An All-Band Attic Antenna

Nothing beats an "aluminum cloud" on a tall tower, but when choices are limited, an indoor antenna can be amazingly effective.

Kai Siwiak, KE4PT

If zoning rules or aesthetic considerations make outside antennas prohibitive, an indoor antenna might just provide enough performance for casual operation on all bands ranging from 80 to 6 meters. With only 100 W, I've managed contacts with hams in over 130 DXCC countries and all 50 states, including 25 states and 13 countries confirmed on 6 meters. I've even made contacts on the 160 meter band, but the efficiency there is poor, and I don't recommend operating on 160 meters with this antenna.

This isn't a design article for a specific indoor antenna, but rather a description of the performance of one indoor antenna, and some guidelines that might help you understand the limitations, performance and RF safety aspects of antennas of this type.

The KE4PT Attic Antenna

I've been operating with an indoor inverted-L antenna in my attic for several years. I drive the antenna with an ICOM IC-706MKIIG running 100 W through a current balun and an ICOM AH-4 automatic antenna tuner located at the antenna feed point.[1] The tuner is what makes this antenna capable of operation on all of these bands. The basic idea was to place as much of the wire as possible into the clearest space of a cluttered attic in my one floor home in south Florida, as seen in Figure 1.

Design Approach

My basic design approach was to provide a fat radiating conductor using two parallel conductors of fairly thick wire spaced nearly 3 feet apart. This tends to smooth out impedance variations versus frequency and lets the automatic tuner do its work smoothly. I chose aluminum wire for its availability and cost. These wires were placed as far as physically possible from other conducting objects in the attic.

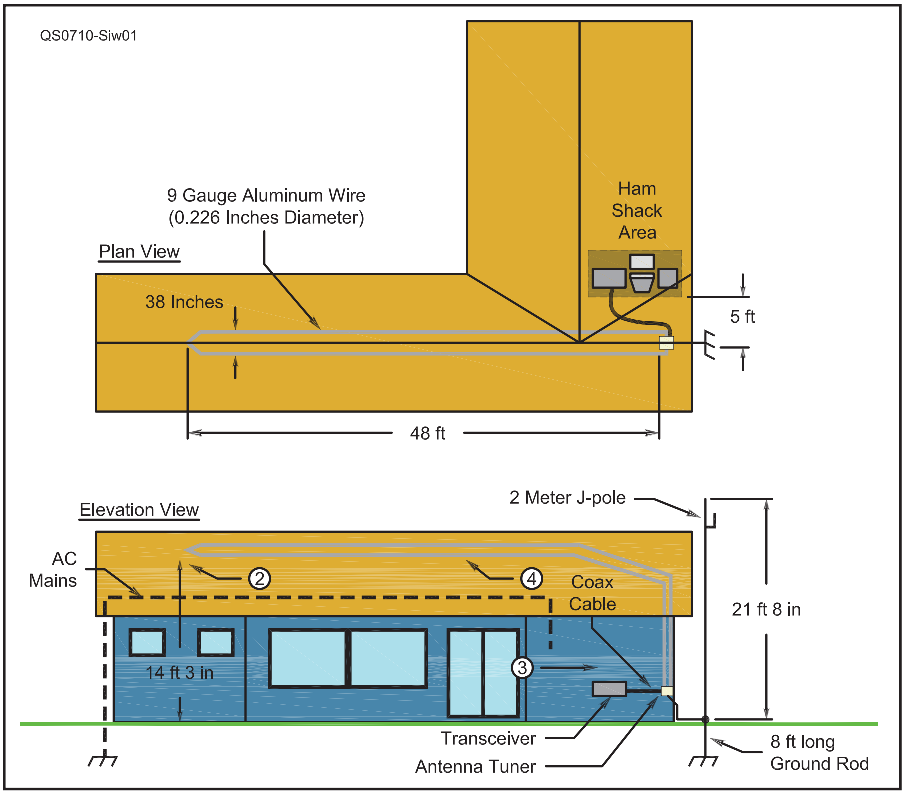

Figure 1 — Plan and elevation views of the attic inverted L antenna. The numbers are keys to the photographic views.

