Optically Controlled Phased Array Antenna

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Abstract: A coplanar dipole antenna array with optical feeder network operating at 20 GHz is presented. The RF input signal modulates an optical carrier. The modulated light is transferred via optical singlemode fibres to the antenna elements, where the signal is locally detected and amplified by a hybrid-integrated photoreceiver.

RF feeders and electronic beamforming networks (BFN) for antenna arrays are very costly and bulky components. We present the concept and preliminary results for a sending-mode 20-GHz dipole antenna array with an *optical* BFN (OBFN), consisting of true time delay (TTD) optical singlemode fibre feeders and opto-electronic converters. Besides the conceptual simplicity of removing the BFN from the array face, such a TTD feeder avoids a frequency dependent beam squint [1] [2]. By switching the time delays of the OBFN adaptively, an intelligent space-diversity antenna may be designed, where each beam tracks possible movements of a mobile subscriber.

The right side of Fig. 1 shows the coplanar antenna structure etched on a 63 mm × 63 mm RT Duroid 5880 substrate with a thickness of 1.57 mm. The radiating slot length is 5 mm. The slot width of the 50-Ω coplanar feeding line decreases from 100 µm near the dipoles to 50 µm near the photoreceiver (PR). The PR is marked by a rectangular; an enlarged display is seen on the left side of Fig.1. The DC path of the coplanar feeder is blocked by an interdigital capacitor of 0.2 pF for decoupling the PR output from DC ground. Fig 2 shows the measured input reflection coefficient $|S_{11}|$ as a function of RF frequency f_m with and without the blocking capacitor. The 14dB- bandwidth amounts to 7.5%.

The opto-electronic integrated circuit PR is grown on a semi-insulating GaAs substrate with dimensions 2.5 mm × 1 mm [3]. It consists of a pin photodiode

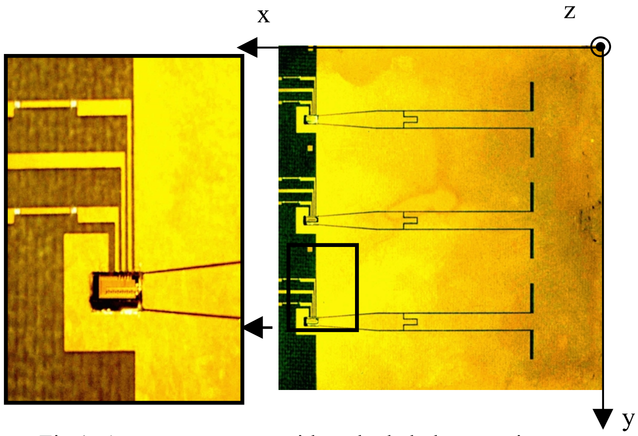

Fig 1: Antenna structure with embeded photoreceiver

(PD) with a circular light-sensitive area of 10 µm diameter and a four-stage distributed amplifier made of pseudomorphic HEMTs. Each stage of the distributed amplifier consists of a cascoded pair of

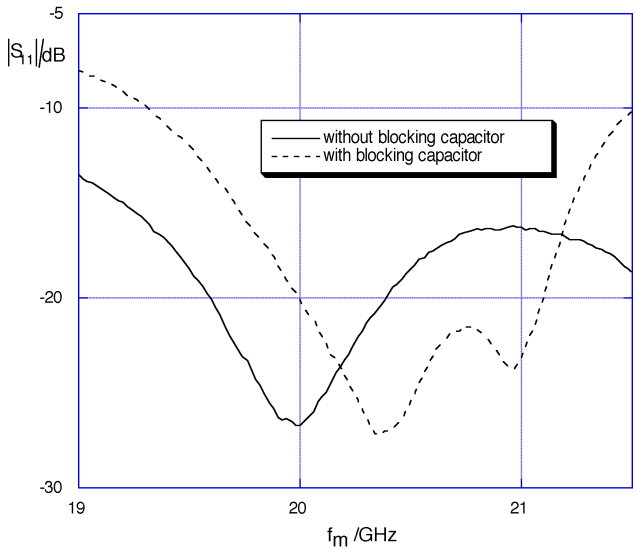

Fig 2: Modulus of input reflection coefficient $|S_{11}|$ for single antenna element

HEMTs with 90 µm gate-width, embedded in 70 Ω coplanar transmission lines. To achieve a high bandwidth, the input impedance is kept as low as 30 Ω. At $\lambda = 1.55$ µm, the responsivity, dark current, and capacitance of the PD are 0.34 A/W, 15 nA and 109 fF at -2V bias, respectively. The entire pin-

HEMT PR has a transimpedance of 146 Ω corresponding to an O/E conversion factor of 50 V/W, and a bandwidth suitable for NZ or NRZ data transmission up to 40 Gbit/s.

