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USING ALTERNATIVE APERTURE GEOMETRY HORN ANTENNAS IN WIDE-BAND MULTIFREQUENCY MEASUREMENTS

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Application of horn antennas in non-destructive testing by multifrequency reflectivity measurements has several advantages in comparison with simple antennas such as open-ended waveguide, in particular, higher gain and narrower directional characteristic. However, having two reference discontinuities hinders from using them for the purpose because of superposition of echoing characteristics being retrieved. General solution lies in extracting single echoing characteristic whether by mathematical post-processing measurement results or by strong reducing one of reference discontinuity reflectivity levels by altering discontinuity's geometry, that is the subject of this paper.

1. Introduction

Wide-band multifrequency measurements of reflectivity in free space allow testing the internal structure of complex multi-layered materials containing discontinuities of different kinds (both inter-layer borders and defects of different kinds). Due to applying the method of synthesising radio-pulse envelope [1] spatial distribution of insertion reflectivity may be obtained, which then is used to locate the defects and/or derive dependency of dielectric constant and other parameters of structure under test on the distance along the measurement axis.

Existing real-time measurement systems [2] use waveguide reflectometric circuit for acquiring reflectivity data. Reflectivity is obtained as ratio of reflected to incident wave power, correspondingly received and radiated by a probe. The most frequently used probes are open-ended waveguide (OEW) and different types of horn antennas.

Every probe represents one or more discontinuities serving as references, thus spatial echoing characteristic appears a superposition of similar reflectivity characteristics, corresponding to cross-correlation of reflection signals of structure under test with that of each reference discontinuity. Superposing hinders clear interpreting reflectivity signals and estimating structure's parameters, so only characteristics derived with OEW may be used directly for this purpose. Horns, though of higher gain and narrower directional diagram than OEW, have two discontinuities (throat and aperture), so the superposition may be avoided whether by mathematical filtering raw echoing data, or/and by strong reducing the minor discontinuity (i. e. having lower reflectivity, typically, aperture) by special designing its geometry.

2. Alternative Aperture Design

Modified horn may be derived from usual horn by framing its aperture in cylindrical metal surface, as it is shown in Fig. 1. Outer diameter (D) of the cylinder lies in range 0.5-1 wavelength at minimum fre-

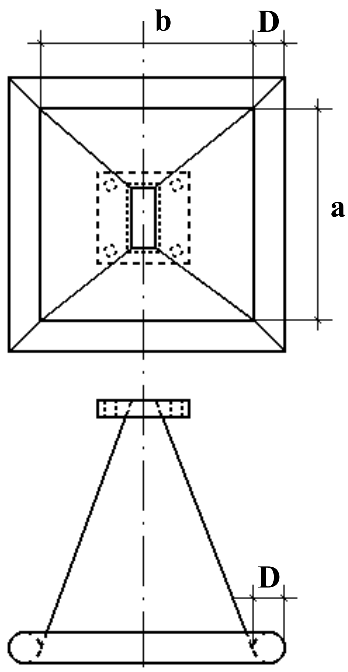

Fig. 1. *Alternative design of horn antenna*

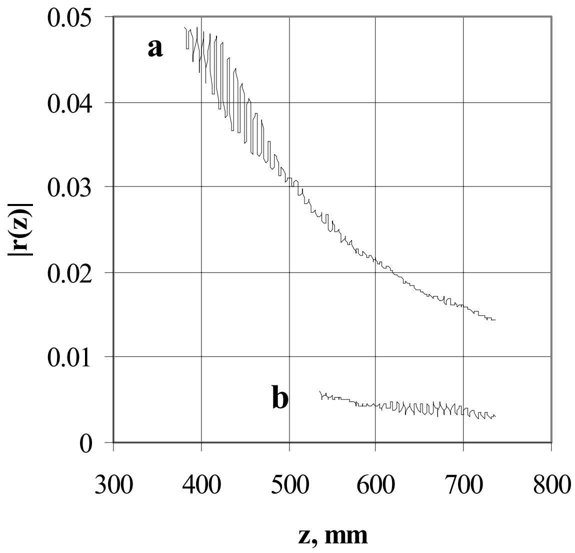

Fig. 2. *Spatial oscillations of reflectivity characteristics of metal plate moving along probe axis, derive with horn's throat (a) and aperture (b)*

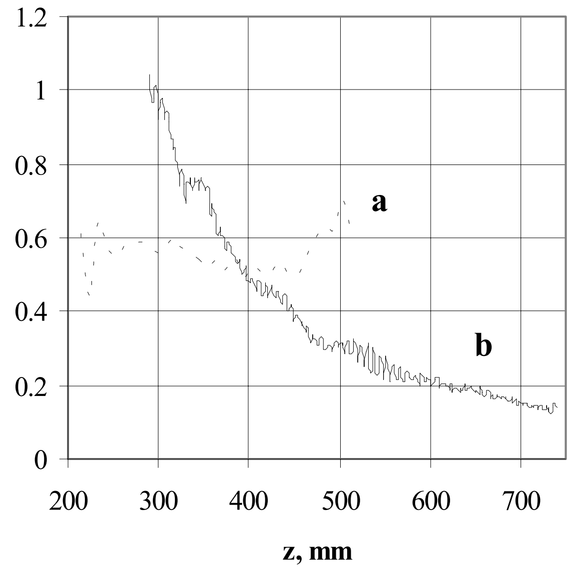

Fig. 3. *Aperture-to-throat reflectivity module ratio for usual horn (a) and the same horn with altered aperture geometry (b)*

