300 GHz transmission system

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A 300 GHz transmission system, designed for terahertz communication channel modelling and propagation studies, is introduced. It consists of an autarkic transmitter and detector units based on Schottky diode mixer technology. The system performance is characterised with regard to link budget and noise. For demonstration, analogue video signals have been transmitted over distances of up to 22 m.

Introduction: The increased demand for unoccupied bandwidth for fast data transmission applications requires the extension of communication systems to higher, still unregulated frequencies [1, 2]. Despite high path losses, pico-cellular short-range indoor communication systems could operate in atmospheric transmission windows around 300 or 350 GHz. Although the required compact components for such systems like planar integrated sources, amplifiers and antenna arrays do not exist yet, recent technological progress in key technologies such as SiGe BiCMOS, InP and others suggest that they might be available in a few years from now [2]. However, the design of such terahertz (THz) communication systems requires reliable indoor channel modelling, which has not been done up to now, including the study of propagation effects and the evaluation of appropriate modulation schemes.

In this Letter, we introduce a transmission system that is designed to cover a vast variety of measurement tasks involved in channel modelling at 300 GHz. It is based on existing Schottky diode mixer and metal waveguide technology [3] as used in scientific applications like radio astronomy or atmospheric sensing. We discuss the distance dependent link budget and the noise performance of the system. Furthermore, we use it to demonstrate data transmission at 300 GHz by establishing a 22 m indoor link for analogue video signals, which is far beyond previous demonstrations at THz frequencies based on optoelectronic sources and room-temperature semiconductor modulators [4].

Setup: The transmission system consists of autarkic transmitter and receiver units as shown in the block diagram in Fig. 1 and has been build by Virginia Diodes, Inc. A subharmonic mixer is used to upconvert a signal (DC–10 GHz, delivered by a signal generator) up to 300 GHz. It is then transmitted with a horn antenna that is directly attached to the mixer block (300 GHz carrier signal power of 50 μW). The local oscillator is provided by a 16.66 GHz phase-locked dielectric resonator oscillator (DPRO with 10 MHz reference crystal oscillator), which is first amplified and tripled, then tripled a second time.

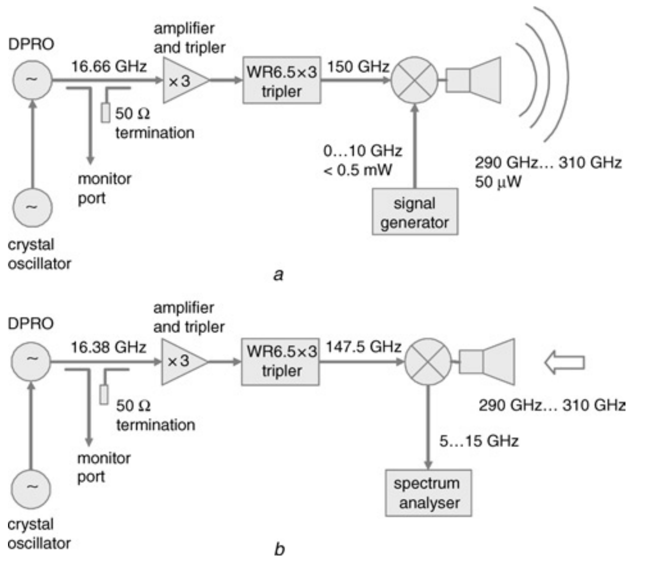

Fig. 1 *300 GHz transmission system block diagram*

a Transmitter
b Receiver

At the receiver side the same components have been used except that the DPRO is tuned to 16.38 GHz. This results in a downconversion of the received signal to an intermediate frequency (IF) of 5 GHz. The upper sideband of the downconverted signal is displayed on a spectrum analyser in the frequency range 5–15 GHz.

System performance: The conversion factor of both mixers at the transmitter and the receiver side are specified by the manufacturer to be $G = G_{TX} = G_{RX} = -9.7$ dB for single-sideband operation. Assuming the same gain $g = 26$ dB as specified for both transmitter and receiver antenna, the distance dependent power at the receiver IF output is [5]

$$P_{OUT} = P_{IN} + 2G + 2g - s - 10\log\left(\frac{4\pi rf}{c}\right)^2$$
$$= P_{IN} - 49.4\,\text{dB} - s - 20\log\frac{r}{\text{m}} \quad (1)$$

where P_{IN} is the input power, r the distance between the antennas, $f \simeq 300$ GHz the transmission frequency, s additional system loss and $c = 3 \times 10^8$ m/s the speed of light. The free-space loss has been split into a distance dependent part and a constant part, which has been combined with mixer and antenna gains. Fig. 2 shows the measured received signal power in the intermediate frequency range as a function of input frequency for four different antenna separations between 5 and 80 cm and an input power of −10 dBm in comparison to the calculated power according to (1). Here, an additional system loss of $s = 6$ dB has been assumed for the calculations.

