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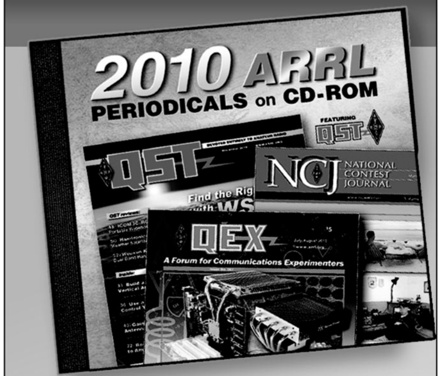

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UHF Antenna Ratiometry

Inconsistent results in checking antenna gain? Here is a technique that can restore your faith in measurements and speed up empirical design.

By Richard T. Knadle, Jr.,* K2RIW

Uhf antenna gain-measuring contests are in vogue across the country. One of the largest detriments to designing competitively is the uncertainty factor in checking whether a change yielded a gain or a loss. It was to be expected that someone who is well-known for uhf antenna design would become chagrined at the nonrepeatability syndrome and find and describe a cure. Here is a condensed version of a paper presented by the author at IEEE Intercon 75, New York City, April, 1975.

Trenton State College has frequently been the location of the antenna-measuring contest held by the East Coast VHF Society for the last six years. During this annual event antenna gain is measured at 432, 1296 and 2304 MHz.

To date there have been 231 antenna entries by contestants from seven states.

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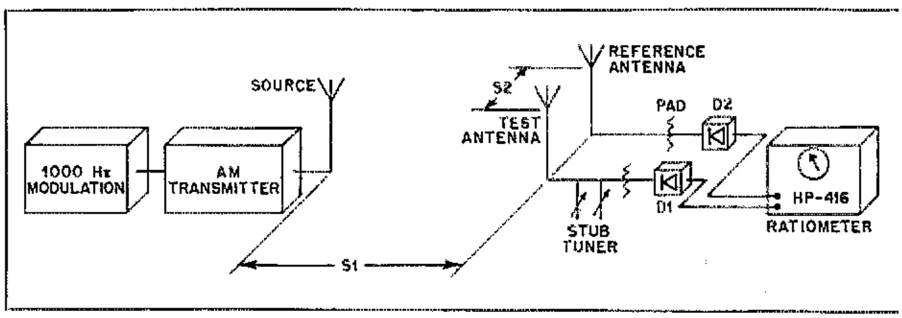
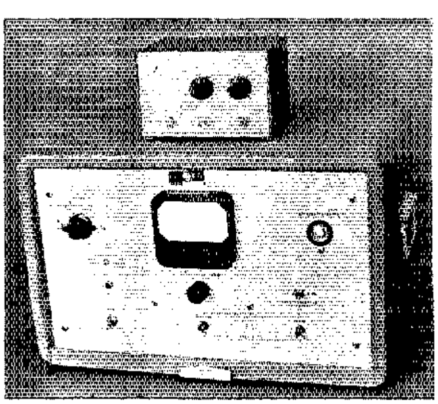


Fig. 1 — Antenna ratiometry set-up, isometric view. D1 and D2 are matched diode-detector assemblies.

The receiving system for antenna ratiometry is a ratiometer, such as the HP-416A shown here. It is basically a dual amplifier with separate input connections for each. The difference between the two signals is shown as a ratio, or dB. The small box on top is a square-wave generator that is used to modulate the signal source at the range-illuminating antenna.



It is interesting to note that every winning antenna during the six years has been homemade. This, coupled with the difficulty in confirming the gains claimed for a number of commercially made antennas, has created a credibility gap. As a result there has been a recent upsurge of antenna measurement and gain maximization, which is being done in backyards, open fields, and on towers by a considerable portion of the amateur fraternity.

Antenna-parameter measurement done in an anechoic chamber by an experienced technologist, using modern equipment, yields repeatable results which are traceable to the Bureau of Standards. By comparison, the amateur fraternity traditionally takes pride in its ability to make sufficiently accurate measurements by substituting craftiness and existing equipment for the ideal or expensive laboratory variety. For most "bench" type measurements this has proved adequate. However, high-gain antenna measurements are quite complex, and the control of the equipment and environment has not been as complete; thus, repeatable and absolute antenna gain measurements have not generally been realized.

