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Title: Update on Compact Transmitting Loops, An
Author: John Belrose, VE2CV

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An Update on Compact Transmitting Loops

What did you say you were using on 40 meters? A one-meter loop?

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Canada

Electrically small transmitting loops have been around since 1957,[1] but this type of antenna has not been widely used by radio amateurs, except perhaps in Europe. This is unfortunate, given the fact that a compact loop can be both an effective and an inconspicuous, neighbor-friendly radiator.

Fig 1A sketches the method of tuning and matching used by Patterson. Subsequent experiments by Lew McCoy[2] patterned after the Patterson loop did not shed a favorable light on the performance of such an electrically small loop for use by radio amateurs for the 75- and 40-meter bands. McCoy cited the critical elements of loop conductor and connection losses and the difficulties in keeping these low with typical construction techniques available to most radio amateurs. In Germany, Christian Käferlein, DK5CZ, developed the AMA series of electrically small loops, and has been manufacturing them since 1983. AMA stands for *Abstimmbare Magnetische Antennen* – tunable magnetic antennas. The electrical design for these loops was worked out by Hans Wurtz, DL2FA. AMA loops are currently available for the 160- to 10-meter amateur bands. Four sizes are sold, ranging in diameter from 0.8 to 3.4 meters.[3] In 1986, Robert T. (Ted) Hart, W5QJR,[4] independently analyzed the compact loop and described practical designs for the radio amateur. But still it has not been widely used in Canada and the United States. I have not made an on-the-air contact with any North American amateur who was using a compact loop, but I suspect that will change. Recently, two US companies catering to the Amateur Radio market have developed small loops for the 30- through 10-meter bands: the Isoloop (AEA[5]) and the Super Hi-Q Loop (MFJ[6]). Brian Battles, WS1O, reviewed the AEA Isoloop for *QST*, and ran a number of comparison tests between it and a reference dipole.[7]

Table 1 summarizes the various types of compact loops currently available. High radiation efficiencies, 38% to 95% depending on the size of the loop and the frequency, are claimed, with conductor losses better than −4.2 dB. However, there are conflicting opinions concerning the performance of such loops, and overly enthusiastic claims sometimes heard about the compact loop can be misleading. This article is meant to give an overview of the actual characteristics and expected performance of electrically small transmitting loops.

Characteristics of Compact Loops

Electrically small loops (perimeters 0.04 to 0.1 λ) are characterized by a very small radiation resistance. Therefore, such loops must be fabricated from large-diameter tubing to keep conductor losses small. In many designs, 2.5- to 10-cm-diameter aluminum tubing has been used. Since the loops are inductive, they can be readily tuned by means of a series capacitor. Power is coupled into them by means of a small coupling loop, a more convenient method of tuning and matching than the original method of Patterson. See Fig 1B.

The radiation efficiency and gain of elec-

[1]Notes appear on page 40.

