This is independent of Z_0, as long as Z_0 is not perfectly resonant at this requency. Thus, for these values of frequency the network acts like a current transformer.

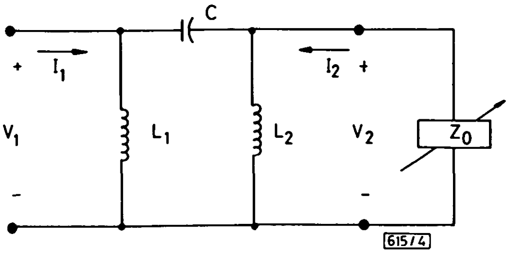

Fig. 4 *'Pi' circuit with arbitrary load impedance*

The circuit of Fig. 3 is not suitable as a current transformer. However, the 'pi' circuit of Fig. 4 acts as a current transformer at the frequency

$$\omega = \frac{1}{\sqrt{[(L_1 + L_2)C]}} \tag{13}$$

In summary, it has been shown that an arbitrary two-port network will operate as a voltage transformer at those frequencies for which $g_{22} = 0$ and as a current transformer at those frequencies for which $h_{22} = 0$. These results are independent of load provided that, at the frequencies of interest, $Z_0 \neq 0$ and $Z_0 \neq \infty$, respectively.

J. A. HEINEN
R. J. NIEDERJOHN

Department of Electrical Engineering & Computer Science
Marquette University
Milwaukee, WI 53233, USA

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DEMODULATION OF OPTICAL DPSK USING IN-PHASE AND QUADRATURE DETECTION

Indexing terms: Optical communication, Optical modulation

A 140 Mbit/s optical DPSK system experiment employing a 90 degree optical hybrid to achieve in-phase and quadrature detection is reported. The principle of the optical hybrid is outlined and the effect of polarisation misalignment on the optical performance is compared with that for standard homodyne/heterodyne detection.

Introduction: Heterodyne detection has been shown to improve receiver sensitivity at moderate bit rates,[1] but, owing to the wider receiver bandwidth required, this has not yet been possible for gigabit/second data rates. Even though homodyne detection overcomes this limitation, the optical phase lock loop requirement is, at present, a formidable problem.[1] A suitable alternative is multiport detection.[2,3] This technique offers heterodyne system performance, overcomes the need for an optical phase lock loop and allows homodyne receiver bandwidths to be used. However, for multiport detection to be practicable, the required quadrature phase relationships must be achieved without the need for continual optical path length adjustments. One experiment[3] solved this by using a three-phase technique (a 3 × 3 multiport). This letter reports the first use of an alternative approach based on the 90 degree optical hybrid;[4] this technique uses the phase relationship between the field components of linear and circularly polarised light. Experimental results based on such a hybrid are reported here for a 140 Mbit/s DPSK transmission system.

Optical hybrid principle: The received signal and local oscillator fields are summed in a 2 × 2 fibre coupler and the resulting output applied to a polarisation-selective cube beam splitter (see Fig. 1). This resolves the signal and local oscillator into orthogonal field components: those aligned with the ordinary axis appear at output O, while those aligned with the extraordinary axis appear at output E. Squaring each of these outputs after photodetection (with phase modulation the squaring process is replaced by a delay multiplier, otherwise the modulation term is lost), ignoring DC terms and summing gives

$$V_{o/p} = 4P_L P_S f(t) f(t - T)\{P_{OS} P_{OL} \cos^2(\Phi(t)) + (1 - P_{OS})(1 - P_{OL}) \cos^2(\Phi(t) + d_L - d_S)\} \tag{1}$$

where L and S subscripts indicate association with the local oscillator or signal, respectively, P is the power at the input to the optical hybrid, P_O is the proportion of P in the ordinary reference plane, d is the phase difference between the extraordinary and ordinary field components, $\Phi(t)$ is the instantaneous phase difference between the field components in the ordinary plane, $f(t)$ represents the modulation (a mark is $+1$, a space is -1), and $f(t - T)$ is $f(t)$ delayed by the bit time T.

