The arrays of GaAs antenna-coupled Schottky barrier diodes in millimeter wave imaging systems.

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Abstract.

Microstrip arrays of GaAs antenna-coupled Schottky barrier diodes for millimeter wave imaging systems were developed. A method for estimating the imaging properties of such arrays in videosystems with Fuko test objects and arrangement for forming the monochromatic spatial incoherent radiation is suggested. Circular asymmetry of modulation transfer function of the receiving elements was experimentally revealed. It seems to be inherent to the majority of such kind of the arrays. This asymmetry is ought to be taken into account during the development of imaging systems on the basis of these arrays.

Introduction.

The possibility of using the antenna-coupled nonlinear element arrays in videosystems for imaging the spatially distributed electromagnetic fields in millimeter wavelength range in real time (an analog of TV camera in the visible and near-infrared regions) is under active study nowadays. The application field for such videosystems resulting from peculiarities of this spectrum range is wide enough to make such investigations to be significant. In particular, it becomes possible to obtain the images of the objects covered with media opaque to visible spectral range (including media introducing the aberrating distortions) when spatial incoherent millimeter wave radiation is used [1]. Schottky barrier diodes, thin metal-metaloxide-metal film diodes, resonant tunneling diodes, SIS junctions or other detecting elements may be used as nonlinear elements [2-5]. It allows to speak about basically new class of imaging arrays with the properties being determined by the type of the used antenna and characteristics of nonlinear elements and the substrates.

In this paper we propose to use a modulation transfer function (MTF) of video detecting arrays as a criterion of adequate imaging of field spatial distribution (MTF is usually used for testing imaging systems operating in visible and near-infrared wave range [6]). Such an approach seems to be promising because the arrays ought to operate in the image plane of the imaging systems under the conditions of arbitrary spatial field distribution when the usually used radiation patterns of the antenna become deficient for adequate array assessing. Moreover, the evident spatial (including planar) shape anisotropy inherent in practically all antenna configurations leads to inhomogeneous response from antenna-coupled nonlinear elements being dependent on spatial frequency vector components in spectrum representation of the final image obtained by the array. The crevasses or boostings in MTF of receiving arrays predetermine the emphasizing or suppressing of the certain details in the image up to their distortion resulting in impossibility to identify the observed objects. This dependence being absent in optical receivers is obviously inherent in the discussed class of the receivers.

Design and characteristics.

The log-periodic antenna (Fig.1) was chosen as a basic antenna configuration. The geometry of this antenna is characterized by nondimensional period $R_n / R_{n+1} = 0.5$, form coefficient $R_n / r_n = \sqrt{2}$, where R_n and r_n are the outer and inner radii of n-tooth, maximum R_4 value 3.5 mm, α and β angles 60° and 30°, respectively [7]. GaAs Schottky barrier diodes were found to be the most suitable for antenna-coupled video detecting elements. The parameters of used GaAs diodes (ideality factor <1.2, series resistance <8 Ohm, shunt capacitance <25 fF, junction capacitance <7 fF) allowed their optimum operation in 90÷200 GHz range. GaAs diode application is also preferable because it becomes possible to change nonlinear element impedance by varying the bias current. The thickness of polytetrafluorethylene-based substrate was chosen to be 125 μm in order to sup-

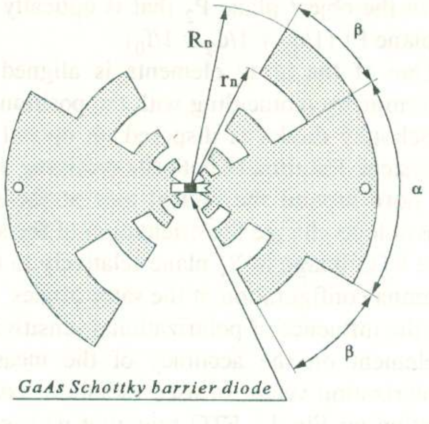

Fig.1. Geometry of antenna-coupled receiving element.

