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PHOTORECEIVERS FOR PRECISION LASER MEASUREMENT SYSTEMS OF LENGTH

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Abstract – The developed photoreceiver modules (PRM) for two-frequency laser radiation at wavelengths in the range of 0.6328 to 0.4416 µm are presented. The discussed PRMs were created as per the results of theoretical calculations and experimental studies of the structure oscillations of cavity resonator depending on geometry of the concentrators.

Keywords: photoreceiver, microwave resonator, laser measurement system.

INTRODUCTION

The two-frequency laser measurement systems of length designed in NIST (USA) and NMIJ (Japan) is analyzed in the paper [1].

In the paper [2], the two-frequency LMS of length with the measurement range from 1 to 1000 m and relative uncertainty of measurements of about 10^{-7}, when k = 2, is presented.

High accuracy LMS of length [2] was achieved by creation and implementation of two-frequency helium-neon lasers with microwave excitation of neon-20 atoms both at main and weak emitting junctions.

The presented results theoretical studies designed PRMs for high accuracy two-frequency LMS of length in this paper could be used for prototypes of surveying devices for EURAMET Join Research Project SIB60 [3].

1. MEASUREMENT EQUATION

Let in two-frequency mode the laser emits two linearly polarized harmonic oscillations, which can be represented as

$$\begin{aligned} E_1 &= E_{01}\sin(\nu_1 t + \varphi_{01}) \\ E_2 &= E_{02}\sin(\nu_2 t + \varphi_{02}), \end{aligned} \tag{1}$$

where E_1 and E_2 are amplitudes of electrical field of emission with angular frequencies ν_1 and ν_2 and initial phases φ_{01} and φ_{02}.

After passing the measured distance the radiation is received on PRM. Under photoelectric conversion of two coherent laser oscillations of the same polarity and equal relative phases in PRM, intensity of luminous flux is determined by the value of Umov-Poynting vector

$$P = \frac{c}{4\pi}E^2, \tag{2}$$

where $E = E_1 + E_2$.

Then, at time point t the square of amplitude of the resultant electrical field is equal to

$$\acute{A}_t^2 = \acute{A}_{01}^2 + \acute{A}_{02}^2 + 2\acute{A}_{01}\acute{A}_{02}\cos((\nu_1 - \nu_2)t + \varphi_{01} - \varphi_{02}), \tag{3}$$

and power

$$P_t = P_1 + P_2 + 2\sqrt{P_1 P_2}\cos((\nu_1 - \nu_2)t + \varphi_{01} - \varphi_{02}). \tag{4}$$

Taking into account that synchronizing the frequency difference of two harmonic oscillations of the laser radiation the equation $P_1 \cong P_2$ can be achieved, we obtain

$$P_t = 2P(1 + \cos\theta), \tag{5}$$

where $\theta = \omega_{12}t + \Delta\varphi_0$ is current phase;

$\omega_{12} = \nu_1 - \nu_2$ is frequency difference of two harmonic oscillations;

$\Delta\varphi_0 = \varphi_{01} - \varphi_{02}$.

In high accuracy LMS of length [2] the small part of the laser radiation (≤10 %) after the reflection from the beam splitter is received to PRM reference channel (reference signal), the bigger part of the laser radiation is sent to the measurable distance and having reflected is received to PRM measuring channel (measuring signal).

When passing the measurable distance of two-frequency laser radiation to the reflector and back, the current phase is incremented equal ratio $\omega_{12}\dfrac{2D}{\upsilon}$ and is equal to

$$\theta' = \omega_{12}\left(t + \frac{2D}{\upsilon}\right) + \Delta\varphi_0, \tag{6}$$

where D – the measurable distance;

υ is group velocity of propagation of two-frequency laser radiation in atmosphere.

During the passage reference distance of a two-frequency laser radiation from divider through waveguide to the photoreceiver the current phase is incremented equal ratio $\omega_{12}\dfrac{d}{\upsilon_0}$ and is equal to

$$\theta'' = \omega_{12}(t + \frac{d}{\upsilon_0}) + \Delta\varphi_0, \quad (7)$$

where d is the waveguide length;

υ_0 is group velocity of propagation of two-frequency laser radiation in waveguide.