The measurement setup is seen in the upper part of Fig. 3. A CW DFB laserdiode (LD) is followed by a Mach-Zehnder-Modulator (MZM), which modulates the optical carrier with a sinusoidal RF signal of frequency f_m = 20 GHz.

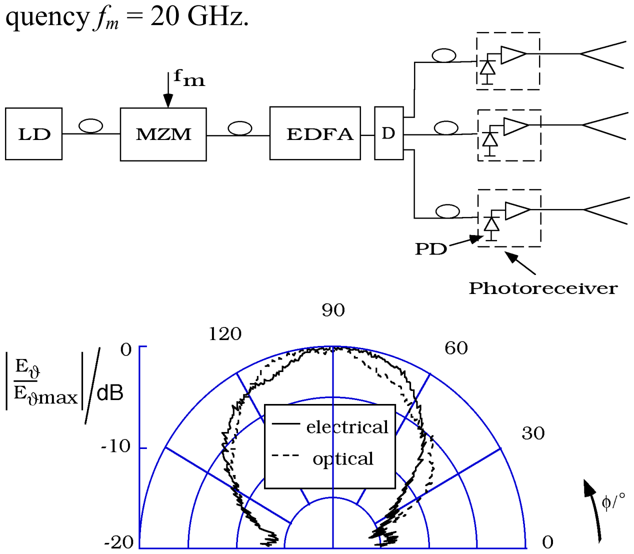

Fig 3: Measurement setup and H-plane radiation pattern of a single antenna element

An erbium-doped fibre amplifier (EDFA) increases the optical power. The modulated light is symmetrically distributed by an 1:3 fibre-optical power divider (D), and finally coupled to the PD of each of the PR. We measured the radiation pattern of a single element in the H-plane (y-z-plane in Fig. 1), lower part of Fig 3, both for an all-electrical excitation of the antenna, and for an opto-electric feeder as described above. The differences in both radiation patterns stem from the masking of the non-excited antenna elements for preventing a radiation coupling for the single-element measurements.

External optical modulators are expensive components, so we tried a direct intensity modulation (IM) via the injection current of the LD. Associated with injection current changes, we see – besides AM sidebands – also a large number of frequency modulation sidebands (chirp) in the optical spectrum. Because a PD cannot detect FM, we employed a dispersive optical fibre as a FM-AM converter, so that the receiving PD can detect the kth harmonics of the LD modulation signal f_m [4].

As an illustration, a LD has been directly modulated at f_m = 1.95 GHz with a relative injection current modulation amplitude m (= modulation degree = injection current amplitude with respect to the difference of bias and threshold current). The LD output is launched into a single mode fibre of length L, and the light is detected at the remote fibre end. Fig. 4 shows the photodetector AC current amplitudes $|2I_k|$ of differents harmonics k as a function of L. The amplitudes increase strongly towards the optimum near L = 100 km and 70 km, respectively, depending on m. By employing overmodulation m = 1.5, i.e., by driving the LD temporarily below threshold, a strong 9th harmonic at 17.6 GHz for L = 12.8 km can be achieved [4]. Further improvements towards a more compact FM-AM converter are possible using long-period fibre gratings and Bragg fibre gratings.

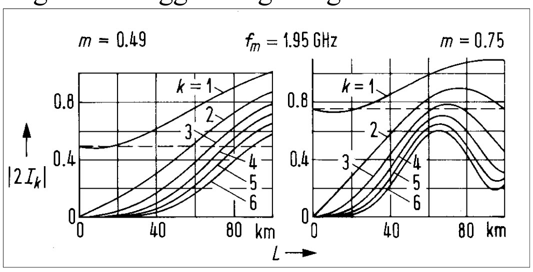

Fig 4: PD harmonic current amplitudes

In conclusion, we designed a coplanar phased array antenna with an optical feeder, and investigated the system using an external modulator. We also demonstrated harmonic upconversion using a chirping LD and a dispersive fibre.

References

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