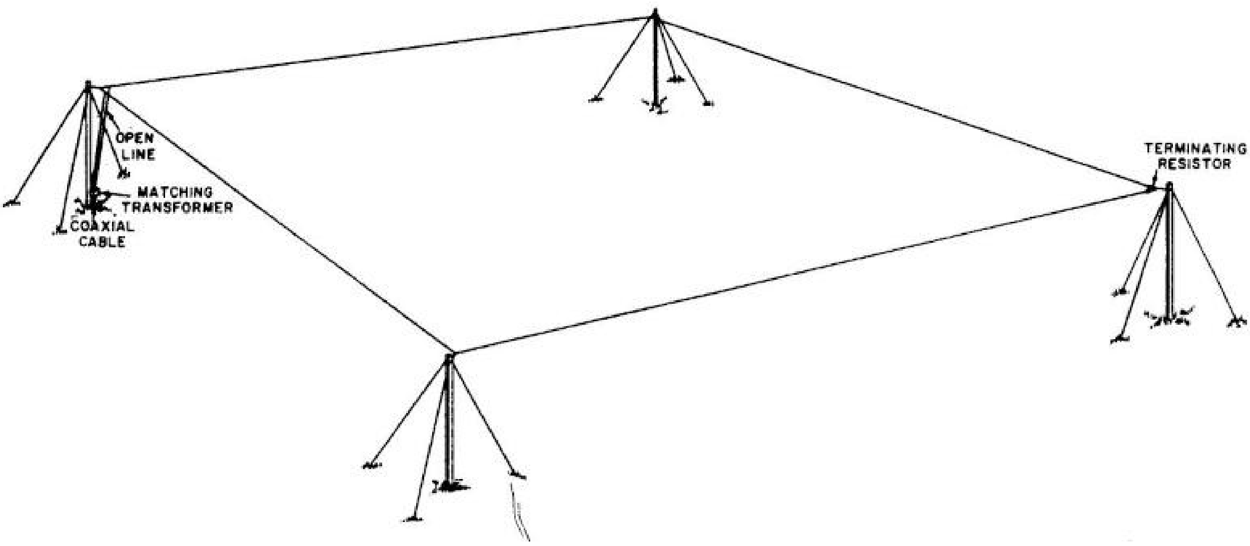
The Queen of Antennas



We built a rhombic antenna, 50m per leg, a bit over 90m in the long axis, 42m across, including insulators and distance to the masts. Here is how we went about it. It takes about 3 weeks to build this:

This antenna project uses only materials available in a farmer's co-op or a proper hardware store, and a electrical supplier. All great projects start with someone digging a hole, only for it to be filled again with concrete. Keeping it simple, start with two full wheelbarrows of concrete per hole, this will accommodate a tilt-over 12 meter guyed mast. Note the early emphasis on using concrete: sledge hammer driven stakes holding up the masts are not safe for this type of antenna, a rhombic antenna presents a considerable wind load.

A guyed mast needs anchor points to tie at least 2 layers of guy wires.

The masts are then raised with the aid of a gin pole, making it light enough for a reasonably fit person to right up the mast, while a second person keeps a close eye on the proceedings, and deals with the guy ropes. Don't fight gravity - make it work for you.

Apart from the copper wire for the antenna itself the preparations will make for a substantial part of the overall costs. Earthing and lightning protection must be taken into account, safety is -not- an afterthought. Plan 'larger' than for what a single vertical antenna needs: consider lateral pressure - a storm will try to shift the whole thing sideways.

It involves a lot of walking back and forth to get everything in place. before we started with the actual antenna a number of trees, bushes and over-hanging branches were turned into fuel. Without clear paths to raise the masts and wires the construction would have taken a lot longer.

The shopping list:

- A one ton big-bag of mixed aggregate. Mortar sand, mixed with whatever clean gravel and stones found while digging the foundations will be fine, too. Use clean water, non-chlorinated if in any way possible.

- Around a dozen bags of cement, depending on the ground and the size of the holes and your enthusiasm at the cement mixer. One shovel of cement for four of five shovels of aggregate. A liquid mix is easier to pour, but takes a lot longer to set and is not as strong.

- Ferrous metal for strengthening of the foundations. It doesn't have to be a pretty cage made from re-bar: scraps of chicken wire, tie wire, anything not too chunky that can be encased by the concrete. Drive spikes into the ground inside the prepared holes, like an inverted hedgehog, it helps anchoring the foundation.

