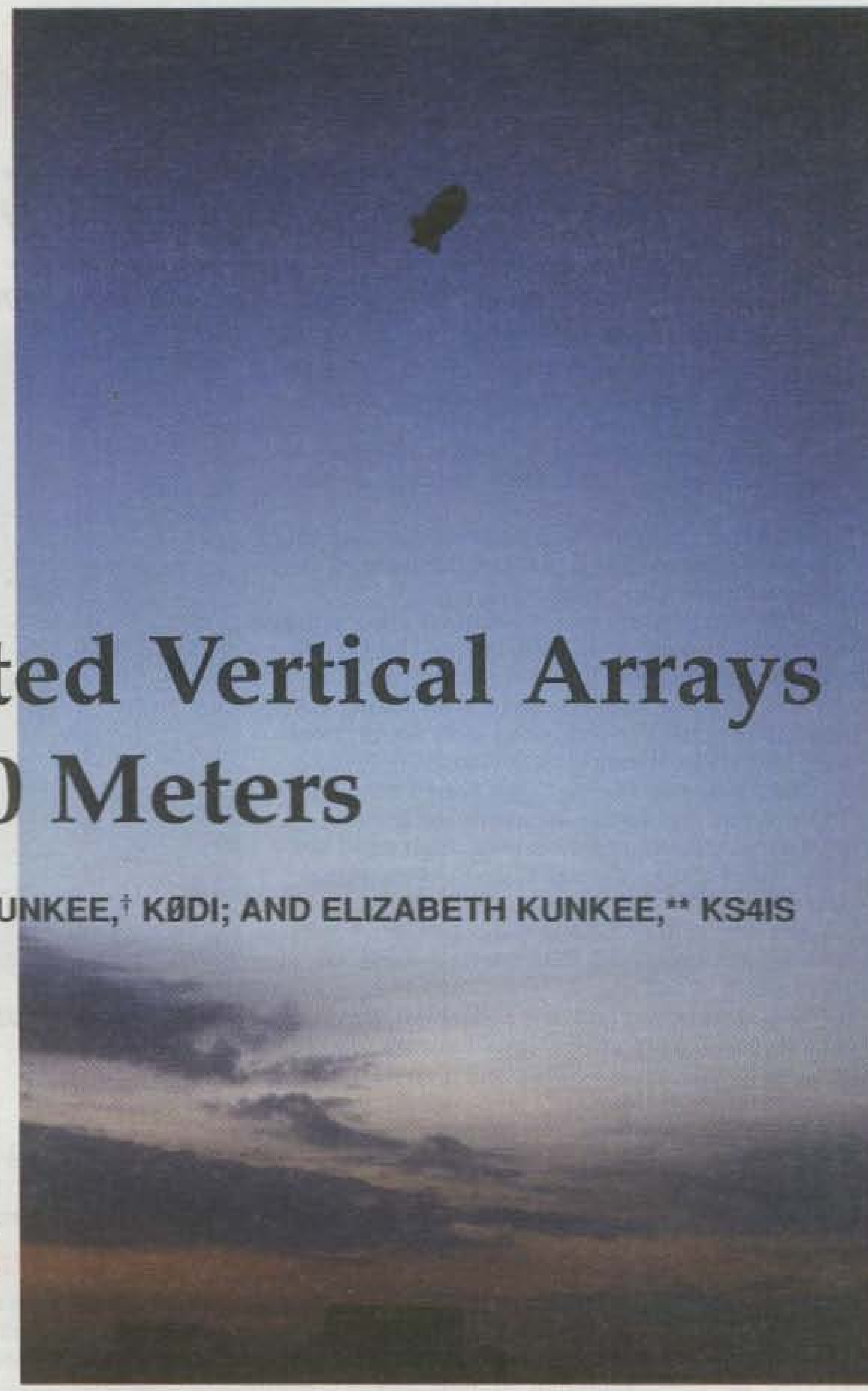
Antennas for 80 and 160 meters are long, which means they usually need a fair amount of space over which to spread out. However, if your horizontal space is limited, you might think about vertical space. . . . That's right; look up!

Balloon-Supported Vertical Arrays for 160 Meters

BY PETER M. LIVINGSTON,* W3CRI; DAVE KUNKEE,† KØDI; AND ELIZABETH KUNKEE, KS4IS**



On the air with the balloon-supported vertical antenna at sunset during the 2001 CQ World-Wide 160 Meter Contest.

Have you ever wished you could set up a low-emitting-angle vertical array for the long wavelength bands? Work all states and a few foreign countries on 160? "Sure," you say, "I just happen to have a spare back 40 acres, an infinite supply of money, and hundreds of ground wires forming the counterpoise!" It's true that this project can't be done for a 10-dollar bill and a little time, but it is within the capabilities of many clubs. With all preparations in place, we can erect and take down this two-element vertical array in a little under two hours, making it ideal for Field Day, 160 meter contests, and emergency operation (see photo A).

This article will tell you how we of the TRW Radio club did it and with what results. First, however, here is a little background on how this project got started.

Some Background

I (W3CRI) began experimenting with antenna designs about five years ago when I bought Roy Lewallen's EZNEC, an easy-to-use, Windows®-oriented, antenna-modeling program. Although I have been licensed continuously for slightly more than a half century, I was inactive for many years and recently came back to active ham status—to a completely changed amateur radio vista.

As a teenager, I saved up my paper-route money to buy military-surplus gear, which I modified and put on the air mostly on 80 and 40 meter CW. In those days, stripping down a surplus chassis and building your own transmitter was fun and gave us an outlet for whatever creativity we could bring to bear. After waking up from a 30-year snooze like Rip Van Winkle, I found that amateur radio had changed completely. Rigs are almost 95% professionally built, and the technology no longer prizes 807 and 813 transmit tubes as it did back then. In fact, many hams may not even recognize these tubes!

After getting reacquainted with the hobby, I cast around for the modern equivalent of rig building with surplus parts. I found that there still were a lot of wire-antenna ideas waiting to be invented, so I happily set about my new amateur radio hobby! I experimented with fat dipoles, and fat deltas, mostly on paper, until I met Dave and Elizabeth Kunkee, members of TRW's radio club. Dave had bought a small aerostat (balloon) and had used it for several years to hoist a quarter-wave vertical anchored by a mag-mount to the roof of his auto for the annual international 160 meter contest.

I persuaded Dave to loan the balloon to the club for the year 2000 Field Day. He complied, and with it we hoisted an open-

