Six-Port Receiver Front-End MMIC for V-Band MBS Applications

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Abstract— **A V-band six-port receiver front-end MMIC for 65.5 GHz has been designed, manufactured, and measured. The circuit combines all the essential functions, namely the six-port and three GM Schottky diode detectors, on a single 3.0 mm × 2.0 mm OMMIC ED02AH MMIC. The MMIC shows good compliance with six-port theory, and the minimum discernible system is estimated to be -40 dBm.**

I. INTRODUCTION

A six-port receiver is a special form of a direct down-conversion receiver. Like most direct receivers, and in contrast to the conventional superheterodyne structure, it offers a very simple architecture making it easy to integrate and mass-produce [1]. It also avoids the image-rejection problem of superheterodyne receivers, which results in reduced filtering requirements [2]. At the core of this receiver form is the six-port device, which was initially developed as a high-performance vector voltmeter for use in vector network analysers [3]. However, in 1995 technology had progressed to a level that would allow for six port devices to be mass-produced at a reasonable cost, and hence Li et al. suggested its use as a phase sensitive receiver [4]. Extensive measurements on lower microwave frequencies have shown that the six-port receiver yields significantly better bit-error rates than conventional direct conversion receivers [2], and furthermore offers the option for self-calibration, making it less sensitive to environmental and long-term effects [4].

As a consequence, the six-port receiver has received widespread interest either as a device for broadband communications such as WLAN and MMDS [2], or software radio [5]. So far, efforts have concentrated on the microwave or lower millimetre-wave range up to 31 GHz [1], [2], [4], [5], and relied on hybrid [1] or coaxial [4] technology. Here now, to our knowledge for the first time, a fully integrated six-port receiver MMIC for V-band applications is introduced.

II. THE SIX-PORT RECEIVER MMIC

A six-port receiver front-end MMIC for the MBS band with a nominal operating frequency of 65.5 GHz was designed and manufactured using the OMMIC ED02AH 0.20 μm GaAs pHEMT process. The block diagram of the circuit can be seen in Fig. 1, and a chip photograph of the completed MMIC in Fig. 2; the die size is 3.0 mm × 2.0 mm.

The LO signal is fed to the left edge of the chip, split via an integrated Wilkinson divider, and fed to the three 90°-hybrids, here Lange couplers. The first detector and port V1 for signal LF_1 are located at the top edge, and the remaining two detectors with ports V2 and V3 for signals LF_2 and LF_3, respectively, at the lower edge. Return loss at the RF port is -8.6 dB, and at the LO port -5.7 dB. LO to RF port isolation is better than 10 dB over the entire MBS band (60 to 70 GHz).

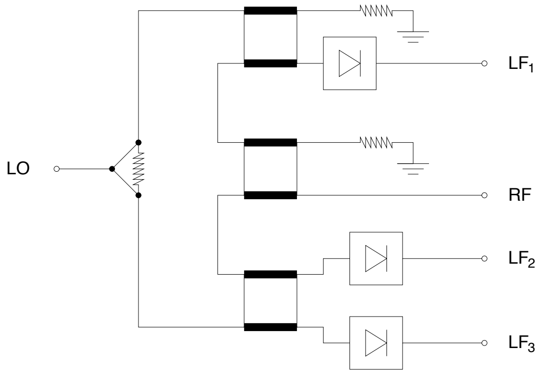

Fig. 1. Block Diagram of Six-Port Receiver MMIC (based on [6]).

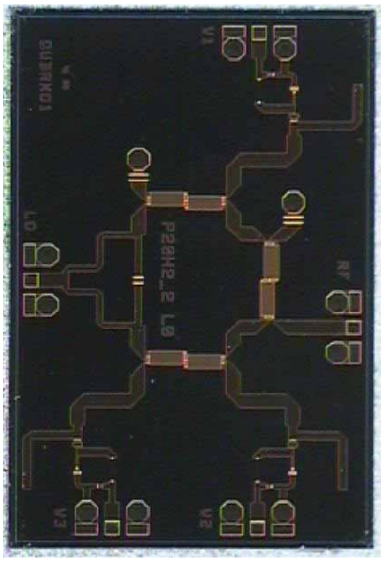

Fig. 2. Photograph of Six-Port Receiver MMIC

The six-port MMIC does not include carrier recovery circuitry, but Li et al. showed that this can be achieved by deriving a reference signal for the LO from the LF signal, since a frequency difference between RF and LO signal is represented by phase fluctuations in the LF signal [4].

The circuit schematic of the detectors is given in Fig. 3. The diode is a 0.20 μm GM GaAs Schottky diode, created by connecting drain and source of a GaAs 2 × 15 μm pHEMT. In contrast to standard detector topology, the cathode rather than the anode of the diode is connected to ground to allow for positive bias voltages. At the design frequency of 65.5 GHz, the detector achieves a sensitivity of nearly 1100 mV/mW.

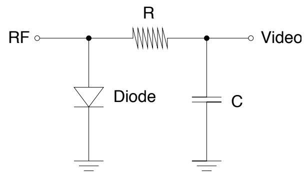

Fig. 3. Circuit Diagram of Diode Detector.

