This invention relates generally to omnidirectional transmitting antenna for microwave signals, and more particularly to novel horn antennas with toroidal configurations that effectively radiate "Tacon" navigational radio patterns.

The "Tacon" system derives from the military tactical air navigation system for aircraft. It utilizes the UHF range of 960 mc. to 1215 mc. The Civil Aeronautics Administration now requires that "Tacon" transmitter antennas be directly adaptable to efficiently transmit the patterned signals over any frequency in the low band (960 to 1024 mc.) or high band (1150 to 1215). A suitable radiator therefore needs to be relatively broadband. A further important requirement is that the transmitted "Tacon" pattern remain effective over an elevation range from the horizon to at least 60° above the horizon.

Prior antennas that provide the correct azimuth pattern generally fail to give a suitable vertical radiation pattern. A further serious limitation has been that the phase of the signal components that constitute the "Tacon" azimuth pattern was not constant with frequency over the bands. Critical dimensional relations with frequency prevented their general application over the "Tacon" bands as a particular antenna suitable for transmitting at a specific frequency, would radically distort the requisite pattern if used at a different frequency, even with moderate alteration.

The antenna of the present invention overcomes the aforesaid prior art shortcomings. The modulation of the carrier wave required for the azimuth is effected within a relatively small radiator, and the energy is thereafter radiated over a suitably shaped toroidal aperture or omnidirectional horn. The 360° horn configuration of the invention is stationary, and is coupled to the central modulation unit through a pair of parallel discs. The horn aperture is circular in the XY plane, and can be suitably flared in the Z or vertical plane to obtain a desired vertical radiation characteristic.

The radius of the omnidirectional radiator controls the match of the signal components to free space. By utilizing a relatively large radius, at least about seven times wave length the lowest carrier frequency used, excellent radiation characteristics result over the whole Tacon operation range. The modulator of relatively small radius is made concentric within the horn. The vertical height of the horn aperture is preferably made about half-wavelengths to be. There is no feedback to the coupling system, and the radiation is practically all outwardly in the desired pattern.

The invention radiator is not critical or frequency selective over a relatively broadband for UHF signals. It is efficient, stable, and mechanically rugged. The principles and features of the invention system, to be set forth in more detail, permit one to construct a radiator with any one of a wide diversity of nondirectional radiation patterns. It is relatively simple to meet the rigid requirements of the CAA stated herein above, therewith, where a rotating central modulator is used a toroidal choke couples the stationary discs for the horn with the peripheral region of the modulator.

It is accordingly a principal object of the present invention to provide novel toroidal radiators of microwave signals.

Another object of this present invention is to provide novel omnidirectional horn radiators suitable for producing "Tacon" system radiation patterns.

A further object of this present invention is to provide novel 360° horn radiators efficient over a relatively broadband of UHF signals.

Still another object of this present invention is to provide novel omnidirectional horn microwave radiation systems that are relatively of simple construction, and rugged.

These and other objects of the invention will become more apparent from the following description of exemplary embodiments thereof, illustrated in the drawings, in which:

**FIGURE 1** is a polar representation of an idealized Tacon radiation pattern, in a single elevation plane.

**FIGURE 2** is a polar representation in an azimuth plane of the Tacon modulated signal pattern.

**FIGURE 3** is a diagrammatic illustration in perspective of an XY omnidirectional signal source.

**FIGURE 4** is a plan view of an XY signal source like that of **FIGURE 3**, with a modulator to produce a Tacon signal pattern.

**FIGURE 5** is an enlarged cross-sectional view through the line 5—5 of **FIGURE 4**, illustrating a modulator element.

**FIGURE 6** is a partial plan view of an exemplary form of the horn radiator system of the invention.

**FIGURE 7** is an enlarged cross-sectional view taken along the line 7—7 of **FIGURE 6**.

**FIGURES** through 19 are illustrations of a number of exemplary configurations that the invention horn radiator may embody, and accompanying polar representations of the corresponding radiation patterns.

