PLANAR ANTENNAS FOR MICROWAVE PHOTONICS

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Abstract- *Planar antennas are often called upon to bridge the gap between the photonics and microwave fields. Design of such antennas requires a culmination of knowledge acquired from the study of both research areas. This paper will discuss our efforts in the design of novel planar antenna structures for microwave-photonics applications, which stress a high level of integration of photonics and microwave components.*

I. Introduction

The microwave-photonics field has received a tremendous amount of attention in recent months. The marriage of two once completely independent fields has found its way into a number of venues and applications, including giga-bit data transmission, cable-TV signal distribution, antenna remoting for cellular and micro-cellular radio using analog fiber links, optically fed phased-array antennas, and generation of millimeter-wave signals for applications such as radio astronomy.

Photodetectors are one of the key components in any microwave-photonic system. High-power, high-frequency photodetectors can significantly reduce RF insertion loss, increase spurious-free dynamic range, and enhance system signal-to-noise ratio. They are also imperative for the generation of millimeter-wave and THz frequency power by optical heterodyning. One of the challenges encountered in the realization of such devices is the very small absorption volume had by high-speed photodetectors, making it difficult to achieve very high saturation power. The technique discussed in [1] introduces a velocity-matched distributed photodetector (VMDP) to increase optical saturation power by using an array of diode photodetectors without sacrificing operational bandwidth.

In addition to the development of novel photonic devices, we believe that the overall performance of microwave-photonics systems can greatly benefit by the integration of such devices with antennas. Research done in the author's group has been focused on the integration of active microwave devices with planar antennas [2]. In this scenario antennas are utilized as power combiners/splitters, harmonic tuners, and mode filters, as well as acting as the radiating element. This offers a tremendous savings in overall circuit size and insertion loss, which becomes a serious concern at millimeter-wave frequencies. The same benefits can be obtained by the integration of antennas and microwave-photonic devices such as VMDP.

This paper includes the development of a high-efficiency endfire antenna that is well suited for fabrication on high dielectric constant substrates such as InP, allowing for the integration with photonic devices. In addition, we propose dipole-like antennas which function as impedance matching circuits for maximum microwave power extraction generated by photomixing, while also serving as DC bias feed lines.

II. Uniplanar Quasi-Yagi Antenna and Waveguide Transition

Antennas printed on high dielectric constant substrates typically suffer from undesired affects due to generation of surface-waves, including low radiation efficiency, high cross-pol radiation, and strong mutual coupling. In complete contrast, the presented novel printed quasi-Yagi antenna [3] takes advantage of the generation of surface-waves. This fact makes it ideal for construction on III-V materials such as GaAs and InP.

The printed antenna configuration is very similar to the configuration of the Yagi-Uda dipole array in such a way that all three dipole components, which include the driver dipole, director dipole and the reflector, can be readily identified. However, the role of the driver dipole has become the generator of surface-wave power in the high dielectric substrate on which the antenna is printed. The generated TE_0 surface-wave energy directly contributes to free-space radiation. The endfire nature of the antenna comes

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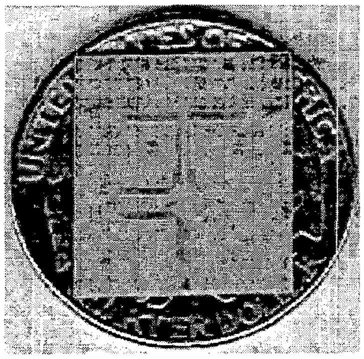

Fig. 1. Photograph of fabricated X-band quasi-Yagi antenna.

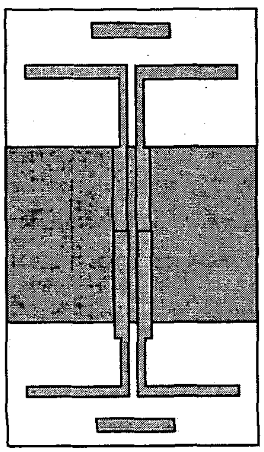

Fig. 2. Schematic of quasi-Yagi back-to-back coupled microstrip line to waveguide transition.

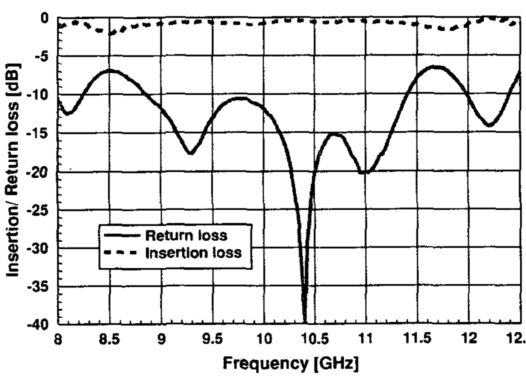

Fig. 3. Measured results of back-to-back coupled microstrip line to waveguide transition.

