MUltIfunct ionAl anTeNNa device foR PrOtect ion oF RAdio communication channels of units of law enforcement forces

Abstract. Safe conduct of mass events requires from law enforcement forces to protect the units’ radio communication channels, detection and suppression of counterparty control radio channel. It also requires finding and destroying single-use interference transmitters, the presence of which is a manifestation of the aggressive intentions of the crowd. This requires means using antennas with directional properties, frequency ranges of which are determined by the established standard and mass radio communications. In general, the antenna parameters of radio systems, radio intelligence, radio monitoring, suppression are different requirements. Therefore, it is difficult to implement a universal antenna for many applications and conditions. Ideal for operating an antenna can be considered one that could predictably change the properties when adding (replacing) elements (modules), the parameters of which are known and consistent with the basic (basic) design. But serial antenna of radio electronic means is finished devices and are not always amenable to improvement. So the article discusses the possibility of using improvised antennas that have adequate models, as confirmed by numerous experiments, with the main parameters whose values can be purposefully changed: frequency range, width and shape of the directionality chart, its reflector properties, etc. An addition, software for such antennas is publicly available. Considering the functional requirements, we have analyzed the designs of antennae “Radiator over a cylindrical surface”, angular antennas and antennas "Radiator over a plane", characteristics of which at the same sizes are approximately the same and are calculated by the same formulas. The possibilities of angular antennas of the "open-book" type with different angles between reflectors have been investigated. To do this, analytical simulations of technical solutions suitable for use in radio communications of units of law enforcement forces were conducted. The efficiency of the proposed constructs was checked and their characteristics were determined. Thus, the proposed technical solutions for angular antenna devices are able to protect the radio communication channels of law enforcement units during mass events.

Keywords: law enforcement; radio communication; angular antenna; opening angle.

Introduction

When performing assigned tasks of law enforcement units (LEU) of Ukraine (especially during mass events), there is a need to protect the information of their own radio channels, detection and suppression of counterparty control radio channels and search and destruction of installed transmitter of single-use interference, the presence of which is a manifestation of the aggressive intentions of the crowd.

These tasks require radio communications using antennas with directional properties, frequency ranges of which are determined by the regular and mass radio communications that are being used. The following requirements are imposed on such antennas: small size, design and operational simplicity, masking ability, embedding into special devices or equipment, the ability to use regular radios and/or interference generators as sources of interference etc [1]. Currently, such means in LEU are practically absent. Additional restrictions also impose a special features of the conditions of units’ radio communication use: LEU usually work in campus – a limited area of constant composition and locations (student or military town, city squares, etc.); there is an urgent need to ensure the mobility and stealthiness of the use of radio communications; the use of standard directional antenna devices available in the Armed Forces is not possible in direct contact with the of counterparts.

We emphasize that the antenna parameters of radio systems, radio intelligence, radio monitoring, suppression have different requirements, so it is difficult to implement a universal antenna for many applications and conditions. In addition, during the operation of radio electronic means (REM), the requirements for the properties and values of their parameters may change (increase), but the REM serial antennas are complete devices and are not always upgradable [2, 3].

In general, the ideal antenna for operation can be considered one that could predictably change the properties when adding (replacement) elements (modules), the parameters of which are known and consistent with the basic (basic) design. Natural is also a requirement to minimize the number of elements the basic design and allowable geometric sizes. Additionally, should take into account the need for installation (mounting) antennas on vehicles or protective equipment, and low sensitivity to variations of geometrical sizes of the design and the possibility of its implementation in terms of maintenance, etc. [4].

Analysis of recent studies and publications.

Within annotated purpose appropriate to consider improvised antennas – construction (products) that meet the following functional requirements:

- the antenna has an adequate model, confirmed by numerous experiments, the software for which is in the public domain;
- basic design is simple, supplemented with variable elements to achieve the required properties and predicted values of characteristics;
- the main parameters which values can be purposefully changed are frequency range, width and
shape (single-beam and multipath) of the directionality chart (DC) and its reflector properties, etc.

