The PF4 Antenna Tested

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Introduction

Two months ago Bill Graham, VE3ETK, introduced a new and exciting antenna in the pages of *antenneX*. Bill's invention, the PF4 Phased Field antenna, is the result of much work and three different models. The idea of such a compact antenna yielding good performance started a lengthy discussion at the *antenneX Discussion List*. The discussion involved these main issues:

- Is feedline radiation responsible for the good performance?
- Are the radiation fields really phased and combining or is conventional antenna theory at work here?

I decided to build a PF4 to see how well this 2-foot diameter, 14-MHz dipole works and if the performance could be explained by conventional antenna theory. First we'll go over the theoretical aspects of the PF4 and then we'll look at actual field measurements of the PF4.

Theoretical

The PF4 is analyzed with paper-and-pencil calculations as well as NEC-2 simulations. NEC-Win Plus+ antenna modeling software is used for the antenna simulations. The NEC model is shown in Fig. 1. The model consists of 211 segments and the NEC Win-Plus+ *Average Gain Test* reports “Model is usable for most cases” and gives a goodness number of 1.05.

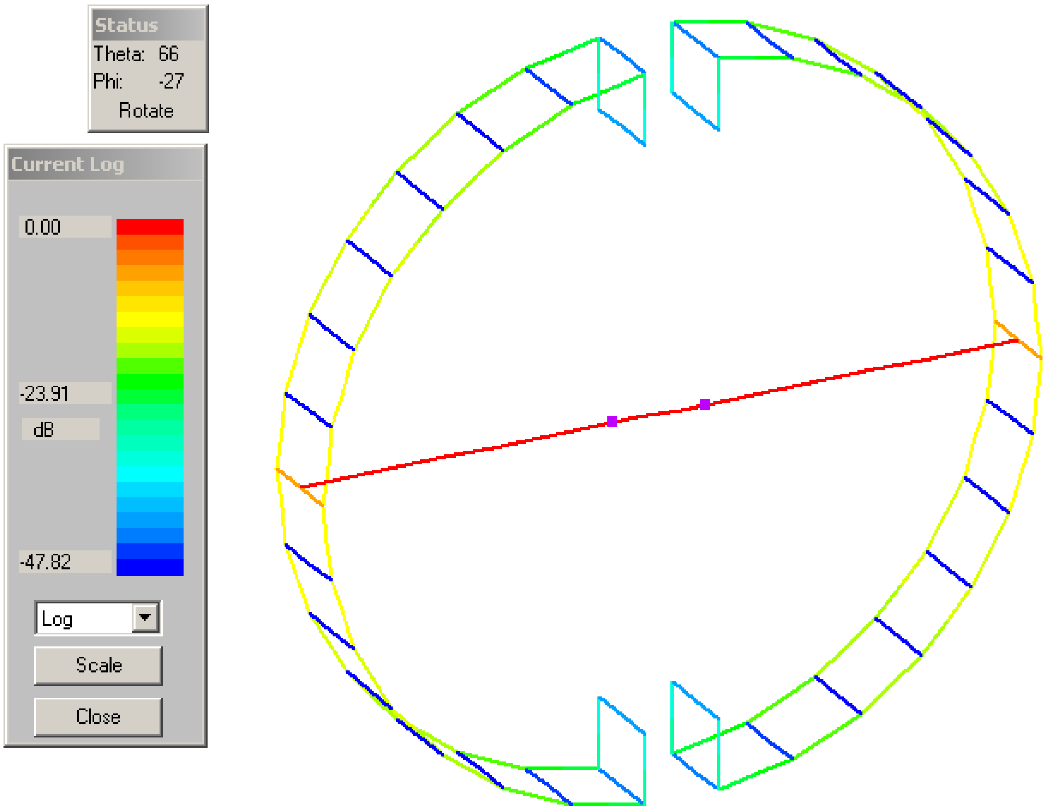

Fig. 1

The 14 MHz model consists of a 2-foot diameter dipole with circular capacitive loading structures at the ends and two 6.3 uH loading coils. The loading coils are modeled as inductors having a Q of 240, which is what is predicted by the Brian Beezley, K6STI, *COIL 1.17* program. Each inductor is modeled as 6.4 uH in series with 2.36 ohms of inductor loss. The PF4 capacitance is 10 pF.

