K- AND KU BAND MMICs FOR RADIO LINK COMMUNICATIONS

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Abstract

A set of MMICs at Ku and K band including a LNA, an I/Q Demodulator and a VCO to be integrated into a radio link receiver has been designed, fabricated and tested. Along with the evolution of digital communication, a fully integrated direct I/Q demodulator is presented. Experimental results verify the good operation of the device showing less than 10.7dB SSB conversion loss, +18dBm IMP3 at the RF terminal and a P1dB higher than +9dBm throughout the operating bandwidth.

Introduction

There is a fast growing demand for small size radio links working in the higher GHz range. These include mobile radio link stations for TV transmission and low capacity urban links. To find a widespread acceptance today, these products must be cheap and have low volume and small size characteristics. These requirements incite for a higher level of integration. Especially the microwave section, which has long been the domain of discrete circuitry, needs to be scaled down to a monolithic level, providing a natural playground for GaAs MMICs.

This paper presents the design and the performances of a 3 stage Low Noise Amplifier, a Voltage Controlled Oscillator and an I/Q Demodulator. These functions have been designed in both Ku and K civil allocated radio bands, i.e. 12.7 -15.5 GHz and 17.7 - 23.7 GHz. Because of the low noise figure and the high gain performance required for these functions, the 0.25μm HEMT process of HUGHES was chosen. The demodulator and VCO designs forced the development of a non linear HEMT model directly implementable into the EESof Libra simulator [1]. The measurement results obtained show a good agreement with the simulated designs. All MMICs can be operated with a 3V biasing supply leading to a total consumption of 450 mW for each front end.

LNA chip

Both Low Noise Amplifiers designs rely on a 200μm T-gate HEMT whose model has been extracted from on-wafer measurements up to 26 GHz. At 26 GHz, the associated gain of the transistor is 11 dB while its minimum noise figure F_{min} is 1.8dB. All matching networks are realized with distributed elements, that is high or low impedance transmission lines and open stubs. MIM capacitors, more sensitive to process variations, are only used for DC-blocking and bias filtering. To guarantee the unconditionnal stability of the HEMTs, the transistors of the first stages are fed-back with a series high impedance transmission line at their sources. Moreover this technique tends to improve the input return losses for a minimal noise figure degradation. The third stages are RC fed-back which, adding to overall stability, insures the gain flatness. The chip layout of the two LNAs appear on Fig. 1 and 2.

The K-band LNA exhibits a noise figure of 3.5 dB and a gain of 17 dB in the defined frequency range as shown on Fig. 3. For the Ku-band LNA, we obtain a noise figure of 3 dB with a gain of 20 dB. Both amplifiers draw a current of 120 mA.

