RADAR POLARIZATION MODULATION METHOD FOR DETERMINING THE PITCH ANGLE OF AN AIRCRAFT

Gulko V. L., Mescheryakov A. A.
Tomsk State University of Control Systems and Radioelectronics
Tomsk, Russia
e-mail: msch@rts.tusur.ru

Abstract

Polarization-modulated probing signals with angle-modulated polarization planes are used to determine the pitch angle of an aircraft. The pitch angle is estimated at the receiver output based on the phase of the spectral component at twice the rotation frequency of the polarization plane of the emitted signals.

Introduction

Known methods for measuring the pitch angle of an aircraft are based on the use of complex inertial navigation systems, in particular gyroscopic orientation systems [1-4]. This paper discusses a radar method for measuring the pitch angle of an aircraft using a passive radio beacon based on the use of polarization-modulated probing signals with an orientation angle of the polarization plane.

Description of the method

The essence of the method under consideration is as follows.

Let us place a passive radio beacon at a point with known coordinates in the form of a polarization-anisotropic radar corner reflector with horizontal linear intrinsic polarization.

Let the aircraft have a pitch angle $\pm\xi$ in general. The transceiver antenna on board the aircraft irradiates a polarization-anisotropic corner reflector with a known scattering matrix with a radio signal. The axis of symmetry of the antenna's directional pattern is perpendicular to the direction of the aircraft's movement. The plane of polarization of the emitted radio signal rotates at a frequency Ω.

Using Jones' vector and matrix formalism [5], we will find the Jones vector of the received signal at the output of a linear polarizer in a linear polarization basis, whose orthonormal vectors coincide with the vertical and longitudinal structural axes of the aircraft [6].

$$\vec{E}_{out} = C \cdot \{[\Pi][R(-\alpha)][R(\mp\xi)][S][R(\pm\xi)][R(\alpha)]\vec{E}_i, \qquad (1)$$

where $\vec{E}_i = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ is the Jones vector of the initial horizontally linearly polarized wave emitted by the transmitter, coinciding with the longitudinal axis of the aircraft;

$\left[R(\alpha)\right]=\begin{bmatrix}\cos\alpha & \sin\alpha\\ -\sin\alpha & \cos\alpha\end{bmatrix}$ - Jones operator of the linear plane of polarization of the emitted electromagnetic wave rotated by an angle $\alpha=\Omega t$ (Ω - rotation frequency, t – time) [5];

$\left[R(\pm\xi)\right]=\begin{bmatrix}\cos\xi & \pm\sin\xi\\ \mp\sin\xi & \cos\xi\end{bmatrix}$ - direct pitch angle $\pm\xi$ rotation operator;

$+\xi$ - positive pitch angle of the aircraft when the longitudinal axis of the aircraft is above the horizontal plane [4];

$-\xi$ - negative pitch angle of the aircraft when the longitudinal axis of the aircraft is below the horizontal plane [4];

$\left[S\right]=\sqrt{\sigma_m}\begin{bmatrix}1 & 0\\ 0 & 0\end{bmatrix}$ - Scattering matrix of a polarization-anisotropic corner reflector with horizontal linear intrinsic polarization coinciding with the horizontal plane;

$\left[R(\mp\xi)\right]=\begin{bmatrix}\cos\xi & \mp\sin\xi\\ \pm\sin\xi & \cos\xi\end{bmatrix}$ - reverse pitch angle $\mp\xi$ rotation operator for an aircraft;

$\left[R(-\alpha)\right]=\begin{bmatrix}\cos\alpha & -\sin\alpha\\ \sin\alpha & \cos\alpha\end{bmatrix}$ - Jones operator of the polarization plane rotator of the electromagnetic wave received on board the aircraft by an angle $-\alpha$;

$\left[\Pi\right]=\begin{bmatrix}1 & 0\\ 0 & 0\end{bmatrix}$ - linear polarizer operator (transition from circular waveguide to rectangular waveguide) with horizontal linear intrinsic polarization coinciding with the longitudinal axis of the aircraft;

C - a constant value that takes into account the transmitter's potential, the distance from the transmitter to the corner reflector and back; its maximum possible effective scattering surface, and the receiver's sensitivity.

After performing the necessary calculations in (1), we obtain the Jones vector of the received signal at the output of the linear polarizer in the form

$$\vec{E}_{out}=C\begin{bmatrix}\cos^2(\alpha\pm\xi)\\ 0\end{bmatrix}. \qquad (2)$$

Then the signal directly at the receiver input will look like this

$$E_{in}=C\cos^2(\alpha\pm\xi). \qquad (3)$$

The amplitude of the signal at the output of a receiver with a logarithmic amplitude characteristic and a linear detector as a function of angle α will be equal to

$$E_{out}(\alpha) = \lg C + \lg\left|\cos^2(\alpha \pm \xi)\right|. \qquad (4)$$

After transformations (4), taking into account that the signal amplitude in the case of using a logarithmic receiver is usually measured in decibels, we obtain at $\alpha = \Omega t$

$$E_{out}(\Omega t)[\partial Б] = 20\lg C + 10\lg\left\{\frac{1}{2}\left(1+\cos\left(2\Omega t \pm 2\xi\right)\right)\right\}. \qquad (5)$$

The ratio (5) allows us to calculate the dependence of the output signal amplitude of a logarithmic receiver on the angular position α of the polarization plane of the emitted signal for different values of the pitch angle ξ.

