NEW INTEGRATED PHASED ARRAY FOR LFM RADAR

E. Zaitsev, A. Guskov, A. Cherepanov, E Svechnikov (1), G.Yufit (2)
(1) The St.Petersburg State Technical University, St.Petersburg, Russia,
(2) Beltran, Inc, NY, USA,
Politechnicheskaya, 29, Saint-Petersburg, 195251, Russia
E-mail: guskov@radio.stu.neva.ru

1. Introduction

The new class of electrically scanned antennas proposed by the authors — integrated phased array (IPA) — are developed on the basis of controlled triplex ferrite-dielectric-ferrite structures [1,2]. One of the fundamental advantages of such antennas is ability of continuous scanning of beam, as if it was a mechanical rotation of the antenna. Such mode of scanning is impossible for the conventional phased arrays. Therefore application of IPA to linear frequency modulation (LFM) radars opens up new possibilities and allows to develop unique radar systems.

2.Beam control fundamentals

All phased arrays, including IPA, have effect of frequency scanning. IPA allows to compensate frequency scanning at the expense of controlled scanning and thus to receive non-movable beam for LFM signal. As a result it is possible to choose such a mode of IPA operation, when in operating sector of the antenna during scanning cycle some non-movable beams for LFM signal are formed. The number of beams can be promptly varied. For example, if during one period of beam scan high frequency signal sweeps k times, then we can obtain k fixed beam positions (if sweep and scan velocities are coordinated, see below). The scanning frequency can be in limits from shares of a hertz up to several hundreds kilocycles.

Beam position of linear IPA can be determined by means of formula [1]

$$\sin\theta = q - n\lambda / d, \tag{1}$$

where θ is an angle between beam direction and the normal to antenna in H-plane, $q=c/v$ — moderation factor of waveguide mode (q is about 4–6), c — velocity of light, v — phase velocity of waveguide mode, n – an integer (usually n=2,3), λ — wave length, d — distance between dipole radiators.

If to differentiate (1) by time, assuming θ=const, we can obtain

$$\frac{dq}{dt} + n\frac{\lambda}{d}\frac{1}{f}\frac{df}{dt} = 0. \tag{2}$$

This formula gives the relationship between velocities of moderation factor variation and frequency sweeping, which provide fixed beam position.

At the same time we can obtain from (1) the formula for frequency scanning:

$$\frac{\Delta f}{f} \approx \frac{\Delta\theta}{q}. \tag{3}$$

If to accept the discreteness of beam position equal to beam width and to assume $\Delta\theta=2.5^0$ (0.044) and q=4, then we obtain $\Delta f/f$=0.044/4=0.011, it corresponds to Δf = 385 MHz for f=35 GHz.

It is rather easy to provide linear motion of antenna beam. Regime of periodic sweeping can be realized by applying a voltage of rectangular shape to the winding; this causes beam sweeping in horizontal (azimuth) plane with almost constant speed (Fig. 1).

