The Impedance-Transformation Properties of Common 4:1 Balun Types
Part 3: Voltage Baluns: Some Preliminary Measurements

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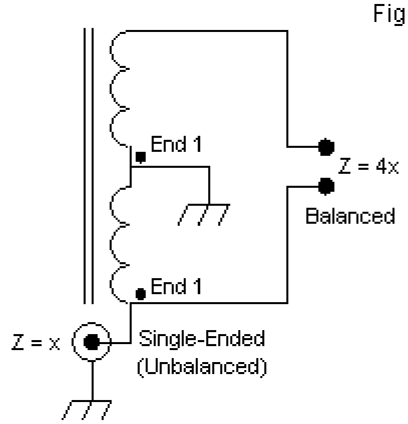
Perhaps the most common 4:1 balun is the voltage type, shown schematically in **Fig. 1**. The unit consists of two series windings, with a ground (common to the input connector ground) at the junction. The dots in the photo indicate the start of a bifilar winding, a parallel run of two wires around the core. In the past, many voltage baluns used air cores, but since the advent of the age of easily available ferrite and powdered iron cores, most voltage baluns have used them to produce compact devices that are relatively free of unwanted coupling. The most usual core for the task is the T200-2 powdered iron core where µ = 10 (or for coverage down to 1.8 MHz, the T200-1 for which µ = 20). We can easily recognize the T200-2 core by its red paint job. (Mix 1 is normally blue.) The core has a 2" outside diameter and is about 0.5" thick.

Fig. 1



Conventional 4:1 Voltage Balun

This set of notes will examine two examples of voltage baluns. One is a commercial unit, while the other is a homemade unit. The units differ in the number of bifilar turns and the number of cores in the stack. We shall be interested both in their similarities and their differences.

The MFJ-911 W9INN 4:1 Balun Box

Bob Cerreto, WA1FXT, was kind enough to loan me his 10-year-old MFJ-911 4:1 voltage balun. In the current catalog, MFJ describes the unit in the following terms:

> MFJ-912: 1.8 - 30 MHz W9INN Balun Box: Price: $69.95: Use coax from antenna tuner to MFJ-912 mounted outside. MFJ-912 converts unbalanced coax to balanced transmission line (ladder). Giant 2-core 4:1 balun wound with Teflon wire connects to high voltage ceramic feedthru insulators. Handles full legal limit with ease. SO-239 connector.

The giant double core turns out to be 2 toroidal cores (probably T200-2) with a 2" outside diameter and a total thickness of about 1". The winding consists of two wires wound for 18 turns in the same direction with somewhat random spacing between them. The windings appear to be #18 or possibly #16 insulated wires.

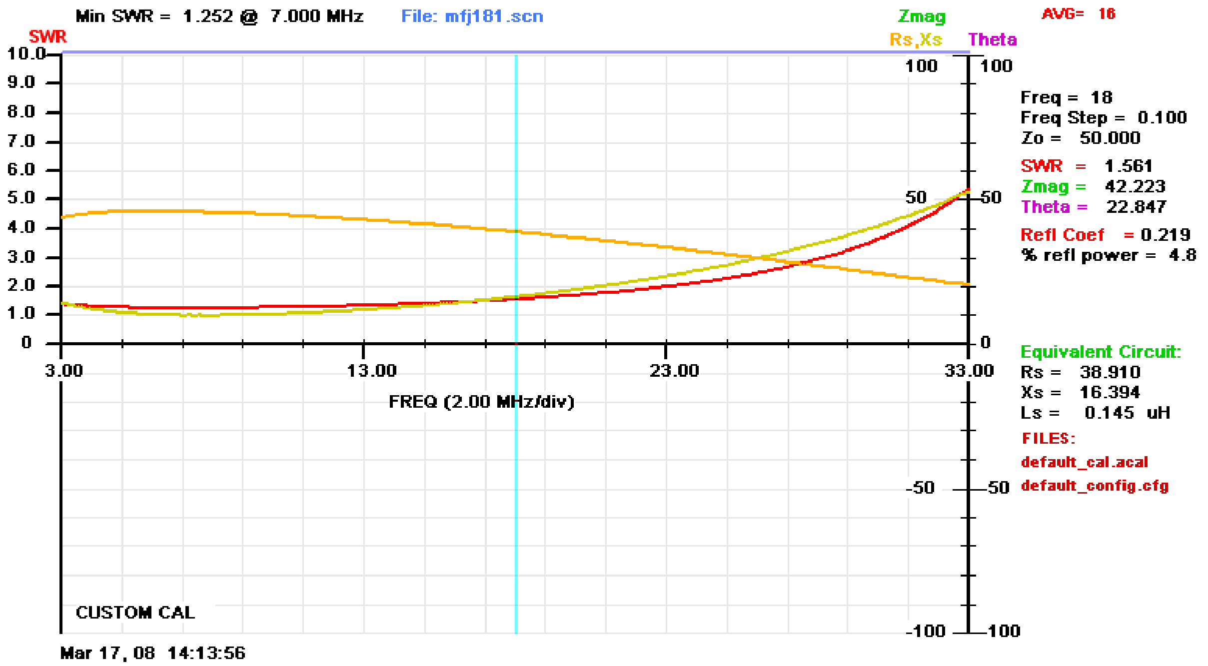
I subjected the unit to the same battery of tests that I applied to the Wireman W2DU-type balun kit. **Fig. 2** shows the test set-up. In common with the earlier tests, I used a 3" RG-58 connecting cable, but calibrated out of the measurements. Each test resistor connects across the wide-spaced output terminals. The resistors were all ¼-watt carbon-film types, pre-measured for value. The bottom plate of the balun in the photo has been removed to show the interior, including the routing of some wires against the case sides. The insulating plates for the large bolt appear to be Bakelite or a similar material.

We shall use the same set of loads for testing the impedance transformation properties of the voltage balun, and the results will have the same appearance. Graph lines will include resistance (orange), reactance (ochre) and the 50-Ω SWR (red) over the 3 to 30 (33) MHz range. Test tables will show basic sample measurement values for 3.7, 7.0, 14.0, and 20.0 MHz. The column headings SWR50, R, and X correspond to the lines on the graph at the designated frequencies. The entries contain sufficient decimal places to allow easy identification of trends. The graphs have two supplemental sets of values. At the top is the load value based on the DC resistance measurement of the test resistor. Beside it is the calculated "ideal" input resistance based on that load value followed by the 4:1 theoretical impedance transformation of the balun. The right two columns take into account the scans of the actual load resistors and create adjusted "ideal" resistance and reactance values based on simple proportional-parts calculations. The goal is to provide an estimate of the input values that might be produced by an ideal 4:1 balun

Test 1: 180 Ω and Test 2: 220 Ω: Since the nominal design load impedance for the 4:1 balun is 200 Ω, we may combine the first two tests. The resistor values bracket the nominal load value. Along with the two side-by-side test tables, **Fig. 3** and **Fig. 4** provide the basic performance data.

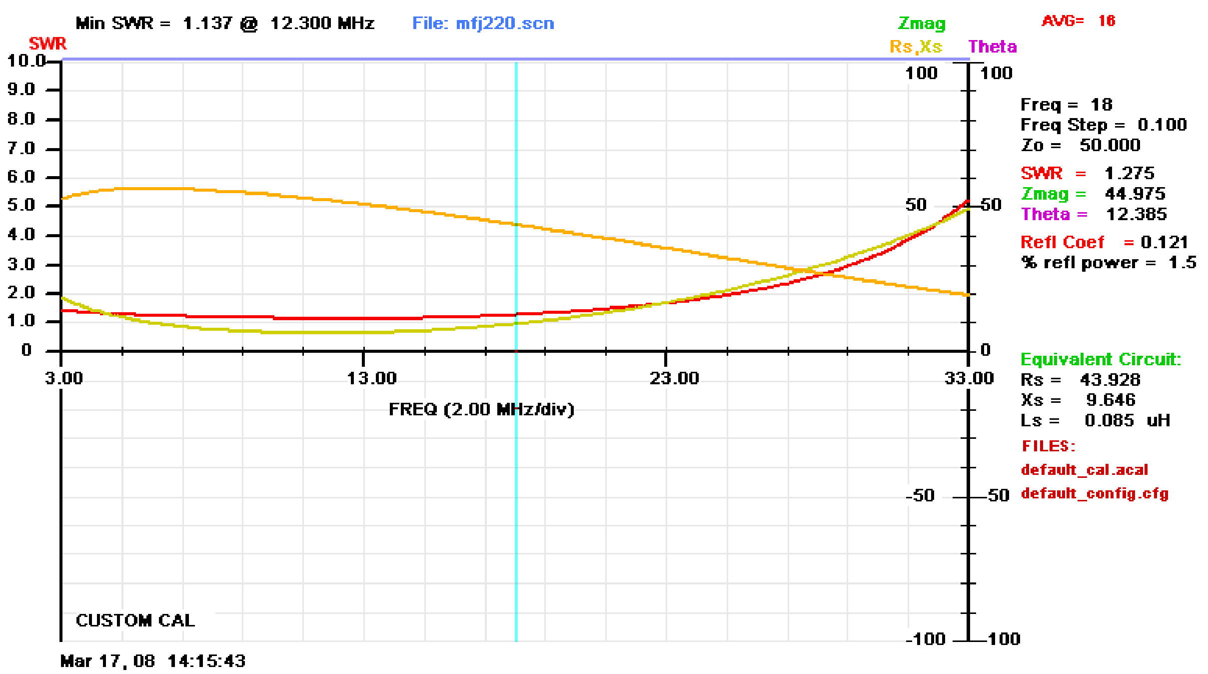
Test 1: Balun with resistive load of 181.2 Ohms					
Load R	Ideal In R	Ideal SWR			
181.2	45.300	1.104			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.35	44.89	13.20	45.54	-0.19
7.0	1.25	45.92	9.97	45.52	-0.37
14.0	1.38	42.34	12.68	45.50	-0.74
28.0	2.94	27.09	34.89	45.46	-1.49

