Some Notes on Turnstile Antenna Properties

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The turnstile antenna is one solution to the occasional need for an omni-directional, horizontally polarized antenna. Often described as a "fairly simple" antenna consisting of 2 dipoles and a 90° phasing line, the turnstile has often disappointed builders. In the belief that much of the disappointment stems from a lack of understanding of how the turnstile does its work within its limiting factors, I have compiled the following design and performance notes. I hope that they will lead to better turnstiled antennas.

Why Does the Turnstile Seem So Simple?

The most usual turnstile antenna design consists of 2 resonant horizontal dipoles for a given frequency. We set them at right angles to each other, using any convenient form of support. The main feedline goes to one of the two dipoles. A 90° length of transmission line--the phasing line--connects the feedpoint of Dipole 1 to Dipole 2. **Fig. 1** shows the general scheme.

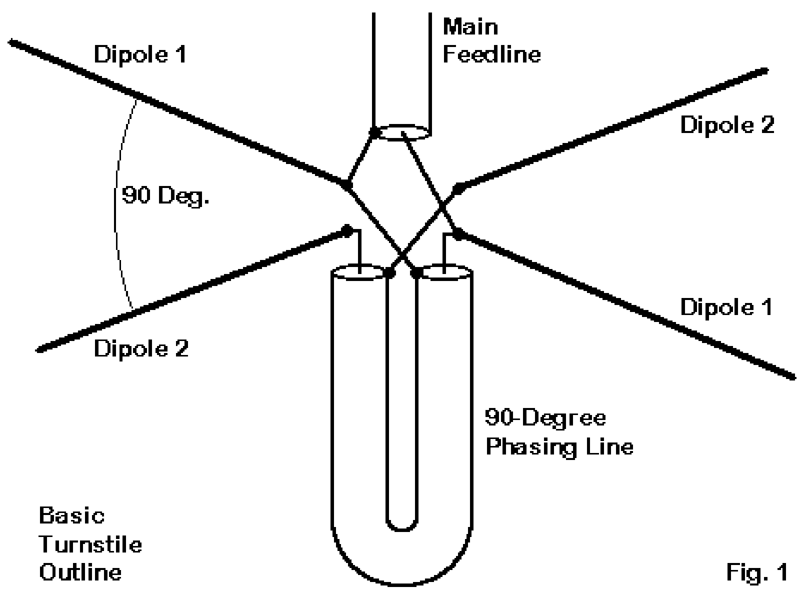


Fig. 1

If we construct such an antenna and place it 1 λ above ground, then the lowest elevation lobe will form--at 14° above the horizon--an azimuth pattern similar to the one shown in **Fig. 2**. Because the beamwidth of each of the 2 dipoles is under 90°, there is not quite enough signal strength from each dipole on the 45° axes to completely circularize the overall pattern. However, the difference between the peaks broadside to each dipole and the "null" between peaks is only about 1 dB. For virtually all purposes, the pattern is omni-directional. The maximum gain of the model used to produce this pattern is about 4.7 dBi, about 3 dB below the maximum gain of a single dipole. In part, the gain reduction is the price of spreading a single dipole bi-directional pattern over the full horizon.

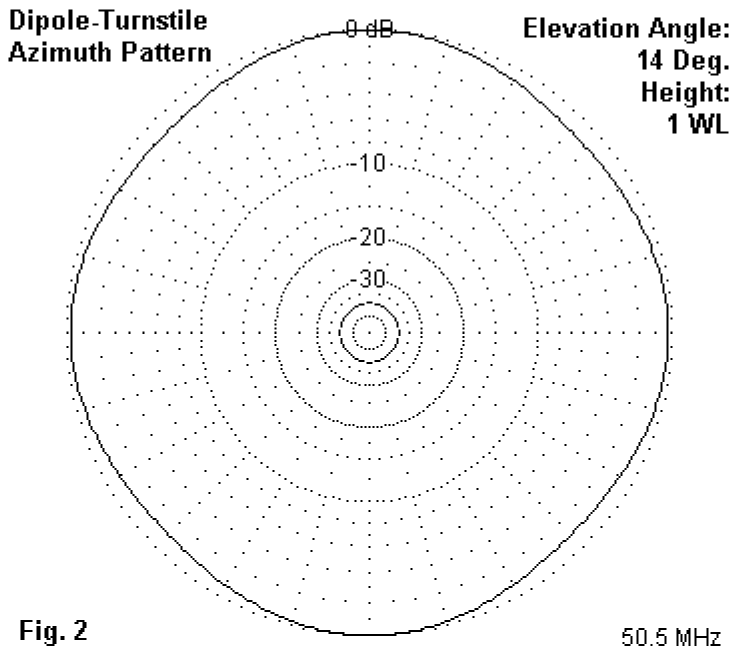


Fig. 2

A turnstile presents a very broad SWR curve, as illustrated by **Fig. 3**. Perhaps this fact more than any other lures the casual builder into believing that the turnstile is an easy antenna to build successfully. However, the very shallow SWR curve is very misleading. Even poorly constructed turnstiles with woefully distorted patterns relative to the omni-directional ideal will exhibit very low SWR values.

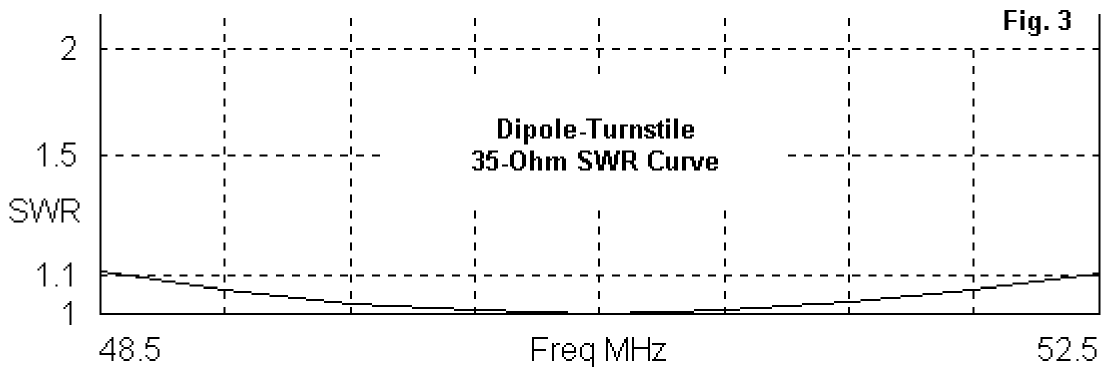


Fig. 3

We may list the conditions for achieving a successful (omni-directional) standard dipole-turnstile antenna fairly briefly. First, the individual dipoles should be resonant, that is, they should show virtually no reactance at each feedpoint. Second, the phaseline characteristic impedance should equal the feedpoint impedance of the individual dipoles. The length of the line should be 1/4 λ or 90° electrically relative to a full wavelength. The physical length of the phaseline should be adjusted by multiplying the required electrical length by the velocity factor of actual line used. For most coaxial cables, the range of velocity factors will run between 0.66 for solid dielectric cables, to 0.78 for many foam dielectric cables, to 0.84 for some specialty cables (such as RG-63).

The impedance presented by the main feedpoint of the assembly will be one-half the impedance of each individual resonant dipole. The key model with which we shall perform our investigations consists of two 50.5-MHz dipoles of 0.44" diameter aluminum. (The diameter results from estimating the effective diameter of elements composed partially of 1/2" tubing and partially of 3/8" tubing.) The element lengths are 111.6" (0.4775 λ) for each dipole. The elements are vertically separated in the model by a little over 1" (0.005 λ) to avoid inaccuracies that occur when even modeled crossing wires are too close to each other. The transmission line is set with a modeled velocity factor of 1.0 in order to use the electrical length of the line throughout. Hence, the line of this initial model is 0.25 λ long at 70-Ω impedance. With the model 1 λ above good ground, the antenna shows a feedpoint impedance of 35.07 - j 0.03 Ω. The overly precise numbers for the source impedance suggest how little reactance the turnstile feedpoint may present.

Although often thought of as an impedance matching line, the cable connecting the dipoles of a standard turnstile is a true phasing line. As such, its task is to present the second dipole with a certain current magnitude and phase angle relative to the first dipole. Essentially, the current magnitude on the second dipole should be equal to that on the first dipole with a phase angle difference of 90°. As we shall see, many of the difficulties that we may encounter with turnstiles result from not fully appreciating the fact that current, and not impedance, is the key parameter for the system. The primary model shows on dipole 1 a current magnitude of 0.489 at a phase angle of -0.07°. Dipole 2 shows 0.501 at -90.05°. The current ratio of the two elements is 0.976, with a phase angle difference of 89.98°, and the azimuth pattern of Fig. 2 is the result. Although the current magnitude and phase angle values may seem superfluous at first sight, they become the heart of understanding turnstile performance.

