Patch antenna for nonlinear radar

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Abstract. The design of a dual-band patch antenna for a nonlinear radar operating at combinational frequencies has been developed. The antenna has a rectangular emitter surrounded by dielectric layers over a metal screen. The emitter has a U-shaped slot. The results of simulation and measurements of the antenna sample parameters are presented. The antenna is matched with the feeder at the frequencies near 1.3 and 1.6 GHz, and in the range beyond these frequencies the antenna operates as a notch-filter. The antenna has a unidirectional pattern. The radiation maximum is directed perpendicular to the plane of the antenna.

1. Introduction

Creation of a multifunctional security system designed to search for and identify dangerous objects at the entrance to the guarded premises implies the presence of sensors and technical means that determine not only the presence of metal objects hidden under the visitor's clothes, but also radio electronic devices - mobile phones, radio fuses, transmitters, and miniature video cameras [1, 2]. To detect and identify objects containing nonlinear electrical contacts, such as metal-to-metal, semiconductor-to-metal or semiconductor-to-semiconductor, nonlinear radar is used. The radar of this type allows determining the position of a nonlinear element in a served space [3].

The operation of most nonlinear radar is based on the reception of harmonics of a power sounding signal. In contrast, the concept of a parametric nonlinear radar means measuring the reflection from a nonlinear object under the influence of an additional electromagnetic effect. A common example is a two-frequency radar [4] containing two sources that generate signals with close frequencies \( f_1 \) and \( f_2 \), and a receiver recording signals at combinational frequencies that do not coincide with the harmonics of the frequencies \( f_1 \) and \( f_2 \). Nonlinearities of the second and third order correspond to the frequency \( f_3 = 2f_1 + f_2 \) and \( f_4 = 3f_2 - f_1 \), respectively. Levels of the signal at these frequencies and their ratio allow determining the type of a nonlinear element. The response of the nonlinear circuit at combinational frequencies is weak, so one should choose the frequencies \( f_1 \) and \( f_2 \), in order that the existing on-air signals in the urban area would not interfere to record the response. When \( f_1 = 500 \) MHz and \( f_2 = 600 \) MHz, the values of the combinational frequencies are \( f_3 = 1.3 \) GHz and \( f_4 = 1.6 \) GHz, respectively, and they are in the frequency ranges which are relatively free from high-power broadcast or communication signals.

In parametric nonlinear radar, an important part is the receiving antenna. The antenna must have frequency-selective characteristics in order to allocate the combinational frequencies and to be a blocking filter for the frequencies \( f_1 \) and \( f_2 \), as well as to have linear polarization of the radiation. The most suitable type of antennas for this task is a two-frequency patch antenna, the prototype of which is presented in [5]. Narrowband resonance matching near the frequencies \( f_3 \) and \( f_4 \) is achieved thanks to a
special cutout in the plate of the emitter. When placing the receiving antenna of the radar inside the housing of a multifunctional security system with plastic walls, it is necessary to take into account and minimize the effect of nearby dielectric parts and fastening elements on the operation of the receiving antenna.

2. Antenna design
The developed antenna consists of a rectangular plate of foiled fiberglass located on a 5 mm thick substrate of Plexiglas (Polymethyl methacrylate) with a dielectric constant $\varepsilon = 2.3$ over a flat metal base (Figure 1). On the top of the radiator there is a 2 mm thick plate of Plexiglas and a housing wall made of 22 mm thick hollow ABS-plastic.

![Antenna model with a set of dielectric layers](image)

**Figure 1.** Antenna model with a set of dielectric layers

An emitter with U-shaped slot (Figure 2) is made by photolithography. The length of the outer edges of emitter determines the resonance at the frequency $f_3$. The size and location of the U-shaped slot determines the resonance at the frequency $f_4$. The plate of the emitter is connected to the coaxial connector through a strip line bent as a metal-strip meander (meander line) [6]. Such inclusion allows changing the share of the energy supplied to the area bounded by the U-slot and control the antenna matching with the feeder by changing the capacitance connection of the meander line with the U-slot.

