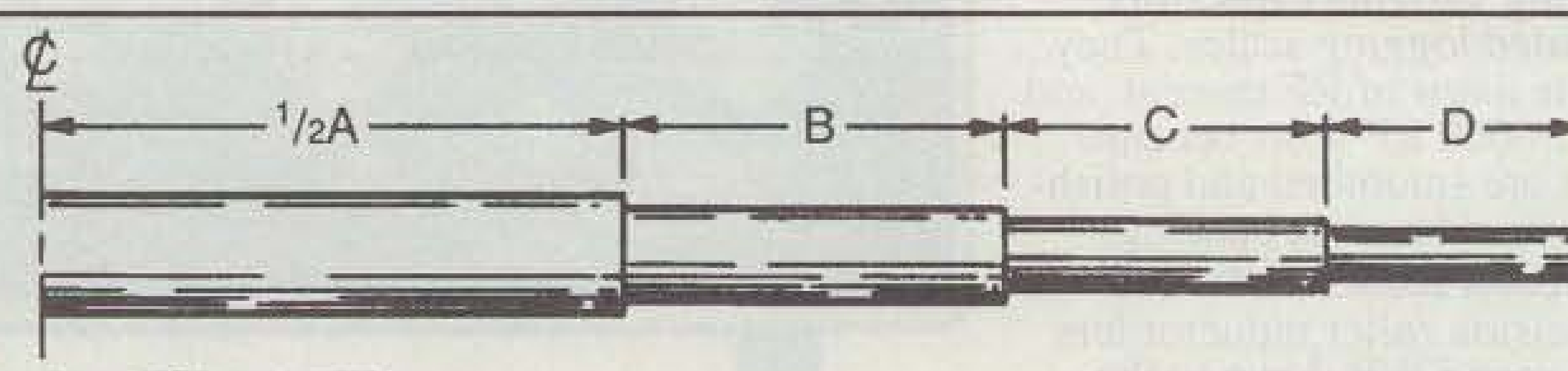
Radio FUNdamentals

BY BILL ORR, W6SAI

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

A Lightweight 2-Element Yagi For 18 MHz



A = 72" x 0.75"
B = 46" x 0.625"
C = 24" x 0.5"
D = Director = 16.25" x 0.375"
Driven element = 18.75" x 0.375"
Spacing between elements center-to-center = 44"

Fig. 1– Dimensions for half-elements of driven element and director.

In my last column I discussed the virtues and deficiencies of the 2-element Yagi beam. The virtues are that it is small, lightweight, and exhibits very high gain for the boom length. The deficiencies are that the front-to-back ratio is mediocre and the feedpoint impedance can be quite low. Moreover, the operational bandwidth defined by the allowable SWR and minimum front-to-back ratio is small compared to that of an optimized 3-element Yagi.

Having said that, I believe the virtues greatly outweigh the deficiencies of this little array. Take an 18 MHz design, for example. It can be built light enough to be mounted easily above an existing triband array and is (relatively) unobtrusive to the cold eye of a neighbor who equates beam size directly with TVI or telephone interference!

The 18 MHz band is narrow (18.068 to 18.168 MHz), only 100 kHz, so operational bandwidth is not a problem, and even though the feedpoint impedance is low (of the order of 12 ohms), the 2-element Yagi can be matched properly with either a Gamma match or a Hairpin match. I think a 2-element Yagi is an ideal antenna for this band!

Average front-to-back (F/B) ratio of the little beam is about 10 dB. This is nothing to get excited about, but the relatively long skip on 18 MHz usually means that when the antenna is aimed in the direction of propagation, relatively little is coming in off the back of the beam. At least that's the way it has worked for me on the west coast!

During my morning hours, when the band is open to Europe and Africa, the Pacific area (off the back of the beam) is closed. And during the afternoon when the band is open to the Pacific, most of the signals to the east of me have faded out. In my case, therefore, F/B ratio is no big deal. If you have a similar propagation situation, the 2-element Yagi may be the right beam for you.

