

A BEAM SHARPENED, LOW SIDELobe ANTENNA SYSTEM**BACKGROUND OF THE INVENTION****1. Field of the Invention**

The invention pertains to the field of antennas and more particularly to antenna configurations and signal processing of antenna signals for beam narrowing.

5 2. Description of the Prior Art

Marine radar antennas are required by the International Electrotechnical Committee (IEC) specifications 936 and 872 to rotate at 20 RPM. Revisions of IEC 936 contain requirements for antennas on High Speed Craft to rotate at 40 RPM while
10 maintaining the azimuth resolution requirements imposed on the 20 RPM antennas. The increased vessel speed and antenna rotation rate requirement, significantly increases the wind loading on the motors that rotationally drive the antenna. Mechanical solutions to this problem have been to enclose the antenna in a radome,
15 thereby shielding it from the wind so that the load on the drive motor is that provided by the antenna alone, placing wings on the antenna to provide better aerodynamic performance, or to provide a more powerful drive motor. All these solutions add significant cost to the radar system.

20 It is well known that the radiation beamwidth of an antenna, which determines the angular resolution of the radar system, is a function of its size. Consequently, reducing the sail area of the antenna, while maintaining conventional antenna design and signal processing techniques, increases the radiation beamwidth,
25 thereby adversely effecting the angular resolution of the radar system.

One technique in the prior art for decreasing the beam width of an antenna of a given size, thereby increasing the angular resolution, utilizes sum and difference signals such as those
30 provided in a monopulse antenna system. Two antennas of equal size and configuration and having independent signal output ports, are placed side-by-side. The signals at the output ports at each half of the antenna are summed and differenced to provide sum and difference signals, the peak of the sum pattern being
35 angular aligned with the null of the difference pattern, thus defining the boresight of the antenna. The sum is divided by the difference, which is a very low signal at boresight. Division

by this low signal provides a spike at boresight. As the antenna is rotated from the target position the sum signal decreases while the difference signal increases. This respective decrease and increase of the sum and difference signals causes the ratio
5 of the sum to difference signal pattern to decrease rapidly. Thus, the radiation pattern of the antenna is narrowed and the target position is more accurately determined.

Though processing the signal returns by dividing the sum signal by the difference signal improves target position accuracy
10 in a single target environment, in a multiple target environment, however, this type of processing may mask true targets and give rise to ghost targets. For example, when two targets having equal radar cross sections are within the same range bin and are positioned at equal angles on opposite sides of the boresight
15 line, the signal at the output of the sum channel will be that of a target at the antenna's boresight having a radar cross section that is twice that of each target weighted by the level of the antenna sum pattern at the angular position of the targets. Concomitantly, the signal at the output of the
20 difference channel will be a deep null. This results in a ratio of the sum channel output to the difference channel output that is near infinite, a strong indication of a target where there actually is no target, i.e. a ghost target indication.

Another monopulse technique utilized in the prior art for
25 beam narrowing derives a sum and difference signal, as described above, and, instead of dividing the sum signal by the difference signal, subtracts the magnitude of difference signal from the sum signal. Since the difference signal is at a null on boresight it has little effect on the peak of the sum signal. At angles
30 off boresight, however, the difference signal becomes significant and its subtraction from the sum signal appreciably reduces the composite signal. If the difference pattern has levels at the angular positions of the 3dB points of the sum pattern that are equal to these 3dB levels, the composite signal is zero at these
35 angular positions. When these conditions are met the beam width of the composite antenna pattern is effectively one half that of the sum pattern beam width.

Monopulse subtraction processing provides a somewhat better multi-target performance than monopulse division processing. In

monopulse subtraction processing, two targets within the difference beam, at equal angles on either side of the boresight line, add to provide a signal that appears to be on the boresight line. When this signal is subtracted from the sum beam signal, which is the sum of the two target signals in the sum beam, a null, which is a function of the angular position of the two targets, appears on boresight at the composite signal output. Thus, the ghost target at the boresight midway between the two targets is eliminated. When the antenna is scanned from its target balanced position, the two targets become asymmetrically positioned relative to the antenna boresight line, one providing a greater return in the sum pattern than the other. When the peak of the sum beam is at the one target position a deep null appears in the difference pattern, thus permitting the resolution of the two targets.

