ANTENNAS FROM THE GROUND UP

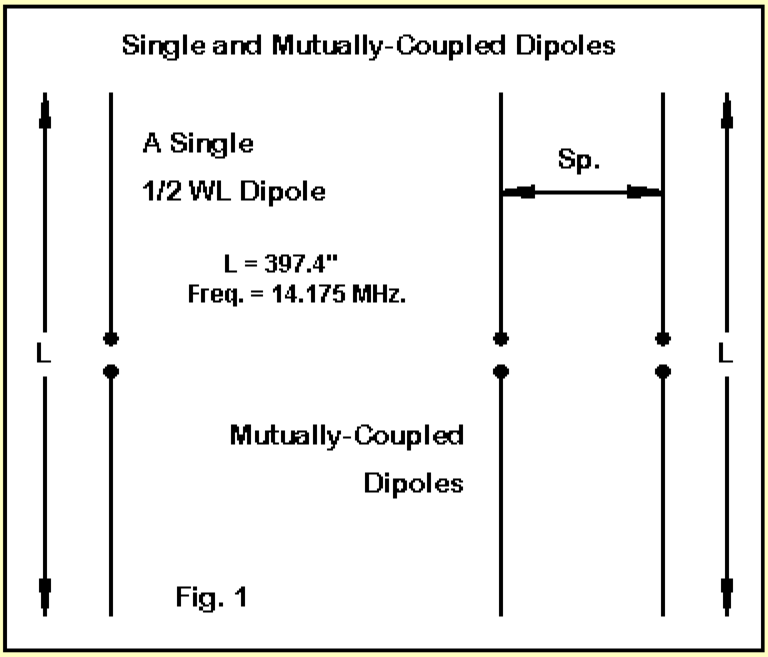
28. Coupling
or Why Parasitic Beams Work

L. B. Cebik, W4RNL (SK)

We know that Yagi-types antennas work well. But most of us do not have a basic understanding of how or why they work like they do. We buy them and trust the manufacturer. Or we build one from an article and trust the writer to have done his design work well. We make contacts with them and marvel at their gain and front-to-back ratios. But we still have only a fuzzy idea of how they do what they do.

Let's break with tradition and get to know the parasitic beam a little better. To get well-acquainted with these antennas, we shall have to use some terms that pop up only rarely in basic antenna discussions. (They should appear more often than they do.) We shall discuss near and far fields. We shall see some of the effects of mutual coupling. And finally, we shall look at one more aspect of antennas besides the usual parameters of gain, front-to-back ratio, and feedpoint impedance: we shall pay close attention to current magnitude and phase on the elements.

Finally, we shall discover that all of these terms are closely inter-related.



Let's begin with the simple dipole, the left-hand sketch in **Fig. 1**. The dipole we shall use as our example is set for 14.175 Mhz and uses 1" diameter aluminum tubing. All the rest of the antennas we shall look at use the same frequency and the same material. However, the principles apply to any dipole of any material on any band. Since we are working on general principles, we shall place our antennas in free space as an environment.

The dipole in question is 397.4" long and is resonant at 14.175 Mhz. The feedpoint impedance is 71.9 Ohms with no reactance.

The antenna produces electric and magnetic fields that we usually divide into three kinds. The far field, a function of the electric lines of force, produces the energy that we receive in our own systems. The near field is a bit more complex. There is a radiating near field that extends a little ways from the antenna. This is the field with which we are environmentally concerned for our own safety and the safety of others. Finally, there is the reactive near field, sometimes called the induction field, because it is the product of the antenna's magnetic field or lines of force. Although the radiation fields are never excluded from the workings of a parasitic beam, the induction field is crucial to beam operation.

If you examine the right-hand sketch of **Fig. 1**, you find two dipoles identical to the one we just examined. We have spaced them apart, but not too far apart. Notice that we feed both antennas. Now the question is what their feedpoint impedances might be.

The answer is this: it depends on how far apart we space them. Here is a table of feedpoint impedances for each of the two dipoles (without changing their length relative to the single dipole) when we place them at different spacings, expressed as fractions of a wavelength. For ease of reading, I have rounded the values of the impedance to integers.

