MININEC: The Other Edge of The Sword

MININEC antenna-modeling software is powerful and popular. But you need to know about its limitations to use it effectively. Here's the lowdown.

By Roy Lewallen, W7EL
5470 SW 152 Ave
Beaverton, OR 97007

Since the dawn of Amateur Radio, *predicting* antenna performance has been justifiably regarded as nearly impossible. No wonder: The only available tools for doing so have been analyses of textbook antennas (that bear a resemblance to our backyard creations to the same extent that a horse resembles a camel), testimonials, folklore and an awesomely lavish dose of "horse puckey."

Now, however, we have been armed with a sharp and powerful sword against decades of antenna-design darkness. But that sword is double-edged and some of us are getting pretty bloody from self-inflicted wounds as we blaze new trails in antenna design.

Our sword is, of course, the powerful antenna-modeling program *MININEC.* One of its edges is its ability to help us answer questions about antennas; its other edge is its limitations which, should we fail to recognize and carefully avoid them, can lead us to conclusions that are embarrassingly and profoundly wrong. For example, from a letter I recently received: "My personal favorite is the 45 dB gain I get [with a dipole] at 0.110 feet [high, over poor ground]. Boy, am I gonna be a big shot on 75 meters now!"

The only error the writer made was not being aware of one of *MININEC*'s basic limitations (discussed later). Tongue firmly in cheek, he had recognized that the answer was ridiculous, but sometimes we're not so lucky and the errors are tougher to spot.

Your ability to avoid the sword's other edge will greatly improve if you take time to gain a basic understanding of what *MININEC* is and how it works.

MININEC was written in BASIC for IBM®-compatible personal computers by J. C. Logan, N6BRF, and J. W. Rockway of the Naval Ocean Systems Center in San Diego. Both the source code and compiled program are available as public-domain software.[1,2] In addition, several commercial programs that use *MININEC* calculation code and additional features have appeared.[3-5] The limitations I'll describe

