

LOST ART OF RHOMBIC ANTENNAS

27 dB of gain is not to be sneezed at!

Big And Old

Of all antennas ever conceived for long-distance communications (and that includes transmitting and receiving), none has endured so long nor has retained its aura as well as the fabled "rhombic". *The rhombic is legendary.* Until the birth of ocean-hopping satellites, the rhombic was the sophisticated workhorse of inter-continental communication circuits. And where the satellites have not yet gained a toe-hold, the rhombic antenna remains the only ingredient of the 1930's created international communication networks still holding its own, original form against virtually all comers to come down the pike in the ensuing 40 years.

The rhombic, for all of its aura, is constructed of wire. It is supported typically at modest heights above ground by unobtrusive wooden poles and the rhombic gains its respect not from its impressive physical features but rather from its performance.

It has been estimated that from 20 to 25% of all early CATV systems employed at least one rhombic antenna for their early-day off-air reception. Remnants of rhombics at early-50's headend sites are still visible in places like Fayetteville, Arkansas and Marathon, Ontario and Sonora, California. Yet in spite of the fabled advantages of the rhombic antenna, surprisingly little hard-design data has appeared in print over the period 1931 (when the rhombic was introduced by a man named Bruce) to the present time.

The rhombic has three primary advantages, even today, over virtually any other antenna system a CATV system or other off-air receiving system for VHF-UHF signals can create. It also has at least one substantial dis-advantage, and a secondary dis-advantage that is primarily a problem at low-band VHF.

Advantage number one is gain. We will explore in construction detail rhombics that offer gain over tuned reference dipoles as high as 27 dB. To put that number into perspective, if you set out to construct a 27 dB gain array utilizing 10 element, 12 dB gain single channel yagi antennas, you would need no fewer than 64 of the ten element yagis to reach the 27 dB gain level.

Advantage number two is pattern. Rejections of unwanted signals can be "tailored" with a rhombic antenna, and nulls can be placed more at less at will where they are required. It is not easy to do, but it can be done, and rejections in excess of 34 dB over the forward direction can be achieved

with relatively simple rhombics, while rejections in excess of 50 dB are possible in most-dis-favored directions with specialized rhombic designs.

Advantage number three is price. There are five primary ingredients in the construction of a rhombic antenna. One is a relatively small amount of copper-weld wire (i.e. copper plated or coated steel cored wire) and some ceramic insulators. Two is a suspension system to provide a method of raising and lowering (i.e. installing) the rhombic antenna to the desired location (this primarily consists of ropes and pulleys). Three is a support system, typically up to four utility poles of some height to get the antenna the design-height above ground for proper performance. Four is a suitable location to erect the antenna. And five is the manpower required to make the installation. On the assumption you have the land available, and the manpower is part of a regular payroll or can be recruited for a few hours work in exchange for a case of beer and some good fellowship on an otherwise dull Saturday, the balance of the ingredients can usually be put together for around \$50-\$100.00, plus the cost of the support poles. For gains of up to 27 dB, that is an extremely cost-effective antenna system!

Then there are the dis-advantages.

Dis-advantage number one is the care and skill required to make the antenna system perform to specification. The rhombic, for its apparent simplicity in form, is a very sophisticated antenna. One reference source calls the rhombic "the highest development of the long wire antenna". Those who believe a long wire antenna is itself not much of a development may believe otherwise when we have finished. The rhombic is extremely sensitive to ground reflections, and to obtain the design-pattern in real life (versus getting it on paper) requires more than a small bit of skill and probably a great deal of patience.

In talking with dozens of "old-timers" in CATV who have had occasion to try a rhombic or two, it is our belief that probably only one or two of the hundreds constructed by CATV operators in the 1950's ever worked within even a couple of dB of their theoretical gain capacity. We'll try to see why that might be so here.

Dis-advantage number two is the space required for a rhombic. Perhaps to be more precise, not just the space required, but the "lay of the land required" to erect a rhombic. If you are in the mid-

west or south, finding a plot of ground at a suitably quiet location where you can mark-off an area say 400 feet long by 175 feet wide for installation of the rhombic support poles might not present a problem. But if you are on a mountain peak in Oregon or a hilltop in West Virginia, finding that much flat-ground could be a problem. However, the space requirement diminishes with frequency, and a full sized rhombic at high band requires an area around 130 feet long by 60 feet wide. And at UHF, well, you could almost put 27 dB gain of antenna above a typical suburban lot home roof!

And you may find that, for say 14-19 dB of gain, you can get by with less than a full sized rhombic, and thereby reduce the space requirements so that even a low band rhombic will fit into a much smaller space. We'll look at all of this here.

The Art of Design

Designing a rhombic is largely a matter of knowing what you want it to do, and then fitting the pieces of the puzzle together for that end achievement. Most rhombic design data is heavily slanted towards shortwave communications, where the incoming wavefront (to a receiving rhombic) is arriving at some vertical angle greater than zero degrees (the horizon is assumed to be zero degrees). Shortwave propagation utilizes the reflection/refraction medium of the ionosphere and once a shortwave signal (typically 3-30 MHz) exits the transmitting antenna, it is beamed towards the intended receiving location at some angle greater than zero degrees with reference to the actual horizon, so as to enter the ionosphere at the proper point between the transmitting and receiving location to produce signal reflection/refraction to the desired receiving point.

Therefore a great deal of conventional rhombic design data is needlessly (for our purposes) wrapped up in producing an antenna design which concentrates the antenna's pattern say 12.5 degrees above the horizon, 8 degrees above the horizon, and so on, but seldom if ever, on the horizon itself.

In spite of the multiple-thousands of commercial rhombics in service throughout the world even today for communication purposes, there remains a dearth of material for reference. There are, in fact, but four generally referenced sources for rhombic design data, and none are generally available to the casual practitioner of the art. CATJ was successful in running down three of these for our own use here, but the fourth never was found except by reference.

During the evolutionary days of television, or the 50's, there were a number of articles published by magazines such as *Radio-Electronics*, *Radio-TV News* (and later *Electronics World*) which provided some very basic rhombic design data. Unfortunately, much of that data was either incomplete or inaccurate and while such publications had universal circulation in those days (and were considered the only reference works of that era), the

data they published was sufficiently lacking as to leave a reader desirous of constructing his own rhombic system with inadequate data to do the job correctly. Consequently, many of the rhombics constructed in that era, by TV (and CATV) desirous people probably never functioned as well as they might have. A listing of the material in print in that era along with the major reference works in this antenna field is included at the end of this report.

Of all of the serious workers in the rhombic field, only one seems to have been concerned with overcoming the major shortcoming of the rhombic, that being...

"... long wire antennas always radiate large numbers of sidelobes..."

A sidelobe in a long-wire antenna is not unlike a sidelobe in a yagi or a log; it is simply antenna-gain-response in a (side) direction, which is undesired.

That worker was Edmund A. Laport of RCA's international division; who published his work initially in the March 1952 edition of *RCA Review* ("Design Data For Horizontal Rhombic Antennas"), and who subsequently came back in the March 1960 *RCA Review* with "Improved Antennas Of The Rhombic Class". It was his improved design developed in the late 1950's and published in 1960 which resulted in his name being attached to the now cadillac of the rhombic antenna family, the "Laport Rhombic". This 27 dB gain (plus) version will be studied carefully here.

Laport in 1952 wrote *"... most engineering methods provide information on the main lobe at one frequency... but omit(s) consideration of other lobes that can be, and often are, very large and which greatly compromise (rhombic) antenna performance..."*

Laport in 1960 wrote *"Sidelobe reduction is a matter of finding conductor configurations and current distributions that provide an exceptional degree of destructive interference in all directions except that desired for the main beam..."*

Rhombic design data is filled with phrases which are not readily recognized for their true meaning. *Destructive interference* to Laport, was a design handle that allowed the rhombic antenna designer to purposefully create antenna currents in each of the four legs of the rhombic antenna so that natural radiation from any single leg could be "corrected" when it headed off in some direction other than the single-desired "main beam" design direction. To understand what Laport was saying, it is necessary to go back to just a little bit of basic long-wire antenna design theory.

A Hank Of Wire

Virtually any conductive-wire can be made to radiate a signal, if there is a way to couple transmitter energy into the antenna-wire-load. This is essentially a match-problem, and it reciprocates for receive-only antennas. That is, virtually any conductive-wire can be made to receive a signal, if

there is a way to match the impedance of the antenna-wire to the input impedance of the receiver.

A simple dipole antenna (diagram 1) is an example of a resonant length of wire (although at VHF a dipole is usually constructed for mechanical convenience out of aluminum tubing). Because the dipole is a precise length that corresponds to the electrical half-wavelength at the designed (and desired) operating frequency, there are certain known current-flow-characteristics associated with such an antenna. Matching such a resonant antenna to a transmitter or receiver operating at the same frequency as the antenna is a fairly simple task and the energy from one transfers to the other with little difficulty.

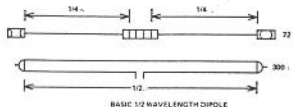


DIAGRAM 1

In such an antenna, the current distribution along the full half-wavelength form is well known (diagram 2). Now as the physical and electrical length of the (resonant) dipole antenna is increased, while the operating frequency of the equipment connected to the "length-extended-dipole-antenna" remains the same as the purely resonant condition, the antenna assumes a new radiation pattern, the "new" pattern being created by the multiplicity of harmonic-antenna patterns created by the "series connected" half wave length segments. See diagram 3.

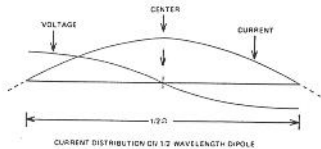


DIAGRAM 2

What happens (in diagram 3) is this. Each half-wave segment of the "wire" antenna has current (i.e. signal) flowing in it. In adjacent half-wave segments of wire, the current flows in opposite directions and this fact causes the antenna lobes to be split up from the basic half-wave dipole "donut" pattern (diagram 3A) into a number of lobes. If there are an even number of half wave segments, then there is always a null in the antenna pattern (i.e. lobe[s]) at right angles to the antenna wire axis. On the other hand if there is an odd number of half wave segments in the wire, alternate sections cancel one another in the perpendicular (i.e. right angle) direction, but the "odd" or "end" seg-

ment radiates perpendicular (or at right angles) because there is no alternate segment to cancel its perpendicular radiation.