The maximum radiation resistance possible in a 2-foot dipole at 14 MHz is about 0.6 ohms. This can be achieved using end-loading spokes mounted perpendicular to the dipole axis. The current is uniform along the length of such a dipole and results in a current area of 2 amp-feet, normalized to a current of one amp. The PF4 simulated radiation resistance is a low 0.15 ohms and is due to antenna current flowing in the circular end-loading structures opposite to the current flowing in the dipole arms. These opposite currents produce partial cancellation of the magnetic field, resulting in a current area of 1 amp-foot.

Simulated Radiation Efficiency

The radiation efficiency is calculated by dividing the radiation resistance by the loss resistance. In the case of the 14-MHz PF4 device these numbers are 0.15 and 4.7 ohms respectively, giving a radiation efficiency of 3.2%. The Power Budget window in NEC

Win-Plus+ reports an efficiency of 3.0%, which means the PF4 signal will be 15 dB below that of a 100% efficient dipole.

10LOG(0.03) = -15.2 dB

Simulated Bandwidth

With physically small antennas there is always a tradeoff between bandwidth and efficiency. This can be summed up like so:

SMALL
WIDEBAND
EFFICIENT

PICK ANY TWO

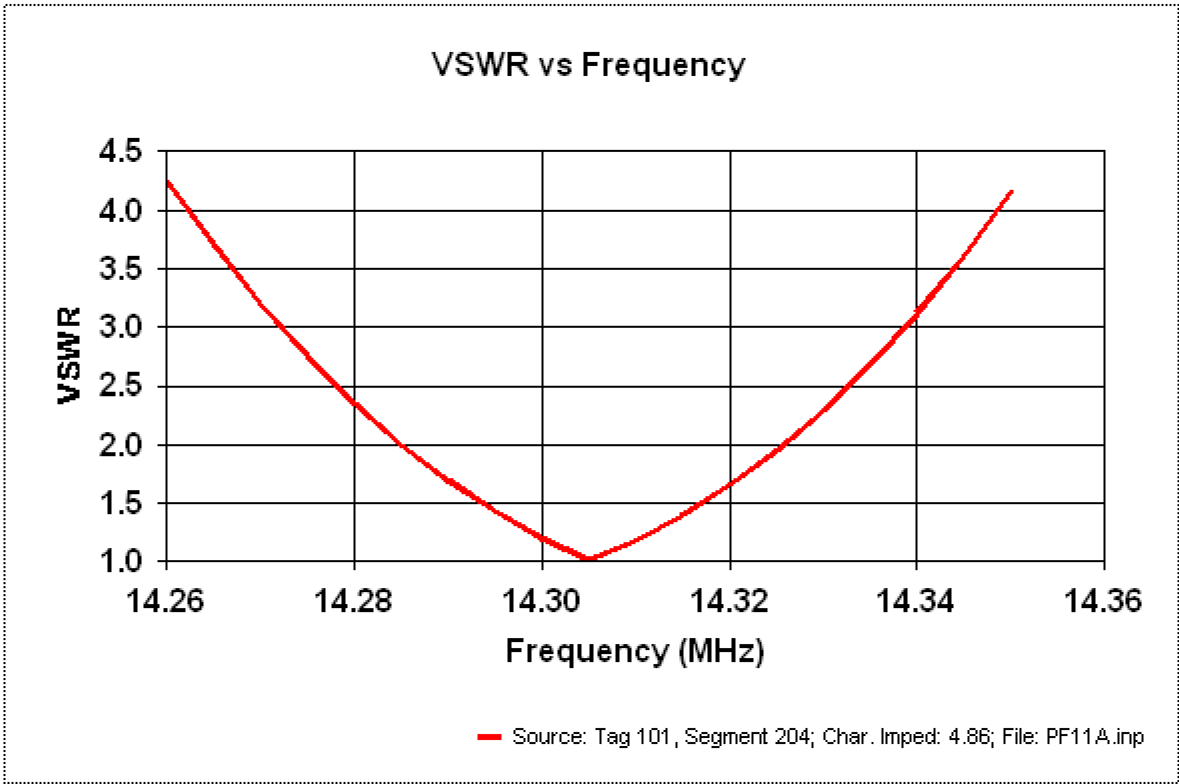

Fig. 2

The simulated PF4 3:1 VSWR bandwidth is 70 kHz, as shown in Fig. 2. This bandwidth is quite useful for the 14 MHz CW sub band. The bandwidth is set by the antenna reactance and resistance. Fig. 3 shows a resistance of 5 ohms throughout the 70 kHz band and a reactance that varies from –j8 to +j8 ohms. The resistance can be changed by using loading coils having more or less loss. Given lossless loading coils the input resistance would simply be the radiation resistance of the antenna, which is 0.15 ohms. The 3:1 VSWR bandwidth in this case would drop to about 2 kHz and the efficiency would be

100%. Notice that the tradeoff between bandwidth and efficiency is linear - double the efficiency and you halve the bandwidth.

