PSK AND QPSK MODULATORS FOR GIGABIT DATA RATES

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Abstract

The basic QPSK modulator of the 1970-75 era in worldwide telecommunications has yielded new modulation techniques of BPSK, SQPSK, 8-QPSK, and FFSK which use the basic PSK device technologies. The PSK modulators must, today, meet many new requirements which were not of importance only a few years ago; i.e., the ability to switch phase at subnanosecond rates, the ability to produce PSK and QPSK carriers at data rates from 50 Mbps to in excess of one gigabit, the ability to produce modulated carriers at power levels in excess of one watt, and the ability to produce QPSK carriers at millimeter wave frequencies up to 100 GHz. This paper will review the original technologies employed during the 1960's and 1970's for low data rate carriers at lower microwave frequencies and will address new advances in switching speeds using dual gate FET's, higher power modulators using special driver circuits, and the use of multipliers to develop PSK carriers well into the millimeter frequencies above 50 GHz.

Introduction

The art of phase shift keyed (PSK) carrier modulation has been a part of the microwave techniques involved with communications for the last decade and has given rise to significant development of the doubly balanced phase modulator and the path-length switched waveguide-type phase modulator for PSK modulation for carriers operating up to 100 GHz and for PSK data rates up to 500 megabits per second using switching times as fast as 600 picoseconds. These modulators, which were highly experimental only a few years ago, are now the heart of many terrestrial radio and satellite communication systems, and data rates at 274 Mbps and 800 Mbps are now in operational use in BTL's T4M system and in the Japan NTT guided millimeter wave system.

This paper will introduce new technologies which are now advancing the techniques of PSK modulation in three directions - toward switching speeds of less than 100 picoseconds, using FET's, toward higher power of several watts, produced directly from a PSK modulator, and toward developing PSK carriers at the millimeter waves using frequency multipliers to avoid the significant switching diode technological demands of direct PSK modulators or power up-converters at the millimeter waves. This paper will serve to both provide a status report of many of the new applicable technologies, and also introduce new concepts in the use of dual gate FET's and high efficiency millimeter wave multipliers to advance PSK modulation technique to well above one gigabit data rates, and to frequencies above 50 GHz, where newly approved communication bands can properly accommodate such data rates.

The Basic PSK Modulator

The basic PSK modulator is, as shown in Figure 1, essentially a switch, which connected between two phases of a carrier, switches bursts of each carrier phase to a common output point. In a digital bit stream using, for example, zero's and one's to represent the digital code, then one phase of the carrier will represent the zero and one phase will represent the one. The key consideration in the modulator is the switching time that is required to switch from one phase to the other.

The switching time capability of the PSK switch has significant impact on the data rate which the modulator can produce from an applied carrier. For a data rate of 10 Mbps, for example, each bit duration is allotted 100 nanoseconds and a rise time of, say, one nanosecond will not significantly detract from the rectangularity of each bit. For higher data rates, the rise time becomes an increasingly large interval of the bit interval, i.e.:

Data Rate	Bit Interval	20% Bit Interval
100 Mbps	10 ns	2 ns
200 Mbps	5 ns	1 ns
500 Mbps	2 ns	400 ps
1 Gbps	1 ns	200 ps
2 Gbps	0.5 ns	100 ps

If we arbitrarily allot 20 percent of the bit interval to rise time, then, as shown in the above table, data rates above 200 Mbps require subnanosecond switching time, and the recent disclosure by Dr. Charles Leichti[1] at the 1974 European Microwave Conference of switching a carrier at 70 ps has the impact of advancing the existing 200-500 Mbps rate made possible by the switching times of 500-800 ps now obtainable from Schottky-barrier diodes, PIN diodes and bipolar transistors, to two gigabits per second and higher, assuming that logic circuits of similar speeds can also be developed to operate with the modulator.