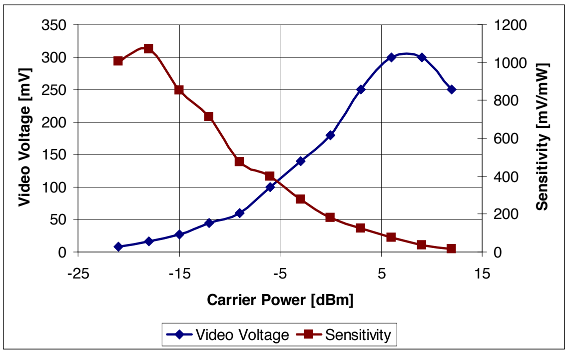

Fig. 4. Video Voltage and Sensitivity of Detector versus Input Power Level.

The RF suppression is achieved by a simple R/C lowpass with a 3-dB bandwidth of 9 GHz, since the frequency separation between the RF and Video signal is over 65 GHz.

The detectors are biased close to the pinch-off voltage of the Schottky diodes, and the positive bias voltage is applied through the Video port. Since the diode is biased very close to pinch-off, the bias current is only in the order of μA, and hence does not cause any significant voltage drop over the resistor R of the R/C lowpass. The RF ports of the detectors are matched to 50 Ω using distributed L-matching circuits, visible in Fig. 2.

Fig. 4 finally shows the measured performance of the diode detectors, namely video voltage and sensitivity over input power level for envelope detection mode. The video voltage, shown as the graph with the diamond symbols, reaches it peak for about 7 dBm input power. Above that level, the diode is saturated and further increase in input power level does no longer result in an increase of video voltage. Sensitivity, shown as the graph with the square symbols, is best for about -10 dBm input power.

III. SIMULATION RESULTS

The circuit was designed and simulated using the Advanced Design System (ADS) [7]. The linear and nonlinear models of the MMIC components were supplied by the OMMIC foundry. Fig. 5 shows simulation results for 10-kHz operation. The results were obtained using Harmonic Balance simulation, and then converted to the time domain using the Fourier transform function of ADS. LO and RF power levels were set to 0 dBm, and the predicted video voltage for this setup is 82 mV peak-to-peak for the reference channel, signal *Vout1* in Fig. 5 and signal LF_1 in Fig. 1, and 70 mV peak-to-peak for the other two channels, signals *Vout2* / LF_2, and *Vout3* / LF_3.

IV. MEASUREMENT RESULTS

The measurement setup can be seen in Fig. 6. An Agilent HP 83650 B synthesised source was used to produce the LO signal. The RF signal was derived from the LO signal using a 5-dB directional coupler, and the phase difference between RF and LO signal was introduced using a waveguide phase shifter. The maximum sweep rate of this phase shifter limited the experiments to a few Hz maximum LF frequency, however the simulation results discussed in section III suggest that the circuit works for much higher baseband signal frequencies. The connections to the MMIC were made by probing the RF and LO ports of the six-port receiver on a Cascade Summit 12000 probe station. The LF ports were probed using needle probes, and fed to the input of a Tektronix TDS 784D digital oscilloscope set to three-channel operation.

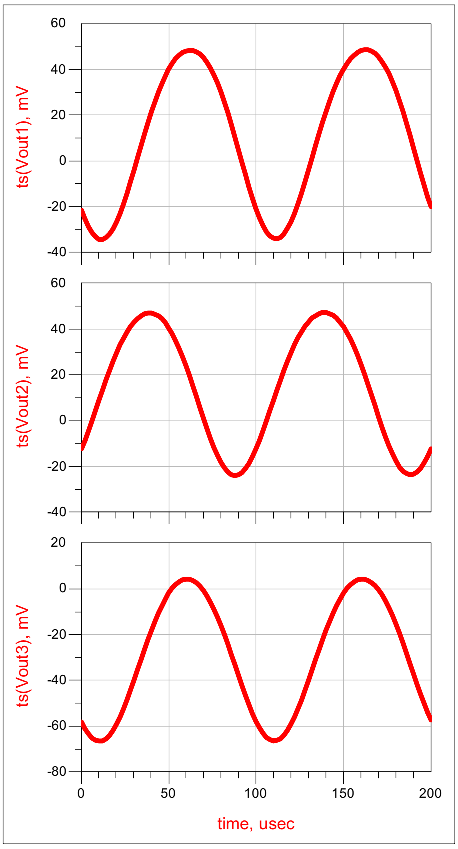

Fig. 5. Simulation Results for Six-Port MMIC.

Since the RF and LO signal were derived from the same source, they were inherently phase locked to each other, and hence carrier recovery circuitry was not required at the receiver. This meant however that the difference in signal level between RF and LO signal was fixed, and consequently measurements for low RF power levels automatically resulted in low LO power levels. It is believed that this effect was likely to have impaired the sensitivity of the detectors. It is therefore possible that the six-port MMIC is performing better than the results presented here.

