SHORTENED, LOADED ANTENNAS

HF monopoles used as verticals, mobile antennas and in pairs as elements of beams & dipoles

Actual Measured Performance Comparisons

Barry A. Boothe, W9UCW
With the help of many

Part One

This report contains the <u>real-world measured differences</u> between many 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 actual empirical measurements rather than modeling or theoretical calculations. It also compares "conventional wisdom" to reality, and identifies differences in published literature on the subject.

Figure 1. Typical mobile antenna with multiple resonators

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

Conventional wisdom can be a valuable tool. It may be experience based or derived from the works and writings of learned researchers. But it may be shaped by wives tales, 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, and in manuals or even become a part of today's computer modeling programs. That results in design & 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.

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,” etc., etc., ad Infiniti. If all that’s 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 feedpoint 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.

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 can and 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 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.

And one other thing…. Let’s not overreact. Allow me to explain. I have been a Ham 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 homebrewed pair of 6L6’s (tubes!) running 25 watts 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. OK, let’s get started!

Thinking About Basics

Are we all singing from the same hymnal? So that we’re 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 groundplane 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) causes electrostatic and electromagnetic fields to be created between the two elements of the capacitor/device/antenna.

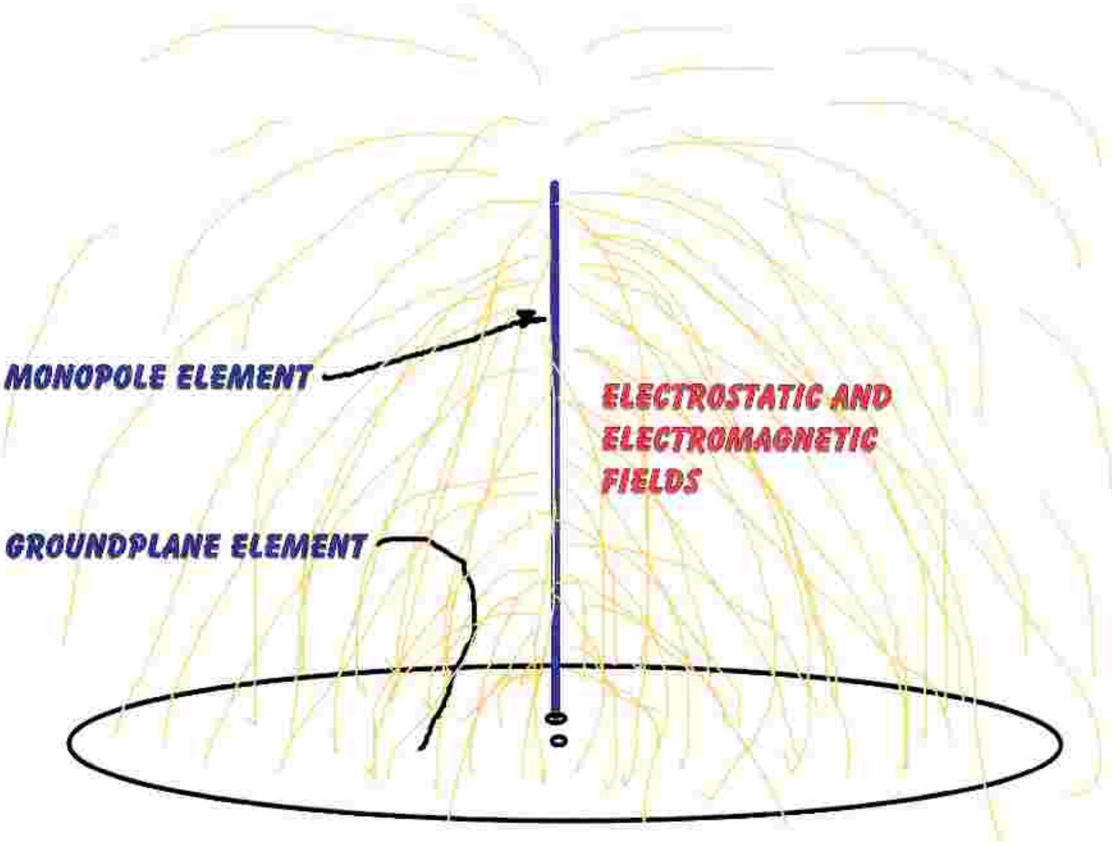


Figure 3. A Monopole/Groundplane and its fields

The energy in those fields is proportional to the RF current flowing 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/groundplane include losses in conductors and in the plane itself. These are <u>heat</u> losses. Plus, there is "radiation resistance". This figure is the apparent resistance of the antenna that can be <u>*attributed to the radiated energy*</u>. 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 flow.

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 groundplane, 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 feedpoint, or as close as we can come to that condition.

Applying these basics to the case in point, the “full sized” monopole over a groundplane 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 will cancel. The monopole is a series-resonant circuit in itself, when fed against an appropriate counterpoise such as a plane or an apposing monopole.

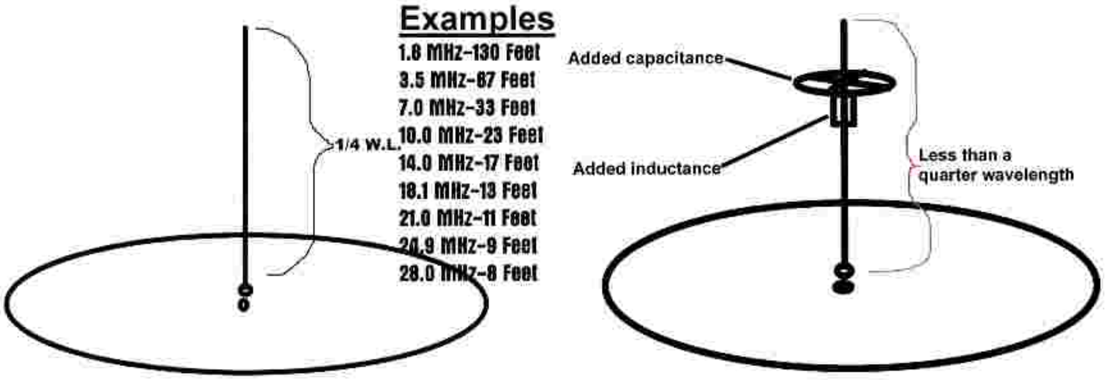


Figure 4. The “Full Size” monopole & the loaded monopole. (L+C)

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 achieveresonance 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.

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 & 3.8 MHz in the mid 1950’s. 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 closewound coils on a form were very lossy and if you use them, you won’t be heard as well. They’re low “Q”, comparatively speaking. Those warnings are often repeated in today’s publications.

Figure 5. High Q coil

Figure 6. Low Q coil (20 meters)

We were using A.M. (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-67’s.

Figure 7. The author operating mobile in the 1950's with modified WW2 surplus gear.

Some mobilers used base loading coils on an 8 foot whip and Johnson made a bandswitching version. But a lot of antennas were patterned after Master Mobile, Basset and other commercial producers. 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’-5’ 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, if you were lucky enough to have one, 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.

In the early 60's 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. The whip could be slid in 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 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 <u>seemed</u> just as good** as with the old antenna….. but that wasn't very scientific. Besides, it flew in the face of conventional wisdom. This antenna used a relatively low-Q coil. My next step was to add more inductance and a "lampshade" capacity hat to resonate the Bandspanner on 1.8 MHz.

Figure 8. The modified "Bandspanner" using a tank mount and spring from WW2

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, closewound 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. And, raising the coil on the mast lowered the SWR at resonance…..that's a <u>good</u> thing, right?

Anyway, I was "happier than a hog in waller" as they say down on the farm. I had no corona problems, the antenna was "loadable" for 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, K9PAW arranged an antenna signal measurement test at a "160 Meter Reunion" held in Joliet, Illinois in the summer of 1969 (The first "shootout"?).

Figure 9. George, K9PAW at the 1969 "160 Meter Reunion"

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” in diameter, with spaced turns of #10 wire and an air core. The other used my skinny 7/8” diameter close wound #20 on a piece of PVC and a 20 to 1 length/diameter ratio. And, worse yet, it was covered with shrink tubing! As was expected, the higher Q antenna was better…. but, **by only .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, & improve the measurements. So, we kept modifying and redoing the tests.

Figure 10. Early 1980's tests

Figure 11. Late '80's tests with chicken wire fencing for a groundplane

New test stands were built, equipment was improved, but time after time, the results were the same….as were doubts about accuracy. After all, we were in violation of conventional wisdom. Meanwhile, my friend Greg, WA9EYY (now W7MY) was the first to use my long skinny coil arrangement as a base station top-loaded vertical for 160 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[1] as well as publications in several other countries. 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', collapsible, all band versions. They made a good showing on DXpeditions for many years.

Figure 12. Greg, WA9EYY (W7MY) at the '69 160M Reunion in Joliet Illinois

Figure 13. "Minooka Special" set up on St.Pierre (FP) by Arch, K8CFU and John, W3ESU (SK).

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". At that time, Minooka was a half mile west of "Resume Speed."

During this time period, some interesting works on this subject were published by Sevick[2], Belrose[3], Lee[4], Michaels[5], Brown[6], Byron[7], Maxwell[8], Schulz[9] and many others. 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.[10]

My XYL is Joyce, WB9NUL. 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.


Figure 14. Joyce, WB9NUL helping with a test setup.


Figure 15. The author giving an antenna session at a County Hunters convention.

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.

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[11], folded monopoles, etc. 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.

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.

Figure 18. The Test Stand over a paved area

Figure 19. The test stand antenna mount

The test stand was designed and built by Arch, 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 (Rg) 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 ohms on 14.2 MHz and 38 ohms on 3.8 MHz, for instance. The test stand was a sheet of aluminum "5V" roofing material, 6 ft. X 15 ft. elevated 30 inches above a large brick paved area. The antenna mount was in the geometric center.

Figure 20. Antennas under test on the stand with Arch, W7ACD (K8CFU) at the equipment

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.

Pickup points for field intensity were located at different angles and distances to the test stand. The first was only 100 feet away using a 4 foot whip fed against an Iron table as a groundplane.