Types of PSK Modulators

Figure 2 illustrates the principal types of PSK modulators which can be used to develop PSK modulated carriers. They include the path-length switched circulator-coupled waveguide PSK modulator shown in Figures 2a and 2b which is principally used and X-band and millimeter wave frequencies; the two-diode and four-diode modulators shown in Figures 2c and 2d, respectively, which represent the most commonly used circuits, particularly the doubly balanced modulator of Figure 2d for frequencies from audio frequencies to K-band and the dual gate FET PSK modulator of Figure 2e as first discloded by Dr. Liechti, which is a new technique suited to low power and for frequencies up to K-band. This later modulator is still experimental but gives promise of high applicability in PSK modulator applications due to exceptionally fast switch speeds and applicability to MIC construction.

Waveguide Path Length Modulators

The waveguide path length modulator of Figures 2a and 2b was given considerable attention at the millimeter waves in the early 1970's by Cuccia and Spilker[2] of Philco-Ford, R. Garver and others, and extensive work was done at Bell Telephone Laboratories by Clemetson, Kurakawa and Schlosser[3] in 1971 and 1972 at the Hughes EDD by Kuno, English, and Chang[4]. These waveguide path length modulators used Schottky-barrier diodes or PIN diodes to switch from short to open circuits across the waveguide to essentially switch between either of two path lengths coupled to Port 2 of the circulator.

PIN diodes or Schottky-barrier switching diodes have impedance characteristics which, as a function of bias voltage, cross from one point on the Smith Chart to a corresponding point 180° or 90° around the chart. Figure 2 shows typical Smith Chart characteristics of a PIN diode in a waveguide which illustrates the crossing of the Smith Chart, passing through the high resistive or high-loss center of the chart which will result in the "notching" of the carrier power during this transition. Such transitions can only be accomplished by a diode driver circuit which performs the transition to the diode from the logic voltage as shown in Figure 3a.

Normally path length waveguide PSK modulators have an output power of from 50-200 mw and require post amplification usually supplied by Impatt amplifiers to build the modulator carrier power up to from 4 to 10 watts. Y. Yakayama and Y. Higo[5] of NEC have disclosed the development of a high power QPSK PIN diode waveguide type PSK modulator with 4-watt output at 3.8 GHz which was capable of operating at rates of 30 Mbps. In order to obtain the high power level, PIN diodes with high breakdown voltage of 60-70 volts and low junction capacitances of 0.1 pf were used. A special high power driver for the PIN diodes, shown in Figure 4b, was developed using PNP-type and NPN-type transistors in complementary operation.

In 1972, Y. Ito, et al,[6] of Fujitsu described a serial QPSK modulator for the 19.7-21 GHz band for 400 Mbps operation using GaAs Schottky-barrier diodes and introducing unique MIC waveguide technology. The MIC in a waveguide was composed of two half divided waveguides; a rectangular waveguide was half divided at the center in parallel to the E-field of the TE_{10} mode. The return loss and the insertion loss from the waveguide to the 50-ohm microstrip (based on 0.6 mm thick ferrite/alumina substrate) were more than 25 dB and less than 0.05 dB respectively over a 20% bandwidth in the K-band.

As the carrier frequency required of a PSK modulator carrier exceeds 30 GHz, it becomes more and more difficult to develop the solid state switching diodes of the PIN and Schottky-barrier variety for path length waveguide PSK modulators to provide accurate 0-90° and 0-180° PSK without significant amplitude modulation. A new approach of generating high mm-wave frequency PSK carriers is to use a lower frequency mm-wave PSK modulator driving high efficiency varactor multipliers. A 60 GHz 0-180° PSK modulator of the later type was developed involving a 30 GHz 0-90° waveguide path length modulator driving a times-2 varactor multiplier to produce a 0-180° PSK modulated carrier at 60 GHz having a 250 Mbps data rate. The circuit employed is shown in Figure 5. Of special interest was the design of the path length waveguide modulator, using a special varactor having a cutoff frequency of 350 GHz. Figure 6 shows a very key characteristic of the diode-waveguide system, that is the insertion loss versus waveguide height (Figure 6b). This waveguide height was very critical as shown and variation in the diode parameters and position in the guide could rapidly alter the insertion loss ratio between forward and reverse bias.

Dual- and Quad-Diode PSK Modulators

The two and four (quad) diode modulator circuits of Figures 2c and 2d operate at low power and are ideally suited for use in MIC techniques. An integrated circuit version of the PSK modulator of Figure 2c and was built by NEC using two PIN diodes and essentially switched between the 0° and 180° ports of a hybrid coupler and $\pi/2$ delay line. This circuit was developed in Japan for 4 GHz digital radio systems.

