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Actual Measured Performance of Short, Loaded Antennas — Part 2

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.

What are the Bottom Line Numbers?

In this second part of the article, I present the actual measured results for our Series 1 and Series 2 tests. The field strength numbers throughout the Tables are comparisons to a perfect, zero-loss ground-plane antenna with a ¼ λ resonant vertical monopole. This is the "zero" point or benchmark. As you read the charts, keep in mind that the least negative field strength number is the most desirable, because it represents how much weaker the test antenna is than a perfect monopole/ground-plane antenna on that frequency. These tests were conducted in Fletcher, North Carolina and in Harlingen, Texas, and repeated many times over several years. The deviation was very small. These are the averaged numbers from dozens of Series 1 and Series 2 runs.

Each run through Series 1 and Series 2 resulted in nearly 300 measurements. When excursions to other bands occurred, the number of measurements 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 Doty, K8CFU/W7ACD.

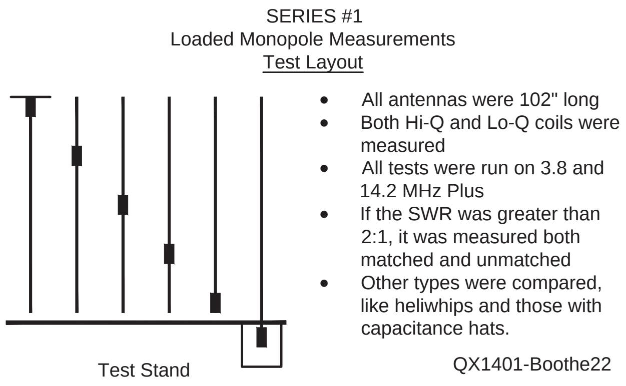

Figure 22 — **This drawing illustrates the Series 1 test antenna configurations.**

Series 1

How the Position and Q of the Coil in a Shortened Monopole Affects Efficiency

In this series, the test antenna was a fixed length of 8½ feet**.** Starting with the loading coil at the very top of the mast, a balanced horizontal capacitance above the loading coil was adjusted for resonance. Field strength and all other measurements were collected. Then the coil was moved down 24 inches, the antenna was adjusted for resonance again, and all data collected. Then, down 24 inches more, then another 24 inches, and finally the coil was installed at the base. Figure 22 illustrates the variations in antenna configuration for these tests.

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, one additional configuration was added. That was where the loading coil was *below* 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 high-*Q* coils in our tests were made using #12 or #10 silver tinned copper air core coil stock with spaced turns, either 2, 3, or 4 inches in diameter. Our low-*Q* coils were all either #20 enameled copper (1.8 MHz and 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 and 3.8 MHz were 7/8 inch in diameter, while the 7.2 and 10.1 MHz coils were 5/8 inch in diameter, and those for 14.2 to 21 MHz were 3/8 inch in diameter. Table 1 shows the results on 20 m and Table 2 shows the results on 80 m.

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[1] Notes appear on page 31.

Table 1
Series 1 Bottom Line Results
20 Meters, 14.2 MHz

Antenna Configuration	*Resistance at Resonance (Ω)*		*2:1 Bandwidth (kHz)*		*Field Strength (dB) Below Reference Antenna*	
	High-Q	*Low-Q*	*High-Q*	*Low-Q*	*High-Q*	*Low-Q*
¼ λ 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

Table 2
Series 1 Bottom Line Results
80 Meters, 3.8 MHz

Antenna Configuration	*Resistance at Resonance (Ω)*		*2:1 Bandwidth (kHz)*		*Field Strength (dB) Below Reference Antenna*	
	High-Q	*Low-Q*	*High-Q*	*Low-Q*	*High-Q*	*Low-Q*
¼ λ 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

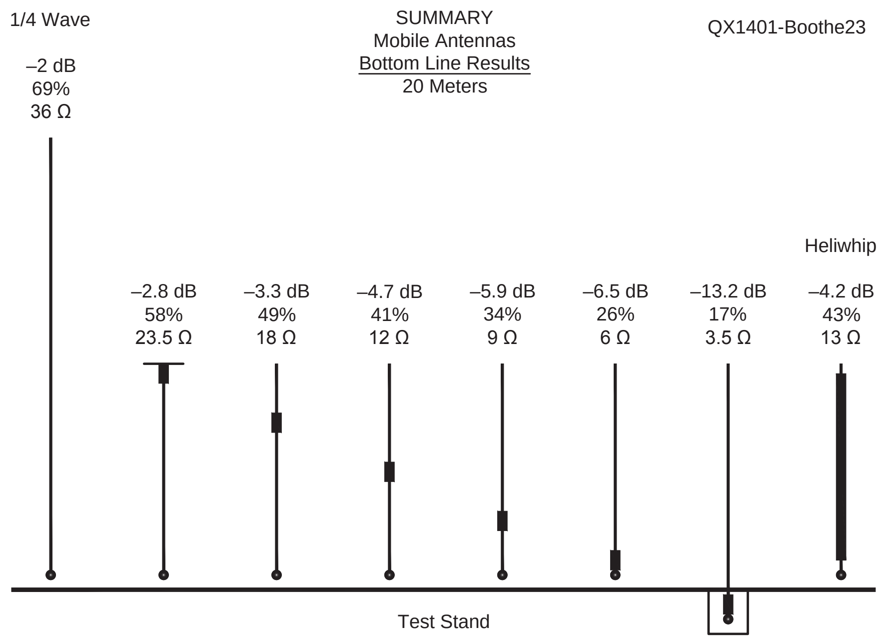


Figure 23 — This drawing summarizes the Series 1 test results for the various antenna configurations on 20 m.

Series 1 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 W down to 0.4 W! On 14.2 MHz, it's not so bad, like going from 100 W down to 10 W. No correlation was ever seen with the "optimum" positioning of the coil near the center of the mast.

Also, from the results shown, it's obvious that in the case of a *base loaded* antenna, a significant portion of the radiated field comes from *the coil itself*. 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 high-*Q*, big wire, air wound coils, and low-*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 ground plane like a vehicle or over a good ground plane like an extensive radial system. There is more about this in "High-*Q* and Low-*Q* Resonators Over Truck Versus Radial System" later in the article.

