Radio FUNdamentals

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

The Three-Element Yagi

In my last column I discussed the advantages and disadvantages of the two-element Yagi beam. Its principal virtue is a high gain figure for a short boom. At the design frequency, gain is approximately 5 dBd. This is achieved at a boom length of less than 0.1 wavelength. Better performance is obtained with a director element than with a reflector.

The main disadvantage of the two-element Yagi is poor front-to-back ratio. Typically, it will run from 10 to 15 dB. Input impedance is about 12 to 15 ohms, depending on parasitic element tuning. This value permits a simple match system such as a gamma or hairpin match to be used.

All things considered, the two-element Yagi is a good performer for amateurs who desire a good gain figure, but are not worried about mediocre signal rejection from the rear of the antenna. It is small and light weight. In other words, it delivers a lot of "bang for the buck."

The three-element Yagi is the antenna of choice on the HF bands. It provides a little more gain than the two-element version, improved front-to-back ratio, and higher input impedance. The price paid for better performance is a longer boom and more aluminum up in the air.

Boom lengths for HF three-element Yagis usually run from 0.2 to 0.4 wavelength. Short boom designs provide good gain and front-to-back ratio, but restricted bandwidth. That is, they cover only a narrow frequency range before the SWR rises over 2 to 1 on the feedline. Wider spaced arrays provide much improved bandwidth, good gain, but poorer front-to-back ratio.

As you can imagine, designing a Yagi antenna consists largely of balancing the various attributes in a mix that is suitable for the user. Commercial antennas usually shoot for a user-friendly array. The old 204BA four-element beam is a case in point. It exhibits excellent bandwidth and SWR performance. Front-to-back ratio is very good. These attributes come at the expense of gain, which is only a little higher than that of a two-element design.

There is nothing wrong with this concept. It is easy for the user to check SWR and front-to-back, but it is difficult to check power gain. The antenna provides what the user wants to observe. And he can work plenty of DX with the antenna, so the question of power gain is secondary.

