155 Mbit/s DATA TRANSMISSION AT 60 GHz USING A 1x4 PATCH ARRAY ANTENNA WITH VARIABLE OPTICAL DELAY LINES

G. Grosskopf, R. Eggemann, D. Rohde, M.S. Choi

Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH

Einsteinufer 37, D-10587 Berlin, FRG

Abstract — **155 Mbit/s data transmission at 60 GHz was carried out successfully with bit error rates below 10^{-9}. The experimental transmission system included a 1x4 patch array antenna. It was fed by optically generated RF-signals and its beam was steered by tunable optical delay lines. Bit error rates below 10^{-8} could be maintained for azimutal angles over a range of 120 degrees. The antenna is part of an experimental radio-over-fiber system for proof-of-concept of optical beamforming to be applied in broadband mobile communication systems.**

I. INTRODUCTION

The frequency range of 60 GHz is of special interest for the wireless access in broadband mobile communication systems providing services with bit rates up to 155 Mbit/s. Optical millimeter-wave techniques are of great practical interest for the implementation of the pico-cellular indoor systems due to the low fiber loss. By optical heterodyning 60 GHz signals with excellent properties can be generated and easily distributed [1]-[3]. Optical millimeter-wave techniques are also advantageous for beamforming or for steering phased array antennas (Fig. 1). The delay spread can be reduced and frequency reuse within the radio cell by space division multiple access operation (SDMA) is possible. Constrained beamforming is achieved by amplitude and phase control of the individual millimeter-wave signals feeding the phased array antenna elements [4]-[5]. One may be able to keep an optimum response in the direction of a desired mobile terminal while the far field nulls are in the directions of the interfering unwanted terminals. In contrast beamsteering may be achieved by controlling the time delay of the millimeter-wave signals [6]-[7].

Applying optical beamforming or beam steering may thus improve the radio link performance between the base station (BS) and the mobile station (MS). The splitting of the millimeter-wave signals for the different array antenna elements is carried out in the optical domain by an optical distribution network. After optoelectronic conversion it provides a number of optically steered millimeter-wave signals which are individually controlled for feeding the elements of an array antenna. In contrast to millimeter-wave systems no matching problems arise when the optical signals are split up. Due to the large bandwidth of the optical fiber the group delay is negligible within the millimeter-wave transmission bandwidth. Since it is comparatively easy to control the delay time or the phase of an optical signal continuously, the far field pattern can be steered over a large spatial angle.

In this paper we report on initial data transmission experiments. 155 Mbit/s data signals in the OQPSK format, have been transmitted over a short radio link using a 1x4 patch array antenna. The millimeter-wave signals feeding the antenna elements were controlled by optical delay lines. The 60 GHz carrier was generated by optical heterodyning using an injection locked laser configuration [1],[8].

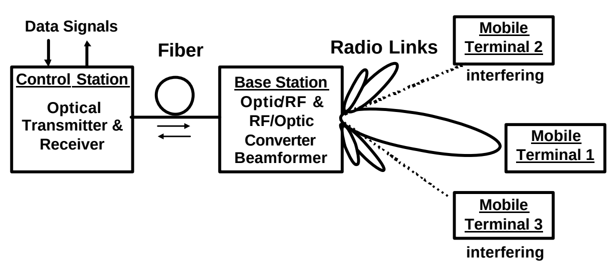

Fig. 1. Principle of a mobile communication system applying hybrid fiber radio technology and beamforming.

II. EXPERIMENTAL SETUP

A previously published experimental setup [1] was extended by the components for beam steering, Fig.2. The carrier near 60 GHz was generated by optical heterodyning the signals of two DFB lasers at λ=1,54 µm depicted as signal laser (LDS), and as reference laser (LDR). By applying modulation sideband injection locking [8] the desired millimeter-wave frequency was stabilized and the phase noise was significantly reduced. This technique may be described as follows: A master laser (LDM) is subharmonically modulated by a synthesizer signal (OSC1) at f=3.2 GHz via its injection current. LDS and LDR are coupled to the +10th and -9th modulation sidebands by adjusting injection current and laser temperature yielding a frequency spacing of 3.2*19=60.8 GHz. The phase noise components of the two optical waves are correlated by injection locking. Thus millimeter-wave signals with high spectral purity (<-100 dBc/Hz at offset frequencies ≥ 1 MHz) were obtained at the optic/millimeter-wave converter (OMC) outputs.

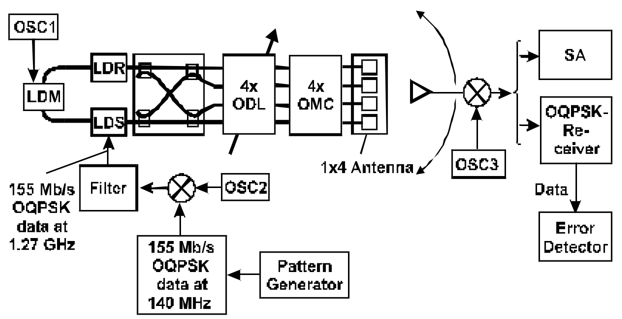

Fig.2. Experimental setup: LDM: Master laser, LDS: Signal laser, LDR: Reference laser, OSC1, OSC2, OSC3: Oscillators, 4xODL: 4 tunable optical delay lines, 4xOMC: 4 Optic/millimeter-wave converters, SA: spectrum analyzer.