As mentioned earlier, other antenna variations were "thrown in" during Series 1 and 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 point 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. They might intimidate your competition, though.

3) Two things result in 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 snows or, in the case of a mobile setup, you get close to trees or smack a bug with the coil.

Figure 23 shows the series of antenna configurations that we measured on 20 m. Figure 24 shows the configurations measured on 80 m.

Series 2

How the Length of the Base Mast Affects 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. Figure 25 illustrates the various antenna configurations that we tested.

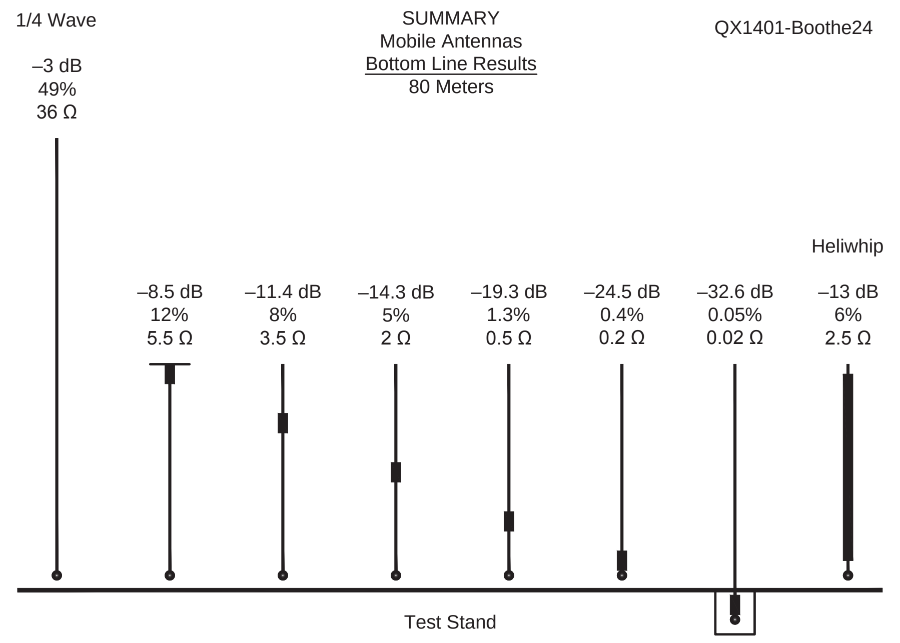
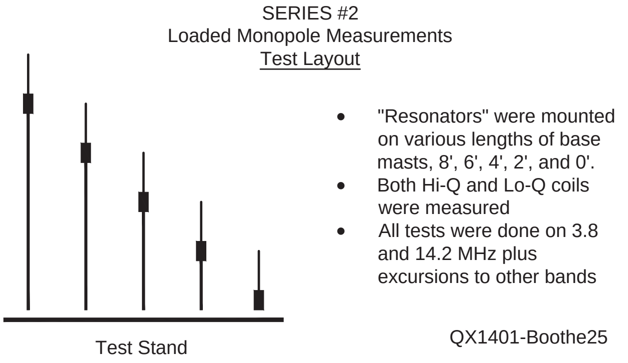


Figure 24 — Here are the Series 1 test results for the various 80 m antenna configurations.



- "Resonators" were mounted on various lengths of base masts, 8', 6', 4', 2', and 0'.
- Both Hi-Q and Lo-Q coils were measured
- All tests were done on 3.8 and 14.2 MHz plus excursions to other bands

Figure 25 — This drawing illustrates the Series 2 test antenna configurations.

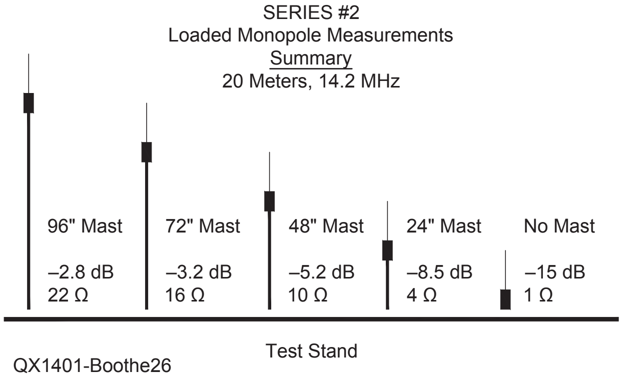


Figure 26 — Here is a summary of the Series 2 test results for 20 m.

Table 3
Series 2 Bottom Line Results
20 Meters, 14.2 MHz

Antenna Configuration	*Resistance at Resonance (Ω)*		*2:1 Bandwidth (kHz)*		*Field Strength (dB) Below Reference Antenna*	
	High-Q	*Low-Q*	*High-Q*	*Low-Q*	*High-Q*	*Low-Q*
¼ λ 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

Table 4
Series 2 Bottom Line Results
80 Meters, 3.8 MHz

Antenna Configuration	*Resistance at Resonance (Ω)*		*2:1 Bandwidth (kHz)*		*Field Strength (dB) Below Reference Antenna*	
	High-Q	*Low-Q*	*High-Q*	*Low-Q*	*High-Q*	*Low-Q*
¼ λ 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

Table 5
Effective Ground Resistance (Ω)

Band	*Frequency*	*Big Vehicle (Truck Stand)*	*Small Vehicle (1993 Ford 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
160 m	1.8 MHz	84	91	24

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 and 3.8 MHz, with occasional excursions to the other bands. Table 3 shows our results on 20 m and Table 4 shows the results on 80 m. Figure 26 shows a summary of our 20 m tests and Firuge 27 summarizes the results for 80 m.

Series 2 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 2 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 low-Q and high-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.

The rest of this report will present actual measured performance comparisons dealing with the following subjects:

- Ground resistance of large and small vehicles and a “typical” on-ground radial system.
- High-*Q* and low-*Q* coil loaded monopoles over a vehicle versus 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 versus 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.

Ground Resistance of Large and Small Vehicles Versus 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, Texas test site. We used helium filled balloons to support ¼ λ antennas fed against each subject ground plane. Although one would expect the actual numbers to be different for every vehicle, location, and climatological condition, the comparisons are interesting. See Part One for a description of the "Truck Stand" and the radial system. Table 5 shows our measurements across the HF bands for our three ground systems.

