Tapered Slot Antenna Integrated with Velocity-Matched Distributed Photodetector

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ABSTRACT

We propose and demonstrate the integration of tapered slot antenna (TSA) and velocity-matched distributed photodetector (VMDP) which is potentially useful for millimeter-wave power combining and phased arrays, as well as RF front-ends for analog fiber optic links. The concept is confirmed by photomixing and antenna measurement with an X-band prototype, and is readily scalable to higher frequencies where the inherent tremendous bandwidth of optics can be fully employed.

I. INTRODUCTION

Analog optic links have been extensively used for applications such as the distribution of cable TV signals, antenna remoting and beam forming of phased arrays. We could define a link as the hardware required to recover the RF from the optical carrier, including any passive impedance-matching circuits used to match the modulation device and photodetector impedance to the RF source [1], as shown in Figure 1. A high-performance fiber-optic RF link needs to meet the following specifications [2]:

1) operation at high frequencies,
2) low input/output microwave loss,
3) large spurious-free dynamic range.

The near-zero dispersion and attenuation characteristics of optical fiber render itself an attractive medium for microwave and millimeter-wave antenna remoting. Its large bandwidth, low loss and immunity to electromagnetic interference (EMI) also account for the promising potentials over conventional electrical cables.

In this paper we propose a novel optics-assisted active integrated antenna, where a tapered slot antenna is fed by a high power, wideband velocity-matched distributed photodetector (VMDP) through photomixing [3]. This approach greatly facilitates the generation and processing of microwave and millimeter waves, which at the same time overcomes several fundamental limitations such as large feedline losses and the lack of convenient power sources at higher frequencies [4].

II. ANTENNA DESIGN

The tapered slot antenna (TSA) is known for its relatively narrow beamwidth (~30^0 at –10dB), wide bandwidth and small transverse spacing between TSA array elements [5]. These unique features make TSA a strong candidate for power combining and phased arrays at millimeter-wave frequencies.

Figure 2 shows the tapered slot antenna used for this work. The opening angle(2α) can be adjusted to control the antenna beamwidth. Furthermore, as the length (L) is increased, the beamwidth narrows and the directivity increases. For a travelling wave antenna with constant phase velocity, there is an optimum phase velocity ratio [4]

$$p = c / v_{ph} = 1 + \lambda_0 / 2L$$

which results in maximum directivity. Based on the arguments above, an opening angle of 12^0 and aperture size of $L=1\lambda_0$ is designed. As a tradeoff between the preference to using low dielectric constant materials for antennas and high dielectric constant ones for circuit components, we remove the dielectric substrate from the tapered region, resulting in a TSA with improved cross-polarization characteristics [5,6].

III. EXPERIMENTAL SETUP

The experimental setup is shown in Figure 3. The input source consists of two external cavity tunable lasers at 1.55 μm, with which the frequency of each laser can be tuned in 1GHz steps. The optical signals are combined by a 3-dB coupler, amplified by erbium-doped fiber amplifier (EDFA), and coupled to the VMDP through a lens fiber. Two probes are used to bias the VMDP at 4V and the average photocurrent (DC) is 2.5 mA. The microwave signals generated by optical mixing in the VMDP are collected at the output end of the CPS. By adjusting the optical polarization controllers, we can optimize the photomixing efficiency. Two bonding wires are used to bridge the VMDP and LTSA. The RF power output from the tapered slot antenna is picked up by a horn antenna connected to spectrum analyzer.

IV. RESULTS

The linear tapered slot antenna is built on 25 mil thick RT/Duroid with ε_r=10.2. The measured radiation pattern in both E and H field is shown in Figure 4. By cutting off the dielectric in the tapered region we are able to achieve 10dB 30^0 beamwidth in E-plane and sidelobe level less than 10 dB. The output power level shown in Figure 5. is more than 25 dB above the noise floor when the tapered slot antenna and horn antenna are spaced 5cm apart, and still maintains 15 dB above noise in the far field zone. Thus, the feasibility of fiber optic link using VMDP-fed TSA through photomixing is demonstrated.

V. CONCLUSION

The integration of tapered slot antenna (TSA) and velocity-matched distributed photodetector (VMDP) which is potentially useful for millimeter-wave power combining and phased arrays, as well as RF front-ends for analog fiber optic links, is proposed and demonstrated. This active integrated antenna structure is readily scalable to millimeter-wave frequencies where the extremely broad bandwidth of optics can be fully employed.

ACKNOWLEDGEMENTS

The authors wish to thank Shawn Thomas and Thomas Jung for generous assistance in wirebonding and Andrew Rollinger for providing the lens fiber. This project is supported by US ONR MURI on RF Potonics.

