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The FCP: A 160 Meter Counterpoise for a Postage-Stamp Lot

Here's a compact Top Band antenna system that actually plays with the big boys — no kidding!

Let's begin at WØUCE's original 6 acre site in North Raleigh, North Carolina. Jack greatly enjoyed big 160 meter transmit and receive antennas, as his contest scores proved. But when he downsized to a much smaller property, he was left with only a 100 × 150 backyard, and he all but gave up on ever operating on 160 meters. According to his wife and friends, Jack suffered 160 meter withdrawal, with periods of unconscious moaning and groaning. This pushed us to come up with a workable antenna system to fit his property that also might help other acreage-challenged hams to get on Top Band.

Jack erected a ¼ λ inverted L for 160 that had a 47 foot vertical leg and an 85 foot horizontal leg. Anything that might be done in terms of radials would be a huge reduction from the splendid 90 × 125 on-ground radials below the fan vertical at his old place. We tried two *elevated* ¼ λ radials across the backyard's long dimension, folding the ends back to the middle to make them fit. Jack was now on 160 again making contacts! Other hams tried this approach and improved their results in the process. One 100 W Minnesota ham who switched from two ¼ λ radials mostly over frozen ground went in 3 weeks from generally not being heard to logging 30 DXCC entities.

These results turned on the light in the K2AV "*Aha*!" closet. Modeling indicated that the fields from the folded wire were cancelling by the fold, producing sharply reduced fields at the ground only ⅛ λ from center. The losses in the folded radial due to induced ground currents seemed proportional to the square of the field strength at the ground below, summed beneath all of the wire, a smaller traverse equaling less loss. It was a short mental leap to a single 50 meter (5⁄16 λ) wire folded twice to traverse a mere 20 meter (66 feet), with the sharply reduced fields at ground now just 10 meter (1⁄16 λ) from center. When we installed this as a counterpoise at WØUCE — at 2.5 meter (8 feet) above ground — Jack started being heard well on 160 from his small lot using his smallish inverted L. So began 2 years of experimentation on layout, construction, methods and materials to perfect what became the 5⁄16 λ single-wire folded counterpoise or "FCP."

I had not had a good 160 meter antenna in decades, so when lightning turned a 120 foot tulip poplar into toothpicks and cleared a long strip in the woods between 100 foot trees, I strung up a ⅜ λ inverted L, up 90 feet and out 105 feet, over an FCP. The FCP runs parallel to the driveway, which partly explains the open strip in the trees and the reason why there's no possibility for conventional radials. It seemed to work fairly well, but I had feed problems from the start.

The peak common-mode current on my ½ λ, elevated 450 Ω feed line was higher than the differential current from the transmitter. This was despite a proper 4:1 ferrite current balun at the antenna, which we discovered had to block 900 V common mode. The ferrite's 4000 Ω blocking resistance, quite good in a normal situation, was dissipating 200 W at 1500 W from the amplifier, and it burned up. Jack had similar problems, and we cracked or burned up stuff there too. The only block that seemed to work at Jack's was a choke of RG-400 coax on a powdered-iron toroid with a parallel tuning capacitor.

At K2AV, after adding the tuned choke between the 4:1 balun and the FCP, the feed-line common-mode current was still too high, the balun got warm and the choke heated up when I ran high power. It was time for a new approach. Taking inspiration from a W2FMI voltage balun[1] wound on a huge 4 × 1 inch #2 powdered-iron toroid, I wound a trifilar 4:1 isolation transformer that ran stone cold at high power and made the FCP the only possible path for the counterpoise current. The R, X, Z and SWR curves taken anywhere along the line with an AIM4170 vector impedance antenna analyzer all changed. The dip on the big vacuum variable series tuning capacitor moved by several turns of the shaft, and somebody turned on all the lights.