The CAA specifications for the radiated Tacon pattern is represented in polar form in **FIGURE 1**, in an elevation plane. Radial distance from the origin represents signal field strength as a function of elevation angle. The minimum requirement pattern is outlined as follows: starting at the origin 0, by the horizontal abscissa 21 to point 25 corresponding to six db gain over an isotropic course by an arc 26 to point 27, 5° above the horizon by cosecant line 28 parallel to the horizon to point 29, 60° above the horizon, and by a radial line 30 to the origin O. Radiation pattern 20 is a typical one, that encloure the minimum requirement pattern, and thus meets the specifications.

The basic "Tacon" signal pattern 35 comprises a uniform nine lobed spatial modulation 31, 31a as shown in **FIGURE 2**. The zero cycle is represented by the broken circle 32 centered on the side modulation is seen as essentially circular at 33, with its center at C displaced from the reference center C. Polar curve 35 is for a typical azimuth plane with point C as origin. The radiation per pattern 35 is rotated about origin C to effect the "Tacon" system operational signal distribution, in azimuth. The vertical distribution is represented by the polar configuration 20 of **FIGURE 1**.

The "Tacon"-type spatially modulated signals are generated by a suitable rotatable modulator. Reference is made to the copending patent applications Serial Number 742,646, filed June 17, 1958, entitled "Broad-Band Antenna," inventor David F. Bowman, now Patent No. 2,990,545; and Serial Number 809,690, filed April 29, 1959, entitled "Micro-Wave Strip Line Modulator," in-
ventor David F. Bowman, both assigned to the assignee of the instant application for illustrations thereof. The omnidirectional radiators of this invention may be used with such, and other omnidirectional modulators or generators, and with the modulator 50 incorporated in the secondary radiator system illustrated in FIGURES 6 and 7, corresponds to that described more fully in the aforesaid copending patent application, S. N. 742,546.

Reference is now made to FIGURES 3, 4 and 5 for an understanding of the operation of such modulators. FIGURE 3 illustrates converter 40 that is fed with a UHF or microwave signal $S_0$ at central coaxial transmission line 41. Two spaced metal discs 42, 43 are sandwiched between the two terminals of coaxial line 41. A uniform axial or $360^\circ$ signal pattern is projected by the transmission discs 42, 43, as indicated by the radial lines 45. Rotation of the disc array 42, 43 as indicated by arrow $a$ effects a direct rotational pattern of the source pattern 45.

The signals from source $S_0$ impinge at center $c$ of the discs 41, 42, and then radiate across the discs to their perimeters, as will be understood by those skilled in the art. To effect the multi-lobe spaced modulation for the Tacan modulator 50, a series of beam modulator elements are incorporated as a set of spaced discs 52, 53 as shown in FIGURES 4 and 5. Elements 51 are arranged in the peripheral region to modulate an incident uniform radial carrier signal with the nine multiple lobes (31, 31a) in accordance with FIGURE 2. The modulator elements 51 may be bolts secured through opposed apertures in the discs.

Nine uniformly positioned modulator elements 51 produce the requisite lobes. A tenth modulator element 54 is located radially closer to center $c$, and constitutes the fundamental modifier corresponding to curve 33 of FIGURE 2. A layer 55 of low dielectric loss material is sandwiched between discs 52, 53 for mechanical advantage. Suitable material therefore is polyform, Styrofoam, etc. As hereinabove stated, the particular omnidirectional signal pattern, or the spatial modulator source, utilized for the unit 50 in conjunction with the omnidirectional radiator system of this invention, is optional.

