A Comparison of Two Power Combining Elements for LWA Active-Baluns - 180° Hybrid versus Wideband Transformer

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May 9, 2007

We present a detailed study of the performance and cost issues related to the selection of either a 180° hybrid or a simple transformer for use as the primary power combining element for future LWA active-baluns. Noise figure, 1 dB compression point, IP2, IP3, Gain and VSWR measurements have been performed on two balun prototypes in order to do a side-by-side performance comparison. The prototypes had identical layouts with the exception that one used a 180° hybrid and the other used a transformer as the power combining element. Based on this analysis and our experience with the design of active-baluns, we recommend the use of a 180° hybrid for the LWA active balun power combining element.

I. Introduction

Future active balun designs will almost certainly share the basic structure of the baseline LWA active-balun design (Figure 1). Each dipole arm is connected to a separate gain stage and the output of these two gain stages are combined through a either a 180° hybrid or a transformer to produce cancellation of in-phase power. This arrangement is known to provide good IP2 performance, and also provides an impedance of 100Ω at the antenna feedpoints.

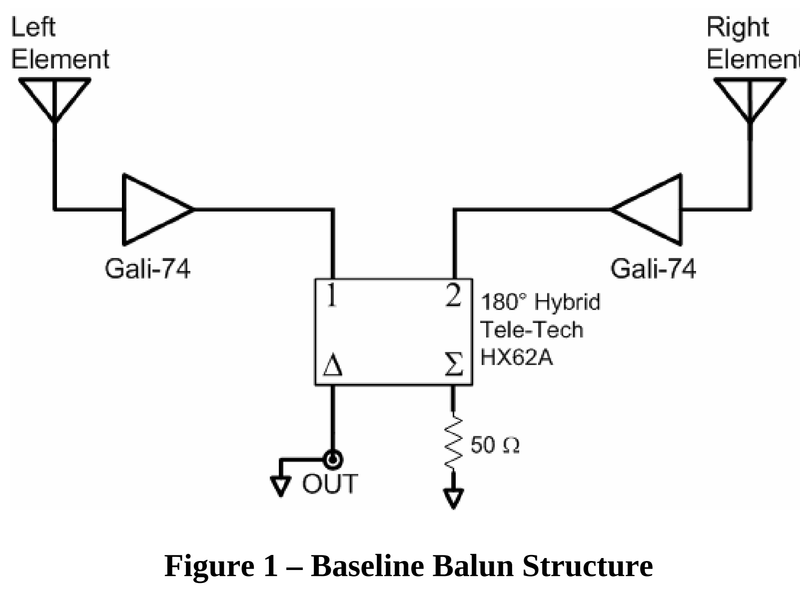


Figure 1 – Baseline Balun Structure

Despite these desirable characteristics, the cost of a 180° hybrid is typically greater than an RF transformer, such as the *MiniCircuits* ADT2-2-1T-1P used on the Experimental Test Array (ETA) [1]. A detailed performance and cost comparison of the two options has therefore been undertaken to determine which element would be the preferable choice for the LWA active baluns.

II. Test Configurations

To ensure an accurate comparison, two single polarization baluns were constructed which are identical in circuit configuration with the exception of the power combining component (Fig. 2). The printed circuit board (PCB) layouts differ only in accommodations (e.g. component footprint, terminating load for hybrid) for the power combining element. Each unit features a local voltage regulator to ensure consistent biasing and connectors with conductive backshells to minimize RFI leakage during noise testing. Schematic diagrams are presented for both units in section VIII.

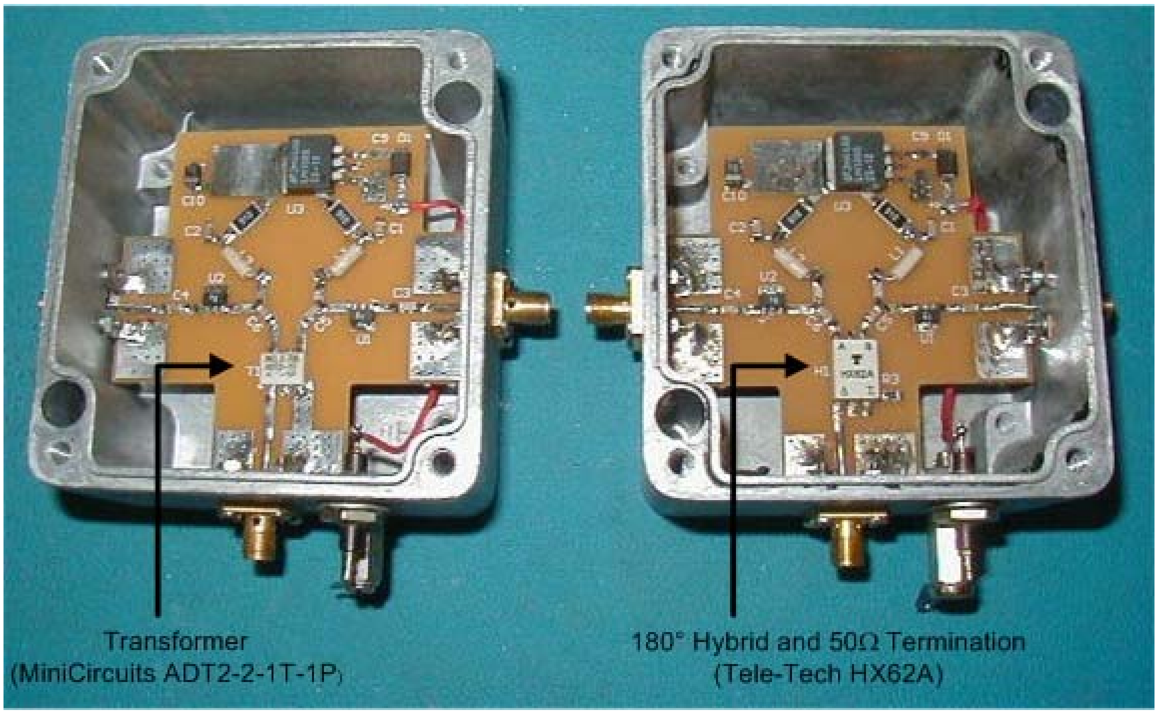


Figure 2 – Single Polarization Test Baluns

III. Performance Data

Both units were extensively characterized using the same measurement systems. Test setups for intermodulation distortion and noise figure measurement are given in section VI. Impedance measurements were derived from s-parameter data obtained with a calibrated network analyzer. A summary of the specific test equipment used is detailed in section VII.

