Balance Quality Measurements on Baluns

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***Abstract*—Two different methods of measuring the balance quality of baluns are described.**

Section I describes the balance comparator, a mechanical test device requiring only a signal source, and receiver to perform the measurements on the test balun.

Section II describes the use of a network analyzer, computer controlled to plot out all the graphical data on the balun measurements.

Measurements on a balun having known balance characteristics show both methods obtain satisfactory balance data.

I. Balance Quality Measurements on Baluns with a Balance Comparator

A. Description

THE BALANCE COMPARATOR is a test device for measuring the balance quality of baluns. The original development was carried out at RCA Laboratories [1]–[3]. More recently, a simpler and more accurate design approach was developed and is described herein; however, the basic operation is unchanged.

This present design is based on a rotatable loop in a circular waveguide section, operating below cutoff (Fig. 1). Assembled and exploded views are shown in Figs. 2 and 3. The loop is electrostatically shielded so as to excite only the linearly-polarized, dominant TE_{11} mode and to suppress the higher order modes, the TM_{01}, TE_{21}, TM_{11}, TE_{01}, etc. Two small resistor-loaded loops are aligned at right angles at the other end of the waveguide section. The common junction of the two loops is grounded at the center of the end plate, and the other ends of the loops are brought out through holes in the end plate to connect to the balanced terminals of the test balun. As seen in Fig. 2, a ground return from the case or ground terminal of the unbalanced side of the test balun back to the balance comparator is provided by the metal support shelf.

The value of the resistors are chosen to be equal to one-half of the balanced impedance for which the balun is designed. As most of the recent work here has been on baluns for the television frequencies using a 300-Ω balanced line, then each resistor was chosen to be 150 Ω.

B. Operation

In operation, a signal generator is connected to the coaxial input of the rotatable loop and a receiver is connected to the unbalanced port of the test balun, supported on the shelf. Referring to section A-A of Fig. 1, the loop is first aligned in the horizontal plane and the receiver reading is then taken. In this position, the currents in the two resistor loops excite the desired balanced mode (push–pull) to the balun. Next, the loop is rotated to the vertical plane

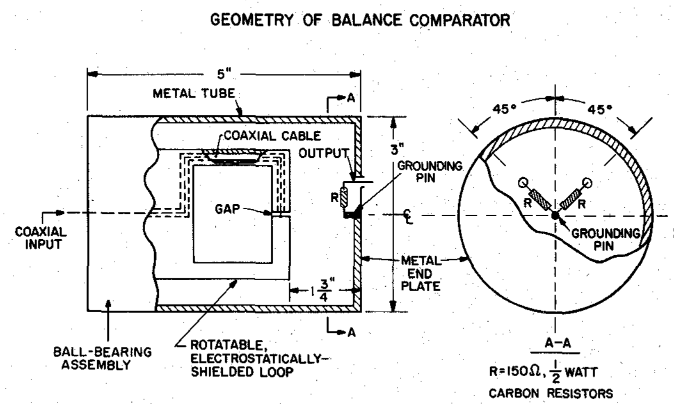

Fig. 1. Geometry of balance comparator.

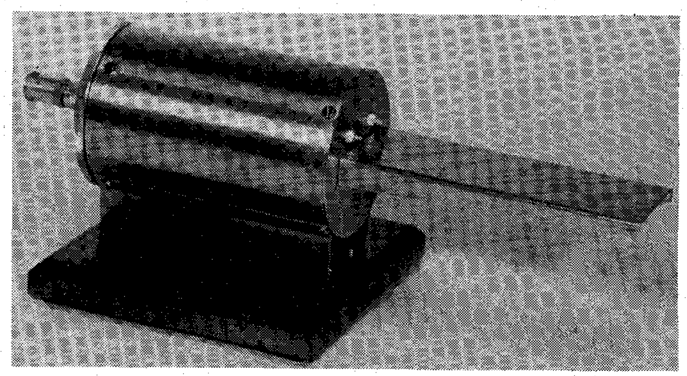

Fig. 2. Balance comparator (assembled view).

