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Actual Measured Performance of Short, Loaded Antennas — Part 1

With the help of many friends over many years, the author studied HF monopoles used as verticals, mobile antennas and in pairs as elements of beams and dipoles.

This report contains the real-world measurements for many short, loaded antennas: sizes, shape factors, loading methods, coil and capacity hat placement, coil *Q*, matching, mounting techniques, and more. It documents a long term effort to quantify and compare the effectiveness of shortened, "loaded" antenna elements by making empirical measurements rather than modeling or theoretical calculations. It also compares "conventional wisdom" to these measurements, and identifies differences in published literature on the subject.

Conventional wisdom can be a valuable tool. It may be based on experience, or derived from the works and writings of many researchers. It may also be shaped by myths, the claims of merchants, or misapplications of accepted theory. Usually it isn't quantified. Sometimes it's buried in fathomless calculations. Sometimes it's preached more like a sermon. A misapplication of accepted theory, unconfirmed by actual measurement, often finds its way into popular literature. If left unverified, that misapplication can take on a life of its own, to be repeated in articles, books, on-line articles, and in manuals or even become a part of today's computer modeling programs. That results in design and evaluation errors.

The case at hand is that of shortened, loaded elements often used as vertical monopoles fed against some sort of ground plane, like typical 1.8 to 30 MHz mobile antennas, backyard verticals for the lower frequency Amateur bands, and other medium and low frequency antennas. Such elements are used in pairs in balanced antennas like dipoles and beams. A "shortened element" usually means less than a resonant length, most typically less than a quarter wavelength. "Loaded" means that either an inductance, such as a coil, or a capacitance, perhaps a "capacity hat," or both has been added to the element to achieve resonance on a desired frequency when fed against a conductive plane, a counterpoise, or perhaps a second identical element.

Figure 1 — Typical mobile antenna with multiple resonators .

Conventional wisdom has a lot to say about this subject, like "Bigger is better," "High-Q coils are good," "Low-Q coils are lossy," "One or another position of the coil is best," "Helically wound is best," "Capacity hats are good, but only in certain locations," "Don't use loading coils, only top hat wires," and on and on. If all that is really true, how much better or worse is one or the other, and what are the trade-offs?

There are questions about the effects of multiple resonators on one mast. "That can't work as well, can it?" "What about using mag-mounts for mobile antennas? That won't make any difference, will it?" "Should we match at the feed point or at the transmitter or match at all?" "Why adjust the antenna element to frequency when the auto-tuner at the radio makes the standing wave ratio (SWR) one-to-one?" "Should the mobile antenna be mounted on the bumper or the roof?" "Why do I need radials on my vertical? Even some commercial antenna manuals say ground rods will do the job." And there are a lot more questions.

Figure 1 shows a typical mobile antenna, using multiple resonators. Figure 2 is a short, top loaded vertical for 160 meters, set up on Mellish Reef by Bob Walsh, WA8MOA.

This report is not going to bombard you with formulas and mathematics. That's not my forte. I am a serious student of antennas, plus the theory, formulas, and math involved, but I am not an expert. The important tasks of explaining this subject mathematically or relating it to referenced literature will be left to others more qualified in those fields. What I will do in this report is tell you about my work in one segment of the subject — measurements! I'll tell you what I've done, how I did it, the results I have recorded, and the conclusions I have drawn from those

[1]Notes appear on page 42.

results. Use the data however you choose. If you question any of our methods, I hope that you will set up a measurements program and document your results. I would be interested in reading your report, and I'm sure many others would, too.

One other thing: Let's not overreact. Allow me to explain. I have been an Amateur Radio operator since I was in eighth grade. As a Novice licensee in 1954, while I waited for my General class ticket to arrive, I was "testing" my microphone and modulator on a home brewed pair of 6L6's (tubes!) running 25 W on 160 meters. I was in my basement shop. My dummy load was a light bulb in a socket connected to the transmitter with 4 feet of lamp cord.

At the local club meeting a few days later some of the adults pulled me aside and told me that it would be better if I turned myself in rather than have the FCC come to get me. I had been heard all over town. That's when I realized that when it comes to antennas, everything works!

My point is this: It might be easy to read more into the information in this report than need be. It would be a mistake to interpret my results and conclusions as saying that a particular antenna or technique won't work — or that a particular design is the only one that will work. The numbers involved are degrees of better or worse. As I said, "Everything works!" But, compromises and trade-offs made in the name of achieving your goals can be better made using this kind of information. Okay, let's get started!