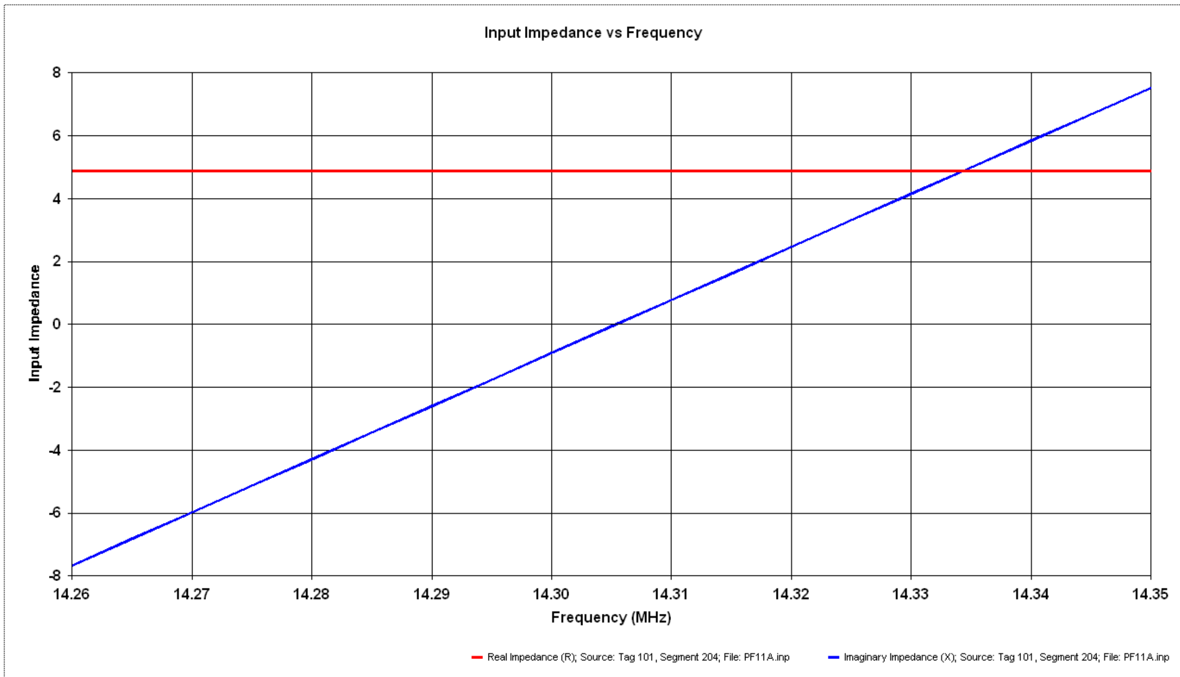

Fig. 3

Radiation Pattern

The radiation pattern of a small dipole is nearly the same as a half-wavelength dipole. The Azimuth pattern shown in Fig. 4 shows the PF4 having a dipole pattern with a beamwidth a bit wider than a half-wavelength dipole.

