Dimensional and Electrical Considerations

Mechanical dimensions

The loop antenna described here has octagon shape with a width of 5.5 ft. This dimension was chosen somewhat arbitrarily as a tradeoff between area and handling convenience. The loop is primarily made from 1 in. square fiberglass tubing and consists of 24 turns of 18 AWG coated magnet wire.

The perimeter distance of an octagon is given by

$$p = 8 \cdot W / (1 + \sqrt{2})$$ **Eq. (1)**

where
W   = octagon width (flat-to-flat)

Therefore, for the loop in question

$$p = 8 \cdot 5.5 \cdot 0.3048 / (1 + \sqrt{2}) = 5.56 \, \text{m}$$

The physical area of the octagon is

$$A = w^2 \cdot \left[1 - \frac{1}{\left(1 + \sqrt{2}\right)^2} \right] = (5.5 \cdot 0.3048)^2 \cdot \left[1 - \frac{1}{\left(1 + \sqrt{2}\right)^2} \right] =$$ **Eq. (2)**
$$25.06 \, \text{ft}^2 = 2.33 \, \text{m}^2$$

Inductance

The loop is wound with 18 AWG magnet wire, which has a coated diameter of 0.042 in. = 1.07 mm = 0.107 cm and uncoated diameter of 0.040 in. = 1.02 mm = 0.102 cm.

The approximate inductance of a polygon in µH is given by[1]

$$L \approx \frac{0.03948 \cdot a^2 \cdot n^2}{b} \cdot K$$ **Eq. (3)**

where

a   = Average of inscribed and circumscribed radii, $r \cdot \cos^2\left(\dfrac{\pi}{2 \cdot N} \right)$ (cm)   **Eq. (4)**

r   = radius of circumscribed circle (cm)
N   = number of sides (8 for an octagon)

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[1] Circular C74, Radio Instruments and Measurements, US Department of Commerce, National Bureau of Standards, 1937

n = number of turns
b = length of coil, or $n \cdot d$ (cm)
d = distance between turn centers = wire diameter for close spacing (cm)
K = function of $2 \cdot a / b$ from table in the reference NBS document

The radius of a circumscribed circle for an octagon is

$$r = \sqrt{\left(\frac{W}{2}\right)^2 + \left(\frac{W}{2 \cdot (1 + \sqrt{2})}\right)^2} = 0.91\,\text{m} = 91\,\text{cm, and}$$

Eq. (5)

$$a = 0.91 \cdot \cos^2\left(\frac{\pi}{2 \cdot 8}\right) = 0.875 \text{ m} = 87.5 \text{ cm.}$$

The coil length is $b = 24$ turns $\cdot\ 0.107$ cm $= 2.57$ cm. K is based on
$2 \cdot a / b = 2 \cdot 87.5 / 2.57 = 68.1$ and is found in Table 10, page 283 of the reference NBS
document by interpolation, or

K = 0.0479.

Substituting the above values, the calculated inductance is

$$L \approx \frac{0.03948 \cdot 87.5^2 \cdot 24^2}{2.57} \cdot 0.0479 = 3{,}245\,\mu\text{H} = 3.25 \text{ mH}$$

Open circuit voltage

From Faraday's law of induction

$$V = -\frac{d\varphi(t)}{dt}$$

Eq. (6)

where
V = open circuit rms voltage (v)
$\varphi(t)$ = magnetic flux (weber = $v \cdot s$)
t = time (s)

Therefore, an induced voltage appears across the terminals of a circuit immersed in a changing
magnetic field. If the circuit consists of an electrically small air core loop antenna with N turns,
the voltages in the turns are additive, or[2]

$$V = -N \cdot \frac{d\varphi(t)}{dt}$$

Eq. (7)

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[2] An electrically small loop antenna has circumference much less than a wavelength. Note that for any frequency <
300 kHz one wavelength in free space is > 1,000 m, and the circumference of any practical loop antenna is much
smaller.

