MICROWAVE OPTO-ELECTRONICS IN EUROPE

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ABSTRACT

The field of microwave opto-electronics is one of intense research interest in Europe. In this paper recent developments in components, sub-systems and applications are reviewed. Particular attention is given to work on coherent systems for signal generation and processing and to the impact of optical amplifiers on microwave opto-electronic system design.

INTRODUCTION

Research on microwave opto-electronic devices and systems has been actively pursued in Europe for approaching 20 years. Initial work was directed towards optical signal processing and techniques for the optical control of phased array antennas. More recently, very high data-rate transmission systems and wideband signal distribution have provided renewed impetus to the field, whilst the European Space Agency's imaginative programme for the development of optical beam formers for space-based phased array antennas has led to pioneering work in coherent techniques.

In this paper recent European work on components, sub-systems and applications of microwave opto-electronics will be reviewed with particular emphasis on areas, such as coherent techniques and the use of optical amplifiers, which are likely to have a strong impact on new system design.

COMPONENTS

A microwave opto-electronic system includes a modulated optical source, transmission path, possibly including amplification, and means of signal recovery to the electrical domain. Component developments in these areas will be considered in turn.

Modulated Sources

Direct modulation of semiconductor lasers remains an attractively simple technique but the associated wavelength chirp penalty becomes significant for high rate transmission through step index single mode fibre over distances in excess of 1 km . External modulators are therefore important components in microwave opto-electronic systems. GaAs/AlGaAs loaded line travelling wave modulators have been developed with 3 dB (electrical) bandwidths of over 36 GHz [1]. Renewed interest in electro-absorption modulators has come with the development of growth techniques for multiple quantum well (MQW) materials. Figure 1 shows the structure of a reflection modulator for use at a wavelength of 810 nm, using the asymmetric Fabry Perot modulator (AFPM) technique developed at University College London [2].

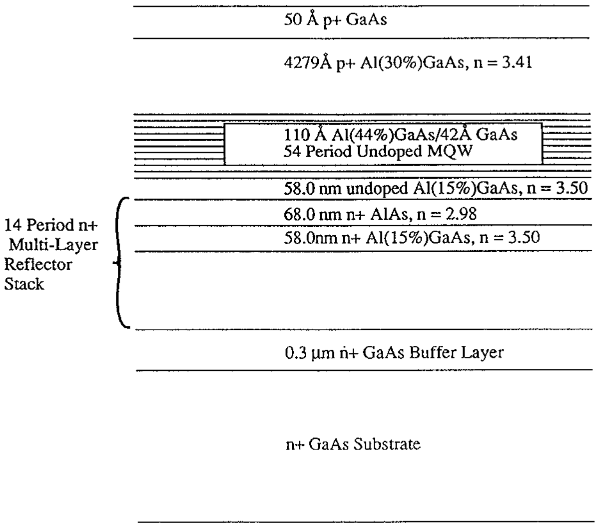

Fig. 1: Asymmetric Fabry-Perot modulator (AFPM) structure.

This consists of a PIN mesa structure operated in reverse bias. The N region includes a Bragg reflector stack with a reflectivity of over 90% and the I region comprises GaAs/AlGaAs MQW material. An asymmetric Fabry-Perot cavity is formed between the high reflectivity Bragg reflector and the 30% reflectivity air/semiconductor interface. By choosing the P and I layer thickness correctly light reflected from the Bragg stack is in antiphase with light reflected from the air/semiconductor interface at the operating wavelength.

In the reflecting state the modulator is unbiased and the e1-hh1 exciton absorption peak is at a wavelength shorter than the operating wavelength. The I region absorption is therefore small and the Bragg stack reflection is dominant. As the modulator is reverse biased the exciton peak is red shifted, increasing the absorption until the Bragg stack reflection is equal in magnitude and in antiphase with the air/semiconductor interface reflection, producing near complete absorption of the incident light. The modulator is particularly attractive for bi-directional links since in its absorbing state it forms a very efficient photo-detector. Similar modulators for operation at 1.55 µm wavelength have been realised in the Inp/InGaAs system [3] and show satisfactory operation at microwave frequencies.

Optical Amplifiers

One of the most important recent developments in opto-electronics has been the development of practical optical amplifiers. The two most important types are the semiconductor laser amplifier (SLA) and the erbium doped fibre amplifier (EDFA).

For microwave opto-electronic applications the response of the amplifiers to intensity modulated signals is important. Figure 2 shows the modelled distortion of an SLA as a function of modulating frequency [4]. Severe distortion occurs when the modulating frequency is less than the reciprocal of the carrier lifetime, typically 2 ns.