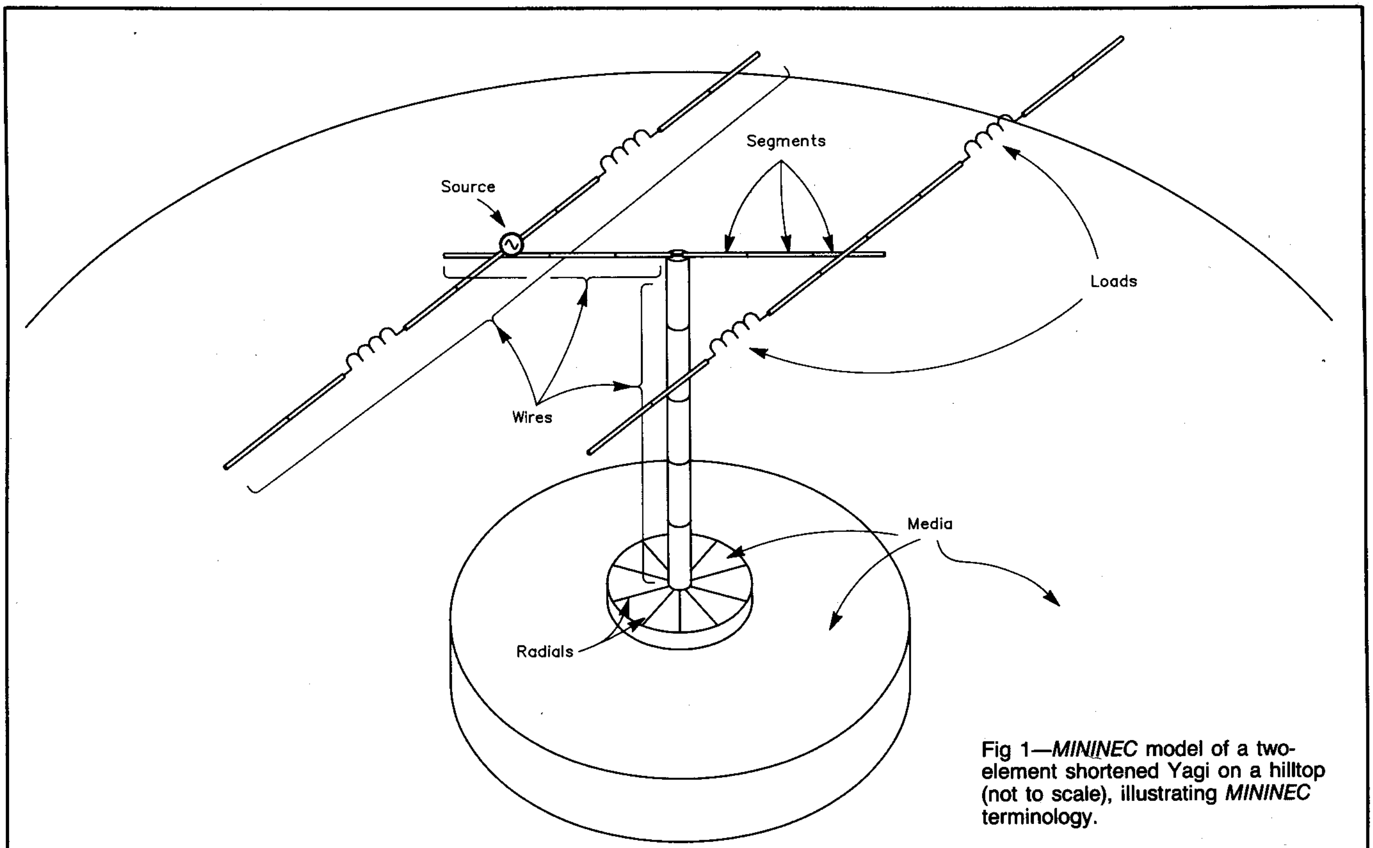

Fig 1—*MININEC* model of a two-element shortened Yagi on a hilltop (not to scale), illustrating *MININEC* terminology.

[1] Notes appear on page 22.

are, in general, shared by these and other derivative programs. Some variants work around some of the program's limitations, but some also add constraints of their own. Before you use any modeling program, thoroughly *read the documentation* and carefully observe the program's limits.[6] The most important thing you can do is to ask yourself: Does the result *make sense*?

How *MININEC* Works

MININEC is an extremely versatile and powerful program that permits you to "build" an antenna of straight conductors (called *wires*—you choose the diameter), put voltage *sources* and lumped impedances (*loads*) wherever you choose, place the structure over a realistic ground (if desired), and observe the input impedance, current distribution, and near and far fields at any azimuth or elevation angle. (See Fig 1.) Active (driven) and passive (parasitic) structures can be modeled. With some skill and understanding, you can accurately model anything from rhombics to rain gutters and towers to tribanders.

Let's take a closer look at *MININEC's* operation. You enter the antenna description by specifying the diameters and end points of the wires and the number of *segments* into which they're to be divided for calculation (more about this later). End points are defined in an XYZ coordinate system. A free-space or ground-plane environment can be specified. If you choose a ground plane, it can be perfect or made of one or more sections (*media*) having finite depth, conductivity and permittivity and, if desired, radial wires. Sources and loads can be placed in series with any of the wires. (See Fig 1 for an example.) After entering the antenna description, you select one of several analysis options.

MININEC uses a procedure known as the *method of moments.*[7] In *MININEC,* each wire is divided into a group of equal-length segments for calculation. A uniform current is assumed to flow in a region extending to both sides of each segment junction (see Fig 2). These regions of uniform current, centered about the segment junctions, are called *pulses.* In any analysis, the program first calculates the self-impedance at each pulse and the mutual impedance between each pulse and all the others. If a ground plane has been specified, the impedances to and from the "image" antenna created by the ground plane are also calculated. This operation consumes the majority of the total computation time, reported by the program as *fill matrix.* The result is an internally stored matrix of impedance values. The program then solves an Ohm's Law equation using the values in the impedance matrix, a source-voltages matrix, and a matrix of the unknown pulse currents, reporting *factor matrix.* After this step, the impedances seen by the sources, as well as the currents at each pulse, are available. If near- or far-field analysis is requested, the contribution of each current pulse to the total field is calculated. If a ground plane has been specified, direct and reflected rays are summed to obtain the total field strength at each point of the near or far field.

