IOP Conf. Series: Materials Science and Engineering 457 (2018) 012010 doi:10.1088/1757-899X/457/1/012010

Determination technique of quasireference value of a carrier radio signal frequency of uncooperated onboard lighting source during radio monitoring

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Abstract. The article discloses the technique defining quasireference value of a carrier radio signal frequency of uncooperated onboard lighting source by calculation and compensation of the Doppler shift at radio monitoring. Provided simulation results show checked operability of the offered technique with assessment of observation accuracy and received quasireference value of a carrier frequency accepted a radio signal compared with real sample under various conditions.

1. Introduction

Last years the theory and practice of complex application of radio monitoring and a radar-location in the conditions of the composite alarm and interfering situation a path of integration of land and air complexes of radio monitoring (RM) actively develops in spropercture of multiposition radar-tracking systems (radar station).

At the same time, in difference with classical multiposition radar station, the onboard radar complex (ORCOM) can be used as uncooperated integral lighting source for land and air complex of radio monitoring [1]. Uncooperated integral lighting source is understood in this article as an onboard radar complex, contact with which is not kept, and the operator of a land and air monitoring complex cannot exert impact on it. Parameters of such source signal and the characteristic of its carrier to a radio monitoring complex are not known in advance. The RM land and air complex is understood as a multiposition complex of radio monitoring composed of a ground station of management and processing (GSMP) and not less than four receiving positions – unmanned aerial vehicles (UAV-sensors) with designly placed onboard equipment of radio monitoring and controlled remotely with GSMP (Figure 1).

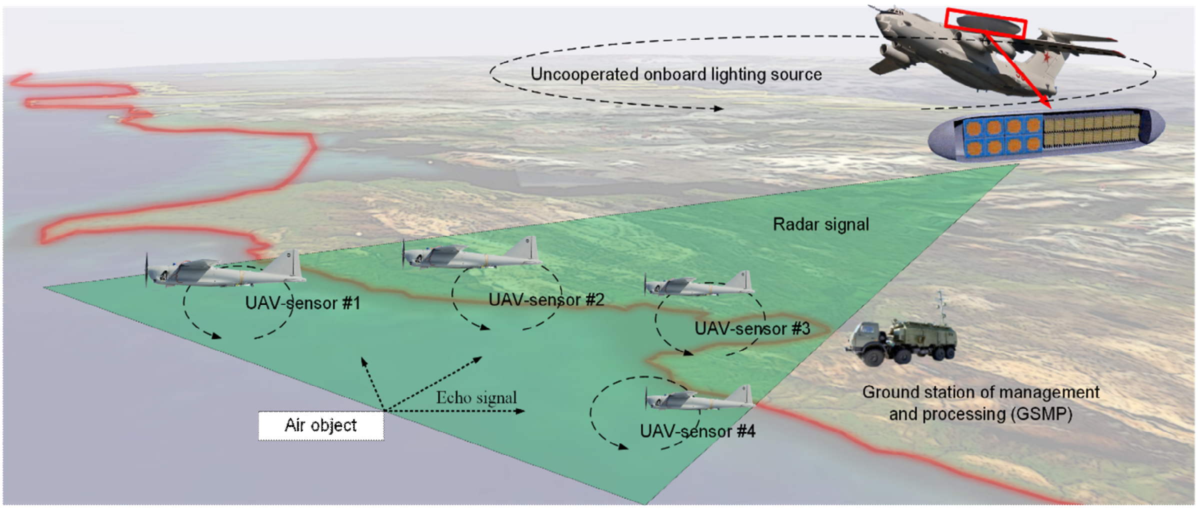

Figure 1. Structure of a multiposition complex of radio monitoring composed of a ground station of management and processing (GSMP) and not less than four receiving positions – unmanned aerial vehicles (UAV-sensors).

Implementation of similar fissile and passive system demands on the adaptation of devices of reception and processing of the RM complex to functioning in the conditions of dynamism where the received values of a carrier radio signal frequency can differ substantially from the proper in view of presence of the Doppler shift. The specified feature, in a consequence, complicates process of detection of the signals reflected from air objects with low power availability (echo signals) [2–6]. For the purpose of elimination of the designated feature within this article, there is presented the determination technique of quasireference value of a carrier frequency by the way of staying and compensation of the arising Doppler shift. The quasireference value of a carrier radio signal frequency of a source of integral lighting is understood within article as value of frequency of the considered radio signal taking into account compensation of the Doppler shift.