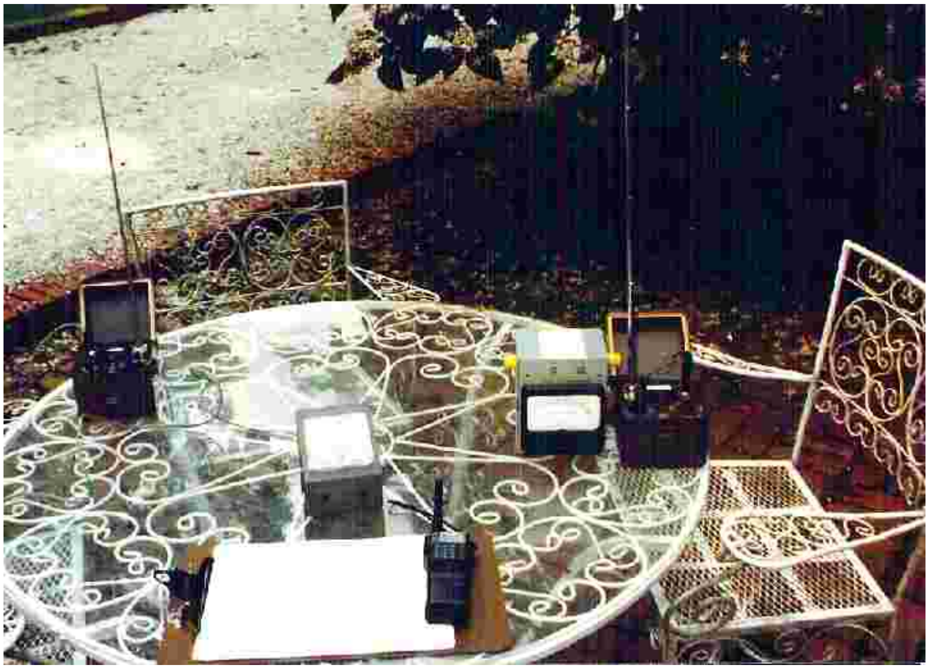


Figure 21. The closest field strength pick-up point, about 100’ from the test stand.

The second 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 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.

Figure 22. The author at the base of the elevated monopole at Fletcher, North Carolina

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 watts to the test antenna for the field strength measurements. Then, at the test stand, every configuration was measured and documented for bandwidth in KHz between 2:1 SWR points, for feedpoint 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 feedpoint matching.


Figure 23. Barry, W9UCW at the Fletcher test stand.


Figure 24. Arch, K8CFU at the Fletcher test stand.

The Fletcher Program was where the bulk of the data concerning the Q of coils and the position of the inductor in the mast vs. 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 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 & #2 tests. We measured multiple resonator setups, mounting angle of resonators to masts and alternative types of coils, like pie-wound and toroidal cored. 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 most 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 HI-Q vs. LO-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 & far) between long, skinny coils on a form vs. big diameter, large wire, spaced turns, air wound coils, all other factors being the same, was **.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 LO-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 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 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 watt 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 & #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 vs.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 vs. in the shack or cabin of a vehicle
8. The comparison of the HI-Q/LO-Q results on a vehicle vs. 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.

Figure 25. The "Truckstand" used for the "Six Shooter Junction" program

On the underside of the cover, a "radial" system made of 2" 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" 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 and Mike Carver, KJ5PQ & KG5UZ. 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 26. Base mount over the radial system.

Figure 27. Radial system site with a test antenna.

The field strength pickup point was at our home, two miles to the west.

Figure 28. The pickup antenna was this 80' caged, folded monopole for the Harlingen measurements.

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 wave 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. HI-Q and LO-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. 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.

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.

What are the Bottom Line Numbers?

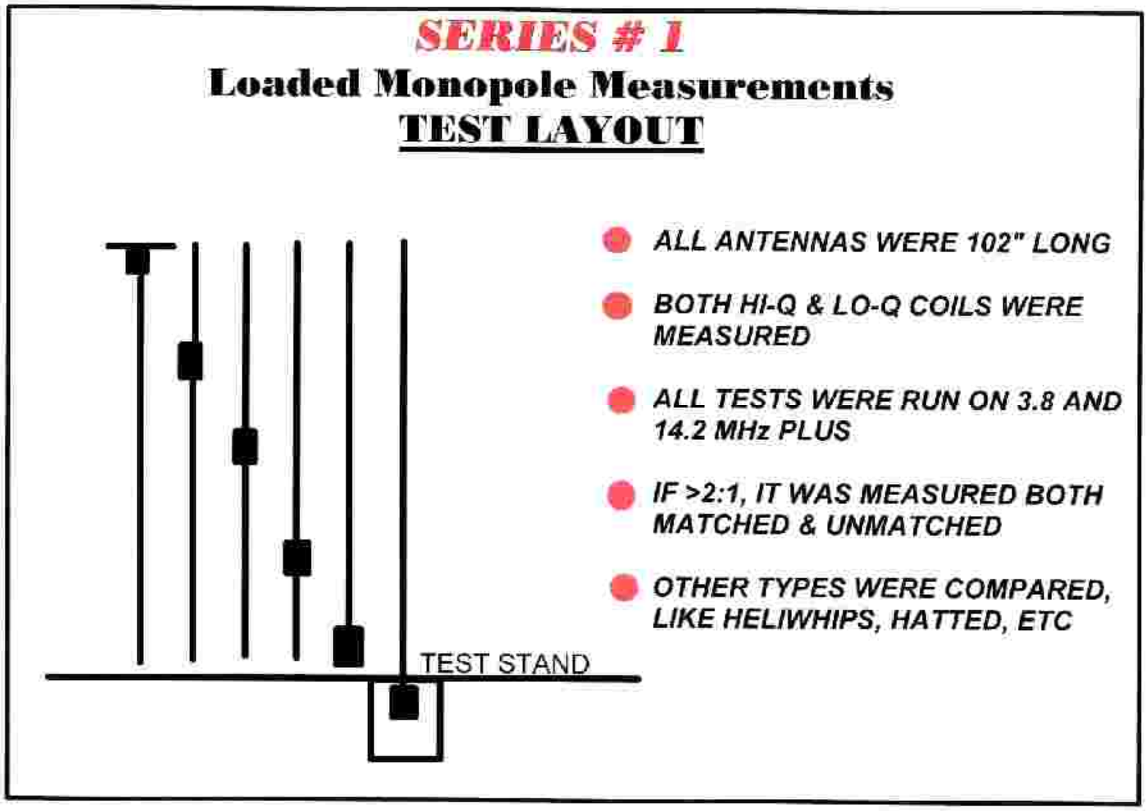
What follows are the actual measured results for Series #1 and Series #2 tests. The field strength numbers throughout the charts are comparisons to a perfect, zero-loss groundplane with a ¼ wave resonant vertical monopole. This is the “zero” point or benchmark. As you read the charts, keep in mind that the smallest field strength number is the most desirable because it represents how much weaker the test antenna is than a perfect monopole/groundplane antenna on that frequency. These tests were conducted in Fletcher and in Harlingen, repeated many times over several years. The deviation was very small. These are the averaged numbers from dozens of Series #1 & #2 runs.

Each run through Series #1 & Series #2 resulted in nearly 300 measurements. When excursions to other bands occurred, the numbers increased proportionally. The two programs resulted in many thousands of measurements. Field intensity readings were converted to decibels and all data was collected, entered into the computer and printed out each day by Arch, K8CFU/W7ACD.

Series #1

How does the position and "Q" of the coil in a shortened monopole affect efficiency?

In this series, the test antenna was a fixed length of 8 1/2 feet. Starting with the loading coil at the very top of the mast, a balanced horizontal capacitance above was adjusted for resonance. Field strength and all other measurements were collected. Then the coil was moved down 24", adjusted for resonance, and all data collected. Then, down 24" more, then another 24", and finally the coil was installed at the base.



SERIES # 1

Loaded Monopole Measurements

TEST LAYOUT

- ALL ANTENNAS WERE 102" LONG
- BOTH HI-Q & LO-Q COILS WERE MEASURED
- ALL TESTS WERE RUN ON 3.8 AND 14.2 MHz PLUS
- IF >2:1, IT WAS MEASURED BOTH MATCHED & UNMATCHED
- OTHER TYPES WERE COMPARED, LIKE HELIWHIPS, HATTED, ETC

Figure 16. Series #1 Test Layout

This was done using high-Q coils and then low-Q coils on both 14.2 MHz and 3.8 MHz, with occasional excursions to 1.8 MHz through 21 MHz to insure the trend was uniform on all the lower ham bands. Besides the base loading position, <u>one additional configuration was added.</u> That was where the loading coil was <u>below</u> the test stand in a shielded box, to simulate some of the commercial autotuner and "in the trunk" mobile installations as well as fixed monopoles, base loaded with shielded tuners.

All the "HI-Q" coils in our tests were made using #12 or #10 silver tinned copper coil stock with spaced turns, either 2", 3", or 4" in diameter and an air core. Our "LO-Q" coils were all either #20 enameled copper (1.8 MHz & 3.8 MHz) or #18 enameled copper (7.2 MHz to 21 MHz). They were close wound on either a PVC or paper phenolic form. Coils for 1.8 & 3.8 MHz were 7/8" diameter, while 7.2 and 10.1 MHz were 5/8" diameter, and those for 14.2 to 21 MHz were 3/8" diameter.

SERIES #1 Bottom Line Results
20 Meters

14.2 MHz

ANTENNA CONFIGURATION	*RESISTANCE AT RESONANCE IN OHMS*		*2:1 BANDWIDTH IN KHz*		*FIELD STRENGTH IN db BELOW REF. ANT.*	
	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q
¼ Wave-No Coil	53		690		-2	
102”-Coil At Top	42	42	340	456	-2.8	-2.8
102”-Coil At 72”	36	35	353	478	-3.3	-3.3
102”-Coil At 48”	31	30	361	509	-4.7	-4.7
102”-Coil At 24”	27	27	349	490	-5.9	-5.9
102”-Coil At Base No Match	23.5	23.5	----	----	-7.5	-7.5
102”-Coil At Base Matched	50	50	390	580	-6.5	-6.5
102”Coil Shielded at Base-No Match	20.5	20.5	-----	------	-14.2	-14.2
102”Coil Shielded at Base-Matched	50	50	382	572	-12.2	-12.2

SERIES #1 Bottom Line Results
80 Meters

3.8 MHz

ANTENNA CONFIGURATION	*RESISTANCE AT RESONANCE IN OHMS*		*2:1 BANDWIDTH IN KHz*		*FIELD STRENGTH IN db BELOW REF. ANT.*	
	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q
¼ Wave-No Coil	74		105		-3	
102”-Coil At Top	43.6	43.5	12	25	-8.5	-8.6
102”-Coil At 72”	41.5	41.4	14	30	-11.3	-11.4
102”-Coil At 48”	40	40	17	32	-14.2	-14.3
102”-Coil At 24”	38.6	38.5	20	34	-19.3	-19.3
102”-Coil At Base	38.3	38.2	25	36	-24.5	-24.5
102”-Coil At Base Shielded	38	38	25	38	-32.6	-32.6

Plain Language Conclusions:

1. All other factors being the same, the coil loaded monopole with the coil closest to the top or end of the element will produce the greatest radiated signal. The lowest field strength by far will be seen from the one with a shielded coil at the base of the mast or whip. For a mobile antenna on 3.8 MHz, the difference is 24 db! That's like going from 100 watts down to .4 of a watt! On 14.2 MHz, it's not so bad… like going from 100 watts down to 10 watts. No correlation was ever seen with the "optimum" positioning of the coil near the center of the mast, as put forth by some authors.

