Collected LWA Engineering Memos from the Development of the Front End Electronics (FEE)

2008 May 23 - 2009 May 15

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- FEE0015: Brian Hicks, Filter for FEE, 2008 October 7
- FEE0022A: Brian Hicks, LWA FEE Version 1.7, 2009 March 17
- FEE0023: Brian Hicks, Jacob Hartman, and Norman McGlothlin, Long Wavelength Array Front End Electronics (LWA FEE) Version 1.7: Fabrication, Assembly and Testing Instructions and Bill of Materials, 2009 July 2
- FEE0024: Jacob Hartman and Brian Hicks, FEE0024: Linearity measurements of FEE version 1.7, 2009 May 15

LWA Engineering Memo #FEE0002 Brian Hicks May 27, 2008

Failure Analysis of MMIC-Based FEE Units

This document is intended to present a succinct description of observed failure modes of recently examined MMIC based FEE units.

I. G250R FEE Observations

We examined six G250R units that had recently been fielded at the LWDA site for approximately seven months (S/N 003, 005, 008, 020, 021, and 023). No fault could be found with unit #021; all of the other units had failed due to mechanically induced component and PCB trace failure.

The predominant failures in the G250R units were microscopic breaks in the PCB traces leading in and out of the MMIC amplifiers. Cracked coupling capacitors were also found on most of the units.

The power supply, including the voltage regulator and bias-T circuits, were found to be fully functional in all of these units.

II. <u>Single Polarization (GASE) Unit Observations</u>

Eight single polarization active-baluns were recently returned to NRL for repair. The circuit diagram for these units is given in Figure 1.

The failure modes were virtually identical for all eight units. The MMIC amplifiers (U1, U2) were found to be defective and the capacitors (C3, C4) used to couple signals into the amplifiers had failed shorted. In one unit (S/N 6), a tantalum bypass capacitor (C10) had also catastrophically failed shorted. With the exception of the sixth unit, all of the voltage regulators and bias networks functioned perfectly.

All eight units suffered extensive water damage due to failure of the integral gasket of the NEMA enclosures (Hammond Catalog Number 1590Z110). It has been suggested that a nearby lightning strike, rather than the water damage, was responsible for the failure of U1, U2, C3, and C4 in these baluns.

A detailed description of the evaluation of each of these units is provided in section V.

III. <u>Commonality</u>

All of the G250R baluns failed due to mechanical deformation of the PCB. All of the single polarization (GASE) baluns most likely failed due to a nearby lightning strike.

IV. Recommendations and Future Actions

The G250R baluns were created as an expedient to enable a field testing campaign. They were never intended to withstand the mechanical forces that resulted from makeshift mounting arrangements. In the future, care will be taken to ensure that circuit boards in the FEE subsystem never be required to bear any mechanical load.

The unexpected failure of the seals on the GASE balun units should serve to caution us about how we rely on gaskets in the LWA FEE. The damaged units had been deployed in the field for approximately one year.

We are investigating the use of a hub assembly for the FEE that will enable the egress of condensation instead of attempting to produce a hermetically sealed enclosure. We should keep in mind that seals are likely to become a maintenance item wherever they are located, particularly if they are subjected to thermal cycling.

With respect to prevention of lightning damage, as may have been found in the GASE units, we are planning to incorporate a back-to-back diode structure on the feedpoints of future FEE units. The 74 MHz VLA system incorporated 1N4153 diodes, and the MIT MWA utilizes 1N4148 diodes. We are exploring the availability of these parts in packages suitable (e.g. surface mount) for use in the LWA FEE. It is important to realize that it is not reasonable to believe we can design the FEE to withstand a direct lightning strike. We are only endeavoring to protect against ESD, and provide some level of protection against indirect lightning activity.

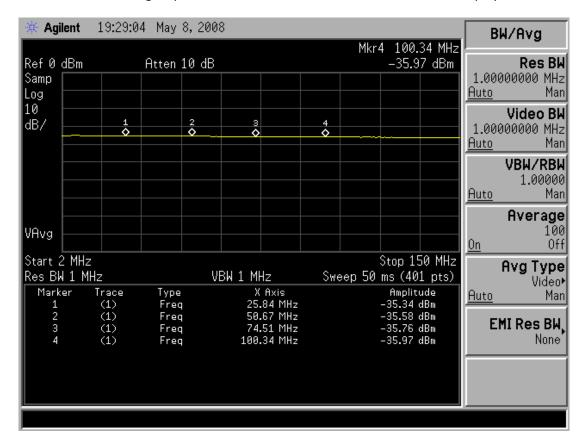
V. GASE Active-Balun Failure Data

GASE Balun #1

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.2 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open. **Gain:** Unit was tested using an Agilent E4401B with tracking generator. Balun inputs were driven via a 180 degree hybrid, with the hybrid input connected to the tracking generator output and the hybrid outputs connected to the balun inputs via 10 cm SMA jumpers. Source amplitude for the tracking generator was -60 dBm. A gain plot with markers at 25, 50, 74, and 100 MHz is displayed below.

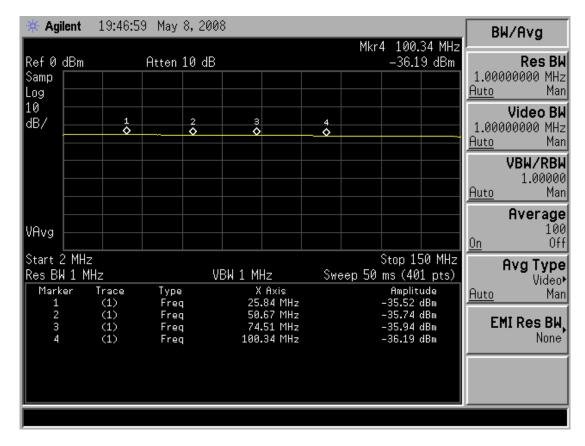


GASE Balun #1
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.1 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.

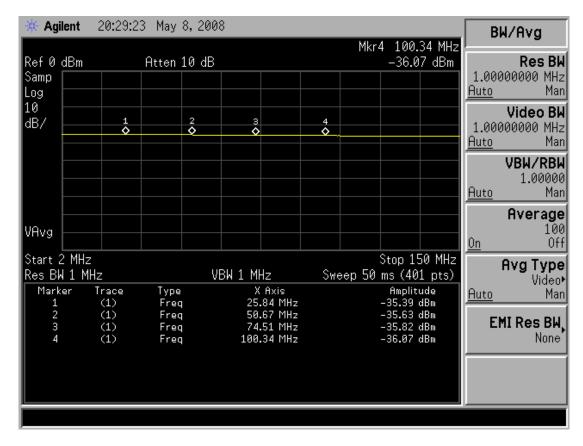


GASE Balun #2
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.3 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.

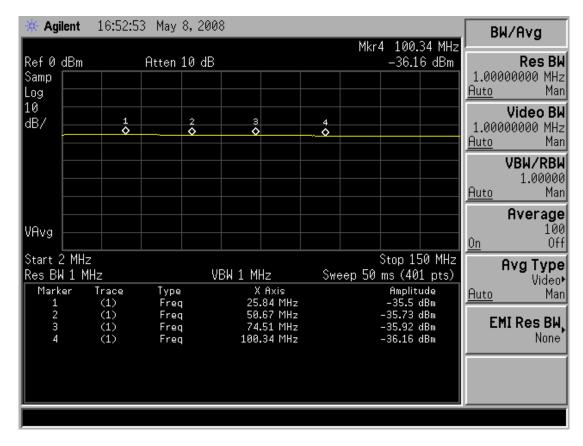


GASE Balun #3
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.2 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.

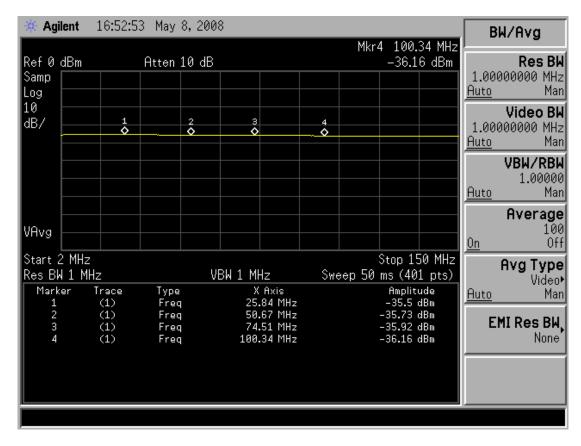


GASE Balun #4
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.1 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.

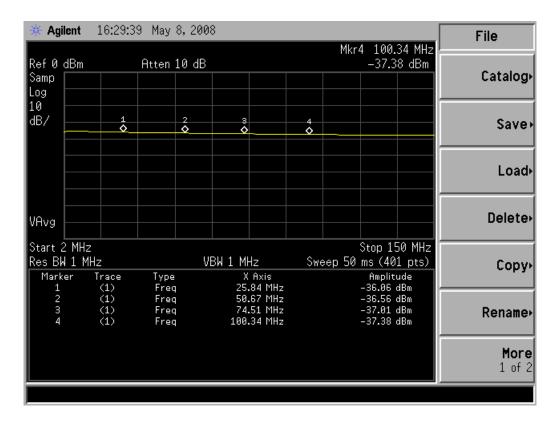


GASE Balun #5
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective. Capacitor C10 was found to have catastrophically failed shorted and burned. The coupling capacitors (C3, C4) were found to have failed shorted. Due to the extensive damage to this board, an entirely new PCB was assembled for this unit with all new components. The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.2 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.

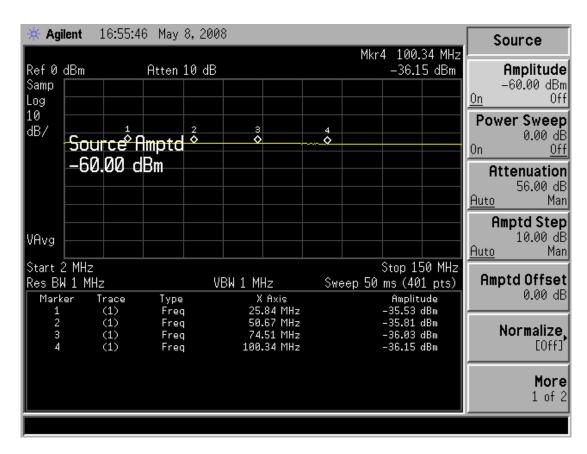


GASE Balun #6
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.1 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.

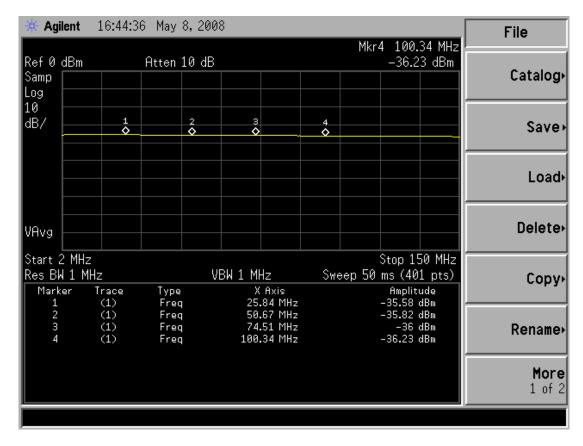


GASE Balun #7
Gain vs. Frequency. Source Amplitude is -60 dBm

Inspection: Box was flooded, rust and corrosion were present. The unit was completely disassembled, the enclosure and PCB were thoroughly cleaned. The Gali-74 amplifiers (U1, U2) were found to be defective and were replaced. The coupling capacitors (C3, C4) were found to have failed shorted and were replaced (Figure 1). The failure of the coupling capacitors suggests an overvoltage condition at the feedpoint connections, likely due to nearby lightning. The appeared to be some oxidation inside the SMA connections used for feedpoint and output connections; these were all replaced. Connectors and box were sealed with RTV silicone.

Current Consumption: 160 mA at 15.0 VDC

Stability: No oscillations were observed (1 MHz and 8 GHz). Unit observed with 50Ω loads and open.



GASE Balun #8
Gain vs. Frequency. Source Amplitude is -60 dBm

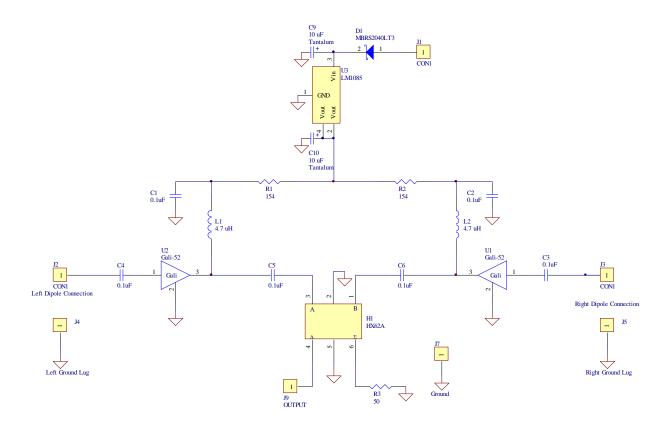


Figure 1 - GASE Balun Schematic

NRL Engineering Memo #FEE0003A Brian Hicks May 23, 2008

Preliminary Mechanical Interface Specifications between the LWA FEE and STD

This document presents a preliminary mechanical interface concept to integrate the FEE and STD subsystems. An engineering sketch of a potential 'hub' assembly has been provided by Mr. Stephen Burns of Burns Industries and is included here (Figure 1).

While the final mechanical design for the 'hub' may differ significantly from the concept provided here, we feel that it is sufficient to enable the establishment of several key dimensions.

Subsequent FEE designs will adhere to the following parameters:

Diameter of FEE PCB	127.0 mm (5 inches)
Feedpoint Distance	9 cm (~3.54 inches)
FEE Thickness	3.2 mm (0.126 inches)
Feepoint Interconnect	Clearance holes for M5 studs in gold-plated PCB pads

Contact Information for Burns Industries, Inc.