The magnetic flux is related to the time varying magnetic induction by

$$\varphi(t) = B(t) \cdot A_e \cdot \cos(\theta)$$ **Eq. (8)**

where
$B(t)$ = magnetic induction (tesla, $T = v \cdot s / m^2$)
A_e = Area of equivalent circular loop with radius a (m)
θ = angle between magnetic field lines and normal of loop frame (radians)

Note that $B(t) = B \cdot \cos(\omega \cdot t)$

where
B = rms magnetic induction
ω = radian frequency ($2 \cdot \pi \cdot f$, radians/s)
f = frequency (Hz)

Differentiating Eq. (8) gives

$$\frac{d\varphi(t)}{dt} = \frac{dB(t) \cdot A_e \cdot \cos(\theta)}{dt} = -B \cdot A_e \cdot \omega \cdot \sin(\omega \cdot t)$$ **Eq. (9)**

Substituting Eq. (9) in Eq. (7), the open circuit rms voltage across the loop terminal is

$$V = 2 \cdot \pi \cdot n \cdot A_e \cdot f \cdot B \cdot \cos(\theta)$$ **Eq. (10)**

The above expression indicates the loop antenna responds to the magnetic field component (magnetic induction or flux density, B) of a signal and converts it to a voltage at the antenna terminals.

The voltage at the terminals is related to the electric field strength, E, by

$$V = h_e \cdot E$$ **Eq. (11)**

where
h_e = effective antenna height (m)
E = rms electric field strength (v/m)

The relationship between the electric field strength and magnetic induction is

$$E = c \cdot B$$ **Eq. (12)**

where
c   = speed of light ($3 \cdot 10^8$ m/s)

Substituting Eq. (10), (11) and (12), the effective height of an air-core loop is

$$h_e = \frac{2 \cdot \pi \cdot f \cdot n \cdot A_e \cdot \cos(\theta)}{c} = \frac{2 \cdot \pi \cdot n \cdot A_e \cdot \cos(\theta)}{\lambda}$$ **Eq. (13)**

where
λ = wavelength (m)

For the loop in question, the equivalent area $A_e = \pi \cdot a^2 = 2.41 \text{ m}^2$

where
a   = 0.875 m, as found before

It is seen that, for a given electric field strength, the rms voltage at the loop terminals is proportional to the effective height, and therefore is proportional to the frequency, number of turns and loop area. Note that the effective height is not related to the physical height of the loop. For a given frequency the effective height can be increased by increasing the number of turns or loop area.

For the case where the loop frame is parallel to the propagation direction and the magnetic field is normal to the propagation direction, in which case $\theta = 0$ deg. = 0 radians, and if the frequency is 24 kHz

$$h_e = \frac{2 \cdot \pi \cdot n \cdot A_e \cdot f}{c} = \frac{2 \cdot \pi \cdot 24 \cdot 2.41 \cdot 24 \cdot 10^3}{3 \cdot 10^8} = 0.02907 \text{ m}$$

For example, at the given frequency and a field strength of 500 µv/m, the open circuit (unloaded) loop terminal voltage for the loop in question is

$$V = h_e \cdot E = 0.03 \cdot 500 = 15 \ \mu v$$

In air and free space, the magnetic field strength and magnetic induction are related by

$$H = \frac{B}{\mu_0}$$ **Eq. (14)**

where
H   = rms magnetic field strength (a/m)
μ_0 = permeability of air or free space ($4\pi \times 10^{-7}$ henry/m)

Therefore, when the loop frame is parallel to the line of signal propagation, the loop terminal voltage is