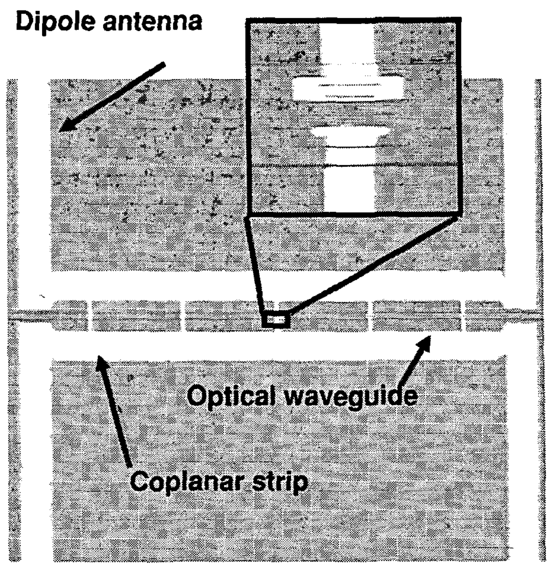

Fig. 4. VMDP integrated with two dipole antennas.

in part due to the truncated microstrip ground plane on the backside of the substrate that acts as an ideal reflector for the TE_0 mode. Because they share the same field polarization the TE_0 surface-wave is strongly coupled to the parasitic director dipole element of the quasi-Yagi antenna, influencing the antenna's radiation pattern and impedance bandwidth. A photograph of an X-band (8-12 GHz) prototype of the antenna fabricated on 0.635 mm RT/Duroid with permittivity of 10.2 is shown in Fig. 1.

Measured results show that the quasi-Yagi antenna radiates an endfire beam, with a front-to-back ratio better than 15 dB with cross-pol less than -12 dB across a large frequency range (50%). Antenna radiation efficiency was measured to be 93%. This planar antenna will also be beneficial in the design of phased array antennas due to its broad main beam, compact size, and low mutual coupling (<-22 dB). Additionally, the antenna is easily scaled to cover various frequency bands. This has been experimentally verified at C-band (4-6 GHz) and V-band (50 -75 GHz) with no difficulties.

The same antenna structure has been successfully demonstrated as a low loss microstrip-to-waveguide transition [4] which exhibits a 35% bandwidth with return loss better than -12 dB and insertion loss -0.3 dB at X-band frequencies.

Integration of the quasi-Yagi antenna and VMDP offer the flexibility of being able to collect generated microwave power into metallic waveguides or launch it directly into free-space for applications such as quasi-optical power combining. Instead of the single microstrip feeding, coupled microstrip feeding is employed to provide complete compatibility and integration of the two components (Fig. 2). We rely on the odd-symmetric nature of the VMDP to generate the balanced field configuration needed to excite the driver dipole. In addition, this structure is able to provide heat sinking through the metal backing under the coupled lines while still ensuring broad band operation and unidirectional radiation. The X-band prototype of the back-to-back coupled line-to-waveguide transition exhibits a bandwidth of 26% for return loss less than –10dB (Fig. 3). The insertion loss ranges from –0.5 to –1.2 dB. This structure can be readily scaled to other frequency ranges and be optimized for an increase in operational bandwidth.

III. Printed Dipole Antennas

One of the most well known planar antennas is the printed dipole. As in the quasi-Yagi antenna case, because of the manner in which the dipole is excited, integration with VMDP or any other two-terminal device is straightforward. This is again exploited in the

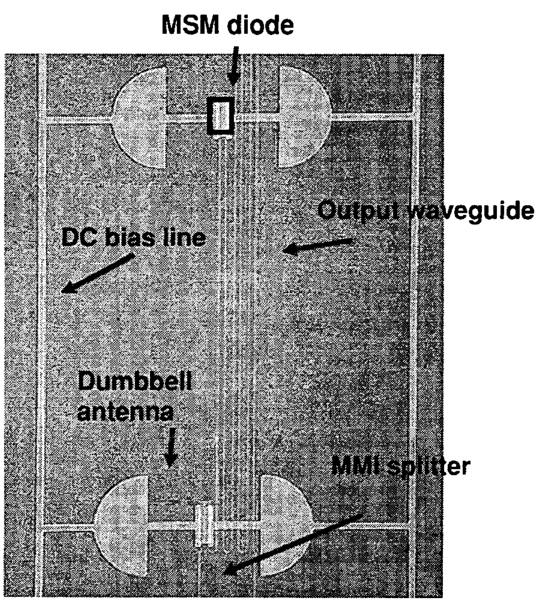

Fig. 5. 675 GHz dumbbell antenna array with parallely-fed MSM photodetectors.