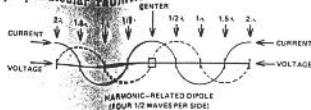


DIAGRAM 3

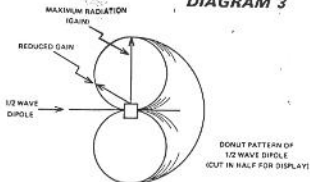


DIAGRAM 3A

The more half wave segments to the antenna (wire), the more lobes there are created. And that means a greater number of splits of the original half-wavelength antenna pattern. The lobes are not strictly the function of individual half-wave segments, rather they are the composite result of the total number of half wave segments in the wire, with some segments adding in phase and some segments canceling out of phase the half wave segment individual patterns. This becomes a very complex antenna in a big hurry, when you study it from the radiation pattern aspect.

Finally, the strongest or most potent lobe in a multiple-half-wavelength antenna is always the one which forms the smallest angle with the axis of the wire (diagram 4), and this "main lobe" gets closer and closer to the axis of the antenna wire as the number of half wavelengths increase (i.e. as the antenna gets longer and longer).

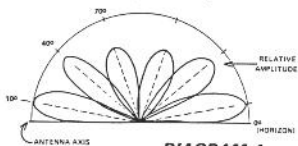


DIAGRAM 4

So suppose, without regard to impedance matching for now, you took a long (more than one halfwavelength) dipole-type antenna and rather than stringing the wire out in a straight line (i.e. singular axis), you bent it into a "V", as shown in diagram 5. Then what?

If the two sides of the "harmonic-dipole" are formed into a "V" so that the apex angle of the "V"

is at least *twice the angle* created between the major lobes (i.e. those closest to the axis) and the axis-wire orientation of the "harmonic-dipole", the radiation patterns *combine* so that the pattern portion bisecting the "V" tends to add together from the two separate half-lengths (not wavelengths), and the pattern or lobes in the opposite directions tend to cancel (out of phase).

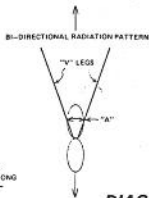


DIAGRAM 5

All of this can be worked out on paper for various lengths and various "apex angles", and in the case of two "V" antennas back to back (i.e. a rhombic), with the aid of stereographic charts originally designed for this exercise by Edmund Laport. But at some point the designer has to get out of the design room and build the antenna, and that is where the real fun begins!

Ground Reflections

As many and as varied as the lobe structure may be for four separate, but combined lengths of wire (i.e. in a rhombic) in real life the problem is "times 2". This is because when a length of wire (or four *coherent* lengths of wire as in a rhombic) is placed above a *ground reflection surface*, there is created by the presence of the ground an almost "mirror image" lobe pattern that approaches the antenna from the underside. In a word, there is no such thing in real life as the "free space" antenna patterns laboriously worked out on paper by the rhombic antenna designer. The performance of the rhombic, particularly with respect to its directive properties, is often considerably modified by the presence of the earth beneath it.

In everyday CATV language, "as high as practical" is not the total answer. *There are good and bad heights for a rhombic above ground.* For practical CATV installations, you cannot go high enough to *totally* escape the effects of ground reflections (or ground loading as it is sometimes called), and this is probably the key area where many CATV rhombics constructed to date fall down. And this problem is complicated by the fact that the height above ground we are concerned with is height above electrical ground or "reflection ground", which almost never corresponds to the real physical ground. In the case of dry earth, the electrical or reflection ground may be up to several wavelengths below the physical ground surface. Only when the installation is over

RHOMBICS — NOT HIGH ENOUGH?

Many systems dismiss the rhombic concept on the theory that because of the support poles required, a rhombic cannot be placed high enough above ground to get the gain needed for beyond horizon paths.

There are, of course, two ways to get gain. One is to raise the height of the antenna array. Another is to make the array larger, at the "same" height. Let's assume we have a (large) four bay leg array with 17 dB of gain at 500 feet above ground. How would such an antenna array compare with say a Laport rhombic at 60 feet above ground?

(1) Let us assume the path length is 100 miles, give or take 20 miles either way.

(2) If we lower the four bay array to 250 feet, we will have lost 2 dB of our height gain (i.e. the difference in received level for a 100 mile path is 2 dB for halving the height of the four bay array).

(3) If we lower the four bay array from 250 feet to 125 feet, we will lose another 2 dB from our 500 foot height level.

(4) If we lower the four bay array from 125 feet to 62.5 feet, we will lose yet 3 dB more: or a total of 7 dB of "height-gain-loss" by dropping from 500 feet to 62.5 feet.

Now if we install a 27 dB gain 60 foot above ground, this antenna has 10 dB more gain than the four bay leg. Seven of this ten dB has been lost when the four bay array dropped from 500 feet to 62.5 feet. But we are still 3 dB ahead of where we were, with the rhombic at 60 feet. Plus, the downline loss from the rhombic's 60 foot height has got to be less than the downline loss from the four bay leg array's height of 500 feet. So we probably pick up an additional 2-3 dB of real signal voltage (i.e. level) here. Sometimes antenna gain is a good trade for height!

a very (i.e. constantly) moist ground is the electrical or reflection ground *near* the physical ground surface. A swamp, or along or over a (constant level) water surface such as a lake would be an example of a dependable and coincidental real ground and electrical ground. But there are ways to handle this, as we shall see.

Ground reflections, then, *modify the pure lobe structure* of the "paper rhombic". They create side lobes where no side lobes previously existed, and this means a loss of control over co-channel (or adjacent channel) sources. We'll re-visit this later.

The Rhombic Design

The basic rhombic design is not unlike an aperiodic configuration. The key word here is the *aperiodic* portion of aperiodic. This means that when the antenna is terminated in its characteristic impedance at the forward (i.e. towards transmitter) end, the antenna is useful over a wide band of frequencies. In other words, the antenna, when properly terminated, if it presents a match of say 20 dB at channel 2 will present pretty much the same match at channel 6 and probably only a tad worse at channels 7 or 13.

That says the rhombic is a broadband antenna. If you dig back into past antenna articles in CATV, one of the things we learned is that the usefulness of an antenna was always pretty much determined by the portion of the bandwidth covered where the antenna match is acceptable to the receiving equipment downline. This is not the limiting factor for a rhombic.

Unfortunately, *there is no relationship between the antenna's input impedance characteristics and*

the radiation characteristics (i.e. pattern or lobe structure). It is the latter which determines the range of frequencies over which the rhombic antenna may be utilized.

The rhombus(bic) has two controlling parameters, the length of the individual (four) leg(s) . . . diagram 6 . . . and the acute (or apex) angle "A" (also diagram 6).

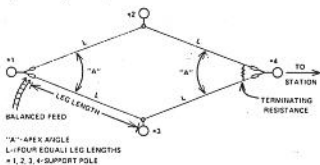


DIAGRAM 6

The total lobe pattern of the antenna is a composite of the patterns of the four individual legs and the geometry of the rhombus. The radiation pattern of each leg (which becomes 1/4th of the contribution to the total pattern) is a function of the length of the leg (remember diagram 3).

Laport in 1952 said "The composite free-space pattern for a (traveling wave) rhombus is the result of interference between the patterns for the individual legs as a result of their spacial separations, and their mutual orientations. The multiplicity of lobes in the individual leg patterns causes a large number of lobes in the composite pattern, and interference effects in space give each lobe a different orientation in azimuth (i.e. left and right of axis) and elevation (i.e. from the horizon which is always zero degrees to dead overhead which is 90 degrees). When the rhombus is placed above a reflecting surface, such as the earth, interference with the image pattern further complicates and modifies the basic pattern. If arrays of horizontal rhombics are used, still higher orders of complication are introduced by additional interference effects."

Laport also noted "The complete solution of such patterns for practical antenna designs by conventional methods (i.e. without a computer program) involved an enormous amount of skillful computation, and is seldom attempted."

As noted initially, most if not all of the skillful work on rhombic design has been done for antennas designed to operate in the 3-30 MHz region, where ionospheric reflections (i.e. "skip") are the normal communication mode. And as noted, such

communication circuits rely on wavefronts arriving at the receiving antenna at angles above the horizon, typically in the 8-13 degree region with respect to the horizontal plane of the antenna. It is worth noting that a horizontally polarized rhombic, with all of its elements parallel to the earth (i.e. pointing at the horizon at zero degrees elevation) can be "electrically steered" by the designer so that while the physical antenna points at zero degrees elevation the main antenna lobe is pointing upwards at say 12.5 degrees elevation.

Because CATV systems want the lowest possible angle of radiation (i.e. all of our important signals in areas where rhombics would be utilized arrive parallel to our horizon or in the 0 to 0.5 degree elevation region), we obviously don't wish to "steer" our elevation upward. Yet most of the rhombic design data assumes that is precisely what you wish to do, and there are therefore some design modifications to be taken into consideration when you structure a VHF-UHF system.

Because of ground reflections, and the effects of the acute angle (diagram 6) and leg length as a function of frequency, there is an optimum design frequency for any rhombic, and then as the use-frequency deviates lower than and higher than the design frequency, two things happen to the radiation characteristics of the antenna. Remember that the impedance stays quite constant, even as frequency changes, because of the 'traveling-wave' or aperiodic (like in log-periodic) design of the antenna.

Number one — The carefully controlled minor (or side, rear) lobes, reduced to practical minimums on the design frequency, begin to pop-up at unexpected places (i.e. in directions not totally predictable . . . as the operating frequency changes away from the design frequency.)

