

Title of invention: Jamming device with stacked multiband antenna

FIELD

- 5 [001] The present invention relates to a jamming device with a stacked antenna arrangement that allows for multiband jamming.

BACKGROUND

- 10 [002] Unmanned aircraft systems (UAS) sales are largely unregulated, making it challenging to ensure that vehicles like drones are not used for mischief (such as spying) or more nefarious activities (such as to mount attacks). Law enforcement and security agencies must thus find countermeasures against the proliferation of such unauthorised use of UAS.
- [003] Drones, being small and nimble, present hard targets for conventional projectile based
- 15 countermeasures. Designing an effective projectile based countermeasure may also be expensive and not cost effective when compared against low cost drones.
- [004] Electronic countermeasures are thus the preferred way to disrupt UAS operation, typically by interfering with signals received by the UAS. Such electronic countermeasures need to work over several frequency bands to cater for the different frequency bands in which a UAS may operate.
- 20 [005] An antenna array which uses several antennas to provide jamming that spans over a wide frequency band and is effective up to operation range tends to be bulky. A bulky antenna array is not practical and is not deployable into a portable and compact handheld device.
- [006] There is thus a need to provide an antenna arrangement that address the above shortcomings.

25 SUMMARY OF THE INVENTION

- [007] According to a first aspect of the present invention, there is provided a jamming device including a reflector plate; a plurality of antennas mounted to the reflector plate and extending from the reflector plate, each tuned to transmit at least one different centre frequency so that the plurality of
- 30 antennas transmit at different centre frequencies; wherein the plurality of antennas is arranged such that the antenna(s) tuned to transmit at lower centre frequencies are placed between the antenna(s) tuned to transmit at higher centre frequencies.
- [008] The antenna(s) tuned to transmit at the higher centre frequencies may be located outermost relative to the antenna(s) tuned to transmit at lower centre frequencies.
- 35 [009] The antenna(s) tuned to transmit at the higher centre frequencies may be mounted along or adjacent to one of two opposing edges of the reflector plate.

[010] The antenna(s) tuned to transmit at the higher centre frequencies may be mounted in series along or adjacent to a respective one of the two opposing edges of the reflector plate. The two opposing edges are the lengths of the reflector plate.

5 [011] The antenna(s) that transmit at the highest centre frequencies may be mounted along or adjacent to a same edge of the reflector plate.

[012] The antenna(s) that transmit at the highest centre frequencies may each transmit only a single frequency. The two highest frequencies may be 2400 MHz and 5800 MHz.

[013] At least the antenna that transmits at the highest centre frequency may have its top and bottom surfaces exposed.

10 [014] The antenna(s) tuned to transmit at the higher centre frequencies may be staggered relative to the antenna(s) tuned to transmit at lower centre frequencies.

[015] The dimensions of the reflector plate may be determined by form factor requirements imposed onto the jamming device.

15 [016] The design specification of the plurality of antennas may be determined by each achieving a threshold voltage standing wave ratio (VSWR) at a maximum operation range. The design specification may also include any one or more of antenna length, spacing between adjacent antennas, antenna type and mounting position for each antenna.

[017] The plurality of antennas may include Yagi Uda and Log-Period Dipole Array (LPDA) antennas.

20 [018] The Yagi Uda antenna(s) may be tuned to transmit at only a single centre frequency; and the Log-Period Dipole Array (LPDA) antenna(s) are tuned to transmit at least two centre frequencies. One of the two Log-Period Dipole Array (LPDA) antennas may be tuned to transmit at the centre frequencies 433 MHz and 915 MHz, while the other Log-Period Dipole Array (LPDA) antennas may be tuned to transmit at the centre frequencies 1200 MHz and 1500 MHz.

25 [019] The reflector plate may include a meandering microstrip to connect each of the plurality of antennas to their driving circuitry. One or more of the meandering microstrips may have a plurality of bends, the number and length of each determined by interference of generated harmonic frequencies to minimise.

30 [020] The jamming device may further include spacers, each positioned between adjacent antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

[021] Representative embodiments of the present invention are herein described, by way of example only, with reference to the accompanying drawings, wherein:

35 [022] Figure 1 shows functional blocks of a jamming device of the present invention.

