

# Accuracy Analysis of Phase Array Antennas Beam Steering Based on Digital Phase Shifters and Fibre Optic Delay Lines

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**Abstract:** - Electronic and optical methods of shaping wall antenna direction-finding characteristics have been presented. Advantages and disadvantages of each method have been described, with particular attention paid to weight systems being of key significance for beam forming process. It has been proved that in case of digital beam forming, the calculated weight values must be approximated following the resolution of the applied phase shifters. The authors conclude that the method selection depends upon required antenna beam width. It is preferred to apply optical method for very narrow antenna beam.

**Key-Words:** - phase array antenna, fibre optic, laser, beam steering

## 1 Introduction

Weigh units, which consist of phase shifters and attenuators, play most important role in antenna beam forming techniques (Fig. 1). Phase shifters provide main lobe position of antenna characteristic control while attenuators provide antenna characteristic shape control. Weigh units can be realised as analog, digital or optoelectronic type. Digital phase shifters are most often applying into weigh units in classic microwave applications.

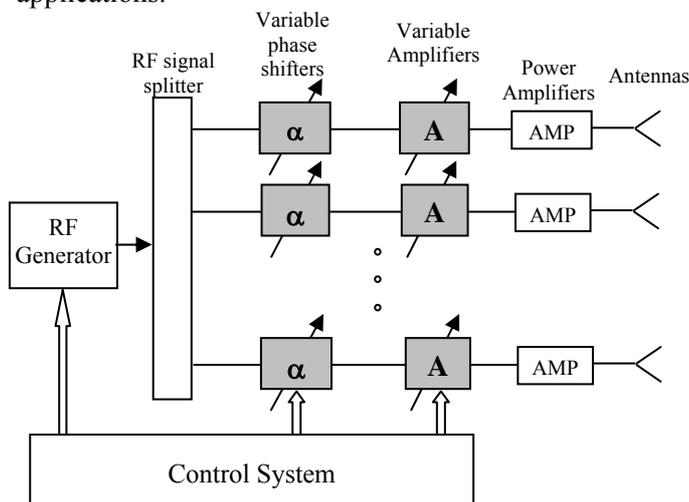


Fig.1. Phase Array Antenna Control System Configuration

Resolution of phase shift depends on number of control bits. Using 4-bits phase shifter 22.5 degree of resolution can be achieved while using 5-bits phase shifter 11.25 degree is provided. Phase shifts values for main lobe of antenna characteristic positioned at 15° and 22° applying 5 bit phase shifter is presented in table 1.

Table 1.

15°		22°	
Requires phase shifts	Available phase shifts	Requires phase shifts	Available phase shifts
0	0	0	0
46.59	45	67.43	67.5
93.17	90	134.86	135
139.76	135	202.29	202.5
186.35	191.25	269.72	270
232.94	236.25	337.15	337.5
279.52	281.25	404.58	45
326.11	326.25	472	112.5

Presented values of phase shifts shows that maximum error is equal half of resolution of shifter. In this case it is 5.625°. Using 8-bit digital phase shifter with resolution 1.4° errors of beam positioning is negligible, but practical realisation of them is quite complicated. Application of adaptive algorithm allows determine weight values for any angles of main beam of antenna characteristic. Errors of beam positioning for 8 elements linear antenna is presented numerically in table 2 for required beam angle  $\theta_0=5.8^\circ$ .

Table 2

Output number	1	2	3	4	5	6	7	8
Phase required	0	17.7	35.4	53.1	70.9	88.6	106.3	124.1
Phase approx.	0	22.5	33.7	56.2	67.5	90	101.2	123.7
Phase Error	0	4.7	-1.7	3.06	-3.4	1.35	5.13	-0.3

In practice all errors are compensated from antenna element to element then error influence for mail lobe positions of antenna characteristic is not so large and is equal few degrees.