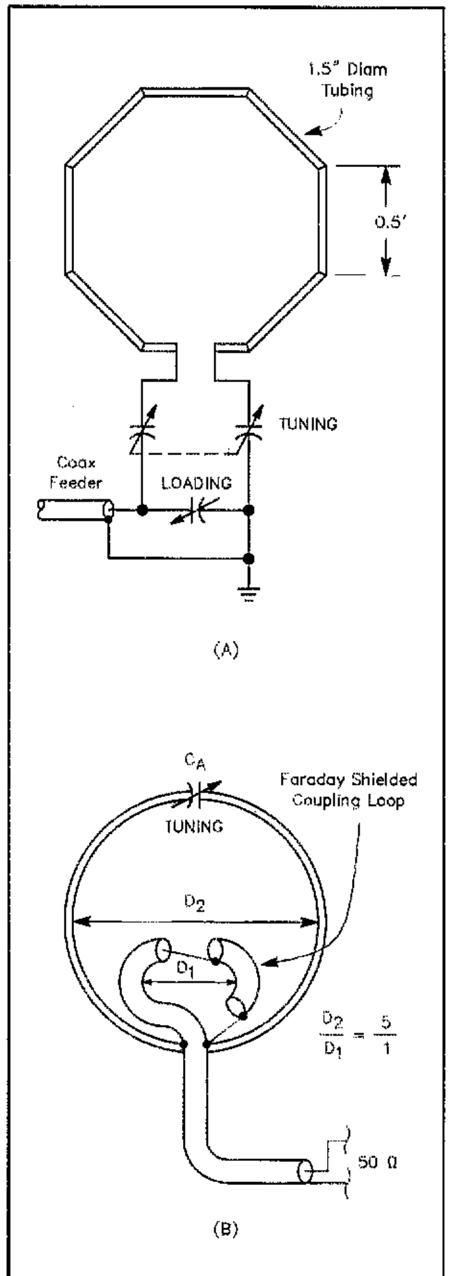

Fig 1—Equivalent circuit of compact loops, showing two methods of tuning and matching. At A, original Patterson loop. At B, AMA loop with coupling link.

Table 1
Some Examples of Commercially Available Compact Transmitting Loops for the Radio Amateur

Type	*Diameter (m)*	*Conductor Diameter (mm)*	*Frequency Range (MHz)*
AMA-7	3.4	32	1.75-8
AMA-2D	1.7	32	6.9-16
AMA-10D	1.3	32	7-22
AMA-3D	0.8	32	13.5-30
AEA Isoloop	0.89	Flat Strip 1.5 × 38.1	10-30
MFJ Super High-Q	0.91	26.7	10-30

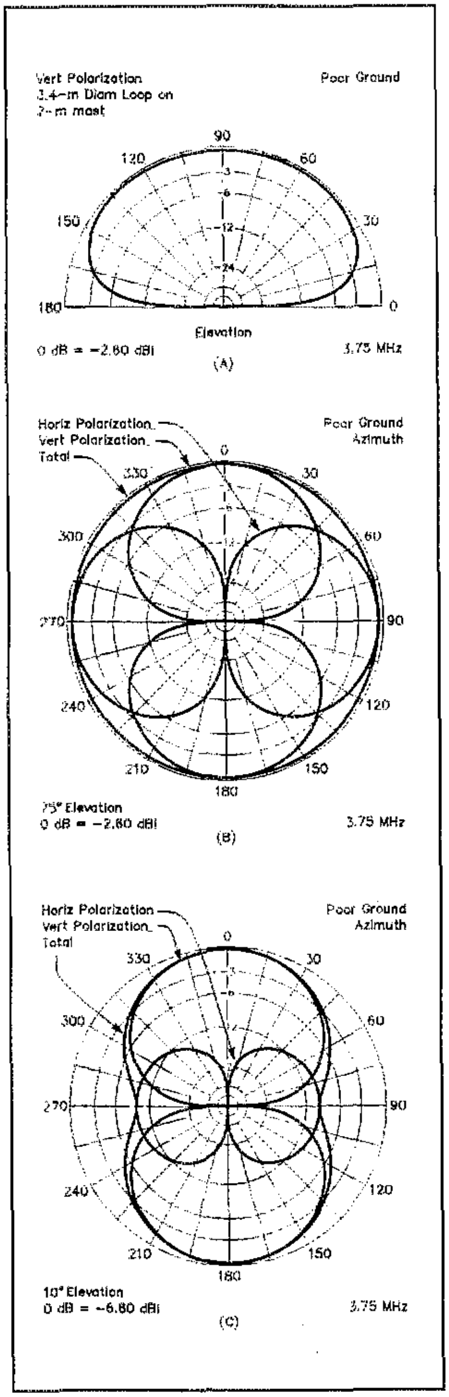

Fig 2—Elevation and azimuth plots for a 3.4-m-diameter vertically polarized hexagonal loop mounted 2.5 meters (height to center of loop) over poor ground, with a conductivity of 3 mS/m and a dielectric constant of 13. The loop is in the 0° to 180° plane. The elevation pattern at 0° azimuth is shown at A, where the radiation is mainly going straight up. B shows the total azimuthal pattern for the loop at a takeoff angle of 75°, plus the horizontally polarized and the vertically polarized field components, which vectorially add to create the total pattern. At this high angle of elevation, the two contributory fields are almost identical, but rotated in azimuth by 90° from each other. C shows the total azimuthal pattern, plus the overlaid horizontal and vertical patterns, for an elevation angle of 10°. Now the vertical field dominates the plot.