Test 2: Balun with resistive load of 221.4 Ohms					
Load R	Ideal In R	Ideal SWR			
221.4	55.350	1.107			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.38	54.29	16.43	55.11	-0.36
7.0	1.22	56.06	8.73	55.09	-0.70
14.0	1.15	49.68	6.76	55.05	-1.39
28.0	2.64	27.21	29.50	54.97	-2.76



MFJ-912 4:1 Balun: Load 181.2 Ohms

Fig. 3



MFJ-912 4:1 Balun: Load 221.4 Ohms

Fig. 4

The windings of a typical voltage balun, such as the 911, make no effort to approximate a parallel transmission line or to sustain a constant spacing. Hence, the nominal impedance load and its counterpart 50-Ω input value are somewhat arbitrary numbers. The selection of a T200-2 (red) core pair and fixing of the number of turns have largely evolved from experience.

For both loads, the SWR indicates serious departures from a 4:1 impedance transformation in the upper portion of the HF spectrum. The reactance becomes increasingly inductive with a rate of increase that rises with frequency. At the same time, the resistance curve shows decreasing values with the rising frequency. Both the graphs and the test tables indicate incipient problems at the lower end of the spectrum. Near 3 MHz, the resistance decreases, while the inductive reactance increases. Had the scan extended to the specified lower frequency limit for the unit, 1.8 MHz, the curves would become more vivid. In terms of the values shown in the test tables, the unit approaches the calculated ideal values most closely in the vicinity of 14 MHz, with deviant values at all other tabulated frequencies.

Test 3: 152 Ω and Test 4: 100 Ω: With resistive loads below the nominally best value (200 Ω), the progression of resistance values across the total frequency span flattens out (at 150 Ω) and reverses direction (at 100 Ω) relative to nearly nominal loads. However, the rate of increase of the reactance (always inductive when the load is lower than the nominal) increases as we reduce the load resistance. The test tables show that the measured input resistance values are always less than the calculated ideal values for each of the two loads. For both lower load values the SWR curve grows steeper as we decrease the load resistance value. Despite these changes in the precise shape of the curves, lower load values continue the general properties that we observed with nearly nominal loads, especially in terms of the frequency limit of effectiveness for the balun.

Fig. 5 and **Fig. 6** provide full scan curves for the lower impedance loads, with the test tables sandwiched between them.

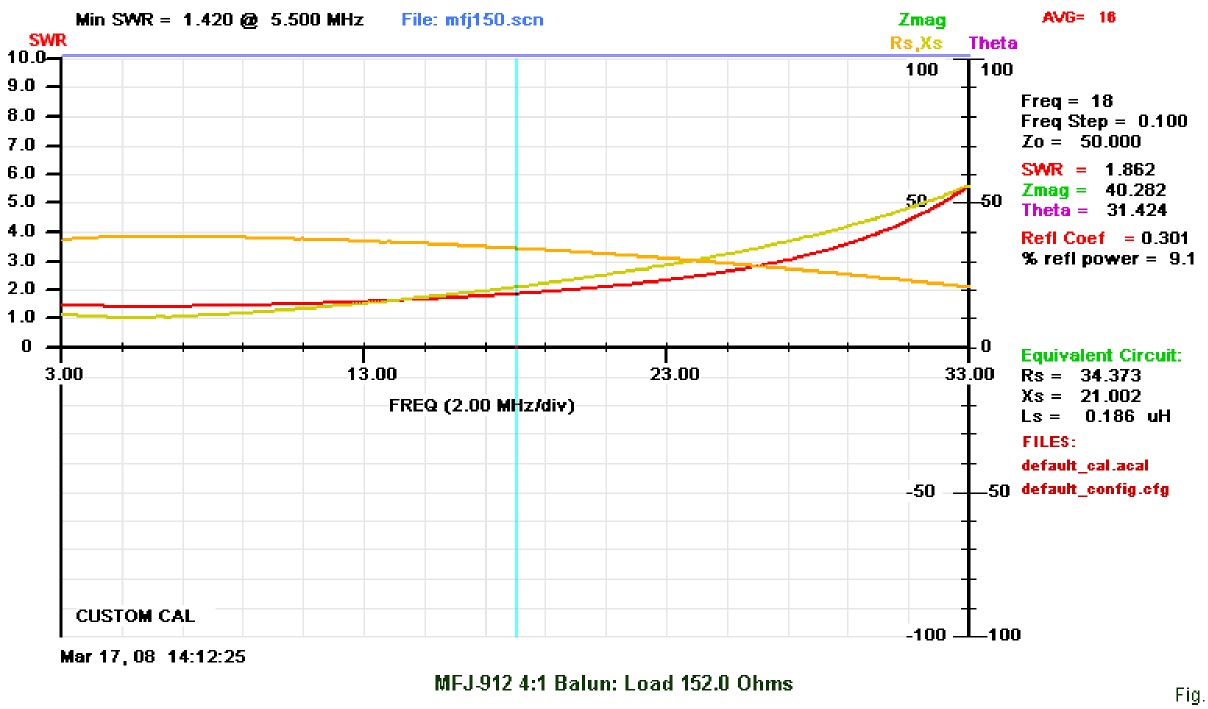


Fig. 5

Test 3: Balun with resistive load of 152.0 Ohms					
Load R	Ideal In R	Ideal SWR			
152.0	38.000	1.316			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.46	37.74	11.25	37.86	-0.15
7.0	1.43	38.49	10.80	37.85	-0.22
14.0	1.64	36.45	16.31	37.83	-0.38
28.0	3.30	26.87	39.32	37.78	-0.68

Test 4: Balun with resistive load of 100.3 Ohms					
Load R	Ideal In R	Ideal SWR			
100.3	25.075	1.994			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.06	25.14	8.39	25.06	0.03
7.0	2.11	25.49	11.77	25.06	0.09
14.0	2.45	25.13	21.39	25.06	0.20
28.0	4.57	21.96	47.71	25.05	0.42