The flourescence lifetime in the EDFA is of the order of 15 ms so that distortion is small for modulation frequencies above a few kHz [5].

High, polarisation insensitive gain and ready compatibility with optical fibre systems has made the EDFA the preferred choice for most communications applications. However, the higher power added efficiency of the SLA remains an important advantage in applications where there are prime power constraints, such as in space.

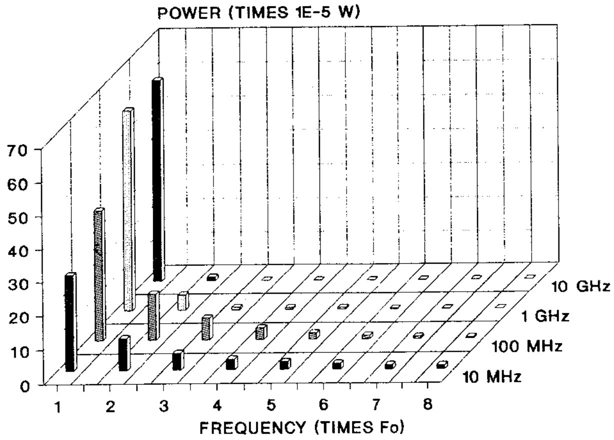

Fig. 2: Modelled distortion performance of semiconductor laser amplifier.

Signal Recovery

The simplest microwave signal recovery technique is to use a fast photodiode and Schottky and PIN structures with bandwidths extending well into the millimetre-wave region have been developed [6,7]. Monolithic integration of fast detectors with amplifiers has received much attention, an example being the development of an 8.2 GHz (electrical) bandwidth receiver using an MSM detector and HEMTs [8]. Block and Jager [9] have developed a travelling wave MSM detector which is compatible with monolithic integration and offers novel possibilities for implementing further signal processing functions such as phase shifting of the recovered signal.

An alternative approach to signal recovery is direct optical control of microwave devices [10]. Bangert and Ludwig have investigated the optical injection locking of a monolithically integrated HFET oscillator operating at 8 GHz [11]. The locking range obtained was 1 MHz, limited by the low optical coupling efficiency to the active device: optimum design of optically controlled devices remains a crucial area for further work.

SUB-SYSTEMS

The application of coherent techniques in microwave opto-electronic systems requires the generation of multiple frequency optical signals having a defined phase relationship. Traditionally this is achieved using a Bragg cell to produce a second, frequency-shifted optical signal from a single frequency optical input. However, it is difficult to realise efficient frequency shifters with microwave offsets. An alternative approach, limited in offset frequency only by the bandwidth of the photodiode used, is to generate the heterodyne signal in an optical phase lock loop (OPLL). Figure 3 shows the arrangement used.

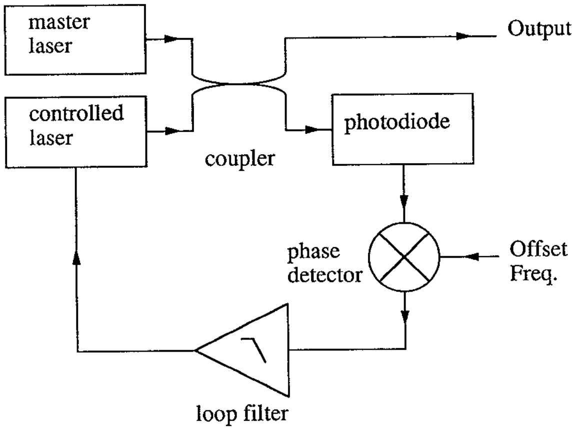

Fig. 3: Heterodyne optical phase lock loop.

The outputs from two single frequency lasers are combined and illuminate the photodiode producing an electrical output at their difference frequency. This is compared with a microwave reference frequency in a phase detector and the output used to tune one laser to achieve phase lock. The main difficulty in realising OPLLs arises from the high phase noise of practical lasers which requires a wide bandwidth, short propagation delay loop to achieve reliable phase lock [12]. Laser diode pumped solid-state lasers or external cavity semiconductor lasers can have linewidths of a few kHz, relaxing the requirements considerably. Wale and Holliday have realised an OPLL for coherent beam forming in phased arrays using diode pumped YAG lasers [13]. At University College London the wideband loop approach has been used to realise the first heterodyne OPLL using semiconductor lasers without external cavities or other line narrowing devices [14]. Figure 4 shows the phase locked heterodyne spectrum obtained at an offset frequency of 5.1 GHz. The phase noise suppression bandwidth is limited by the current tuning characteristics of the quantum well lasers used, and it is planned to increase this by using reverse bias quantum well tuning techniques [15].