From the point of functional requirements view, we will analyze the designs of antennas of type "Radiator over a cylindrical surface", angular antennas and antennas of type "Radiator over a plane", which can be considered as a limited case of an angular antenna with an opening angle of 180°, identified by patent search H01Q19/13, H01Q19/17, H01Q19/19 (the list of which is commensurate with the volume of this publication) and from literature [2, 3, 5]. In addition, the characteristics of these types of antennas of approximately the same sizes are calculated using the same formulas [2, P. 279].

In Fig. 1, a and 1, b show the appearance of the basic designs of antenna devices in accordance with a cylindrical reflector (CR) and an angular antenna (AA) [5]; marked with: 1 – reflector, 2 – radiator.

![Fig. 1 Basic antenna designs](image)

In Fig. 2 shows the appearance of constructs with CR, which are different from the base design (BD); marked with: 3 – separating screen, 4 – additional reflectors. In the table 1 gives a brief description of the constructs and the technical results obtained with the changes.

![Fig. 2 Variants of antenna constructions with CR](image)

The possibility of using radiators of different designs in the BD, which improves the frequency characteristics of antennas and broadens their scope of application, was considered in [8]. Also considered are technical solutions based on the reflector as clippings from a cylinder formed by one [9] or several [10] metal shields of the "Форт-ЦП" type. In Fig. 3 shows the appearance of AA constructs that have differences from the base structure; notations similar to those shown in Fig. 1. In the table 2 gives a brief description of the constructs and the technical results obtained with the changes.

### Table 1 – Description of constructions of antenna devices with cylindrical reflector

<table>
<thead>
<tr>
<th>Construct</th>
<th>Difference from BD Variable element and/or parameter</th>
<th>The technical result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 2-a [3]</td>
<td>Reflector height (2–4)λ. Slit width (0.3–0.7)λ.</td>
<td>Width DC_{11} = 60-180°; Width DC_{12} = 20°; simple power system</td>
</tr>
<tr>
<td>Fig. 2-b [3]</td>
<td>Separating screen Slit width (0.6–1.4)λ.</td>
<td>Width DC_{12} = 20°; Width DC_{13} = 30-60°; reduction of lateral petals</td>
</tr>
<tr>
<td>Fig. 2-c [3]</td>
<td>Additional 2 reflectors Sizes of additional reflectors</td>
<td>Increasing directional coefficient on 1-4 dB</td>
</tr>
<tr>
<td>Fig. 2-d [3]</td>
<td>The second radiator Radiators at an angle to the vertical</td>
<td>Reducing antenna transverse size by up to 30%</td>
</tr>
<tr>
<td>Fig. 1-a [6]</td>
<td>The radiator is asymmetric about the plane of symmetry; location radiator, slit width (0.6–1.4)λ.</td>
<td>Frequency-angle dependence of the DC without complicating the antenna design</td>
</tr>
</tbody>
</table>

![Fig. 3 Angular antenna constructs variants](image)

### Table 2 – Description of the constructions of angular antennas

<table>
<thead>
<tr>
<th>Construct</th>
<th>Difference from BD Variable element and/or parameter</th>
<th>The technical result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 3-a [3]</td>
<td>Separating screen</td>
<td>Reducing width DC_{12} by up to 25°</td>
</tr>
<tr>
<td>Fig. 3-a [7]</td>
<td>The corner antenna is three-dimensional; Opening angle, reflector height and radiator shape</td>
<td>Essential sizes reduction</td>
</tr>
</tbody>
</table>

Obviously, listed in table 2 constructs have not exhausted the basic design, which makes the relevance of the annotated construction of a multifunctional antenna device to protect the radio communication channels of the law enforcement units.

**Highlighting previously unsolved parts of a common problem. The goal of the work**

The purpose of the study is to provide technical solutions for angular antenna devices capable of protecting the radio channels of law enforcement units during mass events.

The objectives of the study are as follows: to conduct analytical modeling of variants of VHF / UHF angular antennas technical solutions suitable for use in law enforcement units' radio communication systems; -
to check the performance of the proposed constructs and determine their characteristics.