2. Determination technique of quasireference value of a carrier radio signal frequency of uncooperated onboard lighting source

The Doppler shift of a carrier frequency on a receiving position of the RM land and air complex (the UAV-sensor) is defined by expression:

$$f_{meas.} = f_{carr.}\left(1 \pm \frac{V_r}{c}\right), \tag{1}$$

where $f_{meas.}$ is the value of a carrier frequency of the probing signal measured on the UAV-sensor; $f_{carr.}$ is the proper value of a carrier frequency of the probing signal; V_r is the relative radial speed of the UAV-sensor and ORCOM carrier.

The technique includes nine sequentially carried-out stages.

2.1. Stage 1. Searching, detection and parameter estimation of a radio signal of integral lighting source (type of modulation, carrier frequency ($f_{carr.}$), signal duration (τ), time of arrival of a signal (t)). Each UAV-sensor having the panoramic receiver, on command with GSMP carries out searching of radio signals of ORCOM in the given frequency range.

2.2. Stage 2. Positioning of the ORCOM carrier by finding of the cross-correlation function of a delay of time of arrival of a radio signal for UAV-sensors (t_1, t_2, t_3, t_4), realizing at ground station of management and processing the difference and ranging system of a fixing.

For ensuring correct work of a difference and ranging way of a fixing of a source of a radio signal in space, the operator of GSMP defines the area of barraging and an echelon of the occupied heights for each UAV-sensor. Coordinates in real time are determined by signals of the block of navigation and time providing, the direction of driving and the real speed of each UAV-sensor, is carried out transfer of this information on GSMP where the high-precision binding to characteristic frame is carried out.

2.3. Stage 3. Calculation of radial speed of the UAV-sensor concerning the ORCOM carrier.

All angles in system are counted concerning one direction (chosen randomly on GSMP). When determining parameters of driving of the carrier of uncooperated source of integral lighting it is necessary to compensate the Doppler shifts, the bound to driving of receiving positions of the RM land and air complex.

Radial speed of the UAV-sensor concerning the ORCOM carrier can be found with that equation:

$$V_{r(UAV_i)} = V_{(UAV_i)} \cos\theta_i , \tag{2}$$

where $V_{(UAVi)}$ is value of the real speed of the UAV-sensor; θ_i is a projective angle of a vector of speed of the UAV-sensor to the line passing through the points characterizing location of number of the UAV-sensor and ORCOM carrier.

2.4. Stage 4. Compensation of the Doppler shift of a carrier frequency caused by driving of UAV-sensors.

Carrying out the mathematical calculation of values of the carrier signal frequency Doppler shift caused by UAV-sensors driving and calculate their compensation on an equation:

$$f_{comp.i} = f_i^{'}\left(1 \pm \frac{V_{r(UAVi)}}{c}\right) , \tag{3}$$

where $f_i^{'}$ is a carrier frequency of the probing signal on the corresponding UAV-sensor; $V_{r(UAVi)}$ is the radial speed of a receiving position concerning the ORCOM carrier.

2.5. Stage 5. Calculation of the intermediate values of parameters of driving of the ORCOM carrier.

Compensation of driving of UAV-sensors and expression projective angles of a vector of speed of the carrier integral lighting source on the corresponding straight lines 15, 25, 35, 45 through α_1, α_2, α_3, α_4, β_1, β_2, β_3, β_4, α, β, receive system from four equations with four unknowns α (roving), β (pitch), V (the real speed), $f_{carr.}$ (reference value of a carrier frequency of the probing integral lighting source signal).

$$\begin{cases} f_{comp.1} = f_{carr.}\left[1 - \dfrac{V\cos(\alpha_1 - \alpha)\cos(\beta_1 - \beta)}{c}\right] \\ f_{comp.2} = f_{carr.}\left[1 - \dfrac{V\cos(\alpha_2 - \alpha)\cos(\beta_2 - \beta)}{c}\right] \\ f_{comp.3} = f_{carr.}\left[1 - \dfrac{V\cos(\alpha_3 - \alpha)\cos(\beta_3 - \beta)}{c}\right] \\ f_{comp.4} = f_{carr.}\left[1 - \dfrac{V\cos(\alpha_4 - \alpha)\cos(\beta_4 - \beta)}{c}\right] \end{cases}. \tag{4}$$

Sequentially solve a set of equations (4) concerning V, α and β by a substitution method, receive equationes for finding of the corresponding sizes.