[023] Figure 2A shows a perspective view of one possible implementation of an antenna module of Figure 1.

[024] Figures 2B to 2E show different views of each of the antennas of the antenna module of Figure 2A.

5 [025] Figure 2F shows another possible antenna layout arrangement.

[026] Figure 3A shows a side view of the antenna module of Figure 1.

[027] Figure 3B shows the reflector plate for the antenna module of Figure 1.

DETAILED DESCRIPTION

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[028] In the following description, various embodiments are described with reference to the drawings, where like reference characters generally refer to the same parts throughout the different views.

[029] The present application relates to a jamming device. The jamming device disrupts or disables the communications of unmanned or remotely piloted vehicles (such as drones) by transmitting a radio
15 signal that interferes with signals received by the unmanned/remotely piloted vehicles over one or more of their operating frequency ranges, so that these received signals are blocked or corrupted. Subsequently, these vehicles do not work as intended. Thus, the jamming device may be used as, but not limited to, an anti-UAV (unmanned aerial vehicle) weapon.

[030] The jamming device has a plurality of antennas, each designed/tuned to handle a designated
20 centre frequency, resulting in the plurality of antennas collectively transmitting at different centre frequencies. The centre frequency refers to the frequency at which an antenna transmits most efficiently and is not necessarily in the middle of a frequency range over which the antenna transmits at an acceptable VSWR (voltage standing wave ratio) value, which is typically below a predefined threshold value. Thus, should the transmission spectrum of the jamming device be analysed, a peak will be
25 detected for each of the centre frequencies of the plurality of antennas. This allows the jamming device to be used against UAVs that operate over different frequencies. The tuning of the antenna refers to the selection of an antenna type (e.g. dipole, log periodic dipole array), fabrication material; determination of the dimensions and shape of the elements of the selected type to achieve the desired centre frequency. The plurality of antennas are typically not used to receive radio signals, although capable of doing so.

30 [031] The plurality of antennas are mounted on a reflector plate, which is a base plate located behind radiating elements of each of the plurality of antennas. The reflector plate serves to reduce back-lobe radiation by absorbing and re-radiating signal in a same direction as that of the radiating elements for each of the plurality of antennas.

[032] Each antenna is tuned to transmit at least one different centre frequency, so that a plurality of
35 these antennas transmit at different centre frequencies. In more detail, each antenna can transmit one or more signals of different frequency bands, each having a different centre frequency. The one or more

centre frequencies that each antenna transmits is also different from another antenna. For example, one antenna may solely transmit at a centre frequency of 5800 MHz; while another antenna may transmit two different frequency band signals, a first having a centre frequency of 1200 MHz and a second having a centre frequency of 1500 MHz. Each antenna is tuned to transmit its designated centre frequency by design specification, such as varying one or more parameters that include antenna length, spacing between adjacent antennas, antenna type and mounting position for each antenna on the reflector plate. “Antenna(s)” refer to one or more of these antennas. The phrase “antenna(s) tuned to transmit at lower centre frequencies” refers to the one or more antennas mounted on the reflector plate that transmit at lower centre frequencies compared to the other antennas mounted on the reflector plate. Similarly, the phrase “antenna(s) tuned to transmit at higher centre frequencies” refers to the one or more antennas mounted on the reflector plate that transmit at higher centre frequencies compared to the other antennas mounted on the reflector plate.

[033] While antenna design is theoretical, final implementation is a result of empirical work and experimentation. Adopting antenna design principles which stipulate a minimum separation distance to reduce signal loss and cross frequency interference when antennas are combined in proximity result in an antenna layout with an undesirable large physical footprint (i.e. requiring a base plate with a large surface area). In designing a reflector plate with dimensions that meet form factor requirements imposed for a compact jamming device, it was found that an arrangement where the antenna(s) tuned to transmit at lower centre frequencies are placed between the antenna(s) tuned to transmit at higher centre frequencies was a starting point to produce transmission signal strength above threshold levels within the jamming device operation range.

[034] In one implementation, the antenna(s) tuned to transmit at the higher centre frequencies are located outermost relative to the antenna(s) tuned to transmit at lower centre frequencies. For example, should the reflector plate have several rows of antennas mounted thereon, the first and last rows will contain the antenna(s) tuned to transmit at the higher centre frequencies.