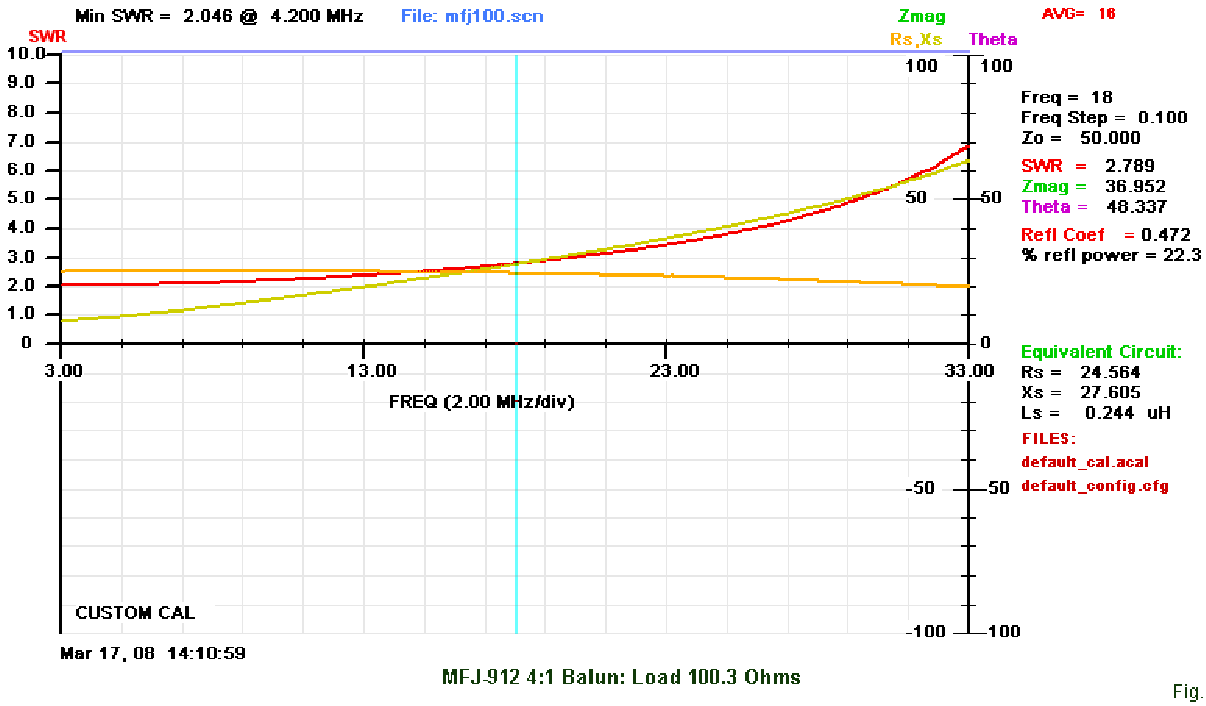


Fig. 6

Test 5: 295 Ω and Test 6: 390 Ω: See **Fig. 7** and **Fig. 8**, along with the table of sample test values. When we employ loads higher than the nominal 200-Ω value but restrict them to the 2:1 SWR limit, we obtain somewhat different curves. Note especially the increasing reactance at the low end of the frequency sweep. With both load values, the reactance becomes capacitive between about 8 and 18 MHz. The resistance curves show a peak in the vicinity of 5 MHz, with a decreasing value at the lowest end of the scan range. The overall resistance and reactance behaviors of the voltage balun with the two higher loads become quite complex.

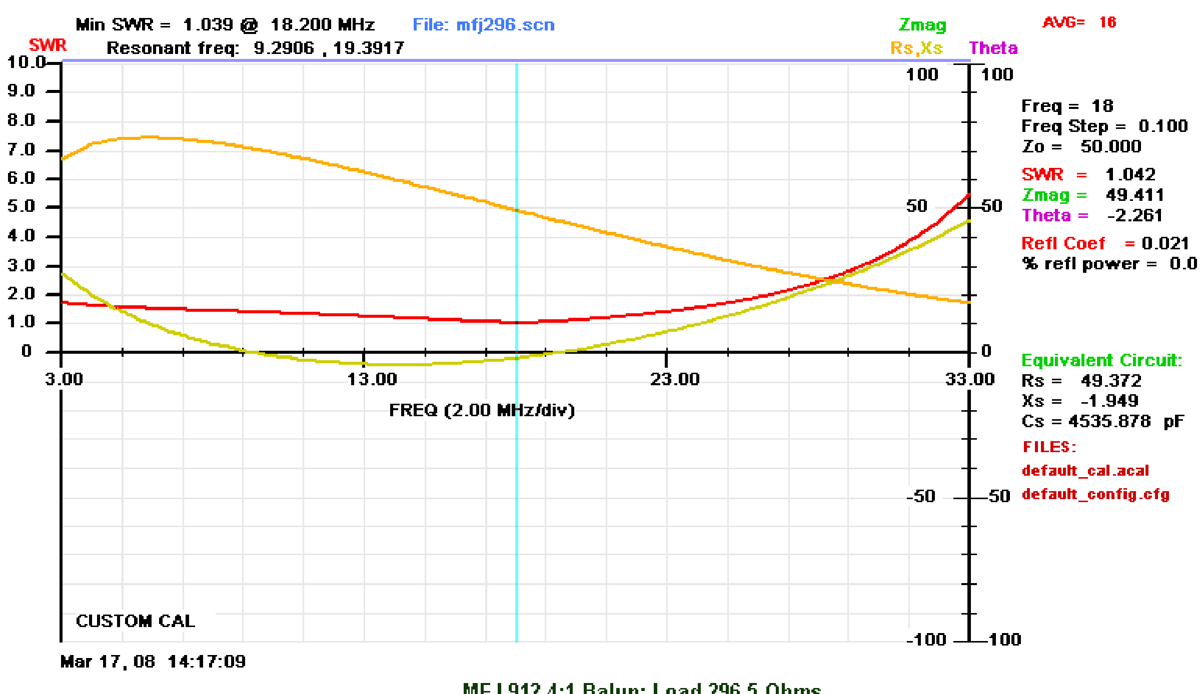


Fig. 7

Test 5: Balun with resistive load of 296.5 Ohms					
Load R	Ideal In R	Ideal SWR			
296.5	74.125	1.483			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.68	69.91	23.70	73.91	-0.42
7.0	1.50	73.95	6.05	73.86	-1.10
14.0	1.22	59.95	-4.23	73.75	-2.46
28.0	2.47	25.55	22.85	73.55	-5.19

Test 6: Balun with resistive load of 391.5 Ohms					
Load R	Ideal In R	Ideal SWR			
391.5	97.875	1.958			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.15	88.24	35.18	97.40	-1.37
7.0	1.93	96.46	0.98	97.27	-2.61
14.0	1.58	68.63	-19.60	97.01	-5.08
28.0	2.53	22.67	17.29	96.50	-10.03

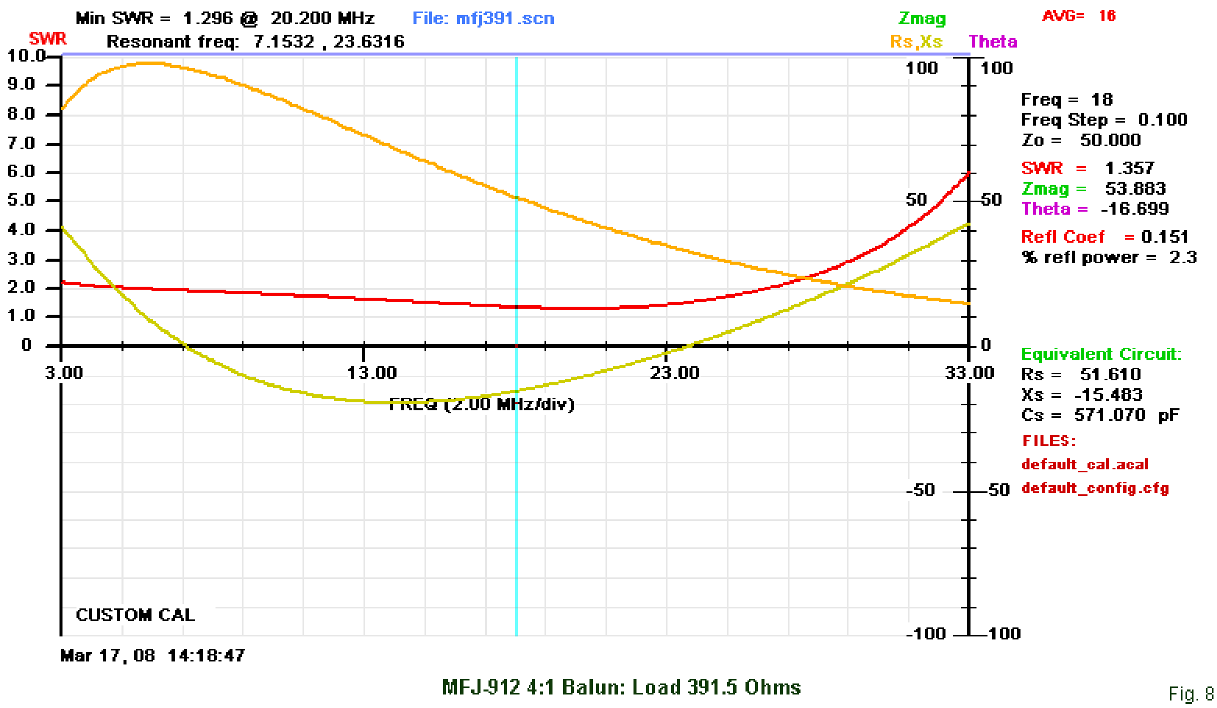


Fig. 8

The tabular values show a widening distance between the values for 3.5 MHz and 28 MHz as we increase the load values. The increasing load values also reduce the frequency at which the test unit most closely approaches the calculated ideal transformation values.