The Basic Properties of Turnstiled Antennas

One useful technique to increase our appreciation of the performance of any antenna type is to systematically vary some of the operating parameters. Since the SWR curve in Fig. 3 is so flat--barely 1.1:1 at 2 MHz above and below the design frequency of our basic model--let's examine other properties as we move away from the center frequency. **Table 1** lists the current conditions of the primary model 1 MHz below and above the design frequency--about a 2% frequency change per step. Although we note some change in the ratio of current magnitudes for the dipole elements, the most drastic change occurs with respect to the phase angle between the two elements--about 12° in each case.

Turnstile Current Conditions Above and Below Design Frequency

Frequency	Dipole 1		Dipole 2		I Ratio	Phase
MHz	I Mag.	I Phase	I Mag.	I Phase		Diff.
49.5 MHz	0.507	14.99	0.518	-87.96	0.979	102.95
50.5 MHz	0.489	- 0.07	0.501	-90.05	0.976	89.98
51.5 MHz	0.460	-15.14	0.513	-93.90	0.897	78.76

Table 1. Turnstile current magnitude and phase angle conditions about 2% above and below the design frequency (50.5 MHz).

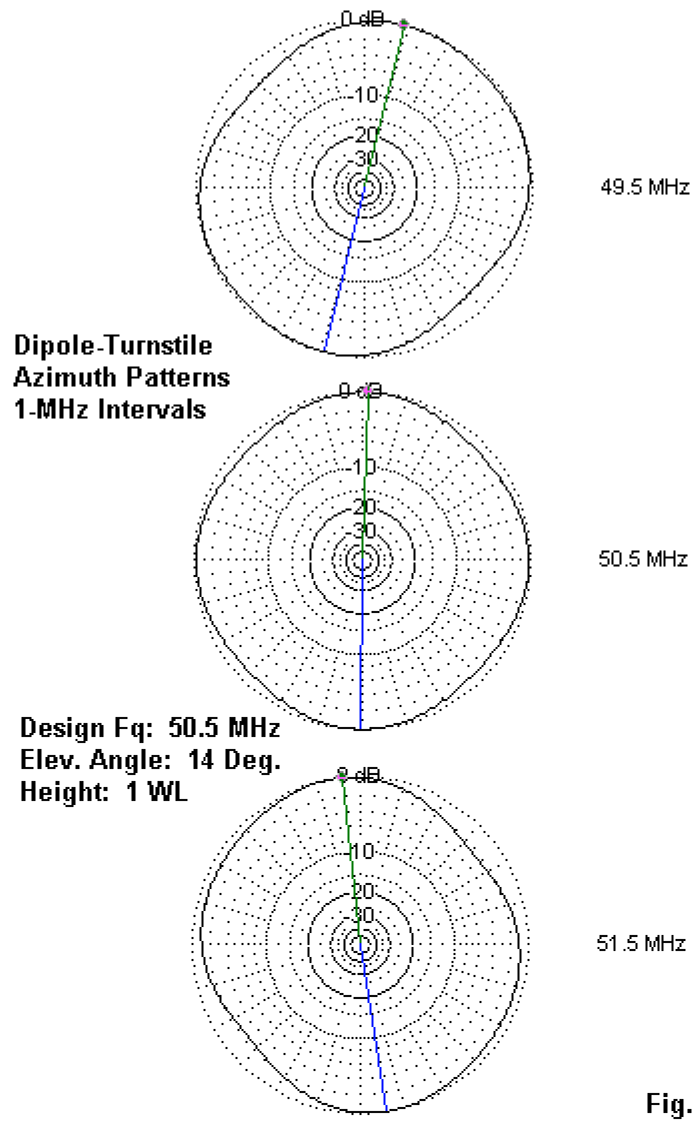


Fig. 4

As **Fig. 4** demonstrates, the change in phasing has consequences for the azimuth pattern of the antenna. Whereas at the design frequency, the maximum gain differential around the pattern was 1.03 dB, the gain differential at 49.5 MHz is 2.21 dB and at 50.5 MHz is 2.51 dB. The differential grows as we further depart from the design frequency, resulting in bi-directional oval patterns rather than an omni-directional pattern. How much "ovalizing" of the pattern one may tolerate is a user judgment based on operating requirements. However, -3 dB is the standard half-power level and the patterns in Fig. 4 are fast approaching this level of distortion of the ideal pattern.

Notice as well that the azimuth angle of maximum gain shifts in opposite directions above and below the design frequency. A larger phase angle tends to force the pattern clockwise relative to the ideal, while a smaller phase angle tends to shift the pattern counter-clockwise.

The exercise in varying the frequency of the dipole-turnstile is equivalent to one in which we might begin with antennas that are not very close to resonance. At 50.5 MHz, the 111.6" dipole impedance is 71.8 + j 0.0 Ω. At 49.5 MHz, the dipole shows an impedance of 68.7 - j 18.0 Ω, while at 51.5 MHz, the dipole impedance is 75.1 + j 18.4 Ω. Dipoles that are off resonance by the same degree at the design frequency but which use an accurately cut phaseline will show similar patterns to the distorted ones in **Fig. 4**.

Turnstile Current Conditions With Short and Long Phaselines

Line Length	Dipole 1		Dipole 2		I Ratio	Phase
λ	I Mag.	I Phase	I Mag.	I Phase		Diff.
0.20	0.490	- 0.41	0.501	-72.05	0.978	71.64
0.21	0.490	- 0.35	0.501	-75.65	0.978	75.30
0.22	0.489	- 0.29	0.501	-79.25	0.978	78.96
0.23	0.489	- 0.22	0.501	-82.85	0.978	82.63
0.24	0.489	- 0.14	0.501	-86.45	0.978	86.31
0.25	0.489	- 0.07	0.501	-90.05	0.978	89.98
0.26	0.489	+ 0.00	0.501	-93.65	0.978	93.65
0.27	0.489	+ 0.08	0.501	-97.25	0.978	97.36
0.28	0.489	+ 0.16	0.501	-100.8	0.978	100.96
0.29	0.489	+ 0.23	0.501	-104.4	0.978	104.63
0.30	0.489	+ 0.30	0.501	-108.0	0.978	108.30

Notes: Phaseline characteristic impedance: 70 Ω.

Table 2. Turnstile current magnitude and phase angle conditions with changing phaseline lengths.

A second way in which we may systematically alter the parameters of turnstiled dipoles is to vary the length of the phaseline from its desired electrical length of 0.25 λ. **Table 2** shows the results of varying the line length up to a limit of 20% shorter and longer. Very noticeable in the table is the fact that the current magnitude ratio between the dipoles does not vary within the limits of the decimal places to which I have carried out the values. In contrast, the relative phase angle between the elements does change very significantly--and virtually linearly. **Fig. 5** shows the linear change of relative phase angle with a linear change in phaseline length.

A change in line length corresponds roughly to errors in the construction of the phaseline that may result from simple slips to failing to take the velocity factor of the line into account when measuring the physical line length. Such errors result in azimuth patterns that depart from the ideal. Of note is the fact that despite a similarity in phase angles between certain line is **Table 2** and **Table 1**, the azimuth pattern distortion increases more rapidly as we increase the line length above the optimum value than when we shorten the line. However, note that the 51.5-MHz pattern in Fig. 4 and Table 1 shows a greater departure from the ideal current magnitude ratio than the lines in **Table 2** that approximate the 103° phase angle. As a consequence, errors that result in slightly short phaseline lengths are less harmful to pattern shape than those that result in lines that are too long.

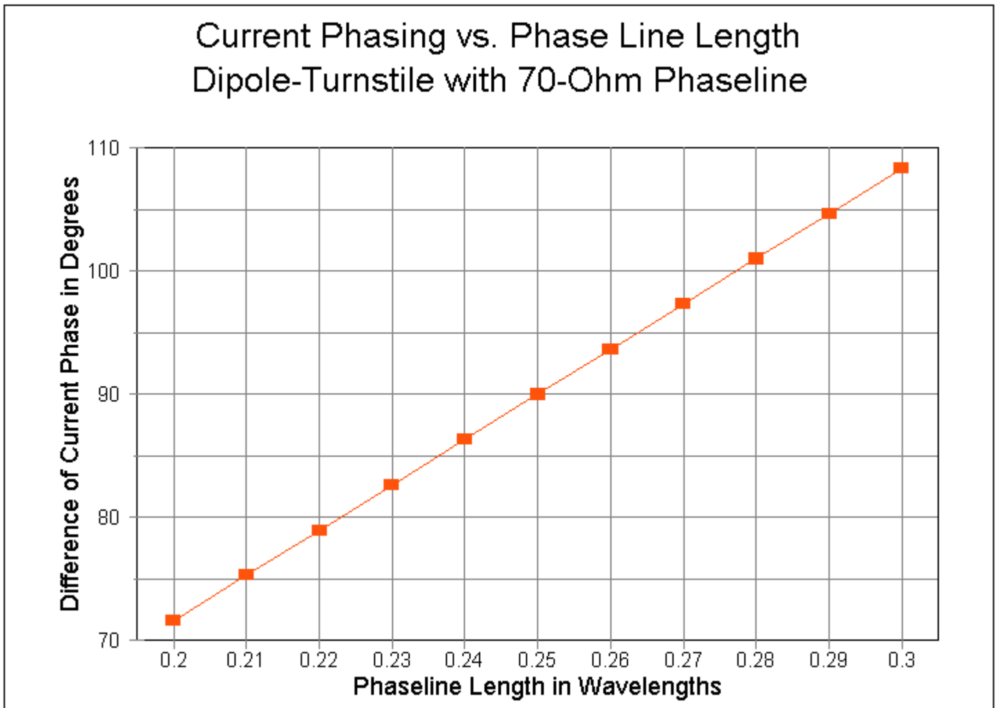


Fig. 5

A comparable set of distortions occurs whenever we press into service phaselines having a characteristic impedance other than the required value. The available lines for an accurately built dipole-turnstile consist of RG-11, RG-59, and similar 70 to 75 Ω cables. A 5-Ω range of characteristic impedance creates no significant variations in patterns. However, let's suppose that we try to use a 50-Ω cable (RG-8, RG-58, etc.) or a 93-Ω cable (RG-62).