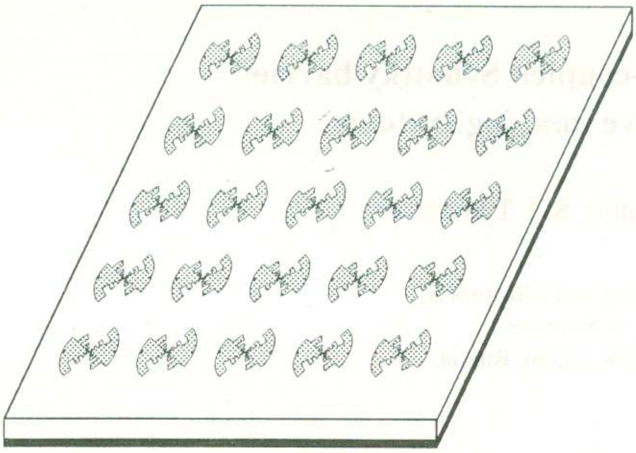

Fig.2. View of microstrip array

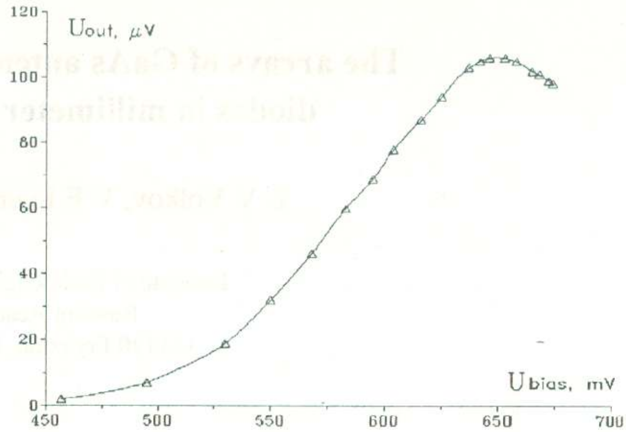

Fig.3. Dependence of sensitivity versus bias voltage.

press the surface waves in the substrate [8].

View of two-dimensional microstrip array (5×5) of GaAs antenna-coupled Schottky barrier diodes is shown on Fig. 2. Spacings between neighboring elements in array were 10 mm. The experimental dependence of the response from the array elements upon the applied bias voltage on GaAs diode is demonstrated on Fig.3. The maximum sensitivity in this case was near 300 mV/(mW/cm^2), that corresponds to results obtained in [9].

It is worth mentioned that the such design of the array has shown a good performance at image formation in real time [10]. Moreover, this design allows also to develop the arrays with various required number of receiving elements.

Imaging properties.

A. Experimental set-up.

The scheme of the experimental set-up for detecting the millimeter wave MFT peculiarities is demonstrated on Fig.4. The array of receiving elements is disposed in the image plane P_1 (Fig. 4 shows one of the array elements in enlarged scale). Polystyrene lens O_1 with diameter D=37cm and focus length f_0=50cm is used to form images. Fuko test objects (FTO) with different periods of spatial structure d_0 is disposed in the object plane P_2 that is optically conjunctive with the plane P1 ($1/d_1 + 1/d_2 = 1/f_0$).

One of the array elements is aligned so that its center of symmetry (coinciding with the position of antenna-coupled Schottky diode) is disposed on optical axis of the imaging system. Rotation of both the receiving array and the radiation horn around the optical axis at the same angles makes possible to change the orientation of the spatial structure of the FTO image in P_1 plane relatively to the structure of the antenna configuration at the same angles. It allows to eliminate the influence of polarizational sensitivity of the receiving element on the accuracy of the measuring data. Linear polarization vector of used radiation coincides with L-L' direction on Fig 4. FTO scanning with small step in the object plane under computer control allows to receive the structure of the field distributions of its images with sufficiently high accuracy.