Also, from the results shown, it's obvious that in the case of a <u>base loaded</u> antenna, a significant portion of the radiated field comes from <u>the coil itself</u>. Moving the coil into a shielded box reduces the field strength 6 db on 14.2 MHz and 8 db on 3.8 MHz!

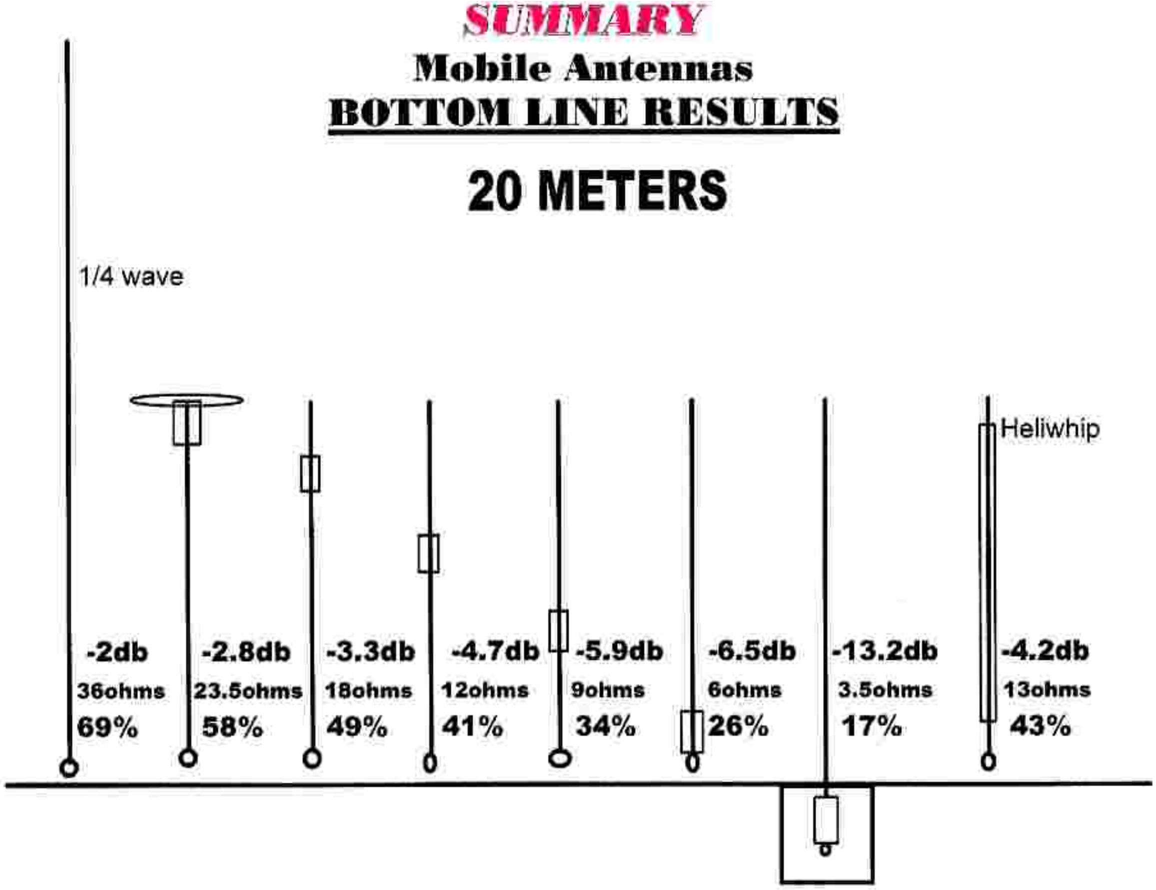
2. For coil loaded monopole verticals, there's almost no measurable difference in field strength between HI-Q, big wire, air wound coils, and LO-Q, close-wound-on-a-form coils, no matter where in the mast they are located. As it turns out, this remains true whether the antenna is mounted over a poor groundplane like a vehicle or over a good groundplane like an extensive radial system. Check out "HI-Q & LO-Q over Truck vs. Radial System" in Part Two. The "great lossiness" we hear about from conventional wisdomites does not reduce our signal strength.

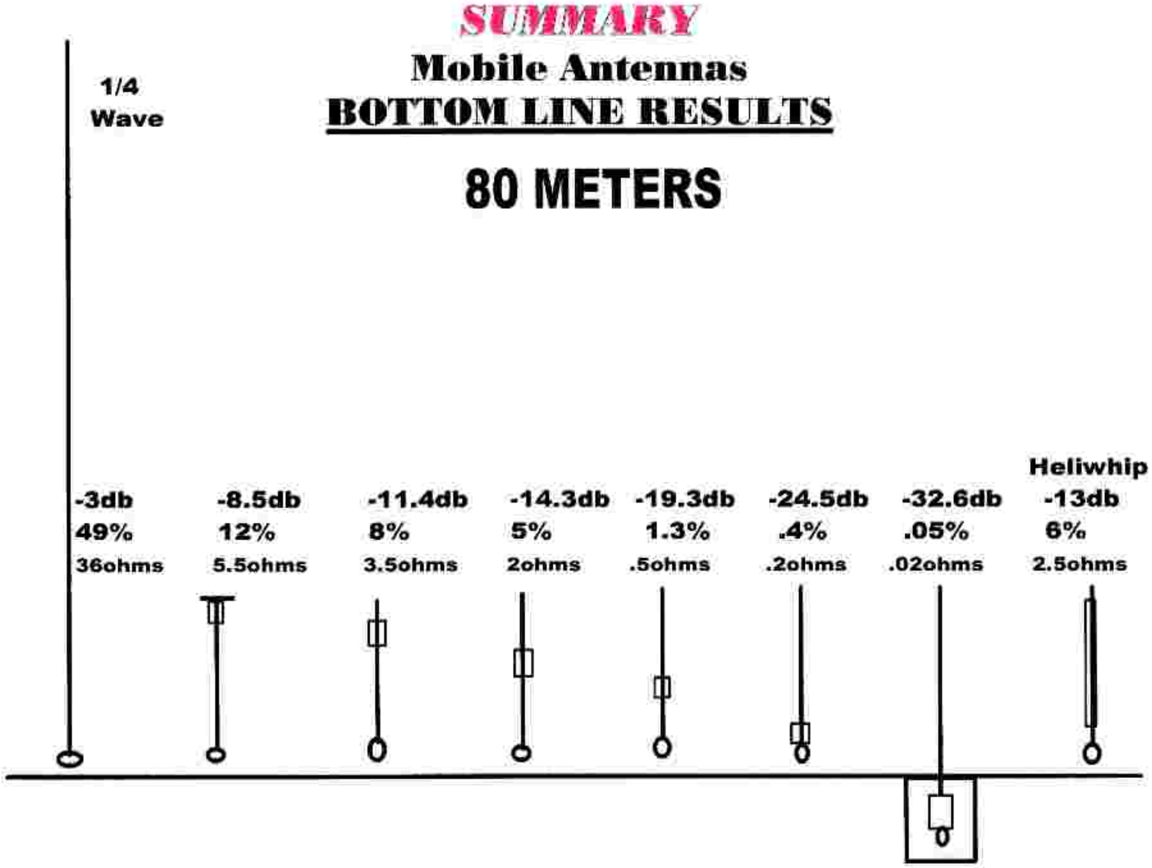
As mentioned earlier, other antenna variations were "thrown in" during Series #1 & Series #2 measurements. They included loaded monopoles with the lowest Q coils we tried, like the commercial "heliwhips" for 3.8 and 7.2 MHz. Results boiled down to the same generalities as stated above and below. Their field strength performance was low and related to the short length of "mast" below the start of the "lumped" inductance. Their bandwidth was high because of the two factors in #3, below.

Personally, I think that big, air wound monster coils look like "Real Radio", but the data we collected show that they offer no advantage in radiated field strength…. But they might intimidate your competition.

3. Two things cause the greatest increase in bandwidth; Coils with higher length-to-diameter ratios and resonators with higher capacitance-to-inductance ratios. So, if you want more bandwidth, use long skinny close wound coils and use a design with as much capacitance (whip or hat) above or beyond the coil as possible. You won't be louder, but you'll be able to use a bigger part of the band without retuning. Also, things won't get "out of kilter" so easily when it rains or you get close to trees or you smack a bug with the coil.

A Visual Summary of Series #1

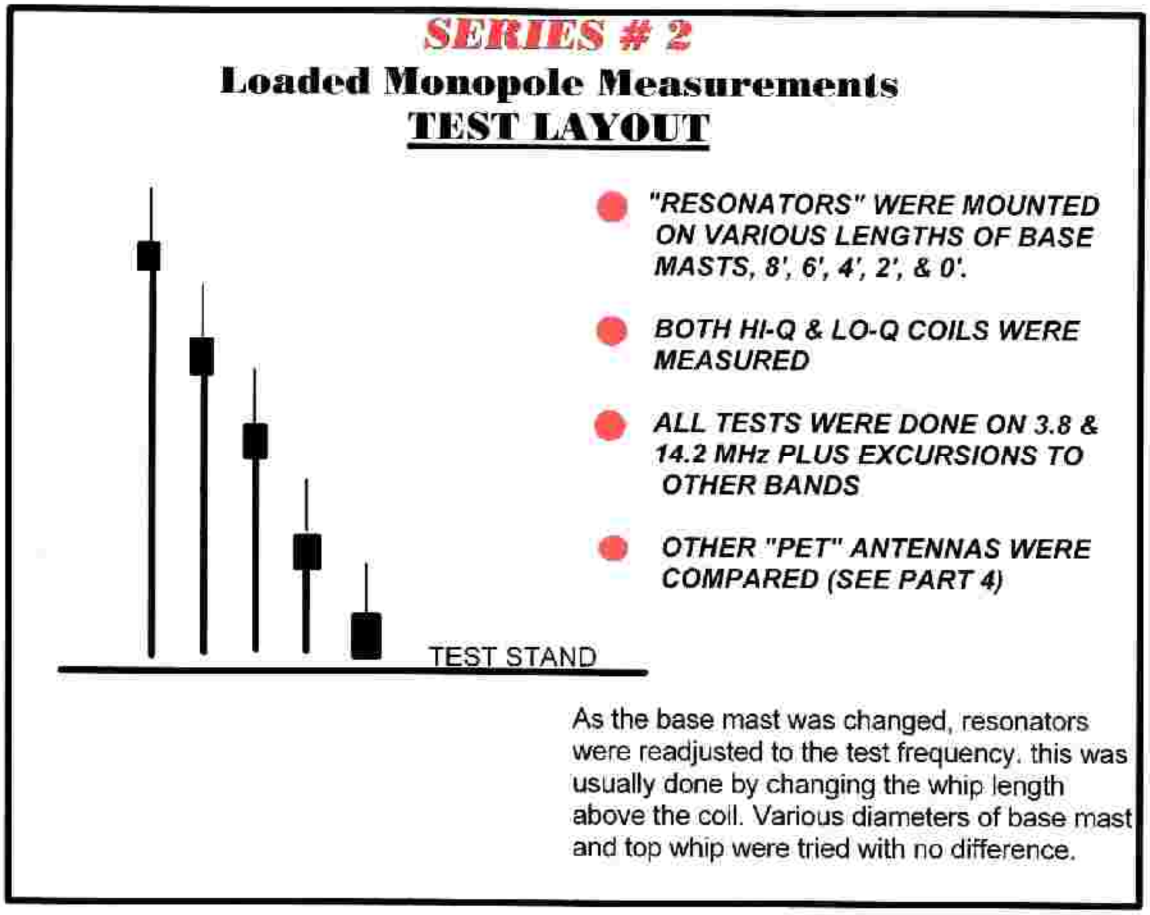




Series #2

How will the length of the base mast affect efficiency?