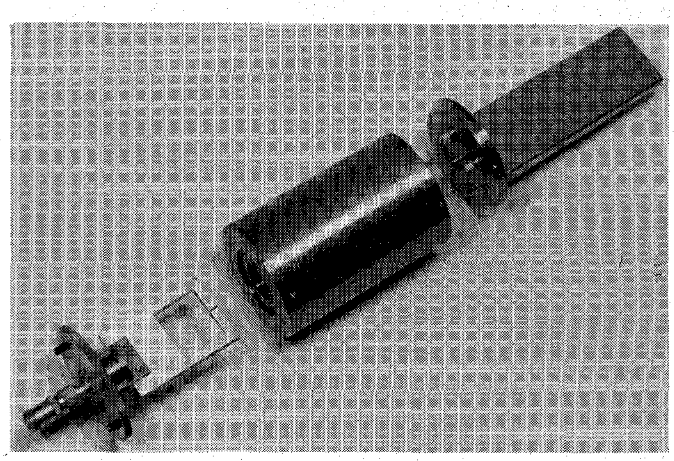

Fig. 3. Balance comparator (exploded view).

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and a receiver reading is taken of the undesired, unbalanced mode (push–push). The ratio of these two absolute magnitude readings, expressed in decibels, is then defined as the "balun ratio." It is considered that this definition of balance quality is more useful in present-day work than the "balance efficiency" term described in the original paper.

In the constructed comparator, the loop rotates in a ball-bearing assembly, and spring-loaded detents are provided to lock the rotor accurately at 90° intervals. The alignment of two loop positions relative to the resistor loops is quite critical.

If the linearity of the receiver is questionable, and if a calibrated attenuator is provided at the signal generator output, a good operating procedure is to change the input levels to give the same receiver reading for the unbalanced and balanced loop positions. The difference between the two attenuator settings is then the balun ratio.

The spacing between the rotatable loop and the resistor loop (Fig. 1) is chosen great enough so that the resistor loop impedances are not materially affected by the angular position of the rotatable loop, yet not too great for excessive insertion loss. A measure of this insertion loss was made and found to vary from about 55 dB at 50 MHz to 45 dB at 1000 MHz. Part of this loss is due to the operation below cutoff; the remainder is due to the large mismatch loss of the electrically small, rotatable loop and the small pickup of the two resistor loops.

Because of this high attenuation through the device, it is necessary for accurate measurements to use well-shielded cables and good connectors when connecting the components to avoid direct pickup between the source and receiver.

Another precaution is given with regard to measuring UHF baluns. Some of these baluns are made with a 300-Ω line, a few inches long, joined to the balanced terminals. The line section is, therefore, close to a quarter-wave long in the UHF band and can radiate considerably when fed with the unbalanced mode. The effect is "hot" equipment with the readings dependent on the hand positions. Better accuracy is obtained with this line section as short as possible. Care must also be taken to maintain symmetry in the connections from the output terminals of the comparator to the balanced terminals of the test balun.

Three pairs of screw holes are provided below the output terminals of the comparator to permit raising or lowering the support shelf for best accommodation of different size test baluns.

Considerable care was taken in selecting the two resistors in the comparator. The heat from first soldering the 150-Ω resistors appears to increase the resistance by a few ohms. Therefore, a large number of resistors were preheated several times, and then two nearly identical ones were selected. After soldering in the comparator, the resistances were found to be within 1 Ω of being the same.

The impedance versus frequency of each output port was measured, referenced to the end plate surface of the comparator. The VSWR, referenced to a 150-Ω line, was less than 1.1 over the low VHF-TV band, and less than 1.2 over the UHF-TV band.