Stephen J. Burns, Owner 141 Canal Street Nashua, NH 03064

Telephone: 603-881-8336 Fax: 603-881-3274 steve@burnsindustries.com

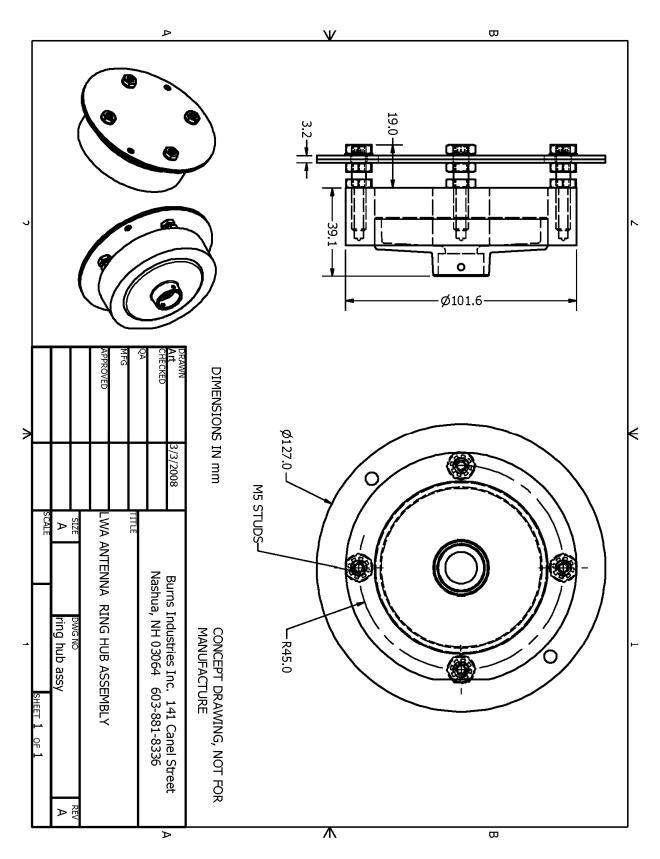


Figure 1 – Preliminary FEE/STD Interface Concept from Burns Industries

NRL Engineering Memo #FEE0003B Brian Hicks May 29, 2008

PCB Layout Considerations for the Addition of a Filter to the FEE

I. Introduction

This document briefly discusses the potential of adding a multiple pole analog filter to the G250R FEE design. The revised filter presented in LWA Memo #89 [1] (Figure 3) is presented here as an example of a filter which could be considered for inclusion in the FEE. It is assumed that any filter to be added to the FEE would be introduced immediately before the final Gali-6 gain stage.

II. Potential Obstacles

A simplified layout of the G250R balun [2] is presented in Figure 1. The ground planes have been removed in this figure to enable a clear view of the area between H1 and U4 (final output amplifier) where the filter is to be placed.

A first draft PCB layout of the filter in Figure 3 is shown in the upper right hand corner of Figure 1 to enable an assessment of the difficulty involved in introducing such a filter to the layout. All of the components in the filter layout use 0603 footprints. An enlargement of the area where the filter is to be inserted is presented in Figure 2. It can be seen that any attempt to modify the G250R layout to include a filter of significant complexity will likely prove to be insurmountably difficult.

III. Conclusions and Recommendations

The structure of the G250R is an incremental development based on extensive experience and hard-won lessons. In its present form, it will readily extend to a dual polarization version that will deliver the same remarkable isolation as the LWDA balun. We believe that extensive modifications of this layout could easily compromise the stability and performance of the FEE.

We also have some concerns regarding the stability and repeatability of a complex filter, particularly in the uncontrolled thermal environment of the FEE.

It has been advocated by William Erickson that an LC slope filter of the type presently utilized in his BIRS [3] system be considered. We believe that a 2-component filter of this type could be easily accommodated, should that be deemed desirable.

IV. References

- [1] "Revision of the Bandpass Filter for the LWA Analog Receiver", M. Harum and S. Ellingson, May 30, 2007, http://www.ece.vt.edu/swe/lwa/memo/lwa0089.pdf, LWA Memo #89.
- [2] "The Rapid Test Array Balun (G250R)", B. Hicks and N. Paravastu, December 12, 2007, http://www.ece.vt.edu/swe/lwa/memo/lwa0120.pdf, LWA Memo #120.
- [3] "The Bruny Island Radio Spectrometer", W. C. Erickson, March 20, 1997, http://www.atnf.csiro.au/pasa/14_3/erickson/paper.pdf, Publ. Astron. Soc. Aust., 1997, 14, 278-82.

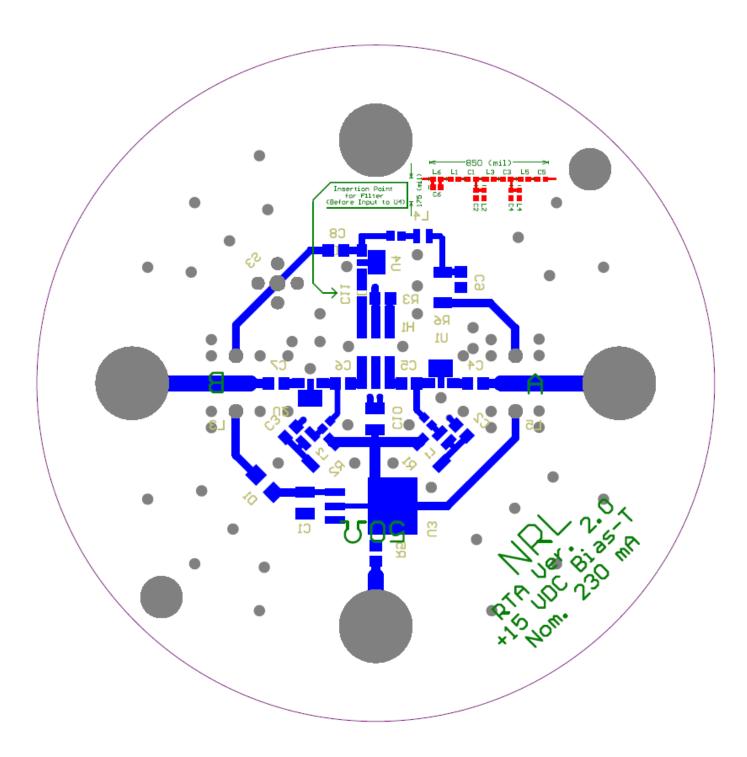


Figure 1 – Simplified PCB Layout of G250R Balun

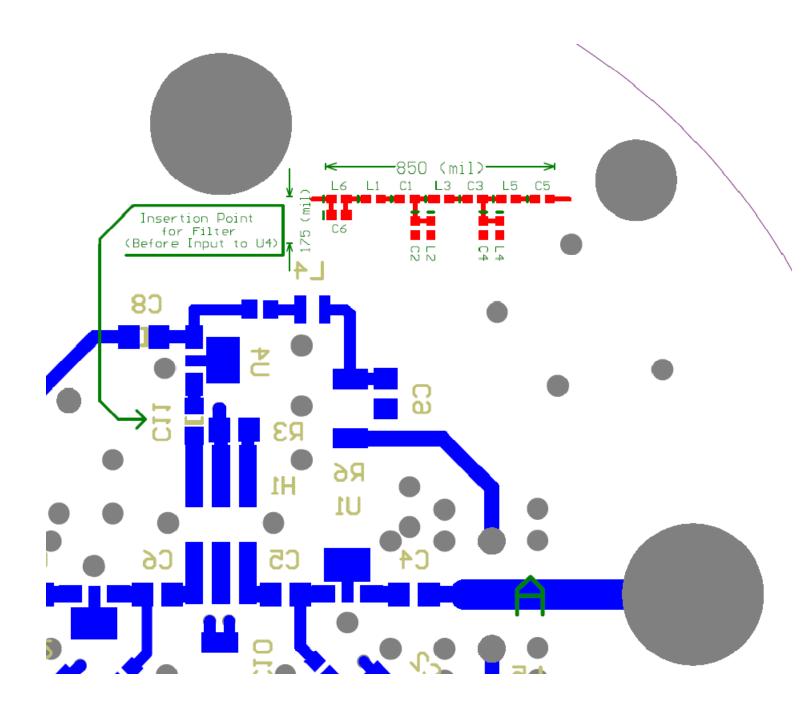


Figure 2 – Insertion Point for Filter

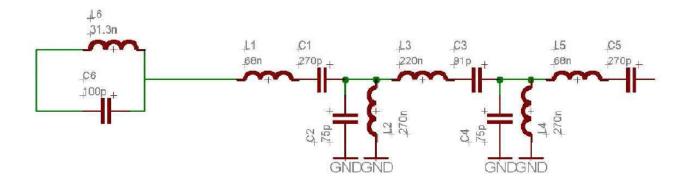


Figure 3 – Revised Filter Design from LWA Memo #80

NRL Engineering Memo #FEE0006 Brian Hicks June 13, 2008

Preliminary LWA FEE Schematic

I. Introduction

This document presents a preliminary schematic for a version of the LWA FEE to be used for future prototyping and testing. It is an incremental revision of the G250R FEE design presented in LWA Memo #120 [1].

II. Modifications to G250R Design

- 1. Diodes D2, D3, D4, and D5 have been added to provide ESD protection to the feedpoint connections.
- 2. A "slope filter" has been added before the final output stage to address linearity concerns related to strong out of band interferers. The filter consists of L6 and C14. Values for these components will be presented in an upcoming memo describing the bandpass and tolerancing of this network. The use of such a filter is discussed in a paper describing the operation of the BIRS Spectrometer [2].
- 3. An additional bypass, or shunt capacitor, (C12) has been added to the bias-T section of the FEE. The need for this component is discussed in LWA Memo #135 [3]. Per Joe Craig's suggestion, an additional footprint has been provided as C13 which can be selectively populated.
- 4. The FEE will be a dual polarization device consisting of two of the units covered by the schematic in Figure 1. Each polarization will be fabricated on a single sided PCB with a ground plane. The two polarizations will be rotated 90 degrees with respect to one another, and assembled with the ground planes facing together. This method of assembly was used for the baseline FEE the LWDA balun.

III. References

- [1] "The Rapid Test Array Balun (G250R)", B. Hicks and N. Paravastu, December 12, 2007, http://www.ece.vt.edu/swe/lwa/memo/lwa0120.pdf, LWA Memo #120.
- [2] "The Bruny Island Radio Spectrometer", W. C. Erickson, March 20, 1997, http://www.atnf.csiro.au/pasa/14_3/erickson/paper.pdf, Publ. Astron. Soc. Aust., 1997, 14, 278-82.
- [3] "Bias-T Design Considerations for the LWA", B. Hicks and B. Erickson, May 21, 2008, http://www.ece.vt.edu/swe/lwa/memo/lwa0135.pdf, LWA Memo #135.