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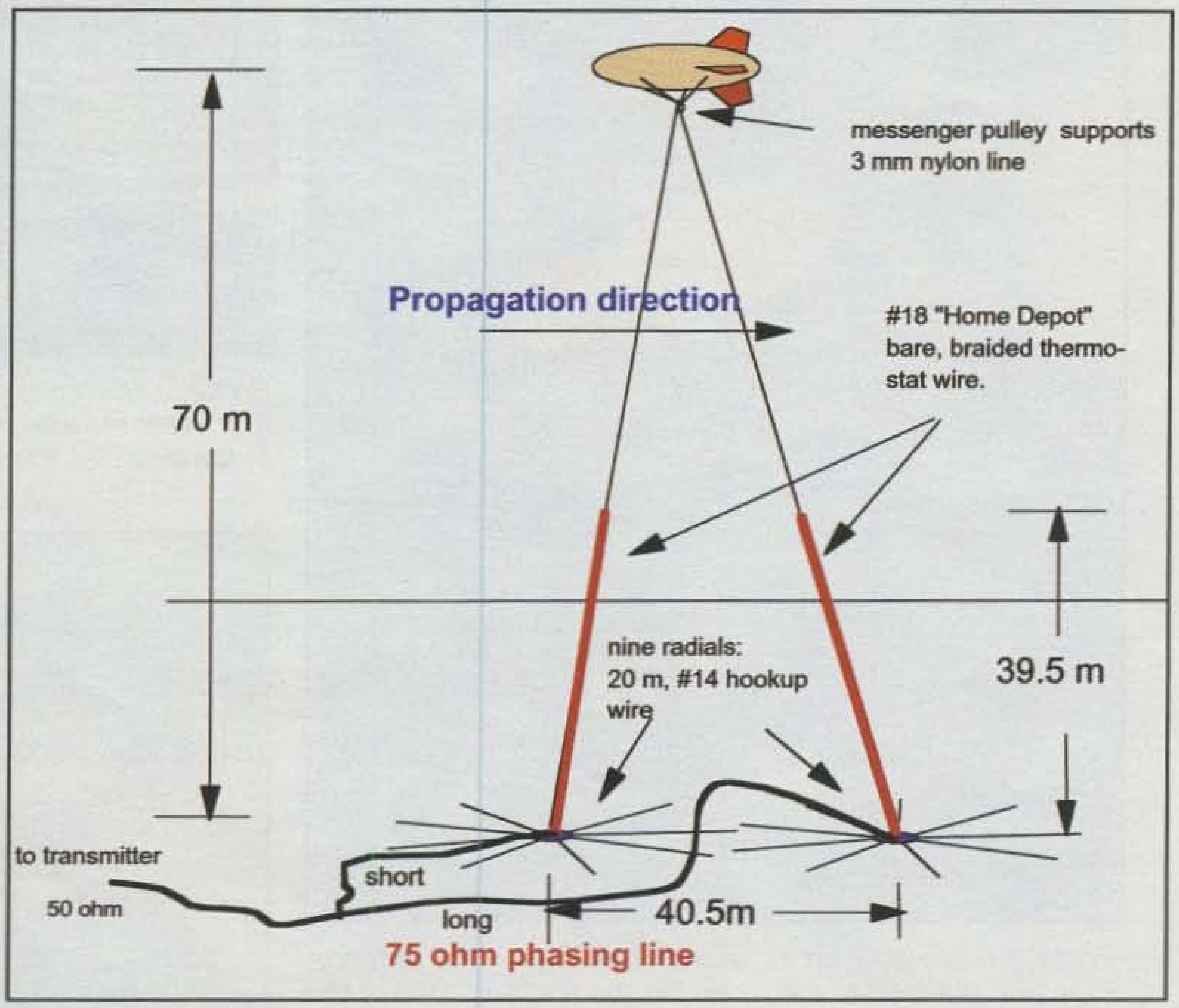
Photo A– The authors operate various 160 meter contests from the shore of the inland Salton Sea, using a rental truck to transport their equipment, including the aerostat (balloon) to support the antenna.

Fig. 1– Schematic illustration of the balloon-borne, two-element phased array designed and flown for several contests and during the last Field Day in a scaled-down 80 meter version.



topped, corner-fed fat delta of my own design for 80 meters. It worked, but it wasn't clear that all that extra wire had much of an advantage over a simple quarter-wave vertical and ground plane.

After Field Day I went off to mull over why the delta didn't do much better than a quarter-wave vertical. It should have, because as I later deduced, the two arms of the delta acted as a phased array with the bottom of the delta as the phasing line between them. However, if that was the case, maybe it would be better to just consider a vertical phased array instead.

How High Should It Be?

Now vertical phased arrays are not new; two- and four-element vertical phased arrays are described in the ARRL's *Antenna Compendium*, for example. The wrinkle in this case was that we had only one point of suspension causing the two phased elements to "lean" toward one another. Obviously, the higher the balloon, the more vertical the wires would be. The design question was, "How high must the balloon be in order to get a decent front-to-back ratio?" We'll answer this question in the following paragraphs.

Fig. 1 shows a schematic of the balloon-borne, two-element phased array that formed the basis for a NEC-2 analysis (EZNEC 3.0 for Windows®).

While Dave's balloon might have worked, we all thought it was too small to give us adequate lift margin to support phased arrays. After some research we settled on the balloon described next.

The balloon, or aerostat, that the club bought is an aerodynamic lifting body buoyed by helium, the same type commonly seen carrying advertising above large auto dealerships. Unlike a round balloon, this blimp structure is very stable in moderate to strong winds, because air flows around it without creating excessive vortices in its wake. Aerial Billboards, Inc.[1] built our aerostat out of 150-denier nylon coated with urethane. Its 18' × 7' size contains 380 cubic feet of helium at full inflation, which takes about two-and-a-half helium cylindrical tanks filled with welding helium to a standard pressure. Although the balloon can be filled without a gas regulator, it is somewhat more risky to do so, and we highly recommend that you use a gas regulator[2] with the helium gas cylinders. As with all high-pressure gas cylinders, there is an element of risk in handling them, so be well aware of how to handle these gas cylinders safely.

There is a harness attached to the aerostat as shown in fig. 1 and photo B. We used a pulley and swivel to attach the antenna apex to the balloon. For the most part, motions of the dirigible back and forth, as well as "clocking" rotations, did not result in antenna-support fouling.

The net lift of the balloon is about 16 pounds in still air and somewhat stronger with the wind blowing because of aerodynamic lift. Not shown in the drawing, but visible in photo B , is a very important safety tether, which although slack, nonetheless would have prevented our balloon investment from tak-