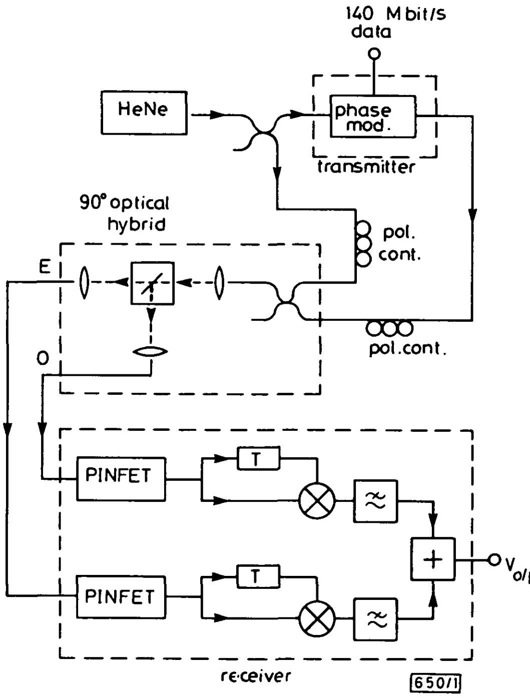

Fig. 1 *Experimental arrangement*

If $P_{OS} = P_{OL} = 1/2$, $d_L - d_S = 90$ degrees and any change in $\Phi(t)$ is negligibly small during the bit time, eqn. 1 becomes independent of $\Phi(t)$ and simplifies to

$$V_{o/p} = P_L P_S f(t) f(t - T) \tag{2}$$

Experimental arrangement: This is shown in Fig. 1. For experimental convenience the local oscillator and transmitter were derived from a single HeNe laser using a fibre coupler; however, the principles involved still apply when separate sources are used. The local oscillator was connected to one input of the 90 degree optical hybrid via a fibre polarisation controller. The transmitter signal, after being modulated at 140 Mbit/s by the $LiNbO_3$ phase modulator, was connected to the other input via a second fibre polarisation controller. Both outputs from the optical hybrid were connected to similar receivers, each of which consisted of a standard direct detection PINFET receiver, modular gain blocks, a DPSK delay demodulator providing a delay equal to the bit time and a lowpass filter. After summing the lowpass filter outputs in an electrical combiner, the signal was regenerated in the usual way and then analysed by an error detector.

Results and discussion: Fig. 2 shows the measured bit error rate for a 10-bit word (×) and a $2^6 - 1$ PRBS (○). Despite the large penalty between theory and practice (14 dB), these results confirm in-phase and quadrature detection is feasible using a 90 degree optical hybrid. However, the causes of the penalty need to be verified and overcome before this detection technique can be considered as being practically viable. At least 2 dB is associated with the local oscillator power being limited to 2 μW; the rest is attributed to polarisation misalignment and/or unequal path lengths between the optical

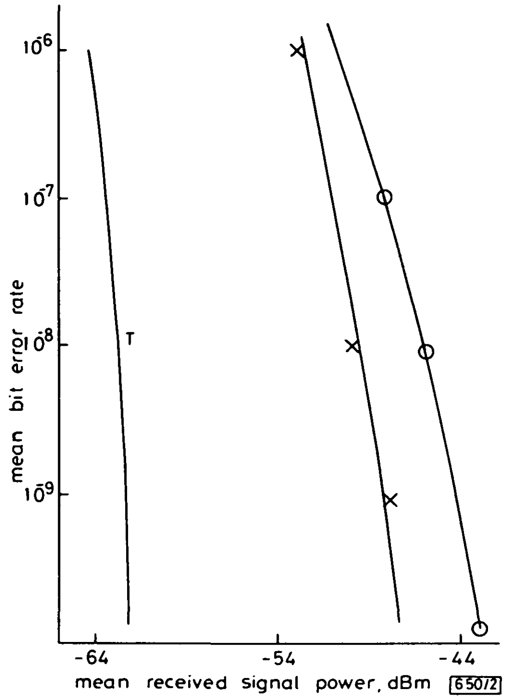

Fig. 2 *Bit error rate curves for 140 Mbit/s DPSK*

Theory: shot-noise-limited performance (T)
Measured: $2^6 - 1$ PRBS (○); 10-bit word (×)