A quasithermal concept of forming spatial incoherent radiation in P_2 plane was applied in this set-up. The rotating random phase mask usually employed for the same purpose in optical spectral range was adopted for this goal [11] (on Fig. 4 the random phase mask is shown as a dashed line box). This mask is characterized by the dimension of phase inhomogeneities near 1.5 mm, modulation depth of the phase more than 2π and correlation time of the field in P_2 plane near 10^{-5} s with the mask being rotating.

Being under computer control the device of the electronic switching and amplification of the signals from the array elements contained the networks of the synchronous detecting and integral weighting of the signals with a characteristic time duration of the order 10^{-2} s. Thus the effective temporal averaging of the statistically stationary signals from array elements was performed to eliminate of coherent noises in the imaging system. The practically monochromatic radiation (λ=3,2 mm) of backward-wave tube was used as radiation source. Additional lens O_2 was used to form the plane wave front in the plane of the location of rotating random phase mask. Metal parts of set-up and FTO were covered by absorber in order to minimize the scattering effects.

B. Results.

MTF of the total imaging system $\Psi_S(\bar{\chi})$ may be determined as FTO image contrast versus spatial frequency vector $\bar{\chi}=\chi_1\bar{i}+\chi_2\bar{j}$ normalized by the contrast value at $\bar{\chi}=0$ [6], where $\chi_1=(1/d_0)\cos\varphi$, $\chi_2=(1/d_0)\sin\varphi$, $(d_0)^2=(\chi_1)^{-2}+(\chi_2)^{-2}$, d_0 is a period of the spatial structure of FTO, φ is an angle between the direction of FTO scanning and highlighted L-L' orientation of the antenna (see Fig. 4). Cross-sections of MTF for imaging system with

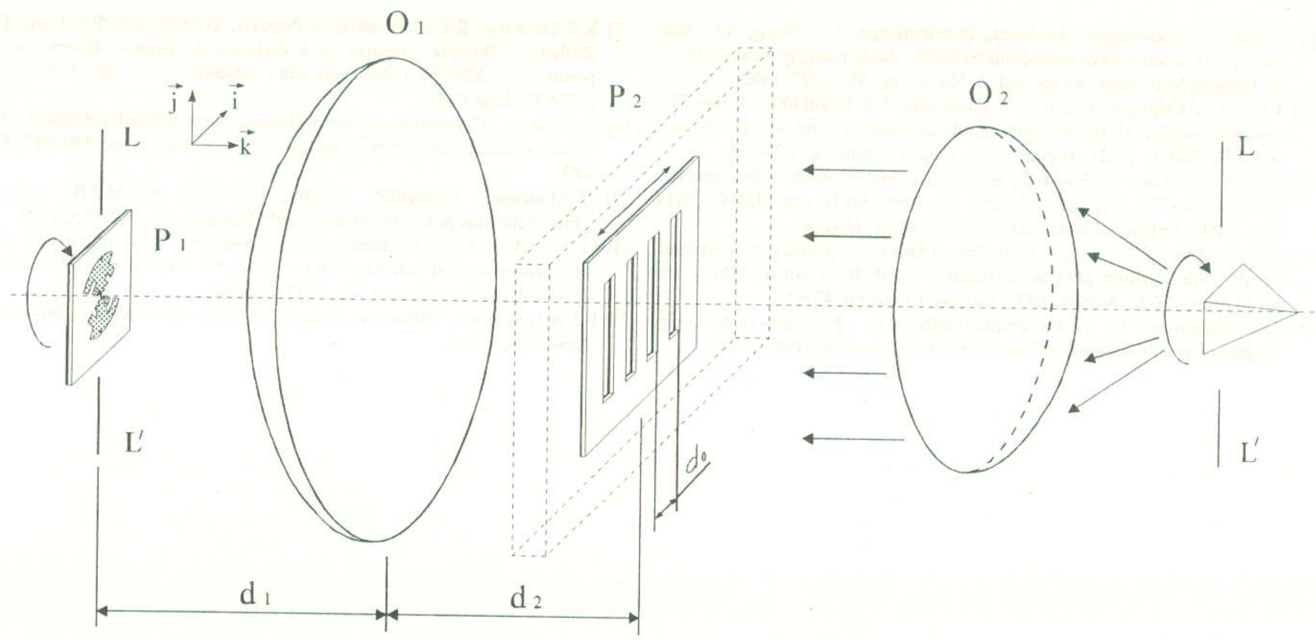

Fig.4. Scheme of the experimental set-up.