Turnstile Current Conditions With Phaselines of Different Characteristic Impedances

Line Zo	Dipole 1		Dipole 2		I Ratio	Phase
Ω	I Mag.	I Phase	I Mag.	I Phase		Diff.
50	0.328	- 0.09	0.470	-90.07	0.698	89.98
70	0.489	- 0.07	0.501	-90.05	0.978	89.98
93	0.628	- 0.05	0.484	-91.14	1.298	91.09

Table 3. Turnstile current conditions with phaselines of different characteristic impedances.

Table 3 shows the results of our little experiment. Phaseline characteristic impedances that are off the required value result in very little change in the relative phase angle of the currents on the two dipoles. However, they do result is radical changes in the ratio of current magnitudes, with the low Zo resulting in a ratio 30% below ideal and the high Zo yielding a current magnitude ratio that is 30% too high. When the phase angle remain very close to the desired 90° value and only the current ratios change, the patterns do not bend clockwise or counterclockwise. Instead, as shown in **Fig. 6**, the patterns become oval bi-directional patterns in the broadside direction to the dipole with the higher relative current. (In all azimuth patterns, 0° is to the right and 90° is straight up, according to the conventions used in EZNEC, the software used for these studies. Think of Dipole 1 as extending vertically on the plot grid, with

Dipole 2 extending horizontally across the grid.) The 50-Ω sample shows a gain differential of about 3.1 dB, while the 93-Ω example shows a gain differential of about 2.3 dB.

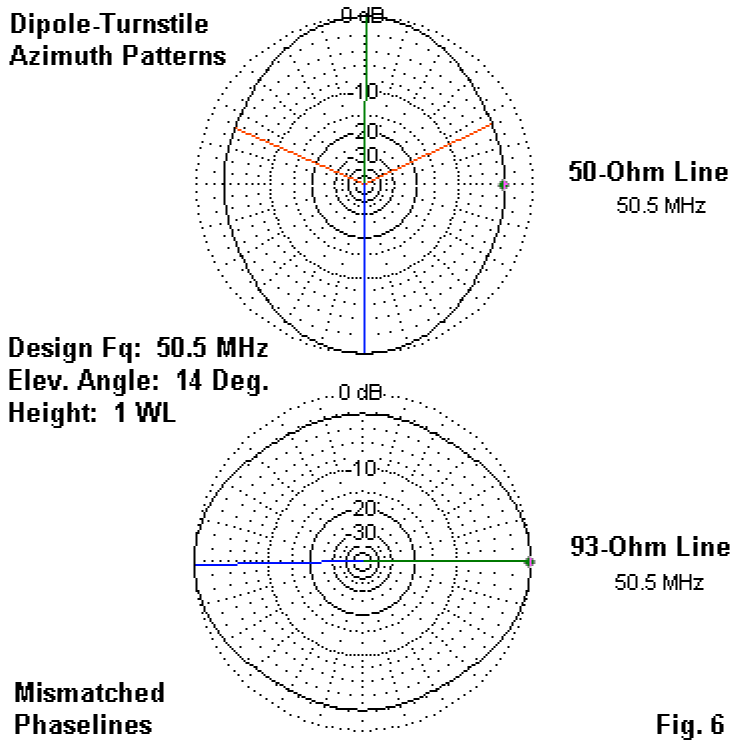


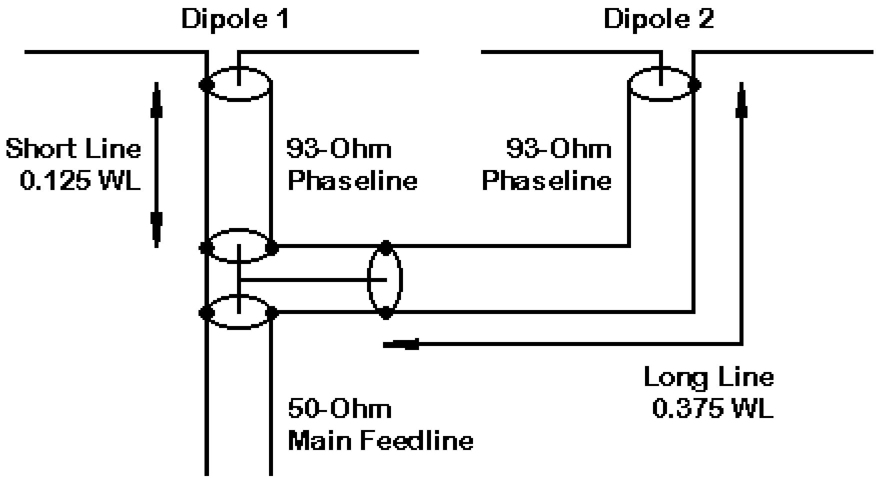
Fig. 6

These notes have related various imperfect conditions of relative current magnitude and phase angle to ways in which we can construct or operate a dipole-turnstile in a non-ideal mode. For a brief discussion of the direct relationship of turnstile azimuth patterns and current conditions, see the Appendix at the end of these notes.

Matching a Turnstile to a Main Feedline

Our survey of basic turnstiled dipole properties has displayed some of the sources and effects of current magnitude and phase angle offsets relative to optimized values. However, the survey has so far not tackled the fact that the overall feedpoint impedance of the dipole-turnstile is 35 Ω (with virtually no reactance). Although numerous users are content with an SWR of about 1.43:1 relative to a 50-Ω main feedline--especially since it does not significantly change over a large bandwidth--other users have striven for a closer match to their main feedline.

One scheme with several variations appears in **Fig. 7**. The principle is to calculate line lengths of a cable that will achieve two goals. First, the selected line and line lengths, when combined in a parallel connection, will yield close to a 50-Ω impedance. The line used in our example will be a 93-Ω cable (RG-62). Second, the relative line lengths to the individual dipoles will preserve a 90° impedance differential between the two dipoles, thus providing the conditions for an omni-directional pattern. The required line lengths are 0.125 λ for the short cable and 0.375 λ for the long cable.



Combined Phasing and Impedance-Matching System

Fig. 7

When we model this system using our basic 50.5-MHz dipole-turnstile, we obtain some interesting results. Version A of **Table 4** shows the numerical results of the dual-cable feed system. As calculated, the feedpoint impedance of the parallel combination of the lines is very close to 50 Ω. However, the relative phase angle between the two dipoles is seriously low. The top azimuth pattern in **Fig. 8** shows the degree to which the pattern has lost its desired omni-directional properties.

Simple and Modified 2-Cable Turnstile Feed Systems

Version	Short Cable Length λ	Zo	Long Cable Length λ	Zo	Feedpoint Impedance
A	0.125	93	0.375	93	48.3 - j 0.2 Ω
B	0.125	93	0.418	93	44.6 - j 0.1 Ω
C	0.080	93	0.375	93	44.5 - j 0.2 Ω
D	0.102	93	0.397	93	44.6 - j 0.1 Ω

Version	Dipole 1		Dipole 2		I Ratio	Phase
	I Mag.	I Phase	I Mag.	I Phase		Diff.
A	0.587	-53.25	0.589	-127.2	0.997	73.95
B	0.542	-53.17	0.587	-143.2	0.923	90.03
C	0.585	-36.40	0.542	-127.2	1.079	90.80
D	0.564	-44.93	0.565	-135.10	0.998	90.17

Table 4. Simple and modified feed system properties for a dual-cable turnstile feed system.

The failure of the impedance-based calculations to achieve the desired omni-directional pattern results from a failure to appreciate that the phasing of a turnstile antenna rests upon current transformations along transmission lines. Only when the cable impedance is a relatively perfect match with the individual dipole feedpoint impedance will the current and impedance track along a line. Since the dual-cable technique requires a mismatch to achieve the desired overall feedpoint impedance, the current will not change its magnitude and phase angle at the same rate as the impedance.