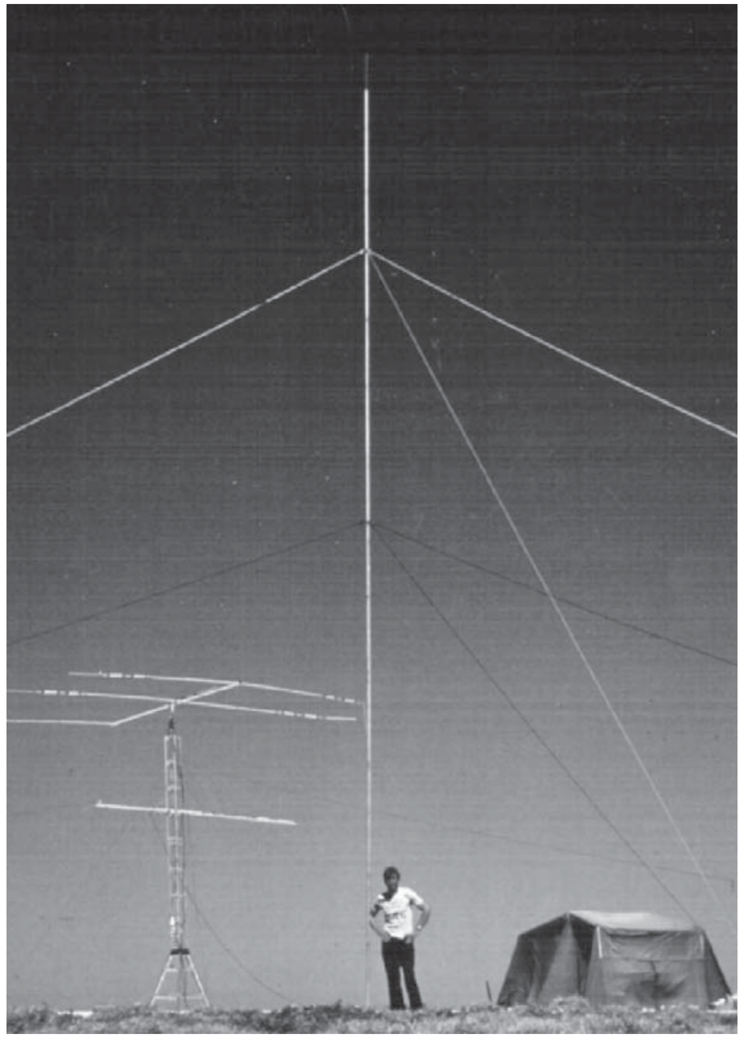

Figure 2 — A short, top-loaded 160 vertical on Mellish Reef set up by Bob, WA8MOA. (Minooka Special)

Thinking About Basics

To make sure we're all on the same page, let's first review a little piece of antenna basics in simple terms. If you know this subject inside-out, skip this segment or your eyes may glaze over. Here we go.

Either the dipole, or its half brother the monopole over a ground plane, is a capacitor-like device we call an antenna, to which we connect the output of an alternating current generator we call a radio transmitter. In order for current to flow, any such device must have two terminals connected to the two output terminals of the generator. The radio frequency (RF) alternating current (AC) creates electromagnetic fields between the two elements of the capacitor/device/antenna. Figure 3 illustrates the basic concept of a vertical monopole.

The energy in those fields is proportional to the RF current in the elements. So, more current in the elements means stronger fields. Energy in those fields is "lost" from the system on each phase reversal of the alternating current. That lost energy is what we call our radiated signal.

As in any circuit, maximum current will flow when resistances are reduced to a minimum. The resistances in a monopole/ground plane include losses in conductors and in the ground plane itself. These are heat losses. Plus, there is "radiation resistance." This figure is the apparent resistance of the antenna that can be attributed to the radiated energy. Therefore, radiation resistance is the only "acceptable" resistance, if you will, and it is determined by the size and configuration of the antenna. Also, if the antenna isn't resonant, there will be either capacitive or inductive reactance present that will act as a resistance to AC and will further "impede" RF current.

Resonance is the condition that exists when the capacitive and inductive reactances are equal, and cancel each other. Therefore, one of the ways to maximize current and radiation is to "resonate" the antenna by adjusting the length and diameter physically and/or electrically. Another way to improve things is to use lower resistance conductors and in the case of a ground plane, make the "plane" part bigger and/or more solidly conductive. That's easier said than done in the case of the vehicle we use for our mobile setup and often the backyard we use to erect a vertical for 1.8 or 3.8 MHz, for example. Nevertheless, to achieve maximum radiation the objective is for the RF energy to "see" only the radiation resistance at the feed point, or as close as we can come to that condition.

Applying these basics to the case in point, the full sized monopole over a ground plane has been sized for resonance. As it turns out, at about a quarter wavelength and multiples thereof, depending on such things as cross sectional area, the inherent capacitive and inductive reactances of the monopole element will be equal and opposite, so they cancel. The monopole is a series-resonant circuit in itself, when fed against an appropriate counterpoise such as a ground plane or an opposing monopole.

The problem is, full size monopoles for the lower Amateur bands are too ungainly for our cars, some of our backyards, and sometimes our pocketbooks, so we often seek to achieve resonance on monopoles much shorter than a quarter wavelength. There are several ways to do this. Since shortening the monopole element reduces both its inherent capacitance and inductance, we can add them back in a more compact form like either "hats" or coils, or maybe both. These may be added anywhere along the monopole, but their positions will determine, to a great extent, the radiation resistance, where in the antenna the current will flow, the size of the fields between elements, and therefore the amount of radiation that occurs. The term "resonator" is often applied to a loading system that has both inductance and capacitance. Figure 4 illustrates the full size quarter wavelength antenna and the shortened, loaded antenna.

What Got This Study Started?

The "*Q*" question, as it relates to loading coils is where it all started for me. *Q*, or quality factor, is most simply expressed as the ratio of reactance to resistance in a component. This was a big issue when I started mobiling on 1.8 and 3.8 MHz in the mid 1950s. Conventional wisdom said that the secret to having a decent mobile signal on the lower frequency bands with an inductively loaded antenna was to use a very large diameter coil, wound with large diameter wire, spaced turns and an air core (no form). In other words, high *Q*. The warning often repeated was that skinny close-wound coils on a form were very lossy and if you use them, you won't be heard as well. They are low *Q*, comparatively speaking.

We were using AM (amplitude modulation) in those days. Most of us had homebrewed rigs, or converted "Command" sets (WW2 surplus) and a few had commercial tube type rigs such as Elmac AF-67s.

