sition temperature. This can be interpreted as the network having weaker bonds in between the atoms. It is therefore conceivable that some sort of dynamic annealing takes place in the P-glass to a higher degree than in the HIPOX which has a more rigid structure.

We have shown that MeV ion implantation of erbium is a viable technique for making silica glass optically active. P-glass appears to be less susceptible than HIPOX and Suprasil to radiation-induced structural damage. This is implied by long lifetimes of $10 \cdot 0 \pm 0 \cdot 5$ ms for Er peak concentrations of 0·1 at. %, independent of thermal annealing. As a comparison, 10 ms is a typical value found for Er doped fibres.

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ANALYSIS OF RECEIVER USING INJECTION-LOCKED SEMICONDUCTOR LASER FOR DIRECT DEMODULATION OF PSK OPTICAL SIGNALS

Indexing terms: Optical receivers, Semiconductor lasers, Demodulators, Optical modulation

A receiver for PSK optical signals is analysed. The demodulation is performed directly by launching the received signal into an injection-locked semiconductor laser. The locked laser converts phase modulation into current modulation, which is sent to the data detection system after some signal processing. The signal to noise ratio of the receiver can reach $4599\phi^2$ for a 100 Mbit/s rate and a 100 kHz emitter linewidth, where ϕ is the phase deviation of the modulator.

Introduction: Optical injection locking of a semiconductor laser is a technique enabling the conversion of frequency to phase modulation,[1–3] homodyne detection of PSK signals[4] and direct demodulation of optical FSK signals.[5]

This technique uses the light from a laser to optically inject another laser. Locking occurs when the frequency difference between the emitter and receiver lasers falls within the locking range. Below a critical injection level, the mode emitted by the locked laser is stable over the whole locking range.[6] The magnitude of the critical injection level depends on a number of factors such as the average emitted power, gain nonlinearities and the amount of spontaneous emission coupled to the lasing mode.[7]

Direct detection is a well known technique for receivers processing amplitude modulated optical signals. The receiver to be analysed performs a *direct* demodulation of *phase* modulated optical signals. The demodulation is performed by launching the received signal into the cavity of a semiconductor laser, which is tuned to obtain injection-locking condition. The modulation phase deviation can take any values in the phase detuning range for all the injection levels below the critical level. The phase detuning range is 180° large for a DFB laser structure,[2] for which the usual nonsymmetrical reduction of locking bandwidth does not occur. In practice, the injected power in the receiver has been sufficiently attenuated during transmission to be below the critical level.

Analysis: A schematic diagram of the receiver is shown in Fig. 1. The received optical signal is launched into a semiconductor laser, whose DC current is set to obtain injection-locking conditions. The electric current flowing through the laser diode varies in connection with the phase of the received signal. The voltage, measured across a load resistor, is integrated, equalised and bandpass filtered. The output signal is then sent to the data detection and decision system.

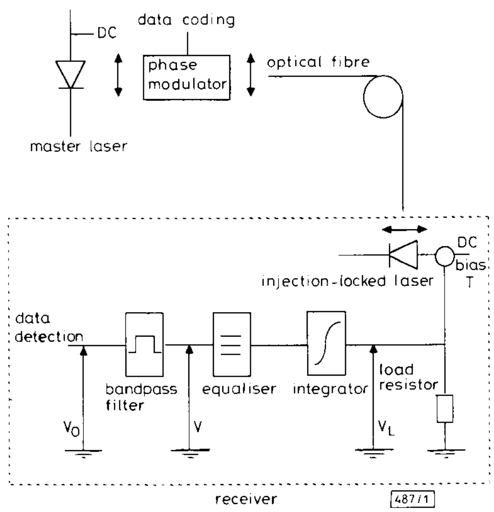

Fig. 1 *Schematic diagram of receiver for direct demodulation of PSK optical signals*

In the following analysis, the lasers are assumed to emit continuously into a single mode. Intensity and polarisation fluctuations of the received signal are neglected. A description of the scalar electric fields in terms of their complex amplitudes is used.

