4:1 Toroidal Current Baluns: Some Preliminary Measurements

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Past 4:1 balun tests have included a dual ferrite-bead current balun and a voltage balun. The present test focuses on a 4:1 Guanella current balun. The history of these baluns has been traced in many sources, including the many works of Jerry Sevick, W2FMI. The design predates the use of ferrite cores and includes air-core baluns. The basic design consists of two windings isolated from each other as well as possible. The windings should have a characteristic impedance that is the square root of the input and output impedances. A 50-Ω to 200-Ω balun dictates a winding impedance of 100 Ω. To achieve the step-up/step-down action, the lower impedance end connects the windings in parallel, while the higher-impedance end connects them in series. The advent of ferrite cores in ready supply allowed placing two windings on separate cores in close proximity. The limited permeability (μ) of early cores—still in wide use today—dictated bifilar windings with 15-18 turns per core.

More recently, cores with much higher permeability values have appeared. The cores permit the use of far fewer turns per winding. Some older Guanella designs have small resonance bumps (in one instance, at about 11.5 MHz) that the need for fewer winding turns eliminates. The requirement for fewer turns per winding also allows both windings to employ the same core.

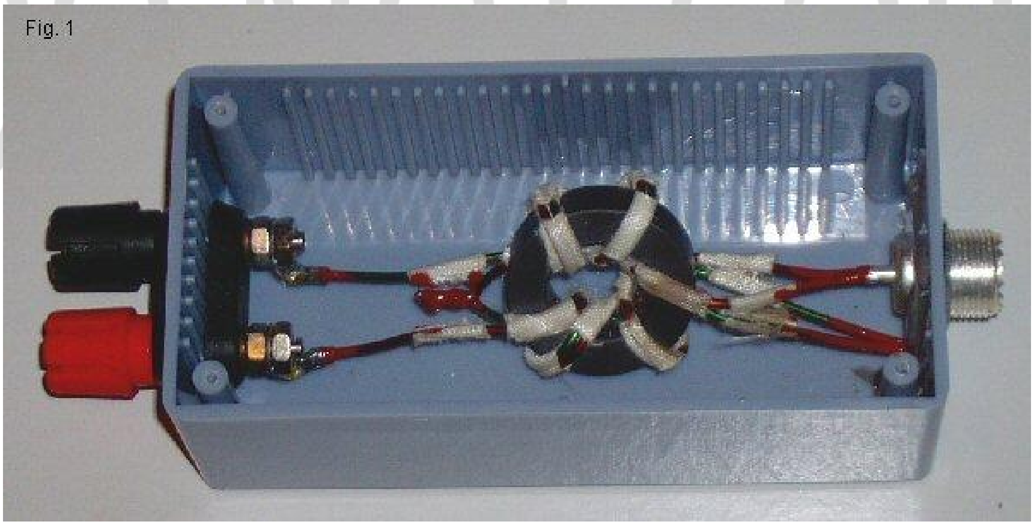
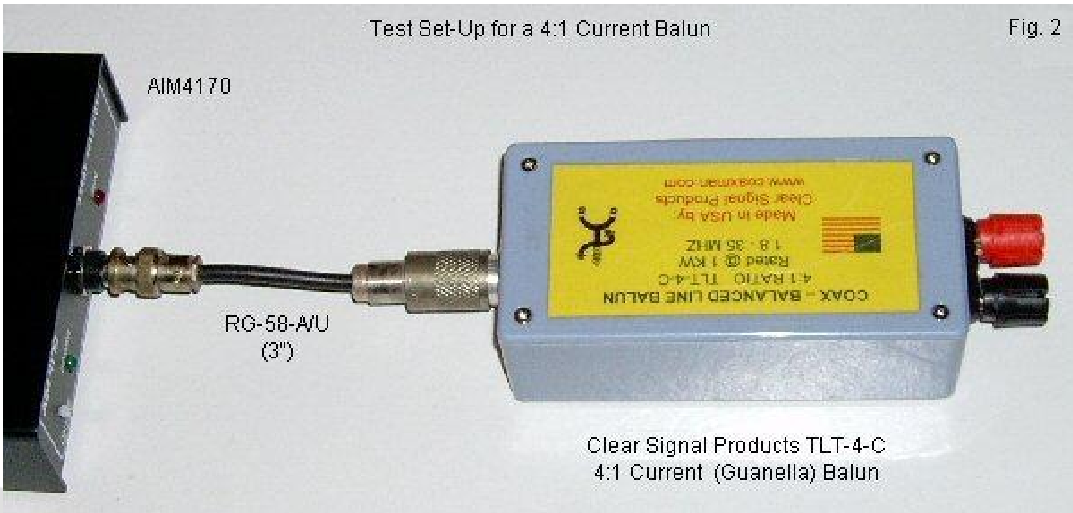


Fig. 1

The photo (**Fig. 1**) shows a version of the Guanella balun concept, but with a much higher permeability core. Clear Signal Products produces this balun (and a fully sealed outdoor version) using a single core for which μ = 1500 from Ceramic Magnetics of Fairfield, NJ. The high-μ allows a single 1.375”-diameter by 0.375”-thick core to carry both windings, which require only 3 turns each with wire spacing set for a 100-Ω characteristic impedance via glass tape. The case uses gray UV-resistant PVC, normally with a compatible sealant. I am indebted to Michael LaPuzza, KM5QX, of Clear Signal Products for sending me an unsealed unit to scan for this series. (See http://www.coaxman.com.)