Some mobilers used base loading coils on an 8 foot whip. Johnson made a band switching version. A lot of antennas were patterned after Master Mobile, Basset and other commercial products. They used a 3 foot base mast, a 5 foot top whip, and an adjustable large diameter, spaced, air wound coil in between. That way, when the coil was completely shorted, the antenna would resonate on 10 meters. Why the 3 foot/5 foot split? I'd guess it was conventional wisdom.

One of the problems we had with this kind of set-up was extremely narrow bandwidth. We could only cover a few kilohertz on the lower frequency bands with a particular setting of the coil. As you drove down the street, the plate current meter or SWR indicator varied all over the place because of changing proximity to trees, overhead lines, and passing vehicles. A little frost, some rain or a small bug could move the resonant frequency out of the band. Therefore, high *Q* coils had a definite downside. Figure 5 shows a high *Q* coil as part of a mobile antenna.

In the early 1960s I scrounged an old Webster Bandspanner at a Starved Rock, IL Hamfest. This was a commercial mobile antenna for 80 to 10 meters. It consisted of a long, perhaps 5 foot phenolic mast about 1 inch in diameter, with an embedded coil for a good part of its length. A whip protruded from the top of the mast. You could slide the whip into or out of the mast, and a sliding contactor on the bottom of the whip moved up and down the coil inside the mast. This allowed for adjustment of the antenna to any

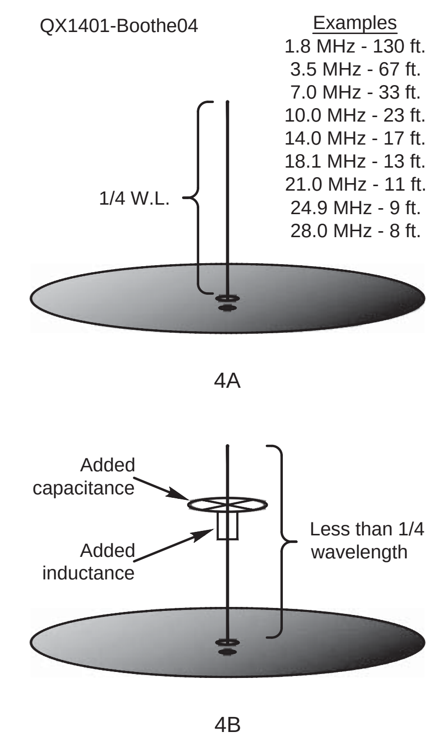

Figure 4 — The "Full Size" monopole and the loaded monopole. (L+C)

Figure 5 — High *Q* coil

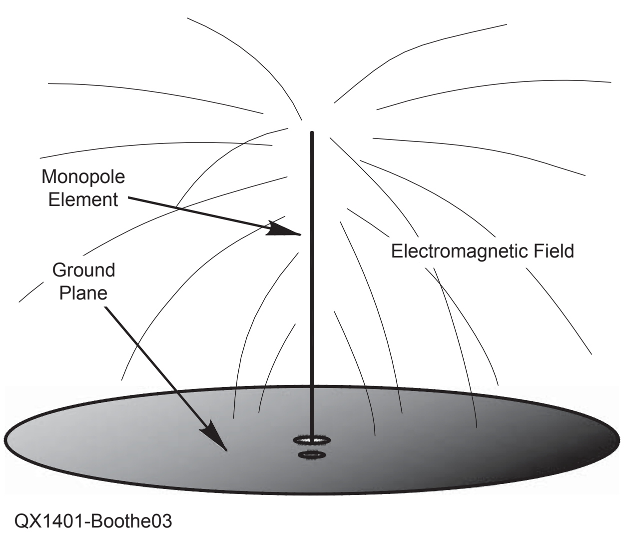

Figure 3 — A Monopole/Ground plane and its fields

frequency from 3.8 to 29 MHz. I tried the Bandspanner on 3.8 MHz. The bandwidth was much greater than with the big air wound coil set-up. Corona and proximity effects were greatly reduced and it stayed on frequency in any weather. Signal reports seemed just as good as with the old antenna, but that wasn't a very scientific evaluation. Besides, it flew in the face of conventional wisdom. This antenna used a relatively low-*Q* coil, as shown in Figure 6. My next step was to add more inductance and a "lampshade" capacity hat to resonate the Bandspanner on 1.8 MHz.

Results were much the same as on 3.8 MHz. The only logical thing to do was to build a 160 meter antenna from scratch, based on the Bandspanner design. A long, close wound coil of fairly small wire (#20) on a PVC pipe form was mounted as high as possible on a base mast and combined with as much capacitance as possible above the coil. My experiments had shown me that higher ratios of top capacitance to inductance further increased bandwidth. Raising the coil on the mast lowered the SWR at resonance, and that's a good thing, right?

I had no corona problems, I could load the antenna over a bandwidth of 10 to 20 kHz, and almost nothing moved the resonant frequency. It seemed to perform as well if not better than previous antennas as far as signal strength — "seemed to" being the operative phrase. By now, quite a few of us in the area were using similar set-ups. But there was unrest brewing.

This heresy could not be tolerated, so, eventually, I was confronted by an irate mob of "Conventional Wisdomites" who were intent on showing me the error of my ways. A cadre of scientific types, led by my friend George Ostrowski, K9PAW, arranged an antenna signal measurement test at a "160 Meter Reunion" held in Joliet, Illinois in the summer of 1969.

I didn't know much about the test equipment they had set up. Added to that were some fancy attenuators and lengthy calculations. The big deal of the day was the comparison of signal strengths between two otherwise similar antennas for 1.8 MHz. One used a big high-*Q* coil with a 1:1 length/diameter ratio, 6 inches in diameter, with spaced turns of #10 wire and an air core. The other used my skinny 7/8 inch diameter close wound coil with #20 wire on a piece of PVC pipe and a 20 to 1 length/diameter ratio. And, worse yet, my coil was covered with shrink tubing!

