Introduction

Have you ever looked at the ***Bilal Isotron*** advertisements and wondered how these tiny antennas worked—or if they really did? Is an Isotron a tiny miracle antenna or just a dummy load? Several of the GARDS are hard at work exploring capacitive antennas and GARDS member Harold Allen has been sharing some very interesting information on his study of the 20-meter Bilal Isotron, which is often sited as an example of a capacitive antenna.

A couple of months ago ***antenneX*** editor, Jack Stone, asked if any of the GARDS would like to examine a different Isotron. I jumped at the chance as I have always been intrigued by the Isotron advertisements and wondered if this little antenna would really work as claimed.

What Does Isotron Mean?

I checked the *US Patent and Trademark* Website to see if Bilal has trademarked the name "Isotron." I found three "live" listings for the word Isotron: two medical devices and an accelerometer—but no antennas. A search of the Internet turned up the Isotron antenna and several industrial and medical devices. Does the Isotron antenna isolate anything? You'll find out later in this article. The word Isotron, to antenna enthusiasts, has become a generic term to describe a general type of "capacitive" antenna.

A learning Experience

This project turned out to be quite a learning experience! I encountered many measurement and simulation problems that had to be surmounted. Fortunately, I had help with the measurements from Craig, my 9-year old son. He built a vertical antenna that we used to measure the ground conductivity and he hoisted the Isotron up and down the mast for the many adjustments and measurements. So, Rather than an article describing only my successes with this antenna I will tell you about the problems too.

What the Isotron Claims to Be

Bilal has been manufacturing the line of Isotron antennas for 22 years and makes some pretty lofty claims for it. Some of the claims are:

- ***Easy, Quick, and Simple Installation***
- ***Tunes & Performs Without Radials or Antenna Tuners***
- ***Excellent Transmitting Quality***

Does it meet these claims and how does it work? Read on to find out.

Design, Quality, and Assembly

I ordered my Isotron online for a price of USD $89.00 plus $10.00 S&H and it arrived a few days later in an amazingly small box. I immediately opened the box to take a look at the parts. Inspection revealed that the parts appear to have been machined in a garage-type machine shop using common parts direct from a hardware store. In a way this is a refreshing change from the injection molded, mass-produced antennas that permeate the market. Good old American ingenuity is alive and well! The coil is made of standard white PVC plumbing pipe and #14 AWG house wire and the insulators are ¼ -inch Acrylic sheet. There are several machined aluminum rods and the screws and nuts are stainless steel. The U-bolts are TV antenna grade and the top and bottom plates are made of aluminum sheet with what looks like stiffening creases.

Assembly took 35 minutes and would normally require only a flat screwdriver and a 5/8-inch open-ended wrench. However, I encountered a few problems and had to pull out a power drill, a pair of pliers, and a spare SO-239 connector. Here is a list of the problems I encountered:

- The top Coil Support Rod did not thread cleanly into the Coil Assembly. A pair of pliers took care of this.
- The Coil wire connecting to the top Coil Support Rod was on the short side. This caused the top coil rod to bind a bit when threading into the coil.
- The U-bolt holes in one of the Non-Metallic Supports were too close together. I had to drill larger holes.
- The Tuning Rod was missing the threads on one end. So, the optional Tuning Rod Capacitor Hat could not be attached.
- The UHF chassis connector receptacle was too small for the UHF connectors I had. I replaced the UHF connector with one from ***Radio Shack***™

If the Isotron I received is indicative of Isotron quality in general then some improvements are in order. I suggest the following manufacturing improvements as a start:

- Dress the ends of the threaded rods.
- Use a template to drill the U-bolt holes.
- Use a go-no-go gauge to check the U-bolt holes.
- Use a check-off sheet to check for defective components.
- Mail randomly selected Isotrons to an auditor to determine the defect rate.
- Set quality improvement goals and continually work to improve quality.

The Instruction Manual

The 40-meter Isotron instruction manual is a small, 18 page manual put together in pamphlet style. The ASSEMBLY section is detailed and not too difficult to follow. The SETUP section says to mount the antenna in the clear and as high as possible. A metal mast is recommended with the coax taped to the mast. The manual recommends against using a coaxial cable that is ¼ wavelengths (90 degrees) long. I actually used a line of this length and had no problems that I attributed to the coax length. Different lengths of transmission line should not alter the VSWR. And when using a line, with impedance that is equal to the system impedance (50 ohms in this case), different line lengths will simply cause the impedance, as seen at the source end, to rotate around the Smith Chart. For example, if the load is 150 ohms, the VSWR is 3:1, then the source impedance will rotate about a 3:1 VSWR circle. An example of this is shown in the ***WinSmith 2.0*** graph (Fig. 1) as the frequency is swept from 7 MHz to 14 MHz. The load is 150 +j0 ohms and the line length is 90 degrees at 7 MHz.