The phase difference between the laser radiation having passed the measurable and reference distances can be found from the expression

$$\theta' - \theta'' = \omega_{12}\frac{2D}{\upsilon} - \omega_{12}\frac{d}{\upsilon_0}. \quad (8)$$

The measurement equation is obtained from the equation (8) by converting it in relation to the measurable distance D

$$D = \frac{(\theta' - \theta'')v}{2\omega_{12}} + \frac{d}{2}\frac{v}{v_0}. \quad (9)$$

Group velocities of laser radiation passed the measurable and reference distances are defined by Rayleigh equation

$$v = \frac{c}{n}; \; v_0 = \frac{c}{n_0}. \quad (10)$$

Considering that the phase difference $\theta' - \theta''$, depending on the measurable distance and frequency ω_{12}, can take values from zero to $2\pi N+\varphi$, where N = 1,2… – integer number, and $\varphi<2\pi$, measurement equation (9) will rearrange into the following form:

$$D = \left(N + \frac{\varphi}{2\pi}\right)\frac{c}{2F \cdot \langle n \rangle} + P. \quad (11)$$

where N - integer number of the laid scale length in measurable distance;

$\varphi = \theta' - \theta''$ - phase difference between measurable and reference signals;

c=299792458 m/s - speed of light, fundamental physical constant,

$\langle n \rangle$ - mean integral refractive index of air;

$P = \frac{d}{2} \cdot \frac{n_0}{n}$ - instrument correction that is physically related to the optical length of the reference channel and determined experimentally.

2 THEORETICAL STUDIES OF DESIGNED PRMS FOR LMS OF LENGTH

The two-frequency laser measurement systems of length designed in NIST (USA) and NMIJ (Japan) are analyzed in the paper [1]. The shortcoming of these PRMs is low quality factor of the microwave resonator with photomultiplier detectors (PDs), embedded into the internal conductor of the microwave resonator.

The novelty of PRMs considered below is the design of the microwave resonator with PDs located beyond the internal chamber (Ω) of the microwave resonator [4]. The drawing is shown in Fig. 1 and the external view of resonators are shown in Fig. 2.

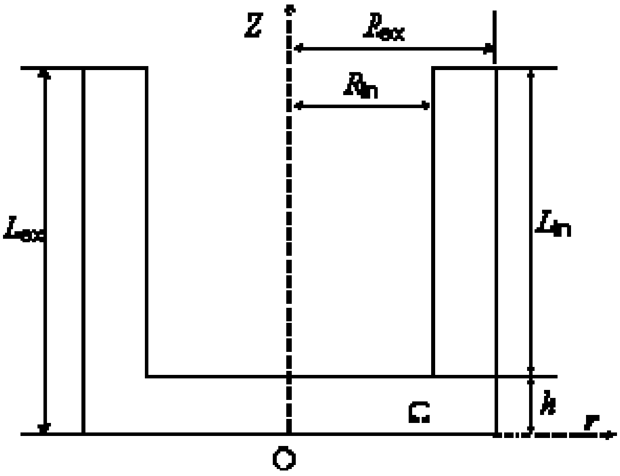

Fig. 1. Drawing of resonator.

Fig. 2. External view of resonators.

Along with the indicated novelty there were implemented concentrators of the electromagnetic field (the drawing is shown in Fig. 3) of different forms and materials, for example of glass fiber or of brass which are shown in Fig. 4.

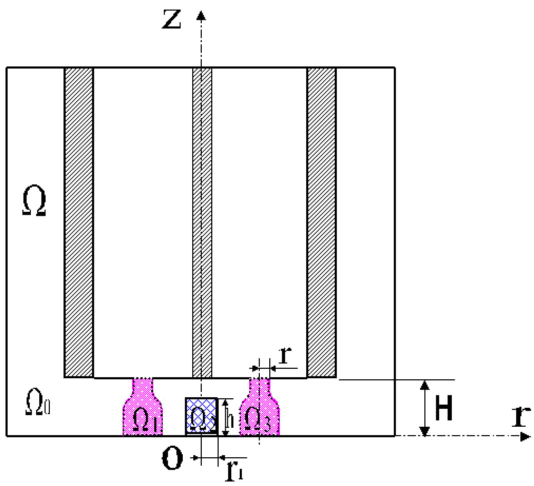

Fig. 3. Drawing of the resonator with concentrators.