$$V = 2 \cdot \pi \cdot \mu_0 \cdot n \cdot A \cdot f \cdot H$$ **Eq. (15)**

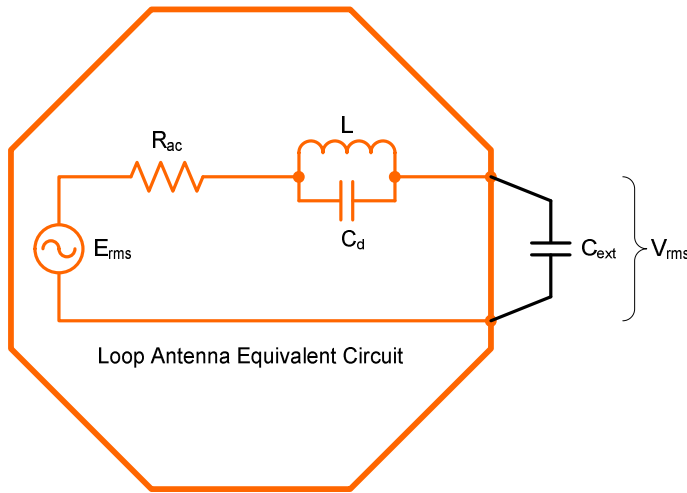*Q factor*

If an external capacitor is connected in parallel with the loop antenna (Fig. 1) and adjusted to resonate the antenna, the voltage across the terminals increases by the factor Q, or

$$V = h_e \cdot E \cdot Q \qquad\qquad \textbf{Eq. (16)}$$

Fig. 1 – Loop antenna equivalent circuit and external resonating capacitor, C_{ext}. The received electric field strength is E_{rms}.

Loop Antenna Equivalent Circuit

Q is determined from

$$Q = \frac{f_r}{\Delta f} = \frac{2 \cdot \pi \cdot f_r \cdot L}{R_{ac}} \qquad\qquad \textbf{Eq. (17)}$$

where
f_r = resonant frequency (Hz)
Δf = bandwidth (Hz)
R_{ac} = equivalent ac resistance of loop winding (ohm)

The ac resistance includes the wire dc resistance as well as skin effects, proximity effects and antenna radiation resistance. For electrically small loop antennas, the radiation resistance is approximately[3]

$$R_R \approx 197 \cdot C_\lambda^4$$

where
R_R = radiation resistance (ohms)
C_λ = loop circumference in wavelengths

Substituting the octagon perimeter length for loop circumference, gives $C_\lambda = 0.0044$ and Rr ≈ 0.09 ohms. The radiation resistance value is much smaller than the dc resistance of the wire (2.79 ohms at 20 °C) and is neglected. Proximity effects are difficult to determine analytically. They

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[3] See Fig. 6-12, Pg. 169, J.Kraus, Antennas, 1950

are presumed to be significant but are neglected here and taken into account later. Neglecting proximity effects and radiation resistance, the ratio of ac to dc resistance at 24 kHz is approximately[4]

$$\frac{R_{ac}}{R_{dc}} \approx 1.04$$

for $d_w \cdot \sqrt{f} = 6.2$

where
d_w = wire diameter (in.)
f = frequency (Hz)

For 18 AWG magnet wire, $d_w = 0.040$ in. and $R_{dc} = 0.006505$ ohms/ft at 20°C; therefore,

$$R_{ac} = 0.006505 \cdot 1.04 = 0.00677 \ \text{ohms/ft} = 0.0222 \ \text{ohm/m at 20°C and 24 kHz}$$

In the case of 438 ft (133 m) of 18 AWG wire, $R_{dc} = 438 \cdot 0.006505 = 2.85$ ohms, and
$R_{ac} = 1.04 \cdot 2.85 = 2.96$ ohms (not including proximity effects).

Resonant frequency measurements

The resonant frequency is given by

$$f = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C_T}}$$ **Eq. (18)**

where
C_T = Total circuit capacitance (F)

The total circuit capacitance includes the external tuning capacitance, if used, as well as the distributed capacitance of the loop itself. For a given frequency, the total capacitance is

$$C_T = \frac{1}{4 \cdot \pi^2 \cdot f^2 \cdot L}$$ **Eq. (19)**

Like proximity effects, the distributed capacitance, C_d, of a loop is difficult to determine analytically. It can be estimated by making some fairly simple measurements as follows:

1.   The loop is connected to a signal generator through a high-value resistance, say 470 kohms, and the voltage across the loop is measured with a high impedance ac voltmeter (Fig. 2). The high resistance prevents the low impedance output of the signal generator from loading down the loop.

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[4] See Fig. 7, Scale A, pg. 130, Reference Data for Radio Engineers, ITT, 1964

2.   The signal generator frequency is adjusted until the voltage peaks, indicating self-resonance. The self-resonance frequency is recorded as f_{sr}.