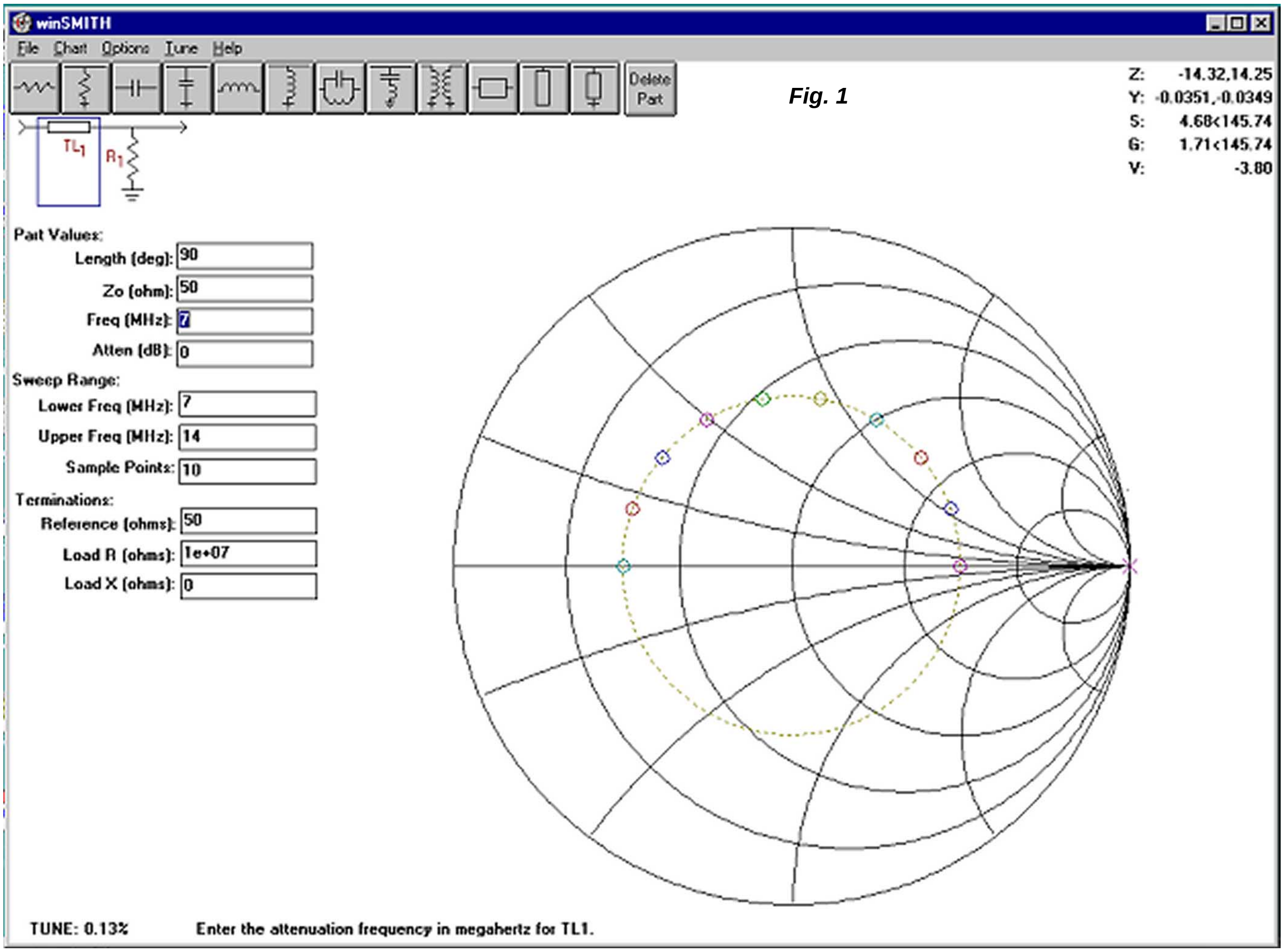


Fig. 1

Part Values:
Length (deg): 90
Zo (ohm): 50
Freq (MHz): 7
Atten (dB): 0

Sweep Range:
Lower Freq (MHz): 7
Upper Freq (MHz): 14
Sample Points: 10

Terminations:
Reference (ohms): 50
Load R (ohms): 1e+07
Load X (ohms): 0

Z: -14.32,14.25
Y: -0.0351,-0.0349
S: 4.68<145.74
G: 1.71<145.74
V: -3.80

TUNE: 0.13%

Enter the attenuation frequency in megahertz for TL1.

The Isotron manual implies that a 3:1 VSWR might be the lowest that can be achieved and that a tuner might be needed. I found this to be true when mounting the Isotron in an upstairs room. But when the Isotron was mounted outside at a height of 15 feet I achieved a VSWR of 1:1. The tune-up procedure details how to tune the Isotron using an SWR meter. Since I used an ***MFJ-259B*** impedance meter I was able to quickly find the resonant frequency and make the appropriate Isotron adjustments.

The manual says that when the Isotron is used where a direct earth ground connection is not possible, you can use the AC power ground but that the input impedance could be as high as 200 ohms. I tried the AC power ground when testing the Isotron in an upstairs room and found the input impedance to be 114 ohms. Using the AC power ground for anything other than what it was intended for does brings some risks. Returning substantial RF current through the AC power ground system could elevate portions of the ground to a dangerous RF potential. And, when trying this in the past I have had AC ground-fault interrupters buzz and trip during 100-watt operation. The use of the AC power ground for an RF ground might best be left to QRP (<5 watt) use.

The section on GROUNDING is interesting in that it says; "Isotrons do not use a ground for performance." I found this to ***not*** be the case. The ground wire is the ***real radiator*** and should be treated as such. Route the ground wire as if it was the antenna, ***since it is!*** For example, one would like to avoid running a vertical antenna down the side of a building, and in the same way the Isotron ground wire should not be run along a building, if possible. Since the Isotron really does use earth ground I recommend that a ground rod and radial wires be used for maximum performance, as with any ground-mounted vertical.

Simulating and Measuring the Isotron

Why simulate the Isotron when measurements can be taken? Measurements tell us *how well* an antenna performs but does not tell us *how* an antenna works. If we can achieve good correlation between simulation and measurement then we have good evidence that we understand how the antenna works. Then the "what ifs", such as how different grounding schemes affect the performance, can be easily tried on the computer.

The NEC-2 simulations proved to be a lot of work. The correlation between the simulations and the measurements was not good at first. This caused me to look more closely at both. After a bit of work, a simplified model was developed that I believe is good enough for exploring the "what ifs." The simplified Isotron was modeled over perfect earth using a coil model consisting of a 49 uH coil with a 25-ohm series loss resistance. Fig. 2 is a graph of the simulated and the measured input impedance versus height above ground when using a ground wire. Note that the actual Isotron was tested over real earth while the simulation used perfect earth. Although this comparison is not perfect, I think the fact that the impedances match closely, as the height is varied, is strong evidence that the model and theory are on the right track.

Note that the simulated Isotron input impedance rises quickly as the height approaches ¼ -wavelength. If an Isotron must be mounted at ¼ -wavelength above ground, and a high input impedance is obtained, it might help to leave the end of the "ground" wire floating. This will reflect a low impedance to the Isotron Bottom Plate. Fig. 3 is a graph of the simulated and the measured resonant frequencies versus height. Again, although the model is not ideal the resonant frequencies do trend in the same direction. Fig. 4 is a graph of the simulated radiation efficiency over perfect ground. This shows the importance of the ground wire in the operation of the Isotron. Fig. 5 is a graph of the measured and simulated 3:1 VSWR bandwidth. I suspect the measured bandwidth is wider than the simulated bandwidth due to ground losses in the near field.