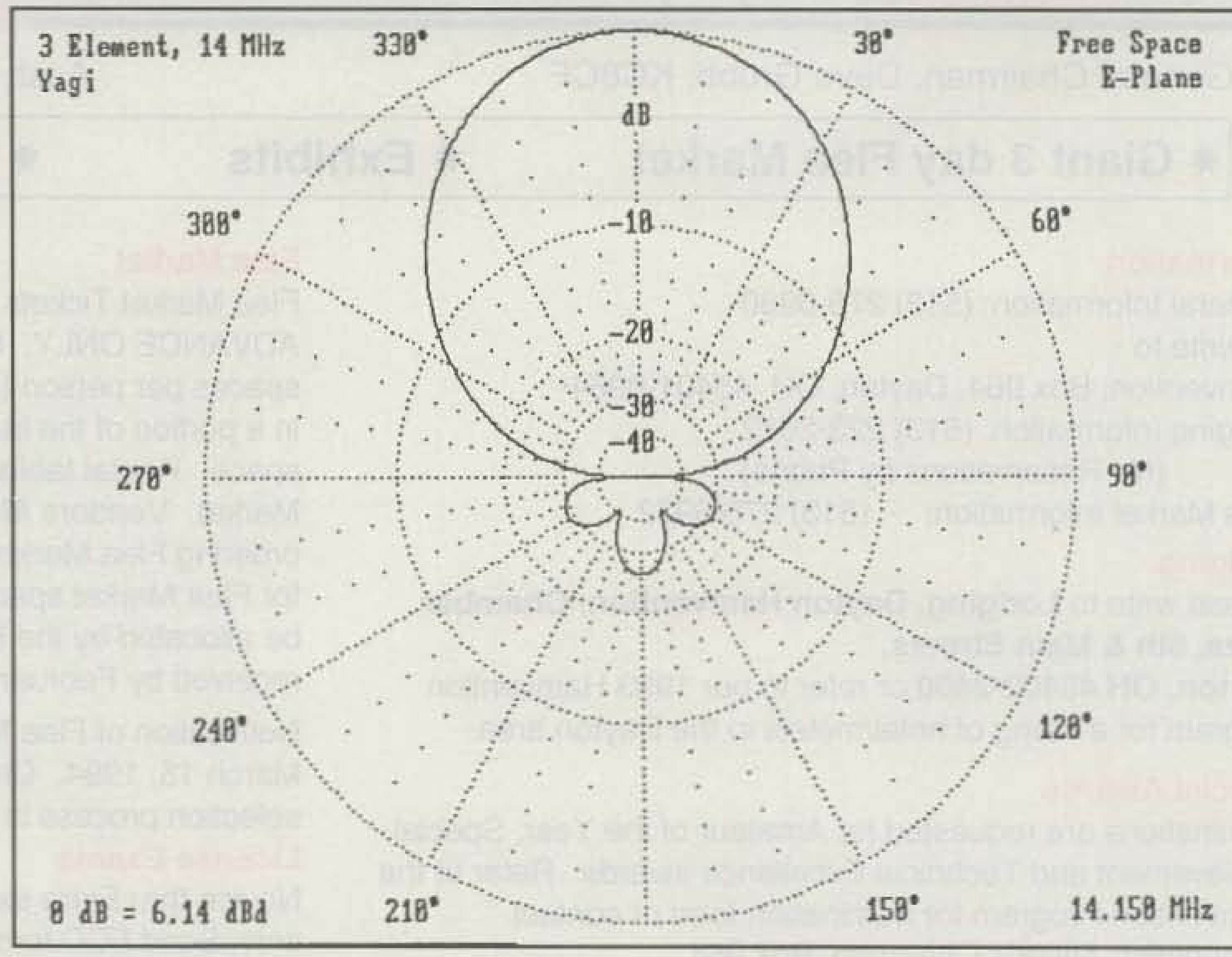

Fig. 1– Polar plot of a three-element Yagi.

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Gain Figure of Merit

What are the factors that enter into antenna gain? The main factors are element lengths and spacing. If you assume the element lengths are optimized, maximum possible gain can be calculated from a gain Figure of Merit (FOM), based on antenna boom length.

One FOM study conducted by Tom Ring, WA2PHW, on an extensive collection of Yagi designs, yields this formula:

$$\text{Gain (dBd)} = 10 \text{ Log } (5.4075B + 4.25)$$

where B is boom length in wavelengths.

Another FOM is proposed by Rainer Bertelsmeier, DJ9BV:

$$\text{Gain (dBd)} = 7.773 \text{ Log } (B) + 9.28$$

The above formula was derived from the gain of DL6WU-design long-boom VHF/UHF Yagis.

A third gain formula is from Bill Myers, K1GQ, for HF Yagis:

$$\text{Gain (dBd)} = 3 \text{ Ln } (B) + 9.85$$

The FOM does not represent the theoretical absolute-maximum gain figure, as this leads to extremely low impedances and impractical designs. The formulas were derived from gains of practical near-maximum gain Yagi designs with real-world losses and design compromises. The FOM is not intended as an overall quality rating for Yagis, as it rates gain/boomlength efficiency only. Most Yagi applications require good patterns, and this constraint always places a limit on forward gain.

Nevertheless, gain FOM provides a valuable yardstick for showing at a glance how close a particular design comes to realizing maximum possible gain.

The FOM concept is particularly helpful when used in combination with a computer-driven antenna analysis or optimization program. With a given boom length, such programs can vary element length and spacing, while displaying a FOM for each variation in the antenna.

The three-element 14 MHz Yagi design

shown in this article was derived on the Yagi Optimizer program of Brian Beezley, K6STI. The goal was to achieve maximum possible gain, consistent with good front-to-back performance, adequate SWR bandwidth, and acceptable input impedance. The WA2PHW formula gives good results for any boom longer than 0.25 wavelength, and it is used in the Optimizer program for the Yagi described here.

A Practical Three-Element Yagi For 14 MHz

Computer analysis of a Yagi antenna is an exercise in compromise. There is no free lunch, so when the designer shoots for maximum gain, for example, he forfeits front-to-back ratio or bandwidth. The trick is to balance these attributes until he achieves his objective.