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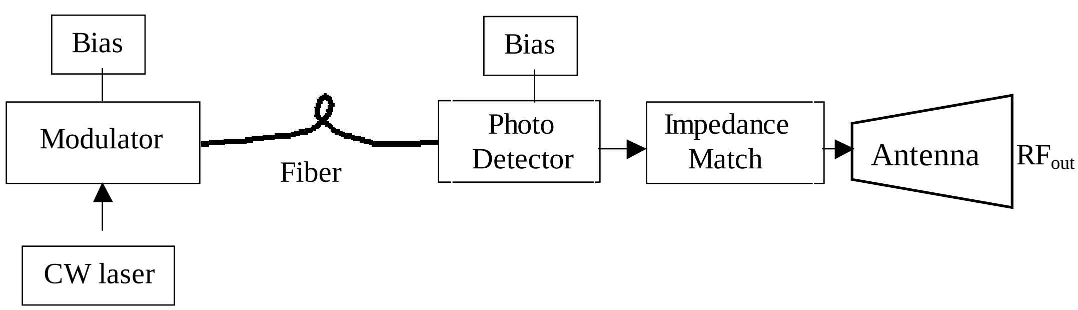

Figure 1. The topology of an analog fiber-optic link

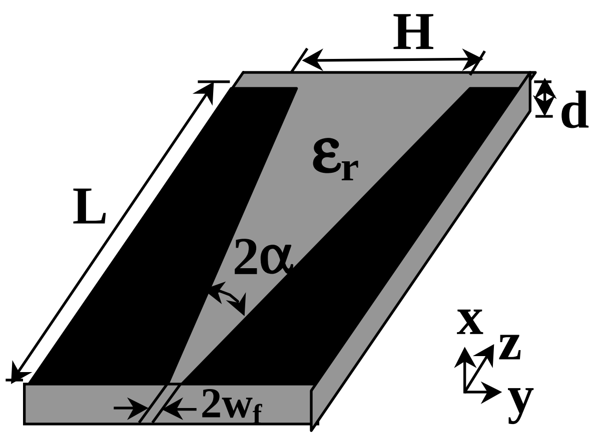

Figure 2. Tapered slot antenna with ε_r=10.2, d=25 mil, H=1λ_0, L=9.5 cm, $\alpha=6^0$, and w_f=2 mil

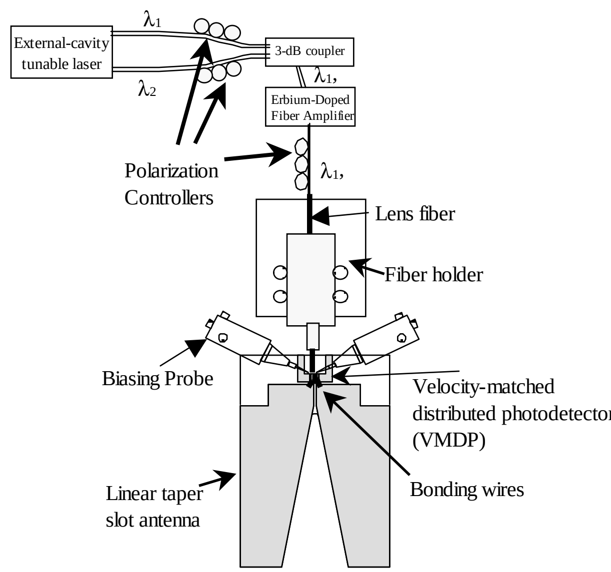

Figure 3. Experimental setup for photo-mixing with the VMDP-fed TSA

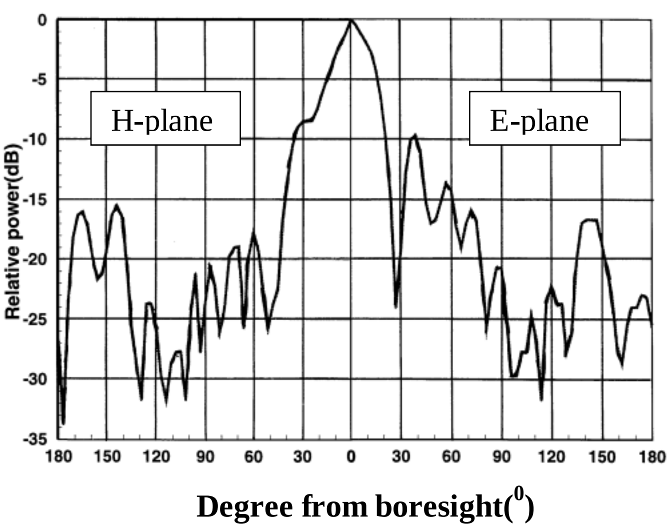

Figure 4. Radiation pattern of LTSA with air-dielectric

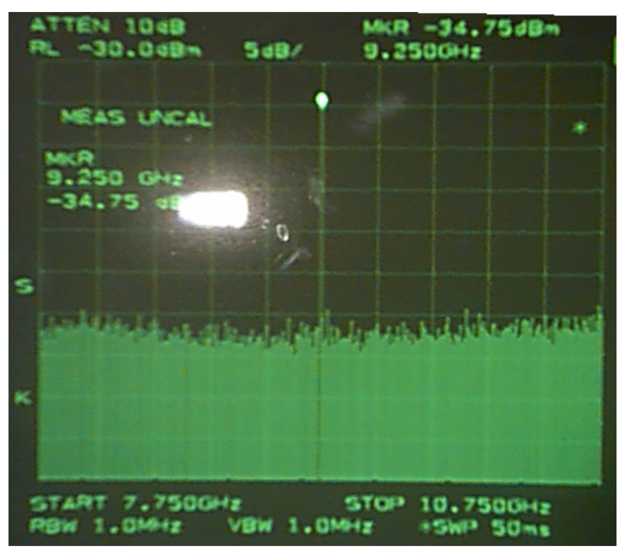

Figure. 5 Output power collected by horn antenna shown on spectrum analyzer(-34.75 dBm @9.25GHz)