hybrid outputs and the point where they are combined. The calculated polarisation misalignment penalty for a stable, circularly polarised local oscillator is given by (a) in Fig. 3. All of the combinations of ΔP_{OS} and $\Delta\theta$ (the offset values of P_{OS} and d_S about their respective optimum values) which intercept on this curve, or within the enclosed area, give a performance degradation of 1 dB or less; (b) is a similar curve for standard homodyne/heterodyne detection. These curves show the optical hybrid is very sensitive to polarisation misalignment, and this is emphasised by the fact that, if the 7 dB penalty curve were to be plotted, it would coincide with curve (b). In practice the penalty may be worse than indicated by (a)

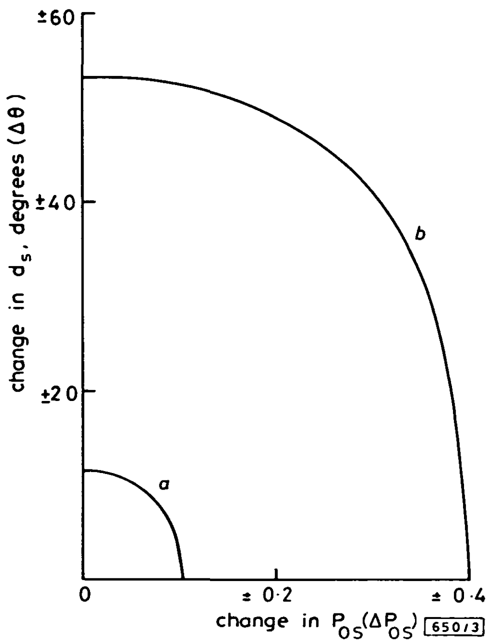

Fig. 3 *Polarisation misalignment penalty*

a Optical hybrid multiport detection
b Standard homodyne/heterodyne detection

because the local oscillator polarisation may not have been set exactly.

Conclusions: This experiment has shown that the optical hybrid can be used for in-phase and quadrature detection of DPSK; ASK can also be detected, provided that the delay in the electrical multiplier is set to zero. The optical hybrid requires less processing electronics than other types of multiport detection, and as polarisation-selective fibre couplers become available[5] it will be a very simple device to implement. Further work is needed to establish whether the increased sensitivity to polarisation misalignment can be eliminated using automatic polarisation control.

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T. G. HODGKINSON
R. A. HARMON
D. W. SMITH

31st July 1985

British Telecom Research Laboratories
Martlesham Heath
Ipswich, Suffolk IP5 7RE, United Kingdom

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PRECISE CONTROL OF REGGIA–SPENCER PHASE SHIFTER

Indexing terms: Microwave circuits and systems, Ferrite devices, Phase shifters

A precise controlled Reggia–Spencer phase shifter is presented. By measuring the stray magnetic density outside the waveguide, a controlling factor for phase shift is obtained which offers the possibility to realise an electronic control system.

Introduction: The Reggia-Spencer phase shifter[1] offers many advantages: very simple construction, low control field, large amount of phase shift per unit length of the ferrite rod and low insertion loss. Its principal drawback is its poor calibration accuracy. Hysteresis can cause changes of 40 degrees or more in the phase shift prevailing of a given applied magnetic field. The method described in this letter permits precise electronic control of phase shift, being independent of hysteresis.

Phase shift analysis: For an unsaturated ferrite medium at microwave frequencies and a DC magnetic field applied in the z-direction, the permeability tensor is given by

$$[b] = \mu_0 \begin{bmatrix} \mu & -jk & 0 \\ jk & \mu & 0 \\ 0 & 0 & \mu_z \end{bmatrix} [h_i] \tag{1}$$