construction of high-frequency diversity antennas

Complete details
on building
new antenna designs
described previously
in
ham radio
magazine

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Four antennas of novel design and unusual characteristics have been described in **ham radio.**[1] Performance data and a brief description of physical arrangements and switching circuits were given. This article presents construction details on these antennas and their related components. Some observations are also given on how to get the best performance from the designs. My recommendations on feeder and element balance, as well as tuner and switching details, should be followed closely if you wish to duplicate the performance I've obtained.

Before deciding whether to build one of these antennas, it might be helpful to consider some of their important aspects. Initial cost is fairly high, but once installed and tuned, maintenance is no problem. My space-dimensional antenna has been performing well for several seasons with no attention.

Another thing to consider is that while these are not beam antennas they raise DX very well. An additional redeeming feature that justifies the initial investment is their excellent response to short-period selective fading. This is accomplished by a switching system that permits instantaneous pattern changes.

bonadio designs

The four antenna designs are the square diagonal, **fig. 1**; the box diagonal, **fig. 2**; the cube diagonal, **fig. 3**, which performs similarly to the box diagonal; and the space-dimensional antenna, **fig. 4.**

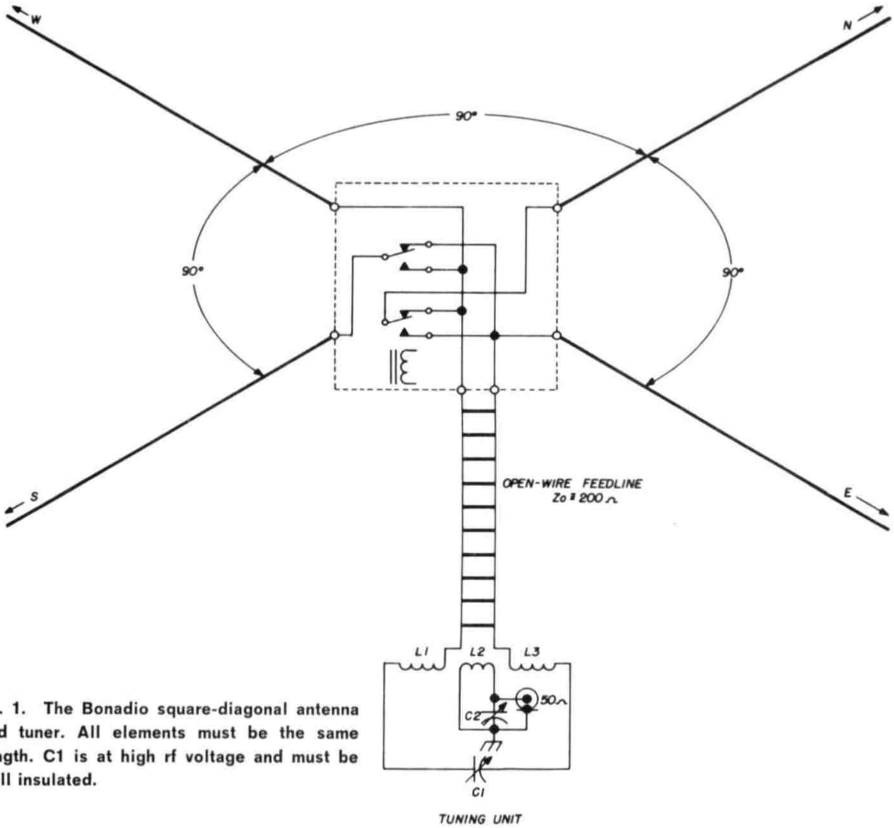

fig. 1. The Bonadio square-diagonal antenna and tuner. All elements must be the same length. C1 is at high rf voltage and must be well insulated.

characteristics

A glance at the diagrams shows many common parameters. The most important is the symmetrical relationship between element length, element spacing, support spacing, and angular element separation. The tuner system is the same for antennas. The coax link is series tuned above 10 MHz and parallel tuned for lower frequencies.

Compass directions are shown for antenna orientation. NU, NL represent north upper element, north lower element, etc. For the cube diagonal, elements must be spaced so that NU NL = NU EU = EU SU, etc. Angular separation of the cube diagonal elements is 70.5 degrees. While an excellent performer, the cube diagonal requires a rather complex switching system, and its nulls and general performance are eclipsed by the space-dimensional antenna. As with the other designs, symmetry and balance are a must in the space dimensional to obtain the deep nulls and optimum standing wave ratio over

Space dimensional antenna used in tests. It uses mobile mounts for elements, which are 9-foot whips whose ends are secured with 60-pound nylon fish line.