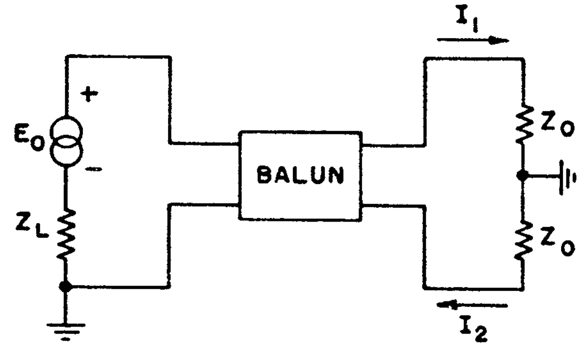

Fig. 4. Block diagram of balun joining an unbalanced mode generator to a balance load.

Since the resistors cannot be soldered in place to the accuracy at which the model maker can construct the comparator, a minor correction was made in the following manner. The four holes in the brass tube for bolting the rotating loop assembly were elongated so that the assembly could be rotated a slight amount. Next, baluns made of transmission-line components giving a very high balun ratio were joined to the comparator, and the assembly was rotated slightly to maximize the indicated balun ratio. The locking screws were then tightened and an alignment scratch made across the junction of the rotating loop end plate and at the edge of the cylindrical tube so that the correct realignment could be re-established if the device were ever taken apart.

C. *Accuracy Check*

Data on the accuracy is presented in Section II.

II. Balance Quality Measurements on Baluns with a Network Analyzer

This part discusses the theory and practices of an alternative method of measurement using only a network analyzer and programming, which results in an automatic plotting of the balun ratio over a wide frequency band.

A. *Balun Ratio Derivation*

Fig. 4 shows the circuitry of the balun joining an unbalanced mode generator to a balanced load. For accurate data, this balanced load must be the same as that for which the balun was designed. Here, the signal generator is applied at the unbalanced port of the balun for simplicity in explanation. From reciprocity, however, the derived balun ratio figure is unchanged from that obtained in Section I.

In the general case of an imperfect balun, the unequal load currents I_1 and I_2 may be resolved into the desired, or push–pull, component I_a, and the undesired, or push–push, component I_b, as shown in Fig. 5. Fig. 6 shows the vector diagram relationship of the output currents. Thus, if I_1 and I_2 are found, the balun ratio in decibels $(20\log[|I_a| \div |I_b|])$ may be determined.

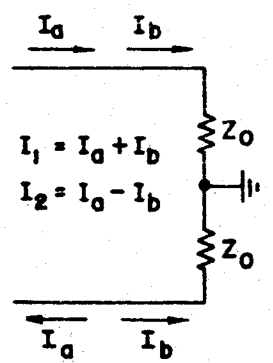

Fig. 5. Resolving the load currents into push–pull and push–push components.

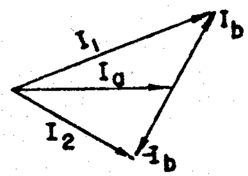

Fig. 6. Vector diagram of the load current components.

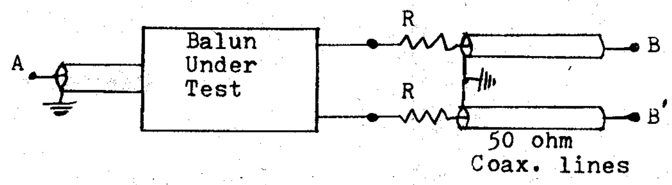

Fig. 7. Test fixture for network analyzer.