We can correct the current values by changing the lengths of one or both cables. Table 4 shows the limiting cases, that is, a correction by changing only one of the two cables. Version B of the dual cable system lengthens the longer cable to 0.418 λ while leaving the short cable unchanged. Version C shortens the shorter cable to 0.080 λ while leaving the long cable unchanged. The table shows phase differentials between the two dipoles within 1° of the ideal phase angle, with current magnitude ratios within 10% of ideal. The lower azimuth patterns in **Fig. 8** display the improved azimuth patterns.

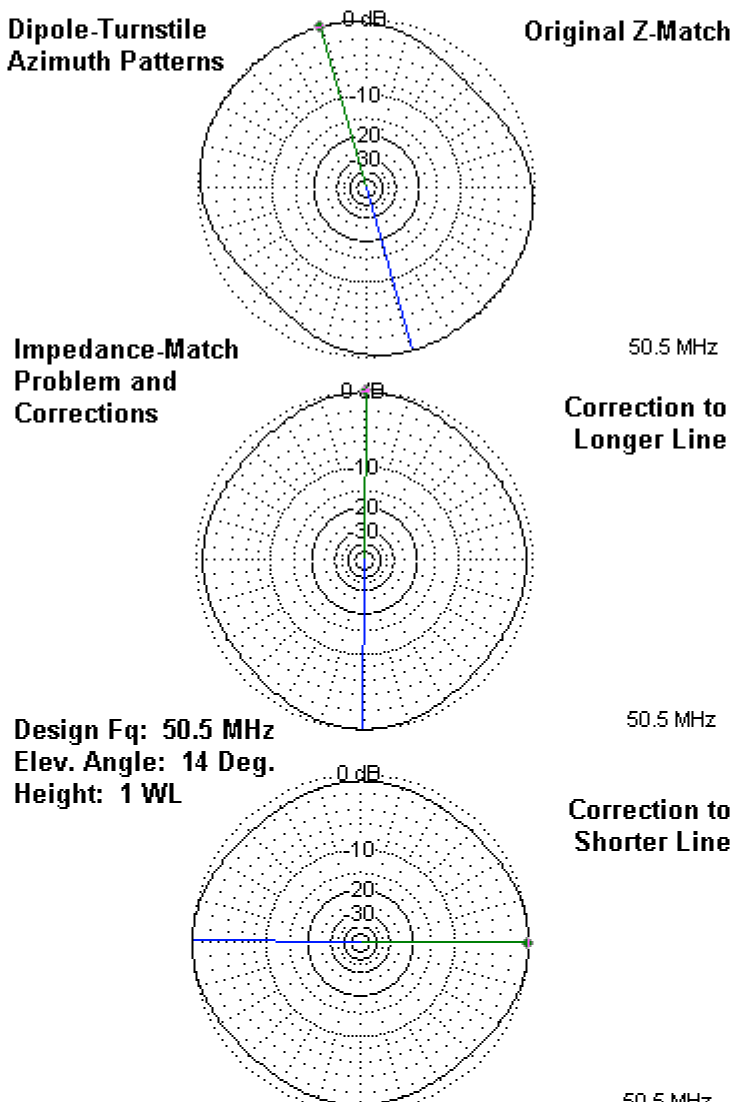


Fig. 8

Many combinations of shortening the short and lengthening the long cable in the system will also yield the desired phase angle differential between the two dipoles. A combinatory change will also remove the 0.7 dB differential between pattern peaks at 90° angles from each other. Although in principle, one may calculate the combination of cable lengths required, trial modeling will likely uncover them more rapidly. Entry D in Table 4 shows a combination of lines that yields a very good result, with only a 0.01 dB variation between peak gain values at azimuth headings of 0° and 90°.

There are a number of matching techniques that we may employ to raise the 35-Ω dipole-turnstile impedance to 50 Ω without altering the original 0.25-λ 70-Ω phaseline. One system owes to Bramham and appears in **Fig. 9**. The system requires two cable sections, one matching the impedance of the load (which should be purely resistive), the other matching the main feedline. For our example we shall use 35-Ω cable (RG-83) and 50-Ω cable (RG-8 or equivalent). Fig. 9 shows a length of the 35-Ω cable between the turnstile feedpoint and the beginning of the matching sections. However, we may reduce that length to zero.

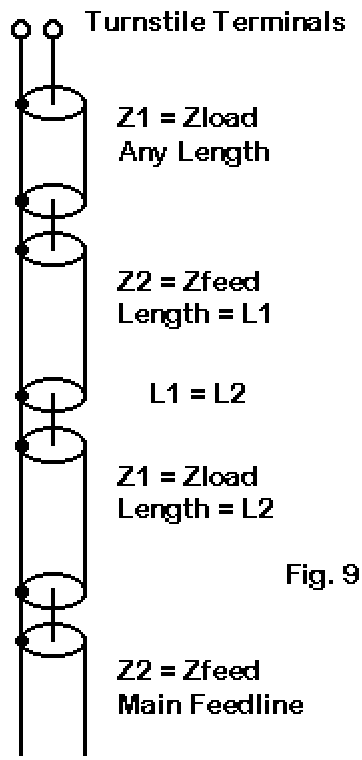


Fig. 9

The Bramham Coaxial Line Matching System

To calculate the required lengths, L_1 and L_2, we begin by calculating a special term, M:

$$M = \left(\frac{Z_2}{Z_1} + 1 + \frac{Z_1}{Z_2} \right) \qquad \mathbf{1}$$

where Z_1 is the load impedance, 35 Ω, and Z_2 is the main feedline impedance, 50 Ω. The line lengths then follow from the equation

$$L_1 = L_2 = \arctan \frac{1}{\sqrt{M}} \qquad \textbf{2}$$

where the answer emerges as an electrical length in degrees for conversion into a fraction of a wavelength and then into a physical line length. L_1 and L_2 will always be under 30°, and the values required for the present case are 29.48°. This length translates into 0.082 λ, or just over 14.1" before adjustment for the cable velocity factor.

The Bramham series matching technique requires a line that matches the load. Often, such lines may not be available conveniently, and sometimes not at all. A more general series solution uses the Regier technique, fully described in *The ARRL Antenna Book* since the 1980s (pages 26-4 and 26-5 in the most recent editions). **Fig. 10** illustrates the technique. We need a section of the main feedline (Z_1 at length L_1) and a second section of a line of choice (Z_2 at length L_2). Not all choices will work, but for our case, we can use sections of 50-Ω line and 70-Ω line, both of which we presumably have, since we already have the dipole-turnstile phaseline and the main feedline for the system. Since our feedpoint impedance is virtually purely resistive, we can simplify the calculations somewhat.

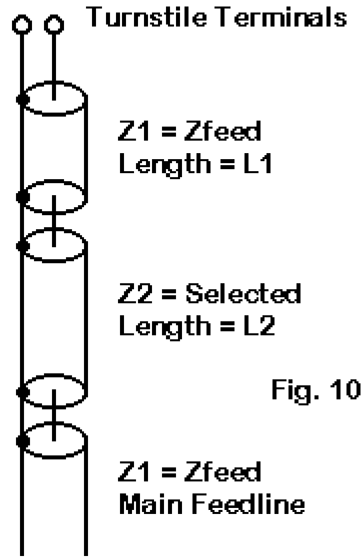


Fig. 10

The Regier Series-Section Matching System

First, we calculate a pair of normalized values, n and r,

$$n = \frac{Z_2}{Z_1} \qquad r = \frac{R_L}{Z_1} \qquad \textbf{3}$$

where Z1 is the impedance of the main feedline, Z_2 is the impedance of the selected line, and R_L is the resistive component of the dipole-turnstile feedpoint impedance. We next calculate the length, L_2, of the series section:

$$L_2 = \arctan \sqrt{\frac{(r-1)^2}{r\left(n-\frac{1}{n}\right)^2-(r-1)^2}} \quad \textbf{4}$$

The series length of feedline, L_1, requires the length L_2 for its result:

$$L_1 = \arctan \frac{\tan L_2\left(n-\frac{r}{n}\right)}{r-1} \quad \textbf{5}$$

Although the Regier calculations appear more forbidding, even without their reactance terms, utility programs such as HAMCALC from VE3ERP contain the necessary steps and require only a few inputs for accurate outputs. For our situation, using 50-Ω and 70-Ω cables, L_1, is 0.329 λ of 50-Ω line, while L_2 is 0.088 λ of 70-Ω cable.

Both the Bramham and Regier series matching networks yield a 50-Ω SWR curve that does not reach 1.05:1 at 49.5 and 51.5 MHz. As well, they have the advantage of not altering the current magnitude and phase angle established by the original 70-Ω phaseline. Equally usable, but at a higher SWR level, would be a 1/4-λ matching section composed of paralleled lengths of RG-62. The resulting 46-Ω line will transform the 35-Ω turnstile terminal impedance to about 61.8 Ω. If a 1.24:1 SWR is acceptable and if the requisite cable is available, the quarter-wavelength series section may be the simplest system of all.

