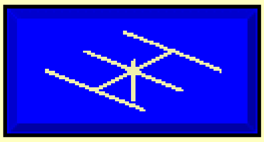

What's Wrong With This Turnstile Stack?

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The turnstiled dipole is perhaps the most common horizontally polarized omni-directional antenna used by amateurs from about 10 meters upward into the VHF and UHF area. From about 50 MHz upward, we can stack a pair of turnstiles with a vertical 1/2-wavelength separation. By feeding the two antenna sets in phase, we increase the low-angle gain considerably, while retaining the omni-directional pattern. These techniques go back to the 1950s or earlier. The general outline of the system appears in **Fig. 1**.

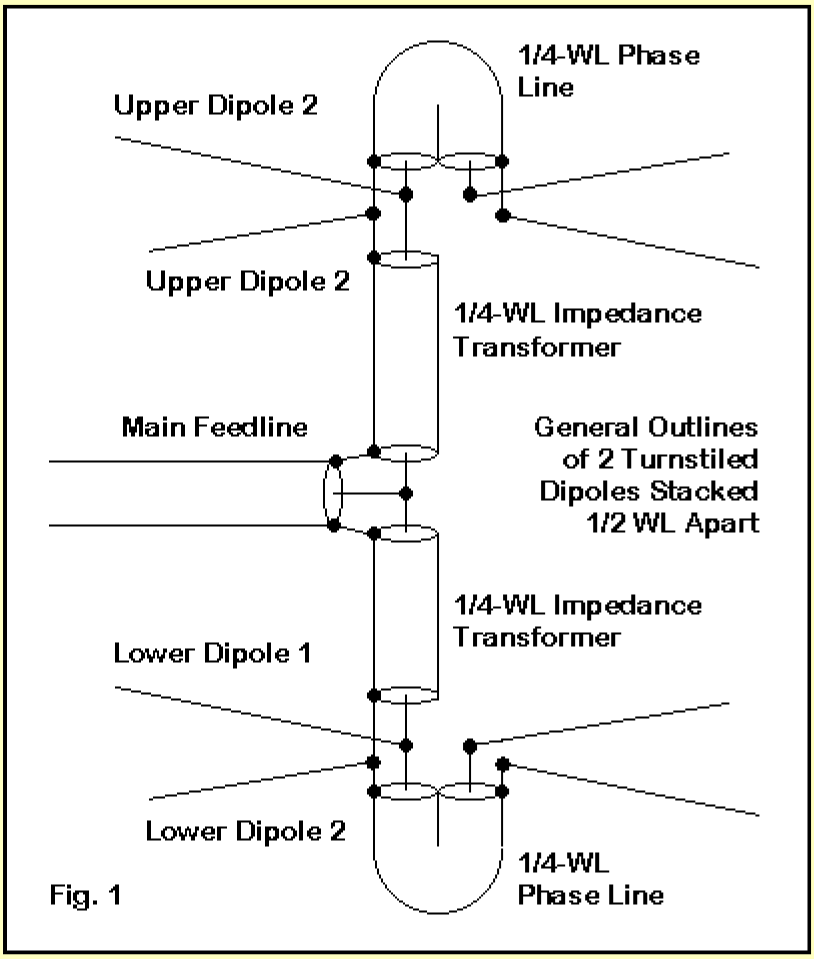


Fig. 1

Each antenna in the stack consists of two dipoles set at right angle to each other. Since each dipole creates a figure-8 pattern, the sum of the two patterns approximates a circle. However, to achieve this goal, we must feed one dipole with feedpoint current that is equal in magnitude to the other but 90-degrees out of phase. The most common method used by amateurs is the 1/4-wavelength phasing line.

The phase lines shown in **Fig. 1** do not specify a characteristic impedance (Zo) of physical length. If we start with a resonant dipole, then the feedpoint impedance is about 70 Ohms. The phase line Zo should be equal to that impedance. 70-Ohm line are common and may be standard or foam dielectric coax or that may be parallel line (which is quite difficult to obtain these days). We need to be as precise as possible in this match or the pattern will lose its circularity.