This basic circuit is not limited to the use of diodes for the phase switch but can use transistors or FET's as the switch elements; i.e., Dr. Carl Ryan[7] developed a 0-90° gigabit rate PSK modulator using a 90° hybrid with one gigabit bipolar logic IC's as a SP2T logic switch for the 0-90° PSK modulator using a circuit similar to that of Figure 2e.

The doubly balanced PSK modulator of Figure 3d is the most widely used PSK modulator in the world today and is available in flat pack units suitable for MIC circuits at very low cost for frequencies up to 20 GHz. This modulator uses quad-diode Schottky-barrier diodes. For PSK operation, the doubly balanced modulator is optimized for exact phase length (0, 180°), minimal amplitude modulation (less than 0.1 dB), and high interport isolation instead of the conversion loss requirements of mixer applications.

Dual-Gate FET PSK and QPSK Modulators

Dr. Charles Leichti of Hewlett Packard has described small signal characteristics of a GaAs FET with two 1 μm Schottky-barrier gates (dual-gate MESFET). These characteristics are shown in Figure 7. At 10 GHz, the MESFET exhibited 18 dB gain. Variation of the second gate potential yielded a 44 dB gain modulation range. Pulse modulation of an RF carrier with 70 ps rise and fall time was demonstrated, showing that an 8 GHz carrier could be switched within around half a cycle. For biphase modulation, as suggested by Dr. Leichti, two dual-gate MESFET's can be operated in parallel with a common drain output. 0° and 180° shifted carriers are fed to the first gates and complimentary modulating voltaged are applied to the second gates as shown in Figure 8.

This approach to PSK modulation has unusual benefits. One benefit is the potential elimination of the normally difficult diode driver circuit and its replacement by equally fast FET logic. The other is a key benefit to the entire digital communication system relative to clock or timing recovery which derives its information from the repetition of this transition region between bits. The conventional diode PSK modulator notches or reduces carrier power during each transition thereby decreasing the power and phase information available to the receiver bit synchronizer (clock recovery circuit). The FET PSK modulator does not notch the carrier during each transition region, but properly designed, virtually <u>inserts</u> each bit burst into the bit stream with the timing and phase ambiguity greatly minimized at the start and end of each bit.

A QPSK modulator can be built as shown in Figure 9 by using four dual-gate FET's operated in parallel with commonly coupled drain output. 0°, 90°, 180°, and 270° shifted carriers are applied to the first gates and one data stream using complementary voltages is applied to the first gates of the FET's driven by 0° and 180° carriers and the other data stream is applied using complementary voltages to the first gates of the FET's driven by 90° and 270° carriers. Because of the under-100 ps transition time capability of the dual-gate FET, QPSK modulated carriers can be produced at data rates up to 2 gigabits with the same phase change rectangularity typical of a 400 megabit signal using standard diode PSK modulator techniques with 1-nanosecond rise time.

References

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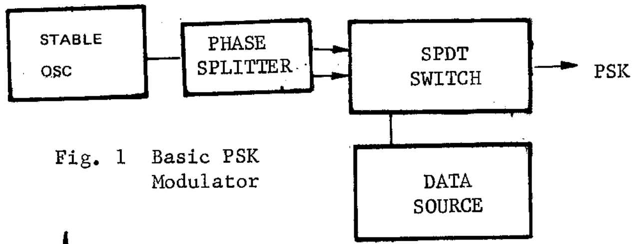