Frequently the antenna being optimized is a long Yagi-Uda array. The often-used pragmatic approach to maximizing the gain of this antenna consists of making minor adjustments to the parasitic element lengths and positions. The changes to each of the considerable number of variables must be systematically tried and the usually small gain variations must be resolved if overall significant gain improvement is to be accomplished. Adjustment of a parasitic element usually changes the gain a fraction of a dB. Variations in the antenna range and equipment have caused ambiguities as large as two or three dB observed over a half-hour period. As such, determining whether an adjustment yielded an improvement or a detriment has been somewhat hit or miss.

The three major pitfalls to repeatable antenna measurement have been the following:

1) Equipment variations.

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2) Changes in the outdoor range characteristics which are beyond the control of the researcher — such as ground-reflection coefficient.

3) Steady-state reflections which cause improper illumination of the antenna under test.

It will be shown that ratiometry, the simultaneous comparison of signal strengths observed with a reference antenna and the antenna under test, will alleviate major pitfalls one and two. Proper technique will reduce pitfall number three. Ratiometry gives continuous gain difference readings in dB with high resolution and decreased ambiguity. It has aided recognition of the small gain changes that occur with parasitic element adjustment of a Yagi-Uda array. As such, repetition of each of the experimental adjustments was not required to resolve improvements over detriments. Thus, antenna gain maximization can be considerably streamlined.

Antenna Ratiometry

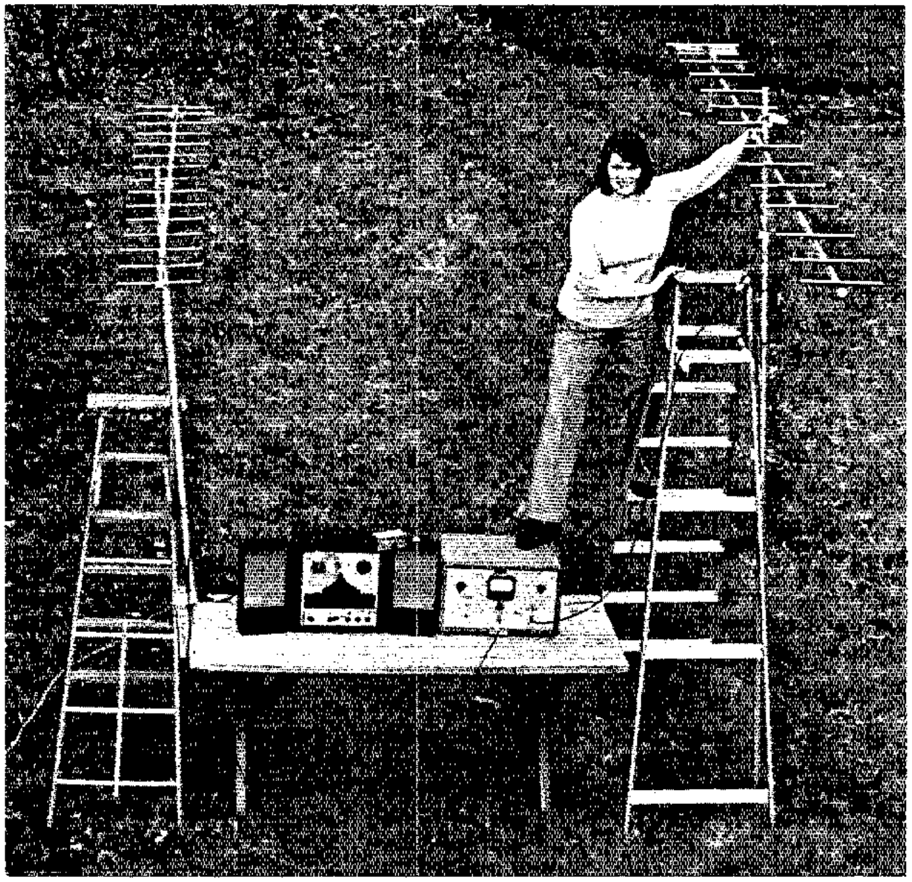
Fig. 1 shows the equipment arrangement used for antenna ratiometry. The reference antenna and antenna under test are horizontally displaced from each other by distance S_2. Each antenna is equidistant from the source by distance S_1. The antenna under test is continuously being compared to a reference antenna in such a way that only the dB difference in signal strength between the two is being displayed on the ratiometer.

