

# Measuring HF Balun Performance

*If you thought you knew everything about balun performance characteristics, there is an important figure of merit you may have neglected.*

Baluns come in many forms. Some include impedance transformation while others do not. In all cases their primary role is to reject undesired common-mode currents with minimal impact on the desired differential-mode currents. In the familiar case of a coaxial feeder connected to a balanced antenna, common-mode conditions result in current flowing on the outer surface of the cable shield, and via the ground. The normal flow of RF energy between the source and load is due to current circulating via the center conductor and inner surface of the shield.

Common-mode conditions often produce undesired results in antenna systems such as “RF in the shack”, altered VSWR and radiated patterns, increased RFI and entry of local noise.

## Performance Standards and Methods

The Common Mode Rejection Ratio (CMRR) of a balun is defined in professional literature<sup>1</sup> as the ratio of wanted to un-wanted transmitted power. As rejection of common-mode transmission is the primary purpose of a balun, it follows that CMRR should be the key figure of merit. However, CMRR is not a measure of power loss or efficiency and should be considered alongside other measures of performance, including bandwidth, transmission loss, precision of impedance matching and power handling. These other factors are generally well covered in amateur publications, but as far as I can tell CMRR has not appeared in either articles or advertisements.

Measurements and calculations of CMRR can be made by directly measuring impedance in the common-mode path, or by observing power flows using a power meter or oscilloscope. CMRR is affected by both amplitude and phase imbalance which can be a source of errors with those techniques. In contrast, Vector Network Analyzers, with associated software, provide accurate data and graphical information by measur-



Figure 1 – The N2PK dual-detector VNA.

ing transmission as complex quantities of amplitude and phase. The VNA hardware in use at W6WO was built in accordance with the design created by Paul Kiciak, N2PK. See Figure 1. Measurement data produced by the VNA is processed by very powerful software called *myVNA* by Dave Roberts, G8KBB. Both of these gentlemen have made their incredible expertise and attention freely available to the amateur community via their Web sites and the N2PK VNA Yahoo group.

## 3-Port Measurements

Any balun or line choke can be viewed as a 3-port device. Let’s call the unbalanced side port 1 and the twin connections on the balanced side ports 2 and 3. The math

involved in deriving CMRR from 3-port transmission measurements can be found in a number of sources.<sup>1</sup> The math is rather challenging, but fortunately it boils down to this simple formula using S –parameters ...

$$\text{CMRR dB} = 20 * \log \left( \frac{S_{21} + S_{31}}{S_{21} - S_{31}} \right)$$

Port 1 is the normally unbalanced port while ports 2 and 3 are on the balanced side. Dave’s software does the complex number calculations and plots the results.

The degree of imbalance inherent in a practical balun dictates its CMRR. Additional imbalance must be avoided, as

<sup>1</sup> [www.anaren.com/content/file/baluntesting.pdf](http://www.anaren.com/content/file/baluntesting.pdf)