Space wl	**Feedpoint Impedance R +/- jX Ohms**
1/16	**147 + j 7**
1/8	**135 - j 10**
3/16	**122 - j 23**
1/4	**108 - j 32**
5/16	**93 - j 37**
3/8	**79 - j 37**
7/16	**67 - j 34**
1/2	**57 - j 28**

Notice that each dipole affects the feedpoint impedance of the other, and the effect is more radical as the spacing between antennas decreases. We call the phenomenon mutual coupling. Each antenna has its own energy to radiate plus some of the energy received from the other antenna. Some of that energy is from the radiation as we usually think of it, but at these close spacings, much is from the coupling of magnetic fields associated with the reactive near field.

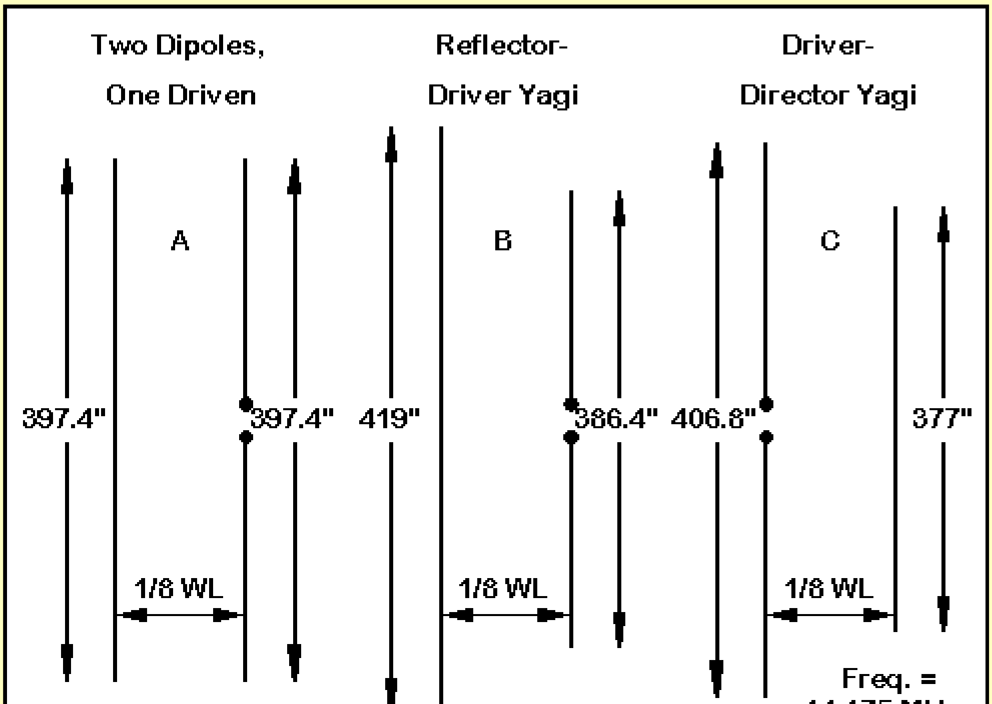


Fig. 2
Some Basic Parasitically-Coupled Antennas

Now, let's go to **Fig. 2**, where we feed only one of the two elements. We shall once more begin with the left-most antenna design, which again uses our two original dipoles. However, only one of them is now fed. What happens in this case?