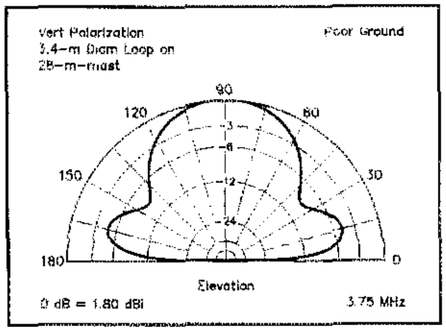

Fig 3—Elevation plot for a 3.4-m-diameter loop at 3.75 MHz, oriented vertically at 28 m in height above poor ground (conductivity of 3 mS/m and dielectric constant of 13). Much of the signal is directed upwards at high elevation angles, but some is radiated at lower angles as well.

trically small loops has been analyzed using simple equations based on standard classical analysis. Equations can be found in various texts for the radiation resistance, conductor loss resistance, and loop inductance.[8] But modern computational electromagnetic codes developed for wire antennas, such as *MININEC*[9] or *NEC*, can be used to calculate efficiency, gain and pattern. The effects of the tuning, feeding and mounting methods on gain, pattern and the bandwidth of the antenna can also be calculated with these programs.

As an example, consider a 1-meter-diameter hexagonal loop using a 2.54-cm aluminum tube as a conductor. Wire models using *MININEC* code must be made up from straight wire sections; therefore, round loops must be modeled as regular polygons. For this loop, the free-space gain is −2.88 dBi at 10 MHz; −0.22 dBi at 14 MHz; 1.14 dBi at 21 MHz; and 1.42 dBi at 30 MHz. The free-space gain of a dipole antenna is 2.15 dBi, and therefore the loop's gain at 10 MHz is 5 dB below that of a dipole. The gain increases and the operational bandwidth decreases as the conductor diameter is increased. I will discuss this in more detail later on.

The disadvantages of using small loops are their high currents and narrow bandwidths, a natural consequence of the very low radiation resistance characteristic of physically small antennas. High-voltage capacitors must be used to tune compact loops. This means that the power used must be limited to about 150 watts, unless expensive vacuum or ceramic variable capacitors (rated at 10 to 20 kV) are used. The problem becomes worse at lower operating frequencies. For the 1-m loop above, which has an impedance of $0.088 + j\,161\ \Omega$ at 10 MHz, the loop current for 150 watts of transmitter power is 41 amperes, and the voltage across the capacitor is 6.6 kV rms. Don't touch your loop when transmitting!

The Q of such a small transmitting loop is extremely high (1824 at 10 MHz), and this results in a small antenna bandwidth — only

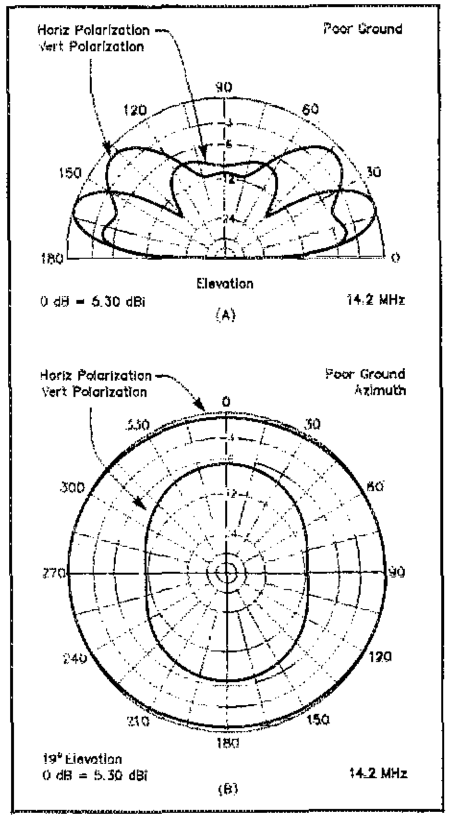

Fig 4—Comparison between horizontally and vertically polarized 1-m-diameter loops placed 15 m over poor ground. The operating frequency is 14 MHz. The horizontally polarized loop has more gain at lower elevation angles than the vertically polarized loop.