Large variations in the source power density or modulation characteristics as observed at the reference antenna are primarily removed from the measurement, since these changes will affect each antenna almost identically. It was observed on the author's Hewlett Packard 416 Ratiometer that a simultaneous 40-dB change into each ratiometer port caused less than 0.2 dB variation on the ratiometer. This implies that a source transmitter power could change by as much as a 10:1 ratio, and less than .05 dB variation would occur on the ratiometer.

Range Setup for Gain Measurements

The outdoor range setup procedure will not be completely described here since this is done in the indicated references. Only those salient features which are required for proper antenna ratiometry operation will be indicated.

For a number of practical reasons, the antenna under test is often used in the receive mode. Antenna ratiometry will require this. If an antenna under test is to display its true gain potential, it must be illuminated across the entire effective aperture of that antenna, with a nearly error-free plane wave. A wave that does not deviate by more than 1 dB in amplitude or 22.5 degrees in phase (1/16 wavelength) is usually sufficient.



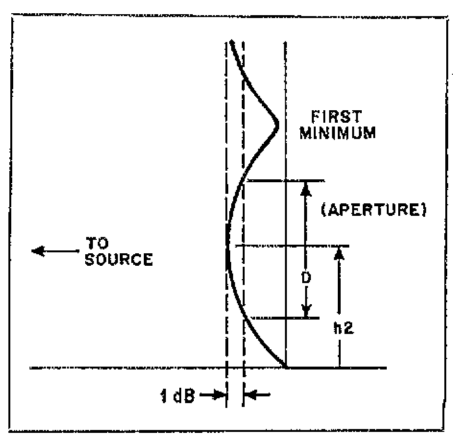
The author's XYL, WB2HJD, is shown here checking the current distribution by listening to an audio tone change when she touches the elements. The tape recorder is used as an audio amplifier, thus eliminating the need to watch a meter as adjustments are made to the antenna.

On an outdoor antenna range, obtaining less than 1 dB of amplitude variation across the aperture of the antenna under test is a more difficult requirement due to ground reflection. Many schemes to achieve this have been devised. One of the more attractive is the low-source technique described by Turrin[1] and Kraus.[2] In this technique the ground reflection is anticipated and the height of the source antenna is adjusted to give the first vertical lobe at least as broad in the vertical plane (at the one dB points) as the anticipated aperture of the antenna to be tested. By selecting proper range geometry, the antenna under test will usually be unable to resolve the source and its image. From the viewpoint of the antenna under test the source will appear as a point source horizontally, and two point sources, displaced less than a resolvable angle, vertically. Although the two sources — the real and the ground reflected image — are unresolved by the antenna under test, they still cause a small pessimistic gain-measurement error.

This error, which could be called reflective range loss, is due to the phase variation in the vertical plane that occurs across the aperture of the antenna under test. The phase variation is due to the angular displacement of the two sources.

Occasionally it has been observed that a properly oriented array of antennas will display increased apparent gain when the individual antennas of the array are moved closer together, even though the effective apertures begin to

Fig. 2 — Field intensity versus h_2 height.



[1] For this and subsequent footnotes see references at the end of this article.

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overlap. This is contrary to array theory, and reflective range loss could account for the discrepancy. As the antenna spacings decrease vertically, the vertical pattern increases in beamwidth, the resolution of the two sources decreases, and the reflective range loss decreases more rapidly than the loss of true gain.