Number two — the apex angle (see diagram 6 again) becomes very critical when the rhombic designer is attempting to achieve very low angles of radiation. It is the careful balance of the electrical leg length versus the apex angle (both as a function of operating frequency) which determines the coincidence of major lobes of radiation, in phase, combining to form the

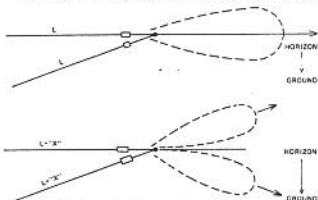


DIAGRAM 7

singular main lobe at the front of the antenna. As Laport notes "... this implied that there is almost no tolerance in the direction of higher frequencies (as the frequency increases and the leg length is physically constant, each leg becomes the equivalent length of more electrical wave-lengths)... and the main forward beam tends to split...". See diagram 7.

Therefore, because of the balancing act which must be done between electrical leg length and the apex angle, what is the proper design approach when the rhombic is to be utilized over a fairly wide excursion of frequencies (such as channels 2, 6, and 8)? If the lobe structure creates multiple non-desired side lobes when you go away from the design frequency optimum (whether you go higher in frequency or lower in frequency with the operation), and if the main forward lobe tends to try to split into two lobes only when you go higher in operating frequency than the design frequency, the logic would seem to be that your optimization of the antenna should be at the highest frequency to be utilized. In this way you maintain a singular front lobe (i.e. non-split) throughout the antenna's use-range, with maximum gain (i.e. smallest number and lowest level side lobes) at that frequency, but accepting lower gain (and larger, more numerous side lobes) for lower frequencies. There may be another option or two, as we shall see.

How Long / How Much Gain?

If the apex or acute angle is optimized for the chosen frequency (frequency here means television channel, at VHF or UHF, the 6 MHz wide television channel is insufficient change in frequency to create any lobe variations or frontal lobe split over a single channel bandwidth, even at channel 2, when the antenna is optimized for the video carrier frequency) and the electrical leg length is similarly optimized for that apex or acute angle, there are known gain maximums to be achieved with a "simple" four-wire rhombic.

The amount of forward gain depends on the number of electrical wavelengths of the leg (and array), with numbers like this to be expected (a range of numbers is shown, to reflect variations in design parameters):

Wavelengths Per Leg	Gain Range
2	10-12 dB
4	12-14 dB
6	13-15 dB
8	14-16 dB
12	15-17 dB

Additional gain can be achieved by stacking the rhombic array, either vertically (i.e. one stack above the other), horizontally (side by side arrays), or by one of several techniques unique to the rhombic design (i.e. the Laport Rhombic, etc.). There is also additional gain to be had by utilizing multiple wires per side, in conical format. Let's begin by looking at the basic Rhombic for VHF-UHF.

Basic Construction Techniques

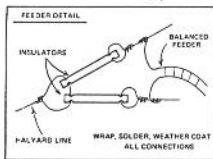
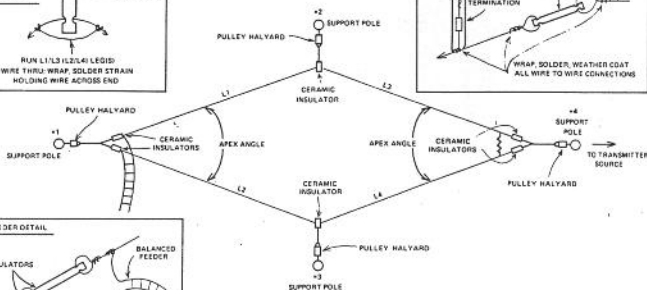
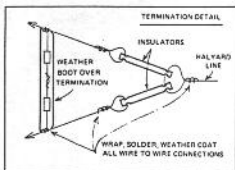
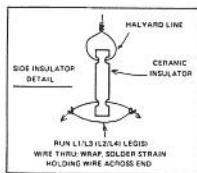
For all of the rhombic-variations to follow, there will be certain parameters which will apply to each. We will run through them at this point so you will understand how they apply to any rhombic design:

(A) *Directional Heading* — The front pattern beamwidth, at the 3 dB points, will be a function of leg length and the companion apex angle. In any case, regardless of the rhombic format chosen, it is exceedingly important that the rhombic's axis lies directly towards the transmitter source. In the worst case (i.e. sharpest front pattern rhombic) to be described here, we will be dealing with a 3 dB front beamwidth of 11 degrees. This is roughly 4 times as "sharp" as a ten element yagi antenna, and 2 times as sharp as two ten element yagi antennas stacked side-by-side in a horizontal array.

However, unlike the yagi which can be manually re-directed to the maximum signal level heading with only minor effort, there is no easy way to pick up the four support (utility) poles and re-plant them to correct for initial errors in heading. It is very important that when the initial array is planned that the front and rear support poles (#1 and 4 in diagram 8) be precisely on-a-line that starts at the back pole location and runs directly towards the transmitter location. This usually involves obtaining a set of USGS (United States Geodetic Survey) maps for the region, and laying out a straight edge line from your precise receiving site to the actual transmitter location. Note that many transmitter sites are from several to 40 miles outside of the town of license, and often off to the side in such a direction that if you chose the license town for a bearing, you might end up being tens of degrees off of the proper heading. With a narrow beam rhombic, that could cost you 3-10 dB of realized signal gain.

NOTE: In the process of establishing your own front and back pole locations (diagram 8, poles 1 and 4) you will undoubtedly utilize a compass to locate magnetic north and either a surveyor's transit and/or an engineering protractor to establish the true headings. Any USGS map contains a correction factor for the difference across the map between magnetic north and true north. Note that on USGS maps true north is indicated, but your compass will be plotting magnetic north. The USGS maps indicate the compensation required to correct for the difference between true north and magnetic north, and this correction must be included in your calculations or the antenna will end up off-heading. Corrections of 8-10 degrees are common for the mid-western portion of the U.S.A., for example.

(B) *Support Poles* — Some method of supporting the rhombic wire legs above ground, and a proper distance apart, is required. In the CATV business, where access to various grades and sizes of utility type wooden poles is commonplace, these would seem to be the best solution to the support prob-



BASIC RHOMBIC

DIAGRAM 8

TABLE ONE — MINIMUM HEIGHTS

To escape devastating ground-reflections, the rhombic must be installed at least high enough so that ground reflections do not distort the antenna's pattern. The actual height should always be as high as possible, to create the highest average signal level. For rhombics 6 wavelengths per leg length and smaller, the minimum height is 3 wavelengths. For rhombics over 6 wavelengths in length (per leg), the minimum recommended height is 5 wavelengths above ground. A 3 wavelength high rhombic will have its maximum radiation angle centered approximately 5 degrees above the horizon. An antenna with a vertical pattern of 10 degrees would therefore have all lobes plus or minus 5 degrees 3 dB down from the maximum lobe. In this example situation, the at-horizon response would be 3 dB lower than the antenna response 5 degrees above the horizon.

Note: Minimum heights are for physical distance between electrical ground reflection surface and lowest bay of rhombic (i.e. bottom bay if two or more stacks high). Electrical ground is either at physical ground (in very moist soil or over water), or some distance below earth-ground surface. To be safe, measure from earth-ground surface.

Channel/Frequency

2 (55.25 MHz)	53' 55"	106' 10"
3 (61.25 MHz)	48' 2"	96' 4"
4 (67.25 MHz)	43' 11"	87' 10"
5 (77.25 MHz)	38' 3"	76' 6"
6 (83.25 MHz)	35' 6"	71' 0"
FM (130 MHz)	29' 6"	59' 0"
7 (175.25 MHz)	16' 10"	33' 8"
8 (181.25 MHz)	16' 4"	32' 8"
9 (187.25 MHz)	15' 5"	31' 6"
10 (193.25 MHz)	15' 3"	30' 6"
11 (199.25 MHz)	14' 10"	29' 8"
12 (205.25 MHz)	14' 5"	28' 10"
13 (211.25 MHz)	14' 0"	28' 0"
14 (471.25 MHz)	6' 3"	12' 6"
30 (567.25 MHz)	5' 2"	10' 4"
50 (687.25 MHz)	4' 4"	8' 8"
70 (807.25 MHz)	3' 8"	7' 4"

lem. Actual height above ground is a function of electrical wavelengths at the operating frequency, with table I here listing the minimum heights tolerable for various channels. Metal poles or tower sections are satisfactory if there's some method of ensuring that the down-guys for the tower/poles do not create interference (through resonances) with the antenna proper. Most rhombic workers agree that the two side supports (#2 and #3 in diagram 8) can be metal(lic), provided they are at least 6 feet removed from the nearest rhombic leg wire conductor. It is also generally agreed that the front and rear supports (poles #1 and #4 in diagram 8) are best if wooden or some other non-conductive material.

If metal towers or metal poles that require guying are utilized, the down guys should be broken up with insulators so that there are no 1/4, 1/2 or 1 wavelength (or multiples thereof) resonant lengths in the down guys at any of the desired receiving channel frequencies.

(C) *Erection Procedures* — Typically, a rhombic is laid out on the ground and all soldered, wrapped, etc. connections made at that point.

Then utilizing ropes or other non-metallic materials, each of the four support points is lifted or raised to the design height using halyard line/pulley arrangements (see diagram 9). This affords more than an easy *ground-up system* for erection, it also provides a way to fine-adjust the antenna for maximum received signal level (i.e. gain), by playing one halyard against the others.

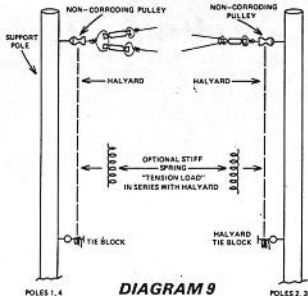


DIAGRAM 9

It may be, because of a design error, construction error, or path abnormality, that the rhombic exhibits maximum gain when the front is (for example) lower than the rear (and side support points). This can be determined through maneuvering the four sets of halyards/pulleys and simultaneously observing a signal level meter on the most critical channel received. If the two side poles (#2, #3 diagram 8) are set far enough back, the apex angle can be adjusted for optimum signal level performance and optimum minor-lobe structure (as deduced by monitoring a receiver for minimum co-channel levels) by gently releasing the halyards on supports #1 and #4 (rear and front) while simultaneously pulling up on the halyards on supports #2 and #3 (both sides). This "pruning" of the apex is not a normal field-adjustment procedure, but it is an option you have, especially if the side supports are far enough back to allow you room to "play".