Conclusions:

1) The size of the vehicle has most to do with its ground resistance on any particular frequency and 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 m, unless you can drag a counterpoise wire.

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 that 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.

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 truck stand sitting in our driveway. The antenna was a 160 m resonator with a long 1 inch diameter close-wound coil of #20 enameled wire mounted on an eight foot mast. I called CQ on 1.824 MHz around sunrise, and was answered by Bob Briggs, VK3ZL. I should add that Bob has good ears.

High-Q and Low-Q Resonators Over Truck Versus Radial System

Some claim that the almost identical performance of high-*Q* and low-*Q* resonator coils is because of their use with poor ground resistance ground planes, like vehicles. This theory has been put forth in Internet discussions of our findings. These tests were done in Harlingen, Texas using a 6 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. Table 6 compares our measurements using the truck stand with measurements made over an extensive on-ground radial system. That radial system, described in Part 1 of the article, consisted of 60 copper radials, with lengths from 40 to 60 feet, stretched out on the ground under the test antenna.

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) The relationship between high-Q and low-Q loading coils remains the same — that is there 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 between the resonator and 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 both our Fletcher, North Carolina and Harlingen, Texas measurements. We used a 6 foot mast, with high-*Q* and low-*Q* coils and a top whip. See Table 7.

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° 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 effect on signal strength.

3) Changing the angle of resonator to mast *will* 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 antennas droop significantly, the losses can become quite significant.

Although the figures are not presented here, during any measurement sequence involving capacitive only top loading,

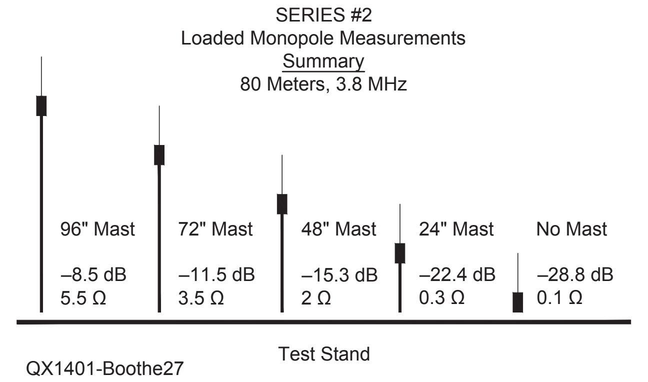


Figure 27 — This drawing summarizes the Series 2 test results for 80 m.

Table 6
Field Strength in dB Below the Reference Antenna

Band	*Frequency*	*Antenna Tested*	*Truck Stand*	*On-Ground Radial System*
20 m	14.2 MHz	¼ λ No Coil	–2 dB	–0.8 dB
20 m	14.2 MHz	With High-*Q* Coil	–3.2 dB	–1.5 dB
20 m	14.2 MHz	With Low-*Q* Coil	–3.2 dB	–1.5 dB
80 m	3.8 MHz	¼ λ No Coil	–3.1 dB	–1.2 dB
80 m	3.8 MHz	With High-*Q* Coil	–11.5 dB	–6.5 dB
80 m	3.8 MHz	With Low-*Q* Coil	–11.6 dB	–6.6 dB

Table 7
Field Strength in dB Below Reference Antenna for Different Resonator to Mast Angles

Antenna	*Vertical 0°*	*45°*	*Horizontal 90°*	*135°*
	Field Strength (dB) Below Reference Antenna			
14.2 MHz Low-*Q*	–3.3 dB	–3.3 dB	–3.3 dB	–3.5 dB
14.2 MHz High-*Q*	–3.3 dB	–3.3 dB	–3.3 dB	–3.5 dB
3.8 MHz Low-*Q*	–11.4 dB	–11.4 dB	–11.4 dB	–11.7 dB
3.8 MHz High-*Q*	–11.3 dB	–11.3 dB	–11.3 dB	–11.6 dB

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 6 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 the other Tables, Table 8 uses a perfect ¼ λ ground-plane antenna as the reference. 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 90° 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 high-*Q* and low-*Q* resonators. Figure 28 shows how resonators were added, and also shows a two-tiered arrangement.

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.”

Table 8

Field Intensity Readings for One to Six Resonators on a Mast Versus a ¼ λ Reference Antenna

Frequency	*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	–0.7 dB			–0.7 dB	–0.7 dB	–0.7 dB

Table 9

Magnetic Mount Characteristics

Mag Mount Type	*Surface Area (In^2)*	*Capacitance To Ground (pF)*
3 Each 3” Diameter Magnets	21	323
4 Each 3” Diameter Magnets	28	431
3 Each 4” Diameter Magnets	38	584
4 Each 4” Diameter Magnets	50	769
4 Each 5” Diameter Magnets	78	1200