5.5 kHz. When the loop is fed by a transmitter, the operating bandwidth is twice the antenna bandwidth. For maximum power transfer, the effective source impedance of the RF amplifier is conjugately matched to the load impedance of the antenna. A more practical operational bandwidth is 1.5 times the antenna's 3-dB bandwidth, which for our 1-m loop at 10 MHz is 8.25 kHz. Either way, the bandwidth is narrow, so the loop must be tuned with care. The operational bandwidth of a 1-m loop increases rapidly with frequency, reaching 590 kHz at 28 MHz.

Radiation Patterns of Compact Loops

The desired radiation pattern depends on frequency and path length. For the 160, 80 and 40-meter bands, high-angle skywave is often a requirement, except for those who wish to work mainly DX on these lower frequencies. For bands higher than 10 MHz, low-angle skywaves are a requirement.

Fig 2 shows the elevation and azimuth patterns for a 3.4-m-diameter loop which has been mounted vertically on a 2-m mast over average ground (conductivity 3 mS/m, dielectric constant 13). The patterns were calculated using the *NEC2* computer program, which incorporates a sophisticated Sommerfeld/Norton ground model that takes into account ground interactions at low heights. For an electrically small loop near

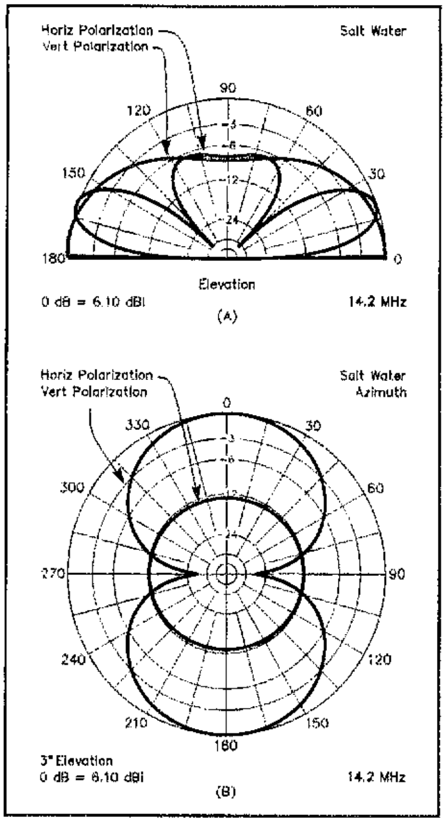

Fig 5—Comparison between horizontally polarized 1-m-diameter loop 15 m over salt water and vertically polarized 1-m-diameter loop mounted on a sailboat transom over salt water. Now the vertically polarized loop has superior gain even at low elevation angles compared to the higher horizontal loop.

the ground, with its plane oriented vertically, the total azimuthal radiation pattern (resulting from the combination of the vertically and horizontally polarized fields emanating from the loop) is omnidirectional at high elevation angles. See Fig 2B. The skywave polarization is characterized as being vertical, because the dominant component, the magnetic component, is parallel to the earth's surface.

In Fig 2C, the azimuthal pattern at an elevation of 10° is shown. The overall pattern is no longer omnidirectional, since the vertical pattern dominates over the horizontal pattern. At low elevation angles, the maximum gain is reached when the loop is approximately 0.35 wavelength above the ground. This would require a 28-m tower at a frequency of 3.8 MHz, a height which is not too practical for most hams. Fig 3 shows the elevation plot for a 3.4-m-diameter loop mounted vertically 28 m above the ground. When the conductivity of the ground is finite, the pattern "cut back" at low elevation angles, characteristic of vertical polarization, makes it difficult to launch skywaves at elevation angles less than about 10°, so there is little advantage in using a vertical loop mounted any higher off the ground.