The target design provides 6 dBd forward gain, better than 20 dB front-to-back ratio over the design range, and an input impedance on the order of 15 ohms or better. The FOM should be better than −1.5 dB. Boom length should be 24 feet or less. (Boom length is chosen so two 12 foot sections of tubing are sufficient.)

The design includes tapered elements, with diameters ranging from 1.25 inches at the center to 0.875 inches at the tip. The elements are mounted on small aluminum support plates attached to the metal boom with U-bolts. Either a gamma match or hairpin match may be used with the antenna.

A polar plot of the computed horizontal pattern is given in fig. 1. At the design frequency the front-to-back pattern is excellent, with three minor lobes to the rear, all of them better than 24 dB down from the frontal lobe. The "3 dB" beamwidth is about 64 degrees.

Important parameters of the antenna are shown in fig. 2. Gain varies from about 5.9 dB at 14.0 MHz to 6.4 dB at 14.3 MHz. At the design frequency (14.15 MHz) it is 6.14 dBd. This is shown in the upper-left-hand graph.

The upper-right-hand graph illustrates SWR response over the operating range. SWR is about 1.6 at the frequency extremities, falling to near-unity at the design frequency.

Front-to-back ratio is illustrated in the lower left plot. Maximum F/B is achieved near 14.12 MHz, where it peaks at 28 dB.

Input impedance falls in the 20 ohm area (lower-right graph), where a match may easily be achieved with either a gamma or hairpin match.

Power gain is about 1.3 dB less that the maximum possible amount, and this falls within the FOM limit.

This beam represents a comfortable tradeoff regarding gain, front-to-back ratio, bandwidth, and input impedance. It is possible to squeeze more gain out of

