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MULTIFUNCTIONAL ANTENNA DEVICE FOR PROTECTION 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 counterparties.

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]. The above determines the relevance and purpose of the publication – to consider building a multifunctional antenna VHF/UHF ranges, to offer recommendations on design elements and to propose measures to increase the efficiency of use when performing assigned tasks of LEU.

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.
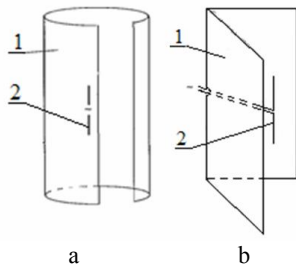

a   b
Fig. 1 Basic antenna designs

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.
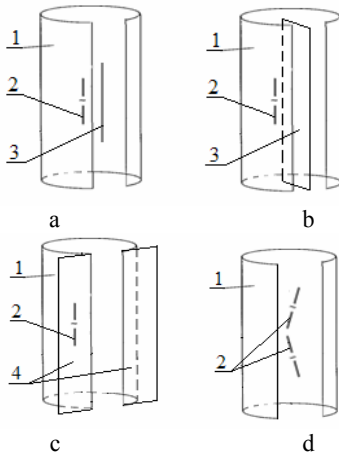

a   b

c   d
Fig. 2 Variants of antenna constructions with CR

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-ЩП" 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**

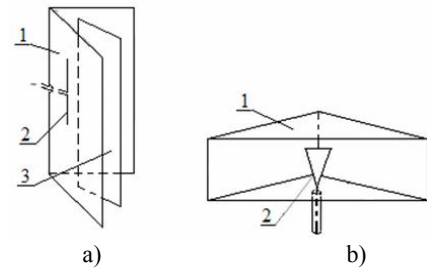| Con-struct	Difference from BD Variable element and/or parameter	The technical result
Fig. 2-a [3]	Reflector height (2-4)λ Slit width (0,3-0,7)λ	Width DC_H = 60-180°; Width DC_E = 20°; simple power system
Fig. 2-b [3]	Separating screen Slit width (0,6-1,4)λ	Width DC_E ≈20°; Width DC_H = 30-60°; reduction of lateral petals
Fig. 2-c [3]	Additional 2 reflectors Sizes of additional reflectors	Increasing directional coefficient on 1-4 dB
Fig. 2-d [3]	The second radiator Radiators at an angle to the vertical	Reducing antenna transverse size by up to 30%
Fig. 1-a [6]	The radiator is asymmetric about the plane of symmetry; location radiator, slit width (0,6-1,4)λ	Frequency-angle dependence of the DC without complicating the antenna design

a)   b)
Fig. 3 Angular antenna constructs variants

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

Con-struct	Difference from BD Variable element and/or parameter	The technical result
Fig. 3-a [3]	Separating screen	Reducing width DC_E by up to 25°
Fig. 3-a [7]	The corner antenna is three-dimensional; Opening angle, reflector height and radiator shape	Essential sizes reduction

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 λ by sizes.

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

Distance S to the reflector	Length of the radiator	Width of the main petal (E), °	Directionality chart shape
$0,2\,\lambda$	$0,46\,\lambda$	77	1 petal
$0,25\,\lambda$	$0,46\,\lambda$	82	1 petal
$0,3\,\lambda$	$0,46\,\lambda$	90	1 petal
$0,4\,\lambda$	$0,48\,\lambda$	105	1 petal
$0,5\,\lambda$	$0,48\,\lambda$	-	2 petals
$0,6\,\lambda$	$0,48\,\lambda$	-	main + 2 lateral
$0,7\,\lambda$	$0,47\,\lambda$	-	main + 2 lateral

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: α_1, α_2, α_3 – the corresponding angles between the reflectors; 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 $\alpha_2 = 90°$. 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.
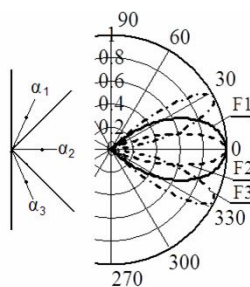
Fig. 4 DC for $\alpha_2 = 90°$

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).
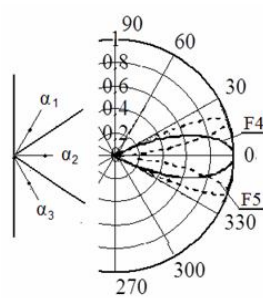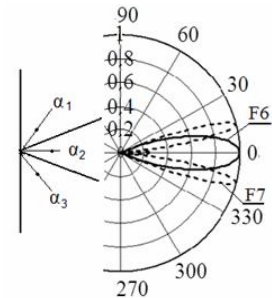
Fig. 5 DC for $\alpha_2 = 60°$

Fig. 6 DC for $\alpha_2 = 45°$

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 α_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 λ (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 α3 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).
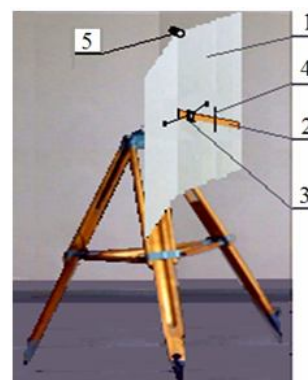
Fig. 7 Antenna layout

Selected reflector sizes: length $L = (1-1,5)\lambda_{max}$, height $H = 1,2\lambda_{max}$, where λ – 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 $\alpha_1 = \alpha_2 = \alpha_3 = 60°$ (see Fig. 9) or $\alpha_1 = \alpha_3 = 45°$, $\alpha_2 = 90°$, or with four antennas having equal angles of 45°, or other variants of the structure.