Fig. 2

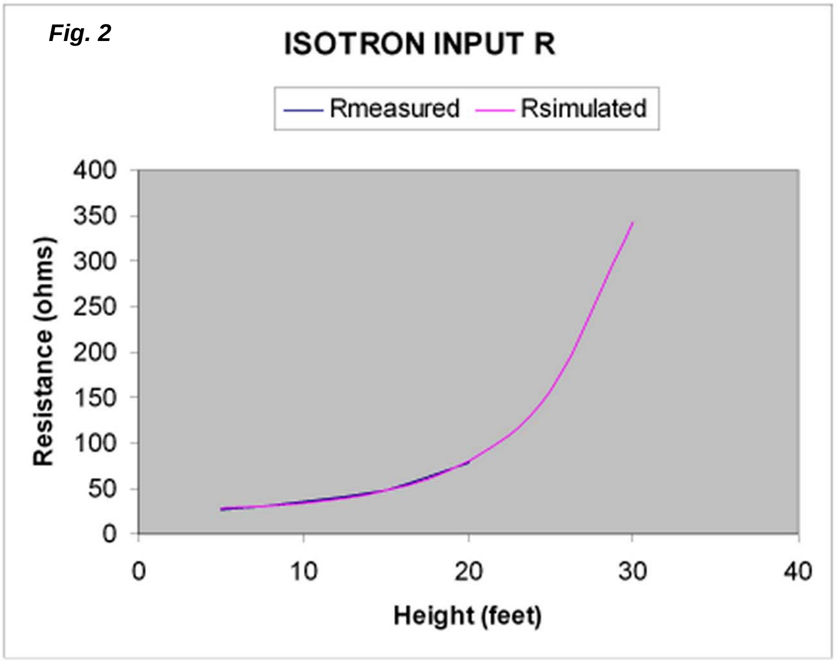


Fig. 3

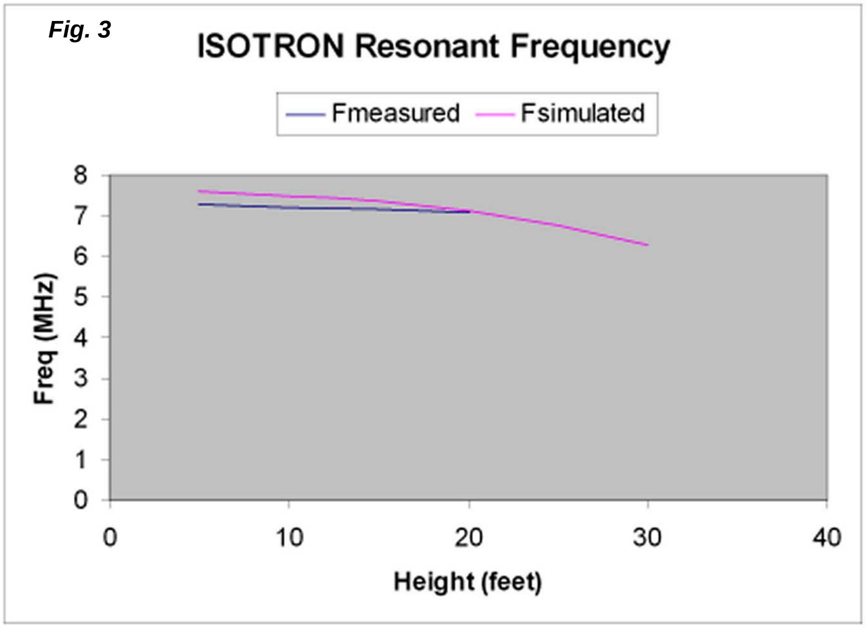


Fig. 4 shows the simulated radiation efficiency versus height.

Fig. 4

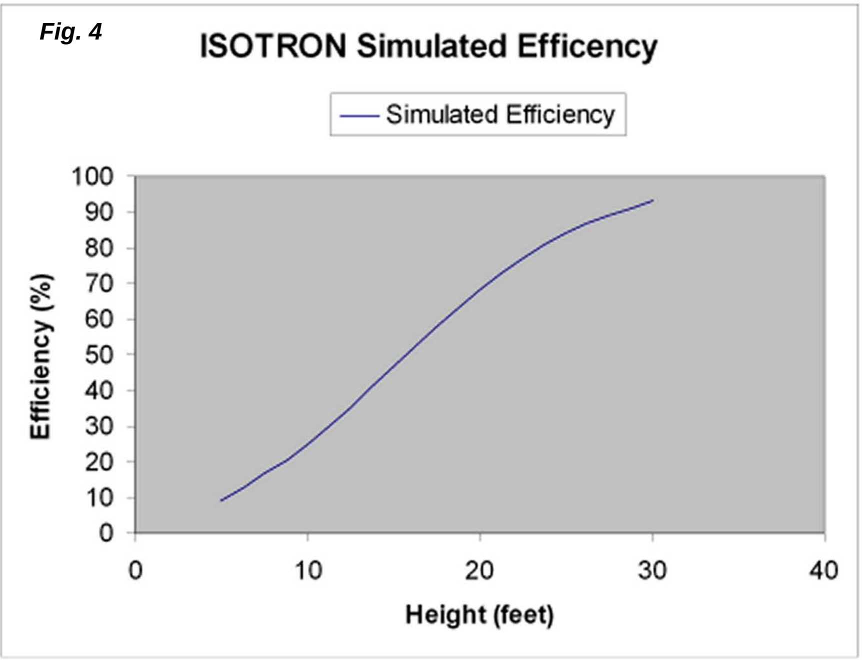
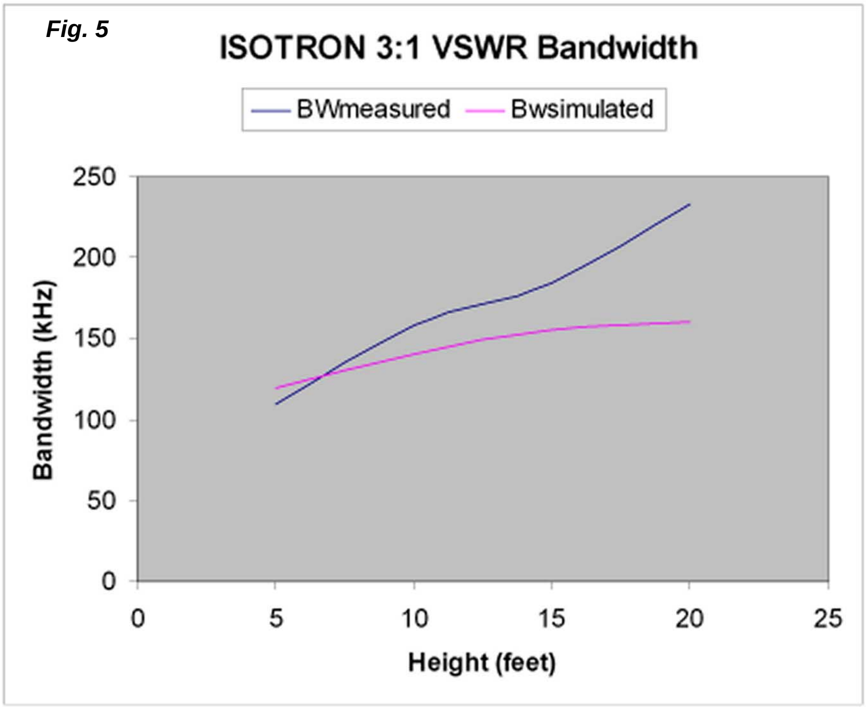


Fig. 5 is a graph of the measured and the simulated 3:1 VSWR bandwidth.

