Optical Dispersion Technique for Phased Array Antenna Beam Steering

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***Abstract:*This paper presents an insight into how Optical Dispersion Technique is applied in Phased Array Antenna Beam Steering. Optical fiber is especially attractive as wave-guide because the signal propagation speed depends on the wavelength, which is characterized by chromatic dispersion (D). By setting appropriate source wavelength or propagation path length (L [km]), the desired time delay Δt can be achieved. If the dispersion is approximately constant over the optical window, then a time delayed microwave modulated optical signal for a fiber of length L (Km) will have definite time delay. Consider a linear phased array antenna consisting of 16 antenna elements. Now by employing the use of optical dispersion technique, the above antenna can be designed by utilising dispersion shifted and unshifted types of optical fibers of suitable length in the path to provide required time delay along with optical source, modulator, RF amplifier, optical splitter & photo diode. The desired phase shift can be achieved and flexible beam steering can be achieved. This new type of EMI free antenna will have simple optical network and will be free from phase variations.**

***Keywords:*Phased Array, Chromatic Dispersion, Dispersion shifted fibre,Dispersion unshiftedFibre, MZM.**

I. INTRODUCTION

Phased array antenna plays an important role in modern world radar environment. Therefore let us construct an antenna system, which contains several antenna elements. Let us control the amplitude and thephase of the antenna elements optically by employing the use of optical dispersion techniques. This way, we are able to controlthe radiation pattern of the antenna system.

II. ELECTRONIC SCANNING OF THE BEAM

The very basic concept of electronically steering the beam is to produce a phase difference between antenna elements. To shift the antenna beam by θ

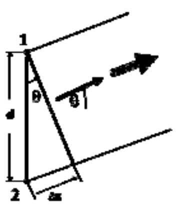

Fig. 1Beam Shifting

Phase Diff(Δϕ) between two elements 1 & 2 is

$\Delta\phi = (2\pi/\lambda) * \text{Path Diff}$

$= (2\pi/\lambda) * \Delta x$

Path Diff, $\Delta x = d \sin\theta$

So, $\Delta\phi = (2\pi d \sin\theta)/\lambda$ (1)

where,
d is distance between radiating elements
λis the wavelength ($\lambda = c/f$)
c is the speed of light in vacuum
f is the microwave signal frequency

Substitutingλ = c/ fin(1)
$\Delta\phi = (2\pi f d \sin\theta)/c$(2)

This indicates phase difference of microwave signals depend on microwave signal frequency.

Substituting in (2) by formula $\Delta\phi = 2\pi f t$,where t is time while the wave changes phase byΔϕ,

So,$t = (d \sin\theta)/c$(3)

So from (3), it is established that the time delay of microwave signal distributed to the antenna to generate beam under angle θdoes not depend on frequency.

III.OPTICAL DISPERSION TECHNIQUE

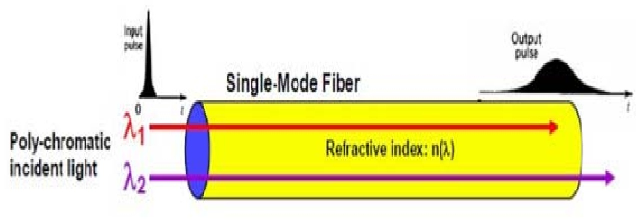

Fig. 2 Beam Shifting[1]

CHROMATIC DISPERSION:

Optical fiber is especially attractive as wave-guide because the signal propagation speed depends on the wavelength, which is characterized by chromatic dispersion (D).Different wavelengths travel at different speeds within an optical fiber causes spreading of light pulse.

The Chromatic Dispersion of a fiber is expressed as differential delay in pico secs per nanometer of wavelength shift, per kilometer of fiber [ps/(nm*km)][1].True time delay is one of the properties of the optical fiber like of any other wave guide. Time delay is a consequence of a finite signal propagation speed at the fixed path length.

By setting the appropriate source wavelength or the propagation path length (L [km]), the desired time delay Δt can be achieved as follows:

$$\Delta t\,(\lambda, \Delta\lambda) = L.\int_{\lambda-\Delta\lambda/2}^{\lambda+\Delta\lambda/2} D(\lambda)\,d\lambda\,[ps]^{[2]} \qquad (4)$$

where $D(\lambda)$ is Chromatic Dispersion.