Reflective range loss can be calculated by superposition assuming that the waves from the real and the image sources independently impinge on the aperture of the antenna under test. The angular displacement of the two sources is the range angle θ_R.

$$\theta_R = tan^{-1}\left(\frac{h_2 + h_1}{S_1}\right) - tan^{-1}\left(\frac{h_2 - h_1}{S_1}\right) \qquad (1)$$

When $S_1 >> h_1$, and $S_1 > 4h_2$ the formula reduces to

$$\theta_R \cong \frac{2h_1}{S_1} \qquad (2)$$

Assuming that the antenna under test has relatively high gain and equal horizontal and vertical half-power beamwidths, the antenna beamwidth θ_A (in degrees) can be estimated by

$$\theta_A \cong \frac{180^\circ}{\sqrt{G}} \qquad (3)$$

where G = gain over isotropic, and is a real number.

If the true vertical beamwidth of the antenna under test is known, it should be used instead of Eq. No. 3. The vertical beamwidth θ_A of the antenna under test can then be compared to the range angle θ_R. Assuming that the power pattern of the antenna major lobe is approximately proportional to $\cos^2\theta$, the reflective range loss L_R in dB is

$$L_R = \log_{10}\left\{\cos^2\left(\frac{\sqrt{G}}{4}\left[tan^{-1}\left(\frac{h_2 + h_1}{S_1}\right) - tan^{-1}\left(\frac{h_2 + h_1}{S_1}\right)\right]\right)\right\} \qquad (4)$$

If the major lobe power pattern is known to be proportional to $\cos^N\theta$, then the exponent of the cos θ term can be changed to N and the constant 4 can be changed to

$$\text{Constant} = 180\left\{\cos^{-1}\left[(.5)^{\frac{1}{N}}\right]\right\}^{-1} \qquad (5)$$

The reflective range loss of Fig. 3 is worse case assuming unity ground reflection. As the ground reflectivity decreases, the reflective range loss also decreases. This is because the boresighting of the antenna under test, when oriented for maximum signal strength, will more closely align with the true source; the image antenna in this case will have less influence. If the estimation of error in gain due to reflective range loss is unacceptable, then usually h_1 will have to be decreased or S_1 increased and L_R recalculated.

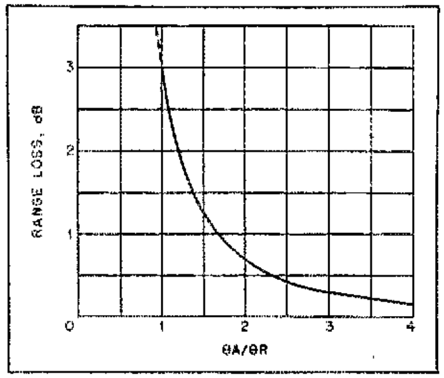

Fig. 3 — Plot of Eq. 4. Reflective range loss versus antenna angle/range angle.

It should be noted that the reflective range loss could also occur simultaneously in the horizontal plane if reflective objects on the side of the range, such as trees and houses, reflect significant energy into the range. This could create image source antennas to the left or right of the true source antenna.

Ratiometry Special Considerations

Once the integrity of the antenna range has been confirmed, ratiometry can be implemented. If a Hewlett Packard Model 416 Ratiometer is used, then the source transmitter will need to be amplitude modulated at a 1-kHz rate. The modulation need not be linear; only the presence of a 1-kHz component is required. Thus, even multiple Class C stages with frequency multipliers can be amplitude modulated in the transmitter early stages if desired. If the source antenna is a simple corner-reflector type and antennas of approximately 10 to 16 dB/d are to be measured, then approximately one watt of source power will be required for a typical range length of 80 feet.

The ratiometry reference antenna need not be a standard gain antenna. It is desirable for the reference antenna to have similar gain to the antenna under test. The reference antenna will then observe approximately the same amplitude of reflections from objects adjacent to the antenna range, and the power to each diode detector will be similar. This will assure more similar diode characteristics and thus greater common-mode rejection of the ratiometer.