The exemplary omnidirectional radiator system is illustrated in FIGURES 6 and 7. The rotatable modulator 59 is centrally positioned within the annular horn radiator 60. As will be described in detail, the shape and flare of toroidal horn 60 may assume many forms for desired radiation patterns. Horn 60 comprises two annular sides 61, 62 extending from respective parallel metal discs 63, 64 which are mounted as a stationary assembly. Efficient electrical coupling is effected between the disc radial transmission line 63, 64 and the peripheral signal output of rotatable modulator 59 through annular chokes 65, 66. Chokes 65, 66 are proportioned to produce an electrical short circuit across respective plates 53, 63, and 52, 64 despite the mechanical break thereacross. Electrical signal continuity is thus maintained between modulator 50 when rotated, and the stationary discs 63, 64. No signal leakage takes place in view of the peripheral location of the chokes 65, 66.

The carrier signal ($f_0$) is fed to the modulator discs 52, 53 through a coaxial transmission line composed of rotatable shaft 70 and a metal tube 71 concentric therewith. The top end 70' of shaft 70 is secured with the center of disc 53 at 68, and forms a terminal for microwave input. Sleeve 71 has its rim connected along a corresponding central aperture at 71 with lower disc 52, to complete the RF coupling. The shaft 70 is connected by coupling 72 to drive motor 73. Rotation of motor 73, as in the direction of arrow $a$, rotates modulator 59 as a unit, including shafts 70, discs 52, 53 with dielectric layer 55, modulator elements 51a, and sleeve 71. A bearing 74 supports sleeve 71 in the vertical rotation.

The basic carrier signal ($f_0$) is fed to modulator 50 through the rotatable coaxial line 76, 71 connected therewith. The carrier signal is coupled to modulator 50 as a unit, including shafts 70, discs 52, 53 with dielectric layer 55, modulator elements 51a, and sleeve 71. Rotation of motor 73, as in the direction of arrow $a$, rotates modulator 59 as a unit, including shafts 70, discs 52, 53 with dielectric layer 55, modulator elements 51a, and sleeve 71. A bearing 74 supports sleeve 71 in the vertical rotation.

The invention section coupled to the radiator is not shown.

The bolt type 5A modulator elements would need simple
repositioning. The invention radiator system is of course
useable for other than Tacan omnidirectional applications.

With horn aperture the dimension A at least \( \lambda + 2 \), there is negligible feed-back on leakage of signal to
the radial transmission discs, and radiation is practically
all outwardly. This results in high radiation efficiency.
With the radius R dimension at least \( \lambda \), there is no
deterioration of the higher frequency signal components
(\( A_3 \cos 99 \)). There is thus no phase distortion among
the Tacan signal components radiated thereby. Also,
making the horn side flare angles \( \theta \) not greater than about
25\(^\circ\) prevents suitable signal strength to the 60\(^\circ\) elevation
temperature referred to.

The horn radiator 90 of FIGURE 10 has equal horn
sides 91, 92 each extending by the same angle \( \delta \), from
horizontal discs 93, 94 to an aperture \( A_3 \). The value of
\( \theta \) is shown at 35\(^\circ\), being substantially larger than that of \( \theta \)
of FIGURE 8 at 25\(^\circ\). The result is to flatten the pattern
radiated, as shown by polar curve 95 in FIGURE 11. Further
enlargements of the flare angles \( \theta \), of sides 91, 92
would still further flatten this output pattern. In special
applications where such is desired, this principle may be
utilized.

With the flare angles reduced to a lower value than
that of \( \theta \) of FIGURE 8, a further bulge occurs in the
radiated pattern, as indicated by polar curve 105 of FIGURE 13.
The corresponding smaller angle \( \theta_2 \)*, illustrated in FIGURE 13, and electrically coupled to each such unit 100
comprizes a shallow flared horn 101, 102 extending
symmetrically from discs 103, 104. It is to be noted that
the radiation patterns 85, 95 and 105 are all symmetrical
about the horizontal. This in turn is due to the
symmetrical arrangement of their corresponding horn
radiators.

