OPTICALLY POWERED REMOTE OPTICAL FIELD SENSOR SYSTEM USING AN ELECTROABSORPTION-MODULATOR

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Abstract

A novel optical sensor system is presented, where the remote transceiver unit is based upon a high-speed electroabsorption (EA) waveguide modulator. The proposed sensor concept allows bi-directional operation, by using the EA-modulator not only as a modulator element to receive signals from the antenna but also as a detector element to transmit signals to the antenna. For optimum dynamic range and highest sensitivity the EA-modulator is biased. The voltage necessary for this is provided from an integrated fiber-coupled photovoltaic cell (PVC) array in order not to reduce the overall EMC of the sensor.

Introduction

In many technical and medical domains there is a great interest in small and remote sensors for the reception of electromagnetic fields, e.g. antenna measurements, automotive applications, EMC compliance testing or hyperthermia measurements in biologic tissue. Although the requirements for a specific field sensor certainly vary between the different applications, it is obvious that optical field sensors offer a number of advantages in comparison to purely electrical sensors. Optical sensors neither interfere with the electromagnetic fields nor suffer from the loss of phase information due to high impedance transmission lines. Furthermore optical sensors are usually of smaller size and offer wider dynamic range as well as a greater sensitivity. Consequently, optical field sensors have been investigated recently by several authors and for different applications [1-4].

So far, optical sensors have been uni-directional as most of the above mentioned applications require only the reception of signals with the antenna. However, for some special

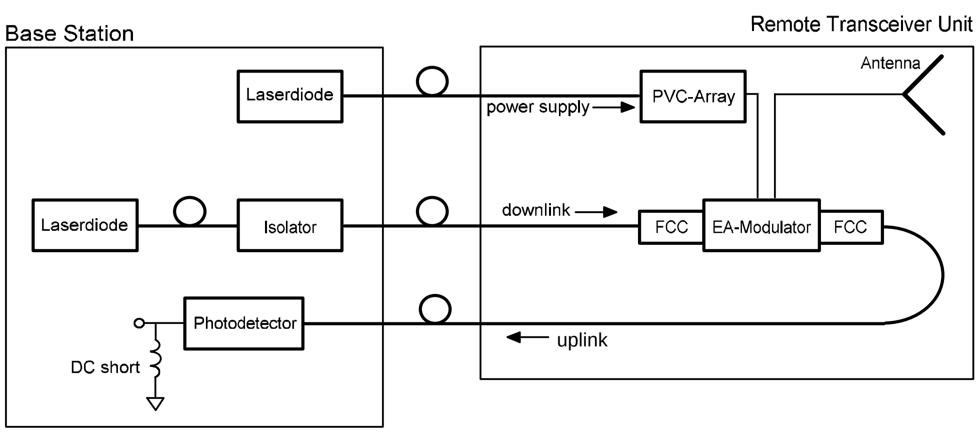

Fig. 1: *Concept of an optically powered bi-directional field sensor system*

applications such as collision avoidance radar bi-directional operation is an unconditional requirement.

In this paper we present a novel concept of an bi-directional optical field sensor system for operation up to microwave wave (MW) frequencies. Here, the remote transceiver unit is optically powered and receiving as well as transmitting functionality is provided by a single electroabsorption waveguide modulator.

Optically Powered Optical Sensor System

In Fig. 1 the concept of our optically powered bi-directional field sensor is shown. As can be seen, the key electrooptical components in the remote transceiver unit are the EA-modulator and the PVC array. As mentioned, most sensing applications only require the signal transmission from the remote antenna to the base station. Therefore the electrical signal from the antenna in the remote receiver unit is transferred into the optical domain using an intensity modulation direct detection (IMDD) scheme [5]. The intensity modulated optical signal is then detected at the base station. For broadband operation up to the MMW regime and in order to avoid expenditure for thermal stabilization, external IM is preferable in comparison to direct IM of a laser diode. However, the major advantage for external IM is to use the EA-modulator not only for the reception of signals from the antenna but also as a detector element to transmit signals to the antenna [6,7].