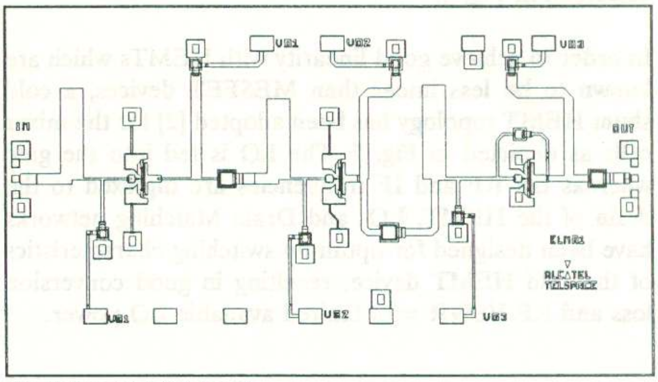

Fig. 1: K-band LNA layout

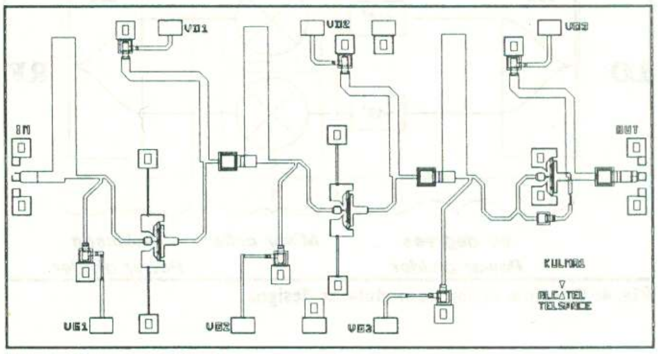

Fig. 2: Ku-band LNA layout

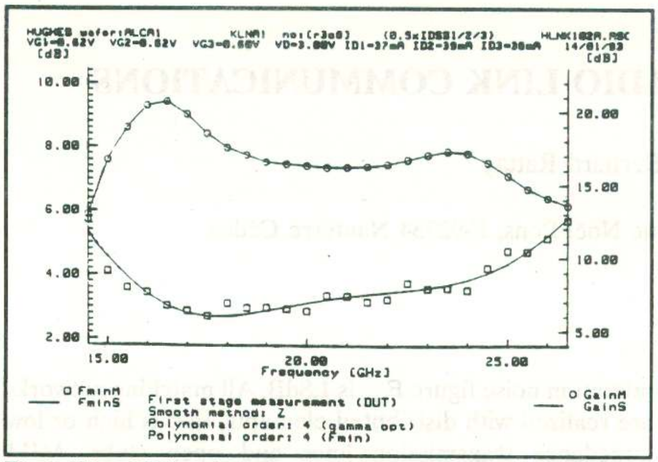

Fig. 3: K-band LNA gain and noise figure

I/Q Demodulator chip

Both Ku (12.7 - 15.5GHz) and K-band (17.7 - 23.7GHz) demodulators have been designed for general use as direct I/Q demodulator or modulator, image rejection downconverter (with external coupler) or upconverter. IF-frequency range is DC-2GHz. The LO is applied through two phase-shifters to a pair of mixer cells which then generate two IF outputs (I & Q) in quadrature. The quadrature can be precisely adjusted at a particular LO frequency by an additional HEMT device mounted as a varactor in one of the phase-shifters. The principle is described in Fig. 4.

In order to achieve good linearity with HEMTs which are known to be less linear than MESFET devices, a cold shunt HEMT topology has been adopted [2] for the mixer cells as depicted in Fig. 5. The LO is fed into the gate whereas the RF and IF frequencies are diplexed to the drain of the HEMT. LO- and Drain Matching networks have been designed for optimum switching characteristics of the cold HEMT device, resulting in good conversion loss and RF VSWR with limited available LO power.

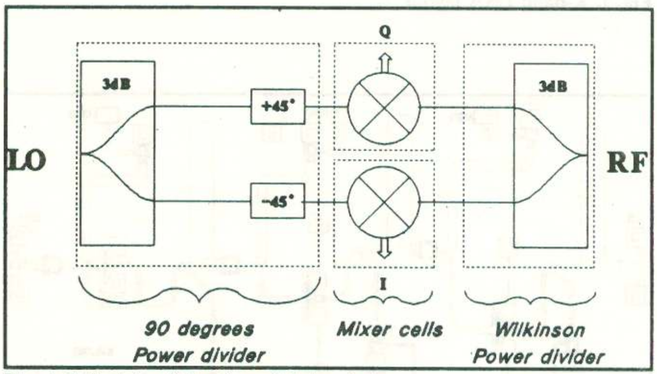

Fig. 4: Principle of the demodulator designs

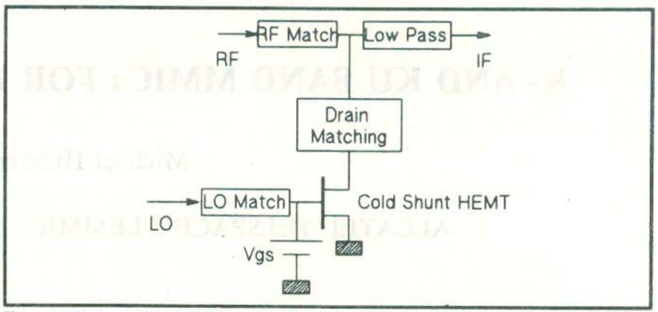

Fig. 5: Cold shunt HEMT topology chosen for the mixer cell

DC power consumption of the whole chip is close to zero since no buffer amplifiers are needed because of good LO and RF return losses. Two negative voltages are required: one fixed for gate bias and one to adjust the 90 degrees between I and Q (variable phase shifter).