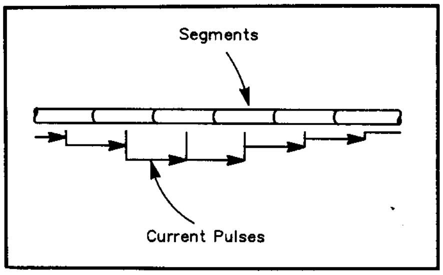

Fig 2—Illustration of the relationship between segments and pulses.

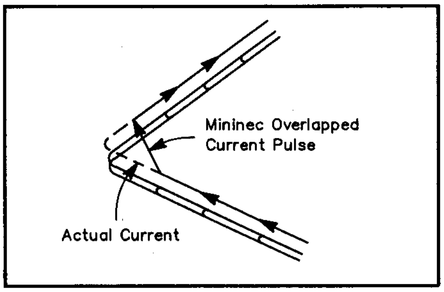

Fig 3—Pulse overlap at wire junctions can cause problems if it's not accounted for.

The Limitations

MININEC's authors did an amazing and commendable job of reducing some very complex mathematical operations to a level that a PC can handle in a reasonable amount of time. But to do so, they had to make some compromises. Most of the program's limitations are due to these consciously chosen compromises.

Wires

In *MININEC,* every antenna must be described using only *straight wires* as the basic model building block. With some ingenuity, though, a wide variety of structures, including towers, top hats, rotators, rain gutters and even garages, can be adequately modeled. But overlapping wires *aren't* automatically connected by the program. For example, four wires are required to model an X-shaped structure if the conductors are connected at the center of the X. No limit is imposed on the minimum wire radius, and the program will produce accurate results with wire radii as large as 0.01 λ.

Number of Segments

It's up to you to decide how many segments to break each wire into for analysis purposes. To make an appropriate choice you have to have some knowledge of the trade-offs involved. Because the results become more accurate as the number of segments is increased, *MININEC* users naturally tend to use a large number of segments. Two factors suggest caution here. First, the size of the complex-impedance matrix calculated by the program goes up as the *square* of the number of pulses. (The number of pulses is approximately equal to the number of segments.) Therefore, *MININEC* and all its derivatives have some limit on the allowable number of pulses. Second, analysis time increases approximately as the square of the number of segments.

So, just how many segments are required to "do it right"? There's no exact answer, because the analysis accuracy nearly always improves with more segments. A straightforward (but time-consuming) way to determine if you've used enough segments is to increase the number of segments, rerun the analysis and see how much the results change. Some rules of thumb work well and can be used as a starting point if particularly good accuracy is required. As I'll describe, you need to take special care at wire junctions, especially where wires are connected at an acute angle.

Straight Wires

If you want to look at the pattern of an antenna with straight elements (like a Yagi), eight to ten segments per half wavelength are adequate. The pattern won't change much as you increase the number, although the program may give more accurate null depths with more segments. If you require *really* accurate feed-point impedances, use more segments.

Connected Wires—General

It's easiest to understand some of the problems of connecting wires if you have an understanding of what *MININEC* does at wire junctions. An unconnected wire is left with a zero-amplitude half-pulse at its end. However, the end pulses of later-defined connecting wires have nonzero current amplitudes. The half-pulse that extends beyond one of these wires is overlapped onto the lowest-numbered connecting wire (Fig 3). *This half-pulse of current takes on the segment length and wire diameter of the lower-numbered wire.*

When the program does its calculations, it considers only the pulse center or end points. When the straight-line path between the pulse ends becomes substantially different from the actual current path, errors result. This occurs wherever wires are connected at a nonzero angle. Accuracy also suffers when wires having greatly different segment lengths are connected. John Belrose, VE2CV, has observed[8] that the best results are obtained with square loops when the segment lengths are the same on all legs. He also observes that, as a rule, segment lengths on connected wires should differ by no more than a factor of two. Both rules are reasonable considering the way *MININEC* handles connections, and both rules have experimentally been proven sound.