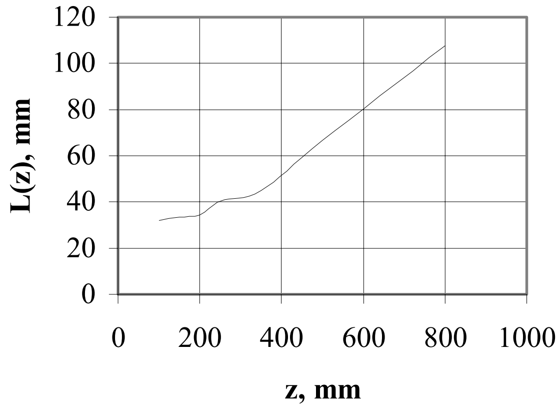

Fig. 4. *Locality of testing* $z = 0$ *at the aperture*

quency [3]. We have tested such a design with three pyramidal-shaped horns having square aperture (one for 8-12.5 GHz band with aperture of size $a = b = 93$ mm, and two for 17-26 GHz band with same parameters of 42 and 82 mm respectively).

3. Using Modified Horns

Studying alternative geometry horns as probes showed that some of their properties, essential for wide-band testing, differ from that of their conventional analogues.

First, insertion reflectivity of any discontinuity obtained with an alternative geometry horn decreases non-monotonously with the distance along the probing axis (further – distance). In particular, the dependence suffers oscillations with period of 1/2 average wavelength (Fig. 2), taking place as (mainly) in the near-field, so (insignificantly) in the far-field region. Maximum amplitude of oscillations depends on own value of discontinuity's reflectivity, so their nature may be supposed to be an interaction of reflecting surface with aperture of the horn, which influences the EM field distribution in the system probe-structure under the test. Thus the system should be considered (especially for near-field measurements) as the whole. For example, when finding out dielectric constant for single layer structure by calculating the ratio of insertion reflectivity of the structure and that of metal surface, correct result may be obtained only if oscillations' "spatial phases" for both surfaces' reflectivities are equal.

It must be said that for usual horns and even open-ended waveguide probes the dependency $r(z)$ has similar oscillations at very low amplitude. They can hardly be detected on the noise background and are anyway incomparable with common levels of informative signals.

Second, inter-influence of the probe and structure under the test leads to strong non-linear dependency of ratio of insertion reflectivities, corresponding to cross-correlation with signals of aperture and throat of the horn (for conventional horns it is linear at least in whole far-field and usually in the most part of the near field region, see Fig. 3). At farther distances the ratio stabilises at considerably low level (typically 0.12-0.14). Thus modifying a horn reduces aperture-referenced reflectivity by 2-3 times. Phase difference and distance between mentioned insertion reflectivity peaks are also constant, so estimating parameters of multi-layered structures having electric lengths equal to or greater than that of the horn used

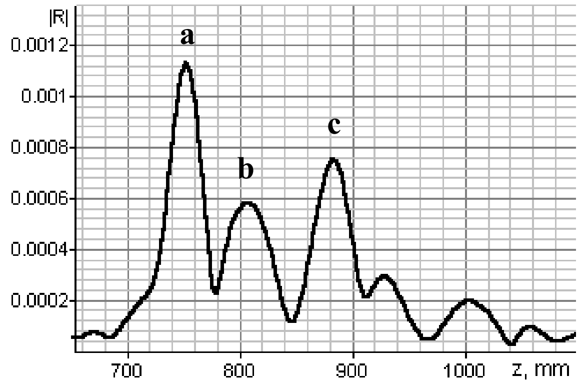

Fig. 5. *Fragment of raw echoing characteristic of two-layer organic glass: a – layer 1 front surface signal, c – layer 2 rear surface signal, b – signal of thin gap due to loose contact between layers*

as probe becomes possible, especially in combination with special mathematical filter deleting aperture constituent of structure's reflectivity characteristic (high quality of filtering is possible only at low and constant aperture-throat reflectivity ratios).

Finally, some words may be said about locality of testing. Locality is the characteristic that shows minimal distance (across the probe axis) between two discontinuities, which allows their clear discrimination. Up to the present this question could not be completely solved due to enormous amount of measurements in the scanning mode, needed to learn how reflectivity dependency, measured along the cross axis, and thus the locality, changes along the probe axis. Now it is observed that locality is a linear direct ratio dependency from the distance along probe axis tending to a zero at aperture, though near the aperture it takes a super-linear character, taking at aperture the value of half its size (see Fig. 4). Linear behaviour may be explained by existence of concrete directional diagram, which at considerably large distances does not depend on structure under test, so there is certain sector, within which the reflectivity changes between its maximum and half the maximum values. Angle 2φ, determining size of the sector, binds the locality (L) with distance (d) to the discontinuity: $L = d \sin\varphi$. For example, the horn used for studying the locality has sector width $2\varphi = 14.8^\circ$, so $L = 0.129\ d$, or $L = 0.134\ z$, where z is the distance along probe axis.