- Something that can be used as mast hinges, holed pins for agri-trailers sunk into the concrete, or two short stubs of scaffold pipes or galvanised angle iron side-by-side work well. Drill the hinge holes after the concrete has well set, or make sure that the pre-drilled stubs are straight and level, and stay that way when the concrete is filled in, e.g. by laying out the lower pole, already attached to the hinge.

- Scaffold pipes. 45mm thin-walled pipe will take a 41mm thick-walled pipe to form a telescoped mast. The burr inside the wider pipe needs to be filed down a bit. About 15cm insertion is enough. The thicker pipe on top will be as heavy as the thin-walled pipe at the bottom, but that has not caused any headaches. Other combos that fit snuggly are hard to find - unless one can weld in-situ. We're limited to using nuts & bolts, being off-grid excludes using an arc welder.
  Wooden masts with nail-on steps are electrically preferable, although vertical steel masts show little or no interaction with a horizontally polarised antenna - unless it's an inverted-V.

- Insulators. Plastic fence-wire insulators are fine for the sides, for the ends we used large glass & ceramic insulators, because we had them. Plastic for all sides should be fine too, as this type antenna does not have excessive voltages at any point. At least a dozen insulators are needed, likely more, depending how the feed-line is tied off.

- Wire. Probably not the best long term solution, but a good conductor: stranded insulated wire, as used in domestic wiring. 1.5 square mm is light and cheaper, but likely to break in a storm. 2.5 square mm is noticeably heavier, will sag a bit in the beginning as it stretches out, but will endure a storm. Copper plated welding wire is probably fine until corrosion blooms through, getting it 'up there' is a nightmare, trying not to kink or tangle the wire is nigh impossible. Galvanised fencing wire has a more losses than copper, at low frequencies the antenna current will penetrate deeper into the lossy iron core beneath the thin outer layer. But it's far cheaper, easy to solder when fresh, yet one loop pulled into a kink is the end of that piece of wire. Using several wires in parallel will reduce the losses, but raising and lowering several of those springy wires will quickly produce a messy tangle. Don't forget the wire needed for the feed-line and termination-line. Aluminium is not suitable as an antenna material, surface oxidation makes good electrical connections short-lived.

- A meaty soldering iron, and lead based solder - if you can get it. Solder based on silver alloys is brittle and crumbles under strain. Buying a 500m reel of wire avoids having to solder critical spots and having to make them watertight, if possible, make the antenna and feed-line out of one piece.

- A termination resistor and a box for it. See below.

- Tent poles. Festival aficionados are encouraged to scour the camp site on a hungover Monday morning for fibreglass tent poles. Or think of some material that can be used for the spreaders of the feed line.

-Either a 9:1, or a 4:1 balun, or no balun, depending on how the antenna is fed. A balanced tuner is good to have handy for the initial setup, but not strictly needed. Depending on the type of feed-line used: some extra 50 Ohm coax for a choke balun.