Besides handling the dipole-turnstile matching challenge, the series matching systems may also be useful in other cases of turnstiled antennas. Not every case of turnstiling involves only dipoles.

A Special Case of Obtaining a Match and Quadrature

Zack Lau, W1VT, brought to light a special case that will yield the 90-degree phase shift while maintaining equal current magnitudes on the turnstile elements in *QEX* for November/December, 2001 (page 55). The conditions required are that antenna 1 have a feedpoint impedance of R + jR and that identical antenna 2 have an impedance of R - jR. Ordinarily, R is the resonant impedance of the individual antenna, and +jR and -jR are inductive and capacitive reactances introduced at the feedpoint of each antenna. Under these conditions, from a single source, the individual antennas will have equal magnitude currents and voltages that are 90° apart, along with a resistive impedance that is the value of the resonant impedance of an individual unloaded antenna.

The parallel combination of the two independent loaded impedances with equal but opposite reactive components equal to the resistive component meets the following condition:

$$\frac{(R+jR)(R-jR)}{(R+jR)+(R-jR)} = \frac{2R^2}{2R} = R \quad \textbf{6}$$

Although there may be numerous combinations of R and +/-jX for each antenna that will yield a 90° phase difference and equal current magnitudes and likewise many impedance combinations that will result in a parallel feedpoint impedance R, the joint requirement severely restricts the system implementation possibilities.

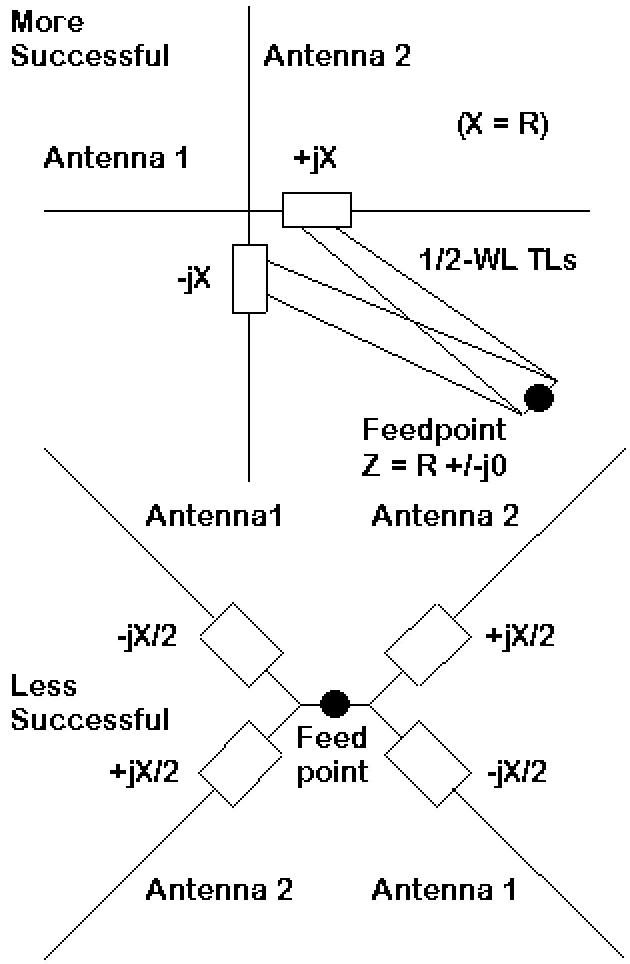


Fig. 10A sketches both a right and a wrong way to implement the phasing system. The correct way (but not the only correct way) shows the conditions under which the system will work, that is, with each antenna isolated from the other. The simple system used to arrive at isolation in this case is to use 1/2-λ lines from each antenna to a parallel junction of the two. Half-wavelength lines or any reasonable characteristic impedance (such as 50-75 Ω) will replicate the feedpoint conditions at their junction. The net source impedance for two 72-Ω dipoles in a turnstile arrangement will be 72 Ω with this system. The system is more sensitive to some changes than others. Using reactances other than values equal to R will yield a non-circular pattern, regardless of whether the inductive or capacitive reactances are equal or unequal. Also yielding pattern distortions are line lengths other than 1/2-λ multiples, since the impedance progression along the two lines is not the same.

A less successful means in **Fig. 10A** of achieving the desired results--that is, one where the pattern is far less circular--reflects ordinary amateur building practice. It shows a single parallel connection of the two antennas, which use split balanced loads in their respective legs.

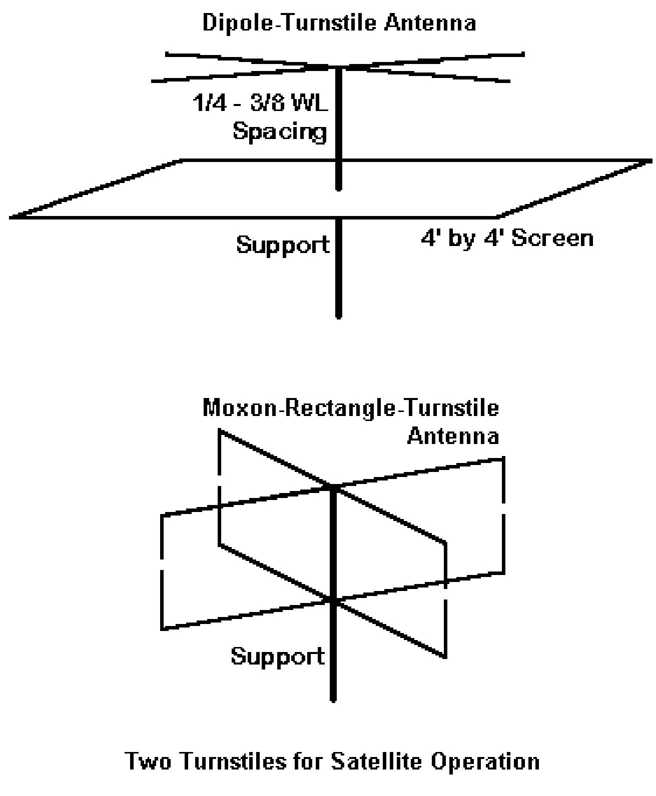
Unfortunately, this system does not isolate the legs from each other, resulting in a non-circular pattern and in currents of unequal magnitude and considerably off from a 90° phase angle difference. Test models of the non-isolated system showed current magnitude ratios of about 1.25:1 with an 80° phase angle difference. As well, the source impedance showed nearly 20 Ω inductive reactance. Increasing the inductive impedance circularized the pattern, but at a penalty: the source impedance moved well away from the resonant impedance of the individual dipoles in isolation.

The complementary-reactance system of obtaining quadrature requires the care of a precision instrument. The key to successfully implementing this system of quadrature lies not only in the selection of reactances for each antenna, but as well in maintaining a satisfactory isolation of the individual antennas. In this small account, I have not insisted upon using dipole turnstile elements, since the system has applications to quadrifilar and other antennas as well.

Which Antennas Can We Turnstile--and Why?

In principle, we may turnstile any pair of identical antennas that we may set at right angles to each other. Creating a turnstile version of a complex array--such as a long-boom Yagi--usually requires a good reason. Very often, we find that reason in the elevation patterns of turnstiled antennas.

Fig. 11 shows two turnstiled antennas designed for satellite reception. The dipole-turnstile over a large screen has been around since the 1970s, while the Moxon-rectangle-turnstile was recently featured in *QST* (Aug., 2001, pp. 38-41). Structural simplicity is only one of the reasons for suggesting a change from the dipole to the Moxon version.



Two Turnstiles for Satellite Operation

Fig. 11

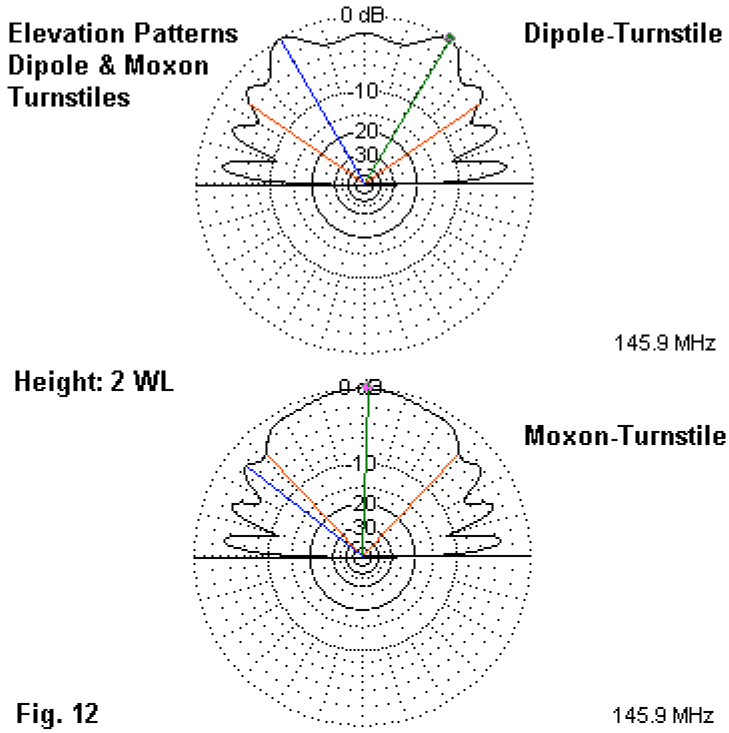


Fig. 12

The other reason appears in **Fig. 12**, which presents the elevation patterns for the two antennas at 145.9 MHz at 2 λ above ground. The Moxon shows a somewhat smoother dome of coverage at higher elevation angles. The individual Moxons have a feedpoint impedance of 50 Ω, so the overall system feedpoint impedance is 25 Ω. A 1/4-λ section of 35-Ω cable (possible composed of parallel sections of 70-Ω cable if RG-83 is not handy) transforms the impedance to 49 Ω for a standard coaxial main feedline.