[035] To maximise separation between adjacent antennas, the antenna(s) tuned to transmit at the higher centre frequencies are mounted along or adjacent to one of two opposing edges of the reflector plate. That is, possible mounting locations for the outermost antenna(s) include along the perimeter of the reflector plate, or with a gap between the outermost antennas and a respective edge of the reflector plate.

[036] In one implementation, the antenna(s) tuned to transmit at the higher centre frequencies are mounted in series along or adjacent to a respective one of the two opposing edges of the reflector plate. Accordingly, one edge of the reflector plate may have the antenna(s) tuned to transmit at the higher centre frequencies, mounted thereto in series. In a further implementation, the antenna(s) that transmit at the highest centre frequencies are mounted along or adjacent to a same edge of the reflector plate.

The remainder of the antenna(s) that transmit at the higher centre frequencies are then mounted along or adjacent thereto the other edge of the reflector plate.

[037] The jamming device is described in greater detail below in conjunction with the accompanying Figures.

5 [038] One or more of the Figures show a jamming device having a multiband antenna arrangement for effective jamming of UAVs, such as commercial drones, customized drones and/or drone swarms operating in one or more of the following RF (radio frequency) bands: 2.4 GHz, 5.8 GHz, 433 MHz, 915 MHz, L2 1.2 GHz and L1 1.5 GHz.

[039] The jamming device can also be used to jam GPS (Global Positioning Signals) / GNSS (Global
10 Navigation Satellite System) signals or telemetry and communications links utilizing these bands.

[040] In contrast with handheld jammers that are bulky because of the use of multiple antennas, including those of wideband configuration, the jamming device of the present invention provides a handheld device with a small-form factor, with its antenna arrangement transmitting in a directed manner (i.e. having a narrow transmission beam that is non-omnidirectional).

15 [041] With the form factor required by a compact jamming device fixed, antennas and their mounting position were chosen based on how operation of one affected the others when stacked together; and whether one or more of the antennas can disrupt a UAV over the jamming device operation distance while maintaining a required jamming ratio performance. "Jamming ratio" refers to the distance between the jammer device to the UAV vs. the distance between the UAV to the UAV operator.

20 Jamming ratio is a general measure of range ratios at which jamming is expected to be effective (with other factors like transmission power of drone and jammer held constant) and provides an estimate of distances at which a jamming operation is expected to be effective. While it was possible to use a single wideband antenna spanning across the frequencies 2.4 GHz, 5.8 GHz, 433 MHz, 915 MHz, L2 1.2 GHz and L1 1.5 GHz, it was found that band assignment using four antennas to cover these six frequency
25 bands ensured effective performance for continuous jamming operation. It was also found that placing the antennas tuned to transmit at lower centre frequencies (433 and 915 MHz) between the antennas tuned to transmit at higher centre frequencies (2.4 GHz, 5.8 GHz, L2 1.2 GHz and L1 1.5 GHz) provided an optimal mounting arrangement for the four antennas on their reflector plate. While it was possible to use antennas of helical configuration, non-helical antennas were eventually selected, such as Yagi
30 Uda and Log Periodic Dipole Array configurations.

[042] Figure 1 shows functional blocks of a jamming device of the present invention. A jamming waveform is first generated by an exciter module 101. The exciter module 101 may have dedicated circuitry for each jamming frequency band. So, in an embodiment where the jamming device is configured to target the bands 2.4 GHz, 5.8 GHz, 433 MHz, 915 MHz, L2 1.2 GHz and L1 1.5 GHz,
35 the exciter module 101 has six exciters, each to generate a waveform for a respective one of these bands.