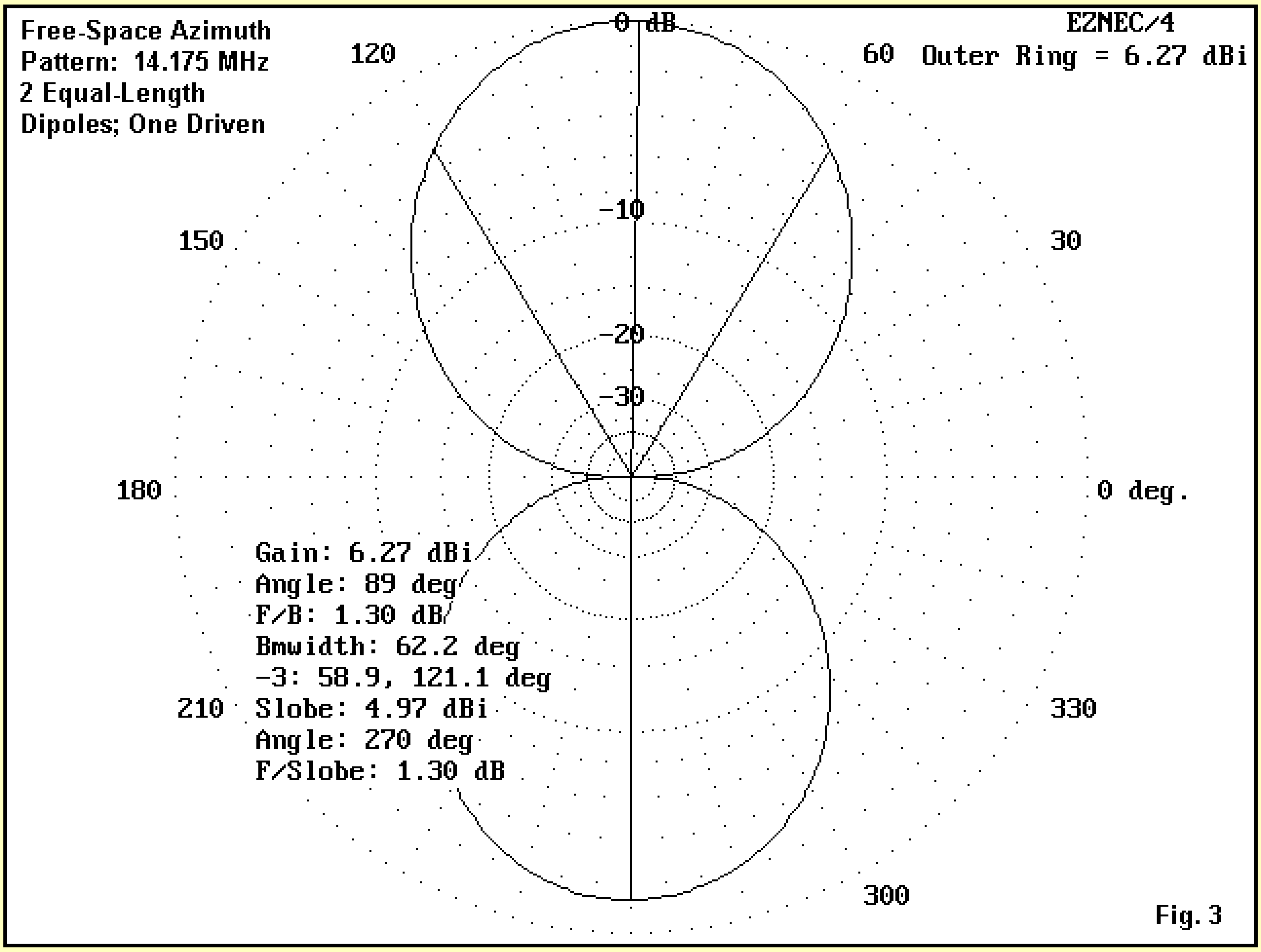


Fig. 3

First of all, we get an antenna pattern that looks like **Fig. 3**. With a front-to-back ratio of only 1.3 dB, there is not much beam action. However, notice the gain value: nearly 6.3 dBi. The gain comes from the fact that part of the energy of the driven element is coupled to the undriven element, which then radiates that energy. Part of that energy contributes to the combined radiation that gives us the gain.

Another part of that energy is coupled to the driven element to be radiated along with the energy from the source. In other words, we have mutual coupling, even though only one element is driven. How do we know? One indicator is that the feedpoint impedance of the driven element is 17 + j 8 Ohms. This value is nothing like the value associated with a single dipole.

The next question is why we get such a poor beam pattern with almost no front-to-back ratio. For the answer to this question, we must look at the current at the center of the two elements. If we arbitrarily set the current on the driven element to a value of 1 with a phase angle of 0 degrees, then we shall discover that when the two element are 1/8 wl apart, the current magnitude at the center of the rear element is about 0.88 with a phase angle of 176 degrees.