The Wire-frame Model and Problems with It

For my first attempt at modeling the Isotron I built a wire-frame model. Segments in NEC should not be shorter than 0.001 wavelengths, which is 1.7 inches at 7 MHz. With this in mind the first model was constructed using 4-inch wires and 2-inch segments and is shown in Fig. 6. The RF source is the violet box while the loading coil (which is not shown) is near the bottom of the vertical section.

Fig. 5



I encountered problems with the wire-frame model and switched to a simpler model. Part of the difficultly with the wire-frame model might have been the errors in the first coil model. I will attempt the wire-frame model again using the improved coil model. But for now, I have replaced the wire-frame Isotron model with a simple capacitive-hat dipole, as shown in Fig. 7 and have obtained much better correlation between the measurements and the simulations. The RF source is shown as the violet-colored square near the center of the antenna. The loading coil, which is not shown, is directly above the source.

Fig. 6

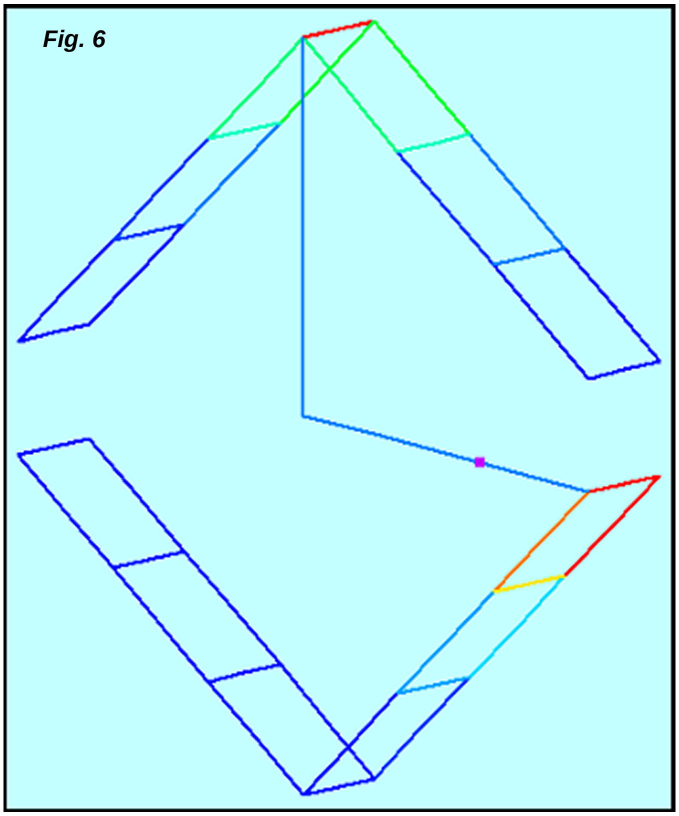
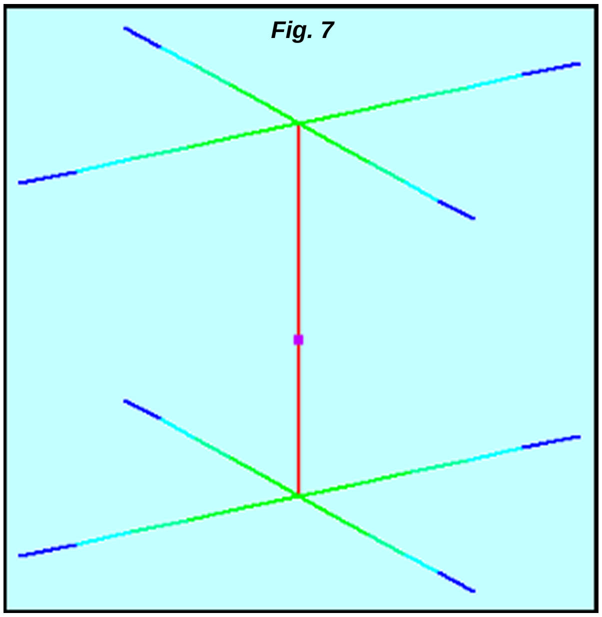


Fig. 7



This model is a 12-inch long dipole with 10-

inch spokes with each segment being 2-inches long. The real Isotron is 20 inches long and the Plates slope toward the center of the antenna, reducing the *effective* antenna length to about 12 inches. For this reason the simplified model was made only 12 inches long. The simplified model substitutes the top hat spokes for the Isotron end plates. The spokes give approximately the same capacitance as the Isotron plates.

Testing an Isolated Isotron

A primary means of testing and understanding the Isotron was to test the Isotron without a feedline. The MFJ-259B was connected to the Isotron using a UHF right-angle adapter and a UHF male-to-male adapter. Based on the initial coil measurements and simulations the impedance reading of 18 ohms at resonance looked wrong. Thinking that perhaps the MFJ-259B was acting up due to being "hot" with RF, I enclosed the meter in an aluminum foil box. This did not change the readings at all. At this point I had a dilemma. Is my MFJ-259B broken? Are my careful coil measurements wrong? Do I look into "alternative" antenna theories?

The first, and easiest step was to calibrate my MFJ-259B. I checked resistors from 1 ohm to 200 ohms and got readings within 5%. I then checked capacitors with capacitive reactances from 5 ohms to 300 ohms and got readings within 20%. This calibration, along with the aluminum foil experiment, gave me confidence in the MFJ-259B readings.

The Loading Coil

The Isotron coil is constructed using standard PVC plumbing components. The coil form is a length of 4.5 inch OD white PVC with two end caps. The coil itself consists of 14 close-spaced turns of #14 AWG house wire forming a coil 1.5 inches long. The coil end-caps have two screws offset from the threaded holes. Wondering what these screws were for (I suspected a capacitor or a resistor hidden inside) I drilled an access hole and looked inside. The screws simply anchor two squares of Acrylic sheet used to reinforce the threaded holes.