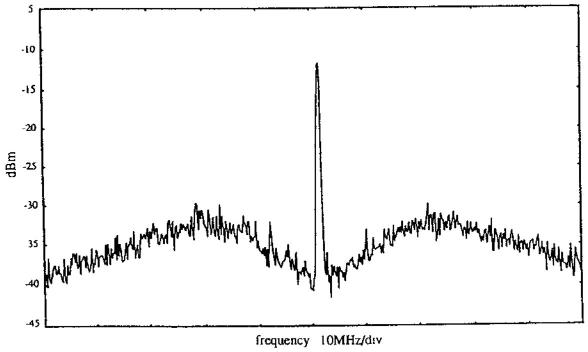

Fig.4: Heterodyne spectrum from OPLL using semiconductor lasers.

APPLICATIONS

Wideband Signal Distribution and Processing

Considerable interest has arisen in linear wideband optical networks both for microwave antenna remoting and to meet the expanding requirements of the cable television industry. Components for the realisation of intensity modulated links with bandwidths up to 35 GHz are available from a number of European manufacturers (GEC-Marconi, Thomson, BT&D, NT-Europe amongst others). An alternative approach, useful where wide dynamic range over more limited bandwidth is required, is to use optical frequency modulation [16].

The low loss and dispersion of single mode fibre permits the realisation of microwave bandwidth long delay lines. Deborgies et al [17] report a 100 μs delay line for use up to 8 GHz. Signal to noise ratio exceeds 127 dB.Hz up to 4 GHz, falling to 115 dB.Hz at 8 GHz. The performance exceeded that obtainable from bulk acoustic wave technology for all frequencies greater than 1 GHz.

Techniques for more elaborate optical processing of complex signals are also being developed. In one example [18] an integrated optic modulator with low bandwidth detector has been used to perform spectral analysis of a frequency modulated sub-carrier signal.

Phased Array Antennas

Optical amplifiers can be used to improve the signal to noise ratio in the multi-way distribution systems which are required in phased arrays. Figure 5 shows results from a modelling study to determine optimum amplifier placement in the distribution system [19].

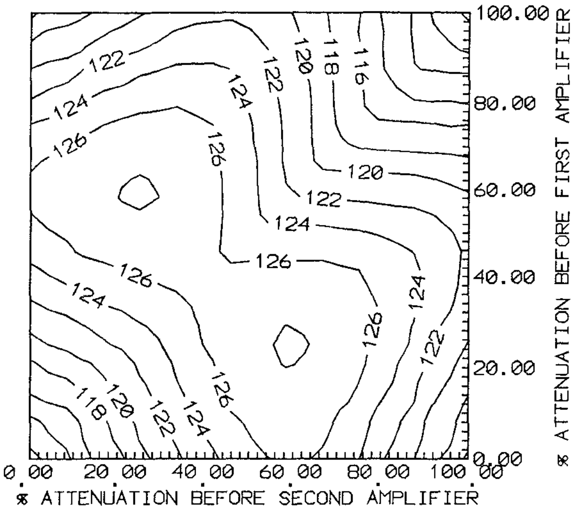

Fig. 5: Signal to noise ratio contours (dB.Hz) of optical link with 2 amplifiers as a function of optical loss preceding each amplifier. (Total loss 35.6 dB).

A number of groups are exploring coherent beam former technology. Dolfi et al [20] have developed an ingenious bulk optics technique for true time delay beam forming, while Volker et al [21] have developed a novel fibre beam former in which beam steering is achieved by changing the frequency of the optical sources used. Finally, Birkmayer and Wale [22] have successfully demonstrated a coherent beam former in lithium niobate integrated optic technology.

CONCLUSION

Microwave opto-electronic components capable of operation well into the millimetre-wave region have been developed to commercial availability by a number of European manufacturers. Optical amplifiers, in particular, seem likely to make microwave bandwidth networks with excellent signal to noise ratio a practical reality. Techniques for the generation of coherent optical signals have shown substantial advance so that it seems likely that coherent processing will become the preferred choice for optical beam forming in phased array antennas and many other signal processing applications. European groups have made substantial contributions to these areas of work and it seems likely that they will continue to do so in the future.

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