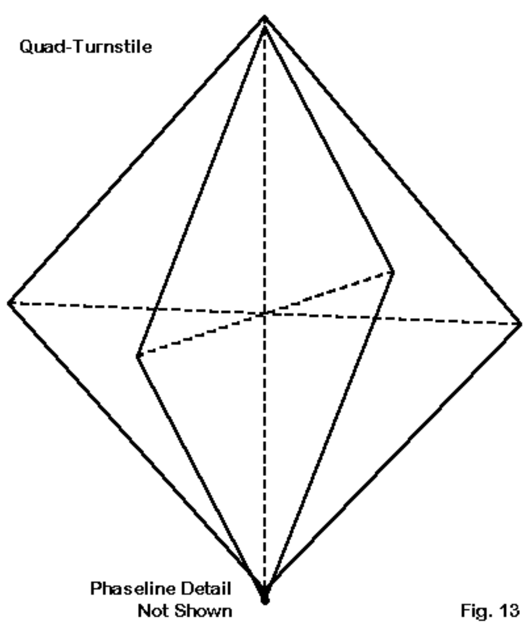


Fig. 13

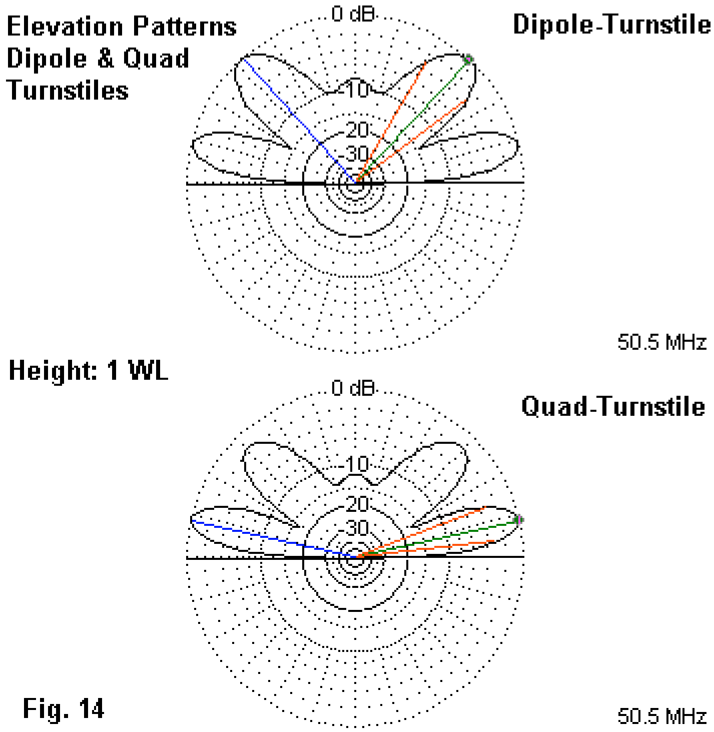


Fig. 14

One limiting factor of a dipole-turnstile for point-to-point communications in omni-directional service is the relatively modest gain: about 4.7 dBi when the antenna is 1 λ above ground. We can increase the gain by a full dB if we turnstile quad loops instead of dipoles. **Fig. 13** shows the outlines of such an arrangement, but without the phaseline. When composed of #14 copper wire for 50.5 MHz, the individual quad loops have an impedance of 125 Ω, and a phaseline made from RG-63 is ideal. The net system feedpoint impedance is about 62 Ω, for a very wide-band 50-Ohm SWR of about 1.25:1.

The improvement of the quad-turnstile over its dipole cousin involves more than gain. **Fig. 14** shows elevation patterns for both a dipole-turnstile and a quad-turnstile with their bases 1 λ above ground. At first sight, the quad elevation pattern seems normal, with the lower lobe being stronger than the second elevation lobe. However, notice the beam width of the second lobe. Now examine the dipole-turnstile pattern. With the simpler turnstile, the strongest lobe is actually the one with the higher elevation angle. Not only is the gain slightly higher than for the lower lobe, but as well, the higher-angle lobe has a wider beamwidth.

The dipole and quad elevation patterns should arouse some suspicions concerning the direction of strongest radiation relative to the structure of a turnstile antenna. As well, the utility of the turnstile for satellite reception should add to our suspicions. The simplest way to resolve the issue is to place a dipole-turnstile model in free space and examine the resulting pattern.

Fig. 15 shows a free-space elevation pattern or H-plane pattern for our 50.5-MHz dipole turnstile. I have superimposed a sketch of the antenna to ensure that we orient ourselves correctly to the pattern. The dipole-turnstile has a higher gain broadside to the dipole pair than it does edgewise, the orientation we use for omni-directional coverage. The difference in gain is well over 3 dB. Only ground reflections allow us to achieve a usable amount of gain at a low elevation angle when we place the antenna over real ground.

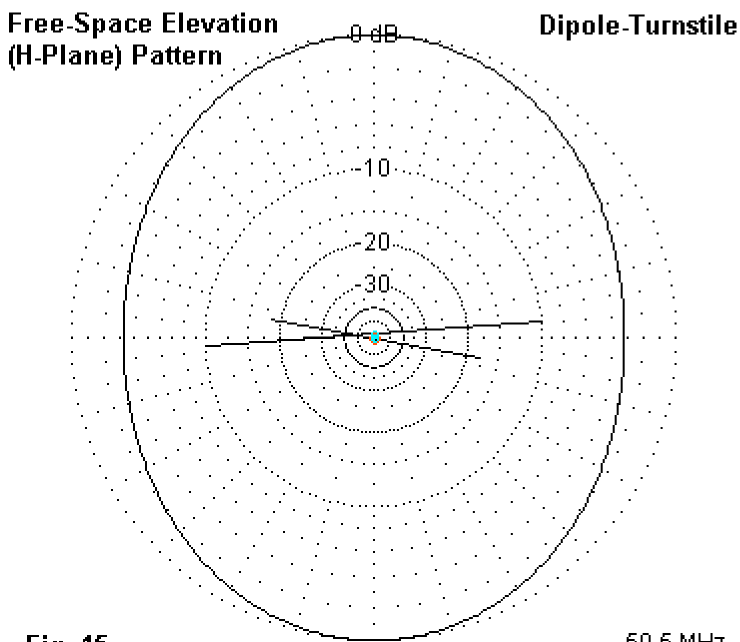


Fig. 15

The quad-turnstile improves both the gain and the elevation pattern by virtue of its form. It consists of two dipoles stacked 1/4 λ apart vertically, with the ends bent to meet. Essentially, we feed the two dipoles in phase. Any two dipoles stacked vertically and fed in phase will tend to suppress some high-angle radiation, with consequent increases in low angle radiation. However, the 1/4-λ spacing is not ideal if our goal is to suppress as much of the high angle radiation as possible. A spacing of 1/2 λ is superior, but has a few pitfalls if we do not design our new array carefully.

Stacking Dipole-Turnstiles

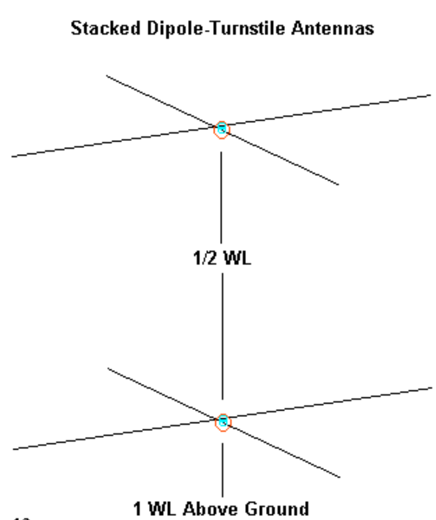


Fig. 16

Fig. 16 shows the outline of two dipole-turnstiles stacked 1/2 λ apart. For our examination, we shall place the lower array at 1 λ above ground, with the upper array at 1.5 λ.

We must supply each turnstile with a phasing line. As well, we shall need to contrive a system for feeding the arrays in phase.