Fig. 7 shows a screen shot for the case when the phase setting of the phase shifter was decreasing with time. As the phase shifter in the RF branch is swept continuously through all 360° of phase angles with respect to the LO reference signal, in accordance with six-port theory, the amplitude of the three different output signals varies with the phase between the RF and LO signal. The three instantaneous amplitude values

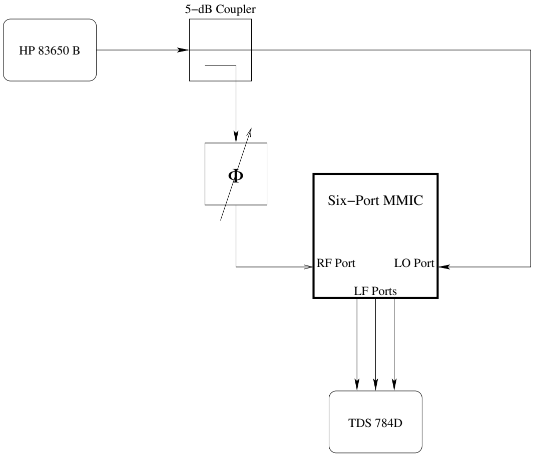

Fig. 6. Measurement Setup.

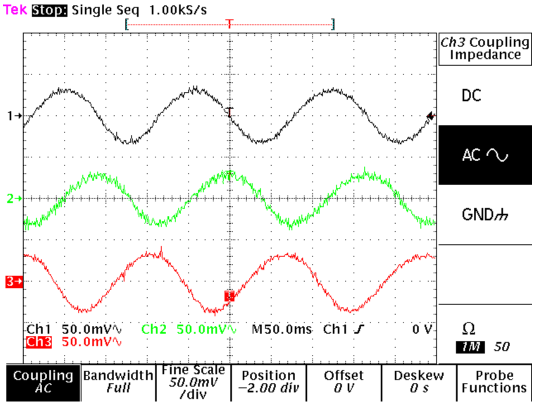

Fig. 7. Screen shot of oscilloscope; phase decreasing.

of the three output signals allow to unambiguously derive the phase difference between RF and LO signal at that point of time [1], which ultimately allows for the demodulation of a QPSK signal. In contrast, Fig. 8 shows a screen shot for the case when the phase setting of the phase shifter was increasing with time. It can be seen how the phase relationship of the three output signals changes accordingly with respect to Fig. 7.

For both setups, Fig. 7 and 8, the LO power was estimated to be about 0 dBm on-chip, and the RF power approximately -5 dBm. The resulting video voltages are approximately 70 mV peak-to-peak for the reference channel, bottom graph, and 60 mV peak-to-peak for the other two channels.

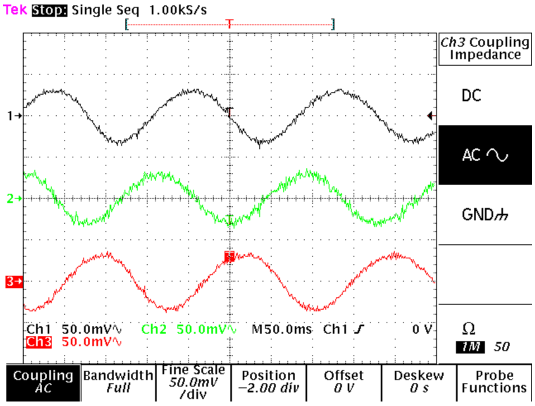

Fig. 8. Screen shot of oscilloscope; phase increasing.

This agrees well with the simulation predictions, section III and Fig. 5.

Finally, the minimum discernible signal without the use of a low-noise pre-amplifier was estimated from the measurements to be -40 dBm. This result has not been corrected for the earlier mentioned low LO power levels. Assuming transmitter power of 0 dBm, an antenna gain of 30 dB [8], and the equation for free-space propagation path loss, a resulting prospective maximum link range of up to 20 m is predicted. Such a link range of 20 m would be sufficient for any pico-cellular network applications, e.g. high-bandwidth wireless LAN.

V. CONCLUSIONS

A V-band six-port receiver front-end MMIC for a centre frequency of 65.5 GHz has been designed, manufactured and measured. All essential components, namely the actual six-port including all terminations plus the LO signal power splitter, and three GM Schottky diode detectors, have all been integrated on a single 3.0 mm × 2.0 mm GaAs MMIC using the OMMIC ED02AH process. To our knowledge, this is the first time that such an MMIC is reported for this frequency range.

The MMIC has been measured, and the results are found to comply well with six-port theory. The minimum discernible signal was found to be approximately -40 dBm. A maximum achievable link range of 20 m was estimated, suitable for short range high-bandwidth digital communication links.

ACKNOWLEDGEMENTS

This project was funded by TDK Electronics Ireland, Ltd., and TDK Electronics U.K., Ltd. The authors would furthermore like to thank OMMIC for fabricating the MMICs using their ED02AH process, and IRTU for funding the development of the diode detectors under grant ST173.

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