Test 7: 560 Ω: The final test that uses a purely resistive load increases the ideal SWR value to nearly 3:1. The test table and **Fig. 9** provide evidence of the extension of the trends that began to emerge with the 220-Ω resistive load and continued with increases in the load resistance. Above 7 MHz, the resistive component of the balun input impedance shows an ever-increasing rate of decrease. With a 3:1 SWR, the highest value in the sweep almost reaches the theoretically ideal value near 7 MHz and, at all other points, is below that value. Across the scan range, the reactance swing also grows in step with the increasing load value. Even though the input impedance at 28 MHz has an SWR value that is seemingly near the proper mark, the actual impedance transformation is far from 4:1.

Test 7: Balun with resistive load of 561.0 Ohms					
Load R	Ideal In R	Ideal SWR			
561.0	140.250	2.805			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	3.06	115.27	60.86	139.82	-2.61
7.0	2.78	137.70	-11.11	139.40	-5.13
14.0	2.27	74.85	-45.20	138.56	-10.16
28.0	2.90	18.37	12.08	136.87	-20.23

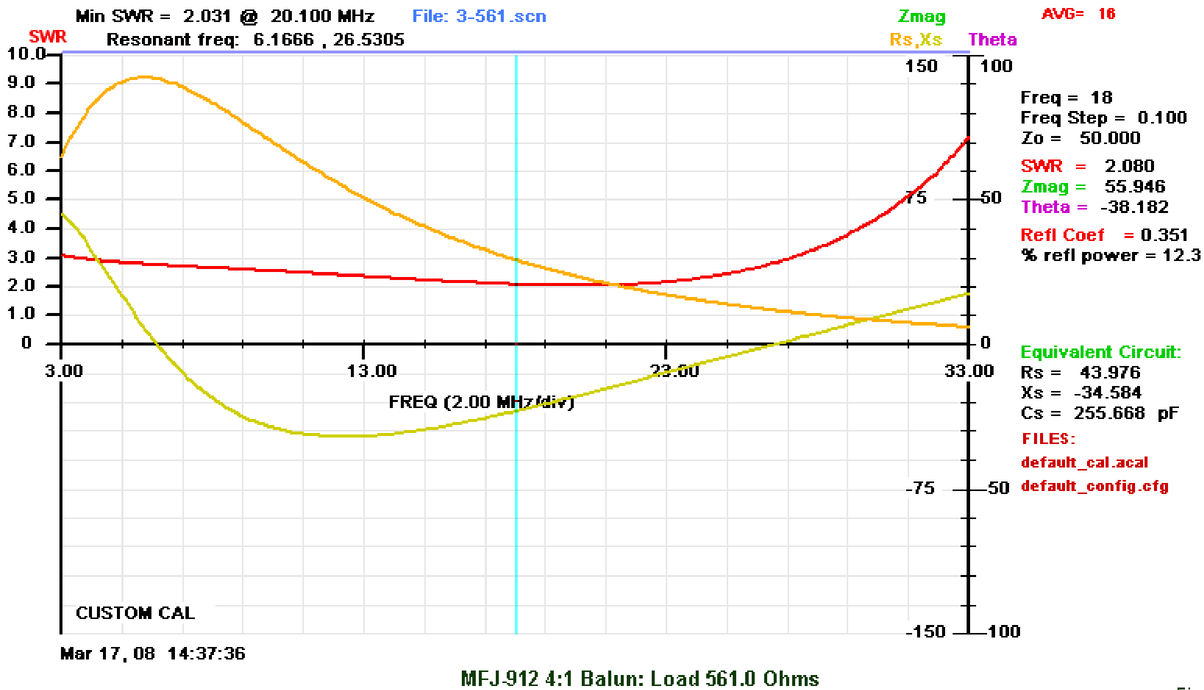


Fig. 9

Test 8: 181.2 – j117.3 Ω @ 14 MHz: A full test sequence would devise many loads for the 4:1 voltage balun with varying levels of reactance in the load. Because all such tests are frequency specific, we shall just use one example, a load of 181.2 Ω resistance with a capacitive reactance of –j117.3 Ω representing a 96.9-pF capacitor at 14 MHz. The graph for this combination appears in **Fig. 10**, which uses a scan restricted to the region from 13 to 15 MHz, with the blue marker line centered over 14 MHz. The scan seems to show that nothing is amiss in the relatively flat curves. The test table shows that the change of reactance in the 14-MHz vicinity is not much greater for the present balun than for the ferrite balun numbers, presented to the right. In fact, the present balun seems to provide a better SWR than the ferrite version, which showed values close to the calculated ideal numbers.

Test 8: Balun with a complex load of 181.2 - j117.3 Ohms					
	Ideal SWR: 1.978:1				
	MFJ-912				
Freq	SWR50	R	X		
13	1.85	32.43	-17.87		
14	1.80	31.17	-13.95		
15	1.77	30.10	-10.34		

Although the average balun user might take the lower SWR as a sign of good performance, it actually indicates just the opposite. Within SWR limits of 2:1, we may roughly calculate the appropriate input resistance and reactance at ¼ their load values. The dual ferrite balun input values quite closely approach the ideal values (45.3 – j29.3 Ω). In contrast, the present balun unit creates input resistance values far below the calculated level, with reactance levels that are far more inductive than the "ideal" value. A good input SWR value is not itself a signal that an impedance transformation device is performing well its design function. Very often, amateurs employ only a single SWR meter between the transceiver and either the balun or an ATU with a balun installed. As a result, the voltage-balun user normally has no idea of what the actual impedance transformation in the balun may be.