When elements are 1/8 wl apart, we can achieve a very high front-to-back ratio (and still have good gain) when the rear element has a magnitude of almost exactly 1.00 (relative to the current on the driven element) and a phase angle of just about 135 degrees. As we get further away from these figures, the front-to-back ratio deteriorates, just as in **Fig. 3**.

Every change in element spacing will require a different rear element current phase angle for maximum front-to-back ratio. We shall look more closely at those requirements in a future column. For the moment, let's retain our 1/8 wl spacing (about 208.2" for our test frequency of 14.175 Mhz). Is there anything that we can do to improve the front-to-back ratio apart from changing the spacing?

We can change the length of the elements. As we change element lengths, the relative current magnitude and phase angle on the undriven element will change. Even here, we have two directions in which we can move.

First, look at the middle diagram in **Fig. 2**. This is a classic driver-reflector Yagi design. With a reflector that is about 419" long and a driver that is about 386.4" long, we can maximize the front-to-back ratio for the fixed spacing we have chosen. The azimuth pattern for this arrangement appears in **Fig. 4**.

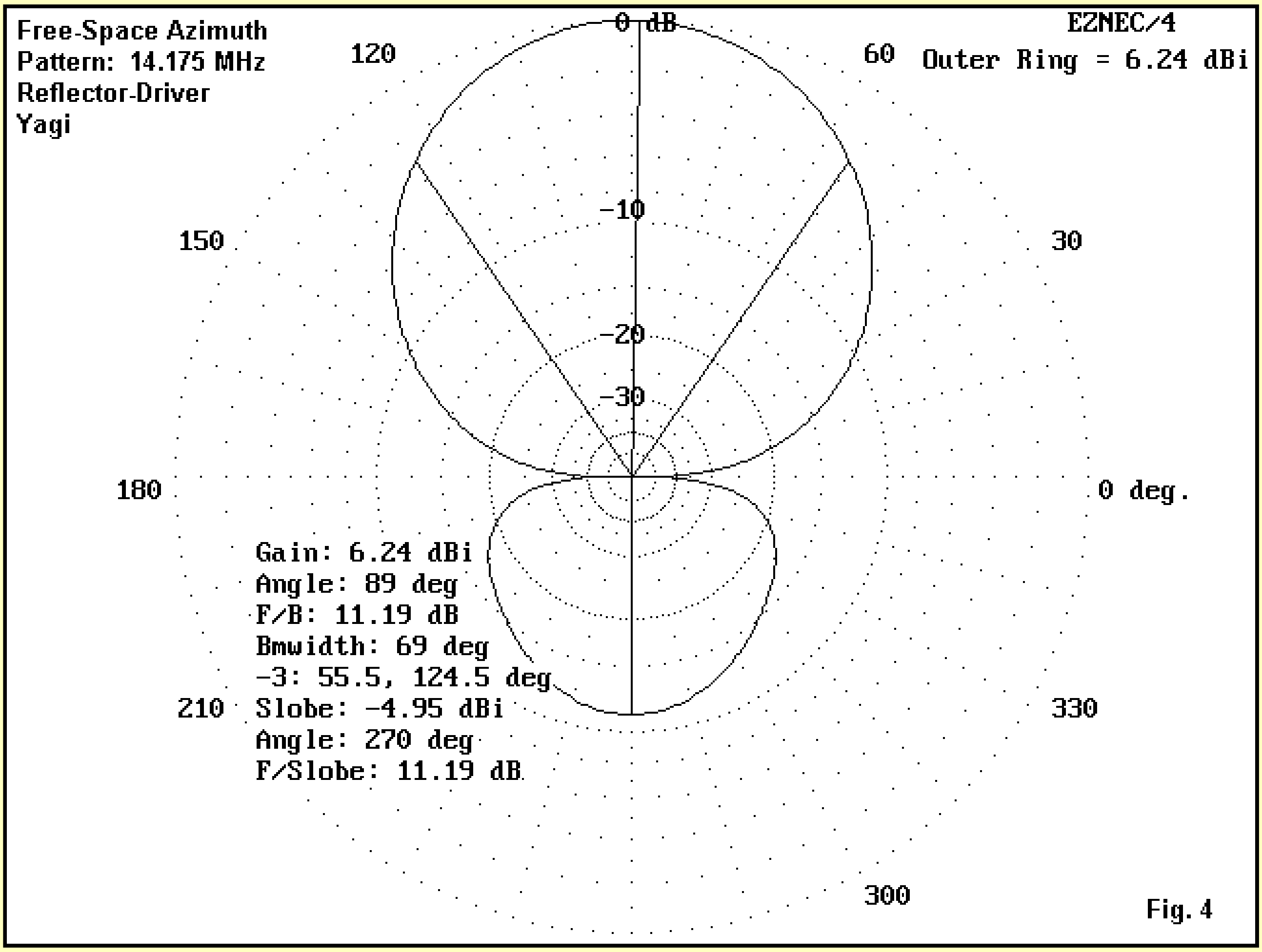


Fig. 4

The 11 dB front-to-back ratio is a big improvement over initial parasitic design. Notice that to achieve this value, we had to lengthen the reflector considerably. At the same time, we shortened the driven element to restore it to resonance. The feedpoint impedance of this model is 34 Ohms with no reactance'a typical figure for antennas of this general design.