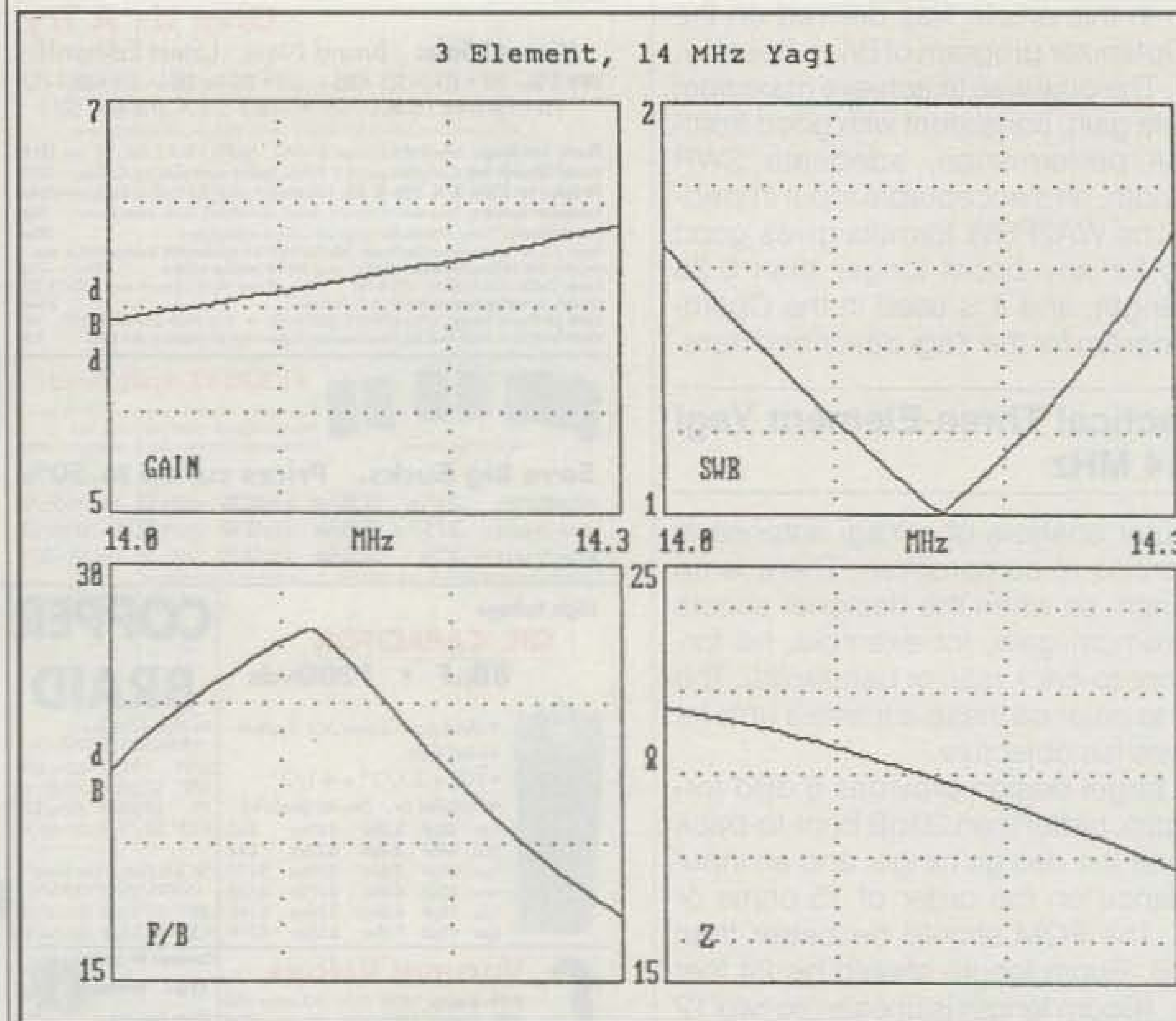

Fig. 2– Graphs for a three-element, 14 MHz Yagi. Top left, gain across passband. Top right, SWR response. Bottom left, front-to-back ratio. Bottom right, feedpoint impedance.

the three-element beam, but front-to-back ratio and input impedance must be sacrificed. I'll discuss a "maximum gain" Yagi in my next column (if I don't forget!)

Antenna dimensions are listed in fig. 3. The center section of each element is a 12 foot length of 1.25 inch tubing with a .058 inch wall thickness. The next sections are cut from a 12 foot lengths of tubing with a wall thickness of .058 inch. The sections with a diameter of 1.0 inch also have the same wall thickness. The tip sections have a wall thickness of .049 inch.

Construction details are not given here, as they are fully covered in the *Beam Antenna Handbook*, published by Radio Amateur Callbook, Box 2013 Lakewood, NJ 08701.

A Mini Flat-Top Antenna For 80 Meters

Problem: How does the 80 meter operator put up an efficient antenna in a small space? That's not easy! One idea that has proven popular "down under" is the fold-