A resonator, consisting of a coil and an adjustable top whip was mounted on an 8 foot base mast on the test stand. After taking all the measurements, the mast length was reduced to 6 feet, then to 4 feet, then to 2 feet, and finally eliminated altogether. In effect, the last of these configurations resulted in a very short base loaded antenna.



SERIES # 2

Loaded Monopole Measurements

TEST LAYOUT

- "RESONATORS" WERE MOUNTED ON VARIOUS LENGTHS OF BASE MASTS, 8', 6', 4', 2', & 0'.
- BOTH HI-Q & LO-Q COILS WERE MEASURED
- ALL TESTS WERE DONE ON 3.8 & 14.2 MHz PLUS EXCURSIONS TO OTHER BANDS
- OTHER "PET" ANTENNAS WERE COMPARED (SEE PART 4)

As the base mast was changed, resonators were readjusted to the test frequency. this was usually done by changing the whip length above the coil. Various diameters of base mast and top whip were tried with no difference.

Figure 17. Series #2 Test Layout

Of course, the resonator was readjusted for resonance as the base mast length was changed. As in series #1, all tests were done with high-Q, air wound, spaced, “square” coils as well as low-Q, close wound on long skinny form types on both 14.2 & 3.8 MHz, with occasional excursions to the other bands.

SERIES #2 Bottom Line Results

20 Meters

14.2 MHz

ANTENNA CONFIGURATION	RESISTANCE AT RESONANCE IN OHMS		2:1 BANDWIDTH IN KHz		FIELD STRENGTH IN db BELOW REF. ANT.	
	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q
¼ Wave-No Coil	53		690		-2	
96” Base Mast	40	40	375	456	-2.8	-2.8
72” Base Mast	34	34	215	342	-3.2	-3.2
48” Base Mast	29	28	120	195	-5.2	-5.2
24” Base Mast Unmatched	22	21	----	-----	-8.7	-8.8
24” Base Mast Matched	50	50	101	188	-8.3	-8.3
0” Base Mast Unmatched	19	18	----	----	-15.7	-15.8
0” Base Mast Matched	50	50	72	94	-14.8	-14.8

SERIES #2 Bottom Line Results

80 Meters

3.8 MHz

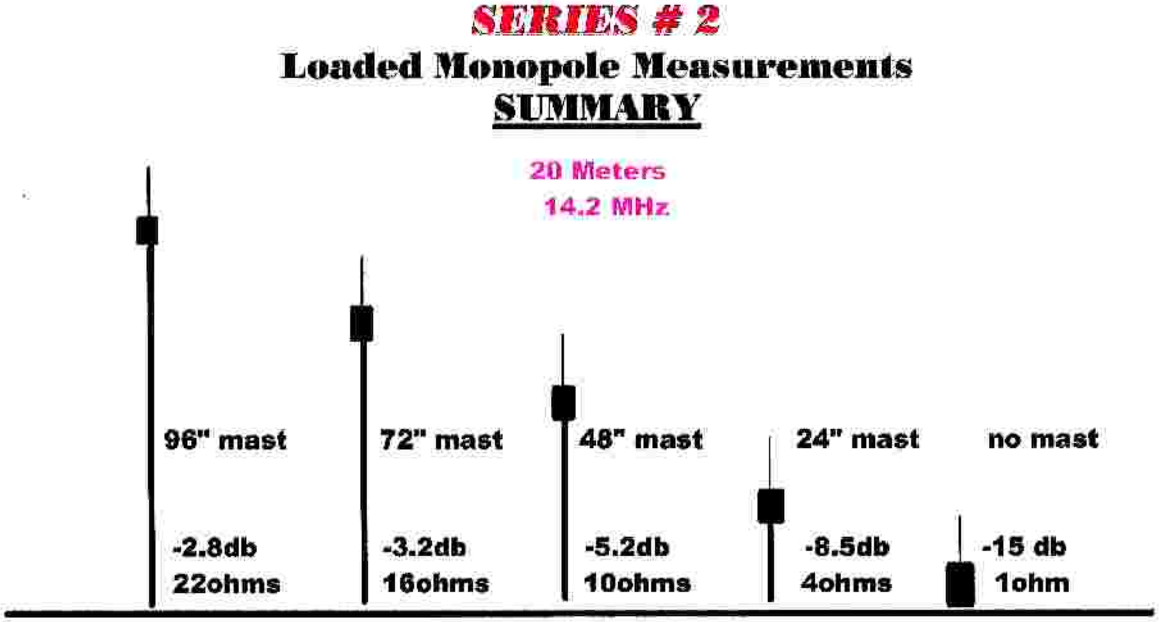
ANTENNA CONFIGURATION	RESISTANCE AT RESONANCE IN OHMS		2:1 BANDWIDTH IN kHz		FIELD STRENGTH IN db BELOW REF. ANT.	
	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q	HIGH-Q	LOW-Q
¼ Wave-No Coil	74		105		-3	
96” Base Mast	44	43.5	19	38	-8.8	-8.9
72” Base Mast	42	41.5	18	38	-11.4	-11.5
48” Base Mast	40	40	15	35	-15.2	-15.3
24” Base Mast	38.3	38.2	12	31	-22.2	-22.4
0” Base Mast	38	38	8	19	-28.6	-28.8

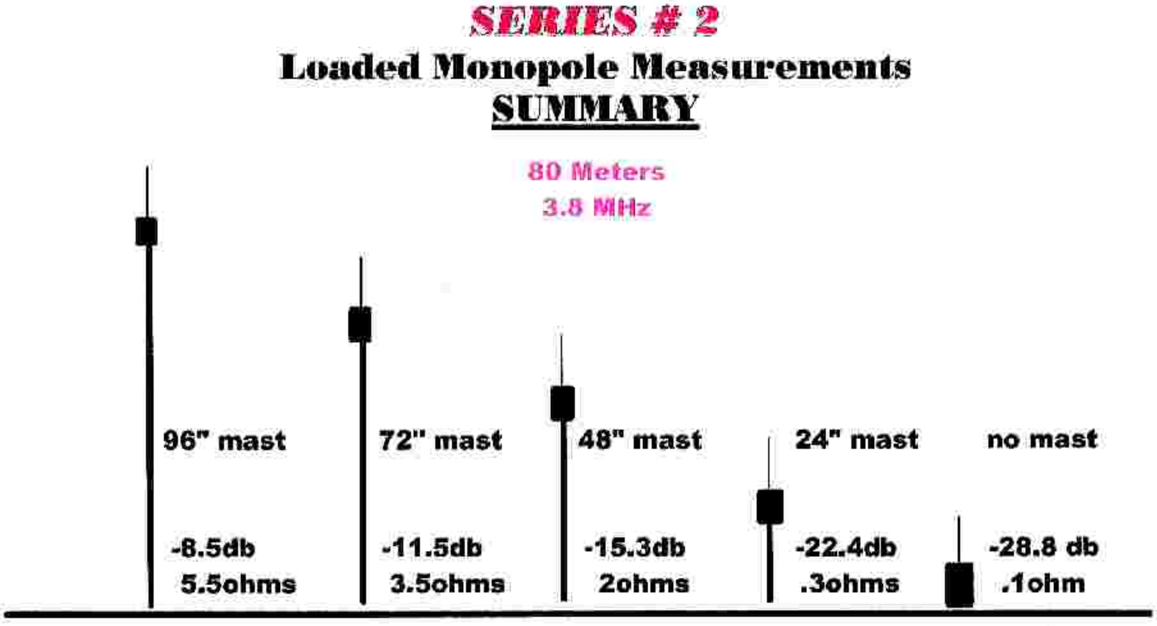
Plain Language Conclusions:

1. The length of the mast below the lumped inductance has the greatest effect on the field intensity of a coil loaded, “short” monopole, all other factors being the same. Combining the Series #1 and #2 numbers, I draw this conclusion: “In the case of shortened, loaded antennas, all other factors being the same, the one with the longest mast between the feed point and the start of the lumped inductance will win the field strength contest”. For example, on 3.8 MHz, adding two feet to the base mast of a mobile antenna is like doubling your power. On 14.2 MHz, adding four feet to your mast is like doubling your power.

2. There is an almost immeasurable difference in field strength between LO-Q & HI-Q coils used to load shortened monopoles, no matter the length of mast below the coil. Note that in all cases, as the mast length is shortened, the bandwidth is reduced as well as the efficiency.

A Visual Summary of Series #2





Part Two of this report will present the remainder of our actual measured performance comparisons dealing with the following subjects;

- Ground resistance of large and small vehicles and a “typical” on-ground radial system.
- HI-Q & LO-Q coil loaded monopoles over a vehicle vs. an on-ground radial system.
- Various mounting angles of resonator to mast on loaded antennas.
- Multiple resonators on single monopole masts.
- Use of “Mag-Mounts” on mobile antenna installations.

- Capacity hat locations on loaded monopoles.
- Coil top loading vs capacity hat only top loading on shortened antennas.
- Various matching and tuning schemes for shortened, loaded antennas.
- Current in loading coils for shortened, loaded antennas.
- Alternate types of loading coils.

