Development and Measurement of a Second Generation Balun Candidate for the LWA

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Abstract

In this report, we present a new active balun that has been developed for the Long Wavelength Array project. The NRL/NRAO balun – so-called because it was developed in a collaborative effort between the Naval Research Laboratory and the National Radio Astronomy Observatory – provides roughly 32 dB of gain with a noise temperature of 120 K across the LWA frequency band of 20–80 MHz. This is 8 dB more gain and roughly half the noise temperature of the Hicks balun, the current baseline balun design for the LWA. This balun could prove to be an attractive replacement for the Hicks balun in the effort to achieve the Galactic noise dominance requirements of the LWA. The following sections provide more detail on the layout and test results of a single-polarization prototype of this balun.

I. Introduction

The Long Wavelength Array, currently in the design stages, is a radio telescope facility that will be built to explore the Universe in the 20 – 80 MHz frequency range. It is a requirement that the instrument performs with a minimum of 6 dB Galactic noise dominance in that frequency range. Achieving this specification will require the use of high gain/low noise active baluns connected to the antenna feed points. Currently the baseline design for this component is the Hicks balun , which has an average gain of 24 dB and an average noise temperature of 250 K in the LWA frequency band [1], [2]. The Naval Research Laboratory and the National Radio Astronomy Observatory have collaborated to produce the NRL/NRAO balun. The NRL/NRAO balun performs with 8 dB more gain, and roughly half the noise temperature compared to the Hicks balun. It could therefore be an attractive alternative to the Hicks balun in achieving the 6 dB Galactic noise dominance requirement for the LWA.

II. Design and Layout

The NRL/NRAO makes use of a previously developed low noise 8 dB amplifier cascaded with a *Minicircuits* Gali 74 MMIC 24 dB amplifier [3]. A circuit schematic of the balun is shown in Figure 1. Figure 2 shows the PCB layout, and a photograph of a fully assembled single polarization prototype is shown in Figure 3. The NRL/NRAO balun prototype uses the HX62A hybrid power combiner, which features 50Ω input and output ports. We have worked with *Tele-tech* Corporation to make available a version of the hybrid power combiner with a 75Ω output port (HX62-27A) that can be used with 75Ω coaxial cable [4], and is the same price as the HX62A hybrid. The HX62-27A hybrid has a slightly larger footprint, but the same pin-out structure the HX62A hybrid, and can therefore easily be accommodated in the balun layout. Specification sheets for the TX60-27 transformer (used in the 8 dB gain stages) and the HX62A hybrid can be found in the Appendix of this report. The specification sheet for the HX62-27A is not yet available from *Tele-tech*. The Appendix also contains parts costs for the NRL/NRAO balun, as well as the Hicks balun.

TABLE I
SUMMARY OF NRL/NRAO BALUN CHARACTERISTICS IN LWA BAND (20 – 80 MHZ)

	Hicks Balun	**NRL/NRAO balun**
Current Draw	160 mA	200 mA
Voltage Range	14.5 V – 20 V	14.5 V – 20 V
Noise Temperature	$\sim$ 250 K	$\sim$ 120 K
Gain	$\sim$ 24 dB	$\sim$ 32 dB
Input Match for 100 Ω load ($\|S11\|$)	$\leq$ -10 dB	$\leq$ -10 dB
Output Match for 50 Ω load ($\|S22\|$)	$\leq$ -12 dB	$\leq$ -12 dB
1 dB Compression Point (Input Power)	$\sim$ -5 dBm	$\sim$ -14 dBm
Input IP2	28 dBm	23.5 dBm
Input IP3	1.5	-6 dBm

III. CHARACTERIZATION

The NRL/NRAO balun was characterized at the NRAO Dynamic Spectroscopy Laboratory in Charlottesville, VA. S-parameter, noise temperature, 1 dB compression point, and intermodulation distortion measurements were performed on this balun. Figure 4 shows the balun noise temperature, which has an average value of 120 K across the LWA frequency band. Figure 5 shows the magnitudes and phases of the measured reflection and transmission coefficients. The gain of this balun ($|S21|$) is ~ 32 dB, and the input return loss for a 50Ω load is ≤ -10 dB over most of the 20 – 80 MHz LWA frequency band. Figure 6 shows the 1 dB compression point measurement. The balun reaches its 1 dB compression point at an input power of ~ -14 dBm. Figure 7 shows the intermodulation distortion measurements. The second order intercept occurs at an input power level of ~ 23.5 dBm and the third order intercept occurs at an input power level of ~ -6 dBm. The measurement results of the NRL/NRAO balun are summarized in Table I. The characteristics of the Hicks balun are also included for comparison.

IV. FUTURE WORK AND COMMENTS

We have reported on a new balun prototype that has been developed for the Long Wavelength array. Laboratory measurements on a single polarization prototype show that this balun delivers ~ 32 dB of gain with ~ 120 K noise temperature over the LWA band of 20–80 MHz. This is an improvement of roughly 8 dB in gain and a factor of two in noise temperature over the Hicks balun. In addition, the NRL/NRAO balun could be built to mate with either 50Ω or 75Ω coaxial cable, lending some flexibility to the design of the electronics chain.

Our next step is to obtain sky noise measurements on the NRL/NRAO balun with a large blade antenna at the LWDA site. Ylva Pihlstrom at the University of New Mexico will be aiding us in this effort. Future memos will contain details on these measurement results, as well as work on a dual polarization prototype.

ACKNOWLEDGMENTS

Basic research in radio astronomy at the Naval Research Laboratory is supported by 6.1 base funding. The authors would also like to thank the National Radio Astronomy Observatory - National Technology Center for providing us with the laboratory resources needed for the amplifier measurements.

