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“Studies of Smart Photonic Antennas for a Wireless Communication System using RF/photonic device”

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Abstract—This paper presents a novel, integrated a photonic antenna with a power control scheme. The controller regulates the levels of radiated power by adjusting the bising voltage of a side-illuminated waveguide photo detector (WGPD). The WGPD converts the RF-modulated optical power into a microwave signal, which is then fed to an antenna The controller uses as input the noise level measurements of a different receiving antenna, and periodically calculates the necessary amount of power that must be radiated. The performance of the RF/photonic device has been studied theoretically and experimentally. The addition of power control capabilities, the device realizes an early attempt to design “smart” photonic antennas.

I. INTRODUCTION

We present a framework for developing faster, adaptive wireless communication using arrays of “smart antennas” .The primary contribution of this paper is on integration of a RF antenna with an optical fiber and a transmission power control system. The antenna and the optical fiber are interfaced through an photo detector, which is built on the same chip as the antenna, increasing bandwidth and communication capacity. On top of this, a simple control system(implemented in software) uses RF noise power measurements to adaptively regulate the bias voltage of the photo detector. Through the bias voltage, the transmission power of the antenna can be adjusted. In this way we can achieve the required signal-to-noise ratio despite of slowly varying noise levels, and control the capacity of the channel at the same time. The need for more bandwidth and capacity in wireless systems fuels the development of wireless communications systems operating at millimeter wave frequencies and higher. The future needs of broad band interactive services(1Gb/s)demand the application of optical fiber feed networks for distribution of the radio signals to and from the antennas at the various base stations. Today, there are three main steps in the evolution of RF/Photonics systems for wireless communications. The first step has been in the direction of using photonics to slowly replace conventionalRFcomponents,suchas,thecoaxthatisusedtointerconnectthe antenna to the electronics. Optical fibers, in contrast to coaxial cable, provide a more ideal medium for broadband RF communication systems. The light weight property of fibers, and its immunity to other signal interference make them very important of future RF distribution systems. The second, and more challenging step, is in the seamless integration of photonics and RF wireless circuits. fiber-optic technologies have reached the stage where insertions into various commercial RF systems are being considered. In this step the aim is to eliminate the need of local oscillators, mixers, amplifiers and a host of other parts by directly feeding an antenna through a fiber at millimeter wave frequencies. An array of RF modulator/photo detectors can be integrated directly to an array of antennas, combining the advantages of both fiber optics and wireless channels. It is possible that a large number of such RF/Photonic antenna elements could be network together into a star configuration, feeding in and out of a radio hub. Despite the fact that the integration of photonics with antennas has recently gained momentum the issue of controlling the output power in photonic antennas has not yet been considered.

Given that in a communication channel of a wireless network each other node introduces noise, it becomes clear that all nodes have to transmit at the minimum possible energy level. This work presents a simple way to automatically regulate the transmission power of each antenna so that, despite noise, the capacity of the channel is adjusted, propagation of information is guaranteed and signal interference is kept at minimum. An array of RF modulator/photo detectors is integrated directly to an array of antennas, combining the advantages of both fiber optics and wireless channels. When combined with an transmission power automatic control system, this new RF/photonic antenna array system, with the appropriate space-time processing and coding, can form a “smart antenna” that can enhance network coverage, capacity, and quality. It is possible that a large number of such RF/Photonic antenna elements could be networked together into a star configuration, feeding in and out of a radio hub. Section II describes the interface of the optical fiber with the antenna on the same chip and the use of an additional antenna to take environment noise measurements.

In Section III, these measurements are used to close the power control loop, through which RF transmission power is regulated so that it is always above a threshold over environment noise. Two simulation cases are provided to demonstrate the ability of the control system to track time varying noise levels. Section IV summarizes our results and states the contributions of this paper.

II. The Photo detector–Antenna System The flexibility in the design of Waveguide Photo detector(WGPD) – provided by optical coupling, optical ab2sorption, transit time and capacitance – offers the ability to optimize it for the given application [4], [5]. TheWaveguide Photo detector converts the RF-modulated optical power into a microwave signal, subsequently fed to an antenna (Figure 1.) The WGPD is a standard p-i-n device grown on a semi-insulated In P substrate. It eliminates the bandwidth-efficiency trade-off that is fundamental to normal, surface illuminated photo detectors. Fig. 1. Schematic representation of the antenna-photo detector system. The photo detector is fed via an optical fiber that is terminated at the facet of the optical waveguide layer. Bias across the photo detector determines the output power, as well as the frequency of operation. The effects of biasing can be seen in Figure 2

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Jcont = Jn + Jp.