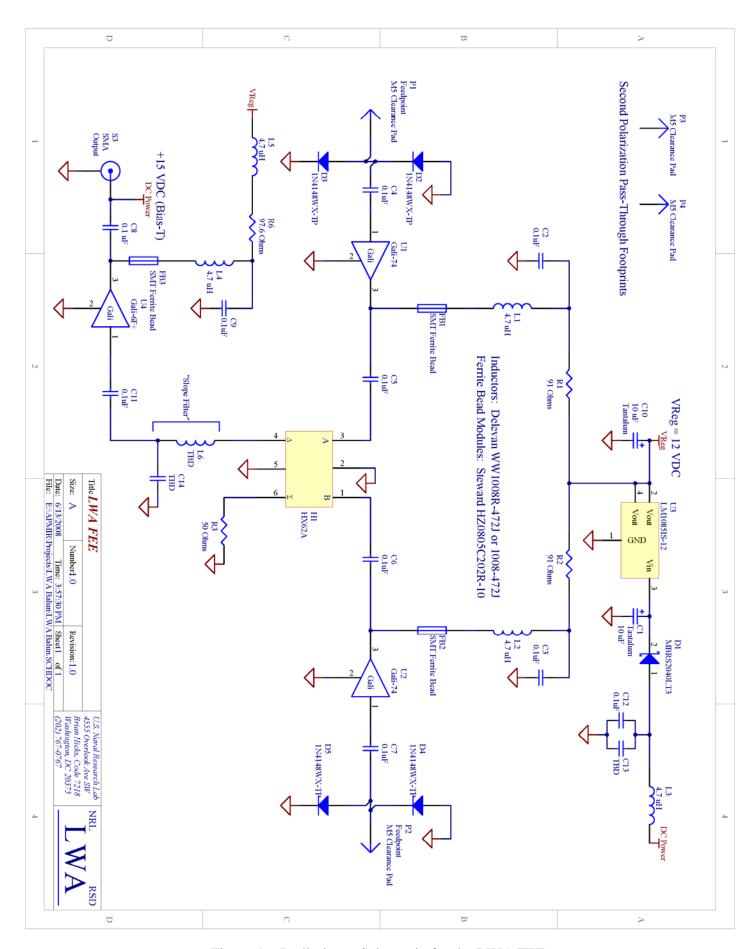


Figure 1 – Preliminary Schematic for the LWA FEE

Bill of Materials LWA FEE 6/13/2008

	Printed Circuit Board	P1, P2, P3, F4	S3	FB1, FB2, FB3	D2, D3, D4, D5	D1	H	U4	U1, U2	U3	R3, R4, R5	R6	R1, R2	C2C9, C11, C12	C1, C10	L1, L2, L3, L4, L5	Designation
	RTA v2.0	1/4-20 Bolt Insert	SMA, Straight	Ferrite 1.5A, SMD	1N4148	MBRS2040	HX62A	Gali-6	Gali-74	LM1085IS-12-ND	51Ω	96.7Ω	91 Ω	0.1 µF	10 µF	4.7 µH	<u>Value</u>
	NA	N A	N A	N/A	N A	NA	N A	NA	N A	NA	5%	1%	5%	10%	20%	10%	Tolerance
	Double Sided, Solder Mask Galaxy Electronic	Electroplated Tin, 1/4-20	SMA Connector	Ferrite, 1.5A	Diode	Diode, Schottky, 40 V, 2A	180 degree hybrid	MMIC Amplifier	MMIC Amplifier	Positive Voltage Regulator	Resistor, 1/4 Watt	Resistor, 1 Watt	Resistor, 1 Watt	Capacitor, Ceramic, X7R	Tantalum Capacitor	Inductor, Ceramic Core	е Туре
	Galaxy Electronics	Penn Engineering	Emerson Network	Steward	Micro Commercial Co.	ON Semiconductor	Tele-Tech, Corp.	Mini-Circuits	Mini-Circuits	National Semiconductor	Panasonic - ECG	Panasonic	Panasonic	Panasonic - ECG	Nichicon	Delevan	<u>Manufacturer</u>
	RTA-2	KFH-0420-8ET	142-0701-201	HZ0805C202R-10	1N4148WX-TP	MBRS2040LT3G	HX62A	Gali-6	Gali-74	LM1085IS-12	ERJ-P08J510V	ERJ-1TNF97R6U	ERJ-1TYJ910U	ECJ-3VB1E104K	F931E106MCC	1008-472J	Manufacturer's Part Number
	N/A	Penn Engineering Part	J500-ND	240-2396-1-ND	1N4148WXTPMSCT-ND	MBRS2040LT3GOSCT-ND	Must Buy Directly	Must Buy Directly	Must Buy Directly	LM 1085IS-12-ND	P51ALCT-ND	ERJ-1TNF97R6U-ND	PT91XCT-ND	PCC1883TR-ND	493-2388-1-ND	DN08472JTR-ND	r Digi-Key Part Number
	N/A	줖	SMA	240-0805	SOD323	SMB (5.59 x 3.81)	TT-HX62A	DF782	DF782	TO-263-3	1206	2512	2512	1206	SMT-C (6.0 x 3.2 mm	1008	Package Style
	\$7.00	\$0.16	\$2.55	\$0.05	\$0.06	0.1	31.50	1.3	1.00	\$ 1.25	0.0	0.1	\$ 0.19	\$ 0.06	\$ 0.33	\$ 0.81	Unit Cost
7440	_	4	_	ω	4	_	_	_	2	5 1 \$ 1.25	ω	_	2	10	2	5	Quantity
•	υ	69	υ	es	υ	()	υ	es	υ	()	ω	es.	υ	υ	69	en.	•
2 7 2	7.00	0.64	2.55	0.16	0.24	0.16	31.50	1.39	3.70	1.25	0.13	0.16	0.38	0.56	0.66	4.05	tende
	>=300									>500							Extended Cost Bracket (*)
	(Note 1)																

Figure 2 – Bill of Materials for LWA FEE

Total Cost: \$ 54.52

Note 1: Price provided 6/25/2007

* Parts only cost for a single polarization balun. Enclosure and connectors not included. * Price and availability verified on 11/6/2007

Note: L6 and C14 are TBD

NRL Engineering Memo #FEE0007 Brian Hicks June 26, 2008

Preliminary LWA FEE PCB Layout

I. Introduction

This document presents a preliminary printed circuit board (PCB) layout for a version of the LWA Front End Electronics (FEE) to be used for future prototyping and testing. The layout process required several modifications to the schematic presented in EM-FEE0006. An updated schematic and bill of materials are provided here that supersedes earlier versions.

II. Modifications to Circuit Design

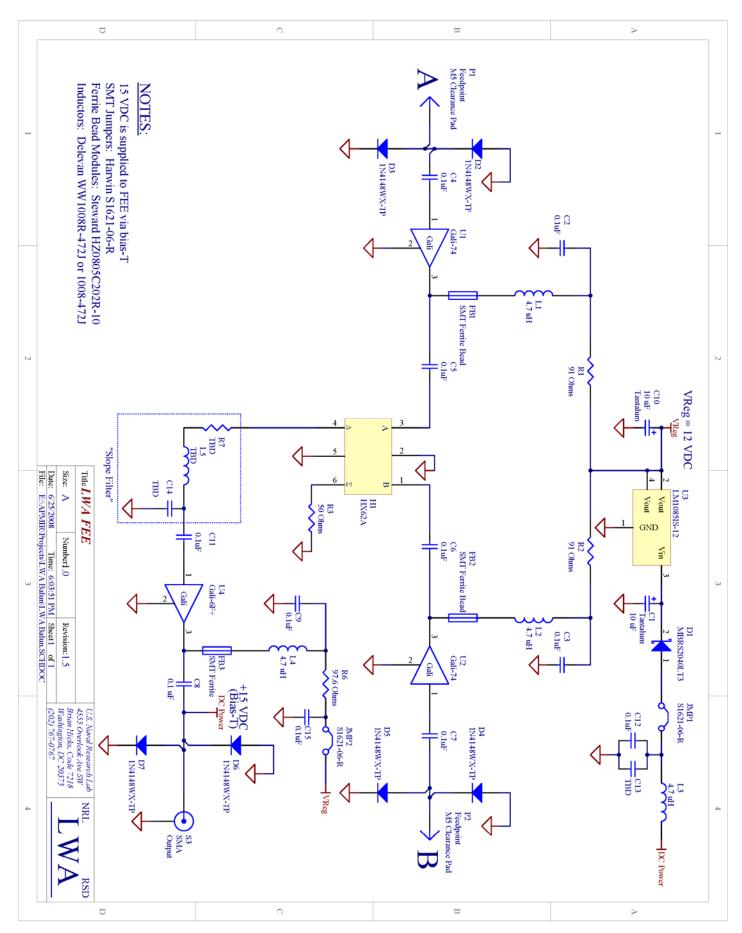
A schematic representing the most recent revision (1.5) of the LWA FEE is given in Figure 1. An updated bill of materials is presented in Appendix D.

The following changes have been made:

- 1. Diodes D6 and D7 have been added to provide transient protection to the output connection. This change was made based on the experience of Bill Erickson while operating at the Clark Lake Observatory. Assuming a forward voltage of 0.7 Volts for D6 and D7, it has been determined that the input of the FEE can be driven up to -26.1 dBm before saturation of the protection network occurs. This calculation is given in Appendix A.
- 2. R7 was added to provide flexibility to control the 'Q' of the slope filter circuit. Design of the slope filter is presently underway. These values will be determined and reported along with the filter response soon.
- 3. Surface mount jumpers were required to complete the PCB layout while retaining the proven characteristics of the design concept. A data sheet for this part is given in Appendix B. A calculation to approximate the capacitive loading of these jumpers is given in Appendix C. Jumpers are utilized only to convey DC power and are always oriented orthogonal to RF signal paths.
- 4. The inductor designated as 'L5' in EM-FEE0006 became superfluous in this most recent design and has been removed. Capacitor 'C15' was added to provide an RF bypass path prior to jumper 'JMP2'.
- 5. It has been determined that 'keying' of the two polarizations can be accomplished by:
 - a. Utilizing an SMC connector instead of an SMA connector on one of the polarizations. These connectors have identical footprints, and a dedicated layout will not be required.
 - b. Using two different size holes for the feedpoint connection pads along with two corresponding support stud sizes (Figure 6).

III. PCB Layout

The PCB layout of the FEE is now complete and all of the files necessary for manufacture (e.g. Gerber and NC drill files) have been generated. A set of assembly drawings are provided in figures 3 through 4. A mechanical detail on each layer depicts areas that will be cut out during manufacturing to enable the PCBs to be assembled with ground planes facing to facilitate dual-polarization FEE units. This layout is designed to adhere to the preliminary mechanical interface presented in EM-FEE0003A and Figure 6.



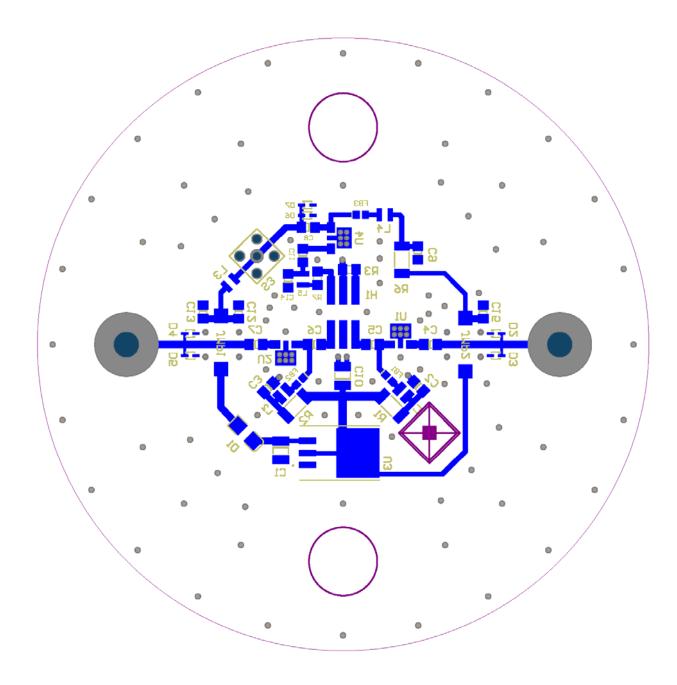


Figure 3 – PCB Layout: Solder Side (Ground network fill removed for clarity)

(Magenta objects will be cut away during manufacture to permit passage of connections from opposite polarization)

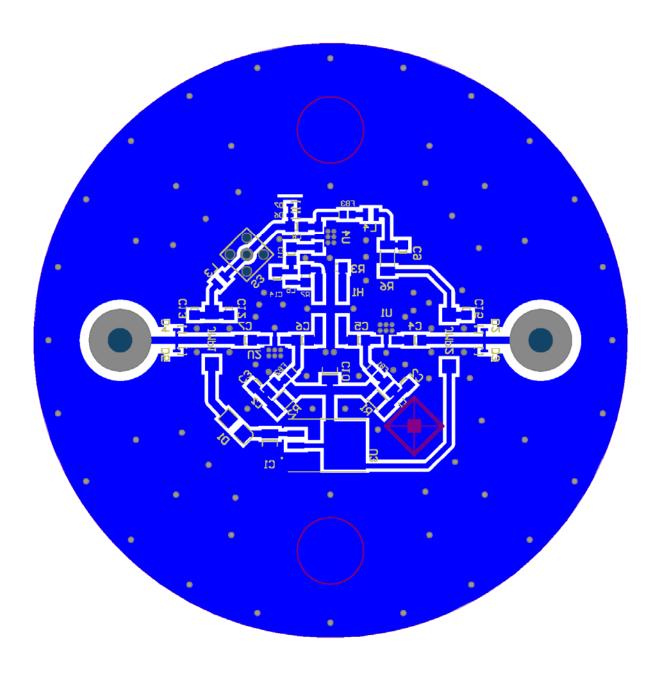


Figure 4 – PCB Layout: Bottom Layer (Ground network fill included)

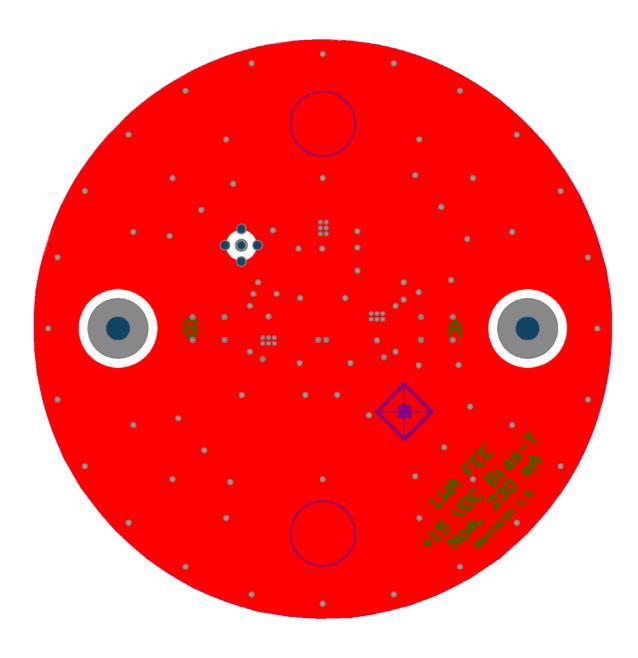


Figure 5 – PCB Layout: Top Layer (Ground network fill included)





Design Rule Verification Report

Date : 6/25/2008

Time: 6:50:34 PM Warnings:0

Elapsed Time : 00:00:00 Rule:0

Filename : E:\APMIR\Projects\LWA Violations

Balun\LWA Balun.PCBDOC

Summary

Warnings	Count
Tota	I 0
Rule Violations	Count
Hole Size Constraint (Min=1mil) (Max=300mil) (All)	0
Height Constraint (Min=0mil) (Max=1000mil) (Prefered=500mil) (All)	0
Width Constraint (Min=10mil) (Max=200mil) (Preferred=10mil) (All)	0
Clearance Constraint (Gap=15mil) (All),(All)	0
Broken-Net Constraint ((All))	0
Short-Circuit Constraint (Allowed=No) (All),(All)	0
Clearance Constraint (Gap=15mil) (All),(OnLayer('Solder Side'))	0
Tota	I 0

file://E:\APMIR\Projects\LWA Balun\ProjectOutputs\Design Rule Check - LWA Balun.ht... 6/25/2008

