Nanosecond switching Phased-Array directional receivers in GaAs-AlGaAs

Guy Matmon, Gil Tidhar, Daniel Majer, Eyal Shekel, Shlomo Ruschin

Abstract *An optical phased array directional receiver based on an array of GaAs-AlGaAs waveguides is demonstrated for the first time. The angular range is ±3.4º and resolution at -10dB crosstalk is 1.6mrad. Switching time is 20-30nsec.*

Introduction

A fast optical scanner, implemented in a GaAs optical phased array (OPA)[1] has many applications such as optical communications switches, atmospheric measurements[2], traffic control[3], barcode readers, printers etc. Analogously to the RADAR case, several of these applications would also benefit from the option of directional receiver, which can be based also on the OPA principle.

In our laboratory, an OPA serves as the switching fabric for an IP router[1]. Here, light from input PM single mode fibers passes through beam shaping optics into the OPA chip, then through an output optical arrangement in free space to an array of multi mode fibers. Single mode fibers could not be used at the output due to loss and NA restrictions. A possible solution to this problem is to replace the optical fiber array with another OPA chip, similar to the transmitting chip. In this way one could benefit both from an electronically tunable, narrow receiving angle and from a high fill factor, unattainable with optical fibers.

Experimental

An OPA chip was fabricated on GaAs. The OPA was flip chip assembled on a ceramic chip carrier, with an analog electrical connection to each wave-guide, controlled by a computer. Beam shaping optics coupled the round SMF spot into the OPA back facet. This module was referred to as the input optics module (Fig. 1a).

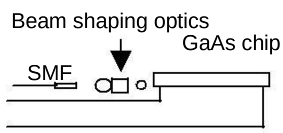

Figure 1a: Input optics module.

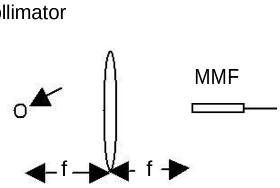

Figure 1b: Output optics module.

A. Far field envelope measurement:

The SMF was connected to a CW, 1310nm laser. The SMF output was adjusted to TE polarization. A fast-axis collimating lens was aligned at the OPA front facet. The light was then passed through a spherical focusing lens and into an array of 64 multimode fibers, which was placed at the spherical lens' focus. This module was referred to as the output optics module (Fig 1b). Each of the MMFs was coupled into a computer-monitored detector. A voltage vector was optimized to direct the light at each of the output fibers. A computer routine was used for this optimization procedure. Once all 64 outputs were calibrated each of the 64 optimized voltage-vectors was reapplied, this time with a large area power meter instead of the MMF array. A schematic of this measurement is shown in figure 2a.

B. Acceptance angle measurement:

The output optics module was removed. A laser was connected to a Collimated SMF and placed in front of the OPA. The collimator was mounted onto a rotating plate and a transverse linear stage, so that light could be directed at the OPA from different angles and the OPA would serve as a directional receiver. The collimator was aimed at the OPA front facet at different angles. For each angle the collimator was aligned in X and Y to coincide with the OPA center. Each wave-guide's voltage was then optimized to deliver maximum power into the SMF. A schematic of this measurement is shown in figure 2b.

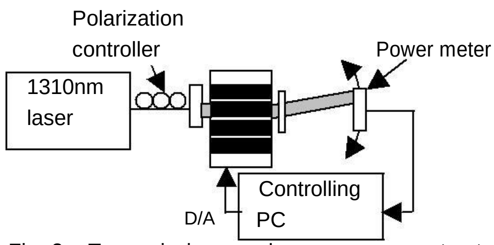

Fig. 2a: Transmission envelope measurement setup. Light entered into the OPA is deflected and measured at different output angles.

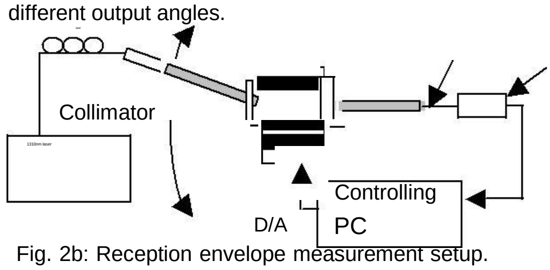

Fig. 2b: Reception envelope measurement setup. Light incident upon the OPA from differnt angles is directed towards the stationary output SMF.