The Design

The Yagi lends itself to accurate computer-aided design. The beam described in this section was taken from a set of generic, untapered dimensions and placed in the Yagi Optimizer (YO) program of K6STI (Brian Beezley, 507½ Taylor St., Vista, CA 92084). This program analyzes and optimizes a Yagi array using performance criteria that the user specifies.

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In this case my specifications called for a short boom (not over 4 feet long), elements tapered from 0.75 inch down to 0.375 inch, and the choice of either Gamma or Hairpin match. Elements are to be mounted directly by U-bolts to small plates attached to a 2 inch diameter boom. Feed-point impedance is to be 50 ohms, unbalanced.

Optimization frequencies are 18.068, 18.115, and 18.168 MHz. The antenna is designed in a "free space" environment.

The YO program permits tradeoffs in the areas of forward gain, F/B, and input impedance. The tradeoffs are expressed in percent, and in this case to keep input impedance and F/B values reasonable, forward gain percentage of trade-off was set at 60%. Input impedance and F/B ratio were set at 20% each. These choices were intuitive. If the gain trade-off was too high, both SWR bandwidth and input impedance would suffer. A nice point about the YO program is that if the results are not to your liking, the trade-offs can be modified quickly.

The YO program iterates the generic design 482 times during the optimization process in this manner: Each element length and position is changed individually by a small amount to calculate the sensitivity of the **objective** to each variable. The objective is the combination of gain, F/B, and impedance defined with the trade-offs. The set of sensitivities is called the **gradient**. The gradient points in the direction that maximizes the objective.

Once the gradient is calculated, element lengths and position are upgraded, each in proportion to its sensitivity. The upgrade yeilds a new design with incrementally higher performance. The optimizer program runs until further improvement is not possible when additional small changes are made.

If the user decides that additional investigation is worthwhile, he can modify antenna dimensions manually and continue automatic optimization.

In the case of the 2-element Yagi there aren't many variables to play with. As far as gain and F/B ratio go, driven-element length is relatively unimportant. It is important, however, in determining impedance matching to the feedline.

This leaves director length and element spacing as variables to investigate. By experience, intuition, or data gleaned from handbooks and magazine articles, the approximate spacing and director length can be determined to a rough degree. Director spacing falls in the 0.07 to 0.12 wavelength range. The forward gain target is 5 dBd. The F/B target is about 10 dB. The feedpoint impedance (before matching) should be 10 ohms or more.

As optimization progresses these criteria, and others, are continually upgraded on the computer screen. With a keen eye and experience the optimizer can be guided in the correct direction to produce the desired results.

Once the program has produced the design, tapering information is available for the tubing diameters specified by the programmer. This information is important, as overall element length is a function of the taper. For a given element, the greater the taper, the greater the element