## 2 Optoelectronic application in phase array antenna steering

Block scheme of optoelectronic unit dedicated for 2-dimensional control of antenna beam is presented in Fig. 2. Microwave pulses from RF generator controlled by pulse generator are routed to electrical input of optical elevation control unit, which generates N microwave signals with independent amplitude and phase. This unit works on optical wave from Laser 1. All outputs of those control units are connected to inputs of N optical azimuth control units, which provide M element linear antennas control. Those units work on optical wave from Laser 2. This way NxM elements of planar antenna control is provided.

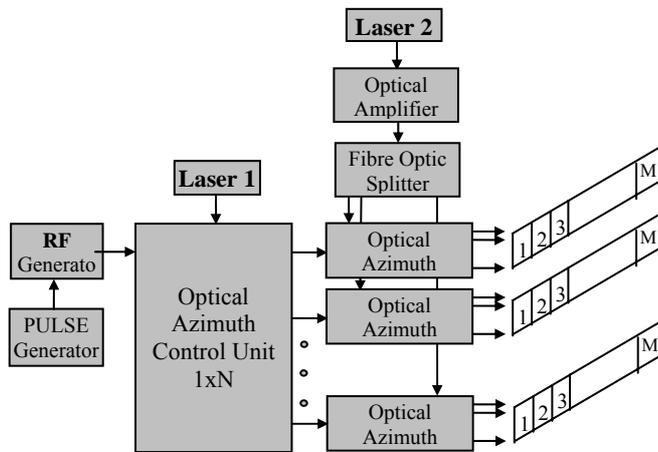


Fig.2. Optoelectronic unit dedicated for 2-dimensional control of antenna beam control scheme.

Block scheme of optoelectronic unit dedicated for 1-dimensional control of antenna beam is presented in figure 3. Optical input of this unit is supply by optical carrier signal from laser. Electrical input is supply by microwave pulses from RF generator. Mach-Zender optical modulator has been used to perform modulation of optical carrier wave by microwave signal. Modulated signal is routed to optical receivers via fibre optic network, where optical signal is splitted on N or M outputs and amplitude and phase control of each signal is provided. Optical to electrical conversion is done by optical receivers.

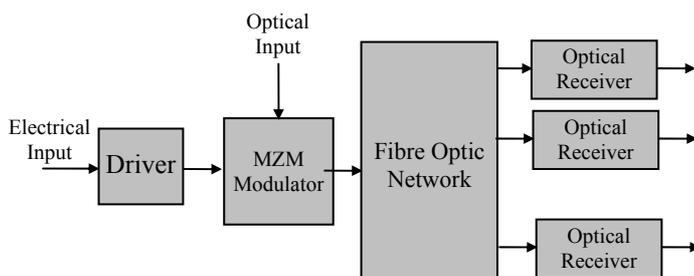


Fig.3. 1-dimentional optoelectronic control unit.

There are many different optoelectronic approaches to arrange fibre optic network to amplitude and phase control, which can be divided into coherent and non-coherent systems. Coherent approach is based on optical signal phase modulation, which is converted into microwave signal phase modulation using optical coherent detection. Non-coherent systems are based on different length of optical paths application to provide various delay time of optical signals. In this case phase shift is proportional to length of optical fibre as follow:

$$\Delta\alpha = 2 \Pi n f L / c \quad (1)$$

where: n – refractive index coefficient, f - microwave signal frequency, L - fibre optic length, c - light velocity. It means that optical signal phase change, required to generate microwave beam from planar antenna propagated in required direction, needs to use large number of different length fibre optic lines. For each beam position another set different length of fibre optic is required, then we need  $M \times N \times R$  fibres, where R – number of beam positions. Thus systems like this are very large and complicated.

Generally large number of different optic techniques were apply to achieve variable phase shift. Most popular applications are based on: optical switches, piezo-electric crystals, liquid and aqustooptic crystals, high dispersion fibres and bragg gratings.

Two types of fibre optic techniques: based on binary fibre optic delay line and dispersion delay line will be considered and compare to classic microwave phase shifters.

