Paper

Application of optical dispersion techniques in phased array antenna beam steering

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Abstract—The paper presents an opto-electronic system for antenna beam control and results of model system measurements.

Keywords—phased arrays antennas, fiber optic, dispersion, laser.

1. Introduction

Active phased arrays antennas [1] play an important role in modern radar systems. This kind of antenna techniques is a flexible way to apply electronic beam scanning in wide angle range without the need for mechanical rotation of the antenna and easy spatial characteristics beam shaping, achieved by independent control of transmitting elements [2].

2. Electronic scanning of antennas beam

Phased array active antennas consist of independent microwave transmitting and receiving elements. Separate control signals are being supplied to them by using independent variable phase shifters or delay lines. The desired direction characteristic of an antenna is achieved by proper power supply and time delay distribution of control microwave signals. Phased array antenna beam steering [3] is based on supplying antenna radiating elements by microwave signals with gradually increasing phases. In the case of one-dimensional active antenna, the phase difference between antenna array consecutive elements required for shifting antenna's beam off an antenna axis by θ angle, can be presented as follows:

$$\alpha = 2\pi \frac{d}{\lambda} \cos\theta , \tag{1}$$

where: λ – microwave signal wavelength, d – distance between radiating elements.

Using formula $\lambda = \mathrm{c}/f$, where c is light speed in vacuum, and f – microwave signal frequency, we obtain:

$$\alpha = 2\pi f \frac{d}{\mathrm{c}} \cos\theta . \tag{2}$$

The above equation indicates that phase difference of microwave signals depend on microwave signal frequency. It means that varying frequencies are positioned in different directions. This disadvantage limits antenna operation to monochromatic signals, excluding wide band systems implementation.

Substituting in Eq. (2) by formula $\alpha = 2\pi f t$, where t is time while the wave changes phase by α, and transforming this equation, we achieve a simple dependence for delay time of microwave signal distributed to the antenna to generate beam under angle θ:

$$t = \frac{d}{\mathrm{c}} \cos\theta . \tag{3}$$

The above equation shows that the time delay of a microwave signal between the consecutive antenna elements, as opposite to phase shift, does not depend on frequency implicating a possibility of wide band operation.

3. Optoelectronic antenna steering system

The concept of developed steering system applies material dispersion phenomenon in single-mode optical fibres to obtain tuned time delay of microwave signals [4, 5] and uses optic fibre sections arranged as binary tree. The scheme of a control system for 16-element linear antenna is presented in Fig. 1. Tuned wavelength laser in range 1520 – 1600 nm and 10 mW 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 10 GHz optical signal modulation. A specialised microwave amplifier has been applied as a modulator control unit.

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 the envelope compatible 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. Delayed signals are attenuated by 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

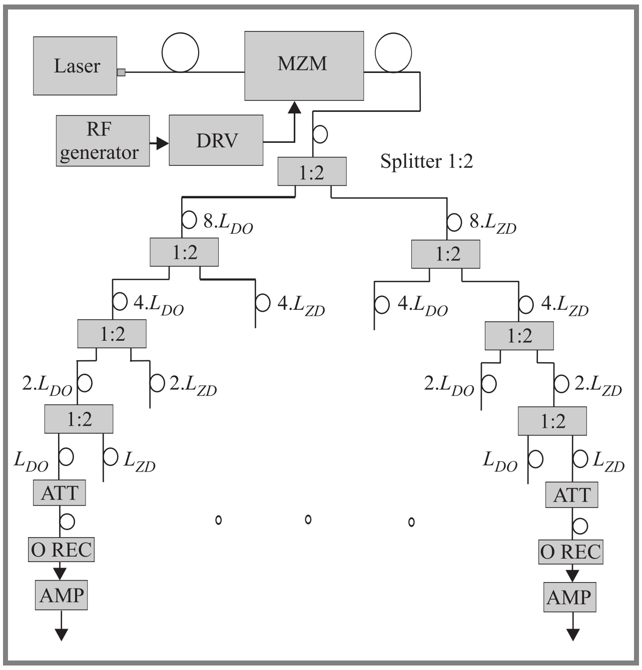

Fig. 1. Antenna control system scheme.

of 22 dB 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.

4. Control system measurements

The system maximum amplification is 25 dB for laser output power equal 10 dB. All optic link bandwidth reaches 8 GHz. Measurement results of microwave signal time delay changes of the control system output, for the microwave signals frequencies 1.3 GHz and 5.6 GHz are presented in Fig. 2.

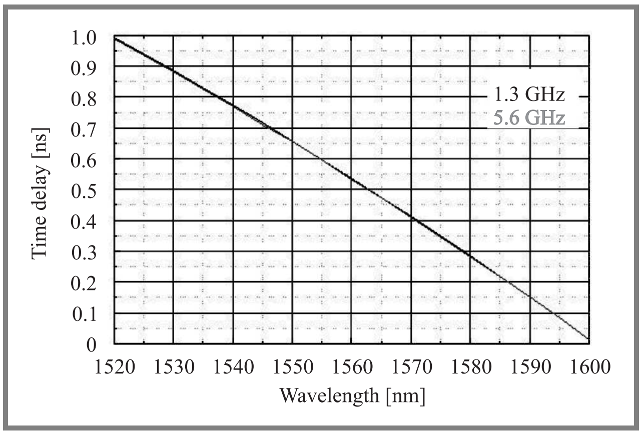

Fig. 2. Microwave signals time delay change versus laser wavelength.