REFERENCES

[1] R. Bradley, "NRAO NTC – DSL Report 1 (LWA Memo 19)," February 2005.
[2] P. Ray, S. Ellingson, R. Fisher, N. Kassim, L. Rickard, and T. Clarke, "A Strawman Design for the Long Wavelength Array," *LWA Memo Series (Memo 35)*, April 2006.
[3] B. Hicks, N. Paravastu, R. Bradley, and C. Parashare, "A Low Noise, High Linearity Lossless Feedback Amplifier for LWA Applications," *LWA Memo Series (Memo 71)*, December 2006.
[4] Tele-Tech Corporation, *http://www.tele-tech-rf.com/*, 2050 Fairway Drive, Bozeman, MT 59715 USA.

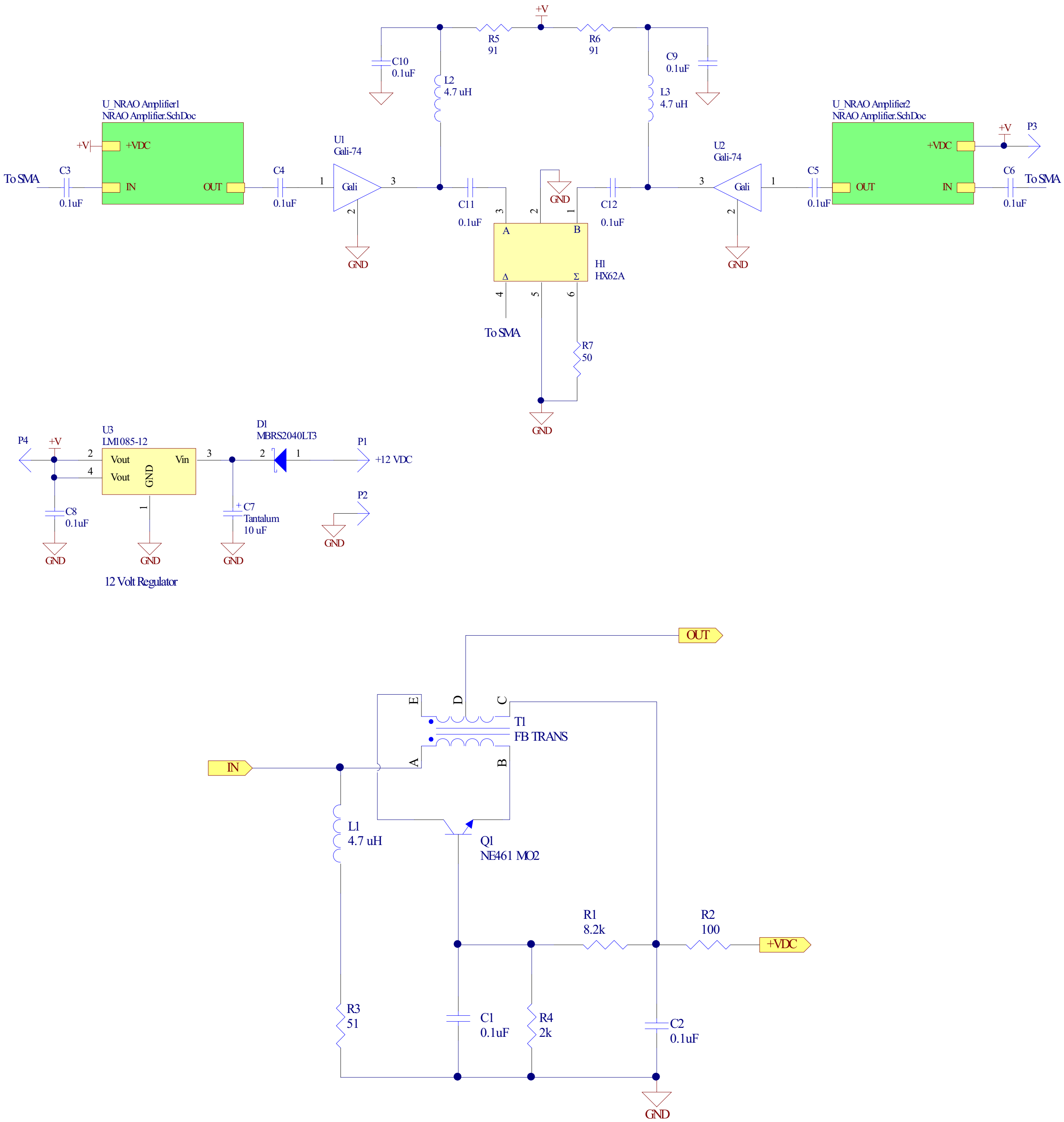


Fig. 1. Top – circuit schematic of the NRL/NRAO balun. Bottom – circuit schematic for the 8 dB gain stage, which are represented by green boxes in the balun schematic.