The performance data for Gain, 1dB compression point, intermodulation distortion, and noise figure are plotted for comparison in Figures 3 through 7. For these parameters the performance of the two test units is comparable, with the hybrid version delivering slightly superior performance overall.

Significant differences in performance become apparent when the input and output VSWR and impedance characteristics are examined (Figures 8 – 11). Input impedance measurements were taken by exciting the test units through a 180° hybrid (Figures 12 and 13). Consequently, it should be noted that the actual balun input impedance is a factor of two higher than the plotted values (e.g. 50Ω translates to a 100Ω feedpoint impedance).

The hybrid version of the balun is shown to deliver close to the 100 Ω (2 x 50Ω) impedance at the antenna feedpoint as required by the baseline antenna design solidly across the entire LWA band (Figures 8, 9). The transformer version of the balun delivers a feedpoint impedance of approximately 50Ω (2 x 25Ω) across the LWA band.

Similarly, the output impedance of the hybrid based balun was found to be flat at ~50 Ω across the entire LWA band with a negligible imaginary component. The transformer based unit presented frequency variant output impedance that ranged from 30 to 40Ω with a significant (and varying) imaginary component.

While the impedance of the transformer is commensurate with its turns ratio (2 to 1), the frequency variation could be problematic. It is probably not reasonable to expect a transformer with a higher turns ratio to provide the requisite feedpoint and output impedances across the entire LWA band.

Furthermore, the 50Ω input and output impedance delivered by the hybrid based balun is a better impedance match to the LWA big blade antenna as well as 50Ω RF coaxial cable. If the decision is made to use 75Ω coaxial cable instead, a version of the hybrid component with an output impedance of 75Ω is also available *at no additional cost*.