Footnotes for Part One

[1] B. Boothe, "The Minooka Special," QST, Dec., 1974
And "The ARRL Antenna Anthology", 1978, P36

[2] J. Sevick, "The Ground-Image Vertical Antenna," QST, July, 1971
J. Sevick, "The W2FMI Ground-Mounted Short Vertical," QST, March, 1973

[3] J.S. Belrose, "Short Antennas for Mobile Operation," QST, Sept., 1953
J.S. Belrose, "Short Coil-Loaded HF Mobile Antennas: An Update and Calculated Radiation Patterns." ARRL Antenna Compendium, Volume 4, (Newington, ARRL, 1995)

[4] P.H. Lee, *The Vertical Antenna Handbook*, New York, Cowan Publishing,1974

[5] C.J. Michaels, "Evolution of the Short Top-Loaded Vertical," QST, March, 1990
C.J. Mickaels, "Loading Coils for 160-Meter Antennas," QST, April, 1990

[6] B.F. Brown, "Optimum Design of Short, Coil-Loaded High-Frequency Mobile Antennas," *ARRL Antenna Compendium, Volume 1* (Newington, ARRL, 1985)

[7] W.J. Byron, "Short Vertical Antennas for the Low Bands: Part 1 & Part 2," Ham Radio May & June, 1983

[8] M.W. Maxwell, *Reflections-Transmission Lines and Antennas* (Newington, ARRL, 1990)

[9] W. Schulz, "Designing a Vertical Antenna," QST, Sept., 1978

[10] B. Boothe, "Weak signal Reception on 160-Some Antenna Notes," QST, June 1977

[11] A.C. Doty Jr., J.A. Frey, & H.J. Mills, "Efficient Ground Systems for Vertical Antennas," QST, Feb., 1983
A.C. Doty Jr., J.A. Frey, & H.J. Mills, "Vertical Antennas: New Design and Construction Data," *ARRL Antenna Compendium, Volume 2,* (Newington, ARRL)
A.C. Doty Jr., J.A. Frey, & H. J. Mills, "Characteristics of the Counterpoise and Elevated Ground Screen," Professional Program, Session 9, Southcon '83 (IEEE) Atlanta GA 1983
A.C. Doty Jr., "Improving Vertical Antenna Efficiency," CQ, April, 1984
J.A. Frey, "The Minipoise," CQ, 1985
A.C. Doty Jr., Technical paper presentation, "Capacitive Bottom Loading and Other Aspects of Vertical Antennas," Technical Symposium, Radio Club of America, New York City, Nov. 20, 1987

SHORTENED, LOADED ANTENNAS

HF monopoles used as verticals, mobile antennas and in pairs as elements of beams & dipoles

Actual Measured Performance Comparisons

Barry A. Boothe, W9UCW

With the help of many

Part Two

Part One covered some basic concepts surrounding this subject, explained the reasons why the long-term measurement effort was initiated, detailed how the studies were done, and gave the bottom line numbers for “Series #1 & Series #2 tests. These tests were the basis of our work to compare the effects of the “Q” and the position of loading coils in shortened, loaded antennas. In general, the numbers indicate that the bulk of the literature and conventional wisdom about these issues is inaccurate.

In Part Two, the bottom line numbers for ten other related issues are given. The tables are followed by my plain language conclusions.

Ground Resistance of Large and Small Vehicles vs. a Radial System

Much has been said about this subject, but little in the way of real numbers has been presented. These measurements were made at the Harlingen test site. Helium filled balloons were used to support ¼ wave antennas fed against each subject plane. Although one would expect that the actual numbers will be different for every vehicle, location, and climatological condition, the comparisons are interesting. See Part One for a description of the “Truckstand” and the radial system.

EFFECTIVE GROUND RESISTANCE IN OHMS

Band/Frequency	Big Vehicle- “Truckstand”	Small Vehicle- 1993 Escort	On-Ground Radial System
10 M--28.5 MHz	5	6	4
15 M--21.3 MHz	10	11	5
20 M--14.4 MHz	19	23	6
30 M--10.1 MHz	25	31	8
40 M---7.2 MHz	31	37	11
80 M---3.8 MHz	40	47	17
160M---1.8 MHz	84	91	24

Plain Language Conclusions:

1. The size of the vehicle has most to do with its ground resistance on any particular frequency & location. The smaller vehicle will have higher resistance and lower efficiency. Stamp collecting might be more rewarding than going mobile with a small motorcycle on 160 or 80 meters… unless you can drag a radial.

2. Ground resistance of a less than perfectly conducting plane is inversely proportional to the frequency of operation. So, if the vehicle is small, expect comparatively poor results on the lowest frequency bands. If you want really top results mobiling on 1.8 MHz, consider making your next vehicle one which can pull a flatbed, lowboy semi trailer, perhaps with a copper plated floor. Mount the antenna in the middle of the trailer. You still won't be king of the band, but you may be king of the road.

I should add that even though the numbers indicate that a mobile antenna for 1.8 or 3.8 MHz may be in the 1% to 3% efficiency range, lots of great contacts, including DX are made by people using that mode. In fact, my first DX contact from our new home was made from the mobile rig in the "Truckstand" sitting in our driveway. The antenna was a 160 meter resonator with a long one inch diameter closewound coil of #20 enameled wire mounted on an eight foot mast. I called CQ on 1.824 MHz about sunrise, and was answered by Bob, VK3ZL. I should add that Bob has good ears.

HI-Q and LO-Q Resonators over Truck vs. Radial System

It was claimed by some that the almost identical performance of HI-Q & LO-Q resonator coils was because of their use with poor ground resistance planes, like vehicles. This theory had been put forth in internet discussions of our findings. These tests were done in Harlingen using a six foot mast below the resonators. They were repeated a number of times with the same results. The truck stand and the radial system are described in Part One.

	FIELDSTRENGTH IN db BELOW THE REFERENCE ANTENNA	
ANTENNA TESTED	***TRUCKSTAND***	***ON-GROUND RADIAL SYSTEM***
14.2 MHz ¼ wave no coil	***-2 db***	***-.8 db***
14.2 MHz w/HI-Q coil	***-3.2 db***	***-1.5 db***
14.2 MHz w/LO-Q coil	***-3.2 db***	***-1.5 db***
3.8 MHz ¼ wave no coil	***-3.1 db***	***-1.2 db***
3.8 MHz w/HI-Q coil	***-11.5 db***	***-6.5 db***
3.8 MHz w/LO-Q coil	***-11.6 db***	***-6.6 db***

Plain Language Conclusions:

1. The lower ground resistance of an average on-ground radial system compared to that of a big vehicle will noticeably improve field intensity of a coil loaded monopole. This is certainly no surprise.

2. On the other hand, the relationship between HI-Q & LO-Q loading coils remains the same, that is, no significant difference in performance between the two, whether used on antennas with high or low ground resistance.

Angle of Resonator to Mast

The question here was what effect changing the angle of resonator to mast would have on performance. These tests were related mostly to coil loaded mobile antennas, but would apply to any shortened, loaded monopole. The tests were performed during the Fletcher Program and in Harlingen. A six foot mast was employed with HI-Q and LO-Q coils and a top whip.

Field strength in db below reference antenna for different resonator to mast angles.

ANTENNA	VERT. 0º	45º	HORIZ. 90º	135º
14.2 MHz LO-Q	-3.3 db	-3.3 db	-3.3 db	-3.5 db
14.2 MHz HI-Q	-3.3 db	-3.3 db	-3.3 db	-3.5 db
3.8 MHz LO-Q	-11.4 db	-11.4 db	-11.4 db	-11.7 db
3.8 MHz HI-Q	-11.3 db	-11.3 db	-11.3 db	-11.6 db

Plain Language Conclusions:

1. The mounting angle of resonators to mast on inductively top loaded antennas has little to no effect on field strength unless the angle is more than 90 degrees from the mast.

2. Mounting resonators at different angles to either accommodate multiple resonators and/or to reduce vulnerability to damage will have no detrimental affect on signal strength.

3. Changing the angle of resonator to mast <u>will</u> affect the resonance, so retuning is usually in order.

Even when the resonator begins to parallel the mast, it does not result in a large cancellation of fields. On the other hand, if the top loading wires of non-inductively loaded verticals or inverted L's droop significantly, the losses can become quite significant.

Although the figures are not presented here, during any measurement sequence involving capacitive only top loading, significantly lower field strengths were observed as the big hat wires were allowed to droop down. The angle to the vertical element also greatly affected the tuning. This subject needs to be the basis of some future studies.

Multiple Resonators on a Single Mast

These tests were aimed at multi-band setups. They were done at Fletcher and in Harlingen on the test stand and the truck stand. A six foot mast was used below the resonator(s). The idea was to compare the signal strength performance to single resonator setups. As resonators were added to the mast, tuning was performed to readjust for resonance. As in other *Bottom Line Results*, figures are referenced to a perfect ¼ wave groundplane. The numbers for 7.2, 10.1, 18.15, and 21.3 MHz are based on only three test runs, but the pattern was the important point. Other mast lengths were tried with similar results as these. Resonators were mounted ninety degrees from the mast. First, each resonator was measured alone. Then, resonators were added one at a time, retuned for resonance, and field intensity was measured. Results were the same for HI-Q & LO-Q resonators.

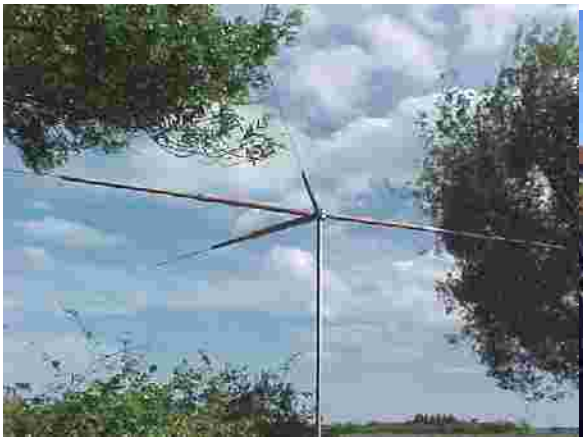


Figure 29. Multi-resonator setup with 40, 30, 20 & 15 meters in place.

Figure 30. Multi-resonator setup with resonators at two Levels.

Field intensity readings for one to six resonators on a mast vs. ¼ wave reference antenna.

BAND	ONE	TWO	THREE	FOUR	FIVE	SIX
3.8 MHz	-11.5 db	-11.4 db	-11.4 db	-11.5 db	-11.6 db	-11.5 db
7.2 MHz	-8.4 db		-8.3 db	-8.4 db	-8.4 db	-8.4 db
10.1 MHz	-5.9 db				-5.8 db	-5.8 db
14.2 MHz	-3.3 db	-3.2 db	-3.3 db	-3.3 db	-3.3 db	-3.2 db
18.15 MHz	-1.3 db					-1.3 db
21.3 MHz	-.7 db			-.7 db	-.7 db	-.7 db

Plain Language Conclusions:

1. Adding resonators to a mast for the purpose of operating on multiple bands/frequencies does not degrade the signal strength performance compared to a single resonator setup.