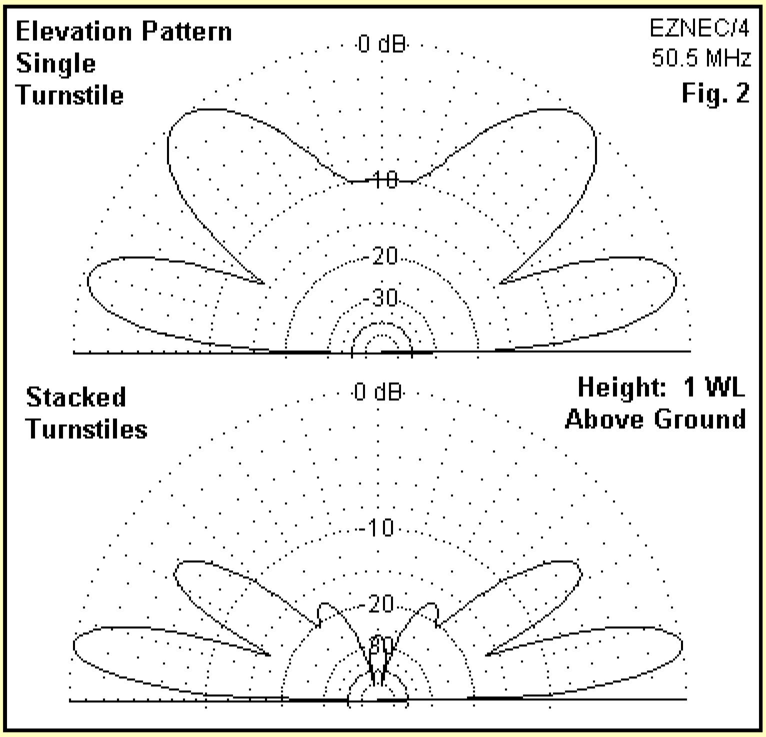
The physical length of the line will be a function of the line's velocity factor (VF). The VF of common coax is about 0.66 to 0.67, while foam lines have a VF in the vicinity of 0.78. The physical length of the line will be the VF times the electrical length, which is 1/4 wavelength at the design frequency.

The net feedpoint impedance to the feedline or to the matching transformer sections shown in **Fig. 1** will be 1/2 the impedance of the individual dipoles. Hence, we can expect a value of 35 Ohms. In order to effect a good match with common 50-Ohm cable used as the main feedline, we need to change this low impedance to something close to 100 Ohms. Then, the two 100-Ohm impedances will be in parallel, yielding a 50-Ohm impedance that closely matches the main feedline Zo.

The required matching transformer Zo is the square root of the product of the feedpoint impedance and the main feedline impedance. 35 times 50 is 1750, and the square root is about 42 Ohms. Hence, we may use 50-Ohm line for the transformer sections, although we shall obtain a 71 Ohm impedance at their ends, or a 35.5-Ohm net impedance for the main feedline. However, if the 1.4:1 SWR is not a problem, the system will work. If we use 63-Ohm line for the matching transformer sections, we obtain an end impedance of about 113 Ohms, or about 57 Ohms for the parallel combination. This selection results in an SWR of about 1.13:1 at the main feedline.

Since the lines--usually coax--used for the transformer sections also have a VF, and since the antenna sets are 1/2-wavelength apart, we cannot use 1/4-wavelength lines as the transformers. However, we can use 3/4-wavelength lines to achieve the same impedance transformation.

Why should we go to all of this trouble to make a stack of 2 turnstiles spaced 1.2-wavelength apart. **Fig. 2** tells the story.



A single turnstile (where the term "turnstile" will mean here a pair of turnstiled dipoles) yields an elevation pattern like the top pattern in **Fig. 2** when we place the antenna 1 wavelength above ground. At 50 MHz, this is just about 20'. Note that the generally useless upper lobe is actually stronger than the lower lobe. We waste power if our goal is omni-directional point-to-point communications.

However, the lower pattern shows what happens if we place the lower turnstile at 1-wavelength and the upper at 1.5-wavelength above ground. The 1/2-wavelength spacing reduces the radiation at higher angles to a practical minimum, and enhances the power available at the lowest elevation angle. Due to the presence of the higher turnstile, the elevation angle of the lowest lobe moves from about 14 degrees for a single turnstile to about 11 degrees for the pair.

