How Efficient is Your QRP Small Loop Antenna?

Amir Findling—K9CHP (sarlabs@gmail.com) and Kazimierz "Kai" Siwiak—KE4PT, (k.siwiak@ieee.org)

These days, many hams have space restrictions and covenants to contend with in setting up a station at home. Other hams, particularly those who favor QRP, have taken to the field to do their operating. Both situations would benefit from a highly portable HF antenna with wide frequency coverage, such as the small loop antenna discussed here.

In 1970, John H. Dunlavy, Jr. discovered and patented the principles of constructing a small and efficient HF transmitting loop that can be tuned over a wide frequency range [1]. Many hams homebrewed, and several manufacturers including MFJ, AEA, and AlexLoop, produced small (approximately 1 m diameter) HF loops based on Dunlavy's now-expired patent. We are interested in QRP, so we want to know the efficiency of the small HF loop. You can easily estimate the efficiency of your loop antenna from a simple measurement of the antenna Q along with a few easy calculations. Here's how to do it...

It's Just a Simple RCL Circuit

A small loop having inductance "L," resonating capacitance "C," and resistance "R" resembles a series RCL circuit. The resistance includes both the radiation resistance, which relates to the amount of power actually being transmitted into space, and the loss resistances of the loop, which relates to the amount of power lost in heat. Dunlavy's discoveries centered around techniques for reducing the loop losses while providing a novel secondary loop to feed the main loop. His invention enabled loop antennas that could be tuned by a simple series capacitor over a frequency range of as much as a 10 to 1, while maintaining a constant match to the feed line through a secondary feeding loop. Ham versions typically can cover 7 MHz through 30 MHz.

The Key is the Q

Three components make up the Q of the small HF loop: (a) the Q_{RAD} of a perfectly conducting loop having just radiation resistance R_{RAD}, (b) the Q_{RES} due to the loop loss resistance R_{LOSS}, and (c) the Q_{CAP} of the resonating capacitor C_{LOOP}. Qs can be combined according to the formula:

$$Q_{TOTAL} = \frac{1}{\frac{1}{Q_{RAD}} + \frac{1}{Q_{RES}} + \frac{1}{Q_{CAP}} + \cdots}$$

The trick in finding the efficiency involves first measuring Q_{TOTAL}, then computing the ideal Q_{RAD}. The efficiency, as described in Section 11.4.6 of [2], then takes the form,

$$Efficiency = \frac{Q_{TOTAL}}{Q_{RAD}}$$

where K9CHP measured Q_{TOTAL}, and KE4PT calculated Q_{RAD}.

Measuring Q, the Eclectic Parameter

Many different but exactly equivalent formulas express the value of the factor Q, see [3]. We use a few of these formulas below, starting with the "bandwidth formula":

$$Q = \frac{\sqrt{F_U F_L}}{F_U - F_L} = \frac{Frequency}{Bandwidth}$$

We must find the 3dB bandwidth frequencies F_U and F_L. If we can measure antenna impedance directly, then find the upper frequency F_U where $R = X$, and next find the lower frequency F_L where $R = -X$. Alternatively and equivalently, you can find those same upper and lower frequencies for VSWR=2.62:1, or Return Loss = 7 dB. Once we know F_U and F_L, we obtain the measured Q from Equation (3).

Estimate Q_{RAD} from the Loop Impedance

For the ideal loop, the radiation resistance is the only "loss". First, find half the ratio of the ideal loop reactance to the loop radiation resistance. Formulas abound for the theoretical loop impedance, but we applied the formula of Equation (4) which is based on one half of the loop reactance divided by the radiation resistance from Section 11.4.1 in [2],

$$Q_{RAD} = \frac{3\left(\ln\left(\frac{8b}{a}\right) - 2 + \frac{2}{3}(kb)^2\right)}{\pi(kb)^3\left(1 + 8(kb)^2\right)\left(1 - \left(\frac{a}{b}\right)^2\right)}$$

