

References

- 1 KAWAMURA, Y., and ASAHI, H.: 'Molecular beam epitaxial growth of InGaP/InAlP quantum well structures for the visible wavelength region', *Appl. Phys. Lett.*, 1984, **45**, pp. 152-154
- 2 TANAKA, H., KAWAMURA, Y., and ASAHI, H.: 'Room-temperature operation of MBE-grown InGaP/InGaAlP MQW visible laser diodes', *Electron. Lett.*, 1986, **22**, pp. 707-708
- 3 ISHIBASHI, T., TARUCHA, S., and OKAMOTO, H.: 'Exciton associated optical absorption spectra of AlAs/GaAs superlattices at 300K'. Int. symp. on GaAs and related compounds, Inst. Phys. Conf. Ser. no. 63, 1982, pp. 578-579
- 4 WEINER, J. S., CHEMLA, D. S., MILLER, D. A. B., WOOD, T. H., SIVCO, D., and CHO, A. Y.: 'Room-temperature excitons in 1.6 μm band-gap GaInAs/AlInAs quantum wells', *Appl. Phys. Lett.*, 1985, **46**, pp. 619-621
- 5 KAWAMURA, Y., WAKITA, K., and ASAHI, H.: 'Observation of heavy-hole and light-hole excitons in InGaAs/InAlAs MQW structures at room temperature', *Electron. Lett.*, 1985, **21**, pp. 371-373
- 6 ALIBERT, C., BCRDURE, G., LAUGIER, A., and CHEVALLIER, J.: 'Electroreflectance and band structure of $\text{Ga}_{1-x}\text{In}_x\text{P}$ alloys', *Phys. Rev. B*, 1972, **6**, pp. 1301-1310
- 7 GONDA, S.: 'Design of semiconductor heterojunctions', *Oyo Buturi*, 1986, **55**, pp. 570-578

POLARISATION-INSENSITIVE OPTICAL HETERODYNE RECEIVER FOR COHERENT FSK COMMUNICATIONS

Indexing terms: Optical communications, Optical receivers

An optical FSK heterodyne communications receiver is proposed using a polarisation diversity technique which has a reduced level of complexity. The proposed receiver is constructed and tested at 100 kbit/s and shown to have a maximum fluctuation in sensitivity of 17% over conditions of originally complete polarisation fading.

Introduction: It is well known that for fibre-optic interferometric systems there is a problem with polarisation drifting, which leads to signal fading.¹ One solution is to use polarisation-preserving or high-birefringence fibre² throughout; however, this is expensive. Another solution is to use a polarisation controller in one arm of the interferometer, which can be manually adjustable³ or electronically adjustable.⁴ With a view to practical field use the latter has been incorporated into automatic polarisation state control systems. Electronic feedback is derived from a set of polarisation analysers and optical detectors (usually four) at one output of the interferometer.⁵ Such systems often do not achieve the endlessness of control that is required.

A third solution is to use a passive polarisation processing technique⁶ in which the output of the interferometer is sampled through three different polarisation analysers, with carefully chosen orientations. Signal processing electronics are used to combine the outputs from three detectors in such a way as to make the resulting output stable over all polarisation conditions. Another such polarisation diversity technique, using only two detectors, has been reported⁷ which uses electronic phase compensation between the detectors. For either method there is a trade-off between the complexity of the electronics and the degree of stability. This letter reports a polarisation-insensitive heterodyne detector system, for use in a coherent communications receiver, using a polarisation diversity technique with an overall reduction in complexity. This is achieved by considering the fact that in a digital FSK coherent communication channel the carrier phase information need not be preserved, but that the frequency of a signal of stable amplitude is required. For this reason one degree of freedom of polarisation drift can be removed without loss of information.

Description of receiver: The proposed receiver architecture is shown in bulk optical form in Fig. 1a together with its test system. The signal processing electronics is shown in Fig. 1b. The receiver itself is shown enclosed by a broken line, and consists of a polariser, a beam-splitter, a polarisation beam-splitter and two optical detectors. The light from the laser is

split into two beams, one representing the local oscillator of the receiver and another providing the transmission signals. The polariser is adjusted so that equal local oscillator power falls on each detector, which is necessary to simplify the signal processing. Data transmission is simulated by pulses of 40 MHz. This is not a full FSK implementation and no intermediate frequency is present, but is used for simplicity. The processing electronics presented can be easily upgraded for use in a practical FSK system. For test purposes an all-fibre polarisation controller³ and a piezoelectric polarisation modulator⁴ are included in the transmission arm of the interferometer. The received light is combined with the local oscillator at the first beam-splitter. The polarisation beam-splitter then produces orthogonal polarisation components of both local oscillator and data at two separate detectors, where they mix to give two heterodyne signals. As the polarisation state of the received light changes there will always be a signal on at least one of the two detectors. Each signal is then filtered to obtain the required frequency (40 MHz) only—the 'frequency decision'. The filter outputs are then amplified and passed through two envelope detectors. It is here that the phase information of each heterodyne signal is removed. This is important since the phase difference between the two 40 MHz signals will change as the incoming polarisation state changes, and recombination without this step will reintroduce the possibility of signal fading. Hence, with this degree of freedom removed, the signal processing consists merely of a square-and-add function. This will compensate for polarisation drift-induced signal power changes at each detector. In the test receiver this was done using two custom differential amplifiers, operating in the nonlinear region, employed as variable transconductance amplifiers. A variable ratio adder was the final stage and can be adjusted to take account of differences in sensitivity between each detection channel. Once the receiver is operational this adjustment need not be repeated.