Figure 6 – Successful Design Rule Verification

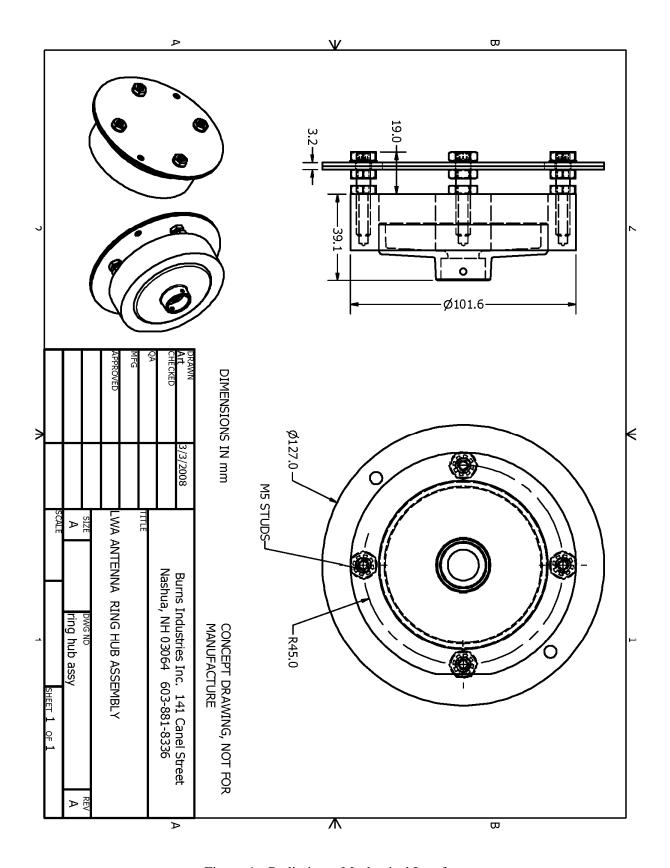
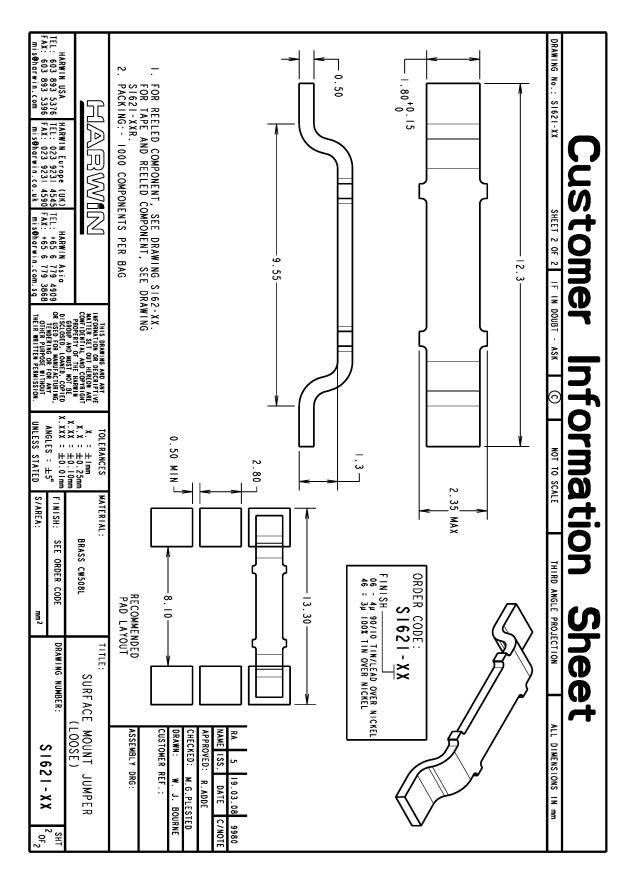
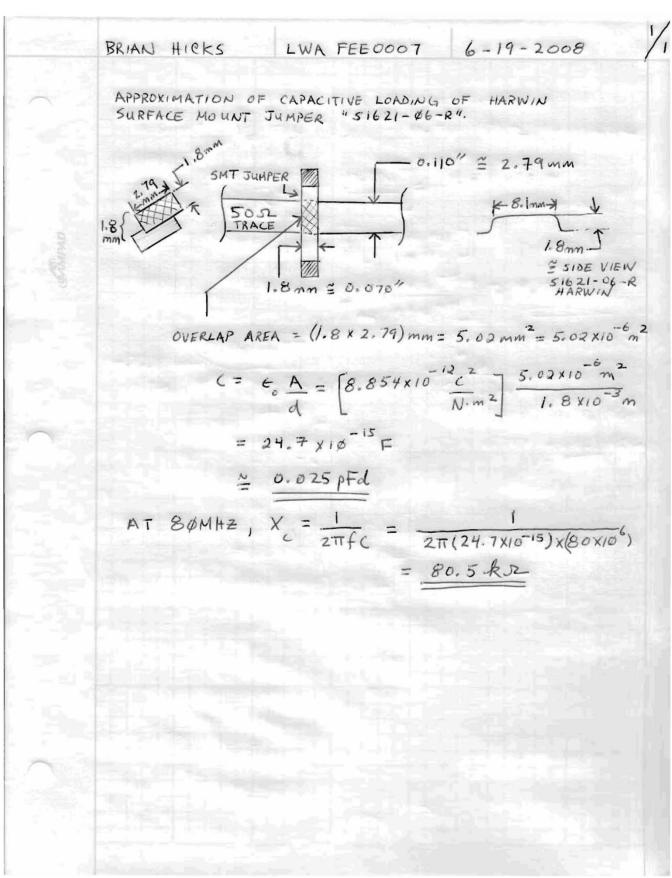


Figure 6 – Preliminary Mechanical Interface

Appendix A – Maximum Signal Input Calculation



Appendix B –Surface Mount Jumper Datasheet (Harwin S1621-06-R)



Appendix C – Capacitive Loading Calculation

Bill of Materials LWA FEE

					6/27/2008								
Designation	<u>Value</u>	Tolerance	<u>Туре</u>	<u>Manufacturer</u>	Manufacturer's Part Number	Digi-Key Part Number	Package Style	Unit Cost	Quantity	Exte	Extended	Cost Bracket (*)	
L1, L2, L3, L4	4.7 µH	10%	Inductor, Ceramic Core	Delevan	1008-472J	DN08472JTR-ND	1008	\$ 0.81		69	3.24		
C1, C10	10 µF	20%	Tantalum Capacitor	Nichicon	F931E106MCC	493-2388-1-ND	SMT-C (6.0 x 3.2 mm)	\$ 0.33		69	0.66		
C2C9, C11, C12, C15	0.1 µF	10%	Capacitor, Ceramic, X7R	Panasonic - ECG	ECJ-3VB1E104K	PCC1883TR-ND	1206	\$ 0.06		€9	0.62		
R1, R2	91Ω	5%	Resistor, 1 Watt	Panasonic	ERJ-1TYJ910U	PT91XCT-ND	2512	\$ 0.19		69	0.38		
R6	96.7Ω	1%	Resistor, 1 Watt	Panasonic	ERJ-1TNF97R6U	ERJ-1TNF97R6U-ND	2512	\$ 0.16		69	0.16		
R3, R4, R5	51Ω	5%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-P08J510V	P51ALCT-ND	1206	\$ 0.04	ω	69	0.13	<4000	
U3	LM1085IS-12-ND	NA	Positive Voltage Regulator	National Semiconductor	LM1085IS-12	LM 1085IS-12-ND	TO-263-3	\$ 1.25		ω	1.25		
U1, U2	Gali-74	N A	MMIC Amplifier	Mini-Circuits	Gali-74	Must Buy Directly	DF782	\$ 1.85		69	3.70		
U4	Gali-6	NA	MMIC Amplifier	Mini-Circuits	Gali-6	Must Buy Directly	DF782	\$ 1.39		s	1.39		
Η.	HX62A	N A	180 degree hybrid	Tele-Tech, Corp.	HX62A	Must Buy Directly	TT-HX62A	\$ 31.50		မာ	1.50		
D1	MBRS2040	N A	Diode, Schottky, 40 V, 2A	ON Semiconductor	MBRS2040LT3G	MBRS2040LT3GOSCT-ND	SMB (5.59 x 3.81)	\$ 0.16		69	0.16		
D2, D3, D4, D5, D6, D7	1N4148	N A	Diode	Micro Commercial Co.	1N4148WX-TP	1N4148WXTPMSCT-ND	SOD323	\$0.06		6 9	0.36		
FB1, FB2, FE3	Ferrite 1.5A, SMD	N/A	Ferrite, 1.5A	Steward	HZ0805C202R-10	240-2396-1-ND	240-0805	\$0.05	ω	69	0.15		
S3	SMA, Straight	N A	SMA Connector	Emerson Network	142-0701-201	J500-ND	SMA	\$2.55	_	69	2.55		
JMP1, JMP2	S1621-06-R	N A	SMT Jumpers	Harwin	S1621-06-R	Buy Through Harwin Dist.	SMT Jumper	\$0.08	2	6 9	0.16		
Printed Circuit Board	RTA v2.0	N A	Double Sided, Solder Mask Galaxy Electronics	Galaxy Electronics	RTA-2	WA	NA	\$7.00	_	co.	7.00	>=300	(Note 1)
Note: 07 - 5 Oct Odd	3 1 2 2								Total Cost	5	\$ 53.40		
Note: R7 L5 C13 and C14 are TBD	TBD												

Appendix D – Updated Bill of Materials: LWA FEE Revision 1.5

Note 1: Price provided 6/25/2007

 * Parts only cost for a single polarization balun. Enclosure and connectors not included. * Price and availability verified on 11/6/2007

NRL Engineering Memo #FEE0008 Brian Hicks August 5, 2008

LWA FEE Prototype Revision 1.5

I. Introduction

This document reports the completion and initial testing of LWA FEE prototype revision 1.5. The completed assembly, shown in Figure 1, was recently tested during a summer measurement campaign at the LWDA site and yielded the nominally expected performance (Figure 2). A mechanical 'fit-test' model was also fabricated from this model and provided to Burns Industries for use in antenna stand prototyping. The mechanical model (connectors only) can be seen bolted into the 'hub' of the present Burns antenna design in Figure 3. This prototype proved that it was possible to extend the G250R balun concept into a dual polarization unit [1].

II. Planned Modifications

- 1. The circular cutouts for the opposite polarization PCB will be replaced with pads having M5 clearance holes.
- 2. The "slope filter" structure will be made more flexible and incorporate changes recently suggested by Joe Craig.
- 3. The protection network on the output will be modified. An additional capacitor is required to clip transients to within $\sim \pm 0.7$ V. A footprint will also be added for a surface mount gas discharge tube to be located near the output connector.
- 4. A provision will be included to connect the ground of both FEE units included in a dual polarization unit which will allow straightforward and efficient connection to a local ground.

III. References

[1] "The Rapid Test Array Balun (G250R)", B. Hicks and N. Paravastu, December 12, 2007, http://www.ece.vt.edu/swe/lwa/memo/lwa0120.pdf, LWA Memo #120.

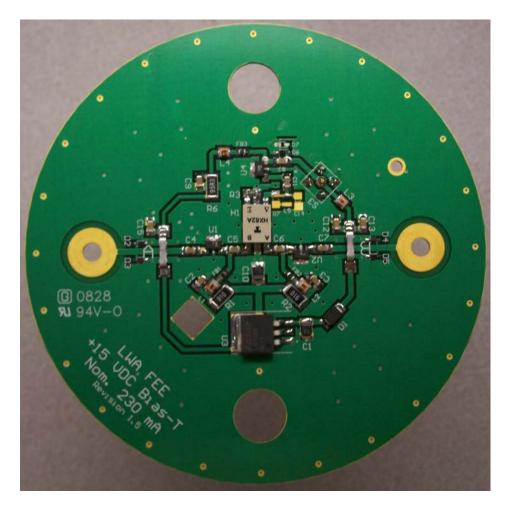


Figure 1 –LWA FEE

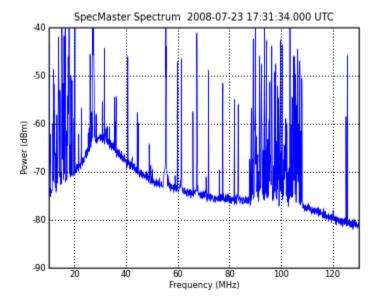


Figure 2 –LWA FEE

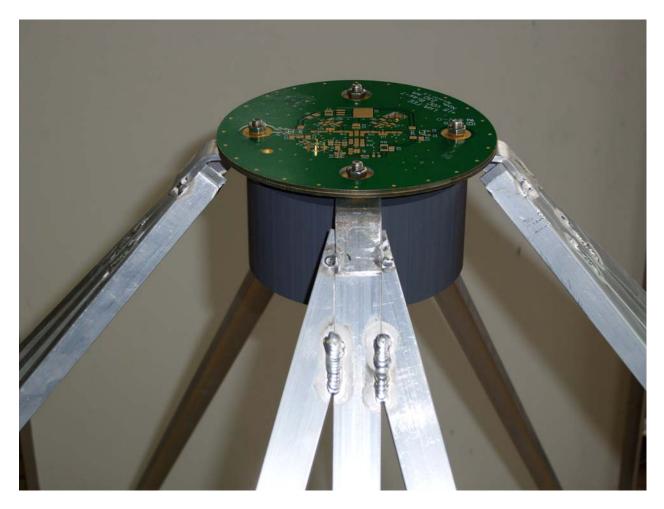


Figure 3 – Mechanical "Fit Test" of LWA FEE Revision1.5

FEE0010: Environmental chamber testing of the FEE

Jake Hartman and Brian Hicks May 15, 2009

Abstract. We measured the effect of temperature on the phase and gain responses of versions 1.6 and 1.7 of the FEE. Both showed a small decrease in gain as the temperature increased ($\approx -0.005 \text{ dB/°C}$) and a small phase dependence ($\approx -0.01 \text{ °/°C}$).

Introduction.

The front-end electronics (FEE) of the LWA antennas will be subject to a wide range of ambient temperatures in the high-altitude New Mexico desert, so it is necessary to characterize the temperature sensitivity of their gain and electrical delay.

Previous work by Bradley & Parashare included environmental testing on an earlier version of the FEE (LWA Memo 19, "Evaluation of the NRL LWA Active Balun Prototypes," Feb 2005). By measuring the FEE response over temperatures of 0–40°C and frequencies of 10–200 MHz, they found a gain sensitivity with temperature of approximately –0.004 dB / °C. The electrical delay was independent of temperature.