Fig. 2 shows the test set-up, with the standard 3” length of RG-58 between the balun and the AIM4170. (Although the line is less than 1% of a wavelength at the highest frequency scanned, it was calibrated out of the test set-up.) We shall use the same set of loads for testing the impedance transformation properties of TLT-4-C balun as in past tests, and the results will have the same graphic appearance. Graph lines will include resistance (orange), reactance (ochre) and the 50-Ω SWR (red) over the 3 to 30 MHz range. (The AIM software automatically increases the range to 33 MHz to arrive at neat increments on its graphic display.)

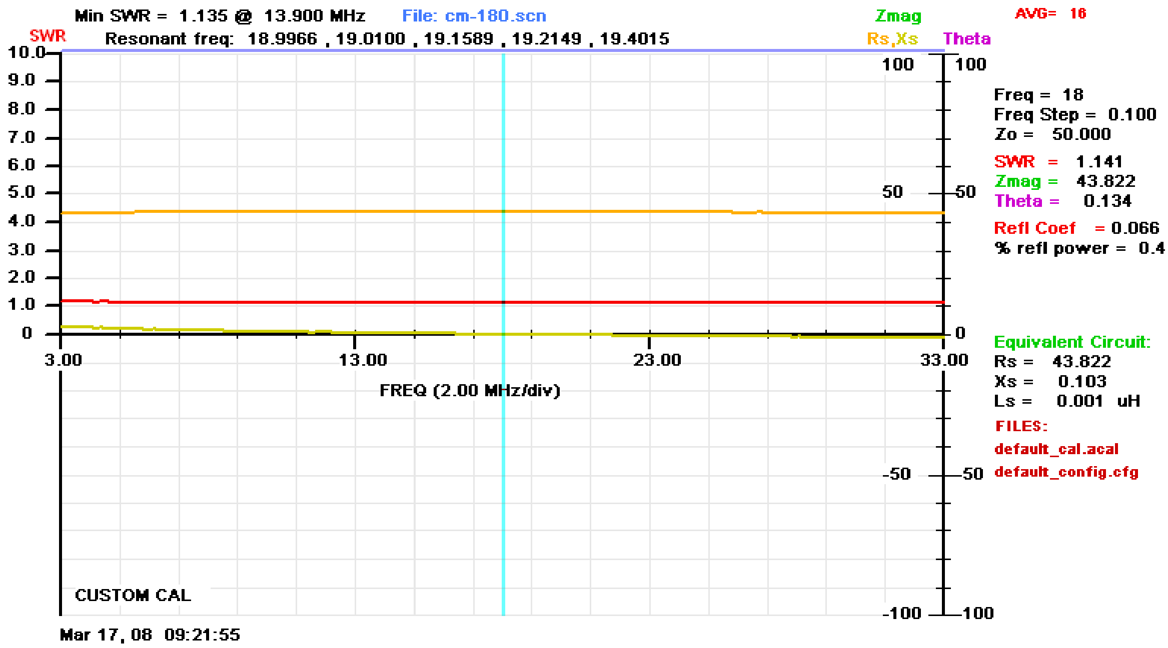


Test Set-Up for a 4:1 Current Balun Fig. 2

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 enough decimal places simply to allow easy identification of trends for some balun units that show only small variations. 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. The bottom row of the tables shows the amount of value change across the frequency range in the table.

The goal of the tests is to determine the accuracy of the impedance transformation using loads both close to ideal value and loads more distant from the ideal value. In many instances, employing simply an SWR measure does not tell the full story of the transformation over the complete frequency range. A given SWR value may result from an indefinitely large combination of resistance and reactance values. To what degree and under what circumstances a 4:1 balun design is a precision impedance transformer is the key question for the scans. The tests do not include determining the maximum power handling capability of the unit or the total impedance to common-mode currents as a measure of the balanced-to-unbalanced function of the unit.

Test 1: 180 Ω and Test 2: 220 Ω: Since the nominal load impedance is 200 Ω, the first two test loads surround it. **Fig. 3** and **Fig. 4** provide scan graphs for the two resistive loads. The test tables are side-by-side between the graphs. Both graphs (and test tables) show quite flat resistance curves with a slight peak in the middle frequency region. The reactance curves are very shallow, but still wider than the calculated range of the reactance associated with the load resistors.

