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Increase of calibrated meter range at distance measurement

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Abstract- In area of metrology there is often a necessity of microwave distance meter calibration. The calibration is executed by distance measuring from the microwave distance meter to conductive plane, of which distance is defined accurately (by means of micro-steps of step motor, which moves the plane or by means of the reference laser distance meter). Some disadvantages may appear at higher distances when accuracy of the measurement are affected by parasitic reflections of microwave radiation from walls of the room, in which calibration is executed. For example, if a flaring angle of the microwave distance meter is 23°, then the first reflection from the sidewall, at 1.5 m distance, occurs at 7 m and from the framework, at 1 m distance, at 4 m yet. Such a situation significantly affects execution of calibration at the distances more than 4 m. There is several manners how to solve such a problem.

I. Introduction

On of the possible solutions is to use non-reflecting materials for prevent false reflections of the microwave energy from the present objects. But to cover the walls and the framework by microwave absorbers is problematic (financially as well as technically).

Other solution is based on a focalization of the microwave beam, i.e. a decrease of the flaring angle of the microwave distance meter. It may be implemented by a change of transmitting antenna – a horn antenna or optical focalization of microwave beam. The first solution is not possible because calibration concerns of the calibrated distance meter. Other one is more practical; other components are added into the distance meter. To focus the microwave beam we may use dielectric or Fresnel lens. In this paper we concentrate on a design of Fresnel lens by means of known formulas, simulation of its properties in conjunction with microwave distance meter and finally on a verification of the obtained results by measurement.

Principles of Fresnel dielectric straps functions are described in [1], [2], [3]. The Fresnel lens was made from homogeneous dielectric material which includes series of the rings with constant depth v. In this manner effective permittivity $\varepsilon_{\mathrm{eff}}$ of dielectric material is changing. Radius of the rings r_i represents Fresnel zones and may be calculated [1]:

where λ_0 is a wavelength in free space and F is focal length. Depth of the rings is chosen to occur 180°

$$r_i = \sqrt{F\lambda_0 i + \left(\frac{i\lambda_0}{2}\right)^2} \quad i = 1,2,3,.... \tag{1}$$

correction of the wave at every Fresnel zones and is given as:

$$v = \frac{\lambda_0}{2\cdot(\sqrt{\varepsilon_r} - 1)} \tag{2}$$

where ε_r is relative permittivity of dielectric material of the lens. Mentioned formulas are based on analysis of a propagation of the microwave beam by means of beam optics. To express radius and depth of particular Fresnel rings it is necessary to know a figure of radiation pattern of the distance meter transmitting antenna and to calculate particular Fresnel integrals. Very important parameter for a calculation of the Fresnel lens is the ratio $F : D$. In the case of inconvenient ratio $F : D$ there occurs side lobes on the Fresnel lens [4].

II. Change of the microwave distance meter flaring angle

Microwave distance meter is RF equipment working on a frequency of 26 GHz. Microwave radiation is excited by antenna, called horn antenna. A draft of such an antenna is shown in Fig. 1.

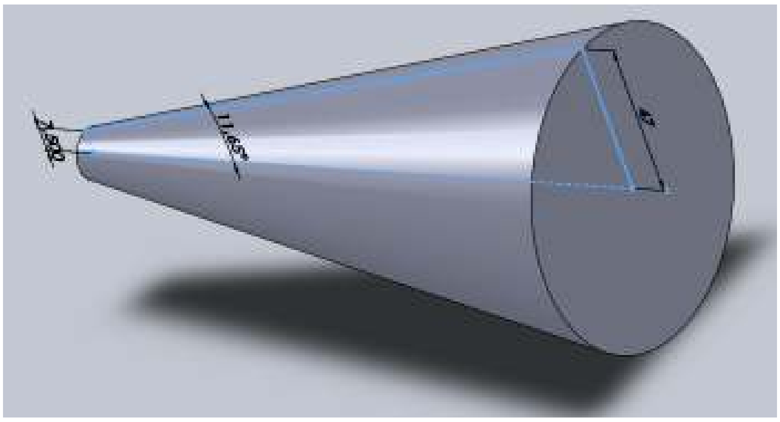

Figure 1.: Horn antenna of the microwave distance meter as a radiator

Role of the transmitting antenna is to direct RF energy into specific, predetermined, place. In our case it is level of which distance is measured. If the energy beam is too wide (as it was mentioned before), it may reflects also from surrounding objects and not only from required measured level. So, a beam width (RF bunch) affects directly validity of the measurement. Hence our task was to calculate the beam width of the distance meter, to design the lens to its focusing and to verify the entire measuring system by means of appropriate numerical simulator.

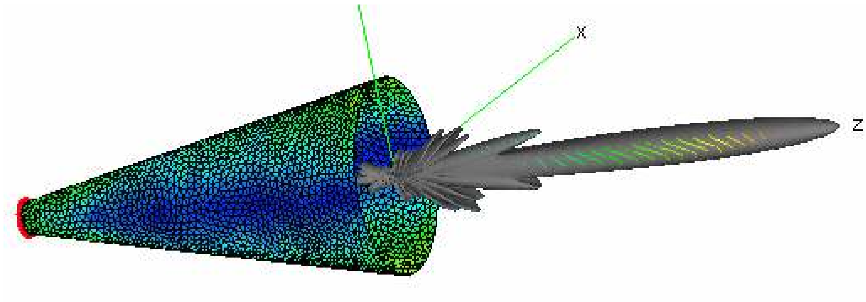

Figure 2.: Radiation pattern of the distance meter

Commercial numerical simulator FEKO was used to calculate radiation patterns. This simulator is based on moment method which is suitable to RF analysis of line, surface or volume objects. Principle of moment method, of which properties may be found in [5], consists in division of geometric objects into segments, in which RF currents are calculated. In Fig. 2 is shown the radiator – horn antenna and its radiation pattern, calculated by FEKO. As it may be seen in Fig. 2 major radiation lobe is relatively narrow, but for some practical applications of distance meter, as it is in the case of calibration, insufficient.

