# Radio FUNdamentals

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THINGS TO LEARN, PROJECTS TO BUILD, AND GEAR TO USE

## The Off-Center-Fed Multiband Antenna

The single-wire, off-center-fed "Windom" antenna is nearly as old as amateur radio itself. The antenna faded into obscurity during the 1940s as newer and sexier antennas came along, but the idea itself remained, as it seemed to have merit (fig. 1A).

In the early 1950s some amateurs resurrected the Windom and substituted a 300 ohm ribbon line for the single-wire feeder and used a balanced antenna tuner at the station to achieve multiband operation. The idea worked, but bringing the feeder into the shack was a direct invitation for TVI!

### The Early Days

It was thought that coax feed might clean up the TVI, so the next variation on the off-center-fed (OCF) antenna was to shorten the ribbon line and add a 4:1 balun and a 75 ohm coax line running to the station (fig. 1B).

Again the scheme worked, and this version of the antenna was shown in both the *ARRL Handbook* and the *ARRL Antenna Book* for almost ten years. The editors of these publications, however, warned readers that "it is claimed that the antenna offers a good match for the 300 ohm line on four bands, and although this is more wishful thinking than actual truth, the system is widely used and does work satisfactorily."

The use of 75 ohm coax with the antenna was a handicap, as very few 75 ohm SWR meters existed at that time. Meaningful information on real-life OCF antenna operation was skimpy and mainly based on heresay, as accurate RF measuring equipment was generally unavailable to the amateur fraternity.

### OCF Antenna Mysteries Are Solved!

Finally, in 1954 William Wrigley, W4UCW, a Research Engineer at the Georgia Institute of Technology, provided in detail the analysis of an off-center-fed dipole antenna.[1] He gathered and organized the available information on the subject and added additional data that he had derived. He investigated harmonic operation of the antenna and provided meaningful numbers concerning the feedpoint resistance (radiation resistance) of a dipole in free space as the feedpoint is moved away from the center (fig. 2).

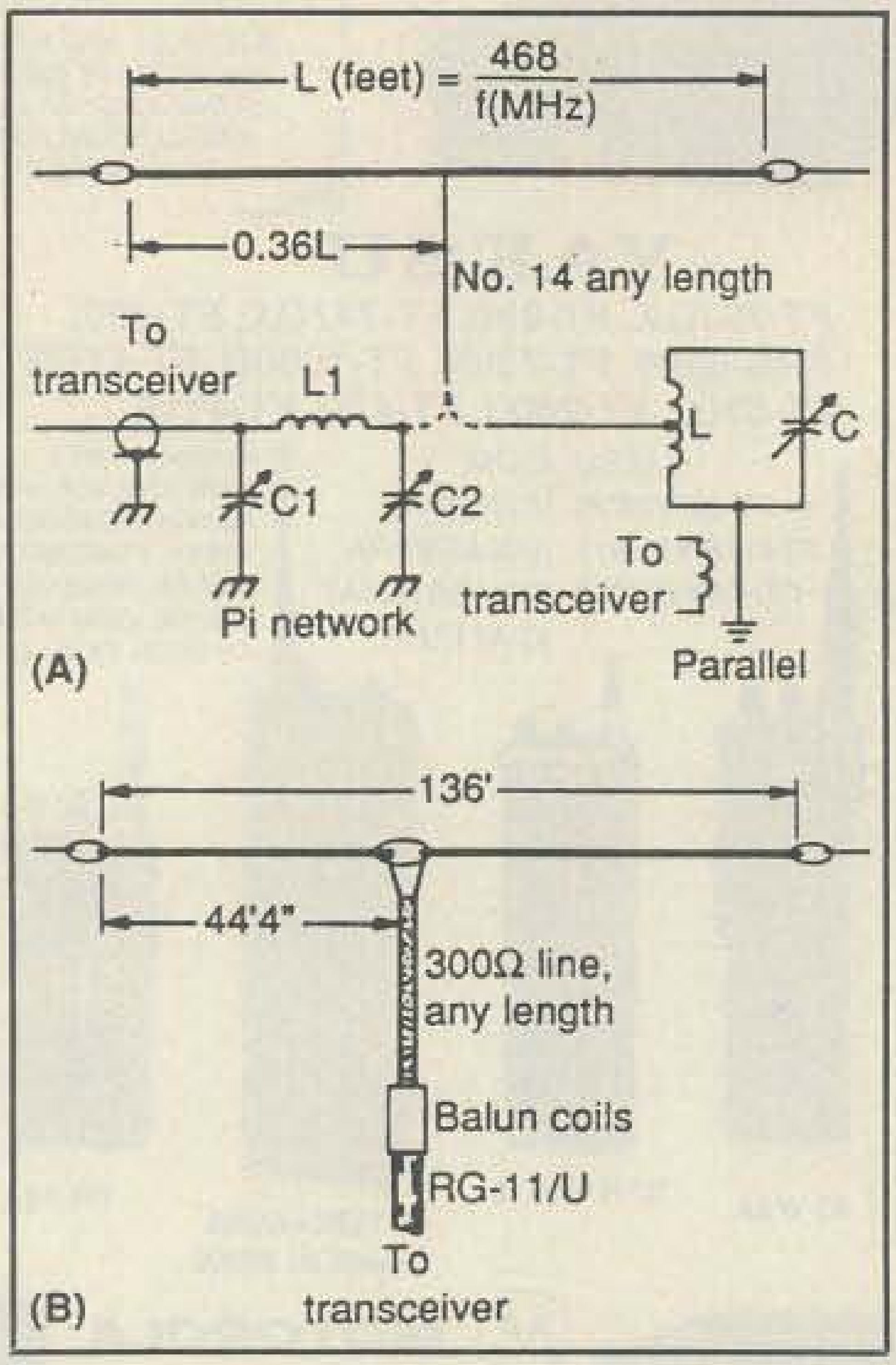

*Fig. 1– The OCF antenna was featured for many years in ARRL publications. (A) The original Windom antenna. (B) The coax-fed version of the Windom. (Original drawing appeared in the* ARRL Handbook.*)*

The plot shows that two points exist along the dipole where a 300 ohm termination is possible, one on each side of the center point. In this example the points are about 60 electrical degrees from the center of the antenna (30 degrees from each end). This is equivalent to a distance of 16.6 percent from either end of the dipole.

When the dipole is mounted 0.1 wavelength above ground, however, Wrigley showed that at this height the 300 ohm tap point is 23 degrees from one end, which is equivalent to 12.7 percent of the total antenna length. Obviously, the tap point varies with respect to antenna height above earth. Either amount is much less than the tap distance shown in the handbook illustration (B).

Next Wrigley showed that this point or any other feedpoint along the dipole is resistive and has no reactive component at antenna resonance, contrary to popular belief.