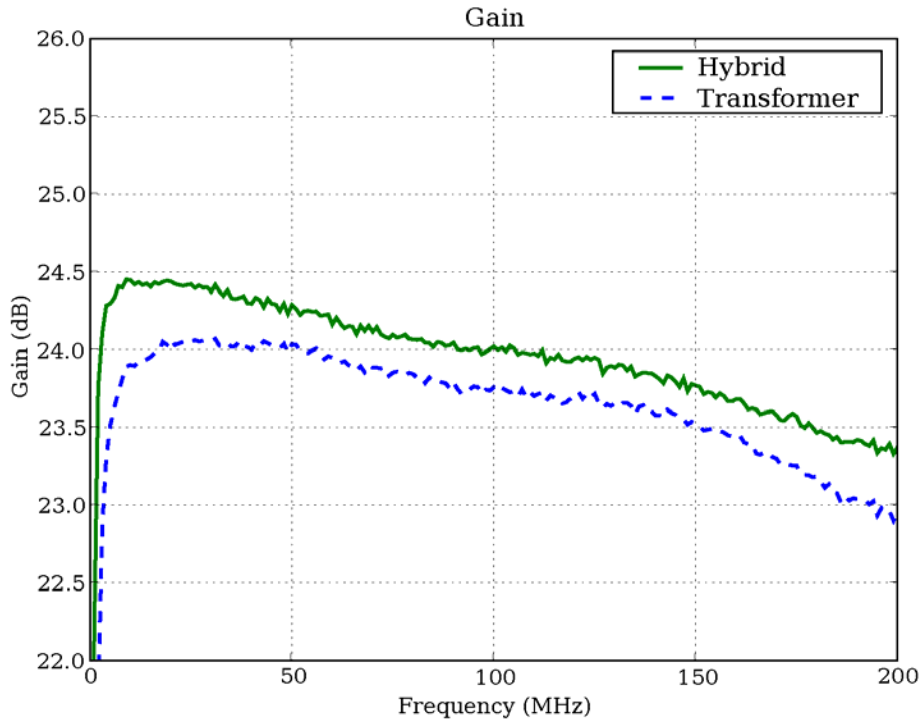


Figure 3

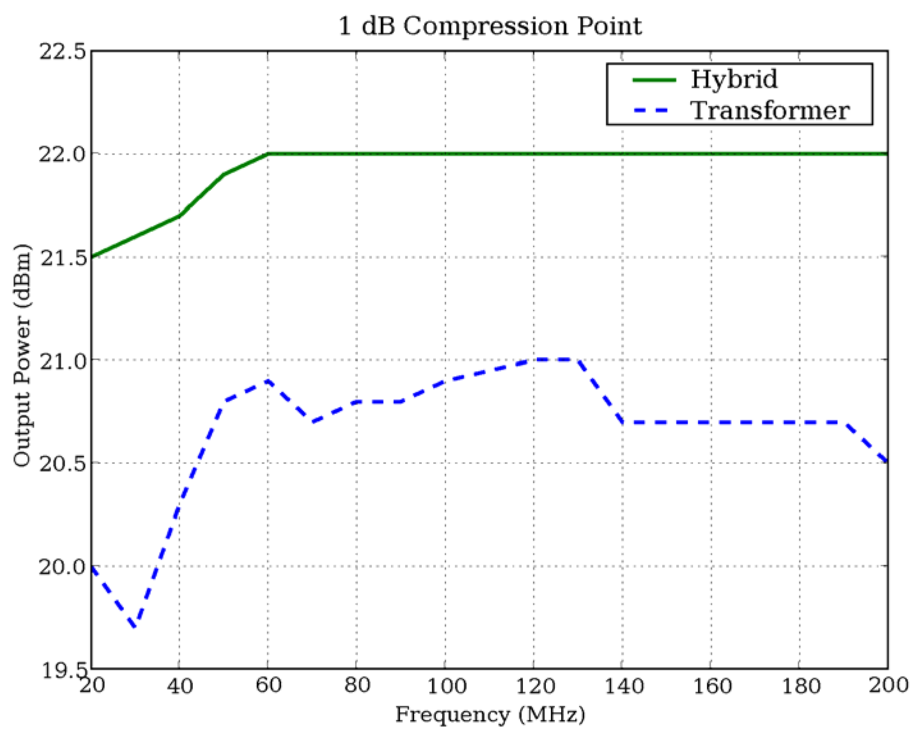


Figure 4

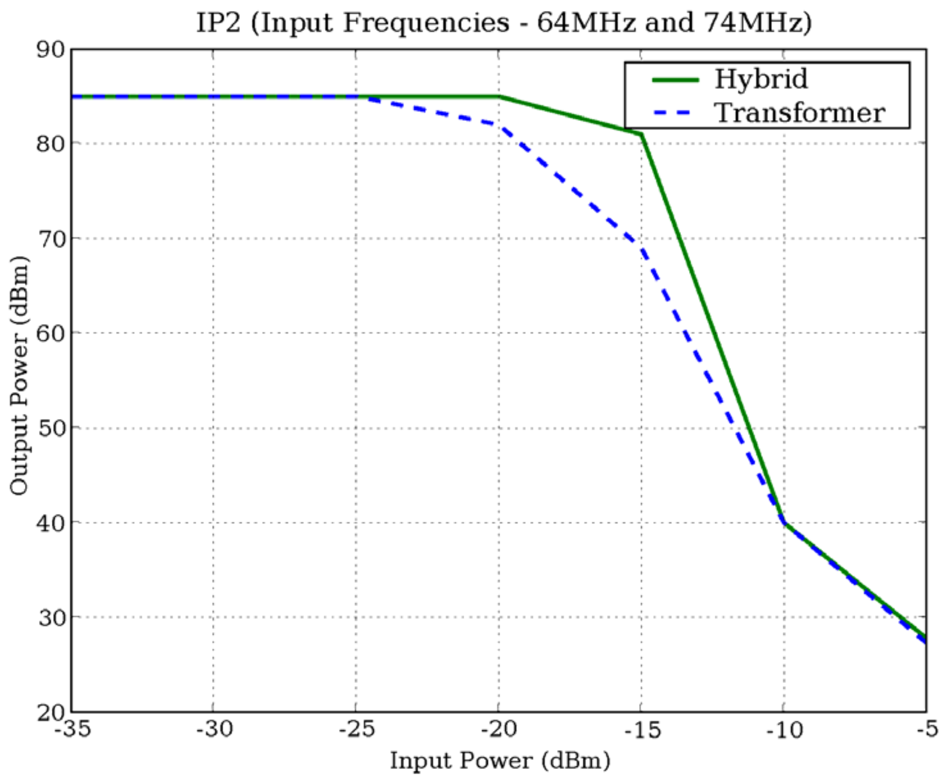


Figure 5

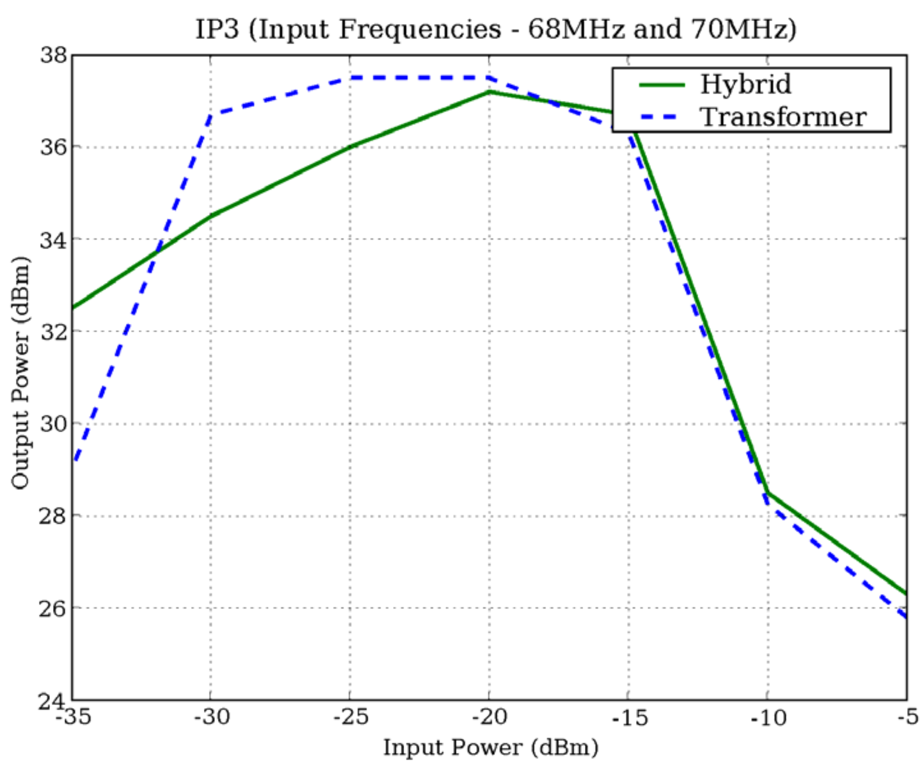
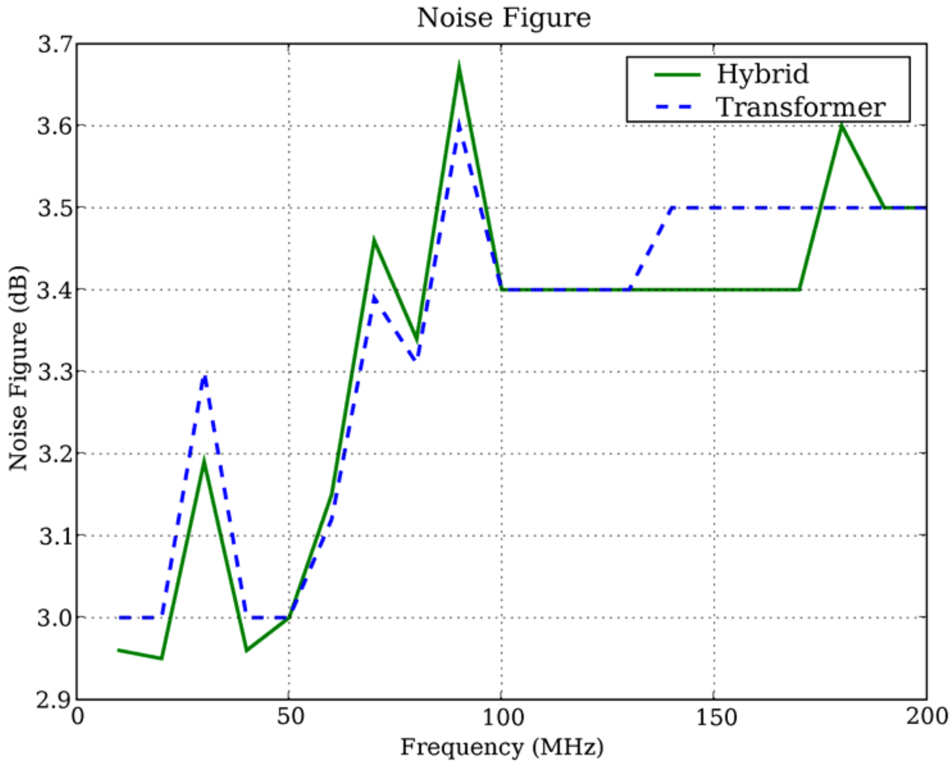


