AN E-PLANE BROADBAND BI-PHASE BALANCED MODULATOR FOR Ka-BAND

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Abstract

A bi-phase p.s.k. modulator for use in 29 GHz Radio equipment has been developed that gives state of the art performance (3 dB insertion loss across 7% bandwidth and 70/100 Mbit/s data rate using beam lead PIN diodes as the switching elements). The circuit maintains the full instantaneous bandwidth without requiring any tuning or alignment during or after manufacture.

Introduction

Radio systems are increasingly using digital techniques for reasons such as robustness to interference and the ability to provide secure communications when encrypted. A commonly used form of digital modulation is phase shift keying (p.s.k.). The modulator to be described in this paper meets the specific requirement for a modulator operating in the 27.5-29.5 GHz frequency band, capable of switching r.f. powers of at least 250 mW, as needed for a local distribution millimetre-wave system under development by British Telecom[1]. The circuit is amenable to low cost fabrication techniques and is versatile in that it can be used also as an amplitude shift keyed modulator with 30 dB on-off ratio without any modification.

Balanced Modulators

The concept of the balanced circuit as a modulator has been widely reported, the most recent implementation being that by Ogawa, Aikawa and Akaike[2]. Using two anti-parallel Schottky barrier diodes as the switching elements, such circuits have severe r.f. limitations for many system applications. They offer low insertion loss at powers of a few milliwatts only, with loss increasing rapidly above 10 mW to typically around 15 dB at 250 mW. This power limitation of the circuit arises because of the use of Schottky barrier diodes as the switching elements. Directly replacing the Schottky barrier diodes with beam lead PIN diodes would allow significant increases in r.f. power, but would severely degrade the switching speed because of the inherent charge storage mechanisms associated with PIN devices; the anti-parallel connection inherent in all balanced circuits reported to date prevents adequate reverse bias being applied to overcome this speed limitation. The modulator to be described in this paper overcomes these problems by adapting the balanced configuration circuit to allow separate biasing to two PIN diodes without unduly impairing the r.f. performance. The circuit makes use of the mode transformation properties of a slotline to microstrip transition to effect a 180 degree phase change using equal length switched paths.

Circuit Configuration and Mode of Operation

The complete modulator circuit (see Fig 1) is fabricated on a Duroid 5880 substrate (t = 125 μm, Er = 2.22) incorporating printed transitions to waveguide.

It is estimated that the pair of transitions contribute 0.7 dB to the overall loss of the circuit. The beam lead PIN diodes are bonded across the emerging arms of the slotline T-junction. The circuit has separate biasing to each diode to allow fast removal of stored charge carriers by the use of a split data source and dual driver. To achieve separate biasing the annular slot-line ring is split symmetrically without introducing

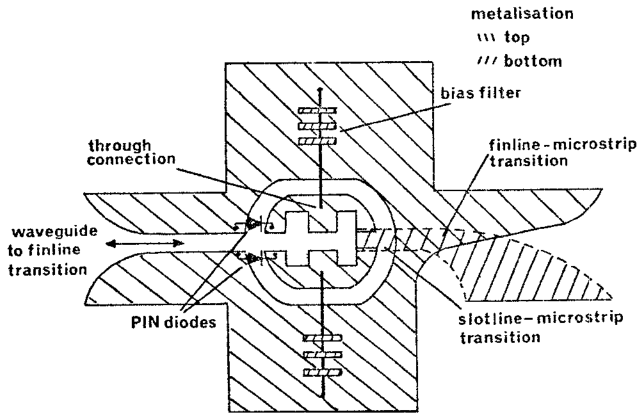

Fig 1 Circuit Layout of P.S.K. Modulator

r.f. discontinuities. This is achieved by inserting into the central 'island' of the annular slotline a double-ended quarter-wave transformer structure in slotline, forming a good open-circuit at all frequencies encountered by digital radio system modulation data streams, whilst maintaining good r.f. continuity. The circuit is the subject of a patent application.

The circuit operation can best be described by referring to Fig 2. This shows the circuit configuration with one or other PIN diode biased into forward conduction approximating a short-circuit condition, the complementary diode being reverse biased. The arrows in Fig 2 are a schematic representation of the r.f. electric field and show how the bias change results in generation of a 180 degree phase shift at the output port.

