60 GHz-MILLIMETRE-WAVE GENERATION AND BEAM-FORMING IN HYBRID-FIBRE-RADIO SYSTEMS FOR BROADBAND-WIRELESS ACCESS

G. Grosskopf, B. Sartorius, C. Bornholdt, B. Kuhlow, G. Przyrembel, S. Zinal,

D. Rohde, R.Eggemann, J. Slovak, M. Möhrle

Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH

Einsteinufer 37, D-10587 Berlin, FRG

Tel: ++49 30 31002 317, Fax ++49 30 31002 213, E-mail: grosskopf@hhi.de

ABSTRACT

We present a novel architecture for broadband mobile indoor communication systems applying hybrid-fibre-radio technology. One issue is the centralized optical generation of millimetre-wave signals which can be distributed easily to several base stations via optical fibres. Key device is a self-pulsating laser designed for 60 GHz operation. It is remotely stabilized by an optical sub-harmonic 10 GHz-pulse signal. A further issue is beam-forming using a Silica-based optical beam-former. By this technique array antennas can be connected selectively to the addressed mobile terminal. The functions of the components have been demonstrated by 155 Mbit/s data transmission experiments at 60 GHz.

INTRODUCTION

The wireless access and beam-forming of array antennas is of increasing importance in broadband communication systems [e.g. 1]. Due to the expected congestion at low radio link frequencies, the 60 GHz-band has been proposed as frequency range for wireless broadband access systems. For this frequency range hybrid-fibre-radio (HFR)-systems are of special interest because this technique enables the generation of high quality millimetre-wave signals which can easily be distributed by optical fibres between a control station and several base stations. With this centralised millimetre-wave generation, simplified and miniaturised base stations may be realised. Among the different millimetre-wave generation methods optical heterodyning seems to be most promising [2]. In this case the beat signal of two optical waves is detected by a high speed photo detector and the desired millimetre-wave signal is obtained at its output. The two optical waves to be heterodyned are emitted by an optical millimetre-wave transmitter (OMT). In general this source consists of arrangements comprising several lasers. An alternative are compact integrated components like self pulsating lasers emitting two modes with a frequency spacing equal to the radio link frequency [3].

Additionally the HFR-technique enables an easy way to form the field distribution of array antennas in the base stations [4-6]. By beam-forming the addressed mobile terminal can be connected via an optimised radio link while the signals of other terminals are suppressed. Furthermore the unwanted emission into the neighbouring environment is minimised at the same time. Beam-forming is usually achieved by amplitude and phase control of the individual millimetre-wave signals feeding the array antenna-elements. In case of 60 GHz this proves to be comparatively difficult. Thus optical beam-forming is considered to be a promising solution because phase shifting is comparatively easy to perform in the optical domain. Again optical heterodyning may be applied. Within a photonic beam-former the antenna weights are controlled individually. By opto-electronic conversion these complex antenna weights are converted to the millimetre-wave domain.

In this paper we propose an indoor-system (Fig. 1) with pico-cellular structure. It consists of four building blocks: a central master control station (CMCS), a number of control stations (CS) which support several base stations (BS) and the mobile terminals (MT). CMCS, CS, and BS are connected by optical fibres. In order to alleviate the EMI-problem the radio links should be shortened to minimum length providing mobility while the millimetre-wave signals are addressed selectively to the MTs only. This means that the fibre links of the fixed network should be close to the MT and the radio links bridge only the last meter-distances. The cost effective realisation of the BSs may be achieved by a centralised millimetre-wave signal generation. In two experiments we investigated the optical heterodyne principle. It was applied to generate the 60 GHz-signals and beam-forming was achieved. Key device for the millimetre-wave generation was a self-pulsating laser in the CS. It was remotely stabilised by an optical pulse source in the CMCS. Error free data transmission at 155 Mb/s was demonstrated. The second key element was the optical beam-forming network developed in planar Silica technology. Its function was verified by field measurements of a 1x4 array antenna and error-free 155 Mbit/s data transmission experiments have been carried out.