Before the Isotron was assembled I measured the coil using an ***Agilent*** 8753ES Vector Network Analyzer. A three-element parallel RLC coil model was then designed using the WinSmith software. The model consists these three devices in parallel; 25.8 uH, 11.0 pF, and 104 k ohms. This resulted in a coil Q of 41 at 7 MHz. At 7 MHz the coil can be simulated as a 57 uH inductor with a 60-ohm series resistance. The coil was then simulated using the K6STI coil program. This program gave a value of 106 uH at 7 MHz while the measured coil inductance was 57 uH. Although the K6STI program and the measurements were off by a factor of 2, they did match much more closely at a lower frequency. The 7 MHz discrepancy appears to be due to the program calculating a higher stray capacitance value (perhaps it models the form as a solid piece). At 7 MHz the coil is nearing the SRF (Self Resonant Frequency) and a small change in stray capacitance causes a large change in the effective inductance

Considerable time was then spent modeling with NEC-2 and measuring the Isotron—but the two were not correlating! The major discrepancy was the measurement of the isolated Isotron (without a feedline). The measurements gave an input impedance of 18 ohms while the NEC-2 model gave 95 ohms. With the radiation resistance of the isolated Isotron being 30 milliohms, the input impedance of the isolated Isotron should be equal to the loss resistance of the coil, which I thought was 60 ohms. I was curious if there was more going on here than just the simple RLC model. Could one of the "alternative" antenna theories be at work here? I tried to think of a way to prove that the coil loss-resistance was really 18 ohms. I inserted a 15-ohm resistor in series at the "cold", or input end of the coil and measured an Isotron input impedance of 30 ohms. I then inserted the 15-ohm resistor in series at the "hot", or output end of the coil and measured an Isotron input impedance of 26 ohms. This gave good evidence that the simple LC model for the antenna is correct and that nothing strange was happening. This is when I doubted the coil measurements that I had taken with the expensive laboratory equipment.

Coil Measurement Techniques and Pitfalls

When conducting any sort of electrical measurement, especially a measurement that is new to me, I *usually* don't simply believe what the instrument measures. To gain confidence in a measurement takes some time and effort. I develop a circuit theory, mathematically model and then measure. If the measurement agrees with the model, within the equipment measurement error, then I begin to have confidence in the measurement and the model. Often times it helps to use two different types of equipment or measurement techniques to see if you are being fooled. The Isotron coil measurement is a classic example of this; the expensive laboratory equipment and the coil model were in rough agreement, but the inexpensive MFJ-259B Isotron measurements did not agree. Time to perform a *measurement uncertainty analysis!*

The equipment used to measure the Isotron coil is an Agilent 8753ES VNA (Vector Network Analyzer) performing an S11, or complex reflection coefficient, measurement. The equipment specifications that apply to this measurement are:

***Magnitude* uncertainty = 0.0075**
***Angle* error = 0.5 degrees**

Let's calculate the complex reflection, for a 50-ohm system, with a coil inductive reactance of j3000 ohms. We will calculate the complex reflection coefficient for the 18-ohm and then the 60-ohm coil loss-resistance.

$$\Gamma = \frac{Zload - 50}{Zload + 50}$$

$$\Gamma = \frac{(10 + j3000) - 50}{(10 + j3000) + 50} = 0.9998\angle 1.909^\circ$$

$$\Gamma = \frac{(60 + j3000) - 50}{(60 + j3000) + 50} = 0.9993\angle 1.908^\circ$$

The magnitude *difference* between 18 + j3000 and 60 + j3000 ohms is 0.0005 while the instrument magnitude measurement *uncertainty* could be 0.0075. This indicates that the measurement is within the instrument “noise”. It is quite possible that this instrument could measure the coil loss resistance as 60 ohms when it is really 18 ohms. This measurement is clearly beyond the capabilities of even this fine piece of equipment, without some help. To lower the reflection coefficient magnitude I series-resonated the coil using a high-Q, 10 pF capacitor. The specified Q of this capacitor is 500, which gives a series resistance of 5 ohms at 7 MHz.

$$R = \frac{Xc}{Q} = \frac{2274}{500} \approx 5ohms$$

I took a new coil measurement and got an impedance of 26 –j268 ohms at 7 MHz. Subtracting the 5-ohm loss resistance of the series resonating capacitor gives a coil loss resistance of 21 ohms. Let’s check and see if the instrument can accurately measure in the range of 26 –j268 ohms. Solving for the reflection coefficient we get a magnitude of 0.9659. Adding or subtracting the measurement uncertainty of 0.0075 from 0.9659 gives a probable reflection coefficient range of 0.9584 to 0.9734. Using these numbers, and solving for the resistive component, gives a probable range of 21 to 32 ohms for the measurement. Subtracting the 5-ohm series resonating capacitor loss resistance of 5 ohms gives a probable coil loss-resistance range of 16 to 27 ohms. We could further improve this measurement by measuring closer to resonance (to reduce the reflection coefficient) and by measuring the series resonating capacitor loss-resistance rather than using the published Q specification. The new coil loss-resistance measurement of 21 ohms correlates with the 18-ohm coil measurement derived from the MFJ-259B measurement of the Isotron.