Fig. 2 – Self-resonance frequency measurements

The loop inductance, L, can be measured with an LCR meter. The value of C_d can be calculated from the above equation using f_{sr} and L. In this case there is no external capacitance, so $C_T = C_d$, or

$$C_d = \frac{1}{4 \cdot \pi^2 \cdot f_{sr}^2 \cdot L}$$
Eq. (20)

The loop inductance also can be measured by resonating the antenna with an external capacitor, C_{ext}. For this measurement the capacitor is connected to the loop terminals along with a signal generator and high impedance ac voltmeter. C_{ext} must be much larger (at least 100x) than C_d so the latter can be ignored. The signal generator is connected through a high-value resistance as before. The signal generator is adjusted for normal resonance, f_n. The inductance, L, is then calculated using f_n and C_{ext}.

In the foregoing discussion, the ac resistance calculation included only dc resistance and skin effects. Additional measurements can be used to find the actual ac resistance, including proximity effects, at a given frequency. The signal generator is again isolated with a very high resistance to minimize loading and artificially lowering the circuit Q.

In these measurements, external capacitors are used to resonate the loop at the desired frequency, f_r. The capacitors consist of a fixed capacitor and a trimmer capacitor or a capacitance decade box. Good results from these measurements are difficult to obtain because the isolation resistance must be very high so it does not artificially lower the circuit Q. However, raising the resistance lowers the measured signal level, and the resistance may be so high that the signal level is not measurable.

1.   Set the signal generator at the desired frequency and adjust the trimmer for maximum voltage, which indicates resonance.
2.   Vary the signal generator frequency on both sides of resonance until the voltage decreases to 0.707x the maximum value. For example, if the voltage at resonance $V_{max} = 2.000$ v, then the frequency is adjusted until $V_1 = V_2 = 1.414$ v.
3.   The difference between the two frequencies f_1 and f_2 is Δf, or $\Delta f = |f_1 - f_2|$.
4.   The antenna Q and ac resistance can be found from the above equations, or

$$Q = \frac{f_r}{\Delta f}$$

and

$$R_{ac} = \frac{2 \cdot \pi \cdot f_r \cdot L}{Q}$$

Measurements of 1.7 m octagon loop

The loop in question was suspended from the shop ceiling and connected as described. The inductance was measured with an LCR meter and found to be 3.32 mH. The self-resonant frequency was f_r = 163.630 kHz, and the calculated distributed capacitance was

$$C_d = \frac{1}{4 \cdot \pi^2 \cdot f_{sr}^2 \cdot L} = \frac{1}{4 \cdot \pi^2 \cdot 163{,}630^2 \cdot 3.32 \cdot 10^{-3}} = 285 \text{ pF}$$

An external capacitor with measured value of 45.6 nF (marked 473, or 47 nF) was connected (calculated resonant frequency = 12.935 kHz). A signal generator was connected and adjusted for resonance at 13.090 kHz, giving the following values:

f1   = 12.977 kHz
f2   = 13.303 kHz
Δf   = 0.306 kHz
Q   = 42.8 (calculated)

Additional measured values for the finished loop antenna are shown in the table below.

Frequency (Hz)	Ls	Q	R or Rp	X	Rp
M³ LCRZ meter, July 15, 2009, T = 23°C					
100	3.33	0.75	2.78	2.1	4.3
120	3.33	0.89	2.81	2.5	5.1
250	3.31	1.9	2.80	5.2	12.3
500	3.30	3.7	2.81	10.4	40.7
1000	3.30	7.5	2.77	20.7	157.7
2500	3.29	17.3	2.99	51.6	896.1
5000	3.29	42.8	3.78	103.3	3287
7800	3.29	42.8	3.78	161.5	6920
12500	3.31	52.0	4.98	259.7	13510
15625	3.31	66.5	4.89	325.1	21650
Aidetek DM4070 LCR meter, July 15, 2009, T = 23°C					
Unknown	3.32 *	N/A	2.86	N/A	N/A
Unknown	3.34 **	N/A	2.86	N/A	N/A

* Measured inductance before copper wrap (see note)
** Measured inductance after copper wrap (see note)

Note: The outside of the loop was wrapped with 0.005 in. thick adhesive copper tape with a 0.25 in. gap. Each former was then wrapped with the copper tape to provide continuous coverage from gusset to gusset. Continuity was measured end-end of the wrap and found to be about 1.13 ohms. The entire loop was not wrapped due to difficulty of obtaining complete coverage around the gussets.

