high-performance Yagis for 432 MHz

Practical application of computer analysis

This article describes two long Yagis for 432 MHz. Both offer excellent gain, given their boomlengths, and exceptionally clean pattern. Details of the development and construction of these Yagis, which were designed to be easily built from a commercial antenna, are given. In addition, dimensions are presented for two higher gain Yagis which offer even better theoretical performance, but have not yet been checked by the construction of test antennas.

The Cushcraft 424B offers sound mechanical construction at a reasonable price.

few 432 MHz designs

Three years ago I was searching for a good Yagi design to use in a new 432-MHz array. The selection of commercially available antennas for 432 MHz has always been very limited because the number of stations active on 432 MHz is small enough to make the design and production of commercial antennas for this frequency a proposition of limited, if any, profitability. Consequently, manufacturers have been slow to incorporate the latest developments in Yagi design.

Fortunately, Günter Hoch, DL6WU, had developed a director spacing and length combination which offered very good gain, a relatively clean pattern, and the ability to easily lengthen or shorten the Yagi without causing the gain peak to shift appreciably.[1] In all, the DL6WU design was a significant improvement over most previous Amateur designs. Several United States Amateurs had discovered this information and successfully built 432-MHz Yagis from it.

The use of Günter's design data required a start-from-scratch approach. However, most Amateurs find building antennas from scratch is unacceptable because of the lack of convenient sources of materials and the necessity of construction equipment and machining skills. Modifying a commercial Yagi to perform as well or better than the DL6WU design allows more Amateurs to experience the benefits of a high performance 432-MHz antenna system.

improving a good design

The starting point for the development of these Yagis was the Cushcraft 424B, which offered sound mechanical construction at a reasonable price. By

By Steve Powlishen, K1FO, 816 Summer Hill Road, Madison, Connecticut 06443

working from a proven design, it was possible to reuse most of the components and hardware to make a good product even better.

better pattern, higher gain

My goal was to increase the gain, clean up the radiation pattern of the antenna, and get an acceptable wet-weather VSWR, while widening the gain bandwidth. The initial project was so successful that an extended boomlength version was also perfected.

An initial look at the 424B shows that it uses one close-spaced director of 0.135 wavelength spacing, a second director spaced at 0.368 wavelength, and the rest of the directors spaced at 0.375 wavelength. The first ten directors have a length taper. The final ten are all the same length. Long Yagis (over 5 wavelengths), which use constant director spacings, generally have radiation patterns with very high sidelobe levels and overly narrow main lobes. In addition, such director arrangements create Yagis with narrow gain bandwidths and a very sharp gain dropoff on the high frequency side of the gain peak. Design improvements are even more beneficial when the Yagi is used in an array. Reference 2 illustrates this relationship. Mutual impedance effects, which tend to lower the gain peak frequency of an array versus the individual Yagis, also magnify these shortcomings in an array.

One little-known aspect of the NBS study was that the researchers tried designs up to 7 wavelengths long. These longer Yagis were not included in the formal NBS report (*NBS Technical Note No. 488*), however — probably because of their poor performance. NBS researchers faced the limitations of constant spacing Yagis over 30 years ago; unfortunately, the NBS study wasn't extended to include variable spacing Yagis.

The development of these new Yagis began on a backyard antenna range. The first step was the addition of another close-spaced director, which improved the pattern but gave no significant gain increase. Application of directors with a constant taper gave further pattern improvements but still no meaningful gain increase. The time and effort required to build and measure the different antenna designs gave me some insight as to why Cushcraft ended their development of the 424B at the point they did: the task of optimizing the directors' lengths while simultaneously keeping the Yagi's gain peak near 432 MHz and maintaining a reasonable driven element match appeared to be overwhelming.

computer analysis helped

The WB3BGU series of articles on the computer analysis of Yagis[3] ended with a description of the computer program, which *ham radio* made available to readers for an SASE. Initially, I set up the program in FORTRAN (in which the original was written) on a computer at work; I then translated it to BASIC, which could be run on a home computer. The translation to BASIC gave me the opportunity to correct some bugs in the program and add graphics routines.

I spent the next three months analyzing every Yagi design for which I could get dimensions, paying special attention to designs with reliable pattern and gain data. Such an examination of the program was deemed necessary in order to ensure that any design created with the program would offer realistic results.

Computer analysis of various designs confirmed the desirability of both additional close-spaced directors and an element taper to improve the pattern of the Yagi. Antenna modeling indicated that continuously increasing spacing, as used by DL6WU, was *not* necessary to create a high performance Yagi. In fact, it appeared that several less complicated spacing patterns could be used as long as all element lengths were optimized for that chosen spacing. An important step in the design of the improved Yagi, it was intended to retain as many of the original 424B element spacings as possible in order to simplify construction.

There are distinct advantages of the DL6WU design approach. The foremost is the ability to add or subtract directors without having the gain peak frequency shift appreciably. A number of designs were examined for frequency shift as elements were added. It was found that the center frequency of all Yagi designs oscillates up and down as elements are added. Even the DL6WU design shows this tendency, though the effect was the least of all designs examined. The wide gain bandwidth of the DL6WU design also minimized any frequency shift effects.

The 24- and 32-element designs presented here all have similar dimensions. Note that the directors of the 24-element Yagi are shorter than the 32-element version. Both Yagis have been adjusted to have a gain peak that's very close to the same frequency (436 MHz), even though the elements lengths are different for the two Yagis. One should be forewarned that if construction of a Yagi from this design with a different number of elements is attempted, its gain peak may be several MHz away from that of the 24- or 32-element antennas.

variable element lengths and spacings

The Yagi designs presented in this article use both varying element spacings and lengths. This was consistently found to give not only the highest gain, but the cleanest patterns and widest gain bandwidths. DL6WU pointed out the theoretical reasons for this condition.[4] Long Yagi designs which use either constant element spacings or element lengths give poorer performance and should no longer be worthy of consideration for use by VHF/UHF weak signal operators.

The formal design of the 432-MHz super Yagis started with a selection of varying director spacings. These were chosen to fit best within the existing element holes to minimize the necessity of drilling new holes in the boom. I tried adapting the DL6WU spacing pattern to the 424B; except for the final director, spacing became 10.25 inches (260 mm) or 0.375 wavelengths, since that was the ultimate spacing of the 424B. The DL6WU design used a final spacing of 11 inches (280 mm) or 0.400 wavelengths. Electrically, this approach appeared to work very well. Mechanically, however, this was not an acceptable solution because eight or nine new holes would have to be drilled into the boom — not in keeping with the relatively simple modification I was hoping to develop.

Next, five different new spacing patterns were examined on the computer. It was apparent that a good progressive spacing pattern didn't fit easily within the existing holes. The solution was to move the position of the driven element. Once this was done, an acceptable spacing arrangement was adapted to the 424B. The extra effort in devising this new director arrangement paid off by making a new design that requires only three new element holes to be drilled in the boom.

Though not yet the ultimate answer, this extensive computer analysis (and in general, use of the computer in antenna design) helps to dispel several long-standing myths Amateurs have maintained about Yagi design. The first myth is the notion that a design has to be optimized for either highest gain or best radiation pattern. It was found that for designs with proper variable spacing arrangements, the best gain and best pattern solutions were convergent. While a design could be adjusted to maximize any particular aspect of the radiation pattern (lowest first sidelobes, highest f/b), the best overall pattern quality occurred concurrently with the highest forward gain solution. The only way to further improve the pattern was to move the operation point of the Yagi lower on its frequency response curve — i.e., slightly shorten all of the directors. I found that first sidelobe strengths were usually close to −18 dB in the E plane and −16 dB in the H plane when a Yagi with a good spacing pattern was optimized. Students of physics will recognize the significance of −18 dB because it's the expected strength of the first sidelobes from a fully illuminated circular aperture.

Another common myth holds that when a Yagi is tuned for maximum gain, its bandwidth will be very narrow. This condition was found to be true for constant spacing and constant length designs, but it was also true for those constant designs *even when they were not gain optimized.* For designs with variable spacings and lengths, the gain bandwidth of such designs was remarkably wide. Even more significant was the fact that the gain bandwidth was best when the elements were optimized for maximum forward gain. As an indication of this wide gain bandwidth the 24-element modified Yagi has a −1.0 dB gain bandwidth of 25 MHz! (Gain bandwidth should not be confused with VSWR-bandwidth. VSWR bandwidth is merely an indication of feed impedance versus frequency and is not normally an indication of forward gain.)

single reflector used over trigon

At this point I decided to drop the tri-reflector arrangement in favor of a single reflector. There have been some exaggerated claims made for various multiple reflector arrangements. Previous experimental work indicated that any of the various multiple reflector arrangements gave about 0.2 dB additional gain over a single reflector, once they were optimized for the individual Yagi design to which they were added. Subsequent computer analysis has indicated that the amount of additional gain obtainable in these multiple reflector arrangements decreases in direct proportion to how well the directors are optimized. That is to say, an antenna that doesn't have its directors fully optimized for maximum forward gain could very well see 0.5 dB additional gain with the addition of a tri-reflector or screen reflector. Conversely, a Yagi with its directors optimized for maximum gain may be fortunate to see a 0.1-dB gain improvement from such a multiple reflector arrangement.

There also seems to be a common misconception that multiple reflector arrangements improve the f/b ratio. Except for screen or grid reflectors such as those used by DL9KR, this has not been observed to be the case.[5] Dual or tri-reflectors show some tendency to increase the bandwidth over which a particular f/b will be maintained, but don't show any consistent tendency to always increase the f/b. Many of these multiple reflector arrangements can be tuned to decrease the strength of the rear lobe right at 180 degrees. Since the overall gain of the Yagi doesn't significantly increase with these multiple reflector arrangements, the strength of other minor lobes increases. It should also be noted that the actual f/b at the 180-degree point of the pattern is not a good indicator of the performance of a Yagi. Many Yagis, including the stock 424B and F9FT-21 element Yagi have nulls at the 180-degree point which give an artificial sense of a high f/b. In order for a Yagi to have an excellent G/T (Gain-to-Noise Temperature ratio), it must have all lobes in the rear hemisphere of the Yagi, *in all planes*, down a significant amount (over 25 dB). Lobes on either side of 180 degrees are actually conical in shape when the antenna pattern is viewed in three dimensions. Therefore, they intercept a large amount of radiated energy and can be a troublesome source of noise reception. The modified Yagis have measured f/b ratios of close to 25 dB. In addition, the lobe at 180 degrees is strongest in the rear hemisphere of the pattern and almost all other rear lobes are down 30 dB or more.

If a high or broadband f/b ratio is desired, a non-tuned grid or screen reflector arrangement will be most effective. If one is concerned mainly with forward gain and pattern at a particular frequency, none of the multiple reflector arrangements is as effective in terms of windload versus additional gain when compared to simply lengthening the boom and adding more directors.

The quad-type feed and reflector were also examined. Many of the performance claims for the quad feed were not substantiated by computer analysis. It was found that on short Yagis (under 1.5 wavelengths) the quad feed added a couple of tenths of a dB in additional gain versus a dipole feed. However, in considering the quad feed and reflector, one must also account for the additional windload and weight that it adds. As in the tri-reflector, the gain-versus-windload war would be won by adding directors to a dipole-fed Yagi. The longer the Yagi was, the less effect the quad feed had. In fact, at 5 wavelengths (boom), no measurable gain advantage was noticed by using a quad feed and reflector.