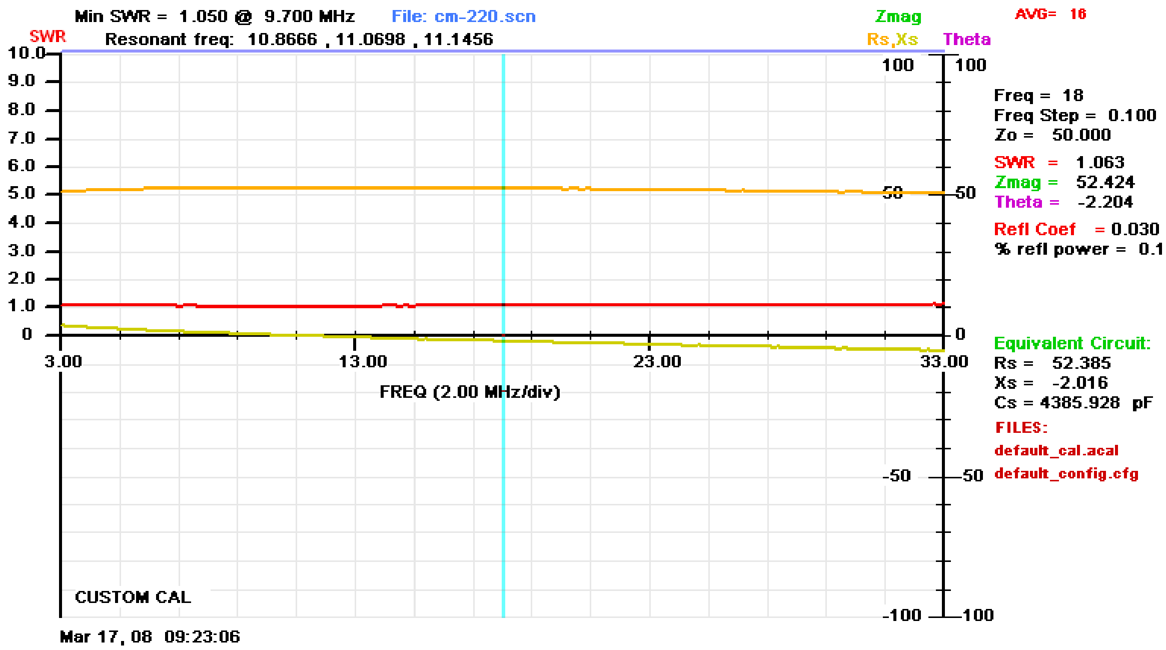


CSP TLT-4-C 4:1 Balun: 181.2 Ohms

Fig. 3

Test 1: Balun with resistive load of 181.2 Ohms						
Load R	Ideal In R	Ld SWR	In SWR			
181.2	45.300	1.026	1.104			
Freq	SWR50	R	X	Adj Id R	Adj Id X	
3.5	1.17	43.13	2.73	45.54	-0.19	
7.0	1.15	43.68	1.71	45.52	-0.37	
14.0	1.14	43.84	0.51	45.50	-0.74	
28.0	1.15	43.34	-0.67	45.46	-1.49	
Delta	0.03	0.71	-3.40			

Test 2: Balun with resistive load of 221.4 Ohms					
Load R	Ideal In R	Ld SWR	In SWR		
221.4	55.350	1.190	1.107		
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.07	51.50	3.31	55.11	-0.36
7.0	1.05	52.30	1.36	55.09	-0.70
14.0	1.06	52.62	-0.95	55.05	-1.39
28.0	1.09	51.35	-4.24	54.97	-2.76
Delta	0.04	1.27	-7.55		



CSP TLT-4-C 4:1 Balun: 221.4 Ohms

Fig. 4

Test 3: 152 Ω and Test 4: 100 Ω: The test loads below the ideal value aim for SWR values of about 1.33:1 and 2.0:1. **Fig. 5** and **Fig. 6** provide the scan graphics, along with side-by-side data sample tables. As appears to be typical of 4:1 current balun designs, the lower load resistance values result in very flat resistance curves with values very close to calculated ideals. The reactance curve for the 100-Ω load shows a small rise in inductive reactance in contrast to reactance curves for more nearly ideal load values.