The biasing of the photo detector is provided through the antenna design. The antenna is a CPW- fed three element folded dipole slot. The transmitting antenna is a transformation of the basic folded dipole design in a patch/slot version [7]. It is operating around 18.5 GHz with a bandwidth of 1 GHz and a gain of 6.5 dBs. Due to magnetic currents generated in the slots, each folded slot antenna radiates like a half wavelength folded dipole with linear polarization.

The main advantages of this particular design are low cross polarization (≤ -23 dB's), and low coupling between its elements [8]. The photo detector is fed via an optical fiber that is terminated at the facet of the optical waveguide layer. Bias across the photo detector determines the output power, as well as the frequency of operation. The effects of biasing can be seen in Figure 2.

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.optical fiber is transformed into RF by the Photo detector/Antenna. The bias voltage of the photo detector behaves as the controlling gate, regulating the output power level of the antenna, P as follows:

P = Ev,

where E is a constant that is obtained from Figure 2, by integrating the pulse responses and considering the linear region of the resulting curves. For the pulse response that corresponds to 15V (the one with the highest peak), integration gives a function that increases linearly between18.3ns and 18.4ns and then saturates (Figures 7-8). We will operate the system at power levels that correspond to the linear region. Computing the slopes of the integrals of different curves in Figure 2, reveals that the rate of increase for the output power increases linearly with the bias voltage (Figure 9). From Figure 9 the rate of increase of the output power with the bias voltage can be estimated to be around E = 75.5 mW/V.

The antenna transmits in an environment with noise, w, due to the transmission of other antennas and reflections of its own signal. Without loss of generality, the noise signal, w can be considered as white Gaussian. In an indoor environment, the noise signal is slowly varying, in which case the bandwidth of the power control system is usually adequate for tracking noise levels. Noise levels are picked up by a second antenna, perpendicularly polarized, in a distance sufficient to exclude coupling effects. This second antenna works as a sensor, measuring only the environment noise.

P′ = w.

The bias voltage, v, is controlled by a microprocessor,based on the sequence of light pulses that arrive through the optical fiber and the noise measurements obtained from these secondary antenna. The microprocessor can directly regulate the bias voltage, and therefore the dynamics of the latter in discrete-time can be expressed as:

vk+1 = vk + uk,

where uk is the control input for power regulation, which is to be determined.

Pk = Evk

Fig. 10. Block diagram of the control system design.

The control system's output signal (Figure 10) is definedas:

yk = P − w = Evk − w, (1)

and expresses the difference between the power of the transmission signal and the noise level. For successful transmission it is necessary that this difference is always above a threshold, namely, the desired signal-to-noise ratio:

y desired = SNR.

,

where rk is the (light) reference signal. Bearing in mind that the system directly measures noise w, rather than output signal yk, the controller structure depicted in Figure 10has to be implemented as shown in Figure 11.yThe control system described above allows the Photo detector/Antenna system to track the noise levels and maintain a constant power level above them (Figure 12, 13).In Figure 12, the high frequency pulse sequence is the response of the Photo detector/Antenna system to the light input signal. The low frequency pulse frequency corresponds to piecewise constant, white Gaussian noise. It is evident that regardless of the variation of the noise levels, the output is always regulated to a precise level above that of noise. To test the tracking performance of the control scheme further, we also simulated a sinusoidal noise waveform. The simulation results are given in Figure 13. From the response, it is clear that tracking ability is not restricted to the particular class of piecewise constant inputs but it extends to more general dynamic signals.

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Fig. 13. Tracking sinusoidal reference noise signals.

IV. CONCLUSIONS

We present a novel “smart antenna” design, in which we integrate photo detectors and antennas on the same chip, and we regulate the power level of radio transmission through a software-implemented control system. Firstly, linking the optical fiber directly with the antenna through a photo detector increases bandwidth without the need for signal amplification. Secondly, the control system adjusts the transmission power so that the desired signal-to-noise ratio is achieved and maintained, regardless of (low frequency)fluctuations of noise levels, ensuring reliable communication and allowing regulation of the channel capacity. The contribution of this work lays on the integration of photonics, RF radio and control towards faster, more reliable and adaptive wireless communications