One area in which a quad feed can offer an advantage is in VSWR bandwidth — i.e., the VSWR could be held under a certain value over a wider frequency range. If a quad feed is used on a long Yagi, I highly recommend using a balun. Pattern measurements on quagi-type antennas have usually shown significant pattern imbalances. Another myth about quagis has been that they have better patterns; yet an examination of existing quagi designs, both on the computer and on my antenna range, indicated that their patterns are substantially poorer than any modern Yagi such as the DL6WU design or the designs presented here. Attempts were made on the computer to adapt the quad feed to more modern director strings. The results were not very successful. The quad feed seemed to require a very wide first director spacing in order to get acceptable forward gain. This wide first director spacing then caused pattern deterioration. The net result was to drop further efforts on quagi-type antennas.

design knowledge reduces computer time

The computer hardware available to me over a year ago required about 2-1/2 minutes to calculate the gain and pattern of the 24-element Yagi and close to 4 minutes to calculate the 32-element version. Considering that every time an element length was changed, every other element had to be checked to see if its length should also be changed, the number of calculations required to optimize each of the elements might require sitting at the computer for half a year. To free me from that chore, I designed an algorithm to optimize the element lengths automatically. This algorithm could also be utilized to optimize element spacings. It could be extended to optimize both spacings and lengths as well; however, with the level of computer power available to most Amateurs, such an optimization of a 32-element Yagi might take considerably longer than we're willing to wait. Therefore, the design must start with some geometry constants determined by the designer's knowledge of antenna designs.

It was found that the Yagi analysis program lacked sufficient accuracy to completely self-optimize a long Yagi. Specifically, the program showed a tendency to make the elements at either end of the antenna longer than desired. In addition, the program would make the elements in the center of the Yagi considerably shorter than would be believable. At the same time, gain figures would become higher than expected. Moreover, the free-running gain optimization would result in an antenna with a low f/b ratio (less than 15 dB). Therefore, it was necessary to go into the design process manually from time to time and correct element lengths that appeared to be out of line. These adjustments were based on real-world experience with designs which were known to work. Final manual element adjustments were made to perform pattern cleanup on the Yagi.

With a good mathematical model in place, the next step was to build and test a real antenna. This is the point where theory meets reality; if an antenna is optimized with even a slightly erroneous model, those errors will surely be designed into the resultant Yagi. A further complication was the use of elements mounted through the boom but insulated. At that time, no reliable element length correction information existed for that method of mounting elements. An additional uncertainty was the fact that very few existing 432-MHz Yagis peaked very close to 432 MHz on the computer. First attempts to build real 24- and 32-element Yagis resulted in antennas which peaked in gain around 444 MHz.

This occurred for several reasons. First, the design was intentionally peaked high in frequency because the Yagis were designed to be used in arrays of up to 16 elements. In addition, at the onset of antenna construction, I expected a much smaller boom correction for insulated through-the-boom elements than the actual correction factor turned out to be. Another set of elements were made 1/16-inch (1.6 mm) longer. This lowered the gain peak to 442 MHz. An additional set of elements were made for the 32-element Yagi again 1/16-inch (1.6 mm) longer. The gain peak moved another 2 MHz lower to 440 MHz. Both the real antenna and additional computer modeling showed that a 432-MHz Yagi with 3/16-inch (4.8 mm) diameter elements shifted in frequency approximately 1 MHz for each 1/32 inch (0.8 mm) added or subtracted from the elements. Since 1/32 inch is also very close to 1 mm, this becomes a handy rule of thumb for shifting the center frequency of a 432-MHz Yagi for those working in either English or metric units.

boom correction

During this phase of antenna development I examined the boom correction. Three different insulators — the original 424B type (Heyco nylon inserts), the Delrin™ RIW Products type, and the KLM polyethylene type — were tried; all three gave similar, but not identical, results. The amount of capacitance between the element and boom appeared to be the major variable in boom correction. In modeling the effect of the insulated elements mounted through the boom, one can think of the element as an inductor. The boom is looked at as additional inductors in parallel with the center portion of the element. For insulated elements these inductances are capacitively coupled, reducing the amount of parallel inductance. This lowers the amount of boom effect over elements mounted through the boom and not insulated.

Figure 1 describes the boom correction model. An additional complication in the model is an apparent shielding effect that the boom has on the portion of the element which is inside the boom. This increases the boom correction over the amount implied by the simple capacitive/inductive reactance model. The correction I normally use for this type of element mounting is 25 percent of the boom diameter. The effect appears to change slightly with boom diameter. For example, a 0.75-inch (19 mm) boom shows closer to 20 percent correction, while a 1-1/2 inch (38 mm) boom requires nearly 30 percent correction. This nonconstant effect was also charted by DL6WU for uninsulated elements mounted through the boom.[6] The -0.5 dB gain bandwidth of a well-designed Yagi is close to 3 percent, or nearly 14 MHz at 432 MHz. Because of this, one doesn't have to be all that fussy in the exact determination of the boom correction.

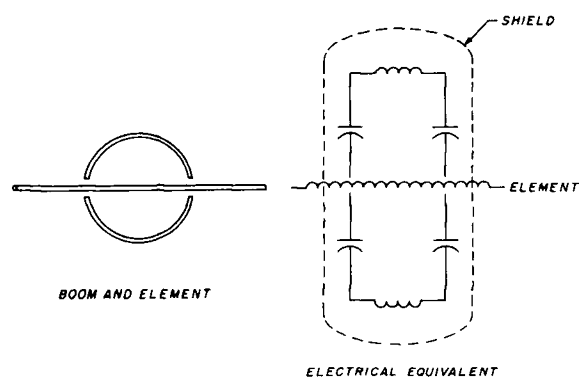


fig. 1. Insulated through-the-boom element modeling.

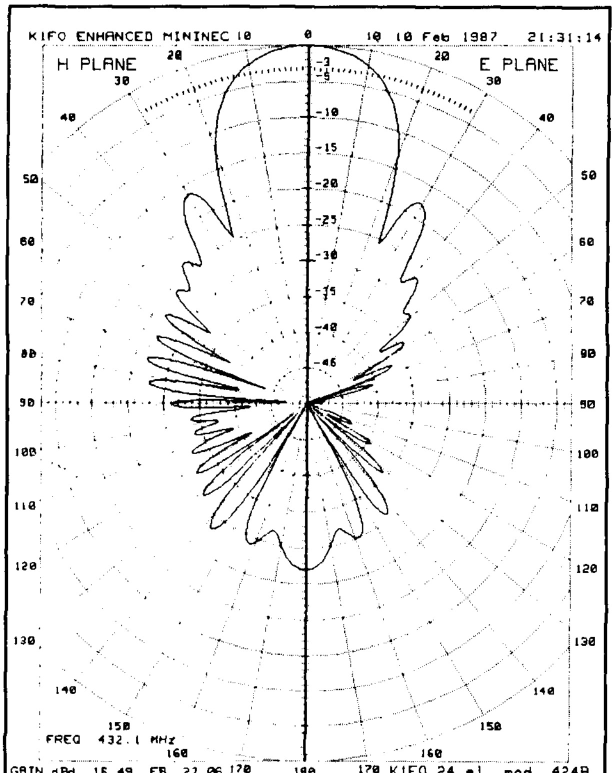


fig. 2. Calculated E and H plane pattern for 24-element Yagi, version 3.

square cut end lengthens element

Another impediment to having the computer model come out right the first time is what I call the *element end effect.* This is an apparent effect where a rod element with square cut ends will appear electrically longer than its physical length. I believe the sharp corners at the end of the element cause a field strength concentration; a more even current and field distribution would be obtained by using elements with spherical ends.

This effect is probably negligible below 50 MHz. At 432 MHz, where a 3/16-inch (5 mm) diameter is a measurable portion of a wavelength, the effect can no longer be ignored. I believe this element end effect is the main reason Amateurs had so much trouble scaling Yagis to 432 and 1296 MHz for many years; it's also further substantiated by persistent stories that the NBS Yagis wouldn't work above 1000 MHz. Most likely the element length graphs provided by NBS did not have this factor taken into account for frequencies significantly different than the 400-MHz test frequency used by the NBS.

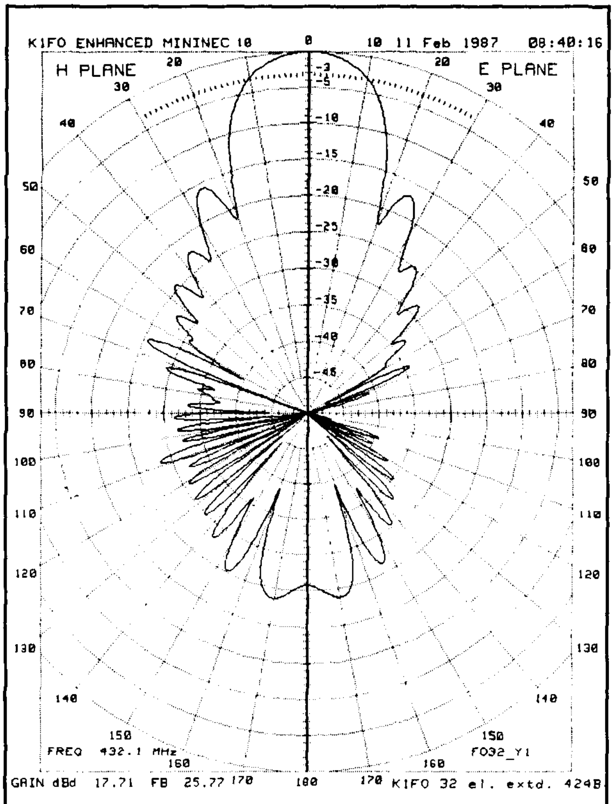


fig. 3. Calculated E and H plane pattern for 32-element Yagi, version 2.

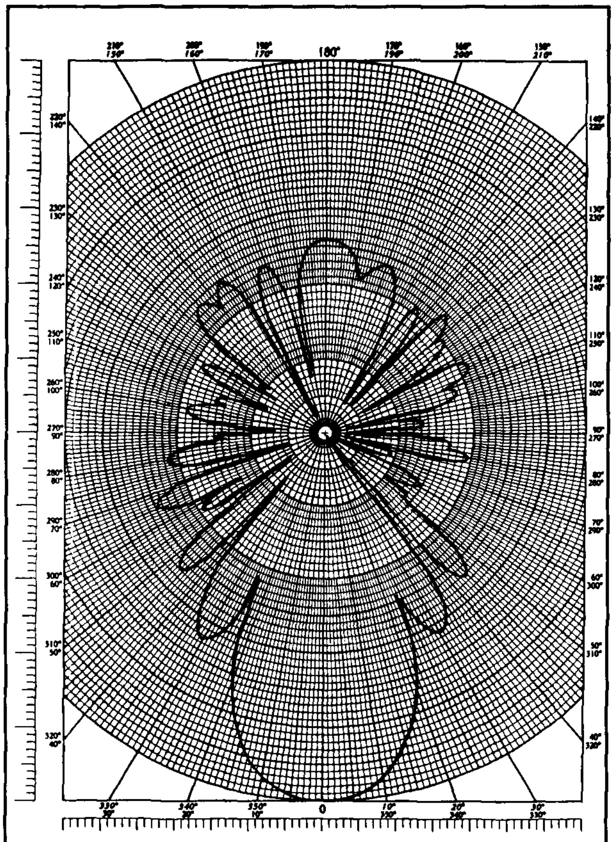


fig. 4. Measured E plane pattern of modified 24-element Yagi, version 3.