- A filtering module 102 then constraints or adapts the generated waveforms for transmission within its targeted bands of 2.4 GHz, 5.8 GHz, 433 MHz, 915 MHz, L2 1.2 GHz and L1 1.5 GHz.
- [043] A power amplifier 103 boosts the transmitted RF signal power. The RF signal is directed through RF cables to transmission antennas 104.
- 5 [044] For the sake of simplicity, Figure 1 omits the following non-exhaustive components of the jamming device: processor and control circuitry and a control panel, of which one or more is in electrical communication with the exciter module 102, the filtering module 102; the power amplifier 103; along with the housing of the jamming device.
- [045] Figure 2A shows a perspective view of one possible implementation of the antenna module 104
- 10 of Figure 1. To adequately support jamming operation, antennas used for the antenna module 104 have the following features:
- (a) sufficient gain and voltage standing wave ratio (VSWR) within targeted frequency of interest,
 - (b) low backlobe radiation for user safety; and
 - (c) ability to support continuous transmission of jammer signals without damage to antenna elements
- 15 [046] Instead of having to design a single wideband antenna to cater for transmissions in the different bands, the antenna module 104 uses four antennas to cover the six frequency bands of 2.4 GHz; 5.8 GHz; 433 MHz and 915 MHz; and L2 1.2 GHz and L1 1.5 GHz. In more detail, the antenna module 104 comprises four submodules: submodule #S1, an antenna 201 tuned to transmit at centre frequency 2.4 GHz; submodule #S2, an antenna 202 tuned to transmit at centre frequency 5.8 GHz; submodule
- 20 #S3, an antenna 203 tuned to transmit at two centre frequencies 433 and 915 MHz; and submodule #S4, an antenna 204 tuned to transmit at two centre frequencies 1200 and 1500 MHz. The specification for the four antennas is summarised in Table 1 below.

Table 1: Antenna specifications

Number	Antenna Description	Frequency Range		Gain (dBi)	VSWR	Front to Back Ratio (dB)	Azimuth Coverage
		Start Frequency (MHz)	Stop Frequency (MHz)				
#S1	2400MHz (201)	2300	2600	12	<1.2	>21	30 Degree
#S2	5800MHz (202)	5100	5900	17	<1.2	>21	30 Degree
#S3	433, 915 MHz (203)	410	460	4.5	<2	>15	45 Degree
		820	960	4.5	<1.8	>15	45 Degree
#S4	1200, 1500MHz (204)	1200	1800	7.5	<1.5	>18	30 Degree
		1800	2680	7.5	<1.5	>18	30 Degree

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[047] Table 1 shows the frequency range over which each of the four antennas, tuned to its respective centre frequency, can operate. The frequency range for each of the four antennas refers to a range where the VSWR is capped at its respective value tabulated in Table 1. That is, while antenna #S1 (201) can transmit below 2300 MHz and above 2600 MHz, operation is between 2300 and 2600 MHz with VSWR < 1.2 and the antenna being most efficient at 2400 MHz. Antenna #S2 (202) is most efficient at 5800 MHz and operates between 5100 and 5900 MHz with VSWR < 1.2. Antenna #S3 (203) is most efficient at 433 and 915 MHz and operates between 410 and 460 MHz with VSWR < 2; and 820 and 960 MHz with VSWR < 1.8. Antenna #S4 (204) is most efficient at 1200 and 1500 MHz and operates between 1200 to 2680 MHz (combination of 1200 to 1800 MHz and 1800 to 2680 MHz) with VSWR < 1.5. As shown in the above table, the centre frequency for each of the four antennas is not necessarily in the middle of its operation frequency range. One or more of the antennas have a centre frequency that is displaced from the middle of their respective operation frequency range. In addition, each antenna #S1 to #S4 need not necessarily transmit at 2400 MHz; 5800 MHz; 433 and 915 MHz; and 1200 and 1500 MHz respectively; but can still transmit within each of their respective operating frequency ranges with acceptable effectiveness because operation under these frequency ranges result in transmission that is below a capped VSWR value.

[048] It will be appreciated that Table 1 provides only one possible antenna number and frequency range combination. In other implementations (not shown), a different number of antennas may be used for the same six frequency bands; or each of antennas in the antenna module 104 is configured to operate at a different frequency range.

[049] The antenna module 104 of the jamming device has a reflector plate 207 on which the antennas 201, 202, 203 and 204 are mounted. The plurality of antennas 201, 202, 203 and 204 extend from the reflector plate 207 towards an opening of the jamming device housing (not shown).

[050] Each of the antennas 201, 202, 203 and 204 is tuned to transmit at least one different centre frequency, i.e. each antenna transmits a centre frequency that is different from another antenna, resulting in the plurality transmitting at different centre frequencies. It was found that such placement reduced mutual coupling or near field interaction among the antennas, resulting in maximum isolation between the antennas and maximising directivity performance of the entire antenna module 104. Changes in the antenna placement affected the performance of the antenna module 104.