Table 1
Feed-Point Impedances Reported by *MININEC*†

Straight Dipole

Segments	*Impedance (ohms)*
10	74.073 +*j* 20.292
20	75.870 +*j* 21.877
30	76.573 +*j* 23.218
40	76.972 +*j* 24.053
50	77.222 +*j* 24.517

Bent Dipole

Segments	*Impedance (ohms)*
10	11.509 −*j* 76.933
20	11.751 −*j* 53.812
30	11.819 −*j* 46.934
40	11.848 −*j* 43.783
50	11.861 −*j* 41.988
14††	11.312 −*j* 43.119

†Impedances for a straight 0.5-λ dipole and dipole bent horizontally at its center at a 45° included angle, with various numbers of segments. Both antennas have a wire radius of 0.001 λ and are placed 0.5 λ above perfectly conducting ground.

††Tapered segment length. See text.

Wires Connected at Right Angles

Wires connected at a nonzero angle require more segments than unconnected wires or those connected at a 0° angle. Eight to ten segments per half wavelength are required for reasonable results if the connection angle is 90° or less and the segment lengths of both wires are equal. Far-field accuracy of a one-wavelength-circumference square loop is reasonably good with four segments per leg, although once again the impedance accuracy improves with more segments.

Wires Connected at Acute Angles

This is where *MININEC* becomes tricky. Accuracy can rapidly degrade as wire-connection angles decrease, although here again the impedance loses more accuracy than the far-field pattern. An example is shown in Table 1. The *MININEC*-calculated impedance of a dipole is reasonably accurate when the antenna is divided into only ten segments. When the same dipole is bent at a 45° included angle, *more than 30 segments are required for similar accuracy.* In both cases, however, ten segments produce far-field patterns that are virtually indistinguishable from those produced using more segments. The only way I know of to evaluate these cases is to change the number of segments and see what happens. Described next, however, is a technique that you can use to reduce the number of segments required for wires connected at sharp angles.

A Technique for Improving Accuracy

MININEC's accuracy can be markedly improved at wire junctions with only a slight increase in the total number of segments. This is done by tapering the segment length, making it short in the vicinity of the wire junction and increasing it at greater distances. Typically, only a few extra wires are required. This technique is illustrated in Fig 4 for the bent dipole of Table 1. Wires 1, 2 and 3 and their counterparts on the other half of the dipole have only one segment each. The remainder of the half-dipole is one four-segment wire. These segments are just slightly longer than when the dipole was made up of 10 segments total. The net result, shown in the last row of Table 1, is that the impedance for this 14-segment model is similar to the 40-uniform-segment model.

Close-Spaced Wires

MININEC documentation includes analysis of parallel wires at various spacings and finds the program to be well-behaved even when wires are very close together. Nonetheless, it cautions, "Whenever a model has close spacing, however, it is advisable to examine the results very closely to ensure proper behavior." Some time ago I analyzed a typical open-wire transmission line and found it necessary to make the segments no longer than three times the wire spacing. With longer segments, dramatic impedance errors resulted. More recent experiments have indicated that the problem is caused not by the close spacing, but by the connection at the ends of the two wires. The wire connecting the end has a maximum possible segment length equal to the wire spacing. The rule of having no more than a 2:1 segment-length ratio (see *Connected Wires—General*) on connected wires is violated unless the main wire-segment lengths are no more than twice the wire spacing. The tapered-segment-length approach outlined above can be successfully applied in this situation.

Additional factors limit your choice of the number of segments to use. Because *MININEC* assumes that current is uniform along a pulse, segment lengths should be short enough that the current in the real antenna doesn't change much in this distance. Therefore, the maximum segment length shouldn't exceed about 0.1 λ. *MININEC* documentation also states that segment length should always be greater than 10^{-4} λ, and greater than 2.5 times the wire radius.

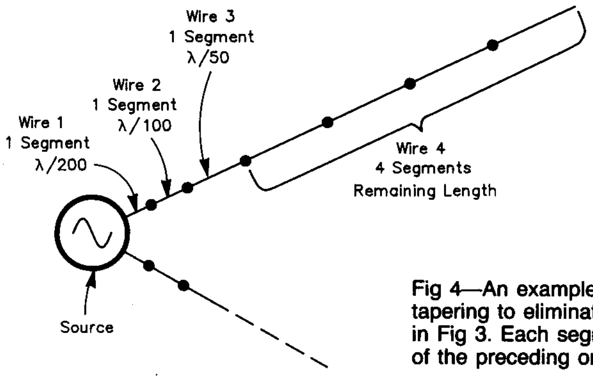

Fig 4—An example of using segment-length tapering to eliminate the problem illustrated in Fig 3. Each segment is twice the length of the preceding one.