The optical signal incident on the receiver can be expressed as

$$E_m = \sqrt{(P_{om})} \exp j[\omega_m t + \Phi_m(t)] \tag{1}$$

P_{om} and Φ_m are the received signal power and phase, respectively. ω_m is the optical carrier frequency of the received signal. The subscript m refers to the master laser.

The received signal phase is given by

$$\Phi_m(t) = \varepsilon(t)\phi + \Phi_n(t) \tag{2}$$

$\varepsilon(t) = \pm 1$ is the transmitted data, ϕ the phase deviation of the modulator and Φ_n the quantum phase noise of the received signal, which is assumed to have a Gaussian probability distribution.[8]

The electric field of the injection-locked laser in the receiver may be written as

$$E_s = \sqrt{(P_{os})} \exp j[\omega_m t + \Phi_s(t)] \tag{3}$$

where P_{os} and Φ_s are the locked laser power and phase, respectively. The subscript s refers to the slave laser.

The interaction between the medium and the laser field can be expressed by a rate equation for the excited carrier density N_s as

$$\frac{dN_s(t)}{dt} = -\frac{N_s(t)}{\tau_e} - G_s E_s^2(t) + \frac{I}{e} + F_{Ns}(t) \tag{5}$$

where τ_e is the spontaneous carrier lifetime, G_s the gain per unit time, I/e the carrier injection rate and F_{Ns} the Langevin noise force which accounts for fluctuations of the carrier number.

This equation is considered together with that describing the time evolution of the electric field of the locked laser.[9] These equations can be linearised under the assumption that the deviation induced by the modulation is small. A larger phase deviation would result in an increase in the signal to noise ratio. Hence the present analysis corresponds to the worst case. It illustrates the general behaviour of the receiver.

The voltage V_1 across the load resistor is related to the carrier number fluctuation in the cavity n_s by the equation

$$V_1(\omega) = \beta(\omega) n_s(\omega) \tag{6}$$

where β is a coefficient depending on the electrical characteristics of the laser, the bias circuit and the load resistance.[10]

Let $S_m(\omega)$, $S_{pn}(\omega)$ and $S_{cn}(\omega)$ be the power spectral density of the data signal, of the phase fluctuations of the received signal and of the carrier number fluctuation, respectively. Thus the voltage power spectral density $S_{V1}(\omega)$ is

$$S_{V1}(\omega) = \beta^2(\omega)\{\omega^2 H(\omega) H^*(\omega)[S_m(\omega) + S_{pn}(\omega)] + S_{cn}(\omega)\} \tag{7}$$

where * represents the complex conjugate. $H(\omega)$ is the overall transfer function. Thermal noise is neglected as the quantum limit of the noise of the receiver is only considered here.

For modulation frequencies well below that of the relaxation oscillations, the transfer function of the message after the equaliser may be approximated by

$$H(\omega) = \frac{2 \sin \theta}{G_n(\alpha \sin \theta + \cos \theta)} \tag{8}$$

where G_n is the differential gain and α the phase-amplitude coupling coefficient of the receiver laser. θ is the phase detuning between the master and slave laser optical fields. The phase θ belongs to the interval $[-\pi/2 + \tan^{-1} \alpha; \pi/2 + \tan^{-1} \alpha]$ for a DFB laser structure. This phase range is wider than for a Fabry-Perot structure because the high mode discrimination resulting from the Bragg reflector avoids the locking range reduction by mode hopping.

Under the same assumption, the power spectral density of the phase fluctuation of the received signal is

$$S_{pn}(\omega) = \frac{\Delta\omega}{\omega^2} \tag{9}$$

where $\Delta\omega$ is the 3 dB angular linewidth of the emitter laser.