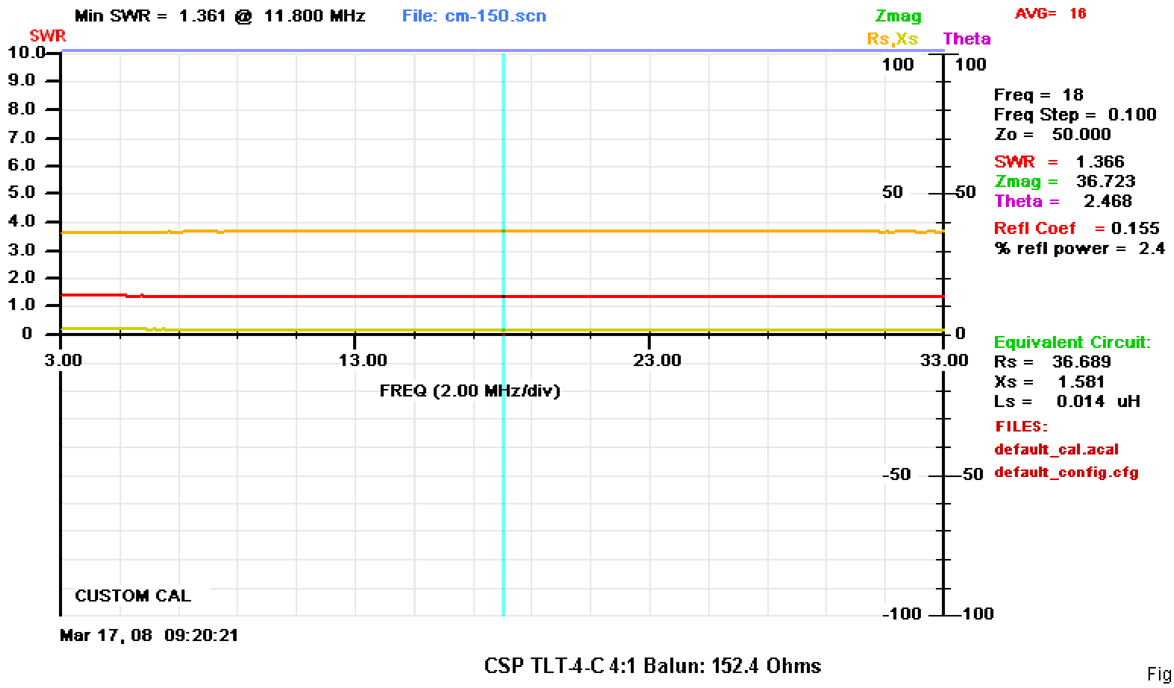


Fig. 5

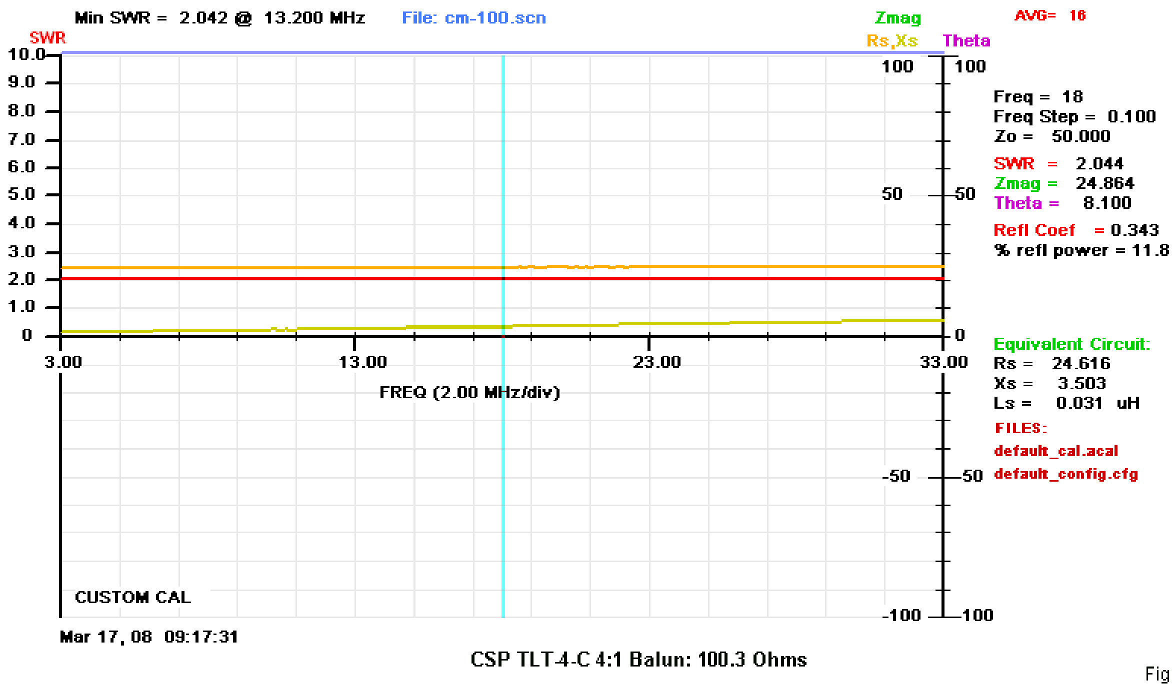


Fig. 6

Test 3: Balun with resistive load of 152.0 Ohms					
Load R	Ideal In R	Ld SWR	In SWR		
152.0	38.00	1.22	1.32		
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.39	36.08	2.32	37.86	-0.15
7.0	1.37	36.49	1.87	37.85	-0.22
14.0	1.36	36.73	1.56	37.83	-0.38
28.0	1.00	36.61	1.70	37.78	-0.68
Delta	0.39	0.65	-0.17		

Test 4: Balun with resistive load of 100.3 Ohms					
Load R	Ideal In R	Ld SWR	In SWR		
100.3	25.08	1.85	1.99		
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.07	24.24	1.76	25.06	0.03
7.0	2.05	24.40	1.99	25.06	0.09
14.0	2.05	24.47	2.91	25.06	0.20
28.0	2.05	24.73	5.00	25.05	0.42
Delta	0.02	0.49	3.24		

As the load value decreases, the total change of resistance decreases, while the change of reactance increases across the frequency spectrum. The amount is more numerically noticeable with respect to reactance than to resistance. However, neither total change would amount to something detectable in operation.