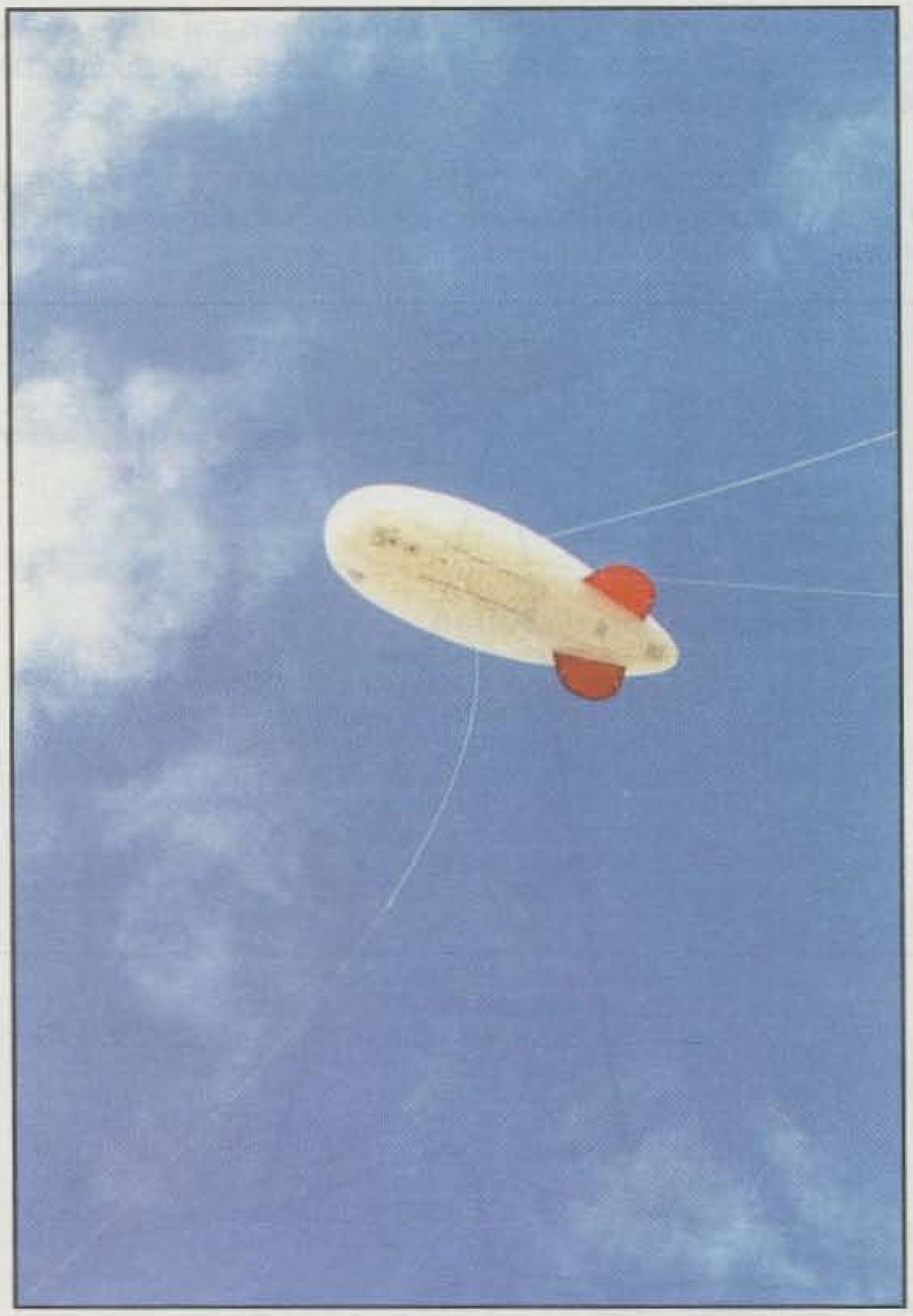


Photo B– The balloon, or aerostat, in flight. The antenna lines are attached to the nylon via the first and third of the lines running up to the attachment point. The middle line is a 400 lb. test nylon safety tether.

Photo C– Bringing down the balloon after a successful contest. Note the size of the man (co-author W3CRI) compared to the aerostat, the technical name for a balloon of this type.

Photo D– Co-authors KS4IS and W3CRI force helium out of the balloon by lying on it and pushing, a process that takes about 40 minutes to empty the gas bag. A vacuum cleaner would have been much quicker...

ing off for Kansas had the antenna wire parted. Pulling down the balloon and deflating it requires careful effort (see photos C and D).

I found that Home Depot sold a #18 braided copper wire used for some sort of ground strapping for low-voltage house (thermostat) wiring. A 42.1 meter length of this wire tied to a 3 mm nylon line having a total length necessary to allow the balloon to fly at an altitude of 70 meters (230 ft.) formed one side of the vertical array "triangle." *Flying the balloon at this height requires permission of the FAA.* We found the FAA at our local airport very cooperative when we flew a reduced version of this vertical array for Field Day last June. I gave them several days notice and received permission easily and well before Field Day. After September 11, it is possible that it now may take longer for permission to be granted, so allow plenty of time to "cross the t's and dot the i's."

As mentioned above, the balloon height of 70 meters for the 160 meter vertical array is not arbitrary, but was decided upon by setting up the antenna in EZNEC for various suspension heights. We chose each antenna base to be made up of nine radial wires (#14 insulated hook-up wire) each cut to 20 meters (65.6 ft.) long. (More about the radial choice below.)

We compared vertical radiation patterns for identical antennas suspended at several different altitudes (see fig. 2). It turns out from this study that nearly full vertical phased-array performance is recovered if the angle that the antenna makes with the ground is 74 degrees or greater. However the fact that 70 meters is the right balloon altitude does not mean that 140 meters will give twice the performance. A little trigonometry will convince one that the cost of the added tether and support weight will offset any marginal gain increase.

The Site

Hoping for better conductivity to give us a low radiation angle and high efficiency, we chose our 160 meter contest site at the shore of a large inland salt-water lake in southern California called the Salton Sea (see fig. 3). The area is a broad salt plain about 200 feet below sea level formed from an ancient inland sea that dried up millions of years ago. An accidental levee collapse filled this 14 × 7 mile long lake in 1905. Presently, Salton Sea State Park occupies its eastern shore, where we flew the balloon for the CQ World-Wide 160 Meter Contest

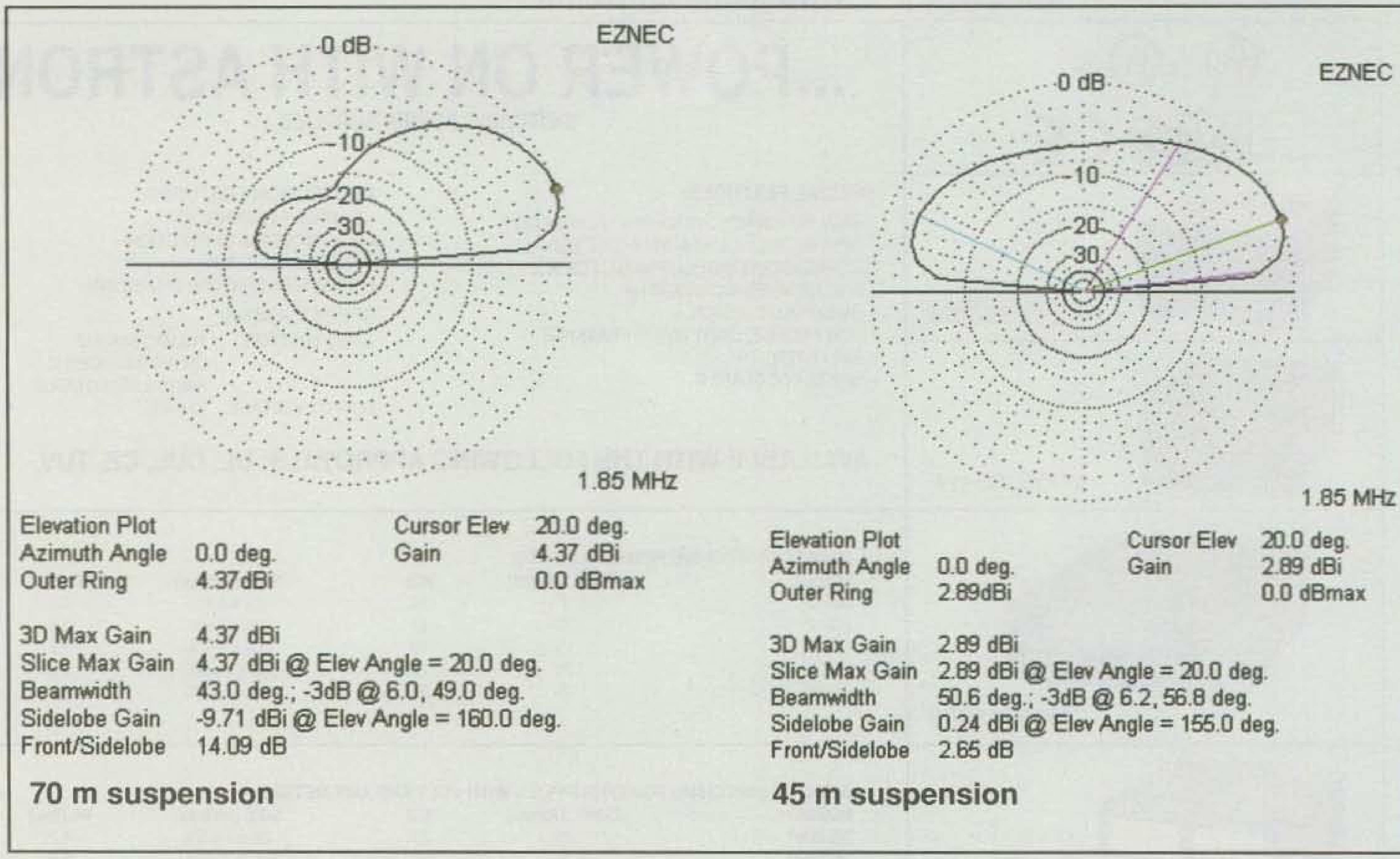


Fig. 2– Comparison of front-to-back ratio of antenna array at different altitudes. Note the significant loss of F/B ratio when the height is reduced by a factor of approximately 3/5, from 70 to 45 meters.