Wrigley now examined harmonic operation of the half-wave antenna. Fig. 3 shows the relationship, illustrating that for good harmonic operation on the higher frequency amateur bands, an 80 meter antenna should be cut to resonate below the low edge of the band. He suggested that a length of 136 feet is an acceptable compromise for multiband operation (80, 40, 20, 15, and 10 meters). This length resonates at about 3.45 MHz.

As a whole, his data agrees closely with that derived by modern computer antenna analysis.

### The Wrigley OCF Antenna Design

As his theoretical example Wrigley chose a 136 foot, 80 meter OCF dipole placed 25 feet above ground (0.1 wavelength at 80 meters, 0.2 wavelength at 40 meters, 0.4 wavelength at 20 meters, etc.). The resonant frequencies of this antenna are 3.42 MHz, 7.10 MHz, 14.27 MHz, and 28.75 MHz. The calculated bandwidths for a 2:1 SWR were 51 kHz on 80 meters, 88 kHz on 40 meters, 194 kHz on 20 meters, and 214 kHz on 20 meters. Not very encouraging!

W4UCW then computed results when antenna height was boosted to 65 feet (0.25 wavelength at 80 meters). He concluded that the best compromise feedpoint position for harmonic operation was at a 150 ohm point on the antenna. Bandwidth was improved on the two lower bands, but the problem of obtaining a 150 ohm line was difficult.

He reasoned that the use of a coaxial pair of 75 ohm lines was impractical, as the coupling effects due to the induced currents in the outer surface of the shields would produce unpredictable distortions in impedance, and that these distortions would vary on different harmonics.

Wrigley's conclusion was that the OCF antenna, tempting as it might seem, was impractical. No feedpoint position could be found that would match a 300 ohm feed system and permit multiband operation, and even if one was found, bandwidth of the antenna was too narrow for everyday use.

And there the matter stood for 17 years.

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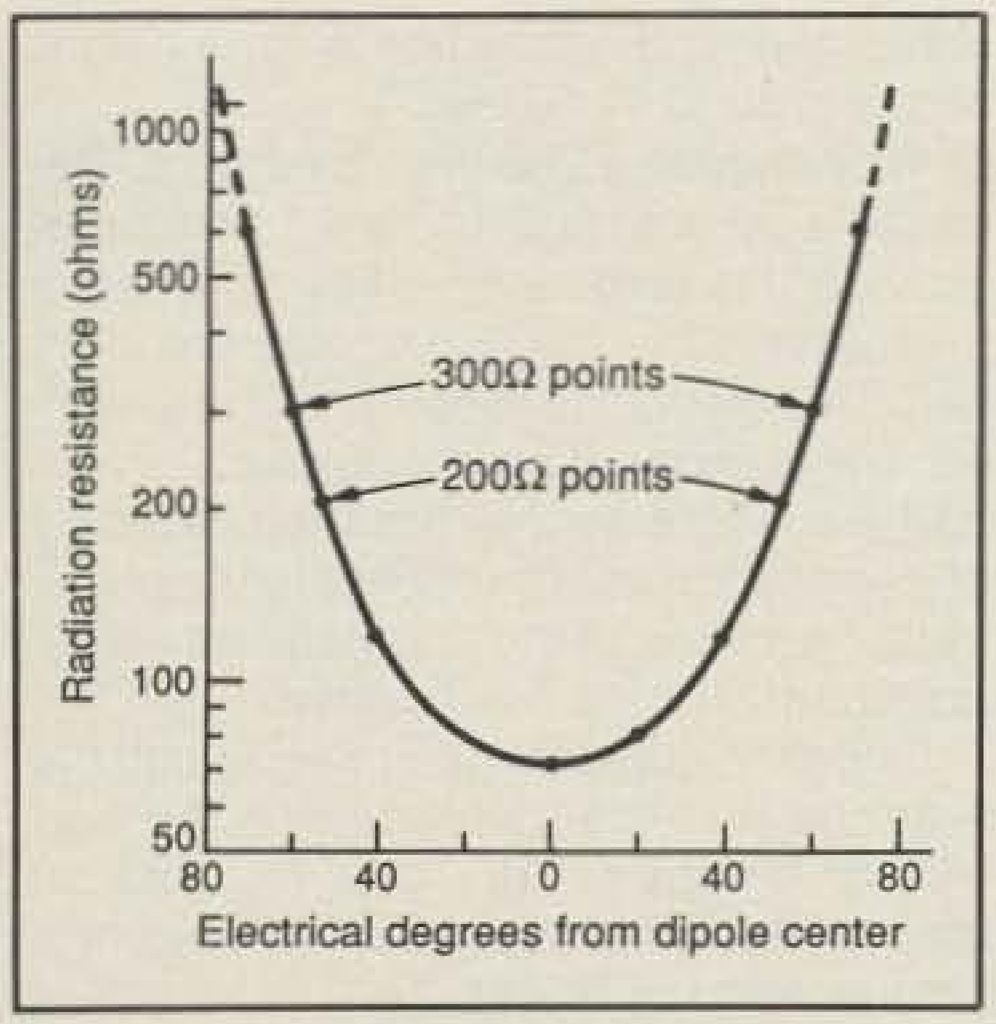


*Fig. 2– W4UCW's graph of radiation resistance of a dipole in free space as the feedpoint is moved away from the center.*

## The OCF Antenna Lives!

It must be remembered that Wrigley's studies were theoretical, based upon an infinitely thin dipole in free space. Imponderable things such as end effect, wire diameter, and the presence of imperfect earth below the antenna could not be taken into account. Of course, these parameters enter into the design of a real-life antenna! But the data supplied by Wrigley formed the basis upon which to build a practical OCF antenna. He pointed the way. It remained for someone to build the antenna and make meaningful measurements on it.

In 1971 a modified form of the OCF antenna was built by Spillner, DJ2KT, and described in the German magazine *QRV* in December. It gained popularity in Europe under the name "FD4 Windom." Fig. 4 shows a version of this antenna, which made use of a simple voltage-type 4:1 balun built by Sorbie, GM3MXN.[2] Sorbie also found that he could load this simple antenna on the 18 and 24 MHz bands, as well as on the harmonic bands of 80 meters.

In 1983 Scholle, DJ7SH, and Steins, DL1BBC, connected two OCF dipoles in parallel for coverage of all amateur bands between 160 and 10 meters. Exceptional bandwidth was shown in SWR plots of the installed antennas. Was W4UCW wrong in his pessimistic bandwidth predictions? Or, at last, was this the ultimate multiband HF antenna?

The DL7SH/DL1BBC antenna was described in a 1990 *QST* article and created quite a stir.[3] Several commercial versions of this design promptly hit the market, and one such antenna was reviewed in *QST* with mixed results.[4] Bandwidth seemed very good, but the antenna was especially susceptible to parallel-mode currents flowing on the outside of the coax shield. This made exact measurements difficult.