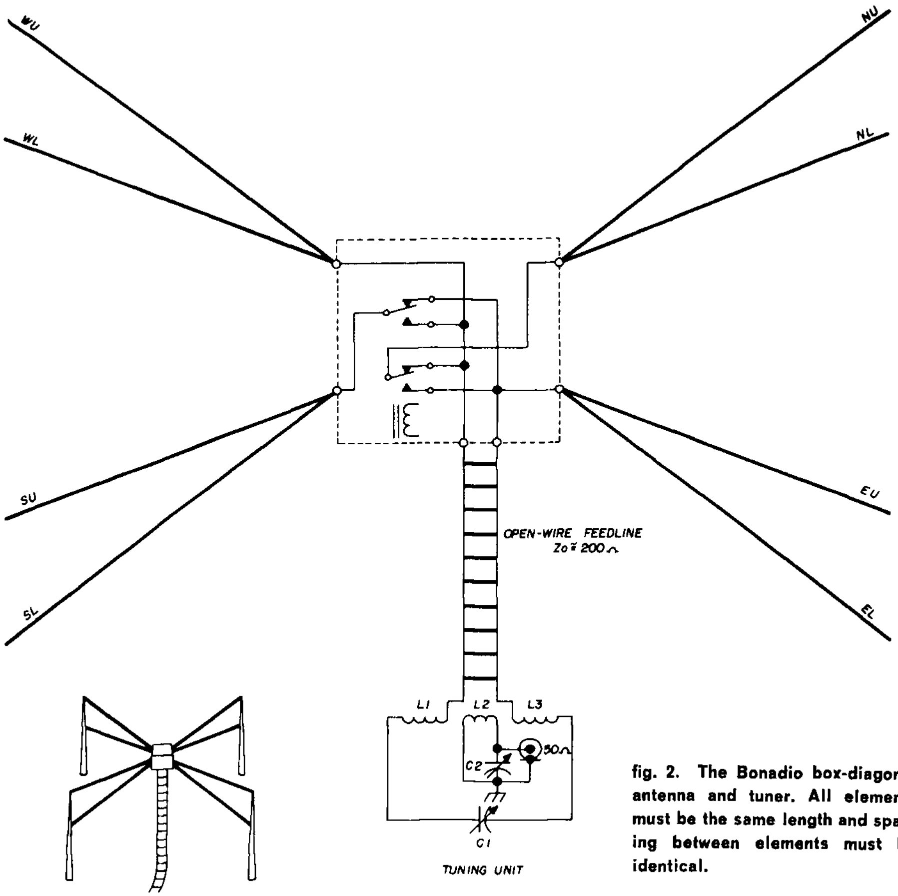

fig. 2. The Bonadio box-diagonal antenna and tuner. All elements must be the same length and spacing between elements must be identical.

its bandwidth. All angles for the space dimensional are 90 and 180 degrees, and all elements are the same length.

Another parameter common to Bonadio antennas is feed-point impedance. It is close to 200 ohms for very short wavelengths, with a small reactance component. The impedance varies in a cyclic fashion as wavelength increases. This is discussed in the description of antenna matching and transmission line design.

obtaining comparative data

To analyze the characteristics of these designs, you should have a control or comparison antenna. The best comparison antenna is the one you've been using. Don't worry about interaction between systems. There will be enough difference in reports between systems to provide valid data. The idea is to obtain as much quantitative data as possible over a given time period, because the larger the sample data size, the more realistic will be the final analysis. You won't need a computer to influence your opinion, nor will you have to rely on qualitative statements of others who might be using the same system. A large quantity of signal reports will convince you.

making a choice

Consider your antenna space. It can be anything from your bedroom ceiling to the back 40 acres. Study the types of supports needed for each of the four antennas. If you plan on three tall and three short flagpoles, for example, you're aiming at a terrific antenna, but a terrific cost for supports. Perhaps by relocating and redesigning your installation, you can borrow some buildings or other towers and trees. If you have the space, guyed towers are relatively inexpen-