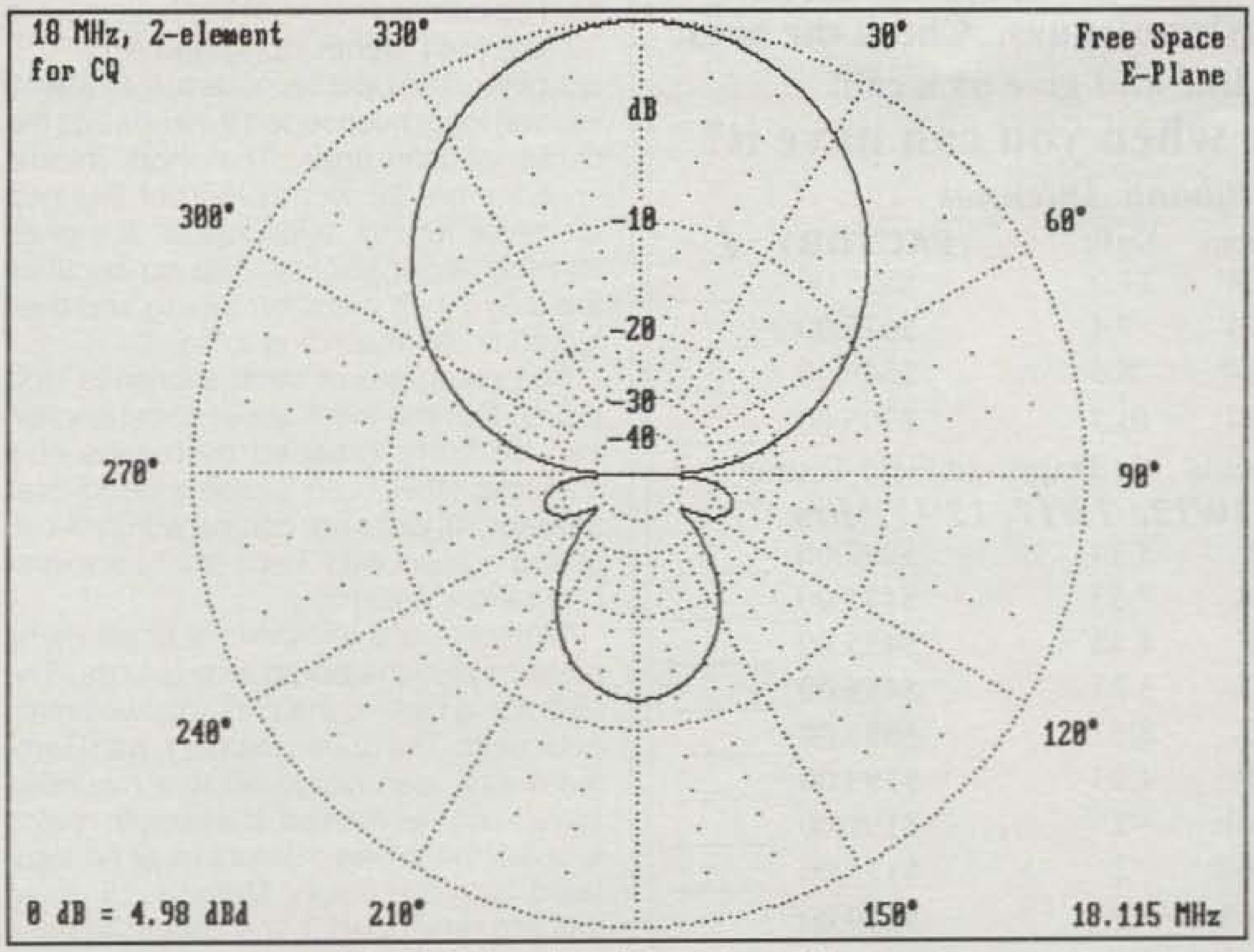

Fig. 2– Polar plot of two-element beam.

length. The final computerized dimensions for this Yagi antenna are given in fig. 1.

Note that in the case of the driven element, if a Gamma match is used, the half-length dimension is from the center of the element to the tip. If a Hairpin match is used, the half-length dimension is from the attachment of the feedpoint of the element to the tip. Because a gap exists at the element center when the Hairpin match is used, the overall physical length of the driven element is slightly longer than in the case of the Gamma match.

Antenna Construction

A 4 foot length of 2 inch diameter aluminum tubing serves as the boom. Element spacing, center to center, is 44 inch-