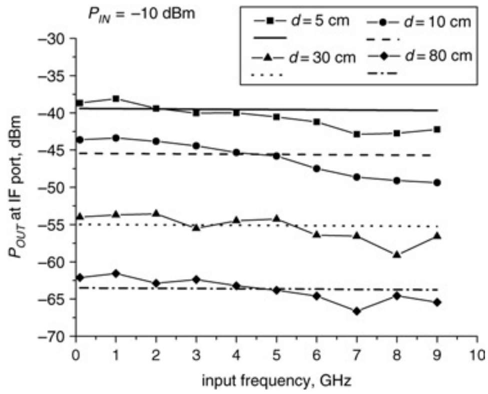

Fig. 2 *Received output power at IF port against input frequency for four different antenna separations and input power of −10 dBm (symbols connected by solid lines) in comparison to calculations (dashed lines)*

The noise temperatures of the mixers at the transmitter and receiver side are specified for single-sideband operation to be $T_{TX} = 960$ K and $T_{RX} = 980$ K, respectively. Fig. 3 shows the noise evaluation of the transmission system. Signal and noise from the signal source are combined with the equivalent input noise of the transmitter and are then multiplied by the transmitter gain before being transmitted. The transmission path loss contains the free space attenuation reduced by the gain of antennas and lenses. At the receiver the incoming signal and noise is combined with the noise of the antenna (noise temperature $T_0 = 290$ K due to the indoor environment) and the equivalent input noise power of the receiver. Output signal and noise are obtained after multiplication by the receiver stage gain. Additional system loss due to connectors or impedance mismatch is not part of the noise budget but might reduce the output signal level further and has to be considered as required system reserve. The block diagram in Fig. 3*a* shows a typical measurement situation with a signal generator (135 dBc Hz^{-1}, corresponding to a noise temperature of 228878 K for a signal power of −10 dBm) as input source, a resolution bandwidth of 1 MHz set at a spectrum analyser used as the detector and an antenna separation of 50 cm.

Analogue video signal transmission: To demonstrate the feasibility of signal transmission, a colour video baseband signal (CVBS) with 6 MHz bandwidth modulated on an ultrahigh frequency (UHF) carrier (855.25 MHz) as provided by a video cassette recorder was amplified (amplifier and 10 dB attenuator) and then transmitted over the 300 GHz link. An additional mixer was used to convert the signal from the 5 GHz IF of the receiver back to the baseband. A standard TV card was used to display the signal on a personal computer. Excellent picture quality has been achieved up to a distance of 0.5 m with the transmission breaking down at a distance of 0.8 m. Using

two polyethylene lenses (5 cm diameter, 12 cm focal length) the antenna gain of both the transmission and receiver antennas could be increased by 14 dB each by collimating the 300 GHz radiation into a nearly parallel beam. This allowed for an increased maximum transmission range of 22 m with excellent picture quality up to at least 15 m.

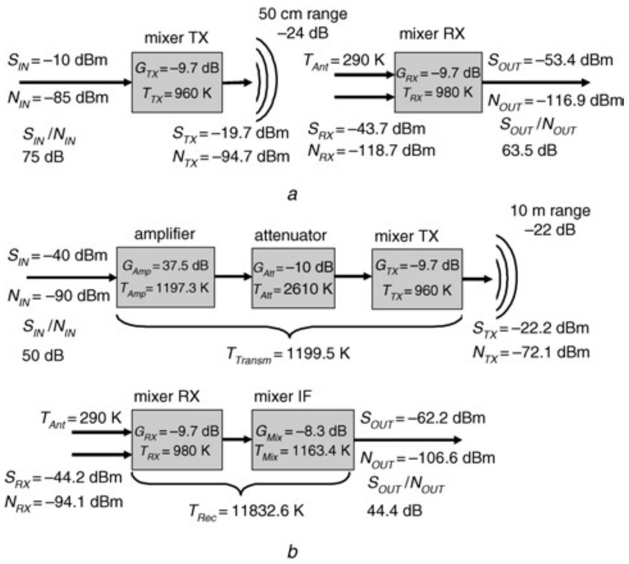

Fig. 3 *Block diagrams for noise evaluation*

a Transmission of signal generator output over 50 cm range assuming 1 MHz measurement bandwidth at spectrum analyser
b Transmission of video signal over 10 m using additional polyethylene lenses

Fig. 3*b* shows the noise analysis for a 10 m video signal link, assuming a noise bandwidth of 6 MHz, the additional gain of the polyethylene lenses and gain and noise properties of the additional components. The equivalent noise temperatures of the transmitter and receiver have been calculated according to Friis' formula for cascaded systems [6]. Clearly, the noise of the video source (corresponding to a noise temperature of 12072 K) dominates the transmission path. Since the signal-to-noise ratio at the TV card input is approximately 44 dB (40 dB required), a reliable link can be maintained.

Conclusions: We have presented a versatile 300 GHz transmission system with a bandwidth of up to 10 GHz that has been designed for channel characterisation of future THz communication systems. By transmitting a video signal at a carrier frequency of 300 GHz we were able to show the feasibility of communication links at sub-millimetre wavelengths.

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