The calculation results are shown in Figure. Positions 1-3 correspond to pitch angle values of 0^0, 15^0 and -15^0.

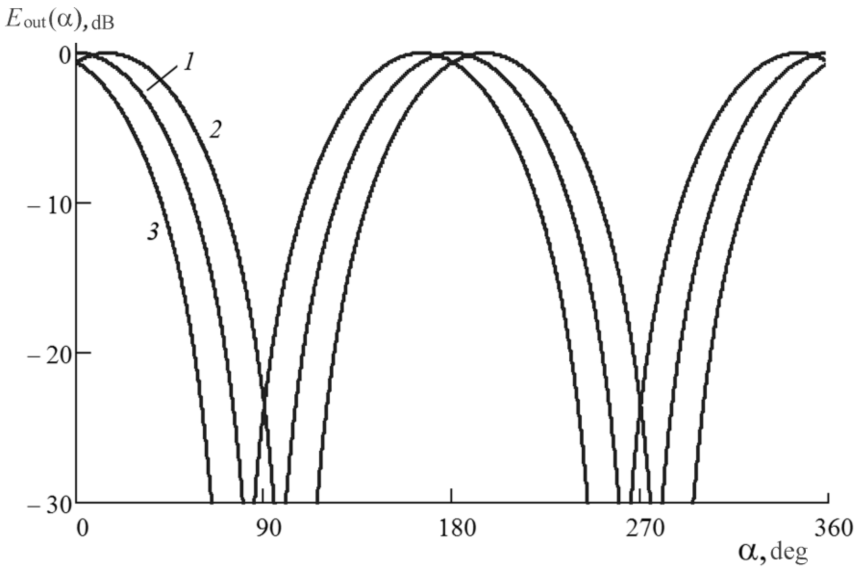

Figure – Dependence of the output signal amplitude of a logarithmic receiver on the orientation angle α of the polarization plane of the emitted signals at pitch angles ξ 0^0 (1), 15^0 (2) and -15^0 (3)

Analysis of Figure shows that the amplitude of the signal at the output of a receiver with a logarithmic amplitude characteristic and a linear detector is modulated by twice the rotation frequency of the polarization plane of the emitted signal.

At the same time, the amplitude modulation of the signal reaches 100% depth and does not depend on the pitch ξ of the aircraft, but only determines its phase shift by twice the pitch angle ξ of the aircraft. Therefore, the spectrum of the receiver's output signal envelope contains a spectral component at a frequency 2Ω.. Its amplitude $A_{2\Omega}$, taking into account (5), can be found using a Fourier transform of the form

$$A_{2\Omega}\left[\partial Б\right]=\frac{1}{\pi}\int_{0}^{2\pi}E_{вых}\left(\Omega t\right)\cos(2\Omega t)d\left(\Omega t\right). \qquad (6)$$

After calculation, the amplitude $A_{2\Omega}$ will be equal to $A_{2\Omega}=17,37\ dB$ and will not depend on the pitch angle. And its phase $\varphi_{2\Omega}$, taking into account (5), is related to the pitch angle of the aircraft by the ratio:

$$\xi\left[rad\right]=\pm\frac{\varphi_{2\Omega}}{2}, \qquad (7)$$

where '+' - corresponds to a positive pitch angle;
the sign '-' - corresponds to a negative pitch angle.

Phase $\varphi_{2\Omega}$ is measured relative to the phase of the reference signal $\cos\left(2\Omega t\right)$, which is determined by the angular position of the polarization plane of the emitted signal. It should be noted that the amplitude $A_{2\Omega}$ and phase $\varphi_{2\Omega}$ do not depend on the transmitter potential, receiver sensitivity, distance from the aircraft to the passive radio beacon, or its effective scattering surface σ_m. The energy parameters determine the constant component of the signal at the output of the logarithmic receiver of the airborne radar.

Conclusions

1. A radar polarization modulation method for determining the pitch angle of an aircraft using a passive polarization anisotropic radio beacon has been proposed, based on the use of polarization modulation of the orientation angle of the polarization plane of the probing signals.

2. It has been established that the phase of the spectral component at twice the frequency of polarization modulation at the receiver output is determined by the aircraft pitch. An analytical expression establishing this relationship has been obtained.

3. The described method is technically simple to implement, since the onboard equipment is single-channel microwave and the measurement of the aircraft's navigation element is carried out at the receiver output at a frequency that is a multiple of the polarization modulation frequency.

Acknowledgements

The work was carried out as part of a project commissioned by the Ministry of Education and Science of the Russian Federation (No. FEWM–2023–0014).

REFERENCES

1. Skrypnik O.N. Radio Navigation Systems for Airports and Airways. Springer, 2019.

2. Pelpor D.S._ Yagodkin V.V. Gyroscopic systems. Moscow, Visshaya shkola, 1988. 213 p.

3. Aleksandrov A.S., Arno G.R. The current state and development trends of foreign means and navigation systems for military and civilian mobile objects. Saint Petersburg, 1994. 120 p.

4. Yarlykov M.S. Statistical theory of radio navigation. Moscow, Radio and svyaz, 1985. 345 p.

5. Azzam R.M.A., Bashara N.M. Ellipsometry and polarized light. Moscow, Mir Publ., 1981, 583 p.

6. Gulko V.L., Mescheryakov A.A. Method for radar determination of the pitch angle of an aircraft. Patent RU, no. 2831987, 2024.