The composite signal output of monopulse subtraction processing, however, exhibits relatively high sidelobe levels. This is due to the fact that the level of the difference pattern lobes in the sidelobe region of the sum beam is appreciably greater than the sidelobe level of the sum beam. Consequently, subtracting the much greater signal of the difference pattern from the sidelobe of the sum pattern creates an undesirable high sidelobe level for the composite signal pattern, which may adversely effect target location determination.

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SUMMARY OF THE INVENTION

It is an object of this invention to provide an antenna and signal processor which has low sidelobes and improves the target resolution and position determination accuracy over that obtainable from a conventional antenna of equal size.

In accordance with the principles of the invention, an antenna of predetermined length is divided into three sections, two sections are combined as an interferometer and the third is a continuous antenna which has a main lobe that is broader than the lobes of the interferometer. The antenna has two modes of operation, transmit and receive. In the transmit mode, the three sections are combined to form a single antenna having a radiation pattern that is determined by the illumination function, which

is chosen to provide a desired sidelobe level for the transmit beam. In the receive mode, the continuous antenna section, which is illuminated by a portion of the illumination function, forms an antenna that is apart from the two sections that form the
5 interferometer. The sections forming the interferometer are illuminated by the remainder of the illumination function. Output signals of the interferometer are added to and subtracted from the output signal of the center section. These sum and difference signals are coupled to a video filter wherein they are
10 processed to provide a narrow beamwidth low sidelobe antenna pattern.

The invention will be more clearly understood from the following description of an embodiment thereof with reference to the accompanying drawings. It should be understood that the
15 embodiment described is an example of the invention and other embodiments may be implemented within the purview of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

20 Figure 1 is a block diagram of a preferred embodiment of the invention.

Figure 2 is a graph of an amplitude distribution which may be applied to the elements of the antenna of Figure 1.

25 Figure 3A is a radiation pattern for the antenna of Figure 1 in the transmit mode when the amplitude distribution shown in Figure 2 is applied.

Figure 3B is a radiation pattern of a central section of the antenna of Figure 1 when the central section of the amplitude distribution of Figure 2 is applied.

30 Figure 3C is a radiation pattern of the interferometer formed by end sections of the antenna of Figure 1 when the end sections of the amplitude distribution shown in Figure 2 is applied.

35 Figure 4 shows radiation patterns established by adding the interferometer pattern of Figure 3C to the central section pattern of Figure 3B and by subtracting the interferometer pattern from the central section pattern.

Figure 5 is a functional block diagram of the video filter of Figure 1.

Figures 6 - 9 are patterns at various stages in the video filter of Figure 1.

Figure 10 is a radiation pattern of the antenna system provided at the video filter output terminal.

5 Figure 11 is a two way radiation pattern of the central and end sections of Figure 1 operating as a continuous antenna.

Figure 12 is a two way radiation pattern at the video filter output terminals for a two target operating environment.

10 Figure 13 is a two way radiation pattern of a conventional antenna for a two target operating environment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Refer now to Figure 1. A segmented antenna system may
15 include an antenna 11 which is of length S. The antenna 11 may be divided into three sections, a center section 13 of length S/2 and left 15a and right 15b edge sections, each of length S/4. Left edge 15a and the right edge 15b are combined in a manner to form an interferometer having a base line that is equal to 3S/4.
20 Interferometer 15a,15b and the center section 13 may be coupled to a magic Tee 17, or other hybrid device, which provides the sum Σ and difference Δ of the interferometer and center section signals. The sum signal output port 17a of the magic Tee 17 may be coupled via a circulator 19 to a receiver 21. The difference
25 signal output port 17b of the magic Tee 17 may be coupled directly to the receiver 21. Since the interferometer 15a,15b has a base line that is longer than the length of the central section 13, it produces an antenna pattern which is narrower than the antenna pattern produced by the central section.
30 Consequently, the interferometer 15a,15b has a higher resolution capability than the central section. Due the higher resolution capability of the interferometer 15a,15b, in the description to follow, its output signal will be designated H, high resolution, and the central section 13 output signal will be designated L,
35 low resolution. Signals representative of the sum Σ and difference Δ signals are coupled from the receiver 21 to a power divider and hybrid circuit 22 wherein signals representative of the high H and the low L signals are derived from $H = (\Sigma - \Delta)/2$ and $L = (\Sigma + \Delta)/2$. These high H and low L representative