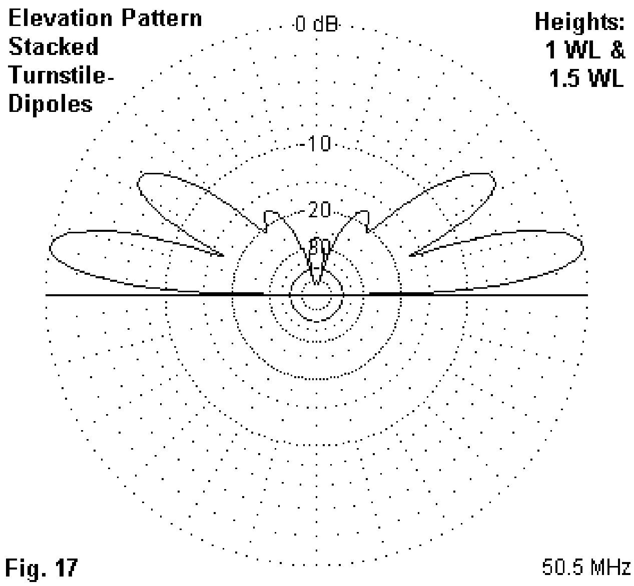


Fig. 17

If our efforts are successful, we shall obtain the elevation pattern shown in **Fig. 17**. Low angle gain increases as the upper lobes decrease in strength, and the stacked dipole-turnstiles show a considerable improvement even over the quad-turnstile. The cost is added overall array height.

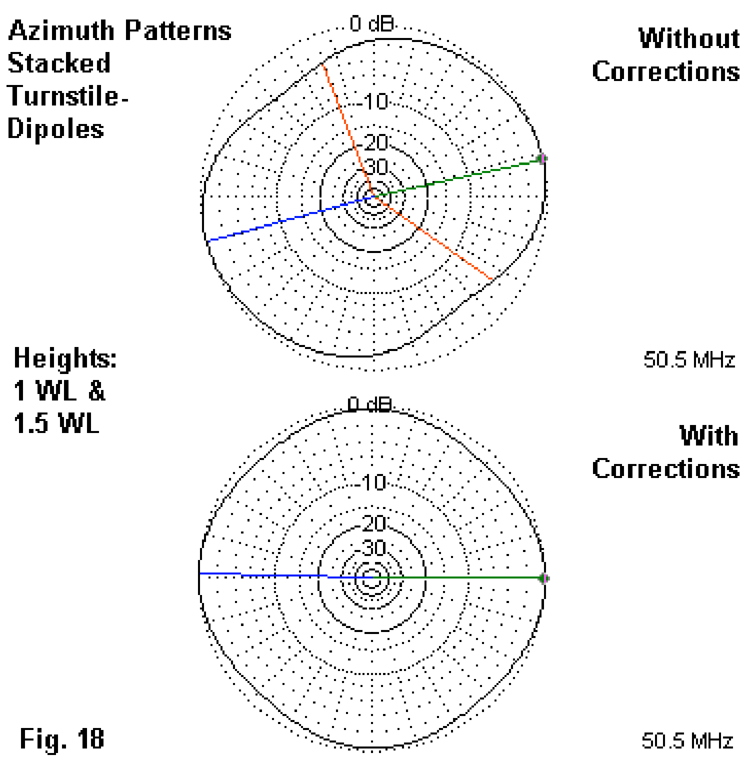


Fig. 18

With many antennas, stacking at a distance of 1/2 λ requires only that we take our original antennas and set them the proper distance apart. However, the dipole-turnstile shows very high levels of radiation both up and down. If we stack our 111.5" dipole system with its 70-Ω phaselines, we shall likely be disappointed. The upper portion of **Fig. 18** shows why. The resulting pattern displays considerable distortion relative to the desired omni-directional pattern. In fact, the differential between maximum and minimum gain is over 3.8 dB. This situation would not show up well in mere SWR curves, since the feedpoint impedance for each array is about 37.1 Ω, very close to the value of individual turnstile dipole pairs.

Table 5 shows the reason why we obtain such a distorted pattern. Within each dipole-turnstile, the current magnitude ratio and phase angle differentials are far from ideal. What we have neglected to take into account is the relatively strong mutual coupling between the dipoles in each array of the stack. The mutual coupling will alter the required element lengths and also the required phaseline characteristic impedance.

Perhaps the simplest way to account for the mutual coupling is to create a stack of two simple dipoles in a model. Each dipole will be in its final position relative to the eventual stack of turnstiles, that is, 1 λ and 1.5 λ above ground. Now we can adjust the element lengths to obtain resonance. Under these conditions, we obtain a resonant length of 114.7" (0.491 λ), with individual feedpoint impedances of 62.2 - j 0.5 Ω (bottom) and 63.4 + j 0.9 Ω. Not only will our stacked dipole-turnstile array need longer elements, as well, it will need a 63-Ω phaseline. Modeling such a line is simpler than constructing one, although we might well parallel sections of RG-63 (125 Ω Zo) for the requisite impedance.

Stacked Dipole-Turnstile Arrays at 1/2 λ

A. Casual Version: each dipole length 111.5" (0.477 λ)

Position	Dipole 1		Dipole 2		I Ratio	Phase
	I Mag.	I Phase	I Mag.	I Phase		Diff.
Bottom	0.620	18.39	0.530	-93.33	1.170	111.72
Top	0.612	17.50	0.529	-93.35	1.157	110.85

B. Careful Version: each dipole length 114.7" (0.491 λ)

Position	Dipole 1		Dipole 2		I Ratio	Phase
	I Mag.	I Phase	I Mag.	I Phase		Diff.
Bottom	0.521	-1.35	0.500	-89.73	1.042	88.38
Top	0.512	-2.24	0.500	-90.19	1.024	87.95

Table 5. Current magnitudes and phase angles for casual and careful stacks of dipole-turnstiles 1/2 λ apart.

The current conditions for our revised stack of dipole-turnstile arrays appears in the lower part of **Table 5**. The current ratio between elements in each turnstile is much closer to the ideal value of 1.0, and the relative phase angles are within about 2° of ideal. The lower portion of Fig. 18 shows the effects of our work upon the azimuth pattern. The gain variation totals just about 1 dB, with a maximum gain of about 8.4 dBi. We have gained nearly 4 dB relative to a single dipole-turnstile and nearly 3 dB over the quad-turnstile array, all with a very acceptable pattern for virtually any omni-directional purpose.

The feedpoint impedance for each array is very close to 31.5 Ω. A pair of 50-Ω lines, each 3/4 λ long will yield a parallel impedance of about 40 Ω. However, for this case, we might wish to use a Regier series match. A 0.037 λ section of 93-Ω cable (RG-62) followed by a 0.165 λ section of 50-Ω cable (RG8/58) would yield a 93-Ω line impedance. Once we include the velocity factors, we can create a short, straight pair of matching lines to a Tee junction for a 46-Ω impedance to the main feedline.

Conclusion

The turnstile array is, like all phased arrays, dependent upon the relative current magnitude and phase angle on each element for proper operation as an omni-directional horizontally polarized antenna. We have examined a number of conditions of construction and of operation that create distorted azimuth patterns, as well as correctives we might apply to restore near-ideal patterns. Among the conditions we explored were impedance-based combined matching and phasing systems, which led to the consideration of numerous alternatives that do not affect the desired antenna pattern.

We also looked at a number of candidate antennas for turnstiling, as well as why they promised certain types of performance. Except for satellite operation, where we wish to enhance the vertical field, most omni-directional operations seek increased low-angle radiation. While the quad-turnstile offers some improvement with simple construction, stacked dipole turnstiles offer the most improvement. However, the very factor that led us to stack turnstiles--a high level of radiation vertically or perpendicular to each turnstile element pair--required us to redesign the stack elements to account for mutual coupling among elements, with consequential changes in the required phaselines.

The turnstile antenna turns out not to be nearly so simple an antennas as we might imagine it to be. However, the better we understand its place among phased arrays, the more we may be able to exploit its potentials.

Appendix

The Relationship of Dipole-Turnstile Azimuth Patterns to Relative Current Magnitude and Phasing of the Dipole Elements

A well-constructed dipole-turnstile antenna consists of 2 dipoles at right angles. For this discussion, Dipole 1 will designate the element at the center of which we find the system feedpoint and the beginning of the phaseline. Dipole 2 will be the element at the far end of the phaseline. Ideally, the two dipoles will show currents of equal magnitude (a 1:1 ratio of currents from Dipole 1 to Dipole 2). Dipole 2 will show a net phase difference of 90° relative to dipole 1. It does not matter operationally whether Dipole 2 is +90° or -90° relative to Dipole 1. However, for consistency in this discussion, we shall use +90° as the ideal phase difference.

Under ideal phasing conditions, the azimuth pattern of a dipole-turnstile will be nearly circular. We cannot eliminate the pattern flattening between 90° points on the compass due to limitations of beamwidth of the dipoles making up the array. Under ideal conditions, the differential in gain between points of maximum radiation and points of minimum radiation will be about 0.9 to 1.0 dB.