Ideal compatibility between those two diagrams conducted for two varying frequencies can be observed – black curve exactly covers the grey one. This indicates no frequency dependence of signals time delay. The obtained results correspond to the theory very well. In both cases, tuning the laser wavelength by 80 nm brings microwave signal time delay change of about 970 ps. The propagation time change resolution of 1.2 ps can be achieved for the applied fibre length equal 790 m.

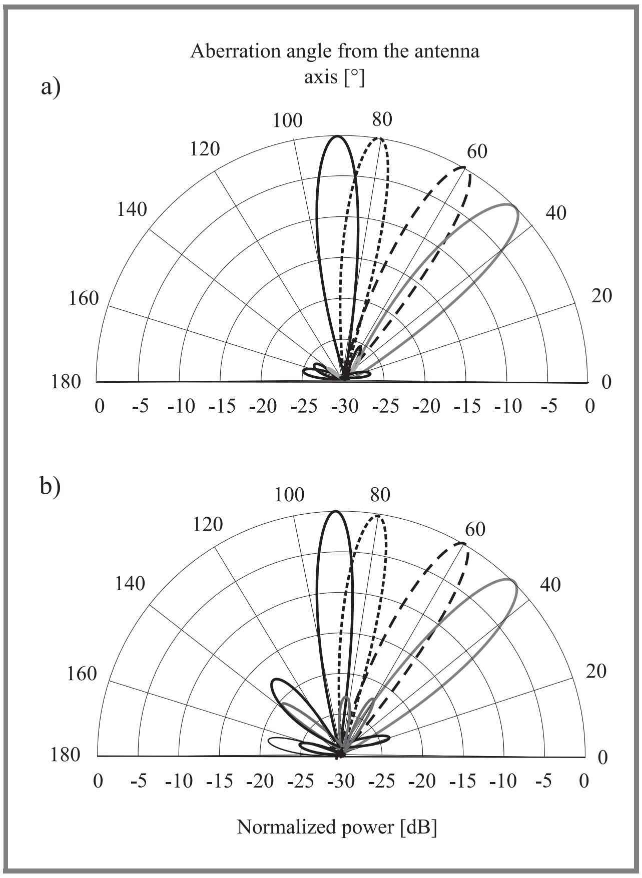

Fig. 3. Elevation characteristics of 16 elements antenna row: (a) calculated in theory; (b) calculations based on measurements.

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 analyzer HP8720B. Power and phase of microwave signal have been measured. The phase was converted into time delay for signal frequency equal 5 GHz. The antenna elevation characteristics have been calculated on the base of obtained results. The characteristics have been developed for 4 optic signal wavelengths. Antenna beam scanning in the range of 0°– 45°, has been achieved. Elevation characteristics of an antenna, calculated theoretically (a) and based of measurements (b) for the distribution of output power like $\cos^2 x + 0.4$ are presented in Fig. 3. Presented radiation characteristics of the 16 elements antenna row, performed for non-uniform signals power distribution at the control system outputs prove considerable compatibility to theoretical simulations.

The developed system ensures an opportunity of the beam propagation direction control with an excellent accuracy 0.1°. This allows to achieve an ideal agreement of the antenna beam propagation angle according to desired direction. For 16 antenna elements the beam width reaches 6.3° for 0° propagation angle and 9° for 45° propagation angle. The side lobes level is –25 dB related to the main lobe in the simulation, while real characteristics side lobes level is about –17 dB. This difference can be reduced by applying higher precision optic attenuators.

5. Conclusions

The paper describes a concept of the optoelectronic components application for the construction of the system targeted at steering 16 element antenna row. On the base of the obtained measurement results excellent optic parameters have been achieved: low optic losses at the level of 15.5 dB, light source power high stability allowing operation at the power level of +8 dB for the wide wavelength tuning range, negligible dependence between the fibre optic links attenuation and laser wavelength. Electric parameters: amplification of single link over 25 dB and 5 dB of the whole control system, dynamic range over 70 dB, 8 GHz signal bandwidth have been achieved. Microwave signal delay resolution measurement, accompanied by changing the optical carrier wavelength, generated by the semiconductor laser, is better than 1.2 ps. Thus, very high resolution and an excellent accuracy of the antenna beam positioning have been achieved.

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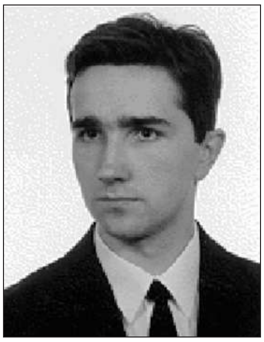

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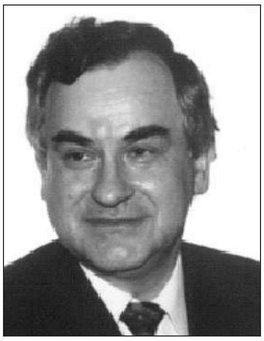

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