Express from the first equation of the f_{carr} system:

$$f_{carr.} = -\frac{f_{comp.1} \cdot c \cdot \left(1 - \dfrac{v \cdot \cos(\alpha - \alpha_2)\cos(\beta - \beta_1)}{c}\right)}{v \cdot \cos(\beta - \beta_1)\cos(\alpha - \alpha_2) - c}. \tag{5}$$

Expression (5) is substituted in the second equation of system (4) and express V_{12}:

$$V_{12} = \frac{c(f_{comp.2} - f_{comp.1})}{f_{comp.2} \cdot \cos(\beta - \beta_1) \cdot \cos(\alpha - \alpha_1) - f_{comp.1} \cos(\alpha - \alpha_2) \cdot \cos(\beta - \beta_2)}. \tag{6}$$

Expression (6) is substituted in the third equation of system (4) and expressed α:

$$\alpha' = \alpha_1 + \arctan\left(\frac{f_{comp1} \cdot \cos(\alpha_1 - \alpha_2) \cdot \cos(\beta - \beta_2) - f_{comp3} \cdot \cos(\alpha_1 - \alpha_2) \cdot \cos(\beta - \beta_2) - f_{comp1} \cdot \cos(\alpha_1 - \alpha_3) \cdot \cos(\beta - \beta_3)}{f_{comp1} \cdot \sin(\alpha_1 - \alpha_2) \cdot \cos(\beta - \beta_2) - f_{comp3} \cdot \sin(\alpha_1 - \alpha_2) \cdot \cos(\beta - \beta_2) - f_{comp1} \cdot \sin(\alpha_1 - \alpha_3) \cdot \cos(\beta - \beta_3) + f_{comp2} \cdot \sin(\alpha_1 - \alpha_3) \cdot \cos(\beta - \beta_3)} + \right.$$
$$\left. + \frac{+ f_{comp2} \cdot \cos(\alpha_1 - \alpha_3) \cdot \cos(\beta - \beta_3) - f_{comp2} \cdot \cos(\beta - \beta_1) + f_{comp3} \cdot \cos(\beta - \beta_1)}{f_{comp1} \cdot \sin(\alpha_1 - \alpha_2) \cdot \cos(\beta - \beta_2) - f_{comp3} \cdot \sin(\alpha_1 - \alpha_2) \cdot \cos(\beta - \beta_2) - f_{comp1} \cdot \sin(\alpha_1 - \alpha_3) \cdot \cos(\beta - \beta_3) + f_{comp2} \cdot \sin(\alpha_1 - \alpha_3) \cdot \cos(\beta - \beta_3)}\right) \tag{7}$$

Expression (7) is substituted in the fourth equation of system (4) and expressed β. As a result of transformations receive formulas for V, α and β on which find the intermediate values as there is an ambiguity of definition of angles α, β and the sign of speed of V.

2.6. Stage 6. Determination of the unique values of parameters of the ORCOM carrier movement.

The uniqueness of values of parameters of driving of the carrier of a source of integral lighting decides on next Equations:

$$V_{12} = \frac{c(f_{comp.2} - f_{comp.1})}{f_{comp.2} \cdot \cos(\beta - \beta_1) \cdot \cos(\alpha - \alpha_1) - f_{comp.1} \cos(\alpha - \alpha_2) \cdot \cos(\beta - \beta_2)}. \tag{8}$$

$$\alpha_{res.} = \alpha' + \left\{\frac{\pi \ at\ V > 0}{0 \ at\ V < 0}\right\}, \tag{9}$$

$$\beta_{res.} = \beta' + \left\{\frac{\pi \ at\ V > 0}{0 \ at\ V < 0}\right\}, \tag{10}$$

