bias points.

The series resistance, R_S, ideality factor, N, and reverse saturation current, I_S, were obtained from the DC data and a parameter extractor was used to find the remaining parameters, C_j, V_j and M, using both the DC and RF data. The ideality factor and series resistance are larger than usually encountered in GaAs diodes because of the heterostructure nature of the device and the material characteristics [3].

The cutoff frequency of the 40 μm diode is estimated to be 130 GHz based on the R_S and C_j of the model at zero bias. Figure 2 shows the model parameters for the diode.

Design

C. *20/4 GHz downconverter*

The topology of the PHEMT downconverter is that of a single-gate FET, transconductance mixer, where the LO is applied to the gate along with the RF signal via an external diplexer. The IF signal is extracted from the drain terminal through a lowpass filter. The circuit layout of the MMIC is shown in Fig. 3.

The RF impedance at the gate and IF impedance at the drain terminal were computed using Microwave Harmonica with the Materka model described above. The bias conditions were chosen to obtain maximum non-linearity of g_m near gate pinch-off i.e. $V_g = -0.37$ V. The drain bias was 3 V, sufficient to operate the device in the current saturation region.

Distributed element matching was used to conjugately match the gate of the device at the RF frequency while also providing a short circuit termination at the IF. This latter requirement prevents the amplification of any IF noise by the pre-amplifier and downconversion of noise of the mixing frequencies. The IF short circuit condition at the gate was achieved by the combination of the gate matching circuit and the gate bias circuit.

A short circuit condition at the RF and LO frequencies, 20 GHz and 16 GHz respectively, was also established at the drain of the PHEMT by the combined effect of the output lowpass filter and drain bias circuit. This short circuit termination, presented ideally at all undesired frequencies except the IF, is necessary to ensure good stability, optimum gain and low noise figure [4]. The drain circuit was designed to provide this condition at the LO and RF as a minimum requirement.

A lumped element lowpass filter was used at the output not only to provide the short circuit condition at the drain terminal, at the RF and LO frequencies, but also to allow transmission of the IF (4 GHz). No IF matching was provided by the filter because of the large drain impedance of the PHEMT at 4 GHz, and the conversion loss was therefore not the optimum value achievable. The lowpass filter section consists of a conventional shunt C, series L, shunt C network and utilizes small MIM capacitors, with via holes connecting their bottom plates to ground, and a series inductor implemented with a 20 μm wide transmission line.

D. *30/4 GHz downconverter*

The topology of this mixer, shown in Fig. 4, is identical to the 20/4 GHz version, and was designed by using the same PHEMT model for the 150 x 0.25 μm device. The gate matching circuit uses distributed elements as before. The lowpass filter at the drain terminal is implemented with a 1 nH spiral inductor instead of a transmission line. The short circuit termination at the drain, for the LO and RF, and at the gate for the IF frequency are provided in the same way as the 20 GHz downconverter.

E. *Single Balanced Diode Upconverter*

The single-balanced diode mixer is shown in Fig. 5 and consists of a novel miniature 180° hybrid coupler design using distributed lines in such a manner as to minimize GaAs area and parasitic mutual coupling of the EM fields. The coupler was optimized with the aid of an electromagnetic simulator and the resulting S-parameters were used in the final circuit simulation. At the time of the upconverter design, the Schottky diode models based on measurements, as described above, had not been developed. Preliminary models were therefore constructed from the established non-linear PHEMT models by connecting their drain and source terminals together. The design was based on this preliminary diode model. This approach was found to be satisfactory as seen in the comparison of the experimental response with the later derived simulation which used the non-linear model described above (Fig. 6). The upconverter was required to operate over the frequency range DC-50 MHz and the IF input is therefore DC-coupled. The mixer is self-biased with 13 dBm LO power applied.

Performance

The measured conversion loss for the 20/4 GHz chip is shown in Fig. 7 and agrees well with the simulated results over the 19.5 - 21.5 GHz range; the loss at 20 GHz was 1.8 dB.