signals are coupled to a video filter 24, to which signals representative of the sum Σ and difference Δ signals are also coupled. A transmitter 23, for providing radiation signals, may be respectively coupled to the interferometer 15a, 15b and the central section 13 of the antenna 11 via the circulator 19 and the sum signal port of the magic Tee 17. Since the transmitter feeds both the central section 13 and the interferometer 15a, 15b simultaneously it provides the radiation signal for the entire antenna 11.

Figure 2 is an illustration of an antenna illumination function 25 that may be applied over the entire aperture of the antenna 11. The illustrative function 25 is a standard Taylor taper having defining parameters $\bar{n} = 2$ and sidelobe level (sl) = 16dB. It should be understood that this distribution function is not limiting and that other illumination functions may be used. Since the distribution is over the entire aperture, the left 15a and right 15b edge sections have distribution functions 25a and 25b, respectively, while the central portion 13 has the distribution function 25c. For S equal to 22.5λ (λ is the operating wavelength of the antenna), the aperture distribution function of Figure 2 gives rise to the antenna patterns shown in Figures 3A - 3C. Figure 3A is the transmit radiation pattern T of the entire aperture of antenna 11; Figure 3B is the receive pattern L for the central section 13; and Figure 3C is the receive pattern H for the interferometer 15a, 15b. The sum $\Sigma = L + H$ and difference $\Delta = L - H$ patterns at the output of the magic Tee 17 are shown in Figure 4.

The four signals (L , H , Σ , and Δ) are coupled to the video filter 24 wherein the signals are coupled through logarithmic amplifiers to a processor such as that shown in Figure 5. A constant A_1 is added to $\log(\Delta)$ in summer 27a. This sum is subtracted from $\log(\Sigma)$ in summer 27b and the difference is multiplied by g_4 in amplifier 29a. Subtraction of logarithms is the equivalent of dividing the antilog of the minuend by the antilog of the subtrahend. Though the constant A_1 is chosen to control the sidelobe level, this division may give rise to spikes in regions where the Δ pattern approaches zero. Spike levels may be controlled by coupling the output terminal of the

amplifier 29a to a limiter 31a having an output terminal 32a at which a signal representative of $\log[\Sigma/(a_1 \Delta)]^{g_4}$ is provided, where a_1 is the antilog of A_1 . With $A_1 = 0$ ($a_1 = 1$) and $g_4 = 1$, the pattern at the output terminal 32a of limiter 31a, as a function of antenna azimuth angle from a fixed target, is given in Figure 6.

Output terminal 32a of the limiter 31a is coupled to summer 27c, wherein the signal at the output terminal 32a is added to a signal coupled to the summer 27c from the output terminal 32b of summer 27d. The signal coupled from the output terminal 32b of summer 27d is the sum of $\log(\Sigma)$ multiplied by g_2 in amplifier 29b plus $\log(H)$ multiplied by g_3 in amplifier 29c, the product being added to A_2 in summer 27e prior to being coupled to summer 27d. The signals at the output terminal 32b of summer 27d and the output terminal 32c of summer 27c are respectively representative of $\log(a_2 \Sigma^{g_2} H^{g_3})$ and $\log\{a_2 H^{g_3} [\Sigma^{g_2+g_4}/(a_1 \Delta)^{g_4}]\}$, where a_2 is the antilog of A_2 . Patterns at the terminals 32b and 32c, when $A_2 = -18$, $g_2 = 0.5$, and $g_3 = 0.5$, are respectively shown in Figures 7 and 8.