Version 1.6 of the FEE is substantially revised. (See FEE0014 for a schematic and further details.) The version tested by Bradley & Parashare used a Gali-74 amplifier (rated for a typical gain of 25 dB) between each feedpoint and the 180° hybrid junction that performs the differencing. These provided an overall gain of approximately 21 dB. The new version uses the same Gali-74 amplifiers before the 180° junction, but also includes a Gali-6+ amplifier (rated for a typical gain of 12 dB) following differencing. The resulting overall gain is approximately 35 dB. Other improvements, such as protective diodes on the feedpoints and output, were also added. This version of the FEE is circular to fit in the round hub of the Burns prototype 2 STD design.

Version 1.7 of the FEE adds a low-pass filter with a cut off of around 150 MHz to prevent out-of-band RFI from driving the amplifiers into nonlinear operation. This version also includes a power-on indicator LED and improved biasing inductors. It is square to simplify manufacturing.

Testing procedure.

For version 1.6 of the FEE, we performed environmental testing on a single side of balun R1.6-001. This balun was installed in the eastern outlier antenna in Sep 2008 (see STD0004). It was used for data taking for one month, after which one side of the balun was damaged during removal and re-installation in the antenna. Shortly after the damage, the FEE was permanently removed and returned to the NRL. We tested the undamaged side.

For version 1.7, we tested an extra single side that had never been used in the field.

RF measurements were made with an Agilent N3383A vector network analyzer (VNA). Port 1 of the VNA output a power of –40 dBm over a frequency range of 10–110 MHz. This power is low enough to avoid any chance of saturation. It drove a 180° hybrid junction identical to the ones in the FEEs to split the signal from the VNA into the two feedpoints of the FEE. Port 2 of the VNA received its signal from the RF-only port of a bias-T connected to the FEE output. The DC port of the bias-T was powered at 15.5

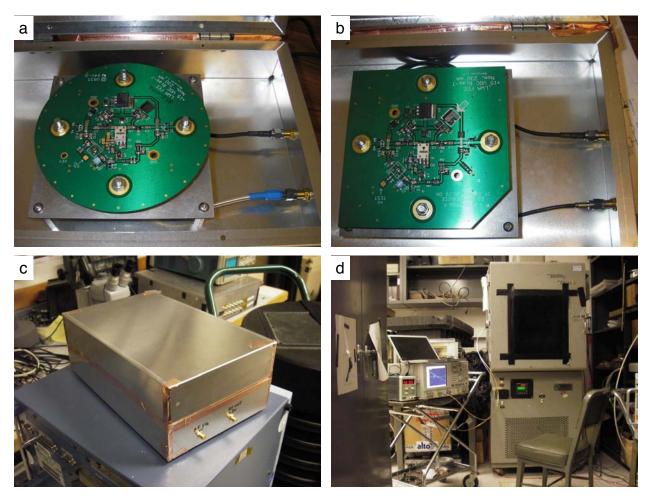


Figure 1. The equipment used for the environmental testing of the FEEs.

V and drew 230 mA for the v1.6 FEE and 260 mA for the v1.7 FEE with LED. The electrical delays of the cables were accounted for in the VNA such that the phase response of the FEE was nearly constant in the 40–80 MHz band.

To reduce RFI, the FEE was placed in an aluminum enclosure during testing. Figure 1a shows v1.6 in the chamber; Figure 1b shows v1.7. The seams of the enclosure were covered with conducting tape to further reduce RFI (Figure 1c). The driven 180° hybrid junction is located underneath the platform to which the FEE mounts.

The FEE and its enclosure were placed in a Tenney Mite 3 environmental control chamber. For testing below room temperature, the chamber was filled with nitrogen to prevent condensation. The temperature was stepped from -20° C to 40° C in 5° increments. For each increment at least 15 minutes were allowed for the temperature of the FEE to stabilize. Its temperature is somewhat moderated by the heat it generates, so it will be warmer than the ambient temperature. Figure 1d shows the environmental chamber, with the VNA and power supply on the stand to its left.

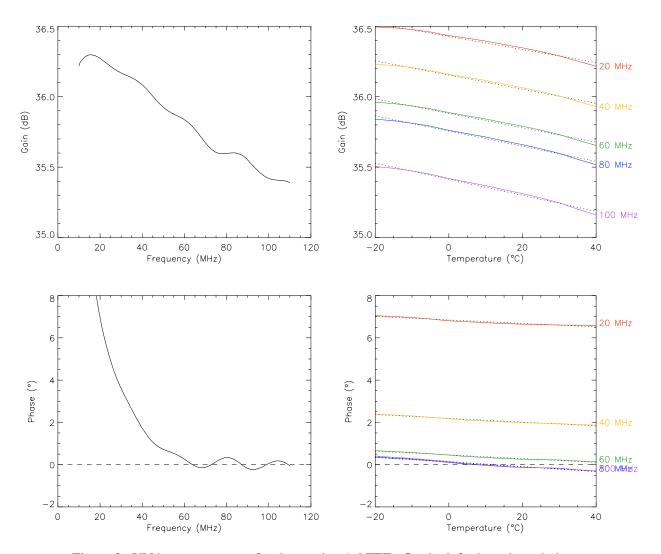


Figure 2. VNA measurements for the version 1.6 FEE. On the left, the gain and phase spectra at 20° C. On the right, the temperature dependence of the gain and phase. The dotted lines show the best-fit slopes for the gain and phase vs. temperature relations.

Results for the version 1.6 FEE.

Figure 2 shows the measurements for the version 1.6 FEE. The electrical delay was held constant at 24.625 ns for all the measurements. These plots show the gain and phase measured with an improved bias-T (the version that can power both polarizations simultaneously), which uses a higher-quality biasing inductor. The earlier bias-Ts had a 0.1 dB notch at 53 MHz due to self-resonance.

The gain dependence on temperature varies between $-0.0047 \, dB/^{\circ}C$ and $-0.0057 \, dB/^{\circ}C$, with the magnitude of the slope monotonically increasing with frequency between 20 MHz and 100 MHz. These slopes are close to the results of Bradley & Parashare, who measured a slope of $-0.0047 \, dB/^{\circ}C$. (They did not report any frequency dependence of the slope.)

The phase also has a weak dependence on temperature, with a slope of -0.008 %C and -0.012 %C. Again, the magnitude of the slope monotonically increases with frequency. Bradley & Parashare did not report any phase dependence on temperature.

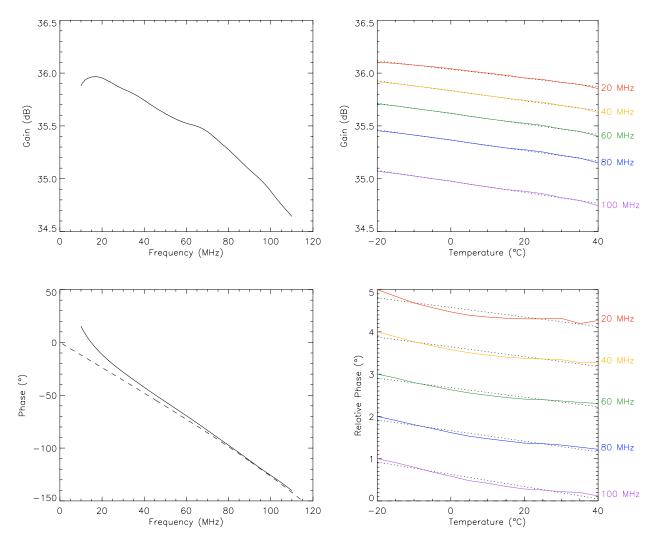


Figure 3. VNA measurements for the version 1.7 FEE. On the left, the gain and phase spectra at 20° C. (Note that the limits of the Y axes differ from those shown in Figure 2.) The dashed line on the phase spectrum shows the expected phase shift produced by the low-pass filter. On the right, the temperature dependence of the gain and phase. The phase plot shows only the relative temperature dependence of phase (with each curve offset by 1° for clarity) so that the trends are not lost in the much larger frequency dependence. The dotted lines show the best-fit slopes for the gain and phase vs. temperature relations.

Results for the version 1.7 FEE.

Figure 3 shows the measurements for the version 1.7 FEE. The addition of a low-pass filter to the FEE had two effects. First, the gain is ~0.4 dB lower than the version 1.6 FEE in the 20–80 MHz band due to resistance in the filter inductors. Second, the filter shifts the phase, as seen in Figure 3. Agreement between the filter model and the observations is good at higher frequencies. At low frequencies the capacitors at the feedpoints become important, so the observations diverge from the filter-only model.

The gain dependence on temperature varies between -0.0042 dB/°C and -0.0054 dB/°C, with the magnitude of the slope monotonically increasing with frequency between 20 MHz and 100 MHz. The phase also has a weak dependence on temperature, with a slope of -0.011 °/°C and -0.014 °/°C. Again, the magnitude of the slope monotonically increases with frequency.

NRL Engineering Memo #FEE0012 Brian Hicks, Nagini Paravastu, Paul Ray Revised, April 15, 2008

Test Scripts for LWA FEE units

We present two test procedure options to generate discussion regarding characterization and quality control methods for LWA active baluns (FEE). The G250R unit is referenced in these documents for purposes of illustration only; these test plans should apply to any candidate LWA FEE design.

A fundamental set of tests which are intended to verify the functionality of an established FEE design are outlined in Table 1. This is the group of tests that have been applied prior to the fielding all LWA prototypes.

Table 2 presents the remaining tests which should be conducted <u>in addition</u> to those listed for the basic functional test to fully characterize a potential FEE design.

An excitation level of -60 dBm is recommended for all gain and other s-parameter measurements.

A standardized test fixture will be developed to ensure consistent results when the mechanical interface between the FEE and the antenna stand is finalized.

After the validity of a new design has been established through a full characterization, we believe that most defects can be detected, or inferred, through the basic test procedure given in Table 1. We recommend that the basic test script be executed at the time of manufacture for all FEE units.

Related LWA memos

[120] B. Hicks and N. Paravastu, The Rapid Test Array Balun (G250R), Dec 12, 2007.

[19] R. Bradley and C.R. Parashare, <u>Evaluation of the NRL LWA Active Balun Prototype</u> (Rev.A), 02/05.

[71] B. Hicks, N. Paravastu, R. Bradley, and C. Parashare, <u>A Low Noise, High Linearity Lossless Feedback Amplifier for LWA Applications</u>, December 12, 2006.

[81] N. Paravastu, B. Hicks, R. Bradley, and C. Parashare, <u>Development and Measurement of a Second Generation Balun Candidate for the LWA</u>, January 25, 2007.

	Nominal Response	vith Test units should be nearly identical to the exemplar. Particular attention should ons. be placed on finding solder bridges, evidence of excessive heat, chemical residue, and obvious physical damage.	A properly functioning G250 R FEE should typically draw 230 mA. Testing should be discontinued if the measured level deviates by more than 5% of 230 mA, and the unit should be flagged for repair.	a If there is any evidence of oscillation, er. discontinue testing and flag the unit for n critical evaluation and repair.	The G250R FEE should nominally provide 36 dB of gain across the entire 500 kHz to 115 MHz range. If the gain of a test unit deviates from 36 dB by more than 0.4 dB at any frequency, it should be flagged for critical evaluation.
Table 1 – Basic Functional Test	Procedure	Compare FEE under evaluation with exemplar and provide detailed comments regarding any deviations.	Apply +15 VDC to FEE under test via bias-T and record the current being drawn.	Connect the output of the FEE to a spectrum analyzer and apply power. Look for evidence of oscillation in the frequency range of 500 kHz to 10 GHz with the FEE feedpoint terminals open and loaded with 50 Ω .	Record gain as a function of frequency from 500 kHz to 115 MHz. If a signal generator is used, record discrete gain points at 5 MHz intervals. An excitation level of -60 dBm will be used.
Table 1 – Ba	Equipment	Photographic image of tested and inspected unit.	Power supply with integral voltmeter and ammeter, or power supply and multimeter.	Spectrum analyzer, power supply.	Spectrum analyzer, 180 degree hybrid, or network analyzer. If the spectrum analyzer to be used does not have a tracking generator, a signal generator will be required.
	Test	Visual Inspection	Current Consumption	Basic Stability	Gain

in Table 1	Nominal Response	o one S21 data should indicate a nominal gain nated, of 36 dB over the given frequency range. Yppical S11 response for FEE units with Gali-74 input stages can be found in LWA memos #19, #71, #87, and #120. er and s-tion	sion S21 data should be indicative of a nominal gain of 36 dB. The input referenced 1dB compression point should be -18.30 dBm. The Input IP3 is typically -1.8 dBm.	EE A noise figure of ~2.7 dB should be sr, expected for all G250R FEE units. rid.	quency The G250R FEE should present negligible gain sensitivity with temperature (GST). The GST for the from 0 Hicks balun was found to be approximately -0.004 dB. See LWA memo #19.	The device will remain stable and exhibit no oscillations between 500 kHz and 10 dHz. See LWA memo #19. The FEE rasitic will exhibit no oscillations when connected to the antenna elements via the standardized mechanical interface.
Table 2 – Full Characterization performed in addition to those	Procedure	Using a VNA connected to one input with the other terminated, record data for S21 (gain), S11 (input match), S22 (output match), and S12 (reverse isolation). Repeat for other feedpoint. Produce plots and sparameter files. An excitation level of -60 dBm is recommended.	Measure the 1dB compression point and 3 rd order intermodulation distortion (IMD) product. See LWA memo #19 for a discussion of measurement techniques.	Measure noise figure of FEE using noise figure analyzer, calibrated diode, and hybrid. Apply loss correction for 180° hybrid.	Measure S21 over the frequency range of 500 kHz to 115 MHz for each feedpoint while varying the ambient temperature from 0 to 40 °C in steps of 5 °C.	Ensure the FEE is unconditionally stable when the balun is presented with varying impedances. Look for parasitic oscillations when the FEE is driven at 10 dB below the 1 dB compression point.
Table 2 – Full Characterization Tests to be performed in addition to those in Table 1	Equipment	Vector network analyzer (VNA), power supply, 50 Ω loads.	Power supply, spectrum analyzer, two RF generators (e.g. HP 8673B), variable attenuators.	Noise figure analyzer (e.g. Agilent N8973A), calibrated noise diode (e.g. HP 346C), 180° hybrid, power supply.	VNA, environmentally controlled chamber (e.g. Thunder Scientific, Corp., Model 2500S), power supply.	Spectrum analyzer, 50 Ω loads, tunable impedance loads (See section #2, LWA memo #19).
Τϵ	Test	Produce full set of s-parameter data for the frequency range of 500 kHz to 6 GHz	Linearity measurements	Noise figure measurement at ambient temperature (25° C)	S21 versus ambient temperature	Unconditional stability test

NRL Engineering Memo #FEE0013 Brian Hicks and Tracy Clarke October 21, 2008

Field Testing of Front End Electronics (FEE)

Field testing of revision 1.6 of the LWA FEE (Fig. 1) was conducted during the September LWA field trip. The FEE was installed in the first prototype antenna stand (STD) delivered from Burns industries (Fig. 2). The electrical performance of the unit was as expected but a several important mechanical interface issues were identified during the exercise.