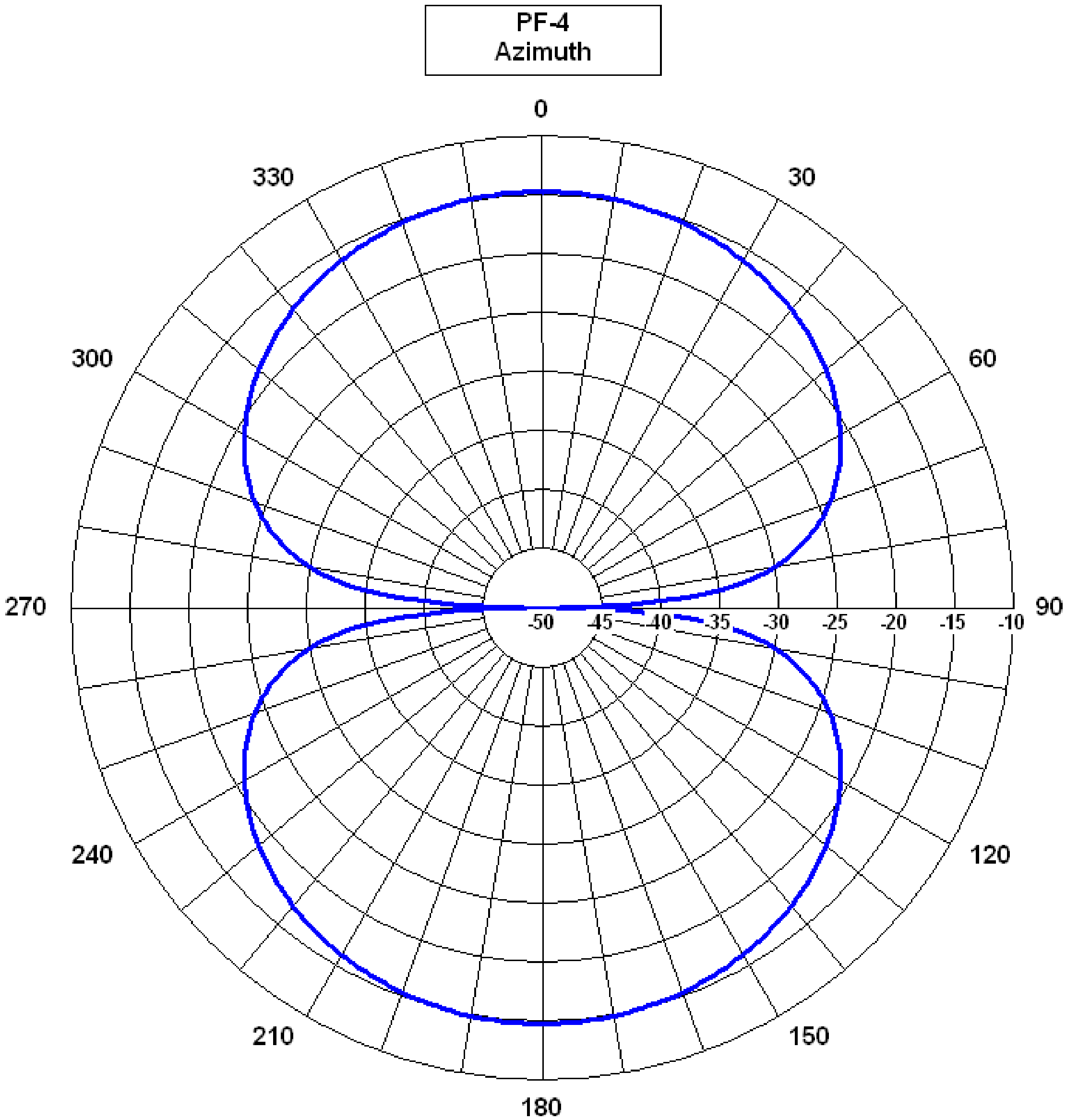

Fig. 4

The 3-D radiation pattern shown in Fig. 5 is that of a rather fat donut.

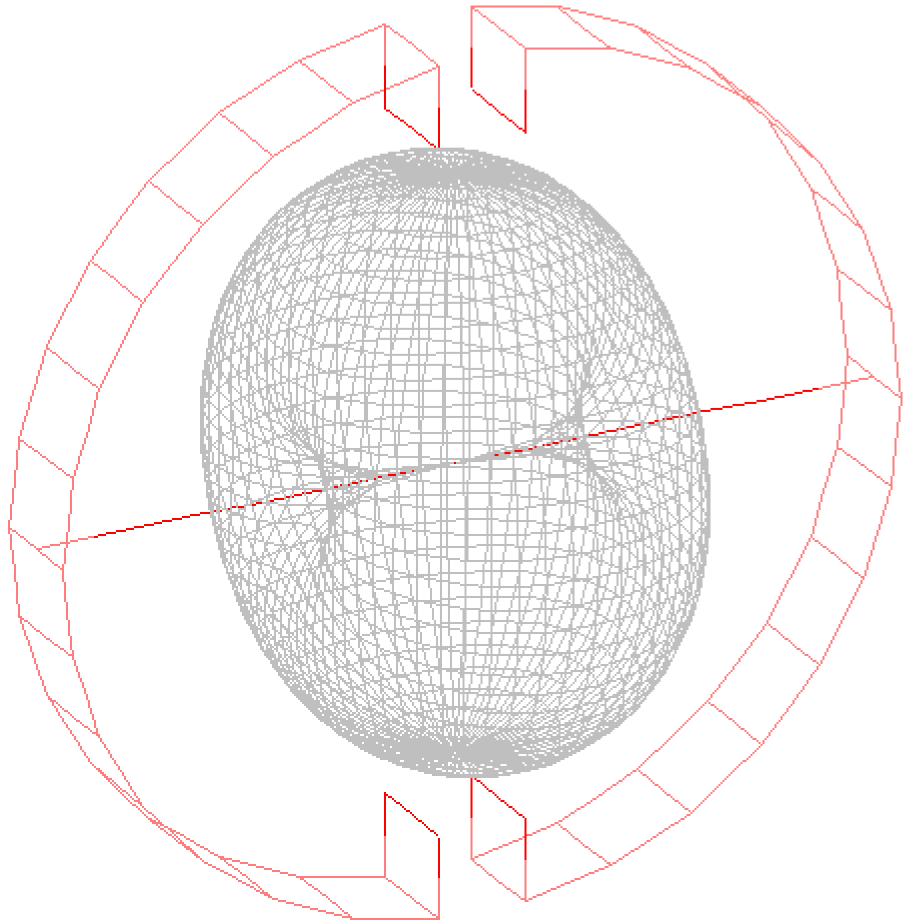

Fig. 5

The Real Deal

Now that the theoretical aspects have been covered let's see what a real PF4 antenna does. The testing consists of a PF antenna, a reference dipole, and a receive dipole. The distance between the transmit and receive antennas is 25 meters and is well into the far field. To reduce feedline radiation the PF antenna and the reference dipole are driven by a floating (battery powered) RF source attached to a 2-meter length of coaxial cable. The receive dipole is connected to a Tektronix 497P Spectrum Analyzer through 100 feet of coax and a resonant balun. To check for excessive feedline radiation the PF4 and the dipole were rotated through 360 degrees of azimuth. The dipole exhibited a front-to-side ratio of 20 dB while the PF4 showed 10 dB. This is good evidence that the antenna is responsible for the horizontally polarized radiation (the receive dipole rejects vertically polarized radiation from the feedline).