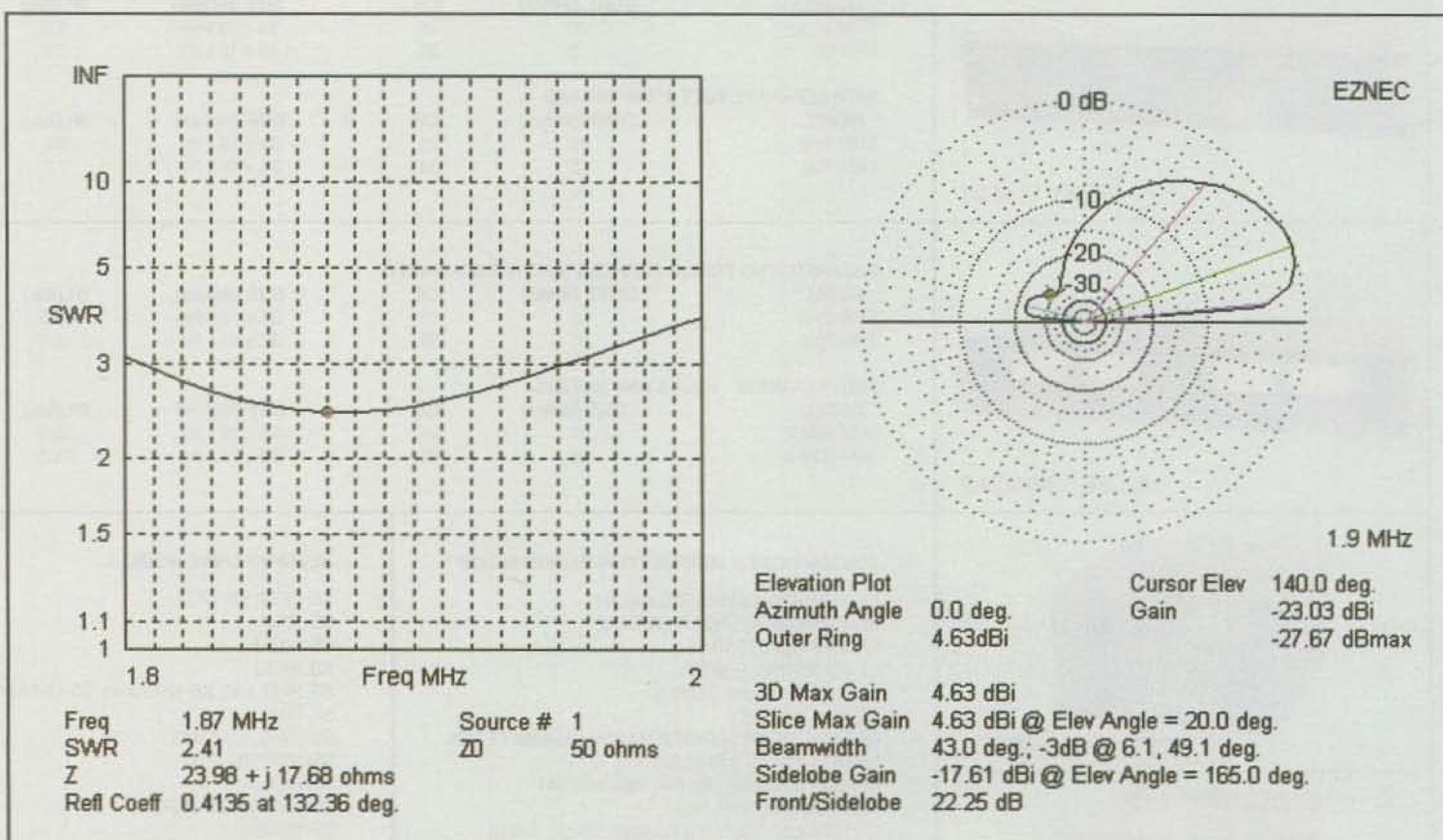


Fig. 3– Calculated VSWR curve (left) and ideal vertical radiation pattern of antenna array over real, high-precision ground with moderately good conductivity (right). Measured VSWR in use was substantially better than predicted. (See text for details.)

and the most recent ARRL International CW 160 meter contest. For our purposes, the site is electrically quiet (S5 noise background on the vertical), unpopulated, flat, and right on the shore of the lake. In fact, the ends of some radials actually were in the water. The park rangers were most cooperative and assisted us in setting up in an unused portion of a lakeside campground.

During the CQ WW 160 SSB Contest in February 2001, we did bring along a network analyzer, and after a bit of experimenting we got it to work. Our team, now including club member Wayne Hogenkamp, KI6GM, measured the base impedance magnitude and phase angle separately at each antenna. Fig. 4 shows a bar graph indicating efficiencies for our two-element phased array over various grounds. According to our measurements of individual antenna base impedances at resonance, we expected an antenna efficiency at the site of 0.65 or better. According to the bar graph, our measurement suggested a soil type somewhere between very rich pasture land and salt water.

