Transmission Line, Power and Protection Considerations for the LWA Antenna System

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1. Introduction

This document provides application details for the Long Wavelength Array antenna system. The LWA antenna system consists of two major assemblies, the crossed-dipole antenna elements and associated support structure, and the active balun assembly (also called Front End Electronics, or FEE) consisting of two active balun printed circuit boards, one for each dipole (figure 1). Each active balun has approximately 35 dB gain in the frequency range 10 to 100 MHz and is located in the enclosure at the top of the antenna assembly. The active baluns are powered through their respective coaxial cable transmission lines and bias-tees. The LWA antenna is a part of a system that includes other interfaces and power supplies (figure 2).

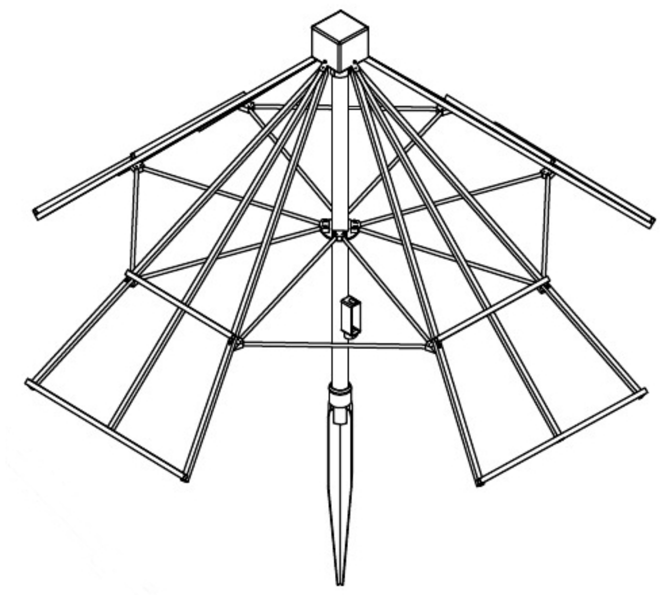

Figure 1 ~ LWA antenna consists of two major assemblies, the mechanical structure and electronics (dual active balun assembly). The dual active balun assembly is in the enclosure at top of the antenna. The ground stake at the bottom of the center post anchors the antenna in earth. The horizontal components from the center post to the antenna blades and between blades are non-conductive mechanical supports. (Image © 2014 W. Reeve)

2. Transmission Considerations

The LWA antenna is a 50 ohm system. Some users may attempt to employ 75 ohm coaxial cable, but comparative measurements have not yet been made to determine if there is performance degradation. Also, using 75 ohm cables inevitably leads to impedance mismatches and the need for RF adapters, and these should be avoided wherever possible. Because the antenna system has considerable gain, it will accommodate most practical transmission line lengths without downstream amplification.

In many applications, the two dipoles are connected through a quadrature coupler to discriminate circular polarizations. It is very important that the proper phase relationships are preserved in these applications, and it is very important that the two coaxial cables are identical manufacturer and type and have identical lengths (< 1% difference), connectors and configurations.

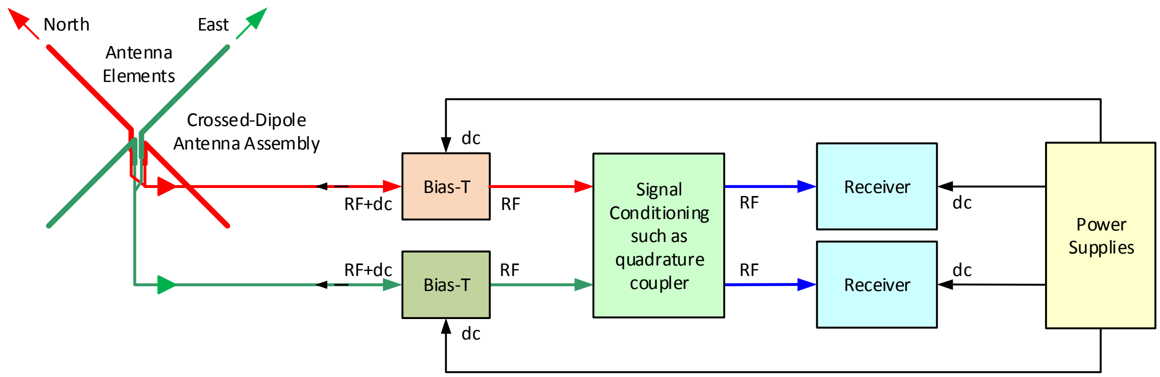

Figure 2 ~ LWA antenna block diagram. (Image © 2014 W. Reeve)

3. Interconnection Standard for Quadrature Coupler

To ensure commonality in LWA antenna installations, the identification and nomenclature described in this section is the recommended standard for antennas purchased from {RvLWA} (figure 3 and table 1). It is possible that after operational experience is gained and results are compared to observatories that monitor solar radio emissions, the RHCP and LCHP labeling of the coupler output may need to be reversed. This will be handled by a revision to this document. For additional information on using a quadrature coupler with the LWA antenna, see [ReeveLWAQC].