Tuning Things Up

The antennas were carefully tuned using an AIM 4170 Antenna Analyzer. This instrument is small portable Vector Network Analyzer that connects to a PC. A screen shot of the AIM 4170 is shown in Fig. 6 and a Smith Chart plot is shown in Fig. 7.

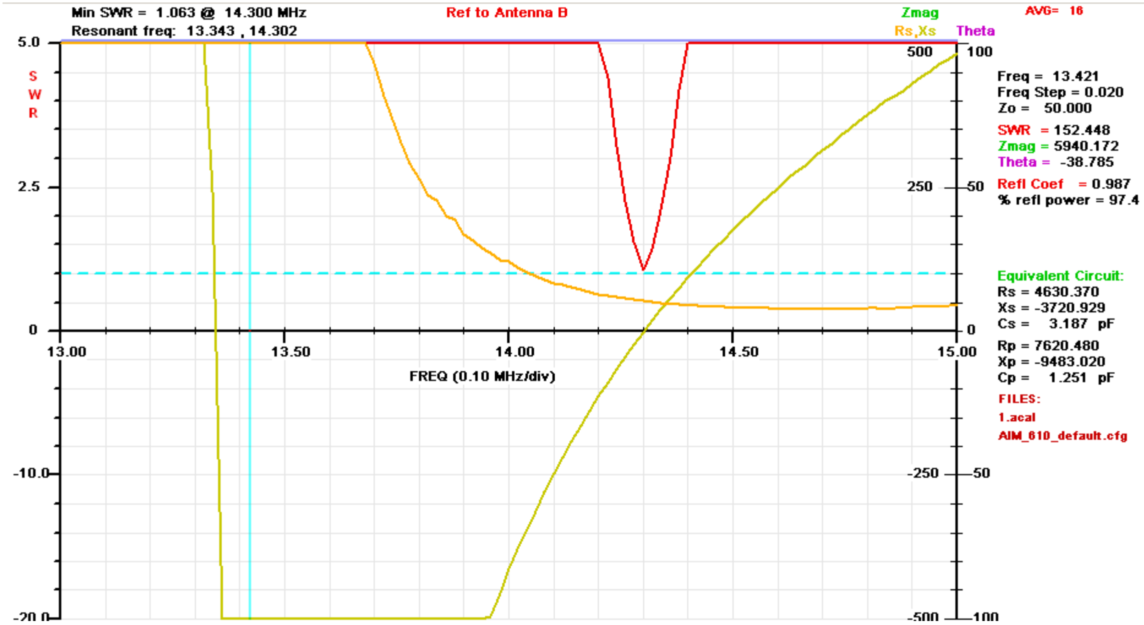

Fig. 6

The AIM 4170 is the ideal instrument for testing antennas and is especially good for narrow bandwidth antenna such as the PF4. Being able to sweep from 0.1 to 170 MHz makes finding the antenna resonant frequency easy. And the AIM 4170 allows the measurement *reference plane* (measurement point) to be moved along the feedline right to the antenna itself. So the impedance at the antenna can be measured without having to tediously account for the impedance transformation of the feedline.