Output terminal 32c of summer 27c is coupled to summer 27f wherein a constant A_3 is added. The signal at the output terminal of summer 27f is multiplied by g_5 in amplifier 29d and coupled to summer 27g wherein $\log(L)$, multiplied by g_1 in amplifier 29e, is subtracted therefrom. The difference signal at the output terminal of summer 27g is multiplied by g_6 in amplifier 29f and coupled to limiter 31b having an output terminal 32d at which a signal is provided which is representative of

$$\log\{[(a_2 a_3)^{g_5 g_6}/a_1^{g_4 g_5 g_6}] [H^{g_3 g_5 g_6}/L^{g_1 g_6}] [\Sigma^{(g_2+g_4) g_5 g_6}/\Delta^{g_4 g_5 g_6}]\}$$

A pattern for this signal is given in Figure 9, when $A_1 = 0$, $A_2 = -18$, $g_2 = g_3 = 0.5$, $g_4 = g_5 = g_6 = 1$.

The output terminal 32d of limiter 31b is coupled to summer 27h to which the output terminal 32c of summer 27c and a constant A_4 are also coupled. The three signals coupled to summer 27h are added to provide a signal at the output terminal 32e which is representative of

$$\log[C(H^{n1}/L^{n2})(\Sigma^{n3}/\Delta^{n4})].$$

Thus the sharpened antenna pattern is given by:

$$C(H^{n1}/L^{n2})(\Sigma^{n3}/\Delta^{n4})$$

where:

$$C = (a_2 a_3)^{g_5 g_6} a_2 a_4 / a_1^{g_4 (1 + g_5 g_6)}$$

$$n1 = g_3 (1 + g_5 g_6)$$

$$n2 = g_1 g_6$$

$$n3 = (g_2 + g_4) (1 + g_5 g_6)$$

$$n4 = g_4 (1 + g_5 g_6)$$

The output pattern of the video filter, the desired antenna pattern, when $A_1=A_4=0$, $A_2=-18$, $A_3=6$, $g_1=g_4=g_5=g_6=1$, and $g_2=g_3=0.5$ is shown in Figure 10. The beamwidth of the antenna pattern is approximately 1.40.

All of the above patterns are two way patterns, i.e. they are the result of transmitting the pattern shown in Figure 3A and processing the received L and H patterns of Figures 3B and 3C, respectively. As stated above, the antenna has an overall length of 22.5λ and a Taylor distribution with $\bar{n} = 2$ and $s_1 = 16\text{dB}$ over the entire antenna. A conventional antenna having a length of 22.5λ and a Taylor distribution with $\bar{n} = 2$ and $s_1 = 16\text{dB}$ will have an antenna pattern as shown in Figure 11. It is apparent from these Figures that a significant reduction in the beamwidth and sidelobe levels has been achieved with the segmented antenna and the video filter.

The above discussion has considered but one target. In a multiple target environment the beam narrowing realized with the segmented antenna 11 and the signal processing performed by the video filter 24 provides significant improvements in target resolution over that achievable with a conventional antenna of equal size without generating ghost targets. A two way pattern generated by the segmented antenna 11 and video filter 24 combination is shown in Figure 12. The targets are of equal radar cross-section, are at equal ranges, and are in Rayleigh distributed noise with an angular separation of 2.50° . The video filter processing parameters for the pattern of Figure 12 are:

$A_1=8$; $A_2=1$; $A_3=A_4=0$; $g_1=g_4=g_5=g_6=1$; $g_2=g_3=0.5$. Two discernible pattern peaks 35a and 35b, respectively representing target detections, are clearly indicated in Figure 12. These pattern peaks are separated by 2.5° and positioned 1.25° on either side of a deep null 37, no ghost targets are discernible. A conventional antenna having a length equal to the length of the segmented antenna 11 and a Taylor aperture taper with $\bar{n}=2$ and $s_1=16\text{dB}$ would have a beam width of approximately 2.8° . This conventional antenna would not be able to resolve two targets with 2.5° of angular separation.