All of this information was intriguing, so I decided to use a computerized antenna modeling program to examine an OCF. If it looked promising, I decided I'd build one myself and try it out.

## An Examination of The OCF Antenna

The antenna feedpoint data provided by Wrigley and others can quickly be checked by using a modern computerized antenna modeling program such as MN 4.5 produced bv Brian Beezley, K6STI.[5]

Operation of the MN program is interesting. It divides an antenna into segments. The program user chooses the number of segments for his analysis. MN then uses the wire segmentation to model conductor current in sections called *pulses*. Current is uniform within each pulse. In my case I chose 68 pulses, as each pulse is equivalent to a foot distance on a 7 MHz antenna. This made computation easy. By iteration, the feedpoint may be moved along the antenna from the center towards one end. A readout is obtained of antenna resistance and reactance at each specified point, and the SWR for a match to a 200 ohm feed system can be

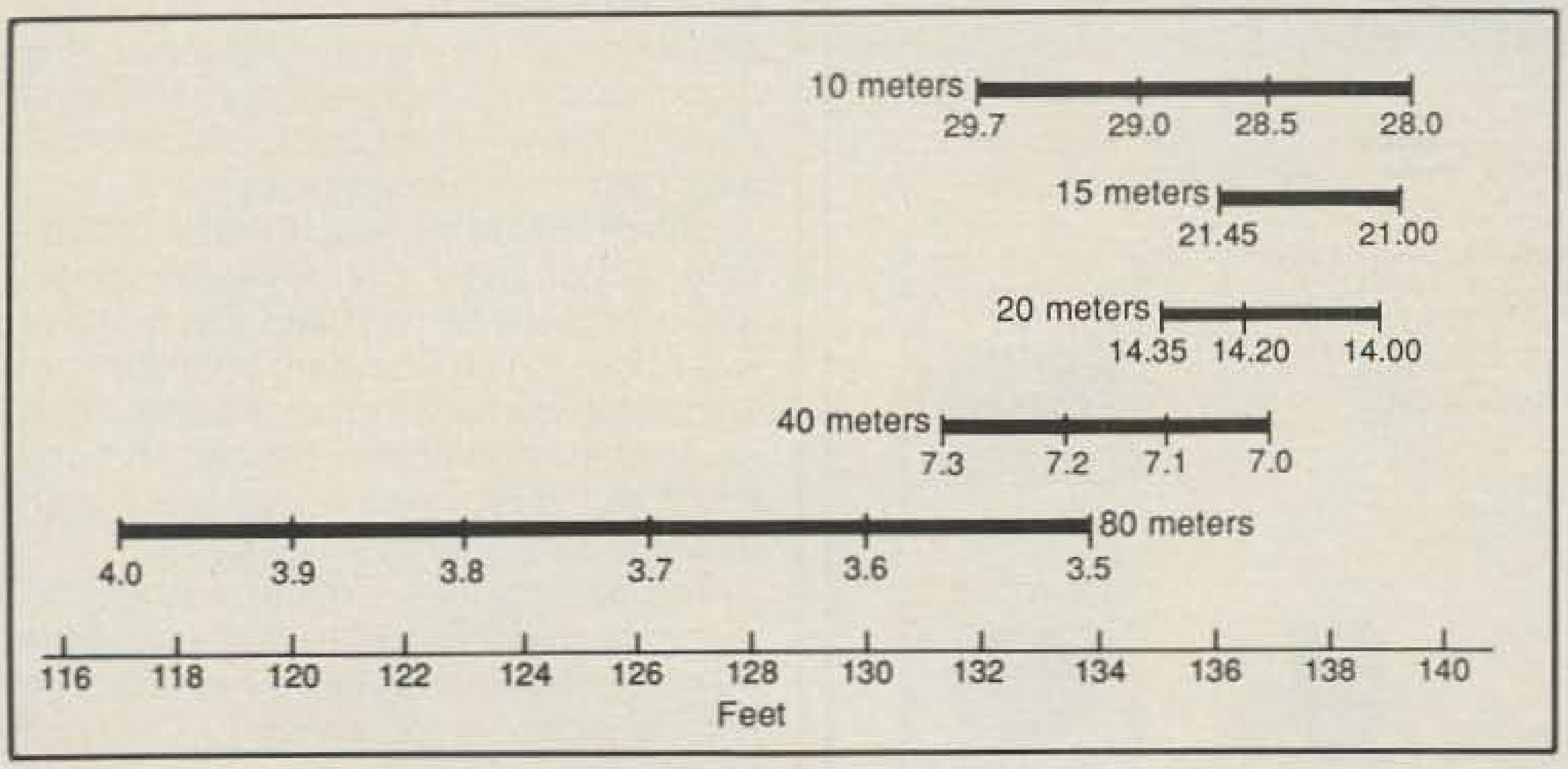
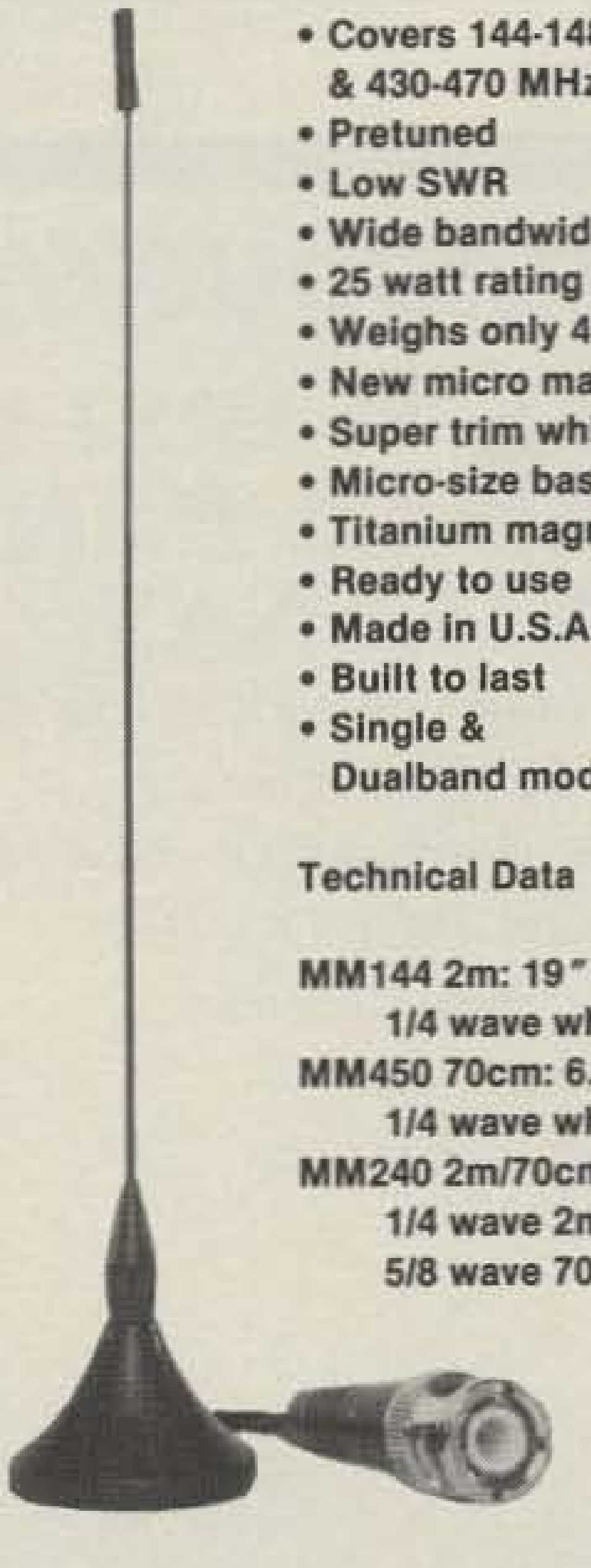
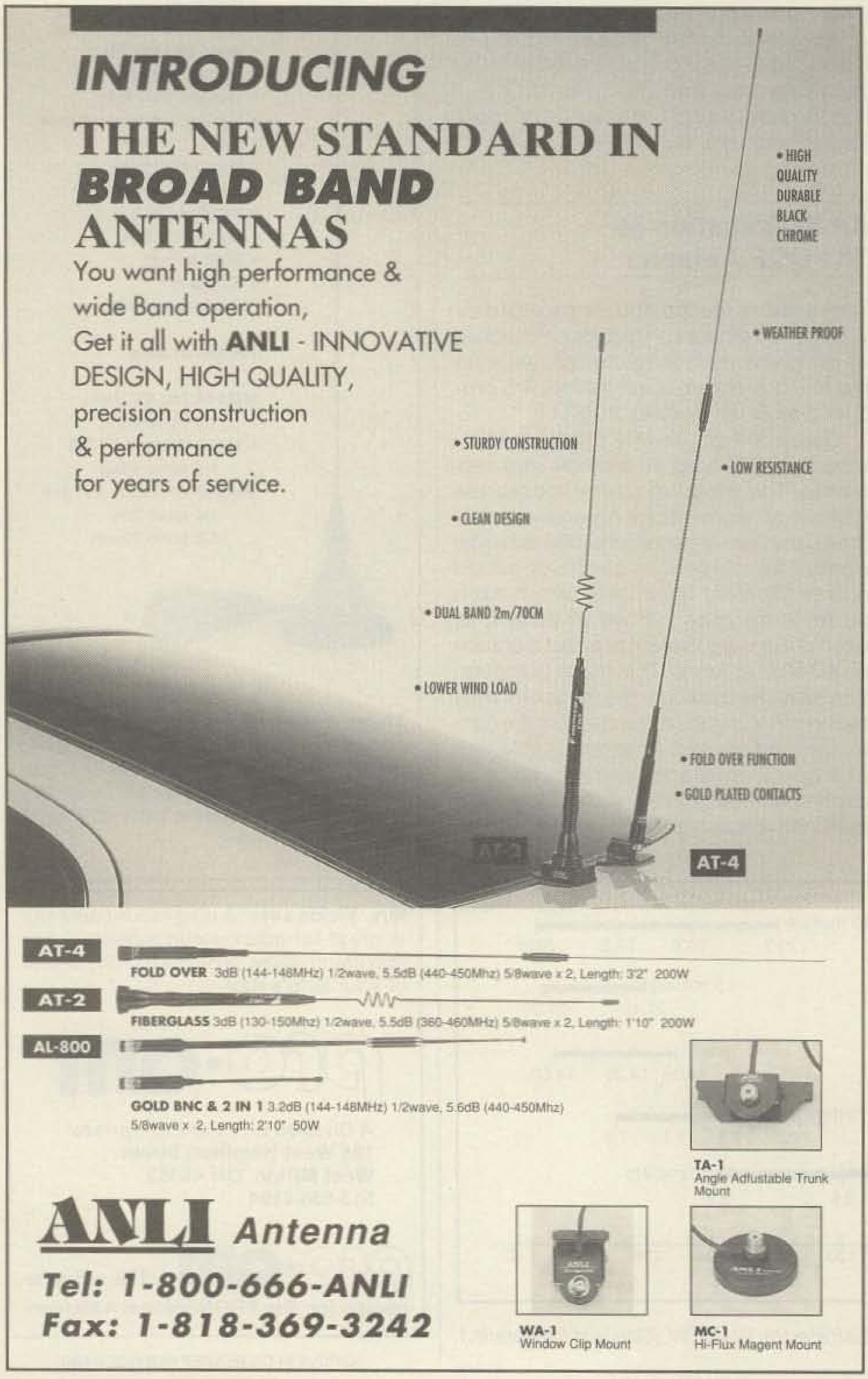