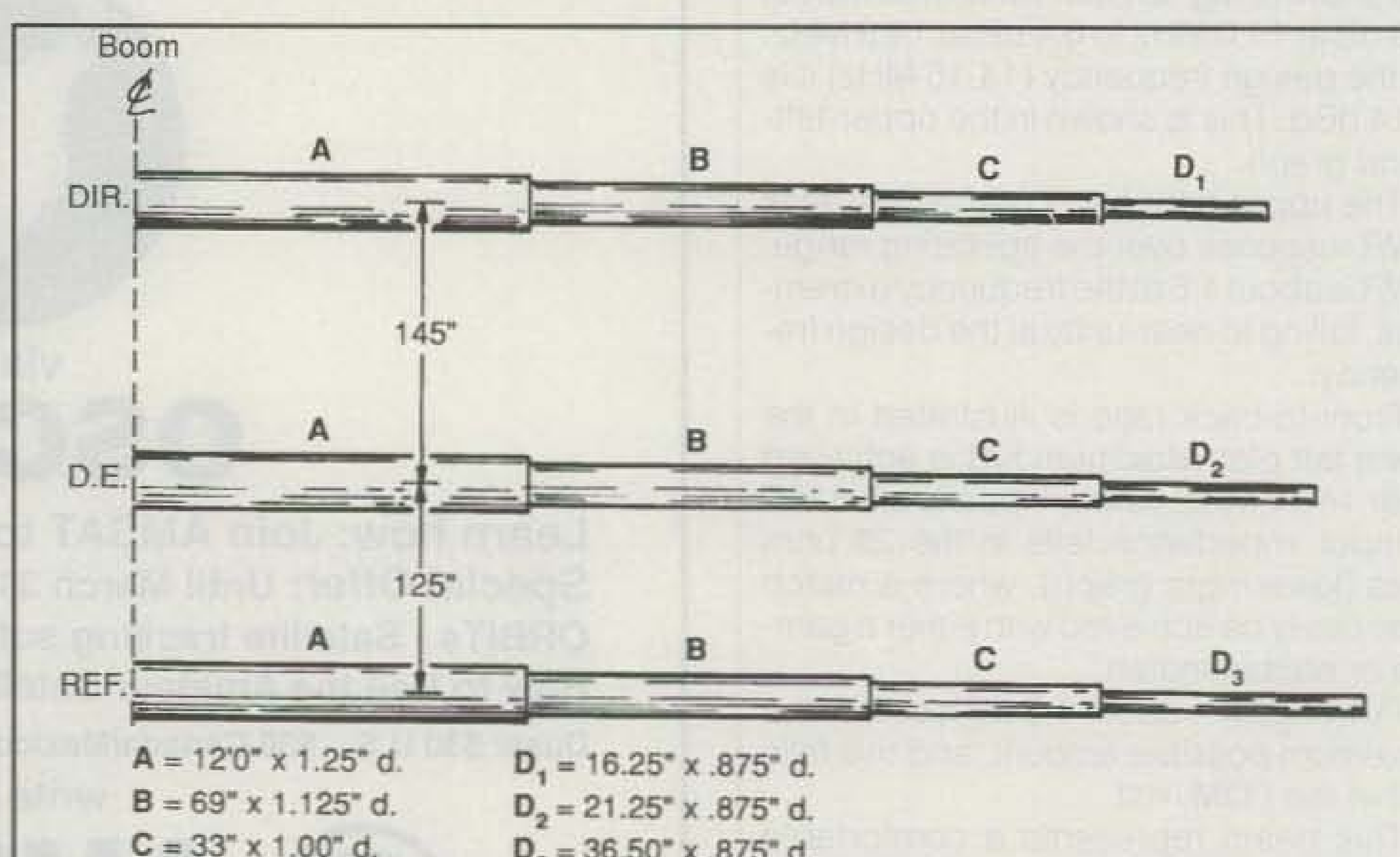

Fig. 3– Half-element dimensions (with the exception of section A, which is full length). Add 3 inches to B, C, and D for overlap when cutting the tube.

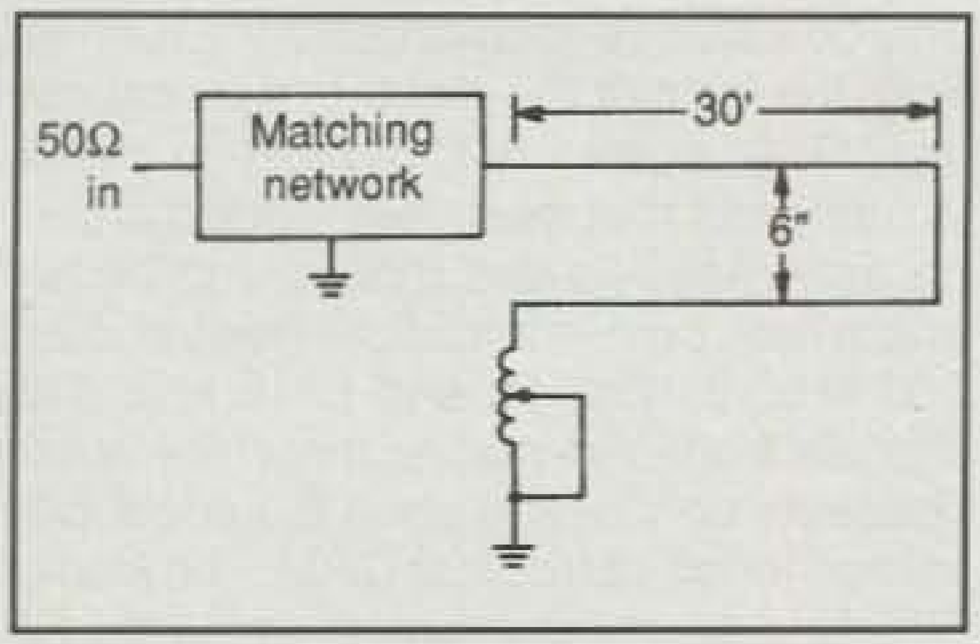

Fig. 4– Half folded dipole grounded by variable inductor. Used by ZL1AYN for 80 meter operation.