Figure 6



Noise Figure
Hybrid
Transformer
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
Noise Figure (dB)
0
50
100
150
200
Frequency (MHz)

Figure 7

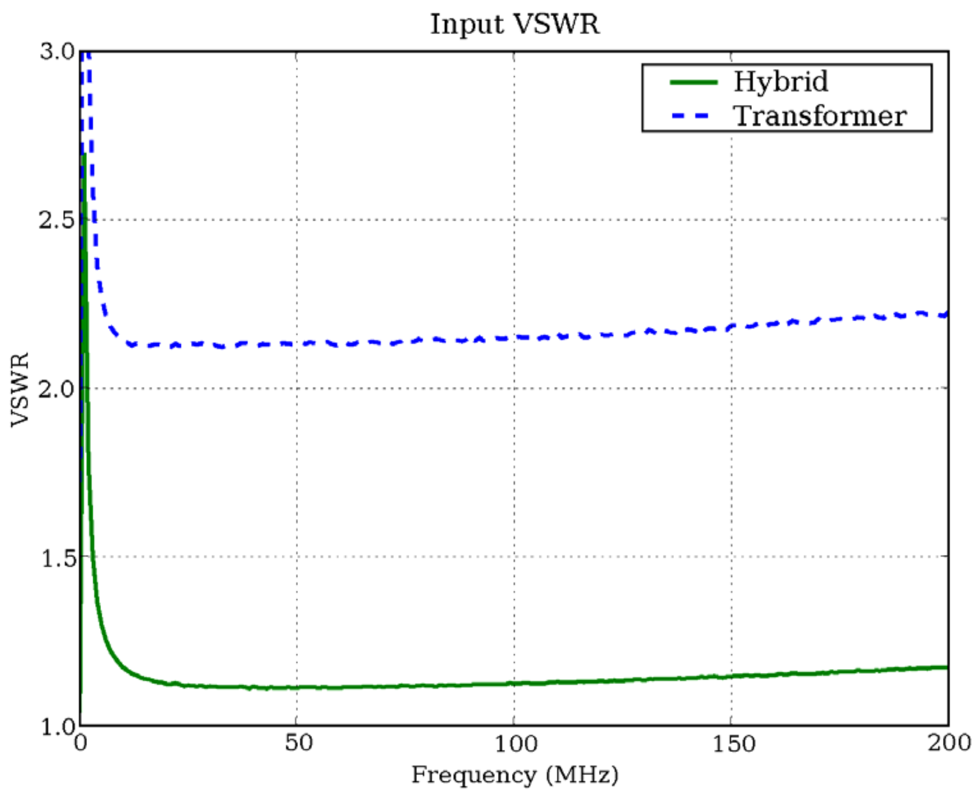


Figure 8

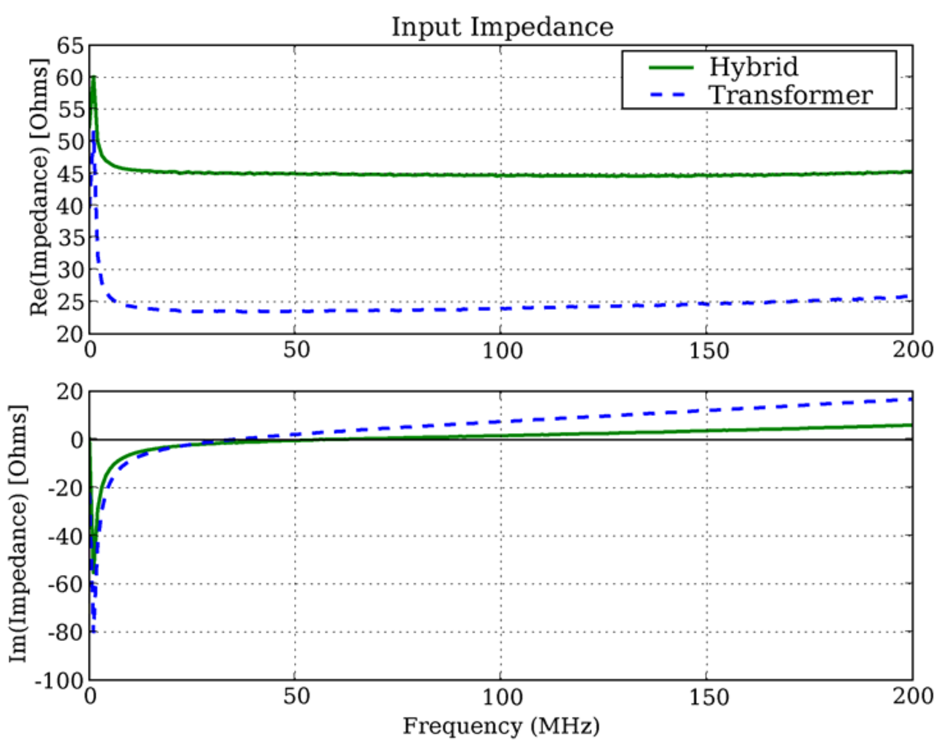


Figure 9

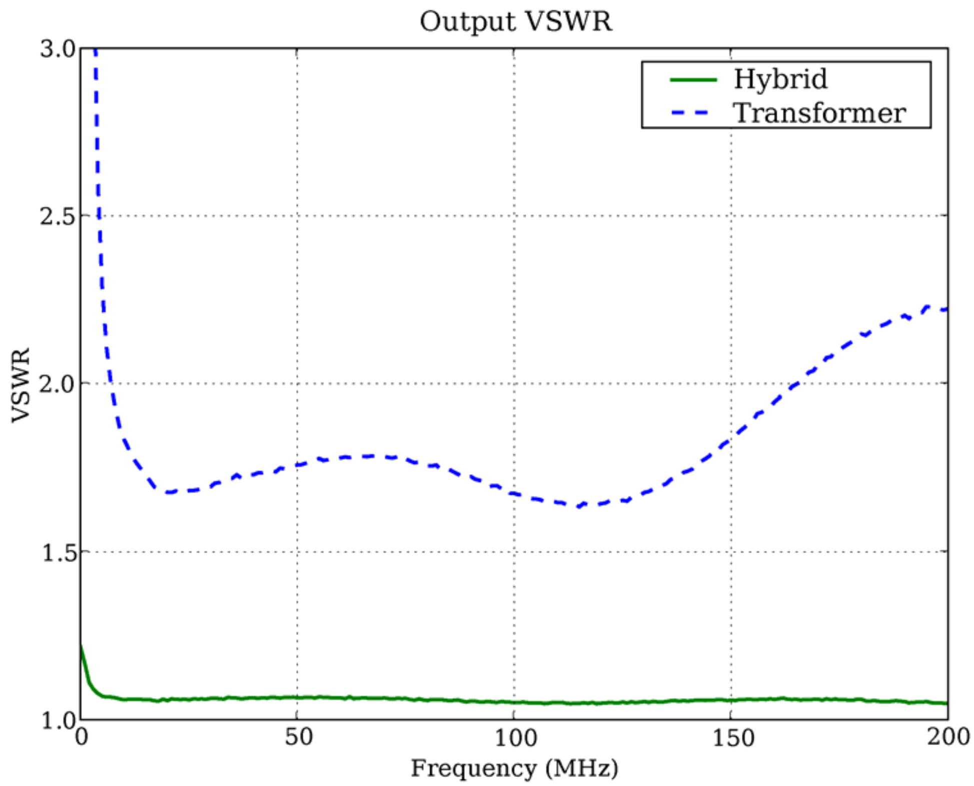


Figure 10

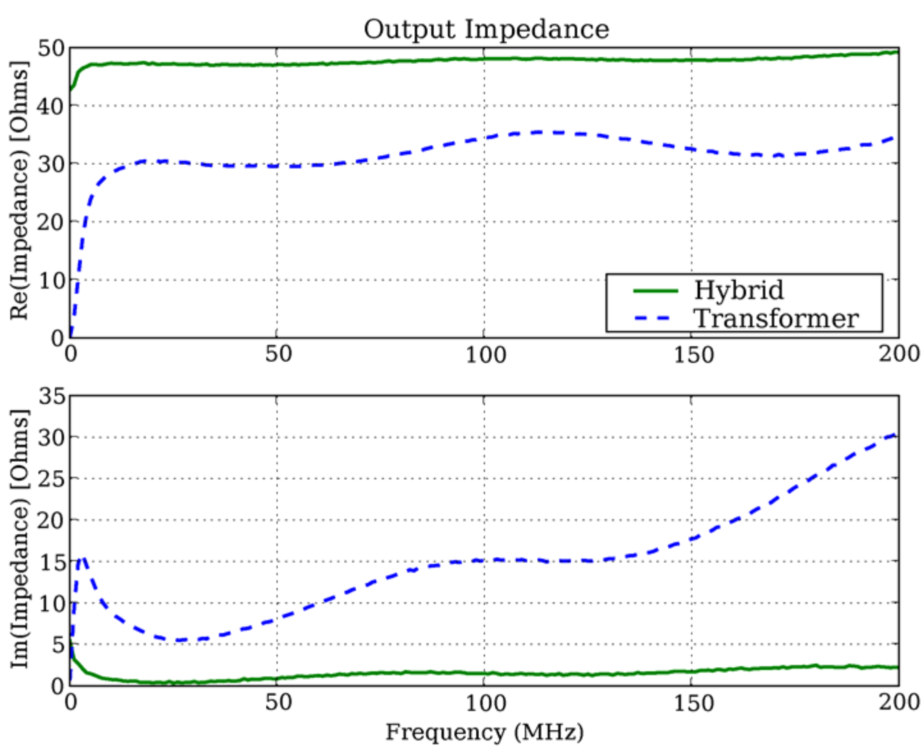


Figure 11

IV. Cost Considerations

Present costing information for quantities greater than 2500 gives the price of the MiniCircuits transformer explored in this report at $3.40 and the price of the Tele-Tech hybrid at $10.50. We can estimate using this pricing that a station with 256 elements would cost $3635.20 more if the hybrid is used. We feel that the improvement in consistency and compatibility gained by using the hybrid justifies this cost difference.

V. Summary and Recommendations

We have presented a performance comparison of two candidate power combining elements for the LWA active balun – the 180° hybrid made by *Tele-Tech,* and the wideband transformer made by *Minicircuits*. Two single polarization active baluns were fabricated that were identical in circuit configuration and layout with the exception that one used the 180° hybrid and the other used the transformer as the power combining element. Gain, noise figure, intermodulation distortion, 1 dB compression point, and input and output VSWR were measured on each balun using the same test equipment. The two baluns performed comparably (with the hybrid-based balun being slightly superior) in every area except input and output VSWR. While the hybrid-based balun had input and output VSWR's corresponding to a ~50Ω impedance, the transformer-based balun had input and output VSWR's corresponding to impedances ranging from 25Ω - 40Ω. The transformer-based balun therefore presents a less effective impedance match to the LWA baseline big blade antenna, as well as to 50Ω coaxial RF cable. The standard *Tele-Tech* hybrid (HX62A) provides a good impedance match to 50Ω coaxial cable, and a version with 75Ω output impedance is available at no additional cost should the LWA project decide to use 75Ω cable.

Furthermore, the hybrid is resistively terminated to provide a means to dissipate the anti-phase power component that will result if the amplifiers in the balun are not perfectly matched. Should a transformer be used, this anti-phase component will add to the desired signal and raise the excess noise level of the system. While we expect this effect to be small given the return loss of amplifiers such as the GALI-74 (15 to 22 dB), we still feel that it would be wise to eliminate this source of error. Although the cost of the hybrid is likely to be higher than the transformer, we believe this extra cost is justified. Based on the information presented in this report, we recommend the 180° hybrid as the more appropriate choice for the power combining element in the LWA active balun.