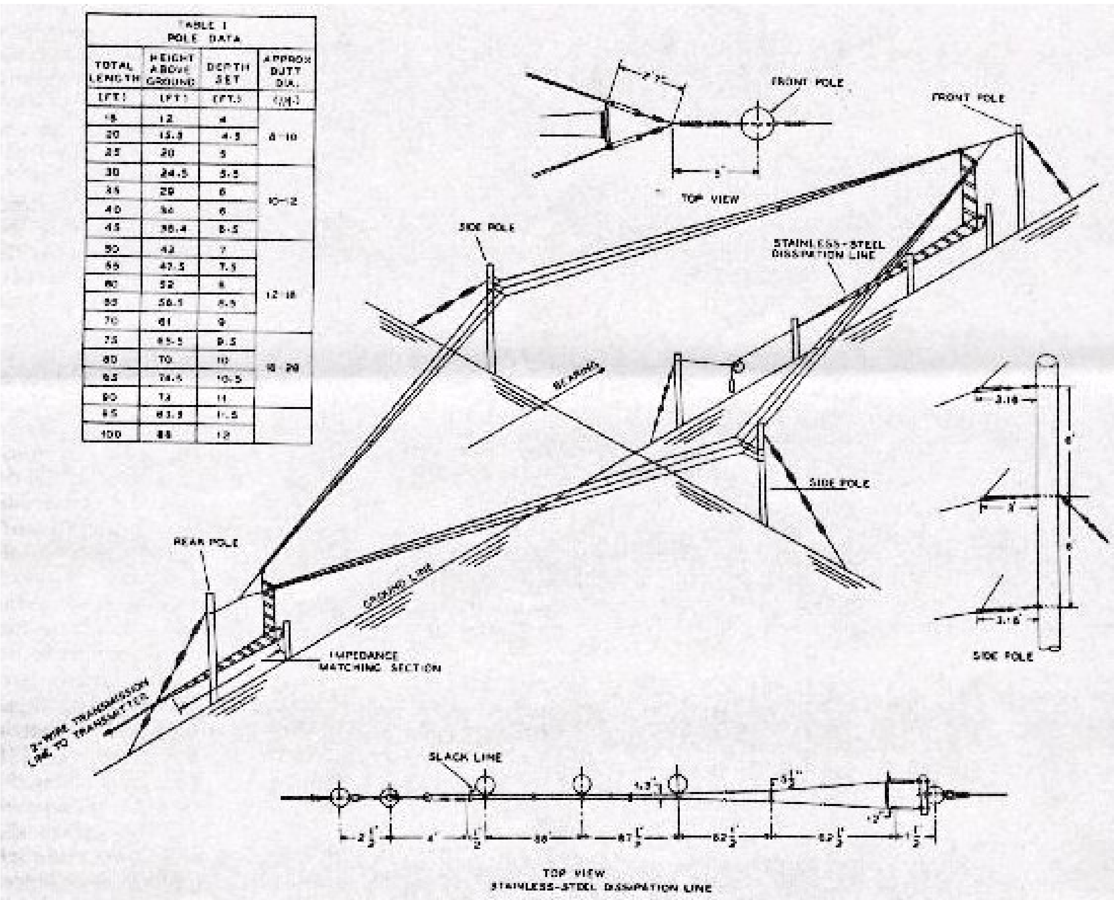
- Nuts and bolts, long enough to form the hinge pin, bolting the scaffold poles together, and for tie points for the guy wires.

- Guy wires or platted non-stretch ropes. Single throw twisted rope stretches and twists under load. Four 12m masts with 8 guys each require at least 400 meters of rope or wire. Plus enough rope to raise the masts. There is less waste when starting with a 500m reel, Using 100 or 50m reels mean a lot of cut-offs. Rope soaks water, creating some hard to specify losses in the antenna. Wire guys need to be broken up into non-resonant lengths with insulators - or they become part of the antenna. Manufacturing wire guys is very time consuming, and require hundreds of wire clamps. Stranded soft galvanised wire, as used for chimney lashing kits, can be spliced around the insulators - much more elegant and durable.

- Pulley blocks. Avoid anything that has a gap between the wheel and the casing. Deep grooved wheels will cut into the rope. Smooth eyelets are preferable to bad pulley blocks, at least for raising the wires at the sides. The feeder side is fixed to the insulators and raised first, then the sides - the still slack antenna wire slips through the side insulators, then the down-hill insulators are raised, the wire is allowed to the slip through the insulators, then the whole lot is tensioned from the terminated side by pulling the antenna wire down to the termination box.

The technical bit:

The commercial and military operators of yesteryear left behind a wealth of documentation about practical designs of their antennas, from ad-hoc tactical field installations to permanent multi-rhombic arrays used for the early transatlantic telephone circuits.



Translating those instructions into practical ham-radio antennas means not only scaling down the size, but also getting familiar with concepts of the feeder arrangement and termination methods.