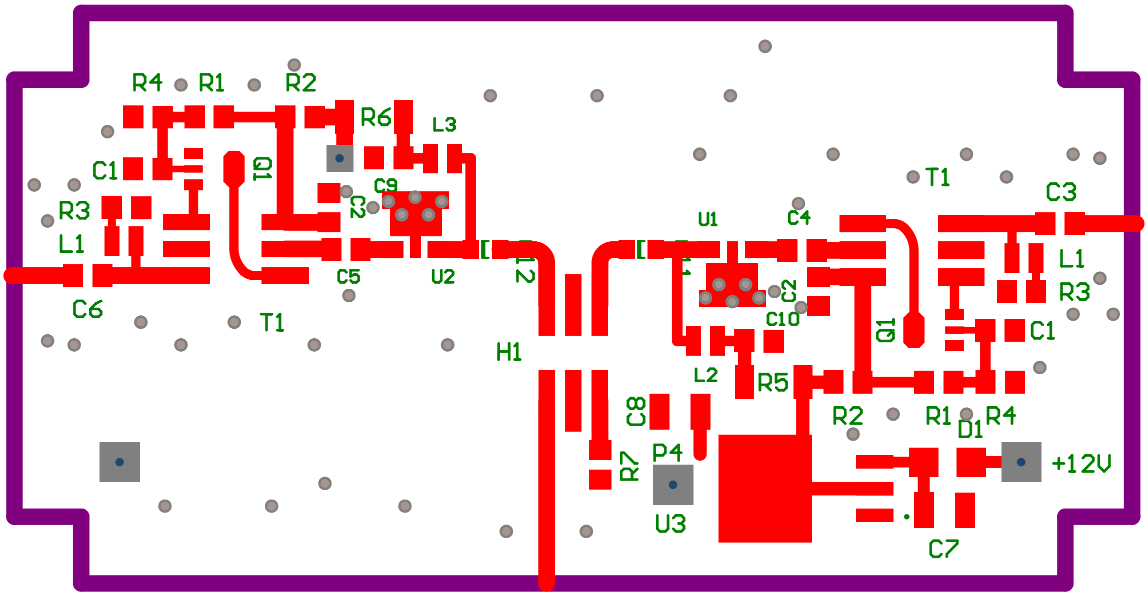


Fig. 2. The PCB layout for the NRL/NRAO balun.

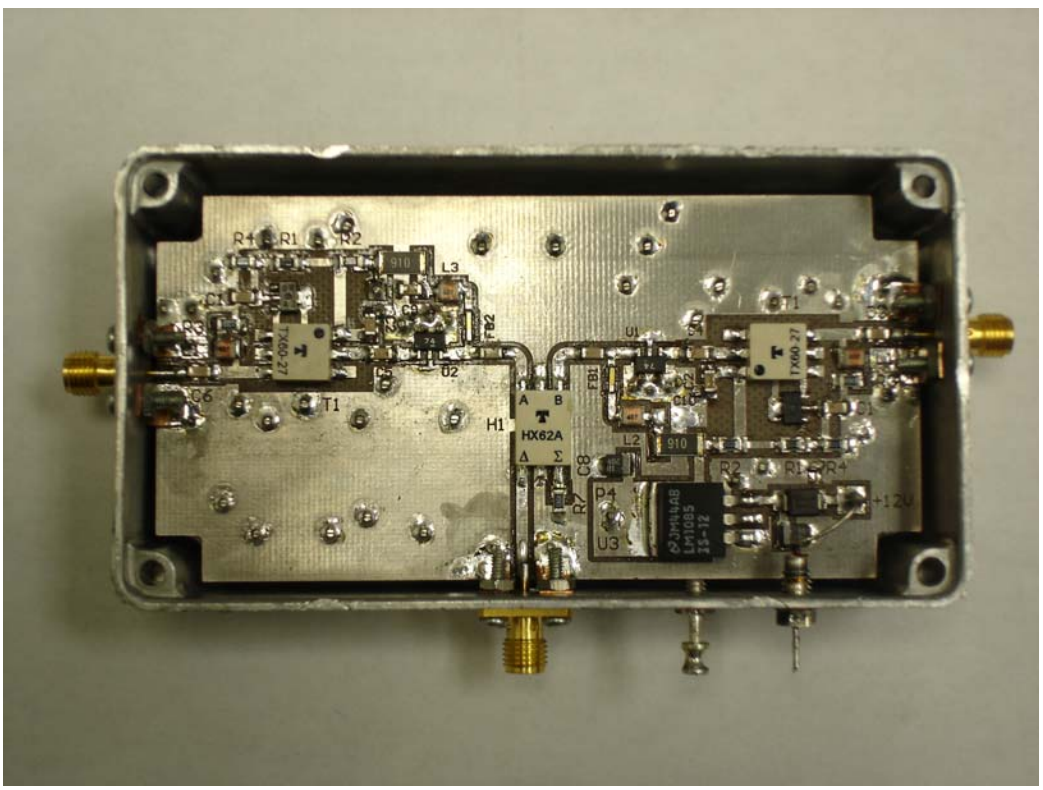


Fig. 3. A photograph of a single polarization prototype of the NRL/NRAO balun.