*Fig. 3– Harmonic relationship of HF bands as illustrated by W4UCW. (See text for details.)*





computed. The simulation is for a height above ground of 40 feet.

Why choose a 200 ohm feedpoint? Because a 50 ohm line and a 4:1 balun can provide this termination. For Europeans and others who use 75 ohm line and a 4:1 balun, a 300 ohm feedpoint can be selected. The number of segments in the antenna file and the source are then carefully chosen by the user to duplicate the physical dimensions of the antenna and the requirements of the feed system.

Once the 200 ohm point was found, the antenna was then scanned on the harmonic frequencies—20, 15, and 10 meters. It was quickly found that Murphy's Law was in full flower. The optimum tap point was different on each band and also varied with height above ground. In addition, if the shorter section of the flattop approaches a half-wavelength on 10 meters (about 17 feet), the antenna presents a high feedpoint impedance and is useless on that band.

The only practical solution was to find a compromise point that provided a reasonable feedpoint impedance on all bands. A practical antenna height of 40 feet was chosen. Otherwise, I could spend the rest of my days juggling height versus feedpoint versus SWR versus wire size. I settled on #14 wire, and my goal was a maximum SWR limit of 2:1 on 40 meters and the harmonic bands.

## The W6SAI OCF Antenna

It is not readily apparent to me that any feed system by itself could alter the intrinsic bandwidth of a dipole antenna. A computer run on a sample antenna to check bandwidth seemed like a good idea. Using the MN technique, the 7 MHz dipole 40 feet high was chosen as the program guinea pig. In turn, it was fed at the center, 31 percent from one end and then 19 percent from the end. Inputting these data to the computer and making a frequency run from 6.7 to 7.4 MHz revealed that in all cases the bandwidth of the dipole, taken between the 2:1 SWR points, was about 420 kHz, identical within the measuring tolerances of the experiment. This cast doubt in my mind that dipole bandwidth is a function of feedpoint placement.