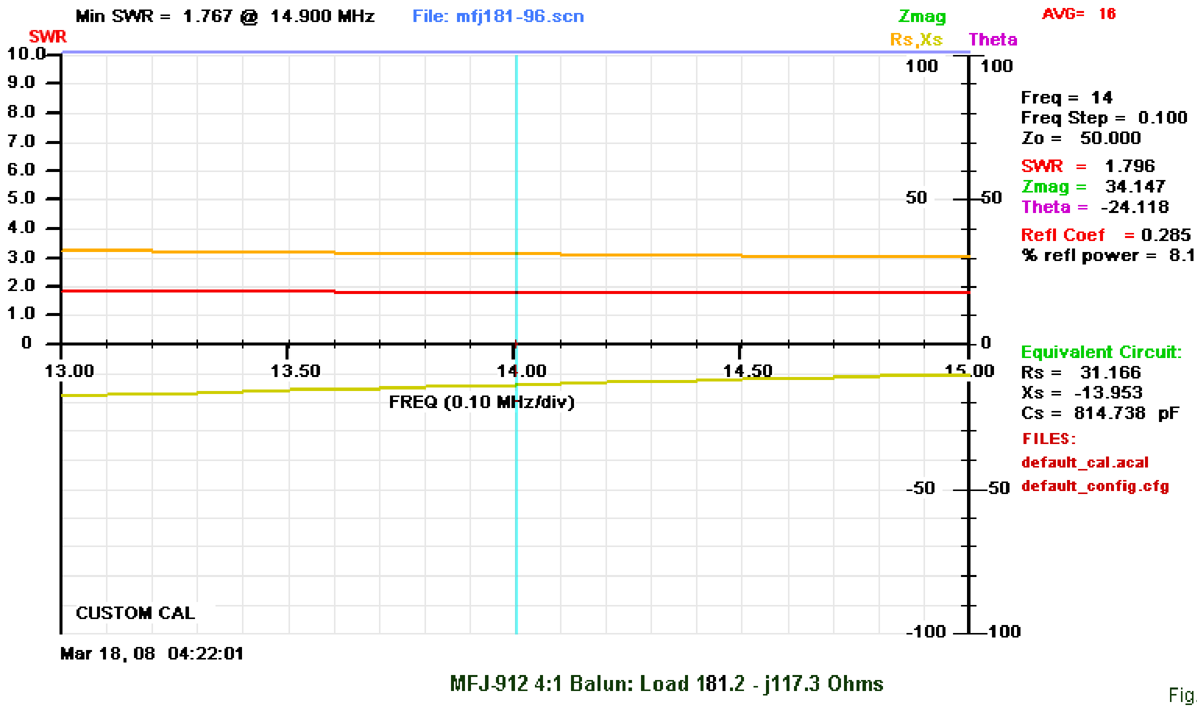


Fig. 10

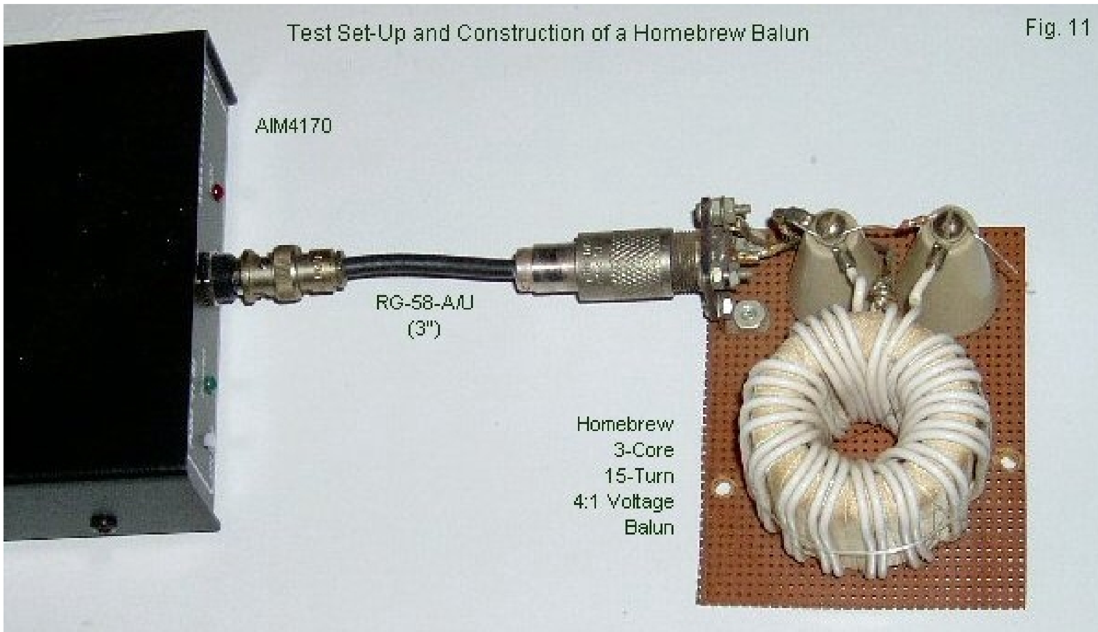
The test unit under a fairly wide variety of load values performs its main function—a 4:1 impedance transformation—only within a relative small frequency range between the 40-meter and 20 meter amateur bands. Outside of that region, the unit shows resistance and reactance curves with characteristics that exceed expectations in a unit designed to serve from 1.8 to 30 MHz. The higher-frequency aberrations occur with all loads, while with load values above the nominal 200-Ω value, the lower-frequency range also shows deviant characteristics. Compared to the dual ferrite balun, the present unit does not come close to serving the entire HF spectrum with a 4:1 impedance transformation.

Given the age of the unit and somewhat casual lead wiring, one might well question whether the characteristics shown by the scans are functions of the idiosyncrasies of the particular unit or generic to 4:1 voltage baluns that use T200 cores. Therefore, we may usefully examine a second unit of the same general design.

A 3-Core Homebrew 4:1 Voltage Balun

In the mid-1980s, I built a 3-core 4:1 voltage balun to the best specifications of the day. The T200-2 cores form a stack 1.5" tall. I wrapped them in glass tape to fix their relative positions and to improve insulation between the powdered iron core material and the windings. The 15 bifilar turns used AWG #14 wire with Teflon insulation to cover 3.5 through 30 MHz.

Because the balun had an indoor place during the tests for which I constructed it, the base is a simple piece of perfboard. The unit has minimal hardware. I used 20-lb nylon line to hold the cores in place on the perfboard and to wrap the windings. An SO-239 is the input connector, while ceramic insulators serve as output terminals. With no box to dictate connector positions, the balun uses the shortest practical leads at both ends. **Fig. 11** shows the unit in its test set-up. All components of the set-up are the same as for the first voltage-balun test runs except the balun itself. My only concession to the test situation was to remove 25 years of dust from the unit.



Test Set-Up and Construction of a Homebrew Balun

Fig. 11

Since the tests employ the same load resistors used for all other balun tests in this collection of notes, you may directly correlate the graphs and test tables for the 3-core balun with those for the MFJ-911. Apart from any comments that I may make along the way, you may draw your own conclusions concerning common traits and differences.

Test 1: 180 Ω and Test 2: 220 Ω: **Fig. 12** and **Fig. 13** show the curves for the two resistive loads that bracket the nominal load. The side-by-side tables appear between the graphs. Perhaps the most striking feature is their resemblance to the MFJ-911 graphs in **Fig. 3** and **Fig. 4**. The 3-core resistance and reactance drop lower at 28 MHz than corresponding 911 values.

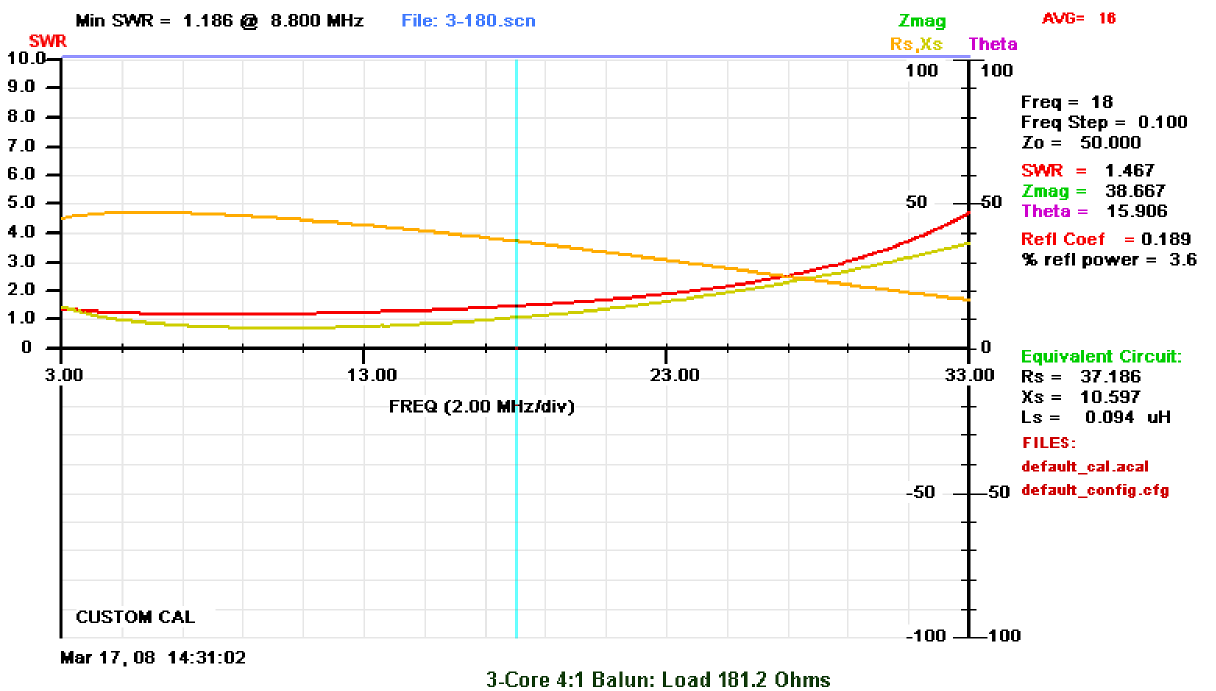
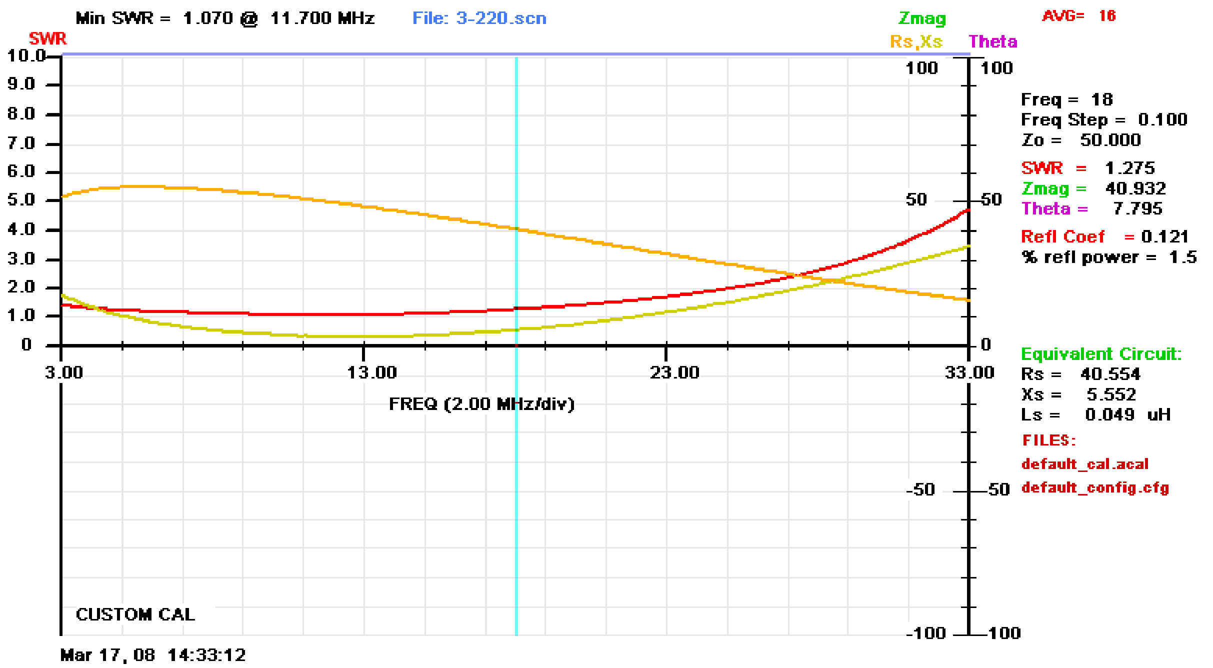