After I installed the isolation transformer, the local field strength at 1500 W increased so much that it began shutting down my and my neighbor's AT&T U-verse® (TV, internet and phone over VDSL on copper subscriber lines). This was not a matter of occasional pixilation interference. We went from no interference at all while running 1500 W to a "I-refuse-to-even-reboot" gateway shutdown at 400 W, a bump of at least a 6 dB in field strength. We proved that RF from the antenna was causing the shutdowns by inserting a dummy load at the point where the coax transitions to a long stretch of 450 Ω window line. U-verse was clean in both houses when I ran 1500 W into the remote dummy load, even with my gateway in the room next to the ham shack. Common-mode losses on the 450 Ω feed line had been dissipating most of my power.

It was only a week before the January 2011 CQ World Wide 160 Meter CW contest, so I decided to run 100 W in the event to avoid interfering. I ran high power only while testing late at night for the AT&T techs. Interference issues were resolved over the next few months, thanks to some very helpful people at AT&T.[2]

After initially S&Ping in the contest, I found I could easily hold a run frequency at 100 W, with the rate meter sometimes peaking 180. I may have blundered by starting out S&Ping, but I did not repeat the error and only resorted to S&P for multipliers and when rates were down. The certificate from CQ says my low-power, single op, unassisted effort was No. 1 North Carolina, No. 1 in the Fourth Call Area, No. 4 in the USA and No. 8 in North America out of some 400 entries in that class. With nearly 1000 QSOs at low power from the US Southeast, this was not a score you'd expect to achieve with a compromised antenna.

After the contest, we replaced Jack's tuned choke with a bifilar 1:1 isolation transformer, with Jack now reporting, "I feel loud." Now we always specify an isolation transformer for an FCP installation, 1:1 for connecting to coax. Conventional balun and choke devices do not work well with an FCP, if they don't burn up first. A helpful side effect of switching an existing antenna system to the FCP and isolation transformer is a common report that the antenna is quieter afterward.[3]

At W4KAZ, Keith replaced 30 miscellaneous short (≤ 37 feet) elevated radials below his 160 meter inverted L with an FCP and an isolation transformer. He established a field strength reference point at 100 W to the antenna using radials. After installing the FCP, he was able to attain the reference level with only 20 W to the antenna. Before-and-after Reverse Beacon Network (RBN) figures supported at least that 7 dB difference. In the 2012 CQ 160 Meter CW contest, he ran 100 W with the FCP. An avowed phone op who called himself a "CW lid," Keith held a run frequency for 4 hours in the early going, averaging 75 contacts per hour. He finished with 593 contacts claimed in 20 hours, far and away a personal CW best. In the wake of that performance, we stripped him of his "CW lid" title, specifying that a phone op's fist was insufficient in and of itself for "lid" status.

At K5AF, Paul is on a 75 × 120 corner lot that is even smaller than WØUCE's backyard. For an all-band antenna he has a 180 foot tuned doublet, strung from a friendly neighbor's backyard tree to a streetlight post out front on the opposite corner. He ran an FCP above the back fence and then routed a badly bent inverted L having just a 40 foot vertical leg through trees and barely over the top of the house to a front yard tree. RBN readings around the country comparing Paul's doublet to the antenna with the FCP gave the FCP an average 7 dB advantage, with some differences of 15 dB. Since his L is so compromised by running over the house, he is experimenting with more efficient designs for a short radiator.

Word about the FCP and the isolation transformer has spread via the Top Band reflector and by word of mouth. At last check WØUCE's Web reference on the FCP had logged more than 10,000 hits from nearly 6000 individuals in 90 countries around the world.