My work leads me to believe that at 432 MHz, a 3/16-inch (4.8 mm) diameter element with square cut ends acts as if it were close to 0.15 inch (3.8 mm) — electrically longer that its physical length. Using the previously outlined nominal 1-MHz frequency shift per 1/32 inch (0.8 mm) of element length change rule of thumb, this element end effect accounts for close to a 5-MHz lowering in center frequency at 432 MHz. To minimize this effect and to help lower the field concentration at the element ends, I use about a 1/32-inch (0.8 mm) chamfer on the element ends. This appears to reduce the frequency shift to less than 2 MHz. *This rounding of the element ends also appears to help wet weather performance.*

After being sidetracked by the element end effect investigation, it was decided that an additional 1/8 inch (3.2 mm) would be added to the length of all the elements. This would move the gain peak down to 436 MHz. This tuning makes the gain at 432 MHz approximately 0.1 dB lower than the maximum at 436 MHz — the most desired frequency to which the antenna would be tuned — because the pattern at 432 MHz is somewhat cleaner and mutual impedance effects from the other Yagis in arrays would not be detrimental. These mutual impedance effects tend to lower the center frequency of an array of Yagis relative to the free-space center frequency of a single Yagi.

An array of four medium-sized Yagis (RIW-19s) had both a measured and calculated frequency shift of about 600 kHz. Based on this, an array of 16 Yagis could have a frequency drop of nearly 2 MHz. *If these mutual impedance effects cause the array to move over the high frequency gain dropoff point, the array will never perform as well as expected.* In fact, it is for this reason that some Yagis can never obtain the theoretical 3-dB stacking gain. In addition, the radiation pattern of most Yagis deteriorates rapidly above the gain peak. It is for these reasons that Amateurs were not very successful in getting EME arrays made from some of the early Amateur Yagi designs to work properly.

Computer-generated patterns for the 24-element, 17-foot, 3-inch (5.2 m) and the 32-element, 24-foot (7.3 m) Yagis are given in **figs. 2** and **3**. Actual E plane pattern measurements for both Yagis are shown in **figs. 4** and **5**. A comparison with the patterns of the stock 424B (**figs. 6** and **7**) demonstrates the attention paid to improving the radiation patterns. When comparing the patterns, keep in mind that the revised Yagis use a single reflector instead of the tri-reflector on the

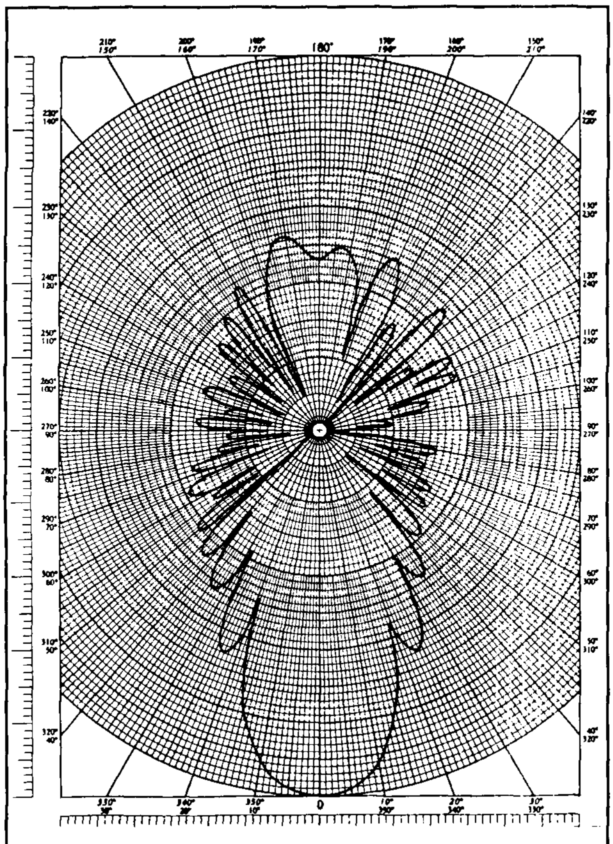


fig. 5. Measured E plane pattern of 32-element Yagi, version 2.

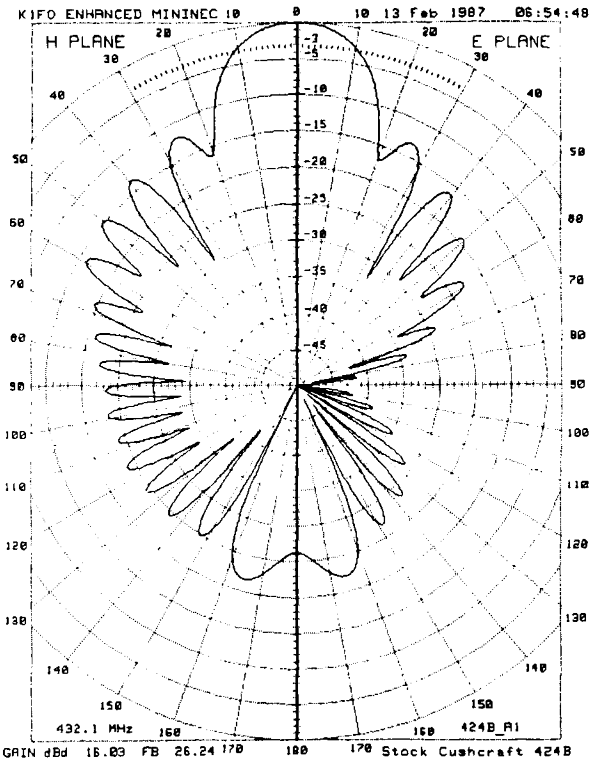


fig. 6. Calculated E and H plane pattern for unmodified 424B Yagi.

original antenna. The calculated gain-versus-frequency plots (**fig. 8**) provide more interesting data. The maximum gain point of the modified Yagis has been moved 4 MHz higher, to 436 MHz. In addition, the high-side gain cliff, the point at which the gain of the Yagi rapidly drops off, is moved almost 8 MHz higher in frequency. A smooth gain-versus-frequency curve is an indication that the directors are operating in a synergistic mode and hence at or near their maximum possible performance.

Between the 24- and 32-element versions of the Yagis, eight different test Yagis were built before the published dimensions were selected. There's still room for a little improvement in the 32-element Yagi; this will be covered in more detail later.

It's obvious that with the accuracy of antenna analysis programs available to most Amateurs, an important post-computer optimization process is required. One shouldn't put too much confidence in any analysis program until the results have been confirmed with real antennas. With the help of the more sophisticated method of moments analysis programs, I now need only one or two tries building a real antenna to get it right. Getting to this point required two years of learning both the limitations of the programs I use and more about the design of Yagis.

design procedure

The design cycle is still an iterative process. It first uses a rough optimization using WB3BGU's computer program. Next, the results of the YAGI program are confirmed by a more sophisticated but vastly slower method of moments program. If the design is believable, a test Yagi is made and measured at this point. From that data, further computer tuning is done and other test antennas are made. **Figure 9** shows the flow chart for the computer-aided Yagi design process.

The calculated patterns were done on an enhanced version of MININEC. This program's results appear to have gain figures and calculated patterns that more closely represent the real world than those generated by the YAGI program. It should be noted that the calculated gain figures are slightly optimistic because they do not account for balun and element resistive losses, mechanical tolerances, or unwanted radiation from the feed. Likewise, the calculated patterns are also optimistic for the same reasons. One may expect that the real Yagi's sidelobes will be 1 to 2 dB poorer than calculated, with the main lobe slightly narrower than

CONTINUOUS COVERAGE ANTENNAS
FOR COMMERCIAL & AMATEUR SERVICE

Model AC 1.8-30 1.8 to 30 MHz

- SWR Max 2:1, 1.4:1 average from 1.8 to 30 MHz
- Can be installed in approximately 80 ft. space
- Ideal for commercial services for multi frequency operation without the need for antenna tuners or additional antennas
- Handles 1 KW, 2 KW PEP ICAS
- Higher power models available on special order. Contact your dealer or factory

$159.50
SHIPPING & HANDLING ADD $4.00

RF TRANSFORMER — 50 FT. — 25-30 FT. — 50 FT. — BALANCING NETWORK — DIRECT COAX FEED

U.S. Patent No. 4,511,898

Model AC 3.5-30 3.5 to 30 MHz

- SWR less than 2:1 from 3.5 to 30 MHz
- Complete assembled. Balun terminated with standard SO-239 connector
- Power capability 1 KW - 2 KW PEP ICAS. Higher power model is available on special order.
- Designed for 50 ohm feedline
- Weather proof balun and balancing network

$167.50
SHIPPING & HANDLING ADD $4.00

Only 90 feet long

U.S. Patent No. 4,423,423

ALL OUR PRODUCTS MADE IN USA
B·W **BARKER & WILLIAMSON**
Quality Communication Products Since 1932
At your Distributors. Write or Call.
10 Canal Street, Bristol, PA 19007
(215) 788-5581

INTERNATIONAL MONTHLY MAGAZINE BY AND FOR ACTIVE RADIOAMATEURS

Radiosporting

THIS IS IT! - FOR BIG GUNS & LITTLE PISTOLS

A magazine dedicated to quality and sportsmanship in amateur radio operating. Fresh, timely, practical and down to earth reading for little pistols and big guns. Written by the world's best in their fields: ON4UN, SM0AGD, LZ2CJ, VE3BMV, KH6BZF, DJ9ZB, ZS6BRZ, W1WY, N2AU, K7GCO, K4ZN, W4GF, VE3JTQ, WB4ZNH, WB9TBU, KQ2M, NS6X, W3FG, KA3B, K1PLR, N7CKD, VE3XN, AB0X, JE1CKA and others.

Includes DX News, QSL Info, 160m, 80m, 10m, 6m columns, DXpeditioning, Propagation, Awards, Contest rules and results, Traffic - Emergency, FCC News, New Products, Antennas, Technical news and articles, equipment reviews and modifications, computer programs, Radio Funnies, Club Life, RTTY, VHF/UHF, Mail Box, Classified Ads and much more in a magazine format with the speed of a bulletin.

RADIOSPORTING sponsors DX Century Award, Contest Hall of Fame and World Radio Championship contest.

"Your publication is superb! Keep it up!" **Joe Reisert, W1JR**

"Your W2PV articles are priceless. Your magazine is super!" **Rush Drake, W7RM**

"Let me congratulate you on a very impressive magazine. Just what I've been looking for as a DXer and Contester!" **Dick Moen, N7RO**

"RADIOSPORTING, once received, cannot be tossed aside until it is read from cover to cover. Then reviewed again and again." **Chas Browning, W4PKA**

Subscription rates: 1 year USA $18, Canada CDN$26, Overseas US$23; 2 years $33, $48, $42 respectively. Single issue $2. USA First Class Mail add $8/year, DX Air Mail add $15/year.

TRY US! SUBSCRIBE OR SEND $1 FOR YOUR SAMPLE COPY.
RADIOSPORTING Magazine
PO Box 282, Pine Brook, NJ 07058, USA

✓ 155

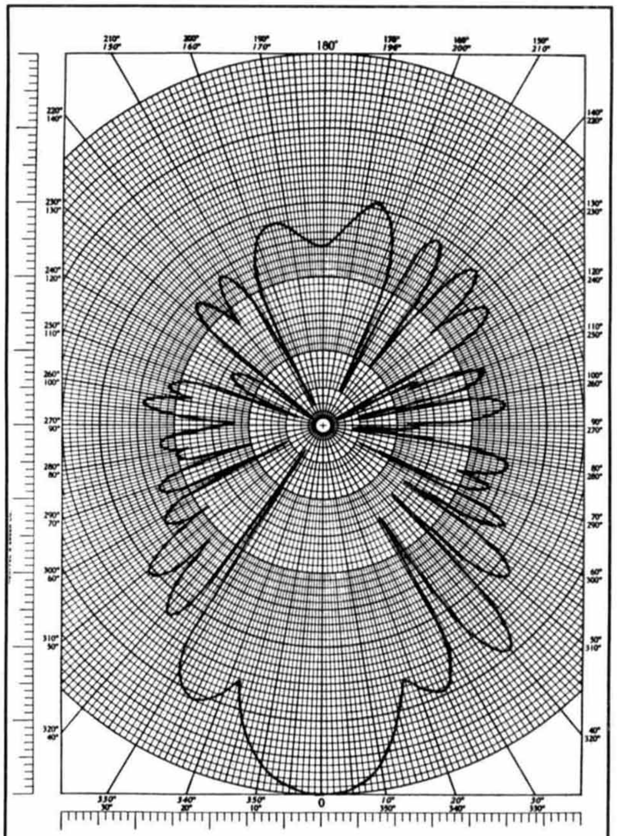


fig. 7. Measured E plane pattern for unmodified 424B Yagi.

calculated and gain typically 0.1 dB lower than calculated.