Fig. 1 Basic PSK Modulator

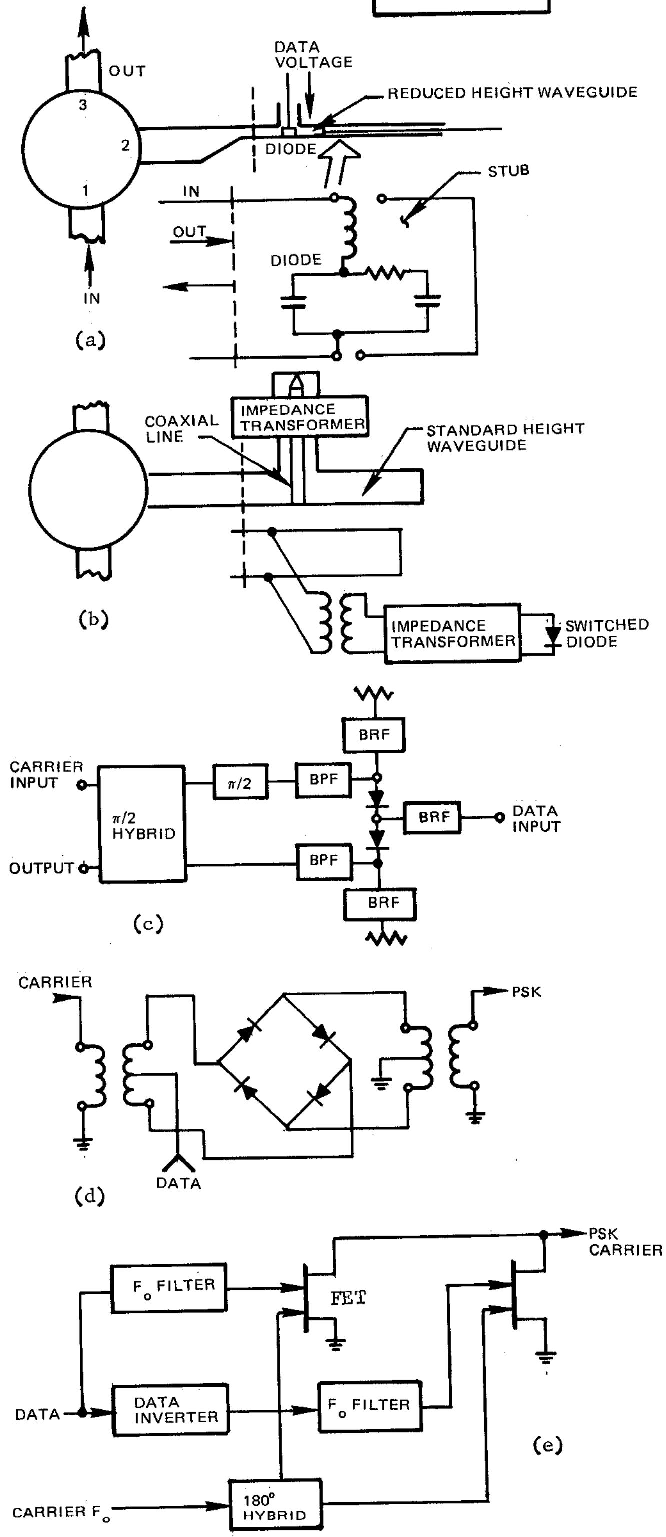
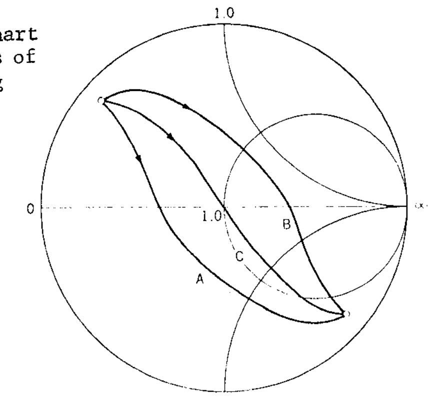