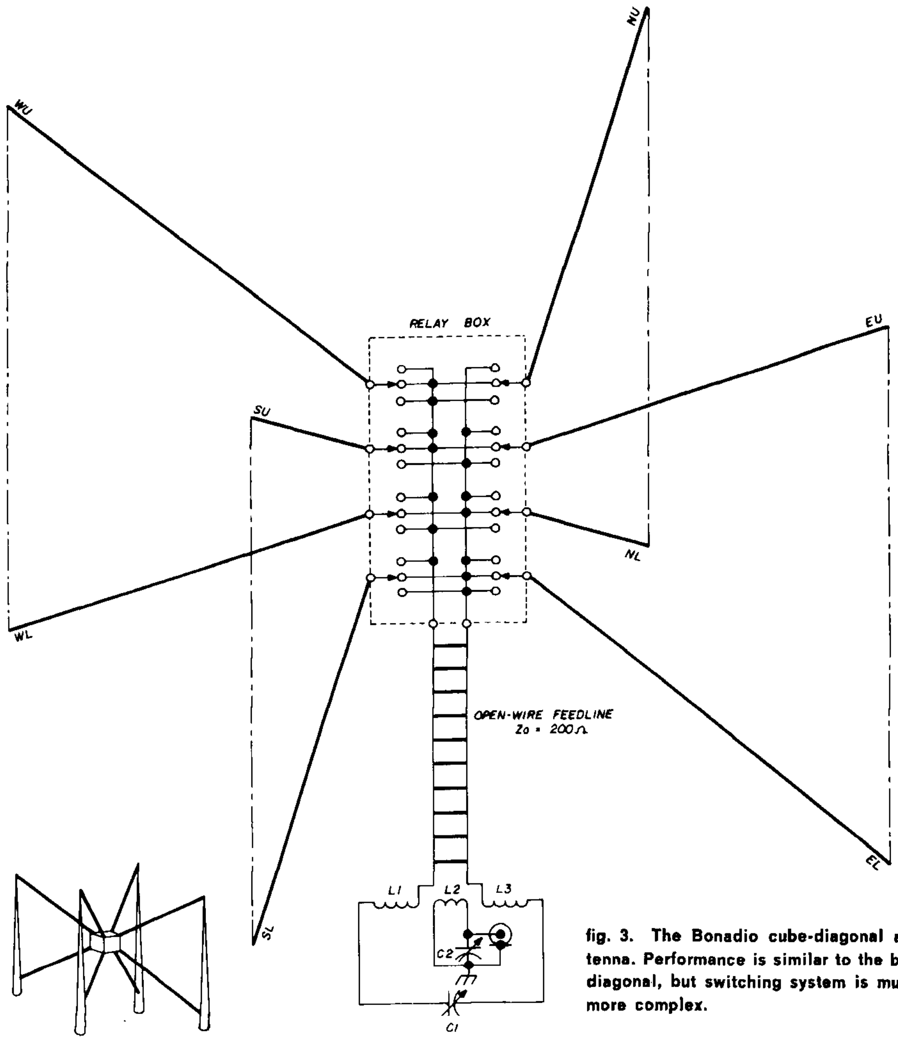

fig. 3. The Bonadio cube-diagonal antenna. Performance is similar to the box diagonal, but switching system is much more complex.

sive. Guy wires should be broken every twelve feet with strain insulators to avoid pattern discontinuities. Self-supporting towers are nice, but they cost a lot and require concrete bases. Flagpoles bear investigating.*

some definitions

Before starting construction, it's necessary to calculate the wavelength representing the lowest frequency at which an antenna of a given size will perform at full efficiency. The natural wavelength of an antenna will be termed λ_n. A wavelength that corresponds to λ_n plus 50 percent is called λ_L—the longest available wavelength at top efficiency. This is a parameter on which all Bonadio antennas are based and is extremely important. Here's how it is determined.

The λ_L of a square diagonal antenna is the distance around the perimeter of the square (which is its λ_n) plus 50 percent **(fig. 5)**.

The λ_L for either the box diagonal or cube diagonal is the distance around three sides of the top of the box or cube, then down both the two attached sides of the box or cube, then across the bottom connecting edge (this is its λ_n) plus 50 percent **(fig. 6)**.