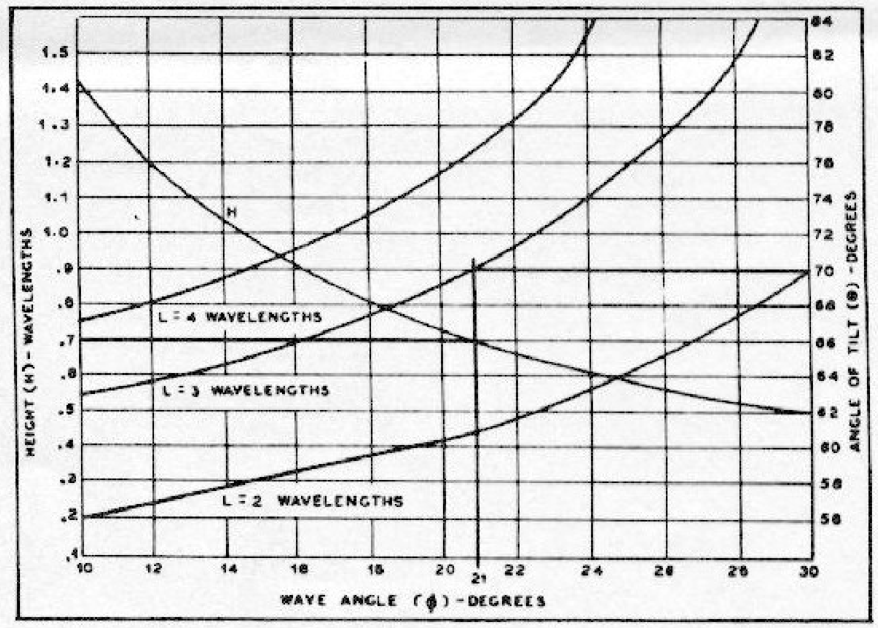
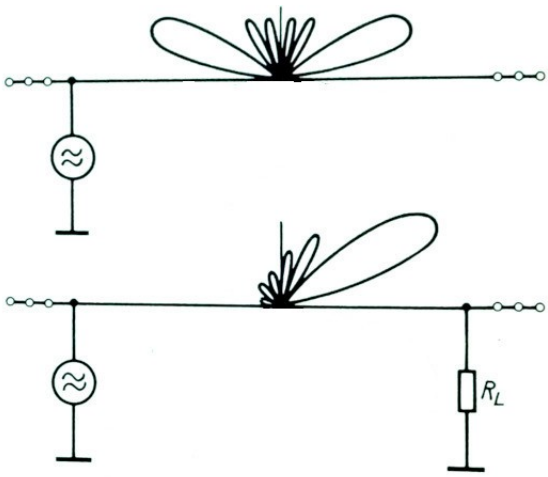
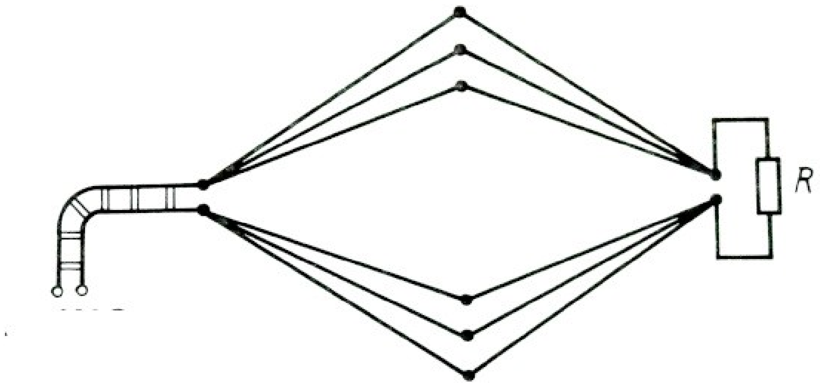


Figure 191. Design Chart for Constructing Rhombic Antennas by the Compromise Method. If the length (L) and either the tilt angle (θ) or wave angle (φ) are known, the other dimensions can be found.