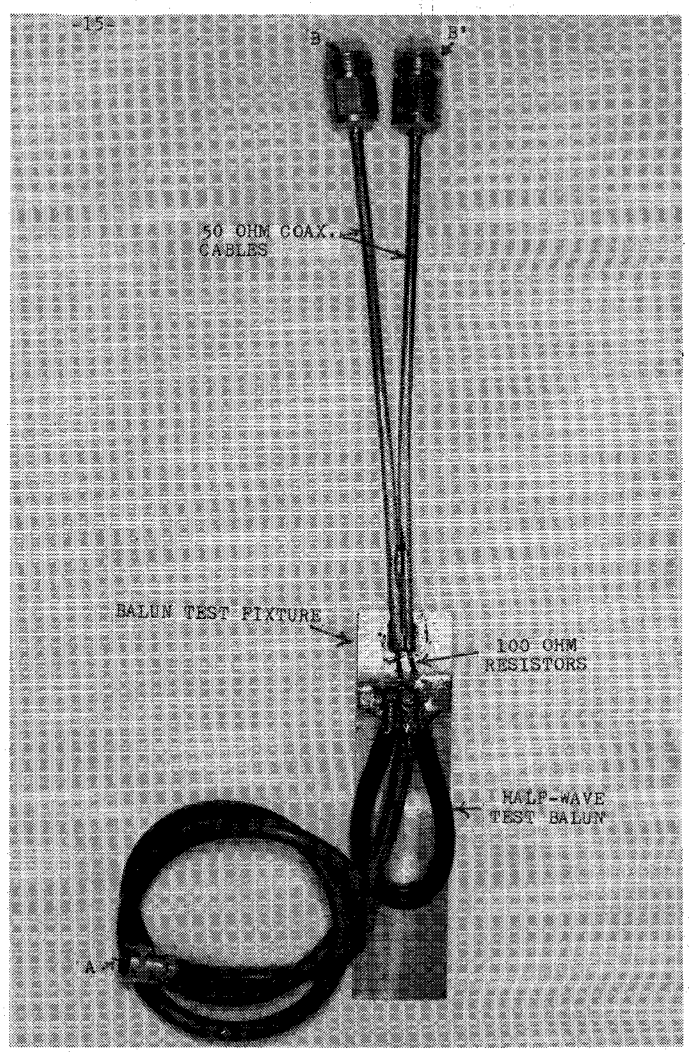

Fig. 8. Balun test fixture.

B. Network Analyzer Method

Any piece of equipment which is capable of measuring transfer gain and phase can be used to determine the load currents. A test setup, which is comprised of a computer-controlled network analyzer, is an ideal measuring device since it not only is capable of accurate measurements, but will also perform all the necessary calculations and will print out and plot the data.

The complete program for the network analyzer approach may be obtained by contacting the authors.

Calibration of the network analyzer is done by the usual procedure of terminating each port with a load, a short, and an open. These measurements, along with the thru measurement, completely characterize the analyzer and its associated connectors and lines. This characterization is then applied to the measured data to correct for any errors associated with the test equipment itself.

The actual measurement of the balun-under-test is performed by placing the balun in a test fixture which provides the proper load for the balun. Fig. 7 shows the circuitry of the test fixture. Point A is connected by a coaxial line to Port 1 of the network analyzer. Point B is connected to Port 2, while Point B' is terminated in a 50-Ω precision load. A measurement of gain from A to B is then performed. Point B' is then connected to Port 2 of the analyzer, and Point B is terminated with the 50-Ω load. A second measurement is then made. This time, the gain from A to B' is measured. Since the power gain is measured with Port A as the reference port in both cases, the currents I_1 and I_2 are proportional to the square roots of the power gains to Points B and B'. The value of the two matched resistors R is chosen so that $R+50$ is one-half the required balanced load for the balun. In terms of the measured S-parameters, the balun ratio is

$$BR = 20\log\left|\frac{S_{21B}+S'_{21B}}{S_{21B}-S'_{21B}}\right| \text{dB}$$

where S_{21B} and S'_{21B} are the current or voltage gains from Point $\boldsymbol{A}$ to Points $\boldsymbol{B}$ and $\boldsymbol{B'}$, respectively.

Fig. 8 shows the balun test fixture. The two equal-length coaxial lines are made of solid copper outer conductor, 0.141-in OD, and teflon dielectric. Type N connectors are attached at one end to join the network analyzer ports or a matched 50-Ω load. The other ends are soldered close together on a small brass plate. Small (1/8 W) resistors join the inner conductors of the coaxial lines to the test balun. This design thus permits very short connecting leads from the test fixture to the test balun, an important feature at UHF frequencies.

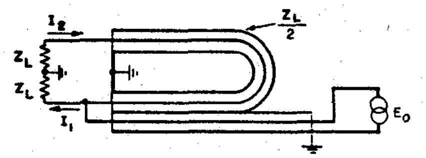

Fig. 9. Schematic diagram of half-wave balun feeding a balanced load.