I wanted an antenna that could be operated over the widest frequency range possible; so the L length was chosen as long as possible to obtain reasonable efficiency at the lowest frequencies, but with tolerable antenna pattern ripples at the highest frequencies. The actual length was constrained by the available attic space. Next, I used an antenna ground post to act as a counterpoise element. The whole system was match tuned at the feed point with an automatic tuner.

It All Came Together

The horizontal part of the L element comprises two parallel lengths of 9 gauge aluminum wire shorted at the far end, and spaced about 38 inches, as shown in Figure 2. The horizontal portion is about 48 feet long, and a bit more than 14 feet above the ground, under the roof of the house. The horizontal length is approximately a wavelength at 21 MHz so the antenna pattern is very nearly omnidirectional from the 20 down to 80 meters.

The parallel wires are brought together and emerge from the ceiling on a far wall of the house in a storage closet, as shown in Figure 3. Both of the parallel wires are joined together and connected to the antenna post of the AH-4 tuner. A copper ground wire runs from the tuner ground connection to an outside 8 foot deep ground rod. The antenna shares this ground rod with a conductive mast supporting a 2 meter J-pole that tops out at 21.7 feet. This mast also functions as part of the HF radiating system. A length of 50 Ω coaxial cable connects the tuner through an eight turn 5 inch diameter choke balun to the transceiver at the operating position in the ham shack on the other side of the wall of the storage closet.

We're Not Alone

The antenna isn't alone in the attic. There are air conditioning ducts as well as the ac mains power distribution for the house, which are marked by the heavy dashed line in Figure 1. This conduit can also be seen in Figure 4. I modeled the inverted L, the ground post with the attached J-pole mast, and the ac mains including its own ground post by using *4nec2* antenna modeling software.[2] The pro-

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[1] Notes appear on page 37.

Figure 2 — The inverted L element is supported by egg insulators suspended from the rafters in the attic.

Figure 4 — The ac conduit parallels the antenna elements.

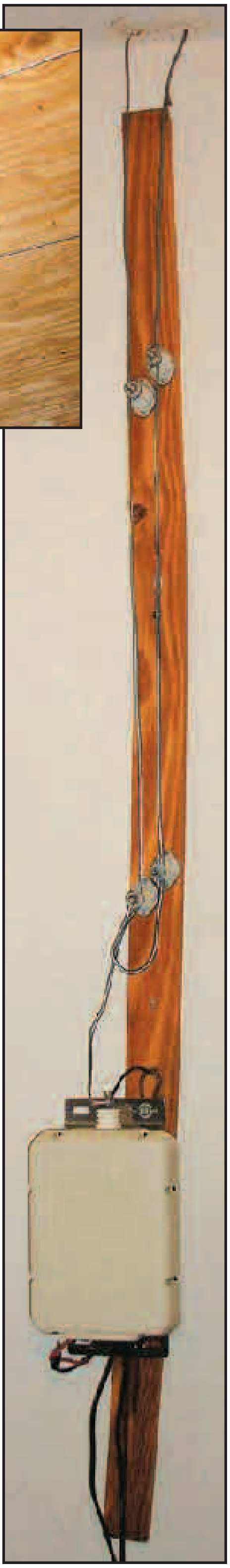

Figure 3 — The ham shack and transceiver are 6 feet to the left of the AH-4 tuner shown in the lower part of the photo.