SELF-PULSATING LASER AS MICROWAVE SOURCE IN HYBRID-FIBRE-RADIO SYSTEMS

The 60 GHz source in the CS (Fig. 2) was a self-pulsating laser (SPL) comprising two active DFB sections and an integrated phase tuning section [3,7]. The advantage of this component is that only three dc currents are required and no millimetre-wave electronics are necessary. The Bragg-wavelengths in the two DFB sections were detuned in order to generate two DFB modes. The mutual injection of lasing modes from one DFB section into the opposite one and in addition the proper phase adjustment of the light waves via the integrated phase tuning section led to a coupled dual mode lasing system with a very stable beating signal in the 60 GHz-band at an optical wavelength λ=1540 nm. Further noise reduction (phase noise value of 100 dBc/Hz @ 100 kHz) (Fig. 3) was achieved by injecting subharmonic 10 GHz optical pulses into the SPL that were generated remotely by a gain switched laser (GSL) in the CMCS. This stabilisation signal can be of arbitrary polarisation. The wavelength should be within the SPL gain spectrum (e.g. λ=1550 nm). It was transmitted via a 6.4 km long fibre connection comprising a standard single mode fibre and a dispersion compensating fibre (DCF). For the data transmission (Fig. 4) the SPL output signal was externally modulated using a MZ-modulator (MOD). A 1.27 GHz sub-carrier modulated by a 155 Mbit/s data signal in the offset quadrature phase shift keying (OQPSK) format was applied to the external modulator. After transmission over a single mode fibre to the BS the optical waves were split up and applied to the OMCs. The RF-signals feeding the 1x4 phased array antenna were obtained by optical heterodyning (f=62.07 GHz). The look direction of the antenna was steered by a fibre based beam-former (OBF) in front of the OMCs. It consisted of optical delay lines and attenuators. For a broadside look direction equal delay times and equal amplitudes have been adjusted. At the mobile terminal (MT), the received signal was down converted and fed to an OQPSK receiver. Error-free operation at 155 Mb/s (BER less than 10^{-10}) was demonstrated, without penalty for the distribution of the optical microwave signal over 1.1 km of standard single mode fibre (SMF).

SILICA BASED BEAM-FORMER IN A 60 GHz HYBRID-FIBRE-RADIO SYSTEM

In a further experiment we investigated the 4-channel Silica based optical beam-former (OBFN, Fig. 5). In this case the optical millimetre-wave transmitter (OMT) comprised two separate lasers which were stabilized by a master laser and modulation sideband injection locking [2,8]. After amplifying by EDFAs the two optical input waves (ν_1 and ν_2) were split up manifold according to the number of antenna elements for individual amplitude and phase control. The OFBN was implemented in form of two planar light wave circuits in cascade [6]. In the first OBFN stage the relative phases of optical waves were controlled utilizing the thermo-optic effect (TO). The advantage of this method is that for a desired phase shift of the millimetre-wave signal only one of the optical waves has to be shifted by the same amount of the phase in the optical domain. Next the optical waves were combined in pairs using 3dB-couplers. Amplitude control was accomplished by tuneable Mach-Zehnder interferometers (MZI) in the following stage. Again the TO effect was applied. Details of the OFBN fabrication are described in [6]. Chip sizes were 2x30 mm^2 and 2x25 mm^2 for the sections of phase and amplitude control, respectively. The electrical resistances of the heaters for phase and amplitude control were 250 Ω and 150 Ω, respectively. The total optical excess loss of the OBFN (i.e. without splitting loss of the couplers but including all fibre-to-chip coupling losses) was approximately 10 dB at minimum attenuator setting. Finally the waves were coupled to optic/millimetre-wave converters (OMC) for heterodyning. Each OMC contained a high speed photo detector and a MMIC amplifier. Thus individually weighted 60.8 GHz signals were obtained which were connected to the elements of a 1x4 H-plane patch array antenna [9].

The spatial power distribution was determined by a spectrum analyser (ESA) of our antenna measurement set-up. The complete set-up including the OBFN, the OMCs, and the elements of the 1x4 array antenna with a short radio link has been calibrated using a vector voltmeter at the receiver site. The amplitudes and phases of the received signals were measured after down conversion to 1 GHz (Fig.5 arrangement a.). One of the channels has been used as reference while the remaining three channels were tuned in phase and amplitude. In this way the required heater voltages of the weight vector elements were determined for a desired field pattern. The Maximum Directivity (MD) beam-former algorithm enables constrained beam-forming i.e. steering the antenna's main beam and, in case of the 1x4 array, allowing to position up to three nulls of the radiation characteristic [10]. Three examples with different settings for look direction and nulls are presented (Fig.6 and Tab.I). There is a fairly good agreement between calculated (dotted lines) and measured field patterns (full lines). Especially the locations of the measured nulls can be notified close to the desired values. For the data transmission (Fig. 5 arrangement b.) one of the optical waves was externally modulated using a phase-modulator (MOD). As in the previous experiment a 1.27GHz sub-carrier was applied to the optical modulator. The subcarrier was modulated by a 155 Mbit/s data signal in the OQPSK-format. The mobile terminal was moved and after adjusting the array antenna's look direction bit error rates between 10^{-12} and 10^{-8} have been obtained for various MT locations.

