Hybrid Integrated Photonic Millimeter Wave Emitter

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Abstract—In this paper, the concept of a photonic millimeter wave transmitter featuring hybrid integration of a photodetector and a millimeter wave low noise amplifier on a high-resistive silicon motherboard and a high-resistive silicon lens is presented and experimentally verified for a frequency range of 50-75 GHz.

Keywords—Millimeter wave, photonic emitter, dielectric lens, quasioptic, hybrid integration.

I. INTRODUCTION

In the past decade data rates of wireless communication systems increased at fast pace. For example the WLAN IEEE standard evolved from 802.11 with 2 Mb/s gross data rate at 2,4 GHz approved in 1997 to the up to date most common IEEE standard 802.11g with 54 Mb/s gross data rate also at 2,4 GHz approved in 2003 and 802.11n with a gross data rate of 540 Mb/s approved in 2009 [1]. The implementation of digital communication by fiber optics up to street- and house-level requires for even higher data rates for wireless communication in the future.

There are different options to satisfy this demand. One relatively simple way would be to increase the transmission power allowing to operate at higher modulation schemes which is however limited to legal regulations. Another option would be to consume more bandwidth which is limited as well within the microwave regime.

A solution to this would be to operate within the millimeter wave range, where more bandwidth is available allowing increased transmission speeds. The frequency range around 60 GHz is especially attractive for the reason that it is unlicensed all around the world. For example in Europe, an unlicensed frequency range of 57-66 GHz is available, whereas in the USA and Canada, the range from 57-64 GHz is allocated for unlicensed operation. Moreover, a multitude of manufacturers offer a wide range of components commercially available. A significant disadvantage of 60 GHz communication is the atmospheric gaseous attenuation mainly due to the resonance of oxygen and water molecules at 60 GHz thus limiting the wireless path range.

However this property can be beneficial as it allows a frequency reusability and an inherent safety from interception.

A typical application example of 60 GHz wireless communication is in-house communication, i.e. the pico-cell scenario. In this example, a building is connected to an optical network by a gateway, which is further distributing the data modulated onto a photonic millimeter wave carrier to each room of the house (pico-cells) equipped with a 60 GHz transmitter. The incoming optical signal is converted into an electrical signal and wireless transmitted. To give some examples, typical applications would be 1 GbE wireless (IEEE802.3z), 10 GbE wireless (IEEE802.3ae), WPAN (IEEE802.15.3c) and Wireless HDTV.

The aim of this work is the realization of a potentially low cost photonic emitter capable of data rates up to 10 Gb/s in the frequency range around 60 GHz. Another important aim is the realization of a small-scale solution, therefore upconversion of an optical data signal is not performed electrically. In contrast, a radio-over-fiber signal with photonic upconversion is delivered to each pico-cell. Here, the data-modulated photonic millimeter wave signal is o/e-converted, amplified and transmitted applying a small-scale planar antenna. This vastly reduces the electrical complexity in the emitter.

II. CONCEPT OF THE PHOTONIC MILLIMETERWAVE Emitter

In this chapter the general concept of the photonic millimeter wave emitter is presented. The motivation of this work is the realization of a compact and potential low cost solution by avoiding external millimeter wave components like large horn antennas or external amplifiers. The concept is shown in Figure 1. It is based on the idea of hybrid integrating the photodetector (PD) and the amplifier on a silicon motherboard placed on a quasi-optical system.
The optical input is achieved by an optical fiber, which is coupled into a hybrid integrated PD which converts the optical signal into an electrical signal. The signal is then amplified by a high electron mobility low noise amplifier (HEMT-LNA) and after that radiated by an antenna which is directly integrated on the high resistive (HR) silicon motherboard. The motherboard itself is integrated in a quasi-optical package.

A. Antennas on Extended Hemispherical Dielectric Lenses

Planar antennas integrated on a dielectric substrate suffer from power loss due to reflections at the substrate-air interface. These reflections are called substrate modes because they are coupled into the substrate and are trapped in there. One option to avoid this is the application of a very thin substrate, typically 0.2 x λ for dipole antennas [2] [3]. Hence the substrate becomes very thin and fragile applying this option to millimeter and sub-millimeter wavelength another option can be used, the application of a dielectric lens. The dielectric lens has the same dielectric constant as the substrate and thus reflections between the lens and the substrate are negligible. In addition to that the structure of the dielectric lens does not support surface-waves.

Dielectric lenses can be hemispherical, hyperhemispherical, or ellipsoidal. A hyperhemispherical lens is a hemispherical lens with an attached extension. Radiation patterns of these lenses are broad and in some cases even multi-lobed [2] [4]. Moreover, the hyperhemispherical lens satisfies the sine condition and is aplanatic [5]. This guarantees avoidance of the circular coma and spherical aberrations. For the antenna this means that the radiation pattern is sharpened and thereby the gain of the antenna is increased.

The hyperhemispherical system is a very practical system because it allows adjustment to a wide range of quasioptical systems by just varying the extension length.

B. Simulations and Optimization

Simulations and Impedance matching were carried out in Microwave Office®. Regarding the in- and output of the LNA matched to 50 Ω and the coplanar waveguide of the PD also designed to match 50 Ω, the waveguides between the components have to satisfy this match accordingly to achieve an anechoic transmission line.

To get an impression of the performance of electrical part of the system all transmission lines are connected with predefined bond wire models and a predefined amplifier model with a small signal gain of 21 dB similar to the LNA used in this work. The output power of the simulated electrical signal source is set to 0 dBm. For termination an element with an input impedance of 50 Ω is used. Figure 2 shows the magnitude of the simulated forward gain S_21 for this simulation scheme. An overall forward gain of about 17 dB is simulated. Attenuation of all transmission lines and bond wires is calculated to about 4 dB.

III. EXPERIMENTAL RESULTS

Figure 3 shows the frequency response of the motherboard equipped only with the LNA (MB2 – AMP) and the frequency response of the motherboard without the LNA (MB2) at the same input power of -12 dBm.

Comparing these two frequency responses reveals an average gain of about 15 dB. This corresponds with the simulation results carried out in chapter II, which suggested a gain of about 17 dB.
Figure 4. Comparison of the frequency responses of final photonic millimeter wave emitter equipped with LNA and PD with an optical mm wave signal applied compared to the motherboard solely with mounted LNA and applied electrical input signal.

For a comparison the frequency response of the emitter with mounted LNA without the PD (MB2 – AMP) and an electrical input of -12 dBm is included in Figure 4. The electrical output power of the PD was measured to be about -25 dBm in the frequency range of 50-75 GHz at a photocurrent of 1mA. The difference of the average detected output power of the two frequency responses is about 15 dB. The frequency response of the photonic millimeter wave emitter is flat, no decay is observable in the given frequency range. If identical input powers are assumed at the input of the LNA, the maximum difference between signal feed by the synthesizer and by the o/e-converted photonic millimeter wave signal is about 3 dB, indicating that the RF connection between photodetector and amplifier is properly designed.

In addition, the emitter shows a flat frequency response up to 75 GHz, showing that operation even at much higher frequencies is possible.

V. CONCLUSION

Measurements of the device with an amplifier compared to antenna measurements showed a gain of about 15 dB. This corresponds with the simulation results which suggested a gain of about 17 dB instead of the specified 21 dB, if losses due to the applied transmission lines are considered. Summing up the results, a compact photonic millimeter wave emitter was successfully designed and constructed allowing broadband operation within 50-75 GHz.

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References