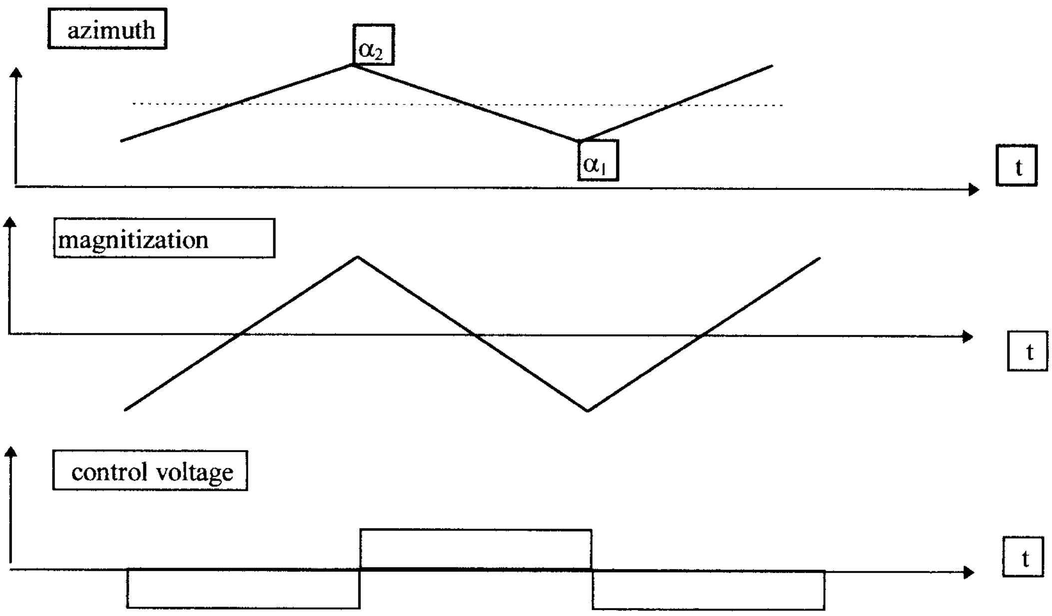

Fig. 1.

It is enough to provide constancy of amplitude and frequency of control voltage: beam sweeping is being stabilized automatically and its parameters do not depend on temperature and other factors because relation between the voltage and magnetic flux is given by Faraday law.

At a low frequencies of scanning we should take into consideration existence of active resistance of the control winding. It causes non-linearity of beam rotation. The greater this resistance or the less frequency of sweeping, the greater non-linearity. If to consider a problem in linear approximation, and to accept that a fixed voltage U_0 is applied to control winding having constant inductance L and resistance r, the current in the winding increases under the law

$$i=\frac{U_0}{r}\left(1-e^{\frac{r}{L}t}\right), \text{ but not } i=\frac{U_0}{L}t,$$

the last one would be if $r \to 0$. The value $\tau = L/r$ –time constant of control winding — is here of great importance. If scanning period T satisfies the inequality $T << \tau$, then we can neglect resistance r, and the method in Fig. 1 can be utilized. If to accept L=10^{-3} H, r=1 Ohm (typical values for antenna under consideration), then $\tau = 10^{-3}$ S, i.e. scanning frequency is about tens of kilocycles and higher. But the regime of low frequency scanning can be useful, because it relieves requirements to signal processing system of the radar.

This problem can always be solved by digital methods, by synthesis of the necessary compensating non-linearity in the digital controller with subsequent usage of a digital-analog converter. However, taking into account possible application of IPA in inexpensive systems, it is desirable to consider more simple and cheap decision of this problem.

Possible solution is shown in Fig.2, where the required non-linearity is synthesized by analog method.

In Fig. 3 the initial angle-current curve of the antenna has been shown. Parameters of circuit in Fig. 2 (R_1, R_2, R_2', R_3 are chosen such a way, that non-linearity of the circuit would compensate non-linearity of the angle-current curve. Result of linearization by means of proposed design is shown in shown in Fig. 4.

3.Pattern diagrams of the antenna for LFM Radar.

It was experimentally shown for the first time, that in the LFM radar it is possible to achieve discrete (stepped) movement of the IPA's beam by selecting the proper frequency sweep parameters despite the continuous change of control current. This operating mode is important because it allows the constant spatial orientation of the main beam to be maintained during the full time of frequency sweep with no major changes in the existing IPA control system.

Fig.5 shows the envelopes of the received signals for three directions, 1, 2 and 3 vs. time, when the antenna beam is linearly scanning. Here the transmitter frequency was constant, and the signals' envelopes simply duplicate the radiation pattern of the IPA for the chosen directions. Fig.6 also shows the envelopes of the received signals vs. time but with the linear frequency modulation of from 34.2 to 34.7 GHz turned on. Comparing this with Fig.5, direction 3 was not changed, while the direction 1-2 was placed right in between two adjacent beams (the former directions 1 and 2 in Fig.5). It is easy to see that now the beam moves in discrete steps. Oscillations at the tops of the signals are caused by parasitic mixing of the direct waves with the strong reflections from the laboratory's walls and somewhat resemble real radar returns (especially those received from the direction 3).