CONCLUSION

We investigated a noval architecture of broadband wireless access for future mobile communications using optical 60 GHz millimetre-wave sources and array antennas controlled by a photonic beam-former. Key device for the millimetre-wave generation was a self-pulsating laser designed for 60 GHz operation. It was remotely stabilised by a sub-harmonic pulse source. Error-free data transmission at 155 Mb/s was demonstrated, without penalty neither for fibre distribution of the optical microwave signals nor for the remote stabilization of the self-pulsating laser via fibre.

The optical beam-forming network was developed in Silica technology. Its function was verified by field measurements of a 1x4 array antenna and by data transmission. The beam-former is well suited to obtain optimal system performance. By applying a constrained beam-former algorithm the weights i.e. the values for the amplitudes and phases of the individual millimetre-wave signals have been calculated and used to control the optical signals within the beam-former. Thus a beam pattern was obtained, that exploits spatial filtering for an optimised radio link and multipath interference reduction. Furthermore due to the concentration of the electrical field within a small spatial angle the EMI problem may be alleviated. Future broadband wireless connections can be done in a cost effective way by the proposed system based on the self–pulsating laser as optical millimetre-wave source and applying optical beam-forming.

REFERENCES

[1] H. Ogawa, H. Tsuji, M. Hirakawa,"Novel Fiber Fed WDM Links for Millimeter-Wave Wireless Access Systems", *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1213-1216, June 1999.

[2] R.-P. Braun, G. Grosskopf, D. Rohde, F. Schmidt, “Low Phase Noise Millimeter-Wave Generation at 64 GHz and Data Transmission Using Optical Side Band Injection Locking”, IEEE Photonics Technology Letters Vol. 10, No. 5, May 1998,pp. 728-730.

[3] G. Grosskopf, D. Rohde, R. Eggemann, C. Bornholdt, S. Bauer, B. Sartorius, M. Möhrle, “Optical Millimeter-Wave Generation and Wireless Data Transmission Using a Dual-Mode Laser”, Phot.Techn. Letters, Vol. 12, No.12, pp.1692-1694, Dec. 2000.

[4] M. Völker,"Coherent all-fibre optical beam-steering technique for phased array antennas", *IEE Proc.-J,* vol. 139, no. 4, pp. 305-308, August 1992.

[5] J. Stulemeijer, F.E. van Vliet, K.W. Benoist, D.H.P. Maat, M.K. Smit,"Coherent Photonic Integrated Beamformer for Phased-Array Antennas", *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1113-1116, June 1999.

[6] B. Kuhlow, G. Przyrembel, H. Ehlers, R. Ziegler, J. Knüppel, G. Grosskopf, R. Eggemann, D. Rohde, ” Silica Based Optical Beam Former in a 60 GHz Radio-Over-Fibre System”,. Zurich Seminar on Broadband Communications 2002 (IZS\'02).

[7] C. Bornholdt et al., “All-optical clock recovery at 80 GHz and beyond“, 27th Europ. Conf. on Opt. Comm. ECOC 2001 Amsterdam, Netherlands, paper Th.F.1.2.

[8] L. Goldberg, R.D. Esman, K.J. Williams,” Generation and control of microwave signals by optical techniques”, IEE Proc. J., vol. 139, pp. 288-295, August 1992

[9] D. Rohde, A. Kortke, R. Ziegler, R. Eggemann, G. Grosskopf, M.S. Choi, " Optically Steered 1x4 Patch Array Antenna for 60 GHz", Microwaves and Optronics, 11th. The German Wireless Week (MIOP’2001), Sindelfingen, Germany, Conference Proceedings pp.128-132.

[10] T. Kuhwald, H. Boche and M. Bronzel, "A New Optimum Constrained Beamforming-Algorithm for Future Mobile Communication Systems Based on CDMA", Proc. ACTS Mobile Communications Summit '99, Sorrento (Italy), pp. 963-968, June 1999.

ACKNOWLEDGEMENT

The work was partly supported by the Bundesministerium für Bildung und Forschung and by the State of Berlin. The authors are grateful to their colleagues H. Ehlers, R. Ziegler, and J. Knüppel for technical support.

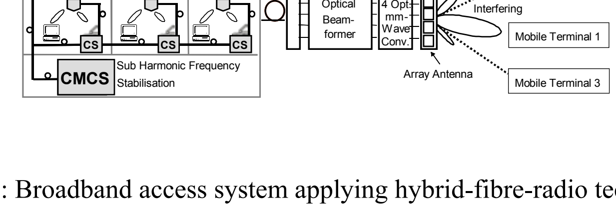


Fig. 1: Broadband access system applying hybrid-fibre-radio technology,
CMCS: central master control station, CS: control station, BS: base station, MT: mobile terminal