Here $k = 2\pi/\lambda$ is the wave number, where λ is wavelength, b is the loop radius, and a is the loop conductor cross-sectional radius. Use the same units for all dimensions. Formula (4) includes first order dipole-mode contributions to Q. Alternatively you can find the loop impedance $Z = R_{RAD} + jX_{LOOP}$ (without the resonating capacitor) by using NEC (Numerical Electromagnetic Code). But don't forget to use perfectly lossless wires in the model and omit ground reflections. Then apply another equivalent expression for the ideal loaded Q,

$$Q_{RAD} = \frac{X_{LOOP}}{2R_{RAD}}$$

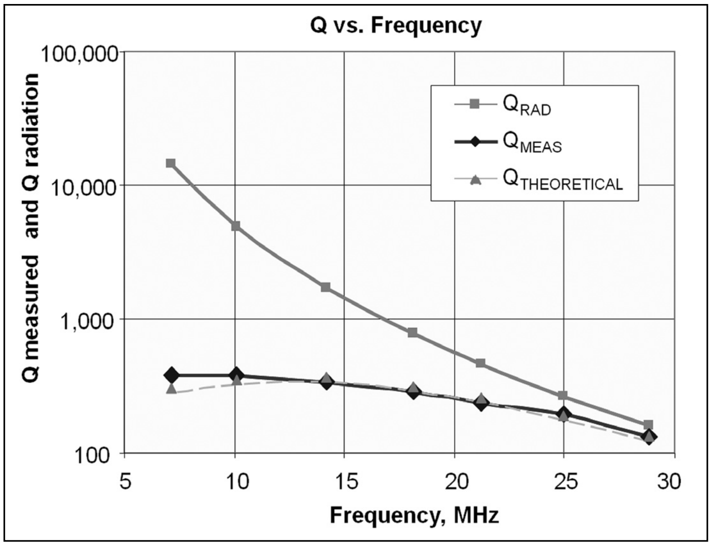
Calculate and measure Q on your ham bands of interest and finally apply Equation (2).

The Results

We applied the above technique to find the efficiency of a 36 inch diameter loop constructed from a section of RGC-213 coaxial cable and marketed as the

Band	F_U	F_L	Q_{MEAS}	Q_{RAD}	Efficiency, dB
10m	28.993	28.775	132.49	160.65	-0.84
12m	25.007	24.880	196.40	265.95	-1.32
15m	21.273	21.182	233.27	457.72	-2.93
17m	18.160	18.096	283.25	770.00	-4.34
20m	14.188	14.146	337.31	1702.7	-7.03
30m	10.138	10.111	374.98	4882.7	-11.15
40m	7.159	7.140	376.29	14223.3	-15.77

Table 1—Measuring the efficiency of a small loop.



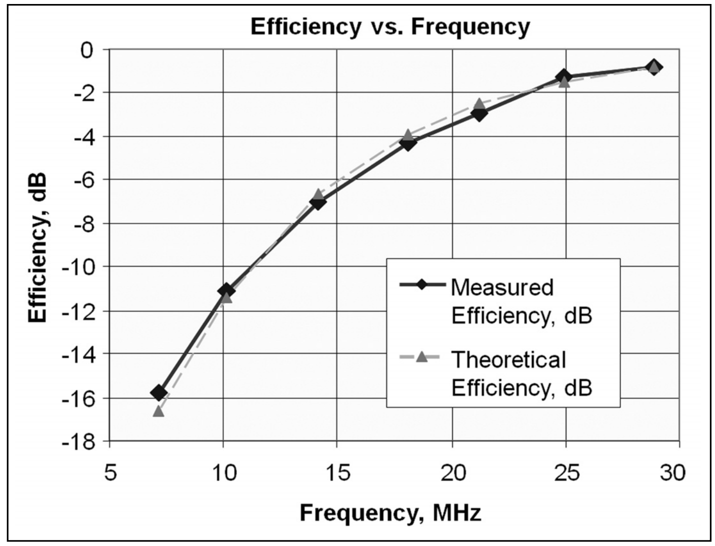


Figure 1—Measured, theoretical and ideal radiation Q versus frequency.