The antenna spacing S_2 should be selected to be at least twice the sum of the effective diameter of each antenna. This is to assure that the mutual coupling between the antennas is at least -30dB. Should there be any doubt of the isolation between the antennas, then the insertion loss between them can be confirmed during the set-up procedure by connecting a transmitting source to one and measuring the received power on the other.

Of special interest to ratiometry is a seldom discussed antenna characteristic called scattering area.[3] Each antenna represents a disturbance to the medium, as such a proportion of the energy incident on each antenna is scattered in many directions even if perfect impedance matching is accomplished. In fact, the scattering area of a general antenna is equal to the effective intercept area when ideal conjugate matching exists.[4]

Mutual coupling and scattering are each greatly aided by the usual high front-to-side ratio of most antennas that are likely to be used in the two locations. Should excess scattering between the two be suspected, it can be evaluated by monitoring the received power from the normal source by the antenna under test, while the reference antenna is terminated and translated through a horizontal distance of at least one wavelength. This will rotate the phase angle of the scattered signal through 360. If less than 0.27 dB of peak-to-valley variation occurs, the two antennas can be considered sufficiently isolated for most testing. For complete thoroughness the received power should be observed on the reference antenna while the antenna under test is terminated and translated one wavelength.

For most situations the source antenna should be boresighted on the antenna under test so as to create the most error-free plane wave at this location. It is acceptable for the reference antenna to be located on the sloping side of the source-antenna major lobe, as long as the source antenna is not allowed to rotate in azimuth. This positioning of the reference antenna introduces an additional attenuation to the reference antenna, but this will be compensated for in the calibration procedure.

Calibration consists of placing a standard gain antenna on the range in the position of the antenna under test. The ratiometer is calibrated with the standard gain antenna oriented for maximum signal strength. The standard is removed from the range, and then the antenna under test is substituted and oriented for maximum signal strength. The dB change on the ratiometer is noted and recorded.

Vertical polarization ratiometry measurements could be accomplished with the techniques previously outlined except that Eqs. 1, 2 and 4 will become invalid. Many undesired reflectors such as trees, cars, rain-gutter downspouts and plumbing have greater scattering areas to vertical polarization. Horizontal polarization would seem to have an advantage in the environments where antenna testing frequently takes place

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Antenna optimization with ratiometry can be more effective if an audio range voltage-to-frequency converter module is connected to the 0-10 volt output jack on the ratiometer. Many times the process of antenna optimization takes place from the top of a ladder which is eight feet from the meter movement of the ratiometer. By listening to the change in pitch of the audio tone, a judgment of improvement or detriment can immediately be made without seeing the meter movement or removing the eyes from the antenna or ladder. The feedback of information by this method is so rapid that random movements of a hand near a parasitic element can cause a gain change, which was not anticipated, to be sensed.

Ratiometer Alternatives

The Hewlett Packard 416A Ratiometer is less frequently used today for its intended purpose of swept frequency VSWR measurements. It therefore occasionally appears in surplus stores at attractive prices.

For ratiometer measurements up to 1,000 MHz, the H.P. 8405A Vector Voltmeter is an appealing substitute having 80 dB of dynamic range and phase-measuring capability. No 1-kHz source modulation should be used with any of the alternates.

A Dicke-Switched receiver[5,6] may be used to sample the signal strength of the reference and test antennas rapidly and alternately. This could be implemented with an electronic switch between the antennas and an ordinary receiver, plus some not-too-extensive receiver modifications.

An automatic noise figure meter such as the AIL Model 75, or 7300, which alternately samples virtually two receiver channels at a 400-Hz rate, could have an electronic switch added before its input circuits. The two-channel comparison circuitry with attractive common-mode rejection and agc is already built in. The dB scale would need minor recalibration.[7,8]

Ratiometry Advantages

1) Major immunity to source power variations – up to 30 dB.

2) Moderate immunity to source modulation variations in amplitude and waveshape.

3) Major immunity to the often-occurring receiver gain variations.

4) Broadband; swept frequency measurements possible without receiver afc circuits.

5) Gives continuous answers in dB with reference to a standard antenna.