Careful comparative gain measurements between these Yagis and both the RIW-19 Yagi (14.9 dBd) and the KLM 432-30-LBX Yagi (17.3 dBd) indicate that the 32-element version 2 Yagi has 17.7 dBd forward gain and the 24-element model has about 16.4 dBd gain, or 0.5 dB over the original 424B. Computer analysis by both the WB3BGU program and the more sophisticated method of moments programs agrees with these gain comparisons. As a reference, a 31-element, 24-foot (7.3 m) DL6WU design Yagi measures 17.5 dBd and has a slightly poorer pattern. The optimized 31-element DL6WU design for which I calculated the revised element lengths has a slightly better pattern than the 32-element version 2 Yagi, but lower gain at 17.6 dBd.[7] The improved 32-element design (version 3) theoretically has as good an overall pattern as the optimized DL6WU design, but with almost 0.2 dB higher forward gain. Accuracy of these gain figures should be within 0.2 dB.

I believe that the maximum theoretical gain that can be obtained with a 17-foot (5.2 m) 432-MHz Yagi is 16.6 dBd and that the maximum for a 24-foot (7.3 m)

Yagi is 18.0 dBd. Thus, these Yagis are near the theoretical maximum possible gain, given their boomlengths. Further performance increases would require radical changes in element spacings, and therefore defeat the objective of devising an improved antenna that was easy to build from an existing commercial model. These theoretical gain improvements are also very small (approximately 0.2 dB). Keep in mind that a measured gain of 18.0 dBd for a 24-foot (7.3 m) 432-MHz Yagi may never be obtained because of resistive losses, construction tolerances, unwanted feed radiation, and feed imbalance. Although the original design objective was to create an easy-to-copy modification of a commerical Yagi, the above performance comparison indicates that the design is worthy enough to be considered for construction from scratch. This is verified by the fact that the 32-element, 24-foot (7.3 m) design has never been beaten at an antenna gain contest by a similar size Yagi. The only Yagi ever to exceed its gain at an antenna contest was almost 29 feet (8.8 meters) long, which is 5 feet (1.5 meters) longer in boomlength.

Table 1. Dimensions for a 24-element Yagi, version 3.

Spacing	Length	Boom (inches)	
1.000,	13.6250	1	REF
5.250,	13.2500	1	DE
7.875,	12.6250	1	D1
11.563,	12.2500	1	D2
16.813,	12.1875	1	D3
23.563,	12.0625	1	D4
31.875,	11.8750	1	D5
42.125,	11.6875	1	D6
52.375,	11.5625	1	D7
62.625,	11.3750	1	D8
72.875,	11.3125	1 1/8	D9
83.125,	11.2500	1 1/8	D10
93.375,	11.1875	1 1/8	D11
103.625,	11.1250	1 1/8	D12
113.875	11.0625	1 1/8	D13
124.125,	11.0000	1 1/8	D14
134.375	11.0000	1 1/8	D15
144.625,	10.9375	1	D16
154.875,	10.8750	1	D17
165.125,	10.8750	1	D18
175.375,	10.8125	1	D19
185.625,	10.8125	1	D20
195.875,	10.7500	1	D21
206.125,	10.7500	1	D22

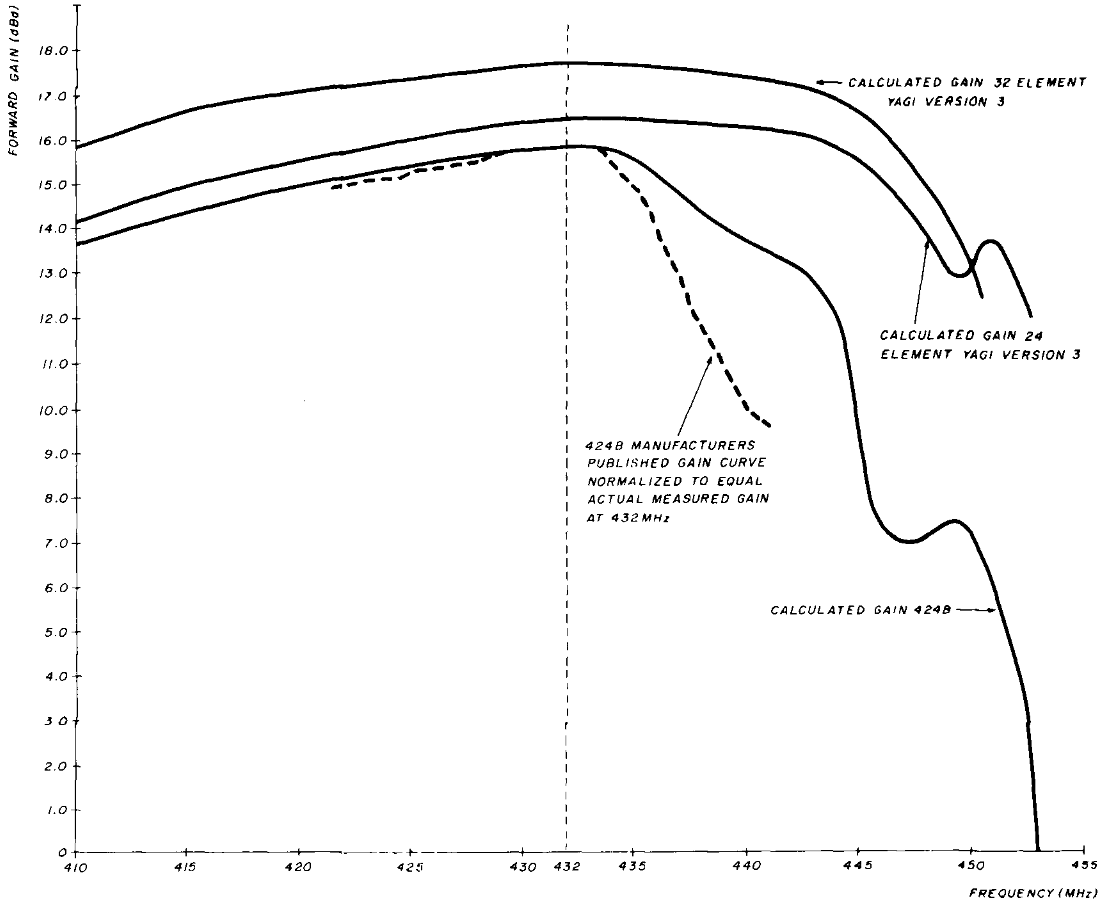


fig. 8. Calculated gain versus frequency is higher than actual gain, since 100 percent power transfer is assumed at all frequencies — i.e., feed impedance changes are ignored.

HIGH PERFORMANCE
PRESELECTOR-PREAMP

The solution to most interference, intermod, and desense problems in **AMATEUR** and **COMMERCIAL** systems.

- 40 to 1000 Mhz - tuned to your frequency
- 5 large helical resonators
- Low noise - High overload resistance
- 8 dB gain - ultimate rejection > 80 dB
- 10 to 15 volts DC operation
- Size - 1.6 x 2.6 x 4.75" exc. connectors
- **FANTASTIC REJECTION!**

Typical rejection:
±600 Khz@144 Mhz: −28dB
±1.6 Mhz@220 Mhz: −40dB
±5 Mhz@450 Mhz: −50dB

Price - CALL bipolar w/RCA jacks
Connector options: BCN $5, UHF $6, N $10
SUPER HOT! GaAs Fet option $20

AUTOMATIC IDENTIFIERS

ID-1 ID-2

- For transceivers and repeaters - **AMATEUR** and **COMMERCIAL**
- Automatic operation - adjustable speed and amplitude
- Small size - easy installation - 7 to 15 volts DC
- 8 selectable, reprogrammable messages - each up to 2 min. long
- Wired, tested, and programmed with your message(s)
Model ID-1 - $49.95 Model ID-2 w/2 to 10 minute timer - $69.95

We offer a complete line of transmitter and receiver strips and synthesizers for amateur and commercial use.
Request our free catalog. *Allow $2 for UPS shipping - Mastercard and VISA welcome*

GLB ELECTRONICS, INC.
Dept H, **151 Commerce Pkwy., Buffalo, NY 14224**
716-675-6740 9 to 4

✓ 156

ICOM DAY
presented by
VHF
COMMUNICATIONS
915 North Main Street
Jamestown, New York 14701
(716) 664-6345

Western New York's finest
Amateur dealer at the

BATAVIA HAMFEST
SUNDAY, JULY 12th

at the Alexander
Fireman's Grounds
Rt. 89, South of Batavia, NY

WIN!!! IC-u2AT
plus hourly prizes

No purchase necessary.
ICOM personnel on hand to
answer your questions . . .

SPECIAL PRICES
ON ALL
ICOM EQUIPMENT

✓ 157

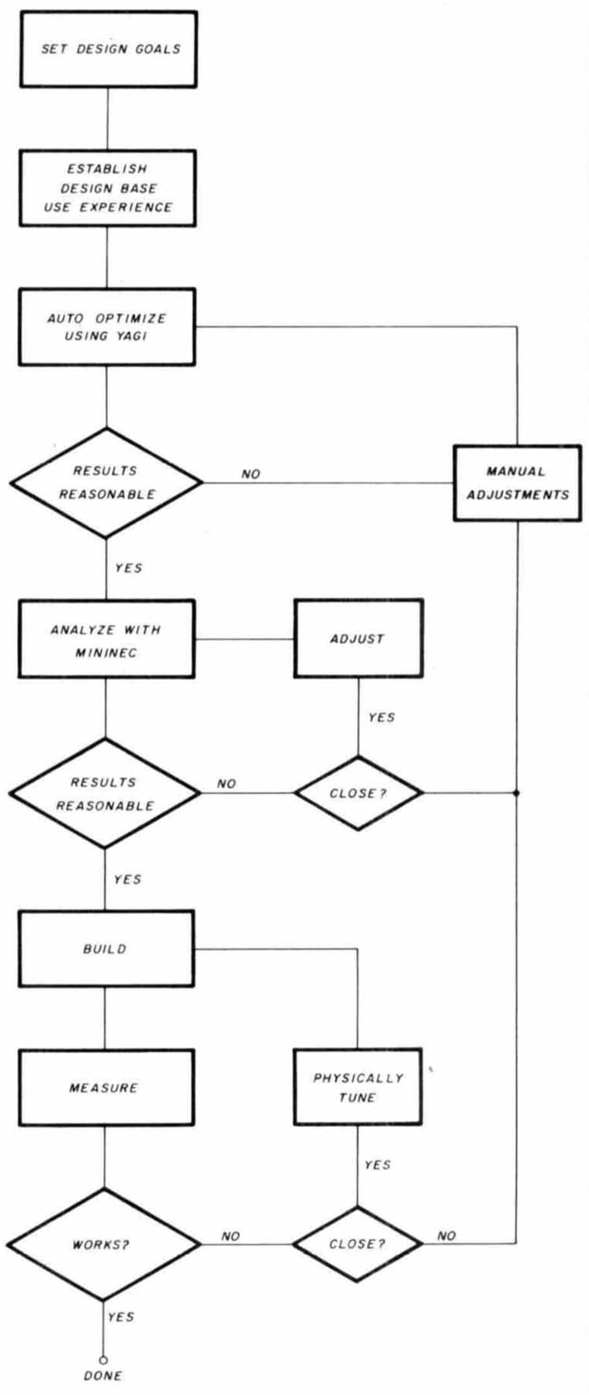


fig. 9. Computer-aided Yagi design cycle.

construction

The actual construction of either of these Yagis starts with the drilling of three new element holes in the boom. The driven element is mounted in a new hole 2.625 inches (66.7 mm) behind the original driven element hole. The old DE location now becomes director 1 and the original director 1 is now director 2. A second new hole is drilled for director 3. The original director 2 hole is no longer used and a final new element hole is added between the original director 2 and 3 holes where a new director 4 now goes. This provides a new antenna with 24 elements — the same number as the original 424B.