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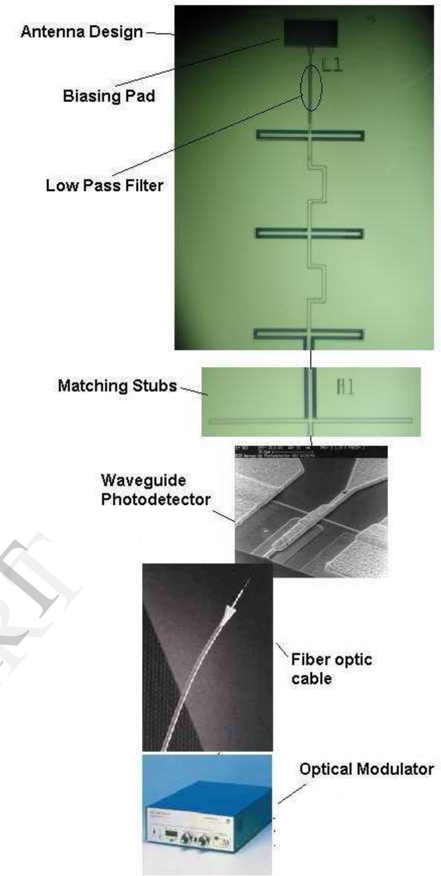

Fig. 1. Schematic representation of the antenna-photo detector system.

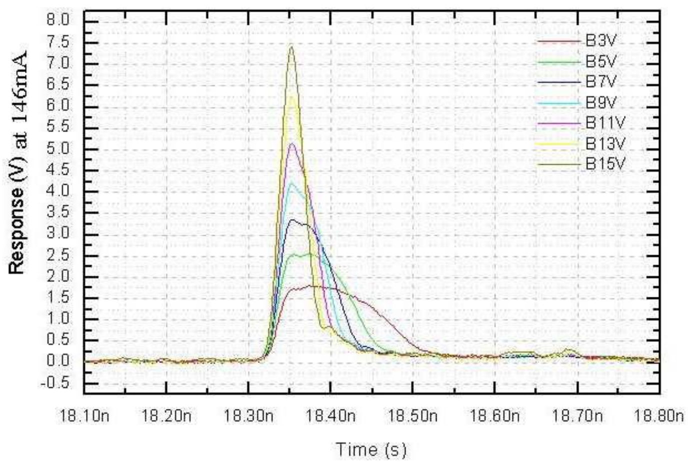

Fig.2The effect of photo detector bias voltage on the antenna output power.

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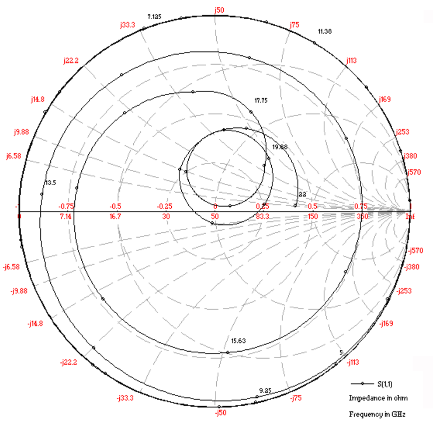

Fig. 3. S11 parameters of the transmitting antenna.

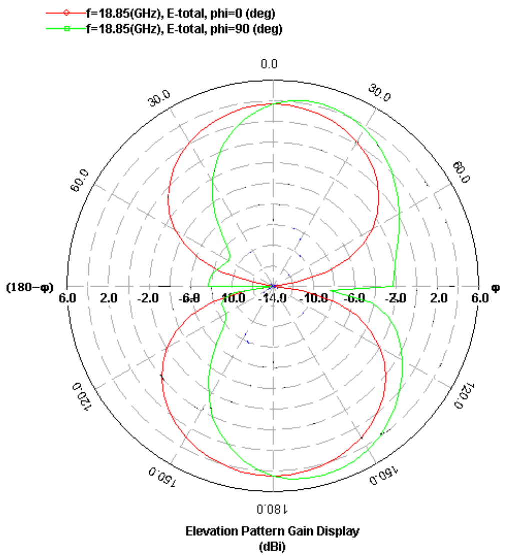

Fig. 4. The radiation pattern of the transmitting antenna.

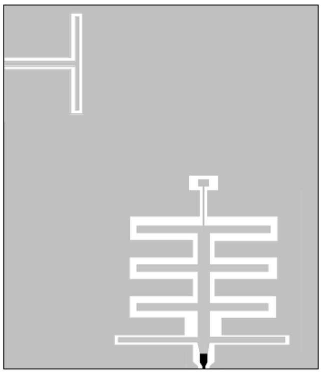

Fig. 5. Layout of the transmitting antenna and the perpendicular polarized antenna monitoring noise.

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