6) Phase measurements require little or no system changes dependent on type of ratiometer used.

7) Gain resolution to a fraction of a dB is possible.

8) Primarily immune to ground-reflection-coefficient changes.

9) Decreases the vulnerability to extraneous signal jamming prevalent with the normal high-sensitivity receiver.

10) Stability such that range calibration usually needs be done only once during a measuring/optimization session.

Ratiometry Disadvantages

1) Requires slightly wider antenna range and may require a wider source antenna pattern.

2) Needs some care to assure that mutual impedance effects and antenna scattering do not contaminate results.

3) Antenna pattern measurements on one half of *E* plane more difficult.

4) Requires matched detector diodes for greatest common-mode rejection – alternative ratiometer needs no diodes.

References

[1] Turrin, "Antenna Performance Measurements," *QST*, November, 1974.
[2] Kraus, *Antennas*, p. 451, McGraw-Hill Book Co., N.Y., 1950.
[3] Collin and Zucker, *Antenna Theory*, Part 1, p. 123, McGraw-Hill Book Co., New York, 1969.
[4] See Reference 2, p. 45.
[5] Kraus, *Radio Astronomy*, p.248, McGraw Hill Book Co., New York, 1966.
[6] Steinberg and Lequeux, *Radio Astronomy*, p. 43, McGraw-Hill Book Co., New York, 1963.
[7] Pastori, "Direct Reading Measurements of Receiver Parameters," *Microwave Journal* April, 1973.
[8] Edden and Pastori, "Digital Monitoring Receiver Performance," *Microwave Journal*, August, 1973.

Strays

□ As part of its continuing work in the field of radio-frequency interference (RFI), the ARRL RFI Task Group recently provided information to assist operators and consumers in resolving RFI problems which are related to electronic home-entertainment products. Released during the RFI Technical Symposium at the ARRL 1975 National Convention (12-14 September 1975), the information serves to indicate who within a given company is responsible for handling RFI complaints, and who might be able to expedite replies to inquiries and to initiate investigations which will help resolve problems.

Assembled with the cooperation of over 40 manufacturers, the type of information available is shown in the following examples:

Baldwin Piano & Organ Company, 1801 Gilbert Avenue, Cincinnati, Ohio 45202. Tel. (513) 621-4300. Mr. Robert C. Scherer, Manager, Organ Technical Service. Electronic Organs: RFI complaints are usually handled by the local Baldwin service technician. Factory personnel are available to assist the technician when needed. Baldwin maintains its own staff of technical representatives who travel in the field and may be called upon to assist the dealer technician with difficult problems, including RFI.

Baldwin provides technicians with a detailed instruction bulletin entitled "Hints on Suppressing RF Interference." RFI complaints should be referred to the local Baldwin dealer.

Harman-Kardon, Inc., subsidiary of Jervis Corp., 55 Ames Court, Plainview, New York 11803. Tel. (516) 681-4000. Mr. Robert Brady, Director of Engineering.

Receivers, amplifiers, turntables, a-m/f-m tuners, preamps, record players, tape recorders – Customers should refer RFI problems to Mr. Len Gaynor, Manager of Customer Service.

Customer RFI problems are handled on an individual basis. If local, the customer is invited to bring the affected set into the plant. Non-local customers are referred to the nearest warranty station. Corrective action is provided at no cost to the customer.

The listing, by the way, was summarized from statements contributed by manufacturers and distributors, and as such, should not be construed as an endorsement by the ARRL of the policies or products of any particular manufacturer.

Because the ARRL list of manufacturers can be an invaluable aid in resolving RFI problems, the League is now including it in its recently revised RFI packet. To obtain your copy of the packet, send a large (9" X 12") self-addressed, manila envelope with sufficient postage for 5 ounces to:

RFI Packet
American Radio Relay League
225 Main Street
Newington, CT 06111

If you already have a copy of the RFI packet and wish to obtain a copy of the list of manufacturers, send a business-sized, self-addressed envelope with postage for one ounce to League Headquarters, requesting this list. – *W4CIZ*