If the dispersion is approximately constant over the optical window, then a time delayed microwave modulated optical signal for a fiber of length L (Km) will have time delay as:

$$\Delta t = L.D.\Delta\lambda \qquad [ps](5)$$

where $\Delta\lambda$ = Wavelength Change
D = Chromatic Dispersion
L = Fiber Length

IV. EXISTING LPA SYSTEM

Consider the case of aLinear Phased Array(LPA)antenna in L-band which consists of 16 antenna elements followed by microwave feed network and multiple RF cablesthat are used to provide the microwave path.This type of LPA suffers from phase variations at various stages because RF cables are used to interconnect various elements in the array.This arrangment of antenna elements is fixed for a particular type of pattern as the phase profile required to shift the beam from 0° to 45° is fixed for each element for a particular angle.As antenna beam shift is generally the order of 1° and it does not provide any flexibilty to change the phase of antenna elements if beam shift of less than 1° is required.

V.PROPOSED METHOD

Now by employing the use of optical dispersion technique, the above antenna can be designed with the use of optical components as:An Optical Laser source of optical third window (1550-1625nm), 10mW optical output is used to modulate Mach Zehder Modulator (MZM)[2]. The RF Generator is used to generate RF for particular frequency followed by RF Amplifier(AMP).An Optical Splitter (1:2) is used to split optical power at various stages. Dispersion shifted (L_{ZD}) and Dispersion unshifted (L_{HD}) types of optical fibers of suitable length are used in the path to provide required time delay. Attenuator is used to cater for ISI of the signal. A Photo Diode (PD) is used foroptical to electrical conversion. Finally energy is amplified and fed to sixteen antenna elements (AE_n where n=1,2,…16).

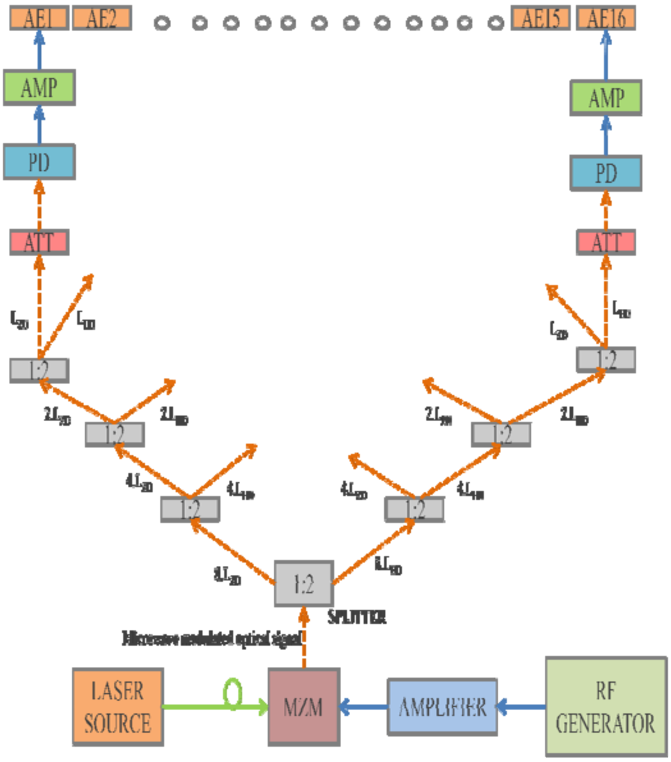

Fig. 3 Proposed Network of 16 Element LPA

VI.DESIGN CALCULATIONS

Select fibre length L_{ZD}&L_{HD} for each stage after 1:2 optical splitting.The length of two different types of fiber is selected to ensure a proper time delay.
Chromatic dispersion in wavelength range 1550-1625 nm (Optical third window):
Fordispersion unshifted fiber (G.652), D_H= 18 ps/nm·km[3], dispersion shifted fiber (G.655), D_Z= 4 ps/nm·km[3].
Taking L_{ZD}& L_{HD}=0.0079Km(i.e.7.9m) in design considerations;
Using (5), the time delay in 16 paths (for 16 antenna elements) is derived as:
For 1st antenna element

$$\Delta t_1 = 8L_{ZD}\,.D_Z.\Delta\lambda + 4L_{ZD}\,.D_Z.\Delta\lambda + 2L_{ZD}\,.D_Z.\Delta\lambda + L_{ZD}\,.D_Z.\Delta\lambda$$
$$=15\,L_{ZD}\,.D_Z.\Delta\lambda(6)$$

For 2nd antenna element

$$\Delta t_2 = 14L_{ZD}\,.D_Z.\Delta\lambda + L_{HD}\,.D_H.\Delta\lambda(7)$$

For 3rdantenna element

$$\Delta t_3 = 13L_{ZD}\,.D_Z.\Delta\lambda + 2L_{HD}\,.D_H.\Delta\lambda(8)$$

So for 16th antenna element

$$\Delta t_{16} = 15\,L_{HD}\,.D_H.\Delta\lambda(9)$$

The general formula for time dealy for 16 antenna elements will be:

$$\Delta t_n = (16-n)L_{ZD}\,.D_Z.\Delta\lambda + (n-1)L_{HD}\,.D_H.\Delta\lambda \quad \text{(in ps)} \qquad (10)$$

where n= 1,2,……….16

If the time delay is achieved, the corresponding phase shift can be calculated for individual antenna element as:

$\Delta\phi_n = \Delta t_n . f. 360$ (in degrees)(11)

where n= 1,2,……….16 and f=1.03GHz

By varying the Δλ, the desired phase shift for all the individual elements can be determined and controlled. The following tables with the use of (10) and (11) illustrate the calculation of time delay and phase shifts for antenna elements (AE) 1, 2, 3, 14, 15 &16 for the respectiveΔλ.

