TuB1.2
9:30 am – 9:45 am

Dispersion Enhanced Photonic Crystal Fibers for True Time Delay Lines

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SUMMARY

Recently, there has been growing interest in optical true time delay (TTD) techniques for phased array antennas (PAAs) because of the features of wide bandwidth, compact size, reduced weight, and low electromagnetic interference compared with electrical TTD techniques [1-2]. However, most of the techniques require a large number of precisely time-delay matched optical elements such as lasers and optical delay segments. The result is complex system designs that may suffer from large power losses, specialized component needs or instability. Esman et al proposed a fiber-optic TTD using conventional high dispersion fiber and commercial dispersion compensating fiber (D = -100 ps/nm·km) to meet these requirements [2]. However, because the dispersion is fairly small, long fibers are still needed in the TTD module to get the total amount of required time delay. If the fiber group velocity dispersion value can be designed to be higher, the total fiber length will be decreased proportionally. Photonic crystal fibers (PCFs) provide large dispersion tuning ability by increasing the dispersion value to reduce the fiber length [3-5]. With conventional single-mode fibers (SMFs), dispersion cannot be changed significantly because of the small index variation from doping over the transverse cross section. This shortcoming may be overcome by the design of PCFs, which can be tailored to exhibit high dispersion. The novel cladding structure of PCFs consisting of an array of micrometer-sized air holes allows for flexible tailoring of the dispersion curve.

The dispersion, $D(\lambda)$, of PCF is strongly related to the structure and doping, which can be changed significantly to achieve the desired characteristics of $D(\lambda)$. Fig. 1 shows the scanning electron micrograph (SEM) image of highly dispersive photonic crystal fibers (HDPCFs) fabricated using the stack-and-draw technique [4]. The chromatic dispersion experimental results of these HDPCFs are also shown in Fig. 1. The dispersion is –550 ps/nm·km at 1570 nm, which is increased 31 times compared to telecom SMF-28 with dispersion at 18 ps/nm·km at 1550 nm region.

A 1x4 TTD module is designed and assembled using the fabricated HDPCF delay lines mentioned above. The lengths of the HDPCFs are 10.5m, 7m, 3.5m and 0m, respectively, as shown in Fig. 2. The insertion loss of each delay line is less than 4dB. Each line has the same nominal group delay but with slightly different net dispersion. This is easily made by connecting varying lengths of HDPCFs with dispersion shifted fibers (DSFs) ($D \approx 0$ ps/nm·km around 1550nm). Thus, the relative time delay of the signals among the links can be changed by tuning the optical wavelength. At the central tuning wavelength λ_0, say 1550 nm, all the time delays are matched by trimming the DSFs. Thus, at λ_0 the main antenna beam will be directed broadside. At wavelengths less (or greater) than λ_0, each of the fiber delay lines adds (or subtracts) a time delay proportional to its dispersion coefficient D and the HDPCF length, resulting in phase changing so that the main antenna beam is steered. The measured phase differences versus modulation frequency curves are shown in Fig. 3 at different wavelengths. The time delay can be derived from the slope of the each curve. The wavelength at 1550 nm was chosen as a reference for zero time delay. By tuning the wavelength from 1520 nm to 1570 nm, time delays can be achieved ranging from –39 to 45 ps. The phase versus frequency curve verifies the true-time delay and wide bandwidth capability of the proposed scheme.

The assembled X-band PAA system is demonstrated and the block diagram is shown in Fig. 2. A microwave signal is generated from the HP network analyzer. [6] The optical carrier is distributed into the four sub-units of the TTD delay lines by a one-to-four splitter. After the desired time delays, the microwave signals, with correct phase relationship, are detected by InGaAs high-speed photodetectors and fed into four antenna elements individually after amplification. Since our PAA radiation elements emit most efficiently around the two frequencies of 9 and 10.3GHz, far field patterns of the PAA are measured to verify the instant broad RF band at these two frequencies. Fig. 4 shows the far field patterns at a 23° scanning angle corresponding to 17 ps with a laser wavelength of 1557nm after we get 0° scanning angle at 1550 nm. From Fig. 4, it can be seen that the simulation results and measured data agree pretty well at the main beam region. As expected, the measurement shows negligible beam squint effect in the assembled system.

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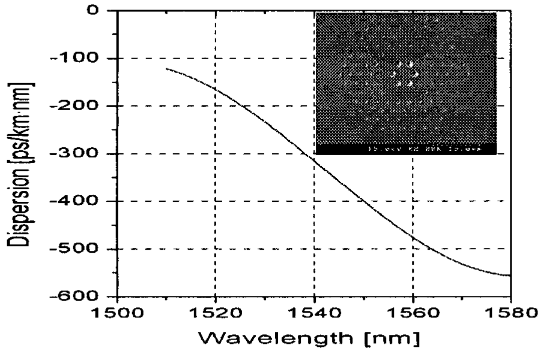

Fig 1. Scanning electron micrograph (SEM) image of the fabricated highly dispersive photonic crystal fiber (HDPCF), and the chromatic dispersion measurement of the fabricated HDPCF.

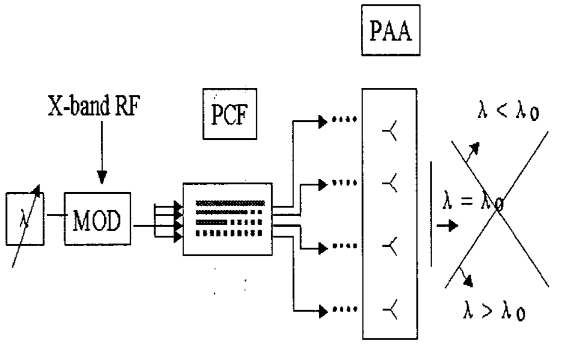

Fig 2 . HDPCF enhanced wavelength continuous tunable PAA system structure. (Dashed line: HDPCF; solid line: dispersion shifted fiber; MOD: modulator)

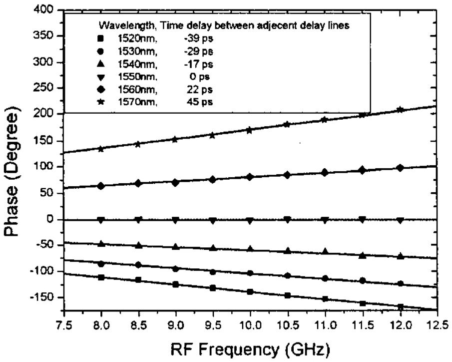

Fig 3 . Measured phase as a function of frequency. The time delays are calculated from the slope of the phase versus RF frequency.

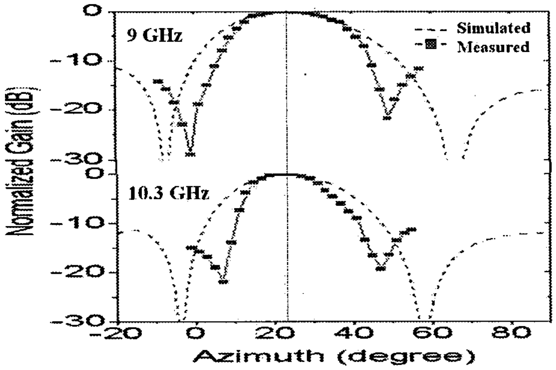

Fig 4. Comparison of far-field patterns of the PAA at 23° scanning angle at two different frequencies, 9 and 10.3 GHz, with an optical wavelength of 1557 nm.