As was expected, the higher *Q* antenna was better, but by only 0.3 dB. That's right, three tenths of a decibel! That was not expected! Even those of us that thought the lower *Q* setup was a good deal could not believe it was that close. This was no less a shock to me than it was to the "Wisdomites." We all agreed that the test had to be flawed and George said that modifications were called for. Nevertheless, he and his cohorts were duly impressed with the close outcome, as was I.

Improving and expanding the measurements became an ongoing obsession. Over the next 20 years, sandwiched between life, a job, and a family, I hit the books and the workshop whenever I could. Every time we set up a new measurement program lots of suggestions were implemented that came from interested parties to fix, correct, and improve the measurements. So, we kept modifying and redoing the tests.

New test stands were built, equipment was improved, but time after time, the results were the same — as were doubts about the accuracy of the measurements. After all, we were in violation of conventional wisdom! Meanwhile, my friend Greg Chartrand, WA9EYY (now W7MY), was the first to use my long skinny coil arrangement as a base station top-loaded vertical for 160 meters when he was living in Worth, Illinois. It gave him his first transatlantic reception reports and he dubbed the antenna "The Minooka Special." It was described in *QST* as well as publications in several other countries.[1] Subsequently, it was used by many top band hams as base station verticals as well as mobile antennas in the Chicagoland area and around the world. I put together a number of 43 foot, collapsible, all band versions. They

Figure 7 — Here is my test setup from the early 1980s .

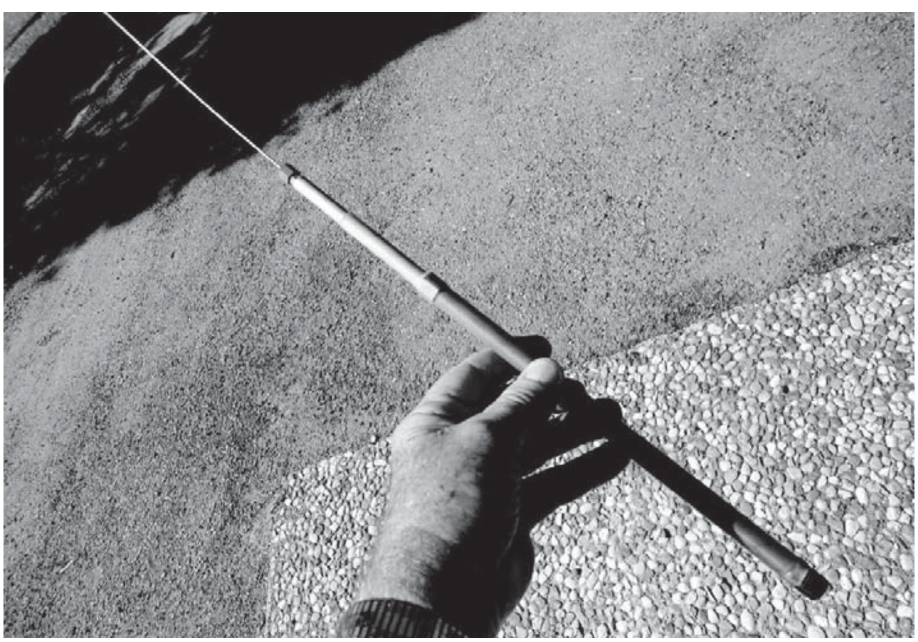

Figure 6 — Low *Q* coil (20 meters)

Figure 8 — Late '80s tests with chicken wire fencing for a ground plane

made a good showing on DXpeditions for many years.

By the way, "Minooka" is the name of a village close to where I lived at the time. I think it's an Indian word that means "wide spot in the road."

During this time, some interesting works on this subject were published by Sevick, Belrose, Lee, Michaels, Brown, Byron, Maxwell, Schulz and many others.[2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12] I devoured all of this material. Over half of what I read differed with the results of my own experiments. I was determined to set up a measurement program that was as flawless as we could make it in order to sort it all out. Meanwhile, I spent a lot of my limited experimentation time working on receiving antennas for my favorite band, 160 meters.[13]

My YL is Joyce, WB9NUL. See Figure 10. She has always helped with my experiments and measurements, plus, she is a diehard county hunter. County hunting is mostly about mobile operation. So it was natural to concentrate on mobile antennas in order to answer the questions concerning shortened, loaded antenna elements.

We often shared our information with the county hunters at their conventions and also at other clubs and groups. Our efforts were aimed at helping people better evaluate commercial antenna designs as well as to demonstrate ways to "roll your own." I began working on scores of mobile installations to solve problems and improve performance. It was a great learning experience and I collected a treasure trove of tricks and techniques. I designed a complete line of mobile antennas and accessories that was sold under the name of "Custom Enterprises" and eventually by "E-Field Antennas." Neither of those is in business any longer because the owners retired.