How the FCP Folds Work

The FCP began as a quest for a counterpoise for small lots and to get Jack back on 160, but people kept asking how the FCP compares to conventional radials, even if radials were impossible for the questioners' small lots. Digging into this question unearthed a significant and surprising revelation: The FCP is no weak-sister substitute just for postage stampers. Contest results already seriously hinted at the FCP's effectiveness, unless you attributed scores to emerging super-op status curiously coinciding with FCP installation. So,

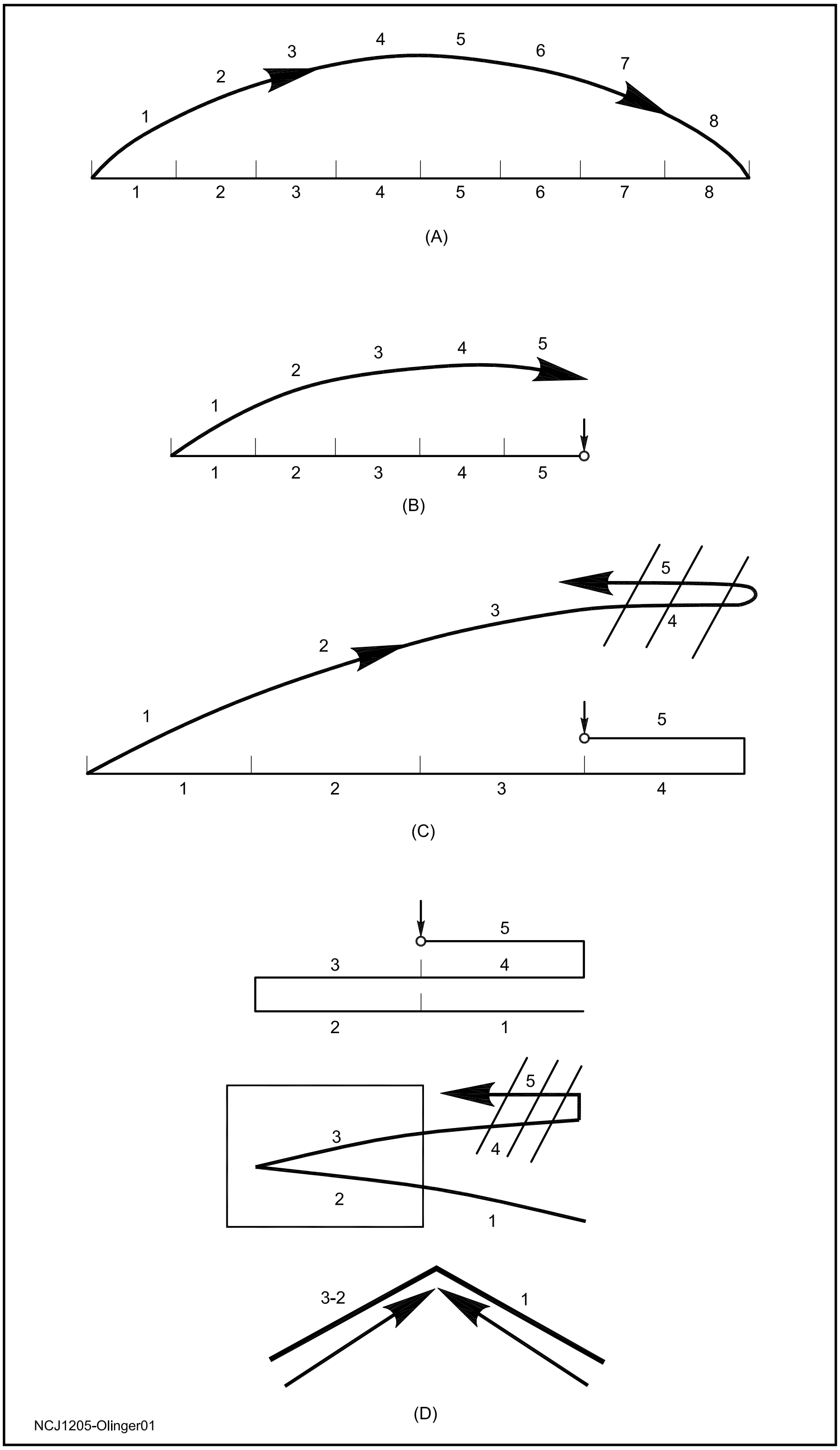

Figure 1 — FCP folding arrangement

it is important to understand how and why an FCP works.