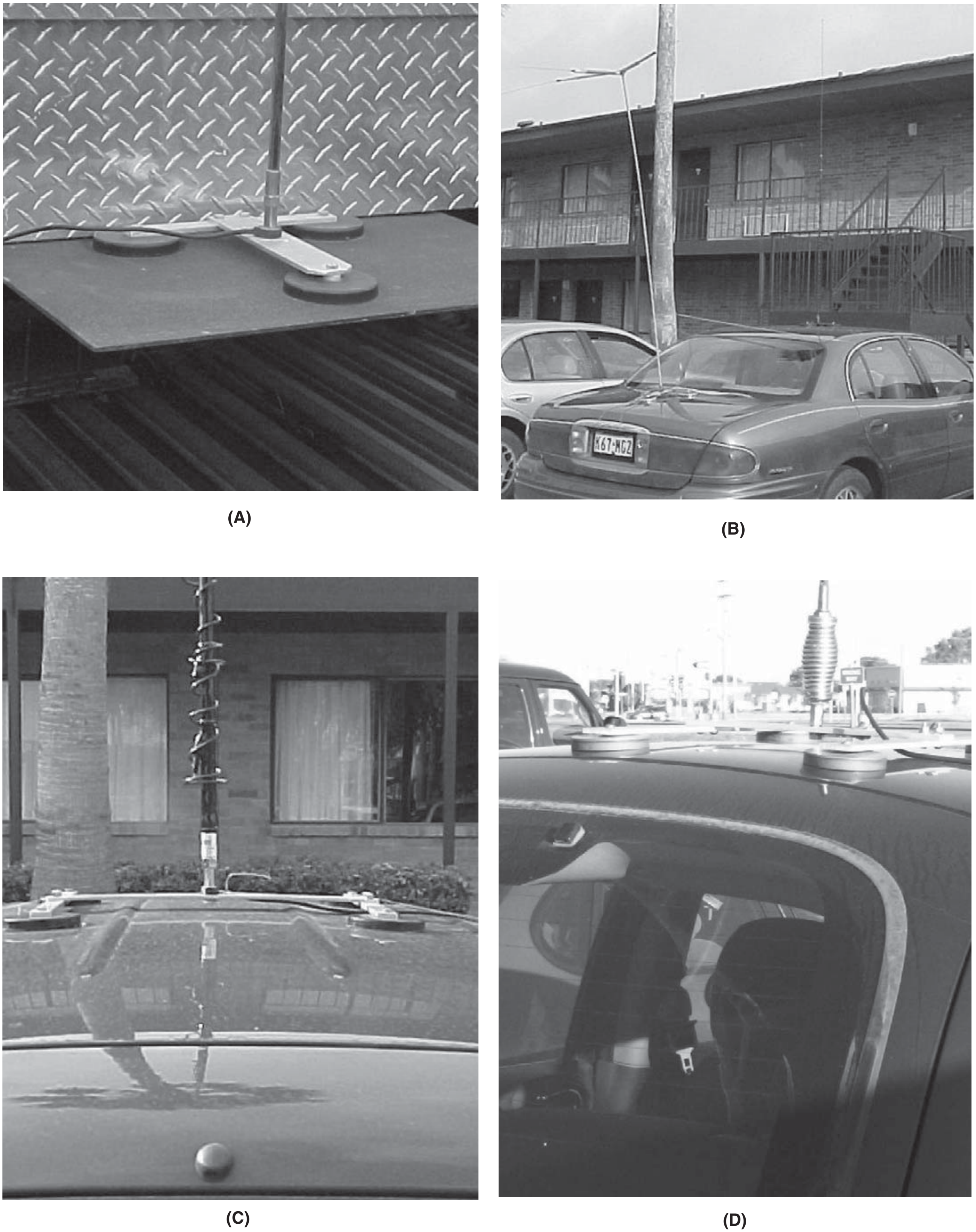
Table 10

Mag Mount Reactance by Type and Band

Frequency	*3 Each 3” Diameter Magnets*	*4 Each 5” Diameter Magnets*
	Reactance (Ω)	*Reactance (Ω)*
28 MHz	17	5
21 MHz	25	7
14 MHz	35	10
7 MHz	70	20
3.8 MHz	140	40
1.8 MHz	280	80


(A) (B)

Figure 28 — Part A shows a multi-resonator setup and Part B shows a setup with resonators at two levels.



(A)

(B)

(C)

(D)

Figure 29 — Photo A shows a mag mount on a tool box plate in a pick-up truck bed. Photo B shows a mount on the roof of a car. The mount in Photo C is on a car trunk lid, with wide ground braids attached to the car body. Photo D shows the mag mount on another car roof.

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 29 shows the various vehicles and mag mount styles tested. Table 9 gives the physical details of the various mag mounts we tested. Table 10 lists the reactance by band for two of the mag mounts, and Table 11 shows the field strength measurements. Figure 30 is a simple illustration of the problem with mag mounts.

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, or even up to ten.

Capacity Hat Location

Many articles have stressed 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 versus well above the coil. See Figure 31. These tests were done in Harlingen, Texas. Antennas for 1.8, 3.8, and 14.2 MHz were tested over both the truck stand as well as the ground radial system. See Table 12.

Conclusions:

1) 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.

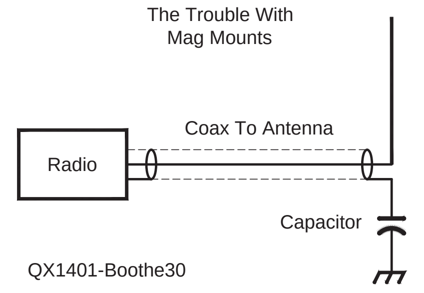
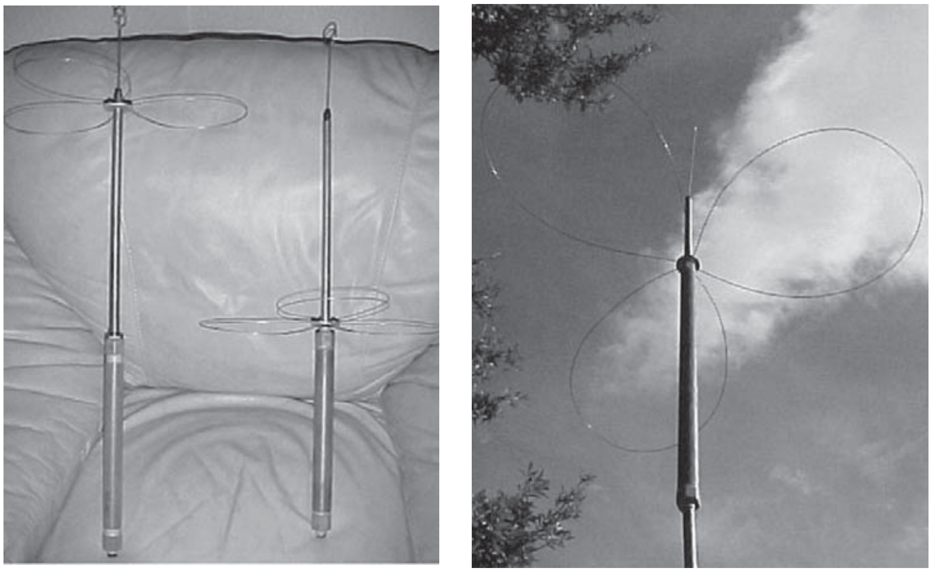


Figure 30 —This drawing illustrates the problem with using mag mounts. You are placing an unknown capacitor between the bottom of the antenna and the vehicle body/ground plane.