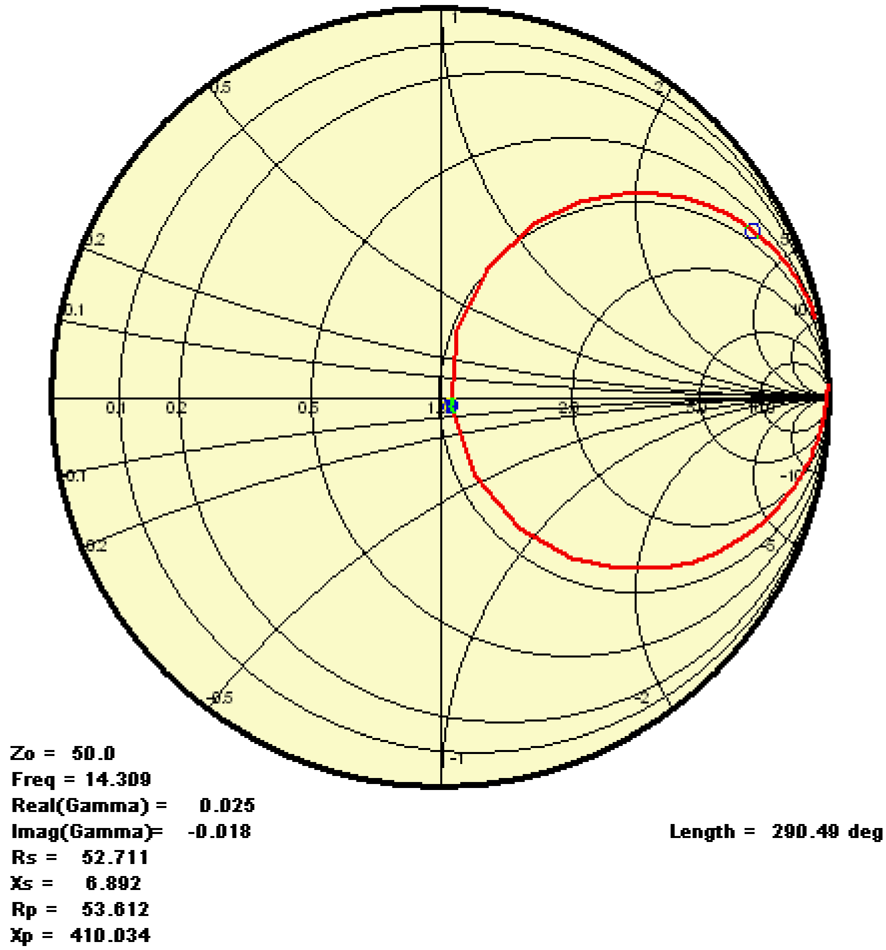

Fig. 7

Results

The measured versus simulated results are shown in table 1. It is interesting to note that the measured bandwidth is 60% wider than simulated and the measured signal power is 60% higher than simulated. The 60% wider measured bandwidth should be accompanied by a 60% *reduction* in signal power. The increased bandwidth might be due to feedline radiation and could be measured with a vertically polarized receive antenna. Although there is not perfect correlation between the simulation and the measurement, the correlation is more than good enough to say that the PF4 performance is easily explained using conventional antenna theory.

Parameter	**Measured**	**Simulated**
Bandwidth	110 kHz	70 kHz
dB relative to dipole	-13 dB	-15 dB

Table 1

Feedline Radiation

The possibility of feedline radiation affecting on the air testing of the PF4 was extensively discussed on the *antenneX* discussion forum. Remember the current-area numbers we went over? The PF4 has a current-area 1 amp-foot with 1 amp flowing uniformly along the dipole element. Now let's connect the PF4 to a 17-foot feedline having a shield current (traveling on the outside of the shield) also of 1 amp. The shield current is not uniform and we can approximate it as a triangle. The shield current length is therefore 8.5 amp-feet. The feedline radiation is 18.6 dB higher than the PF4 radiation.

$$20\mathrm{LOG}(8.5'/1') = 18.6 \text{ dB}$$

This demonstrates how easy it is for the feedline to do more radiating that a small antenna. In the case of the PF4 a transformer provides galvanic isolation between the antenna and the feedline. However, *perfect* symmetry is needed to prevent all shield current. This was explored using NEC-2; one of the simulations is shown in Fig. 8.