First, the folds: Figure 1A shows the familiar sine wave RF current pattern over a ½ λ wire. The numbers represent eight ¹⁄₁₆ λ segments. We begin the ⁵⁄₁₆ λ folded counterpoise in Figure 1B by reducing the wire to sixteenths, numbered 1 through 5, the sine wave truncated on the right. The current maximum occurs between segments 4 and 5, and the current shape in segment 4 mirrors the current shape in

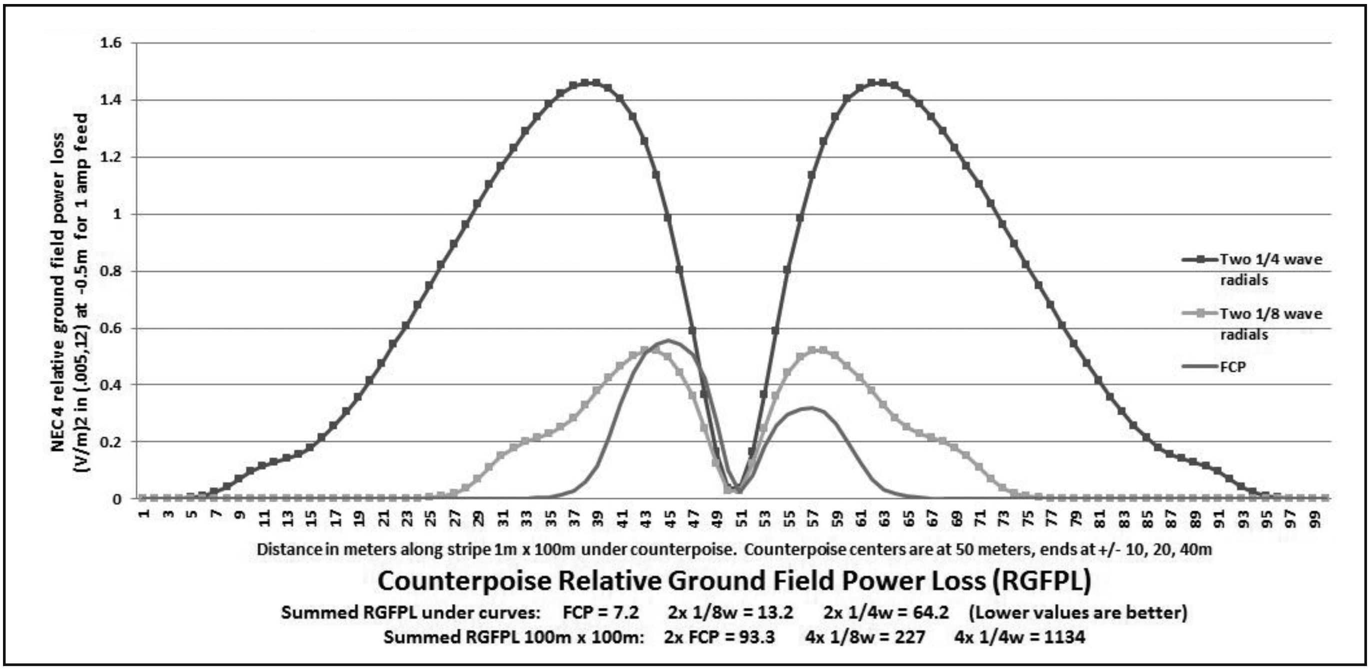

Figure 2 — Relative ground-field power loss

segment 5. In Figure 1C segment 5 folds back above segment 4. This causes the current in segment 5 to flow in a direction opposite to that of segment 4, creating opposite and equal fields that cancel and cannot generate ground fields. In Figure 1D, segments 1 and 2 fold back below segments 3 and 4. In segments 1 and 2 current now travels in the opposite direction as that in segments 3 and 4. On the right side, segments 5 and 4 have cancelled, leaving the current in segment 1 as the phase-reversed effective current on that side. On the left side the smaller phase-reversed current in segment 2 is subtracted from that in segment 3. At the left end of segment 3 the effective current is zero, while at the right end the effective current mirrors that flowing in segment 1. This opposite and equal effective current at the center is the pattern for any opposed equal radial feed; the FCP behaves like a pair of $\frac{1}{16}$ λ opposed radials, but with a far more usable feed-point impedance.