Electroabsorption Waveguide Modulator

The electroabsorption modulator in the transceiver unit is an InP based multiple quantum well (MQW) waveguide device designed for operation at 1.3µm wavelength (see Fig. 2). The device consists of an slightly Silicon doped lattice matched InAlAs top cladding layer and a highly Silicon doped lattice matched InAlAs bottom cladding layer. The active region is formed by 20 n.i.d quantum wells with a

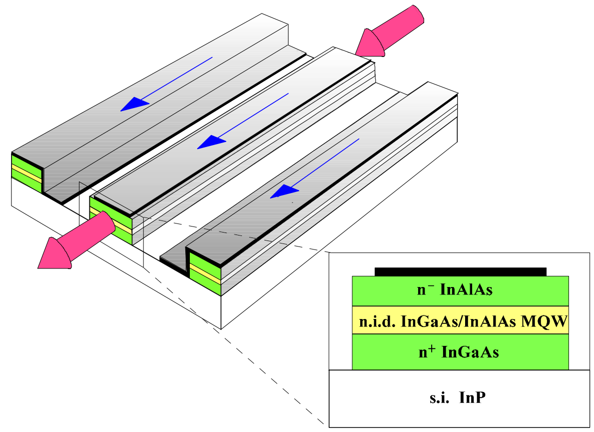

Fig. 2: *Sketch of coplanar waveguide modulator*

thickness of 7.7nm each. By implementing 1% tensile strain in the InGaAs quantum wells and 1% compressive strain in the InAlAs barrier layers polarization insensitive operation is achieved, which avoids expensive measures for polarization control within the system. For operation up to the (M)MW regime we used a hybrid coplanarmicrostrip configuration for the metallization of the modulator. In a former experiment we have demonstrated millimeter wave operation of up to 70GHz using such *nin*-EA-modulators with hybrid coplanar-microstrip metallization [8].

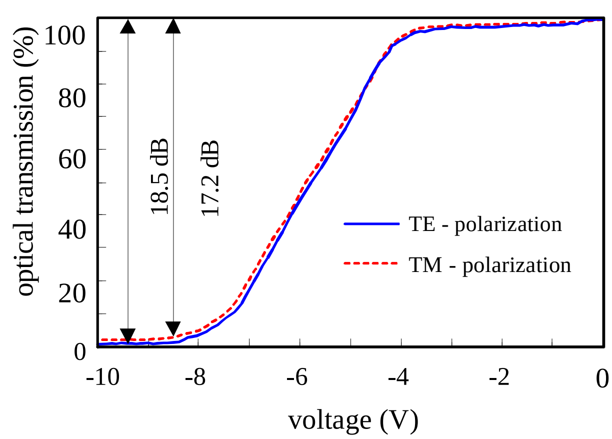

Fig. 3: *Optical transmission characteristic*

The optical transmission characteristic for a 1mm long waveguide modulator at DC is shown in Fig. 3. As can be seen the device exhibits a maximum optical contrast ratio of more than 18dB/mm with a polarization sensitivity of about 1dB. The modulator can be switched to a detector element simply by applying a reverse bias. In that case the IM optical carrier is almost completely absorbed with a measured maximum detector sensitivity of 1.03 A/W.

Photovoltaic Cell Array

To achieve low cost operation a complete passive sensor head would be desirable using an external modulator operating at zero bias and a passive antenna [6]. However, to meet specific requirements, such as a very large dynamic range or a very high sensitivity, it is necessary to reverse bias the external modulator and for some broadband applications it might also be necessary to use active antennas to match the impedances of the antenna and the modulator. For our approach we fabricated a fiber-coupled photovoltaic cell array for optical power supply of the transceiver unit. This enables the sensor to be used in almost any environment, with minimum EMI.