Space limited me to a 40 meter OCF dipole. Accordingly, the computer model was configured for that band. The tap point was chosen at 20.5 percent from one end. This point was based on data gathered on an 80 meter computer model, and one which would provide a reasonable match to a 200 ohm source on all bands.

The dimensions were fed into the computer file, and a run was made across the 40 meter band and its harmonics. The results looked good enough to warrant construction of a real antenna and to hang it from a yardarm on the tower.

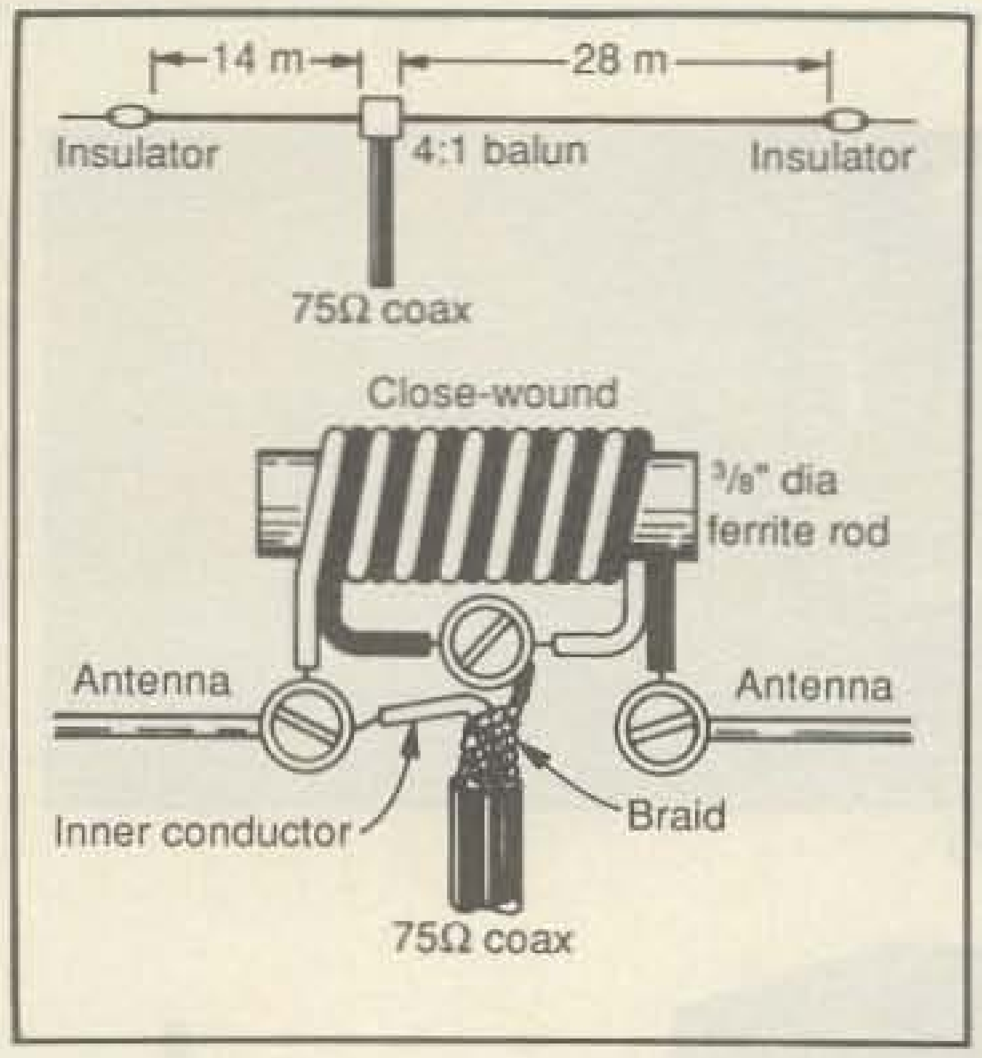


*Fig. 4– The "FD4 Windom" with balun placed at feedpoint. This version was used by GM3MXN. The "m" refers to meters, whereas 14m = 45′ $11\frac{3}{16}$″ and 28m = 91′ $10\frac{5}{16}$″. (Drawing courtesy of the British magazine* Radio Communication.*)*

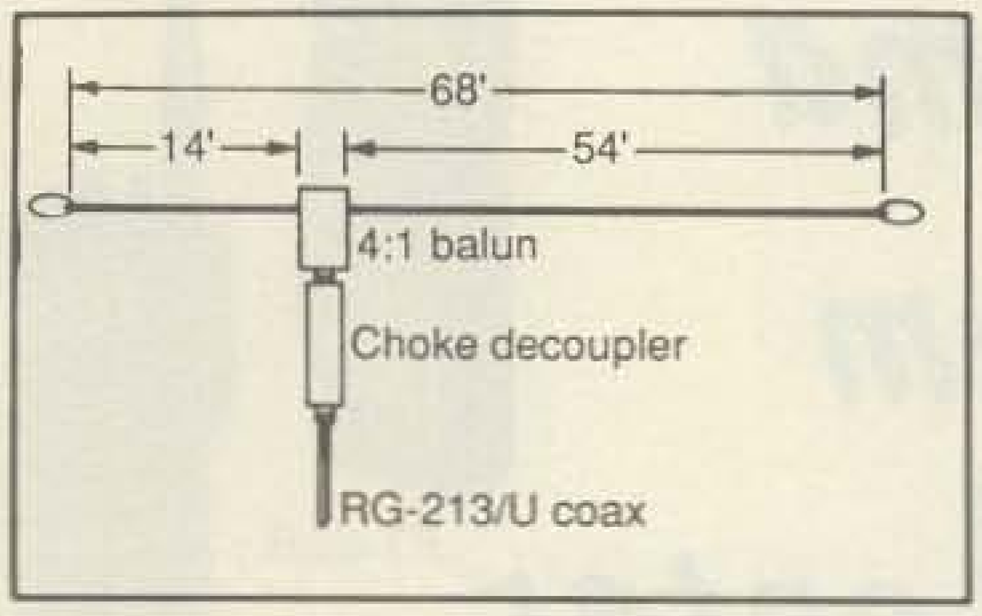


*Fig. 5– The OCF dipole at W6SAI for 40, 20, 15, and 10 meters.*

## Building An OCF Antenna

The next step was to build an OCF dipole and make direct impedance and SWR measurements. Perhaps the amazingly broad SWR curves exhibited by the German antenna were a result of ground loss caused by the low height of the test antennas. At DL1BBC the antenna was only about 22 feet above ground at the center, rising to 26.25 feet at the ends. The DL7SH antenna was only 16.4 feet above ground and partially passed over a garage roof. The antenna was in an inverted-V configuration. I was curious to see what my OCF antenna would do at a reasonable height above ground, when checked with reliable instrumentation.