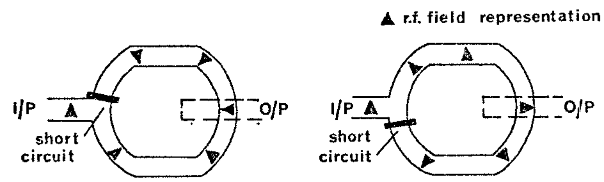

Fig 2 Principle of Circuit Operation

The circuit is potentially wideband because the phase change does not depend upon path length changes.

PIN Diode Switching

PIN diodes have two states, a low impedance forward bias state and a high impedance reverse bias state. Switching from the reverse bias state to the forward bias state is the faster of the two switching times and is dependent upon the charge build up within the diode. Charge Q is governed by the equation:

$$dQ/dt = I_f - Q/T$$

where If is the forward current
and T is the carrier lifetime of the diode.

When T is large, say more than 20 ns, then slow switching speeds result if a constant forward current If is used to inject the charge. To ensure fast switching, current spiking has in the past been used to inject a large amount of charge in a short time, and these spiking circuits have usually been RC networks. However, RC networks although giving fast rising edges result in slow falling edges. This limits the modulation rate of PIN diode switching. Instead of an RC spiking network a fast monostable of 10 ns duration (rising and falling edges typically 4 ns) has been used for this drive amplifier.[3] Changing the diode from its low impedance state to its high impedance state requires the stored charge to be removed, the equation governing this is:

$$dQ/dt = -Ir - Q/T$$

where Ir is the reverse current. The drive amplifier provides a high reverse voltage and a low impedance condition to remove the stored charge.

The three diode types that appeared to best meet our requirements were measured to ascertain the comparative minority carrier lifetimes under identical conditions. The measured results are shown in Fig 3 and show the GEC DC2602 preproduction devices[4] to have a shortest minority carrier lifetime. The best commercially available low capacitance device for our circuit was the Alpha 4380E diode even with its 76 ns minority carrier lifetime.

The 4001 diode has a low minority carrier lifetime but for our circuit operating at Ka-band the capacitance is too large.

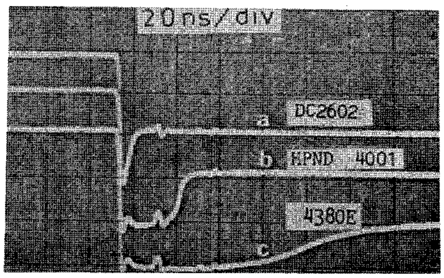

Fig 3 Measured PIN Diode Minority Carrier Lifetimes

Practical Results

Swept frequency static measurements were made of the modulator insertion loss, amplitude imbalance, and phase imbalance. Lowest insertion loss is obtained using Alpha diodes as shown in Fig 4.

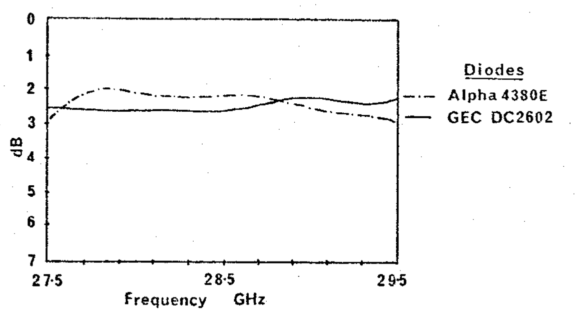

Fig 4 Modulator Insertion Loss

Amplitude imbalance remains less than 1 dB and the phase imbalance has been measured as less than 3 degrees over a 27.5-29.5 GHz band. The dynamic response was evaluated by using a pseudorandom 1023 bit sequence and measuring the demodulated waveform.

Eye patterns for a modulation rate of 70 Mbit/s are shown in Fig 5 and 6.

5 ns/div

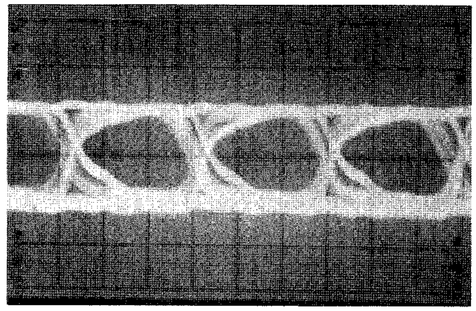

Fig 5 70 Mbit/s Eye Pattern, DC2602 Diodes

5 ns/div

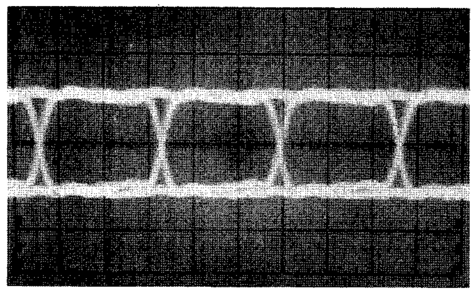

Fig 6 70 Mbit/s Eye Pattern, 4380E Diodes

A circuit using GEC preproduction diodes [3] was tested at the higher rate of 100 Mbit/s and the response is shown in Fig 7