Test 5: 295 Ω and Test 6: 390 Ω: The next two tests use load resistance values higher than ideal, but with the SWR values of 1.33:1 and 2.0:1 as rough targets. **Fig. 7** and **Fig. 8** show the results graphically, with test sample tables to aid the identification of trends. The progression of higher load values show remarkably flat SWR curves. However, the resistance and reactance curves show distinct slopes. The resistance curve peaks in the 7 MHz region and declines thereafter. The decline is sharper with rising load values and the values never reach calculated ideal values. The reactance curves begin inductively at 3 MHz but become significantly more capacitive with rising frequency.

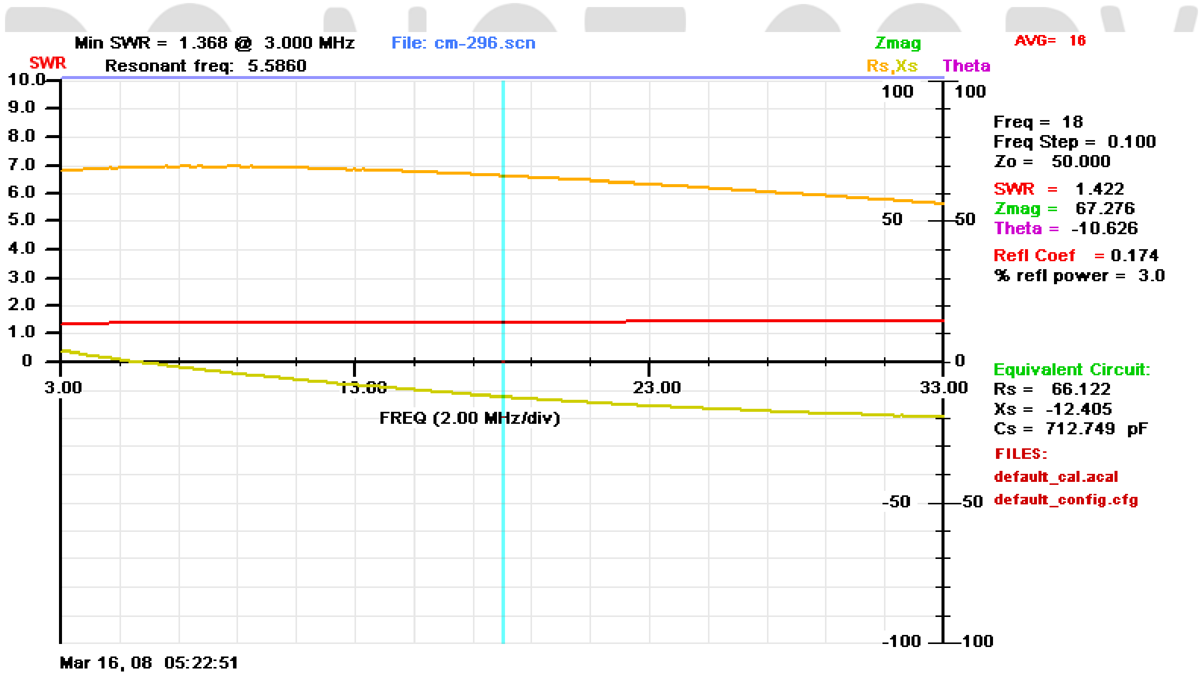
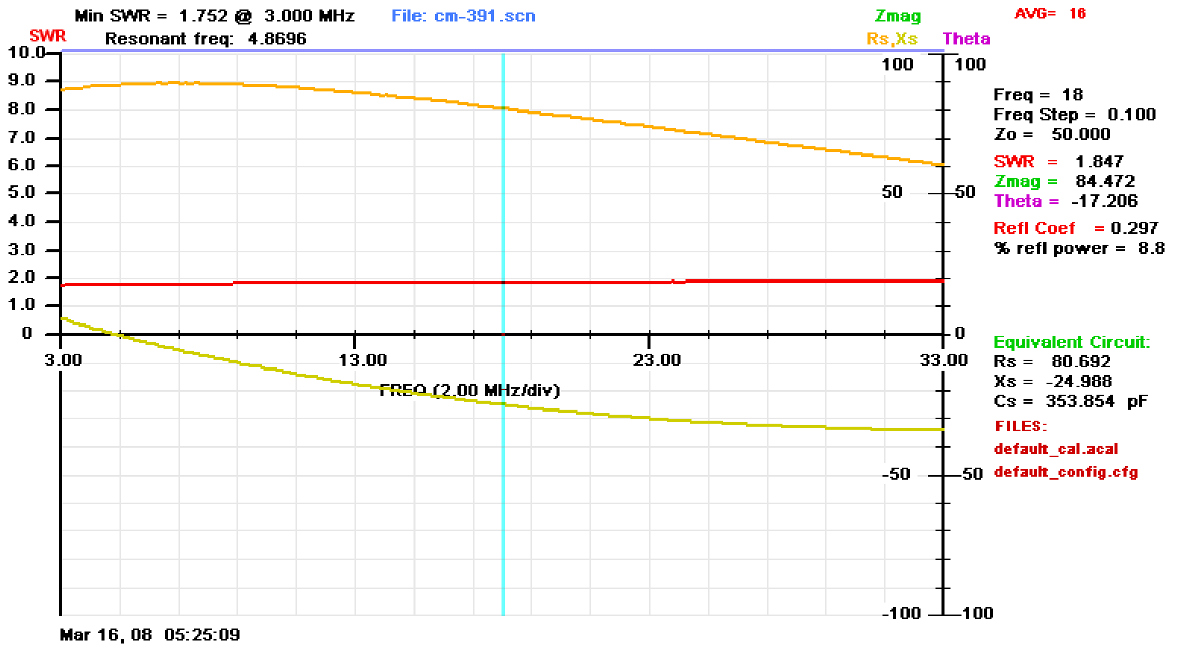