Fig. 12

Test 1: Balun with resistive load of 181.2 Ohms					
Load R	Ideal In R	Ideal SWR			
181.2	45.300	1.104			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.33	45.91	13.08	45.54	-0.19
7.0	1.20	46.86	8.04	45.52	-0.37
14.0	1.29	41.56	7.91	45.50	-0.74
28.0	2.77	23.47	24.90	45.46	-1.49

Test 2: Balun with resistive load of 221.4 Ohms					
Load R	Ideal In R	Ideal SWR			
221.4	55.350	1.107			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.36	53.13	15.54	55.11	-0.36
7.0	1.17	54.71	6.75	55.09	-0.70
14.0	1.10	46.88	3.44	55.05	-1.39
28.0	2.63	23.33	21.54	54.97	-2.76



3-Core 4:1 Balun: Load 221.4 Ohms

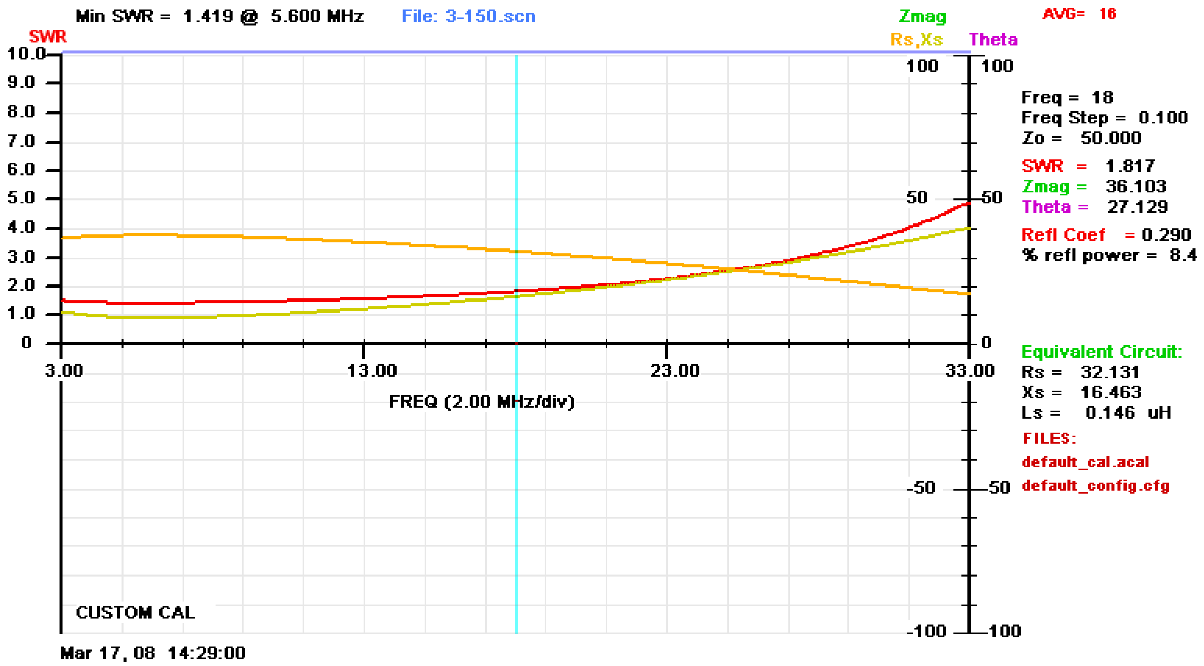
Fig. 13

Although the higher frequency resistance values for the 3-core version of the 4:1 voltage balun are lower, the SWR does not rise to 911 values. The lower reactance values for the 3-core balun are the chief reason for the limits to the rise in 50-Ω SWR.

Test 3: 152 Ω and Test 4: 100 Ω: As we decrease the load values below the nominal impedance level, the 3-core balun continues to produce curves that almost (but not quite) replicate the curves for the 911. With a load of 150 Ω, the resistance curve shows a lower value at 3 MHz, while with a 100-Ω load, the resistance curve flattens considerably at the lowest frequency in the scan. In addition, the large higher-frequency drop in input resistance that we saw in the 180-Ω scan slows its rate of decline and, with a load of 100 Ω, is not far from the values for lower frequencies. See both the test tables and **Fig. 14** and **Fig. 15**. Still, the SWR margin continues to grow due to the high inductive reactance at the highest frequencies in the scan. The amount of reactance increases is somewhat less for the 3-core balun than for the 911 version. These differences are somewhat minor compared to the relatively close tracking between the two voltage baluns of the scan curves at each load level.

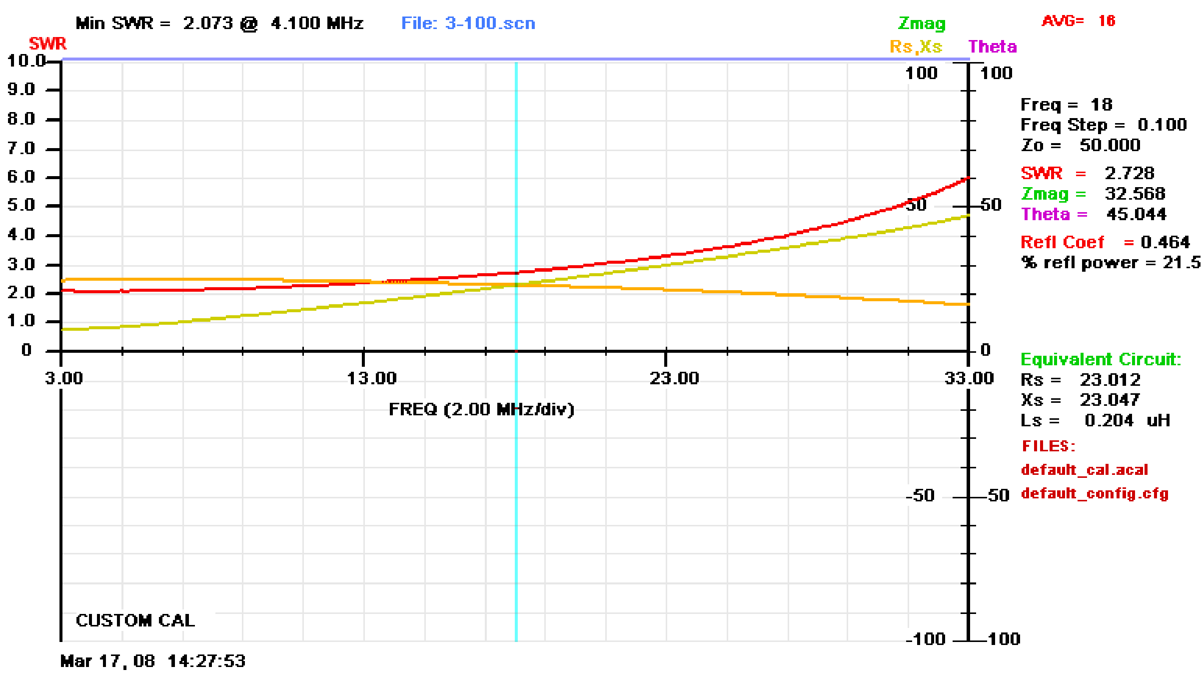
Test 3: Balun with resistive load of 152.0 Ohms					
Load R	Ideal In R	Ideal SWR			
152.0	38.000	1.316			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.47	36.99	10.39	37.86	-0.15
7.0	1.43	37.89	9.21	37.85	-0.22
14.0	1.61	34.69	12.87	37.83	-0.38
28.0	3.13	22.68	30.04	37.78	-0.68