A comparison of the two target pattern generated by the segmented antenna 11 with the video filter 24 processor to a two target pattern, shown in Figure 13, generated by a conventional antenna having a length twice that of the segmented antenna, indicates the superior performance of the segmented antenna system. The target indication peaks 35a and 35b in Figure 12 are substantially at the same angular positions as the target indication peaks 39a and 39b in Figure 13. The sidelobes 41 in Figure 12 have substantially the same peak levels as the sidelobes 43 in Figure 13. The null depth 37 between targets in Figure 12, however, is substantially greater than the null depth 45 between targets for the conventional antenna pattern of Figure 13.

While only certain embodiments of the invention have been described, it will be apparent to those skilled in the art that various changes and modifications may be made within the purview of the appended claims without departing from the true scope and spirit of the invention in its broader aspects.

CLAIMS

We claim:

1. An antenna system comprising:

5 an antenna (11) segmented and arranged to provide a first received signal at a first port and a second received signal at a second port, said second port coupled to segments of said antenna in a manner to establish an interferometer;

10 hybrid means (17) coupled to said first and second ports for adding said first received signal to said second received signal and for subtracting said first received signal from said second received signal, thereby forming sum and difference signals, respectively; and

15 processing means (21,22,24) coupled to receive said sum signal and said difference signal for processing said sum and difference signals in a manner to provide antenna beam sharpened signals.

2. An antenna system in accordance with claim 1 wherein said 20 antenna is segmented in a manner to provide a central section (13) and two end sections (15a,15b), said two end sections coupled to said second port to form said interferometer.

3. An antenna system in accordance claim 2 wherein said antenna 25 is of length S, said central section (13) is of length S/2, and each end section (15a,15b) is of length S/4.

4. An antenna system in accordance claim 2 wherein said processing means includes:

30 means (22) for extracting said first and second signals from said sum and difference signals; and

filter means (24) coupled to receive said first and second signals and said sum and difference signals for providing said antenna beam sharpened signals.

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5. An antenna system in accordance claim 4 wherein said filter means includes:

logarithmic amplifier means coupled to receive said first and second signals and said sum and difference signals for providing first and second log signals representative of logarithms of said first and second signals, respectively, and sum and difference log signals representative of logarithms of said sum and difference signals, respectively;

first sum means (27a,27b,27c,27d,27e) coupled to receive said sum and difference log signals and said second log signals for providing first addition signals representative of additions of said second log signals to signals representative of subtractions of said difference log signals from said sum log signals;

second sum means (27f,27g) coupled to receive said first addition signals and said first log signals for providing second addition signals representative of said first log signals subtracted from said first addition log signals; and

third sum means (27h) coupled to said first and second sum means for providing signals representative of additions of said first and second addition signals, thereby providing said antenna beam sharpened signals.

6. An antenna system in accordance claim 5 wherein said first sum means (27a,27b,27c,27d,27e) include first amplifier means (29a,29b,29c,29d) for respectively multiplying said second log signals, said sum log signals, said difference log signals, and said first addition signals and wherein said second sum means (27f,27g) includes second amplifier means (29e,29f) for respectively, multiplying said first log signals and said second addition signals.



7. An antenna system in accordance claim 6 wherein said first sum means (27a,27b,27c,27d,27e) includes means for respectively adding constants to said second log signals and to said difference log signals, said second sum means (27f,27g) includes means for adding a constant to said first addition signals, and said third sum means (32) includes means for adding a constant to said additions of said first and second addition signals.

3. An antenna system in accordance claim 1 wherein said processing means (21,22,24) includes:

means (22) for extracting said first and second signals from said sum and difference signals; and

filter means (24) coupled to receive said first and second signals and said sum and difference signals for providing said antenna beam sharpened signals.