Measured dc resistance of wire on spool = 2.83 ohms at 24°C with regular DMM (corrected to 2.79 ohms at 20°C)
Measured inductance of wire on spool = 18.87 mH with Aidetek DM4070 LCR meter
Measured inductance of wire on spool = 18.70 mH and Q = 32.4 at 1000 Hz and 18.71 mH and Q = 36.9 at 2500 Hz with M³ LCRZ meter

Operational Capacitance

For the above loop, the capacitance required for resonance at VLF station frequencies is shown in the table below (L = 3.3 mH).

Station	ID	Frequency (kHz)	Capacitance (nF)
USA			
Cutler, ME	NAA	24.0	13.33
Jim Creek, WA	NLK	24.8	12.48
Lualualei, HI	NPM	21.4	16.76
LaMoure, ND	NML	25.2	12.09
Aquada, PR	NAU	40.75	4.62
Antarctica			
South Pole	VLF	20.0	19.19
Australia			
North West Cape	NWC	19.8	19.58
China			
Changde	3SA/3SB	20.6	18.09
Datonge	3SB/3SA	10.6	68.31
Unknown		24.1	13.22
Unknown		21.1	17.24
Germany			
Rhauderfehn	DHO	23.4	14.02
France			
Rosnay	HWU	20.9	17.57
St. Assie	FTA	16.8	27.20
LeBlanc (NATO)	HWV	21.75	16.23
Iceland			
Keflavik (US Navy)	NRK	37.5	5.46
Keflavik	TFK	37.5	5.46
India			
Katabomman	VTX3	18.2	23.17
Italy			
Tavolara	ICV	20.27	18.68
Sicily	NSC	45.9	3.64
Japan			
Ebino	JJI	22.2	15.57
Norway			
Kolsas	JXN	16.4	28.54
Russia			
Arkhanghelsk	UGE	19.7	19.78

Construction

Material required

- 1 in. square fiberglass tube, (6) 8 ft sections
- 1/4 in. AB marine plywood, (1) 4 ft x 4 ft section
- 10-32 x 2 in. SS machine screw, (57) ea.
- No. 10 x 1 in. OD SS flat washer (fender washer), (114) ea.
- 10-32 SS hex elastic stop nut (57) ea.
- 10-32 hex nut (for temporary assembly), (57) ea.
- Exterior primer paint
- Exterior color paint to match fiberglass tube (olive drab)

Power tools

- Table saw
- Miter saw
- Drill press
- Electric hand drill

Methods

The methods described here require checking and rechecking all measurements. All holes are initially drilled with a relatively small pilot drill and then enlarged with the final drill size. It is tempting to bypass steps or take shortcuts; however, without jigs it is impossible to ensure perfect alignment without the extra steps. Also, some effort is required to mark the pieces with their location and orientation. Even though the pieces are drilled identically, without a jig the drilled holes will vary enough to preclude proper alignment if the pieces are not assembled in their original locations and orientation. Therefore, it is imperative that all pieces be marked during initial assembly so they can be properly placed during final assembly.

Drill all pilot holes in plywood and fiberglass tube with brad-point drills. Enlarge all holes with regular drills. The fiberglass tube is slick so, even with considerable clamping pressure, the wood-fiberglass interface can slide; therefore, after each and every drilling operation, recheck alignment. Where two or more holes a called out, drill one of them with a pilot drill. Use a 1/8 in. alignment pin and clamps to hold the components together while drilling the next hole. Insert another alignment pin and drill the third hole, and so on.