VI. Measurement Setups

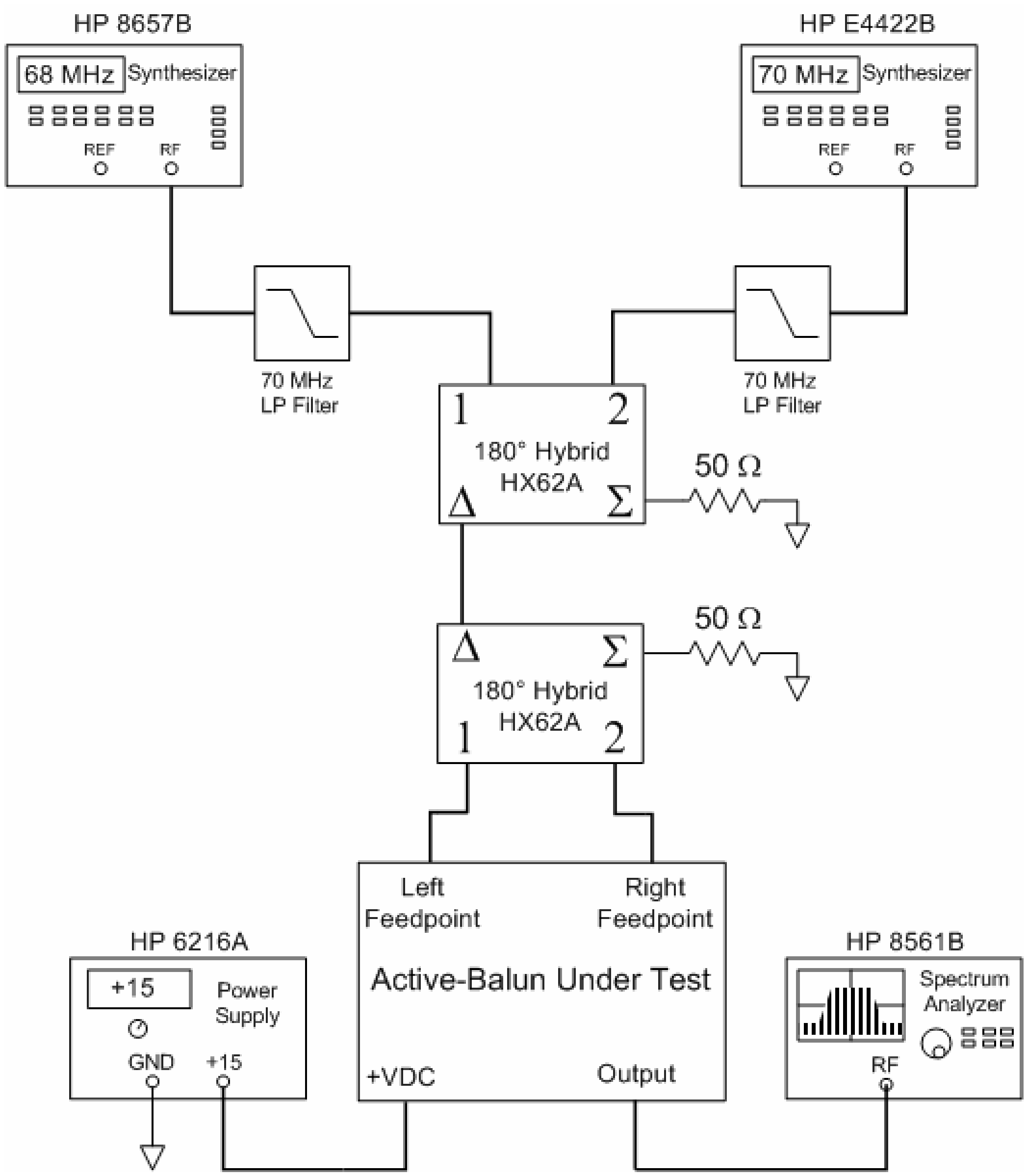


Figure 12 - IMD Measurement Setup

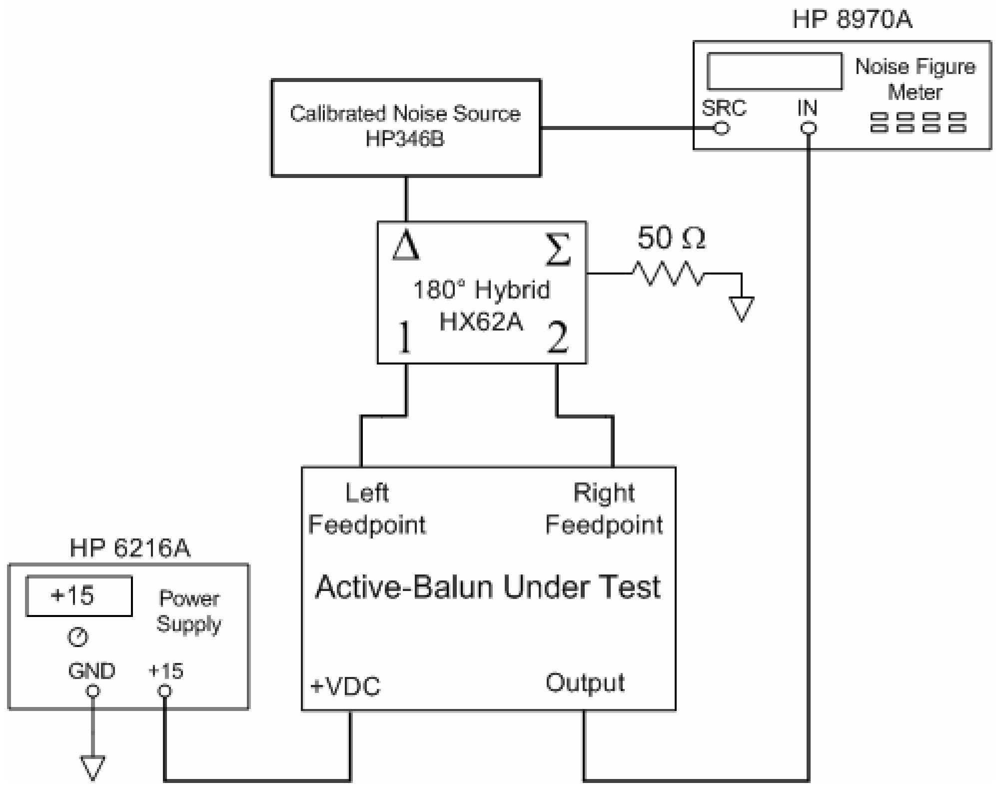


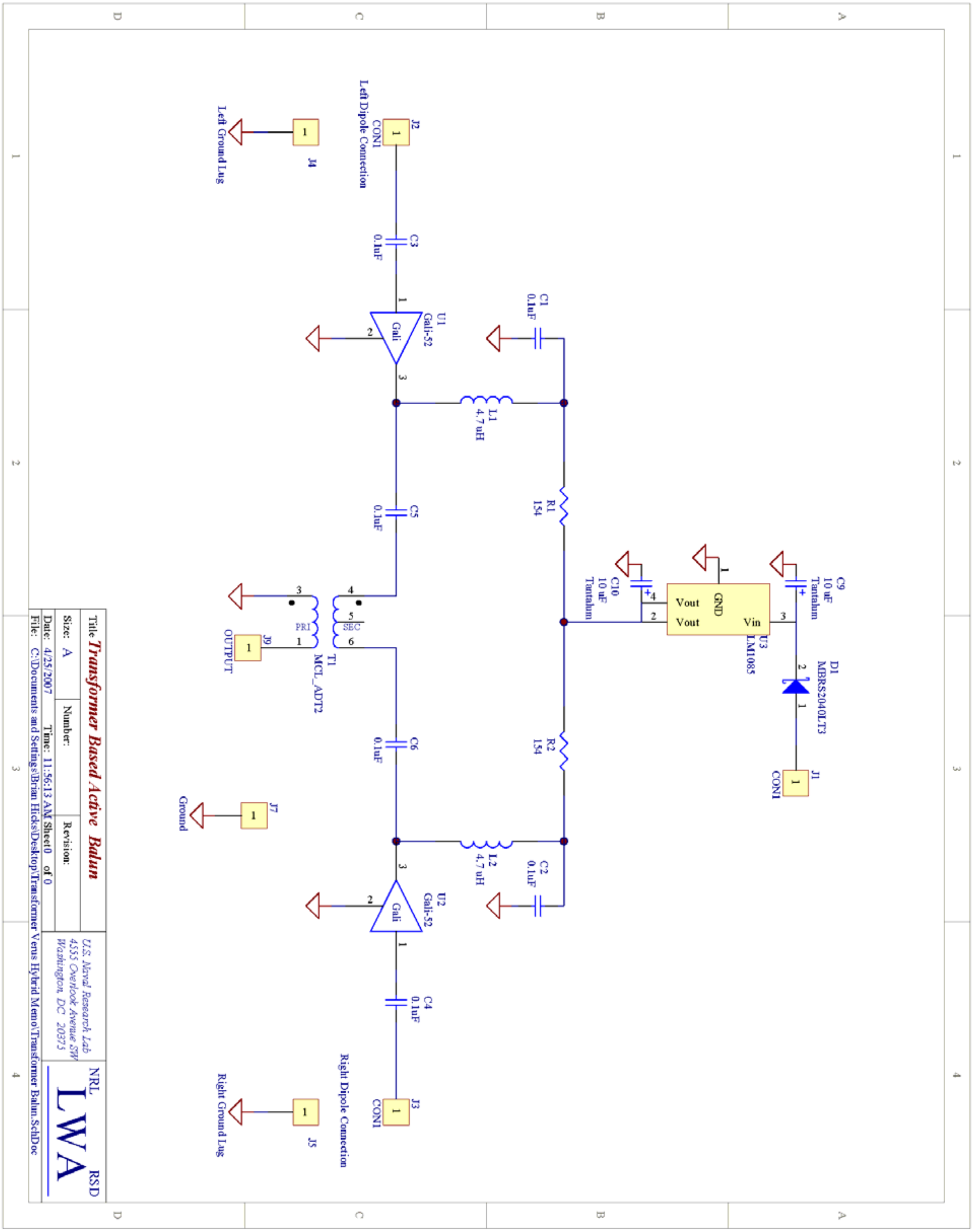
Figure 13 - Noise Figure Measurement Setup

VII. Test Equipment