The space dimensional antenna's λ_L is equal to the total length of its six elements;

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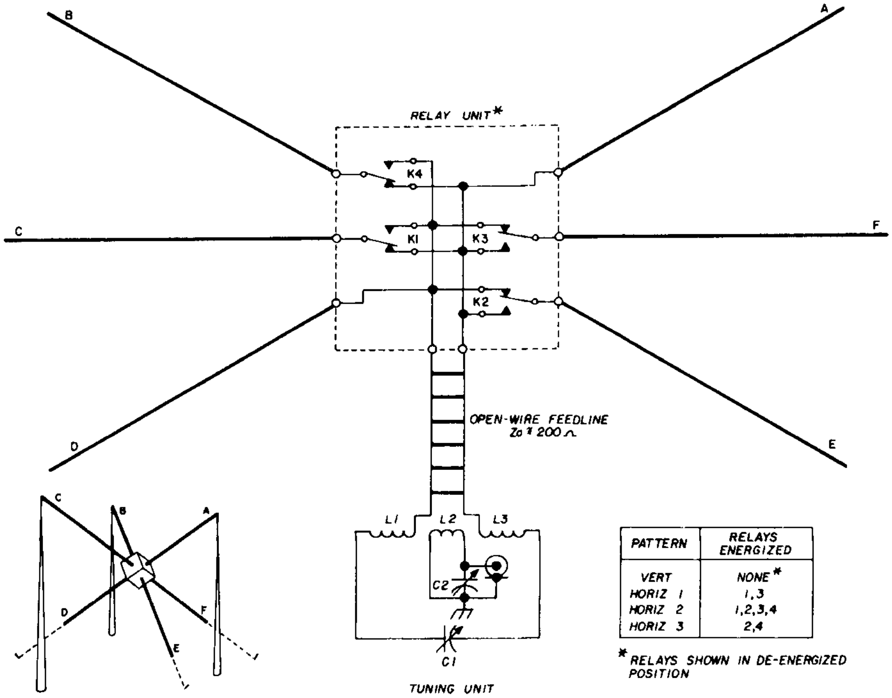
* John E. Lingo & Son, "B" Division, 28th Street and Buren Avenue, Camden 5, New Jersey.



PATTERN	RELAYS ENERGIZED
VERT	NONE*
HORIZ 1	1,3
HORIZ 2	1,2,3,4
HORIZ 3	2,4

*RELAYS SHOWN IN DE-ENERGIZED POSITION

fig. 4. The space-dimensional antenna. Geometry and balance requirements are the same as for the other antennas, but performance is better. Three horizontal radiation patterns from this antenna are shown in fig. 11.

its λ_n is equal to the total length of any four of the six elements. If any of these antennas are driven with waves which are longer than its λ_L, it will still operate, but with less efficiency, about −6 dB per octave.

size losses

To determine the falloff of signal strength with antenna size, I compared a box diagonal with a space dimensional. The box diagonal antenna used 60-foot elements of number 8 aluminum wire, and the space dimensional had 10-foot elements and number 4 copper-wire feeders. These antennas, which were instantly switchable, were at a conveniently low height of 22 feet above ground at their centers.

On 20 meters, the antennas performed essentially the same (**fig. 7**). The space dimensional, with an λ_n of 23 MHz and λ_L of 15 MHz, was better on 15 meters and 10 meters. However, as expected, it fell off on 40, 80 and 160. On 160 meters, some of this loss was due to an outboard loading coil (number 16 silver-plated wire) that ran very warm. The larger antenna being used as a standard also fell off, since it was operating beyond λ_L. Also, as expected, the larger antenna exhibited a slightly smaller range of fading depth.

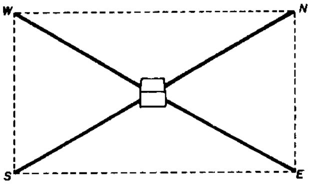


fig. 5. Resonant wavelength of square-diagonal antenna equals NE + ES + SW + NW.

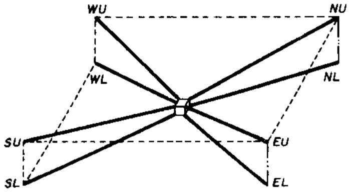


fig. 6. Resonant wavelength of box-diagonal antenna equals NU EU + EU SU + SU SL + SL WL + WL WU + WU NU.

Lay out your four, six, or eight elements side-by-side. Cut them all the same length. Connect them to their insulators using the same ties and the same length of wire. This balance is most important. An unbalance here will change your swr during pattern switching, because your elements will present different impedances to the feeders. On a box diagonal, the angular separation of elements must be identical. An error of 5 degrees will unbalance the system.