The PF4 is modeled with a perfect balun. However, the feedline is offset slightly to the right and a fair amount of shield current is the result. In this particular simulation the feedline current is just 0.15 amps (while the PF4 current is 1 amp) yet the feedline radiation is 5X the PF4 radiation.

The PF4 is acting as more of a shield-current inducing device than as an antenna. The "antenna" is really a vertical consisting of the feedline shield. This phenomenon accounts for the performance of small antennas such as the Bilal Isotron. Preventing this type of operation with any physically small dipole takes extremely careful attention to symmetry.

Ed note: To see the previous discussions on the *antenneX* antenna-discussion list referred to in this article, please go to the List Archives:

- If you have a login: http://www.antennex.com/listlogin/index.html
- To obtain a login: http://www.antennex.com/listhub/php_mm/register.php
- To join the antenna-discussion list: http://www.antennex.com/subscribe.htm

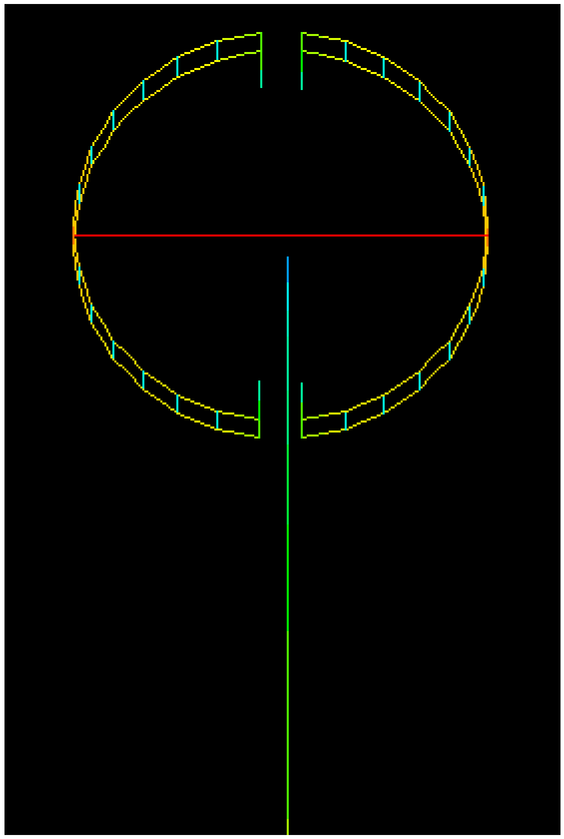

Fig. 8

Conclusion

In this article we have investigated four things:

1. How the PF4 and small dipoles in general operate and the bandwidth-efficiency tradeoff.
2. Compared simulation to the real world and achieved good correlation.
3. Provided good evidence that the PF4 performance is explained by conventional antenna theory.
4. Explored how small antennas such as the PF4 can achieve good performance through feedline shield radiation.

You are now better able to evaluate the potential and actual performance of small dipoles.

-30-

BRIEF BIOGRAPHY OF AUTHOR
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- **1979-1988 Huges Aircraft – Designed a wide variety of test equipment for high-power microwave tubes.**
- **1988-1995 Tektronix - Worked on microwave hybrids, PLL design and in-house test equipment**

design. Sustaining engineering and switching power supply design for several oscilloscope lines.

- **1995-1997 Advanced Energy – Product engineer for multi-kilowatt plasma power supplies.**

- **1997-2006 Micron Technology – Analog, Signal Integrity, and EMC engineering to support IC design and manufacturing. A Micron Fellow since 2001 and a NARTE Certified EMC engineer.**

- **EMC and antenna consulting.**

- **2006- present Linear Technology – Senior Test Engineer supporting analog IC test.**