Theory: If we define S as the detector signal after filtering, L as the local oscillator power, D as the data signal power and ϕ as the data signal phase, then

$$S_A = (L_A D_A)^{1/2} \cos(2\pi ft - \phi_A)$$

and

$$S_B = (L_B D_B)^{1/2} \cos(2\pi ft - \phi_B)$$

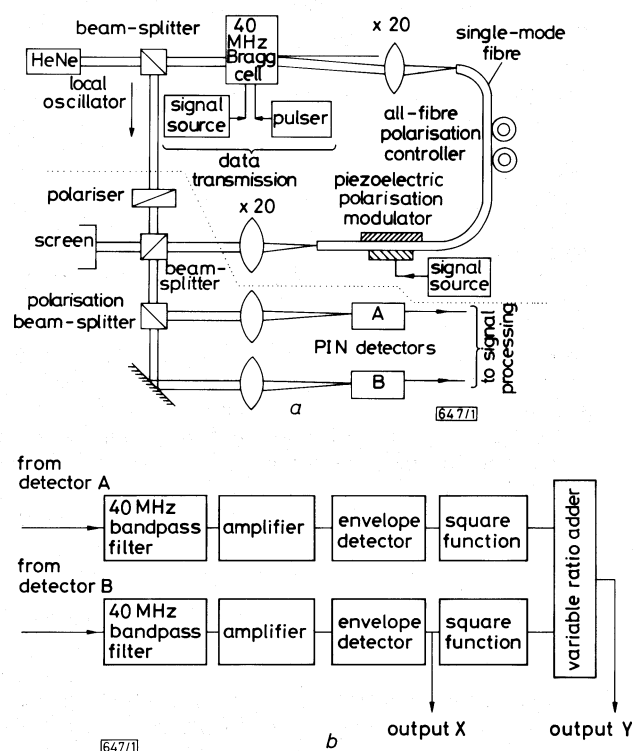


Fig. 1
 a Polarisation-insensitive optical heterodyne receiver (enclosed by broken line) together with coherent FSK test system
 b Decoding circuitry for optical receiver

are the signals in channels A and B (assuming equal detector gains) and $f = 40$ MHz.

As the transmitted optical polarisation state changes then D and ϕ in each channel will change. There exists then the possibility that $S_A = -S_B$, and hence simple addition may result in fading. For this reason the modulus of each signal is taken, using envelope detection; then

$$|S_A| = (L_A D_A)^{1/2}$$

$$|S_B| = (L_B D_B)^{1/2}$$

By making $L_A = L_B = L$, using the polariser, then

$$|S_A|^2 + |S_B|^2 = L(D_A + D_B)$$

Therefore, since $D_A + D_B = \text{constant}$, then a square-and-add operation produces a constant bit signal output.

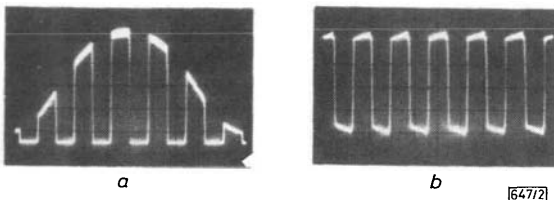


Fig. 2 Single-detector (a) and two-detector (polarisation diversity—b) bit signal outputs from optical receiver under conditions of severe polarisation fading at 15 kHz

Experiment: The receiver was tested by first operating the polarisation modulator at a frequency of 15 kHz and by transmitting 40 MHz pulses at a frequency of 100 kHz. The signal representative of straightforward heterodyne detection, with the polarisation beam-splitter removed, was taken at output X (see Fig. 1b) and is shown in Fig. 2a. The corresponding signal at the processed output Y, with the polarisation beam-splitter in place, is shown in Fig. 2b.

The receiver was further tested by moving the fibre polarisation controller through a series of small steps and measuring the pulse heights at X and Y, with the polarisation beam-splitter removed and in place, respectively. The results of normalised pulse height are plotted in Fig. 3.