The Advantage of CW

With a maximum of 100 W from my transmitter, my CW average power is 40 W, but with SSB it is an average of only 20 W (3 dB advantage for CW). At the receiver end of the propagation link the CW receiver noise bandwidth is typically 300 Hz compared with 2700 Hz for SSB (9.5 dB more for CW). Finally, the CW operators appear to listen a bit more intently to my CW, especially many of the DXpedition operators, perhaps tolerating 6 dB SNR whereas comfortable SSB listening needs 10 dB SNR (another 4 dB advantage for CW). The net advantage of CW over SSB might be as much as 16.5 dB or the equivalent of about 3 S-units!

gram uses the *NEC2* (Numerical Electromagnetic Code) calculation engine, and is available for free. I started the *NEC* based analysis to make sure that I could adequately assess the RF exposure that results from this unusual antenna. As a by-product of that effort I was able to learn about the antenna patterns and radiation efficiency of this antenna.

The *NEC* modeling revealed that substantial RF currents exist on the J-pole mast, and they contribute significantly to the overall radiation from the antenna. The J-pole mast contributes a vertical polarization component to the overall radiation pattern that helps keep the far field patterns relatively omnidirectional, especially at the higher frequencies. This was an unplanned benefit, with the interesting lesson that all conductors radiate, even when connected across an earth ground connection!

Indoor Antenna Performance

What can be better that an extended on-the-air test? I kept track of many of my contacts (QSOs) by plotting them using *DxAtlas* by Alex Shovkoplyas, VE3NEA.[3] The results can be seen by the color-coded points on the maps in Figures 5, 6 and 7. The QSOs are between my south Florida location and the mapped points. Figure 5 shows QSOs in the 160 meter band (a few dark red marks), and in the 80, 60, 40 and 30 meter bands. The very close distances are covered well, although there were contacts as far away as Australia, South Africa and India and into Europe on 40 and 30 meters. The green points shown in Figure 6 show 20 meter coverage. A distinct skip zone occurs around my location. Coverage beyond that is worldwide. Figure 7 shows dark blue points for 17 and 15 meter band QSOs, light blue points for 12 and 10 meter QSOs and distinctive gold points marking the 6 meter "magic band" QSOs with 14 states, Puerto Rico and Spain. The 17 through 10 meter coverage has a prominent skip zone of about 1000 km around my location.

Propagation predictions using *HAM-CAP* freeware basically confirm the actual performance of the antenna over the long term, including the skip zones and the tendency for the 17 through 10 meter bands to dominate coverage into South America.[5]

I get my fair share of the rare and distant ones (VU7, 9Q1, VK9N, 1A0, VQ9 and KH8/S on all five bands), not because of awesome RF power — I use just 100 W — or a high "aluminum cloud" antenna, but by listening and operating carefully, although those rare DX catches are as much a testament to the operating skills of the DXpedition operators! I also take advantage of the extra 2 to 3 S-units of signal-to-noise enhancement that operating on CW provides.

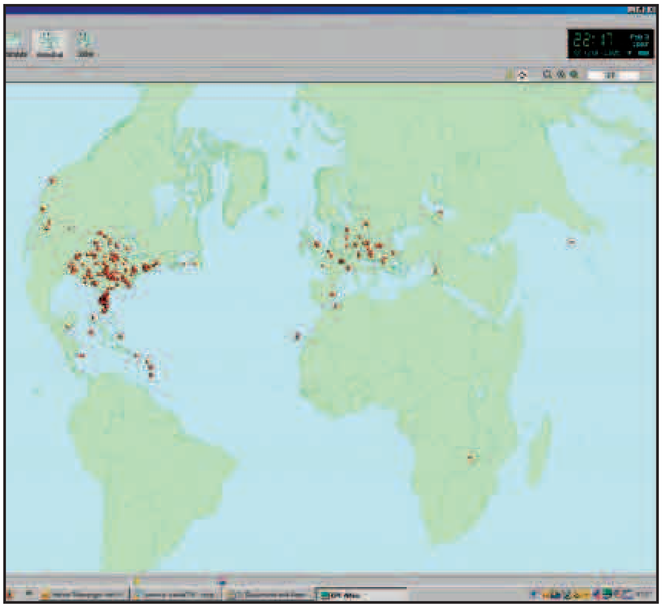

Figure 5 — Some contacts from KE4PT in South Florida. Dark red 1.8 and 3.6 MHz, red 5.4, 7 and 10.1 MHz.

