# A 60GHz 256 QAM Balanced Vector Modulator for Short Range LOS Communication Applications

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## Abstract

An I-Q type vector modulator employing two orthogonal bi-phase amplitude reflection type modulators has been demonstrated which sets a new benchmark for a multilevel direct carrier modulator for digital communications. The 60 GHz modulator uses design techniques and technology capability to reduce hardware complexity in communication applications. The modelling and design of the balanced I-Q vector modulator are reported, followed by the measured performances.

## I. Introduction

Recently extensive work has been carried out regarding direct carrier modulators for a variety of applications [1-10]. These are mainly divided into two distinct areas for microwave vector modulators; the I-Q type employing two orthogonal bi-phase amplitude modulators [2-6] and the phase shifter/attenuator type using separate amplitude and $360^o$ phase control circuits [5,8]. Recently reported direct carrier modulator performances are summarised in Table I. The 256 QAM vector modulator operating at 60GHz described in this paper is believed to be the highest multi-level modulation at 60GHz reported for the I-Q balanced vector type configuration. Fig. 1 represents a complete block diagram of the balanced vector modulator.

| Type | Modulation | Frequency | Others |
|---|---|---|---|
| SPDT switching [1] | BPSK | 1.7GHz | $1^o$ phase and 0.2 dB amplitude imbalance |
| I-Q type with RT [2] | QPSK | 8~12 GHz | $\pm10^o$ phase error |
| I-Q type with RT [3] | QPSK | 8.2 GHz | $\pm8^o$ phase error |
| I-Q type with DBM [4] | QPSK | 1~2.7 GHz | $4^o$ phase imbalance |
| I-Q type with SBM [5] | 64-QAM | 5.9~8.5 GHz | $\pm1.5^o$ phase error |
| Phase shifter/attenuator type [6] | QPSK | 4~18 GHz | |
| Phase shifter/attenuator type [8] | QPSK | 16.7~17.8 GHz | 6.5 dB insertion loss |
| I-Q type with RT [9] | BPSK | 94 GHz | $\pm5^o$ phase error |
| I-Q type with RT ***Presented in this paper*** | 256 QAM | 55~65 GHz | 5dB insertion loss $\pm2^o$ phase error $\pm$0.3 dB amplitude imbalance |

RT : reflection termination , DBM : Double Balanced Mixer and SBM : Single Balanced Mixer

Table I. Summary of recently reported direct carrier modulator performances

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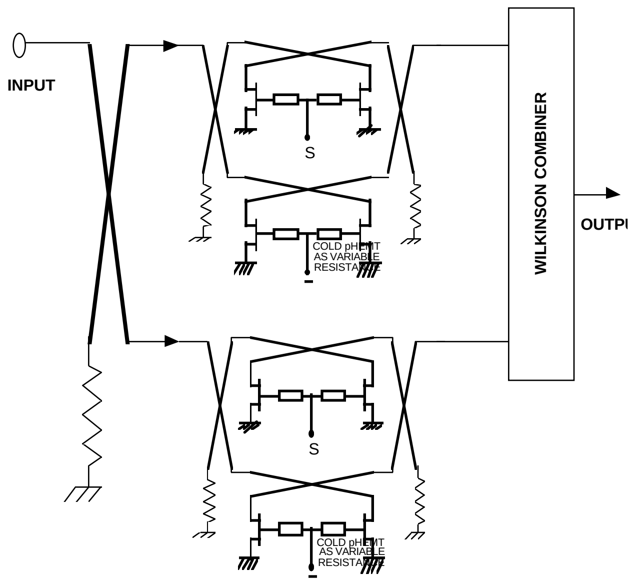
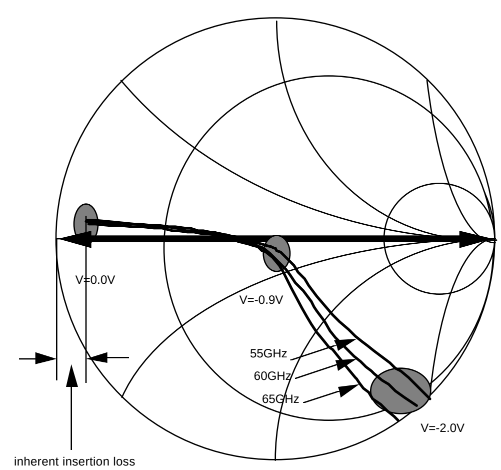