The power spectral density of the carrier number $S_{cn}(\omega)$ is given by

$$S_{nc}(\omega) = \frac{2R}{P_s G_n^2(\alpha \sin \theta + \cos \theta)^2} \tag{10}$$

To improve the response flatness for the message to transmit, V_1 must be integrated and equalised. For high bit rate communications, the equaliser may be designed to dampen the relaxation oscillation frequency peak. The noise power increases dramatically with decreasing frequency as a consequence of the integration. The impact of this particularity on the receiver performance may be minimised with a message code that has low power at small frequencies, as will be shown in the following Section.

The signal is bandpass filtered and the signal to noise ratio before data recovery is obtained from the ratio of message power to noise power.

$$\frac{S}{B} = \frac{\int_{\omega_1}^{\omega_2} S_{Vm}(\omega)\, d\omega}{\int_{\omega_1}^{\omega_2} S_{Vn}(\omega)\, d\omega} \tag{11}$$

where ω_1 and ω_2 are the edges of the ideal rectangular bandpass filter. Finally, the signal to noise raito becomes

$$\frac{S}{B} = \frac{\omega_1 \omega_2}{\omega_2 - \omega_1} \sigma \phi^2 \frac{1}{\dfrac{R}{2P_s \sin^2 \theta} + \Delta\omega} \tag{12}$$

where σ indicates the fraction of the message power going through the filter. β has been assumed a constant within the filter bandwidth.

Results: As an example, an MDP-2 coded signal is studied. The MDP-2 code is generated from the complex envelope of the data to transmit and an NRZ type impulsion. The MDP-2 power spectral density is a frequency translation around a subcarrier of that of the binary NRZ. The filter bandwidth is chosen to be equal to that of the mainlobe of the signal power spectral density. The width of the mainlobe is $2/T$, where T is the bit duration. In this case the parameter σ accounting for the message filtering is 91%. The receiver laser is biased at 10 mW, the subcarrier is 500 MHz and the bit rate 100 Mbit/s.

Fig. 2 shows the signal to noise ratio of the receiver as a function of the phase detuning in the case of negligible thermal noise. It is normalised to ϕ^2 and plotted for different linewidths of the emitter laser. The highest value is obtained for a phase detuning of 90° and dramatically depends on the laser emitter linewidth. This optimum phase detuning can be obtained in practice by tuning the DC bias current of the receiver laser. For an emitter linewidth of 100 kHz, the signal to noise ratio is about 4500 ϕ^2.

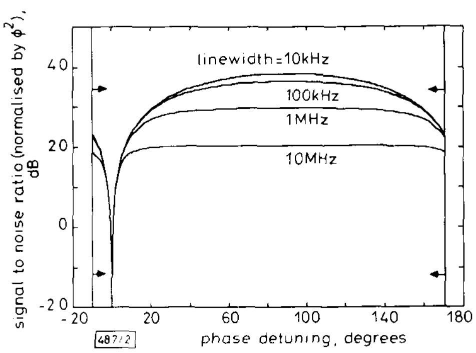

Fig. 2 *Signal to noise ratio of receiver as function of static phase detuning between emitter and receiver lasers*

Directions of arrows indicates locking range

This receiver may recover transmitted data from multiple optical carriers. The receiver frequency can be adjusted so that the selected carrier falls within its locking range. The frequency spacing between optical carriers has to be greater than the locking bandwidth. The difference must also be important enough so that intermodulation interferences do not fall within the receiver bandwidth.

The analysis of the receiver can be easily extended to the calculation of the performance of a receiver processing FSK optical signals. This type of reception has been demonstrated experimentally.[5] There, the maximum frequency deviation of the emission frequency is the half locking bandwidth, which depends on the amount of injected power in the receiver.

Conclusions: The performance of a receiver for direct demodulation of optical PSK signals has been analysed. The receiver performance has been shown to be limited by carrier and phase induced noises. The signal to noise ratio increases with decreasing emitter laser linewidth and increasing average optical power of the receiver laser. It is also enhanced by tuning the static phase difference between the laser optical fields to a 90° value. The signal to noise ratio can reach $4500\phi^2$ for a 100 Mbit/s bit rate and a 100 kHz emitter laser linewidth, where ϕ is the phase deviation generated by the modulator.

