DESIGN OF DIRECT PHASE MODULATORS FOR HIGH SPEED DIGITAL RADIO SYSTEMS USING MIC TECHNIQUES

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Abstract

The design and performance of serial four-phase modulators constructed in microstrip operating in the 19 GHz band at a symbol rate of 140 Mbauds is described. In a complete radio system, good performance within 4 dB of the ideal system, has been achieved consistently.

Introduction

As a result of the growing importance of digital microwave communication systems,[1,2,3] an increasing interest is being shown in the design of phase modulators. Direct r.f. modulation is of interest as it simplifies transmitter designs compared to i.f. modulation schemes, leading to more compact, cheaper and efficient systems.

This paper describes the design approach adopted to realise a serial four-phase modulator on microstrip for operation in the 17.7 - 19.7 GHz band. A model of the modulator is developed and the predicted performance is correlated with experimental results. The modulator phase accuracy is an improvement over that obtained by various researchers at s.h. frequencies[4,5].

Design Considerations

The QPSK signal can be produced using serially-connected 180^o and 90^o modulators, or by the parallel connection of two 180^o modulators (Figures 1(a), 1(b)). The choice of serial rather than parallel modulation was made for two basic reasons; (a) mismatches and inaccuracies in the recombination paths of the parallel type are difficult to adjust; (b) it is difficult to construct 3 dB hybrids which maintain the required phase and amplitude balance over the 17.7 - 19.7 GHz band. One potential disadvantage of serial mode operation is that two of the phase transitions are such as to produce cross-talk between the two transmitted bit streams. However, our work has shown that if transitions occupy a time of less than about 0.2 bit period, the cross-talk is negligible.

The choice of a PIN diode as the switching element was made in view of its power handling capability[6] and low forward resistance. Using silicon diffused mesa-etch techniques, PIN diodes were fabricated which could be switched in less than 1 ns, adequate to avoid cross-talk at the bit rates considered. The diodes have low forward resistance (<2 Ω) to minimise amplitude imbalance between states, and overall insertion loss.

Each modulator consists of a PIN diode terminating one arm of a circulator together with a shunt stub line and the switched path length behind the diode. The basic design procedure adopted was first to establish an equivalent circuit for the diode and its associated parasitics. The circulator leakage power, which contributes to the overall phase and amplitude balance, was then measured. A computer microstrip analysis program was used to analyse the equivalent circuit of the modulator (Figure 2(b)) in order to arrive at values of the length of the switched path, the position and length of the shunt stub, and the line length between stub and circulator. The design aim was to realise a circuit which allowed the required phase accuracy (within 2^o) and amplitude balance (better than 0.3 dB) to be achieved at any frequency in the 17.7 - 19.7 GHz band with a minimum of circuit adjustment. The circuit arrived at for the 180^o modulator is shown in Figure 2(a); the 90^o unit is similar. Final alignment to a particular channel frequency is made by trimming the two open circuit lines.

Experimental Realisation

The 180^o and 90^o modulators were each fabricated on a 20 mm × 35 mm × 0.5 mm alumina substrate. Physical separation of the modulators was found to be desirable in order to reduce unwanted cross-coupling effects, and the input and output ports of the modulator were isolated using iso-circulators incorporated on to the same substrate. The circulators were constructed with the use of ferrite discs inset into the substrate in order to reduce circulator insertion loss and eliminate the necessity of bonding between separate substrates.

The baseband drive was required to switch the diode in less than 1 ns with a minimum of jitter;particularly in switching to the off state this required the rapid removal of the accumulated stored charge. The essential features of the baseband drive circuit are shown in Figure 3. The incoming bit stream is initially retimed; the PIN diode is switched either to a constant current source ('on' state) or to a reverse voltage supply ('off' state) via a transistor.