(A) **(B)**

Figure 31 —Photo A shows a 3.8 MHz resonator with high and low capacity hats. Photo B shows a 1.8 MHz resonator with a low capacity hat.

Table11
Field Strength by Mount Type

Frequency	*Mount Type*	*Field Strength (dB)*	
		Unmatched	*Matched*
14.2 MHz	Direct Car Body	–3.2 dB	------
14.2 MHz	3×3” Mag Mount	–6.2 dB	------
14.2 MHz	4×5” Mag Mount	–5.2 dB	------
3.8 MHz	Direct Car Body	–11.3 dB	------
3.8 MHz	3×3” Mag Mount	–21.3 dB	–18.7 dB
3.8 MHz	4×5” Mag Mount	–15.3 dB	–14.7 dB

Table 12
Field Strength Compared to Reference Antenna

Frequency (MHz)	*Low Hat Truck Stand*	*High Hat Truck Stand*	*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

Coil Top Loading Versus Capacity Hat Only Loading

Many articles have indicated that 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, Texas. We used balanced capacity hats as opposed to "inverted L" configurations to avoid directional effects and any significant horizontal polarization. Table 13 shows our results. These antennas were erected on only three separate occasions, but the results were consistent.

Conclusions:

1) There is almost *no* 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 high-*Q* and low-*Q* coils used for loading monopoles. Bandwidth was nearly identical on these examples.

2) 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.

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. Its performance can be best likened to a large, unshielded dummy load, as experienced by Arch Doty, W7ACD when he built a big one for 160 m.

3) The various Inverted L designs may have an advantage over top loaded straight verticals (coil or capacitor) of the same size due to increased horizontally polarized radiation and bandwidth. 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.

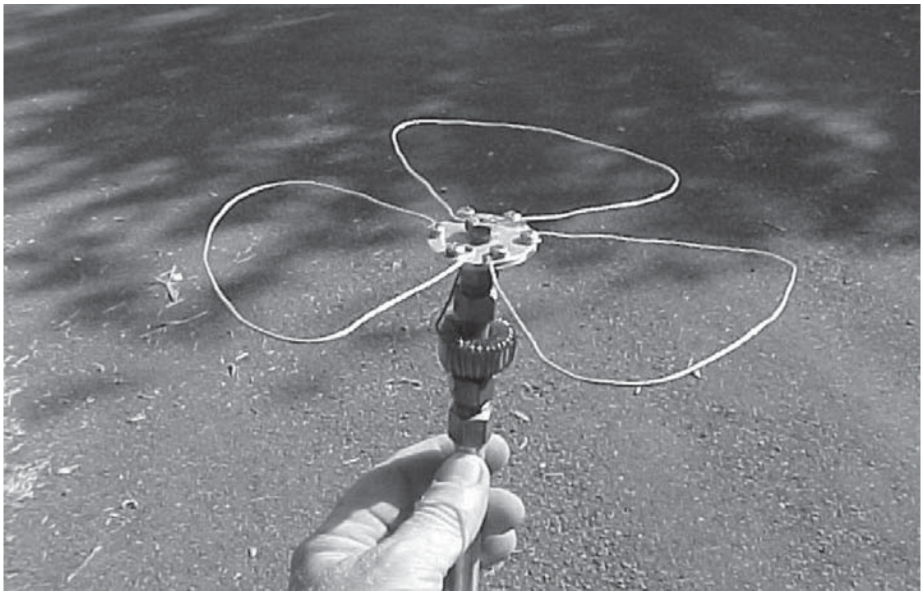


Figure 32 — You Can see the 14.2 MHz toroidal resonator below the loop wires.

Table 13
Field Intensity Compared to the ¼ λ Reference Antenna

Frequency (MHz)	*Mast Height (Ft)*	*Coil/Whip Resonator (dB)*	*Capacity Hat Only (dB)*
14.1	8	–1.1	–1.1
3.8	31	–3.1	–3.0

Table 14
Field Strength below Reference Antenna and Bandwidth for Less Than 2:1 SWR

Frequency	*Standard Coil*		*Toroid Coil*		*Pie-Wound Coil*	
	Field Strength	*Bandwidth*	*Field Strength*	*Bandwidth*	*Field Strength*	*Bandwidth*
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

Table 15
Matching at the Antenna Base versus Matching in the Vehicle Cabin
Field Strength in dB Below a Perfect Antenna

Antenna	*No Match*	*Matched at the Base*	*Matched in the Cabin*
3.8 MHz 6' Mast on Truck Stand	–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

Alternate Types of Loading Coils

The object here was to compare the performance of antennas with several types of loading coils. These tests were done in Fletcher, North Carolina as well as Harlingen, Texas. 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 Amateur Radio bands. See Figure 32. The one used for the 3.8 MHz test overheated at 10 W. 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 Amateur 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 truck stand. Table 14 summarizes our results.

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 and I ran the 14 MHz pie-wound resonator, shown in Figure 33, 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 to the lift. The antenna had a nearly flat SWR across the whole 20 m 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. The earliest, and probably closest to our stated design purpose, was filed in 1925 by J. O. Mauborgne and Guy Hill. See Figure 34. We came away much enlightened but convinced that there was no need to pursue a patent. We learned a lot from the experience.

Figure 35 shows the various antenna arrangements we tested with alternative mobile antenna designs, along with a summary of our test results.