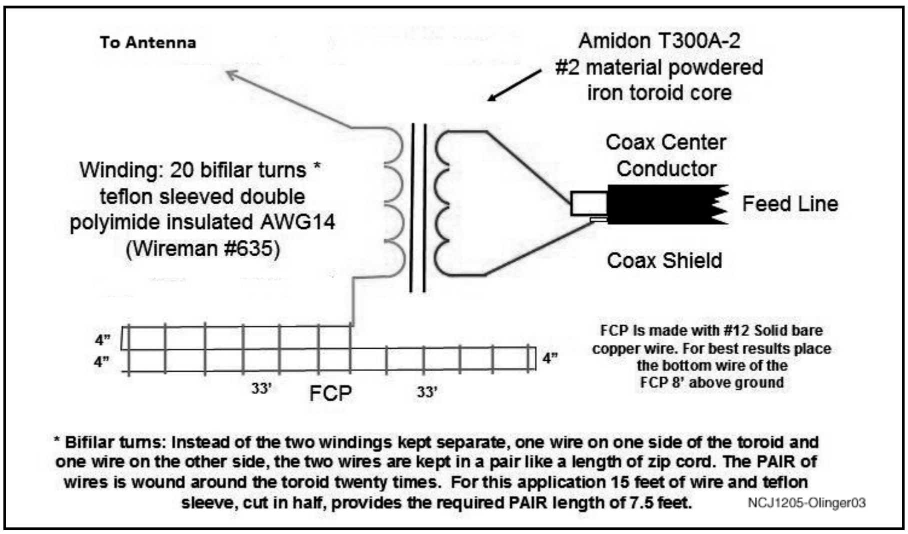

Figure 3 — FCP diagram

The FCP Versus Full-Size Radials

For the sake of comparison we'll divide counterpoises into two groups: (1) full-size, dense, uniformly spaced radials, and (2) the FCP, sparse or short radials, mixed-length or irregularly spaced radials, or any in or on-ground radials that don't fit into the first group. Full-size, dense, uniformly spaced radials can do what any of the possibilities in the second category cannot do — largely cancel the *vertical radiator's* near-field ground losses with the radials' uniform and opposite field. With an entirely vertical ¼ λ radiator over more than eight ¼ λ raised radials, this cancellation is worth up to 1.7 dB greater than anything possible in the second group.

The FCP is *not* an equivalent for dense, uniform ¼ λ radials. The approximate break-even point between the FCP and ¼ λ raised radials is somewhere around four radials. Two radials definitely belong in the second group. The FCP and the possibilities listed in the second group must do their jobs by minimizing their *own* ground losses, because they *cannot* significantly cancel the radiator's ground fields. The reason for the FCP is twofold: minimal space and a low-loss alternative to radials.

What Works Best?

The best choices in the second group would be those that exhibit so little ground loss that their only disadvantage compared to the gold standard in the first group is the 1.7 dB. For the worst, consider the Minnesota ham's case. Modeling his original two ¼ λ radials lying on frozen ground, *NEC4* estimated 15 dB of ground losses. This dropped his 100 W to the equivalent of QRP, easily explaining his before-and-after results. In Jack's new backyard, Paul's postage-stamp lot or next to my