Sources and Loads at Multiwire Junctions

This one can be a real surprise. When you place a source or load at a junction of more than two wires, you have to be very careful, or the source or load won't end up where you thought! Sources and loads can be placed only at pulses (segment junctions), so to understand the problem you need to know how *MININEC* assigns pulse numbers. Here are the rules it uses:

See Fig 5. Pulse numbering begins at end number 1 of wire number 1. A pulse number is assigned to each segment junction on the wire, and at a wire end if the end is connected to ground or an already-defined wire. No pulse numbers are assigned to open wire ends. After pulse numbers are assigned to the first wire, pulses are assigned to wire number 2, again beginning at end 1, and so forth.

Wire 1, shown by itself in Fig 5A, has four segments to which three pulses are assigned. Pulse numbers 1-3 belong to wire 1. In Fig 5B, wire 2 is added. Note the assignment of pulse number 4, which belongs to wire 2 since it didn't exist until wire 2 was defined. When wire 3 is added in Fig 5C, pulse number 8 is assigned *to the same physical junction as pulse number 4,* in accordance with the above rule. Pulse 8 belongs to wire 3. Now suppose the antenna in Fig 5 is a groundplane with two drooping radials, and we want to place a source at the base of wire 1, the main radiating portion. If we specify pulse 4 for the source position, *the source ends up on wire 2,* as shown in Fig 6. If the source is producing I amperes, I amperes flows in wire 2, and the return current of I amperes splits between wires 1 and 3—not the desired result. The same thing happens if pulse 8 (Fig 5C) is specified, except that wire 3 gets the full current and the return current splits between wires 1 and 2. Putting the source at pulse number 1 gets it on wire 1 all right, but 25% of the way up from the junction. *There is no way to place the source on wire 1 at the wire junction as this antenna has been defined.* This is because there's no pulse belonging to wire 1 at the bottom (end 1) of wire 1. *The only way to achieve the desired result is to avoid placing the source in the lowest-*

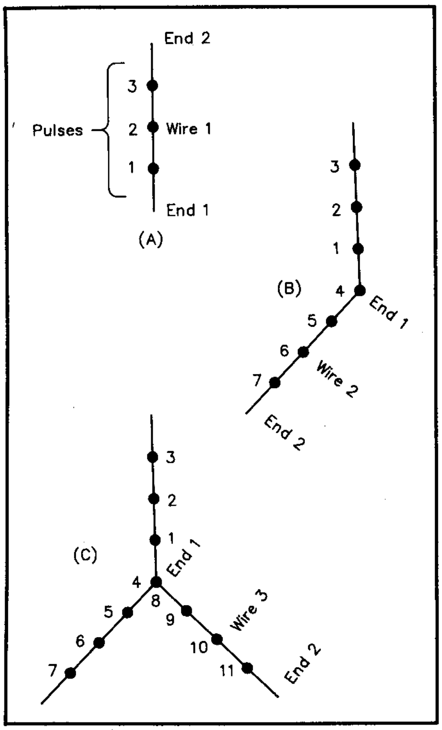

Fig 5—Pulse assignments are made in the order that wires are defined. See text for explanation.

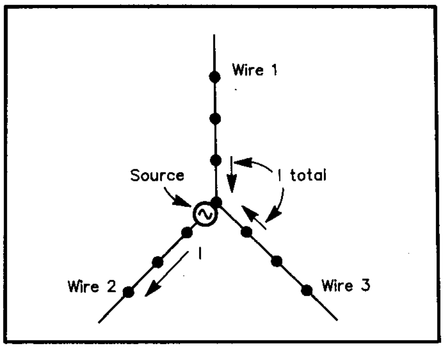

Fig 6—Result of placing a source at pulse 4 on the antenna shown in Fig 5C.

numbered wire (the one defined first) in the group sharing a common junction. To make sure you've put the source where you think you have, always look at the currents and *make sure they make sense.* Load placement behaves the same way, but mistakes can be harder to spot, so be extra careful when placing loads at multiwire junctions.