Cutting

Plywood:
Cut two identical octagon shaped center pieces from 1/4 in. plywood
Cut 16 gussets from 1/4 in. plywood (mark No. 1 Top/1 Bottom through No. 8 Top/8 Bottom, see note)

Fiberglass tube (see note 1):
Cut one long stringer from 1 in. fiberglass tube (mark No. 1 and No. 5, see note 2)
Cut two intermediate length stringers from 1 in. fiberglass tube (mark No. 3 and No. 7, see note 2)
Cut four short stringers from 1 in. fiberglass tube (mark No. 2, 4, 6, and 8, see note 2)

Cut eight formers from 1 in. fiberglass tube (mark No. 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, and 8-1, see note 2)

Note 1: When working with fiberglass tube, wear a respirator and eye protection. Make all cuts on a miter saw with a metal cutting abrasive blade. All cuts are 22.5 deg., 45 deg. or 90 deg. Make an initial cut so that piece is 1/32 – 1/16 in. longer than finished dimension. Then using the saw blade as a sander, slowly remove material so that piece is the exact correct length. It should be easy to attain 1/64 in. accuracy using this method.

Note 2: To minimize error propagation and to ensure easy final assembly, as each stringer and former is initially assembled, mark it with a number and orientation. For example, mark the stringers No. 1 Top through No. 8 Top, and mark the formers No. 1-2 Top, 2-3 Top, and so on to No. 8-1 Top (the two numbers indicate the stringer number on the left and right). Mark the gussets in pairs, No. 1 Top and No. 1 Bottom through No. 8 Top and No. 8 Bottom. The top and bottom face out.

Mark one of the center pieces with pencil lines that connect each octagon corner. If the center pieces are accurately cut, the four lines should cross at one location, the exact center. Mark the holes for the stringer screws as shown on the drawings. Also, mark the lines No. 1 through 8 to indicate the stringer number. With an awl, center-punch the center and sixteen stringer hole locations.

Drilling and initial assembly

This loop antenna consists of 18 wood pieces and 15 fiberglass pieces. The simplest way to get all pieces to fit properly is to drill and fasten one hole at a time. Shortcuts will lead to alignment problems and skipping steps will ensure that any individual error cascades through the assembly process to become larger and larger.

Overlay the two center pieces, aligning all eight edges. Clamp the two center pieces together and with a drill press drill seventeen 1/8 in. or 9/64 in. pilot holes. While the two pieces are clamped together, drill an alignment hole through both center pieces; offset this hole about 1 in. to the right of stringer No. 1 and approximately 1 in. from the outer edge. Drill one additional hole through only the top center piece about 1 in. to the left of stringer No. 1 and approximately 3 in. from the outer edge. The alignment holes will ensure that the top and bottom center pieces can be correctly identified and oriented after painting. Enlarge the center hole to 0.1935 in. (No. 10 drill).

With a drill press drill a 1/8 in. or 9/64 in. pilot hole in the exact center of the long stringer (use the same drill size that was used for the center pieces). Be sure the hole is on the same edge as the vertex. Enlarge this hole to 0.1935 in. (No. 10 drill). Assemble stringer No. 1 and the top and bottom center pieces with a 10-32 x 2 in. machine screw, two flat washers and a regular hex nut. Line the end marked No. 1Top with the pencil line marked No. 1 on the top center piece. When the three pieces are perfectly aligned, the vertices on the top and bottom center pieces should line up with the center of stringer No. 1 and 5. When the components are aligned, place two clamps to hold everything in alignment. Enlarge the four pilot holes on a drill press with a No. 10 drill. Place four sets of 10-32 fasteners in these holes and moderately tighten.

Place the assembly in a bench wood vise so that the stringer is horizontal and the top center piece is facing away from the workbench. Use a piece of scrap fiberglass tube as a spacer between the center pieces. Insert stringer No. 7 making sure it is in contact with stringer No. 1/5 and centered and that the vertex is properly oriented. The measurements from the bottom of stringer No. 7 to the end of stringer No. 1 and to the end of stringer No. 5 should be exactly the same. Place a clamp to keep stringer No. 7 from moving. Make measurements from the top of stringer No. 7 to the end of stringer No. 1 and to the end of stringer No. 5. Slightly move the top of stringer No. 7 until the two measurements are exactly the same. Place another clamp and re-measure the top and bottom of stringer No. 7.