Conversion loss of the 30/4 GHz downconverter is shown in Fig. 8. At 30 GHz, the loss was 3 dB for an input RF signal of -15 dBm and 3.5 dBm LO drive power. The overall trend in conversion loss response agrees with the non-linear simulation, although a ripple of ±0.5 dB is present due, it is thought, to measurement difficulties.

Both downconverter chips had LO and spurious signal levels below -35 dBm at the IF output terminals. The LO-RF isolation of 25 dB was determined by the external diplexer.

Conversion loss of the diode upconverter, using a 50 MHz IF input signal and 13 dBm LO at 29.15 GHz, was 10 dBm. The LO-RF isolation was 22 dB.

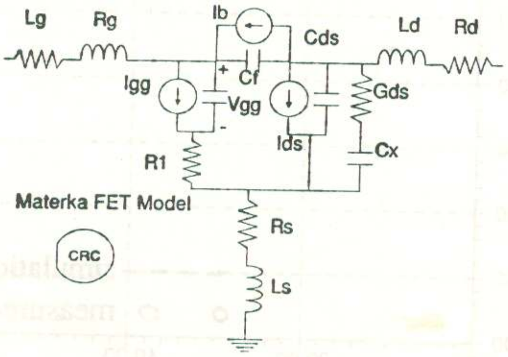

Fig. 1: Materka non-linear model

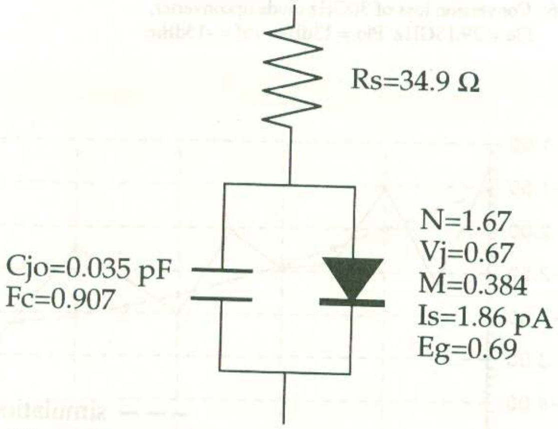

Fig. 2: Non-linear PHEMT diode model, 40um x 0.25um

Conclusion

Non-linear PHEMT models have been developed and successfully used in the design of 20/4 GHz and 30/4 GHz MMIC downconverters. A baseband to 30 GHz diode upconverter was also developed in conjunction with a diode non-linear model.

Acknowledgement

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References

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[2] H. Fukui, "Determination of the Basic Device Parameters of a GaAs MESFET", BSTJ, vol. 58, No.3, pp 771-797, 1979.

[3] Y. Kwon, D. Pavlidis, P. March, G.I. Ng and T. Boch, "A Planar Heterostructure Diode W-Band Mixer Using Monolithic Balanced Integrated Approach on InP", 1992 GaAs IC Symposium, pp 67-70.

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Table 1: Materka model parameters for COMSAT PHEMT, 150um x 0.25um, 2 gate fingers, Pi type

PARASITIC ELEMENTS

Lg	22E-12
Ld	0
Ls	3.1E-12
Rg	0.67
Rd	0.48
Rs	0.0068
Rds	522
Cx	3.3E-12
Cds	35.35E-15

NON-LINEAR PARAMETERS

IDSS	1.72177E-2
VP0	-0.4926
GAMA	2.56125E-8
E	1.55383
KE	0.4121
SL	0.030581
KG	-6.49465E-8
T	1.32525E-12
SS	0.000275
IG0	5.7874E-4
AFAG	0.355
IB0	1.535E-3
AFAB	0.005474
VBC	4.7
R10	9.698
KR	0.2552
C10	1.7766E-13
K1	0.8101
C1S	4.358E-19
CF0	1.357E-13
KF	11.41