My real-life 40 meter OCF antenna was 68 feet long and fed 14 feet from one end. A 4:1 current-type balun was used (Radio Works B4-2KX) along with a ferrite choke decoupler (Radio Works C1-2K) to "cool off" the coax line and permit accurate measurements.[6] A 50 ohm transmission line connected the antenna to the test equipment (fig. 5). The antenna was placed in an inverted-V configuration, with the balun and decoupler at the 40 foot elevation and the antenna ends at a height of about 30 feet.

## Antenna Measurements

The first step was to check antenna R (resistance) and X (reactance) at various frequencies. An HP-606A signal generator and a calibrated General Radio 916 RF bridge were used. A Kenwood R-2000 receiver served as a null detector. After these tests, measurements would be repeated with an SWR meter.

Alerted by the *QST* review, citing transmission line problems, ferrite sleeves were placed along the coax line to decouple it from the antenna field and to increase the common-mode impedance. Each sleeve consisted of six ferrite beads (Amidon FB-43-1020) placed close together and held in position by plastic cable ties.[7] The coax line was RG-213/U. The line was run down to ground level (at which point a sleeve was placed) and then taken away from the antenna at right angles to it.

The R and X figures derived from the RF bridge were converted to SWR measurements, and the resulting curves are shown in figs. 6 through 9. Operational bandwidth on each band exceeds the values predicted by W4UCW, and in fact, are comparable to figures previously predicted by the computer program. It seemed as if the multiband antenna was at hand.

## Line Current Problems

The last step was to add an additional 50 feet of coax to cover the distance to the operating position. SWR measurements on all bands were run using the station transceiver, a Bird 43 directional wattmeter, and a Daiwa model CN-720 SWR meter. Curves for the General Radio Bridge measurements can be compared with those made with the SWR meter.

On 40 meters the operational SWR was approximately 2:1, dropping to about 1.6:1 at the high end of the band. Antenna resonance was near 7.35 MHz (fig. 6). On 20 meters highest operational SWR was at the low end of the band, being about 1.9:1 (fig. 7). At the high end, SWR ran close to 1.4:1.

SWR response on 15 meters was very good, running from about 1.4:1 at the low end to 1.35:1 at the high end (fig. 8).

The 10 meter curves were quite flat, running from about 2:1 at the low end to about 2.4:1 at the high end (fig. 9).

Why the difference in the readings between the instruments? There are several reasons. First, common-mode current tends to flow on the outer surface of the coax shield even with extensive ferrite suppression. Second, it is difficult to decouple the line running to the transceiver, as it runs parallel to the antenna, near the ground, for some distance. Ferrite sleeves along the line helped a lot. Finally, neither the SWR meter nor the Bird wattmeter can be classified as a precision instrument. It would take a lot more line decoupling and a network analyzer (costing many kilobucks) to get more accurate SWR readings. Unfortunately, even with the best isolation possible, it is still possible for unwanted parallel currents to flow because the line is asymmetrically coupled to the antenna. Current induced from the short leg probably will not be equal to that induced from the long leg. The currents will not cancel completely. Hence, some parallel current is bound to flow on the outside of the coax shield.

Given the choice, I believe the RF bridge measurements to be the more accurate of the two sets because of the residue shield current.

In any event, the curves looked good. It was easy to load the antenna directly with a tube-type transceiver. A solid-state job required the service of the built-in antenna tuner to achieve full output when the SWR approached 2:1.

The G.R. bridge told me that operation on the 18 and 24 MHz bands would be difficult, as the SWR on those bands would be very high. However, SWR measurements run at the station indicated SWR values less than 3:1 on those bands! To