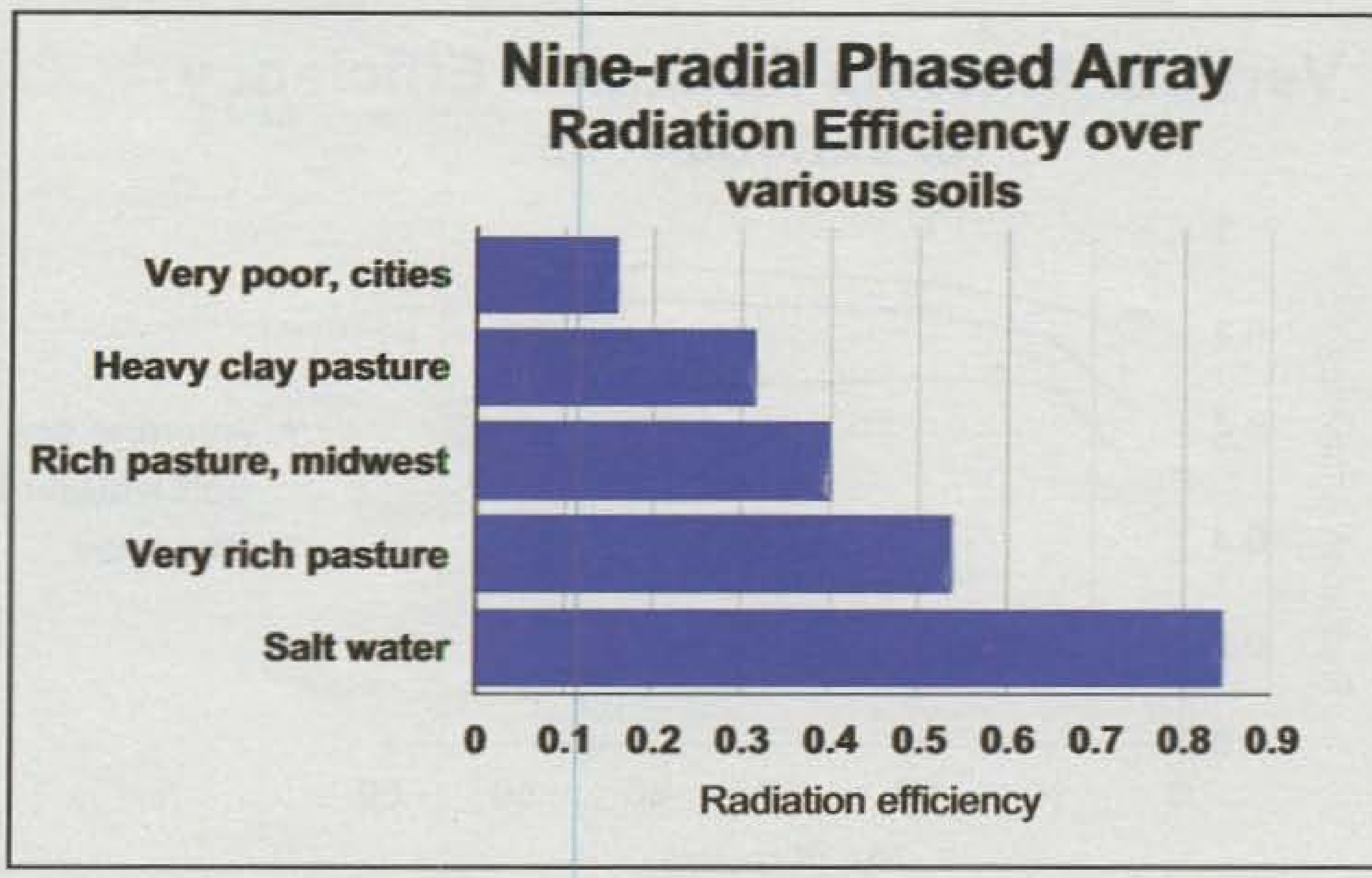


Fig. 4– Our two-element phased-array antenna efficiency as computed by EZNEC over various soil types. Given 36.5 ohms as the base impedance of a lossless vertical dipole, our measurement shows an efficiency of 0.65, which lies between "Very rich pasture" and "Salt water" as expected. Soil characterizations are those given in EZNEC.

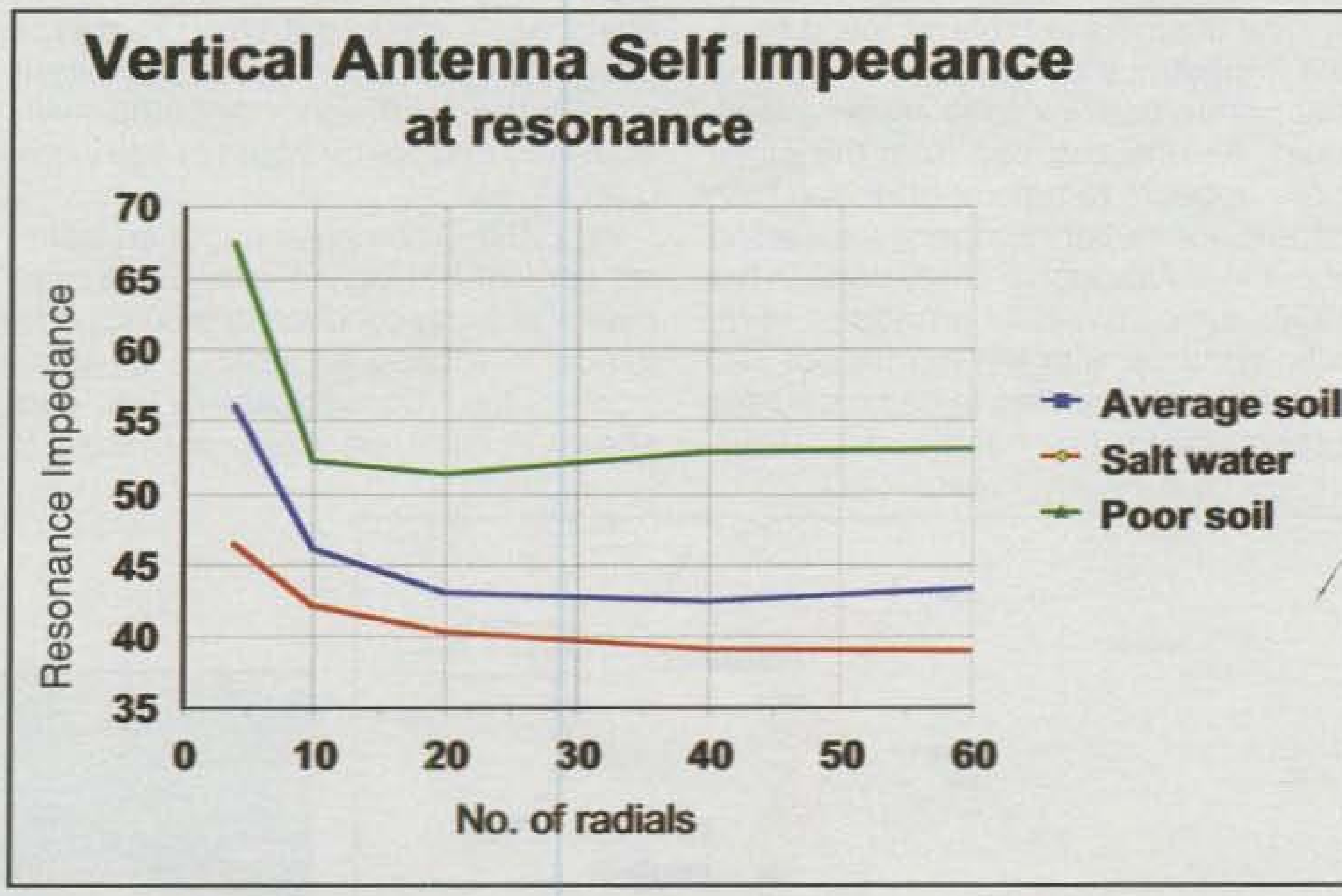


Fig. 5– Resonant self-impedances of an isolated vertical antenna, shown as a function of radial number and ground type. Note the diminishing improvement above about ten radials.

Antenna Specifics

The two antennas are driven out of phase by a nominal 90 degrees. (In fact, the EZNEC computation shows that the phase difference is more like 112.6 degrees for the maximum front-to-back ratio at the operating frequency.) In our case, the quarter-wave slanting "verticals" are separated by a quarter wave each. If each antenna radiates a nominally cylindrical wave, then the quarter-wave spacing provides maximum reinforcement of the overlapping cylinders in the plane of the antennas in one direction and a near cancellation in the other. In other words, the phased array is end-fired. As it turns out, our no-tune (described below) phasing lines connecting each antenna are unequal in length.

Avoid a mistake that cost us a few QSOs the first time we used it—connect the phasing lines correctly. For example, if the antennas lie in an east-west plane and you wish to beam east, connect the easterly antenna with the long line and the westerly one with the short piece. Array direction can be selected from the comfort of the operating position with a switchbox and three DowKey coaxial relays.

There are several ways to achieve an out-of-phase feed from a common source. One is to use a quadrature feed system shown in the *ARRL Antenna Book* (p. 8-14, fig. 17).[3] This method will guarantee maximum front-to-back ratio at any frequency within the antenna's operating range, but requires tuning. For contesting, we sought a phasing method that requires no tuning, even at the expense of optimum front-to-back ratio.