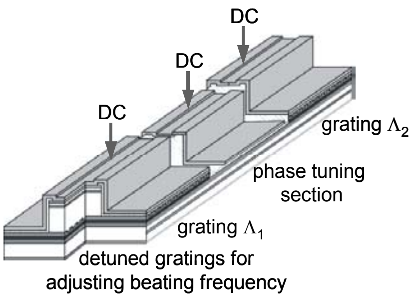


Fig. 2: Device structure of the self-pulsating laser

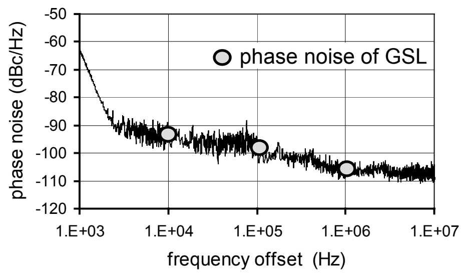


Fig. 3: Phase noise of the sub-harmonically locked self-pulsating laser at 60 GHz, the circles indicate the phase noise of the optically injected 10 GHz reference signal.

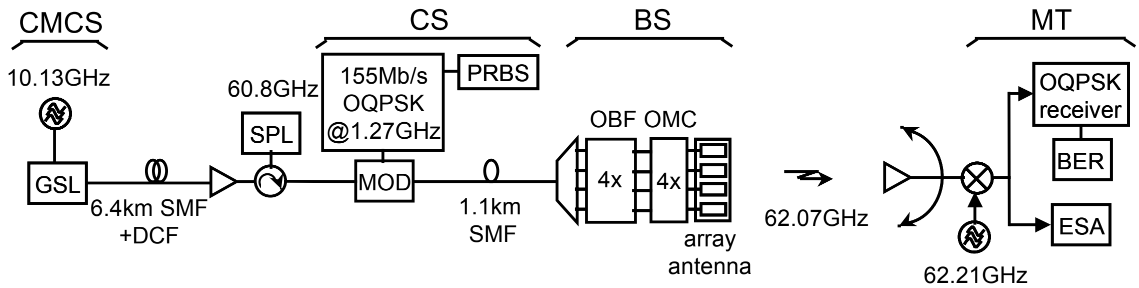


Fig. 4: Principle set-up for transmission experiment using a self pulsating laser and a fiber based beam-former, abbreviations see text.

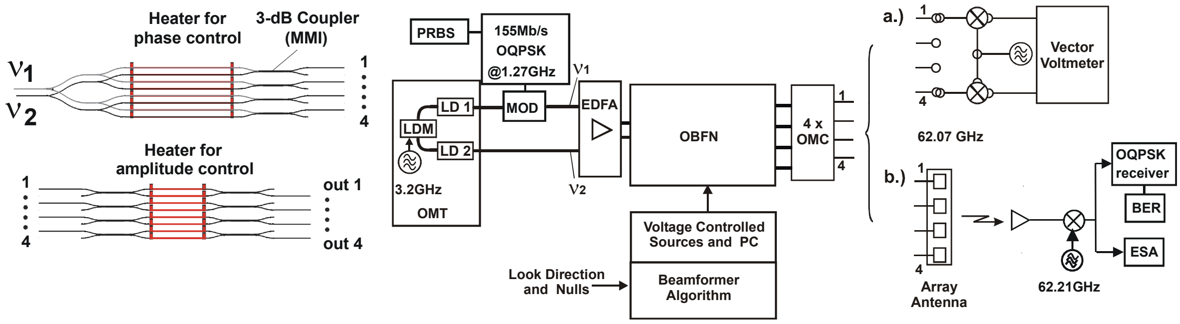
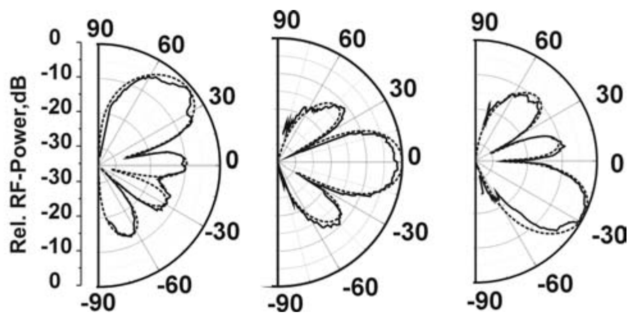


Fig. 5: Structure of the optical beam-former OBFN (left) and experimental set-up for beam-forming and millimetre-wave generation (right); OMT: injection locked laser configuration in the optical millimetre-wave transmitter, OMC: optic/millimetre-wave converter, OBFN: Silica based-optical beam-forming network, further abbreviations see text.

Tab.I.

	a.)	b.)	c.)
Look direction	Null	Null	Null
45°	15°	-15°	-45°
0°	+30°	-30°	-
-30°	-70°	0°	27°



a.) b.) c.)

Fig.6:Field patterns for various look directions and nulls @60 GHz using the 4-channel photonic beam-former Theory: dotted line, Measurement: full line.