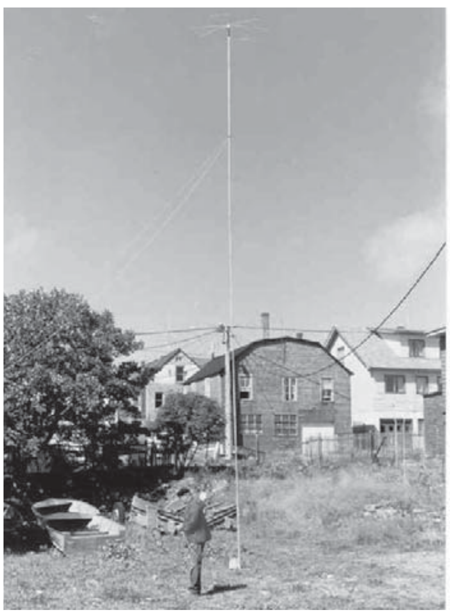

Figure 9 — "Minooka Special" set up on St.Pierre (FP) by Arch Doty, K8CFU (now W7ACD), and John Frey, W3ESU (SK).

Figure 10 — Joyce, WB9NUL helping with a test setup.

How Was it Done?

A plan was hatched. Joyce and I had become involved with the work of our good friend Arch Doty, K8CFU (now W7ACD), and his cohorts, John Frey, W3ESU (SK), and Harry Mills, K4HU (SK). Their work concerned vertical antenna ground systems, elevated radials, folded monopoles and so on.[14, 15, 16, 17, 18, 19] As that work wound down, Arch and I talked about the long suffering subject of shortened monopole loading and my quest for practical data. He was intrigued with the previous test results.

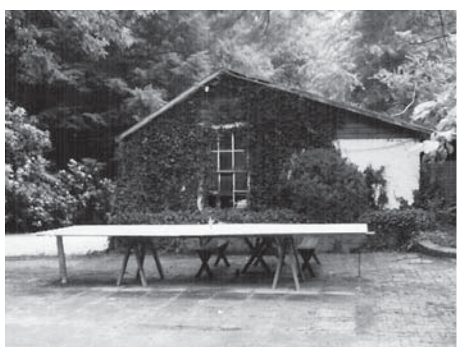

Figure 11 — The test stand over a paved area.

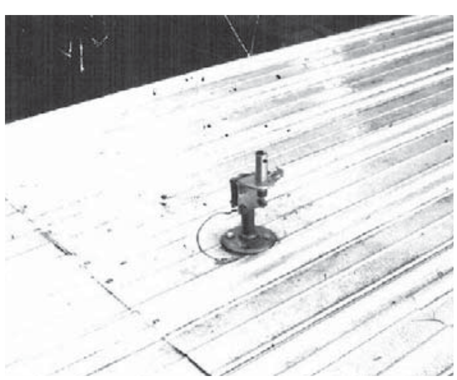

Figure 12 — The test stand antenna mount

We devised a plan to set up a measurement program that would evaluate 1.8 to 30 MHz monopoles empirically, and accurately. We would take into account all the information from Amateur and professional sources that we could gather to design the test set-up. We agreed that measurements would only be accepted as reliable if they were repeated numerous times with the same results. The tests were expanded to include all the parameters mentioned previously plus many more.

The first two or three summer sessions of tests would be conducted in Fletcher, North Carolina at Arch's estate. Then we would continue tests after moving the equipment and operations to the Lower Rio Grande Valley in Texas. We would run the main two series of tests repeatedly each summer for the first few years, noting the differences tied to changes in ground conductivity and looking for "quirks" or anomalies. John Frey, Harry Mills and others expressed their willingness to work on the Fletcher part of the plan. Each year we added parameters that needed to be measured or quantified. These came from participants in the test program, outside suggestions from interested parties, and in an effort to explain unexpected results.

The test stand shown in Figure 11 was designed and built by Arch Doty, K8CFU/W7ACD. He had just been through thousands of measurements regarding ground resistance and return currents in his previous project. He built a test stand that to some extent simulated the characteristics of a vehicle. The ground resistance (R_g) of the test stand varied over the period the tests were run due to changing precipitation, week to week and year to year. The average ground resistance was a little lower than we have measured on several vehicles — about 17 Ω on 14.2 MHz and 38 Ω on 3.8 MHz, for instance. (These measurements were made using the techniques Arch had developed and published. See the references to his many articles in the Notes.) The test stand was a sheet of aluminum "5V" roofing material, 6 feet × 15 feet, elevated 30 inches above a large brick paved area. The antenna mount was in the geometric center. See Figures 11 and 12.

There was a plastic pipe support structure at the side of the test stand with an arm extending over the antenna mount and a rope to allow pulling up and holding various test antennas in position for measurement. This would allow for quick changes of many dozens of configurations without demanding that each be self supporting. I had used a wooden version of this support scheme in earlier tests but was worried about the possible effects of dampness or other contaminants in the wood. See Figure 13.

Pickup points for field intensity were located at different angles and distances from the test stand. The first was only 100 feet away using a 4 foot whip, fed against an iron table as a ground plane, as shown in Figure 14.

The second pickup point was a 10 meter vertical dipole hung about 30 feet above ground in a tree 190 feet away. It was not resonant near any frequency we used in the tests. The third pickup point was an elevated 110 foot folded vertical monopole with 120 elevated radials each 120 feet long about a quarter mile from the test stand. Two GRC ME-61 military field strength meters were used, one modified with a balanced amplifier. The big monopole had a simple detector unit at its base. I am at that detector unit in Figure 15.

For those manning the pickup points, the tests were "blind." That is, a test number was issued via VHF radio and then the personnel at the test stand would apply a calibrated 10 W signal to the test antenna for the field strength measurements. Figures 16 and 17 show me and Arch at the Fletcher test stand. Then, at the test stand, every configuration was measured and documented for bandwidth in kilohertz between 2:1 SWR points, for feed point resistance at resonance, reflected power in watts and two independent SWR readings. Any configuration that showed an SWR of 2:1 or more was measured with and without feed point matching.