Fig. 7

Test 5: Balun with resistive load of 296.5 Ohms					
Load R	Ideal In R	Ld SWR	In SWR		
296.5	74.13	1.59	1.48		
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.37	67.86	4.91	73.91	-0.42
7.0	1.39	69.41	1.00	73.86	-1.10
14.0	1.40	69.42	-4.46	73.75	-2.46
28.0	1.42	65.90	-12.32	73.55	-5.19
Delta	0.04	3.52	-17.23		

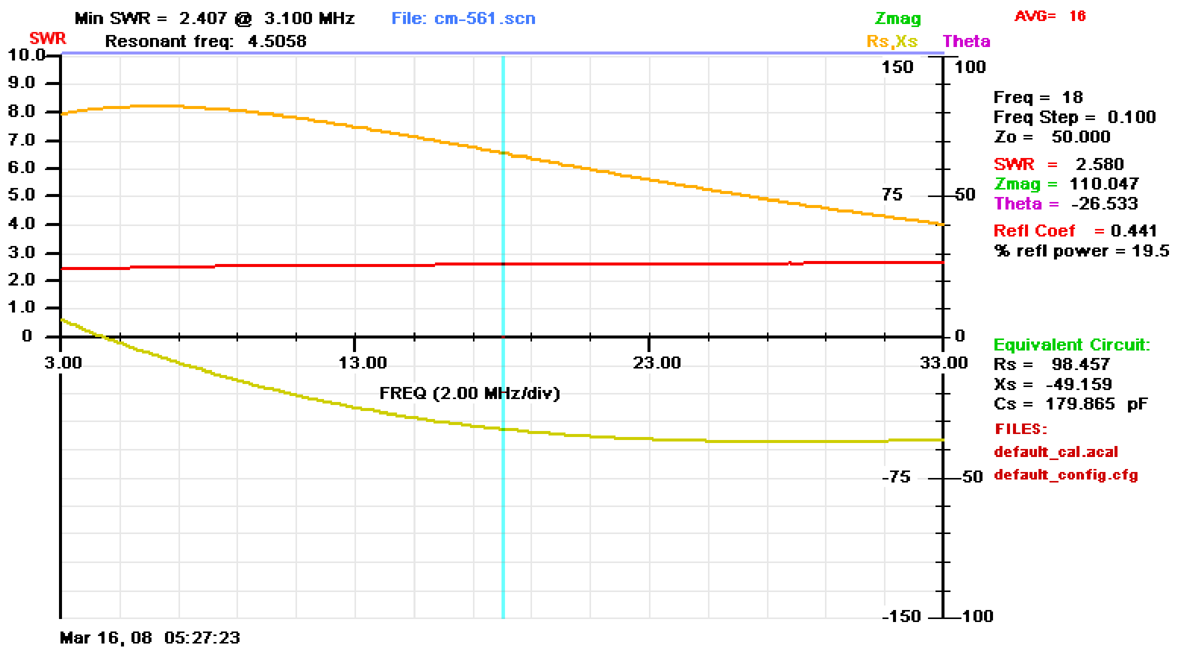
Test 6: Balun with resistive load of 391.5 Ohms					
Load R	Ideal In R	Ld SWR	In SWR		
391.5	97.88	2.10	1.96		
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.76	87.12	7.07	97.40	-1.37
7.0	1.80	89.77	-0.14	97.27	-2.61
14.0	1.82	88.99	-10.66	97.01	-5.08
28.0	1.84	80.49	-24.98	96.50	-10.03
Delta	0.09	9.28	-32.05		



CSP TLT-4-C 4:1 Balun: 391.5 Ohms

Fig. 8

Test 7: 560 Ω: The final test load simulates an SWR value of about 3:1 at the load end of the balun. **Fig. 9** supplies the scan graph, with the test table below it. The trends that first appeared with the 296-Ω load continue. (Note the Y-axis expansion to 150 Ω maximum value to accommodate the input values.) The curves become steeper, except for the SWR line, which is close to flat. The slight rise in its value results largely from the fact that the capacitive reactance levels off above about 23 MHz and begins a slow decline toward the upper end of the scan spectrum.