Fig. 2 Various PSK Modulators

Fig. 3 Smith Chart Showing Results of Diode Switching



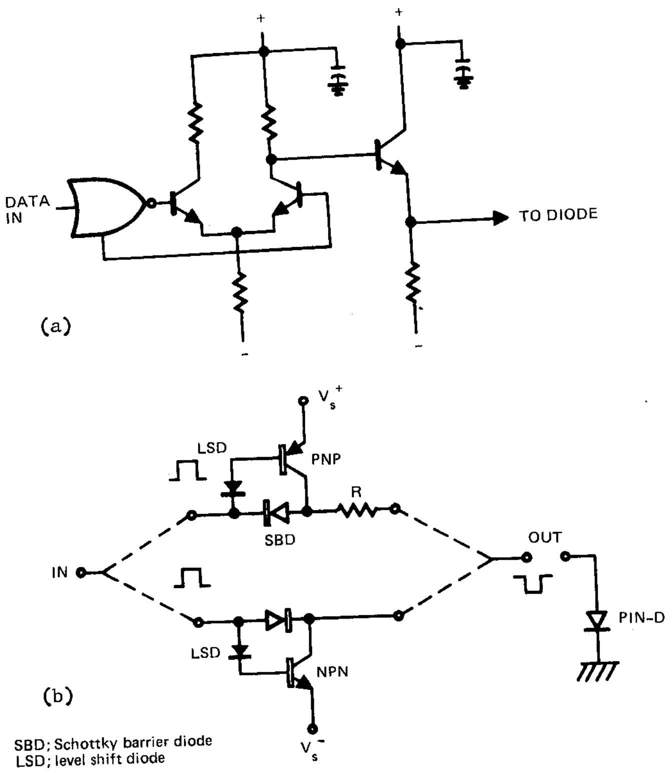


Fig. 4 Low Power (a) and High Power (b) Diode Switching Driver Circuits

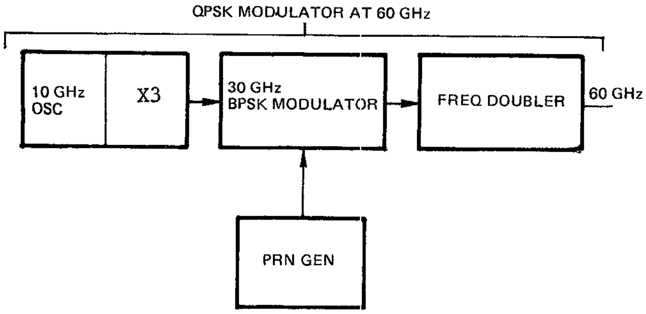


Fig. 5 60 GHz PSK Modulator System

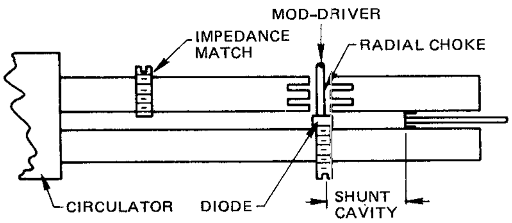


Fig. 6a Cross Section of 30 GHz Waveguide PSK Modulator

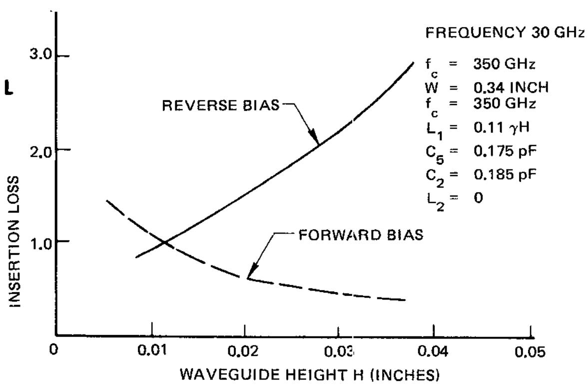


Fig. 6b Insertion Loss vs Waveguide Height for Specific Diode Parameters