(D) *Termination Procedure* — The basic rhombic is a bi-directional antenna, that is, it has equal signal gain in two directions, even though the transmission or downline is connected to a single end. To create a front-to-back ratio (typically in the high 20's to low 30's in real life), the front of the antenna (where the sides join in the apex formed at pole #4 in diagram 8) is terminated with carbon resistors. It is exceedingly important that the resistor(s) chosen for this termination be carbon resistors, not wire-wound. A large percentage of the 2 watt resistors commonly available in this ohmage range are wire wound, and you are advised to take one apart before making up your own termination to determine whether there is a wire

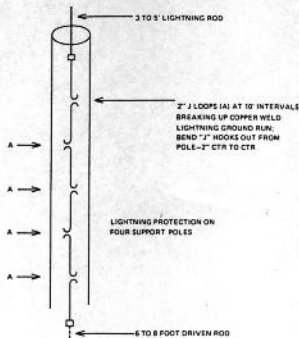


DIAGRAM 10

spiral inside of the resistor core. If there is, the resistor should not be utilized for this purpose.

A simple single-wire-per-leg rhombic has a characteristic feed impedance of approximately 800 ohms. This is the value of the termination resistor, and two 390 ohm carbon 2 watt resistors in series will create the termination needed. It is recommended that after the terminating resistor(s) has been soldered in place that a piece of heat-shrink tubing or plastic hose be placed over the termination to keep moisture and corrosion out of the connection. A liberal coating with a common CATV line insulating compound (Dow, etc.) will also be useful.

The (optional — to be discussed) *multiple-wire-per-leg* rhombic design utilizes two or three wires in a fan arrangement. This does several good things for the rhombic design, including lowering the feed impedance of the overall antenna to approximately 600 ohms. We'll have more to say about multiple wire sides shortly, but keep in mind that if you choose to go this way, the terminating resistor(s) must still be carbon (i.e. low in inductive and capacitive qualities), but now will be approximating the 600 ohm feed impedance of the antenna, not the simpler design 800 ohm feed impedance.

(E) *Line Matching Procedure* — The rhombic antenna is a balanced antenna (as in a 300 ohm dipole antenna), and our own low-loss downlines are typically 75 ohms, unbalanced. It is therefore necessary to make an impedance transformation from either the 800 ohms or 600 ohms (or impedance presented by a stacked array) down to 75 ohms, and to also transform our balanced feed antenna to the unbalanced input of either the downline coaxial cable or the input to our typically 75 ohm unbalanced signal preamplifier.

There are numerous techniques for accomplish-

RHOMBIC CONSTRUCTION MATERIALS

Aside from the pole support system and the mechanics to raise and lower the rhombic (a rope and pulley system), the only component parts for a typical rhombic are the insulators and the wire. This assumes you can locate termination resistors and materials to construct your feed-impedance-matching system in your own system shop.

Steel wire is a "no-no" unless it is copper coated. Copperweld wire, #10 to 14 is adequate for any but the 12 wavelength per leg low band antennas. Stranded wire is to be avoided because of the long term mechanical problems (primarily wire-stretch) which it harbors. Where lengths must be "spliced" use a good over-wrap technique and solder the spliced sections together. After soldering, coat the soldered segment with a good moisture proofing compound such as one of the many Dow lubricants.

The insulators present the only real "problem". Our concern is with proper insulating properties and breaking strength. Until December of 1974, the E.F. Johnson Company (Waseca, Minnesota) manufactured a complete line of strain-insulators; insulators which just about every rhombic construction article published since 1940 referenced for insulator type sources. This line was sold in late 1974 to the H.H. Smith Company in New York City (212-272-9400) and as the table here shows, H.H. Smith has a complete line of these insulators reportedly available through their distributors or "direct". An alternate source, untested by CATJ, is the Birn Bach Company, also in New York City (212-255-6600); with a competitive line of strain insulators.

E.F. Johnson advises most of their distributors returned their in-stock strain insulators to Johnson in 1974, when Johnson announced they were shutting down that product line. Thus the chances are not good that you will find dusty strain insulators at former E.F. Johnson distributors. Some "wholesale houses" that handle "amateur radio equipment" may still have these insulators in stock, however, in as much as hams still build their own antennas and they probably represent the largest users of strain insulators in electronics today in the United States and Canada.

H.H. Smith insulators now available are as follows:

Antenna Strain Insulators —

H.H. Smith #9604 (E.F. Johnson 136-0104-001) ... 5/8" square dry process, glazed porcelain; 400 lbs. breaking strength, 4 inches long overall... \$0.43 each.

H.H. Smith #9607 (E.F. Johnson 136-0107-001) ... 1" diameter (round), wet process glazed porcelain; 800 lbs. breaking strength, 7 inches long overall... \$2.20 each.

H.H. Smith #9612 (E.F. Johnson 136-0112-001) ... 1" diameter (round), wet process glazed porcelain; 800 lbs. breaking strength, 12 inches long overall... \$2.50 each.

Feedline Insulators

H.H. Smith #9662 (E.F. Johnson 136-0122-001) ... 3/8" x 1/2" cross section, silicone impregnated porcelain, for 2" feeder spacing... \$0.48 each.

H.H. Smith #9624 (E.F. Johnson 136-0124-001) ... 3/8" x 1/2" cross section, silicone impregnated porcelain, for 4" feeder spacing... \$0.48 each.

H.H. Smith #9626 (E.F. Johnson 136-0126-001) ... 3/8" x 1/2" cross section, silicone impregnated porcelain, for 6" feeder spacing... \$0.60 each.

The H.H. Smith Company home office is located at 812 Snediker Avenue, Brooklyn, New York 11207.

array is installed in and around and under a typical CATV tower, the risk for additional lightning strikes (to the rhombic itself) are minimal as long as the rhombic is "shadowed" by the presence of the larger metal tower (with antennas). The generally accepted "cone of protection" for such an installation is roughly 3-4 times the height of the prominent metal tower, starting at the base of the tower and working outwards (see *CATJ for February 1975; page 14*). In other words, if you have a 200 foot tower installed, and all of the rhombic will be within 3 x 200 feet or 600 feet of the base of the existing metal tower, your rhombic should be shielded from direct strikes by the existing (200 foot) tower.

If this is not the case, and the rhombic with its rather large metallic surface (made up of the four rhombic legs) is going to be all alone, some precautions are advised. See diagram 10 here.

The Basic Rhombic

This is the simplest form of rhombic of all. There are four single wire sides, all equal in length, arranged so that the axis of the array is pointed directly at the desired station. Opposite angles within the rhombic are equal (see diagram 11).

Using table II here choose the gain you require at the highest channel the rhombic is to be utilized for. Lower channels, on the same axis heading, will have corresponding lower amounts of gain. The maximum frequency spread recommended is on the order of 1.8 of an octave (i.e. 50-90 MHz, 174-313 MHz and so on), to avoid front-lobe "beam splitting" on the high frequency end of the range and to avoid excessive unpredictable lobes on the low frequency end. This is not to say that a 6 wavelength per leg high band antenna will prove useless on low band (it turns out that 6 wavelengths on high band is roughly 3 wavelengths on channels 5 and 6); but it is to say that superior performance would be achieved with a designed-for-low band array.

Keep in mind that a set of four support poles selected for a particular axis heading (such as the transmitter tower cluster in Philadelphia, or the Sears Tower in Chicago, etc.) can support multiple-layers of rhombics, such as one set for channels 2 and 5 (in the case of Chicago) and another set for channels 7, 9 and 11 (also in the case of Chicago). The high band rhombic could be hung above, below or even inside of the low band array; although hanging it inside of the low band array might be the least advisable technique for both mechanical and electrical reasons. Once the support poles are in place, the additional expense of specialized wire arrays for the various channel combinations sought is minimal, as long as the axis-heading path from your rhombic receiving site to the distant transmitters is the same or within a degree or two of being the same.

Another suitable technique, if you have stations in different directions, is to utilize at least the base pole (i.e. the pole located at the feedline point) a

ing this transformation, and the technique you choose will be largely dictated by the actual antenna design you choose. Suffice to say that unless some form of transformation is employed, very large signal losses are going to occur at the entrance to the downline/pre-amplifier if any 75 ohm device is tied directly to the much higher (balanced) feed impedance of the rhombic array.

(F) *Lightning Protection* — A large rhombic array is a sitting duck for lightning strikes. Now if the

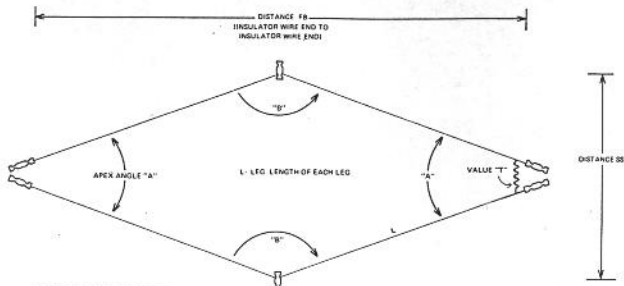


DIAGRAM 11

number of time; as an "anchor" for rhombic arrays heading off in several different directions. It is also possible if you are clever with your planning to use one of the two side-mount poles a second time as well, thereby cutting down on the total number of poles required for a multiple-heading installation.

The UHF versions are very small. So small in fact, that back in the 50's a firm in Central California manufactured an aluminum-tubing (side leg) version which many people had mounted on rotators. If you have a marginal UHF channel in your area, a UHF version might well be the place to start experimentation. If you have a UHF path with ghosting on it, one of the rhombic variations (such as the Laport Rhombic to be described) with its extremely narrow 3 dB beamwidth (11 degrees) might be the answer to ridding yourself of ghosts.

Stacking The Basic Rhombic

A rhombic, as almost any other antenna, can be stacked for additional gain. There are a couple of specialized rhombic designs, such as the Laport design, which will be covered separately here. For now, let's look at two (and four) stacking the basic rhombic.