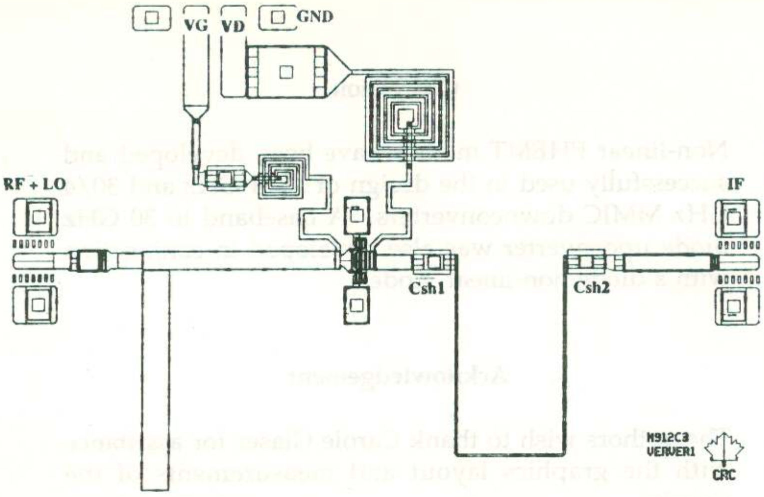

Fig. 3: 20GHz PHEMT downconverter,
Chip dimensions : 3.0 x 1.6 mm

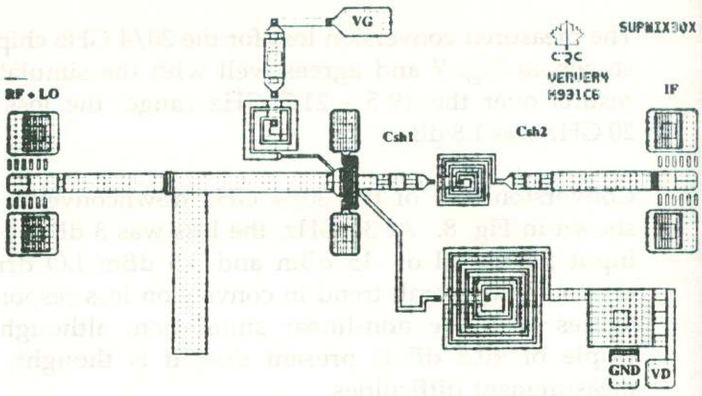

Fig. 4: 30GHz PHEMT downconverter
Chip dimensions : 2.5 x 1.4 mm

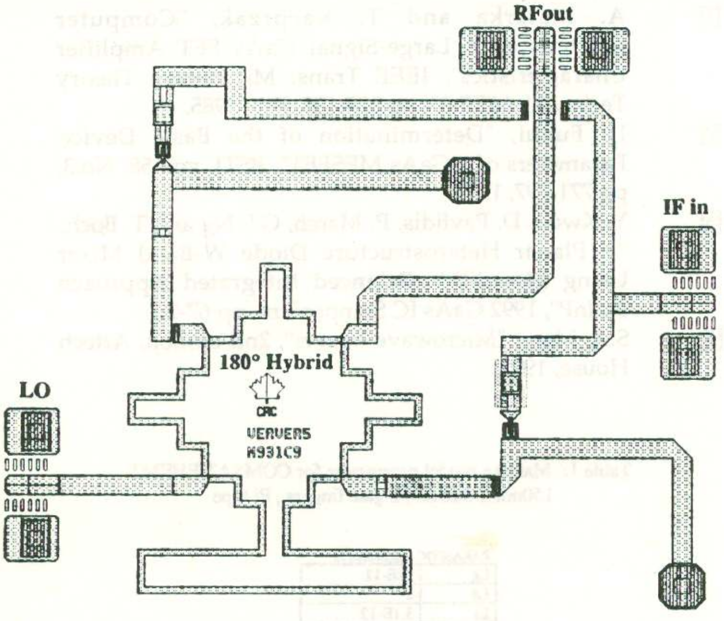

Fig. 5: Baseband / 30GHz single-balanced diode upconverter
Chip dimensions : 2.4 x 2.0 mm