The Fletcher Program was where the bulk of the data concerning the *Q* of coils and the position of the inductor in the mast versus radiated field strength and bandwidth was collected. Two series of test measurements formed the framework of The Fletcher Program, although many additional factors were looked at during those tests. Both series were run repeatedly over a two week period each summer to verify the data. Anomalies were analyzed and the data was averaged to get reportable numbers. Besides our "core" team, many local hams from the Hendersonville, NC area showed up each year to help or observe and to offer suggestions to improve the process. Sometimes they brought their own antennas for evaluation on the test setup.

Other measurements were intermixed with the repetition of Series 1 and Series 2 tests. We measured multiple resonator setups, mounting angle of resonators to masts and alternative types of coils, like pie-wound and toroidal core

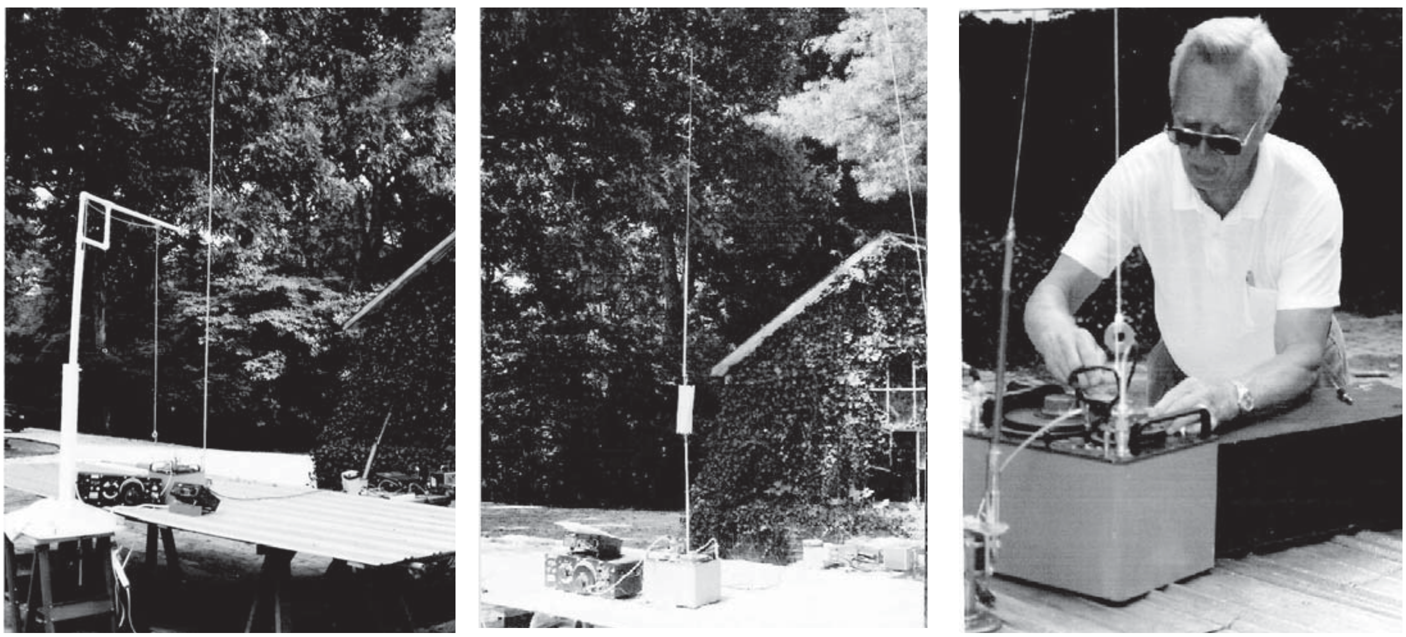

Figure 13 — Antennas on the test on the stand with Arch Doty, K8CFU (now W7ACD), at the equipment.

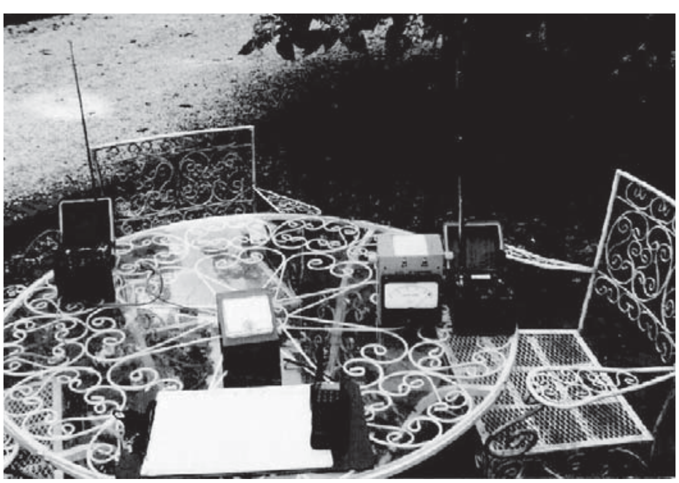

Figure 14 — The closest field strength pick-up point, about 100 feet from the test stand.