To narrow the major lobe of radiation pattern we decided to use Fresnel lens, as it was mentioned before. The distance meter works at frequency of 26 GHz. Then the wavelength λ is:

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{26 \cdot 10^9} = 0{,}011538\ \mathrm{m} \qquad (3)$$

Based on (1) and (2) using expression of the wavelength (3) the Fresnel lens for frequency 26 GHz was calculated. The lens was designed from synthetic with relative permittivity $\varepsilon_{\mathrm{eff}} = 2{,}6$.

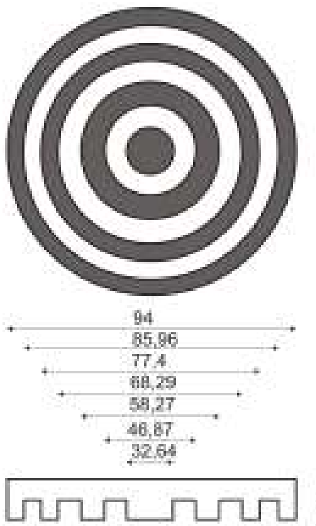

Figure 3.: Dimensions of the Fresnel lens

The calculated dimensions of the designed lens are shown in Fig. 3.The entire depth of the material is not crucial, it is just the depth between two Fresnel rings. The ratio F:D was chosen 0,5.

Since Fresnel lens should be situated in appropriate distance from the radiator, equal to focal length, it was necessary to execute another simulations of behaviour of the radiation pattern as a function of distance between lens and radiator. Such a task was more complicated in consideration of computational power and a time necessary to its execution. Because electromagnetic beam goes through the lens, at we needed modelling the lens as a 3D object. Therefore, the number of segments, necessary to calculate internal (currents or voltages) as well as external (electromagnetic fields) tasks, increased – cca. 15 000 segments. Such a calculation needs a 12.043 GB of RAM memory and it takes 20 hours using two processors. The results of numerical simulation are shown in Fig. 4. It is evident that major radiation lobe is narrowed, so we may assume an improvement of calibrated distance meter parameters.

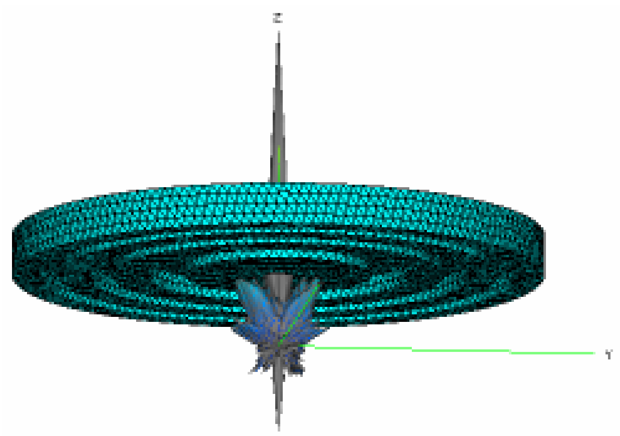

Figure 4.: Radiation pattern of microwave distance meter with Fresnel lens

III. Measurement

Verification of the Fresnel lens calculation was executed at calibration of the microwave distance meter. The measurement was performed at Slovak Legal Metrology, Ltd. Using the microwave distance meter the distance from conductive plane was measured, first without using the Fresnel lens and thereafter with it. Conventionally right value of the distance was verified by a laser interferometer.

Table 1.1: Measured values of verifying the microwave distance meter - measure with Fresnel lens

Conventional true value (mm)	822,300	2820,690	4818,871	6817,144	8815,437
Measurement value (mm)	822,300	2819,600	4815,850	6816,200	8812,700
Error (mm)	0,000	-1,090	-3,021	-0,944	-2,737

Table 1.2: Measured values of verifying the microwave distance meter - measure without Fresnel lens

Conventional true value (mm)	822,269	2820,666	4818,856	6817,130	8815,430
Measurement value (mm)	822,2	2818,4	4815,2	6815,5	8813,1
Error (mm)	-0,069	-2,266	-3,656	-1,630	-2,330

In Fig. 5 it is shown the microwave distance meter with fixed Fresnel lens. This figures shows also the detail of reflective conductive plane of which distance was measured.

Figure 5.: View of microwave distance meter with fixed Fresnel lens

As it may be seen on measured values, the lens improved measured values of verified microwave distance meter. It means that the width of radiated bunch of distance meter was narrowed and such bunch incidence less with surrounding objects. However to achieve minimization of undesired reflections it is necessary to find the ideal position of the Fresnel lens and so to narrow the major lobe of the radiation pattern. As it is shown in Fig. 5 the conductive plane of electromagnetic beam incidence is not a perfect plane. It is inserted into a frame, which may affect , in case of the wide lobe, the results of verification measurement.

IV. Conclusions

One of possible ways of improving the accuracy of the microwave distance meter was shown in this paper. The accuracy of the distance measurement in closed space was affected by reflections from surrounding objects. We used a Fresnel lens, which focused the microwave beam, to minimize these reflections. Then the beam did not incident to dummy targets and the error of the measurement decreased. To additional reduction of distance measurement error it is necessary to perform the measurements in open space area or in space equipped with electromagnetic absorbers.

Acknowledgement

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