**Materials and methods**

Ideal for use is an antenna that can change parameters depending on the operating conditions, meet the requirements of manufacturability of the basic design, minimize the number of components and so on.

From this point of view, the possibilities of angular antennas of the "open-book" type with different angles between reflectors were investigated.

**Study results of the antennas of "open book" type.** Table 3 shows the results of the authors’ simulations of the antenna "Radiator over a plane" (opening angle 180°) for reflectors with proportional to the wavelength \( \lambda \) by sizes.

**Table 3 – Characteristics of antenna type "Radiator over a plane" variants**

<table>
<thead>
<tr>
<th>Distance S to the reflector</th>
<th>Length of the radiator</th>
<th>Width of the main petal (F), °</th>
<th>Directionality chart shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,2 ( \lambda )</td>
<td>0,46 ( \lambda )</td>
<td>77</td>
<td>1 petal</td>
</tr>
<tr>
<td>0,25 ( \lambda )</td>
<td>0,46 ( \lambda )</td>
<td>82</td>
<td>1 petal</td>
</tr>
<tr>
<td>0,3 ( \lambda )</td>
<td>0,46 ( \lambda )</td>
<td>90</td>
<td>1 petal</td>
</tr>
<tr>
<td>0,4 ( \lambda )</td>
<td>0,48 ( \lambda )</td>
<td>105</td>
<td>1 petal</td>
</tr>
<tr>
<td>0,5 ( \lambda )</td>
<td>0,48 ( \lambda )</td>
<td>-</td>
<td>2 petals</td>
</tr>
<tr>
<td>0,6 ( \lambda )</td>
<td>0,48 ( \lambda )</td>
<td>-</td>
<td>main + 2 lateral</td>
</tr>
<tr>
<td>0,7 ( \lambda )</td>
<td>0,47 ( \lambda )</td>
<td>-</td>
<td>main + 2 lateral</td>
</tr>
</tbody>
</table>

In Fig. 4 in the azimuth plane shows a diagram of one of the antenna’s variant and the directionality chart as a result of a machine experiment. Marked with: \( \alpha_1 \), \( \alpha_2 \), \( \alpha_3 \) – the corresponding angles between the reflectors; \( \text{F1, F2, F3} \) – DC for different conditions of radiators location (marked with black dots on bisectors of corresponding angles).

The calculations are made for the opening angle of the central sector \( \alpha_3 = 90° \). At a distance \( S \) of the radiator from the top of the angle by 0,25\( \lambda \), width of the DC F1 the width at the zero level is about 90°. It can be reduced by increasing \( S \) by up to 0,75\( \lambda \), which reduces the width of the main petal F2 of the directionality chart by almost half. At a value of \( S = \lambda \), a zero dip (F3) is formed in the DC.

Fig. 4 DC for \( \alpha_3 = 90° \)

Similar calculation experiments were performed for the values of angles \( \alpha_2 = 60° \) and \( \alpha_2 = 45° \). Their results are shown in Fig. 5 and 6 (similar to those shown in Fig. 4).

For the variant of the opening angle of the central sector at 60° (see Fig. 2) calculable width of the antenna’ directionality chart F4 at the zero level is about 60° and practically does not change at distance of the radiator from the top of the angle \( \alpha_3 \) on distances from 0,25\( \lambda \) to 0,5\( \lambda \). The shape of the directionality chart can be substantially altered to form a dip along the optical axis by increasing \( S \) to magnitude \( \lambda \) (F5).

If the opening angle of the central sector is equal 45° (see Fig. 3), calculable width of the antenna’ directionality chart F6 at the zero level is about 45° and practically does not change at the distance of the radiator from the top of the angle \( \alpha_3 \) at a distance from 0,25\( \lambda \) to 1,0\( \lambda \). The shape of the directionality chart can be substantially altered to form a dip along the optical axis by increasing \( S \) to magnitude, which is approximately 1,2\( \lambda \) (F7).

Thus, changing the opening angle of the antenna together with the change of radiator location allows to vary widely the DC shape of the single antenna.