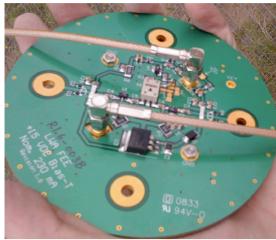


Figure 1 - FEE Ready for Testing

Figure 2 - FEE Installed in STD from Burns Industries

Mechanical Issues

- 1. <u>Bending Radius:</u> The right angle adapters shown in Fig. 1 were necessitated by the lack of space in the antenna hub for an acceptable bending radius of the FEE output cables. Future STD revisions will address this concern.
- 2. <u>Mechanical Keying:</u> The mechanical keying scheme used in revision 1.6 did not present an adequate deterrent to incorrect installation of the FEE in the antenna 'hub' assembly. New mechanical keying schemes are presently being investigated for inclusion into the next FEE/STD revision.
- 3. <u>Feedpoint Connection Holes:</u> Installation of the FEE onto the bolt circle of M5 studs on the hub assembly was found to be difficult. Even though the holes in the FEE feedpoint pads were sized larger than 'free-fit' clearance holes for M5 bolts, installation was cumbersome and subjected the FEE to excessive mechanical stress. This problem will be corrected in revision 1.7 of the FEE.
- 4. <u>Coupling Between Mechanical and Electrical Interfaces:</u> The present STD design places all of the reacting support forces directly on the hub assembly via bolts which also serve as feedpoint connections (Fig. 3). While this arrangement could have offered many advantages, it became obvious while evaluating the STD design that mechanical stress was being applied to the board. Subsequent revisions of the FEE and STD designs will aim to maintain the simplicity and economy of 'bolt down' feedpoint connections while *completely* isolating mechanical and electrical interfaces.



Figure 3 - FEE Feedpoint Connections at STD Hub

Electrical Performance

Revision 1.6 of the FEE was able to pass all of the basic functional tests described in table 1 of EM-FEE012. Current consumption, gain, stability, and RF performance were all as anticipated. The slope of the Galactic background is clearly visible in the spectrum taken with the FEE installed on the first Burns prototype (Fig.3). Initial drift curve data taken with the Specmaster system is shown in figure 5.

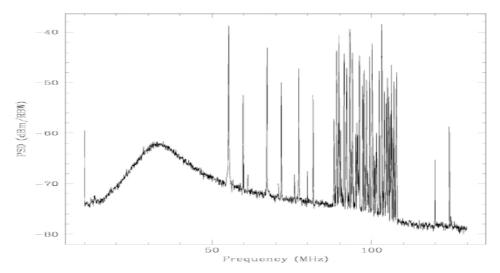


Figure 4 - Spectrum from 10 to 130 MHz of the FEE/STD prototype near the shelter taken on 20080910 at 05:10:03 UTC.

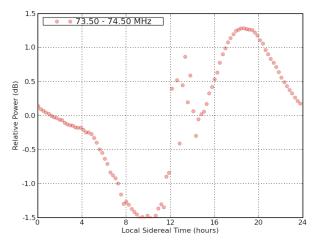
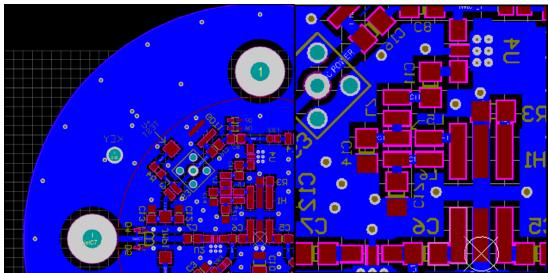


Figure 5 - Initial Drift Curve Data at 74 MHz

NRL Engineering Memo #FEE0015 Brian Hicks October 7, 2008

Filter for FEE

A five-pole filter has been added to the FEE to define the front-end bandpass and mitigate IMD concerns. This filter resides between the output of the 180° hybrid and the final output amplifier (Gali-6). To overcome the obstacles related to incorporating the filter structure discussed in EM FEE0003B into the FEE, Joe Craig recommended a five pole circuit which I have folded into revision 1.6 of the FEE PCB layout.



FEE Filter on PCB

An end-to-end test of the entire analog signal chain was conducted at Joe Craig's laboratory in Albuquerque, NM on September 10, 2008. During this test a spool of cable representative of the longest anticipated LWA station cable run was connected between the FEE and ARX. Power was provided to the FEE from the ARX via the RF cable using the integral bias-T on the ARX. Gain measurements as a function of frequency were taken using a Rhode and Schwarz FSH3 spectrum analyzer. The tracking generator of the FSH3 provided the RF signal to the FEE via the hybrid in the text fixture. Initial tests were conducted with the FEE configured without any filtering installed. All of the available filter and gain modes of the ARX were exercised and the ability to control DC power to the FEE was demonstrated. The anticipated performance of the signal chain was recorded without the FEE filter.

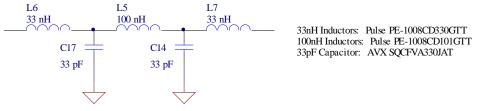


Open FEE Test Fixture with FEE Installed

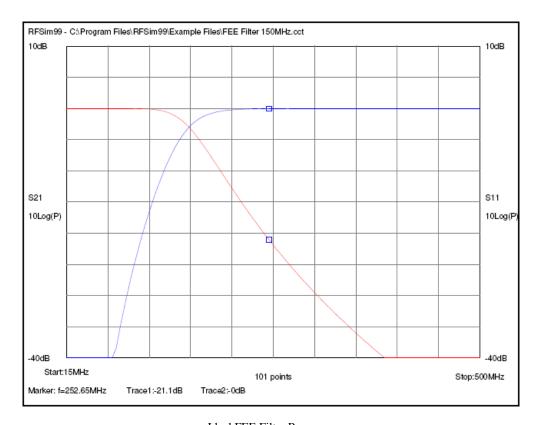


FEE Test Fixture Closed for Testing

Joe then provided a Butterworth filter design which was installed in the FEE and found to provide the desired bandpass. The specific filter is shown is given here:



FEE Filter Schematic



Ideal FEE Filter Response Red: S21 (Forward Gain of Filter) Blue: S11 (Insertion Loss of Filter)

All of the ARX modes were exercised again with the new FEE configuration, and Joe mentioned that the bandpass provided by FEE filter was suitable for use in subsequent prototyping. It was also decided to configure future FEE units with the feedpoint coupling capacitors (C4, C7) changed from 0.1 μ F to 1000 pF. Based on experience with the ARX, this should limit the lower bound of the FEE bandpass to approximately 3 MHz.

NRL Engineering Memo #FEE0022 Brian Hicks March 17, 2009

LWA FEE Version 1.7

I. Introduction

This document presents a description of version 1.7 of the LWA FEE. An updated schematic, PCB layout, and bill of materials are provided that supersede earlier versions.

II. Modifications to Circuit Design

A schematic representing the most recent revision (1.7) of the LWA FEE is given in Figure 1.

An updated bill of materials is presented in Appendix A.

The following changes have been made:

- 1. L3 has been replaced with a component from Coilcraft (1008PS-472KLB) that is rated for higher current (900mA). The previous part was subject to long availability lead times and was marginally acceptable in terms of current rating. Suspicious failures of the previously specified part were observed.
- 2. The inductors used in the bias networks (L1, L3, and L4) of the 'Gali' amplifiers have also been changed to a component from Coilcraft (1008CS-472XJLB). The new part is more readily available and less expensive than the previous component (\$0.81 versus \$0.20, each). A PCB layout change was not required.
- 3. The diameter of the holes in the feedpoint pads has been changed 0.270" to freely accommodate 1/4-20 studs suggested by Burns Industries.
- 4. To prevent mixing up polarizations, one polarization (N-S) is now clearly delineated with a white outline and white arrow that will match the white jacket or heat shrink on the cable for that polarization.
- 5. An LED (D8) has been added to indicate when the FEE is powered. Text has been added to the silkscreen to warn against servicing the FEE when it is powered.
- 6. The coupling capacitors (C4, C7) at the feedpoints have been changed from 0.1 µF to 1000 pF.
- 7. Final assembly instructions and manufacturing details for dual polarization FEEs can be found in EM-FEE0023.

III. PCB Layout

The revised PCB layout for version 1.7 of the FEE is provided in Figure 2.

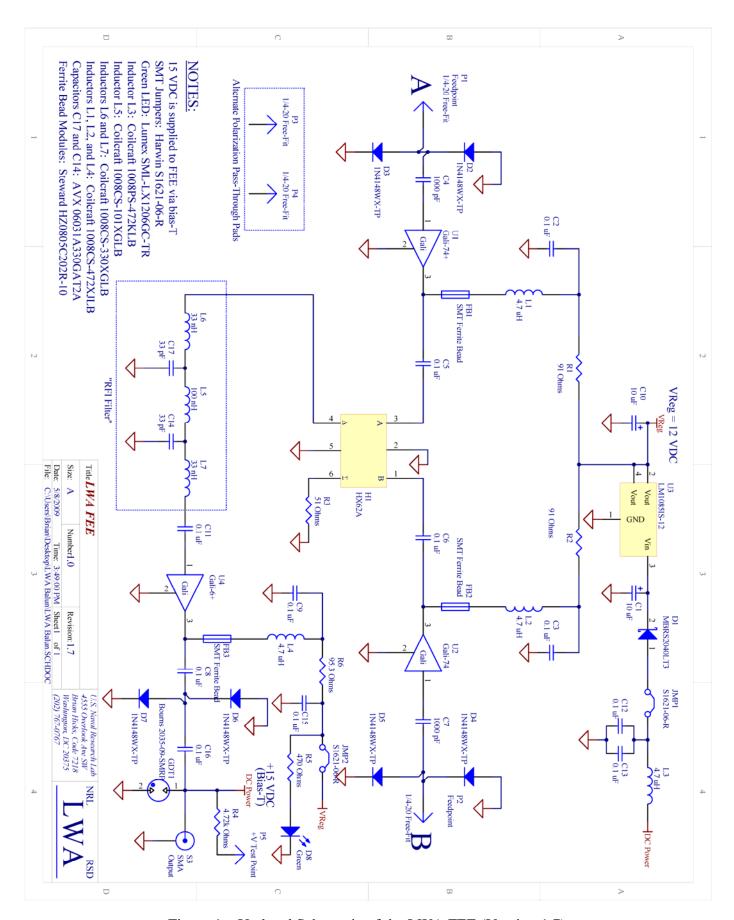


Figure 1 – Updated Schematic of the LWA FEE (Version 1.7)

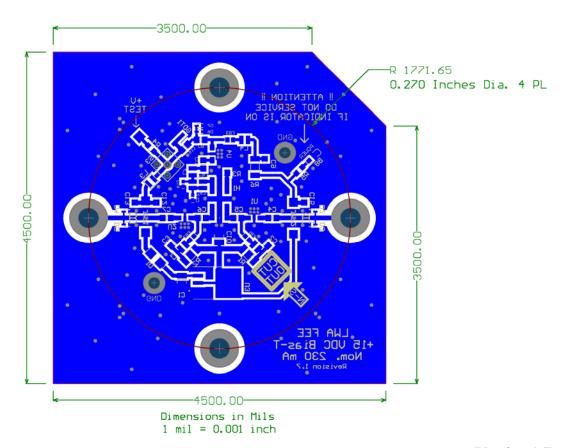


Figure 2a – FEE PCB Layout: Component Side (Version 1.7)

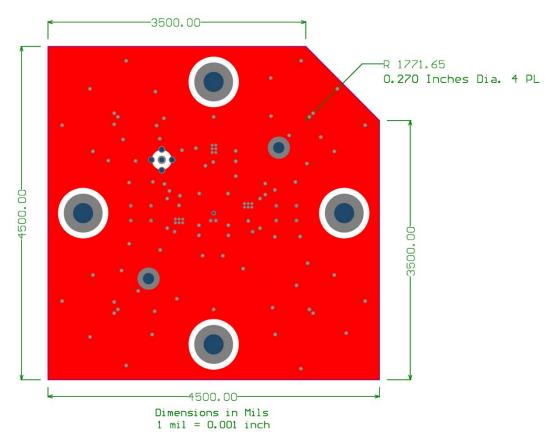


Figure 2b – FEE PCB Layout: Top Side (Version 1.7)