There are some arguments about how far apart you should stack a two-bay array. Most decisions seem to have been based upon the desire to capitalize on parallel antenna impedances, which creates a better (i.e. easier) impedance matching network to 300 or 75 ohm feed impedances.

If a single bay rhombic has a feed impedance of 800 ohms, then two 800 ohm rhombics connected in parallel have a feed impedance of 400 ohms (diagram 12). If a single bay of a multi-wire rhombic has a feed impedance of 600 ohms, two such antennas connected up in parallel have a feed impedance of 300 ohms.

Thus for convenience of creating a 300 ohm balanced feed (which can be transformed to 75 ohms unbalanced by using a 300 to 75 ohm CATV

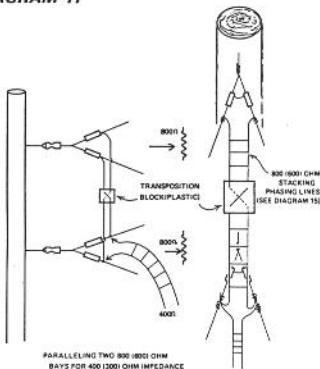
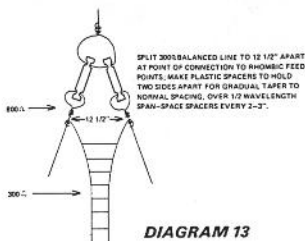


DIAGRAM 12

transformer), two multiple-wire rhombics connected in parallel the appropriate stacking distance apart creates the easy-to-use 300 ohm balanced condition we would like to see.

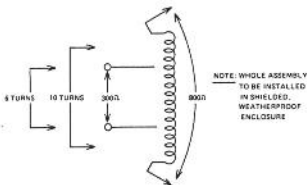
Let's deal with the 800 ohm impedance basic rhombic first. One approach is to take a length of 300 ohm twinlead (non-shielded variety) and connect one side to each of the two rhombic feed points. Then take a sharp knife and split the twinlead so that at the rhombic feedpoint you have the two halves of the twinlead spread apart 12.5 inches, and then allow it to fan back to the normal (non-split) 300 ohm width at a distance of 1/2 wavelength back down the line. This impedance matching section (a tapered line) will transition the 800 ohm antenna impedance to the 300 ohm



balanced line impedance. This technique has a bunch of problems (including the fact that it is frequency sensitive), but it could be used for a temporary system to check the performance of the antenna during initial testing.

Any line matching technique employed should be as broadband as possible, unless you are really only after a single television channel. There are undoubtedly some 800 ohm balanced to 300 ohm balanced (or 75 ohm unbalanced) core transformers which could be wound, but few builders have access to the proper cores in the field. There is an autotransformer approach (see diagram 14) which is suitable for VHF use or UHF use as described here. The autotransformer sees 800 ohms at the coil end, and the 300 ohm balanced feed is taken off a couple of turns in from the ends (as noted). At this point a standard 300 ohm balanced to 75 ohms unbalanced transformer can be attached.

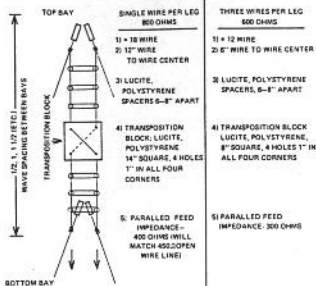
FOR VHF - 10 TURNS + 14 TAPPED WIRE COPPER ON 1/4" FORM EVENLY SPACED (1 1/4" LONG) TAPPED 2 TURNS IN FROM EACH END FOR 300Ω (BALANCED)



FOR UHF - 10 TURNS + 14 TAPPED COPPER ON 1/4" FORM EVENLY SPACED (1 1/4" LONG) TAPPED 2 TURNS IN FROM EACH END FOR 300Ω (BALANCED)

DIAGRAM 14

NOTE: If your antenna is to be used for UHF, any 300 ohm balanced to 75 ohm unbalanced transformation must be made with a transformer known to be good for the UHF range. Normal back-of-set matching transformers are not good at UHF, and have excessive losses. Check your



supplier for a 300 to 75 ohm balanced to unbalanced transformer that is manufacturer-rated for UHF service.

Now if you stack a two-stack array (of the 800 ohm variety rhombic), you can reasonably expect to pick up additional gain. The "book" says to expect 2.5 to 3.0 dB additional gain over the single bay. However, because of the excessive capture area of the rhombic, there will be times when the extra gain netted by the second bay will be much greater than the 2.5/3 dB expected (i.e. during heavy fading conditions). The long term average, on the other hand, should be in the 2.5 to 3dB region.

By stacking the antennas a half-wavelength apart, or multiples thereof (i.e. 1 wavelength, 1.5 wavelengths and so on), and interconnecting the feed points of the two (or more) stacks as shown in diagram 15, we can use some system-constructed 800 ohm line (or 600 ohm line for multi-wire rhombics) for stacking purposes. The principal is that at 1/2 wavelength intervals, the feed impedance of the antenna repeats itself. Therefore, if you stack two bays of 800 ohm impedance rhombic 1/2 wavelength in space apart, and tie the top bay to the bottom bay with a length of 800 ohm line, the impedance at the bottom bay is the combination of two 800 ohm impedances in parallel: or 400 ohms. Conversely, if you stack three identical rhombics at 1/2 wavelength (or multiples thereof) spacing, you have three 800 ohm impedances in parallel, which would result in a feed impedance of 267 ohms (close enough to 300 ohms). A four stack array results in a feed impedance of approximately 200 ohms (balanced).

In diagram 15 here we have a two-stack array tied together at 1/2 wavelength spacing by a homebrew section of 800 ohm line. Note that in the middle of the stacking line there is a transposition block alternating the balanced antenna feeds to maintain phase parity.

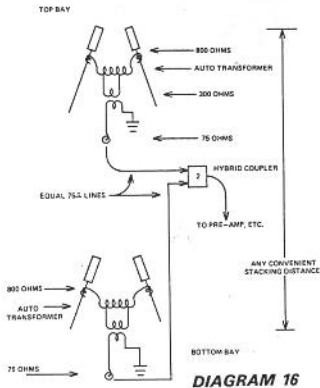


DIAGRAM 16

Unfortunately, again, this is a frequency sensitive arrangement, because of the half wavelength functions which must be tied to some particular desired frequency/channel. An alternate approach is found in diagram 16 where we use the autotransformer to get to 300 ohms balanced at each an-

tenna as quickly as possible. Then by using exactly equal lengths of 75 ohm cable and 300 to 75 ohm transformers, we can stack the antennas some physical distance apart (such as one wavelength for the design channel) and not worry so much about losing signal voltage in the matching process on non-optimized channels. In effect, this becomes a broadband type of matching system where the limitation to the antenna system's effectiveness returns to the limitation of the rhombic leg lengths and the apex angle (as previously discussed); and not the artificial limits imposed by a frequency-selective/sensitive matching system.

Once again, your choice will depend upon your antenna system requirements, and you are advised to select the approach that produces the best results for your requirements. If single channel design is your criteria, by all means stick to a single channel matching approach.

The Multiple Wire Rhombic

For a rhombic of given leg lengths and a given apex angle, if the builder chooses to follow the multiple-wire format for his legs, he can expect approximately 1 dB of additional signal gain. This may or may not be adequate reason to invest in several more hundred feet of wire initially.

Most rhombic designers recommend that multiple wire rhombics be three wire (per side or leg) devices. Increasing the number of wires per leg from 1 to 2 is an advantage, but experience has

TABLE TWO — BASIC DIMENSIONS

Dimensions are given for all VHF channels, FM (100 MHz), and four UHF channels. The .5 wavelength and 1.0 wavelength columns are for vertical stacking purposes (see diagrams 12 and 15). Rhombics larger than 6 wavelengths at low band are spaceobblers and the Laopt design is recommended because it is more efficient for space consumed (although more complex to construct). Twelve and eighteen wavelength per leg rhombics require extreme construction care at any frequency to insure construction sloppiness does not create undesired side lobes. When maximum gain is required, the Laopt design is typically a better choice than 12 or 18 wavelength designs.

Channel	1/2 Wave (*)	1 Wave (*)	2 Wave	3 Wave	6 Wave	12 Wave	18 Wave
2	8' 11"	17' 10"	35' 8"	53' 5"	106' 10"	213' 2"	
3 (**)	8' 0"	16' 0"	32' 1"	48' 2"	96' 4"	192' 8"	
4	7' 4"	14' 8"	29' 4"	43' 11"	87' 10"	175' 3"	
5	6' 4"	12' 9"	25' 6"	38' 3"	76' 6"	153' 0"	
6	5' 8"	11' 10"	23' 8"	35' 6"	71' 0"	142' 0"	
100 MHZ	4' 11"	9' 10"	19' 8"	29' 6"	59' 0"	118' 0"	
7 (**)	2' 9"	5' 7"	11' 2"	16' 10"	33' 8"	67' 4"	101' 5"
8	2' 8"	5' 5"	10' 10"	16' 4"	32' 8"	65' 4"	98' 0"
9	2' 7"	5' 3"	10' 6"	15' 9"	31' 6"	63' 0"	94' 6"
10	2' 6"	5' 1"	10' 2"	15' 3"	30' 6"	61' 0"	91' 6"
11	2' 5"	4' 11"	9' 10"	14' 10"	29' 8"	59' 4"	89' 0"
12	2' 4"	4' 9"	9' 6"	14' 5"	28' 10"	57' 8"	86' 6"
13	2' 3"	4' 7"	9' 2"	14' 0"	28' 0"	56' 0"	84' 0"
14	2' 3"	4' 1"	8' 2"	13' 6"	27' 0"	54' 0"	81' 0"
30 (**)	1' 1/2"	2' 1"	4' 2"	6' 3"	12' 6"	25' 0"	37' 5"
50	0' 10 1/2"	1' 9"	3' 5"	5' 2"	10' 4"	20' 3"	31' 0"
70	0' 8 1/2"	1' 5"	2' 10"	4' 4"	8' 8"	17' 4"	26' 0"
70	0' 7 1/2"	1' 3"	2' 6"	3' 6"	7' 4"	14' 8"	22' 0"

*—Stacking distances, vertical; **—composite design LB, HB, UHF

shown that 3 wires is optimum for most designs.