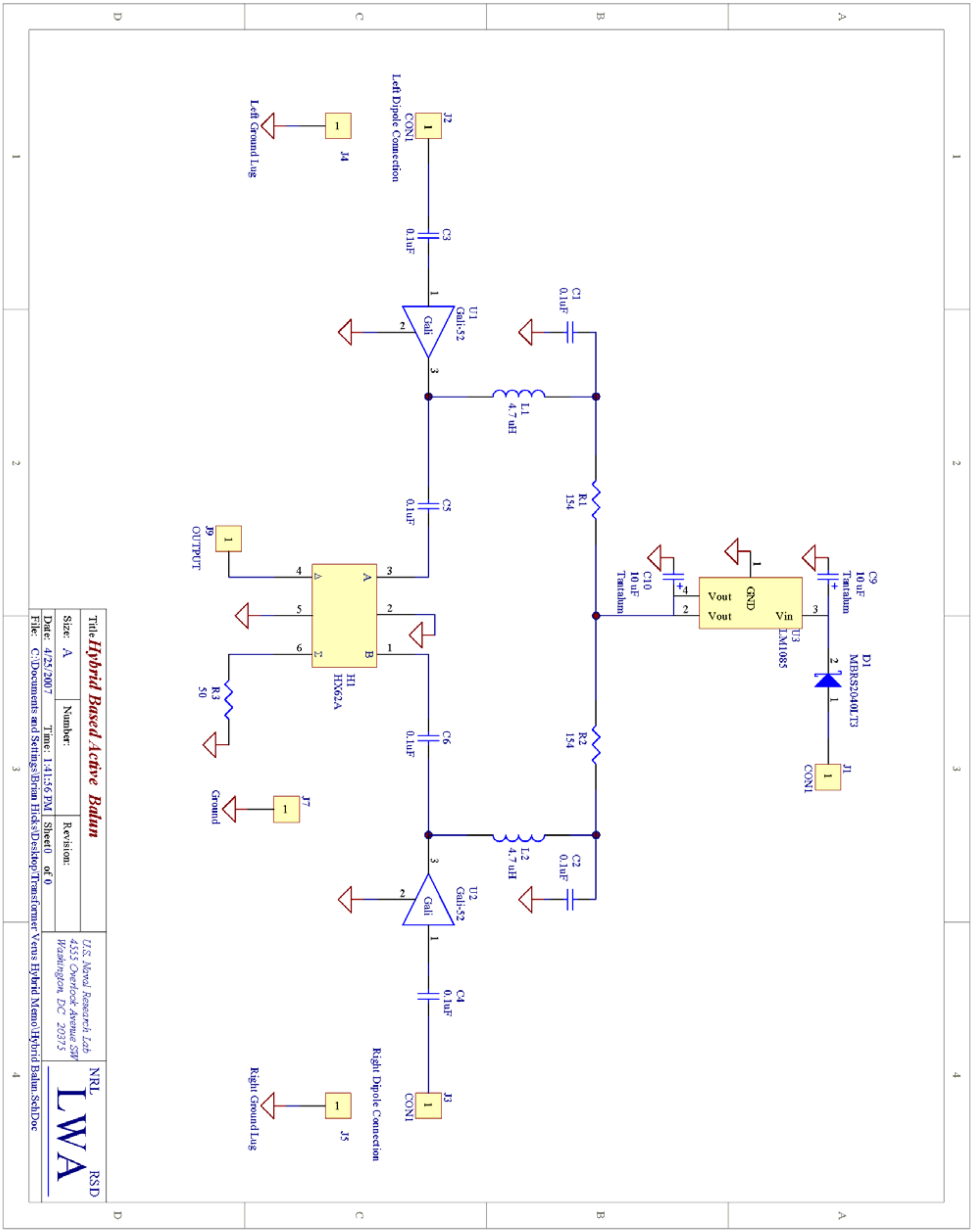
1. HP 8657B Signal Generator
2. HP E4422B Signal Generator
3. HP 8561B Spectrum Analyzer
4. HP 8753D Network Analyzer
5. HP 8970A Noise Figure Meter
6. HP 346B Calibrated Noise Source
7. HP 6216A DC Power Supply