2. As resonators are added, retuning will be required.

Using Magnetic Mounts for Mobile Antennas

Putting a mobile antenna on a "mag-mount" without low impedance grounding straps to the vehicle is the same as putting a capacitor in series with one half of that antenna. Depending on the size and number of magnets, plus the frequency of operation, this results in some amount of reactance. The reactance must be cancelled, or "tuned out". We wanted to compare various designs of mag-mounts, and to look at the performance compared to standard body mounts to see if there was a difference in field strength. All this information was derived from measurements made in Harlingen using a variety of mag-mounts on various vehicles. The capacitance of any particular mag-mount may vary from those we measured if a different thickness of protective covering is used on the bottom of the magnets. We used a Ballentine Labs Model 520 capacitance meter. On the field strength chart, figures for 3.8 MHz include both "matched" and "unmatched" numbers because at resonance, the SWR was more than 2:1 when using mag-mounts.

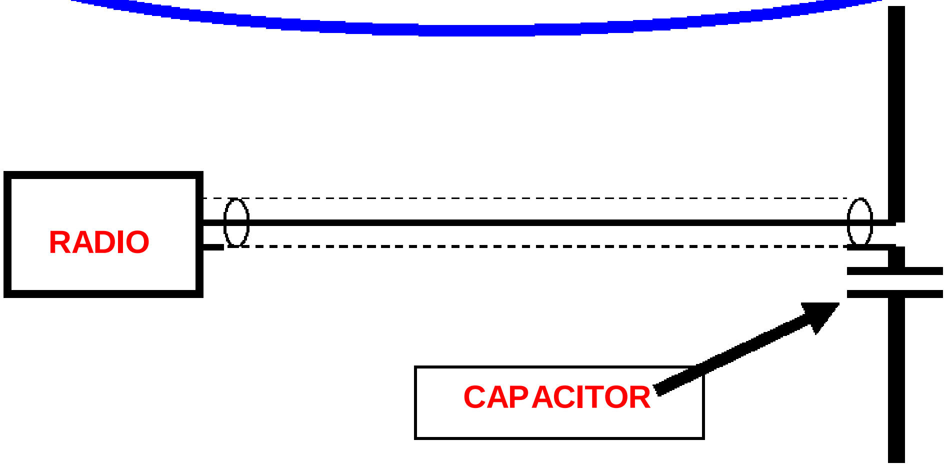

Figure 31. On a tool box plate in a pick-up truck bed.


Figure 32. On the roof of a car.


Figure 33. On a trunk lid with wide ground braids.


Figure 34. On another car roof.

THE TROUBLE WITH MAGMOUNTS



Magnetic Mount Characteristics

MAG-MOUNT TYPE	*SURFACE AREA*	*CAPACITANCE (TO GROUND)*
3 ea-3” Diameter Magnets	*21 sq. in.*	*323 pf*
4 ea-3” Diameter Magnets	*28 sq. in.*	*431 pf*
3 ea-4” Diameter Magnets	*38 sq. in.*	*584 pf*
4 ea-4” Diameter Magnets	*50 sq. in.*	*769 pf*
4 ea-5” Diameter Magnets	*78 sq. in.*	*1200 pf*

Mag-mount Reactance by Type & Band

BAND	3 ea-3” Diam. Magnets	4 ea-5” Diam. Magnets
10 Meters-28 MHz	17 ohms	5 ohms
15 Meters-21 MHz	25 ohms	7 ohms
20 Meters-14 MHz	35 ohms	10 ohms
40 Meters- 7 MHz	70 ohms	20 ohms
80 Meters-3.8 MHz	140 ohms	40 ohms
160 Meters-1.8 MHz	280 ohms	80 ohms

Field Strength by Mount Type

BAND	*MOUNT TYPE*	*FIELD*	*STRENGTH*
		UNMATCHED	**MATCHED**
20M-14.2 MHz	**BODY-DIRECT**	**-3.2 db**	**------**
20M-14.2 MHz	**3x3” Magmount**	**-6.2 db**	**------**
20M-14.2 MHz	**4x5” Magmount**	**-5.2 db**	**------**
80M-3.8 MHz	**BODY-DIRECT**	**-11.3 db**	**------**
80M-3.8 MHz	**3x3” Magmount**	**-21.3 db**	**-18.7 db**
80M-3.8 MHz	**4x5” Magmount**	**-15.3 db**	**-14.7 db**

Plain Language Conclusions:

1. The use of a mag-mount for a mobile antenna will result in a significant reduction of field strength. The loss will be worse for smaller mag-mounts and for lower frequencies. Use of the smaller type on 14 MHz cuts the power radiated in half from that of a body mount. On 3.8 MHz, use of even the larger type results in a similar loss when matched.

2. The reactance added to a mobile antenna system by a mag-mount is inversely proportional to the total surface area of the magnets. In other words, to least affect the original antenna design, use the mag-mount with the most magnets of the greatest diameter available.

Better yet, if it’s possible, add a low impedance connection to the vehicle skin. The difference, depending on mag-mount and frequency, can be like multiplying your power by four and up to ten.

Capacity Hat Location

Conventional wisdom stresses the importance of mounting capacity hats well above loading coils to avoid losses. Our object here was to quantify the difference in performance between hats adjacent to the top of the coil vs. well above the coil. These tests were done in Harlingen. Antennas for 1.8, 3.8, & 14.2 MHz were tested over both the “truck stand” as well as the ground radial system.

Figure 35. An 3.8MHz resonator with HI & LO hats.

Figure 36. A 1.8MHz resonator with a low hat

FIELD STRENGTH COMPARED TO REFERENCE ANTENNA

FREQ MHz	LOW HAT TRUCKSTAND	HIGH HAT TRUCKSTAND	LOW HAT RADIALS	HIGH HAT RADIALS
14.2	-3.3 db	-3.3 db	-1.4 db	-1.4 db
3.8	-11.6 db	-11.4 db	-6.6 db	-6.4 db
1.8	-19.4 db	-19.1 db	-10.5 db	-10.2 db

Plain Language Conclusions:

1. Well, conventional wisdom is correct, but, once quantified it's not a very big deal. On 1.8 and 3.8 MHz you can get a couple tenths of a db by moving the hat up away from the coil. You have to decide whether it's worth the work and risk for that kind of payback.

.

2. We also compared coils with and without metal end caps and found no difference in field strength performance, but, a pronounced effect on tuning. This was especially true at lower frequencies, depending on coil size and proximity of windings to cap.

Coil Top Loading vs. Capacity Hat only Loading

There is a preponderance of conventional wisdom that says capacity hats or wires should be used for top loading shortened monopoles rather than coils, for the sake of efficiency. We wanted to quantify the difference in performance. Sevick had offered valuable information on this subject in his work in 1973. We compared antennas over the radial system at the citrus grove test site in Harlingen. We used balanced capacity hats as opposed to "inverted L" configurations to avoid directional effects and any significant horizontal polarization. These antennas were erected on only three separate occasions, but the results were consistent.

Field intensity compared to the ¼ wave reference antenna

FREQ. MHz	MAST HEIGHT	COIL/WHIP RESONATOR	CAPACITY HAT ONLY
14.2	8 FEET	-1.1 db	-1.1 db
3.8	31 FEET	-3.1 db	-3.0 db

Plain Language Conclusions:

1. There is almost <u>no</u> signal strength advantage to using only top loading capacity hats or wires in lieu of top loading coils to resonate short monopoles, all other factors like vertical mast length being the same. This coincides with the fact that there is no significant difference in performance between HI-Q & LO-Q coils used for loading monopoles. Bandwidth was nearly identical on these examples.

2. <u>BUT, during the tests on capacity-only loading it was noted that when the wires or hat, skirted or not, drooped down from the top of the mast, there was a significant drop in field strength. Although the numbers were recorded in our raw data, we have never matched the exact angle or number and size of wires to the particular field strength. We found that we had to keep the wires horizontal or higher in order to get top performance… which was a real task at the test site. We wanted to try this test on 1.8 MHz, but the logistics were beyond our practical capability at that location.</u>

More work should be done in this area to better quantify the losses of drooping capacity hats. There are many "umbrella" and guy wire hat designs in articles and books that should be evaluated. An ultimate example, somewhat related to "umbrella" wire loading and linear loading is the "Meandered Line" antennas published in the IEEE Transactions, December, 1998. It's performance can be best likened to a large, unshielded dummy load, as experienced by Arch, W7ACD when he built a big one for 160.

3. The various "Inverted L" designs may have an advantage over top loaded straight verticals (coil or cap.) of the same size due to <u>increased horizontally polarized radiation and bandwidth</u>. This depends on the intended use and propagation variables, as well as the ratio of vertical to horizontal sizes and the angle of the top of the "L" to the vertical element.

<u>Alternate Types of Loading Coils</u>

The object here was to compare the performance of antennas with several types of loading coils. These tests were done in Fletcher as well as Harlingen. A lot more work needs to be done in this area. For instance, toroidal cores of the right "mix" and size must be found, especially for common power levels on the lower Ham radio bands. The one used for the 3.8 MHz test overheated at 10 watts. Nothing could be found for the 1.8 MHz toroid test. Also, a method for spacing the turns on pie-wound coils had to be developed. One way would involve printed circuit technology. That solution is an economic show stopper for the quantities needed for the Ham radio market. The turn-to-turn capacitance, especially on the lower frequency units caused significant losses. The pie-wound coils in these tests were our earliest prototypes.

These tests were run using a 72 inch base mast on the test stand and the truckstand.

Figure 37. 3.8 mHz pie-wound resonator on a ½" mast.

Figure 38. 14.2 mHz toroidal resonator.

Figure 39. 14.2 mHz pie-wound, side view.

Figure 40. 14.2 mHz pie-wound, top view.

F.S. = Field Strength below ref. ant. B.W. =Band Width of < 2:1 SWR

BAND	*STD. COIL*		*TOROID COIL*		*PIE-WOUND COIL*	
	F.S.	*B.W.*	*F.S.*	*B.W.*	*F.S.*	*B.W.*
14.2 MHz	*-3.3 db*	*478 kHz*	*-4.6 db*	*590 kHz*	*-4.4 db*	*490 kHz*
3.8 MHz	*-11.4 db*	*30 kHz*	*-21.2 db*	*122 kHz*	*-15.1 db*	*52 kHz*
1.8 MHz	*-19.4 db*	*5 kHz*	*N.A.*	*N.A.*	*-23.5 db*	*27 kHz*

Plain Language Conclusions:

1. These alternatives show great promise if materials and processes can be further developed. They are particularly attractive considering their small size, weight and wind resistance combined with exceptional bandwidth.