Figure 2—The efficiency of a small HF loop drops dramatically as frequency is lowered.

AlexLoop Walkham, Portable Magnetic Loop Antenna by PY1AHD. Table 1 reports the details of our measurements and the calculation of Q_{RAD} and *Efficiency* in decibels (dB).

We can see in Figure 1 that the loop Q decreases with increasing frequency and that the spread between the ideal Q_{RAD} and measured Q_{MEAS} increases as frequency drops.

Figure 2 shows the measured loop efficiency (solid curve), which is the ratio of Q_{RAD} to Q_{MEAS}, expressed in decibels. We also calculated and plotted (dashed curve) the theoretical Q ($Q_{THEORETICAL}$ in Fig. 1) and theoretical efficiency of a loop having 10% of the conductivity of copper. We see that the measured efficiency behaves like a theoretical loop, having 10% the conductivity of copper. This is consistent with the loop construction since the outer conductor of RGC-317 comprises tinned copper braid over aluminum foil. This small loop is just a little more than an S-unit down from perfect efficiency at 14 MHz and steadily improves with increasing frequency. In the 40m band, efficiency is still useable. Note that the 3 dB bandwidth (VSWR<2.62:1) is just 19 kHz within the 40m band and increases steadily to nearly 220 kHz within the 10m band.

In Summary

We found the efficiency of a small HF loop antenna by calculating the ratio of measured Q to theoretically ideal Q. Our results are consistent with expectations for a loop constructed from RGC-317 coaxial cable. The same high Q which results in efficiency also means that the loop needs retuning when changing frequency, even slightly. One of us (K9CHP) is flirting with the 1,000 watts per mile level on European QSOs, and has worked all over W and VE land using the small HF loop. Our measurement technique works well with small HF loops and may also be applied to other types of antennas.

Finally, we'd like to thank Dai, KE4QXL, for reviewing and editing this article.

—73/72, Amir, K9CHP and Kai, KE4PT

Who We Are

Amir Findling, K9CHP, holds an Extra Class amateur radio operator license and an active QRP membership #14,430. He is heavily involved in K9 Search and Rescue, and his call sign memorializes his first Search and Rescue dog "Chip". Amir enjoys DXing, "relaxed contesting", operating QRP, and has earned the WAC and WAS Awards. He holds memberships in ARRL and volunteers as a VEC for both ARRL and W5YI. He counts mobile, portable and maritime mobile operations among his amateur radio pastimes, and enjoys phone, digital modes (PSK-31 and RTTY) as well as LEO satellite operations. Amir earned his Graduate Degree in French Linguistics at Indiana University.

Kazimierz (Kai) Siwiak, KE4PT, an Extra Class amateur radio operator and QRP ARCI membership (#2194) earned a Ph.D. in electrical engineering. He consults in intellectual property and in antennas and radiowave propagation. Kai is a life member of AMSAT and an ARRL member where he serves on the RF Safety Committee and is a Technical Advisor. Kai is an avid DXer and earned WAC on 8 bands, DXCC and WAS-TPA from his low power station and indoor attic antenna. On travel he packs an HF QRP "DX-go-bag" station with which he's earned the "1,000 Miles per Watt" award. As former team member of SAREX (Space Amateur Radio Experiment) he facilitated many SAREX operations and school contacts. His other interests include flying (instrument and multiengine commercial pilot), hiking and camping.

References

[1] John H. Dunlavy, Jr., "Wide range tunable transmitting loop," U. S. Patent 3,588,905, issued 28 June, 1971.

[2] K. Siwiak and Y. Bahreini, *Radiowave Propagation and Antennas for Personal Communications*, Third Edition, Artech House, Norwood MA: 2007.

[3] K. Siwiak, "Q and the Energy Stored Around Antennas", (to be published mid 2013), *QST*.

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