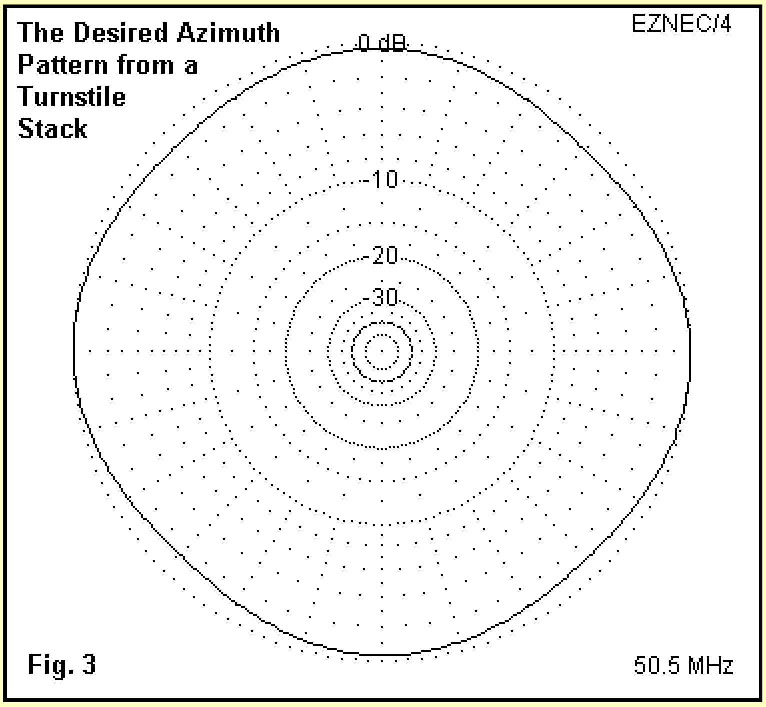


Fig. 3

Now, if we have done our work well, we shall obtain the azimuth pattern in **Fig. 3**. The gain will be close to 8.5 dBi maximum. Because the dipoles cannot yield a perfect circle, there is a maximum variation in the outer circle of about 1.3 dB, but for most purposes, that value is acceptable. (If we wish a more precisely circular pattern, we would have to turn to squares, rectangles, circles, and triangles for the shape of our antenna, but that turn would lead us to an entirely different set of design considerations.)

Now let's freeze a design for 50.5 MHz and see what we actually obtain. We shall use 0.44" diameter aluminum as our element. This diameter approximates the effective diameter of a dipole composed of 1/2" inner sections and 3/8" outer tips. We shall perform our design exercise using NEC-4, although NEC-2 would do as well. The total length of a dipole that is resonant at a height of 1 wavelength (20') is 111.5". The impedance is almost exactly 70.0 Ohms.

We create a turnstile pair by placing one dipole above the other with a spacing of not more than 1" to ensure that we simulate well the turnstile with dipole at the same level. In the model, we can use a 90-degree long 70-Ohm phase line between the center segments of the dipoles, with a source on only one of the dipoles. Then, we create the second dipole turnstile at 30' or 1.5-wavelength above ground. We use the same the line system. Use care to place the source on dipoles that align with each other, or else the final pattern will not approximate a circle, but show a figure-8 pattern at 45-degrees to the dipole lengths.

We need not model the matching transformers, since they will in no way affect the final antenna pattern--unless we create them with serious flaws. We can use separate source for the two dipole sets, so long as we design into the model the require phase lines. The TL facility in NEC makes this part of the design simple, although the lines will not have any loss. However, since the lines are only 1/4-wavelength long, no significant error should emerge from the result.

Now, what do we get. See **Fig. 4**.