Modulator Performance

Static phase and amplitude balance within 2^o and 0.5 dB's are maintained over the temperature range 0 - 50^{o}C for the complete four-phase modulator. The four phase states are shown in Figure 4(a). The insertion loss of each diode switching circuit is typically 0.75 dB. The variations of amplitude and phase setting with frequency are shown in Figure 5 where the agreement between theoretical predictions and experimental results can be seen.

The dynamic performance of the four-phase modulator was tested in a complete 19 GHz radio system using coherent carrier extraction in the receiver. The modulated carrier waveform is shown in Figure 4(b) with alternate bits nulled by addition of unmodulated carrier so as to reveal the phase change. Switching speeds of under 1 ns have been achieved. Typical eye diagrams for the system using a pseudo-random pattern for each baseband input are shown in Figure 4(c). No evidence of cross-talk can be seen; in fact for the switching speeds attained, eye closure due to cross-talk is estimated at less than 1%. Figure 6 shows corresponding measurements of b.e.r. against C/N ratio; it can be seen that the performance obtained is less than 4 dB away from that of the ideal system including filtering, of which approximately 1 dB is attributable to the modulator.

Conclusion

A serial four-phase modulator in microwave integrated circuit form has been developed, operating directly at the carrier frequency in a 19 GHz digital radio system. A design technique has been developed to realise these modulators with a minimum tuning requirement. The predicted performance correlates well with experimental results obtained. Good dynamic four-phase performance within 3 - 4 dB of the ideal system has been achieved consistently.

References

1. L.J. Stagg, "High Capacity Digital Microwave Radio Systems", Microwave, Optics and Accoustics, vol 1,No.1, September 1976.

2. T.A. Abele et al., "A High Capacity Digital Communication System using TE_{01} Transmission in Circular Waveguide", IEEE Trans. on MTT, vol 23, No.4, pp.326-333, April 1975.

3. P.J. Mountain, "19 GHz Short Hop Radio Relay Systems", IEE Conference on Telecommunication Transmission, pp.175-177, 1975.

4. S. Seki et al., "Modulation and Demodulation Circuits for a Trial 4-phase PSK Millimeter-wave repeater", Rev. of Elec. Comm. Labs., vol 23, No.1-2, pp.85-98, February 1975.

5. H. Yamamoto and K. Kuhiyama, "400 Mb/s QPSK Repeater for 20 GHz Digital Radio-relay System", IEEE Trans. on MTT, vol MTT-23, No.4, pp.334-341, April 1975.