the influence of both the receiving elements and used objective lens for characteristic angles $\varphi = 0°$, $45°$ and $90°$ are shown on Fig. 5 by small symbols ($|\vec{\chi}| = \chi = 1/d_0$).

Since MTF of the objective lens $\Psi_L(\vec{\chi})$ has a circular symmetry any deviation from it in $\Psi_S(\vec{\chi})$ is determined by the peculiarities of the receiving element operating. MTF of the receiving element $\Psi_R(\vec{\chi})$ being characterized by the contrast response from the receiver at spatial field distribution formed by objective lens in P_1 plane can be estimated from the following relation [6]

$$\Psi_R(\vec{\chi}) = \Psi_S(\vec{\chi}) / \Psi_L(|\vec{\chi}|).$$

MTF of the objective lens (taking into account the small aberrating distortion of the lens with the circular shape of the pupil) can be written in form:

$$\Psi_L(|\vec{\chi}|) = \frac{2}{\pi}\left[\arccos(|\vec{\chi}|/\chi_0) - \{|\vec{\chi}|/\chi_0\}\sqrt{1-\{|\vec{\chi}|/\chi_0\}^2}\right],$$

where $\chi_0 = D/(\lambda d_1)$.

Corresponding $\Psi_R(\vec{\chi})$ dependencies are shown at the Fig. 5 by the same but larger symbols. The certain $\Psi_R(\vec{\chi})$ asymmetry is easily noticed from this Fig. 5. This characteristic feature resulting from consequence of principle of the GaAs antenna-coupled diode operation has not been inherent to optical and near-infrared multielement photodetectors. The existence of these operating peculiarities of the developed arrays causes the necessity to take into account their influence on the characteristic of the millimeter wave imaging systems. In particular, the possibility appears to highlight selectively the characteristic details in images obtained by videosystems.

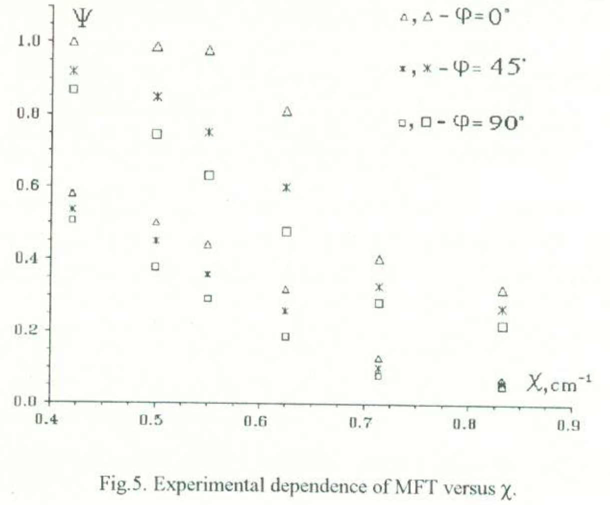

Fig.5. Experimental dependence of MFT versus χ.

Conclusion.

Microstrip arrays of GaAs antenna-coupled Schottky barrier diodes for millimeter wave imaging systems capable to operate in real time with sufficiently high sensitivity were developed. These arrays in contract to optical and near-infrared photodetectors can be characterized by asymmetric modulation transfer function. This asymmetry of modulation transfer function is ought to be taken into account at designing of configuration for such type arrays in order to reduce the caused distortions and to obtain the images with required quality for reliable identification of observed objects.

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