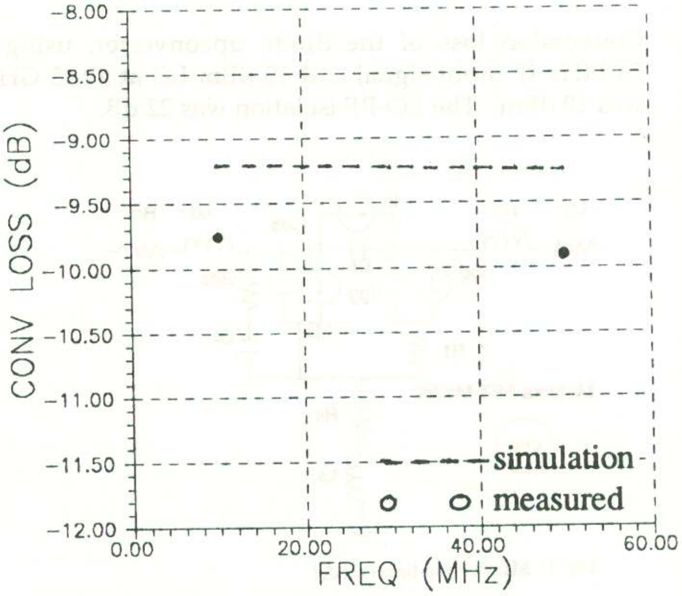

Fig. 6: Conversion loss of 30GHz diode upconverter,
Flo = 29.15GHz Plo = 13dBm Prf = -15dBm

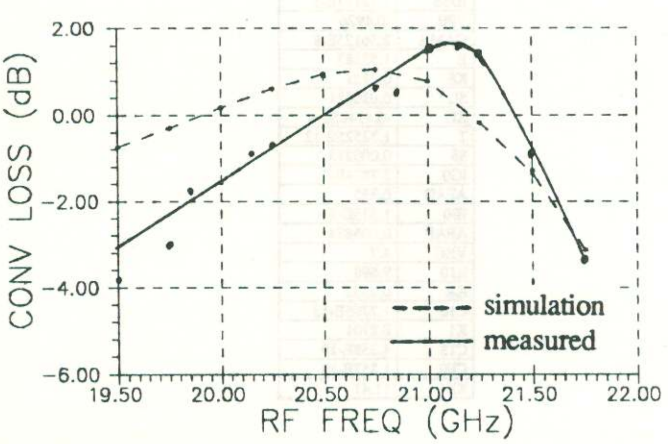

Fig. 7: Conversion loss vs RF frequency for 20Ghz mixer,
Flo = 16GHz Plo = 3.5 dBm Prf = -15dBm Vd = 3V Vg = -0.37V

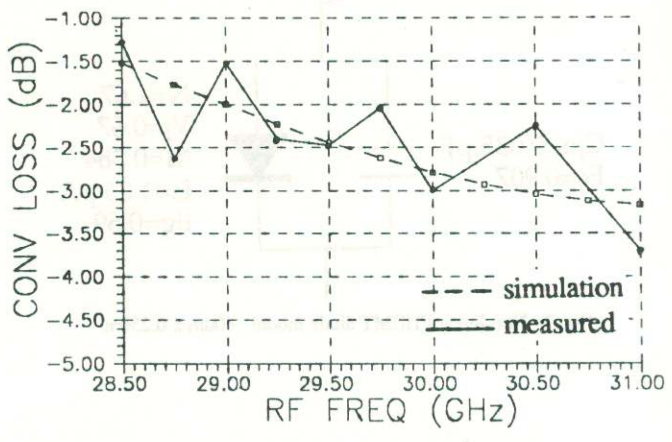

Fig. 8: Conversion loss vs RF frequency for 30GHz mixer,
Flo = 26GHz Plo = 3.5dBm Prf = -15dBm Vd = 3V Vg = -0.65V