AN L-BAND, HIGH BAUD-RATE DCPSK DETECTOR/AFC DISCRIMINATOR IN MICROSTRIP

H. F. Lenzing
Bell Laboratories, Incorporated
Holmdel, New Jersey

ABSTRACT

A DCPSK detector/AFC discriminator circuit designed for a proposed millimeter-wave waveguide transmission system is described. The circuit operates at the system IF, 1.404 GHz. The baud rate is 280.8 Megabits/s. The circuit is built in micro-strip on alumina substrates.

Introduction

The digital millimeter-wave waveguide transmission system presently being designed by Bell Laboratories[1] employs an IF of 1.404 GHz and a baud rate of 280.8 Megabits/s. Path-length modulated-differentially coherent phase-shift keying (PLM-DCPSK) will be the modulation technique used on the initial two-level system.[2] In this scheme a phase reversal between two successive pulses of RF (or IF) indicates a binary "ONE" and no reversal indicates a binary "ZERO." This paper describes an IF phase detector which decodes the information residing in the phase reversals of the IF signal and also provides an automatic frequency control (AFC) error signal to control the local millimeter-wave oscillator.

DCPSK Detection

The method used to extract the information from the phase reversals in the IF signal is shown basically in Figure 1. In order to compare the phases of the successive pulses of IF signal, the delay line must be one time slot in length. In addition, the delay line must be an integral number of half-wavelengths at the IF center frequency to obtain maximum differential output voltage;

$$L = v_g \tau = \frac{v_g}{f_b}$$

where L is the delay-line length, v_g is the velocity of the wave on the delay line, f_b is the baud frequency, and τ is one time slot. Also;

$$L = \frac{M}{2} \cdot \lambda_{IF} = \frac{M}{2} \cdot \frac{v_g}{f_{IF}} ,$$

where M is an integer. Or

$$f_{IF} = \frac{M}{2} \cdot f_b$$

Choosing $M = 10$, then $f_{IF} = 5f_b$, making the delay line five wavelengths long at IF.

An example is given for decoding binary message 110. Assume the input signal amplitude equals two. The initial ONE is represented by the phase change from 0 to Π at point A. Disregarding phase retardation from left to right, since it is common to both paths, the Π phase change also occurs at points B, C, and D. The phase at point E does not yet experience this phase change, however, because it is one time slot retarded in time. This causes the recombined signals to be in phase at point F and out of phase at point G. Upon arrival of the second ONE at the input, points B, C, and D again experience a phase change of Π radians; point E is just feeling the effect of the initial ONE. Phase reinforcement and cancellation again occur at points F and G, respectively. The arrival of a ZERO does not change the phase at points B, C, or D; but because of the previous ONE the phase changes Π radians at point E. The combined signals at point G are now in phase and those at point F are out of phase producing a ZERO output.

Circuit Description

Figure 2 shows schematically the DCPSK demodulator. The difference in electrical length between the two paths is, as stated previously, five wavelengths at 1.404 GHz. The detector diodes used are Schottky-barrier diodes with forward bias applied through resistive voltage dividers. Ground return for the diodes is obtained by high-impedance quarter wavelength lines.

Simple by-pass capacitors at the output of each diode would not suffice for this application since the baud rate is one-fifth of the IF. Instead, five section low-pass filters were used for this purpose. The filters have less than 1 dB insertion loss up to 450 MHz and more than 40 dB at 1.404 GHz.

The couplers employed are (nominally) 3-dB hybrid couplers. The input coupler is slightly undercoupled to correct for delay line attenuation.

In order to derive an AFC signal from the detector additional circuitry had to be added since the DCPSK demodulator output is an even function of frequency, centered at f_o, whereas an AFC discriminator characteristic must necessarily be an odd function of frequency. This was accomplished by "tapping" the delay line at a point corresponding to 5/4 wavelengths with two 4.8-dB couplers as shown in Figure 3. Recombining these "tapped" signals in a 3-dB coupler provides the discriminator characteristic required.[3] The diodes used are the same as in the DCPSK detector connected in a shunt configuration and biased by means of resistive voltage dividers. The voltage unbalance between points A and B is differentially amplified and used as the AFC error signal.

Figure 4 shows the swept frequency characteristics of the DCPSK demodulator outputs across 50-ohm loads. The "ZERO" output is maximum and the "ONE" output is zero at the center frequency of 1.404 GHz. This situation reverses at the frequencies at which the delay line is nine half-wave lengths long or eleven half-wavelengths long. Denoting these frequencies by f_L and f_U, respectively, then

$$f_L = \frac{9}{10} f_o$$

$$f_U = \frac{11}{10} f_o$$

and

$$f_U - f_L = \frac{1}{5} f_o = f_b$$

therefore the minimum bandwidth at IF is the baud frequency.