Fig. 1 Block diagram of the designed I-Q balanced vector modulator

## II. I-Q balanced vector modulator design summary

The designed balanced vector modulator employs two reflection type attenuator modulators [9] using cold-PHEMT reflection terminations and operating in a push-pull fashion. The modulator design starts with S-parameter simulation of the cold PHEMT to use it as a switch or variable resistor in the reflection type attenuator. The simulation results for 55, 60 and 65 GHz are shown in Fig. 2a for different gate bias points, starting from 0.0, -0.9 and -2.0V. The results show that the cold-PHEMT provides a nearly pure resistive component of up to 50Ω (-0.9V), but between -0.9 and -2.0V the parasitic capacitance (channel capacitance) has an increasing effect.

The inherent parasitic capacitance of the cold-PHEMT over -0.9V to-2V can be tolerated in the balanced modulator because of the vector summing by the "complementary" control signal to the gate and the 180$^o$ phase shift by the two couplers, as illustrated in Fig. 2b. The resultant output is the vector sum of the two in-phase signals emerging from the two branches. The Wilkinson combiner has been used for the in-phase signal summing. In this case of an ideal coupler and combiner, the minimum channel parasitic resistance ($R_{ds}$) of the Cold-PHEMT determins the inherent insertion loss of the modulator. The minimum channel resistance at the maximum gate bias have been found to be around 10Ω at +0.3V gate bias voltage. For simple estimation of the insertion loss by the existing $R_{ds}$, the parasitic shunt capacitance and series inductance of the Cold-PHEMT can be ignored. The insertion is calculated with $L_i = |(Z_o - \Gamma_T)| \div |(Z_o + \Gamma_T)|$, where $\Gamma_T$ is the reflection coefficient of the terminator and $Z_o$ is the characteristic impedance. An insertion loss of 1.76dB is expected for the single-stage attenuator (modulator). In addition to this loss, the shunt capacitance and the series inductance also produce loss, which contribute to the total loss along with non-ideal coupler and combiner loss. Fig. 3 shows the fabricated 60GHz MMIC balanced vector modulator. The high value gate bias resistors are used in order to limit or prevent RF leakage and forward bias current.



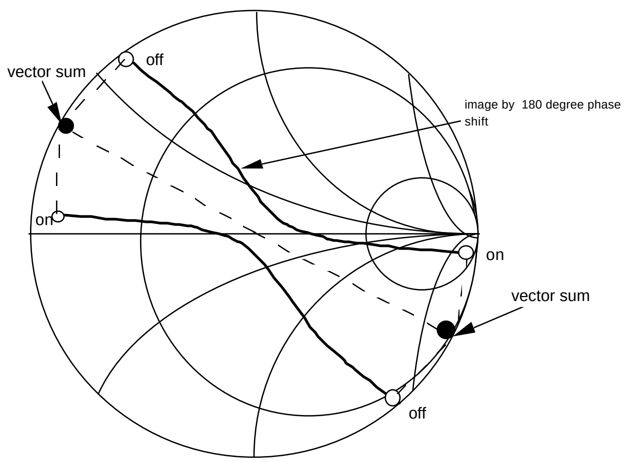



Fig. 2 (a) Simulated S11 of the Cold-PHEMT (b) S21 representation of the balanced vector modulator

## III. Measured results

The balanced vector modulator at 60GHz has been fabricated on GEC Marconi's H40 foundry which offers an AlGaAs/InGaAs PHEMT process with the chosen dimension of the gate with 0.25 μm gate length by 2 fingers of 60 μm gate width. The random baseband signal shown in Fig. 4a represents 16 different amplitude levels for 256 QAM modulation. The corresponding modulator output spectrum to this injected baseband signal is shown Fig. 4b. The spectrum has been measured at 60GHz with a symbol rate of 125 Kbps which implies that 1Mbps bit rate has been obtained. An insertion loss of 5dB average and a maximum input/output return loss of -10dB have been achieved over the frequency range of 55GHz to 65GHz as shown in Fig. 5. A ± 2$^o$ phase error with ±0.3 dB amplitude imbalance were obtained. The measured bandwidth has been limited by the bandwidth of the available RF source.

