Plasma semiconductor antenna

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Abstract. The purposes of this work was to study the possibility of using photoconductive semiconductor antenna based on Ge or GaAs for receiving information signals in the frequency communications and satellite navigation bands and to study a scattering parameter S11 – a return loss (a reflection coefficient) of configurable loop antennas with laser-plasma control based on semiconductor photoresistor. It is shown that the addition of semiconductor photoresistor element in the loop antenna makes it possible to significantly expand its functionality and control its characteristics using an external laser source.

1. Introduction

It is known that the use of plasma antennas, as well as the use of materials with variable electromagnetic characteristics can significantly improve the functional properties of radio and telecommunication devices [1-4]. Usually, gas-discharge plasma obtained during breakdown of gas gaps under reduced pressure was used as plasma antennas [1-3]. An alternative approach was proposed in [5,6], where the efficiency of using a laser plasma semiconductor antenna for transmitting microwave signals in the spectral range of 6-7 GHz was shown. Photoconductive plasma was formed in a transmitting antenna under irradiation of Ge with an IR laser diode or a fiber laser [6,7]. The purpose of this work was to study the possibility of using such a photoconductive semiconductor antenna based on Ge and GaAs for receiving information signals in the frequency band used in cellular communications and satellite navigation.

Integration into the outer contour of the loop antenna of the element we offer: photoresistance + laser diode will allow reproducible changes in antenna characteristics. The purpose of this work was to verify the effectiveness of this approach for matching loop antennas with a radio path.

2. Experimental Setup

2.1. Receiving plasma semiconductor antenna

The experiments were carried out on the setup shown in Fig. 1. As a radio signal receiver, we used the Satellite Multi-functional Handheld Meter Twinkler SF-620S. Radiation from a laser or LED source of visible light - I was directed to a thin semiconductor plate; as a result, a rectangular illumination region was formed on the semiconductor (plates 5–8 mm wide, 25–45 mm long, 0.5–0.8 µm thick were used).
Semiconductor plate - 4 through ohmic contact - 5 was soldered to the connector of the coaxial cable, which was connected to the radio signal receiver. The main research was carried out when Ge single crystals or GaAs single-crystal plates were used as a semiconductor antenna. To obtain a semiconductor plasma in Ge, LED arrays were used, the total power of which could reach 3 W. In experiments with GaAs plates, we used a blue diode laser emitting at $\lambda \approx 450$ nm with a maximum power of up to 2.5 W. The semiconductor illumination intensity was controlled by varying the supply current of the diode emitters. The experimental technique was as follows: with the laser turned off and the LED emitter, the amplitude and width of the spectrum of the received radio signals were recorded on the radio signal receiver, when the semiconductor plate served as the receiving antenna. Then a comparative analysis of the signals at the receiver, obtained under the conditions of irradiation of the semiconductor with visible radiation and without irradiation, was carried out. The change in the temperature of the semiconductor antenna during laser exposure was monitored using a Seek Thermal imaging camera.

**Figure 1.** Schematic of the experimental setup: 1 - radiation source; 2 - radiation beam formation system; 3 - semiconductor plate; 4 - ohmic contact on a semiconductor plate; 5 - radiation receiver with spectrum analyzer.

### 2.2. Configurable loop antenna with laser-plasma control

On the experimental stand was made the research of the effect of the radiation intensity of the laser module with the MLG5506 photoresistor on "rhombic" and "circular" type of loop antennas (Fig. 2).

**Figure 2.** Photoresistors in the form of "rhombic" and "circular" loop antennas. Structural image of a conventional loop dipole

In the circuit shown in Fig. 1, the SMA connector, to which is soldered the loop antenna with the MLG5506 photoresistor, is connected by a coaxial cable to the 50-ohm input of the complex transmission and reflection coefficient meter "OBZOR-304/1" (Fig. 2).
3. Results and discussion

