Low gain antenna beam forming using metamaterial

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Abstract. The work considers the possibility of using metamaterials to design of low-gain antennas with improved parameters of antenna pattern. It is shown that additional elements of the antenna, made of metamaterial, can be considered as antenna array of parasitic emitters, forming antenna pattern of the required shape. It is shown that the use of metamaterial inserts allows to optimize irradiators for reflector and lens antennas.

1. Introduction
A number of technical applications use low gain antenna with the special-shape antenna pattern. Examples include irradiators for reflector or lens antennas, as well as sensor antennas as part of near-field measurement equipment (figure 1).

Figure 1. Low-gain antennas and required antenna patterns a) and b) - irradiators for classic reflector and offset antennas, c) - antenna sensor near-field planar scanner.
A number of techniques was developed for these applications, for example, multi-mode or wide-angle of drawbacks. In recent years, there has been an active interest in exploring the possibility of using negatively dielectric (ENG) and/or magnetic (DNG, MNG) permittivity for the technique of antennas. The work considers an alternative option for antenna design, including antenna irradiators, using material with negative magnetic permittivity.

2. The principle of a low-gain antenna using metamaterial

The antenna of this type is the simplest radiator, for example in the form of an open end of a rectangular wave guide, with an insert or shell made of ENG or MNG metamaterial.

![Antenna model](image)

Figure 2. Antenna model.

This insert (shell) can be interpreted as a system of passive emitters. The antenna radiation field is the result of interference between fields emitted by the primary radiator \( r \) and re-emitted by the passive elements system. Thus, the presence of insertion or shell, made from the metamaterial creates the necessary prerequisites for the formation of the antenna pattern of the required shape. The representation of the block from metamaterial by a system of passive emitters allows not only to give a qualitative explanation of the observed effects, but also in some cases to obtain their quantitative estimates.

3. Assess the ability to form antenna pattern of the desired shape

It is appropriate to assess the possibility of forming the required focus chart in two stages. The first stage considers a simplified model in the form of an antenna array (figure 2). The initial form of the metamaterial area is selected for intuitive or other considerations. Antenna pattern of the system can be presented as:

\[
F(r_0) = \sum_N g_n(r_0) I_n e^{j k(r_n r_0)}
\]

where \( I_n \), \( r_n \) and \( g_n(r_0) \) are complex amplitude of the electromagnetic radiated by n-elements, their coordinates and antenna elements pattern, \( r_0 \) - direction to the observation point.

For preliminary estimates, the value of the module \( I_n \) calculated according to known ratios for the antenna elements mutual coupling, the phase - as \( 2 \pi r_n / \lambda + \Delta \psi \), where \( r_n \) the - distance to n-th element, additional phase shift \( \Delta \psi \) is accepted equal to \( \pm \pi / 2 \) for ENG and MNG material respectively.

Next, you select the type of material and the coordinates of the emitters by varying these parameters to minimize the deviation of the antenna pattern from the given. The resulting solution is the starting formula for later optimization.

The second step is to refine the resulting solution using electrodynamics modeling using software tools such as HFSS or CST MWS.
4. Illustration
The illustration is the formation of antenna pattern of the axis symmetrical type reflector antenna irradiator. Here are the results of the calculations according to (1). The desired antenna pattern, which provides the maximum gain, is shown on figure 1 a). Figure 3 and figure 4 shows the geometry of the axis symmetrical type reflector antenna irradiator with an insert made of MNG metamaterial and its antenna pattern.

![Figure 3. Antenna model configuration.](image1)

![Figure 4. Antenna pattern.](image2)

The second example is the formation of the required antenna pattern of the offset reflector antenna irradiator in line with figure 1b. Figure 5 and figure 6 shows the geometry of the offset type reflector antenna irradiator with an insert made of MNG metamaterial and its antenna pattern.

![Figure 5. Antenna model configuration.](image3)

![Figure 6. Antenna pattern.](image4)

The second stage is an electrodynamics’ simulation of the antenna with an insert from the metamaterial. Initial for local optimization are the data obtained at the preliminary assessment. Illustrating results are shown below Figure 7 and figure 8 shows the axis symmetrical type reflector antenna irradiator with an insert made of MNG metamaterial and an antenna pattern.

![Figure 7. Reflector antenna irradiator with MNG material.](image5)

![Figure 8. Antenna pattern.](image6)
Figure 9 and figure 10 shows the axis symmetrical type reflector antenna irradiator with an insert made of ENG metamaterial and an antenna pattern.

![Figure 9](image1.png) ![Figure 10](image2.png)

**Figure 9.** Reflector antenna irradiator with ENG material. **Figure 10.** Antenna pattern.

Similar data for the offset antenna irradiator with MNG slab are shown on figure 11 and figure 12.

![Figure 11](image3.png) ![Figure 12](image4.png)

**Figure 11.** Offset antenna irradiator with MNG material. **Figure 12.** Antenna pattern.

Figure 13 and figure 14 shows the offset antenna irradiator with ENG slab and an antenna pattern.

![Figure 13](image5.png) ![Figure 14](image6.png)

**Figure 13.** Offset antenna irradiator with ENG material. **Figure 14.** Antenna pattern.
5. Conclusion
The use of metamaterials allows you to create antennas with improved properties. In particular, this approach can be used to create optimized reflector and lens antenna irradiators.

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