Fig. 4. External view of concentrators.

The boundary value problem of the elliptic type is solved by the method of R-functions [5]. In this problem $\Omega = \Omega_0 \cup \Omega_1 \cup \Omega_2 \cup \Omega_3$ is the research area; $\partial\Omega$ is the area boundary Ω.

The theoretical distributions of the electromagnetic field potential in the resonator's cavity are given in Fig. 5 and Fig. 6.

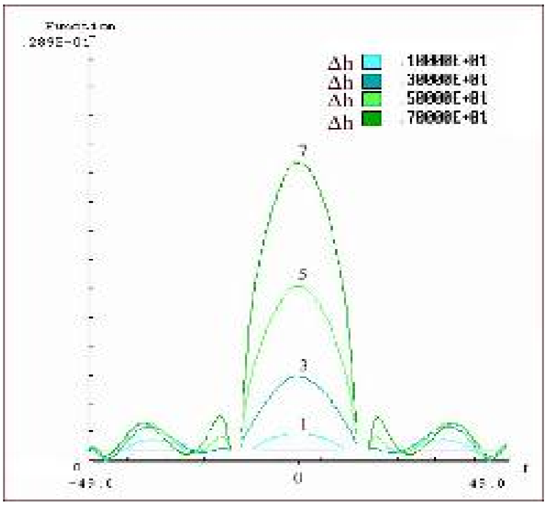

Fig. 5. Distribution of the electric potential of the electromagnetic field in the resonator's cavity (h = 8 mm) with two cylindrical concentrators of brass.

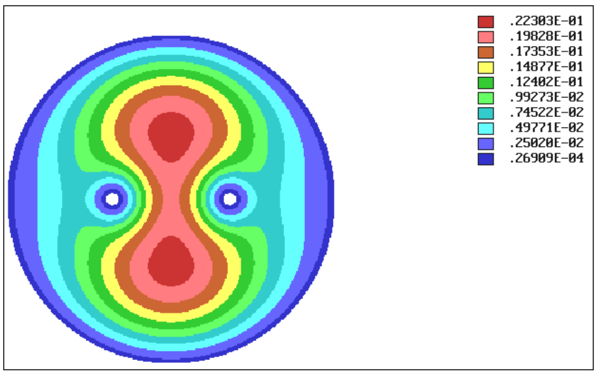

Fig. 6. Isolines of the electric potential in the resonator's cavity for z = 7 mm (h = 8 mm) with two cylindrical concentrators of brass.

3 COMPARISON OF THEOTETICAL AND EXPERIMENTAL STUDIES OF THE ELECTOMAGNETIC FIELD IN THE PRM

To check the accuracy of numerical experiments of PRMs there were conducted experimental studies of RMC vibrations by the method of travelling probes. The experimental installation was developed with application of elements of measuring line R1-17 and PRM is shown in Fig. 7. To excite the resonant oscillation in the PRM there was used the generator type G4-144 with the range of frequency 400…820 MHz, frequency instability after two-hours heating $\Delta F/F \leq 2{,}5 \cdot 10^{-4}$ and output power ≤ 1 W

Fig. 7. Experimental installation for measurements of distributions of the microwave field in the PRM.

Application of the methods for determination and decrease of uncertainties of measuring line R1-17 allowed to get in the range of frequencies 490 – 540 MHz the input standing-wave ration as per voltage not over than 1.04. The accuracy of measurements of line detector currents was raised with the digital multimeter instrument B7-28. The probe coordinates were determined with the help of the engineer's dial gauge ICH200.

At reworking of P1-17 there were conducted the following operations:

– measuring wave conductor of line R1-17 was changed for the PRM with the gap cutout along the generatrix of the external cylindrical conductor with the width of 2 mm and length of 124 mm;

– to measure the radial component of the electric component of the electromagnetic field measuring probe R1-17 was changed onto the spindle of chemically pure copper wire with the diameter of 0.5 and length of 20 mm.