[051] Antennas whose radiating elements produce a narrow transmission beam, as opposed to a wide transmission beam, are used for the plurality of antennas 201, 202, 203 and 204. To provide such a narrow transmission beam (and avoid jamming untargeted UAVs in the vicinity, being more probable when using a wide transmission beam), the antennas are driven to have a high gain (from Table 1: 12 dBi for antenna 201; 17 dBi for antenna 202; 4.5 dBi for antenna 203 and 7.5 dBi for antenna 204). Optimisation to improve VSWR (voltage standing wave ratio) and antenna gain sees the plurality of antennas 201, 202, 203 and 204 stacked such that the antenna(s) tuned to transmit at lower centre

frequencies are placed between the antenna(s) tuned to transmit at higher centre frequencies. Stacking also achieves a compact design, resulting in a stacked multiband directional antenna.

- [052] The antennas selected for each of the four submodules, with Yagi Uda and Log-Period Dipole Array (LPDA) being two possible choices, result from criteria imposed to optimise antenna design specification as follows. Using one antenna to transmit two centre frequencies for submodules #S3 and #S4 reduces the number of antennas required for stacking. Submodule #S3 uses a printed LPDA antenna tuned to transmit at centre frequencies 433 and 915 MHz, instead of a separate antenna for each of the two frequencies. Similarly, submodule #S4 uses a LPDA antenna tuned to transmit at centre frequencies 1200 and 1500 MHz, instead of a separate antenna for each of the two frequencies.
- [053] Turning to the LPDA used for the submodule #S3, more clearly shown in the top view 203_T and isometric view 203_I of Figure 2B, the bulk of the transmission at centre frequency 433 MHz occurs at active region 230, while the bulk of the transmission at centre frequency 915 MHz occurs at active region 232. The length 260 of the longest dipole element is around 275 mm, the length 262 of the shortest dipole element is around 95 mm and the distance 264 between the longest dipole element and the shortest dipole element is around 230 mm. The arms of each dipole pair 266 are offset to each other.
- [054] Similarly for the LPDA used for the submodule #S4, more clearly shown in the top view 204_T and isometric view 204_I of Figure 2C, the bulk of the transmission at centre frequency 1200 MHz occurs at active region 240, while the bulk of the transmission at centre frequency 1500 MHz occurs at active region 242. The length 268 of the longest dipole element is around 90 mm, the length 270 of the shortest dipole element is around 16 mm and the distance 272 between the longest dipole element and the shortest dipole element is around 235 mm. The arms of each dipole pair 272 are offset to each other.
- [055] From the isometric view of Figure 2D, submodule #S2 uses one Yagi Uda antenna 202 tuned to transmit at 5.8 GHz (the highest frequency), which allows for higher tolerance towards high-power transmission in that band. The length 274 of the longest dipole element is around 23 mm, the length 276 of the shortest dipole element is around 18 mm and the distance 278 between the longest dipole element and the shortest dipole element is around 253 mm. The antenna 202 for this highest centre frequency has its top and bottom surfaces exposed, to further facilitate heat dissipation. In contrast, the other antennas 201, 203 and 204 are provided on a substrate. For the next highest frequency, submodule #S1 (see isometric view of Figure 2E) uses a LPDA antenna 201 tuned to transmit at 2.4 GHz. The length 280 of the longest dipole element is around 61 mm, the length 282 of the shortest dipole element is around 27 mm and the distance 284 between the longest dipole element and the shortest dipole element is around 260 mm.
- [056] Summarising, the antennas 201, 202 that transmit at the highest centre frequencies are tuned to each transmit only a single centre frequency. As for the other antennas 203 and 204, each is tuned to transmit two different centre frequencies.