When everything is aligned and clamped, use a Sharpie ultra fine point permanent marker to mark the stringer holes through the top center piece. Remove the stringer and center-punch the hole locations. Drill 1/8 in. or 9/64 in. pilot holes in a drill press. Replace the stringer in the center pieces and align with two short lengths of 1/8 in. piano wire or 1/8 in. wood dowel or two 1/8 in. drill bits. Clamp the components and repeat all measurements, adjusting the stringer as necessary.

Once clamped, remove one of the alignment pins. Carefully and slowly drill out the two holes in the top center piece with an electric drill and No. 10 drill bit, drilling all the way through the fiberglass tube and bottom center piece. The pilot holes in the fiberglass tube will help guide the drill but it still will be necessary to carefully hold the drill in horizontal and lateral alignment. Place a set of 10-32 fasteners and tighten. Confirm measurements once again. Remove the other alignment pin and enlarge the hole as before. Place another set of 10-32 fasteners, and recheck all measurements. Very little adjustment, if any, should be required. Repeat the above steps for stringer No. 3. The precision at which the four stringers, No. 1, 5, 7 and 3, are placed determines how accurately the remaining four stringers can be placed. Skipping any steps in an attempt to speed up the operations increases the risk that the stringers and formers will not properly align.

Repeat the above steps for stringers No. 2, 4, 6 and 8, one at a time. These stringers have a 90 deg. vertex at one end and should fit perfectly at the base of the stringers already assembled. Be sure the bottoms of these stringers contact the adjacent stringers and that the distances from the top of the stringer being placed to the two adjacent stringers are exactly the same. If care is taken, the distances between the tops of all the stringers should be within 1/32 – 1/16 in. Set the stringer assembly aside.

Mark the hole locations on four gussets as shown on the drawings. Stack and align one marked gusset and three unmarked gussets. Be sure the gussets are paired and oriented (top and bottom) as marked. Clamp the four gussets together and drill five 1/8 in. or 9/64 in. pilot holes in a drill press. Repeat for the remaining 12 gussets, four at a time.

Now drill extra holes in the gussets to indicate their number and orientation. Stack a pair of gussets, say No. 1 Top and Bottom. In a clear area to the right of center, drill one hole in Gusset No. 1 Top all the way through Gusset No. 1 Bottom; this will be the alignment hole. To the right of center in Gusset No. 1 Top only, drill another hole one-half-way through; this will be the count hole for the top. Flip the pair of gussets over and to the right of center drill a hole one-half-way through Gusset No. 1 Bottom; this will be the count hole for the bottom. There only is one way the two gussets can be aligned: With a pin in the alignment hole, the alignment and count holes for Gusset No. 1 Top are to the right of center. The alignment hole for Gusset No. 1 Bottom, when facing the gusset, is left of center and the count hole is to the right of center.

Repeat these steps with Gusset No. 2 Top and Bottom except drill one alignment hole all the way through and two holes one-half-way in Gusset No. 2 Top. Flip the pair over and in Gusset No. 2 Bottom only, drill two holes to the right of center. For Gusset No. 3, drill one alignment hole and three one-half-way holes, and so on for the remaining five gusset pairs (Fig. 1x). After painting, the gusset pairs can be identified by finding pairs with the same number of holes one-half-way through and then orienting them so a pin can be inserted through the alignment hole.

Fig. 1x – Gusset-pair with a pin in the alignment hole. The four holes one-half-way through indicate this is Gusset No. 4 and since the alignment hole and count holes are right of center, Gusset No. 4 Top is facing the camera.

Place the gusset marked No. 1 Top on the top-left end of Former No. 1-2. Carefully align the two components so that the gusset vertex is aligned with the former vertex and also that the top of the gusset is parallel to and overhangs the former by 1/16 – 1/8 in. This overhang is necessary to prevent the antenna wire from slipping off the assembly while winding the loop. Use two clamps to securely hold the two components. Use a drill press to cut two 1/8 in. or 9/64 in. pilot holes through the top gusset and fiberglass tube. Remove the clamps and place the corresponding bottom gusset, using two 1/8 in. alignment pins to roughly align the three components. Adjust the alignment so that the vertices and overhang line up and place two clamps to hold everything together. Remove one of the alignment pins and use an electric drill and No. 10 drill bit to enlarge the hole, cutting through the top gusset, tube and bottom gusset. Place a set of 10-32 fasteners and tighten. Remove the other alignment pin, enlarge the hole and place another set of 10-32 fasteners. Repeat the above steps for gusset No. 2 on the other end of former No. 1-2.