Microwave beam position generated from linear antenna can be described as follows:

$$\theta = \arccos\left(\frac{c}{d} \frac{\alpha}{2\pi f}\right) \quad (2)$$

where  $\alpha$  is phase difference of signals supplying antenna neighbour's elements, and  $d$  is a space between antenna elements. Concerning classical microwave systems applying 5 bits microwave phase shifters the maximum phase resolution is 11.25 degree. Then maximum beam position angle is 4.77 degree. Using optic delay line with optical switches and different length of fibres the maximum resolution of fibre length can be equal 5mm then maximum beam position angle is 1.7 degree for 5GHz microwave signal frequency. Much higher resolution can be achieved using dispersion delay line. I this case we need to apply variable wavelength laser with 0.1nm resolution. Then maximum phase resolution is equal 0.25 degree, thus maximum beam position angle is equal 0.09 degree for 5GHz microwave signal frequency.

The scheme of a control system applies material dispersion phenomenon in single-mode optical fibres for 16-element linear antenna is presented in Fig. 4. Tuned wavelength laser in range 1520 ÷1600nm and 10mW optical output power has been used as an optic signal source. The optic signal is routed to electro-optic modulator. The applied modulator operates in a third optic window, allowing for 10GHz optical signal modulation. A specialised microwave amplifier has been applied as a modulator driver.

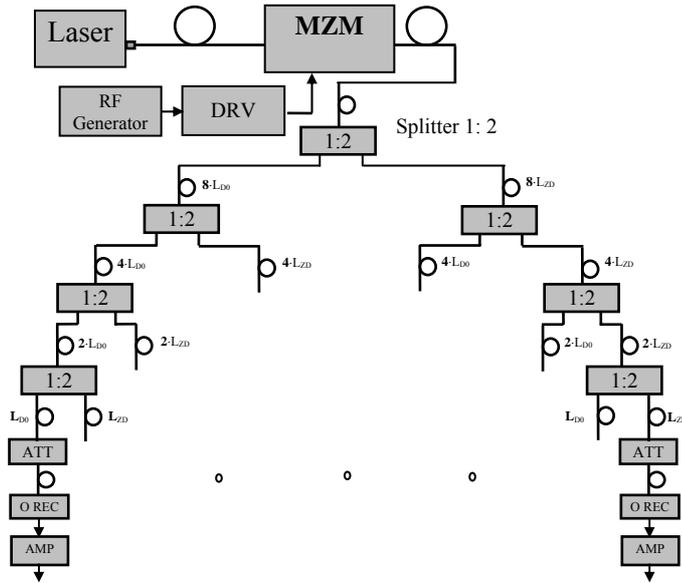


Fig. 4. Antenna control system structure.

Microwave input signal, following relevant amplification in a driver, is routed to the modulator electric input. Thus, an optic signal on the modulator output is amplitude modulated with envelope according to the control microwave signal from RF generator. Next, the modulated optic signal is distributed to a binary tree introducing the relevant microwave signal delays on individual outputs of the system. Optical signals are attenuated in fibre optic attenuators to obtain required power distribution. Next, they are routed to the inputs of 16 optical receivers, performing optic to electric signal conversion and finally distributed to the microwave amplifiers, thus additional amplifying of 22dB is performed. Antenna beam control system requires selection of high dispersion fibre optic length  $L_D$  and zero dispersion fibre optic length  $L_{ZD}$ , according to operation laser wavelength range, to obtain the desired antenna beam scanning range.

### 3...Control system measurements

Detail measurements of the developed system are based on measurements of output signals power distribution and microwave signals delay, between a

modulating signal and 16 outputs signals of the control system. The measurements have been done on microwave network analyser HP8720B. Power and phase of microwave signal have been measured. The phase was converted into time delay for signal frequency equal 5GHz. The antenna elevation characteristics have been calculated on the base of obtained results. Antenna beam scanning in the range of  $0^\circ \div 45^\circ$ , has been achieved.

In figure 5 high compatibility between position angle of 16-element linear antenna characteristic in theory (black curve) and measurement (red curve) for fibre optic dispersion delay line application can be observed.