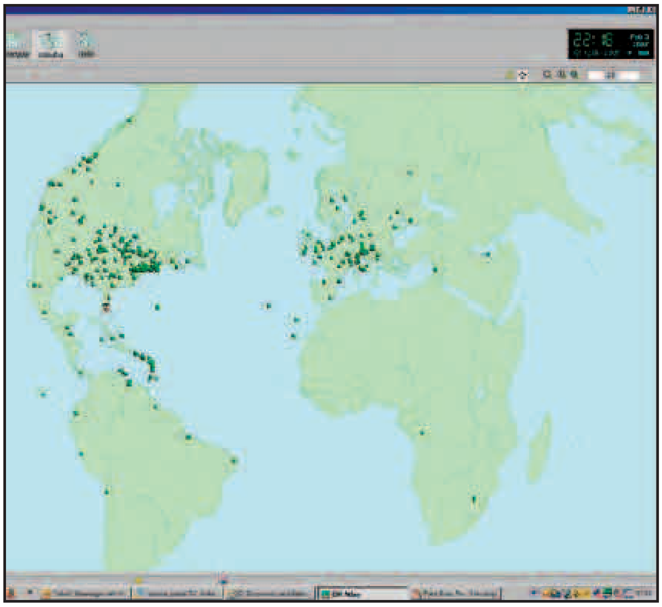

Figure 6 — Contacts from KE4PT in the 14 MHz band.

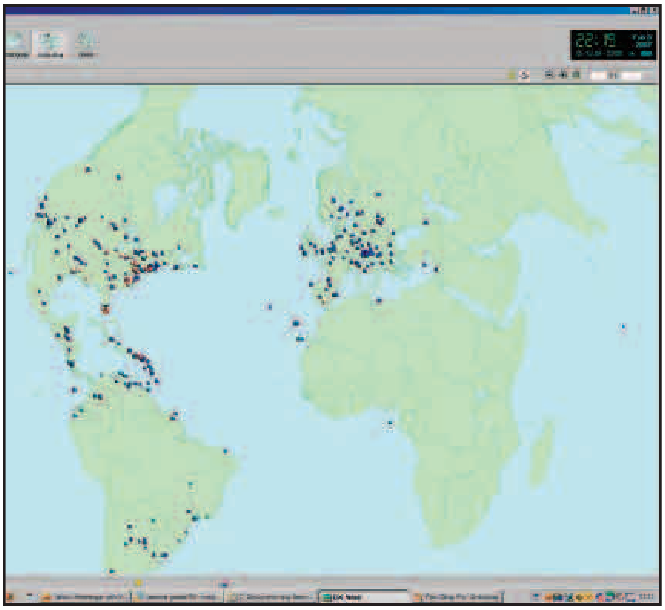

Figure 7 — Higher frequency contacts. Dark blue 18 and 21 MHz, light blue 24 and 28 MHz, gold 50.1 MHz.

What *NEC* says

The proof is in the antenna currents. I modeled the antenna and ground system, along with the ac mains and the J-pole mast using *4nec2,* which employs the *NEC2* calculation engine. The basic radiation pattern in the lower bands is a flattened cardioid pattern pointing upward as seen in the 10.1 MHz pattern shown in Figure 8. The antenna pattern in the figure is centered on the feed point of the antenna. To a receiver anywhere on the horizon, the pattern at 10° elevation varies less than an S-unit for 20 meters and longer wavelengths.