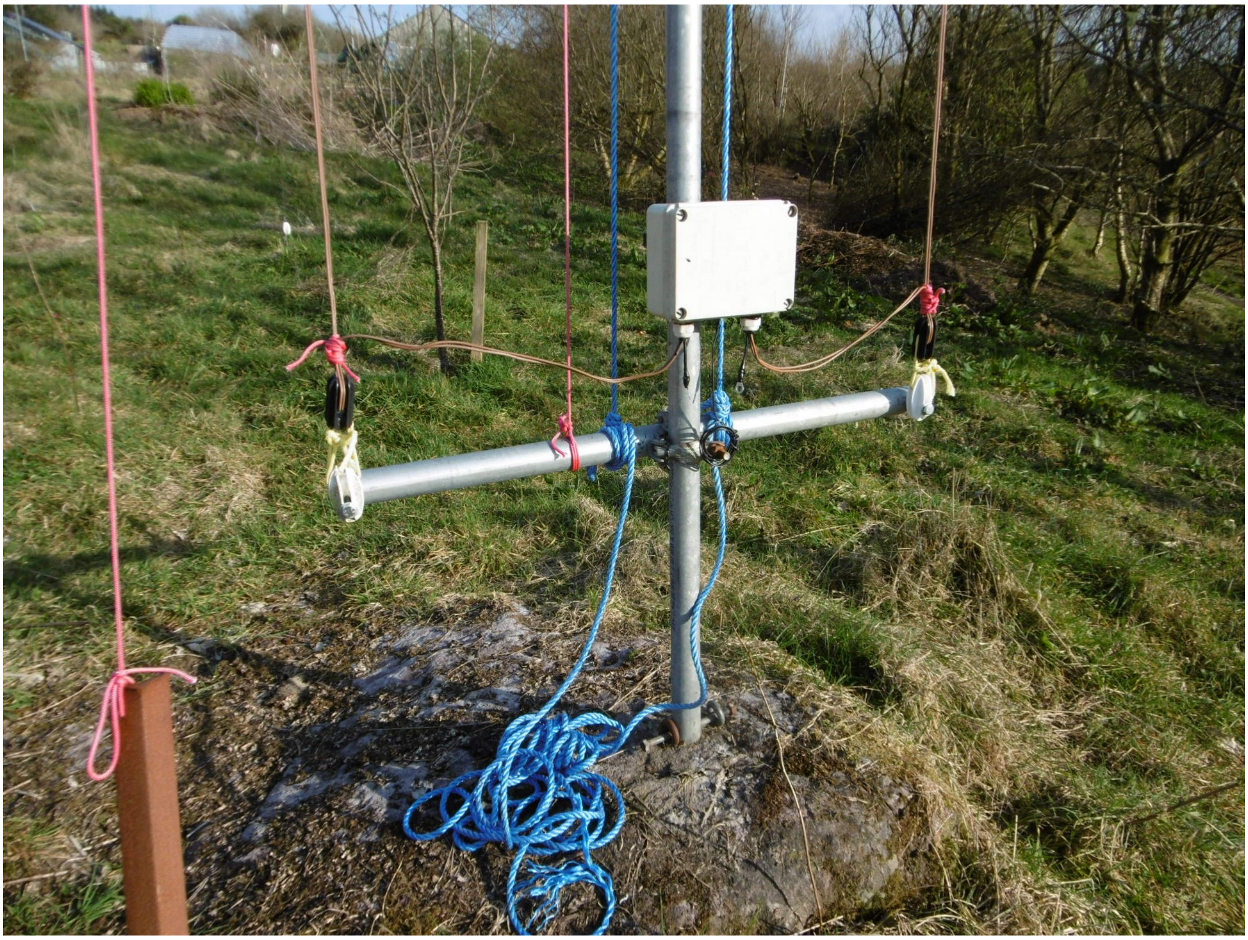
A single 1/2 wave element radiates perpendicular to the wire. When extending the wire to several wavelength the individual lobes combine, some cancelling out, some adding up. Due to the delay as the current flows along the wire, those lobes combine into a cone of radiation towards the end of the wire. Reflections from the ground combine with that cone of radiation, leaving two distinct main lobes along the length of the antenna. A longer wire has a lower angle between those two lobes. The angle is therefore dependent on the number of wavelengths on the wire. Arranging four long-wires into a diamond shape combines the individual pattern from each wire into one direction, while cancelling out the unwanted directions. An open-ended rhombic radiates most energy in the forward direction, whatever power has not left the antenna will travel back towards the feed-point, creating radiation towards the rear of the antenna and is accompanied with frequency dependent SWR swings. Connecting a resistor to the open ends at the far side will 'swallow' any power that would otherwise return to the feed-line. This suppresses all rear lobes, and makes the SWR a nearly flat line.



The Impedance of a terminated rhombic is somewhere between 400 to 800 ohms, depending on the height and ground conductivity. Using two or more wires per leg lowers the impedance and tames the impedance swings.

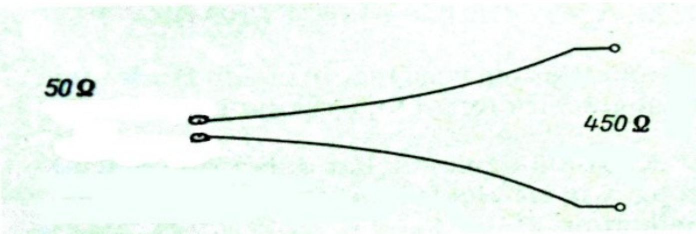


The termination resistor must be non-inductive, otherwise it becomes a frequency dependent component. 22 pieces of 2 Watt 10 kiloOhm metal-oxide resistors in parallel are about right for a 100 Watt transceiver. The resistor does not have to dangle high up in the air, one simply runs an open-wire feeder to a box at ground-level, allowing for easy access to tinker with other resistor values until the SWR is flat, and it allows for a switch or relay to switch between bi-directional and directional mode.