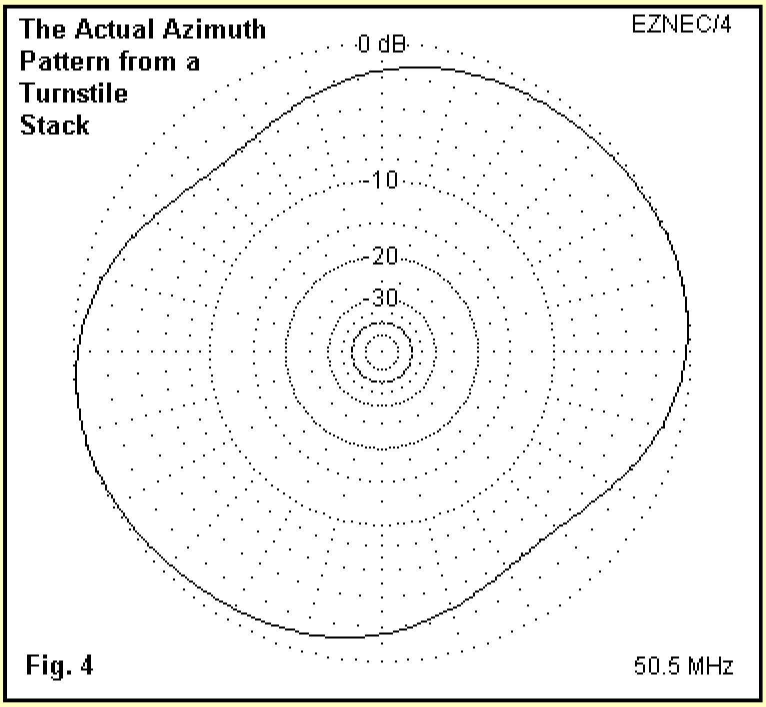


Fig. 4

The pattern in **Fig. 4** is no illusion. It has a maximum gain of about 9.1 dBi at 11 degrees elevation angle. The gain variation is more than 3.8 dB around the perimeter. This shape is far from what we intended in our original design. However, the impedance of the turnstile feedpoints will not give us a clue as to what has gone wrong. Each feedpoint reports an impedance of about 37 Ohms, with a 2-Ohm capacitive reactance. Surely this is close to ideal.

Unfortunately, designing a turnstile for impedance is one of the most common ways to be misled by the antenna. Turnstiled dipoles exhibit a very broad and flat SWR curve well beyond the frequencies at which the pattern goes to pot. The amateur designer needs to look at the currents at the dipole centers to get a sense of what is happening.

The lower dipole pair shows relative currents of 0.62 at 17.6 degrees phase angle and 0.53 at -93.3 degrees. The ratio of currents is not the desired 1:1 but closer to 1.16:1. The phase angle difference is not 90 degrees, but 110.9 degrees. The upper dipoles show values of 0.61 at 17.5 degrees and 0.53 at -93.3 degrees. Once more, the current is 1.15:1, with a phase difference of 110.8 degrees. Little wonder that our resulting turnstile stack shows an azimuth pattern in **Fig. 4** that is seriously distorted relative to the ideal pattern in **Fig. 3**.

What Went Wrong and How Do We Fix It?

What went wrong in our stacked turnstile array was a failure on our part to appreciate a fundamental aspect of antenna elements for the same frequency set in close proximity. 1/2-wavelength is not distant for dipoles, and we did align them with each other. Moreover, we set them in a vertical alignment so that radiation downward would reflect upward and enter into the element interactions.

The mutual coupling of elements is a primary aspect of both phased arrays and parasitic arrays. In many types of amateur antennas, such as the Lazy-H, we tend to ignore mutual coupling, because we intend only to achieve the highest possible gain n a bi-directional pattern and to feed the antenna with parallel line going to an antenna tuner. Since the tuner will take care of any impedance variations owing to construction, we tend to overlook the fine points of Lazy-H design.

However, we cannot be so cavalier with a stacked turnstile array. Where our initial design went awry was in our use of a single dipole as the baseline element in the array. To design a more nearly perfect stack of turnstiles, we need to start over again. This time, let's use a 1/2-wavelength spaced stack of single dipoles with the lower one 1-wavelength above ground. This procedure will take into account the mutual coupling between elements as we strive to obtain a resonant length for the 0.44" diameter aluminum elements.

If we start by stripping away from our stack model the phase lines and 1 dipole from each set, we can glimpse what went wrong. The resulting stack of dipoles, each 111.5" long, shows a feedpoint impedance of 56 - j 22 Ohms for the lower element and 56 - j 23 Ohms for the upper. These elements are far from resonant in their stacked environment.