CSP TLT-4-C 4:1 Balun: 561.0 Ohms

Fig. 9

Test 7: Balun with resistive load of 561.0 Ohms					
Load R	Ideal In R	Ld SWR	In SWR		
561.0	140.25	3.02	2.81		
Freq	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.42	119.47	12.13	139.82	-2.61
7.0	2.49	124.42	-2.01	139.40	-5.13
14.0	2.54	121.63	-23.09	138.56	-10.16
28.0	2.57	100.63	-47.69	136.87	-20.23
Delta	0.15	23.79	-59.82		

Test 8: 181.2 – j117.3 Ω @ 14 MHz: The final test employs a single sample of a series combination of a load resistance and capacitance. The reactance shown results from the use of a 96-pF capacitor in series with the listed resistor. The goal of this test was to determine, at least for the sample, how close to ideal calculated input values that the balun transformation of resistance and reactance would come. The results from 13 to 15 MHz appear in the following test table.

Test 8: Balun with a complex load of 181.2 - j117.3 Ohms					
	Ideal SWR: 1.978:1				
	CSP TLT-4-C 4:1 Current Balun				
Freq	SWR50	R	X		
13	1.94	35.48	-24.41		
14	1.88	34.76	-22.03		
15	1.82	34.39	-19.63		

Ideal calculated values are 45.3 – j29.33 Ω at 14 MHz. The TLT-4-C balun values come closer to the ideal than any other balun in this series of tests (except for the ferrite bead balun) Of course, the test units for this series fall far short of sampling even a significant, let alone a major portion of the marketplace.

Conclusion

Standard use of a Guanella 4:1 current balun targets a relatively narrow range of load and input impedance values. The test scans used here are not intended to form a positive or negative judgment about baluns based on the use of load values with a considerable span of values. Rather, the goal has been to characterize balun performance within the limited scope of test units available for scanning with the AIM4170.

The CSP TLT-4-C balun has very similar impedance transformation characteristics to the dual ferrite-bead balun, even with high resistance loads. These characteristics are generally superior to those of common dual-core Guanella designs using lower permeability cores and larger windings, such as the MFJ-912 (independently tested but not shown here). The TLT-4-C design also—if the wire size is an indicator—can handle higher power levels than the ferrite bead balun that uses RG-62 cable and relatively small beads.

The similarities in transformation characteristics between the two current baluns might lead to concern that something in the test set-up produces the resistance and reactance trends with higher load values. The following table, which includes summery values for both current baluns, also includes values for the MFJ-911 voltage balun, whose reactance curves show quite different characteristics among the values. Details on the tests on the other listed baluns in the table appear in separate reports.