Figure 15 — The author at the base of the elevated monopole at Fletcher, North Carolina

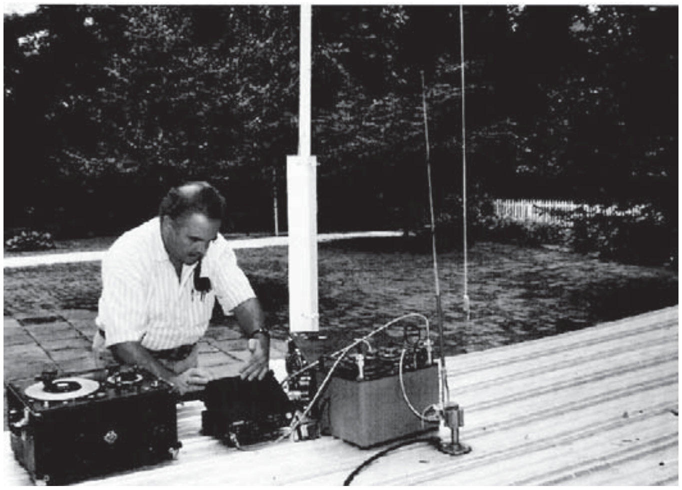

Figure 16 — The author at the Fletcher test stand.

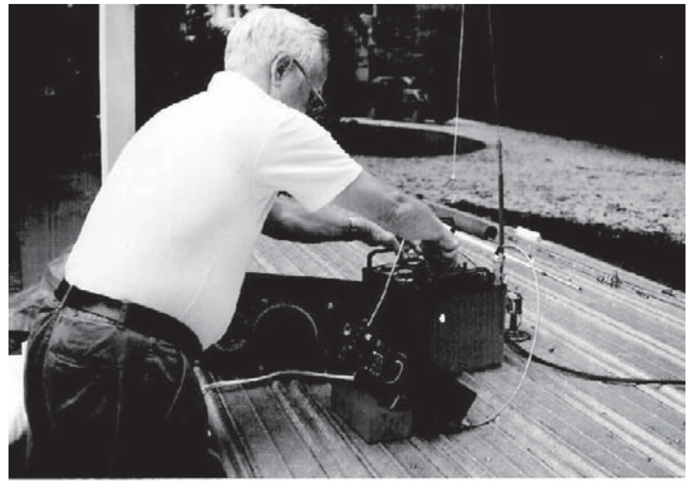

Figure 17 — Arch Doty, K8CFU (now W7ACD), at the Fletcher test stand.

Figure 18 — The "Truckstand" used for the "Six Shooter Junction" program.

Figure 19 — Base mount over the radial system.

inductors. As time went on, hams in the area, some of whom helped take readings, brought their pet antennas for evaluation. These were both commercial and homebrewed types. We measured them all, but that data was not included in the "Bottom Line" figures. The pet antennas included no startling breakthroughs. Measurements were consistent with our test antennas. No one had invented "dB paint" or some other secret weapon.

When we were satisfied with the repeatability of what we collected at Fletcher, we packed up the General Radio 1606A impedance bridge and 1330 oscillator, the Bird 43P wattmeter, and the ME61 field strength meters and headed to the Mexican border. Other equipment used in the measurements was more universal and would be supplied locally, or added as we saw the need.

But wait! It's time to figure this out! When we pulled up stakes in Fletcher, we assessed what was left to measure and what we had to resolve. Two things seemed to disagree with a lot of the literature on the subject. One was that after a dozen test programs over 25 years, we had not resolved the almost immeasurable difference in performance between high *Q* versus low *Q* loading coils in shortened monopole antennas. Every test so far had reconfirmed the K9PAW tests back in Joliet, Illinois in 1969. That is, that the greatest difference in field intensity (near and far) between long, skinny coils on a form versus big diameter, large wire, spaced turns, air wound coils, all other factors being the same, was 0.3 dB, and that was on 1.8 MHz. The difference could hardly be measured on higher frequency bands.

Also, we could not verify the assertions of authors who put forth formulae locating loading coils at a particular point in the mast to get the best performance. The point indicated was usually close to the center or a bit above. In all of our tests, we found that the field intensity was highest when the coil was moved as close to the top of the mast as possible.

These two items made us pour over the writings to see where we might have gone wrong. In the process of reviewing the literature, we noted a trend that might be important to unraveling the mysteries.

Eureka! We have it —maybe. All of the writings on the subject that predicted big losses in low Q coils in monopoles and also those that located the coil optimally down the mast from the top had one similarity. These authors had made the calculations assuming that the current was constant throughout the loading inductance. About half of the available literature on the subject as well as some modeling programs held that condition as factual. We noted that the other half showed tapering current in loading coils used for making shortened monopoles appear to be resonant quarter waves. Meanwhile, in our experiments, we had seen rather unscientific indications that the current

Figure 20 — Radial system site with a test antenna.

diminished severely as it passed through the coil. For instance, one indicator was the great increase in voltage from the bottom of the coil to the top. When calculations were done using tapering current, the results were very close to those from Fletcher and earlier tests.

It was obvious from this that we needed to verify more scientifically the issue of current taper in loading coils. Even though this was a secondary issue in terms of our original objectives, we wanted to know if this issue could help explain the results we were getting. Inputs from recognized experts told us to compare results using the test stand to those using an extensive radial ground system.

Our first task was to set up the test stand and replicate the Fletcher tests in Texas, so that there was a common reference point, a benchmark. Then we could go on from there.

The Six-Shooter Junction Program was the continuing effort to measure things. Six Shooter Junction was the original name of Harlingen, TX, and that seems appropriate. Harlingen is where we set up our test facilities. Its name is from a town in Holland, pronounced 'har-len-jen.

Our first effort in Texas was a bust. Arch and I became quite frustrated trying to replicate the Fletcher numbers. At first we thought the ground conductivity in the coastal plane was so much greater than Fletcher that the test stand was giving us completely different readings. Eventually we found that the cause was a 50,000 W broadcast station on 1530 kHz, just a few miles north of our location. It had a monster six element antenna array aimed right down our throat toward Mexico. After adding high pass and "suck-out" filters to some equipment and with a little tweaking, it was fixed! A run of Series 1 and Series 2 measurements confirmed the Fletcher data, and we were in business. We had our benchmark.