Using a completely non-linear approach and the EESof-Libra Harmonic Balance simulator, good agreement has been obtained for conversion loss, LO and RF VSWR, P_{1dB} and third order intermodulation. On-wafer measurements have been made on the total demodulator function in Ku-band and on one mixer cell composing the K-band chip. All demodulators were driven with the predicted LO-power of +14.5dBm, simplifying correlation between measurement and initial simulations. For an IF-frequency of 50MHz, a conversion loss of 6.2-6.9dB has been reached for the mixing cells in K- and Ku-band (6.2-6.7dB simulated). The Ku-band demodulator presents less than 10.7dB conversion loss (1dB higher than the conventional 3dB increase for considering each output I and Q separately). In case of an image rejection downconverter, both I & Q outputs are recombined by an external coupler, thus improving by 3dB the reported conversion losses.

All measurements were done on a point-by-point basis and on-wafer. The frequency-axis of the following figures represents the LO frequency. The corresponding RF lies 50MHz above the LO.

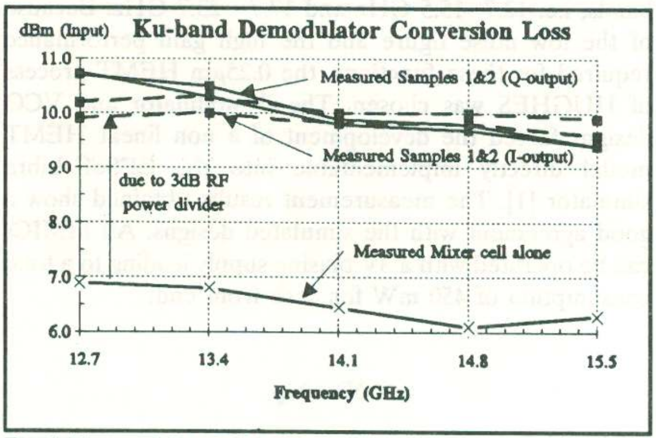

Fig. 6: Measured Conversion Loss

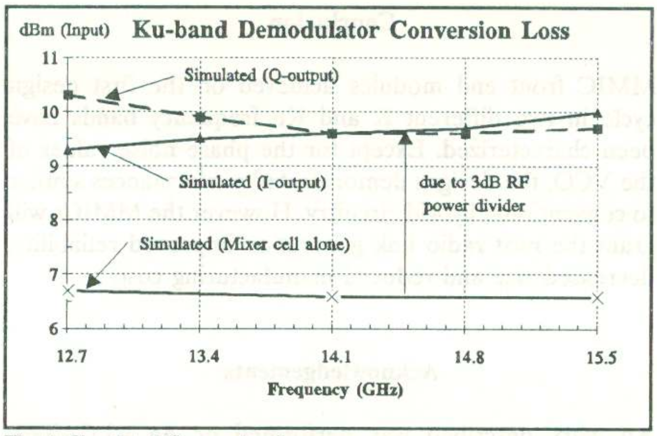

Fig. 7: Simulated Conversion Loss

The 1dB compression point at the RF-input is 6.5-8.0dBm for the K-band mixing cell (simulations indicated 4.0-8.0dBm). The complete Ku-band demodulator exhibits a P_{1dB} between 8.8 and 11.8dBm (8-11dBm simulated). The modified Tajima model described earlier [1] proves to give a good indication of a mixer's gain compression, however no accurate result could be obtained: measured values are 0.5 to 3dB higher than simulated as depicted on Fig. 8.

Concerning intermodulation our model predicted an input third order intercept point in the range of +15.5 to +17dBm for the Ku-band demodulator which is 2 to 3dB pessimistic compared to the measurements presented on Fig. 9.

Both Ku- and K-band mixer cells show return losses better than 10dB on the LO- and RF-ports. The isolation between the LO and the RF is better than 17dB on the Ku-band demodulator.

Fig. 10 and 11 show the layouts of the complete Ku- and K-band demodulator designs.