The radiation patterns may be readily tilted to the
horizontal with the invention system. One method is to
use a different flare angle for the horn sides. This is
illustrated by horn 110 in FIGURE 14. The angle \( \theta_3 \)
of horn side 111 to disc 113 is greater than angle \( \theta_3 \)
of side 112 to disc 114. The sides 111, 112 extend equal
to radius R, and form aperture \( A_3 \). The length \( L_3 \)
and \( L_4 \) of these sides are determined once spacing \( S \) is
selected. The result is that the pattern 115 is tilted upwardly
by an angle \( \phi_4 \)* as noted in FIGURE 15. This tilt angle is
controlled by the selected azimuth angle \( \phi_4 \).

Another way to tilt the radiated pattern is shown by
horn system 120 of FIGURE 16. The lower horn side
121 is made longer (LB) than that of (LA), the upper
122. Also, lower side 121 is an extension of disc 123,
and upper horn side 122 is an extension of disc 124.

The result is pattern 125 of FIGURE 17 with a tilt angle \( \phi_5 \)
greater than angle \( \phi_2 \) of FIGURE 15. The degree tilt \( \phi_5 \)
controlled by the relative proportioning of \( L_3 \) to \( L_2 \)
and \( \theta_5 \).

In FIGURE 18, the lower horn side 131 of array 130
is longer than side 132, as in horn 120, but is flared by an
angle \( \phi_4 \)* to disc 133. Upper side 132 is arranged at
an angle \( \phi_4 \)* to disc 134, greater than \( \theta_4 \). A tilted pattern
in the manner of FIGURE 17 results. The relative
lengths of the horn sides are more effective in producing
the tilt than the relative angles thereof. A further form
of horn array for radiation pattern tilting is shown at 140

In FIGURE 19. A symmetrical horn arrangement 141,
142 extends from discs 143, 144. A toroidal lens 145
arranged between horn sides 141, 142 suitably shaped to
slow down the waves along the upper horn section, as
along side 141. The lens 145 sees to be thicker at the base
146 contiguous with side 141. Lens 145 is of low-lose
dielectric material, as polystyrene, Teflon, etc.

In summary, it is now evident that a wide variety of
radiation pattern characteristics can be obtained by suit-
able shaping of the horn aperture in the vertical or A plane.
Further, the opposite horn sides may be made curved in
conventional horn practice. The aperture of
the horn antenna hereof can be considered equivalent to
ring layers of local electric and magnetic currents, the
amplitude of which is a function of azimuth angle and
is directly related to the azimuth pattern. With the apar-
"
References Cited in the file of this patent

UNITED STATES PATENTS

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Inventor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,283,935</td>
<td>King</td>
<td>May 26, 1942</td>
</tr>
<tr>
<td>2,549,143</td>
<td>Tinus</td>
<td>Apr. 17, 1951</td>
</tr>
<tr>
<td>2,564,703</td>
<td>Litchford</td>
<td>Aug. 21, 1951</td>
</tr>
<tr>
<td>2,565,506</td>
<td>Litchford</td>
<td>Aug. 28, 1951</td>
</tr>
<tr>
<td>2,567,220</td>
<td>Litchford</td>
<td>Sept. 11, 1951</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Inventor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,596,190</td>
<td>Wiley</td>
<td>May 13, 1952</td>
</tr>
<tr>
<td>2,677,766</td>
<td>Litchford</td>
<td>May 4, 1954</td>
</tr>
<tr>
<td>2,700,138</td>
<td>Craick</td>
<td>Jan. 18, 1955</td>
</tr>
<tr>
<td>2,711,533</td>
<td>Litchford</td>
<td>June 21, 1955</td>
</tr>
<tr>
<td>2,939,141</td>
<td>Casabona</td>
<td>May 31, 1960</td>
</tr>
</tbody>
</table>

FOREIGN PATENTS

<table>
<thead>
<tr>
<th>Country</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Britain</td>
<td>Dec. 31, 1952</td>
</tr>
</tbody>
</table>

885,073