In addition to the *slight* extra gain, here is what a three-wire-leg does for you:

1) The feed impedance of the rhombic goes down from the 800 ohm region to approximately 600 ohms;

2) The broadband nature of the antenna gets even better (i.e. it covers an increased frequency range).

However, the increase in frequency range is without regard to what happens with split-main-lobes or an increase in some (usually unpredictable) sidelobes, so that factor may not prove to be a "net" improvement at all.

Focus then on the 1 dB additional gain, and, the lowered feed impedance. If the (now) 600 ohm rhombic is terminated with some close value of non-inductive (i.e. carbon) resistors, we have an antenna which if double stacked ends up with a parallel(ed) feed impedance of 300 ohms; which is

conveniently re-transformed to 75 ohms through commonly available 300 ohm balanced to 75 ohm unbalanced transformers. This (following the directions in diagram 15) is still a frequency-sensitive matching network (because 1/2 wavelength or multiples thereof determine that point), but for single channel use, it has a nice (simple) ring to it.

When you go to three wire-per-leg design, it is important to follow a couple of design criteria:

1) All leg wires are exactly the same length, including the two that are respectively above and below the middle wire.

2) The wires fan-out as they head towards the middle poles (#2 and #3) so that at the middle poles they are 3-4 feet above and below the normal (middle) wire.

3) The extra wires-per-leg (i.e. above and below the respective normalized single wire) must connect at the feeder-end to the normal single wire at

TABLE TWO-A MORE BASIC DIMENSIONS

Dimensions given here are (with one exception) frequency sensitive. From Table Two, select the leg-length desired. From this table, select the front to back distance (F/B in diagram 11) and the side to side distance (S/S in diagram 11). Note F/B and S/S are rhombic edge to rhombic edge (i.e. wire perimeter to wire perimeter) and are not pole to pole spacings (i.e. #1 to #4 for F/B and #2 to #3 for S/S). See text for instructions regarding back-setting poles proper distance to allow antenna "tweaking".

The "Apex Angle" (angle "A" in diagram 11) and the "Side Angle" (angle "B" in diagram 11) are leg-length sensitive but not frequency sensitive.

Channel	Three Waves Per Leg		Six Waves Per Leg		Twelve Waves Per Leg		Eighteen Waves Per Leg	
	F/B	S/S	F/B	S/S	F/B	S/S	F/B	S/S
Angle "A"	63°		44°		28°		14°	
Angle "B"	117°		136°		152°		166°	
2	91' 0"	55' 9"	198' 0"	80' 0"	414' 6"	103' 4"		
3 (*)	82' 1"	50' 4"	178' 8"	72' 2"	373' 9"	93' 2"		
4	74' 11"	45' 11"	162' 11"	65' 10"	351' 5"	85' 0"		
5	65' 3"	40' 0"	141' 11"	57' 4"	296' 10"	74' 0"		
6	60' 6"	37' 1"	131' 7"	53' 2"	275' 5"	68' 8"		
100 MHz	50' 3"	30' 10"	109' 4"	44' 2"	228' 11"	57' 1"		
7 (*)	28' 8"	17' 7"	62' 6"	25' 3"	130' 8"	32' 7"	201' 6"	24' 9"
8	27' 10"	17' 1"	60' 8"	24' 6"	126' 8"	31' 7"	194' 9"	23' 11"
9	26' 9"	16' 5"	58' 4"	23' 7"	122' 4"	30' 6"	187' 4"	23' 0"
10	25' 0"	15' 11"	56' 6"	22' 10"	118' 4"	29' 6"	181' 10"	22' 4"
11	25' 3"	15' 6"	55' 1"	22' 3"	115' 0"	28' 8"	176' 5"	21' 8"
12	24' 7"	15' 1"	54' 5"	21' 7"	112' 0"	27' 11"	171' 8"	21' 1"
13	23' 11"	14' 8"	52' 0"	21' 0"	11' 6"	27' 1"	166' 11"	20' 6"
14	10' 7"	6' 6"	23' 1"	9' 4"	48' 5"	12' 1"	74' 8"	9' 2"
30 (*)	8' 10"	5' 5"	19' 2"	7' 9"	40' 1"	10' 0"	61' 9"	7' 7"
50 (*)	7' 4"	4' 6"	16' 1"	6' 6"	33' 9"	8' 5"	51' 7"	6' 4"
70	6' 3"	3' 10"	13' 7"	5' 6"	28' 5"	7' 1"	43' 5"	5' 4"

* — Compromise frequency for respectively LB, HB or UHF designs.

Note that as the leg length increases, the apex angle decreases and the side angle increases. This results in a longer, skinnier antenna as the individual leg antenna lobes come closer and closer to the tangent point of the individual leg wires. The front (azimuth) lobe of the rhombic also decreases (in width) resulting in more precise forward pattern directivity as the antenna size increases. Offsetting this desirable feature is a tendency for minor (non-desired) lobes to pop up at unexpected points.

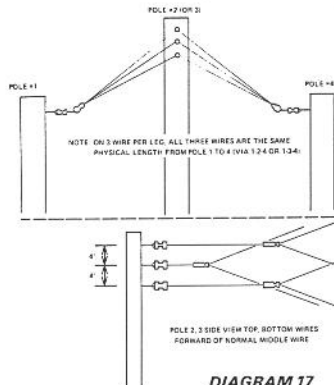


DIAGRAM 17

the strain-insulator, and, at the termination leg at the strain insulator. Because, all wires must be the same length, it follows that the wires above and below the normal single wire will, at the side support poles, be closer to the center of the rhombus than the single wire. See diagram 17.

Infinite Front To Back Ratio

The individual antenna construction layouts and their associated tables list various leg lengths and apex angles for various amounts of gain. As touched upon briefly earlier, in practice front-to-back ratios of the high 20's to the low 30's (in dB) are realizable in normal installations.

In theory, it is possible to have an infinite front-to-back ratio with a terminated rhombic. This is possible only at the design frequency, however, because the ability to achieve an "infinite front to back ratio" depends upon the leg lengths being an odd multiple of a quarter wavelength in overall length. For example, 1/2 wave and full wave multiples of the wavelength are considered even multiples of the quarter wavelength, while 1/4, 3/4, 1-1/4 and so on are considered odd multiples.

Therefore, for any of the dimensions given, there is a notation of the length of the leg for the table-given-data, and then a second column indicating the leg length for the same general-size antenna for "infinite front-to-back" ratio. In this column, we have provided the leg length as a function of the length at the nearest (larger) odd-multiple of a quarter wavelength. We have not corrected the other dimensions given for this condition; the apex angle(s) remains as given for each adjacent size (i.e. normalized) antenna; but the pole #1 to pole #4 and pole #2 to pole #3 spacings

would move out slightly for the additional leg length added for infinite (in theory) front-to-back rejection.

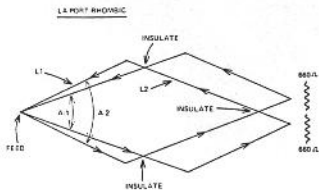
The actual amount of rejection, front to back, which might be expected in a situation such as this is in the mid 40's to low 50's (in dB); the exact number will depend upon your construction techniques and the surroundings.

There is one other technique worth commenting on, particularly because it may have real practical applications for CATV use. If you should happen, on purpose, to decrease the front-of-rhombic termination impedance, below the proper value, you will in turn create an on-purpose mis-match for signals entering the antenna from the rear and flowing (as a current) towards the termination. This mis-match creates a reflection, which cancels out at the input end the residual response. There is of course a balance point between lowering the front termination impedance (with its attendant effects on the downline match and power transfer), and the purposeful mis-match created to create reflections for rear of antenna signal paths. If you have a 6 wavelength or larger rhombic array, you can often experimentally change out the terminating impedance (checking both higher and lower termination values in say 25-30 ohm steps) while simultaneously observing (1) the desired signal level on a field strength meter, and, (2) the co-channel pick-up from the rear of antenna source on a TV receiver. Purposeful mis-matches of a hundred ohms or more at the termination end will cause the minor rhombic lobe to the rear to split, and then "steer" first one direction and then another. By this technique, you may be able to "steer" the rear lobe into a null in the direction of the rear-of-antenna co-channel source, creating in excess of 50 dB of direction-sensitive pick-up attenuation reference the front lobe pattern. This technique can usually be made to apply (through termination value experimentation) to signals that are +/- 20/25 degrees off of the directly-to-the-rear heading (i.e. 155 degrees through 205 degrees with 0 degrees being the antenna's axis heading).

The Laport Rhombic

The ultimate in the rhombic art is a highly developed rhombic design created by Edmund A. Laport of RCA in the late 1950's. There is no special black magic in the design. Rather, Laport has laboriously worked out the many hundreds of computations associated with raw rhombic design to effectuate a final design that does more for the control of un-wanted sidelobes than any other rhombic (and wire) antenna design ever offered.

Recall from basic antenna theory that the only way one obtains superior forward gain is by (1) reducing unwanted radiation in non-desired directions, and, (2) by narrowing the front horizontal beamwidth of the antenna so that all of the gain is "packed" into as narrow a beamwidth as possible. The same general thesis dictates antenna design for all microwave frequencies, and if there is a comparative antenna to the Laport Rhombic, it



NOTE:

- 1) ALL "SHORT" SIDES—SEE L1 DIMENSION
- 2) ALL "LONG" SIDES—SEE L2 DIMENSION
- 3) NOTE ANGLE A-1 (FROM TABLE III) IS BETWEEN TWO "LONG" SIDES CONNECTED TO FEED POINT POLE (4:1)
- 4) NOTE ANGLE A-2 (FROM TABLE III) IS BETWEEN TWO "SHORT" SIDES CONNECTED TO FEED POINT POLE (4:1)

DIAGRAM 18

would have to be the prime focus feed parabolic utilized (for example) in the TVRO service at 4 GHz.