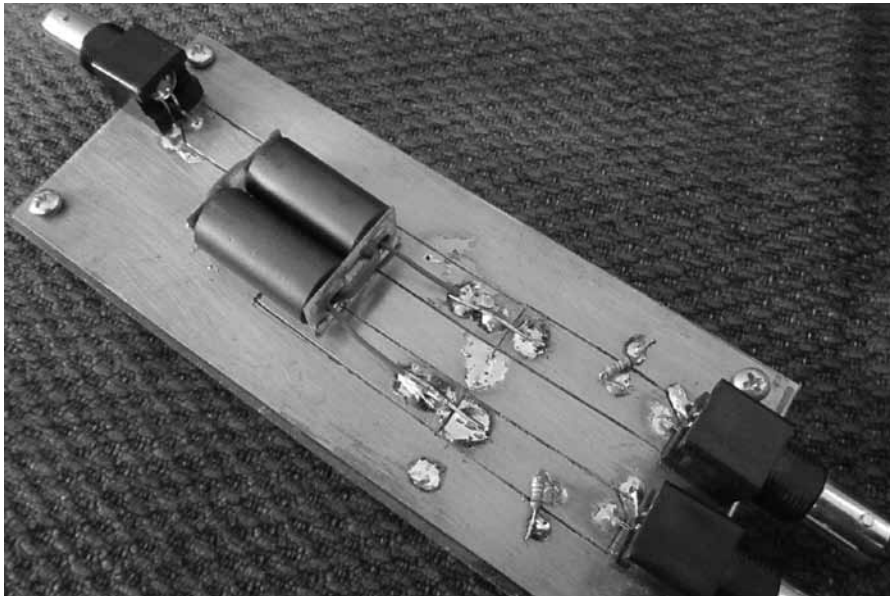


Figure 2 – The author’s test fixture for measuring CMRR of HF baluns.

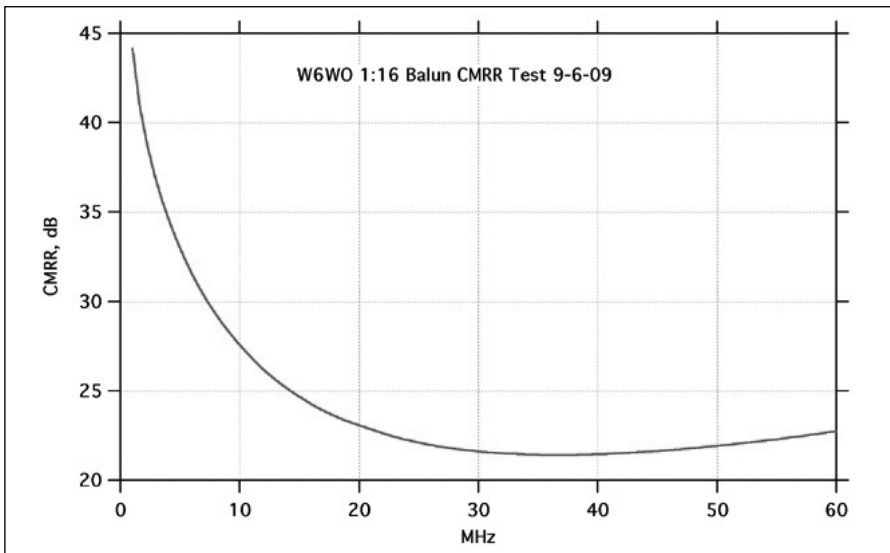


Figure 3 – Common-mode rejection ratio of a 1:16 balun/transformer. This graph is the result of complex number calculations using VNA measurements.

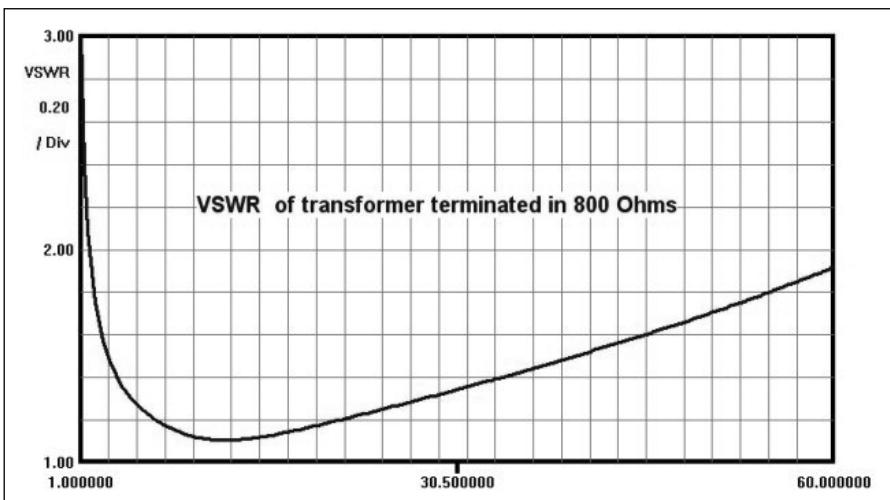


Figure 4 – VSWR measured from 1 to 60 MHz.

this would mask the true performance of the device under test. To this end a test fixture was constructed with connections that are low impedance and well balanced with respect to a ground plane.