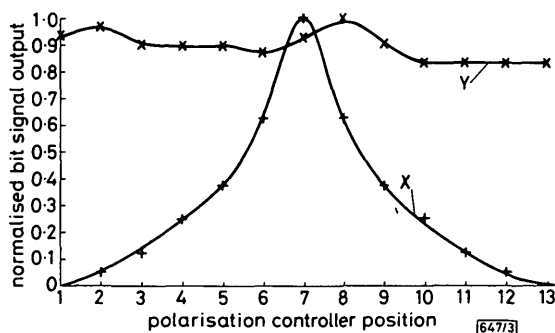


Fig. 3 Normalised bit signal strength against polarisation controller setting for single-detector (X) and two-detector (polarisation diversity—Y) optical receiver

Discussion: The polarisation fading evident in Fig. 2a is seen to be quite small in the processed output of Fig. 2b. The fluctuation in sensitivity that is indicated in the plotted processed output of Fig. 3 is due to imbalances in the optical circuit and imperfections in the square-and-add circuits. The results indicate a significant reduction in sensitivity to polarisation changes, from DC to at least 15 kHz, over unprocessed detection. The bit signal strength variation, over original conditions of complete fading, has been reduced to a maximum of 17%; however, the proposed receiver performance could be significantly improved by more accurate balancing of the two detection channels.

Conclusion: An overall reduction in complexity over previous processing techniques has been achieved by considering the specific requirements of a coherent heterodyne FSK communications receiver. This should lead to improved noise performance and, combined with its passive operation, it lends itself to the production of a stable and compact receiver

module, in fibre-optic or integrated-optic form. The accuracy of the square function circuit and the stability of the local oscillator polarisation state are the most important design features of this receiver. An integrated-optic front end with fixed polarisation laser diodes and thin-film waveguide interferometry should provide the best solution.

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References

- 1 STOWE, D. W., MOORE, D. R., and PRIEST, R. G.: 'Polarization fading in fiber interferometric sensors', *IEEE J. Quantum Electron.*, 1982, **QE-18**, pp. 1644–1647
- 2 BLASZYK, E., and HAWK, R. M.: 'Polarization retaining single-mode fiber with improved coil performance'. SPIE conference on fiber optic and laser sensors III, 1985, **566**, pp. 381–386
- 3 LEFEVRE, H. C.: 'Single-mode fibre fractional wave devices and polarisation controllers', *Electron. Lett.*, 1980, **16**, pp. 778–780
- 4 JOHNSON, M.: 'In-line fiber-optical polarization transformer', *Appl. Opt.*, 1979, **18**, pp. 1288–1289
- 5 HONMOU, H., YAMAZAKI, S., EMURA, K., ISHIKAWA, R., MITO, I., SHIKADA, M., and MINEMURA, K.: 'Stabilisation of heterodyne receiver sensitivity with automatic polarisation control system', *Electron. Lett.*, 1986, **22**, pp. 1181–1182
- 6 FRIGO, N. J., DANDRIDGE, A., and TVETEN, A. B.: 'Technique for elimination of polarisation fading in fibre interferometers', *ibid.*, 1984, **20**, pp. 319–320
- 7 OKOSHI, T., RYU, S., and KIKUCHI, K.: 'Polarization-diversity receiver for heterodyne/coherent optical fiber communications'. IOOC '83, June 1983, Paper 30C3-2, pp. 386–387

NEW CUT OF A QUARTZ RESONATOR WITH A LINEAR TEMPERATURE/FREQUENCY CHARACTERISTIC

Indexing terms: Piezoelectric devices and materials, Resonators

The letter describes a new cut of a quartz resonator with a linear temperature/frequency characteristic used as a sensor for precise temperature measurements. The newly developed thermosensitive quartz resonator has some important advantages: obtaining comparatively easily and reproducibly a precise orientation of the piezoelement, good linearity of the temperature/frequency characteristic and a clear frequency spectrum in a wide temperature interval. The first-order temperature coefficient is 38 parts in $10^6/\text{deg C}$ and the frequency of operation on the third overtone is about 26.5 MHz at 0°C . That leads to an increase of approximately 1000 Hz/deg C, with a sensitivity of 0.0001 deg C. These qualities of the thermosensitive quartz resonator make possible its use in devices for precise temperature measurements.

Introduction: The letter concerns the subject of piezoelectric resonators and, in particular, a new cut of a quartz resonator with a linear temperature/frequency characteristic used as a sensor for precise temperature measurements.

In devices of this type, the frequency change f as a function of the temperature T may be expressed by

$$\frac{\Delta f}{f_0} = T_f^{(1)}(\Delta T) + T_f^{(2)}(\Delta T)^2 + T_f^{(3)}(\Delta T)^3 \quad (1)$$

where $\Delta f = f - f_0$, $\Delta T = T - T_0$ and f_0 are the frequencies of the resonator at a definite temperature T_0 , which is usually 25°C .