Laport Rhombics have been utilized with considerable success by any number of services, although they have not previously had wide exposure to an industry group such as CATV. Amateur radio operators have utilized the Laport Rhombic to direct 144 MHz signals to the moon, utilizing the moon as a passive reflector for communication with other amateurs here on earth. Very long haul voice and data 99.9% "reliable" tropospheric scatter circuits in the VHF range utilize the Laport Rhombic for paths as long as 500 miles at 200 MHz in various parts of the world. And at shortwave frequencies, where they were first employed by RCA Communications, Laport Rhombics standing side by side stacked multi-wire-per-leg optimized rhombics on the same trans-atlantic circuit at the same time have proven to be 42-43% more effective than the best non-Laport Rhombic installations.

The Laport Rhombic construction is not complicated, but to achieve the type of sidelobe control (and therefore the gain theoretically possible) will require more than the usual amount of "slap it together" skill often practiced around CATV antenna installation sites. Remember the Laport Rhombic design is a *refinement* of all past Rhombic experience and while it appears to the eye to have a substantial design variation from a more normalized rhombic configuration, the *secret of its performance* is not so much in the uniqueness of "a" design as it is the care and pains the duplicator goes to insure that his Laport Rhombic is as close as humanly possible to the design parameters set forth here.

The gain possible is 27 to 27.5 dB, reference a dipole at the same height. Again, that is the equivalent of an array of 64 12.0 dB gain yagis (or logs).

The other general parameters at the design frequency are as follows:

Vertical beamwidth (i.e. elevation beamwidth either side of the axis line, which should be on the horizon) . . . 6.0 degrees; horizontal beamwidth (azimuth width at 3 dB points) . . . 11 degrees. Because the Laport Rhombic is usable over a fairly wide frequency range, (Laport Rhombics in use at RCA with a center design frequency of 8.5 MHz cover the useful range of 5 to 12 MHz, or from Fo of .59 to an Fo of 1.41) it is interesting to note what happens at Fo (i.e. operating frequencies) as low as .58(%) of the operating frequency and as high as 1.41 (141%) of the operating frequency.

If we assume a design frequency of channel 2 (visual), or 55.25 MHz, channel 6 aural represents an Fo of 1.58 (or 158%). The Laport Rhombic may be useful *that far above* the Fo, but there is no readily available data to confirm nor deny this. However, if we change the design frequency to 62.25 MHz (channel 3 visual is 61.25 MHz), we have a 1.41 (141%) Fo of 87.77 MHz, or past the channel 6 aural carrier frequency. At the same time, our .58(%) Fo becomes 36.1 MHz, obviously adequate to cover channel 2 visual at 55.25 MHz.

For high band, if we assume an Fo of 175.25 MHz, we find that our 1.41 (141%) Fo is 247 MHz; well beyond the 215.75 MHz requirements of channel 13 aural.

Finally, for UHF if we assume an Fo of 471.25 MHz (channel 14 visual carrier), our 1.41 (141%) Fo becomes 664 MHz, or channel 43. However, if we select an Fo of 630 MHz, our 1.41 Fo becomes 888 MHz (channel 83 visual is 885.25 MHz). And, with a 630 MHz Fo, our .58 Fo becomes 365 MHz, well below channel 14's visual carrier frequency of 471.25 MHz.

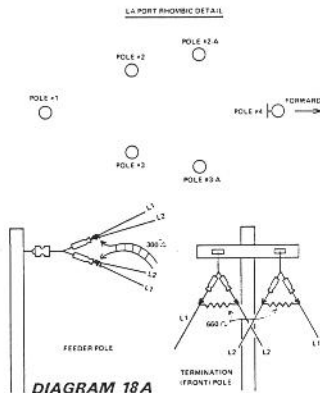


DIAGRAM 18A

TABLE THREE — LAPORT DIMENSIONS

The Laport rhombic is shown in diagrams 18 through 18-B. Note that each individual rhombic has four sides, and the four sides are made up of two sets of equal legs. Overall, there are four equal-length legs in the two-stack rhombic, but only two legs per stack are the same length. This results in the front or nose being offset as shown in diagram 18 and 18-B. Leg lengths (L1 and L2) are shown here, along with the approximate front-to-back (F/B) and side-to-side dimensions. Because the rhombic requires six support poles (or seven if two are used at the front termination point), we have side to side dimension Bk/Ss (the dimension between poles #2 and #3 in diagram 18-B) and side to side dimension Ft/Ss (the dimension between poles #2-A and 3-A in diagram 18-B). We also have the dimension between the two individual noses of the two stacks (dimension F/Nn in diagram 18-B).

L1, L2 and angle dimensions given here are exact. Dimensions F/B, Bk/Ss, Ft/Ss and F/Nn are approximate to serve as guides only in determining your ground space requirements. The Laport rhombic should be laid out initially on 1/10th inch square graph paper, to scale, for your own site. Construction should begin by laying out the antenna bearing line from pole 1 through 4 to the transmitter site. Then use a surveyors transit to stake poles #2, 2-A, 3 and 3-A following the X and Y angles given.

Angle X = 52.2 degrees

Angle Y = 37.7 degrees

Channel	L1	L2	Approximate F/B	Approx. Bk/Ss	Approx. Ft/Ss	Approx. F/Nn
2	62' 5"	106' 10"	160' 6"	57' 1"	71' 4"	14' 3"
3	56' 0"	96' 4"	144' 0"	51' 2"	64' 0"	12' 10"
4	51' 4"	87' 10"	131' 11"	46' 11"	58' 8"	11' 9"
5	44' 8"	75' 6"	114' 9"	40' 10"	51' 0"	10' 2"
6	41' 5"	71' 0"	106' 6"	37' 10"	47' 4"	9' 6"
100 MHz	34' 5"	59' 0"	88' 6"	31' 6"	39' 4"	7' 10"
7	19' 6"	33' 8"	50' 3"	17' 10"	22' 4"	4' 6"
8	19' 0"	32' 8"	48' 9"	17' 4"	21' 8"	4' 4"
9	18' 5"	31' 6"	47' 3"	16' 10"	21' 0"	4' 2"
10	17' 9"	30' 6"	45' 9"	16' 3"	20' 3"	4' 1"
11	17' 3"	29' 8"	44' 3"	15' 9"	19' 8"	3' 11"
12	16' 8"	28' 10"	42' 9"	15' 2"	19' 0"	3' 10"
13	15' 0"	26' 0"	41' 4"	14' 8"	18' 4"	3' 8"
14	7' 3"	12' 6"	18' 9"	6' 8"	8' 4"	1' 8"
30	6' 2"	10' 4"	15' 9"	5' 7"	7' 0"	1' 5"
50	5' 0"	8' 8"	12' 9"	4' 6"	5' 8"	1' 2"
70	4' 5"	7' 4"	11' 3"	4' 0"	5' 0"	1' 0"

Leg length L1 is 3.5 wavelengths, leg length L2 is 6.0 wavelengths.

Thus for our purposes here, we can design three separate Laport Rhombics, one to cover low band, one to cover high band, and one to cover UHF. See table III here.

The Laport Rhombic design is shown in diagram 18. It requires some explanation, since in schematic form it may appear to be a double stack array with an offset front end. That is not the case.

At the rear of the antenna, there are four legs covering, two on each side. Overall, there are eight actual legs, but four of them are one length (3.5 wavelength long at Fo) and the remaining four are another length (6.0 wavelength at Fo). Note that in both cases the total leg lengths are multiples of 1/2 wavelengths, so the in-phase symmetry is maintained.

With two 3.5 wavelength legs and two 6.0 wavelength legs tied together at the rear feedpoint (i.e. one each 3.5 and 6.0 wavelength leg to each of the ceramic insulators), we in effect have placed in

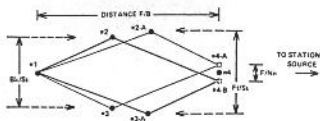


DIAGRAM 18B

parallel the two separate but equal rhombics at the feedpoint.

The Laport Rhombic is an "equivalent" two wire per leg design, meaning the actual impedance is lower than the single wire per leg 800 ohm variety, but not as low as the afore mentioned three wire per leg variety. It turns out that the feed impedance of each four-leg-rhombic, because of the influence of the companion four-leg rhombic, is around 660 ohms. The front of each individual rhombic is terminated, then, with an equivalent resistance (series a pair of 330 ohm 5% carbon two watt resistors). However, at the rear where two discrete four-leg-segments are joined for balanced feeding, we have two 660 ohm impedance antennas in parallel, which not surprisingly creates a balanced feed at the antenna of 330 ohms. This is sufficiently close to 300 ohms (10%) to allow us to hang a 300 ohm to 75 ohm balanced to unbalanced transformer across the feed points and come out of the Laport Rhombic with our desired 75 ohm unbalanced line. Alternately, we could feed the antenna with a long length of 300 ohm open wire line if we had a fair distance to go before getting to pre-amplification and a coaxial network.

Because both four-leg segments are in the same plane, there are going to be three points where the same-plane wires will want to rub against one another. At these points you install a durable all-weather insulating sleeve over both of the wires, tying them down so that the wind and weather don't move them about and leave the respective leg wires shorting together at that point.

Again the caution of Laport, "All dimensions, and angles must be as precise as possible to maintain sidelobe control". You will note that we are dealing with fractional angles (accurate in Laport's instructions to .2 of a degree). This may be difficult to duplicate precisely in the field using less-than-RCA construction techniques. It should go without saying, however, that very precise planning go into such an array if you expect to obtain the 27 dB forward gain numbers experienced by Laport and others, and that more than casual planning go into the method by which the suspended legs will be held in position under varying winds and ice loading.

Four Is Better

Laport suggests the theoretical improvement of a four-wire-per-leg quadruple-rhomboid system (see diagram 19). The antenna would (in theory) have in excess of 30 dB gain and a front lobe

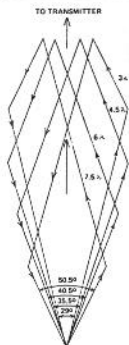


DIAGRAM 19

pattern with 3 dB points under 6 degrees wide. Apparently, although his March 1960 *RCA Review* paper described this "Quad-Rhombic" such an antenna had *not* been constructed and subsequent interest in rhombics for its principal users (short-wave communication paths) has waned since that date because of the introduction of satellites for trans-oceanic communication paths.