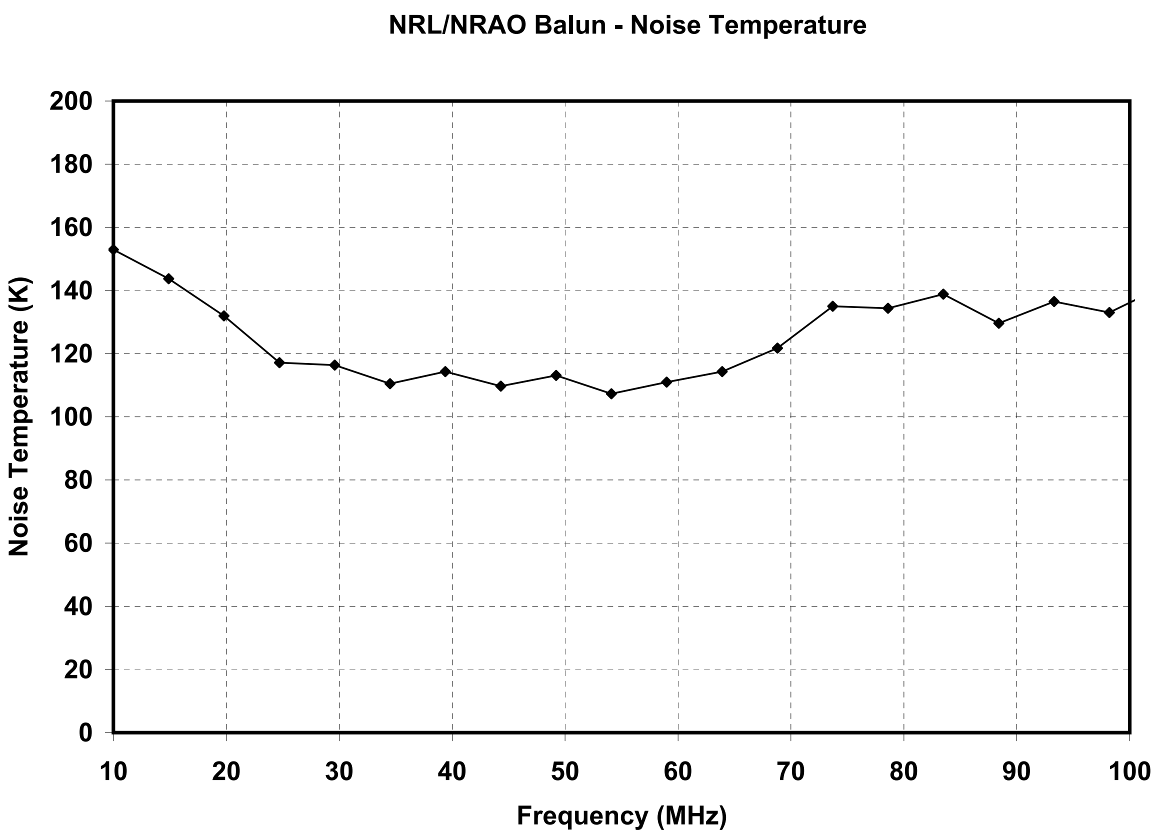
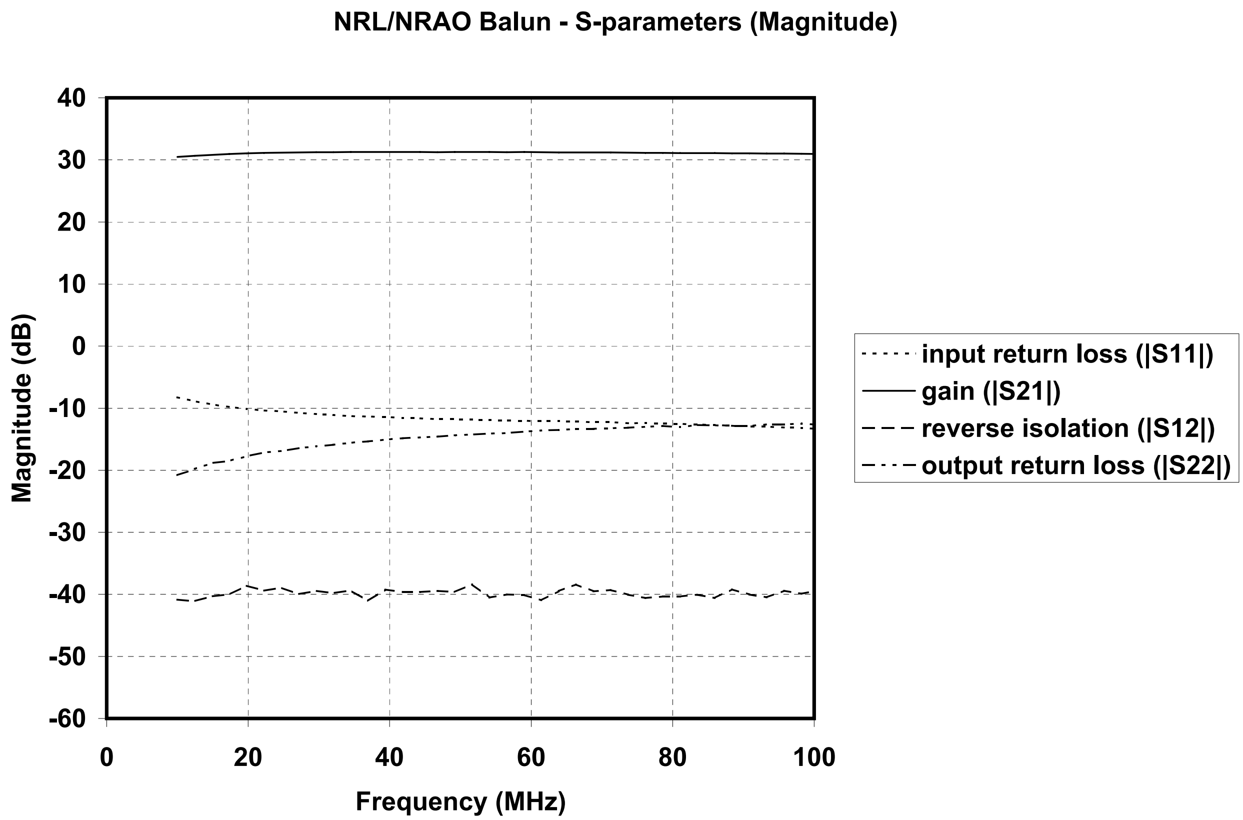


Fig. 4. The NRL/NRAO balun exhbits an average noise temperature of 120 K in the LWA frequency band. This is roughly half the noise temperature of the Hicks balun.