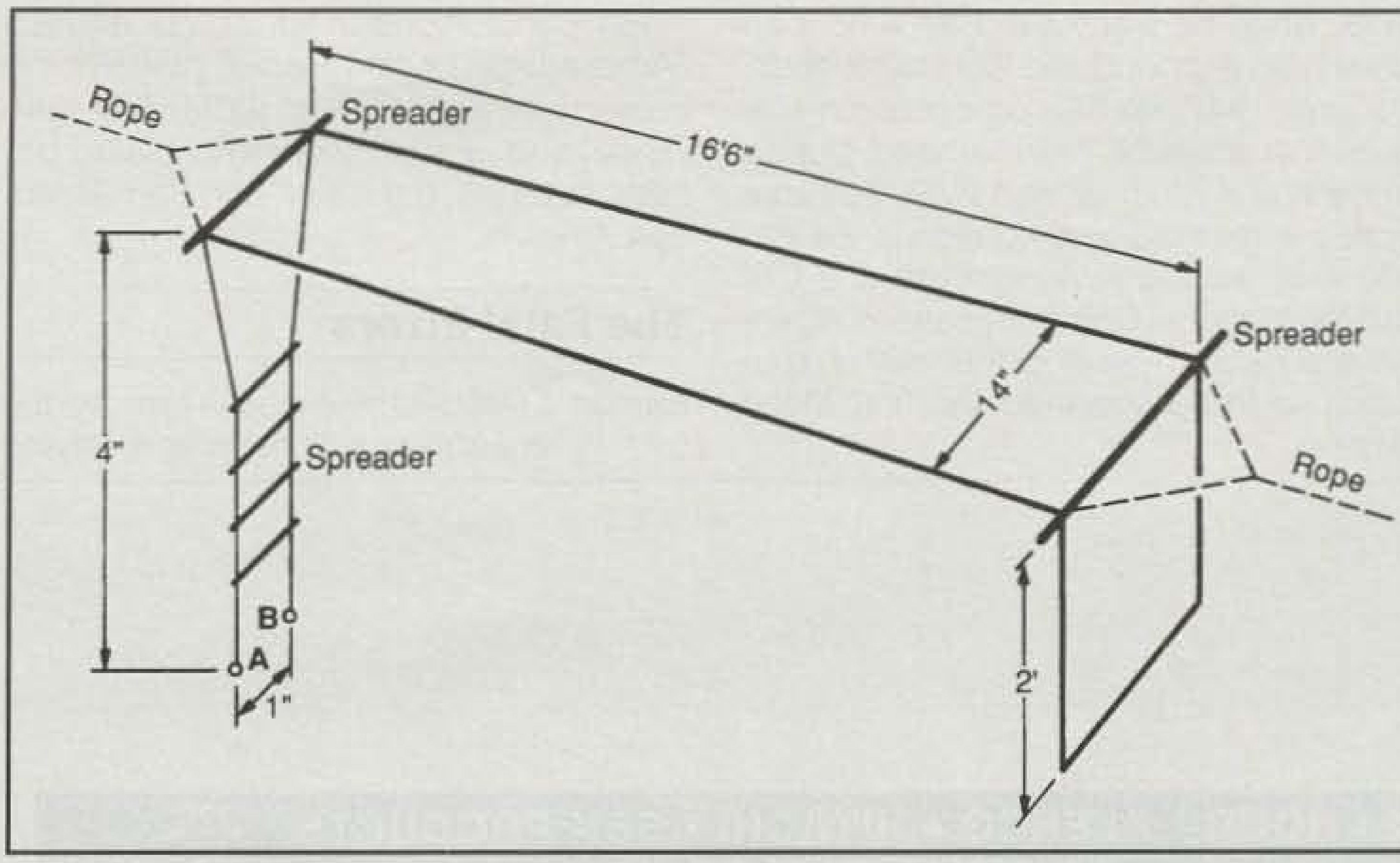

Fig. 5– Oblique view of the G2BZQ indoor 80 meter antenna. The total wire length is 46 feet 2 inches.

ed antenna in use by R. A. Lowe, ZL1AYN, and described in *Break-in*, a publication of the NZART. It was reprinted in the October 1993 issue of *Amateur Radio* in the "Random Radiators" column by Ron Fisher, VK3OM, and Ron Cook, VK3AFW.