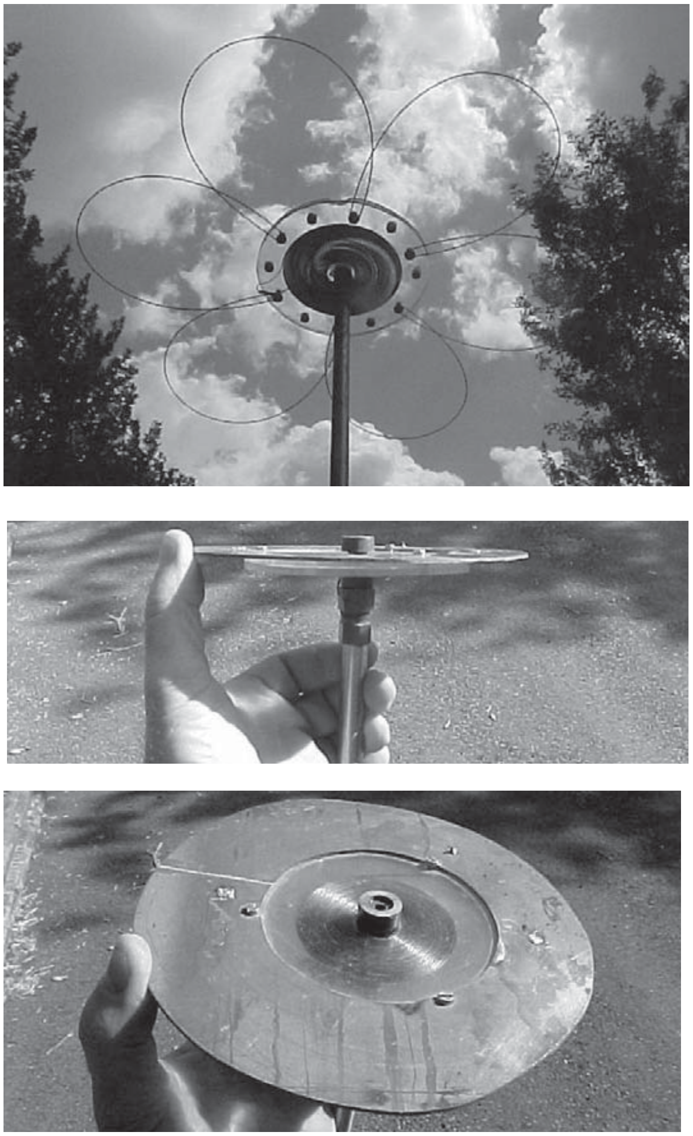
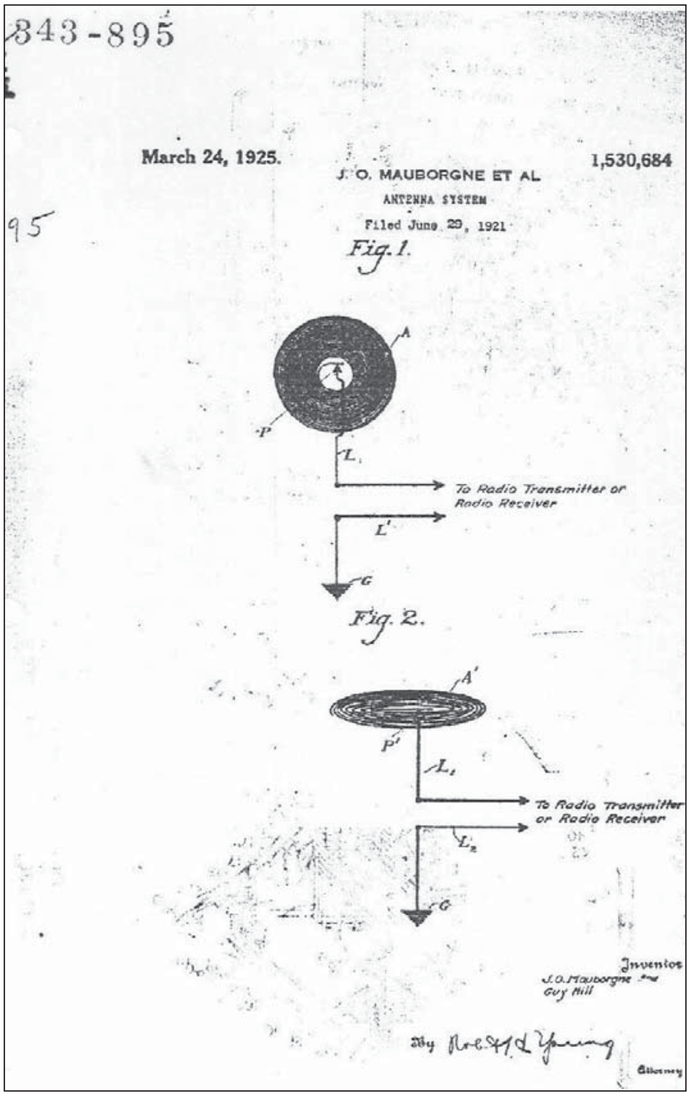


Figure 33 — Photo A shows a 3.8 MHz pie-wound resonator on a ½ inch mast. Photo B shows a side view of the 14.2 MHz pie-wound coil. Photo C shows a top view of the 14.2 MHz pie-wound coil.



343-895

March 24, 1925.

1,530,684

J. O. MAUBORGNE ET AL

ANTENNA SYSTEM

Filed June 29, 1921

95

Inventor
J.O. Mauborgne and
Guy Hill

By Robert L. Young
Attorney

Figure 34 — This page is from a 1925 pie-wound antenna patent.

Matching and Tuning Schemes

When a mobile antenna under test in Series 1 and Series 2 had an SWR of 2:1or greater at resonance, readings were taken with both matched and unmatched conditions. The matching was done at the feed point of the antenna. See Figures 36 through 40 for various examples of matching arrangements.

Comparisons were made between matching at the antenna base versus in the vehicle cabin during the Harlingen, Texas tests. This can be likened to a tuner at the base of a short vertical in the backyard versus a tuner in the shack instead. This was an effort to simulate the use of autotuners and others at the transmitter end of the coax feed line. In order to get some examples, we used a 3.8 MHz antenna with a 6 foot mast on the truck stand, and a 7.2 MHz antenna on a Ford Escort at the Citrus Grove test site. Both antennas had 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 feed point 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 W was sent to the antenna system being tested. Table 15 summarizes our measurements.

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 Ω you start with, and the frequency.