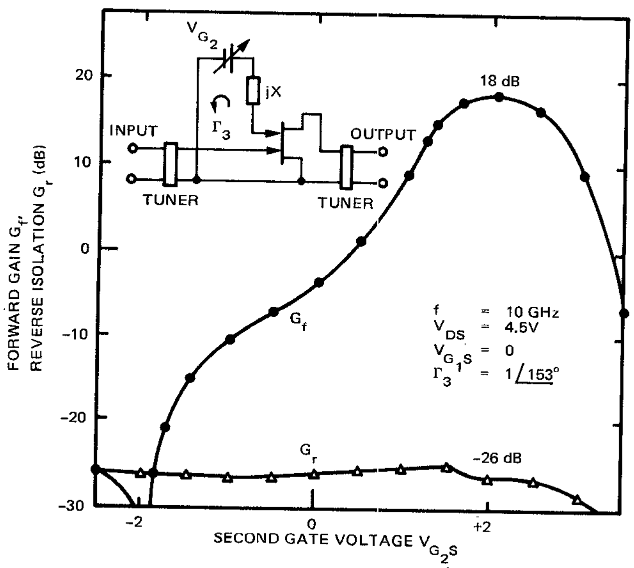
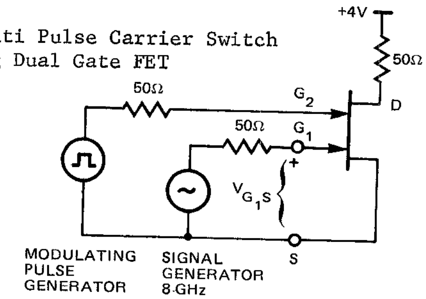


Fig. 7a Dual Gate FET Second Gate Control Characteristics - After Leichti

Fig. 7b Leichti Pulse Carrier Switch Using Dual Gate FET



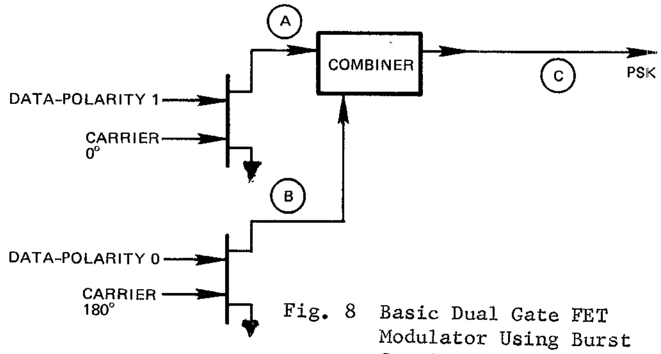
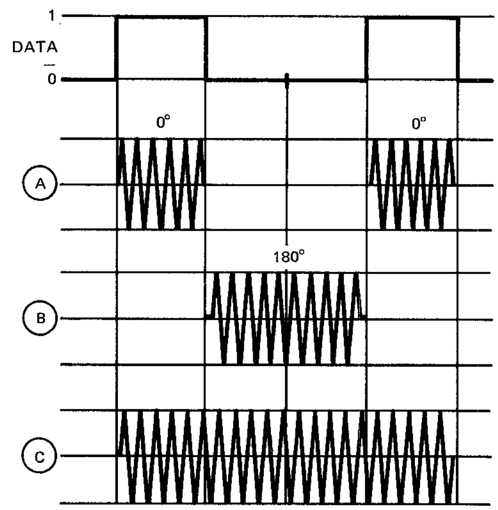


Fig. 8 Basic Dual Gate FET Modulator Using Burst Carrier Combination



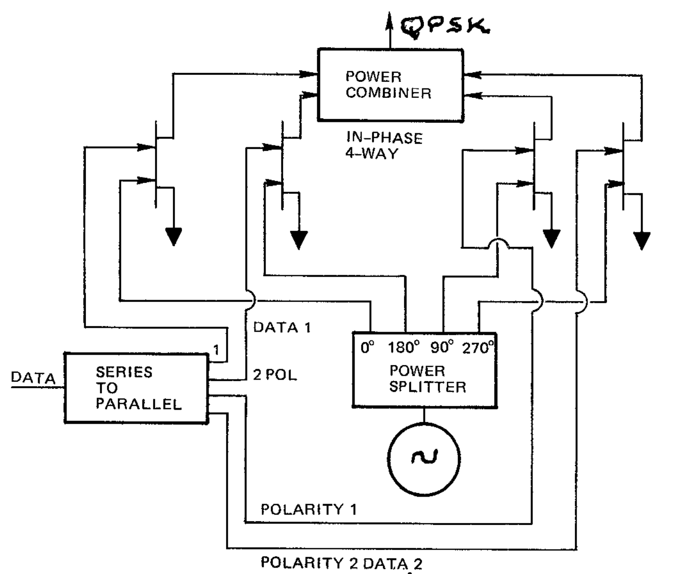


Fig. 9 Dual Gate FET QPSK Modulator