This simple antenna is shown in fig. 4. It is a short folded dipole loaded by a variable inductor in the return lead. The design may also be considered as a narrow loop, and Richard Marris, G2BZQ, came up with the idea of opening the loop out to increase the efficiency of the design. His antenna is shown in fig. 5.

Loop configuation can be altered to fit the circumstances. The far end need not be folded down if sufficient space is available for a run of 20 feet or so. And the length of the feedline portion of the antenna can also be varied.

This design was intended for indoor use and was mounted horizontally across the ceiling of a room. It was slung diagonally from corner to corner and used nylon cords and plastic spreaders for support. The length of the loop should not be changed, but the amount that is bent can be adjusted to fit room size. The article states that a ground connection is recommended but may not be essential.

G2BZQ suggests that low power be used with this antenna to reduce problems of interference with nearby home entertainment equipment as well as to minimize concern over operator exposure to RF fields. For outdoor use, the basic rule of "the higher the better" applies, so a longer feeder may be necessary. Experimenters may also try increasing the width of the loop.

G2BZQ uses a simple home-made tuner unit with this antenna, shown in fig. 6.

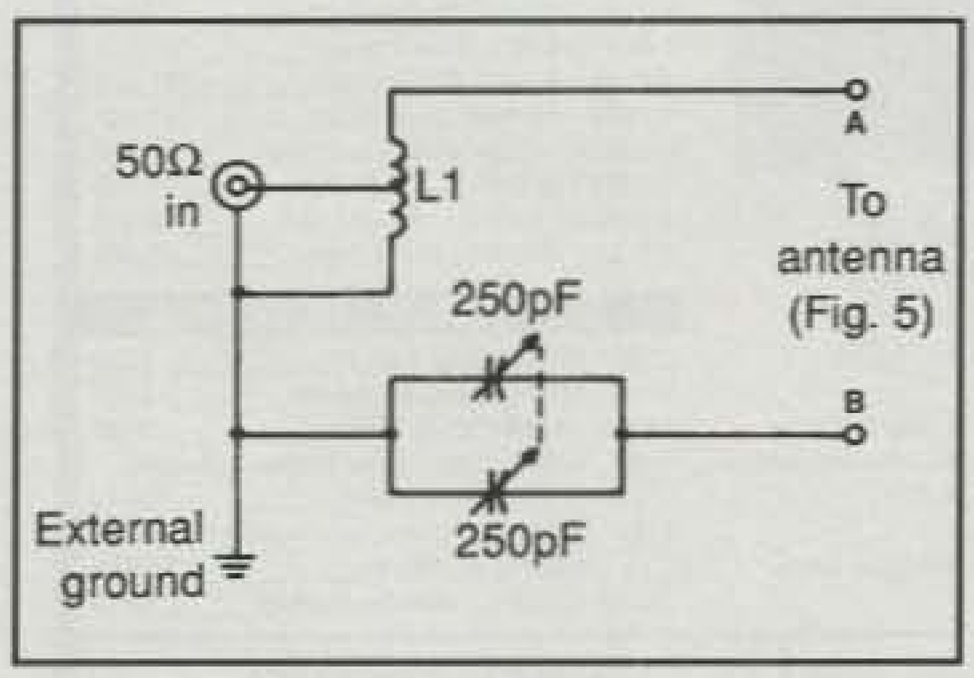

Fig. 6– Tuner for G2BZQ antenna. Coil L1 is 19 turns of #16 enamel wire wound on 1 inch diameter form. Coil length is 2 inches. Tapped 10¾ turns from ground end.