When the loop is mounted horizontally (ie, parallel to the ground), the polarization

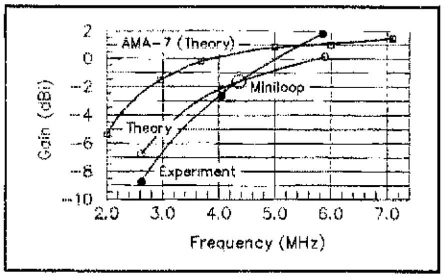

Fig 6—Measured and theoretical NVIS gain for the Antenna Research Associates Miniloop over poor ground, compared with the theoretical gain of the AMA-1 loop (3.4-m diameter).

for the skywave is horizontal, and the azimuthal response is omnidirectional. As with any horizontally polarized antenna, the takeoff angle will depend on the height of the antenna above ground. As the height is increased from 3 to 30 meters (0.14 to 1.4 λ for a 14-MHz loop) the gain increases from 0.5 to 5.5 dBi, and the takeoff angle decreases from 42° to 10°. Fig 4 shows the elevation and azimuth patterns for a 1-m-diameter horizontal loop mounted at a height of 15 m above ground, compared to the patterns for a vertical loop at the same height.

Clearly, the preferred polarization for working DX is horizontal, and the antenna should be mounted as high as possible, as with any dipole or Yagi antenna. The exception is the case of salt water in the direction of propagation, where vertical polarization can be used effectively. See Fig 5A and 5B, where a vertically polarized loop mounted on the transom of a sailboat in sea water is compared to a horizontally polarized loop which is 15 meters high. The vertical loop's response at a 3° elevation angle (close to the horizon) is far better than the much-higher horizontal antenna.

Measured/Predicted Performance of a Compact Loop

The performance of a commercial high power (1 kW) HF Miniloop[10] has been measured[11] on a near-vertical-incidence skywave (NVIS) link, where the distance between transmitter and receiver was 100 km. This loop has a diameter of about 1.6 m, and extreme measures were taken to reduce the conductor loss so that the antenna could be used even at low frequencies: the conductor was made of 10.2-cm aluminum tubing. ARA specifies the operating band to be 2 to 16 MHz.

The measured and theoretical gain for the Miniloop mounted 3 meters above poor ground (conductivity of 1 mS/m, dielectric constant of 13) is shown in Fig 6, compared with the theoretical gain of a larger AMA-7 (loop diameter 3.4 m, conductor diameter 4.8 cm). For reference, the gain of a full-size 4-MHz half-wave dipole at 9.1 m over poor ground is about 4 dBi. Clearly, if a compact loop is used on 75 or 40 meters, the largest diameter loop possible should be used.

The bandwidth of a compact loop de-

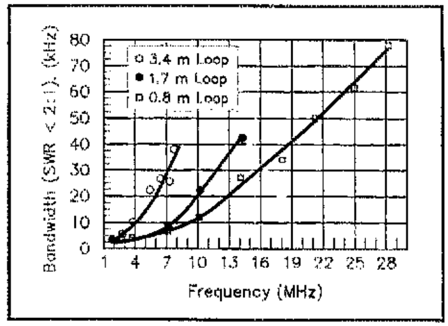

Fig 7—Measured bandwidth versus frequency for three different loop sizes.

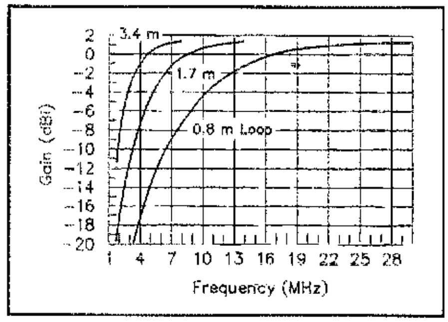

Fig 8—Free-space gain versus frequency for three different loop sizes.

pends on its operating frequency and its overall size, as well as on the conductor diameter and the conductor resistance. The bandwidth also depends on the degree of inductive coupling between the coupling loop and the main loop—and of course on the minimum SWR at resonance. Obviously the bandwidth for SWR less than 2:1 cannot be defined if the minimum SWR is greater than 2:1. Fig 7 shows the measured bandwidth (SWR < 2:1) versus frequency for well-matched AMA 3.4-m, 1.7-m, and 0.8-m-diameter loops. Fig 8 shows the theoretical free-space gain for these loops.