When only two wires are connected, there's no problem. Regardless of which wire the common pulse belongs to, the entire source or load current flows in both wires.

Ground—General

Probably the most misunderstood limitation of *MININEC* is its ground-modeling capability. Even though the program permits you to define a real ground in considerable detail, this definition is used *only for calculating far-field patterns. MININEC* uses *perfectly conducting ground* when calculating impedances and currents if either a perfect or real ground is specified. Ground has several effects on antennas.[9] Let's look at them one at a time and see how this simplification affects the accuracy of results.

Impedance and Gain

The feed-point impedance of an antenna changes with antenna height. The magnitude of this effect depends on antenna length, diameter, and orientation, and the ground characteristics. The impedance change of a half-wave dipole above ground is well documented.[10] When a dipole is at least 0.2 λ above ground, its impedance is nearly the same whether the ground is real or perfect, so *MININEC* results are adequate. If the antenna is lower, however, *MININEC* results can deviate greatly from the true impedance of an antenna over real ground. Specifically, the resistance reported by *MININEC* will be lower than it really is. This in turn leads to excessively high reported gain, as noted by the correspondent quoted earlier. I don't have any information on longer dipoles (such as the extended double Zepp), but I suspect that these antennas must be somewhat higher than 0.2 λ before *MININEC* gives accurate impedance results. Vertical dipoles have about the same impedance over real ground as over perfect ground, so *MININEC* results are satisfactory for these antennas at any height.

Ground System Losses and Efficiency

Efficiency of ground-mounted low-impedance vertical antennas is frequently the most severe limitation on such an antenna's performance. In such antennas, power is lost due to feed-point return current flowing through lossy ground in the vicinity of the antenna base. Placing radial wires around the base of the antenna raises efficiency by reducing this loss. A common way to determine the loss in such an antenna is to measure the feed-point resistance and compare it with the resistance of a similar element over lossless ground. The loss is simply the difference in the resistances, and usually this is nearly all ground loss.

Because *MININEC* uses a perfect ground for impedance calculations, it always reports the impedance seen over a perfect ground. Therefore, *MININEC* can't be used to determine the impedance or efficiency of antennas fed against ground; you can't use the program to evaluate the effectiveness of radial systems, for instance.

Low-Angle-Radiation Attenuation

Vertically polarized waves, in particular, are attenuated when reflected from lossy ground, leading to the well-known phenomenon of low-angle radiation attenuation.[11] *MININEC* models this correctly as part of the far-field calculation. If radials are specified, they modify the conductivity of the ground on which they are placed. *MININEC* documentation cautions that the radial calculations are accurate only for large numbers of radials.

One additional caution is necessary when specifying ground constants. It's frequently convenient to model antennas at 299.8 MHz, where a wavelength is one meter. If you do this, *you must scale ground conductivity in proportion to the frequency.*[12] For example, an antenna operating at 7 MHz over ground having a conductivity of 0.002 S/m will behave like a size-scaled antenna operating at 299.8 MHz over ground with 0.002 × (299.8 ÷ 7) = 0.086 S/m conductivity. However, even with a ratio this large, neglecting to scale ground conductivity usually won't be apparent in the far-field patterns, except at very low angles.

Multiple Media

Other limitations appear when the ground is broken up into several pieces (*media*). Once again, it's helpful to understand how *MININEC* functions in this regard.

Height of Ground Under the Antenna

It's important to realize that *MININEC* always assumes a ground-plane height of 0 (Z = 0 in *MININEC*'s XYZ coordinate system) when calculating impedances and currents. Also, it regards a wire-end Z coordinate of zero as meaning that the wire is connected to ground (except when the antenna is being modeled in free space). For these reasons, the region of the ground plane immediately under the antenna must have a height (Z coordinate) of zero. If you're modeling an antenna on top of a hill, the top of the hill must have a Z coordinate of zero, with the rest of the hill having negative Z coordinates.