The improved Yagis use a single reflector instead of the 424B's tri-reflector. Thus two additional close-spaced directors are added in the new design. A new hole for the N connector bracket is drilled 2.625 inches (66.7 mm) behind the original. The hole for the balun clamp is moved 3.125 inches (79 mm) further back to accommodate the shortened baluns used on the modified Yagis. **Figure 10** shows the new hole drilling pattern for the rear boom section. This revised element spacing is common to both the 24-element and 32-element versions.

Constructing a 24-element Yagi from an unassembled 424B requires only 27 inches (0.69 m) of 3/16-inch aluminum rod and 2 inches (5 cm) of No. 12 copper wire. Modifying an assembled 424B requires the same parts plus a number of element retainers to replace those which will be destroyed in disassembly. One should note that most of the directors could be filed down while in place on the boom, provided that one was careful in checking dimensions during the filing process. It's easier, however, if the element lengths are checked carefully when they're removed from the Yagi. Cutting tolerance should be kept within ± 1/32 inch (0.8 mm). for reassembly of an existing 424B, suitable stainless steel element retainers (No. 6100-18) made by Industrial Retaining Ring Company of Irvington, New Jersey, can be ordered from most local industrial hardware distributors. Suitable retainers can also be ordered from Cushcraft.

Table 1 is a list of the dimensions for the new element lengths of the 24-element Yagi. There are few common dimensions with the original 424B. No attempt was made to save existing element lengths.

The listed dimensions are for version 3 of the 24-element Yagi; they supersede any information I distributed before August, 1986. The version 3 Yagi incorporates additional element adjustments which were modeled on MININEC and confirmed on a test antenna. The latest version features improvements in both gain and pattern. Be sure to put a slight chamfer on the end of the elements — otherwise the antenna will tune lower in frequency and the driven element match may not be acceptable.

The driven element is described in **fig. 11**. Note that the rectangular black spacer insulators used between the driven element and T match bars are no longer used. The No. 16 wire used to connect the T match to the N connector is replaced by a No. 12 wire. This was done both to improve the VSWR bandwidth and reduce unwanted radiation from the jumper wire. Measurement of a stock 424B gave a VSWR of 1.15:1 when dry and over 10:1 when doused with water from a garden hose. The revised match arrangement on the modified Yagi has a VSWR less than 1.12:1 when dry and about 2.0:1 (measured at the feed) when drenched with water.

When radiation patterns were first made on the modified Yagis, an imbalance in the sidelobes was noted. A similar pattern distortion was also measured on a stock 424B. Several more measurements were made to determine whether the pattern distortions were occurring in the measurement method or were actually in the Yagis. To confirm that the imbalance was really in the antenna, the test 424B was flipped over. The pattern imbalance changed sides when the Yagi was turned over. This indicated that the pattern distortion was in the antenna and not attributable to range reflections.

After checking a number of possible causes for the imbalance, it was determined that the balun on the 424B was 1.00 inch (25.4 mm) too long. A length error of exactly 1.00 inch (25.4 mm) leads me to believe that the error in balun length was due to a simple number translation mistake when the 424B's designer calculated the balun length, and that it wasn't made that length intentionally. The main objective of a half-wavelength balun is to provide a 180-degree phase shift to feed the other half of the drive element. The actual length of the balun should be 180 electrical degrees, including the ends of the balun that protrude from the shield. One should not change the length of the balun to obtain a good match; this will cause pattern distortion. The shorter balun also appears to help the wet weather VSWR. If you don't shorten the balun, the driven element dimensions will be different for a proper match.

designing (and mounting) a longer Yagi

The success of the 24-element, 17-foot (5.2 m) Yagi inspired a longer version. The design objective of the long Yagi was simply to outperform any available commercial or homemade Yagi. The appearance of the 22-foot (6.7 m) KLM 432-30-LBX, based upon the DL6WU design (with 17.3 dBd gain), plus the increasing use of homemade DL6WU Yagis up to 24 feet (7.3 meters) long, added to the challenge. A secondary design objective of the longer version was to make it from readily available parts.

A 24-foot (7.3 m) length was selected because I believed it to be a practical size limit, so the Yagi would be reasonably easy to handle. While longer Yagis may appear practical on paper, the construction of an EME array, which requires elevation movement, places

Table 2. Dimensions for a 32-element Yagi, version 2.

Spacing	Length	Boom (inches)	
1.000,	13.9375	1	REF
5.250,	12.8750	1	DE
7.875,	12.9375	1	D1
11.563,	12.3750	1	D2
16.813,	12.3750	1	D3
23.563,	12.2500	1	D4
31.875,	12.0625	1	D5
42.125,	11.8750	1	D6
52.375,	11.7500	1	D7
62.625,	11.5625	1	D8
72.875,	11.3750	1 1/8	D9
83.125,	11.3750	1 1/8	D10
93.375,	11.3750	1 1/8	D11
103.625,	11.3125	1 1/8	D12
113.875,	11.0625	1 1/8	D13
124.125,	11.0625	1 1/8	D14
134.375,	11.1250	1 1/4	D15
144.625,	11.1250	1 1/4	D16
154.875,	10.9375	1 1/8	D17
165.125,	10.9375	1 1/8	D18
175.375,	10.9375	1 1/8	D19
185.625,	11.0000	1 1/8	D20
195.875,	10.9375	1 1/8	D21
206.125,	10.9375	1 1/8	D22
216.375,	10.8125	1 1/8	D23
226.625,	10.8125	1	D24
236.875,	10.8125	1	D25
247.125,	10.8125	1	D26
257.375,	10.8125	1	D27
267.625,	10.8750	1	D28
277.875,	10.8750	1	D29
288.125,	10.8125	1	D30

Table 3. Dimensions for a 32-element Yagi, version 3 (not tested).

Spacing	Length	Boom (inches)	
1.000,	13.6250	1	REF
5.250,	12.9375	1	DE
7.875,	12.7500	1	D1
11.563,	12.3125	1	D2
16.813,	12.3125	1	D3
23.563,	12.1875	1	D4
31.875,	12.0000	1	D5
42.125,	11.8125	1	D6
52.375,	11.6875	1	D7
62.625,	11.5000	1	D8
72.875,	11.3438	1 1/8	D9
83.125,	11.3438	1 1/8	D10
93.375,	11.3438	1 1/8	D11
103.625,	11.2813	1 1/8	D12
113.875,	11.0938	1 1/8	D13
124.125,	11.0313	1 1/8	D14
134.375,	11.0625	1 1/4	D15
144.625,	11.0000	1 1/4	D16
154.875,	10.9688	1 1/8	D17
165.125,	10.9688	1 1/8	D18
175.375,	10.9063	1 1/8	D19
185.625,	10.9063	1 1/8	D20
195.875,	10.9063	1 1/8	D21
206.125,	10.8438	1 1/8	D22
216.375,	10.8438	1 1/8	D23
226.625,	10.8125	1	D24
236.875,	10.7500	1	D25
247.125,	10.7500	1	D26
257.375,	10.7500	1	D27
267.625,	10.7500	1	D28
277.875,	10.6875	1	D29
288.125,	10.6875	1	D30

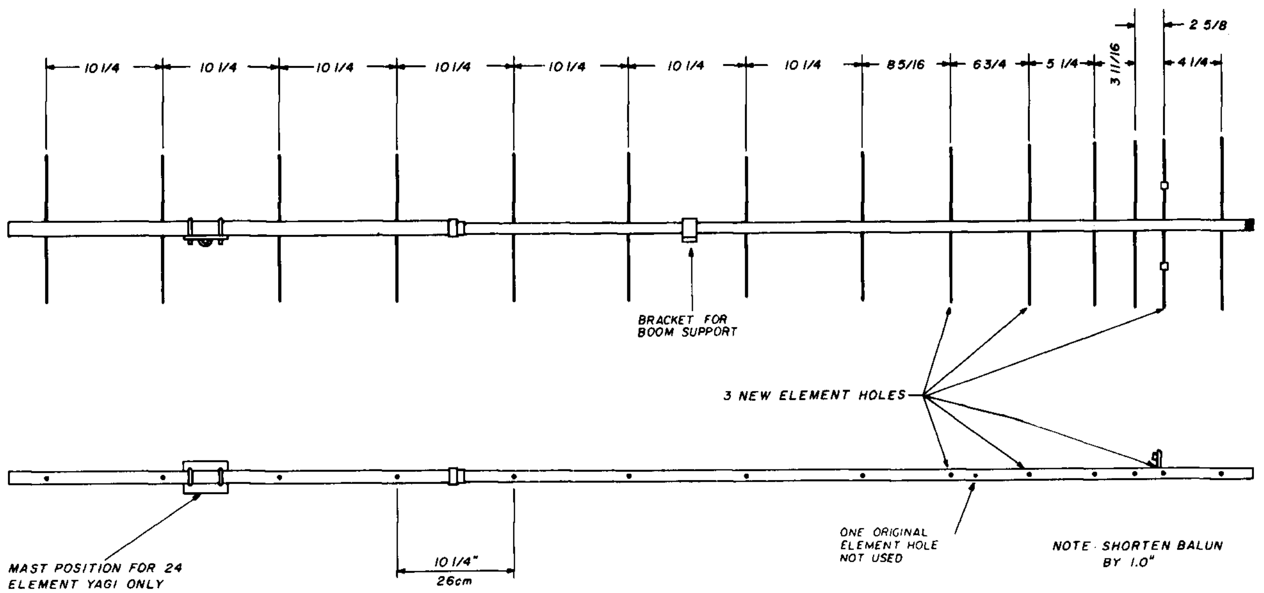
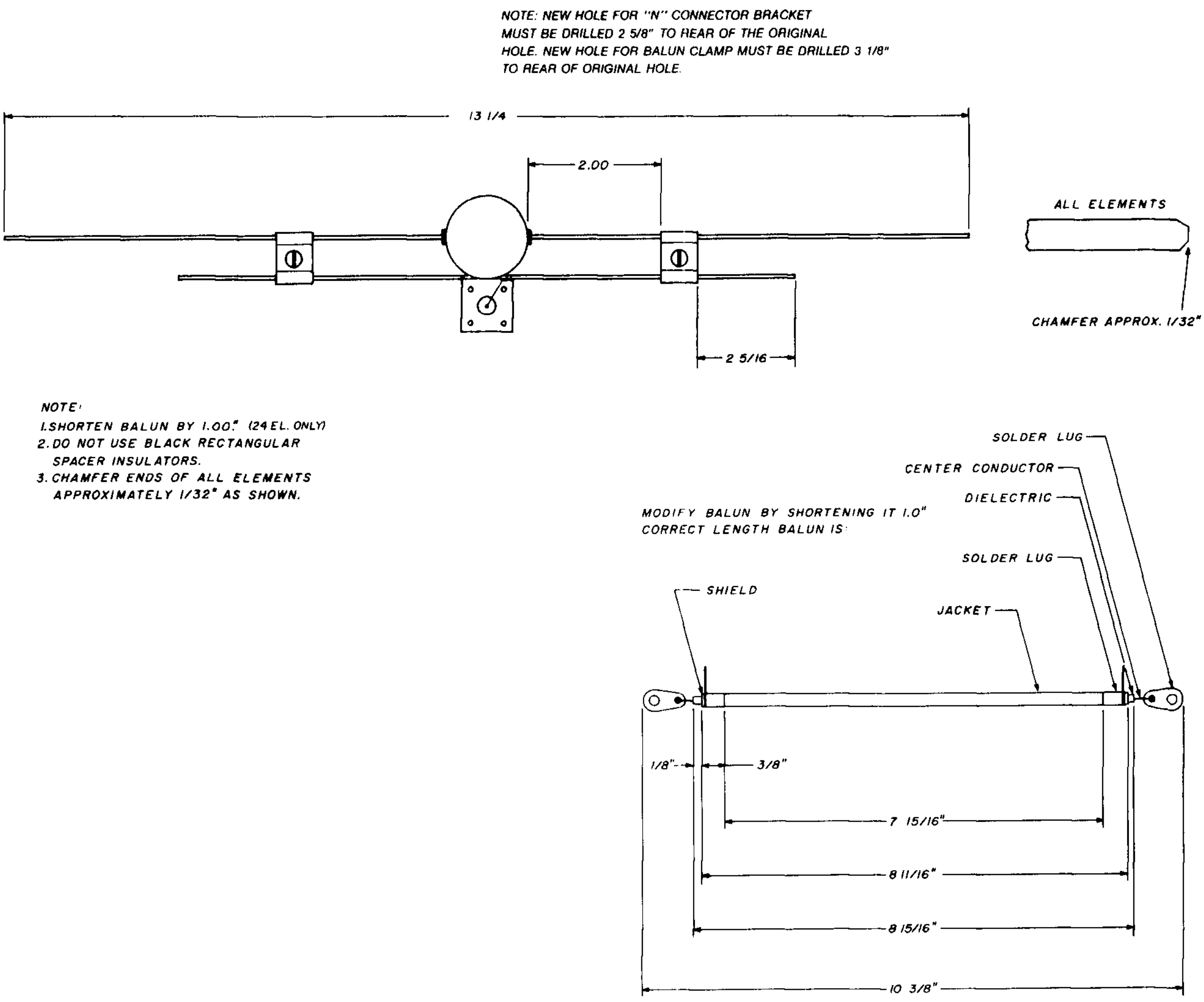