C. Directional selectivity measurement:

To measure the directional receiver's selectivity, light was again coupled into the phase array from different incidence angles using the same set-up as in section B. This time several voltage vectors were applied at each incidence angle. Each voltage vector matched a different "viewing" direction, including the actual incidence angle of the light from the collimator. The difference between incidence angles was sufficient to move the output diffraction spot by 9µm. 5 incidence angles were chosen. The power measured through the output SMF, compared with the power measured with the incidence angle matching the viewing angle, indicates the directional receiver's selectivity.

Results and discussion

A. Far field envelope:

The far field envelope is calculated by taking the Fourier Transform of a single wave-guide's mode.

$$E(k) = \sum_n R_n \int E_n(x) e^{-ikx} dx$$

Where k is the far field transverse coordinate, R_n is the overlap integral between the wavefront incident on the wave guide and the waveguide's n^{th} guided propagation mode, E_n is the n^{th} mode field and x is the near field horizontal transverse coordinate. Measured results are shown in figure 3, compared with a calculated envelope. The irregularities in the calculated plot arise from other effects that were simulated, including a change in transmission loss as a function of applied voltage.

B. Acceptance angle:

The relation between the incidence angle and the power coupled into a single waveguide is given by the overlap integral:

$$R = \frac{\left| \int_{-\frac{d}{2}}^{\frac{d}{2}} E_m(x) E_f^*(x) dx \right|^2}{\int_{-\frac{d}{2}}^{\frac{d}{2}} \left| E_m(x) \right|^2 dx \int_{-\frac{d}{2}}^{\frac{d}{2}} \left| E_f(x) \right|^2 dx}$$

Where x is the horizontal transverse coordinate, $E_m(x)$ is the wave guide mode field distribution, $E_f(x)$ is the incident field distribution, and d is the waveguide width. R would be at a maximum when both field phases are parallel to each other, i.e. when the incident beam is perpendicular to the waveguide facet. The total coupled power into a phased array is expressed by: $P_t = \sum_n R_n P_n$

Where n is the waveguide number and P_n is the total power incident on the n_{th} waveguide. As can be seen

Fig. 3: Loss in dB vs. incidence angle in degrees. The far field envelope of an OPA is denoted by open squares (section 3*A*). Solid triangles shows the acceptance angle results (section 3*B*). Solid line is the theoretical line simulated for the fundamental mode.

from figure 3, the transmission and reception envelopes are in good agreement over the whole scanning angle. This angle is defined as the angle between to adjacent diffraction order, and is given by:

$$\theta_{scan} = \frac{\lambda}{nd}$$

Where λ is the wavelength, n the index of refraction (1 in this case) and d the pitch of the wave-guides.

C. Directional selectivity:

To calculate the expected results, the output far field main lobe was measured. An overlap integral between the simulated diffraction pattern and the SMF mode was calculated at different transverse offsets, corresponding to the differences between the receiver viewing angle and the actual incidence angle. A good agreement with the measured results was achieved when the simulated phase modulation was limited to 70% of 2π radians, thus creating a noisy diffraction pattern. This limited efficiency can occur when the propagating light is not completely TE polarized, as was the case. Results are shown in

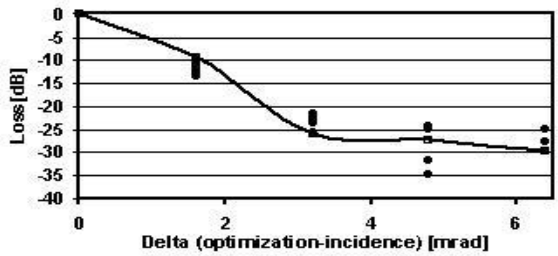

Fig. 4: Directional receiver response to light incident in different angles. The solid circles denote the measured attenuation. The line shows simulated results at 70% phase efficiency. A 1.6mrad deviation from the tuned angle is sufficient to reduce the measured power by 10dB.

figure 4.

Conclusions

An optical phased array directional receiver was demonstrated for the first time. The receiving angular range was 6.8°. The number of resolution points at –10dB crosstalk is approx. 70. The attenuation due to the incidence angle agrees with the OPA far field envelope measurements and simulation. Application in future design of an optical switch will allow the use of single mode fibers at the output, thus standardizing output detectors as well as ensuring a long haul compatible MHz·km product. Other applications of such a receiver include barcode readers, LIDARs, optical surveillance systems etc.

References

1 E. Shekel et al, OFC 2002 Technical Digest, pp. 27-29.
2 *Wei Gong et al,* CLEO '02. Technical Digest, vol.1, pp. 218 –219.
3 D.M. Gavrila et al, Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference, 2001, vol.3, pp. 2044-2048.