In theory, such an array would have a paralleled feed impedance of around 140 ohms (balanced) at the rear feed point.

Relay Rhombic

Finally, there was a flurry of interest in a "passive-booster" system published in the April 1953 *Radio Electronics* magazine. As shown in diagram 20 here, two rhombic antennas (each was originally indicated to be common garden variety rhombics, 4.5 wavelengths per leg on the design channel) are connected "back-to-back" with a length of 600 ohm open wire line. The principal was that the substantial signal voltages developed across the receiving rhombic were transferred (less line loss and match loss) to the feed terminals on a second rhombic, which re-radiated the signals "on channel" to yet a third antenna several miles away.

As installed at a location 55 miles from Denver, the signal voltage built up on the receiving antenna ("A" in diagram 20) was sufficient to allow reception up to a couple of miles further on by yet a third rhombic.

Assuming the presence of +10 dBmV at the receive terminals of antenna "A", less 3 dB of transmission line and match loss in getting the signal to antenna "B", a 4.5 wavelength per leg

rhombic as a transmitting antenna ("B") could be expected to produce a re-radiated signal "power" of +19 dBmV (roughly 1/100th of a volt). Allowing for spread losses, it is conceivable that with an identical rhombic at the antenna "C" (i.e. valley-floor) receiving location, there *might* be as much as -10 dBmV level possible at a distance of a mile, decreasing to a level of -20 dBmV at a distance of approximately two miles. In such a situation antenna "B" should be directed *down* into the desired valley receiving location and antenna "C" should be directed back "up" at the antenna "B" location.

If the theory behind all of this escapes you, try this on for size. The first rhombic (receive rhombic "A") has gain, and because of the gain, it builds up some known level of signal voltage across the feed point. This signal voltage is transported to "transmit" rhombic "B" through a piece of impedance-matched-to-antennas low loss open wire line. The second rhombic also has gain, and thus the signal "voltage" delivered is "amplified" by that gain, and radiated in the forward direction. *It is not exactly getting something for nothing, but it is close.*

There is no requirement that both antennas be identical, although no pre-amplifiers, converters, etc. may be introduced into the system *unless* you are willing to go through the hassle of licensing the "system" as an "on-channel-booster". As long as the "system" remains totally passive, no FCC license is required.

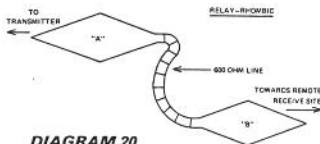


DIAGRAM 20

Rhombic References

- Antenna Engineering Handbook (Jasik), pages 4:12 to 4.34, 21:17 to 21.23, 24:25 to 24.27.
- ARRL Antenna Book, pages 165-177, 240.
- Design Data For Horizontal Rhombic Antennas (Edmund A. Laport, RCA Review, March 1952), pages 71-93.
- DXing Horizons — "Bringing TV To Marathon", August 1960 (page 11).
- DXing Horizons — "Bring TV To Marathon — Part Two", September 1960 (page 10).
- High Gain Rhombic For TV (Paul Ralford, Jr.), Radio-Electronics, May 1953 (page 51).
- Improved Antennas of the Rhombic Class (Edmund A. Laport and A.C. Veldhuis, RCA Review, March 1950), pages 117-124.
- Relay Rhombic, Radio-Electronics April 1953 (page 35).
- Rhombic Antennas For TV (Robert B. Cooper, Jr.), Radio-TV News, February 1958 (pages 64-65).
- Rhombic Antenna Query, Radio Electronics January 1953 (page 156).
- Rhomboids For TV Reception, Radio Electronics May 1957 (page 86) and correction June 1957 (page 119).
- TV Rhombic Antenna, Radio Electronics August 1956 (page 100).
- Directional Patterns For Rhombic Antennae, A.W.A. Tech Review, Vol. 7, page 33 (September 1946). Note: This reference not located by CATJ.

The October *CATJ* treatment of Rhombics was . . . well, traditional. In the *CATJ* tradition, we tried to boil down mounds of data into concise *CATV*-oriented data so the user could apply the material presented in its printed form.

Apparently we struck a responsive cord with the Rhombic material; one of the first operators to see the issue (while the ink was still wet he dropped in for a visit) spent an hour in a corner pouring over the material, and finally got up and headed for a door. "What was it you wanted to talk about?" we asked. "Some other time . . . I'm heading back to my system to build two rhombics."

The Laport design is leading in the early "returns", that 27 dB of gain just naturally sets people to thinking about 140 mile distant signals they have written off in the past because they could not afford microwave hops! The available Laport data aside from the October referenced RCA Review for March 1960, is slim at best. One reader called to note "On page 240 of the *ARRL Antenna Handbook*, they give about 50 words on the Laport and a set of dimensions for 144 MHz. But they have 4.32 wavelength long L1 sides and 7.42 wavelength long L2 sides. Yet your published design is for 3.5 and 6.0 waves respectively. What gives?"

The original Laport material described an antenna that was optimized with 3.5 and 6 wavelength legs, respectively. The antenna was "modeled" in the 600 MHz region, and then constructed in the 8.5 MHz region. For the particular real-world use RCA intended in 1959, the Laport design was utilized on a trans-Atlantic path where the incoming wave front was around 7.75 degrees above the horizon. Laport reported in 1960 that as the operating frequency of the 8.5 MHz Rhombic increased and the leg lengths stayed constant at 3.5 waves and 6.0 waves at 8.5 MHz, the vertical angle of radiation dropped, so that at 12 MHz

RHOMBICS POST SCRIPT

Fine Tuning The October *CATJ* Report On Rhombic Antenna Design

(or 141% of the design frequency) the maximized radiation that had been measured at 7.75 degrees at 8.5 MHz was now lowered to 6.5 degrees above the horizon.

But all of this was based upon a fixed, pre-determined height above ground. For a height of 1.53 wavelengths at the design frequency of 8.5 MHz, the antenna with leg lengths of 3.5 and 6.0 wavelengths respectively produced a maximum radiated signal 7.75 degrees above the horizon. As the leg lengths increase with operating frequency, and the effective height above ground increases with operating frequency, the vertical angle of radiation comes down.

You can achieve the same effect by simply raising the Laport design above ground and leaving the operating frequency constant. The *ARRL Antenna Handbook* design, which is as noted 4.32 and 7.42 wavelengths respectively for L1 and L2, is for an on-purpose maximum radiation at an angle 7.5 degrees above the horizon at a height of 1.8 wavelengths. Our over-the-horizon signals, however, are either right at the visual horizon

or up to 0.5 degrees above it via the tropospheric scattering mode. So for our purposes, we want the radiation angle (i.e. maximum lobe) right at or on the horizon. This is achieved by simply raising the antenna high enough above ground that ground reflections are inconsequential. For the Laport design, this would be no less than three full waves above ground and preferably six waves above ground (see table 1, page 16, October *CATJ*).

Now it may well be possible that for your own installation, because of restrictions in obtaining adequate-height support poles and so on, that you cannot get that high above ground. The answer to this problem is simple enough, tilt the whole plane of the antenna down so that the nose portion (i.e. terminated end) is below a straight line drawn from the rear of the antenna (feed line end) to the actual visual horizon. There is some guidance in the Laport design data for this approach. If a 3.5 wavelength L1 and 6.0 wavelength L2 Laport Rhombic has its maximum radiation 7.75 degrees above the horizon at a

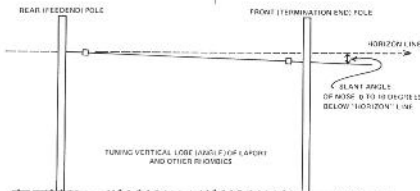


DIAGRAM 1

height above ground of 1.53 wavelengths, you can "steer" the maximum radiation angle back down to the horizon by lowering the front (termination) end by 7.75 degrees relative to the rear. This suggests that when you design your own Laport suspension system that you include an accurate way of determining when your nose is 1,2,3 etc. degrees (up to say 10 degrees) lower than the rear. Keep in mind you must lower more than just the front halyard lines. If the front lines are slacked off so the front support insulators end up 7.75 degrees (for example) below the straight line from the rear of the antenna to the horizon, then the side-pole supports, located approximately half way between front and rear, will have to be designed to slack off 7.75 degrees divided by 2, or 3.875 degrees. This will keep the "cant" of the antenna constant, from rear to front, so it forms a "level plane".

You may find, as many have in the past, your own "best performance" (which will depend

upon the height of the actual ground below your antenna plane, the terrain around you and the angle of your arriving signal) will come only after some experimentation. It would be best to select a "cant" or "slant" angle and set the array at that angle and then measure for at least an hour or more the relative signal level at that selected measurement angle versus a known test antenna (such as a yagi) at the same site. Then recant or re-slant the plane of the antenna up or down, and compare it for another hour against the reference antenna. After three or four such test-hours, you should find exactly where your own installation works best, and that may well end up being when the Laport rhombic does not cant or slant at all!

If this leaves you cold, you probably would be better off not playing with the Laport design. Remember, the performance difference between this 27.5 dB maximum gain antenna and a "store bought yagi" is largely

based upon the skill with which you design, erect and "tune" the Laport.

Finally, keep in mind that with the 3.5 and 6.0 wavelength per leg Laport design described in the October CATJ, the vertical beamwidth is only 6 degrees. That means that 3 degrees above the plane of the antenna and 3 degrees below the plane of the antenna the maximum gain realizable is not 27.5 dB but 24.5 dB (i.e. 3 dB points). So if your radiation angle is 7.75 degrees above the horizon, you are down in signal response around 6-8 dB at the horizon itself. This is a needless waste of 6-8 dB of antenna gain; especially after you have gone to all of the trouble of installing the Laport to begin with. So before you get all done, if you have any reason to suspect performance is not in the 27 dB gain region, re-adjust the antenna plane and make some reference readings as outlined here. You may have another 6-8 dB of real gain just waiting for you to drop the nose a few degrees!

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