6. W.J. Clemetson et al., "An Experimental MM-wave Path Length Modulator", BSTJ, vol 50, pp.2917-2945, 1971.

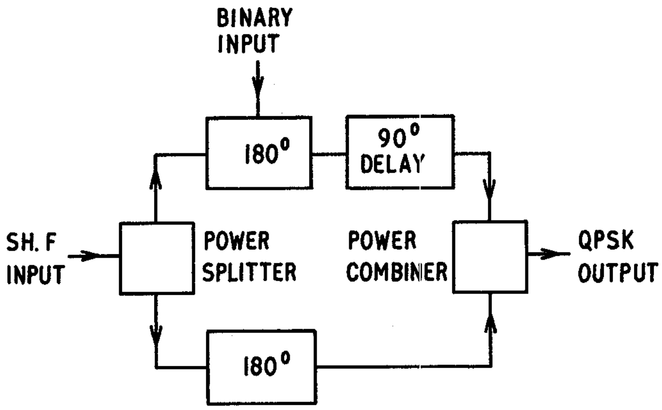

Fig. 1(a) - Parallel 4 phase modulator scheme

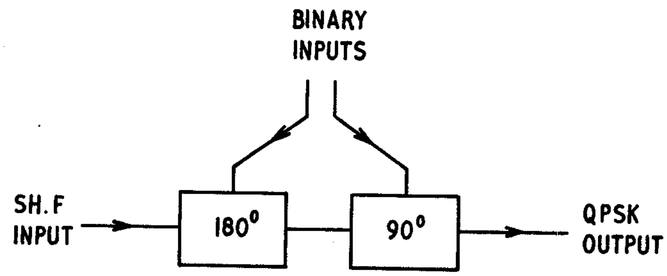

Fig. 1(b) - Serial 4 phase modulator scheme

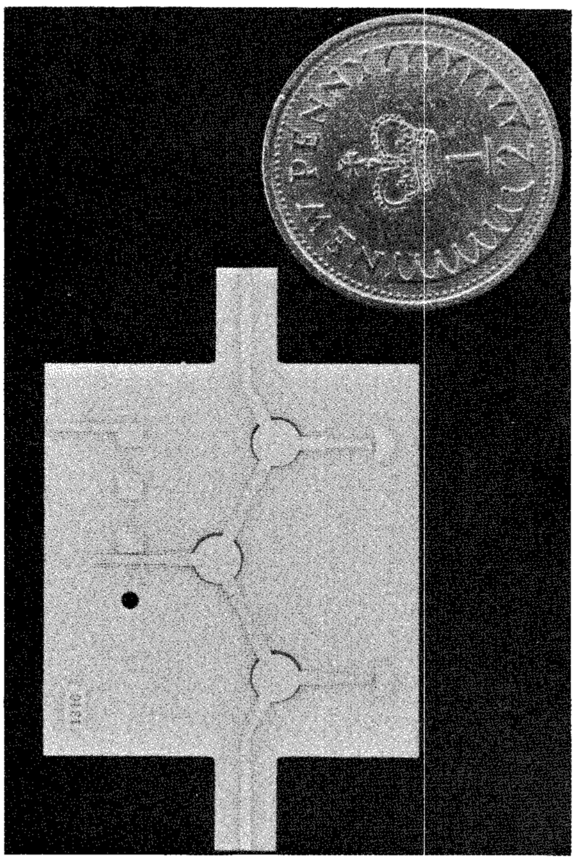

Fig. 2(a) 180° direct phase modulator

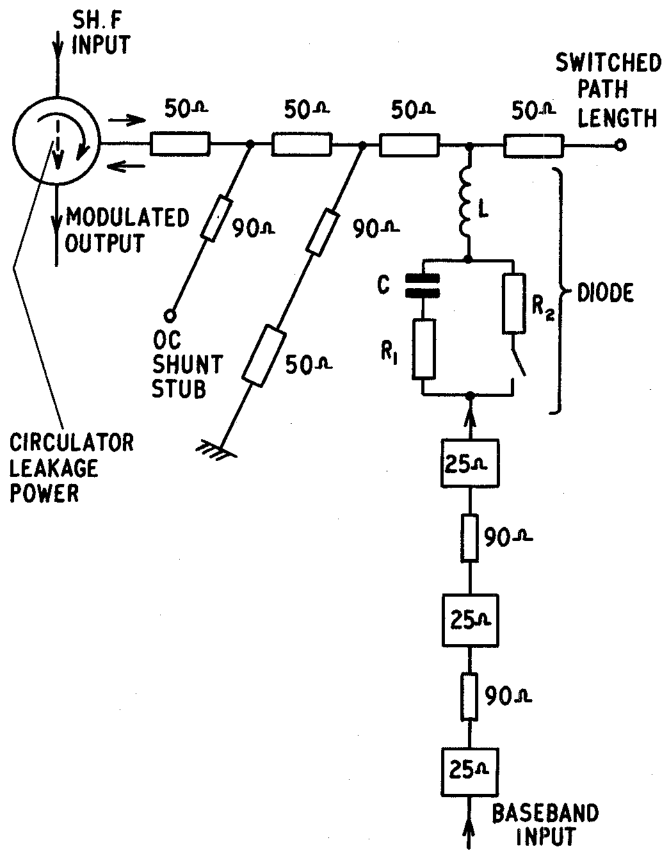