Uncertainties caused by changeability of the probe connection with the electromagnetic field inside the resonator (Θ_1), the detector current meter (Θ_2) and the probe coordinate measuring machine (Θ_3), are equal to $\Theta_1 = \pm 2$ %; $\Theta_2 = \pm 0{,}3$ %; $\Theta_3 = \pm 3{,}5$ %.

The results of the comparison of theoretical and experimental studies of distribution of microwave fields of the PRM are given in Fig.8.

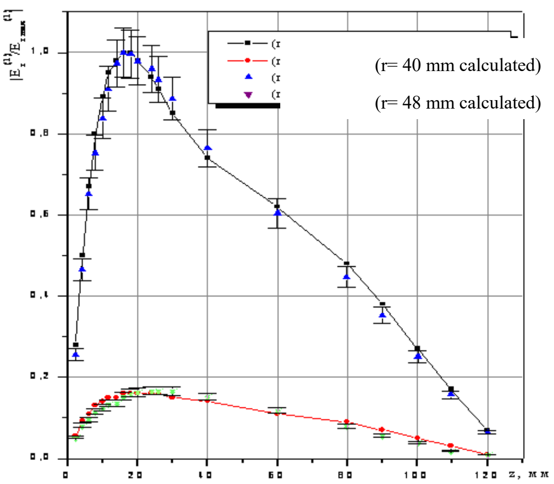

Fig. 8. Calculating and experimental distributions of normalized radial component of the electric element of the electric field along 0Z axis in PRM

4. CONCLUSIONS

As per results of the researches carried out in NSC "Institute of Metrology" there were created PRMs (fig. 9) for single-wave two-frequency LMS of length and PRM (fig. 10) for two-wave and two-frequency LMS of length with uncertainty of phase difference of two-frequency laser radiation less than 40" for k = 2 that complies with the requirements of EURAMET project JRP SIB60.

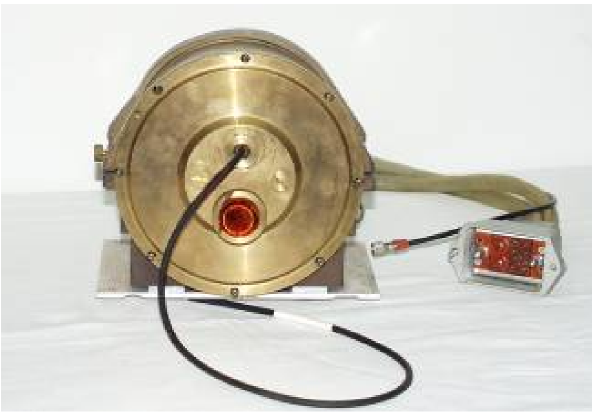

Fig. 9. PRM for single-wave two-frequency LMS of length

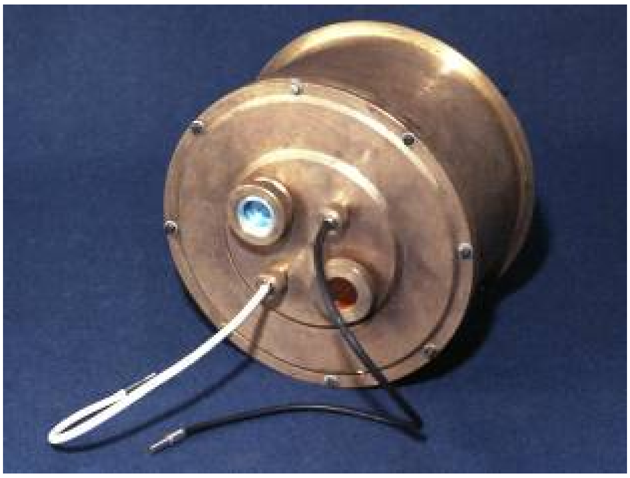

Fig. 10. PRM for two-wave and two-frequency LMS of length

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