2) Matching a mismatched antenna with a tuner in the cabin or the shack, 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 or shack tuner, and so the concern becomes one of noise reception and energy radiated 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. Table 16 summarizes these measurements

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

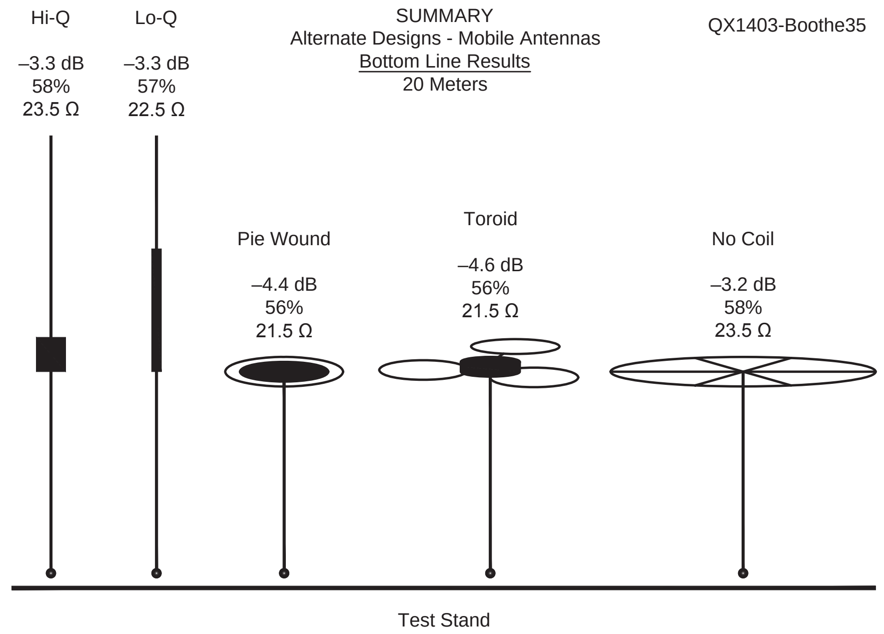


Figure 35 — This drawing illustrates the various alternative mobile antenna designs that we tested. The field strength, feed point impedance and efficiency of each antenna type is also shown.

Table 16
Antenna Tuned to Phone Band but Used on CW, With a Cabin Tuner
Field Strength in dB Below Perfect Antenna

Antenna Resonant on 80 m, 3815 kHz		
Measured at 3815 kHz (Resonant)	*Measured at 3525 kHz (CW)*	*Measured at 3525 kHz (CW)*
No Matching	*No Matching*	*Matched in Cabin*
–11.5 dB	*–28.7 dB*	*–27.7 dB*
Antenna Resonant on 40 m, 7240 kHz		
Measured at 7240 kHz (Resonant)	*Measured at 7040 kHz (CW)*	*Measured at 7040 kHz (CW)*
No Matching	*No Matching*	*Matched in Cabin*
–9.0 dB	*–15.5 dB*	*–14.5 dB*

Figure 36 — A small commercial "screwdriver" antenna.

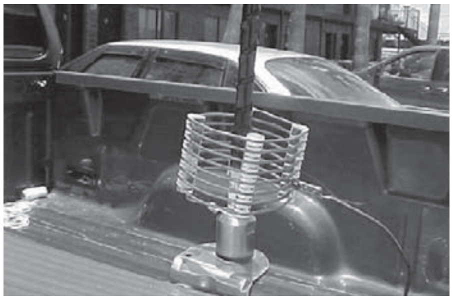


Figure 37 — Shunt matching coil at the base of an antenna.

Figure 38 — A large commercial "screwdriver" motorized antenna.

One of the ways operators get around this problem today is through the use of remotely tuned antennas, like the various "screwdriver" designs. To achieve the ever sacred 1:1 SWR without leaving the drivers seat, however, 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.

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. See Figure 41. 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

Figure 39 — Note the parallel beam mounting structure.

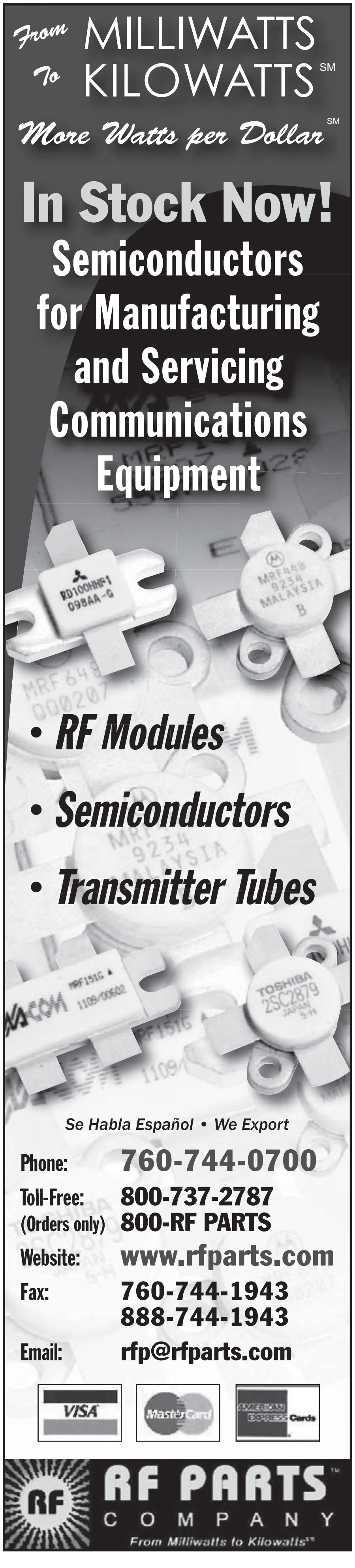


Table 17
Current at Top of Coil With 100 mA of RF at the Bottom of the Coil

Antenna	*Base Loaded (mA)*	*Center Loaded (mA)*	*¾ Top Loaded (mA)*	*Very Top Loaded (mA)*
7.2 MHz 92” High Q Coil	66	45	37	NA
7.2 MHz 92” Low Q Coil	64	43	35	NA
10.1 MHz 92” High Q Coil	75	60	52	NA
10.1 MHz 92” Low Q Coil	74	60	50	NA
3.8 MHz 72” Mast and Resonator			79	NA
1.8 MHz 96” Mast and Resonator			65	NA
14.2 MHz 116” Toroid Coil			79	47

high-*Q* and low-*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 truck stand and the big radial system. Table 17 is a sampling of current readings when the current at the base of the coil was 100 mA (RF). Figure 42 shows the RF ammeters installed at the top and bottom of a loading coil.