Roy Lewallen's article "The Simplest Phased Array Feed System . . . That Works,"[4] has the answer. We've elaborated some on his ideas in Appendix A, which appears on the *CQ* magazine website[5] as a companion to this article. For those mathematically inclined hams (I'm one) interested in the definition and computation of the antenna mutual impedance and the answer to the question "Why are the phasing line lengths different?" refer to the appendix.

The Radials

The last element of the antenna design to be discussed is the radial layout. Generally speaking, the self-imped-

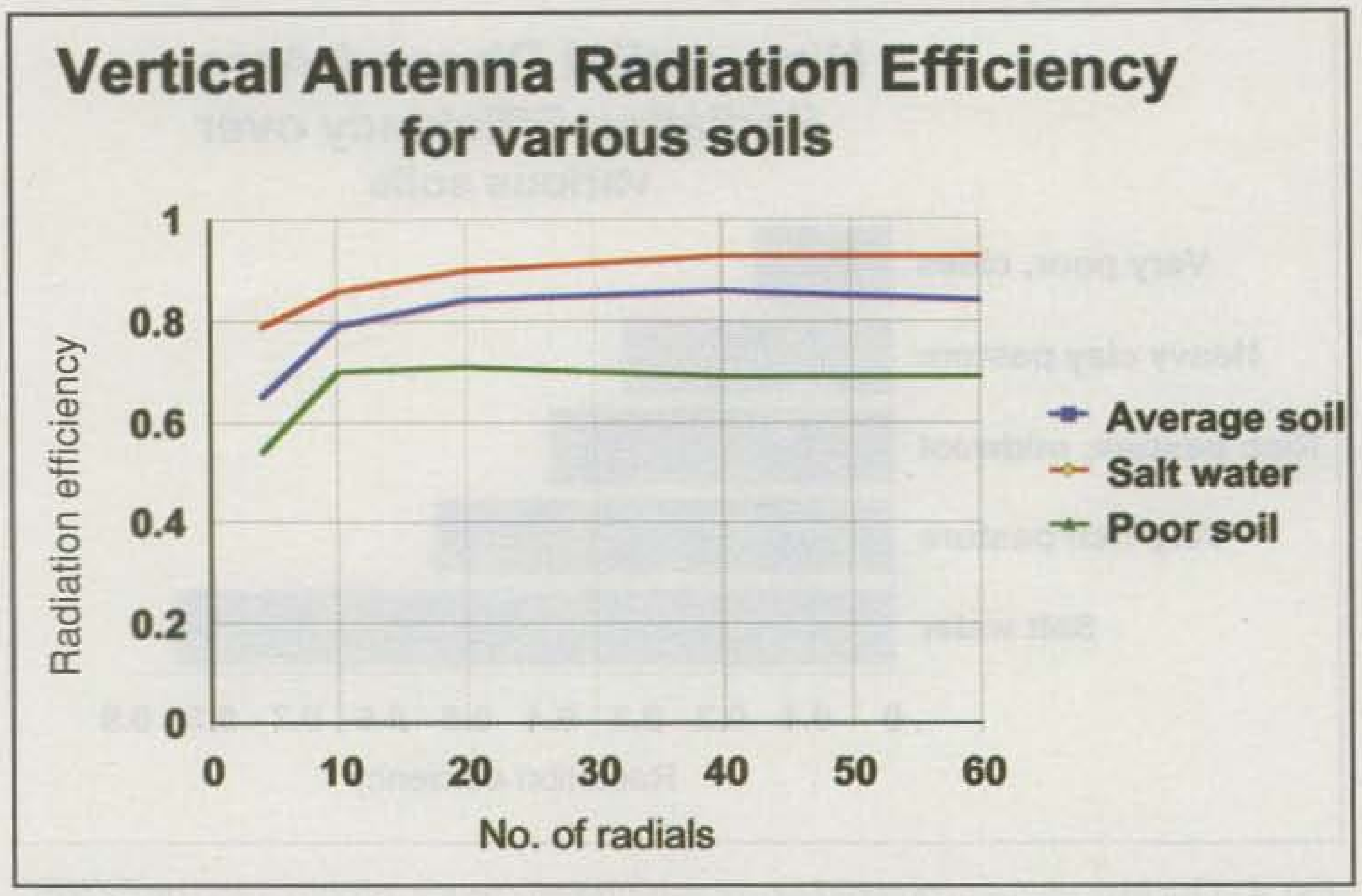


Fig. 6– Vertical antenna efficiency shown as a function of number of radials. Again, note that there is little benefit from having more than ten radials.

ance of an isolated vertical antenna decreases with added radials (see fig. 5). The desire is to have as low a base self-impedance as possible, indicating that non-radiative losses are at a minimum. As one can see from the plots, there appears to a point of diminishing returns for radial numbers exceeding about ten. Although a study done in the 1930s for commercial broadcast verticals came up with the number of 120 radials, there appears to be no detailed justification for that number over different soil types. It is also clear from the plots that one cannot completely overcome one's basic soil type. That is, a poor, low-conductivity urban soil will still yield a lower efficiency antenna array than very rich pasture land or salt water (see fig. 6).

An EZNEC computation for an isolated vertical having no resistive losses over a perfectly conducting ground plane indicates a base impedance of about 36.5 ohms. Consequently, the data shown in fig. 6 are easily converted to efficiencies by dividing the base impedances into 36.5 ohms. Again, the payoff for more than ten radials is relatively small and is worth the effort only if you are working QRP and need to make every milliwatt count. The curves do not cross, so according to this calculation, one cannot make up for poor soil by lots of radials. This argument does *not* apply to a true ground plane, such as screening or a chicken-wire layout.

Thus, based on the curves above, we selected nine radials per antenna as being the best compromise between handling ease and antenna efficiency. We attached the radials to a ground rod and the antenna feed at the feedpoint (see fig. 7 and photo E).

The VSWR performance of the array was quite a bit better than expected based on the EZNEC model. Fig. 8 shows a comparison of measurements made last January with the EZNEC prediction. We don't fully understand why this is so, but it may be that the random length of 50 ohm feed line partially compensated for some excess capacitive reactance presented to it by the antenna/phasing-line combination. Although we brought along an antenna tuner for the contests, we found that for the most part it was unnecessary.

It can't be expected that the antenna array and phasing line will provide maximum front-to-back ratio over the entire 160 meter band. However we found that we had good front-to-back behavior except at the high band edge. (*Note:* This estimation assumes phasing-line