Test Site and Field Strength Measurements

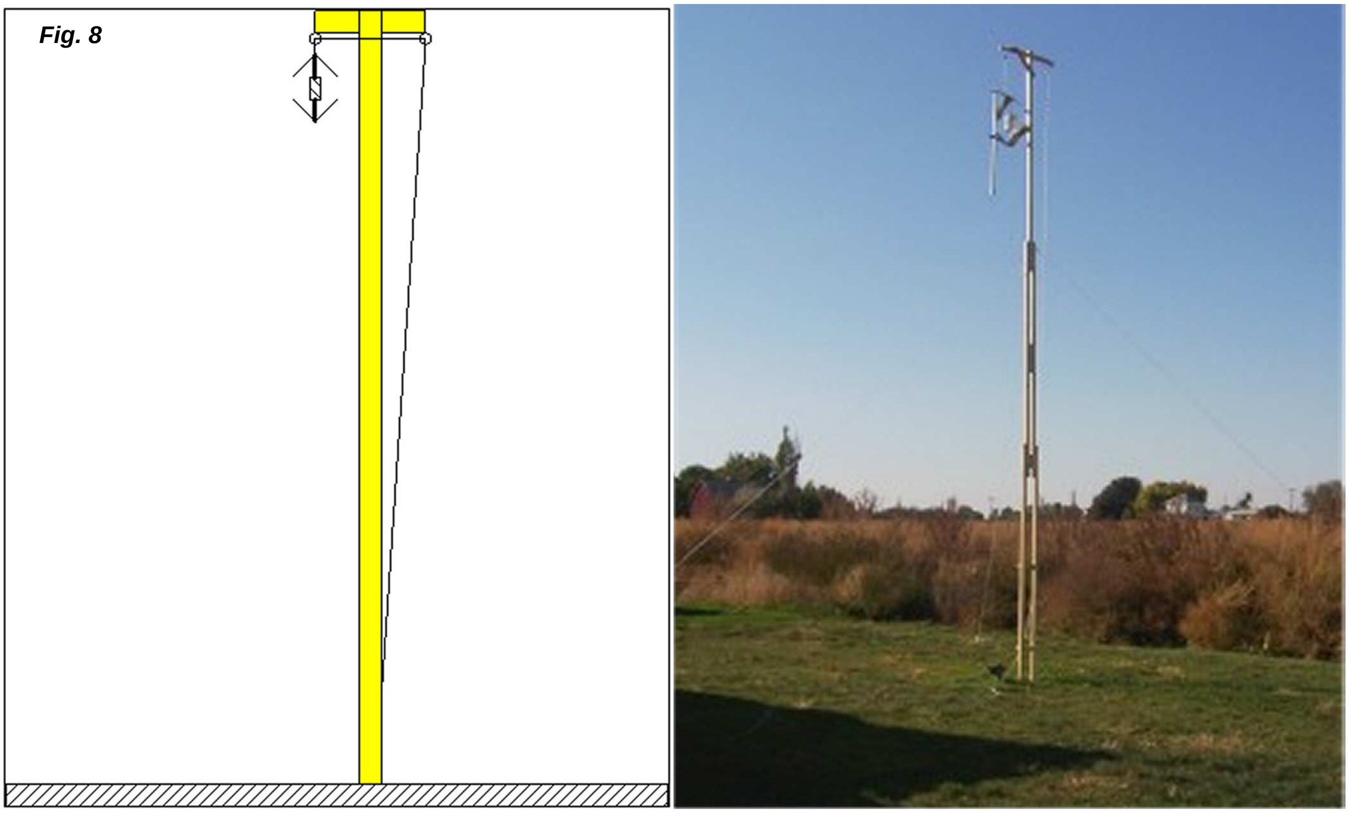


Fig. 8

The outside testing was conducted in my back yard using a 22-foot wooden mast built especially for the Isotron tests. The mast is constructed of 2 x 2 lumber, varnished and then assembled with a minimum of metal parts. A yardarm at the top and two pulleys serve to hoist the Isotron up and down for testing. The ground system consists of a single copper ground rod and two 33-foot ground-mounted radials. A drawing of the installation is shown in Fig. 8.

Two field strength measurements were taken early in the testing cycle. These two Isotron measurements were, first, with the Isotron at a height of 20 feet without feedline and then, with the Isotron at 20 feet utilizing an *ungrounded* 20-foot feedline (counterpoise). An MFJ-259B was used as the signal source. The receive antenna was a 10-foot untuned whip connected to an Agilent E4411B Spectrum Analyzer. Simulations were then run over perfect ground to see if the field strength measurements made sense. The simulation used a 10-foot vertical, terminated into 50 ohms, and placed 235 meters from the Isotron. The vertical base-current was multiplied by the 50-ohm termination to obtain the voltage.

	MEASURED	**SIMULATED**	**DIFFERENCE**
ISOTRON 20' counterpoise	**48 dBuV**	**50 dBuV**	**2 dB**
ISOTRON no counterpoise	**37 dBuV**	**34 dBuV**	**3 dB**
Difference	**11 dB**	**16 dB**	

The measured Isotron without feedline was 11 dB below the Isotron version with a 20-foot counterpoise while the simulation showed a difference of 16 dB. Five dB is a fairly large discrepancy but considering the simplified simulation I consider this good enough to show that the counterpoise does most of the radiating. A simulation of the Isotron and counterpoise current is shown in Fig. 11. The "current-area" of the Isotron is 31 mA-ft. and the current-area of the counterpoise is 265 mA-ft. Therefore the counterpoise radiation exceeds the Isotron radiation by 19 dB.

$$20LOG\left(\frac{265}{31}\right) \approx 19dB$$

Figures 9 and 10 are Elevation plots of the two field strength simulations.