The data shown in Figs 7 and 8 allow you to choose the loop diameter which best meets your operating requirements, including the bands you use most often, and your favorite application (for example, Field Day or base station use). Obviously, the gain of a 1-m-diameter loop at 3.75 MHz (a band of interest to me) is not impressive, but your outlook on loop gain will be highly dependent on the antenna used as a reference. If the reference antenna is a half-wave dipole, a small loop's gain seems poor. But if the reference antenna is a 2.8-m center-loaded mobile whip, the loop's gain is comparable, and a vertical loop is clearly superior for NVIS paths.

Operational Experience

I have carried out a series of experiments to evaluate operationally the performance of several loops. The AMA-7 and the AMA-2D loops were mounted in a vertical plane on pipe masts at the corners of a field laboratory. The height was 3.6 meters, and the comparison antenna was a stagger-tuned droop-

Loops Really Work!

For me, one of the more interesting experiences during September's IARU Region 1 Conference in De Haan, Belgium, was a demonstration by Gaston Bertels, ON4WF, of his home-brew, 2-meter-diameter magnetic loop antenna. Gaston is president of the UBA, the IARU member-society for Belgium.

Gaston's version of the loop antenna uses a conductor made of RG-213 coaxial cable, held in shape by ordinary plumbing parts: eight PVC spokes radiating from a center hub. His tuning capacitor is homemade, and is tuned remotely by a 1.5-volt dc motor designed for a barbeque rotisserie. Unlike the commercial versions of the loop antenna described here, Gaston's use of simple yet highly efficient homemade capacitors does limit frequency coverage; his basic capacitor tunes the loop throughout the 20-meter band, and he plugs in a parallel fixed capacitor, also homemade, to tune the antenna to 40 meters. It is designed for portable operation and can be set up in about five minutes.

Gaston demonstrated the antenna during a lunch break. He set it up in a parking lot, surrounded by cars and buildings, with the bottom of the antenna perhaps a foot above the ground. Using a 100-watt mobile rig on SSB, his first call on 20 meters netted a station in Thessaloniki, Greece. Switching to 40 meters, his first call on that band brought back an Italian station more than 500 miles away. Both contacts were ragchew quality, with signal strengths in each direction well above the noise.

Reading an article about the effectiveness of these small antennas is one thing; seeing a live demonstration is a lot more persuasive!—*Dave Sumner, K1ZZ*

ing dipole for 80, 40 and 20 meters, with an apex height of 15 m. Numerous test QSOs were conducted during daytime on 80 and 40 meters. As shown in Fig 8, the free-space gain of the AMA-7 for these bands is about −3.6 dB and −1 dB respectively, referenced to the comparison dipole, and the 40-meter gain for the AMA-2D is −3.4 dB. By and large, test QSOs confirmed these gain differences. An S unit is about 6 dB, and when comparing antennas with different polarizations and patterns, the signals typically fade differentially on the two antennas.

I took an AMA-6, a 0.8 m diameter loop which tunes 6.7 to 25 MHz, on a camping trip during July and August 1993. I mounted it vertically on a 3-m mast attached to the side of the travel trailer. Initial tests confirmed that it did indeed work on all bands. From a site in the San Fernando Valley in Southern California, schedules were kept with radio amateurs in Toronto, Woodstock, Smith Falls and Ottawa on 20 meters, and in spite of the poor gain of this antenna on 40 meters, QSOs were made with several amateurs in San Francisco, Phoenix and Tucson under daytime propagation conditions. Clearly, the AMA-6 is far easier to install at a campsite than is a dipole. If I had purchased an AMA-13, which is a 0.8-m-diameter loop that tunes from 3.5 to 21.5 MHz, I could have had a bit of fun working the 80-meter band as well.

Concluding Remarks

The Patterson loop was developed for a military tactical communications requirement, where the interest was in NVIS links. Hence the interest was to use the low end of the HF spectrum, between 2 to 8 MHz, and to use high takeoff angles. Notwithstanding limitations on transmitting efficiency and bandwidth, the compact loop can be used with advantage for particular applications. The motor drive for a remotely tuned loop must have no mechanical backlash, and should have a slow fine-tuning speed. A stepper-motor drive is unlikely to prove satisfactory with small loops, since no matter how small the step, you never seem to be able to get the SWR down to exactly 1:1.