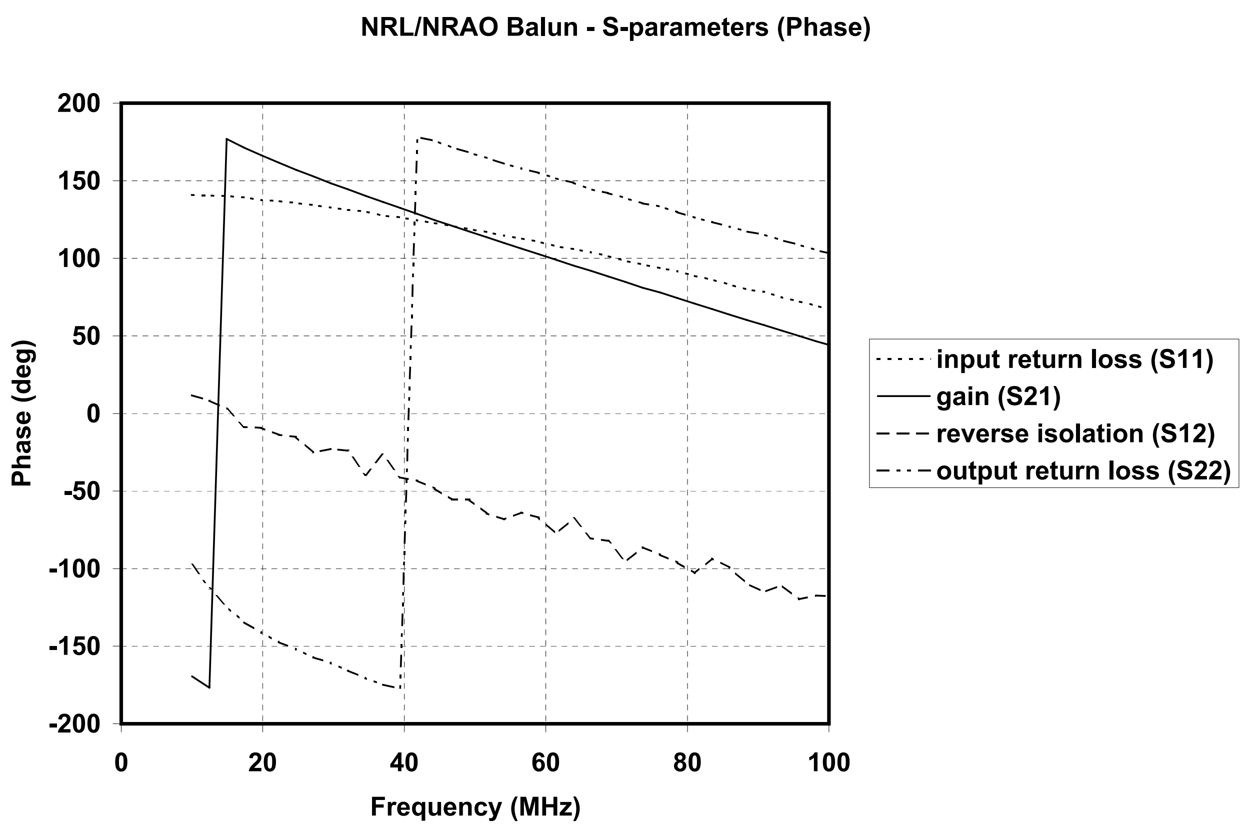


Fig. 5. Top – the magnitudes of the reflection and transmission coefficients of the NRL/NRAO balun. Bottom – the phases of the reflection and transmission coefficients of the NRL/NRAO balun. The balun gain ($|S21|$) is $\sim$ 32 dB across most of the LWA frequency band - 8 dB greater than the Hicks balun.

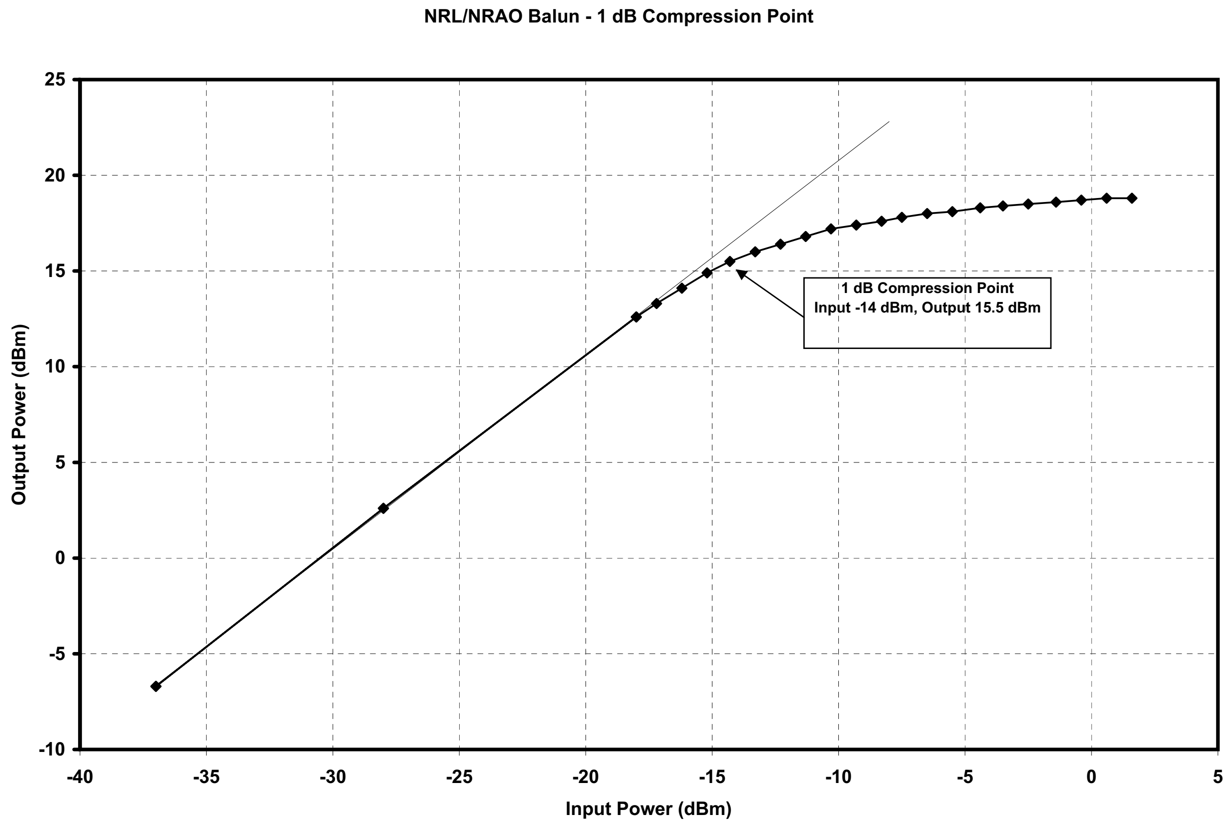


Fig. 6. The 1 dB compression point of the NRL/NRAO balun occurs at an input power of ~ -14 dBm.