WB9NUL & I ran the 14 MHz pie-wound resonator, shown above, on a cross-country trip to the west coast. It was on an 8 foot mast. It was interesting that we didn't need the fishing line guy string that we normally used on a long mast mobile antenna. At 50 MPH or faster, the antenna was frozen at about 20° back from vertical. Apparently at that angle the drag was equaled by the lift. The antenna was nearly flat (SWR) across the whole 20 meter band.

As an aside, I should add that we were so impressed with the possibilities of the pie-wound design, that we went to Washington D.C. and did a patent search. Once into the sub-sub-sub category of our interest, we had 15,000 patents to review. It took 3 days to go through them and we found less than ten that were even vaguely related. Most were recent and held by large armed forces contractors. But the earliest, and probably closest to our stated design purpose, was filed in 1925 by J.O.Mauborgne & Guy Hill. We came away much

enlightened but convinced that there was no need to pursue a patent. We learned a lot from the experience.

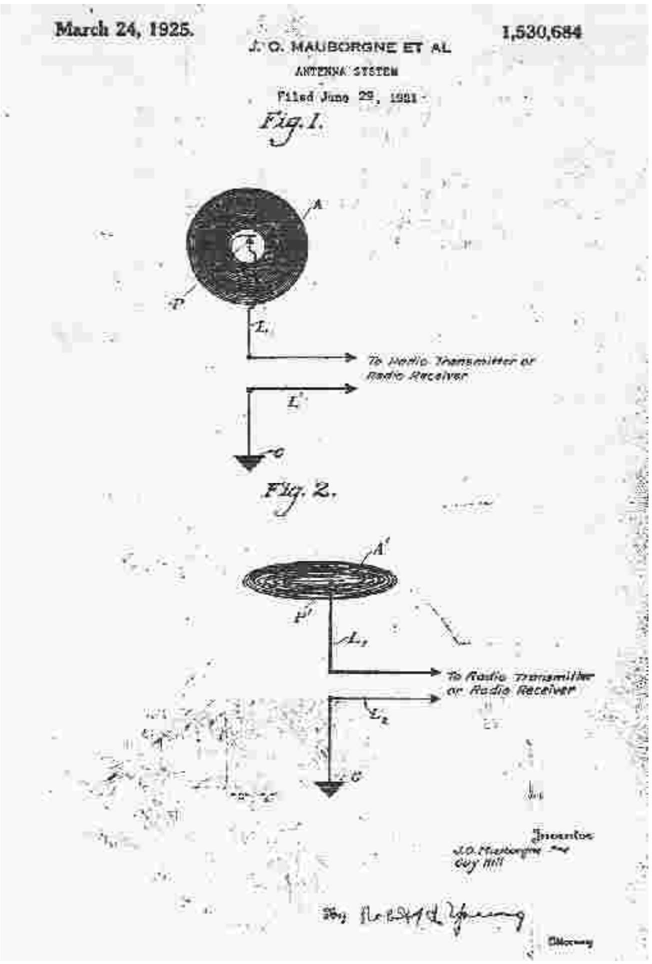
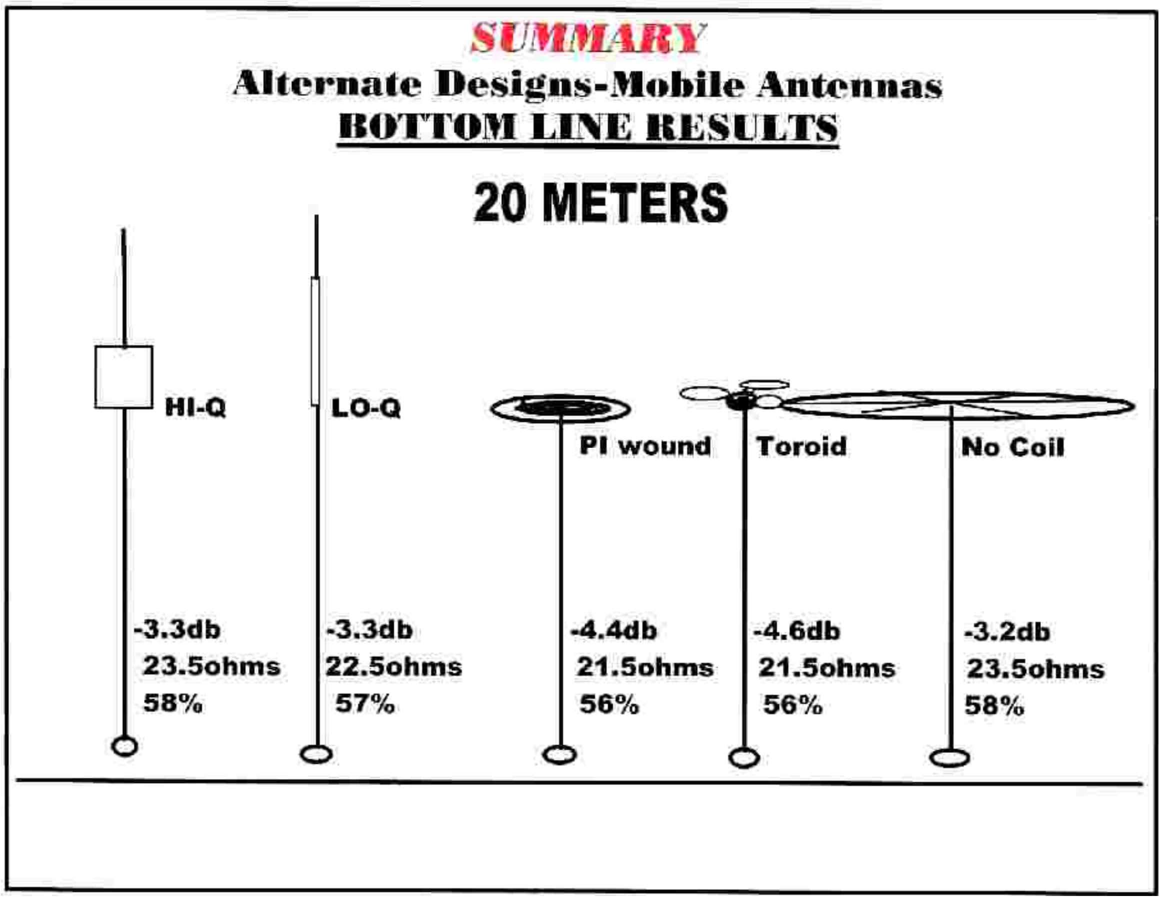


Figure 41. 1925 pie-wound antenna patent.



SUMMARY
Alternate Designs-Mobile Antennas
BOTTOM LINE RESULTS

20 METERS

Matching and Tuning Schemes

When a mobile antenna under test in Series #1 and Series #2 was 2:1 SWR or greater at resonance, readings were taken both matched and unmatched. The matching was done at the feedpoint of the antenna. The results are shown in Part One.

Comparisons were made between matching at the **antenna base vs. in the vehicle cabin** during the Harlingen tests. This was an effort to simulate the use of autotuners and others at the transmitter end of the coax feedline. This has become particularly common with the advent of very small solid state radios. They cannot dissipate any significant heat associated with a less than perfect SWR and are designed to reduce power as the SWR goes up. In order to get some examples, we used a 3.8 MHz antenna with a six foot mast on the truckstand, and a 7.2 MHz antenna on a Ford Escort at the Citrus grove test site. Both antennas were under 2:1 SWR, but high enough in SWR that in both cases small solid state rigs would reduce their power levels when transmitting on them. For these measurements, the feedpoint matching device was either a shunt coil, or shunt capacitor to ground. Of course, the antenna was retuned to resonance. The in-cabin matching device was a small commercial “mobile tuner” or a home brewed “T” or “L” network. As in all measurements to this point in this report, a precise 10 watts was sent to the antenna system being tested.

MATCHING AT THE ANTENNA BASE VS. MATCHING IN THE CABIN

FIELD STRENGTH IN db BELOW PERFECT ANTENNA

ANTENNA	NO MATCH	MATCHED AT BASE	MATCHED IN CABIN
3.8MHz-6'mast on Truckstand	*-11.5 db*	*-11.1 db*	*-12.5 db*
7.2 MHz-6' mast on Ford Escort	*-9.0 db*	*-8.5 db*	*-9.7 db*

Plain Language Conclusions:

1. Matching at the base of a loaded monopole to achieve 1:1 SWR will usually result in some degree of improved field strength. The amount of improvement will depend on how far from 50 ohms you start with, and the frequency.

2. Matching a mismatched antenna with a tuner in the cabin, like an autotuner or "mobile" tuner will result in some small amount of loss of signal strength, assuming the same power is delivered to the system. This is likely due to losses in the tuner itself rather than in the short piece of coax used in a mobile installation. Of course, several other factors come into play here. This sort of setup is often employed so that the modern miniaturized solid state transceiver is "happy" and will deliver full power to the antenna but power is lost due to the efficiency of the tuner. The SWR on the coax will not be improved by the cabin tuner, and so the concern becomes one of noise reception and energy radiated into automobile controls by the mismatched coax. In a base station, with perhaps 100 feet of coax, losses could be severe, especially on the higher frequency bands.

Also, at Harlingen, measurements were taken to quantify the loss when an antenna was tuned to the high end of the band and was being used on the low end of the band with a tuner in the cabin. This situation is common with operators using top loading resonators who want to quickly switch from phone to CW "on the run," as county hunters often do. The matching devices were the same as above.

ANTENNA TUNED TO PHONE BAND BUT USED ON CW, w/CABIN TUNER

FIELD STRENGTH IN db BELOW PERFECT ANTENNA

ANTENNA RESONANT ON 80M-3815 KHz

MEASURED AT 3815 KHz (RES) NO MATCHING	MEASURED AT 3525 KHz (CW) NO MATCHING	MEASURED AT 3525 KHz (CW) MATCHED IN CABIN
-11.5 db	*-28.7 db*	*-27.7db*

ANTENNA RESONANT ON 40M-7240 kHz

MEASURED AT 7240 KHz (RES) NO MATCHING	MEASURED AT 7040 KHz (CW) NO MATCHING	MEASURED AT 7040 KHz (CW) MATCHED IN CABIN
-9.0 db	*-15.5 db*	*-14.5 db*

3. Using a cabin tuner to match a mobile antenna to a frequency far from its resonance will result in a <u>goodly</u> reduction of signal strength. It <u>will</u> allow the transmitter to work into a matched load and that is certainly better than using <u>no</u> matching or retuning, but it is not the desirable way to operate on a long term basis.

One of the ways operators get around this problem today is through the use of remotely tuned antennas, like the various "screwdriver" designs. But, to achieve the ever sacred 1:1 SWR without leaving the drivers seat, most designs sacrifice efficiency due to the short mast below the lumped inductance and the very lossy mounting structures many employ. As I said in the introduction to this report, "everything works," it's just a matter of what compromises we wish to make to satisfy our own priorities.


