Ultra-broadband Photonic Patch Antenna

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Abstract—This paper presents a demonstration an ultra-broadband photonic antenna. The antenna utilizes external optical intensity modulators and optic fiber to photonically remotes the Aperture Stacked Patch antennas and replaces microwave diplexers with simple photonic combination. The resulting photonic antenna is demonstrated to provide a bandwidth of 110% with gain of 7 dBi.

Index Terms—Microstrip antennas, Microwave Photonics, Optical Fiber Antenna Remoting.

I. INTRODUCTION

The demand for wireless services of ever increasing bandwidth continues to drive antenna engineering research. Emerging and next generation wireless communications applications, such as broadband peer to peer networking and particularly the exchange of video information, will require greater bandwidths than are possible with present day wireless infrastructure.

The extraordinary expense of deploying new physical infrastructure is prohibitive, thus the next generation of technology must be flexible such that it can accommodate continuous development in communications technologies and applications. Software defined radio (SDR) has been conceived as a method by which the same physical hardware can be used for multiple formats with new protocols being substantially possible with a software upgrade [1]. New infrastructure should thus be designed to accommodate as broad a bandwidth as could be conceived useful. Similar to SDR, Ultra wide-band (UWB) technology applications require different design and optimization requirements such as power, throughput, distance, cost [2]. Extremely broad bandwidth antennas will be key components in such versatile wireless communications systems.

Printed antennas offer the advantage of low-cost manufacture and, specifically, can be engineered with compact, low-profile and even conformal geometries. Traditionally, printed antennas had only offered relatively narrow bandwidths, insufficient for the SDR or UWB applications. Further, photonic remoting of broadband antennas has also attracted much attention in recent years [3]. Replacing traditional coaxial cable with optic fiber can greatly increase the bandwidth of the antenna feeding system and remote placement of high-frequency antennas [4]. Optic fiber can also significantly reduce bulk and weight.

In this paper we demonstrate a technique by which two adjacent band optic fiber remoted Aperture Stacked Patch (ASP) antennas can be photonically combined to realize a single broadband radiating element.

This paper is organized in five main sections. Section II introduces and verifies the operation of the ASP antennas originally used in [5]. Section III details the proposed ultra-broadband photonic patch antenna system. It explains the configuration and setup, and describes the measurement process undertaken. Section IV presents the characterization of the photonically combined system including gain bandwidth across the useable band. Section V discusses the findings of this investigation and suggests some avenues for further research.

II. VERIFICATION OF ASP ANTENNA PERFORMANCE

The investigation presented in [5] aimed to develop and enlarge the effective bandwidth of base-station antennas. An ultra-broadband patch antenna was realised using two broadband ASP antennas combined into a single radiating element using a microwave diplexer and the assembly was characterised as a single antenna.

To conduct the current investigation, it was proposed that the same ASP antennas used in [5] be reused to implement an ultra-broadband antenna unit, but with the passive diplexer replaced with photonic combination. Before the photonic combination experiments could be conducted, it was necessary to verify that the antennas still operated as reported in [5].

Fig. 1 and 2 show the gain response of ASP1 and ASP2, respectively. The results show that the average gain is 7 dBi for both patches.

![Fig. 1. Electrical Gain of ASP1.](image-url)
In order to prove the validity of our photonic approach, it is necessary to demonstrate that our proposed system obtains essentially the same bandwidth and gain as when using microwave diplexer. Therefore, we attempt to demonstrate whether or not the system is valid, undertaking an analysis of the gain performance of the system created using the photonic configuration.

Fig. 3 depicts the photonic configuration proposed by this investigation that substitutes the diplexer analyzed in [5]. A single optical source is divided by a 3 dB coupler and directed through Polarization Controllers (PC) into Mach-Zehnder Modulators (MZM). The PCs are used to adjust the polarization received by the modulators, which are used to modulate the optical carrier with the electrical signal provided by each antenna. Once converted into the optical domain, the signals of the antennas are propagated using Polarization Maintaining fibers (PM), through another set of PCs, up to a Polarization Beam Splitter (PBS). The polarization rotating characteristic of the PBS makes possible to use this device to combine two optical carriers without coherent interference [3], [6]. The PCs ensure that the signals arrive at the PBS, at the correct polarization. After the PBS, the single optical carrier contains the information of both antennas propagating at different polarizations (ASP1, TE mode; ASP2 TM mode). This optical carrier is amplified using an erbium-doped fiber amplifier (EDFA) before being converted by a Photo Detector (PD) back into the electrical domain. Finally, the PD directs the electrical carrier into the Vector Network Analyzer (VNA) through a broadband amplifier.
Fig. 4a) shows a photograph of the photonic combination setup, and Fig. 4b) shows the configuration of the antennas inside of an anechoic chamber, the electro-optical modulators and the microwave trombone phase shifters.