Next, the non-linear locality dependency near the aperture is due to non-zero size of the aperture, so the locality value anyway cannot be lower than half the size of the aperture.

As for resolution, or minimal size of discontinuity, which can be discovered by measurements within certain frequency range, it is, in general, not restricted by anything save sensitivity of measurement system and other like factors, but strongly depends on its spatial orientation and electric properties. For example, testing in 17-26 GHz band allows sure detecting cavities in the dielectric structures having size of about 0.5 mm (see Fig. 5 for example) along the probe axis (average wavelength makes about 15 mm). Existing measurement system allows determining position of a small local discontinuity with error less than 20 % average wavelength in all directions (see Fig. 6 for example).

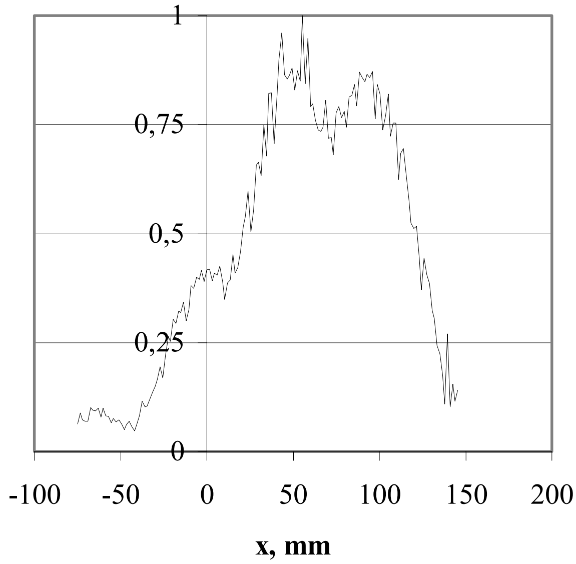

Fig. 6. *Normalized reflection signal of a defect (small metal plate) within dielectric layer moving across the probe axis.* $x = 0$ *corresponds to edge of the dielectric crossing the probe axis*

4. Conclusion

Described properties of modified horn antennas allow recommending their use in relatively remote part of far-field region for measuring echoing characteristics of thick multi-layered dielectric structures and estimating their parameters, such as dielectric constants and widths provided that remaining minor aperture reflection constituent is removed by additional digital filtering. Using modified antennas for measurements in the near-field and adjacent part of the far-field region is undesirable because of high nonlinearity of probe-structure system's parameters: usual horns with or without (for thin structures) additional filtering or the open-ended waveguide (for the shortest distances) should be used instead.

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ИСПОЛЬЗОВАНИЕ РУПОРНЫХ АНТЕНН С АЛЬТЕРНАТИВНОЙ ГЕОМЕТРИЕЙ АПЕРТУРЫ ДЛЯ ШИРОКОПОЛОСНЫХ МНОГОЧАСТОТНЫХ ИЗМЕРЕНИЙ

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Применение рупорных антенн для неразрушающего контроля посредством измерения многочастотных характеристик отражения имеет ряд преимуществ по сравнению с простыми антеннами (такими как открытый конец волновода), а именно: более высокий коэффициент усиления и более узкие характеристики направленности. Однако, наличие двух стандартных неоднородностей приводит к многократным переотражениям и препятствует использованию этих антенн. Основное решение состоит в выделении отдельных характеристик отражения либо путем математической обработки результатов измерений, либо за счет значительного снижения уровня отражений от одной из стандартных неоднородностей изменяя геометрию этой неоднородности, что и является предметом исследования в настоящей статье.

ЗАСТОСУВАННЯ РУПОРНИХ АНТЕН З АЛЬТЕРНАТИВНОЮ ГЕОМЕТРІЄЮ АПЕРТУРИ ДЛЯ ШИРОКОСМУГОВИХ БАГАТОЧАСТОТНИХ ВИМІРЮВАНЬ

О.О. Дробахін, Є.В. Кондратьєв

Застосування рупорних антен для неруйнівного контролю за допомогою вимірювання багаточастотних характеристик відбиття має низку переваг у порівнянні з простими антенами (такими як відкритий кінець хвилеводу), зокрема: вищий коефіцієнт підсилення та вужчі характеристики спрямованості. Однак, наявність двох стандартних неоднорідностей приводить до багаторазового перевідбиття і перешкоджає застосуванню цих антен. Основне рішення полягає у виділенні окремих характеристик відбиття або за допомогою математичної обробки результатів вимірювань, або за рахунок значного зниження рівня відбиття від однієї зі стандартних неоднорідностей змінюючи геометрію цієї неоднорідності, що і є предметом дослідження у даній статті.