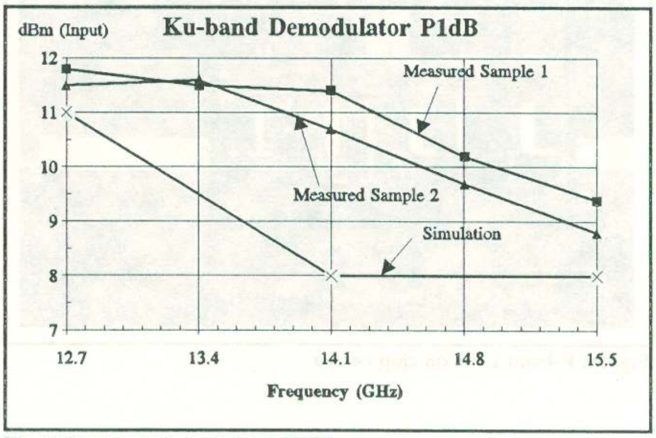

Fig. 8: Ku-band Demodulator P1dB

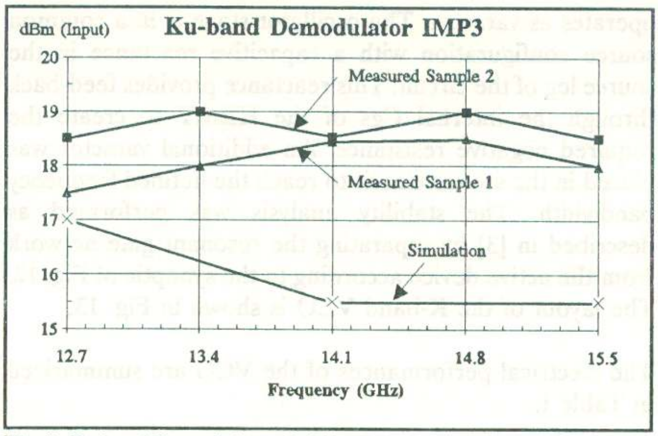

Fig. 9: Ku-band Demodulator IMP3

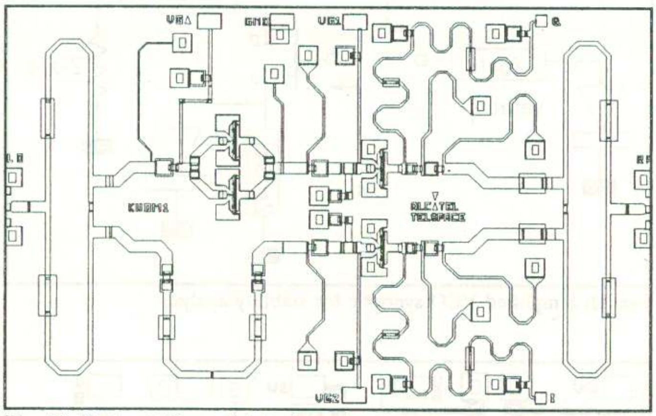

Fig. 10: Ku-band Demodulator layout

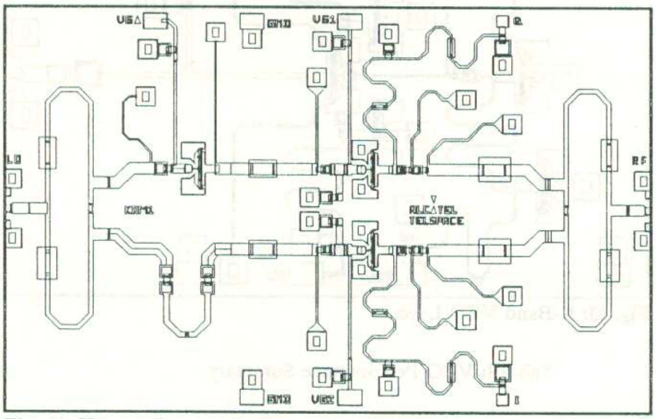

Fig. 11: K-band Demodulator layout

VCO chip

Conventional MMIC VCO designs are usually realised with an off-chip varactor diode which is connected to the negative resistance terminal of the MMIC. This design makes use of the HEMTs gate-to-source junction which operates as varactor. The oscillator stage is in a common source configuration with a capacitive reactance in the source leg of the circuit. This reactance provides feed-back through the internal Cgs of the HEMT to create the required negative resistance. An additional varactor was placed in the source circuit to reach the defined frequency bandwidth. The stability analysis was performed as described in [3] by separating the resonant gate network from the active device according to the synoptic of Fig. 12. The layout of the K-band VCO is shown in Fig. 13.