Fig. 2(b) - Equivalent circuit of modulator used in analysis

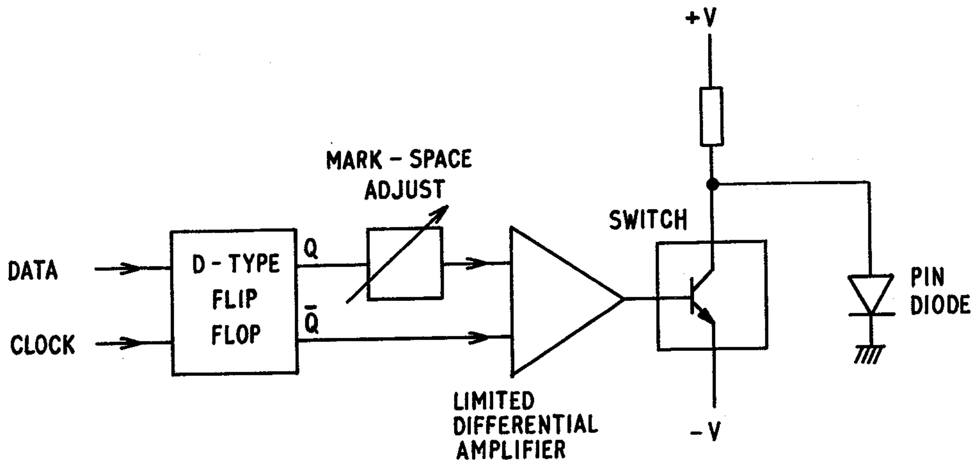

Fig. 3 - Drive circuit for SH.F PIN modulator

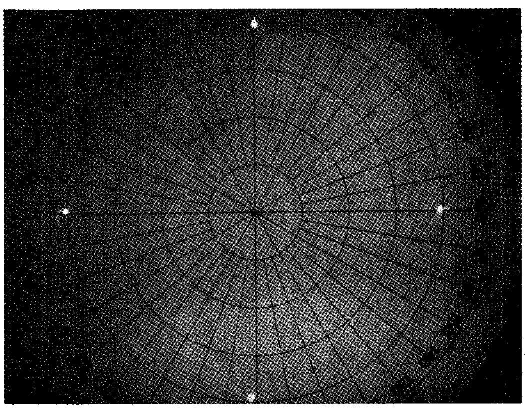

Fig. 4(a) - Static 4 phase states

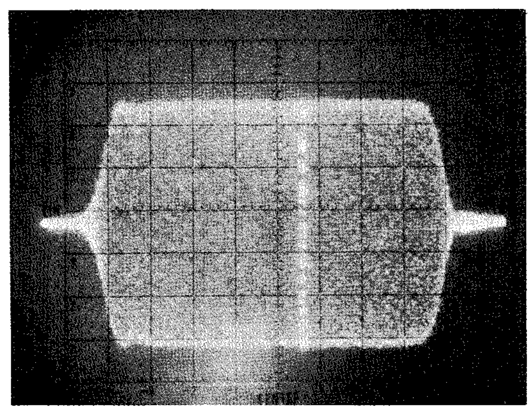

Fig. 4(b) - Phase switching performance (adjacent bits nulled by means of adjustable reference) 1 ns/div