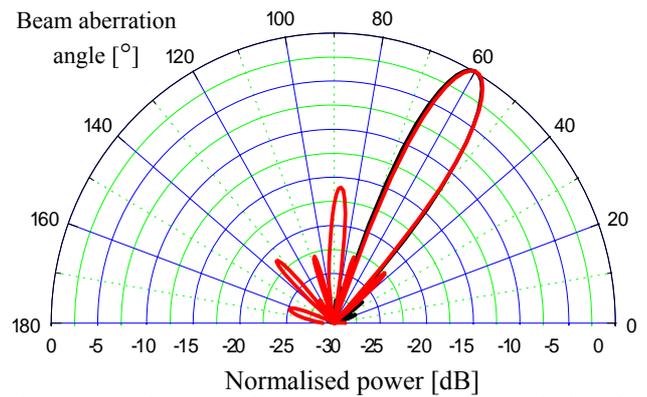


Fig. 5. 16-elements linear antenna characteristics for 30° degree antenna beam position.

Elevation characteristics of an antenna, calculated theoretically and based of measurements for the distribution of output power like  $\cos^2x + 0.4$  are presented in Fig. 6 and Fig. 7. Radiation characteristics of the 16 elements antenna row, performed for non-uniform signals power distribution at the control system outputs proves considerable compatibility to theoretical simulations. The developed system ensures an opportunity of the beam propagation direction control with an excellent accuracy equal  $0.1^\circ$ .

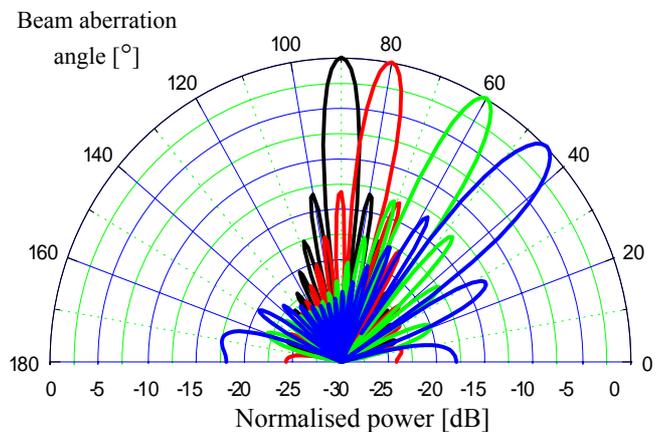


Fig. 6. 16-elements linear antenna characteristics for  $0^\circ$ ,  $10^\circ$ ,  $30^\circ$  and  $45^\circ$  degree antenna beam position (simulation)

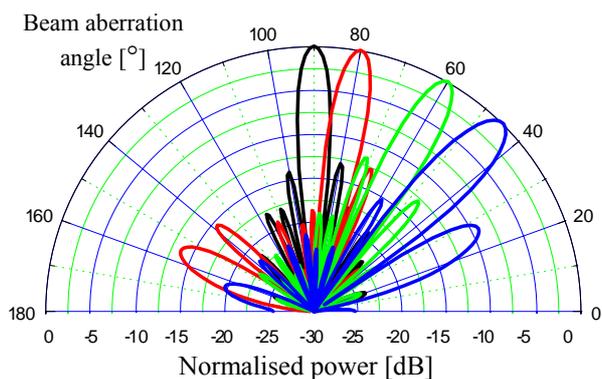


Fig. 7. Antenna characteristics for 0°, 10°, 30°, 45° degree antenna beam position (measurements)

#### 4 Conclusion

Using digital microwave phase shifters calculated phase shift must be approximated according to phase shifter resolution, then accuracy of beam positioning is equal few degrees. Application of optical weigh units in phase array beam forming provide fully antenna characteristic control. Very high resolution and an excellent accuracy of the antenna beam positioning can be achieved. Optimal technique depends on number of antenna elements, which implicates beam width. For very narrow beams the best solution is optical delay lines application in weigh units providing high angle resolution and positioning accuracy.

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