Fig. 9

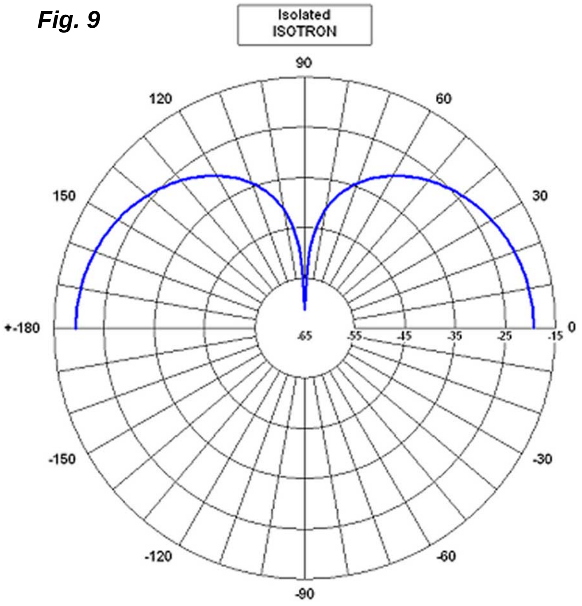


Fig. 10

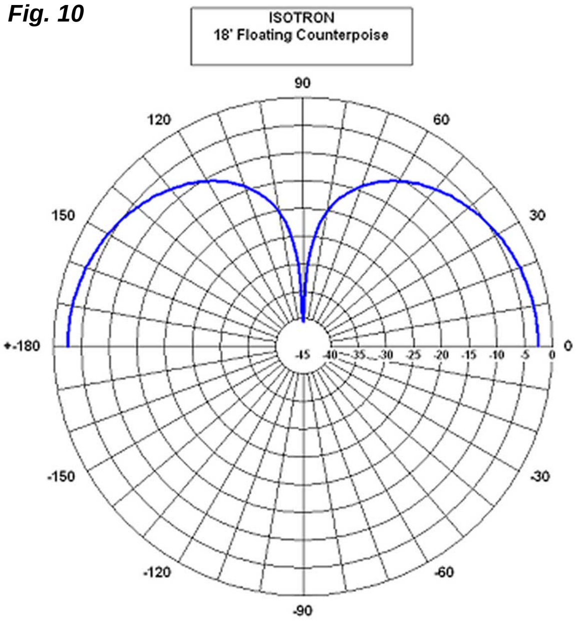


Fig. 11

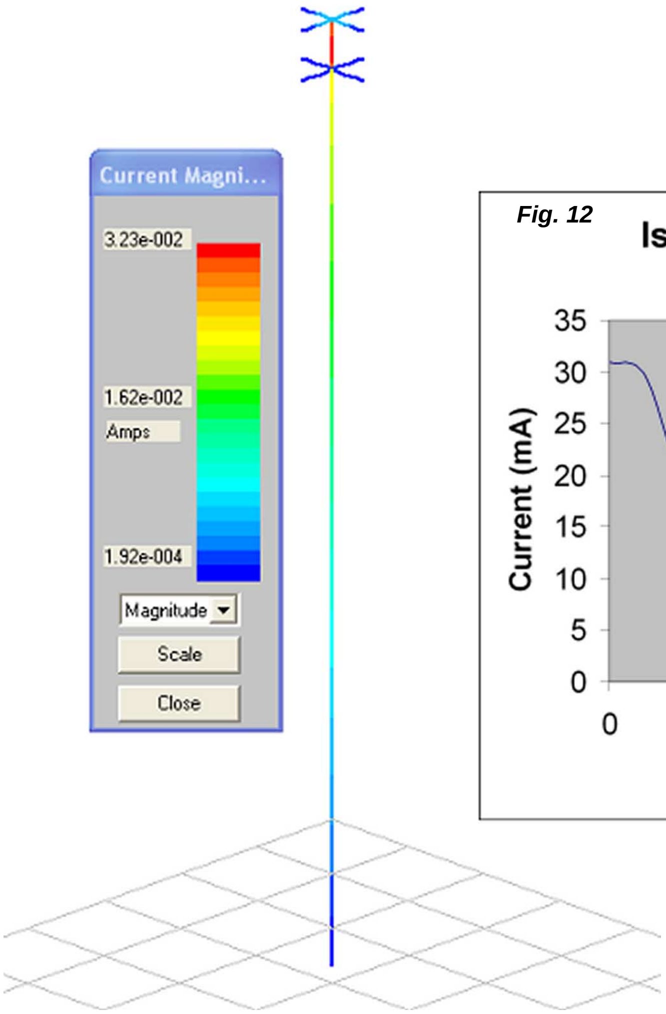
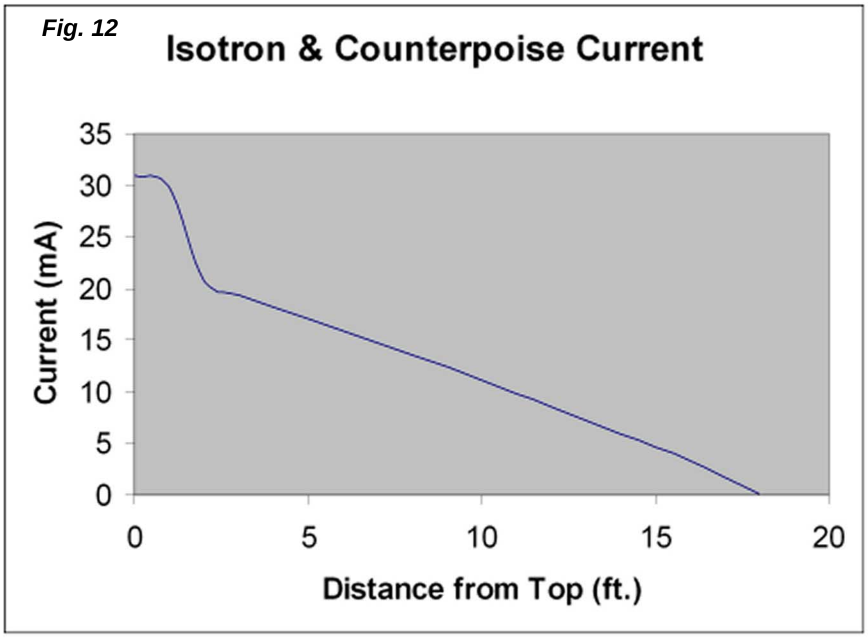


Fig. 11 is a current-temperature plot of the Isotron simulation used in the field strength experiment. Note that the current approaches zero at the ungrounded bottom end and that the Isotron bottom top hat does provide a *small* amount of isolation (the current drops from 32 mA to approximately 20 mA) between the counterpoise and the Isotron bottom plate.

Fig. 12



Coil Radiation

I wondered if the coil could be responsible for the field strength discrepancy between the isolated Isotron versus the Isotron utilizing a counterpoise. This was simulated in NEC by building a single-turn square coil 4 inches on a side. At 7 MHz the radiation resistance of this is only 1 micro-ohm. A 14-turn coil has a radiation resistance of:

$$Rr_{14} = (TURNS)^2 Rr_1 = (14)^2 (1e^{-6}\Omega) \approx 0.2m\Omega$$

The radiation resistance of the Isotron was found by running a simulation with the coil resistance set to zero ohms. With the isolated Isotron radiation resistance being approximately 30 milliohms, and the coil radiation resistance being 0.2 milliohms, the coil radiation is 22 dB below the Isotron radiation (10LOG (30/0.2) = 21.7 dB). So, the coil radiation is not a significant contributor.

What the Isotron Really Is

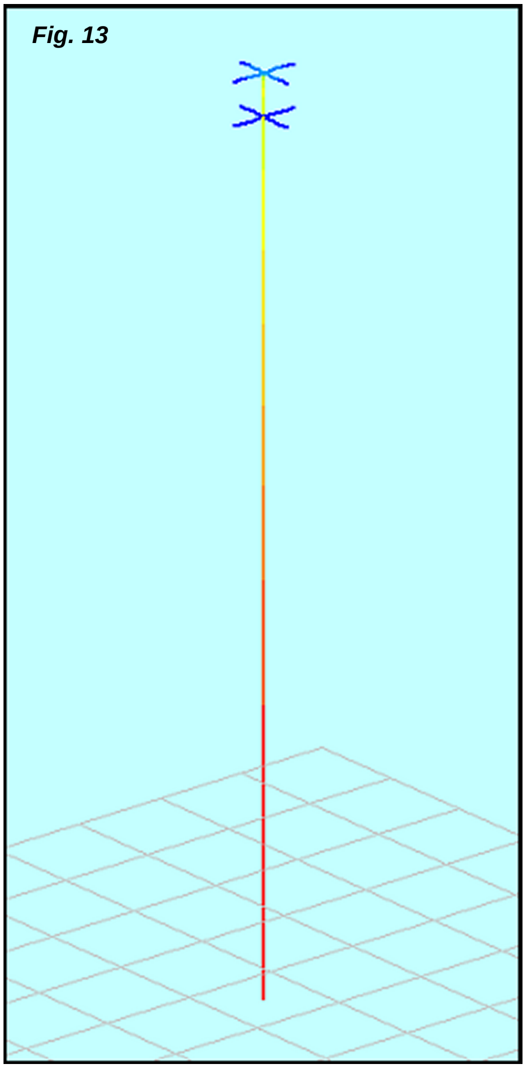
So, is the Isotron a small miracle antenna or dummy load? Well, it's neither. Electromagnetic (EM) radiation from an antenna is caused by the acceleration of charge through a conductor having a non-zero length. This is often referred to as "current-area" and the field strength in the far field is proportional to:

$$20LOG(current \times area)$$

The EM radiation from the Isotron itself is due to current along the axis of the antenna, which is 20 inches long. Due to symmetry the capacitive plates do not radiate. In fact, they actually cancel a portion of the radiation from the 20-inch section, since current flowing along them is opposite to the current in the 20-inch section. When operated by itself, the Isotron is a ***dipole***.

The NEC simulations and field measurements confirm that nothing out of the ordinary is happening. But what about when a grounded wire is attached? Now the Isotron and ground wire form an antenna system that is accurately described as a ***Top-Loaded Vertical with Elevated Feed***. The ***ground wire does most of the radiating*** while the Isotron serves mainly to resonate the antenna system. Fig. 13 is a current-temperature graph of the Isotron, using a grounded wire, mounted 20 feet above perfect ground. The antenna current is actually quite uniform with the current at the base being only 1.5 times the current at the top of the antenna. This arrangement offers somewhat higher radiation resistance and lower ground losses than a base-loaded vertical.

Fig. 13



And, if the Isotron is used with a non-grounded counterpoise this antenna system will operate as an ***asymmetrical dipole***.

So, there are at least three modes in which the Isotron can operate:

Dipole
Asymmetrical dipole
Top-Loaded Vertical with Elevated Feed

Who Would Use the Isotron?

So, where would one use this antenna? If you have the room to put up a ¼ -wavelength vertical then the Isotron probably offers no performance improvement. But, if you live in an apartment, or operate from an upstairs room and don't want to run a coaxial cable down to the ground, the Isotron might be just the thing for you. Or, if you need to mount a low-band antenna at a random height then the Isotron might be just the antenna for you.

Mounting and Grounding

I have somewhat limited experience in mounting configurations in that I only tested the Isotron at two locations: on a 22-foot wooden mast and inside a second-story room of my house. There are other mounting situations that could present circumstances I have not encountered. These include higher mounting, metal tower mounting, and roof-of-house mounting, to name a few. I did experiment with the Bilal-recommended ground wire and then using only the coaxial cable shield as the ground wire. I fed the Isotron using a 20-foot length of RG58 coax, which was tested with the MFJ-259B and found to be 90 degrees at 7.89 MHz. All impedance readings were "moved" to the Isotron input connector using the WinSmith 2.0 software. Using the coaxial shield without a ground wire resulted in some strange impedance readings. When the input of the coax was left floating, the meter was "hot" with RF. Grounding the meter with a short wire to earth ground cooled things off, but the impedance readings were still not what was expected. Adding a separate ground wire improved things immensely and this is a subject that needs more study.

Ground Wire Safety!

Remember that only the end of the ground wire that is attached to earth ground is near earth potential. Other parts of the ground wire can have a high RF voltage and could become a safety hazard! The ground, or counterpoise wire, should be routed as if it had high voltage on it. If it must come in contact with anything then that portion of the wire should be properly insulated.

Tuning Up the Isotron

For most of my experiments I measured the Isotron at whatever frequency it was resonant at. When tuning (by moving the tuning rod) was necessary I was glad I was using my MFJ-259B and not a SWR Meter.

Topics to Be Covered In a Follow-on Article

There is more to the Isotron than has been presented in this first article. Some topics that will be covered in a follow-on article are:

- Counterpoise wires
    - Vertical and horizontal
    - Length; all lengths and with particular attention to ¼-wavelength and ½-wavelength wires
    - Multiple counterpoise wires
    - Ground wire and feedline shield currents

- Feedline decoupling
    - The use of ferrites
    - Coaxial chokes
    - Counterpoise wires at the rig
    - Using the feedline as the counterpoise
    - Effect of removing the bottom capacitive plate

- Simulation
    - How to simulate the Isotron
    - Modeling feedline and counterpoise radiation
    - Refining the model

- Electric Field
    - E-field versus distance
    - Safe distance from the Isotron

- Miscellaneous Topics

Power handling capability- coil heating
High voltage effects- corona
Alternative feed methods
Operating the Isotron as a dipole
Weather detuning
Effective volume of a small antenna and the Isotron in particular

Conclusions

Standard NEC software proved capable of modeling this antenna and confirmed that standard antenna theory applies to this antenna. Three pieces of evidence have been presented to prove my theory of the Isotron:

- **Field strength simulations and measurements**
- **Impedance simulations and measurements**
- **Current area simulations**

Now that we understand how the Isotron works we can design better installations using this unique antenna. Also, the reader will now know a little bit more about what to expect in return for the price of purchasing one of these devices. **–30-**

References

Basic Antenna Modeling: A Hands-On Tutorial by L.B. Cebik

Brief Biography of Author:

- 1979-1988 Hughes Aircraft ~ Designed a wide variety of test equipment for high-powermicrowave tubes including high voltage and RF designs.
- 1988-1995 Tektronix ~ Worked on microwave hybrids, PLL design, and in-house test equipment design for the 2784 Spectrum Analyzer. Sustaining engineering and switching power supply design forseveral oscilloscope lines. Designed a 0.025 lambda monopole for a commercial control device.
- 1995-1997 Advanced Energy ~ Sustaining engineering for multi-kilowatt plasma power supplies.
- 1997- present Micron Technology ~ A Micron Fellow since 2001, Analog and EMC engineering to support IC manufacturing.
- Five FCC licenses including a commercial radiotelegraph license.
- Certified NARTE (National Association of Radio and Telecommunications Engineers) Electromagnetic Compatibility Engineer.
- As part of my amateur radioactivities I have built small antennas since 1972

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