Now let's look at the rear element current (always taken at the element center, which corresponds to the centered feedpoint of the driven element). The relative current on the rear element is 0.67 with a phase angle of 143 degrees. Although the magnitude is lower than for the first parasitic design, the phase angle is much closer to the ideal.

However, we have all seen designs of multi-element Yagis and other antenna types with higher front-to-back ratios. Unfortunately, we have done just about all we can do with this design to maximize the front-to-back design while keeping the spacing at the 1/8-wl mark. Lengthening or shortening the reflector from the given mark will decrease the front-to-back ratio, and changing the length of the driver will have far more effect on the feedpoint impedance' especially the reactance'than it will have on the other performance factors. In fact, for a driver-reflector design, 1/8 wl spacing yields about the best front-to-back values we can obtain from a 2-element parasitic beam of this configuration.

Alternatively, we can let the driven element be longer than the undriven element, as in the right-most sketch in **Fig. 2**. In this case, the antenna becomes a 2-element driver-director type of Yagi.

The listed dimensions (again, with a constant 1/8 wl spacing) were chosen for maximum performance. With a driver that is 406.8" long and a director that is 377" long, we end up with a resonant antenna. The feedpoint impedance is just about 36 Ohms, with no reactance.

Note that the two elements in this configuration are shorter than those used in the driver- reflector design. To make a driver-director design, we cannot simply swap the element we drive. We have to redesign the antenna completely.