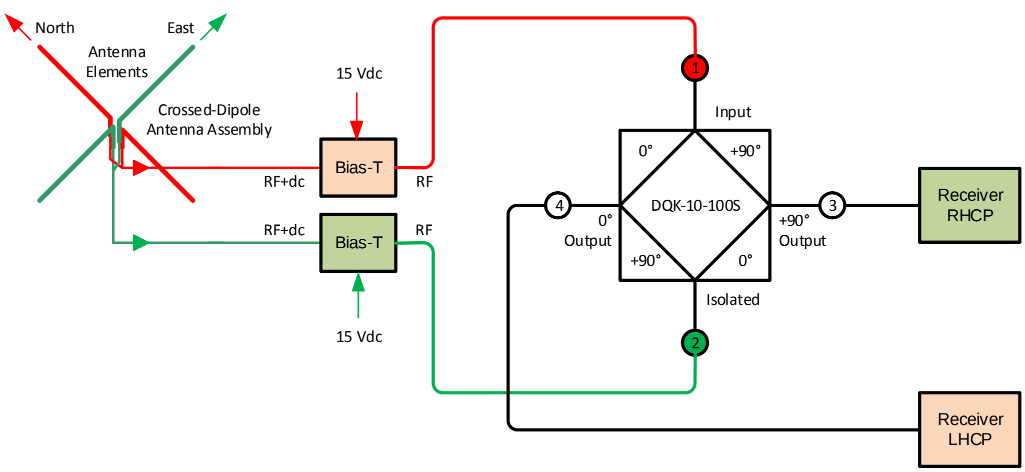

Figure 3 ~ LWA antenna system and DQK-10-100S quadrature coupler interconnection diagram. (Image © 2014 W. Reeve)

Table 1 ~ Quadrature coupler nomenclature for Synergy DQK-10-100S. Applies to Rev. 1.x of this document.

Coupler port number	Coupler port name	Connect to	Remarks
1	Input	North-South Antenna	Active balun SMA connector marked **N-S**
2	Isolated	East-West Antenna	
3	+90° Output	RHCP Receiver	
4	0° Output	LHCP Receiver	

4. Coaxial Cable Transmission Line

The coaxial cable transmission line serves both as power and RF feed, so it must be adequate for both purposes. Recommendations for coaxial cables:

- Name brands only (see below) – no unbranded cables
- 50 ohms characteristic impedance
- ≥ 8 mm (0.3 in) outer diameter main transmission lines for mechanical strength
- 6 mm (0.24 in) outer diameter flexible jumpers where connecting to SMA-type connectors
- Suitable for outdoor applications (use waterproof cable for direct buried or ground-laid installations)
- Dual shielded (multi-ply bonded foil + tinned copper braid) or better
- Twin or dual cable may simplify installation

Some name brand USA manufacturers (not all-inclusive):

- Alpha Wire: http://www.alphawire.com/
- Belden: http://www.belden.com/products/connectivity/coax/coax-connectivity-solutions.cfm
- CommScope (Andrew): http://www.commscope.com/default.aspx
- Radio Frequency Systems (RFS): http://www.rfsworld.com/
- Terrawave: http://www.terra-wave.com/
- Times Microwave: http://www.timesmicrowave.com/

5. Cable Connectors

A typical installation requires numerous RF connectors (figure 4). Recommendations for connectors:

- N-type or SMA-type connectors in all RF paths (use only N-type on outdoor connections)
- No BNC connectors in RF paths
- Name brands only
- Seal and make weatherproof with self-fusing rubber tape or coaxial connector sealing kit
- Avoid use of RF adapters if possible