Test 4: Balun with resistive load of 100.3 Ohms					
Load R	Ideal In R	Ideal SWR			
100.3	25.075	1.994			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.08	24.80	7.72	25.06	0.03
7.0	2.12	24.88	10.24	25.06	0.09
14.0	2.43	23.92	18.06	25.06	0.20
28.0	4.27	19.00	37.61	25.05	0.42



3-Core 4:1 Balun: Load 152.0 Ohms

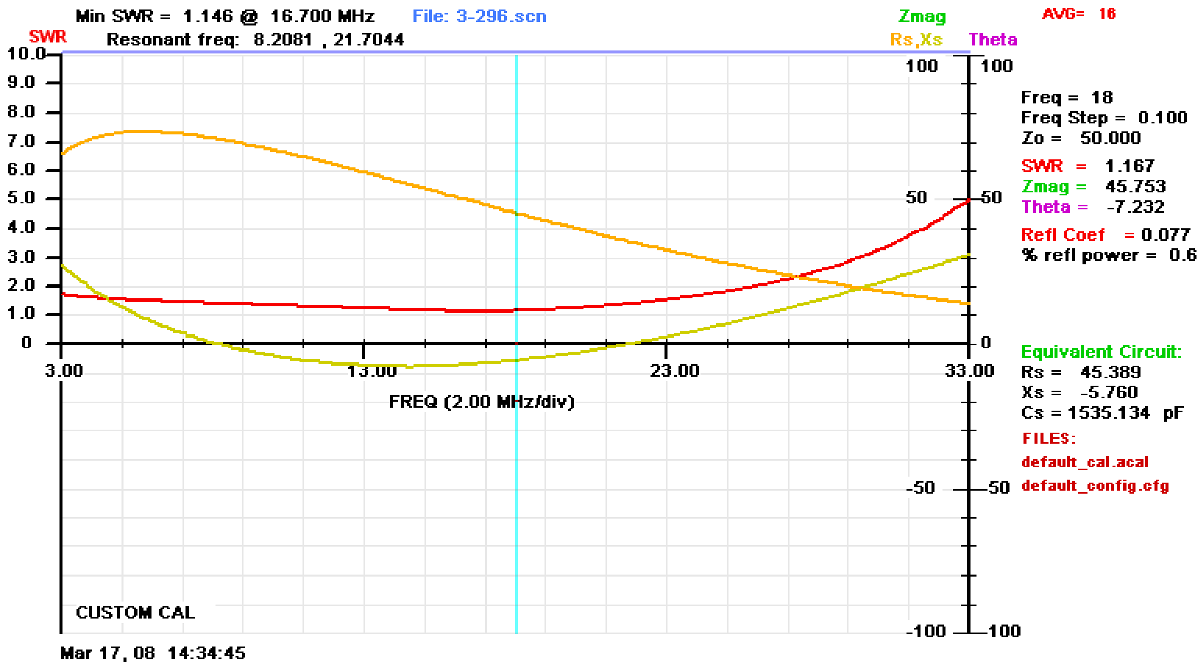
Fig. 14



3-Core 4:1 Balun: Load 100.3 Ohms

Fig. 15

Test 5: 295 Ω and Test 6: 390 Ω: If we raise the load impedance values while staying within an ideal 2:1 SWR limit relative to the nominal load impedance, we obtain the curves shown in **Fig. 16** and **Fig. 17** that surround the next pair of test tables. The resemblance to 911 curves continues unabated, with a drop in resistance at the lower end of the scan, a swing of the reactance curve into capacitive territory in the mid-frequency region, and essentially the same higher-frequency drop in resistance to accompany a rise in inductive reactance. The 3-core balun shows its difference in having lower high-end resistance and reactance values.

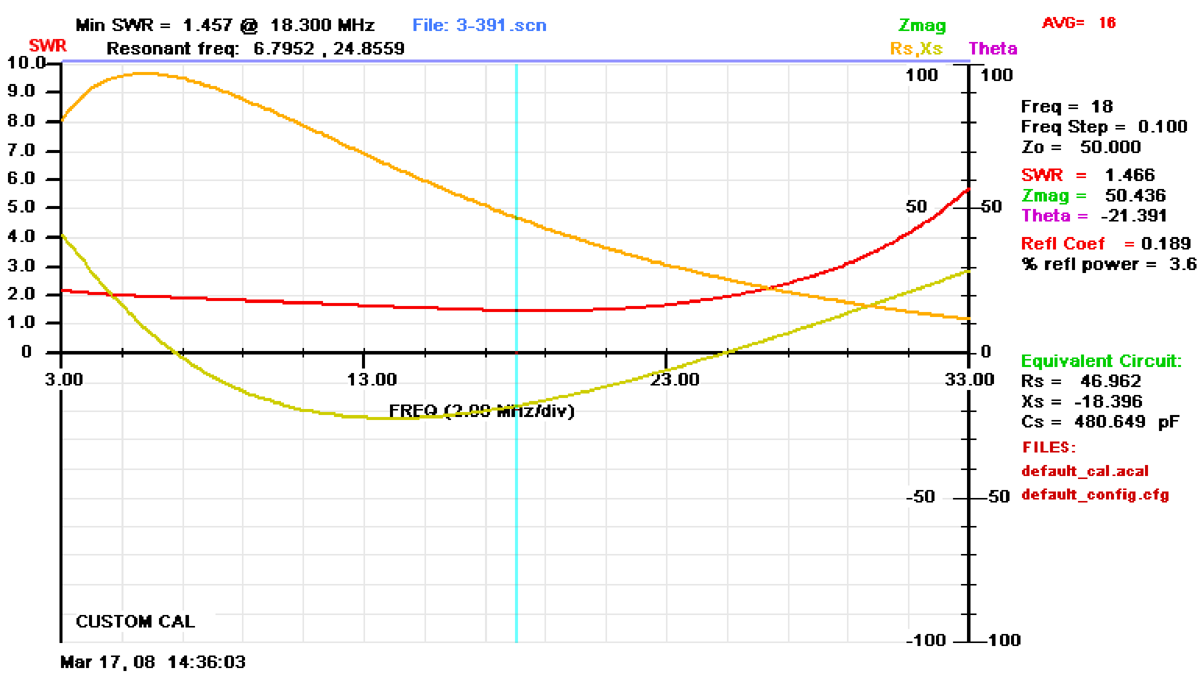


3-Core 4:1 Balun: Load 296.5 Ohms

Fig. 16

Test 5: Balun with resistive load of 296.5 Ohms					
Load R	Ideal In R	Ideal SWR			
296.5	74.125	1.483			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.66	69.24	23.24	73.91	-0.42
7.0	1.46	72.75	3.84	73.86	-1.10
14.0	1.21	56.71	-7.72	73.75	-2.46
28.0	2.54	21.95	15.32	73.55	-5.19

Test 6: Balun with resistive load of 391.5 Ohms					
Load R	Ideal In R	Ideal SWR			
391.5	97.875	1.958			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.12	87.07	34.78	97.40	-1.37
7.0	1.90	95.06	-1.71	97.27	-2.61
14.0	1.60	64.21	-22.68	97.01	-5.08
28.0	2.73	19.24	10.50	96.50	-10.03



3-Core 4:1 Balun: Load 391.5 Ohms

Fig. 17

Test 7: 560 Ω: With the highest test load of the group—ideally simulating a nearly 3:1 SWR relative to the nominal balun output impedance—the curves in **Fig. 18** closely resemble those of **Fig. 9** for the MFJ-911. Once more, as indicated by the associate test table for both baluns, the 3-core version drops to a lower resistance value at the top of the scan, but the inductive reactance does not rise to the level shown by the 911.