1:1 Isolation Transformer and FCP Parts List

- T300A-2 #2 powdered iron toroid, Amidon, **www.amidoncorp.com/items/26**. The identical Micrometals T300-2D can often be found on eBay. A pair of Micrometals T300-2 can be taped together for the core.
- 15 feet of #12 AWG standard wall Teflon tubing, Amidon, **www.amidon.com/categories/15**
- 15 feet of double polyimide insulated wire #14 AWG, The WireMan, #635, **www.thewireman.com**
- Carlon 4 × 4 × 2 enclosure (for isolation transformer) with cover gasket, Carlon E989NNJ-CAR, or equivalent.
- 170 feet of #12 hard-drawn bare copper wire for the FCP, The WireMan, item #538, **www.thewireman.com/antennap.html**

Note: Do not substitute values except as specified or skip the Teflon sleeving in the isolation transformer. This particular combination has been tested at high power; lesser materials have failed. Do not use insulated wire for the FCP. Current instructions and revisions are maintained on WØUCE's Web site, **www.w0uce.net/K2AVantennas.html**

Figure 4 — The K8OZ isolation transformer

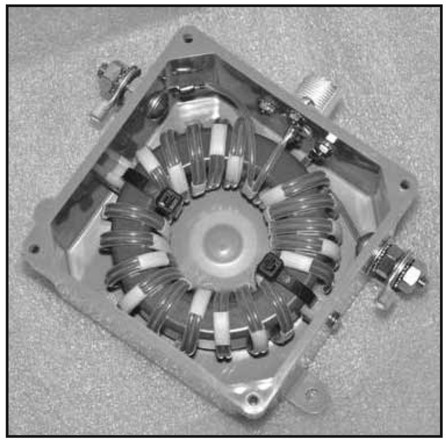

Figure 5 — The Balun Designs 1142s isolation transformer

Table 1 — Counterpoise-only series loss (in dB) for various radial/counterpoise configurations and antennas over average ground with different radiator feed-point impedance. The FCP uses bare #12 AWG wire. An "e" after the device indicates radials elevated 2.5 m. A "g" indicates insulated wires lying on the ground. The "g" figures represent average loss, following an *EZNEC Pro* **3D pattern run. The on-ground and elevated runs cannot reliably be compared to the same detail, other than to say that a few on-ground radials can be really bad, and one radial on the ground can literally be a dummy load.**

Device	36 Ω	24 Ω	16 Ω	10 Ω
4 × ⅛ λ e	0.13	0.20	0.30	0.47
2 × FCP	0.15	0.23	0.34	0.53
FCP	**0.30**	**0.45**	**0.65**	**1.00**
2 × ¼ λ e	1.19	1.68	2.33	3.29
1 × ¼ λ e	2.76	3.67	4.76	6.22
8 × ⅛ λ g	up to 4 dB, depending on ground and radiator			
4 × ⅛ λ g	up to 5 dB, depending on ground and radiator			
8 × ¼ λ g	up to 9 dB, depending on ground and radiator			
4 × ¼ λ g	up to 12 dB, depending on ground and radiator			
2 × ¼ λ g	up to 15 dB, depending on ground and radiator			
1 × ¼ λ g	up to 18 dB, depending on ground and radiator			

driveway we're left with reducing the *counterpoise* ground losses as our only method of attack. How do we identify the best of the rest?

I finally devised a way to model just the counterpoise, so we could see its weaker ground fields unobscured by the much larger field from the radiator. This is like trying to see the beams of a headlight on the ground in broad daylight. *EZNEC Pro*, running the *NEC4* engine, provides the data for *Excel* to sum and graph counterpoise ground losses for comparison.

The ground field data contains 10,000 data points in a 100 × 100 meter area centered on the feed point. This easily contains the entire ground field created by ¼ λ radials. To show how a counterpoise wire reacts with the ground, we graph a strip of data directly below the wire. To get relative loss, we process all 10,000 ground field values. Figure 2 shows results for the FCP and for opposed ⅛ λ and ¼ λ radial pairs.