Other Concerns

At each elevation angle, *MININEC* looks for reflection from ground. It begins at the most distant medium and looks for the intersection of the direct and reflected rays. This process is repeated for all other media. *MININEC* uses the innermost reflection point it finds; it makes no attempt to evaluate multiple reflections or those from corners. *MININEC* doesn't look between the antenna and the reflecting point or beyond the reflecting point. Therefore, the program assumes that RF passes through hills and cliff walls with no shielding or reflections. A puzzling simplification is that the program assumes a height of zero for all media during the process of determining the wave-reflection point to be used for far-field calculations, although media height is taken into account during summation of the incident and reflected rays. This can lead to pattern errors with media of differing heights. If you have access to a compiler, you can easily patch *MININEC*'s source code to overcome this deficiency. See the appendix for details.

These ground approximations were purposely made to keep the program length and speed compatible with PCs. We can hope that improved ground-modeling code will become available in the future as PCs continue to increase in speed and power.

Loss

MININEC doesn't automatically account for loss. Therefore, be wary of antennas with low feed-point resistances. The answers might be entirely legitimate, but only if there is no loss in the antenna structure. In the lossy real world, these antennas just won't work. Whenever you see a surprisingly high gain, look at the feed-point resistance and you're likely to find it's very low. Imitate reality by adding loads having a few ohms of resistance at each source (and anywhere else the current is high) and watch what happens to the gain!

Frequency-Related Errors

At least two writers have reported apparent frequency-dependent errors in *MININEC.*[13,14] This was determined by comparing *MININEC* results to those of *NEC*, a much more sophisticated mainframe program. Their observations were that, for certain frequencies and element diameters, the two programs seem to give similar results at slightly different frequencies. The only specific example of this I've seen was provided by Peter Beyer, PA3AEF.[15] It shows *NEC* and *MININEC* analyses of a 10-element 144-MHz Yagi. The *NEC* analysis was done at 144.5 MHz. *MININEC* analysis is closer to the *NEC* results when done at 145 MHz than at 144.5 MHz. I ran some brief experiments to see if there is, indeed, a frequency-sensitive error *within MININEC.* I scaled the same antenna for different frequencies and analyzed them with *MININEC.* No frequency-dependent effects (resonance shift, etc) were found, but the tests were far from exhaustive, and the program's *absolute* accuracy is what's in question. My feeling is that the differences arise because of the much more sophisticated way in which *NEC* deals with currents. I hope we'll see more about this phenomenon in amateur publications. In the meantime, be careful when trying to get high accuracy from *MININEC* analysis of highly directional structures, especially at VHF and UHF.

Bugs

I know of only two actual bugs in *MININEC.* They both deal with Laplace ("S-parameter") loads. One causes an overflow and the other is very obscure and highly unlikely to affect you. If you'd like some further description and fixes for the bugs, contact me.

Summary

All modeling tools, no matter how elaborate, powerful and expensive, have limitations. Absolutely none of these can be used sensibly unless you're constantly conscious of their limitations. *MININEC* is no exception. You must always be alert for answers that don't seem quite right. Are the impedance and gain values *reasonable?* If the antenna is symmetrical, is the pattern symmetrical about the axis you intended to specify? Do the currents change abruptly from one segment to another?[16] Do the results seem too good to be true? *If so, they probably are!*

We owe *MININEC*'s authors a great debt of gratitude for the pioneering work they have done. They've put fast, accurate antenna analysis within the reach of thousands of amateurs. The program they have created is very useful for analyzing a variety of antenna designs. Wielded properly, *MININEC* can be a powerful tool—a weapon against a decades-long void in knowledge about antenna design. This article should help you avoid the other edge of the sword.

APPENDIX

If you have access to BASIC compiler software (eg, Microsoft® *QuickBasic,* Borland *Turbo Basic*), you can patch the *MININEC* source code to improve *MININEC's* handling of multiple media of different heights, then recompile the program.† Of course, the source code could be run directly with a GWBASIC interpreter, but the speed will be so slow as to render the program virtually useless. In the following code segments, the added lines have no line numbers since such are not required by the compilers.

```
702 T3 = -SIN(U4)
IF ABS(R3) < 0.00001 THEN ATU4 =
  100000 ELSE ATU4 = ABS(T3/R3)
703 T1 = R3 * V2

756 FOR J = 1 TO NM STEP -1
IF B9 > U(J1) * (1 + ATU4) THEN 759
758 J2 = J1
```

Note: Delete line 757
[IF B9 > U(J1) THEN 759].