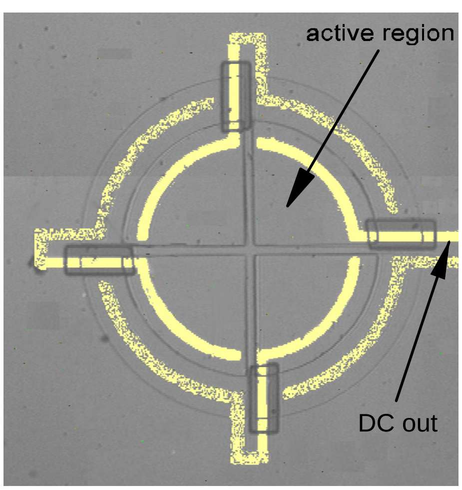

Fig. 4: *Photograph of integrated PVC array*

To achieve highest conversion efficiency of the series integrated PVC array a resonator enhanced PVC layer structure has been designed and grown by MBE. It consists of an AlGaAs/GaAs pin-structure where the efficiency is enhanced by a bottom 15 period AlGaAs-/AlAs Bragg-reflector. The series array of four single PVC's is designed in a circular shape (see Fig. 4) with a diameter of 600µm to ensure optimum coupling efficiency from a thick multimode plastic fiber.

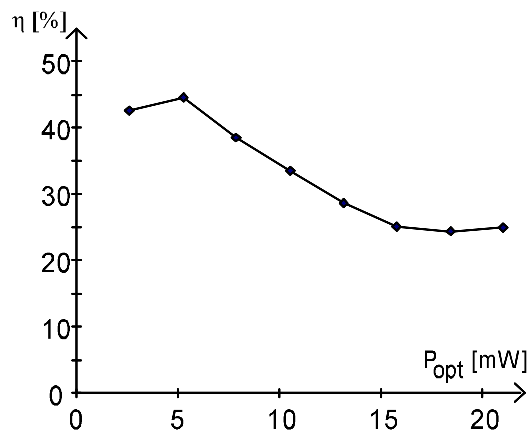

Fig. 5: *Power conversion efficiency of single PVC*

The power conversion efficiency of a single PVC is shown in Fig. 5. A maximum power conversion efficiency of 45% has been achieved. The open circuit voltage of the PVC array is 3.7V, short circuit current is 0.51mA for 11mW optical input power @ 800nm wavelength.

System Performance

The calculated sensitivity of the sensor-system for a signal to noise ratio of S/N=1 is shown in Fig. 6(a) as a function of laser power. As can be seen, the major impact arises from thermal noise at low optical power whereas at higher optical power the system is limited by the relative intensity noise (RIN) of the laser diode together with amplifier and atmospheric noise.