Figure 5A shows the output of the detector (differentially amplified with unity gain) for a pseudo-random word input of 11101000. Horizontal scale represents one time slot per division. For a 3-dBm input signal voltage output is approximately 100 mV across 50 ohms.

The eye diagram corresponding to this output is shown in Figure 5B.

Construction

The entire circuit is constructed in microstrip on 0.025 inch 99.5 percent pure $A\ell_2O_3$ substrates ($\varepsilon_r \doteq 10$) with chrome-gold metallization. Four separate substrates are used with a soldered interconnections. A photograph of the circuit is shown in Figure 6.

The circuit is 3.5×5 inches at the widest points. The entire delay line is approximately 16 inches long, the first 4 inches being used for the AFC discriminator delay line. The bends in the delay line had to be compensated to keep internal reflections, which can cause errors, to a minimum.

The five directional couplers in the circuit are four-line interdigitated quarter wavelength couplers with wire crossovers.[4,5] The Schottky-barrier detector diodes are beam leaded and are TC-bonded to the substrate. The other components, i.e.,; resistors and capacitors, are lumped element and are soldered to the substrate.

Acknowledgment

I wish to thank J. H. Mullins for his many valuable suggestions and advice during the course of this work, P. J. McCleer for his analysis of interdigitated microstrip couplers, and S. Nussbaum for his technical assistance.

References

1. P. T. Hutchison, "A Digital Millimeter Wave Waveguide Transmission System," IEEE Conference on Trunk Telecommunications by Guided Waves, September 29, 1970 - October 2, 1970. Conference Publication #71.

2. W. J. Clemetson, N. D. Kenyon, K. Kurokawa, W. O. Schlosser and B. Owen, "An Experimental MM Wave High-Speed Path-Length Modulator," 1970 ISSCC, February 1970. Digest of Technical Papers, pp. 20-21.

3. R. J. Mohr, "Broad-Band Microwave Discriminator," IEEE Trans. MTT, Volume MTT-11, Number 4, July, 1963, pp. 263-264.

4. P. J. McCleer, private communication.

5. J. Hundewadt and H. Flabb, "Increasing the Coupling Factor of Coupled Microstrips by Means of the Interdigital Structure," Nachrichtentach Z., August, 1971, pp. 424-426.