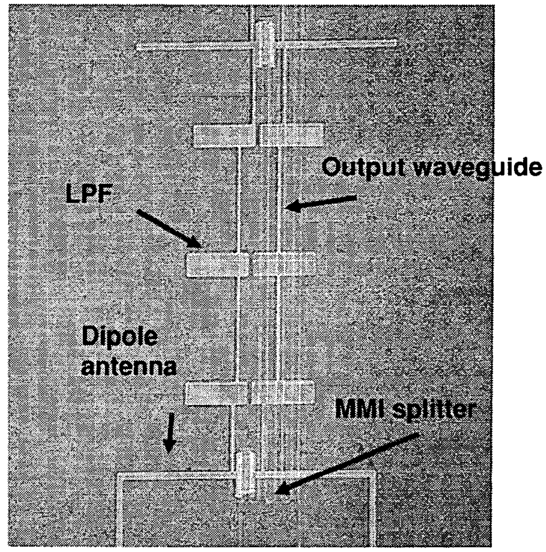

Fig. 6. 675 GHz high impedance dipole antenna array with parallely-fed MSM photodetectors and integrated LPF.

merging of antenna and photonic device shown in Fig. 4. The VMDP section consists of an array of three serially fed diode photodetectors. Microwave power is extracted and combined with the proper phase relationship through the CPS transmission lines. The VMDP is terminated with a pair of

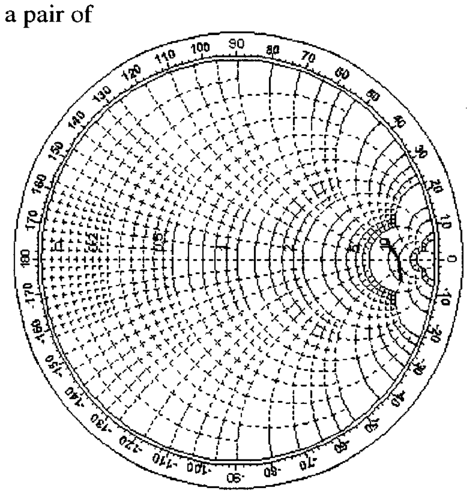

Fig. 7. Impedance of a single dumbbell antenna from 600 – 700 GHz (normalized to 50 Ω).

printed 50 Ω matched dipole antennas at either side of the detector, forming a two-element antenna array for power combining at 40 GHz. The entire circuit is fabricated on 50 μm InP.

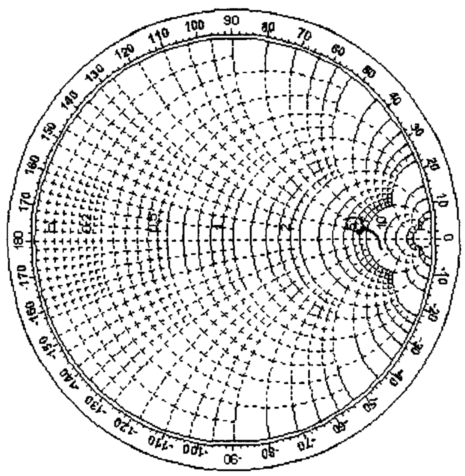

Fig. 8. Impedance of a single dipole antenna from 600 – 700 GHz (normalized to 50 Ω).

IV. Modified Dipole Antennas for Use in 675 GHz Power Combining Array

At terahertz frequencies, generation of power becomes extremely difficult. In order to produce adequate amounts of power, the power from several devices must be combined. This is best done using free-space power combining. Fig. 5 and Fig. 6 show SEM micrographs of two types of modified planar dipole arrays for free-space power combining at 675 GHz. In both examples each MSM photodetector is fed in parallel [5] by a monolithically integrated multimode interference (MMI) power splitter. Each antenna was designed to have high input impedance in order to maximize the power extracted from each diode. The other consideration in the design was to minimize the mutual coupling between each element while simultaneously providing a DC connection between the diodes. The antenna array shown in Fig. 5 achieves this by adding a quarter-wavelength semicircular section at the end of each dipole. This acts to load the antenna, providing high impedance ranging from 250 – 500 Ω in the 600 – 700 GHz range, according to electromagnetic simulation (Fig. 7). The reactive component of the impedance becomes more capacitive with increasing frequency. Additionally, DC lines can be connected directly to the ends of the open stubs without affecting the coupling between the elements. Fig. 6 depicts a design using a more conventional method. The dimensions of the straight dipoles were optimized to provide high impedance and a step-impedance filter was used to reject the undesired flow of microwave signal from one element to the next while providing a path for DC voltage. Simulations predict real impedance ranging from 175 – 325 Ω in the 600 – 700 GHz range (Fig. 8), slightly lower than the previous approach. Fig. 8 shows that the reactive component of the impedance becomes capacitive with increasing frequency.

V. Conclusion

We have proposed several different types of antenna configurations which are highly compatible with photonic devices. Each of them is an example of innovative application specific design. This approach is essential for the complete integration of photonic devices and planar antennas.

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