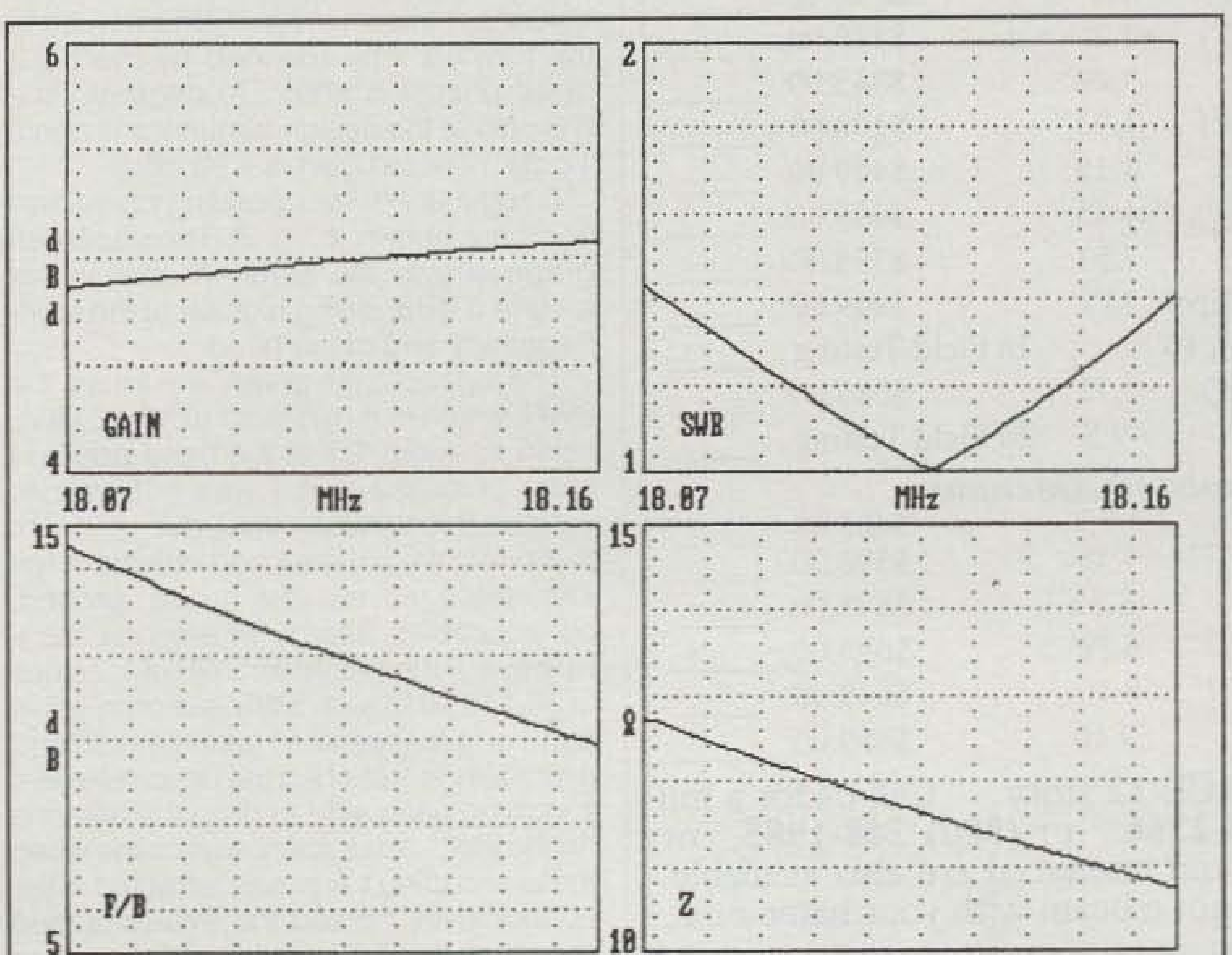

Fig. 3– Parameters of two-element beam. (See text for details.)

es. The center section of each element is 12 feet (144 inches) long and 0.75 inch diameter. The next sections are 4 feet (48 inches) long, telescoped 2 inches into the center section ends. The short, middle sections are 26 inches long of 0.5 inch diameter tubing, telescoped 2 inches into the larger section. The tip sections are 0.375 inch diameter tubing and their length is set according to fig. 1.

The outer end of each section is slotted so that the inner telescoping section can be firmly grasped by means of a stainless-steel hose clamp placed over the joint. All joints are coated with anti-oxidizing compound ("Penetrox," for example) before assembly.

Elements are affixed to a small metal plate held to the boom with U-bolts. The director is held to the plate by two smaller U-bolts. The driven element, with Gamma match, can be bolted to a mounting plate in similar fashion. If a Hairpin match is used, the driven element must be insulated from the boom. Methods of doing this are described in the *Beam Antenna Handbook* (available from Radio Bookstore, Box 209, Rindge, NH 03461; 603-899-6957).