[057] The following arrangement layout of antennas 201, 202, 203 and 204 on the reflector plate 207 was also found to further optimise VSWR and antenna gain. The antennas 202, 201, 204 tuned to transmit at the higher centre frequencies of 5800 MHz, 2400 MHz and 1200/1500 MHz respectively are located outermost relative to the antenna 203 tuned to transmit at the lower centre frequencies of 433/915 MHz. As shown in Figure 2A, each of the antennas 201, 202, 203 and 204 that are tuned to transmit at the higher centre frequencies are located outermost by being mounted adjacent (i.e. with a small gap) to one of two edges 210 of the reflector plate 207. This maximises the available mounting area provided by the reflector plate 207, which in turn facilitates the extent to which adjacent antennas can be separated. The antennas 201 and 202 that are tuned to transmit at 5800 MHz and 2400 MHz respectively are mounted adjacent to one edge, while the antenna 204 tuned to transmit at 1200/1500 MHz is mounted adjacent to an opposite edge. In another implementation (not shown), two or more antennas may be mounted along or adjacent to the two opposite edges of the reflector plate 207.

[058] In yet another implementation (not shown), the antenna tuned to transmit at 5800 MHz and the antenna tuned to transmit at 2400 MHz are located outermost by being mounted along one edge of the reflector plate, while the antenna tuned to transmit at 1200/1500 MHz is located outermost by being mounted along an opposite edge of the reflector plate 207. Accordingly, the antennas 201, 202 and 204 tuned to transmit at the higher centre frequencies are mounted along or adjacent to one of two opposing edges 210 of the reflector plate 207. While Figure 2A shows that the two opposing edges 210 are the lengths of the reflector plate 207 for being polygonal (rectangular), other edges of the reflector plate 207 can serve as the mounting location. For example, if the reflector plate has an irregular shape, opposing locations along or adjacent to its perimeter may serve as mounting points for the antenna(s) tuned to transmit at the higher centre frequencies.

[059] Where there are two or more antennas tuned to transmit at the higher centre frequencies along or adjacent to a respective one of the two opposing edges 210 of the reflector plate 207 (i.e. when the same edge 210 of the reflector plate has two or more antennas tuned to transmit at the higher centre frequencies), the two or more antennas are mounted in series. Accordingly, the antennas 202 and 201 that are tuned to transmit at 5800 MHz and 2400 MHz respectively lie along a line that is parallel to the edge of the reflector plate 207. In addition, these antennas 201 and 202 which transmit at the highest centre frequencies amongst all the antennas are mounted along or adjacent to a same edge 210 of the reflector plate 207. It was found that such a series arrangement reduces interference and improves transmission performance across all frequency bands. The antennas 201 and 202 which transmit at the highest centre frequencies are also configured to only transmit a single centre frequency, namely the centre frequency for which they are tuned, i.e. antenna 201 for 5800 MHz and antenna 202 for 2400 MHz. (In contrast, the antenna 204 is tuned to transmit two centre frequencies, 1200 MHz and 1500 MHz, while the antenna 203 is tuned to transmit two centre frequencies, 433 MHz and 915 MHz. This

is because most drones operate at the higher frequencies of 2.4 GHz or 5.8 GHz, so dedicating the antennas 201 and 202 to have a single centre frequency achieves better performance against such drones.

[060] The implementation of Figure 2A has only one antenna tuned to transmit at the lower centre frequency, i.e. that of antenna 203 tuned to transmit the centre frequencies 413 and 915 MHz located between the antennas that are tuned to transmit at the higher centre frequencies. This is achieved by having the antenna 202 tuned to transmit at 5800 MHz and the antenna 201 tuned to transmit at 2400 MHz located on one side of the antenna 203; and the antenna 204 tuned to transmit at the two centre frequencies 1200 MHz and 1500 MHz located on the other side of the antenna 203. The antennas 201, 202, 204 are also in alignment in that they fall within the width 212 of the antenna 203.

[061] In another implementation shown in Figure 2F, there are two or more antennas 250 (although only two are shown), each tuned to transmit a lower centre frequency and located between antennas 252, 254 that are tuned to transmit at higher centre frequencies. The antennas 252, 254 tuned to transmit at the higher centre frequencies are staggered relative to the antennas 250 tuned to transmit at lower centre frequencies. As shown in Figure 2F, one or more of the antennas 252, 254 (or a part thereof) that are tuned to transmit at the higher centre frequencies falls outside the combined width 256 of the two or more antennas 250 tuned to transmit at the lower centre frequencies.