Undoubtedly, small transmitting loop antennas will see application for Field Day, camp, maritime communications, apartments, and residential use where antenna height and the "look" of the antenna are factors to consider.

Acknowledgment

I work for the Communications Research Centre, Shirleys Bay, ON, and I wish to acknowledge the use of their laboratory equipment to measure antenna gain and bandwidth. I also want to thank Peter Bouliane, VE3KLO, for making the bandwidth measurements.

Notes

[1]K. Patterson, "Down-to-Earth Army Antennas," *Electronics*, Aug 21, 1967, pp 111-114.

[2]L. McCoy, "The Army Loop in Ham Communications," *QST*, Mar 1968, pp 17-18, 150. (See also *QST* Technical Correspondence, May 1968, pp 49-51 and Nov 1968, pp 46-47.)

[3]Magnetische Kurzwellenantennen "AMA," Christian Käferlein, Weinbergstrasse 5, D-6100 Darmstadt, Germany (tel 49-61-51-61272, fax 49-61-51-663009). An English-language brochure is available.

[4]T. Hart, "Small, High-Efficiency Loop Antennas," *QST*, Jun 1986, pp 33-36.

[5]The IsoLoop 10-30 HF antenna, Advanced Electronic Applications, Inc., PO Box C2160, 2006 196th St SW, Lynnwood, WA 98036, tel 800-432-8873.

[6]The Super Hi-Q Loop Antenna, MFJ Enterprises, Inc., Box 494, Miss. State, MS 39762, tel 601-323-5869, fax 601-323-6551.

[7]B. Battles, "AEA Isoloop Antenna," *QST* Product Review, Nov 1992, pp 71-72.

[8]F. Terman, *Radio Engineering Handbook*, (New York: McGraw-Hill, 1943), pp 35, 52, 53, 814.

[9]For example, I use the *ELNEC* version, by Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007.

[10]Antenna Research Associates Miniloop, see P. Wahi, "HF Miniloop Antennas," *RF Design*, Jan 1992, pp 73-77.

[11]J. Belrose, G. Royer, L. Petrie, "HF Wire Antennas Over Real Ground: Computer Simulation and Measurement," AGARD LS 165 on Modern Antenna Design Using Computers and Measurement: Application to Antenna Problems of Military Interest, Sep 1989, pp 6-1 to 6-30. Available from NTIS, Springfield, VA (Ref NASA Access No N90-17932).

New Products

MAP SOFTWARE

◊ Personal computer users can run software that puts the time, day/night indications, distance between two points, phone numbers in a selected city, and notes on a full-color world map. *Sun Clock* version 4.0, developed by MLT Software of Tigard, Oregon, is available for Macintosh and IBM-compatible PCs. Both support a mouse and the IBM-compatible version runs under *Windows 3.1*. As many as 20 user-embedded readouts show the time in specific places, a notepad, pop-up windows linked to map locations, and a "different day" features lets users see the night shadow on any date. Retail price $39.95. The Mac version requires 1 Mbyte of RAM and comes with *Pyro* and *After Dark* screen savers. The *Windows* version requires 640 kbytes of RAM. Palo Alto Software, 2641 Columbia St, Eugene, OR 97403; tel 503-683-6161.

LOW-LOSS COAX

◊ Amateurs looking for an alternative to Hardline for VHF/UHF/SHF applications might want to try AIRCOM Plus cable, manufactured by Germany's SSB-Electronic GmbH. Its loss is claimed to be lower than other cables of similar size, including RG-213. It has a copper foil shield lined with plastic foil to minimize tearing, and 75% copper braid over the foil to increase mechanical stability. The center conductor is supported by a continuous plastic spreader and embedded in plastic to prevent corrosion and to keep it from moving when it's bent, to maintain nominal impedance. The specially developed N connector provides strain relief and is compensated for better return loss at frequencies above 3 GHz. Distributors: In the US, SSB Electronic, 124 Cherrywood Dr, Mountaintop PA, 18707, tel 717-868-5643, fax 717-868-6917. In Canada, Manfred Zielinsky, VE3ZIE, MAS Enterprises, Import-Export UHF Technik, 104 King St S, St Jacobs, ON N0B 2N0, Canada; tel 519-664-1273, fax 519-664-3082.