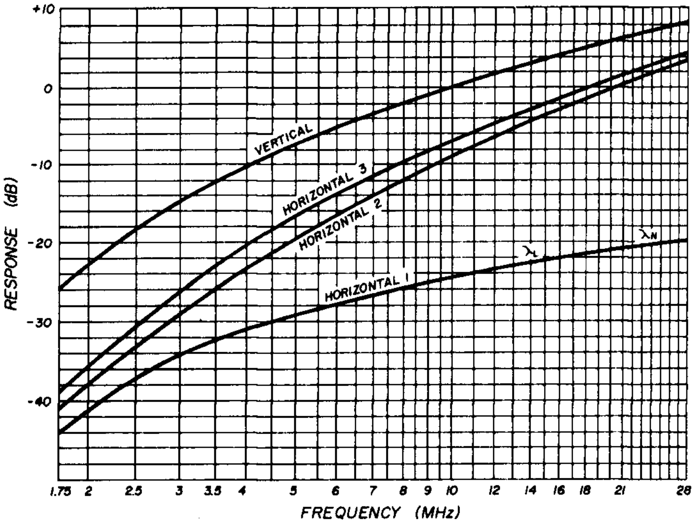


fig. 7. Comparison of two antennas; reference antenna at zero dB. Spread varies from approximately equal performance on 20 meters to about 40 dB difference on 160 meters.

wire sizes

All calculations I've seen on wire skin losses show that antenna elements or feeders smaller than pipe sizes will cause significant losses. There is, however, a diminishing return. I compromised on number 8 aluminum wire for elements and feeders on my larger antennas. On the small space dimensional (used in the tests above) I deliberately extended the number 4 wire feeders to 100 feet to eliminate loading coils through 80 meters. However, number 12 aluminum wire (used for tv grounding) should be satisfactory.

elevation

The advantages of elevation are greater for DX than for near-in hop. When you go higher than 66 feet, your near-in hop on 10 meters begins to suffer. A little higher, and near-in hop is reduced on 15 meters; when you go still higher, it is reduced on 20 meters. When your average, or center, elevation is below 60 feet, every few feet means a greater loss than the last few feet. You can't afford to operate below 16 feet for sheer power waste. Neither can you afford to spend money for a little better DX by increasing height to 100 feet.

The feeder wire size should be consistent with element size. Commercial 200-ohm line is available from Federal Wire Company. However, I can't recommend it for these antennas except for low power.

I used a pair of 93-ohm RG-62/U coax cables, taped together, to feed relays without chokes, **fig. 8.** I found it too wasteful for all-band use; that is, for longer than 1/5 λ_L. The impedance is 186 ohms.

relays

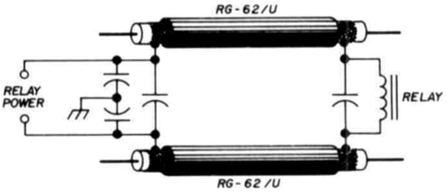
There are no ideal switching relays for these antennas. You must use your ingenuity. I used up several Potter and Brumfield KT antenna switching relays whose insulation broke down from excess voltage at wavelengths beyond λ_L. My 140 watts of a-m demanded a larger relay, the Kurman 252C. This relay operated satisfactorily through rain and snow with the weather hood lost for two winters.

The Jennings Radio Company voluntarily furnished me with two engineering samples of their vacuum relays. These relays required no service after two more winters, but the amateur net price is over $200 per pair. They can switch any amateur power safely, even while transmitting.

The circuits I finally used are shown in **figs. 1, 2, 3** and **4.** For the cube diagonal, I have a Ledex number 250-124-256 relay that can handle only enough power for testing purposes.

The switching system for the space dimensional antenna, **fig. 4,** puts the coils of relays 1, 3 and 2, 4 in parallel. The upper antenna elements, ABC, are opposite the lower elements, DEF, in that order. A three-wire line is used for relay control. The rf chokes shown in the photo of the open control box are in the power leads to the relays. Plastic sleeving is used over leads between chokes and coils. These chokes prevent rf from arcing across relay coil leads. The chokes are 10 mH each. Note particularly the physical arrangement of the relays.

fig. 8. Combination 186-ohm feeders and relay power line. This system is only suitable for very low power.



relay power

It is possible to power the relays with 120 Vac, but this generates noise. I've used it through my feeders; however, on dewy mornings there was an S3 power-leak noise in the receiver when the relays were energized. Conversion to 120 Vdc corrected this. A word of caution: don't use powdered iron core rf chokes. One of mine became red hot with only 100 watts input. Bypass the relay coil with an 0.01 μF ceramic capacitor to be safe. The open-wire switching system is shown in **fig. 9.** Accidental short circuits can damage a choke, because the power supply fuse won't blow. The circuit shown isn't practical for short feeders.