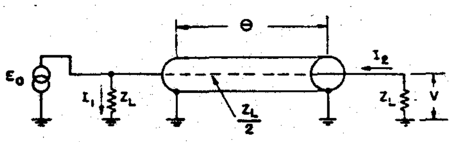

Fig. 10. Equivalent electrical circuit.

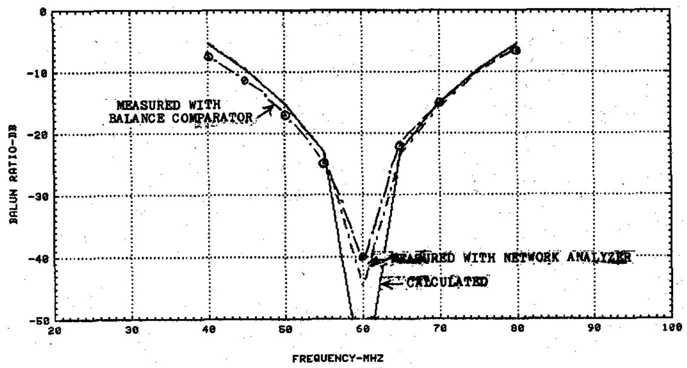

Fig. 11. Balun ratio data on the VHF balun.

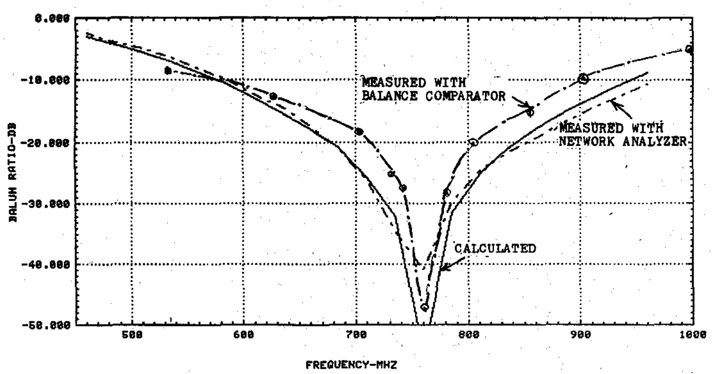

Fig. 12. Balun ratio data on the UHF balun.

The value of the resistors shown in Fig. 8 is 100 Ω; the balanced load for this case is, therefore, 300 Ω. Baluns designed for other balanced loads may be tested merely by changing the value of the resistors.

C. Experimental Checks

In order to check the accuracy of the two measuring systems, measurements were taken on a type of balun having easily calculated balanced quality characteristics. This balun (shown in Fig. 9) is formed from a phase-reversing cable, one-half wave in length, at midband frequency. With a balanced load $2Z_L$ of 300 Ω, the 75-Ω characteristic impedance of the half-wave cable is equal to $Z_L/2$. It should be noted that no cable losses were taken into account on the calculated balun ratios.

Rearranging the circuit as shown in Fig. 10, and solving for the values of I_1 and I_2, the balun ratio may be calculated.

Two different test models of this type of balun were constructed: a VHF balun designed for 60 MHz and a UHF balun designed for 760 MHz. The latter is the one shown in the photograph of Fig. 8. Each balun was measured first with the balance comparator, and then with the network analyzer. The results are compared with the calculated balun ratio in Figs. 11 and 12.

Both of the measured curves check quite well with the calculated data at the VHF band. At the UHF band, the network analyzer curve checks closer to the calculated curve than the balance comparator data. This may be attributed to the somewhat longer leads required to join the test balun to the balance comparator.

References

[1] O. M. Woodward, "Balance measurements on balun transformers," *Electronics*, p. 188, Sept. 1953.

[2] O. M. Woodward, "Radio frequency measuring apparatus," U.S. Patent 2 691 133, 1954.

[3] O. M. Woodward, "An improved design of the balance comparator, a device for measuring the balance quality of baluns," *RCA Laboratories*, Nov. 16, 1979.

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