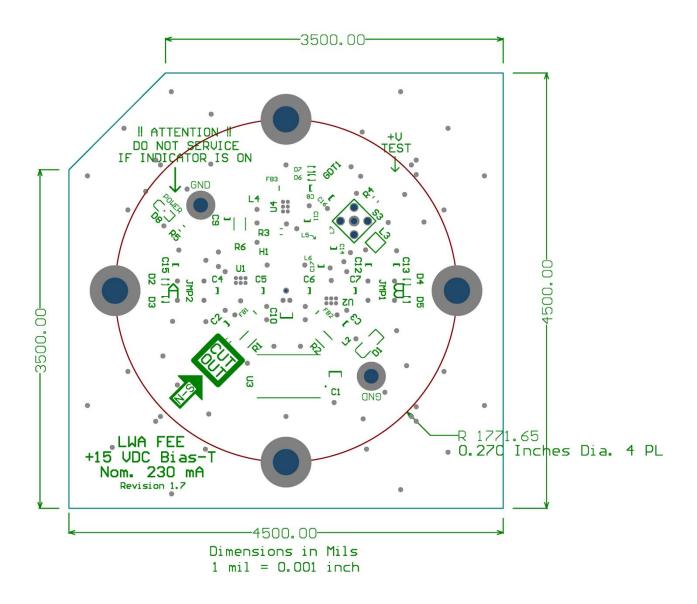


Figure 2c– PCB Layout: Dimensioned with Mirrored Silkscreen (Version 1.7)

Bill of Materials LWA FEE 3/25/2009

Designation Value Type Manufacturer's Part Number Digi-Key Part Number L1, L2, L4 L3, L4 L4 L4 L4 L4 L4 L4 L4	\$0.08
Manufacturer Man	SMT
Part Number	SMA
Manufacturer Man	240-0805
Manufacturer Man	1206
Manufacturer Man	SOD323
Designation Value Type Manufacturer Manufacturer's Part Number	
Designation Value Type Manufacturer Manufacturer's Part Number	TT-HX62A
Designation Value Type Manufacturer Manufacturer's Part Number	DF782
Designation Value Type Manufacturer Manufacturer's Part Number	/ DF782
Designation Value Type Manufacturer Manufacturer's Part Number) TO-263-3
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XLLB Colorath 4.7 μH 10% Inductor, Power, High SRF Colicraft 1008CS-472XLB Colorath 33 nH 2% Inductor, Unshielded Colicraft 1008CS-303XGLB Colorath 10 μF 10 μF 2% Inductor, Unshielded Colicraft 1008CS-303XGLB Colorath 10 μF 10 μF 2% Inductor, Ceramic, X7R Panasonic - ECG ECJ-3F82/102K PR 5, C8, C8, C9, C11, C12, C15 0.1 μF 10% Capacitor, Ceramic, X7R Panasonic - ECG ECJ-3F82/102K PR 91 Ω 5% Resistor, 14 Watt Panasonic - ECG ECJ-3F82/102K PR 91 Ω 5% Resistor, 14 Watt Panasonic - ECG ERJ-P08/150V PR 470 Ω 5% Resistor, 14 Watt Panasonic - ECG ERJ-8GEY/47/V PR 470 Ω 5% Resistor, 14 Watt	2512
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number	1206
Parasonic Parametrion P	1206
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XLLB Coloratt 4.7 μH 10% Inductor, Power, High SRF Colicraft 1008CS-472XLB Coloratt 33 nH 2% Inductor, Unshielded Colicraft 1008CS-30X/GLB Coloratt 10 μF 20% Tantalium Capacitor, Ceramic, X7R Panasonic - ECG ECJ-3F82/102K PR 5, C6, C8, C9, C11, C12, C15 0.1 μF 10% Capacitor, Ceramic, X7R Panasonic - ECG ECJ-3F82/102K PR 5, C6, C8, C9, C11, C12, C15 0.1 μF 10% Capacitor, NPO AVX Panasonic - ECG ECJ-3F82/102K PR 5, C6, C8, C9, C11, C12, C15 0.1 μF 10% Capacitor, NPO AVX PR 6, C9, C11, C12, C15 0.1 μF 10% Capacitor, NPO AVX PR 6, C9, C11, C12, C15 0.1 μF 10% Capacitor, NPO AVX PR 6, C9, C11, C12, C15 0.1 μF	1206
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number	2512
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XLIB Colicraft 100 nH 2% Inductor, Unshielded Colicraft 1008CS-472KLB Colicraft 33 nH 2% Inductor, Unshielded Colicraft 1008CS-101XGLB Colocraft 100 μF 100 mufacturer Inductor, Unshielded Colicraft 1008CS-330XGLB Colocraft 100 μF 100 mufacturer Inductor, Unshielded Colicraft 1008CS-330XGLB Colocraft 100 μF 100 mufacturer Inductor, Unshielded Colocraft 1008CS-330XGLB Colocraft 5, C6, C8, C9, C11, C12, C15 10 μF 20% Tantalum Capacitor, Ceramic, X7R Panasonic - ECG ECJ-3VB1E104K Propertion	603
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XLLB Colorath 100 nH 2% Inductor, Unshielded Colicraft 1008CS-472KLB Colorath 10 μF 2% Inductor, Unshielded Colicraft 1098CS-30XGLB Colorath 10 μF 20% Tantalum Capacitor Nichicon F931E106MCC 42 1000 pF 10% Capacitor, Ceramic, X7R Panasonic - ECG ECJ-3F82J102K PA	1206
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XLLB Colicraft 4.7 μH 10% Inductor, Power, High SRF Colicraft 1008PS-472KLB Colicraft 100 H 2% Inductor, Unshielded Colicraft 1008CS-30XGLB Colors 1008CS-30XGLB 10 μF 20% Tantalum Capacitor Nichloon F931E1096MCC 44) 1206
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472X.JLB Colorest 4.7 μH 10% Inductor, Power, High SRF Colicraft 1008PS-472K.IB Colorest 100 nH 2% Inductor, Unshielded Colicraft 1008CS-330/KGLB Colorest 33 nH 2% Inductor, Unshielded Coloraft 1008CS-330/KGLB Coloraft	SMT-C (6.0 x 3.2 mm)
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core and Colicraft Colicraft 1008CS-472XJLB CO 4.7 μH 10% Inductor, Power, High SRF Colicraft 1008CS-472XJLB CO 100 nH 2% Inductor, Unshielded Colicraft 1008CS-101XGLB CO	1008
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XLB Colorables 4.7 μH 10% Inductor, Power, High SRF Colicraft 1008PS-472KLB Colorables	1008
Designation Value Tolerance Type Manufacturer Manufacturer's Part Number 4.7 μH 5% Inductor, Ceramic Core Colicraft 1008CS-472XJLB C	1008
Value Tolerance Type Manufacturer Manufacturer's Part Number	1008
	Digi-Key Part Number Package Style Unit Cost Quantity Extended Cost Bracket (*)

Note 2: High tolerance (5%) is incidental, component was selected on basis of: Max current (260 mA), Min SRF (90 MHz), and Max DCR (4 Ohms). Note 2: Suffix B indicates "less than a full reel", full reels are availale.

* Parts only cost for a single polarization balun.
* Price and availability verified on 3/25/2009

5

Long Wavelength Array Front End Electronics (LWA FEE) Version 1.7

EM-FEE023

Fabrication, Assembly and Testing Instructions

Bill of Materials

Brian Hicks
Paul Ray, Jacob Hartman, and Norman McGlothlin

U.S. Naval Research Laboratory July 2, 2009

Introduction

The LWA FEE consists of two single sided printed circuit boards (PCB) bolted back to back and rotated to form a single assembly. The two PCBs, designated LWA_FEE_A and LWA_FEE_B, are identical except for selective population of the components designated *D8* and *R5* and the orientation of connector *S3*.

PCB Fabrication

All necessary fabrication files (Gerber, NC Drill, etc.) shall be provided for the purpose of fabrication and solicitation of quotes on turnkey assemblies. A Bill of Materials detailing the parts required to assemble each constitute board is included here as Table 1. The unit cost provided in quotes shall reflect the full cost of two circuit boards bolted together and tested.

Parts LWA_FEE_A and LWA_FEE_B are both based on the same double sided board (FEE_PCB). This board has a solder mask and silkscreen only on the bottom layer (component side). The top layer of the board is primarily a ground plane; gold plating on this layer is all that is needed (no solder mask). The circuit board material is standard FR4 with a thickness of 0.062".

There is an area to be routed out inside the board that is described in the 'Mechanical 1' layer files – this is labeled 'CUT-OUT'. The 'Mechanical 1' layer also describes the outline route of the board which is square in shape with one corner removed.

All printed circuit boards must be "hard gold" plated.

Selective Population

On part LWA_FEE_A, D8 and R5 are both populated. On part LWA_FEE_B, D8 and R5 are <u>not</u> installed. This is denoted in the Bill-of-Materials (BOM) and shown graphically in Figure 1. On this version of the FEE, D6 and D7 should *not* be populated on parts LWA_FEE_A or LWA_FEE_B.

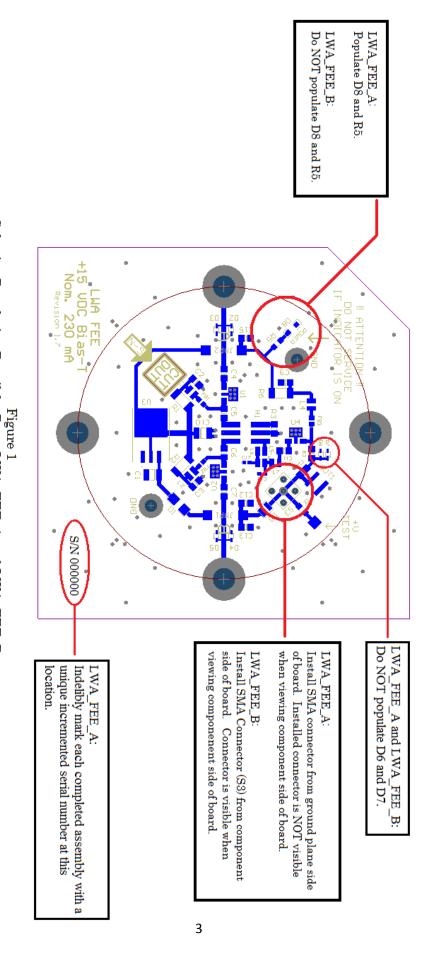
The orientation of connector S3 differs between parts LWA_FEE_A and LWA_FEE_B; this detail is shown in Figure 2.

Final Assembly

The LWA FEE, consisting of parts LWA_FEE_A and LWA_FEE_B, is to be assembled according to the details in Figure 2. Hardware is specified (*SCW1*, *WSH1*, *NUT1*) to fasten the parts together. Only equivalent hardware may be substituted. All fasteners must be made of stainless steel. Each LWA_FEE unit must be 'serialized' by indelibly marking part LWA_FEE_A with a unique incrementing serial number.

Functional Testing

Vendors soliciting to produce turnkey LWA_FEE assemblies must apply the 'basic functional test' described in Table 2 to each board supplied. All non recurring engineering costs (NRE) associated with the production of the LWA_FEE, including the test fixture appropriate for use at the vendor facility, must be included in any quotes submitted.



Selective Population Detail for Parts LWA_FEE_A and LWA_FEE_B.