IPA is a leaky wave antenna, and its base waveguide has two inputs. To obtain a doubled scanning sector both inputs of the antenna may be used. To achieve this the antenna is to be designed in such a way, that being fed from the first input, the scanning sector was displaced to one side from the antenna normal, and being fed from the second input, the scanning sector was displaced to the opposite side from the normal. So if to use switching of the inputs, we obtain a doubled scanning sector.

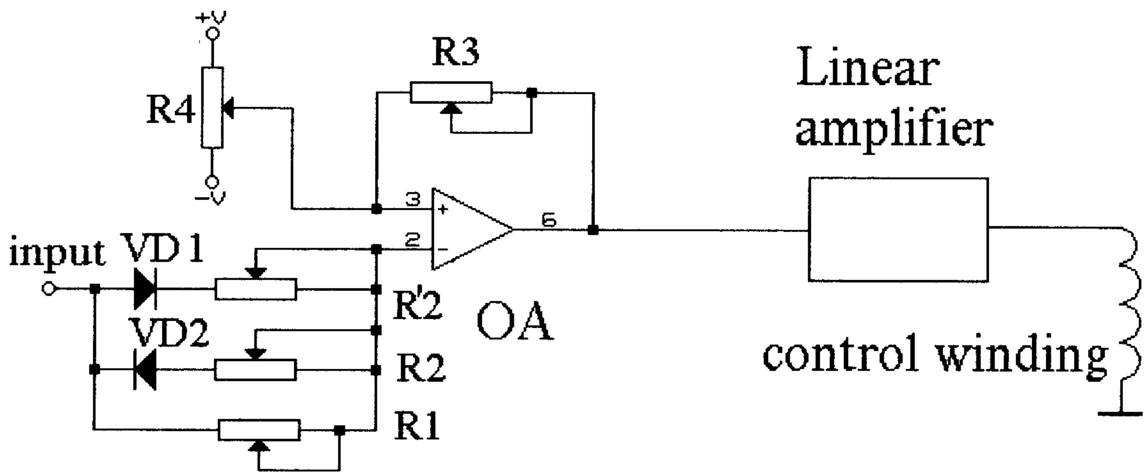

Fig.2

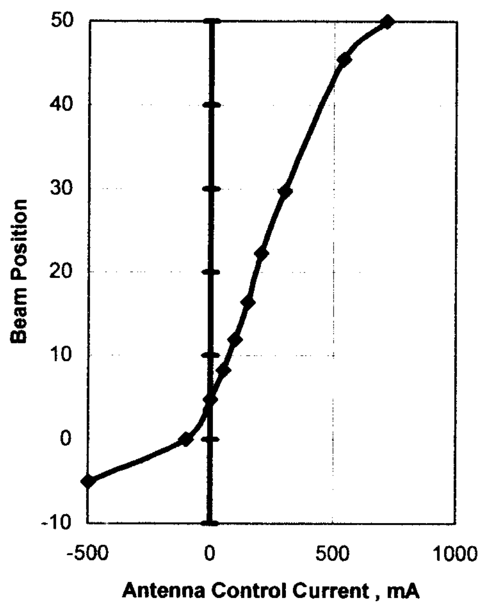

Fig.3

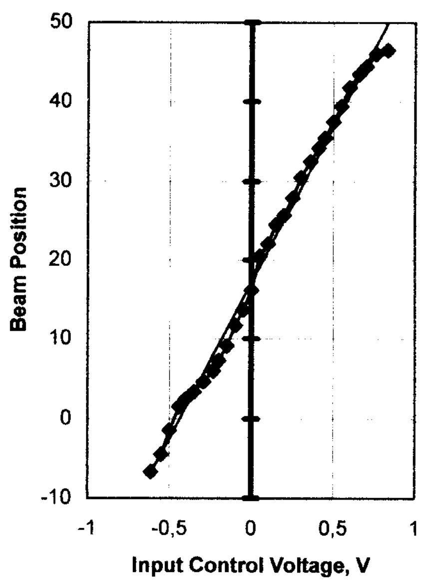

Fig.4

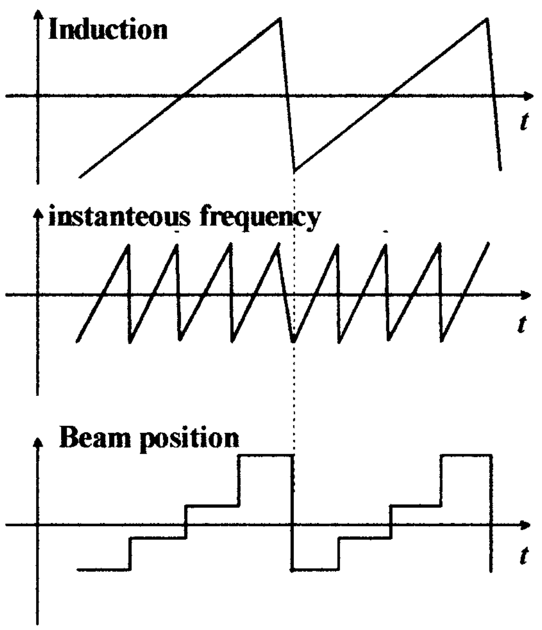

Fig.5

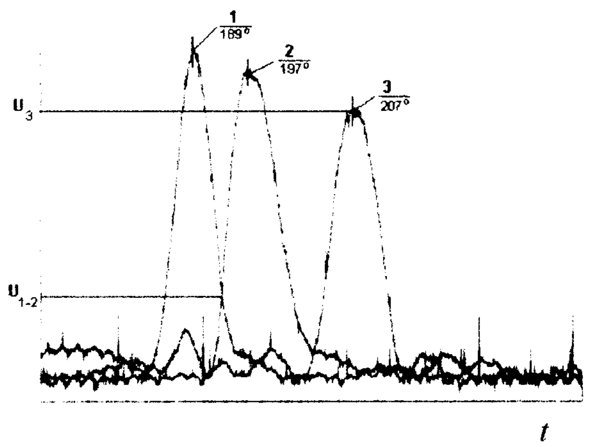

Fig.6

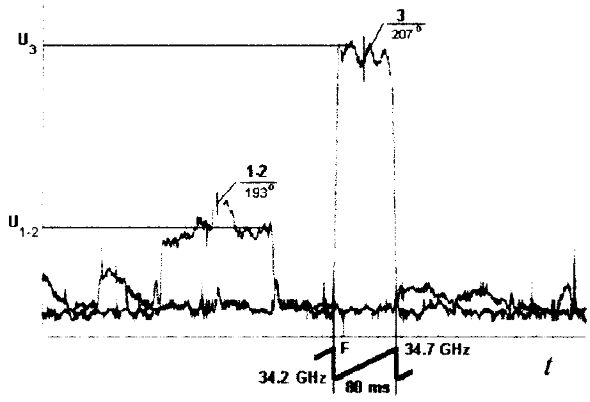

Fig.7

Conclusion

The proposed antenna can be used as imaging sensor for airplanes and helicopters, in altimeters, landing and navigation radars, in collision avoidance automotive radars and so on.

Other important feature of the offered IPA is the opportunity of immediate alternation of operation mode. In particular, it is possible to proceed promptly from a mode of a LFM radar to a mode of a pulse radar with the same parameters of beam scan. It allows to develop a comprehensive system, in which the virtues of both LFM radar and pulse radar are combined.

References.

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2. E.F.Zaitsev, Yu.P.Yavon, Active Integrated FDF-Antennas for Mobile Satellite and Cellular Communications. 1996 International Symp. on Antennas and Propagation, Sept 24-26, 1996, Chiba, Japan

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