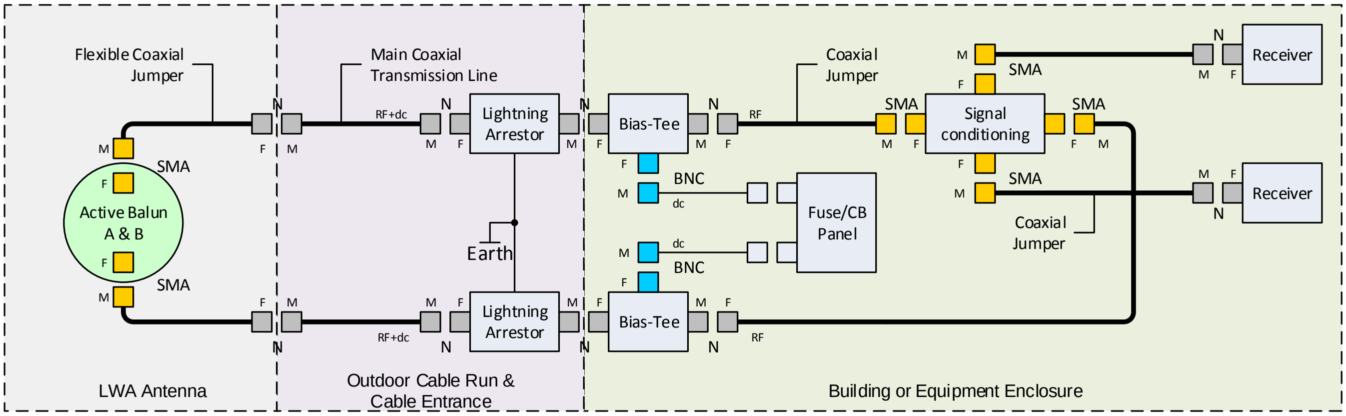

Figure 4 ~ Typical RF connector diagram showing type and gender at each connection. The connector type for most interfaces, such as lightning arrestor, bias-tee and signal conditioning, will depend on the actual equipment used. All connections between the active balun and interfaces should be the same type and length. The dashed lines enclosure the typical locations of the various components and interfaces. (Image © 2014 W. Reeve)

6. Power Requirements

Each active balun on the dual assembly is powered by nominal 15 Vdc. A bias-tee comprised of an inductor and capacitor is included on each of the two active balun printed circuit boards. It is necessary to provide two additional bias-tees (called *source bias-tees*) near the power source to feed RF and power to the transmission line as shown previously. The nominal operating current of each active balun is 230 mA. Current above 242 mA constitutes failure. The dc power feed circuit diagram shows the components in the powering circuit (figure 5).

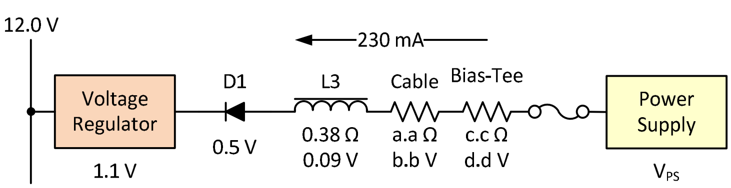

Figure 5 ~ Power feed circuit diagram showing components that introduce voltage drop. The resistances and voltage drop values a.a, b.b, c.c and d.d will depend on the coaxial cable and bias-tee used in the circuit. The power supply voltage V_{PS} must be ≥ the sum of all voltage drops. (Image © 2014 W. Reeve)

The active balun feed voltage is stepped down to 12 V by an on-board low dropout (LDO), linear voltage regulator. The drop-out voltage of the regulator is 1.1 V at 250 mA and 40 °C. A polarity guard diode with a nominal voltage drop of 0.5 V and an inductor with 0.38 ohms dc resistance are in series with the regulator; therefore, it is necessary to use a power source such that the feed voltage measured at the active balun PCB is

$$V_{PCB} \geq 12.0\text{ V} + 1.1\text{ V} + 0.5\text{ V} + \left(0.230\text{ A} \cdot 0.38\ \Omega\right) = 13.69\text{ V} .$$

The source voltage must be increased to account for voltage drop in the source bias-tee and coaxial cable feedline to the antenna. The dc circuit is a loop circuit, so when making voltage drop calculations for the cable it is necessary to include shield + center conductor resistance. For example, LMR-400 cable center conductor has 4.6 ohms/km and the outer conductor (shield) has 5.4 ohms/km dc resistance. If the cable length is 30 m, the cable resistance is

$$R_{Cable} = \frac{(4.6\ \Omega/\text{km} + 5.4\ \Omega/\text{km})}{1000\ \text{m/km}} \cdot 30\ \text{m} = 0.3\ \Omega$$

and the voltage drop is

$$V_{Cable} = 0.3\ \Omega \cdot 0.230\ \text{A} = 0.069\ \text{V}$$

The dc resistance of the bias-tees listed in the next section varies from 0.5 to 4.5 ohms. Assuming worst-case, the voltage drop across the bias-tee is

$$V_{Bias-tee} = 4.5\ \Omega \cdot 0.230\ \text{A} = 1.04\ \text{V}$$

The required total source voltage is

$$V_{Source} \geq 13.69\ \text{V} + 0.069\ \text{V} + 1.04\ \text{V} + 10\%\ \text{margin} = 16.3\ \text{V}$$