fig. 10. New spacing pattern for 24, 32, and 38-element Yagi.



NOTE: NEW HOLE FOR "N" CONNECTOR BRACKET MUST BE DRILLED 2 5/8" TO REAR OF THE ORIGINAL HOLE. NEW HOLE FOR BALUN CLAMP MUST BE DRILLED 3 1/8" TO REAR OF ORIGINAL HOLE.

NOTE:
1. SHORTEN BALUN BY 1.00" (24 EL. ONLY)
2. DO NOT USE BLACK RECTANGULAR SPACER INSULATORS.
3. CHAMFER ENDS OF ALL ELEMENTS APPROXIMATELY 1/32" AS SHOWN.

MODIFY BALUN BY SHORTENING IT 1.0" CORRECT LENGTH BALUN IS:

fig. 11. Driven element details for the 24-element Yagi. Note balun details.

additional demands on the supporting tower. Typical EME arrays are mounted about 20 feet (6.1 meters) above the ground; an array of 16 of the 24-foot (7.3 meters) long Yagis has only 4 feet (1.2 meters) of ground clearance when tilted back. Longer Yagis will need a higher tower and hence one that is considerably stronger than the commonly used Rohn 45. If an array of such long Yagis is intended to be mounted atop a tall guyed tower, for use on tropo, for example, the design becomes more difficult. An array made from even longer Yagis would have to be mounted a large distance above the top guy wires in order to allow elevation movement. In the case of an array made from 24-foot (7.3 meters) Yagis, the height above the guys is 14 feet (4.3 meters). An array made from eight of the Yagis stacked two wide and four high has a total windswept area of over 40 square feet when phasing lines, preamplifier enclosure, and all other required accessories are included. Such an array presents a loading force that is at the limit of what a Rohn 55 can handle. When one considers that an array of eight 29-foot (8.8-meter) Yagis has a wind area approaching 50 square feet and would have to be mounted over 16 feet (4.9 meters) above the guys, one can see how quickly the tower loading can get out of hand.

The 24-foot (7.3-meter) length worked out well because it could be obtained by purchasing an additional center boom section for the 424B from Cushcraft. The availability of the additional boom section, in pre-drilled form, sealed the design length. To complete the boom only a simple, short, 1-1/4 inch (38 mm) OD, 0.058-inch (1.5 mm) wall, 6061-T6 aluminum tube splice was required.

Those who build the Yagi may note that it could have been made with an additional director (10.25 inches/260 mm longer). I decided to keep the anten-

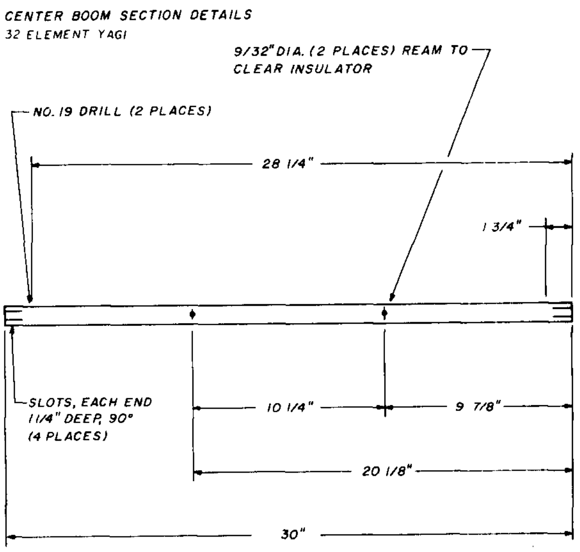


fig. 12. Center boom section details.

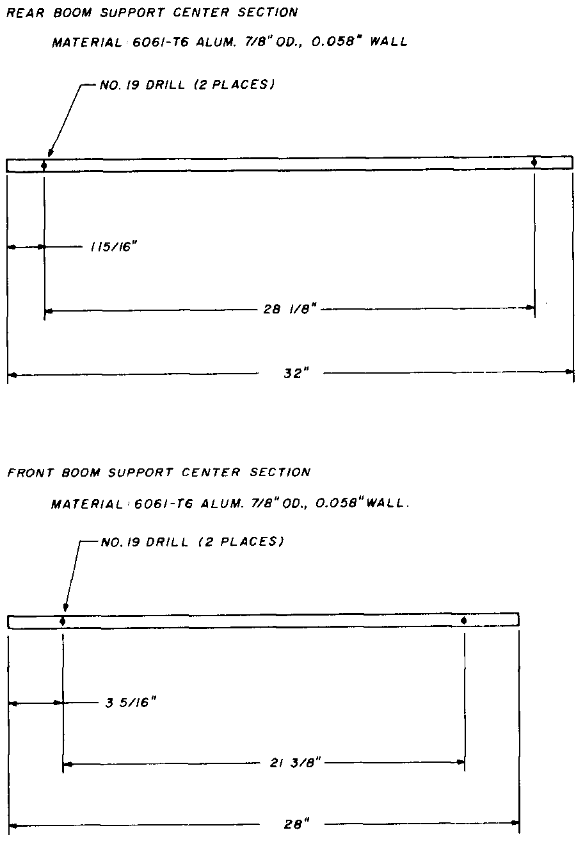


fig. 13. Parts for a 24-foot extended, modified 424B antenna.

na at 32 elements and overlap the rear and center boom sections for additional strength. The selected length and mast mounting position creates a balanced antenna when a feedline is attached. Having a balanced antenna is an important consideration, especially when it will be used in large arrays. The center boom piece is detailed in **fig. 12**.

The longer, 24-foot (7.3-meter) length made the original Cushcraft 424B boom support inadequate. A solution was again found in Cushcraft parts. A new boom support was made from preformed boom support pieces for the 220B antenna. This required only the fabrication of two simple straight splice sections of 3/4-inch (19-mm) OD, 0.058-inch (1.5-mm) wall aluminum tube. The new boom support center pieces are described in **fig. 13**.

Alternately, one can make one's own boom supports. Another possibility would be to lengthen the original 424B supports by using 0.625-inch OD, 0.058-inch wall aluminum tubing. Since the parts for the new boom support were purchased, Cushcraft changed the design of its boom supports. Suitable boom supports can now also be made from the supports used on either the latest A32-19 or 4218-XL 144-MHz Yagis. A rigid boom support is preferable to a simple support wire; it adds lateral strength to the boom, minimizing oscillation in the wind.

Element lengths for the 32-element version 2 Yagi are given in **table 2**. These are the latest tested dimensions and are representative of the version that's been brought to several antenna contests and also used in NC1I's EME array. The director lengths, which don't get progressively shorter, may not seem logical, but I found that this length arrangement was necessary to keep an acceptable pattern, given the closer-than-desired director spacing used in the 424B boom sections.

Since the version 2, 32-element Yagi was perfected, access to more sophisticated computer programs has allowed an improved director string to be calculated. The new director arrangement uses an element length scheme similar to the version 3, 24-element Yagi. That is to say, all directors are shorter than the preceding one. This new director string theoretically has 0.1 dB more gain than the version 2 arrangement. The pattern is also slightly cleaner, in theory. Dimensions for the new arrangement called version 3 are given in **table 3**. These dimensions haven't been confirmed by the construction and measurement of test antennas. Experience with the version 3, 24-element Yagi makes me confident that the revised 32-element design will perform as predicted. One can never be completely certain that it will perform as expected until a real antenna is built and measured. The design data for all of these Yagis is presented here because publishing my work up to this point was long overdue. One

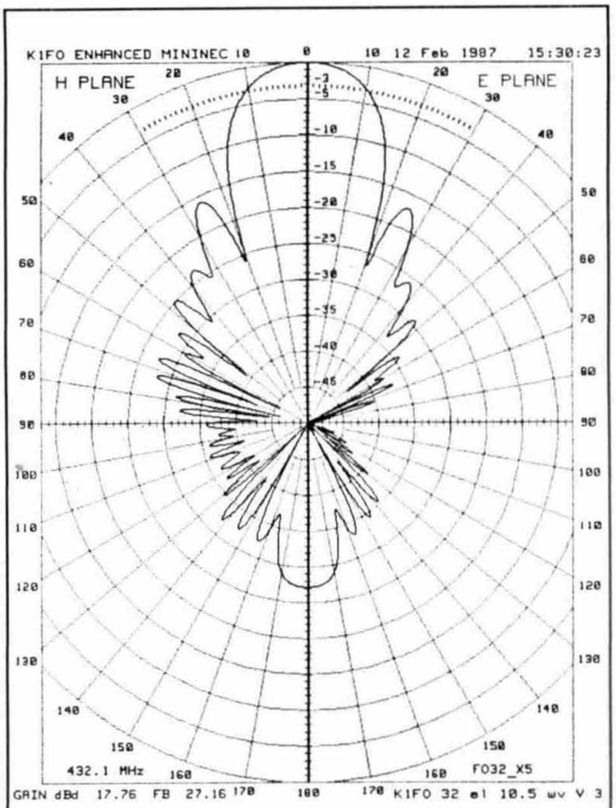


fig. 14. Calculated E and H plane patterns for a 32-element Yagi, version 3.