$$V_{res.} = \frac{|V_{12}| + |V_{13}| + |V_{14}| + |V_{34}| + |V_{23}| + |V_{24}|}{n}, \tag{11}$$

where $V_{res.} \in \{V_{12}, V_{13}, V_{14}, V_{23}, V_{34}, V_{24}\}$ n=6 at $f_{comp.1} \neq f_{comp.2}$, $f_{comp.1} \neq f_{comp.3}$, $f_{comp.1} \neq f_{comp.4}$, $f_{comp.2} \neq f_{comp.3}$, $f_{comp.2} \neq f_{comp.4}$, $f_{comp.3} \neq f_{comp.4}$.

2.7. Stage 7. Determination of radial speed of the ORCOM carrier concerning UAV-sensors.

On the basis of the received vector of speed of the carrier of a source of integral lighting determine its radial speed concerning each UAV-sensor:

$$V_{r(Ill.sour_i)} = V_{(Ill.sour_i)} \cos\alpha_i \cos\beta_i \ . \tag{12}$$

2.8. Stage 8. Definition of a carrier frequency of a radio signal of ORCOM.

On each UAV-sensor the carrier frequency of the accepted probing signal is defined by a formula:

$$f_{carr.i} = \frac{f_{comp.i}}{\left[1 \pm \frac{V_{R(Ill.sour_i)}}{c}\right]}, \tag{13}$$

where $f_{comp.i}$ is the integral lighting source radio signal frequency measured on a receiving position taking into account compensation of the Doppler shift of the UAV-sensor caused by driving; $V_{R(Ill.sour.i)}$ is the radial speed of the carrier of a source of integral lighting relatively UAV-sensor.

2.9. Stage 9. Restitution of quasireference value of a carrier radio signal frequency of ORCOM.

For minimization of the error caused by distinction of measurement accuracy of parameters UAV-sensors of the RM land and air complex, the quasireference value of a carrier frequency of a radio signal of ORCOM is found how average value from calculated:

$$f_{carr.} = \frac{f_{carr.1} + f_{carr.2} + f_{carr.3} + f_{carr.4}}{4}. \tag{14}$$

The deviation of the received quasireference value of a carrier frequency of rather proper depends on accuracy of determination of parameters of driving of the carrier of a source of integral lighting and inspropermental accuracy of a frequency meter on the UAV-sensor.

3. Results and Discussion

For the purpose of operability check of the offered technique the imitation model is developed and consists of the software package with use of the LabVIEW-2014 environment. The model allows to imitate reception by ORCOM radio signal UAV-sensors (uncooperated integral lighting source) and to make error assessment of determination of required sizes a Monte-Carlo method.

Accuracy of finding the Doppler shift size is defined by potential accuracy of positioning and a vector of movement speed of the ORCOM carrier and also from accuracy of positioning of UAV-sensors and instrumental accuracy of a frequency meter on the UAV-sensor. At a simulation modeling as dynamically changeable sizes values of the relation signal/noise and parameters of a vector of speed of the ORCOM carrier and UAV-sensors were chosen. The value of a mean squared deviation (MSD) of positioning of ORCOM and UAV-sensors was accepted by a static fixed value.

Results of a simulation modeling allowed to construct schedules of mistake dependences in determination of carrier parameters of a source of integral lighting at various values of a ratio signal/noise on an entrance of the radio-receiving paths of the imitated RM complex (Figure 2 and 3). Researches were conducted on condition of impact on the radio signal RM complex with the linear - the frequency modulation with the f_{carr} parameters. = 1 GHz, $f_{dev.}$ = 250 MHz, τ = 1 ms and the real speed of the carrier of a source of integral lighting of V = 205 m/s.