The test procedure and the reasons for the measurements are discussed in Part One.

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 in a standing wave antenna like a monopole over a ground plane, the net current at any point is the “vector” sum of currents at that point. 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

Some of the books, articles and modeling programs appear to have it wrong! Designers and builders of short, loaded antenna elements have often used this information, 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 likely in error, and will lead the designer/evaluator astray. Similarly, statements about the effect of losses in loading coils, especially “low *Q*” coils, seem to be grossly exaggerated.

Our objective was to compare the effectiveness of different designs of shortened, loaded antenna elements. In the process, we 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 and offer some sources of important information.

Figure 40 —The coil used to resonate the antenna on 20 m.

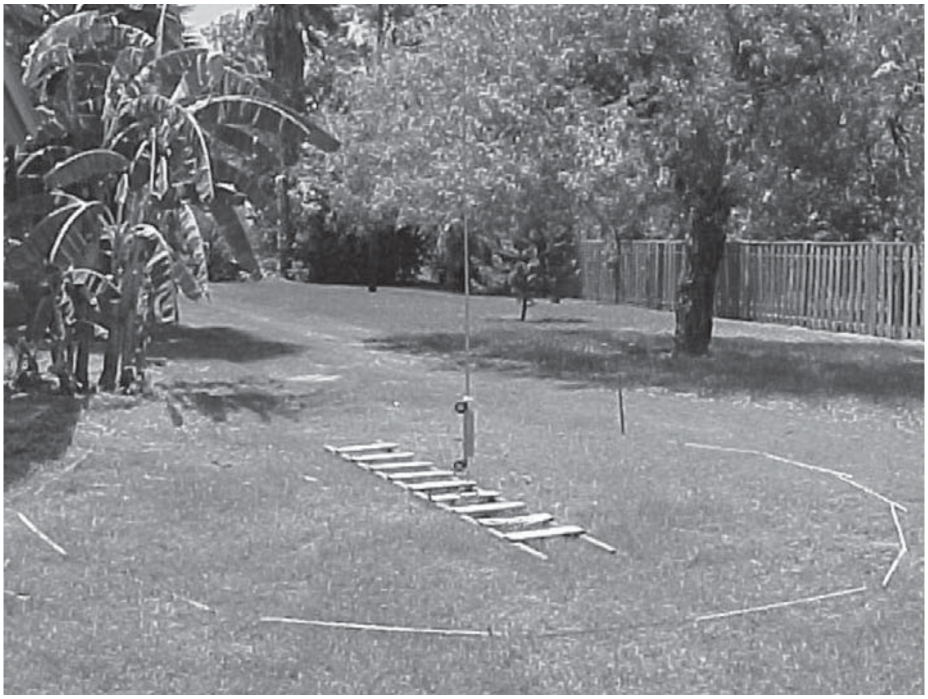


Figure 41 — One of the coil current measurement setups.

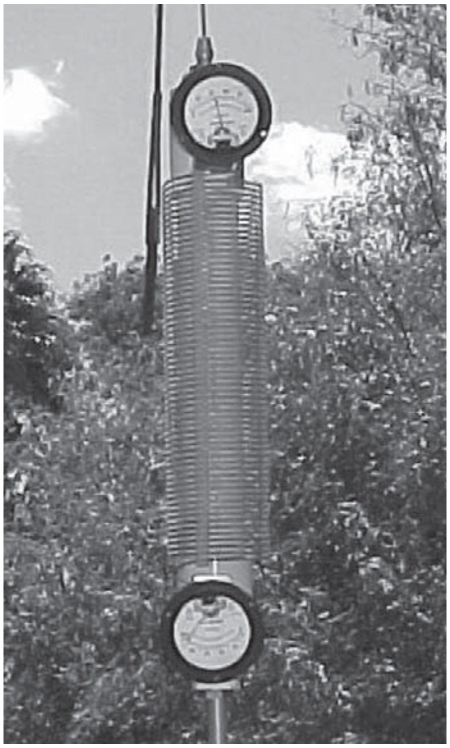


Figure 42 — RF ammeters reading 100 mA on the bottom and 42 mA on the top of the loading coil.

First of all, as seen in the measurements presented in this article, the effectiveness of these kinds of antennas depends in part on the counterpoise against which they are working. We must remember that the loaded monopole is only half of the antenna and that there must be a second half so that an electromagnetic field is established between the two parts. 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 Amateur Radio and broadcast literature about ground radial systems. Material has been published in the last decade on this subject by Robert Sommer, N4UU, Rudy Severns, N6LF, and Arch Doty, W7ACD.[20, 21, 22, 23, 24] I would suggest those works for your perusal. For some earlier classics on the subject, look up the articles by R. C. Hill, G3HRH, as well as G. H. Brown, and G. H. Brown, R. F. Lewis, and J. Epstein.[25, 26, 27]

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

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.

Notes

[20] Robert Sommer, N4UU, "Optimum Radial Ground Systems," *QST*, Aug 2003, pp 39 – 43.

[21] Rudy Severns, N6LF, "Verticals, Ground Systems and Some History," *QST*, July, 2000, pp 38 – 44.

[22] Rudy Severns, N6LF, "An Experimental Look at Ground Systems for HF Verticals," *QST*, March, 2010, pp 30 – 33.

[23] Rudy Severns, N6LF, "Experimental Determination of Ground System Performance for HF Verticals," *QEX*, Jan/Feb 2009 through Jan/Feb 2010.

[24] Arch Doty, W7ACD, "The Effect of Ground Conductivity on Antenna Radials," QEX, Mar/Apr, 2011, pp 15 – 18.

[25] R.C.Hill, G3HRH,"The Ground Beneath Us," RSGB *RadComm*, June, 1966, pp 375 – 385.

[26] G.H. Brown, "The Phase and Magnitude of Earth Currents Near Radio Transmitting Antennas," *Proceedings of the IRE*, February 1935, Volume 23, Number 2.

[27] G.H. Brown, R.F. Lewis, and J. Epstein, "Ground Systems as a Factor in Antenna Efficiency," *Proceedings Of the IRE*, June, 1937, Volume 25, Number 6.