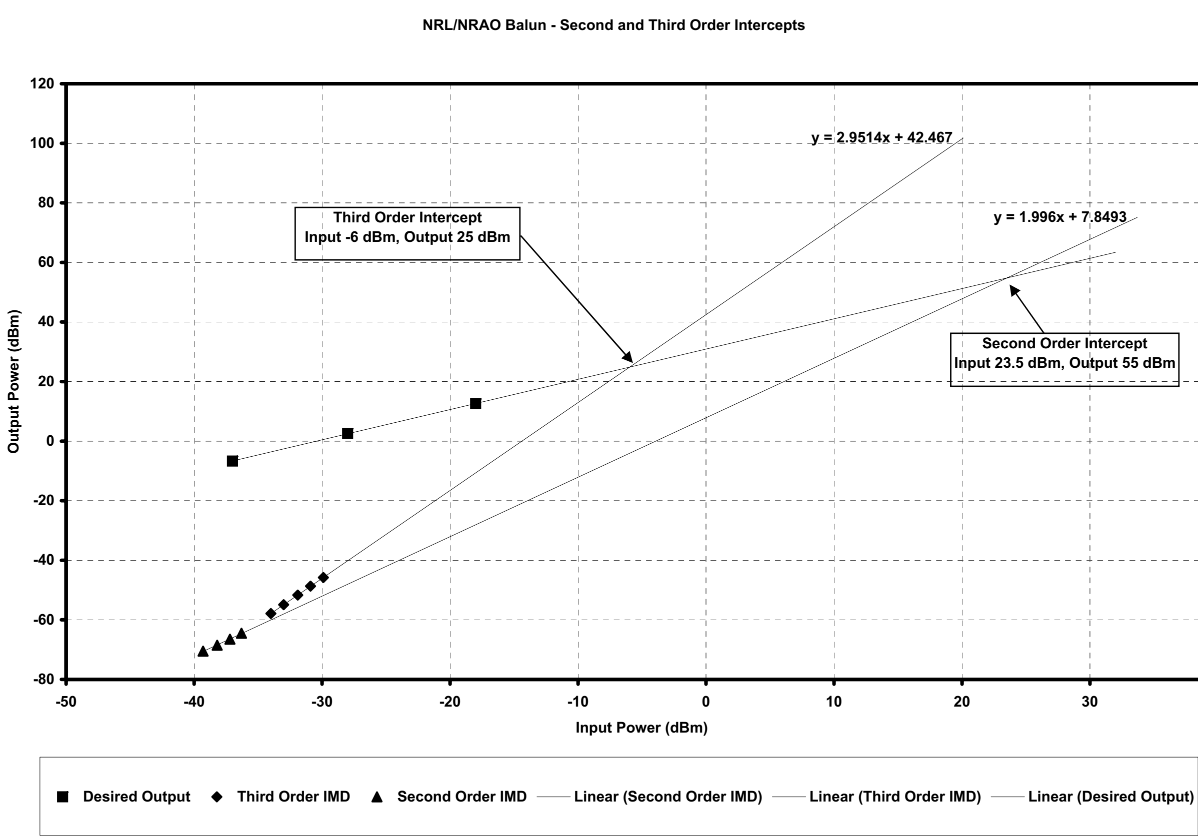
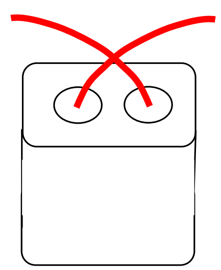


Fig. 7. The second and third order intercept measurements of the NRL/NRAO balun.

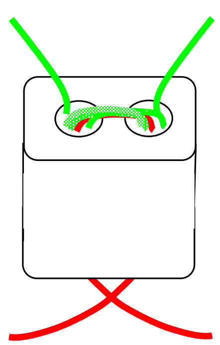
APPENDIX

Assembly Instructions TX60-27
October 16, 2006, drawn by Gib Curtis
PRELIMINARY

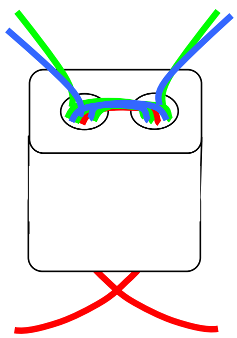
Substrate	21-4860-00	TX60-27	(1)
Cover	60-1132-11	Plastic .3x.3x.15	(1)
Core	50-1024-20	Balun "Fair-Rite" 2843002302-0	(1)
Wire	65-1360-02	#36 HPN blue	(3.0")
Wire	65-1360-02	#36 HPN green	(3.0")
Wire	65-1360-02	#36 HPN red	(2.0")
Clip	59-9820-01	Substrate SMD	(6)



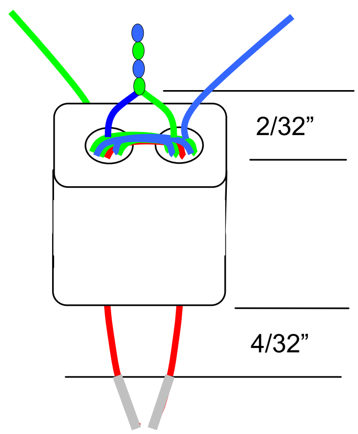
Making the beginning tail 7/8" long, wind 1 turn with 2" of #36 RED wire in the 2 hole core as shown. Red tails cross. This wire must be wound on the core first.



Turn the core over, end for end. Making the beginning tail 7/8" long, wind 4 turns with 3" of #36 GREEN wire over the 1 turn of red wire as shown.



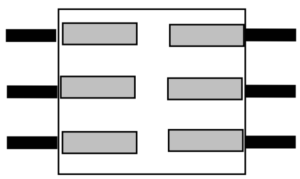
Next, making the beginning tail 1” long, wind 3 turns on the core with 3” of #36 BLUE as shown in the figure.