When terminated there is no resonance point. When un-terminated there will be several resonance points: the ends can be either left open or shorted, allowing to shift those resonant points. Adding an open or a closed stub fine-tunes the resonance points.

The 'feeding of the beast' can be done with a traditional open-wire feed-line and a balanced tuner, or with a 1:9 balun, assuming the impedance to be around 450 ohms - a good approximation in most cases. A more elegant solution is to use an exponential- or linear-taper feed-line: Starting wide at the feed-point and exponentially narrowing the distance of the feed wires towards the transmitter.



The impedance of the feed-line is continuously transformed with such a taper, provided it's a continuous taper of at least one wavelength at the lowest frequency in use. The distance at the connection point at the antenna is not critical, as long as it's continuously narrowed to the point that the insulation of the two wires are touching, like loud-speaker leads, with an impedance of 50 ohms.

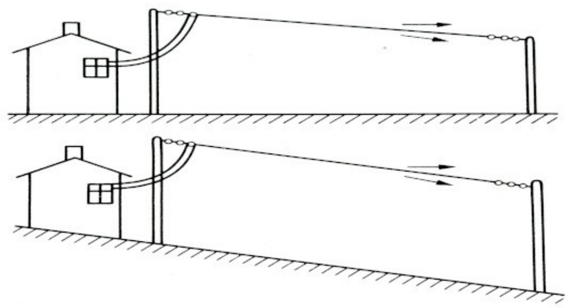
The feed-line can take gentle turns, a zig-zag may be the only way to fit the length of the tapered feed-line into the available space, or to reach the entry point to the shack. Note the transition from fibreglass pieces to ceramic strip-connector blocks, decreasing in size towards the coax-choke at the entry point.

All that's needed at that point in either a 1:1 balun or a coax cable choke. It is difficult to achieve and maintain that geometry with a tapered feed-line of 40m length. A wider taper to 200 Ohm for a 4:1 balun is mechanically simpler: at the low impedance end the ratio of the wire-diameter to the centre-to-centre distance is 1:3. With either version the SWR is on average 1.5 : 1 from 160 to 10m, never rising above 2:1 outside the bands - no tuner needed.

Making or finding a commercially made balun that -really- covers 160m to 10m can be a challenge. The 50 Ohm ‘straight-in’ version will allow medium- and long-wave signals to reach and possibly overload the RX, whereas a balun will act as a high-pass for those unwanted signals. Unless a straight 'Chicken-Ladder' is used, it turns out that the distance at the antenna side is not critical, the splayed out legs of the antenna present themselves as an extension of the tapered line - there is no distinct 'feed-point'. The actual distance is likely dictated by the positioning of the insulators.

In Daily Use:

At 50m per leg and an apex of 45 degrees it's a good compromise for 20, 17 and 15m, with a razor sharp beam and high gain. At higher frequencies the main lobe starts to split up into a useful broader pattern, and there still is a lot of forward gain. On 60, 40 and 30m it's also giving a lot of gain while the take-off angle rises, as with all antennas at that height. On 80 and 160m it turns into a NVIS cloud-warmer due to the limited height of about 12m. Our site is sloped towards the northwest with a clear take-off at 300 degrees. Sloping a rhombic, vee-beam or single long-wire lowers the take-off angle in the forward direction.



Each side has two wires in parallel, lowering copper losses, improving the bandwidth and taming the impedance swings, at the expense of some extra height. Commercial operators used up to five wires, vertically spaced at the sides, and joined at the start and end of the antenna.

It's a lawn-scorcher in North- and Central-America, routinely outperforming high-power stations in pile-ups -within- North America, one quickly get's used to having to call only once to be heard. Reception is much clearer compared with other end-fed single wires and verticals we use here. Western Canada and South America are also well covered, likely from the secondary lobes. Using a 17m band 5/8 wave-length vertical on a large low apex metal roof as reference, the rhombic shows a forward gain of around 18 dB over the vertical. Switching off the termination by feeding DC through the two legs to a relay at the far end makes the stations from the south-east appear, but from a higher incoming angle due to the slope of the antenna. Plenty has been written about the optimum angles, tilt and height of rhombics, but just fitting this large type antenna will likely force a compromise in height, size and angles.

Ei5LC & Ei4KU , July 2022

Literature consulted for the design of this antenna:

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