The usual anti-rust precautions should be observed. All hardware should be stainless steel, or in the case of nuts, bolts, and U-bolts, plated. After assembly it is a good idea to give each joint and connection a shot of rust-preventive paint from a spray can.

Operating Characteristics Of The Antenna

The azimuth, free-space field plot of the antenna is shown in fig. 2. Beam width of the forward lobe (defined by the 3 dB down points) is about 70 degrees. The F/B ratio at the design frequency is about 12 dB. Forward gain is 4.98 dBd.

A summary of the operating characteristics are shown in fig. 3. The upper-left graph shows the antenna gain varies around 5 dBd, being highest at the high-frequency end of the band.

The upper-right graph illustrates the SWR, which is a minimum at 18.12 MHz, rising to about 1.4 at the band edges. I must point out that I was not able to achieve this pristine curve, due no doubt to the fact the antenna had objects in the immediate vicinity (the house, ground, control cables, nearby TV antenna, etc.). However, I measured an SWR of 1.2 close to 18.115 MHz, with SWR less than 1.6 at band edges. I used a Hairpin match and eventually lengthened the driven element 1 inch on each side to drop the antenna "in the slot." Adjustment was made when the telescoping tower was retracted to the 20 foot level. I noted the SWR changed slightly when the antenna was run up to its normal 45 foot elevation.

The lower-left graph illustrates the F/B ratio of the antenna. Note that F/B decreases rapidly, while power gain increases very slowly as the operating frequency is raised. That is characteristic of this type of simple Yagi. At the low end of the band the F/B ratio is quite good, approaching 15 dB.

The lower-right graph shows the feedpoint impedance of the antenna. It runs from about 12.5 ohms to 10.5 ohms, which is within the limits of both the Gamma and Hairpin match systems.

Antenna Matching

So there you are. The antenna is ideal for stacking above a 20 meter beam, for example. I did not derive any stacking information, but I would suggest a stacking distance of at least 6 feet for minimum interaction with a bigger array.

While the builder can hit the design frequency and minimum SWR values quite well, a purist may wish to adjust the match to provide unity SWR at the design frequency. To do this, it is necessary to be able to reach the matching system from a safe perch atop the tower. The short boom makes this job easy. As with any antenna work, a safety belt is mandatory!

With regard to the Hairpin match, the length of the driven element is more critical than is Hairpin length. Enough overlap should be left at the first antenna joints so that the driven element can be lengthened or shortened 3 or 4 inches.

My preliminary Hairpin match was made from two lengths of #10 copper wire, plus a jumper made of back-to-back alligator clips. The length of the Hairpin and that of the driven element can be varied by the experimenter, noting the SWR on the coax line for each adjustment. A notebook to log the dimensions and an assistant to turn on and off the transmitter are most helpful.

The length of the matching rod and the value of the Gamma capacitor are the variables in the Gamma match. Information on building and adjusting both matching systems are given in the *Beam Antenna Handbook*.

Bigger and Better Yagi Antennas

It is interesting to plot antenna gain versus the number of Yagi elements, as I have done in fig. 4. I've taken these points from various antenna designs whose gain measurements have been verified on computer programs or in the field. The graph shows two different antenna types. The higher curve shows power gain for various numbers of elements, where boom length is adjusted for maximum gain. Element spacing is one variable in the search for antenna gain, and the elements in these Yagi designs have been carefully spaced and dimensioned for maximum gain consistent with good F/B ratio. This approach results in a long boom, with plenty of spacing between the elements. This heroic design is practical on 50 MHz arrays and for VHF arrays for 144 MHz and up where beam size is moderate.

The lower curve illustrates practical HF designs where boom length is limited to more practical lengths. These are reasonable gain figures for antennas for the 14–30 MHz region. It is very difficult to achieve more than 8 dBd gain with a Yagi on the HF bands unless you can support and turn a large, heavy, expensive array that has plenty of wind resistance.