As frequency is increased the antenna pattern on the horizon develops more ripples, and the 2 meter J-pole mast contributes more vertically polarized energy to fill in horizontally polarized pattern dips. At 51 MHz, shown in Figure 9, multiple antenna pattern lobes are evident, but coverage again is still roughly omnidirectional in azimuth — effectively within 2 S-units. The total antenna system polarization is randomly elliptical, having both vertical and horizontal components. This can be seen in Figure 10 in which the polarization axial ratio is shown in color on the 51 MHz pattern. Blue indicates a linear polarization, and a trip through the color spectrum shows elliptical polarization culminating in circular polarization in the directions corresponding to the purple colored pattern areas. Informal S-meter tests by a local ham within 20 miles of my location verified that there was substantial energy in both the horizontal and vertical polarization components during an impromptu 6 meter band test.

The antenna radiation efficiency can be defined as the total power radiated into space (that is, above the ground) divided by the transmitter power. Efficiency, predicted by *NEC2*, is between about –7 dB and –1 dB across 3.5 to 54 MHz. Efficiency dips to a dismal –20 dB in the 160 meter band, so the antenna is not too useful there, although I've made a few contacts in several states on that band. I tried modifications of the design by modeling various ground radials attached to the ground post. Efficiency was not significantly improved, however. At my location, the ground radials could be physically placed only perpendicular to the horizontal element, but that configuration produced undesirable deep nulls in the azimuth pattern.

No attempt was made to predict the antenna input impedances because (1) I always intended to use an automatic tuner, and (2) there were simply too many non-modeled coupling effects in the attic, including a substantial barrel-tile roof which sits inches above the antenna wires. As expected, the *NEC* analysis revealed that the currents on the antenna wires, the ac mains wires, and the J-pole structure are indeed standing waves starting with a null at the open end of each wire. This motivated a relatively simple RF exposure analysis described next.

Some Words about RF Safety and RFI

Indoor antennas should be very carefully considered from the RF safety point of view, especially for those within the dwelling. In addition, there is always potential for RF interference within the home. This applies as much to wire antennas as it does to small loops. Two possible hazards exist: the potentially high RF voltage that can exist on the antenna conductors and exposure to electric (E) and magnetic (H) fields. Both potential hazards are avoided by keeping one's distance!

But How Close is Safe?

I initially evaluated this antenna by real-

FIGURES 8, 9 AND 10 GENERATED BY ***4NEC2*** (HOME.ICT.NL/~ARIVOORS/)

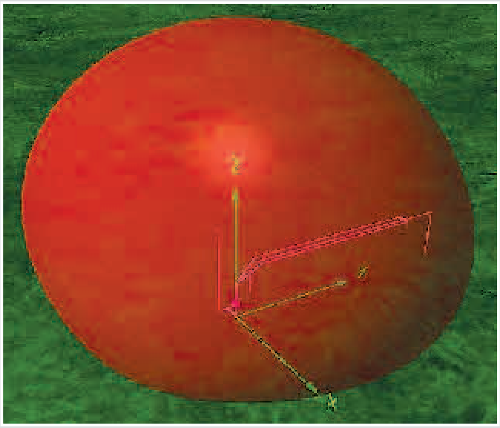

Figure 8 — The antenna and its 10.1 MHz pattern.

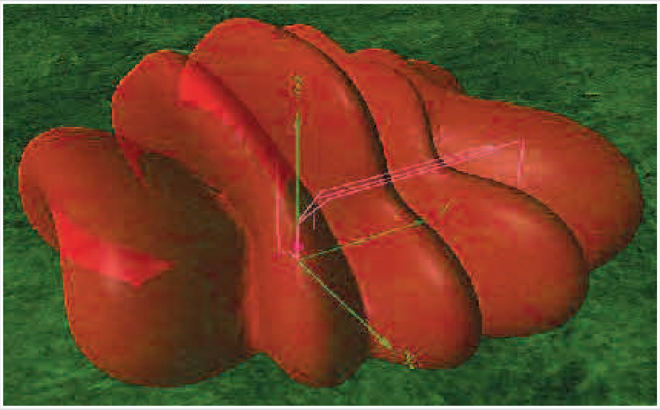

Figure 9 — The antenna and its pattern at 51 MHz.