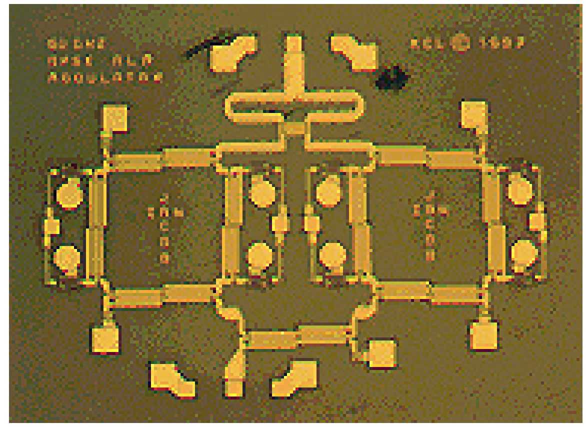


Fig. 3 Microphotograph of balanced vector modulator working at 60 GHz.

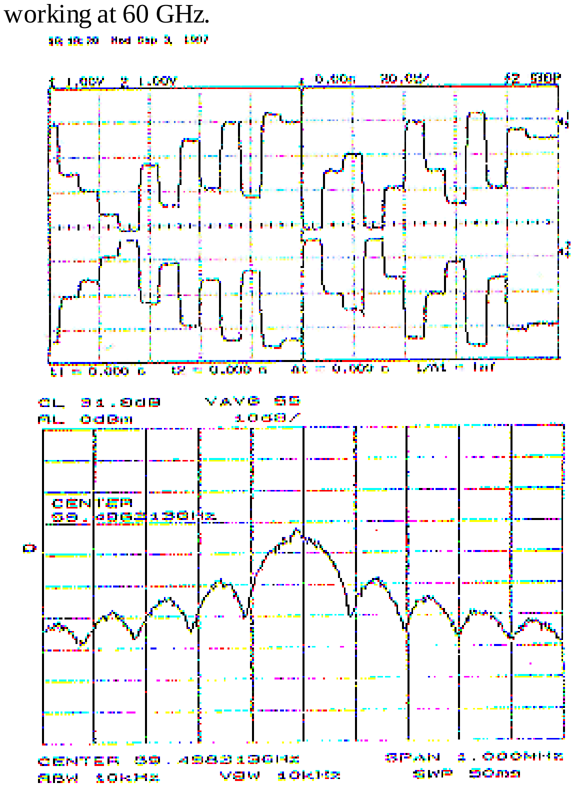



Fig. 4 (a) Injected complementary base band signals for 256 QAM (b) Measured 256 QAM modulated spectrum at 60 GHz carrier

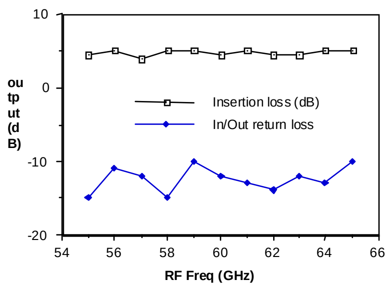



Fig. 5 Measured insertion loss and in/out return loss

## IV. Conclusion

We have demonstrated a wide band 256 QAM balanced vector topology using reflection type attenuators operating as modulators at 60GHz. This work is believed to be the highest reported multi-level and RF carrier frequency. 256-QAM was chosen to highlight the precision which can be achieved using this topology. The modulator achieved its potential of multi-function and wideband application. The main advantage of the multi-function balanced vector modulator is that the modulator can be applied to a wide range of applications including LOS links, short distance indoor radio communication and collide protection systems.

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