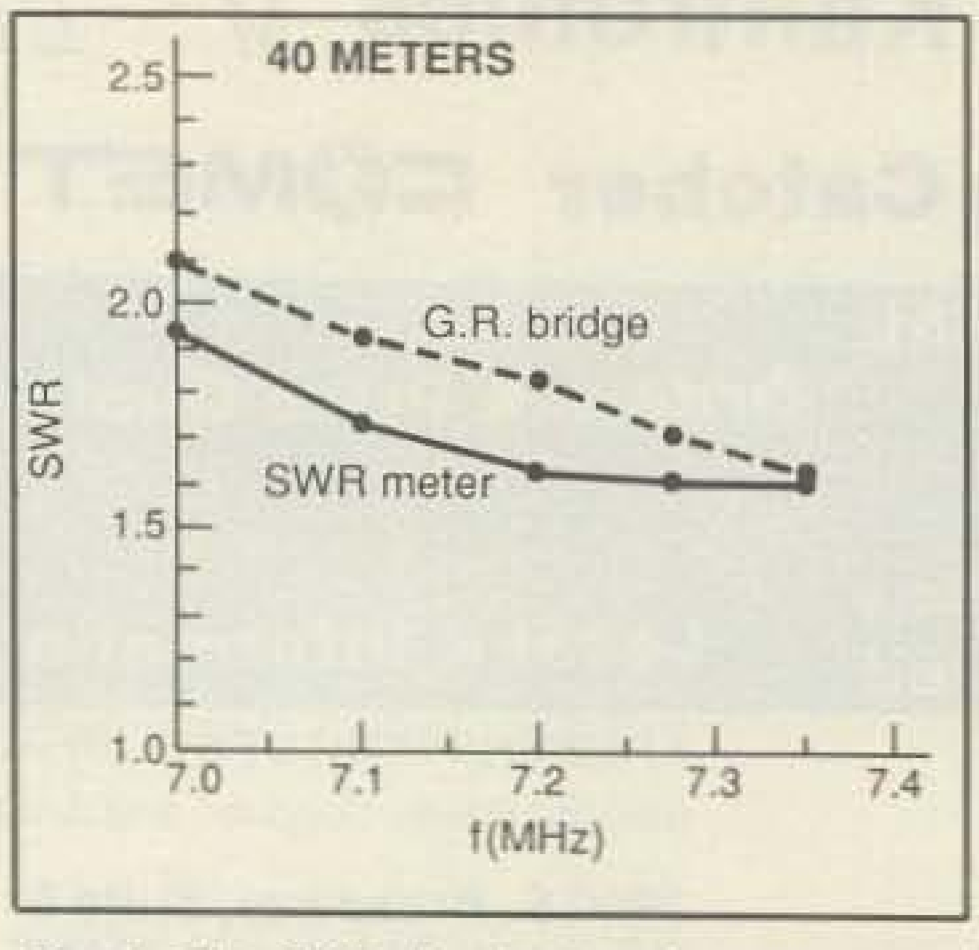


*Fig. 6– The OCF dipole showing measured SWR curves for 40 meters.*

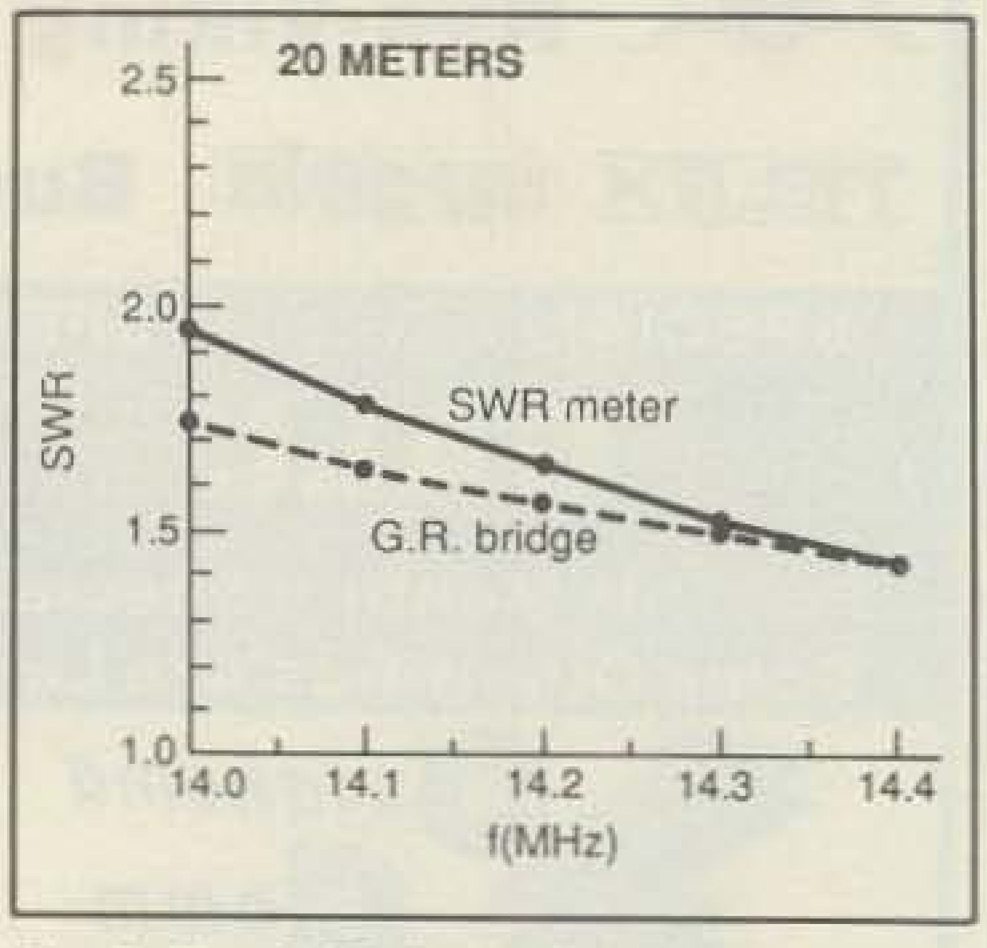


*Fig. 7– The OCF dipole showing measured SWR curves for 20 meters.*

prove it, I worked plenty of DX on 18 MHz, and a few stations on 24 MHz, in spite of the band sounding "flat." Operation on 24 MHz was not as good as I had hoped. All of this bears future investigation.

## The Final OCF Antenna

The conclusions I reached from these interesting tests are that the OCF concept is practical, and a suitable antenna can be designed for harmonic operation provided antenna length and feedpoint are properly chosen. For 80 meter fundamental and harmonic operation the OCF antenna should be about 136 feet long. For 40 meter fundamental and harmonic operation a length of 68 feet is recommended. For a 50 ohm line with a 4:1 current balun the tap point lies about 20 percent from one end, depending upon antenna height and location. I chose a tap point of 20.5 percent. A good, current-type balun is required for proper antenna operation.

A ferrite line decoupler is required just below the balun. Additional ferrite decouplers along the line and at the transmitter are recommended if the line runs parallel to the antenna for any distance.

Either antenna will operate with reasonably low SWR on the harmonic bands, plus provide operation on the higher WARC bands.

If a tube-type transceiver with pi-circuit output is used, an ATU (antenna tuning unit) probably will not be required at the station. If a solid-state transceiver is used, it is less forgiving, and an ATU (built-in or auxiliary) will be required. Otherwise, power output of the transmitter will drop as coax SWR rises.

## The Bottom Line

The OCF antenna seems particularly susceptible to common-mode currents flowing on the outside of the coax shield. The effect of these can be reduced by use of decoupling sleeves. If the proper precautions are taken, the OCF will prove to be a workable, multiband HF antenna that is an asset to the modern amateur station.

There are still unanswered questions: Why does the antenna seem to work on 18 and 24 MHz? What is the effect of the ferrite balun on overall operation? What is the effect of antenna height above ground? Would a sleeve-style W2DU 4:1 balun be more effective than a ferrite toroidal balun? Can the tap point be placed at a more advantageous position? I'm sure other experimenters will enjoy playing with this intriguing antenna and getting the answers to some of these questions.

For more information I suggest reading "How to Design Off-center Fed Multiband Wire Antennas Using That Invisible Transformer in the Sky" by Frank Witt, AI1H, in *The ARRL Antenna Compendium*, Vol. 3, to be published at an early date.