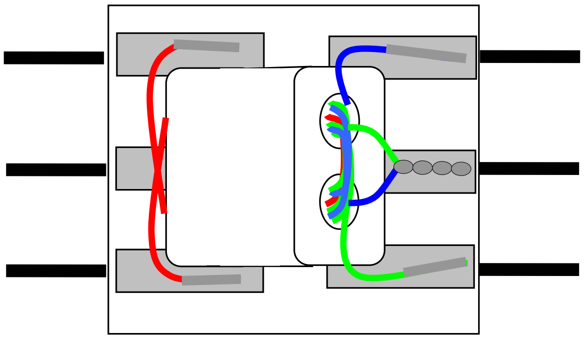


Center tap the core by winding one blue wire with one green wire as shown in the figure. Make the center tap 2/32” from the core body.

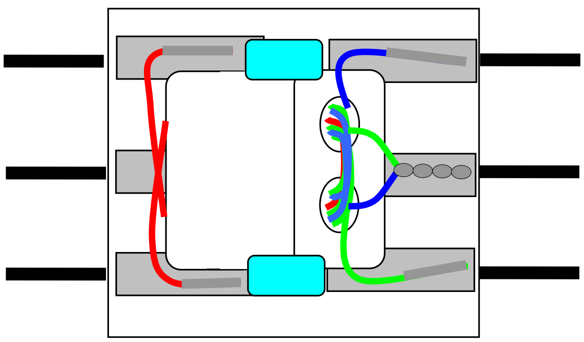
Tin wires using dimensions shown in the figure.

Assemble the Clip leads to the strip of 5 substrates using the lead bender and clencher tools.

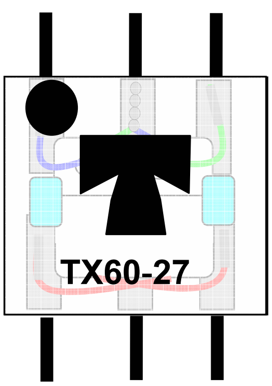




Use High Temp Sn96 solder. Mount the core to the header as shown in the figure. All wires surface mount. Red wires cross.



Encapsulate with white RTV as shown in the figure.



Adhere the cover to the substrate using high temp epoxy. Orientation is as shown in the Figure.
Cut the leads using the lead cutting fixture.

"MAGIC TEE" HYBRID

180° HYBRID JUNCTION — MODEL HX62A

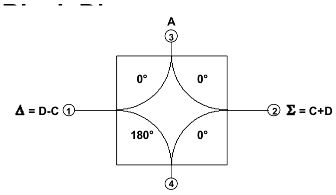
Guaranteed Specifications

Parameter	Range	Limits
Frequency	300 kHz to 300 MHz	Min
Insertion Loss	300 kHz to 300 MHz	1 dB Max
Isolation	300 kHz to100 MHz	35 dB Min
	100 MHz to 300 MHz	25 dB Min
Amplitude Balance	300 kHz to 100 MHz	.25 dB Max
	100 MHz to 300 MHz	.75 dB Max
Phase Balance	300 kHz to 100 MHz	1° Max
	100 MHz to 300 MHz	3° Max
VSWR	300 kHz to 1 MHz	1.5:1 Max
	1 MHz to 300 MHz	1.2:1 Max
Impedance	50 Ohms	Nominal

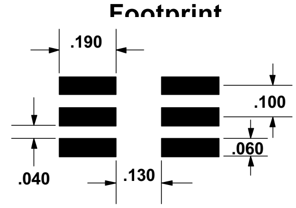
Note: All specifications apply in a 50 Ohm system. Performance will differ slightly in a 75 Ohm system.

Maximum Ratings

Preheat Soldering Temperature	220°C for 180 Sec
Max Soldering Temperature	260°C for 10 Sec
Input Power	0.5 Watt
Operating Temperature Range	-54°C to +85°C



Footprint



Reliability

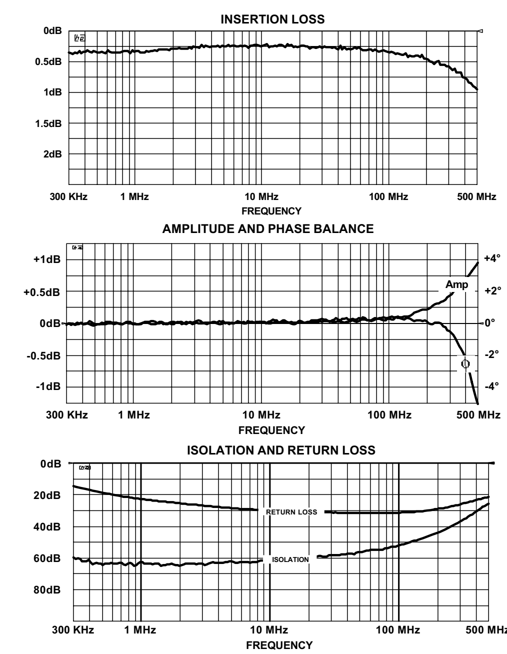
All units are designed and constructed to meet or exceed specifications after exposure to any or all of the following MIL-STD-202 tests which are applicable.

Test	Method	Condition
Temperature Cycle	107G	A
Thermal Cycle	107G	AA
Seal	112E	D
Vibration	204D	A
Solderability	208F	
Terminal Strength	211A	A
Terminal Fatigue	211A	C
Mechanical Shock	213B	C

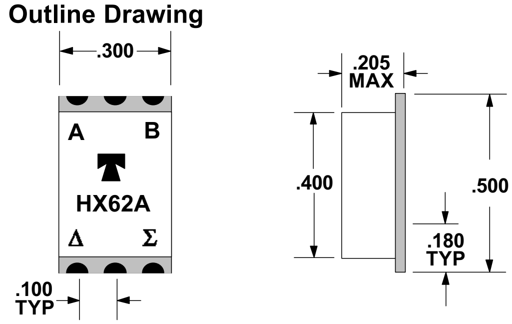
Features

- >3 Decade Bandwidth
- >40 dB Midband Isolation
- <0.5 dB Midband Loss

Typical Performance



Outline Drawing



Weight (Approx.) 5 grams

All characteristics of Tele-Tech products may be modified to meet customer requirements.