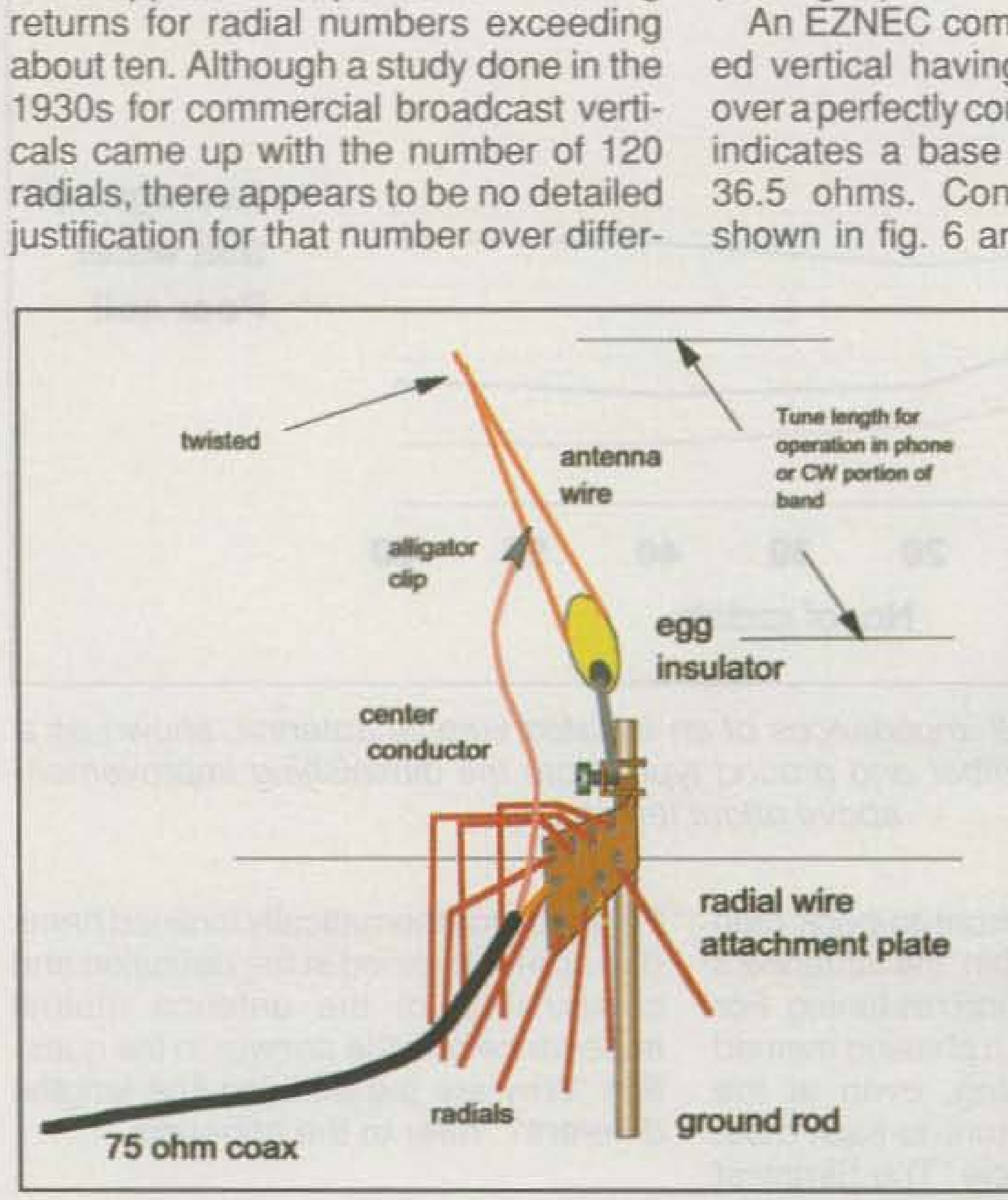


Fig. 7– Details of the nine-radial attachment to the ground rod and antenna feed (see also photo E). Antenna length may be fine-tuned by adjusting the length of the antenna loop through the egg insulator.

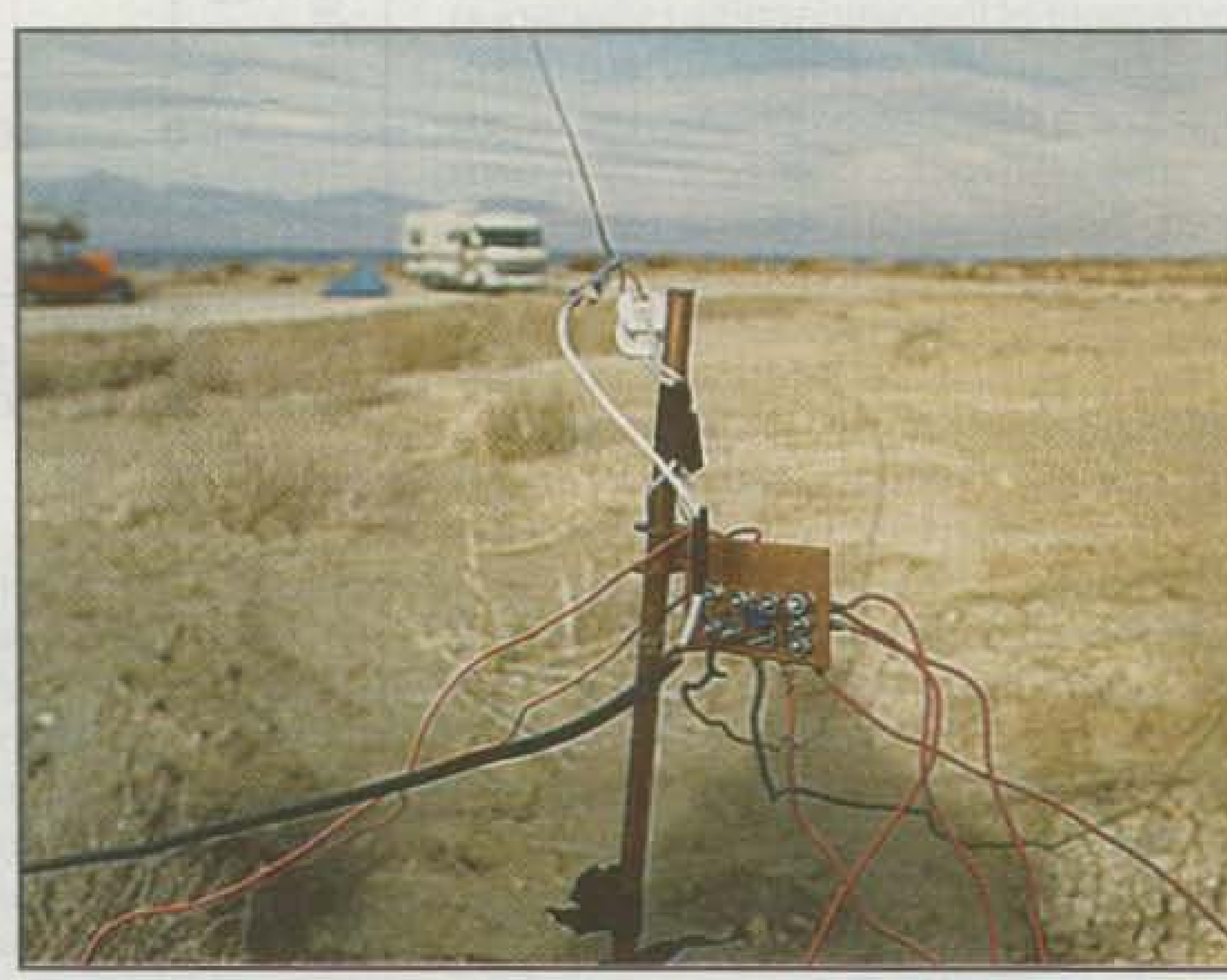


Photo E– The antenna, radials, and feedline come together at this combination anchor/ground rod. See fig. 7 for additional details.