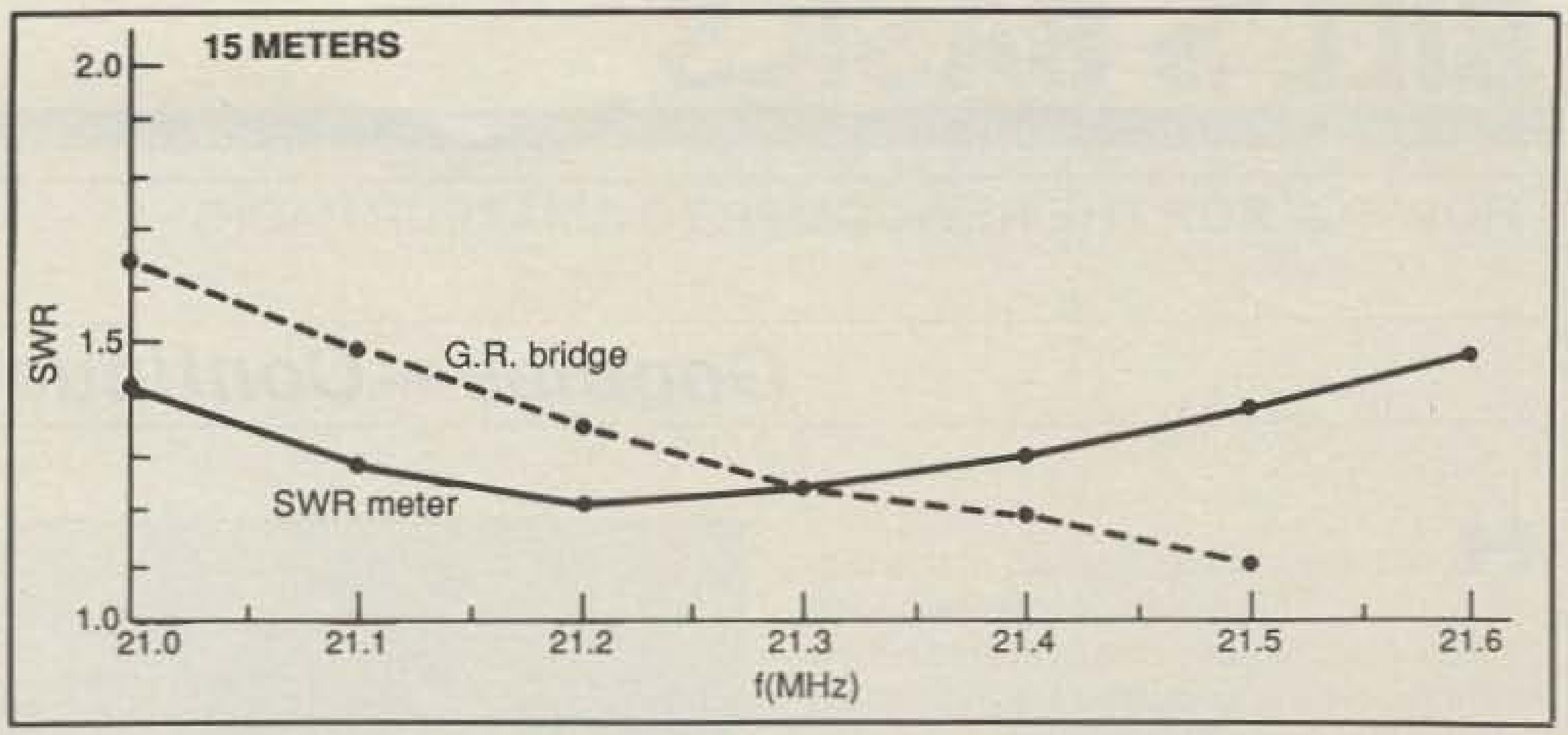


*Fig. 8– The OCF dipole showing measured SWR curves for 15 meters.*

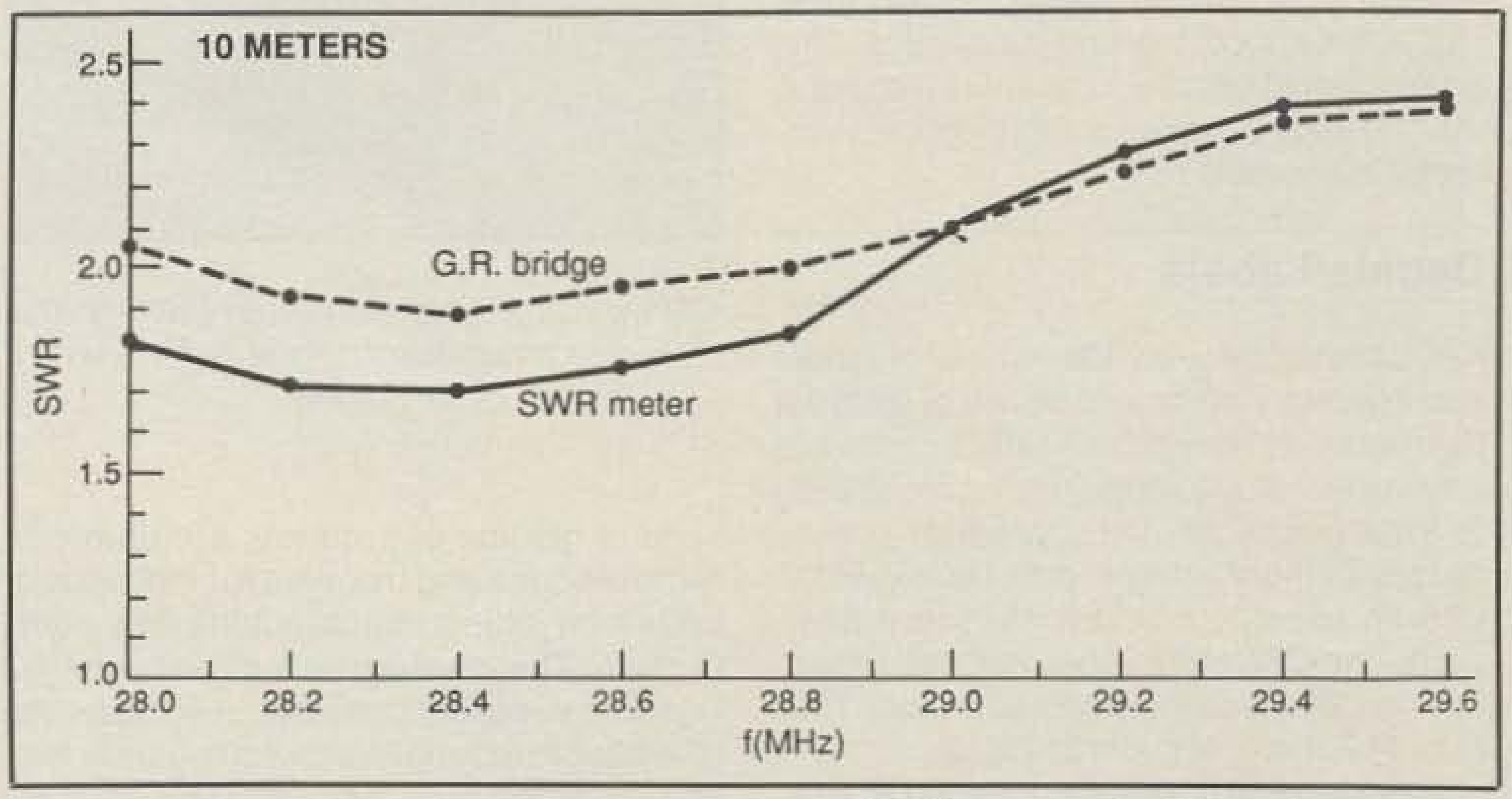


*Fig. 9– The OCF dipole showing measured SWR curves for 10 meters.*

The OCF antenna? Well, as for me, I'll take a 6-element Yagi on an 80 foot boom at 125 feet for 20 meters any day.

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## Footnotes

1. Wrigley, Wm., "Impedance Characteristics of Harmonic Antennas," *QST*, February 1954, pp. 10–14.
2. Sorbie, Tom. See "Technical Topics," Pat Hawker, *Radio Communication*, Dec. 1990, p. 31.
3. Belrose, John and Boulaine, Peter, "The Off-Center-Fed Dipole Revisited," *QST*, Aug. 1990, pp. 28–34.
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6. Radio Works, Box 6159, Portsmouth, VA 23703.
7. Amidon Associates, Inc., Box 956, Torrance, CA 90508.