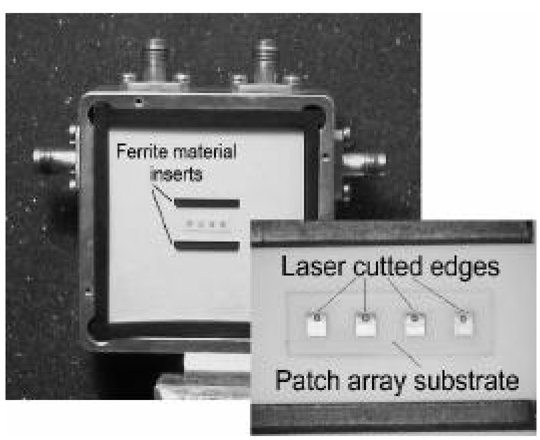

Fig.3. 1x4 patch array antenna and close up view of the array substrate

The optical waves of LDS and LDR were combined and distributed to four OMCs for optoelectronic-conversion (optical input power -8 dBm per OMC, RF-output power -8 dBm). Prior to the OMCs four continuously tunable optical delay lines (ODL) were inserted for beam steering. Each of the OMCs contained a high speed photo detector (0.85 A/W) and an amplifier (20 dB gain). The millimeter-wave signals were applied to the phased array antenna elements.

The antenna was fabricated by applying classical photo lithographic methods. The patches were printed with a $\lambda/2$ spacing. A thin (0.1 mm) aluminum oxide substrate was used which was mounted above the ground plane by inserting a windowed spacing substrate of 0.254 mm providing an air dielectric below the patch ceramic substrate. This lowers the effective dielectric constant of the radiating element carrier by a factor of greater than two which is useful for improving the radiation efficiency and bandwidth.

The antenna elements are fed from the rear side by semi rigid coaxial lines. The photo shows inserted a close up view of the patch substrate which is glued on the spacing substrate mentioned earlier. Final alignment of the feedpoint matching has been done by laser trimming one side of the patches.

On the receiver site a movable 60 GHz-band receiver was used which was connected to a spectrum analyzer and a BER receiver. The receiver antenna was a waveguide horn antenna which was mounted on the positioner of the far field antenna measurement set-up. It allowed a rotation in the azimutal plane of the transmitter far field. The distance between transmitting and receiving antenna was 70 cm. The received signals were down converted using a mixer and OSC3 (f=62.21 GHz) and applied to the spectrum analyzer or to the OQPSK- demodulator and the BER receiver.

III. Experimental Results

A Farfield Measurements

The far field patterns were measured without modulation of LDS. Figs.4a-c show the H-plane far field patterns of the 1x4 patch array antenna for 3 settings of the optical delay lines which have been adjusted for maximum field strengths at Q_{max}=0° (broadside), -20°, and -40°, respectively. For the look directions the main beam shows good performance. However, the poor nulling for the measurement at -20° and -40° directions is attributed to differences of the radiated field strengths of the individual antenna elements. The calculated curves are obtained using the relation for RF-power versus azimutal angle [9]. The resulting far field pattern equals to the squared value of the complex field strengths originating from all patches taking the delay time differences into account.

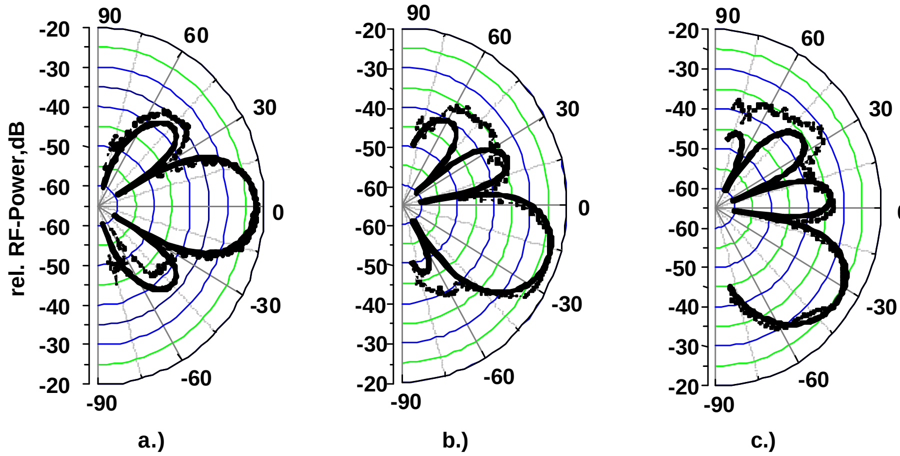

Fig.4. Measured and simulated H-plane far field patterns of the 1x4 patch array antenna at f=60.8 GHz for 3 different settings of the optical delay lines, look directions: 0° (a), -20° (b), and -40° (c).