The narrower width of the FCP reduces ground losses, because there is less beneath to be induced. Cancellation below counterpoise center provides additional ground-loss reduction, where the traces drop to near zero. This happens because counterpoise current (or effective current) spreads out in opposite directions from center, producing opposite and equal fields. Using a counterpoise height of 2.5 meter (8 feet) on 160, this self-cancellation zone, or the width of the notch, extends ±15 meters. The FCP, only 10 meter either side of center, lies *entirely inside* the self-cancellation zone, further driving down the FCP's ground losses. The ¼ λ wave radial pair has 50 m of its 80 m length *outside* the self-cancellation zone. In a dense ¼ λ wave counterpoise, the field outside self-cancellation cancels the field from the vertical radiator. In a sparse version, the 50 meter is mostly loss.

An exhaustive ranking among elevated, on-ground and buried radials and the FCP lies well beyond the scope of this article. Aspects of radials, the FCP and the design of the vertical radiator create a huge matrix of combinations. Table 1 lists the best of the low-loss solutions and some all-too-common and significantly lossy counterpoise attempts.

How to "Do" an FCP

Figure 3 depicts the "simple" FCP configuration. That's all there is to it, a folded wire you support appropriately for your situation, a 1:1 isolation transformer in an enclosure, a radiating wire and coax to the shack. You put it up and prune the radiator to center the SWR, typically somewhat longer than ¼ λ.

Commercial versions of the FCP 1:1 isolation transformer are available from Balun Designs for both 80 and 160 meters,[4] but many are winding their own. Figure 4 is K8OZ's nice 160 meter implementation. Figure 5 is Balun Designs' commercial version built to our specs.

When winding your own isolation transformer, be careful not to flip connections on one end of the winding (see Figure 6). The flip will change the winding into just a so-so choke balun, giving the counterpoise current an easy path to the coax shield, a *de facto* single radial on the ground, arguably the most lossy counterpoise possible. If you wire it wrong, it may *seem* from the broad SWR that it's working, until you start comparing RBN reports.

Make sure there is no short between the coax connector side and the FCP/radiator side. To finish the check, you *should* see a short between the FCP and radiator connections, and a short between the coax connector threads and center conductor.

After wiring everything, you may not see an impedance close enough to 50 Ω to suit you. K5ESW lengthened his radiator to get the resistive component of his transformer's output impedance to 50 Ω. To cancel the remaining inductive reactance, he broke the isolation transformer connection between the coax center conductor and the winding and experimented with various capacitor values, settling on a series 1800 pF capacitor wired inside the transformer housing.

The impedance at the transformer output can vary widely, depending on the radiating wire, the exact nature of the earth, nearby conductors and other factors. In most cases adjusting the length of the radiator for zero *reactance* at center frequency presents an impedance close enough to 50 Ω to allow for tuning in the shack. Or using dimensions from W8WWV's free smc.exe utility,[5] you can construct a coaxial series matching transformer of 75 and 50 Ω coax that both covers feed line length and presents 50 Ω at the shack.

To deal with wind static buildup on the antenna, use a 5 or 10 M Ω high-wattage resistor from the antenna radiator to-ground as a static drain (eg, Mouser 71-ROX210M1%K).[6] To avoid destruction of the winding in the event of a nearby lightning strike, do not mount the resistor inside the isolation transformer housing. Place it externally from the antenna post to ground. Some have placed a non-resistive lawnmower spark plug in parallel with the resistor to protect it. Enclose these in a separate container for ease of examination and replacement. This arrangement will prevent pinhole penetration of the transformer winding insulation and subsequent carbon track failure. *Do not* ground the FCP, as the counterpoise current *will* divert to earth, losing all benefit. Ground the coax shield a short distance (5 to 10 meter) from the transformer.