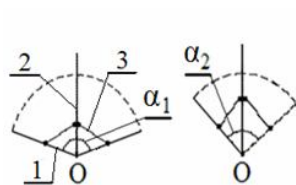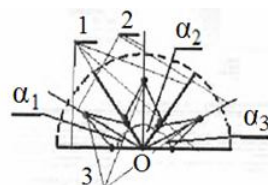**Fig. 8** Example of changing the reflector opening angle   **Fig. 9** Antenna device with equal opening angles

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 α_1 and α_3 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 α_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 qualimetric 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_B as the ratio of the total OC rating to the maximum overall rating;
- rank the OP in the order of reducing the K_B.

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 ($B_{max} = \max\{B_i\}$);
- calculate the value $K_i = B_i / B_{max}$.

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 $D_{max} = \max\{D_j\}$ and the minimum value $D_{min} = \min\{D_j\}$ – this is a sample;
- calculate the value $K_j = (D_{max} + D_{min} - D_j) / D_{max}$.

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

Choose $R_{\Sigma max} = \max\{R_{\Sigma k}\}$, which is taken as the sample.

The coefficient $K_{Bk} = R_{\Sigma k} / R_{\Sigma max}$ is calculated.

The ranked list, which determines the place of the k-th AD in the list in the order of reduction of K_{Bk}, 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 determ 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 directionality 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.

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Багатофункціональний антенний пристрій для захисту каналів радіозв'язку підрозділів сил охорони правопорядку

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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 разової дії, наявність яких є проявом агресивних намірів натовпу. Для цього необхідні засоби, що використовують антени зі спрямованими властивостями, діапазони частот яких визначаються застосовуваними штатними і масовими засобами радіозв'язку. Загалом, до параметрів антен систем радіозв'язку, радіорозвідки, радіомоніторингу, придушення висуваються різні вимоги, тому універсальну антену 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. А серійні антени радіоелектронних засобів є закінченими пристроями і не завжди піддаються удосконаленню, тому розглянуто можливості застосування імпровізованих антен, які мають адекватні моделі, підтверджені чисельними експериментами, програмне забезпечення для яких є в загальному доступі, з основними параметрами, значення яких можуть цілеспрямовано змінюватися: діапазон частот, ширина і форма діаграми спрямованості, її опромінюючі властивості тощо. З огляду на функціональні вимоги проведено аналіз конструкцій антен типу "Опромінювач над циліндричною поверхнею", кутикових антен та антен типу "Опромінювач над площиною", характеристики яких при однакових розмірах приблизно однакові й розраховуються за одними і тими ж формулами. Виконано дослідження можливостей кутикових антен типу "розкрита книга" з різними кутами між відбивачами, для чого проведено аналітичне моделювання варіантів технічних рішень, придатних для застосування в системах радіозв'язку підрозділів сил охорони правопорядку. Перевірено працездатність запропонованих конструктивів та визначені їх характеристики. Таким чином, запропоновані варіанти технічних рішень кутикових антенних пристроїв здатні забезпечити захист каналів радіозв'язку підрозділів сил охорони правопорядку при проведенні масових заходів.

Ключові слова: охорона правопорядку; радіозв'язок; кутикова антена; кут розкриву.

Многофункциональное антенное устройство для защиты каналов радиосвязи подразделений сил охраны правопорядка

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Аннотация. Безопасное проведение массовых мероприятий требует от сил охраны правопорядка защиты каналов радиосвязи подразделений, выявления и подавления радиоканалов управления противоборствующей стороны, поиска и уничтожения передатчиков помех разового действия, наличие которых является проявлением агрессивных намерений толпы. Для этого необходимы средства, использующие антенны с направленными свойствами, диапазоны частот которых определяются применяемыми штатными и массовыми средствами радиосвязи. В общем, к параметрам антенн систем радиосвязи, радиоразведки, радиомониторинга, подавления предъявляются различные требования, поэтому универсальную антенну для множества приложений и условий создать трудно. Идеальной для эксплуатации антенной можно считать такую, которая могла бы прогнозируемо изменять свойства при добавлении (замене) элементов (модулей), параметры которых известны и согласованы с базовой (основной) конструкцией. А серийные антенны радиоэлектронных средств являются законченными устройствами и не всегда поддаются модернизации. поэтому рассмотрены возможности применения импровизированных антенн, имеющих адекватные модели, подтвержденные многочисленными экспериментами, программное обеспечение для которых есть в общем доступе, с основными параметрами, значения которых могут целенаправленно изменяться: диапазон частот, ширина и форма диаграммы направленности, ее излучательные свойства и тому подобное. С учетом функциональных требований проведен анализ конструкций антенн типа "Облучатель над цилиндрической поверхностью", угловых антенн и антенн типа "Облучатель над плоскостью", характеристики которых при одинаковых размерах примерно одинаковы и рассчитываются по одним и тем же формулам. Выполнены исследования возможностей угловых антенн типа "раскрытая книга" с различными углами между отражателями, для чего проведено аналитическое моделирование вариантов технических решений, пригодных для применения в системах радиосвязи подразделений сил охраны правопорядка. Проверена работоспособность предложенных конструктивов и определены их характеристики. Таким образом, предложенные варианты технических решений угловых антенных устройств способны обеспечить защиту каналов радиосвязи подразделений сил охраны правопорядка при проведении массовых мероприятий связи.

Ключевые слова: охрана правопорядка; радиосвязь; угловая антенна; угол раскрытия.