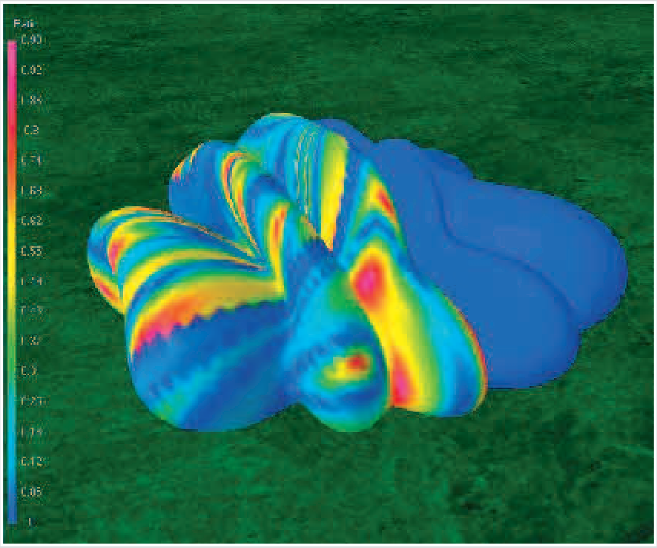

Figure 10 — Polarization axial ratio at 51 MHz.

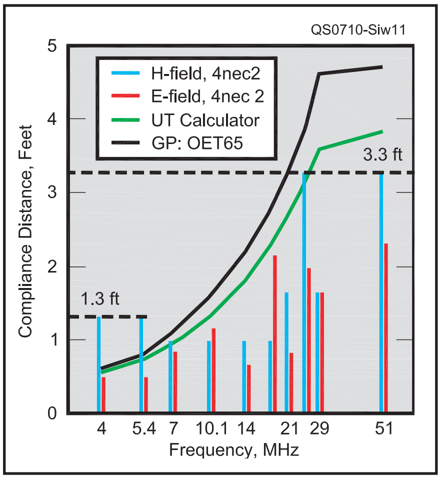

Figure 11 — RF safety compliance distance (at 100 W) from any part of the antenna ranges from 3.3 feet on 6 meters down to under 1.4 feet on 80 meters.

izing that at any particular frequency the currents and voltages along the conductors would be standing waves — just as on a dipole. As verified by *NEC* modeling, the electric charge accumulations are "out of phase" with the currents on the wire. Thus, where the standing wave current in the wire (and hence the H fields around the wire) goes through a null the voltages (and hence the E fields) peak, and vice versa.

To estimate the RF exposure, I then assumed that at any point on the antenna wire the currents would resemble those of a resonant dipole with the full power applied at that point. Then I tried the very simple-to-use University of Texas online calculator to determine a compliance distance.[6] I used the "occupational/controlled environment" since I have full control of access to the RF exposed areas.

Crunching the Numbers

The calculator needs very few inputs — 100 W RF power, an assumed 2.2 dBi gain of a dipole and a choice of whether there is a ground contribution (I selected no ground contribution). The largest compliance distance of 3.8 feet from any part of the antenna occurs in the 6 meter band, and that was initially the number I used for the compliance distance *at all frequencies*.

As an added check, I also used the "General Purpose Tables" in *RF Exposure and You*, with 100 W, 0 dBi and a controlled environment.[7] Finally, I calculated the near E and H fields using *4nec2* with a "real ground" and 100 W. The composite results are shown in Figure 11 in the form of compliance distance versus frequency. The University of Texas calculator and the general purpose tables give similar results. They appear to be adequate above 7 MHz, but they underestimate the exposure compliance distance at lower frequencies for this particular antenna.

A Second Opinion

The *4nec2* calculations predict compliance distances that are up to a factor of two larger than those obtained with the other approximations for frequencies below 7 MHz. The magnetic fields near the ground on the vertical portion of the antenna are the source of this discrepancy.