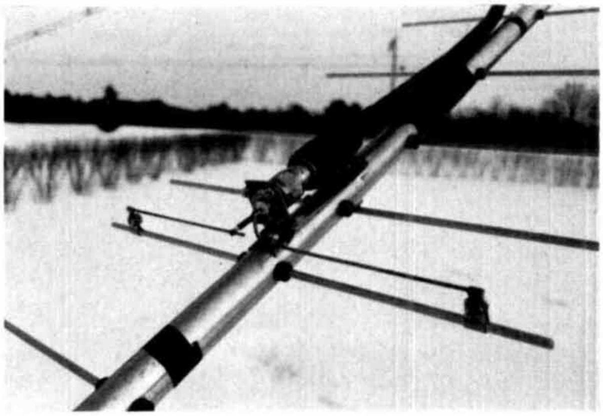


Photo A. Thirty-two element Yagi driven element.

could become consumed in a lifetime project to continually improve upon the last design. If such a cycle were to continue forever — without publishing any of the earlier work — there would be no benefit to the Amateur community. However, be forwarned that if you decide to build a Yagi using the **table 3** dimensions, you'll be entering uncharted territory. Calculated E and H plane patterns for the version 3 Yagi are given in **fig. 14**.

The maximum performance objective for the 24-foot (7.3-meter) Yagi also required a new driven element construction. I felt that the 424B-based driven element had excessive, unwanted radiation from the

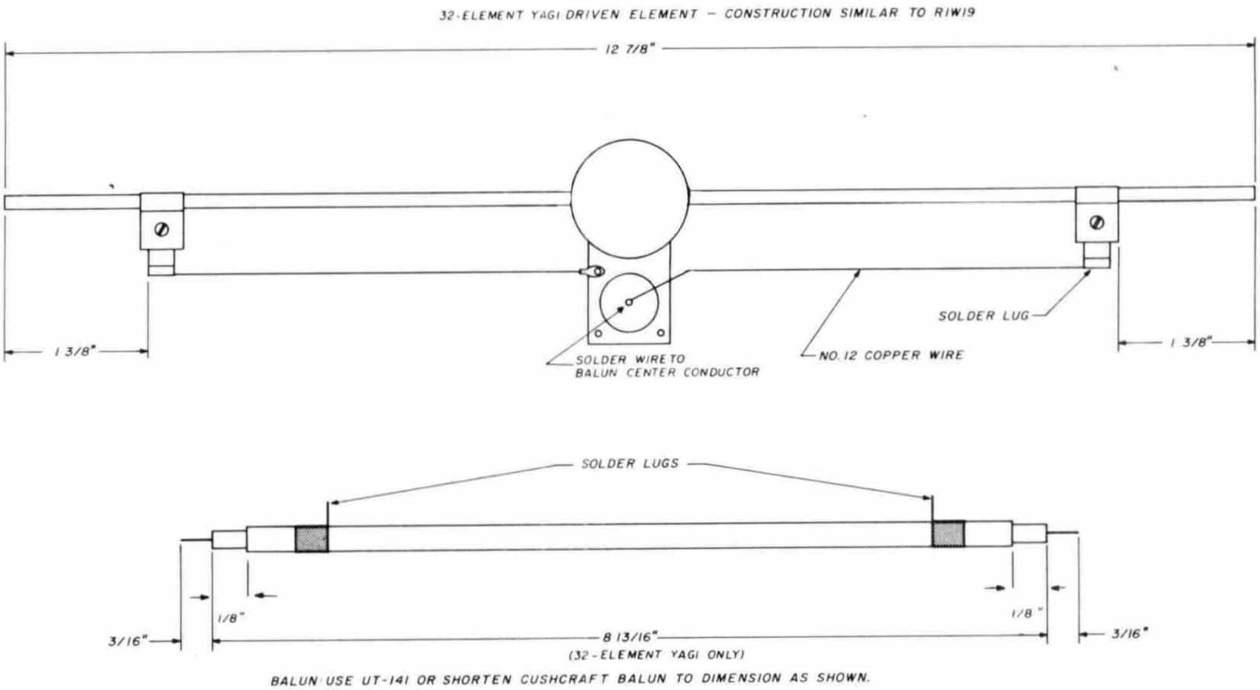


fig. 15. Driven element and balun details for a 32-element, 24-foot, 432-MHz Yagi.

wire between the N connector and T match bars. To remedy this situation, a driven element patterned after that used on the RIW Products 19-element 432-MHz Yagi was made, moving the N connector closer to the boom. This has been done both by cutting down the Cushcraft-supplied connector brackets and also by making copies of the brackets employed on RIW Products' Yagis. The new T match uses No. 12 copper wires, as does the RIW Yagi. A UT-141 balun was used, replacing the Cushcraft RG-303 balun. The Yagi with the new T match appears to have close to 0.1 dB more gain than one with the modified Cushcraft match. Either match can be used on either version of the antenna. The builder will have to decide if the less than 0.1 dB gain increase is worth the added effort. Those perfectionists in the audience may note that the UT-141 balun accounts for about 0.05-dB loss. A larger size copper hardline such as UT-225 or a sleeve balun could be fabricated if one finds that loss upsetting. Construction details of the new T match for the 32-element Yagi can be found in **fig. 15** (see **Photo A**). The boom layout for the 32-element Yagi is shown in **fig. 16** and **Photo B**.

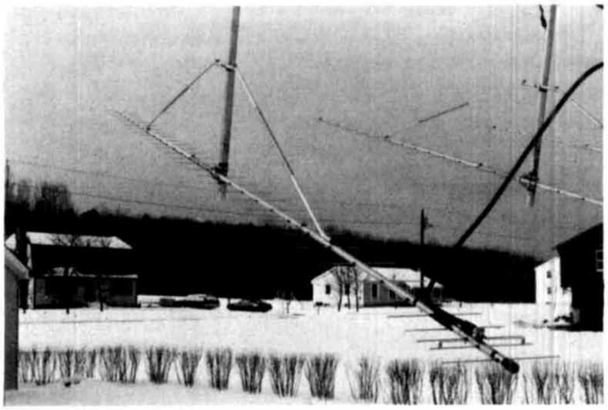


Photo B. Thirty-two element, 24 foot Yagi.

There are sure to be some operators who won't be satisfied with a 24-foot Yagi. For those adventurous souls, element lengths for a 38-element, 29-foot version (see **fig. 17**) are given in **table 4**. The expected gain of this 38-element model is 18.5 dBd. If you attempt to build the 38-element version, please keep in mind that because I haven't built or tested this version, I won't be able to give advice on the construction of a driven element for it or assist in debugging it. As with the improved 32-element Yagi listed in **table 3**, there is a possibility that the calculated dimensions won't work as expected. Other length versions are also possible.

Any of the presented designs can be used in the OSCAR, ATV, and fm portions of the band. For use in the satellite portion of the band, a 1/16-inch shortening of the elements is desirable, but not really necessary. For use on ATV, shorten all elements by 1/4 inch (6.4 mm). The Yagi will still be usable at 432 MHz, but will have about 0.2 dB lower forward gain. To use the Yagis in the fm portion of the band, shorten all elements by 7/16 inch. If the Yagis are to be mounted vertically polarized, they should be used in pairs with a boom support placed in the middle of the pair of Yagis (**fig. 18**). The driven element T match will have to be readjusted for best VSWR if the elements are shortened.

stacking considerations

Optimum stacking distances for the best array gain versus array temperature have been worked out for the antennas. The 24-element, 17-foot (5.3-meter) Yagi should be spaced 70 inches (1.78 meters) in the E plane (horizontal) and 66 inches (1.68 meters) in the H plane (vertical). The 32-element, 24-foot (7.3-meter) version 2 antenna works best with 81-inch (2.06-meter)

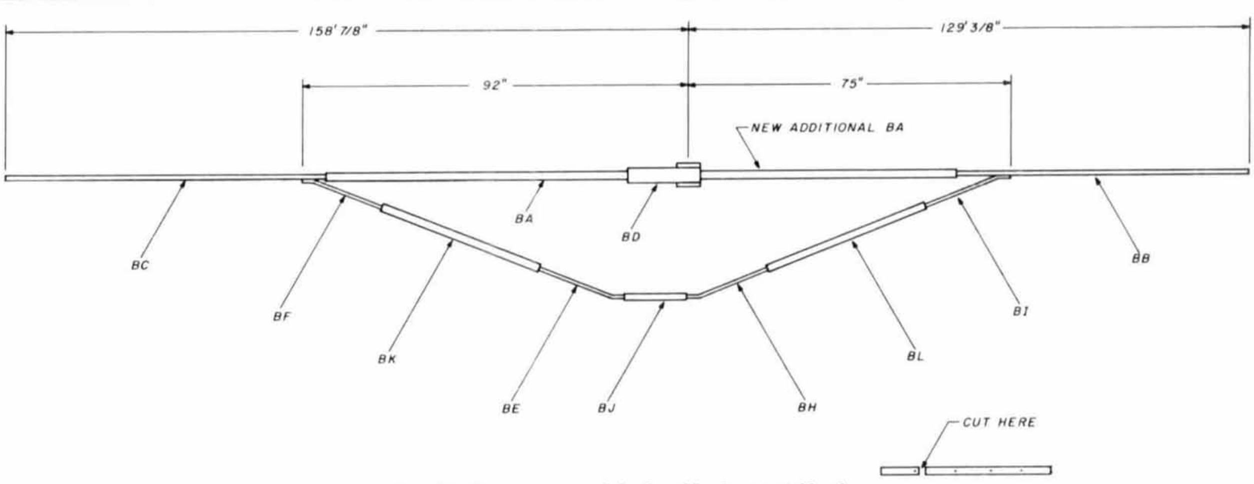


fig. 16. Boom assembly for 32-element Yagi.

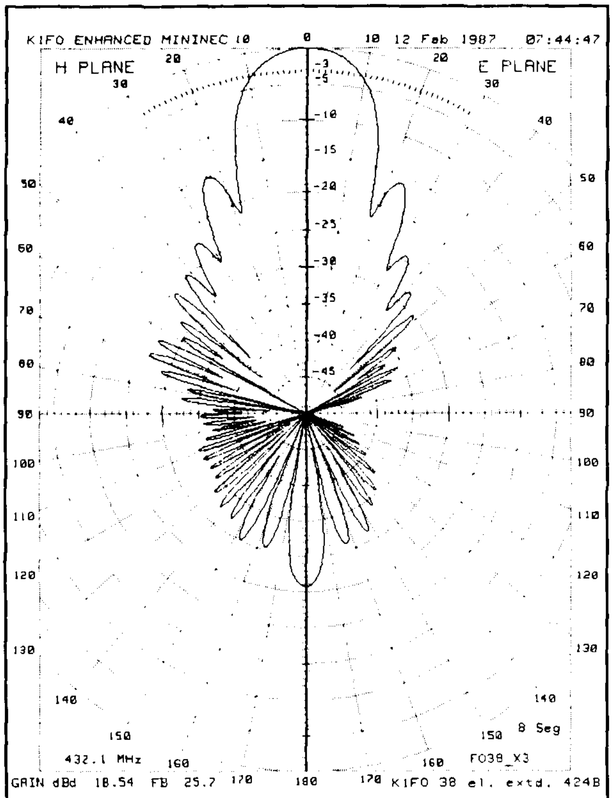


fig. 17. Calculated E and H plane patterns for 38-element Yagi.