There is a systematic relationship between azimuth pattern properties and the degree to which the dipoles depart from ideal phasing conditions. A given dipole-turnstile may have a less-than-ideal current ratio between dipoles or a relative phase angle that is greater or less than 90°--or a combination of both. As we move either variable away from ideal, the gain differential between maximum and minimum values increases and is a useful marker of the degree of azimuth pattern distortion.

Fig. 19 graphs the gain differential in azimuth patterns for the two variables. As with other 50.5 MHz dipole-turnstiles used in these notes, the antenna is 1 λ above ground. The range of current ratios from Dipole 1 to Dipole 2 is 0.75 to 1.25 in linear steps of 0.05. The upper region above a 1:1 ratio of current magnitude becomes a smaller percentage difference and hence yields a shallower curve than the ratios below 1:1. Relative phase angle increments are 10° from 70° to 110°.

As is evident from the graph, a 90° phase angle between the currents on the dipoles yields the shallowest curve with the least distortion. Notably, the two curves that represent 10° departures from the ideal overlay each other, as do the two curves representing 20° departures from ideal. Equal departures from the ideal phase angle above and below that level result in equally great distortions to the azimuth pattern when the relative current magnitude ratio is the same. However, the pattern shapes will differ.

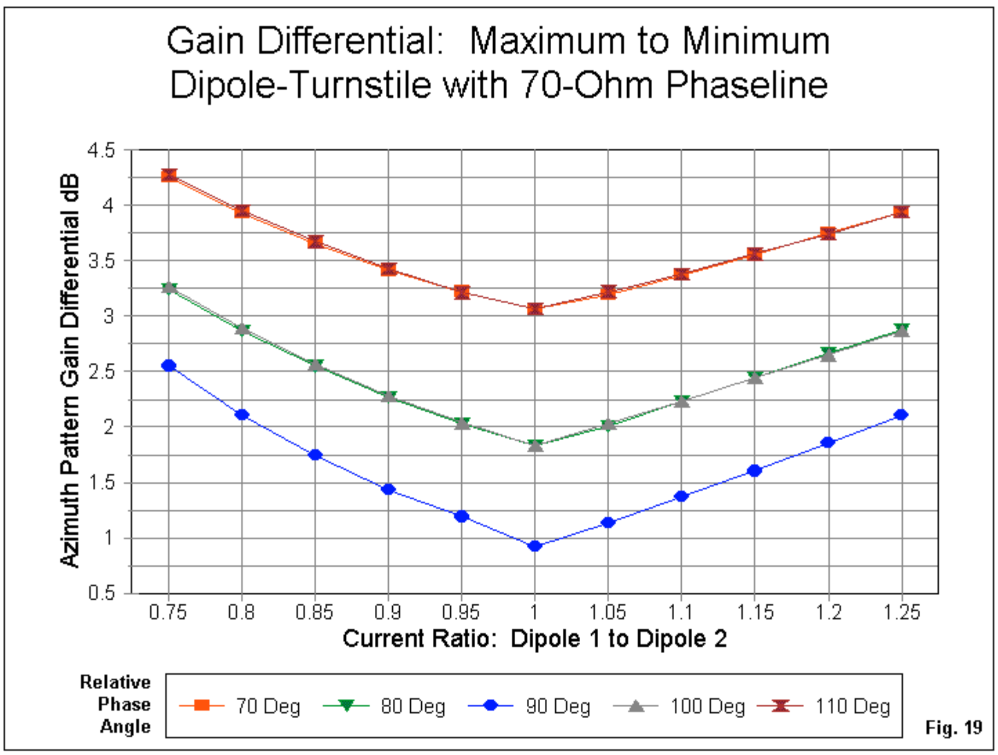


Fig. 19

Fig. 20 shows azimuth patterns for a current ratio of 0.75. In viewing the patterns, consider Dipole 1 to extend vertically through the center of the graph, with Dipole 2 extending horizontally. Because the current on Dipole 2 is higher, patterns will be distended vertically and pinched horizontally. At a relative phase angle of 90°, the pattern is symmetrical, with a gain differential of about 2.5 dB.

With the same current ratio, relative phase angles above and below 90° will bend or push the azimuth pattern as indicated in Fig. 20. At first sight, the patterns appear to be bi-directional ovals. However, the higher-gain portions of the patterns are not symmetrical about a center line. Instead, the current ratio yields an offset in peak gain in a broadside direction relative to the dipole with the higher relative current magnitude.

Fig. 21 presents comparable information for the situation in which Dipole 1 (a vertical line for each plot grid) has a current magnitude that is 1.25 times that on Dipole 2 (a horizontal line). With a phase angle of 90°, we obtain the same symmetry shown in Fig. 20, but at right angles to the earlier pattern. Phase angles of 70° and 110° yield distorted bi-directional patterns with the peak gain once more nearly broadside to the dipole with the higher current.

For a 20° phase angle error and a 25% offset in the ideal current ratio, pattern distortion yields 4 dB or more differential between maximum and minimum gain. The level of pattern distortion is serious relative to a desire for omni-directional horizontally polarized coverage. However, this level of distortion is not difficult to obtain under conditions of haphazard dipole-turnstile construction or operation. As with any phased array, turnstile performance will be a function of the care with which we establish the conditions of correct current phasing between the elements.

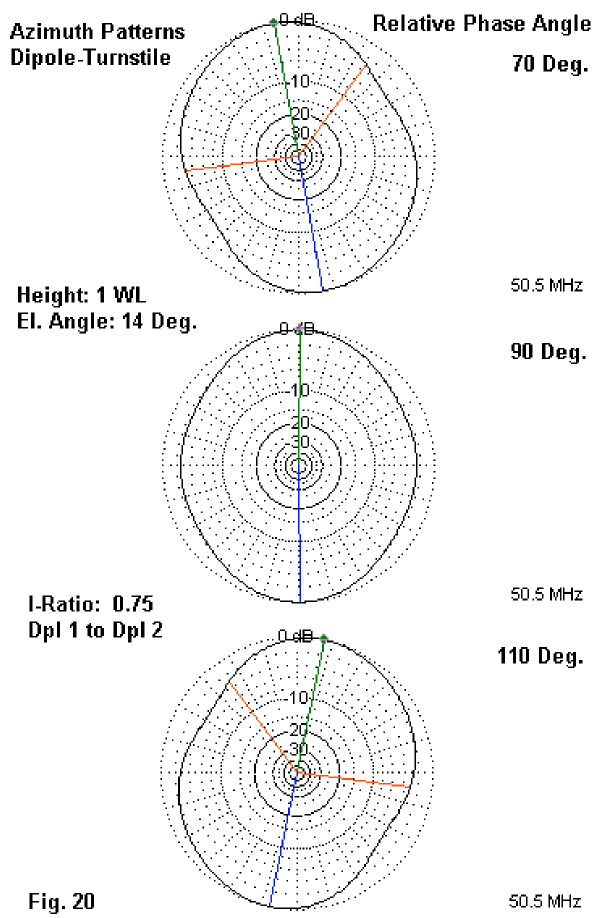


Fig. 20

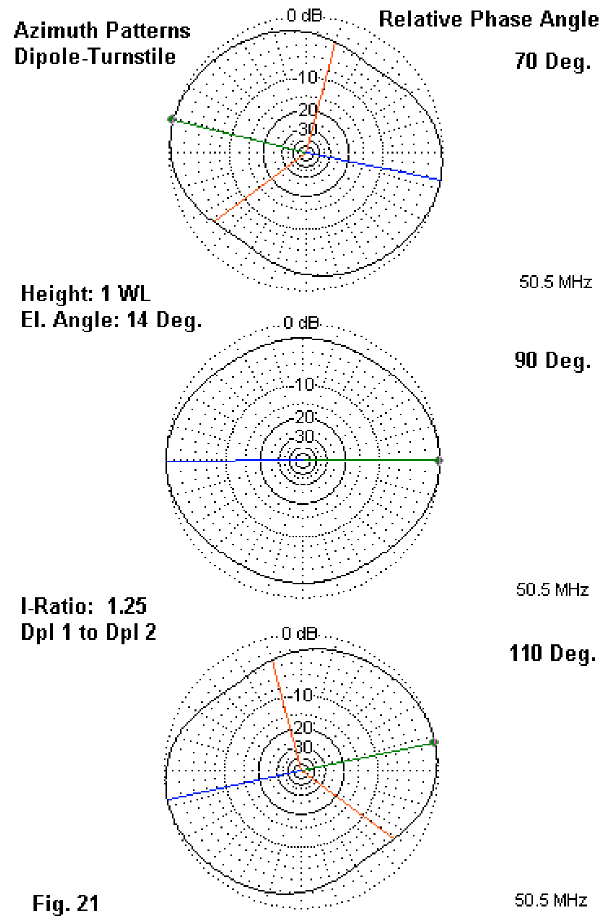


Fig. 21