If the program is to be compiled with Microsoft *QuickBasic,* one other change must be made. In *MININEC,* "IS" is used as a variable. Because "IS" is a reserved word in *QuickBasic,* it must be changed. (If you're using a different compiler, check its documentation to see if this change is required.) Change "IS" to "ISX" in the following lines: 1592, 1593, 1596, 1605-1609, and 1612.

†Patched *MININEC* in compiled form is available from the author on an MS-DOS 5¼- or 3½-inch disk for $3 postpaid to the US, Canada, and Mexico. Add $3 airmail postage to other countries.

Notes

[1] *MININEC* is available from National Technical Information Service (NTIS), US Department of Commerce, 5285 Port Royal Rd, Springfield, VA 22161, tel 703-487-4650. Order no. ADA181681 (software and documentation).

[2] A technical reference describing the program is J. C. Logan and J. W. Rockway, *The New* MININEC *(Version 3): A Mini-Numerical Electromagnetic Code,* NOSC TD 938, Naval Ocean Systems Center, San Diego, CA, 1986. It is available as document number ADA181682 from NTIS (see note 1). This is a highly technical manual.

[3] J. Rockway, J. Logan, D. Tam and S. Li, *The* MININEC *System: Microcomputer Analysis of Wire Antennas,* available from Artech House, 685 Canton Street, Norwood, MA 02062. Includes several programs with source code and a comprehensive manual.

[4] *MN* and *MNjr,* by Brian Beezley, K6STI. Available from Brian Beezley, 507½ Taylor St, Vista, CA 92084.

[5] *ELNEC,* by Roy Lewallen, W7EL. Available from Roy Lewallen, PO Box 6658, Beaverton, OR 97007.

[6] Documentation files for *MN* and *ELNEC* are available on 5.25-inch diskettes from their authors for $5 and $3, respectively. Add $3 for postage to locations outside North America. See notes 4 and 5 for addresses.

[7] A good description of the method of moments is included in J. D. Kraus, *Antennas,* 2nd edition (New York: McGraw-Hill, 1988), pp 359-408.

[8] J. S. Belrose, VE2CV, ARRL Technical Advisor, private correspondence.

[9] An excellent description of these effects appears in G. L. Hall, ed., *The ARRL Antenna Book,* 15th edition (Newington: ARRL, 1988), Chapter 3.

[10] See note 9, p 3-11, Fig 16.

[11] See note 9, pp 3-1 through 3-6 and 3-10.

[12] G. Sinclair, "Theory of Models of Electromagnetic Systems," *Proceedings of the IRE,* Nov 1948, pp 1364-1370.

[13] P. Beyer, "Antenna Simulation Software," *Proceedings of the Third International EME Conference,* Thorn, Netherlands, Sep 9-11, 1988. Thanks to Warren Butler, W2WD, for bringing this to my attention.

[14] R. Cox, "An Update on Computer-Aided Antenna Design," *1990 Central States VHF Conference Proceedings,* published by ARRL. Thanks to *QST* Assistant Technical Editor Rus Healy, NJ2L, for bringing this to my attention.

[15] Peter Beyer, PA3AEF, private correspondence.

[16] Positive current flow is defined as being from end 1 to end 2. Current reversals at wire junctions are normal if wires are connected "head to head," ie, end 1 to end 1 or end 2 to end 2.

New Products

The ARRL and QST *in no way warrant products described under the New Products banner.*

SIMPLEX REPEATER

☐ Brainstorm Engineering has introduced its model SR3 Simplex Repeater. Based on digital voice recording and delayed playback, the SR3 is primarily intended for multistation communications on a single frequency where the stations don't have solid simplex communications capability, or as a voice mailbox. With the optional DTMF decoder, the SR3 can be used as a repeater identifier. Maximum message length is 64 seconds (with four memory ICs installed), and the SR3 comes with 16-second recording capability. Specifications: power requirement, 11.6-15 V dc at 200 mA; audio input, 0.1-2 V rms; audio output, 5-500 mV; 1.75 × 10.5 × 6 inches (HWD). Price class: $230-$330, depending on configuration. For more information, contact Brainstorm Engineering, PO Box 415, Montrose, CA 91021-0415, tel 818-249-4383, fax 818-846-2298.