E plane and 75-inch (1.91-meter) H plane spacing. These relatively wide spacings also confirm both the high gain and pattern cleanliness of the new Yagis. Calculated optimum spacings for the 32-element version 3 Yagis are 82-inch (2.08-meter) E plane by 77-inch (1.95-meter) H plane. For the 38-element Yagi, the calculated stacking distances are 88-inch (2.25-meter) E plane by 83-inch (2.11-meter) H plane. At these spacings, both E and H plane stacking gains will be close to 2.9 dB (negating phasing line losses and mechanical errors.)

when modification is worthwhile

Before you decide to tear down and modify your existing 424B's, you should carefully consider the results. A casual tropo operator using a single Yagi may be hard pressed to tell any forward gain difference between the stock and modified 24-element Yagi. The only noticeable differences will be in the pattern (signals off the main lobe will be weaker) and the better wet weather performance. Certainly most Amateurs aren't capable of detecting 0.5-dB gain variations. For an EME operator using eight or 16 Yagis, changing to even the modified 24-element version will result in significant improvement. On EME receive, it's expected that an eight-Yagi array will have about a 3-dB

Table 4. Dimensions for a 38-element Yagi (not tested).

Spacing	Length	Boom (inches)	
1.000,	13.6875	1	REF
5.250,	12.9375	1	DE
7.875,	12.7500	1	D1
11.563,	12.3750	1	D2
16.813,	12.3750	1	D3
23.563,	12.2500	1	D4
31.875,	12.0625	1	D5
42.125,	11.8750	1	D6
52.375,	11.7500	1	D7
62.625,	11.5625	1	D8
72.875,	11.4063	1 1/8	D9
83.125,	11.4063	1 1/8	D10
93.375,	11.4063	1 1/8	D11
103.625,	11.3438	1 1/8	D12
113.875,	11.2813	1 1/8	D13
124.125,	11.0938	1 1/8	D14
134.375,	11.0938	1 1/8	D15
144.625,	11.0625	1 1/4	D16
154.875,	11.0625	1 1/4	D17
165.125,	11.0625	1 1/4	D18
175.375,	11.0000	1 1/4	D19
185.625,	11.0000	1 1/4	D20
195.875,	11.0000	1 1/4	D21
206.125,	10.9375	1 1/4	D22
216.375,	10.9063	1 1/8	D23
226.625,	10.9063	1 1/8	D24
236.875,	10.8438	1 1/8	D25
247.125,	10.8438	1 1/8	D26
257.375,	10.8438	1 1/8	D27
267.625,	10.8438	1 1/8	D28
277.875,	10.7813	1 1/8	D29
288.125,	10.7500	1	D30
298.375,	10.7500	1	D31
308.625,	10.6875	1	D32
318.875,	10.6875	1	D33
329.125,	10.6875	1	D34
339.375,	10.6250	1	D35
349.625,	10.6250	1	D36

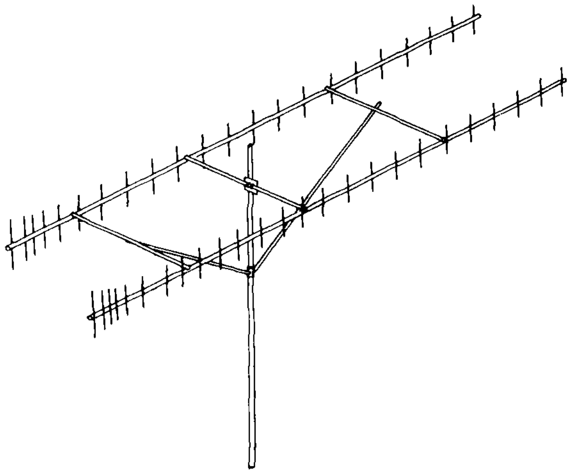


fig. 18. Recommended method of mounting a pair of vertically polarized Yagis.

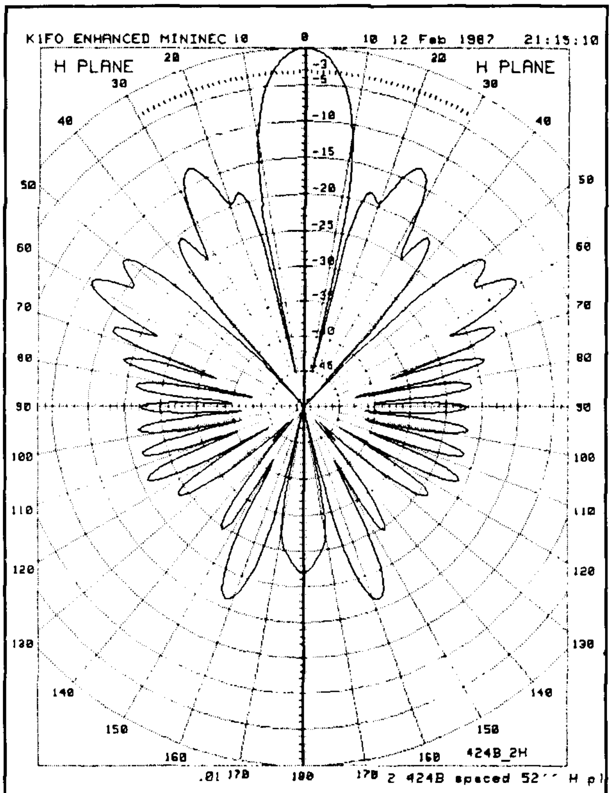


fig. 19. H Plane pattern of a pair of unmodified 424Bs spaced 52 inches apart (H plane). The total array gain is 18.50 dBd.

signal-to-noise improvement with the modified 24-element Yagis. This improvement is attributable to the following: +0.5 dB individual Yagi gain advantage; +1.0 dB higher array gain from wider optimum G/T spacings; +0.5 to 1.5 dB S/N due to lower array temperature from the cleaner array pattern.

On transmit, the gain advantage will be 1.5 dB because only the higher Yagi gain and wider spacings in the array contribute to the improvement. The signal-to-noise improvement is highly dependent upon the total receive system noise temperature. This is a combination of both the system noise figure and total phasing line loss. The actual S/N improvement could be from 0.5 dB to over 1.5 dB, depending upon the loss in the phasing lines and how low a noise figure the preamp has.

importance of clean patterns

In order to understand why a clean pattern on the individual Yagis is important, a computed H plane array pattern for two stock 424B's spaced at 52 inches is given in **fig. 19**. For comparison, the pattern for two of the modified 24-element Yagis, spaced 66 inches in the H plane, is given in **fig. 20**. Note that even at the significantly wider spacing, the array pattern of

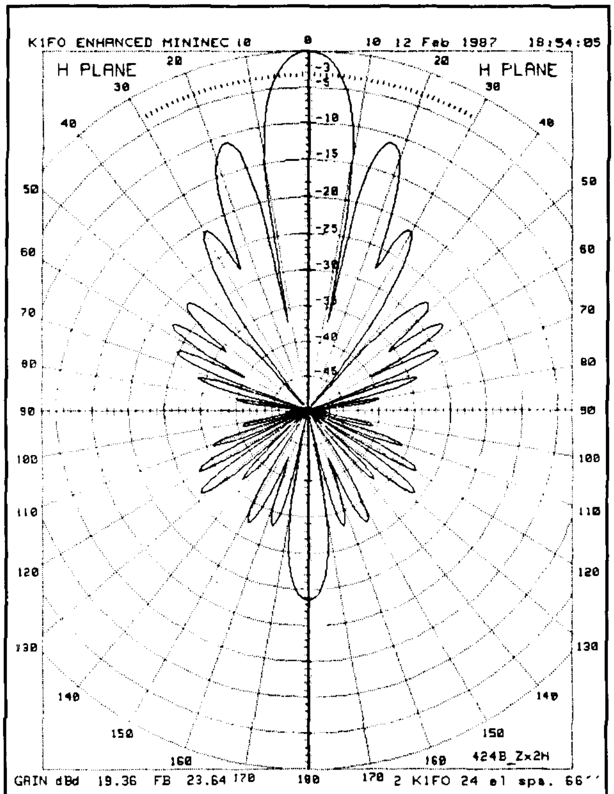


fig. 20. H plane pattern of a pair of modified 24-element Yagis spaced 66 inches apart (H plane). The total array gain is 19.4 dBd.

the modified Yagis is significantly cleaner than the original. At 432 MHz there is approximately a 15-dB difference between cold sky noise and Earth noise. Total Earth noise pickup will be a sum total of all sidelobes pointing into the Earth. This large difference in noise is why clean patterns are so important on 432-MHz EME arrays.

Although not an even comparison, it's informative to relate the experience of NC1I (ex-WA1RWU.) Frank had an array of 16 stock 424B's for 432-MHz EME. The array was rebuilt using 16 of the extended modified Yagis (32-element, 24-foot version). The results of the array rebuild are nothing short of spectacular. The receive improvement is far greater than the 1.8 dB extra gain the 24-foot (7.3-meter) Yagi has over the stock 17-foot (5.2-meter) antenna. Receive signals appear to be 5 to 6 dB above the old array, and echos are nearly 10 dB better. SSB speaker quality echos are frequently obtained with 100 watts output in the shack (approximately 80 watts at the array). Stations running four medium-sized Yagis such as the RIW-19s or F9FT-21s and 500 watts are readily workable.

A more even comparison is given by WA3FFC. Scott used an array of four stock 424B's on EME. Upon switching to the modified 24-element, same boomlength Yagis, his Sun noise increased by 1.5 dB. Cold sky areas became much easier to find. Copy of his own echos was never obtained with the stock Yagis. With the modified 24-element versions, his echos are now regularly copied. Random EME QSOs are now possible with the modified array.

To further expound on how the state of four Yagi 432-MHz EME has evolved, consider the results of a recent portable EME expedition to Vermont by NC1I. Frank took four of the 32-element Yagis to Vermont in the middle of June. Because of higher ionospheric absorption, greater Faraday shifts, increased tropo scattering, and longer daylight hours, the summer months are usually the poorest for 432-MHz EME. In spite of these obstacles, NC1I worked 22 stations on a single weekend. More impressive is that all QSOs were random — no prearranged schedules were used!

conclusion

With Yagi analysis software, the computer has succeeded in moving Amateurs from the dark ages of Yagi design to the point at which a well-performing Yagi can be readily made from materials at hand. The successful use of any antenna analysis program requires that the antenna designer have a thorough understanding of its capabilities and limitations.

In this project, the total design time — from the first correct running of the analysis program to completion of the initial Yagis — was over 10 months of continuous work. This time included physical tuning of the Yagis. Further improvements made to create the version 3, 24-element Yagi and version 2, 32-element Yagis were done during a year's intermittent work on the antennas. While this amount of design time may represent a high initial investment for a manufacturer of Yagi antennas, the design knowledge gained would most likely allow a similarly complex Yagi to be perfected in about one month. Continued enhancements of antenna design programs and more good Yagi designs will allow still further improvements in the quality of tomorrow's Yagis.

references

1. Günter Hoch, DL6WU, "More Gain with Yagi Antenna," *VHF Communications*, April, 1977, page 204.

2. Steve Powlishen, K1FO, "Stacking Yagis Is A Science," *ham radio*, May, 1985, page 18.

3. Stanley Jaffin, WB3BGU, "Applied Yagi Antenna Design," Part 6, *ham radio, October, 1984, page* 93.

4. Günter Hoch, DL6WU, "Yagi Antennas," *VHF Communications*, March, 1977, page 157.

5. Johann Bruinier, DL9KR, "Long Yagi Mark II," *The Lunar Letter*, December, 1983, page 6.

6. Günter Hoch, DL6WU, "Yagi Antennas," *VHF Communications*, March, 1977, page 162.

7. Joe Reisert, W1JR, "VHF/UHF World: A High-gain 70-cm Yagi," *ham radio*, December, 1986, page 75.

ham radio