VIII. Test Balun Schematics

a. Figure 14 -Transformer Based Test Balun Schematic



b. Figure 15 - Hybrid Based Test Balun Schematic



IX. References

[1] "Active Balun Schematic/Parts List", Steve Ellingson, October 9, 2005
http://www.ece.vt.edu/swe/eta/AB/ETA_AB_051026.pdf

X. Datasheets

"MAGIC TEE" HYBRID

180° HYBRID JUNCTION

MODEL HX62A

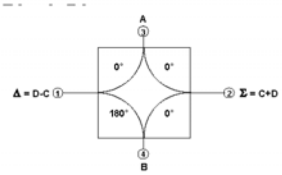
Guaranteed Specifications

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

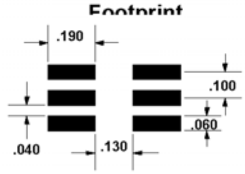
Note: All specifications apply in a 50 Ohm system. Performance will differ slightly in a 75 Ohm system.

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



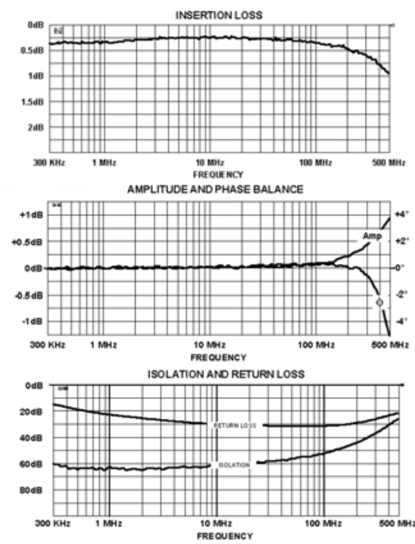
Footprint



Features

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

Typical Performance

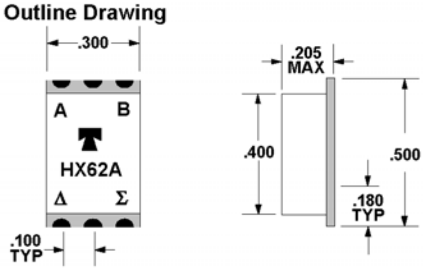


Reliability

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

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

Surface Mount

RF Transformer

ADT2-1T-1P+
ADT2-1T-1P

50Ω 8 to 600 MHz

CASE STYLE: CD542
PRICE: $4.25 ea. QTY (10-49)

+ RoHS compliant in accordance with EU Directive (2002/95/EC)

The +Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications.

Maximum Ratings

Operating Temperature	-20°C to 85°C
Storage Temperature	-55°C to 100°C
RF Power	1W
DC Current	30mA

Pin Connections

PRIMARY DOT	3
PRIMARY	1
SECONDARY DOT	4
SECONDARY	6
SECONARY CT	5
NOT USED	2

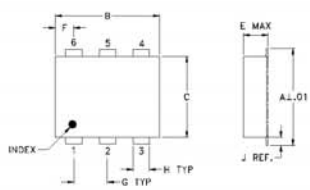
Features

- excellent return loss, 15 dB typ.
- excellent amplitude unbalance, 0.1 dB typ. and phase unbalance, 1 deg. typ.
- high RF power up to 1 watt
- aqueous washable
- protected under US patent 6,133,525

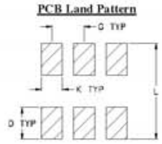
Applications

- impedance matching
- baluns

Outline Drawing



PCB Land Pattern



Suggested Layout,
Tolerance to be within ±.002

Transformer Electrical Specifications

Ω RATIO	FREQUENCY (MHz)	INSERTION LOSS*			PHASE UNBALANCE (Deg.) Typ.		AMPLITUDE UNBALANCE (dB) Typ.	
		3 dB MHz	2 dB MHz	1 dB MHz	1 dB bandwidth	2 dB bandwidth	1 dB bandwidth	2 dB bandwidth
2	8-600	8-600	10-400	13-300	1	1	0.2	0.3

* Insertion Loss is referenced to mid-band loss, 0.5 dB typ.

Outline Dimensions (inch / mm)

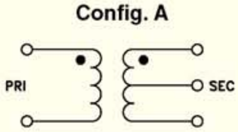
A	B	C	D	E	F	G
.272	.310	.220	.100	.112	.055	.100
6.91	7.87	5.59	2.54	2.84	1.40	2.54

H	J	K	L	wt
.030	.026	.065	.300	grams
0.76	0.66	1.65	7.62	0.20

Typical Performance Data

FREQUENCY (MHz)	INSERTION LOSS (dB)	INPUT R. LOSS (dB)	AMPLITUDE UNBALANCE (dB)	PHASE UNBALANCE (Deg.)
8.00	0.74	14.43	0.00	0.06
9.50	0.72	15.42	0.01	0.06
15.50	0.65	16.83	0.00	0.03
58.75	0.54	18.72	0.01	0.14
100.00	0.56	17.66	0.03	0.00
200.00	0.79	14.80	0.13	0.11
300.00	1.02	12.34	0.33	0.51
400.00	1.05	10.45	0.66	1.24
500.00	1.09	9.00	1.10	2.48
600.00	1.13	7.78	1.78	4.22

Config. A



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