For my compact space-dimensional antenna, I used a three-wire cable to switch the four antenna patterns shown in **fig. 7:** horizontal 1, horizontal 2, horizontal 3 and vertical. Relay switching logic for the patterns is shown in **fig. 4.**

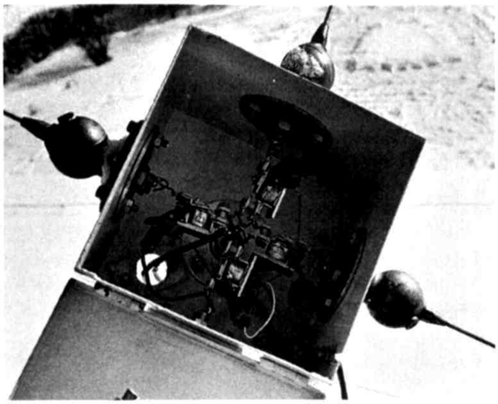
feeder construction

The open-wire 200-ohm line uses Reynolds Metal Company type 2B tv insulators, **fig. 10.** Protected line requires insulators every two feet; swaying line needs them every six inches minimum. Thread the insulators half way down the line from each end, using mineral oil lubricant if necessary; then space them appropriately. If the line is anchored every four feet, insulator spacing can be tripled. Losses are so low that a thousand feet can be used.

matching system

The feed point of these antennas, on the very short wavelengths, looks close to 200 ohms and has very little reactance. However, as the wavelength increases to λ_n the impedance may reach 20 ohms after passing points of over 1,000 ohms. On wavelengths

Control box for space dimensional antenna. The rf chokes prevent rf from arcing to relay coils and leads. Three-wire power cable enters box at lower right.



longer than λ_L, the impedance may fall to less than one ohm, and the capacitive reactance may reach hundreds of ohms. Meanwhile, the standing wave ratio can exceed 200:1 on the balanced feeders, while maintaining 1:1 on the unbalanced coax.

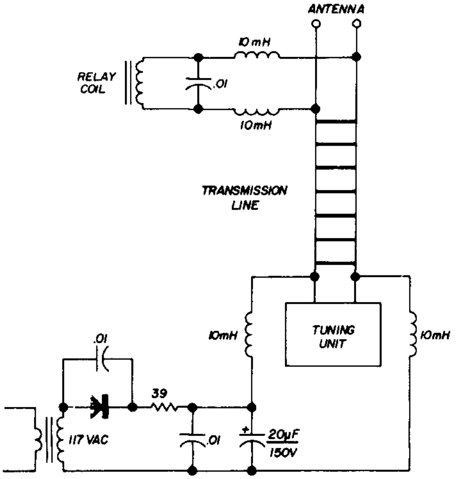
An open-wire line of 160 to 250 ohms impedance is optimum. The modest mismatches of the transmission line will probably produce more feeder-created reactance at the tuner feed point than the antenna displays alone, at anything shorter than λ_L. These broadbanded, low-Q low-reactance combinations are much easier to manage than the common center-fed open-wire feeder antenna systems.

tuners

To deliver all of your available power into feeders, you should use the tuner circuits I have shown, **figs. 1** and **2.** With these tuners you can always tune and load through a standing wave ratio of 1:1. With other tuners you can hit a standing wave ratio of 1:1 quite often and keep a cool tuner, but on some frequencies your tuner will not deliver much of the power to your antennas.

Don't use the tuner of Handbook X, or Handbook Y, or manufacturer Z, and then condemn the antenna as "not especially good."

fig. 9. Providing relay power through the open-wire transmission line. Iron-core chokes should be avoided; power is limited to 250 watts.



tuner values

Table 1 gives optimum tuner values for a 200-ohm resistive load. If λ_L is much greater than optimum for the bands shown, the values will still be good for the larger antennas. However, you may have to change the values somewhat with the smaller versions as you approach λ_L. At wavelengths much longer than λ_L, variations from values for L1, L3 and C1 may be large. The link values should be as shown. They are designed for 52-ohm coaxial cable.