**Field study results of the antennas "open book" type.** The theoretical and practical experience of the authors allow us to consider different variants of multifunctional antenna device "open book" type, which is based on the idea of constructing an angular antenna. Fig. 7 shows the appearance of a device designed to investigate the directional properties of layout such an antenna; marked with: 1 – reflector of two metal plates, 2 – ruler, 3 – slider-hinged knot, 4 – radiator, 5 – optical sight. When changing the opening angle, the ruler always remains in the bisector of the angle due to the design of the slider-hinged knot – the equilateral hinged connection of the slider with the reflector plates (Fig. 8).

Selected reflector sizes: length \( L = (1\text{-}1,5)\lambda_{\text{max}} \), height \( H = 1,2\lambda_{\text{max}} \), where \( \lambda \) – wavelength in a certain
range VHF/UHF. As the radiator used antennas regular radios Kenwood and Motorola.

The use of angular antennas with different opening angles between common adjacent screens makes it possible to create combined antennas for different functional purposes. Examples of such antennas can be an antenna made in one half plane, with three antennas having opening angles \( \alpha_1 = \alpha_2 = 60^\circ \) (see Fig. 9) or \( \alpha_1 = \alpha_2 = 45^\circ, \alpha_3 = 90^\circ \), or with four antennas having equal angles of 45°, or other variants of the structure.

![Fig. 8 Example of changing the reflector opening angle](image1)

![Fig. 9 Antenna device with equal opening angles](image2)

**Practical application of antenna device.** Studies have shown that the "open book" type antenna can operate at different frequencies or in the receiving (to determine the azimuthal angle of the direction of the signal source or radio interference) or/and in the transmitting (for radio communication or radio counteraction) modes.

In the mode of determining the azimuthal angle, two angular antennas with equal angles of aperture \( \alpha_1 \) and \( \alpha_2 \) work in the direction of the radiation source. Their symmetrical directionality charts are summed up, forming a dip in the direction of the bisector of the angle \( \alpha_2 \). Thus, the minimum of the received signal level determines the direction of the radiation source. The same effect can be achieved by changing the position of the radiator of the central antenna until point of dip in its DC.

In radio counteraction mode, a central antenna radiator is connected to the generator, the maximum of the directionality chart of which, by geometrical symmetry, is directed to a certain azimuth of the radiation source, which is set, for example, by means of an optical sight.

As the results of the experiments show, the level of the side petals of the DC of such antennas can be reduced by installing metal rectangular or circular jumpers on the reflector in certain positions.

**Comparative analysis of technical solutions.** To compare constructs based on known technical solutions, an information model of the antenna device (AD) was developed. It contains a list of characteristics (attributes) to be measured by instruments and expert method of expert method of attributing balls, as well as economic indicators that measure on an absolute scale. The economic indicators include the cost of components, the labor costs of different skill levels specialists and the associated cost of AD manufacturing.

The qualitative task of determining the quality of the developed constructs was to calculate the integral index for each of the above-mentioned ADs and to compile their ranking ranked list. There are two methods to form this list.

The first involves the comparison of a certain characteristic of the AD – the object of comparison (OC) – with the corresponding feature of the established sample and the subsequent calculation of the modified coefficient of concordance [11] as an integral quality index.

The second is implemented as follows:
- measure (evaluate) the values of all features for all OCs;
- for each of the characteristics determine the feature-sample (the largest or smallest measurement result) – there is an analogy with the calibration scheme in the field of metrology for multimeters, when the calibration is performed separately for each of the measured parameters, the method of verification – direct verification [12];
- calculate the rating coefficient as the ratio of the measurement result of a particular trait to the numerical value of the feature-sample;
- determine the maximum total rating (adding all rating coefficients) from the calculated;
- calculate the coefficient of conformity \( K_a \) as the ratio of the total OC rating to the maximum overall rating;
- rank the OP in the order of reducing the \( K_a \).

For example, the AD is compared on several features, some of which have a positive effect on the rating (antenna amplification coefficient, geometric sizes, communication range), and others (the width of the main DC, the size of the DC' lateral petals, the cost of manufacture AD) – negative.