Figure 42. A small commercial "screwdriver" antenna.


Figure 43. Shunt matching coil at the base of an antenna.


Figure 44. Large commercial "screwdriver" motorized antenna.


Figure 45. Note the parallel beam mounting structure.


Figure 46. The coil in use to resonate the antenna on 20 meters.

Current in Loading Coils

Our early efforts to determine whether the RF current dropped or remained the same from the bottom to the top of loading coils in monopoles were not too conclusive or very scientific. For instance, we applied excessive power to the antennas, shut down and quickly checked the temperature along the coils. They were warmer at the bottom. But, that certainly didn't satisfy us as a proof. We moved neon and fluorescent bulbs along the coils to indicate relative voltage while transmitting a carrier. Much higher voltage was indicated at the top of the coil and our logic told us that if the voltage went up, the current had to go down. But, that didn't prove anything either.

Our initial metered measurement of RF current in monopole loading coils was done in the yard at our home in Harlingen. Various configurations of short loaded antennas were built and tested over an extensive radial system. We collected data for base, center and near top loaded antennas for 10.1 MHz and 7.2 MHz. We used both HI-Q & LO-Q coils. Eventually, we measured RF currents in many different loading coils on 1.8 and 3.8 MHz at the citrus grove site on both the truckstand and the big radial system. Here is a sampling of current readings when the current at the base of the coil was 100 milliamperes (RF).

The test procedure and the reasons for the measurements are discussed in section #3 of Part One.

CURRENT AT TOP OF COIL WITH 100 MILLIAMPS RF AT BOTTOM OF COIL

ANTENNA	BASE LOADED	CENTER LOADED	¾ TOP LOADED	VERY TOP LOADED
7.2 mHz-92" HI-Q COIL	66 mils	45 mils	37 mils	
7.2 mHz-92" LO-Q COIL	64 mils	43 mils	35 mils	
10.1 mHz-92" HI-Q COIL	75 mils	60 mils	52 mils	
10.1 mHz-92" LO-Q coil	74 mils	60 mils	50 mils	
3.8 mHz-72" Mast + Res.			79 mils	
1.8 mHz-96" Mast + Res.			65 mils	
14.2 mHz-116" Toroid Coil			79 mils	47 mils

Figure 47. One of the coil current measurement setups.

Figure 48. RF ammeters reading 100 MA on the bottom and 42 MA on the top of the loading coil.

Plain Language Conclusions:

1. The current tapers from the bottom to the top of loading coils used to resonate shorter than quarter wave length monopoles. The Q of the coil has little to no effect on the drop.

The amount of taper seems related to that portion of the quarter wave that has been replaced by the coil, but that is an over-simplification. The reason the current tapers, other than a small amount of conductor resistance and radiation, is that the net current at any point is the "vector" sum of currents at that point. And, at any point along the monopole, or a series inductor, there is a phase difference between the current coming from the source and the current reflected back from the open end or top/end of the monopole. The resultant net current is less as you move toward the open end of the monopole, where it is virtually zero, because at that end point, the forward and reflected currents are equal in magnitude and opposite in phase thus superposing to zero.

This information may answer the questions we had about the lack of impact of coil Q on field strength and the inability to confirm the published formulas to "optimally" locate coils in the mast. It may also explain why capacity only loading is no better than top coil loading, all else remaining the same.

Concluding Remarks

Most of the books are wrong!

And that goes for lots of "conventional wisdomites," as well. Designers and builders of short, loaded antenna elements have often used these errors causing misguided decisions.

It would be prudent to question any design stemming from the assumption that the current in monopole loading coils is uniform. Furthermore, any modeling program that considers series loading coils in standing wave antennas to be a single point in the circuit are in error and will lead the designer/evaluator astray.

My objective was to compare the effectiveness of different designs of shortened, loaded antenna elements. In the process, I came to some eye-opening conclusions. More work of this type should be done in order to help builders and buyers make good decisions.

I would like to reinforce a few things, offer some sources of important information and mention a "Gestalt" experience I had that has occupied my experimentation work for some time now.

First of all, as seen in the measurements above, the effectiveness of these kinds of antennas is dependent in part on the counterpoise against which they are working. It must be remembered that the loaded monopole is only half of the antenna and that there must be a second half so that an electrostatic field is established between the two parts. As I said before, that field is the source of radiated energy.

Certainly, mounting the loaded monopole in the center of a large conductive plate will provide the kind of radiating field you need… but unless you have a metal roofed building or such, you'll likely have to simulate that plate some other way. There is plenty of information in Ham radio and broadcast literature about ground radial systems, for instance. Material has been published in the last decade on this subject by Sommer[12], Severns[13], and Doty[14]. I would suggest those works for your perusal. And for some earlier classics on the subject, look up Hills, G3HRH[15], also Brown, and Brown[16], Lewis, & Epstein[17].

Now, as for that "Gestalt" experience. It came to me out of the blue one morning in November 2009. The result has been easy-to-build pie-wound resonators that avoid the problems described in the "Alternate Types of Resonators" section of this report. They have **very** notable characteristics of bandwidth and efficiency. To answer calls for information, I issued the first limited edition of a CD for builders in July of 2010. A goodly number of friends have been building them in the US and a couple other countries. Those builders have contributed greatly to the material list and methodology. Many cross country and mobile contest runs have been made utilizing multi-band "stacks" of these resonators. I'm now working on a much refined 2nd edition of the CD incorporating all the best ideas from builders. I will release it as soon as I can, along with a composition describing the entire saga of **"The Flying Saucer Resonators."**

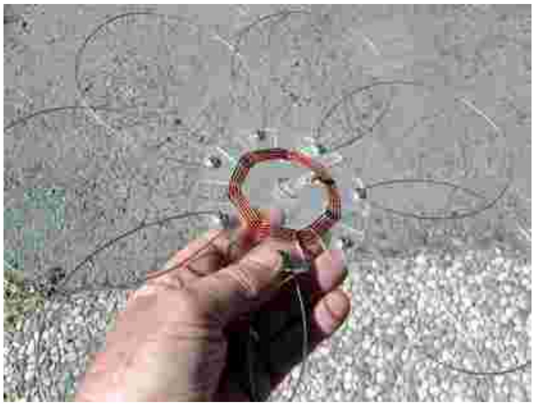


Fig. 49 A 20 meter "Flying Saucer" resonator

Fig. 50 A 10,12,15,17,20, & 40 meter "stack"

Many people contributed to this project. Joyce, WB9NUL, my wife and best friend has worked with me on all my endeavors for 30+ years. It could not have been done without her. I particularly want to thank Arch W7ACD who has been instrumental to the tasks at hand for a similar period of time. Other contributors of note include Cecil W5DXP, Mike KG5UZ, Cheryl KJ5PQ, Walter K3OQF, George K9PAW, Greg W7MY, Terry WQ7A, & Barry N0KV. Of course, our old friends John W3ESU and Harry K4HU, both gone now, did a lot to help us in Fletcher along with so many of their friends from the Hendersonville area plus a few locals in the Lower Rio Grande Valley. All of these friends made our quest for the answers possible.

Barry A. Boothe, W9UCW
21175   FM2556
Santa Rosa, TX 78593
W9UCW@arrl.net

Footnotes for Part One and Part Two

---

[1] B. Boothe, "The Minooka Special," QST, Dec., 1974

[2] J. Sevick, "The Ground-Image Vertical Antenna," QST, July, 1971
J. Sevick, "The W2FMI Ground-Mounted Short Vertical," QST, March, 1973

[3] J.S. Belrose, "Short Antennas for Mobile Operation," QST, Sept., 1953
J.S. Belrose, "Short Coil-Loaded HF Mobile Antennas: An Update and Calculated Radiation Patterns." ARRL Antenna Compendium, Volume 4,

---

(Newington, ARRL, 1995)

[4] P.H. Lee, *The Vertical Antenna Handbook*, New York, Cowan Publishing,1974

[5] C.J. Michaels, “Evolution of the Short Top-Loaded Vertical,” QST, March, 1990
C.J. Mickaels, “Loading Coils for 160-Meter Antennas,” QST, April, 1990

[6] B.F. Brown, “Optimum Design of Short, Coil-Loaded High-Frequency Mobile Antennas,” *ARRL Antenna Compendium, Volume 1* (Newington, ARRL, 1985)

[7] W.J. Byron, “Short Vertical Antennas for the Low Bands: Part 1 & Part 2,” Ham Radio May & June, 1983

[8] M.W. Maxwell, *Reflections-Transmission Lines and Antennas* (Newington, ARRL, 1990)

[9] W. Schulz, “Designing a Vertical Antenna,” QST, Sept., 1978

[10] B. Boothe, “Weak signal Reception on 160-Some Antenna Notes,” QST, June 1977

[11] A.C. Doty Jr., J.A. Frey, & H.J. Mills, “Efficient Ground Systems for Vertical Antennas,” QST, Feb., 1983
A.C. Doty Jr., J.A. Frey, & H.J. Mills, “Vertical Antennas: New Design and Construction Data,” *ARRL Antenna Compendium, Volume 2,* (Newington, ARRL)
A.C. Doty Jr., J.A. Frey, & H. J. Mills, “Characteristics of the Counterpoise and Elevated Ground Screen,” Professional Program, Session 9, Southcon ’83 (IEEE) Atlanta GA 1983
A.C. Doty Jr., “Improving Vertical Antenna Efficiency,” CQ, April, 1984
J.A. Frey, “The Minipoise,” CQ, 1985
A.C. Doty Jr., Technical paper presentation, ”Capacitive Bottom Loading and Other Aspects of Vertical Antennas,” Technical Symposium, Radio Club of America, New York City, Nov. 20, 1987
[12] B. Sommer, “Optimal Radial Ground Systems,” QST, March 2010
[13] R. Severns, “Verticals, Ground Systems and Some History,” QST, July, 2000
R. Severns, “An Experimental Look at Ground Systems for HF Verticals,” QST, March, 2010
R. Severns, “Experimental Determination of Ground System Performance for HF Verticals,” QEX, Jan/Feb 2009 through Jan/Feb 2010
[14] A.Doty, “The Effect of Ground Conductivity on Antenna Radials,” QEX, Mar/Apr, 2011
[15] R.C.Hill, G3HRH,”The Ground Beneath Us,” RSGB June, 1966, pp.375-385

[16] G.H. Brown, “The Phase and Magnitude of Earth Currents Near Radio Transmitting Antennas,” Proc. Of the IRE, February 1935, Volume 23, Number 2

[17] G.H. Brown, R.F. Lewis, & J. Epstein, “Ground Systems as a Factor in Antenna Efficiency,” Proceedings Of the IRE, June, 1937, Volume 25, Number 6