A surprise benefit of these tuners is the small air-gap sizes of the capacitors. The parallel- and series-tuned links must safely handle rf peaks of 350 and 1000 volts, respectively, for full legal power.

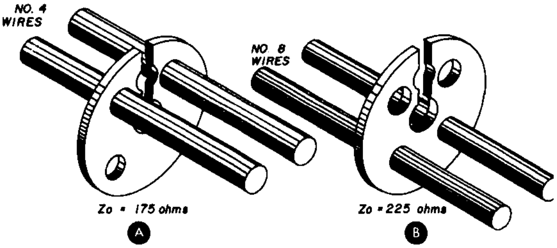


fig. 10. 200-ohm open-wire transmission line using Reynolds Metal Company's type 2B tv line insulators. If suspended in space, a spreader is required every six inches for number 8 wire; every 12 inches for number 4 wire.

Antenna tuning capacitors with a 3000-volt rf peak rating will safely handle full legal power. However, on some bands this requirement will increase to 8000 volts for a kilowatt.

The tuner-bandswitching apparatus shown in the photo has given me no trouble over the past years. I used a speaker box for an enclosure. An attempt has been made to keep the impedance constant by using braid paths equal to the center path of the coax. The coils are made of silver-plated copper wire. Intercoupling is insignificant, because coil resonant frequencies are well separated.

You'll find that a gang switch is more desirable than conventional tuner circuits. You'll have optimum tuning, coupling, and loading control at the flick of a switch. As the tuner is broader than a tank circuit, you can listen across an entire band without retuning. Because the system is double tuned, images are down 30 to 60 dB; generally to extinction. Also, you can load your transmitter quickly anywhere near the last operating frequency on each band.

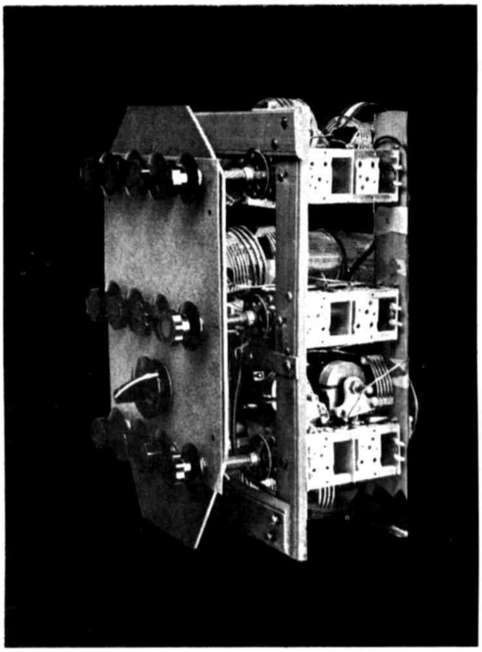
loading

If a tuner resonates but refuses to load at maximum coupling, there are several cures. You can reduce the clearance for L2, between L1 and L3; increase the number of turns equally on L1 and L3, and reduce the capacitance of C1 accordingly; or reduce the lengths of L1 and L3 by using the next smaller wire size to obtain slightly more inductance.

Proper coupling occurs when the swr passes through 1:1 with the link between one-half and fully in. If the swr goes through 1:1 before the link is one-half in, then L1 and L3 have too many turns, and C1 may arc over.

You can wind the links of number 8 solid copper wire, or 1/8-inch tubing (both silver plated, if possible), over a two-inch-diameter bottle. Space the turns about one-half conductor diameter. The links swing between the antenna coils, which are made of number 14, 16 and 18 wire.[2]

The fixed padder-type capacitors are Arco-El Menco series 30.* In parallel-tuned circuits these will handle 140 watts of a-m power. With series tuning, however, this amount of power can cause corona discharge. You can stack these capacitors, using two layers of mica in place of one. For power up to a kilowatt, double the layers of mica. This lowers the capacity, which requires more plates or additional capacitors. Caution: don't use ceramic or moulded micas; they've been known to fail.