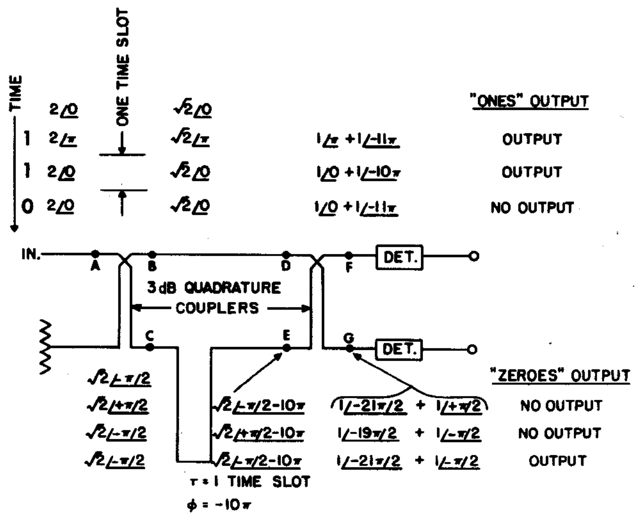

FIG.1 DECODING OF BINARY WORD 110

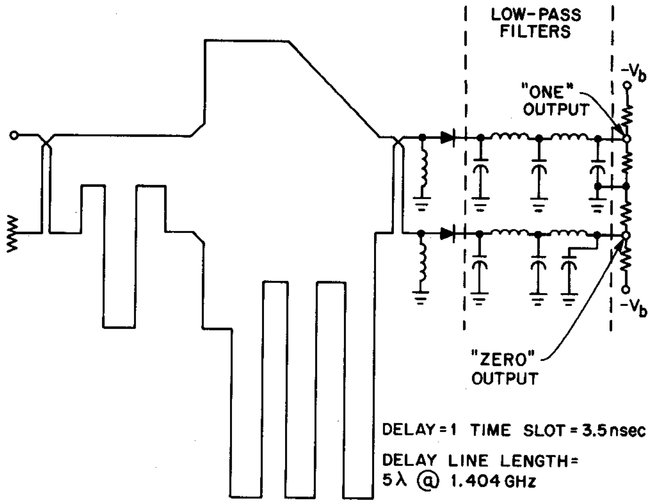

FIG. 2 DCPSK DETECTOR

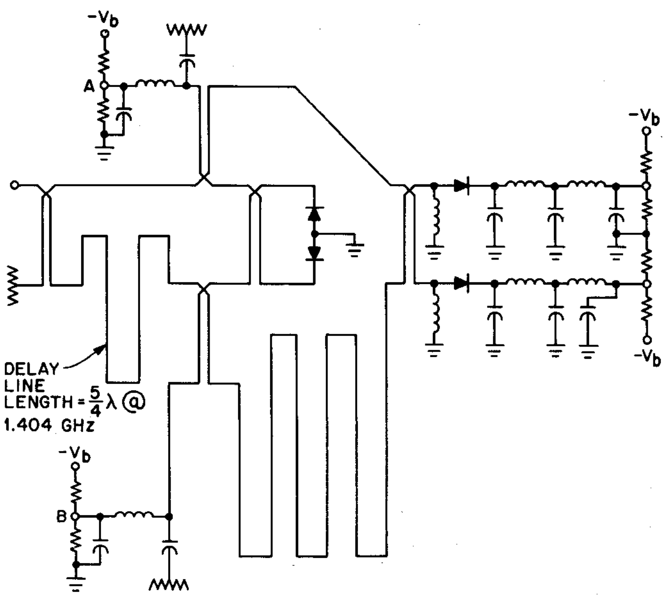

FIG. 3 DCPSK DETECTOR / AFC DISCRIMINATOR

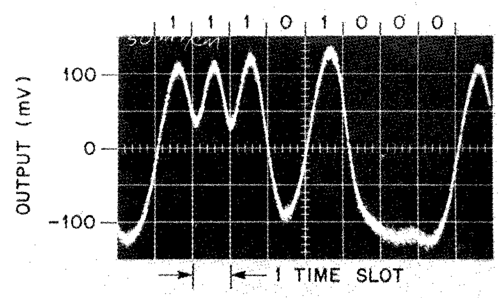

FIG. 5a DIFFERENTIAL OUTPUT OF DCPSK DETECTOR FOR BINARY WORD 11101000

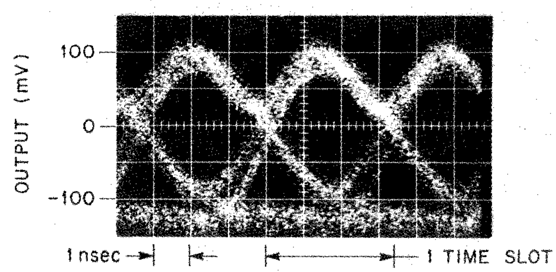

FIG. 5b EYE DIAGRAM FOR OUTPUT SHOWN IN 5a

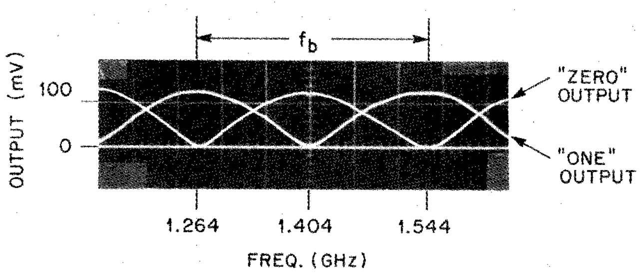

FIG. 4 SWEPT FREQUENCY OUTPUT OF DCPSK DETECTOR

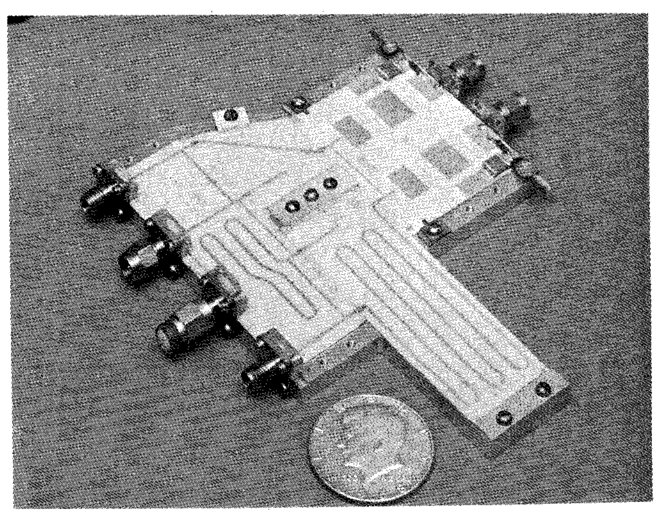

FIG. 6 DCPSK DETECTOR/AFC DISCRIMINATOR IN MICROSTRIP →