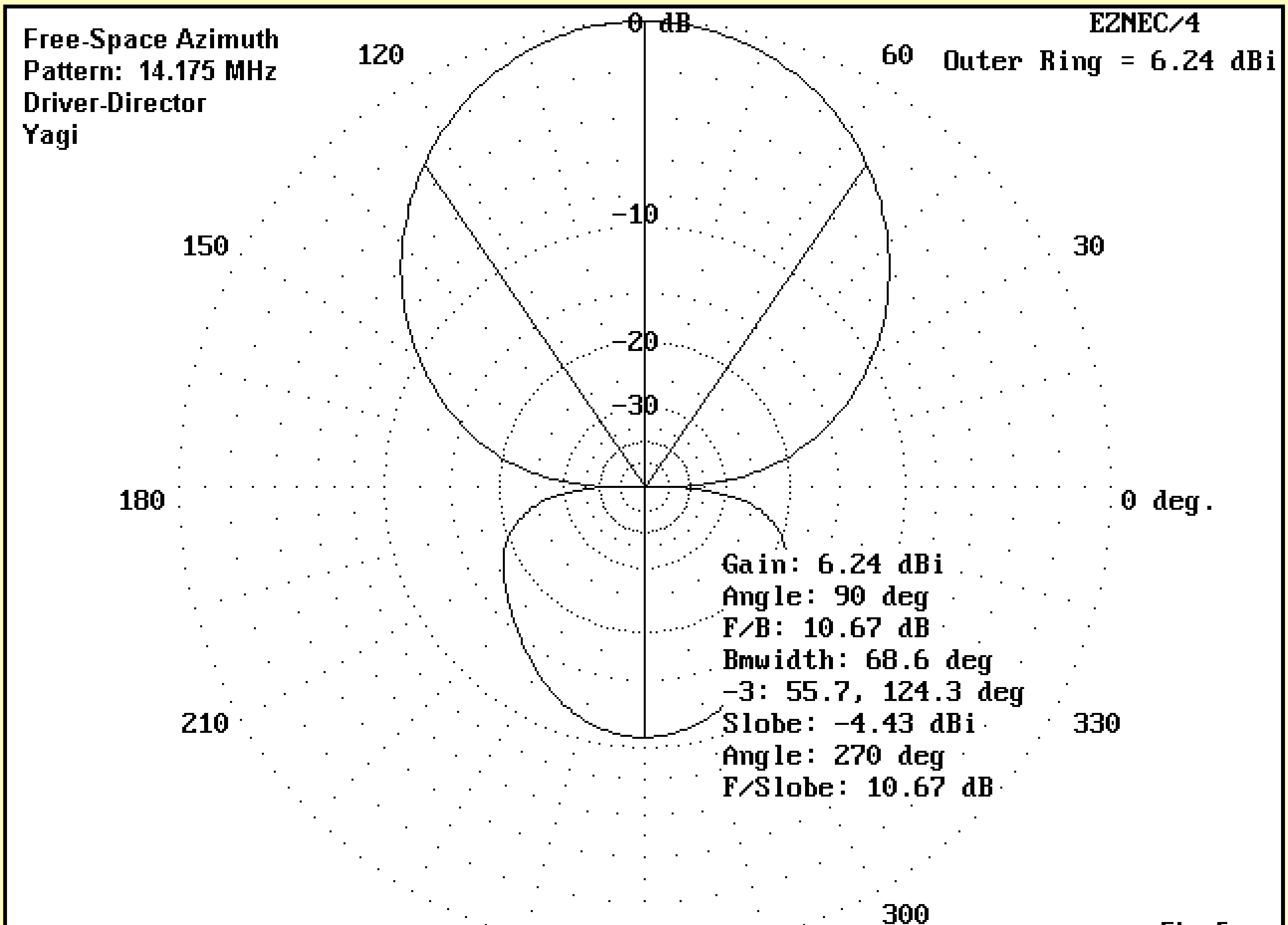


Fig. 5

At the spacing we have selected, the performance of the antenna is almost identical to the performance of the driver-reflector design at 14.175 Mhz, asshown in **Fig. 5**. The relative current on the director is 0.75 with a phase angle of -146 degrees. That is equivalent to having a phase angle of 0 degrees on the forward element and an angle of 146 degrees on the rear element.

Unlike the driver-reflector design, for which 1/8 wl is close to the ideal spacing for a maximum front-to-back ratio, the driver-director design benefits from closer spacing. Free-space gain can approach 7 dBi, and the front-to-back ratio can exceed 20 dB, but at a cost. The resonant feedpoint impedance drops very rapidly to low values that may be difficult to match to 50-Ohm coax. More significantly, the operating bandwidth of the antenna becomes narrower as we decrease the spacing. Hence, the high values for gain and front-to-back ratio are good only over a very narrow portion of any band. For general operation, the reflector-driver version of the Yagi is usually the design of choice.

With only two straight elements, we are limited in our ability to improve the front-to-back ratio. There are some techniques we can apply to achieve a more ideal current magnitude and phase angle on the rear element. One of them is to feed both elements, usually using a phasing line to achieve nearly ideal relative current conditions on the two elements. Alternatively, we can bend the ends of each element toward its counterpart and introduce additional coupling between element ends. This latter technique is the basis of the Moxon rectangle, an antenna that achieves nearly ideal rear-element current magnitude and phasing and which has a very high front-to-back ratio'at only a small cost in gain.

However, for this installment, it is sufficient for us to get a feel for how relatively close-spaced elements mutually couple when at least one of them is driven. One very significant consequence of the coupling is the presence of a relative current magnitude and phase angle on the undriven element. For any given spacing, the closer the current values to the ideal, the higher the front-to-back ratio.

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