Where do you place your ultimate dream-beam on these curves? The die-hard DXer will look at the right-hand portion of the graph. Mere mortals such as you and I may have to put up with smaller arrays that fall at the left-hand portion of the graph!

And, as you can see, to double the gain of a 2-element Yagi (going from 5 dB to 10 dB) means you'll be putting a lot of aluminum up in the air!

As one prominent DXer put it, "A loud signal requires dBs in the air as well as dBs on the desk!"

I Get Letters . . .

I really appreciate hearing from readers of this column. I'm only sorry that I can't reply individually to each letter. I've gotten communications from the following, for which I thank each and every one: KH6GI, KD3OR, W8YFB, WA3EOQ, WU2J, PAØSE, NA2M, VE4AE, WO5H, and KG7BK.

With regard to the Z-match tuner, WA3EOQ, VE7BS, and WØEDS point out that the old Harvey-Wells "Bandmaster" tuner operated on the same general principle. KC1DI and WØEDS both report good results using the little tuner.

Dave, WO5H, alerts me to his monthly newsletter "Packet Power" written for packet buffs. He sent me a sample copy and it really looks first-class. Sample issues usually go for a buck, but Dave says he'll send a free sample to readers of this column who send him an SASE and mention this offer. Write to Dave Wolf, Box 189, Burleson, TX 76097-0189 (FAX 817-295-6232).

And I have two more interesting letters from experimenters who have built the Z-match tuner described in past columns. Dale, W4DM, reports his model tunes down to 3.322 for MARS operation. He has used the tuner on all bands (80–10 meters) with a 170 foot horizontal loop with 65 feet of balanced line, a 4BTV trap verical with radials, an 80 meter dipole,