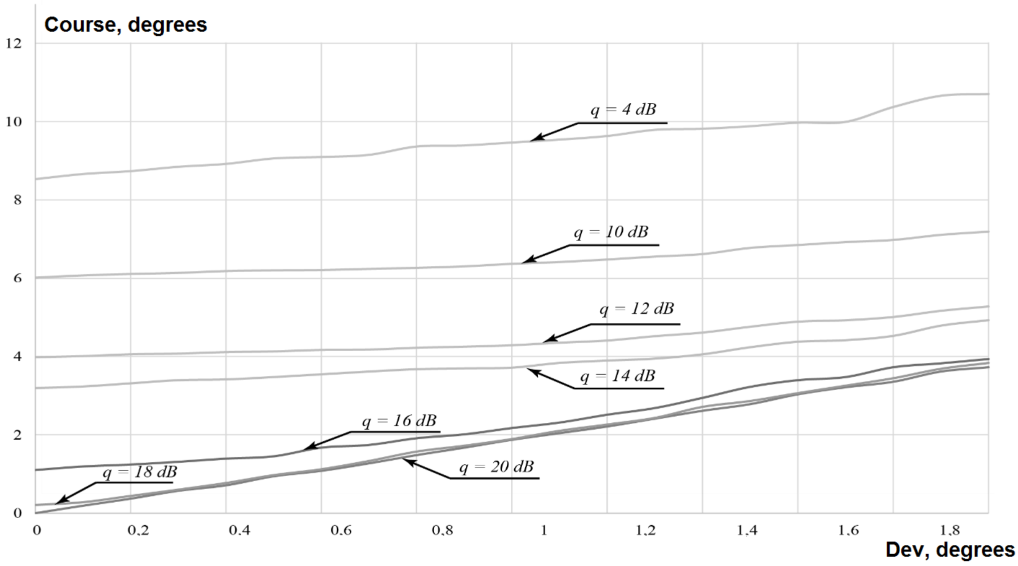

Figure 2. Dependence of an error of definition of the direction of driving of the carrier of a source of integral lighting on positioning MSD at various ratios signal/noise on an entrance of the radio-receiving path of the imitated RM complex.

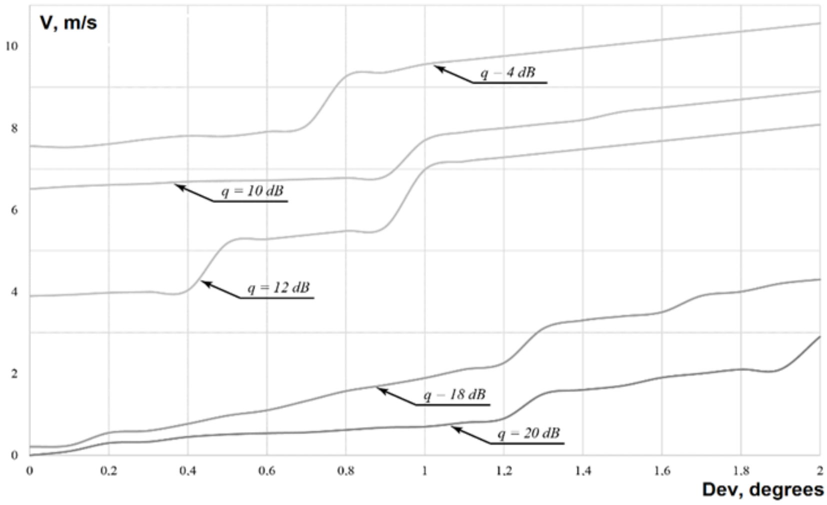

Figure 3. Dependence of an error of speed determination of the carrier of a source of integral lighting on positioning MSD at various ratios signal/noise on an entrance of the radio-receiving path of the imitated RM complex.

Schedules show operability of the offered technique in the conditions of a ratio signal/noise from 20 to 4 dB. Assessment of accuracy of obtaining quasireference values of a carrier frequency of the probing signal from the proper showed that depending on the relation signal/noise elimination of fluctuations, the bound to a Doppler effect, is possible ranging from 86 up to 97%.

4. Conclusion

The article discloses the technique defining quasireference value of a carrier radio signal frequency of uncooperated onboard lighting source by calculation and compensation of the Doppler shift at radio monitoring. Provided simulation results show checked operability of the offered technique with assessment of observation accuracy and received quasireference value of a carrier frequency accepted a radio signal compared with real sample under various conditions. It is established that depending on the relation signal/noise elimination of fluctuations, the bound to a Doppler effect, is possible ranging from 86 up to 97%.

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