The *NEC2* engine in *4nec2* does allow connections of wires to ground, but does not model wires underground such as the ground post that's part of this antenna. It also does not correctly handle the charge distributions at the wire-ground interface, except for the case of a perfect ground. Bill Guy, W7PO, kindly helped me by using *NEC3,* which correctly accounts for buried wires, to check my antenna including the actual buried ground posts.[4] *NEC3* is still under export restrictions and is not generally available.

And the Answer Is —

A spot check of near fields of my antenna both near the vertical and near the horizontal parts of the wires shows that away from the ground connection *4nec2* (using the *NEC2* engine) and *NEC3* predict the same relative field strengths, typically within 10%, for a given radiated power level. Near the ground post connection, however, ground-level field values are similar only if a perfect ground is selected in *4nec2*. For practical RF exposure evaluations, especially for unusual antennas such as this one, modeling should be tried with both a real ground and with a perfect ground, then the most conservative compliance distance should be used.

For this antenna, the 6 meter band *4nec2* result of 3.3 feet gives sufficient compliance distance safety margin on all lower frequency bands. *Lesson: Evaluate unusual antennas very carefully, especially if a ground or ground post is part of the system!*

RFI Rears its Head

Because this indoor antenna is extremely close to wiring in the house, RF interference within the home is a strong possibility. I've noticed coupling RF energy to the ADSL, computer connection, side of my phone line, but only during 160 meter operation. That RFI potential and the generally poor antenna efficiency keep me off the 160 meter band. There is also noticeable coupling to my TV and audio systems, which is remedied by restricting operating during prime family TV viewing times.

Conclusions

An indoor antenna such as this one is not the contester's dream antenna, nor is it a DX hunter's "special," but it can be a useful and effective "stealth antenna" that will get you on the air on all ham frequencies between 3.5 and 54 MHz. Careful operating practices and the use of narrow-band modes, such as CW and digital modes, can yield delightful results. The use of an antenna automatic matching tuner at the feed point allows great flexibility in positioning attic wires, and in my case, allowed for an effective all-band design. Modeling with *NEC* provides great insight into the performance. Finally, great care must be taken in the RF safety analysis.

I'd like to acknowledge and thank Bill Guy, W7PO, for his help with the *NEC3* modeling, and Bob McGraw, K4TAX; Bob Walker, N4CU; Tom Kneisel, K4GFG, and Diana Siwiak, KE4QXL, for their helpful reviews and suggestions.

Notes

[1] R. D. Straw, Editor, *The ARRL Antenna Book*, 21st Edition, pp 26-21. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 9876. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop/**; **pubsales@arrl.org**.

[2] A. Voors, "NEC Based Antenna Modeler and Optimizer," **home.ict.nl/~arivoors/**.

[3] *DX Atlas*, **www.dxatlas.com/**.

[4] K. Siwiak and W. Guy are both members of the ARRL RF Safety Committee, **www.arrl.org/rfsafety/**.

[5] *HAM-CAP*, **www.dxatlas.com/HamCap/**.

[6] Online RF exposure evaluation, **n5xu.ece.utexas.edu/rfsafety/**.

[7] E. Hare, *RF Exposure and You*, ARRL, Newington, CT, 1998.

Kai Siwiak, PhD, KE4PT, was first licensed in 1964. He is a consulting engineer specializing in antennas, propagation, communications systems and ultra-wideband (UWB) wireless technology. Kai has authored several text books on those subjects and also wrote the electromagnetic theory chapter in ARRL's RF Exposure and You. *He holds more than 30 US patents, has been a frequent contributor to IEEE 802 standards, and was an advisor to the US delegation to the ITU-R on UWB technology. He is a member of ARRL, SAREX (Space Amateur Radio Experiment), a life member of AMSAT and a member of the ARRL RF Safety Committee. Kai prefers CW, usually on 40 through 6 meters, depending on those elusive sunspots. He can be reached at* **ke4pt@amsat.org** *for any questions or comments.* QST

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