[062] The jamming device uses spacers 205, each positioned between adjacent antennas to provide mechanical support to keep the four antenna modules #S1 to #S4 apart. In the implementation of Figure 2A, two spacers are used for the antenna pair 202 and 203; four spacers are used for the antenna pair 201 and 203; and six spacers (see Figure 3A) used for the antenna pair 204 and 203. In another implementation (not shown), a different number of spacers, such as only one, is used to keep each antenna pair apart. Although the spacing between the antennas 201, 202, 203, 204 are kept at fractions of wavelength apart to allow for compactness, with antenna submodule #S3 stacked between submodules #S1, #S2 and #S4, effective jamming of drone signals in the targeted bands of 2.4 GHz, 5.8 GHz, 433 MHz, 915 MHz, L2 1.2 GHz and L1 1.5 GHz is still achieved.

[063] The dimensions of the reflector plate 207 (see Figure 3B) are determined by form factor requirements imposed onto the jamming device. For example, there may be a requirement for the jamming device to have certain dimensions, which then constraints the dimensions of the reflector plate 207. In another approach, the reflector plate 207 is designed to achieve a desired forward radiation pattern for all transmission frequency bands, which may be achieved by tuning the shape of the reflector plate 207 to minimize back lobe and maximize forward radiation, resulting in front to back ratios as shown in table 1 for each of the antennas (> 21 dB for # S1; > 21 dB for # S2; > 15 dB for # S3; and > 18 dB for # S4). (With the dimensions of the reflector plate 207 set, the plurality of antennas 201, 202, 203, 204 can then be designed to achieve a threshold voltage standing wave ratio (VSWR) at a maximum operation range. “Threshold” refers to a minimum power transmission efficiency that each of the antennas 201, 202, 203, 204 is required to have at their respective maximum operation range,

with an ideal value of 1 for maximum power transmission from the power source onto the antenna. The design specification for each of the antennas 201, 202, 203, 204 will include determining one or more of the following antenna parameters: antenna length, spacing between adjacent antennas, antenna type and mounting position for each antenna.

5 [064] The antennas 201, 202, 203, 204 are mounted to the reflector plate 207 by an antenna support base 208. The antenna support base 208 is designed to hold the antennas 201, 202, 203, 204 in place and to withstand damage that will arise due to overheating from sustained transmission from an exciter or jamming signal source.

10 [065] The antenna module 104 has five SubMiniature Version A (SMA) connectors, each to connect one of the antennas 201, 202, 203, 204 to its respective exciter module 101 (see Figure 1). The SMA output of Antenna submodule #S1 will be connected to the 2400 MHz exciter module, output from submodule #S2 to the 5800 MHz exciter, output from submodule #S3 to the 433 and 915 MHz exciter module, and the output from submodule #S4 to the 1200 and 1500 MHz exciter module.

15 [066] The reflector plate 207 has one or more meandering microstrips, where each connects one of the plurality of antennas 201, 202, 203, 204 to their driving circuitry. Each meandering microstrip (not shown) has a plurality of bends the number and length of each determined by interference of generated harmonic frequencies to minimise. For instance, these bends can be designed to provide a matching module 206 for a common antenna to be used by exciters targeting different bands during jamming operation, e.g. to optimize the inputs from the 433 MHz and 915 MHz exciters for transmission through
20 the same antenna 203.

[067] The reflector plate 207, placed at the back of the antenna support base, reduces backlobe radiation by the stacked antenna 201, 202, 203, 204 and concentrates jamming power towards the main lobe of the antennas 201, 202, 203, 204. The reflector plate 207 may be made of aluminium, and its effectiveness may be improved by connecting to the chassis of the jamming device. This allows safe
25 operator use 0.3 m behind the antennas 201, 202, 203, 204, in compliance with IEEE Standard C95.1-2005.

[068] In summary, the antenna module 104, when used together with a jamming signal, achieves the following performance:

- 30 i) Jamming of UAVs and GNSS signals within the targeted bands of 2.4 GHz, 5.8 GHz, 433 MHz, 915 MHz, L2 1.2 GHz and L1 1.5 GHz;
- ii) Good back-lobe attenuation that is safe for users (IEEE Standard C95.1-2005 safety standard for an operator 0.3 m behind the antenna);
- iii) An operation range of up to 1000m and a jamming ratio of 2:1. A longer operation range is achievable for drones that operate with lower EIRP (equivalent isotropic radiated power);
- 35 iv) Support continuous jamming operation of at least an hour without damage to any of the antennas 201, 202, 203 and 204 and their supporting structure.