Place former No. 1-2 on the two stringers No. 1and 2. Align the stringer vertices with the former ends and securely clamp the components. Using an electric drill and No. 10 drill bit, cut a hole through the top gusset, stringer tube and bottom gusset at one end of the former. Place a set of 10-32 fasteners, drill the other end of the former, and place another set of 10-32 fasteners.

Repeat the above steps for the right end of former No. 2-3. Place and align the former on the ends of stringers No. 1 and 2. Drill out the holes and place a set of 10-32 fasteners, one at a time to ensure alignment. Repeat these steps for former No. 8-1 except start work at the left end of the former.

Move to the opposite end of the assembly and build former No. 5-6 with gussets at both ends. Install this former on stringers 5 and 6 as described above. Place gussets at the left end of former No. 4-5 and install the gusset on stringers No. 4 and 5 as described above. Do not take any shortcuts.

Now install the last two formers, No. 6-7 and 3-4, being sure to check alignment and fitting. If there are gaps, slightly loosen the fasteners on the already assembled formers and stringers and jiggle the assembly so that the fittings are identical at all corners.

Use a disc sander to touch up the outer edges of the gussets, mainly for appearance. The overhang should be around 1/16 – 1/8 in. and even between the top and bottom.

Drill a 1/16 in. (No. 52 drill) hole at all eight corners for drainage.

The initial assembly is now complete.

Loop mounting arrangements

At this time, decide how the loop frame is to be mounted. The hole in the center of Stringer No. 1/5 can be used as one support and one of the gussets as another support. Alternately, strips of wood or a single strip of wood can be mounted to two stringers for support. Drill all mounting pieces and stringers and formers as required.

Finishing

Before finishing double-check that all pieces are marked as follows:
Stringers marked No. 1 to 8 with the tops indicated
Formers marked No. 1-2 to 8-1 with tops indicated
Center pieces have alignment holes; the top piece has an additional marking hole
Gussets have alignment holes as well as count holes (one-half-way through) to indicate No. 1 Top/Bottom to No. 8 Top/Bottom

Completely disassemble the framework. Sand the flat surfaces of all wood pieces and sand to remove the sharp edges. Round off the outer corners of all formers with a sander and set the formers aside. Prime all wood pieces and then apply the finish paint. After the final coat of finish paint has dried, open the holes with a drill bit if necessary.

Final assembly

Reassemble the frame in the same sequence as the initial construction and assembly. However, this time use the elastic stop nuts rather than plain hex nuts; run the nuts far enough to provide a light clamping force. Start with the two center pieces and Stringer No. 1/5 and then assemble Stringers No. 3 and No. 7 followed by Stringers No. 2, 4, 6 and 8. Finally, assemble the eight formers and sixteen gussets. Check alignment of all pieces and gusset overhang and then tighten all fasteners securely; however, do not tighten them so much they distort the washers and wood pieces. If necessary, apply touch-up paint.

The frame is now ready for winding.

Winding the loop

The loop uses 400 to 437 ft of 18 AWG copper magnet wire, which can be wound on the perimeter with 22 to 24 turns. Set the frame horizontally on a swivel that will allow it to turn freely (Fig. xx). Place the wire spool on a mandrel held in a nearby vise so that the spool can turn freely. Secure the wire free end to a screw in one of the gussets on the frame. Wind slowly so that the individual windings stack evenly. Keep tension on the winding at all times. When the last turn is laid in, secure the wire so that it cannot unravel. Tape the winding to the formers. Place a small terminal block to terminate the wires (Fig. xx). Solder ring lugs to the wire after scrapping or sanding the coating off the ends.