3.1. Receiving plasma semiconductor antenna
In fig. 4 shows photographs of the screen of the twinker SF-620S device, recorded when a rectangular plate with dimensions 5 mm x 45 mm and thickness 0.8 mm from a single crystal of its own Ge (GMO brand, resistivity 47 Ohm-cm) was not irradiated (Fig. 4a) and when the Ge plate was irradiated with an array of LEDs with a irradiation density of 0.2 W/cm² (Fig. 4b). Fig. 2, it can be seen that, upon irradiation of a single-crystal Ge plate, the signal reception efficiency increased significantly. Thus, the electron-hole plasma generated in the illumination region increases the conductivity of the semiconductor wafer, and the reception efficiency of such a plasma antenna becomes better. We have carried out a study of the effectiveness of radio signal reception depending on the illumination intensity. It was found that with an increase in the irradiation density to 1 W/cm², the resistance of the Ge and GaAs antenna decreased monotonically, but the amplitude of the received signal depended on the irradiation density in a nonlinear manner. The maximum increase in the sensitivity to the reception of a radio signal was achieved at relatively low levels of irradiation of the semiconductor, while the frequency response of the semiconductor plasma antenna greatly changed from the illumination intensity.

Figure 4. Photographs of the signal obtained at the receiver: a) the Ge plate was not irradiated; b) the Ge plate was illuminated by an LED matrix.
3.2. Configurable loop antenna with laser-plasma control

As a result of the measurements, the dependences of a scattering parameter S11 – input port voltage complex reflection coefficient (return loss) presented on the graphs, on the frequency were obtained for the "rhombic" loop antenna made of the MLG5506 photoresistor (Fig. 5). The blue curve represents the S11 when the photoresistor is exposed to laser radiation with a power of 0.5 W, and the red curve is without laser action.

![Figure 5](image)

**Figure 5.** Dependence of S11 from frequency for a "rhombic" loop antenna when exposed to laser radiation with a power of 0.5 W (blue line) and without it (red line).

From the graphs shown in Fig. 5, it can be seen that the blue curve in terms of the S11 value does not exceed -10 dB and has a wider range compared to the S11 values in the red curve. This confirms that good controllability of the impedance of the investigated "rhombic" loop antenna with the MLG5506 photoresistor is achieved when exposed to laser radiation. Thus, the matching of the "rhombic" loop antenna with the input / output of the radio path (50 Ohm) is achieved at the S11 threshold of no more than 2 in the frequency range 512-642 MHz.

For a "circular" loop antenna made of a photoresistor MLG5506, when exposed to laser radiation with a power of 0.5 W, the frequency dependences of the complex reflection coefficient S11, presented on the graphs (Fig. 6), were obtained. The blue curve represents the S11 with a 0.5 W laser, and the red curve without the laser.

![Figure 6](image)

**Figure 6.** Dependence of S11 from frequency for a "circular" loop antenna when exposed to laser radiation with a power of 0.5 W (blue line) and without it (red line).
The obtained dependences demonstrate the appearance of S11 values not exceeding -5dB and the frequency range 585-711 MHz.

4. Summary
It was found that the nonlinear behavior of the amplitude of the received signal from the irradiation density is due to the matching of the antenna with the receiving path. The data obtained make it possible to assert that the use of semiconductor elements in the antenna is capable of changing the reflection coefficient and matching the impedance with the input or output impedance of radio paths. This allows using fast light sources (~100 μs) in a wide range to control the sensitivity of radio receivers.

As a result of studies of loop antennas, into the contour of which a semiconductor element was integrated in the form of a commercially available photoresistor, it was shown that the presence of a semiconductor element allows using a laser to effectively control the matching of the antenna contour with the radio path. An experimental stand was created and research methods were developed, which made it possible to study the effect of laser radiation power on the reflection coefficient S11 of photoresistors and loop antennas with a semiconductor element integrated into their circuit. The research results show that the use of semiconductor materials and the formation of a plasma of nonequilibrium carriers in them with the help of a laser makes it possible to change the reflection coefficient and match the impedance with the input or output impedance of radio paths. Comparison of different configurations of plasma antennas is carried out, it is found that the frequency band of the "circular " loop antenna, taking into account the tuning in conditions with the same boundaries of the laser radiation power, will cover a larger frequency range than the frequency band of the "rhombic" antenna.

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