B Bit Error Rate Measurements

We carried out two measurement series, the first one with fixed antenna look direction while the receiver was moved. In the second case the look direction was adjusted towards the moving receiver. The data transmission was carried out using the components of a digital radio-relay system which was fed by a 140 Mbit/s code mark inversion (CMI) coded pseudo random binary sequence (PRBS) with a wordlength of 2^{23}-1. At the modulator output the 155 Mbit/s data signals were obtained in the offset quadrature phase shift keying format (OQPSK) at a 140 MHz subcarrier. After upconverting to 1.27 GHz using OSC2 this signal was directly applied to LDS modulating its optical phase. Thus the optically generated spectral components at the four OMC outputs contained the OQPSK signal at 62.07 GHz.

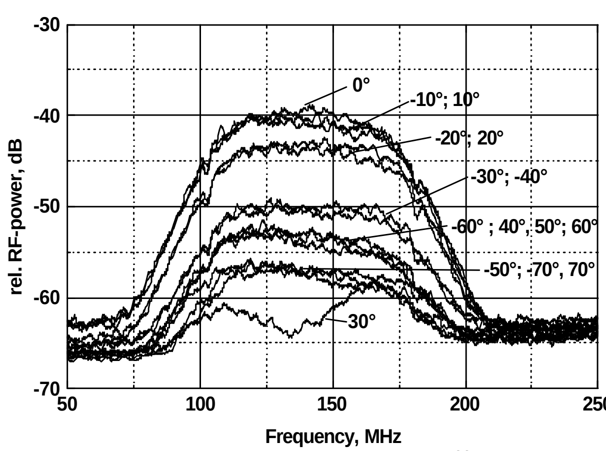

Fig.5. OQPSK-Spectra measured at different azimutal far field angles for a fixed antenna look direction at 0 degrees.

For the data transmission it is important that all paths within the beam steering network are of equal lengths, otherwise the broadband properties of the transmission channel are disturbed and the shape of the OQPSK spectrum is affected when the receiver is moved in azimutal direction. In case of equal feeder lengths the level of the OQPSK spectrum depends directly on the received RF-power level.

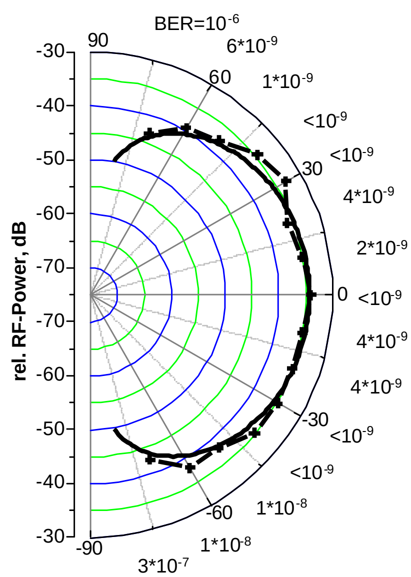

Fig.6. Measured BER and rel. RF-power at the OQPSK-demodulator input versus antenna look directions. It was tuned using optical delay lines.

However, in the case of slight fiber lengths differences the spectral shape of the modulation signal is affected depending on the azimutal angle. In this case the BER increases significantly. Fig.5 depicts experimentally obtained OQPSK-spectra for a fixed look direction of 0°. The receiver was moved over an azimutal range between -70 and -70°. The measured spectra show that our raw trimming of the fiber lengths was sufficient for angles between 20° and -20°.

Thereafter the look directions of the antenna were adjusted to different azimutal angles by tuning the optical delay lines and BER-measurements were carried out. With the given experimental setup the BER below 10^{-8} could be maintained over an angle range of 120°. Fig. 6 shows the measured RF-power and the achieved BER at different angles. The calculated curve represents the RF-power for the actual look direction versus azimutal angle which is proportional to the far field characteristic of a single patch [9].

IV. CONCLUSION

We demonstrated the optical generation of 60 GHz signals for remote feeding and steering the field distribution of a phased array antenna. 155 Mbit/s data transmissions at 60 GHz were carried out successfully with bit error rates below 10^{-9}. The millimeter-wave signals were generated by optical heterodyning and modulation sideband injection locking.

The antenna's properties were investigated by transmission and farfield measurements. The field pattern of a 1x4 patch array antenna was steered using optical delay lines. The far field controllability with respect to broadband data transmission for different beam angles showed good performance. For an improved antenna directivity a larger number of antenna elements is necessary requiring an extended distribution network.

The method described above allows only beam steering. For constraint beamforming the control of the phases and amplitudes of the individual millimeter-wave signals is necessary. This will be achieved by the beamforming network on SiO_2/Si substrate which is presently under development. With this device the optical waves to be heterodyned are controlled individually by applying a thermooptic effect. It will provide an optimized radio link between base station and mobile terminal while the nulls of the antenna far field suppress the signals of other interfering mobile terminals.

ACKNOWLEDGEMENT

The work was supported by the Bundesministerium für Bildung, und Forschung and by the city of Berlin. The authors would like to thank their colleagues A. Kortke and R. Ziegler for simulating and realizing the patch antenna.

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