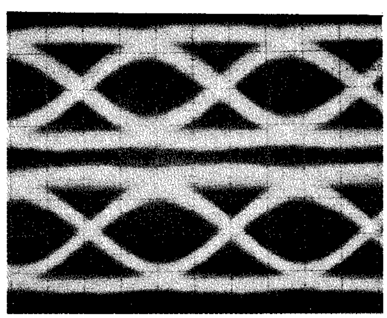

Fig. 4(c) - Eye diagram of demodulated 4 phase signal 2 ns/div

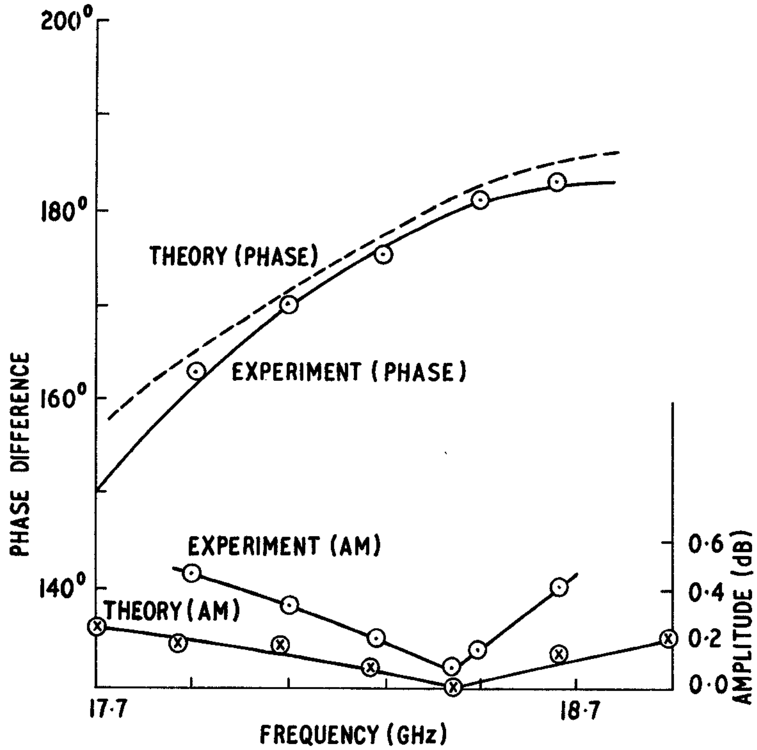

Fig. 5 - Phase and amplitude variation with frequency

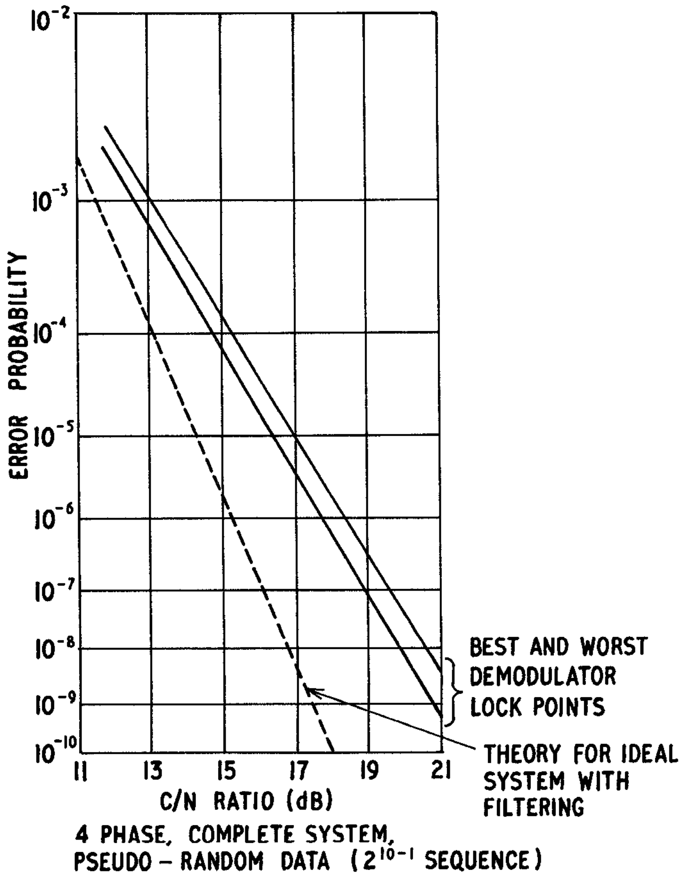

Fig. 6 - 19 GHz system performance