TABLE I

CALCULATION FOR TIME DELAY AND PHASE SHIFTFOR Δλ =1 NM

AE No.	Time Delay(ps)	Phase Shift(°)
1	0.47	0.1757
2	0.58	0.2167
3	0.69	0.2577
14	1.91	0.7088
15	2.02	0.7499
16	2.13	0.7909

TABLE II

CALCULATION FOR TIME DELAY AND PHASE SHIFT FORΔλ =10 NM

AE No.	Time Delay(ps)	Phase Shift(°)
1	4.74	1.7575
2	5.84	2.1676
3	6.95	2.5778
14	19.11	7.0889
15	20.22	7.4990
16	21.33	7.9091

TABLE III

CALCULATION FOR TIME DELAY AND PHASE SHIFT FOR Δλ =50 NM

AE No.	Time Delay(ps)	Phase Shift(°)
1	23.70	8.7879
2	29.23	10.8384
3	34.76	12.8890
14	95.59	35.4447
15	101.12	37.4952
16	106.65	39.5458

TABLE IV

CALCULATION FOR TIME DELAY AND PHASE SHIFT FOR Δλ =75 NM

AE No.	Time Delay(ps)	Phase Shift(°)
1	35.55	13.1819
2	43.84	16.2577
3	52.14	19.3335
14	143.38	53.1671
15	151.68	56.2429
16	159.97	59.3187

The tables clearly indicates time delay and phase shift of first three AEs (1, 2 & 3) and last three AEs (14,15 & 16).The remaining AEs time delay and phase shift is calculated by applying the respected formulas as derived above. This precisely gives an indication that by keeping L_{ZD}& L_{HD}constant and varyingΔλ, the phase shift for the antenna elements can be achieved. Thelength of L_{ZD}& L_{HD}can be varied which in turn can provide the significant time delay and consequently the phase delay for 16 antenna elements. With individual phase shifts of the element under control, the desired shift of the beam can be calculated and beam steering of array antenna can be implemented. This type of antenna design provides a flexibility of beam shifting in desired resolution.

VII. CONCLUSIONS

The proposed method is a new approach to resolve the problem of phase mismatch for RF cables and beam resolution in a phased array antenna environment. The paper describes a concept of using optoelectronic components for the construction of antenna consisting of 16 antenna elements which is analogous to LPA of 16 elements with a microwave feed network and RF cables. This approach is based on utilization of dispersion-shifted and dispersion-unshifted optical fibre of certain length that can provide time delay, which in turn will give phase difference between array elements to produce high resolution beams. In this paper, the basic assumption is made that the dispersion is approximately constant over the third optical window and lengths of Dispersion-shifted and Dispersion-unshifted fibres are equal. This arrangement can provide simple optical network, phase control of the order of approximately 0.1°, antenna free from phase variations, flexible beam shifting resolution, very low electromagnetic interference, highly reliable and ease of trouble shooting.

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Ankit Gupta received B.Tech degree in Electronics and Communication Engineering with Honours from Uttar Pradesh Technical University, Lucknow, Uttar Pradesh (U.P.)in 2004. After graduating, he joined Central Electronics Limited, a Govt. of India Enterprise under DSIR, Sahibabad,Ghaziabad (U.P.) Worked for IFF system and Phase Control Module (PCM) for Battery Level Radar-III of Akash Project. After two years of exposure, he joined Bharat Sanchar Nigam Limited, a Govt. of India Enterprise,Ghaziabad (U.P.) as Telecom Officer. Worked for two years in the field of telecommunications in optical transmission networks. In Dec 2008, he joined Bharat Electronics Limited, Bangalore as a Senior Engineer in Akash Project. Now presently working as Deputy Manager in Development &EngineeringDepartment of Missile Systems SBU in Akash Army and QRSAM Project. He is also a Project Management Professional (PMP) from Project Management Institute (PMI), USAand Certified Reliability Engineer(CRE) from American Society of Quality(ASQ), USA.He has received BEL R&D Excellence Award 2013-14 in excellent R&D project for Akash Missile System for Indian Air Force. His current areas of interest include optical ring networks for radars and active phased array antenna.