Performance Comparisons Among Sampled 4:1 Baluns											
Test 1: Balun with resistive load of 181.2 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.12	44.73	0.56	1.17	43.13	2.73	1.35	44.89	13.20	45.54	-0.19
7.0	1.12	44.67	0.38	1.15	43.68	1.71	1.25	45.92	9.97	45.52	-0.37
14.0	1.14	44.06	0.45	1.14	43.84	0.51	1.38	42.34	12.68	45.50	-0.74
28.0	1.17	42.97	1.25	1.15	43.34	-0.67	2.94	27.09	34.89	45.46	-1.49
Delta	0.05	1.76	0.69	0.03	0.71	-3.40	1.69	18.83	24.92		
Test 2: Balun with resistive load of 221.4 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.08	53.74	0.47	1.07	51.50	3.31	1.38	54.29	16.43	55.11	-0.36
7.0	1.07	53.68	-0.22	1.05	52.30	1.36	1.22	56.06	8.73	55.09	-0.70
14.0	1.06	52.85	-0.93	1.06	52.62	-0.95	1.15	49.68	6.76	55.05	-1.39
28.0	1.03	51.12	-1.24	1.09	51.35	-4.24	2.64	27.21	29.50	54.97	-2.76
Delta	0.04	2.62	-1.71	0.04	1.27	-7.55	1.42	27.08	22.74		
Test 3: Balun with resistive load of 152.0 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.34	37.41	0.80	1.39	36.08	2.32	1.46	37.74	11.25	37.86	-0.15
7.0	1.35	37.21	0.86	1.37	36.49	1.87	1.43	38.49	10.80	37.85	-0.22
14.0	1.36	36.88	1.35	1.36	36.73	1.56	1.64	36.45	16.31	37.83	-0.38
28.0	1.39	36.14	2.90	1.00	36.61	1.70	3.30	26.87	39.32	37.78	-0.68
Delta	0.06	1.27	2.10	0.39	0.65	-0.17	1.87	11.62	28.52		
Test 4: Balun with resistive load of 100.3 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.95	25.65	0.90	2.07	24.24	1.76	2.06	25.14	8.39	25.06	0.03
7.0	1.96	25.59	1.45	2.05	24.40	1.99	2.11	25.49	11.77	25.06	0.09
14.0	1.97	25.45	2.63	2.05	24.47	2.91	2.45	25.13	21.39	25.06	0.20
28.0	2.01	25.22	5.26	2.05	24.73	5.00	4.57	21.96	47.71	25.05	0.42
Delta	0.06	0.43	4.36	0.02	0.49	3.24	2.47	0.00	39.32		
Test 5: Balun with resistive load of 296.5 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.44	71.76	-0.13	1.37	67.86	4.91	1.68	69.91	23.70	73.91	-0.42
7.0	1.43	71.27	-2.13	1.39	69.41	1.00	1.50	73.95	6.05	73.86	-1.10
14.0	1.41	69.77	-4.29	1.40	69.42	-4.46	1.22	59.95	-4.23	73.75	-2.46
28.0	1.36	66.24	-7.13	1.42	65.90	-12.32	2.47	25.55	22.85	73.55	-5.19
Delta	0.08	5.52	-7.00	0.04	3.52	-17.23	1.25	48.40	27.93		
Test 6: Balun with resistive load of 391.5 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	1.87	93.31	-1.07	1.76	87.12	7.07	2.15	88.24	35.18	97.40	-1.37
7.0	1.86	92.38	-5.07	1.80	89.77	-0.14	1.93	96.46	0.98	97.27	-2.61
14.0	1.83	89.72	-10.18	1.82	88.99	-10.66	1.58	68.63	-19.60	97.01	-5.08
28.0	1.75	82.66	-16.22	1.84	80.49	-24.98	2.53	22.67	17.29	96.50	-10.03
Delta	0.12	10.65	-15.15	0.09	9.28	-32.05	0.95	73.79	54.78		
Test 7: Balun with resistive load of 561.0 Ohms											
	Dual Ferrite Bead Current Balun			CSP TLT-4-C 4:1 Current Balun			MFJ-912 Voltage Balun				
Freq	SWR50	R	X	SWR50	R	X	SWR50	R	X	Adj Id R	Adj Id X
3.5	2.65	132.45	-3.28	2.42	119.47	12.13	3.06	115.27	60.86	139.82	-2.61
7.0	2.63	130.29	-12.31	2.49	124.42	-2.01	2.78	137.70	-11.11	139.40	-5.13
14.0	2.56	122.75	-23.38	2.54	121.63	-23.09	2.27	74.85	-45.20	138.56	-10.16
28.0	2.43	107.11	-35.50	2.57	100.63	-47.69	2.90	18.37	12.08	136.87	-20.23
Delta	0.22	25.34	-32.22	0.15	23.79	-59.82	0.79	119.33	106.06		

(*Special Note*: Some of the values in the table differ from those appearing in the earlier reports, since I re-tested all baluns after calibrating the 3" connecting cable out of the measurements. Although the differences will be apparent in a table of values, the shape of the scanned curves did not change. A fuller set of measurements, with added examples of both voltage and current 4:1 baluns will appear at my personal web site.)

Current Balun Behavior: Measurements show that for the current baluns (the ferrite-bead balun and the CSP-TLT-4-C), with loads higher than the ideal load impedance, the resistance value at the input decreases with rising frequency. At the same time, the input reactance becomes increasingly capacitive for the same frequency range. The higher that the load resistance is relative to an ideal load, the steeper that the curves become for both resistance and reactance. At the same time, the 50-Ω SWR values calculated for the resistance and reactance remain relatively constant, even with the 561-Ω load.

The behavior of the resistance and reactance for loads that are not matched to the balun's characteristic impedance and configuration do not represent material limitations or similar possible flaws in design. Rather, they are inherent factors in the design itself. The current baluns consist of sections of transmission line operated over a wide frequency range. When we attach a load to a simple transmission line that is higher than the line's characteristic impedance, the input end of the line will show values of resistance and reactance follow the same patterns displayed by the balun. In fact, the calculated values for simple lines are within a few percent of the measured values for the balun. Since the load resistors for these tests are not perfect, and since the test measurements have a limited range of precision, it is not possible to separate the transmission-line impedance transformation with unmatched loads from any other source of variation. For practical purposes, the values shown by the measurements are in accord with the behavior of the loads relative to the impedance transformation properties of the transmission lines that underlie them.

The use of a very-high permeability core with 3 bifilar turns per winding in the TLT-4C Guanella design provides the unit with impedance transformation performance that approaches the limit for current baluns. When used within its intended range (smaller than the test range), the impedance transformation would be well within operational limits for virtually all applications.

My thanks once more to Michael LaPuzza and Clear Signal Products for supplying the test unit.