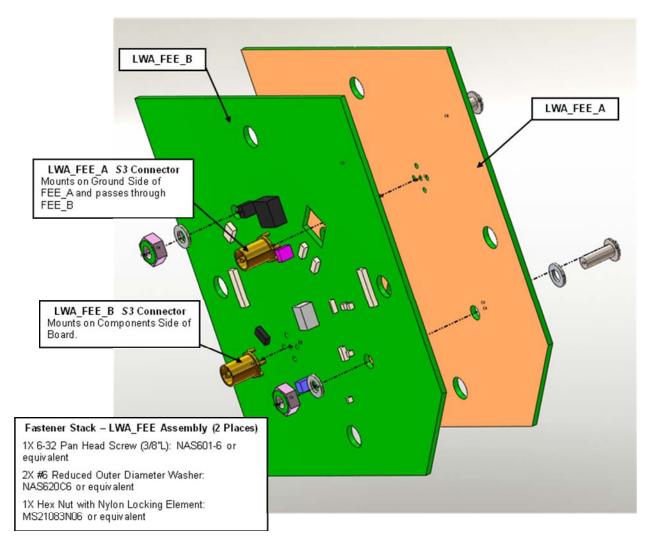


Figure 2 – Final LWA_FEE Assembly Detail

LWA_FEE_A/B - Bill of Materials May 11, 2009

31	30	29	28		27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	ហ	4	3	2	1	Item#	
4	2		1	:	11	4	2	4	ω	ω	2	2	2	2	2	2	2			1	_	1	1		1			1	1	1	1	Item # Quantity	
NUT1	WSH1	SCW1	FEE_PCB	C11, C12, C13, C15, C16	C2 C3 C5 C6 C8 C9	D2, D3, D4, D5	D6, D7	P1, P2, P3, P4	L1, L2, L4	FB1, FB2, FB3	U1, U2	R1, R2	L6, L7	JMP1, JMP2	C4, C7	C14, C17	C1, C10	U4	U3	S3	R6	R5	R4	R3	P5	L5	L3	H1	GDT1	D8	D1	Designator	
Nut w/ Nylon Locking	Reduced Dia. Washer NAS620C6: #6	Pan Head Screw	Printed Circuit Board		nic Capacitor	Diode	Diode	PCB PAD	Inductor	Ferrite Bead	Amplifier G= 25.1	Resistor, 1W	Inductor	SMT Jumper	Ceramic Capacitor	Ceramic Capacitor	Tantalum Capacitor	Amplifier G=12	Voltage Regulator	SMA Connector	Resistor, 1 W	Resistor, 1/4 W		Resistor, 1/3 W	Test Point	Inductor	Inductor	180deg Hybrid	Gas Discharge Tube	SMT LED	Schottky Diode	Description	
MS21083N06	NAS620C6: #6	NAS601-6: 6-32, 3/8"L	N/A	:	0.1 uF	1N4148WX-TP	1N4148WX-TP	1/4-20 Free-Fit	4.7 uH	SMT Ferrite Bead	Gali-74, Gali-74+	91 Ohms	33 nH	S1621-06-R	1000 pF	33 pF	10 uF	Gali-6+	LM1085IS-12	SMA	95.3 Ohms	470 Ohms	4.72k Ohms	51 Ohms	+V Test Point	100 nH	4.7 uH	HX62A	Bourns 2035-09-SMRP	Green	MBRS2040LT3	Value	
SPEC	SPEC	SPEC	SPEC		10%	N/A	N/A	N/A	5%	N/A	N/A	5%	2%	N/A	10%	2%	20%	N/A	N/A	N/A	1%	1%	5%	5%	N/A	2%	10%	N/A	N/A	N/A	N/A	Tolerance	
Non Specific	Non Specific	Non Specific	Non Specific		Panasonic - ECG	Micro Commercial Co	Micro Commercial Co	N/A (PCB Pad)	Coilcraft	Steward	Mini-Circuits	Panasonic - ECG	Coilcraft	Harwin	Panasonic - ECG	AVX Corporation	Nichicon	Mini-Circuits	National Semiconductor	Emerson	Panasonic - ECG	Panasonic - ECG	Panasonic - ECG	Panasonic - ECG	N/A	Coilcraft	Coilcraft	Emhiser Tele-Tech	Bourns Inc.	Lumex Opto	On Semiconductor	Manufacturer	
MS21083N06	NAS620C6	NAS601-6	Non Specific		ECJ-3VB1E104K	1N4148WX-TP	1N4148WX-TP	N/A	1008CS-472XJLB	HZ0805C202R-10	Gali-74+	ERJ-1TYJ910U	1008CS-330XGLB	S1621-06-R	ECJ-3FB2J102K	06031A330GAT2A	F971E106MNC	Gali-6+	LM1085IS-12/NOPB	142-0701-201	ERJ-1TNF95R3U	ERJ-8ENF4700V	ERJ-8GEYJ472V	ERJ-P08J510V	N/A	1008CS-101XGLB	1008PS-472KLB	HX62A	2036-09-SM-RPLF	SML-LX1206GC-TR	MBRS2040LT3G	Manufacturer's Part Number	
Stainless Steel Only	Stainless Steel Only	Stainless Steel Only	Double Sided, Hard Gold		PCC1883CT-ND	1N4148WXTPMSCTND	1N4148WXTPMSCTND	1/4-20 Free-Fit	1008CS-472XJLB	240-2396-1-ND	Gali-74+	PT91XCT-ND	1008CS-330XGLB	S1621-06-R	PCC2291CT-ND	478-5136-1-ND	493-2388-1-ND	Gali-6F+	LM1085IS-12-ND	J500-ND	PT95.3AFCT-ND	P470ECT-ND	P4.7KECT-ND	P51ALCT-ND	Test Point	1008CS-101XGLB	1008PS-472KLB	НХ62А	2035-09-SM-RPLFCTND	67-1357-1-ND	MBRS2040LT3	Comment	
				į	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	SEE ASSEMBLY DETAIL	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	LWA_FEE_A	Selective
				į	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	BLY DETAIL	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	LWA_FEE_B	Selective Population

Table 1 - LWA_FEE Bill of Materials

	. B	С	<		
	Basic Stability Gain	Current Consumption	Visual Inspection	Test	
or network analyzer. If the spectrum analyzer to be used does not have a tracking generator, a signal generator will be required.	Spectrum analyzer, power supply.	Power supply with integral voltmeter and ammeter, or power supply and multimeter.	Photographic image of tested and inspected unit.	Equipment	Table 2 – Ba
frequency from 500 kHz to 115 MHz. If a signal generator is used, record discrete gain points at 5 MHz intervals. An excitation level of -60 dBm will be used.	Connect the output of the FEE to a spectrum analyzer and apply power. Look for evidence of oscillation in the frequency range of 500 kHz to 10 GHz with the FEE feedpoint terminals open and loaded with 50 Ω .	Apply +15 VDC to FEE under test via bias-T and record the current being drawn.	Compare FEE under evaluation with exemplar and provide detailed comments regarding any deviations.	Procedure	Table 2 – Basic Functional Test
provide 36 dB of gain across the entire 500 kHz to 115 MHz range. If the gain of a test unit deviates from 36 dB by more than 0.4 dB at any frequency, it should be flagged for critical evaluation.	If there is any evidence of oscillation, discontinue testing and flag the unit for critical evaluation and repair. The G250R EFF should nominally	A properly functioning G250 R FEE should typically draw 230 mA. Testing should be discontinued if the measured level deviates by more than 5% of 230 mA, and the unit should be flagged for repair.	Test units should be nearly identical to the exemplar. Particular attention should be placed on finding solder bridges, evidence of excessive heat, chemical residue, and obvious physical damage.	Nominal Response	

FEE0024: Linearity measurements of FEE version 1.7

Jake Hartman and Brian Hicks May 15, 2009

Abstract. We characterized the nonlinearity of the FEE version 1.7 through lab testing. We determined its 1 dB compression point to be at an input power of –18.20 dBm. This value is in good agreement with the similar G250R Rapid Test Array balun and with our expectations based on the spec sheets of the FEE components. We measured its IIP3 to be –2.3 dBm, close to the estimate from an earlier cascade analysis.

Background.

Considerable work has been done to characterize the nonlinearity of previous versions of the LWA balun. Bradley & Parashare (LWA Memo 19, "Evaluation of the NRL LWA Active Balun Prototypes," Feb 2005) measured the 1 dB compression point and the IP3 of an early prototype. However, its single-amplifier design differs significantly from the current, CDR-ready version, so their measurements are not directly applicable.

Starting with the G250R Rapid Array Test balun (Hicks & Paravastu, LWA memo 120), the FEE designs use two stages of amplification. Signals from the two feedpoints are amplified by Gali-74 amplifiers (nominal gain of 25.1 dB at 100 MHz), then combined with a Tele-Tech HX61A 180° hybrid junction. The output of the junction's differencing port is amplified with a Gali-6 amplifier, with a nominal gain of 12.2 dB at 100 MHz and an output power at 1 dB compression of 16.5 (minimum) and 18.2 dB (typical). Version 1.7 adds protective diodes around the feedpoints and a low-pass filter after the Gail-5 amplifier.

For the G250R balun, Hicks & Paravastu measured 1 dB compression at an input power of -18.30 dBm. They estimated an IIP3 of -1.8 dBm using a cascade analysis, but they did not measure this quantity in the lab. Refer to LWA memo 120 for full details.

Gain compression.

The FEE was driven at 74 MHz using an Agilent E4424B signal generator. Its output connected to a 180° hybrid junction, and the outputs from the hybrid were connected to the FEE feedpoints. Output from the FEE connected to a bias-T to provide power. The RF output of the bias-T fed into an Agilent E4407B spectrum analyzer to measure the output power.

We stepped the input power from -40 dBm to -10 dBm, concentrating our sampling around the 1 dB compression point. Figure 1 shows the results. Before removing the protective diodes from the FEE, we measured a mean gain of 35.70 ± 0.01 dB at low powers (low enough that there was no significant compression) and 1 dB compression at an input power of -28.00 dBm. We then removed the diodes and repeated the measurement, finding a mean gain of 35.50 ± 0.01 dB at low powers and a 1 dB compression point of -18.20 dBm.

The location of the 1 dB compression point with the diodes in place can be explained by the protective diodes clipping the output. At the input power of -28.00 dBm, the output power was 6.7 dBm. To convert from an RMS voltage V to power in dBm,

 $P[dBm] = 10 \log_{10} (V^2 / RP_0)$,

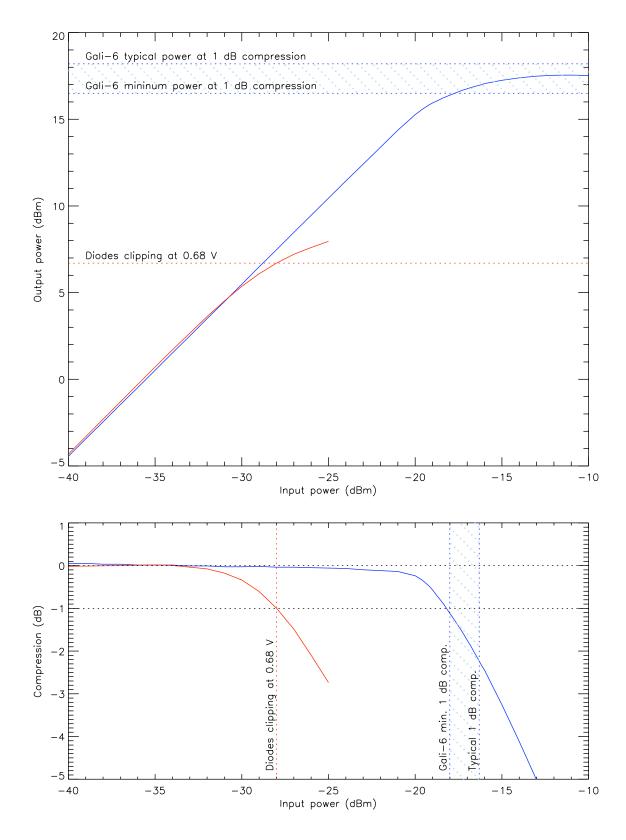


Figure 1. Output power and gain compression as a function of input power for the FEE version 1.7 with protective diodes (red) and without (blue).

where $R = 50 \Omega$ is the impedance and $P_0 = 1 \text{ mW}$ is the reference power. Reversing this relation, the 6.7 dBm output power at 1 dB compression corresponds to 0.484 V RMS and 0.684 V peak. This peak voltage agrees with a typical cut-in voltage for the diodes.

The 1 dB compression point without the diodes is roughly where expected. The first-stage Gali-74 amplifiers provide a nominal gain of 25.1 dB at 100 MHz, so for an input power of –18.20 dBm their output power should be 6.9 dBm. This is well below their minimum rated output power at 1 dB compression of 18 dBm, so compression from this stage should be negligible. The second-stage Gali-6 amplifier has a output power at 1 dB compression of 16.5 dBm (minimum) to 18.2 dBm (typical), in reasonable agreement with the observed FEE output power at the 1 dB compression point of 16.31 dBm. Most likely loss within the filter causes the small difference between the FEE output power and the quoted compression point.

This 1 dB compression point is also in excellent agreement with the G250R Rapid Test Array balun's measured value of -18.30 dBm.

Intermodulation distortion.

Next we measured the intermodulation distortion (IMD) products. A pair of Agilent E4424B signal generators produced tones at $f_1 = 73.875$ MHz and $f_2 = 73.925$ MHz. Harmonic distortion was reduced by passing the two signals through a pair of Lorch GCP-73.9/1.7-S band-pass filters, with a central frequency of 73.9 MHz and a bandwidth of 1.7 MHz. The signals were then summed with a Tele-Tech HX61A 180° hybrid junction, followed by another 180° hybrid junction to drive the two feedpoints of the FEE. The output from the FEE passed through a bias-T and into an Agilent E4407B spectrum analyzer.

Because of the high dynamic range of these measurements (e.g., simultaneously measuring a –10 dBm main peak and a –70 dBm IMD product), they required great care to avoid overdriving the spectrum analyzer. We found an attenuation of 20 dB for output powers below 10 dBm and an attenuation of 30 dB above this level provided self-consistent results while avoiding excess power in the IMD peaks due to distortion within the spectrum analyzer.

For calibration, we measured the losses in our setup outside the FEEs. The coax cable were measured to contribute a loss of -0.2 dB. The bandpass filters introduced an insertion loss of -2.87 dB at 73.875 MHz and -2.64 dB at 73.925 MHz. Combining the signals at the first hybrid produced a loss of -3.31 dB. Splitting the signal at the second hybrid caused a loss of -0.5 dB according to the hybrid junction's specifications. Finally, the spectrum analyzer is not properly calibrated and reported powers to be -0.5 dB lower than indicated by a properly calibrated power meter.

The power output by the signal generators was stepped from -45 dB to -15 dB, and the power of the main peaks (at f_1 and f_2) and the third-order distortion products (at $2f_1 - f_2$ and $2f_2 - f_1$) were measured. All measurements were adjusted for the results of our calibration. Figure 2 shows the results. We measured an IIP3 of -2.2 dBm. This value nearly matches the estimate by Hicks & Paravastu of -1.8 dBm using a cascade analysis based on the manufacturer's specifications for the amplifiers in the FEE.

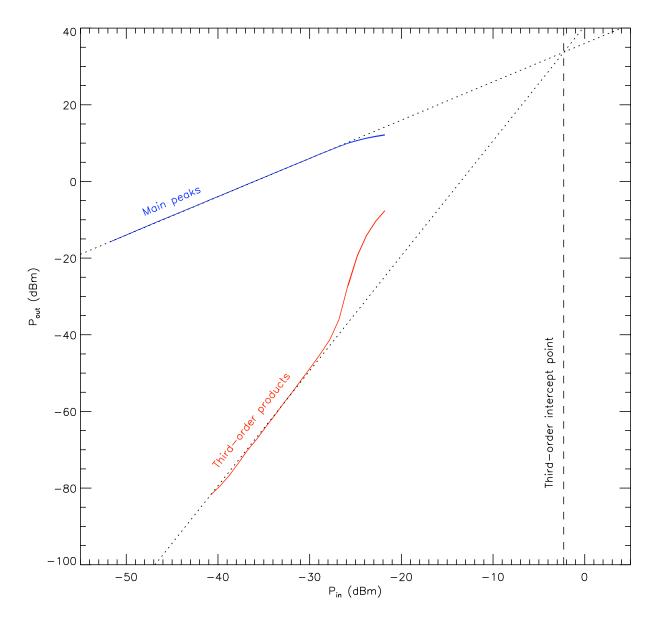


Figure 2. Results of the intermodulation distortion testing. The dotted trend lines have been fit to the vertical offset of the measured powers, but their slopes are fixed to 1 and 3. All powers have been corrected using the results of our calibration. The IIP3 is at -2.2 dBm.