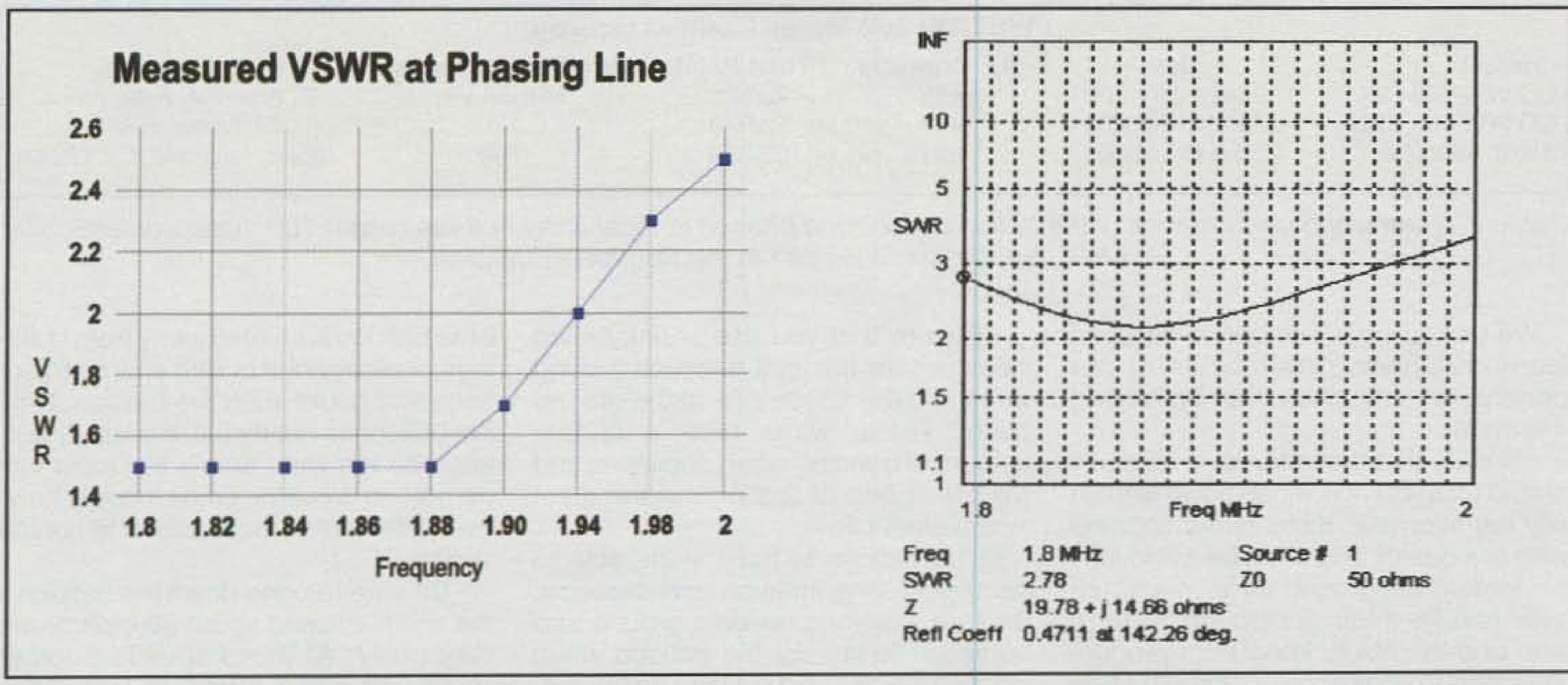


Fig. 8– Actual vs. predicted VSWR for 160 meter phased array. Chart on left shows actual VSWR measured with an MFJ VSWR meter. Chart on right is the EZNEC prediction for the same antenna. The authors still are not certain why the actual performance was so much better than predicted (but they're certainly not complaining!).

W6TRW Balloon-Supported Phased-Array Design

Balloon altitude: 70 m (230 ft.)
Center frequency: 1.87 MHz
Phasing-line impedance: 75 ohms
Feedline impedance: 50 ohms
Short phasing-line length: 53.41 deg.
Long phasing-line length: 155.36 deg.
No. of radials: 9 per antenna
Radial wire size: #14
Radial wire length: 20 m (65.6 ft.)
Antenna length: 42.08 m (138.06 ft.)
Antenna wire size: #18 braided copper
Antenna ground spacing: 40.51 m (132.9 ft.)
Ground type (model): Real, high accuracy
Ground material (model): "Good pasturage" to "salt water"
Maximum front-to-back ratio est.: 25 dB
Beamwidth: 43.3 deg.; –3 dB
Gain: 4.44 dBi
Elevation angle for max. gain: <20 deg.
Radiation efficiency: 0.41 <eff<0.85 depending on choice of ground conductivity

Table I– Design parameters of the balloon-supported phased array that we successfully used in three 160 meter contests. A scaled version was also used on 80 meters for Field Day.

lengths are constant in degrees, not in meters. Therefore there may be an additional 5- to 10-percent droop in the front-to-back ratio for fixed phasing-line lengths.) Note that the peak F/B ratio is the highest for high-conductivity grounds as expected, because the ground-reflected antenna "image" is the least attenuated. For the same reason, the radiation angle becomes lowest with the highest ground conductivity.

Table I shows the balloon-supported phased-array design parameters that we successfully used in three 160 meter contests and a scaled version for 80 meters for Field Day.

How Does it Work?

Now that the design and theory have been fully explored, many will ask, "But how well did it work?" Table II provides the answer.

W6TRW 160 Meter Contest Scores					
Contest	**Date**	**No. Contacts**	**Total Points**	**Worked All States?**	**DX Worked**
CQ WW 160 CW	28–29 Jan. 2001	465	73,580	Missed VT	S. America, Asia, Africa
CQ WW 160 SSB	23–24 Feb. 2001	419	53,940	No	6 countries
ARRL 160 CW	7–8 Dec. 2001	621	102,560	Yes	Japan, Australia, Caribbean

Table II– Real-world performance of the balloon-supported phased vertical array in three recent 160 meter contests. The ARRL contest score was #1 in the Southwest Division.

We picked up a number of "lessons learned" covering the details of our portable aerostat phased array. Among the many:

• Ensure that the antenna is carefully stored on a reel and wiped down with an oily rag after use. Kinks in the antenna wire are deadly and must be avoided.

• Roll up the ground wires in a hand-over-hand fashion, not around the fore-arm and thumb, to keep from producing snags that take time to unravel when in the field.

• Ensure that you use shrink-tubing sleeves over the joint between ground wires and the spade lugs at the ground plate. These wires take a certain amount of bending when deploying and will break free of the lugs at the most inconvenient time.

• The balloon is most vulnerable to damage during inflation and deflation. Be sure that you provide a ground tarp on which to lay out the balloon when inflating it and avoid walking on the balloon fabric at all costs! It is also helpful if the balloon is inflated away from buildings or other objects with sharp projections that could snag the balloon. Until the balloon is nearly full, it is easily buffeted by the wind and is the most vulnerable to damage. Once it is full, however, it becomes much easier to control and "fly."

• Be sure to bring down the balloon if the winds exceed about 30 mph or are very gusty. At these speeds a tether could part and the balloon lost. Dave learned this lesson when his balloon nosedived into a cactus patch at Anza-Boreego State Park during very gusty wind conditions.

It is also helpful to review the federal regulations governing balloons, kites, and so forth. These are contained in FAA Part 101, Subpart B—Moored Balloons and Kites. The source is Docket No. 1580, 28 CFR 6722 June 1963, and the relevant paragraph is Sec. 101.15, "Notice Requirements." It has been our experience that the FAA is most cooperative particularly when the balloon is more than 3 miles distant from an airport or heavily traveled air corridor.

Finally, we want to emphasize that our successful 160 meter Balloon-Supported Phased Array is a TRW club project. While the authors did much of the design and construction, others offered help and encouragement, and the club underwrote the project costs! We couldn't have done it on our own. Look for us in the next 160 contest!

Notes

1. 426 Constitution Ave., Camarillo, California (800-700-5995).

2. Our thanks to John Cheatham, KE6OJM, for donating a suitable gas regulator.

3. *The ARRL Antenna Book,* 17th Edition, American Radio Relay League, 1994.

4. *ARRL Antenna Compendium,* Volume 2, American Radio Relay League, 1989.

5. Go to the January *CQ* highlights page at <http://www.cq-amateur-radio.com/Jan.2003Highlights.html>, then click on the appropriate prompt. ■