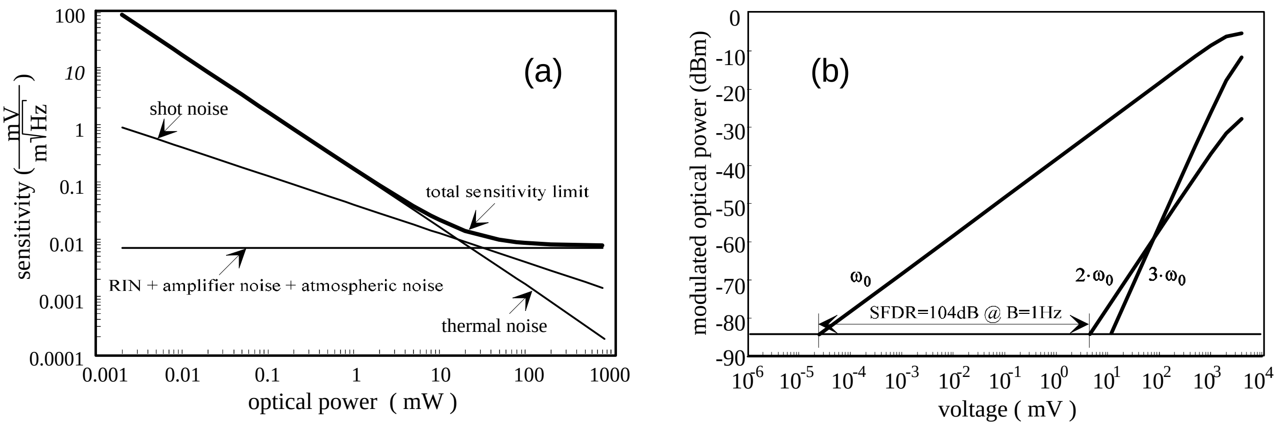

Fig. 6: C*alculated sensitivity limit of the sensor-system @ S/N=0dB and 100MHz as a function of laser power (a) and spurious free dynamic range of the fabricated EA-modulators (b).*

At 4mW optical power the optimum theoretical sensitivity limit for S/N=1 is less than 100µV/m @ 1Hz bandwidth. The spurious-free dynamic range (SFDR) of the fabricated TW EA-modulators is as high as 104dB @ 1Hz bandwidth (see Fig. 6(b)).

Conclusions

The presented optically powered sensor system is a very suitable system for frequency selective measurements of electromagnetic fields at frequencies up to the microwave regime. A maximum frequency of up to 20GHz is expected with no limitation from the optical devices. A large dynamic range and a high sensitivity are achieved. Furthermore, bi-directional operation is achieved by using only a single EA-modulator, providing modulation and detection characteristics.

References

[1] E. Bonek, D. Hornbachner, E. Riedl-Bratengeyer, W. Hadrian, and R. Jobst, *Electron. Lett.*, **"Electro-Optic ELF Field Sensor"**, Electron. Letters, Vol. 28, No. 21, pp. 1994-1195, 1992.

[2] S.-S. Lee, M.-C. Oh, S.-Y. Shin, K.-H Keh, **"Integrated Optical High-Voltage Sensor Using a Z-Cut $LiNbO_3$ Cutoff Modulator",** *IEEE Photon. Technol. Lett.*, Vol. 5, No. 9, pp. 996-999, 1993.

[3] T. Meier, C. Kostrzewa, K. Petermann, and B. Schüppert, **"Integrated Optical E-Field Probes with Segmented Modulator Electrodes"**, *OSA/IEEE J. of Ligthwave Technol.*, Vol. 12, No. 8, pp. 1497-1503, 1994.

[4] R. Heinzelmann, A. Stöhr, T. Alder, R. Buß, and D. Jäger, **"EMC Measurements Using Electrooptic Waveguide Modulators"**, *Topical Meeting on Microwave Photonics,* pp. 177-180, Kyoto, 1996.

[5] C. Cox III, E. Ackerman, R. Helkey, and G.E. Betts, **"Techniques and Performance of Intensity-Modulation Direct-Detection Analog Optical Links"**, *IEEE Trans. on Microwave Theory and Techniques,* Vol. 45, No. 8, pp. 1375-1383, 1997

[6] T.H. Wood, E.C. Carr, B.L. Kasper, R.A. Linke, C.A. Burrus, K.L. Walker, **"Bidirectional Fibre-Optical Transmission Using a Multiple-Quantum-Well (MQW) Modulator/Detector"**, *Electron. Letters.*, Vol. 22, No. 10, pp. 528-529, 1986

[7] L.D. Westbrook and D.G. Moodie, **"Simultaneous Bi-Directional Analogue Fibre-Optic Transmission Using an Electroabsorption Modulator"**, *Electron. Letters*, Vol. 32, No. 19, pp. 1806-1807, 1996

[8] A. Stöhr, R. Heinzelmann, T. Alder, R. Buß, and D. Jäger, **"Electroabsorption Modulators for Broadband Fiber Electro-Optic Field Sensors"**, *Applications of Photonic Technology,* Plenum Press, Montréal, (to appear in January 1998),