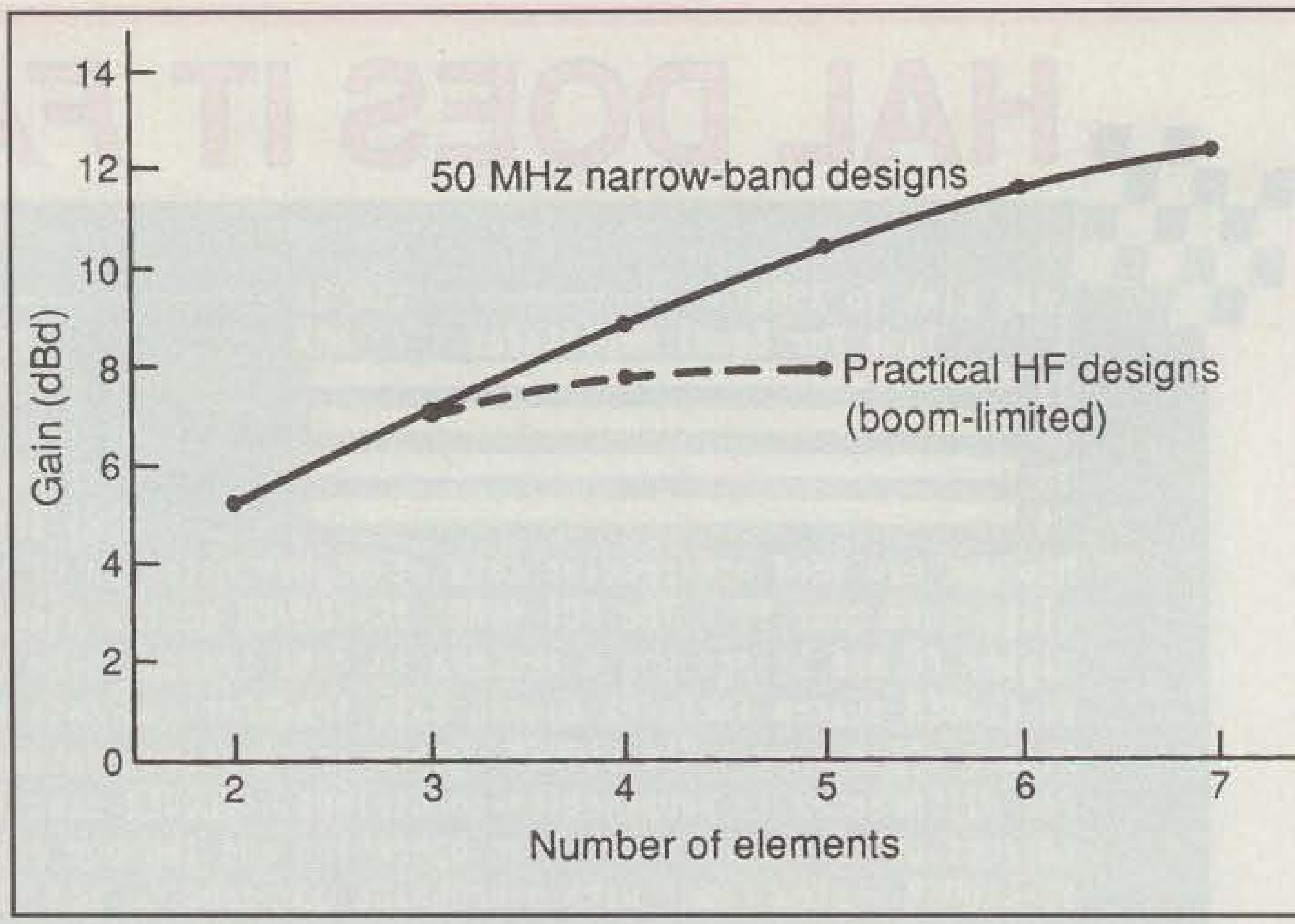

Fig. 4– My best estimate of Yagi gain for a given number of elements.

and a 120 foot long wire. He says it works just great! And he also mentions he's seen a commercial version of the tuner made by the Wanzer Co. in Seattle, Washington (address unknown).

Bryan, G3MND, made a version of the Z-match and found it worked on all bands on a double extended 40 meter Zepp (a 190 foot center-fed affair) and an 80 meter loop of 280 feet circumference. Good reports keep coming in on this little matching device. Try it yourself!

A New SWL/Amateur Listening Guidebook

Harry Helms, AA6FW, has brought out his second edition of the *Shortwave Listening Guidebook*. This 321-page book has been updated to cover the revolutionary changes in international broadcasting since the break up of the Soviet Union. Gone is the monolithic Radio Moscow which collapsed after the failed 1991 coup. To raise money Radio Moscow began renting out its transmitting facilities. Adventist World Radio, the BBC, and even the Voice of America (!) are being relayed over the same transmitters that only a few years before had been used by Radio Moscow to denounce the "lies" of such broadcasters!

Other splinter groups of the old Radio Moscow are on the air: Radio Ukraine International, Radio Estonia, Radio Yerevan, and others have taken over the facilities in their areas.

Harry also notes the break up in Yugoslavia and Czechoslovakia and how these changes have altered shortwave broadcasts from these countries. And Roumania's Radio Bucharest has apologized to listeners for giving misleading news and information in the past!

The political changes have made great changes in the airwaves, and a good way of bringing yourself up to date is to read this book.

In addition to the world update, the book also covers other types of shortwave broadcasts including clandestine and pirate stations. And there's plenty of information on receiving antennas, shortwave receivers, and receiving accessories. Shortwave propagation is also covered in detail.

This is a great book for a friend of yours wanting to break into shortwave listening. And many amateurs are also SWLs and enjoy tuning outside the amateur bands. Either way, I recommend this book highly. I really enjoyed reading it! The *Shortwave Listening Guidebook* is available from book stores and dealers specializing in shortwave radio equipment. It is also available from HighText Publications, Box 1489, Solana Beach, CA 92075 for $19.95 plus $3 shipping, or by calling 1-800-888-4741.

The Dead Band Quiz

I'm still getting answers to the little problem of the three light bulbs. Readers who have solved this quiz include: NØXFK, KB7SFA, W3ZNB/DA1QO, SV1CDN (congratulations Dionisis on your new amateur ticket!), and Scott Muma (call unknown).

73, Bill, W6SAI