If we lengthen the elements to 114.7", we come close to resonance. The lower dipole shows an impedance of 61 + j 3 Ohms, while the upper element has a feedpoint impedance of 61 + j 1 Ohms. First, we should note our close approach to perfect resonance. Second, we should note the resistive part of the impedance. We used a 70-Ohm phase line for a single turnstile because the resonant impedance of a single dipole was just about 70 Ohms. The required phase line Zo for the stack is determined by the resonant impedance of the individual dipoles in the stack, or 61 Ohms. A 63-Ohm line seems in order here. Actually, we can make such a line from parallel sections of RG-63, which has a 125-Ohm impedance and is available from The Wireman (of South Carolina).

Remember that precision is required in any turnstile design. Going to 70-Ohm line will yield distortions of pattern in each part of our turnstile. So to make a turnstile with close to ideal patterns, we must be sure that the phase line Zo closely matches the resonant impedance of the individual dipoles within the array. Of course, in the process, we should not forget to take into account the VF of the line used in determining the physical length of the phase lines.

If we reconstruct our model of the turnstile stack using the new element length and the new phase lines, we obtain exactly the pattern in **Fig. 3**, since that pattern was taken from this final model. The model presumes turnstile heights of 1.0 and 1.5 wavelength above ground. The ground quality will not make a significant difference in the final design. However, a significant lowering of the array may make some difference. For example, if you plan to place the lower turnstile at only 1/2-wavelength above ground, you should remodel the dipole stack before moving to a full turnstile stack model.

The net feedpoint impedances for the turnstiles as re-designed are both 31.5 Ohms with only fractional values for reactance. We need to use 3/4-wavelength impedance transforming sections to arrive at as close to 100 Ohms or a parallel combination of 50 Ohms to match the main feedline. 50-Ohm transformer lines will yield almost an 80 Ohm end impedance or a parallel combination of just under 40 Ohms. Hence, we have a 1.25:1 SWR for the main feedline. A 63-Ohm line (parallel 125-Ohm coax lengths) will yield an impedance of 126 Ohms or a parallel combination of 63 Ohms--again, a 1.25:1 SWR for the 50-Ohm main line. Take your pick, because the SWR value at the main feedline junction will not affect the antenna patterns, but only the level of loss in the main line itself. Most folks have no problems with a 1.25:1 SWR, even at 50 MHz.

Most amateurs do not realize how finicky the simple turnstile can be if an omni-directional pattern is the goal. There are techniques for forcing the current division and phase-angle differential that lie outside the somewhat ancient techniques used in this basic construction project. However, with the simple phase line used in this project, the turnstile yields a pattern far from ideal with only small departures from the design values.

For turnstile construction--usually viewed as quite simple--there are additional issues. Isolating the lines from each other by eliminating external braid currents is sometimes a difficulty. However, the chief problem that I have seen is the fact that builders seem satisfied that all is well if the feedpoint impedances are close to ideal. As noted earlier, for a common turnstile, the feedpoint impedance is one of the least informative performance figures. As well, design modelers often make the mistake of designing only to the design frequency and failing to explore in a frequency sweep just how well the pattern will hold up at frequencies on either side of the design frequency. For an account of some of the effects of being off target with a turnstile, see "Some Notes on Turnstile-Antenna Properties," *QEX* (Mar/Apr, 2002), pp. 35-46.

The turnstile is also not the most ideal antenna if one desires a truly circular pattern--especially one that holds its shape for at least 0.5 MHz each side of the design frequency. Much simpler are well-designed halos of various shapes. Unfortunately, most halos--interrupted loops in the 0.5-0.8-wavelength total circumference region--are not well designed. However, some recent work on triangular designs appears both promising and relatively simple from a construction perspective. The 1.3-dB variation in gain in our ideal turnstile can be theoretically reduced to under 0.1 dB and practically reduced to under 0.5 dB.

Nonetheless, the turnstile remains the most common omni-directional horizontally polarized antenna in use in the VHF/UHF region. If we choose to go that direction and if we wish to stack a pair for higher performance, then we must take into account the mutual coupling between the upper and lower elements to produce a turnstile that comes closer to our goals.

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