The Disappearance of Amelia Earhart: 1937

It has been a puzzle for over half a century. What happened to Amelia Earhart, who disappeared, along with her navigator, Fred Noonan, on their round-the-world flight? According to folklore, they vanished mysteriously on July 2, 1937 at about 2013 GMT (now UTC) on a flight from New Guinea to Howland Island.

Most investigators agree that contact with the plane was lost when her last transmission on 3105 kHz said she was shifting frequency to 6210 kHz. She was not heard from again, or was she?

Books and TV shows have provided possible answers to the puzzle, as have various expeditions sent over the years to find the wreckage of her plane. She was shot down, captured, and executed by the Japanese in the Marshall Islands; no, she was seen as a prisoner by other prisoners of war at a Japanese Pacific base; no, she went down in the Pacific Ocean, leaving no trace; no, she crash-landed on a remote Pacific atoll; no, she is alive and well today and in hiding.

A whole cottage industry has sprung up concerning the disappearance of this famous aviator, and even today new evidence is being produced, most of it spurious, about her baffling fate.

A recent article about this puzzle has been written by Captain Almon A. Gray (USN Ret.) in the December 1993 issue of *Naval History* magazine, published by the United States Naval Institute, Annapolis, Maryland.

I would say Captain Gray has impressive credentials to apply to this problem. He started in 1930 as a commercial radio operator, joined the Navy shortly thereafter, and served on various vessels until

1935, when he went with Pan American Airways as a ground and flight radio operator until 1942. He flew on occasion with Earhart's navigator, Fred Noonan. During World War II he dealt with Navy communications and radio navigation in the Pacific area, and later served with the CIA and the National Communications Agency, and helped develop the telecommunications that supported the first Moon landing.

His conclusions in an article entitled "Amelia Didn't Know Radio" pinpoint the comedy of errors, poor judgment, igno rance, and lack of meaningful dialog between Earhart, the Navy, and Pan American Airways.

The Fatal Errors

Earhart's fatal mistake was to remove the trailing wire antenna on her plane, relying only on a short V-shaped antenna running from the front of the plane to the rear tailfins. Gray covers this blunder in detail, pointing out that the short, loaded antenna only radiated less than a watt on her important communication frequencies: 500 kHz, 3105 kHz, and 6210 kHz. The signals from the plane, therefore, were readable only over a short distance, due to high levels of tropical QRM. The loss of 500 kHz ability prevented accurate DF bearings from being made, and precluded communication with ships and marine shore stations.

Other serious problems existed. Earhart seemed to be confused between kilocycles and meters, leading to a snafu on schedules with Navy ships placed along her route for communication and DF bearing measurements. In addition, Gray points out that improper transmitter loading by the very short antenna made audio modulation almost unintelligible.

Finally, Gray concludes that Earhart's inability to get a bearing from a Navy vessel (Itasca) was probably due to the fact that the send-receive relay in her equipment had been damaged by lightning. (I suggest that the back relay contacts may have been rendered inoperative due to corrosion brought about by the high content of salt in the atmosphere above the Pacific Ocean.)

July 2 seemed to be the end of it. However, the next day, Gray points out, a weak, distorted voice signal on 6210 kHz was heard by a radio operator on Nauru Island, as well as by the Pan-American communication station on Wake Island. The transmissions were also heard faintly at other points, but they were nearly unintelligible. Of great interest was the fact that the voice sounded like Earhart, but the motor noise of the plane was missing! A conclusion by some was that the plane had crash-landed on a remote island, but the radio equipment had survived intact. The signals gradually weakened and finally disappeared after a few hours. Bearings taken on the signals indicated an area in the Marshall Islands, to the west of Howland Island.

Searches of the area were to no avail. Nothing of importance was found. And so the Earhart-Noonan flight passed into history, leaving one of the outstanding mysteries in the long history of the Pacific.

The Mail Bag

Many thanks to the following who have written to me in the past month. I much appreciate your input! WB4HFL, K2OB, KL7CMN, K4WV, VK5BR, KW1L, W5PSA, W1IAF, I4AFQ, W6OAL, W2YYI, W6TC, VE1KD, DK5VP, W1PN, W6JJZ, K6YO and W2FMI—thanks, gang!

73, Bill, W6SAI