5 ns/div

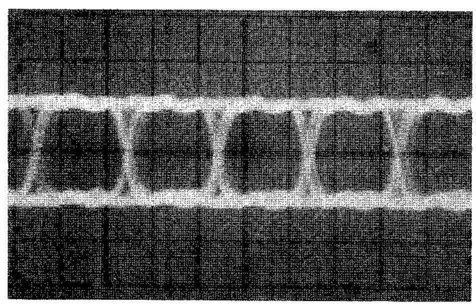

Fig 7 100 Mbit/s Eye Pattern, DC2602 Diodes

Modulators have been tested with r.f. powers up to 150 mW with no observable change in performance. Isolation between the input and output ports has been measured as greater than 25 dB over a 2 GHz bandwidth.

Amplitude Shift Keyed Modulation

A form of modulation that allows simple receiver detection systems to be used and is fairly tolerant of oscillator drift is amplitude shift keying (a.s.k.). The p.s.k. modulator described here can also be used without modification as a simple a.s.k. modulator. The principle of operation of the circuit in this mode is shown in Fig 8 illustrating that a high on-off ratio can be obtained because of the phase cancellation arising from the balanced nature of the circuit when both diodes are reverse biased. With one diode forward biased the circuit is in its on state with a low insertion loss over a wide band as for the p.s.k. modulator.

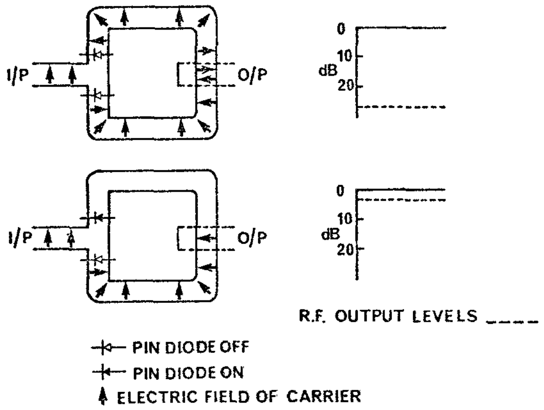

Fig 8 Principle of Operation as an A.S.K. Modulator

Amplitude measurements of the signal in the a.s.k. mode of operation have been made over the full bandwidth and show the on-off ratio to be greater than 25 dB.

Conclusions

A planar bi-phase p.s.k. modulator has been fabricated that operates over a broad bandwidth at Ka-band without requiring any tuning or alignment during or after manufacture. The circuit has demonstrated switching speeds of 100 Mbit/s and shows potential for even higher data rates. The balanced nature of the circuit has provided excellent amplitude and phase balance (typically +/-0.5 and +/-3.0 degrees respectively). The circuit has been shown to be versatile in that without modification it can be operated as a simple amplitude keyed shift modulator with an on-off ratio of at least 25 dB. The balanced circuit design is simple in concept and should easily be adaptable to other frequency bands. The planar construction is amendable to low cost high volume production methods. The modulator and drive amplifier design have been incorporated in 29 GHz radio equipment being manufactured by Mullard Hazel Grove Ltd.

Acknowledgements

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References

1 MOHAMED S, WILSON P: "29 GHz Radio Systems for Local Distribution Network", 12th European Microwave Conference Proc, Helsinki, 1982, pp 709-714.

2 OGAWA H, AIKAWA M and AKAIKE M: "Integrated Balanced BPSK and QPSK modulators for the Ka-band," IEEE Trans. MTT-30, March 1982, pp 227-234.

3 THORPE W, GILLILAND J.D, "29 GHz E-Plane Bi-Phase Modulator", ELECTRONICS LETTERS, 3rd FEBRUARY 1983 Vol 19 No 3, pp 107-109.

4 SISSON M J, BRIGGINSHAW P M et al: "Microstrip Devices for Millimetric Frequencies", 1982 IEEE MTT-S Digest, pp 212-214.