[069] In the application, unless specified otherwise, the terms "comprising", "comprise", and grammatical variants thereof, intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, non-explicitly recited elements.

[070] While this invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes can be made and equivalents may be substituted for elements thereof, without departing from the spirit and scope of the invention. In addition, modification may be made to adapt the teachings of the invention to particular situations and materials, without departing from the essential scope of the invention. Thus, the invention is not limited to the particular examples that are disclosed in this specification, but encompasses all embodiments falling within the scope of the appended claims.

CLAIMS

1. A jamming device comprising
a reflector plate;
5 a plurality of antennas mounted to the reflector plate and extending from the reflector plate,
each tuned to transmit at least one different centre frequency so that the plurality of antennas transmit
at different centre frequencies;
wherein the plurality of antennas is arranged such that the antenna(s) tuned to transmit at lower
centre frequencies are placed between the antenna(s) tuned to transmit at higher centre frequencies.
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2. The jamming device of claim 1, wherein the antenna(s) tuned to transmit at the higher centre
frequencies are located outermost relative to the antenna(s) tuned to transmit at lower centre frequencies.
3. The jamming device of claim 1 or 2, wherein the antenna(s) tuned to transmit at the higher
15 centre frequencies are mounted along or adjacent to one of two opposing edges of the reflector plate.
4. The jamming device of claim 3, wherein the antenna(s) tuned to transmit at the higher centre
frequencies are mounted in series along or adjacent to a respective one of the two opposing edges of
the reflector plate.
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5. The jamming device of claim 3 or 4, wherein the two opposing edges are the lengths of the
reflector plate.
6. The jamming device of any one of the claims 3 to 5, wherein the antenna(s) that transmit at the
25 highest centre frequencies are mounted along or adjacent to a same edge of the reflector plate.
7. The jamming device of claim 6, wherein the antenna(s) that transmit at the highest centre
frequencies each transmits only a single frequency.
- 30 8. The jamming device of claim 6 or 7, wherein the two highest frequencies are 2400 MHz and
5800 MHz.
9. The jamming device of any one of the claims 6 to 8, wherein at least the antenna that transmits
at the highest centre frequency has its top and bottom surfaces exposed.
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10. The jamming device of any one of the preceding claims, wherein the antenna(s) tuned to transmit at the higher centre frequencies are staggered relative to the antenna(s) tuned to transmit at lower centre frequencies.
- 5 11. The jamming device of any one of the preceding claims, wherein the dimensions of the reflector plate are determined by form factor requirements imposed onto the jamming device.
12. The jamming device of any one of the preceding claims, wherein design specification of the plurality of antennas is determined by each achieving a threshold voltage standing wave ratio (VSWR) at a maximum operation range.
- 10 13. The jamming device of claim 12, wherein the design specification comprises any one or more of antenna length, spacing between adjacent antennas, antenna type and mounting position for each antenna.
- 15 14. The jamming device of any one of the preceding claims, wherein the plurality of antennas comprises Yagi Uda and Log-Period Dipole Array (LPDA) antennas.
- 15 15. The jamming device of claim 14, wherein the Yagi Uda antenna(s) are tuned to transmit at only a single centre frequency; and the Log-Period Dipole Array (LPDA) antenna(s) are tuned to transmit at least two centre frequencies.
- 20 16. The jamming device of claim 15, wherein one of the two Log-Period Dipole Array (LPDA) antennas is tuned to transmit at the centre frequencies 433 MHz and 915 MHz, while the other Log-Period Dipole Array (LPDA) antennas is tuned to transmit at the centre frequencies 1200 MHz and 1500 MHz.
- 25 17. The jamming device of any one of the preceding claims, wherein the reflector plate comprises a meandering microstrip to connect each of the plurality of antennas to their driving circuitry.
- 30 18. The jamming device of claim 17, wherein one or more of the meandering microstrips comprises a plurality of bends, the number and length of each determined by interference of generated harmonic frequencies to minimise.
- 35 19. The jamming device of any one of the preceding claims, further comprising spacers, each positioned between adjacent antennas.