9. An antenna system in accordance claim 8 wherein said filter means includes:

logarithmic amplifier means coupled to receive said first and second signals and said sum and difference signals for providing first and second log signals representative of logarithms of said first and second signals, respectively; and sum and difference log signals representative of logarithms of said sum and difference signals, respectively;

first sum means (27a,27b,27c,27d,27e) coupled to receive said sum and difference log signals and said second log signals for providing first addition signals representative of additions of said second log signals to signals representative of subtractions of said difference log signals from said sum log signals;

second sum means (27f,27g) coupled to receive said first addition signals and said first log signals for providing second addition signals representative of said first log signals subtracted from said first addition log signals; and

third sum means (27h) coupled to said first and second sum means for providing signals representative of additions of said first and second addition signals, thereby providing said antenna beam sharpened signals.



10. An antenna system in accordance claim 9 wherein said first sum means (27a,27b,27c,27d,27e) include first amplifier means ((29a,29b,29c,29d) for respectively multiplying said second log signals, said sum log signals, said difference log signals, and
5 said first addition signals and wherein said second sum means (27f,27g) includes second amplifier means (29e,29f) for respectively, multiplying said first log signals and said second addition signals.
- 10 11. An antenna system in accordance claim 10 wherein said first sum means (27a,27b,27c,27d,27e) includes means for respectively adding constants to said second log signals and to said difference log signals, said second sum means (27f,27g) includes means for adding a constant to said first addition signals, and
15 said third sum means (32) includes means for adding a constant to said additions of said first and second addition signals.
12. An antenna in accordance with claim 3 further including means (19) coupled to said hybrid means and said processing means
20 for coupling a transmitter (23) to said first and second ports in a manner to provide radiation from an antenna of length S.
13. A method for narrowing the beam of an antenna of predetermined size comprising the steps of:
25 segmenting said antenna to establish first and second sub-antennas, said second sub-antenna arranged to form an interferometer;
coupling said first and second sub-antennas to provide signals representative of sum and difference of first and second
30 signals at output ports of said first and second sub-antennas, respectively; and
processing said sum and difference representative signals in a manner to provide a beam narrowed signal.

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14. A method in accordance with claim 13 wherein said processing step includes the steps of:

extracting said first and second signals from said sum and difference representative signals;

5 coupling said first and second signals and said sum and difference representative signals to logarithmic amplifiers to obtain first and second log signals and sum and difference log signals;

10 subtracting said log difference signal from said sum log signal to provide a subtraction log signal;

adding said second log signal to said sum log signal to provide a sub-addition signal;

adding said sub-addition signal to said subtraction log signal to provide a first addition signal;

15 subtracting said first log signal from said first addition signal to provide a second addition signal; and

adding said first and second addition signals to provide antenna beam narrowed signal.

20 15. A method in accordance with claim 14 further includes the steps of:

multiplying said subtraction log signal by a first predetermined multiplicative constant;

25 multiplying said sum log signal and said second log signal by second and third multiplicative constants, respectively;

multiplying said first log signal and said first addition signal by fourth and fifth predetermined multiplicative constants, respectively; and

30 multiplying said second addition signal by a sixth predetermined constant.

16. A method in accordance with claim 15 further including the steps of adding preselected constants to said log difference signal, said second signal, said first addition signal, and to 35 said beam narrowed signal, respectively.



17. A method in accordance with claim 13 wherein said antenna is of length S , said first sub-antenna is of length $S/2$ and is a central section of said antenna and said second sub-antenna comprises two end sections of said antenna, each of length $S/4$.

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18. A method in accordance with claim 17 further including the step of coupling said central and said two end sections in a manner to provide an antenna with a radiating aperture of length S .

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19. A method in accordance with claim 13 wherein said processing step includes the steps of:

adding said sum and difference representative signals to obtain said first signal; and

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subtracting said difference signal from said sum signal to obtain said second signal.

20. A method in accordance with claim 18 wherein said processing step further includes the steps of:

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passing said first and second signals and said sum and difference representative signals through logarithmic amplifiers to respectively obtain first and second log signals and sum and difference log signals;

utilizing said first and second log signals and said sum and difference log signals to provide said beam narrowed.

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