The tuner-bandswitching apparatus. All coils are silver-plated. Tuner mounts in a speaker enclosure.

link tuning

Each link is for one band only. At any frequency in the band, the link will present an insignificant reactance to the mutual coupling complex. Operating Q of the links is about three.

table 1. Component values for antenna tuners shown in fig. 1, 2, 3 and 4. L2-C2 is parallel tuned on 160, 80 and 40 meters, and series tuned on 10, 15 and 20.

amateur band	L1 (μH)	C1 (pF)	L3 (μH)	L2 (μH)	C2 (pF)
160	80	32 - 160	80	1.6	4700
80	40	16 - 80	40	0.8	2400
40	20	8 - 40	20	0.4	1200
20	10	4 - 20	10	1.6	68
15	7.5	3 - 15	7.5	1.2	47
10	5	2 - 10	5	0.8	33
6	3	1.2 - 6	3	0.5	22
2	1	0.4 - 2	1	0.16	6.8

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* Allied Electronics 43A7093 through 43A7106 for 2 through 15 plates (130 through 3055 pF).

Grid dip the links with the coil and capacitor in parallel. For final trimming, the link will indicate a dip when placed at least four inches from the grid dip meter's coil. Thereafter, the series links are opened on one side, and the coax is fed between them. The padder capacitors are never adjusted again.

To check for balanced operation, tune the receiver to a strong signal on each band. Short circuit the feeders while watching your s-meter. Signals should drop 30 to 60 dB. A drop of less than 20 dB indicates poor balance, which should be investigated.

Full-sized Bonadio antennas have low Q. When changing frequency you'll have to retune your final amplifier three times as often as your antenna tuner. However, if you use an antenna whose wavelength is longer than its λ_L you'll have to retune the antenna tuner more often.

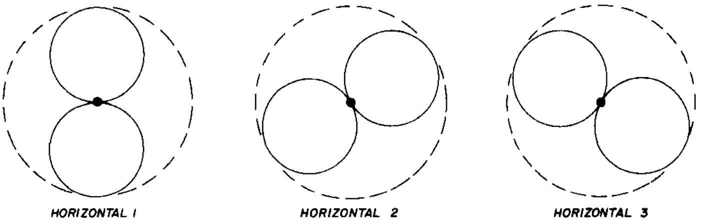

fig. 11. Horizontal radiation patterns for the space-dimensional antenna. Element switching for each of these patterns is shown in fig. 4.

patterns

The horizontal radiation patterns for the four- and eight-element systems are shown in **fig. 11.** For many of the shorter skip paths, the nulls will be —10 dB or less when signals are coming in at high angles. Occasional instantaneous fading differences will exceed —30 dB.

For the space dimensional, the patterns for H1, H2 and H3 are all 60-degree overlapping figure 8's. Line noise is most pronounced with the vertical pattern. Often one H pattern will decrease line noise by 20 or 30 dB. One day the BBC 21.47 MHz echo garble disappeared with an H-pattern null to the north. Later the same day, the BBC signal's flutter smoothed with an H-pattern null to the south of their normal path.

fading

The greater the DX, the greater will be the pattern change differential. On near-in hop, differences are mostly washed out by fading of the received signal, even though your contact tells you your signal has almost no fade.

You'll find that the control of fading signals is a matter of switching your patterns. If the received signal fades on pattern H1, immediately switch to pattern H2. When the H2 signal starts to fade, go back to H1, H3 or V. This is diversity reception on a one-antenna system.

You'll receive fewer reports of fading than other stations. This will be most apparent during round-table contacts, because the difference will be more conspicuous. If the received signal is also from a Bonadio antenna, selective fading will be the least of your problems. You have to experience it to believe it.

As you might expect, for DX the vertical pattern usually is equal to or better than the best horizontal pattern. However, in receiving, certain interferences may be reduced by one of the H pattern nulls, so you may find an H pattern preferable. The V pattern is helpful for quickly finding which area of DX is coming through best.

The Bonadio square-diagonal antenna is protected by U. S. Patent 3,274,606. Patents are pending on the Bonadio box-diagonal and cube-diagonal antennas; the inventor has applied for a patent on the space-dimensional antenna. This protects the inventor against commercial infringement but does not prevent an amateur from building one for his own use. **Editor**

references

1. George A. H. Bonadio, "A Survey of High-Frequency Antennas," *ham radio,* April, 1969, p. 28.

2. Illumitronic Engineering Corp., 680 East Taylor Avenue, Sunnyvale, California. Section 1800, *eem file,* p. 6, 7.

ham radio