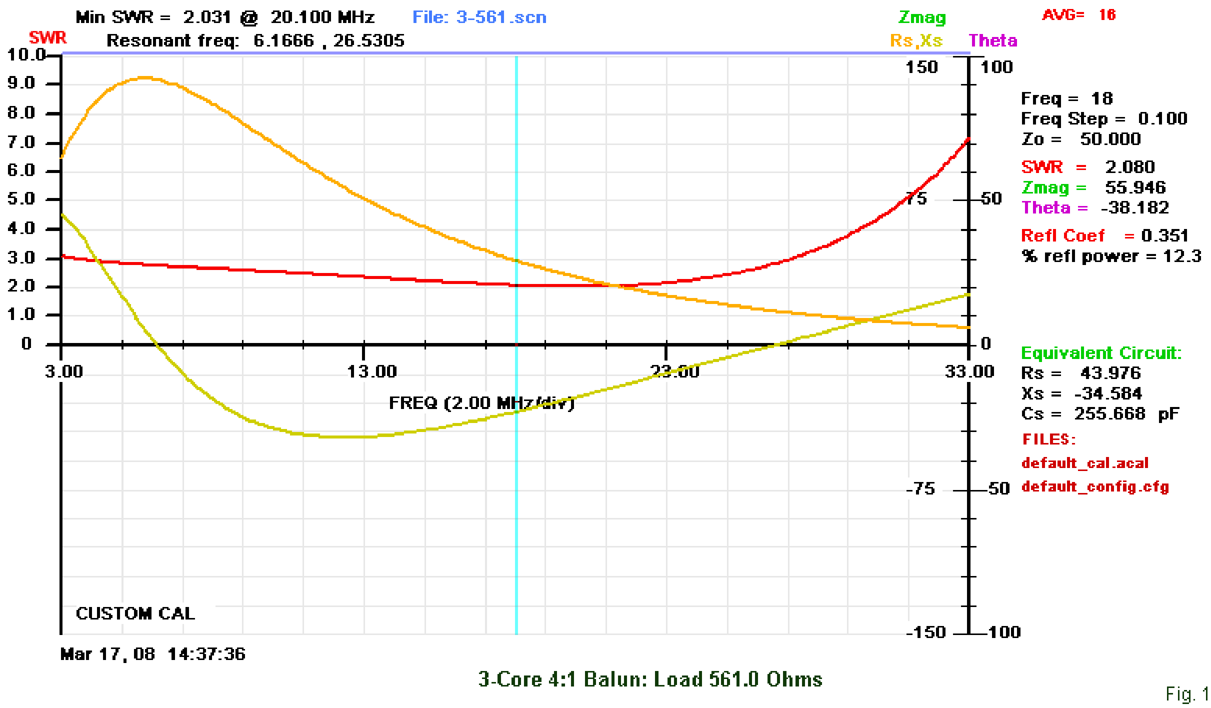
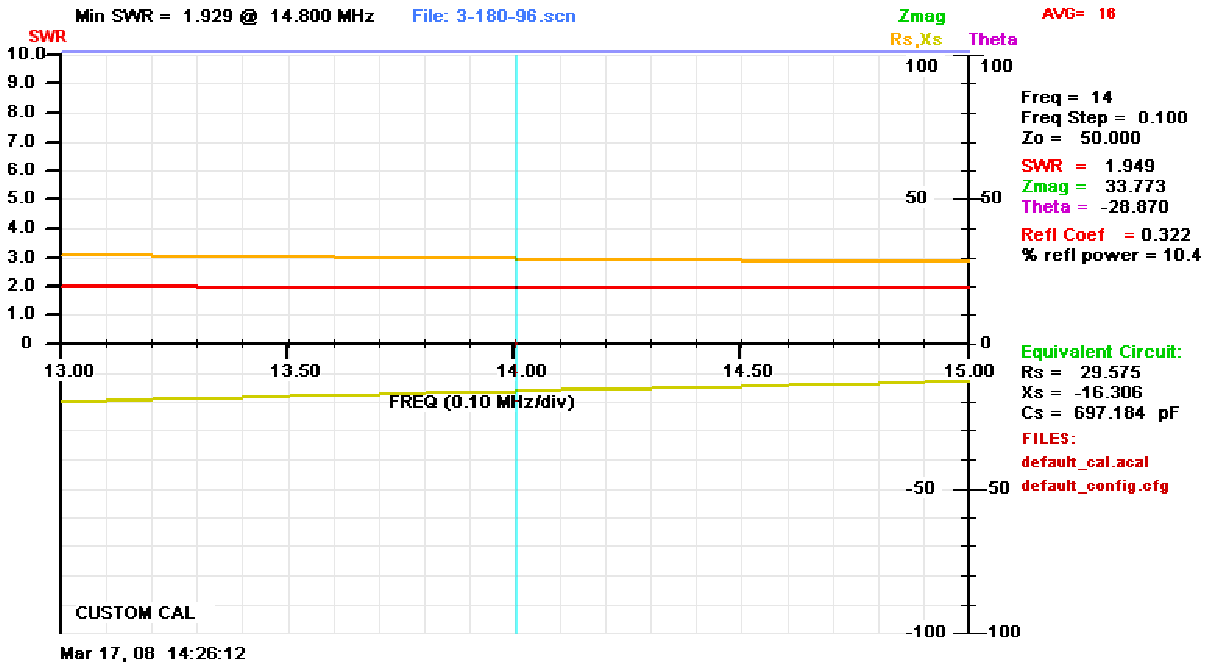


Fig. 18

Test 7: Balun with resistive load of 561.0 Ohms					
Load R	Ideal In R	Ideal SWR			
561.0	140.250	2.805			
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	3.00	112.81	59.63	139.82	-2.61
7.0	2.71	133.64	-14.45	139.40	-5.13
14.0	2.29	68.27	-46.44	138.56	-10.16
28.0	3.35	15.18	6.07	136.87	-20.23

Test 8: 181.2 – j117.3 Ω @ 14 MHz: When we apply the complex load to the balun, both the 911 (**Fig. 10**) and the 3-core balun (**Fig. 19**) show nearly flat curves from 13 to 15 MHz for resistance and a reactance curve that rises slowly across the narrowed scan. Compare the test-table values to the calculated ideal value 45.3 – j29.3 Ω for 14 MHz. Although the 50-Ω SWR for the 3-core balun approaches the desired value, the resistance and reactance show measured values very distant from the ideal.

Test 8: Balun with a complex load of 181.2 - j117.3 Ohms					
	Ideal SWR: 1.978:1				
	3-Core Voltage Balun				
Freq	SWR50	R	X		
13	1.99	30.84	-19.85		
14	1.95	29.57	-16.30		
15	1.93	28.40	-12.93		



3-Core 4:1 Balun: Load 181.2 - j117.3 Ohms

Fig. 19

Conclusions

The 2 versions of a 4:1 voltage balun share a common basic structure: the use of T200-2 cores with 15-18 bifilar turns to form the impedance transformation device. For the nominal load impedance value (200 Ω) and for other values up to an SWR of about 2:1, they also share a common performance limitation: At frequencies above about 18 MHz or so, the resistance drops precipitously and the inductive reactance climbs steadily. As a result, above the limiting frequency, the impedance transformation is much greater than 4:1.

Unlike the dual ferrite bead balun, where the higher-frequency departures from the ideal are relatively minor up through about 30 MHz, the 4:1 voltage balun shows considerable fluctuation of the resistance and reactance components as the frequency increases. The tests do not permit us to attribute a specific source to the fluctuations. It is likely that the core material, T200 powdered iron cores with a μ of 10 (or 20 for T200-1), plays a major role in the frequency limitations. As well, the number and arrangement of the turns may contribute to the limitations and the fluctuations.

At the same time, despite a difference in both the size of the core stack and the number of turns, both versions of the voltage balun have very similar lower-frequency behaviors. At the upper end of the spectrum, the 3-core version shows a more rapid drop in resistance and a lower rate of inductive reactance increase as we raise the operating frequency.

Although some changes of material and winding technique might alter the impedance transformation performance of voltage baluns, there are numerous studies that strongly suggest that the voltage balun is a less perfect way of obtaining the desired 4:1 impedance change than a current balun, of which the ferrite bead balun is an example. Essentially, the assumption that, as we double the voltage, the current neatly halves is flawed. However, the tests that scan performance across a broad range of frequencies do not themselves report the voltage or current at the source end of the device. One might “back out” these values in relative terms from the resistance and reactance values or from the impedance magnitude and phase angle values that form the AIM-4170's most fundamental output.

It is likely that 4:1 voltage baluns will remain available to amateur stations and will continue to be used within ATUs that employ single-ended networks to provide a simulation of a balanced output. Therefore, if one wishes to know exactly what transformation is occurring at each frequency of interest, it would be useful to perform a scan of individual baluns.