Figure 2 shows the test fixture with a 1:16 single-turn primary transformer ready to be measured. The VNA applies a swept RF signal to port 1 to the left and measures the S parameters at ports 2 and 3 in turn. Note that when one secondary port is terminated in the VNA detector the other is terminated in a 50-Ω standard.

It is necessary to preserve both the input and output impedance seen by a balun. In this example the transformer has a 50:800 Ω transfer impedance ratio (this transformer is described in my article “Exploring Near-End-Fed Wire Antennas” that appeared in the March/April 2009 *QEX*). For this balun with one port terminated in 50-Ω at the VNA detector and the other in a 50-Ω plug, an additional 700 Ω is required in the secondary path. As seen in the picture, precise 350-Ω resistors have been added in each of the secondary connections to provide 700 Ω.

The baluns most frequently found in amateur antenna systems use binocular and torroid ferrite cores as either flux-linked or transmission-line transformers. Line chokes also impede common-mode current and often take form of a few turns of coax or a few ferrite cores over the outer sheath. All types can be measured using the test fixture with appropriate impedance-matching resistors.

Attributes other than CMRR, such as the accuracy of the impedance transformation, can be determined by terminating the full secondary in its design impedance and using the VNA to measure return loss at port 1. A reasonably accurate measure of transmission loss can be determined by using the VNA. The approach is to measure the combined loss of two identical baluns with their secondary sides connected back-to-back, and then halving the resultant loss. See Figures 4 and 5.

A realistic CMRR objective for a practical HF antenna balun is open to debate, but the higher the value the better, provided other performance factors are acceptable. In my view CMRR should be at least 20 dB across the whole HF spectrum or 30 dB over segments of the range. To achieve a CMRR of 30 dB, amplitude balance must be within +/- 0.3 dB and simultaneously phase balance must be within +/- 3 degrees. Those with the right tools and expertise are invited to develop 2D or 3D graphs relating frequency, amplitude and phase imbalance.

In conclusion, an important (and neglected) measure of balun performance

has been introduced with the hope that it will be seen more frequently in amateur articles and advertisements. This article focused on measuring the balance accuracy of baluns themselves and it is beyond the scope to consider the superiority of one type or another for particular antennas. I look forward to reader views on this.

*Ron Skelton, W6WO, was first licensed as G3IHP in 1951. Ron has held various call signs in the British colonies over the years. He is an ARRL Member as well as a Life Member of the IEEE and a Fellow of the IEE. His Amateur Radio interests include weak signal and digital communications, and homebrewing.*

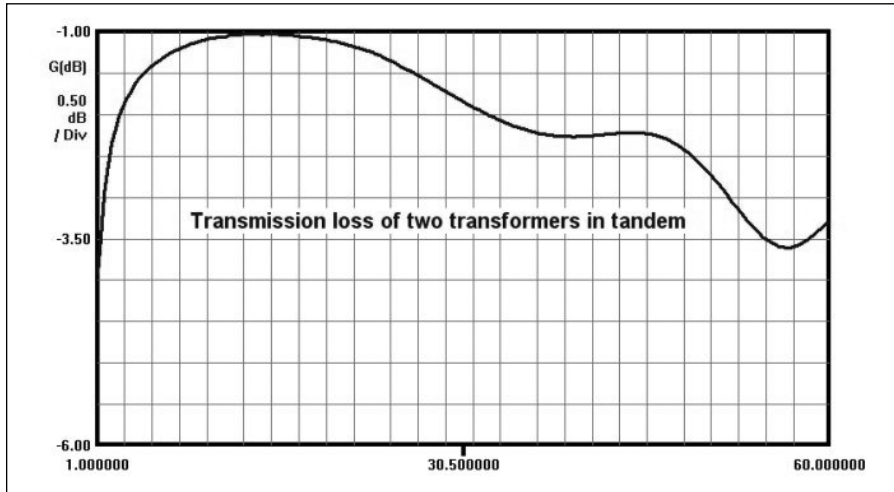


Figure 5 – Transmission loss from 1 to 60 MHz.

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