The electrical performances of the VCO are summarized in Table I.

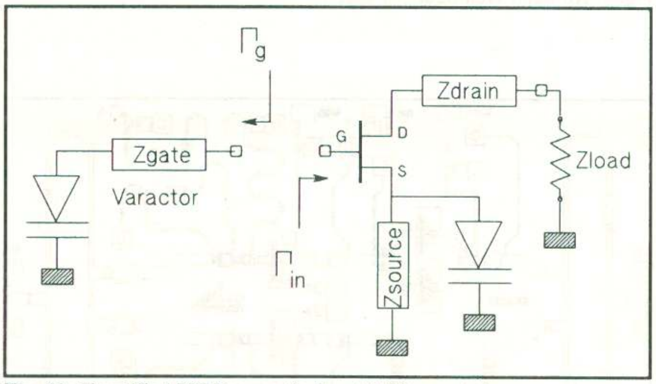

Fig. 12: Simplified VCO synoptic for stability analysis

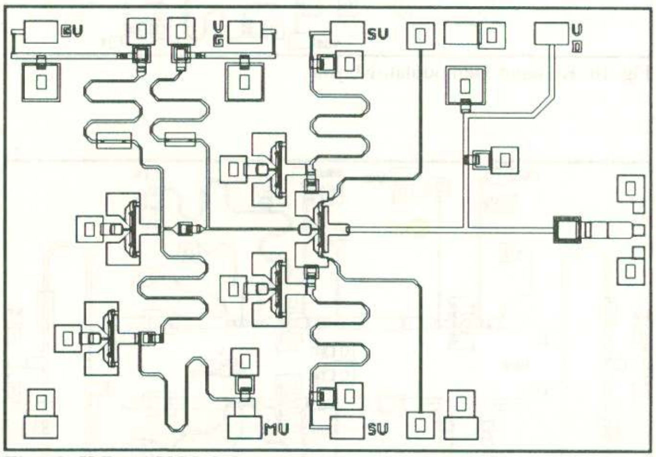

Fig. 13: K-Band VCO Layout

Table I: VCO Performance Summary

Parameter	
Frequency	17 GHz
Output	7 dBm (no buffer stage)
Phase Noise	-80 dBc/Hz at 1 MHz
Tuning Slope	450 MHz/V
Bias Voltage	3V
Bias Current	30 mA

Conclusion

MMIC front end modules achieved on the first design cycle in two different K and Ku frequency bands have been characterized. Except for the phase noise values of the VCO, the designs demonstrated performances similar to conventional hybrid circuitry. However the MMICs will grant the next radio link generation improved reliability, decreased size and reduced manufacturing cost.

Acknowledgements

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References

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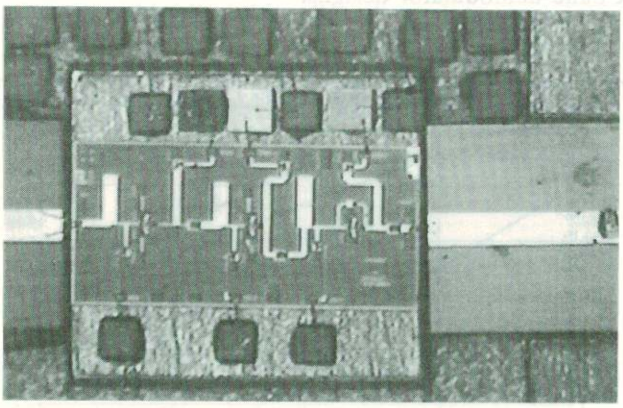

Fig. 14: K-band LNA on chip carrier