P.O. Box 790, Bozeman, Montana 59717
Phone: (406) 586-0291 Fax: (406) 587-0653 E-mail: admin@tele-tech-rf.com

Bill of Materials
NRL/NRAO Balun
1/24/2007

Designation	Value	Tolerance	Type	Manufacturer	Manufacturer's Part Number	Digi-Key Part Number	Package Style	Unit Cost	Quantity	Extended	Cost Bracket (*)
L1, L2, L3	4.7 µH	10%	Inductor, Ceramic Core	JW Miller	PM1008-4R7K-RC	M8483TR-ND	PM1008	$ 0.12	4	$ 0.48	>2000
C1…C12	0.1 µF	10%	Capacitor, Ceramic, X7R	Panasonic - ECG	ECJ-3VB1E104K	PCC1883TR-ND	1206	$ 0.06	13	$ 0.73	>4000
C7	10 µF	20%	Tantalum Capacitor	Nichicon	F931E106MCC	493-2388-1-ND	SMT-C (6.0 x 3.2 mm)	$ 0.52	1	$ 0.52	>10
R1	8.2 kΩ	5%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-P08J822V	P8.2KALCT-ND	1206	$ 0.04	2	$ 0.08	>1000
R2	100 Ω	1%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-8ENF1000V	P100FCT-ND	1206	$ 0.03	2	$ 0.05	>1000
R3, R7	51 Ω	5%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-P08J510V	P51ALCT-ND	1206	$ 0.04	3	$ 0.13	>1000
R4	2 kΩ	1%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-8ENF2001V	P2.00KFCT-ND	1206	$ 0.03	2	$ 0.05	>1000
R5, R6	91 Ω	5%	Resistor, 1 Watt	Panasonic	ERJ-1TYJ910U	PT91XCT-ND	2512	$ 0.19	2	$ 0.38	>1000
Q1, Q2	NE461 MO2	N/A	Transistor	NEC	NE461M02-AZ	NE461M02-AZ-ND	SOT-89	$ 1.35	2	$ 2.70	>1000
T1	TX60-27	N/A	Transformer	Tele-Tech, Corp.	TX60-27	Must Buy Directly	0.3 x 0.3 x 1.5 inches	$ 8.00	2	$ 16.00	>1000
H1	HX62A	N/A	180 degree hybrid	Tele-Tech, Corp.	HX62A	Must Buy Directly		$ 31.50	1	$ 31.50	>500
U1, U2	Gali-74	N/A	MMIC Amplifier	Mini-Circuits	Gali-74	Must Buy Directly	DF782	$ 1.85	2	$ 3.70	>1000
U3	LM1085IS-12-ND	N/A	Positive Voltage Regulator	National Semiconductor	LM1085IS-12	LM1085IS-12-ND	TO-263-3	$ 1.25	1	$ 1.25	>500
D1	MBRS2040	N/A	Diode, Schottky, 40 V, 2A	ON Semiconductor	MBRS2040LT3G	MBRS2040LT3GOSCT-ND	SMB (5.59 x 3.81)	$ 0.16	1	$ 0.16	>500
									Total Cost:	**$ 57.73**	

* Cost bracket was selected on the assumption that four 8 dB gain blocks would be used for each stand, with 256 stands per station.
* Parts only cost for a single polarization balun. Enlclosure and connectors not included.

Bill of Materials
Hicks Balun
1/24/2007

Designation	Value	Tolerance	Type	Manufacturer	Manufacturer's Part Number	Digi-Key Part Number	Package Style	Unit Cost	Quantity	Extended	Cost Bracket (*)
L1, L2	4.7 µH	10%	Inductor, Ceramic Core	JW Miller	PM1008-4R7K-RC	M8483TR-ND	PM1008	$ 0.12	2	$ 0.24	>2000
C1, C2	10 µF	20%	Tantalum Capacitor	Nichicon	F931E106MCC	493-2388-1-ND	SMT-C (6.0 x 3.2 mm)	$ 0.52	2	$ 1.04	>10
C3…C8	0.1 µF	10%	Capacitor, Ceramic, X7R	Panasonic - ECG	ECJ-3VB1E104K	PCC1883TR-ND	1206	$ 0.06	6	$ 0.34	>4000
R1, R2	91 Ω	5%	Resistor, 1 Watt	Panasonic	ERJ-1TYJ910U	PT91XCT-ND	2512	$ 0.19	2	$ 0.38	>1000
R3	51 Ω	5%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-P08J510V	P51ALCT-ND	1206	$ 0.04	1	$ 0.04	>1000
U1	LM1085IS-12-ND	N/A	Positive Voltage Regulator	National Semiconductor	LM1085IS-12	LM1085IS-12-ND	TO-263-3	$ 1.25	1	$ 1.25	>500
U2, U3	Gali-74	N/A	MMIC Amplifier	Mini-Circuits	Gali-74	Must Buy Directly	DF782	$ 1.85	2	$ 3.70	>1000
H1	HX62A	N/A	180 degree hybrid	Tele-Tech, Corp.	HX62A	Must Buy Directly		$ 31.50	1	$ 31.50	>500
D1	MBRS2040	N/A	Diode, Schottky, 40 V, 2A	ON Semiconductor	MBRS2040LT3G	MBRS2040LT3GOSCT-ND	SMB (5.59 x 3.81)	$ 0.16	1	$ 0.16	>500
									Total Cost:	**$ 38.65**	

* Cost bracket was selected on the assumption that four 8 dB gain blocks would be used for each stand, with 256 stands per station.
* Parts only cost for a single polarization balun. Enclosure and connectors not included.