In order to make a correct measurement of the photonic configuration, all the components were adjusted according to following specifications: to ensure each MZM received the correct polarization (TE), the PCs were adjusted for maximum RF signal transmission; the electro-optical length difference of the paths (ASP1 link and ASP2 link) was compensated using the microwave Trombone Lines (TL) to a zero phase difference at 2 GHz (cross-over region); and, the modulated signals have to be identically polarized using the PCs before to reach the PBS.

IV. PHOTONIC UBP ANTENNA RESULTS

This Section presents the gain of the measurement using the procedure and configuration detailed in Section III. It is anticipated that the major difference between the gain response of the photonic configuration and the one reported in [5] will be a signal interference effect that will be present due to the overlapping region of the operational bandwidths of the two ASP antennas in the absence of the diplexer filters.

Fig. 5 displays the gain response of the combined ultra-broadband photonic patch antenna. The response show that the amplitude of the gain varies from 6 dBi to 9.5 dBi and the higher point of this variation is situated around cross-over region at 2 GHz. For comparison, the individual gain responses measured for each antenna, as shown in Fig. 1 and 2, have been numerically summed in-phase and are presented in Fig. 6. The phase difference between the two ASP responses was adjusted to achieve a good match between the measured and numerically summed responses. Both responses follow a similar trend along the entire band.
V. DISCUSSION

The gain response of the ultra-broadband photonic patch antenna, shown in Fig. 5, exhibits more ripple than the system presented using microwave diplexers [5]. Referring to Fig. 1 and 2, ASP1 and ASP2 show simultaneous positive gain at several frequency bands (1.6-2.2 GHz, 2.5-3.1 GHz and 3.5-3.9 GHz). This causes the gain ripple seen in Fig. 5 and 6 at these frequency bands. It is encouraging to observe that the photonic response measured corresponds almost exactly with the numerically summed gain responses of the individual antennas (shown in Fig. 6). This suggests that the photonic combination can be considered as a simple signal summation.

A number of options exist to ensure that the antennas do not interact outside of the band. Firstly, the ASP antennas of [5] were not designed to ensure radiation only within the band; instead emphasis was placed on obtaining the broadest possible bandwidth. It should be possible to redesign the antennas such that there is no significant gain outside of the operational bandwidth of each patch. This redesign would remove much of the ripple seen from 2.5 GHz to 3.1 GHz and from 3.5 GHz to 3.9 GHz in Fig. 5. Even with redesigned ASP antennas, significant interaction would still be expected at the cross-over region at 2 GHz.

To minimize the interaction of the two antennas at the cross-over region it would be necessary to implement low and high-pass filters to isolate the two antenna bands. The design and implementation of these filters would be far easier than the diplexer of [5] as the two filters are not physically connected (each terminates in the broadband 50 Ohm load of the optical modulator) and thus they can be designed and implemented independently. An investigation is currently underway to verify that filtered photonic combination can achieve similar results to those presented in [5], but with far simpler filter designs.

It is also anticipated that the current approach could be extended, through the use of wavelength division multiplexing (WDM) to support three, four or even more broadband patches. Using this approach it may be possible to cover the entire spectral mask for operation of UWB devices approved by FCC, which major part lies between 3.1 and 10.6 GHz [7].

VI. CONCLUSION

An Ultra-Broadband Photonic Patch antenna has been demonstrated. This antenna has been characterized with a radiation bandwidth from 1.1 to 3.9 GHz which represents a bandwidth of approximately 110%. This demonstration exhibited approximately 2 dB ripple in gain over the operation bandwidth. The 2 dB ripple, though tolerable, was higher than a previous demonstration using a microwave diplexer. Two ongoing investigations aim to improve the obtained results. The first aims to show that photonic combination and simple microwave filters can be used to achieve the same results obtained previously using a sophisticated microwave diplexer. These would eliminate the interactions occurring outside of the designated bandwidth of any type of antennas and expand the current definition of ultra-broadband antennas. The second investigation will attempt to expand the technique to enable multiple antennas to be combined to cover a full range required for many UWB wireless applications.

REFERENCES