For the first group of features, the rating is defined as follows:
- the maximum value is chosen from the measured values of the \( i \)-th feature \( B_i \) as an sample (\( B_{\text{max}} = \max \{B_i\} \));
- calculate the value \( K_i = B_i / B_{\text{max}} \).

The rating coefficient of the second group of features is defined as:
- from the measured values of the \( j \)-th feature \( D_j \) choose the maximum \( D_{\text{max}} = \max \{D_j\} \) and the minimum value \( D_{\text{min}} = \min \{D_j\} \) – this is a sample;
- calculate the value \( K_j = (D_{\text{max}} + D_{\text{min}} - D_j) / D_{\text{max}} \).

The total rating of the \( k \)-th AD \( R_{sk} \) is calculated as the addition of all \( K_i \) and \( K_j \).

Choose \( R_{\text{sum}} = \max \{R_{sk}\} \), which is taken as the sample.

The coefficient \( K_{sk} = R_{sk} / R_{\text{sum}} \) is calculated.

The ranked list, which determines the place of the \( k \)-th AD in the list in the order of reduction of \( K_{sk} \), is submitted to the decision-maker.

The described sample ranking method [13] is implemented as a software product in the Microsoft Excel application environment, which has been tested and can be used to support decision-making regarding the choice of OC in any subject area.

The application of the described method to compare the constructs discussed in the article showed the acceptability of constructing a multifunctional antenna device to protect the radio communication channels of law enforcement units based on angular antennas.
Conclusions

The advantages of these antennas are as follows.

1. Multifunctionality: antenna designed to determine and suppress communication, informative, navigative channels and drones' control channels in the UHF, GSM, GPS, GLONASS, Galileo ranges. Work in the frequency ranges is provided by broadband radiators. The height of the antenna allows the placement of several radiators without the effect of dimming. Changing the shape of the directivity chart also possible by deviating the radiator from the bisector of the opening angle.

2. Equipping the antenna device with an optical sight provides simple mechanical aiming, including airborne. The combination of several ways to detect a target – visual, radio frequencial, Wi-Fi – increases the probability of finding it and minimizes the number of activations for non-profile targets.

3. Important additional features are opened when all antennas work together or by switching them. With the proper choice of angles between the antenna plates and the distance from the radiators to the top of these angles, it is possible to provide a favorable addition of the fields of waves reflected from the reflector plates, with the fields of waves created directly by the radiators. But this problem requires separate research.

4. The simplicity of design of the antenna device enables its manufacture even in the conditions of repair shops.

The disadvantage is the insufficient number of practical applications in different variants of simultaneous placement of several radiators in the aperture of one or more angular antennas that make up the antenna device.

The proposed variants of construction and use of the multifunctional antenna device ensure the implementation of electronic warfare measures – directing the source of interference, accurate directionality chart of the main reflector in the direction of the target (object of observation), suppression of the radiation source (interference), which can be placed on the air or surface.

This guarantees the ability to adapt to any situation in the radio communication system and to protect the local radio communication system.

The authors dedicate this publication to the bright memory of their colleagues and co-authors, Yuri Pavlovich Belokursky and Igor Viktorovych Ruzhentsyev.

References


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Анотація. Безпечне проведення масових заходів потребує від сил охорони правопорядку захисту каналів радіозв'язку підрозділів, виявлення і придушення радіоканалів управління протиборчої сторони, пошуку і знищення передавачів завад після обідні дії, наявність яких є провою агресивних намірів натовпу. Для цього необхідні засоби, які використовують антени зі спрямованими властивостями, діапазон частот яких визначаються застосовуваними штатними і масовими засобами радіозв'язку. Загалом, до параметрів антен систем радіозв'язку, радіорозвідки, радіомоніторингу, придушення вибуваються різни вигоми, тому універсальну антенну для безлічі застосувань і умов реалізувати важко. Ідеальною для експлуатації антеною можна вважати таку, яка могла б прогнозовано змінювати властивості при додаванні (заміні) елементів (модулів), параметри яких відомі і узгоджені з базовою (основною) конструкцією. 

Ключові слова: охорона правопорядку; радіозв'язок; кутові антени; кут розкриву.