From that time on, test programs were run periodically in Texas. They included measurements that we had planned when we finished in Fletcher, like;

1) Currents in loading coils

2) Further study of bandwidth factors

3) Alternate resonator design

Over time, and after reporting some of our findings to groups and on the internet, we had the benefit of receiving inputs from many interested persons. This resulted in the addition of quite a few more measurement plans.

4) Ground resistance, band by band, for large and small vehicles versus a "typical" radial system

5) The effects of using magnetic mounts on mobile antenna performance

6) The comparative performance of loaded monopoles with capacity hats located close to or far above the loading coil or with no coil at all.

7) The comparison of monopole matching at the base of the antenna versus in the shack or cabin of a vehicle

8) The comparison of the high Q/low Q results on a vehicle versus over an extensive radial system on the ground.

Besides these, a myriad of antenna design tests were to be conducted. Several configurations of ground mounted monopoles would be built, some as reduced size models.

Methods and equipment changed somewhat. We acquired a big diesel pickup truck. It was a Dodge, extended cab, long bed with a flat cover over the bed. An antenna mount was placed a bit forward of center on the bed cover. See Figure 18.

On the underside of the cover, a "radial" system made of 2 inch wide aluminum roof repair tape was installed. The radials went from the bottom of the antenna mounting plate to the aluminum angle frame that surrounded the cover. The frame was connected to the truck body at all four corners with 1 inch wide braid.

A comparison to the Fletcher test stand showed the truck to have just slightly higher ground resistance on all bands. We decided to use the truck for subsequent tests of mobile antennas on a vehicle. We called it the "truck stand." For those kinds of measurements the truck was placed in a fixed position on a large cement paved area at a citrus grove, two miles from our home, west of Harlingen. The site was generously provided by Cheryl (KJ5PQ) and Mike (KG5UZ) Carver. For "on the ground" tests, there was a grassy space adjacent to the paved area that allowed the installation of an extensive radial system. It consisted of 60 copper radials on the ground, from 40 to 60 feet in length. Figure 19 shows the base mount for the antennas with this radial system and Figure 20 shows an overview of the antenna site.

The field strength pickup point was at our home, two miles to the west. Figure 21 shows the caged folded monopole used at that site.

Every day that tests were run using this site and setup, benchmark readings were taken at the beginning, throughout and at the end of the session. We took note of rainfall and climatic conditions, noting the effect they had on our benchmark readings. Even the change in humidity from morning through midday and to evening hours made a difference in base readings.

Test equipment was also added. Arch, W7ACD provided both the AEA SWR-HF as well as the CIA-HF analyzers, with the plotting software. This provided graphic charts of SWR, resistance, impedance, return loss, and reactance curves plus a Smith chart for every antenna tested. I added the MFJ259 analyzer, an HP 8640A signal generator and a laptop computer for test site plotting. A Yaesu receiver was modified to have calibrated digital field strength readout. It was located 2 miles away at the pickup location.

Helium filled balloons were employed to support ¼ wavelength antennas used in some tests. In order to present the data from both Fletcher and Harlingen in a comprehensive form, and to complete a number of added measurements, we had to use ¼ wavelength resonant elements to determine ground resistance of the "truckstand," other vehicles and the radial system on each band. A wire "reel" was constructed to allow quick infinite adjustment of the balloon supported antennas for perfect resonance.

The elusive "tapering current" question had to be answered. In order to measure RF current in monopole loading coils, Arch obtained four new calibrated RF ammeters. They were mounted together with their thermocouples on small PVC fittings with standard 3/8-24 threads to mate with antenna masts and coils. Measurements were made on test stand antennas, ground mounted antennas, and vehicle mounted antennas. High *Q* and low *Q* coils mounted in various positions from the base to the top of antenna masts were studied on several bands, from 30 meters down to 160 meters. We also measured the current in and out of toroidal wound loading coils. No "heliwhip" or coils considered to be a significant part of a wavelength were used in those tests. Coils with the meters mounted on their ends were always reversible, to allow double checking results for anomalies. Adding the meters to the antennas made very minimal change to the tuning, limited to a slight movement of the resonant frequency downward due to the slight increase in capacitance above the coil. We found no indication that the meters were affected by the RF field. Of course, they were designed for this kind of service.

Figure 21 — The pickup antenna was this 80 foot caged, folded monopole for the Texas measurements.

Then, it all had to stop, because we bought a new home. Even though there were more tests on the agenda, we had to abandon the citrus grove site because our new home was about 8 miles northwest of the old place.

In the second part of this article I will present the actual measured results for our Series 1 and Series 2 tests. I will also offer some conclusions that we came to about all of these measurements.

Barry Boothe, W9UCW is an ARRL member and holds an Extra Class license. He has held his call since 1954 after holding WN9UCW for a couple months. He became interested in Amateur Radio at age 13, after experimenting with electricity and electronics during his junior high school years.

Barry was with Caterpillar for 31 years at facilities in the US and Brazil. He was a division manager when he took early retirement. He taught electricity and electronics classes at a community college for six years.

His primary ham radio interests have always been building, antenna research and low-band DXing. He has made 20 trips to Central and South American countries, always involving Amateur Radio to major degree. Barry won two cover plaque awards for QST articles published in the 1970s. Another of his interests is woodworking.

Barry and his wife Joyce, WB9NUL have lived in the Lower Rio Grande Valley for over 23 years. Joyce has held her call for 40 years. She is a county hunter and was president of MARAC, the mobile awards club for 7 years.

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