![Top view of the patch emitter](image)

**Figure 2.** Top view of the patch emitter

3. Simulation results
The results of calculating the module of the reflection coefficient $|S_{11}|$ from the antenna input are shown in Figure 3. Near the specified resonant frequencies $f_3 = 1.3 \text{ GHz}$ and $f_4 = 1.6 \text{ GHz}$, the antenna
is well-matched with a 50-Ohm feeder. The matching band by the level of -10 dB was 50 and 70 MHz in close proximity to \(f_3\) and \(f_4\), respectively. At the 100 MHz offset from \(f_3\) and \(f_4\), the antenna and feeder are strongly mismatched. At this offset the reflected power is not less than 60% of incident power. At the frequencies \(f_3\) and \(f_4\) the value \(|S_{11}|\) of the developed antenna is no higher than -0.25 dB. Thus, at the frequencies below 1 GHz, the antenna performs the function of a bandpass filter. The measurement results of \(|S_{11}|\) of the manufactured antenna sample are shown at the Figure 3. In the measurements, a compact single-port network analyzer Caban R140 (produced by "Planar" Co., Ltd., Russia) was used. The values of the resonance frequencies of the antenna \(f_3\) and \(f_4\) coincide with the preset ones for the following antenna sizes: \(W = 63.5, L = 50, H = 22.5, D = 16\) mm.

![Figure 3](image-url)

**Figure 3.** Modulus of the coefficient of reflection from the antenna input:

1 – calculation, 2 – measurements

It is assumed that the antenna of nonlinear radar will be mounted inside the wall of archway metal detector. The walls of such a metal detector, as a rule, are made of vertical panels of ABS-resin with internal voids, and the outside is laminated with a decorative film. The radar antenna system under development will be mounted in the inner part of the wall, through which electromagnetic radiation will pass. To study the influence of the plastic panels of archway detector frame on the characteristics of the antenna system, a simulation was carried out with different values of the dielectric permittivity \(\varepsilon_c\) of the panel material. The results of calculating \(|S_{11}|\) from the antenna input of the antenna sample are shown in Figure 4. It was revealed that increase of \(\varepsilon_c\) results in the shifting of resonant frequencies to the low-frequency region. The dual-resonance mode is maintained when changing \(\varepsilon_c\) from 1.1 to 4, the value of \(|S_{11}|\) at the frequencies \(f_3\) and \(f_4\) being no higher than -10 dB.

![Figure 4](image-url)

**Figure 4.** Influence of the housing wall material \(\varepsilon_c\) on the coefficient of reflection from the antenna input
4. Results of measurements of the antenna characteristics

Measurement of the patterns of the developed antenna was carried out in an anechoic chamber. An internal view of experimental setup is shown on Figure 5. The single-port vector network analyzer Caban R140 (Planar LLC, Russia) was used as a generator. Its output was connected to the investigated antenna placed on a rotating dielectric platform. Measuring the power level at the output of the auxiliary receiving antenna was performed using a compact power-meter M3M-18 (Micran Ltd., Russia).

The patterns of the developed antenna measured at a frequency of 1.3 GHz in two planes are shown in Figure 6. The measured patterns are shown in the same Figure. The radiation of the antenna is linearly polarized. The electric field vector is parallel to the vertical edges of the U-shaped slot (Figure 2). In the E-plane, the width of the measured pattern by half power (Δθ₀.₅) is equal to 76.5° which is 4° more than in the calculation. The deviation of the measured pattern maximum from the direction which is perpendicular to the ground plate plane of the antenna (θ₀) is 5°. In the H-plane, Δθ₀.₅ = 71.5° and 74.5° for the measured and calculated patterns, respectively, and the deviation from θ₀ is not higher than 2°.

The measured and calculated antenna patterns at 1.6 GHz are also shown in Figure 6. The antenna polarization has not changed. In the E-plane, Δθ₀.₅ = 75.5° for the measured pattern which is 4.5° more than in the calculation. The deviation of the measured pattern maximum from θ₀ is 5°. In the H-plane Δθ₀.₅ equals to 80° and 83° for the measured and estimated patterns, respectively. The radiation maximum coincides with θ₀. The difference between the calculated and measured patterns in the E-plane can be caused by the fact that the induced currents on the edges of the ground plate are asymmetric with respect to the antenna center resulting in deviation of the pattern maximum. The difference in the antenna pattern bottoms in the rear half-space is obviously affected by the presence of a metal housing of the single-port network analyzer connected directly to the antenna and a power cable, which were not taken into account in the simulation.

Figure 5. Measurement setup for antenna pattern investigations:
1 – power source; 2 – antenna under test; 3 – rotating support
5. Conclusion
Numerical simulation and measurement of the characteristics of a two-frequency patch antenna designed to be used in a nonlinear radar operating at combinational frequencies were carried out. The optimal geometry of the antenna electrodes with a U-shaped slot in the rectangular emitter was found, which provides narrow-band matching of the antenna with the feeder at the frequencies of 1.3 and 1.6 GHz. At the frequencies below 1 GHz, the antenna strongly mismatched with feeder to prevent receiving the sounding signals at frequencies 0.5 and 0.6 GHz. The radiation of the antenna is linearly polarized. Maximum radiation at the frequencies 1.3 and 1.6 GHz is directed perpendicular to the plane of the radiator plate.

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