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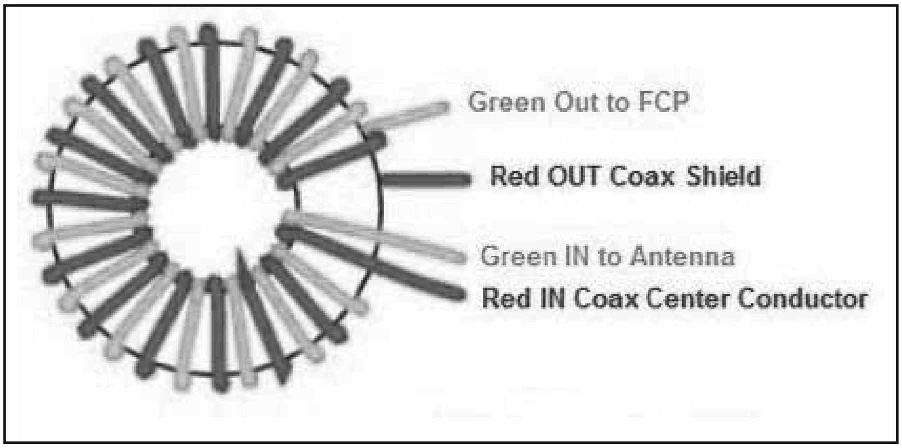

Figure 6 — The proper way to wind the FCP toroid. This is the 80 meter version with 15 bifilar turns.

Using the FCP on 80 Meters

The FCP works well on 80 meters. DL2OBO has constructed an 80 meter 4 square array over FCPs. The FCP spacing between wires remains at 10 cm (4 inches) and the height at 2.5 m (8 feet). The length is 5 meter on a side (16.5 feet). The isolation transformer winding should have 15 evenly spaced bifilar turns (as opposed to 20 turns for 160). If you are switching between 80 meter and 160 meter FCPs in a multiband arrangement, use the 160 meter isolation transformer and tune the 80 meter impedance on the coax side of the transformer.

Acknowledgements

My special appreciation to Jack Ritter, WØUCE, and Howard Hoyt, N4AF, whose patience as guinea pigs and enthusiasm for antenna ideas over the years kept me going after I'd wandered into blind corners. Many thanks too for Jack's Web page and *PowerPoints*, which present these ideas and their updates. These individuals have been involved as all of this grew from an acorn. Thanks also to the gang at the NC East (Raleigh) chapter of the Potomac Valley Radio Club for their involvement, occasional basic research on my behalf, and their reliable "Yeah, yeah, yeah, what now?" poke-in-the-rib support.

Notes

1 Sevick, J W2FMI, *Understanding, Building, and Using Baluns and Ununs. Theory and Practical Designs for the Experimenter*, CQ Communications Inc, Hicksville, NY, 2003, pp 60-61. The FCP's 1:1 isolation transformer uses a 3 inch rather than a 4 inch core.

2 AT&T has a national program to address this kind of interference. A dedicated national headquarters staffer, also a ham, shepherds resolution of interference to U-verse from RF in the VDSL closed-circuit frequency range 147 kHz to 8 MHz. This AT&T program is accessed via the ARRL RFI Task Force, which screens cases to make sure they apply — and that simple fixes will not remedy the issue — before passing them along. In my and my neighbor's cases, there were multiple issues to resolve, some related to freeway construction around AT&T equipment locations. Both of our houses are interference free, regardless of my power level or frequency.

3 Balun Designs LLC, 10500 Belvedere, Denton, TX 76207. (817) 832-7197; **www.balundesigns.com**

4 Followup on these positive reports usually indicates less-than-robust blocking of the coax feed line shield from the antenna before conversion, often with no more than a coil of coax or no block at all. The isolation transformer offers a brute force block of common mode current that is built in to the method and can't be omitted. More than anything, this underscores the value of careful and robust common mode blocking on any 160 meter antenna, whatever the counterpoise configuration or blocking method.

5 Greg Ordy, W8WWV, Seed Solutions Inc, 7505 Sherman Rd, Chesterland, OH 44026. **www.seed-solutions.com/gregordy/Software/SMC.htm**

6 Mouser Electronics, 1000 N Main St, Mansfield, TX 76063. (800) 346-6873; **www.mouser.com**

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