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LOW LOSS WAVEGUIDE FOUR-PORT CROSSOVER CIRCUIT AND ITS APPLICATION FOR CROSS-SLOT ANTENNA FEED

Indexing terms: Waveguides, Antennas

A novel four-port waveguide crossover circuit was developed with an insertion loss of less than 0·7 dB and an isolation of over 18 dB. The circuit was successfully used to feed a dual-polarisation cross-slot antenna backed by a cylindrical cavity.

Introduction: Conformal aperture antennas are becoming more popular as the surface area available for the antenna is becoming more limited. One common example is the implementation of aircraft radar and antenna systems. Owing to wind drag and other physical constraints, aperture antennas provide a mechanism in which to radiate electromagnetic energy without disrupting the integrity of the airframe. Also, aperture antennas can operate at much higher power levels than microstrip antennas.

Slot antennas backed by a rectangular waveguide/cavity have been studied extensively.[1–3] Very little work has been reported on slot antennas fed by a cylindrical cavity. The use of a cylindrical cavity has many advantages such as symmetrical feeding arrangement and the realisation of dual-polarisation feeding.

A four-way crossover circuit using a cylindrical cavity with four rectangular input/output ports was designed to feed a cross-slot antenna to achieve dual polarisation. Because all the input and output circuits are waveguides, the network is especially useful for high power systems and millimetre-wave applications. The crossover circuit exhibits a very low insertion loss and good isolation.

Circuit description and performance: Fig. 1 shows the four-port crossover circuit. The four rectangular waveguides are coupled to a high-Q cylindrical cavity using small rectangular aperture openings. The opening slit is 1 × 22·86 mm. The rectangular waveguide has dimensions of 10·16 × 22·86 mm and the cavity has a radius of 10 mm and a length of 33 mm. The incident wave at port 1 is coupled from the TE_{10} mode of the rectangular waveguide to the TE_{11} mode of the circular waveguide. The energy is then coupled to port 2 at the resonant frequency of the cavity, but isolated from ports 3 and 4 because the electric field in the cavity is perpendicular to the openings in ports 3 and 4. Similarly, the wave incident in port 3 is isolated from ports 1 and 2.

Fig. 2 shows the transmission between ports 1 and 2. An insertiion loss of less than 0·7 dB was measured at 10·24 GHz.

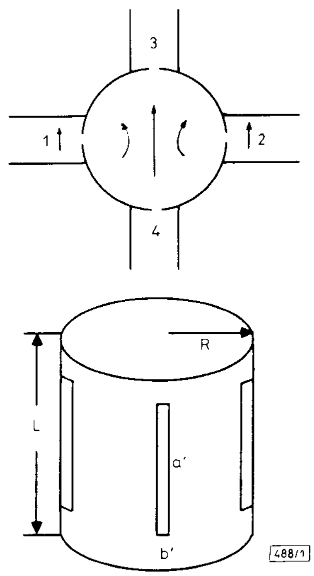

Fig. 1 *Cylindrical cavity with four input/output ports*
$R = 10{\cdot}0$ mm
$L = 33{\cdot}0$ mm
$a' = 22{\cdot}9$ mm
$b' = 1{\cdot}0$ mm

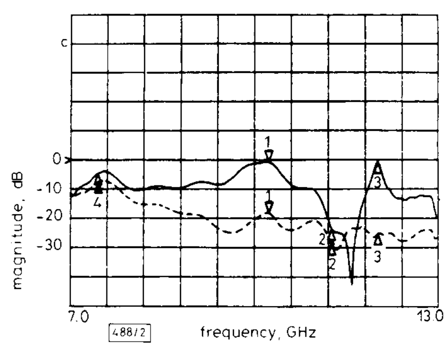

Fig. 2 *Transmission and isolation measurement for four-port crossover circuit*

Marker 1 = 10·24 GHz
——— S_{12}
- - - - S_{13} (isolation)