7. Over-Current and Over-Voltage Protection

The active balun has no built-in over-current protection, so it is necessary to provide current limiting in the power circuits. Over-current protection may be provided by either a fuse or circuit breaker or a current limited power supply. The over-current protection must be designed to protect both the source bias-tee and active balun. To avoid nuisance-tripping, the over-current protection should be rated 150 to 200% of continuous load current, or 345 to 460 mA. An over-current device rated ≤ 500 mA will protect both the PCB and source bias-tees listed in the next section.

Each active balun PCB has a 90 V gas discharge tube for over-voltage protection and diodes (1N4148) to limit static build-up on each antenna element connection to the PCB (see schematic in [LWA0190]. Depending on the installation, additional over-voltage protection may be required at the source end of the power circuit. The top of the antenna is only about 1.5 m above ground level and may be effectively shielded by nearby objects from lightning strikes. However, indirect strikes may induce undesirable currents and voltages in long coaxial cable feedlines, so additional protection may be needed at the cable entrance if the cable if it is susceptible to lightning effects; for example, the Hyperlink AL-NFNFB-9 or AL-NMNFB-9 lightning arrestor are inexpensive and easy to obtain (these models have a 90 V gas discharge tube and the model number indicates connector types).

8. Source Bias-Tee

The source bias-tee for each active balun should be rated at least 30 Vdc and 500 mA. It is recommended that the bias-tees be shielded assemblies with a shielded power feed connection using an RF connector (typically SMA-F or BNC-F). Suitable components are listed (table 2). Alternatively, bias-tees may be fabricated by the user with guidance from [LWA0135] (figure 6).

Table 2 ~ Suitable Bias-Tees

Mfr	Model	Maximum voltage (V)	Maximum current (mA)	Resistance (ohms dc)	Connectors RF/dc	Isolation (dB)	Note
Mini-Circuits	ZFBT-4R2G+	30	500	4.5	SMA/SMA	20	1
Mini-Circuits	ZNBT-282-1.5A+	30	1500	0.5	SMA/SMA	70	
Mini-Circuits	ZNBT-60-1W	30	500	2.0	N/BNC	30	

Table Note 1: Additional power source filtering recommended; see text.

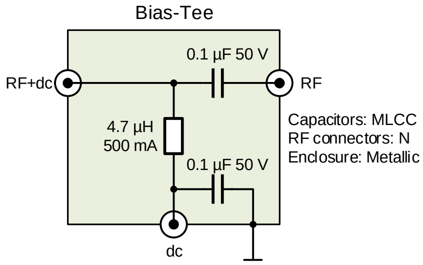

Figure 6 ~ Shop-built bias-tee from [LWA0135]. Install all components in a metallic enclosure for shielding. RF connector types should be N or SMA and power connector may be BNC or SMA. (Image © 2014 W. Reeve)

The listed bias-tees have isolation that varies from 20 to 70 dB in the frequency range of interest (20 to 100 MHz). If using a bias-tee that has lower isolation or where additional filtering is needed, it is recommended to use ferrite beads designed for RFI suppression. Bias-tees with feedthru solder terminals for power connection generally have lower isolation than connectorized counterparts. The isolation of these bias-tees may be improved by placing a 0.1 µF (50 V) capacitor directly from the terminal to ground with leads as short as possible (figure 7). The capacitor should be high quality MLCC or film type. The connection from the power supply to the source bias-tee should be a small coaxial cable such as RG-174/U or RG-316/U with the shield bonded to ground at both ends.

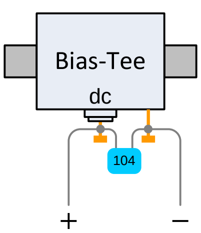

Figure 7 ~ If a low isolation bias-tee has solder terminals for the power connection, a 0.1 µF bypass capacitor may be connected to ground to improve isolation. (Image © 2014 W. Reeve)

9. LWA Power Coupler

The LWA Power Coupler (LWAPC) incorporates two ZFBT-282-1.5A+ bias-tees, an optional quadrature coupler, overcurrent and overvoltage protection and power switching (figure 8).

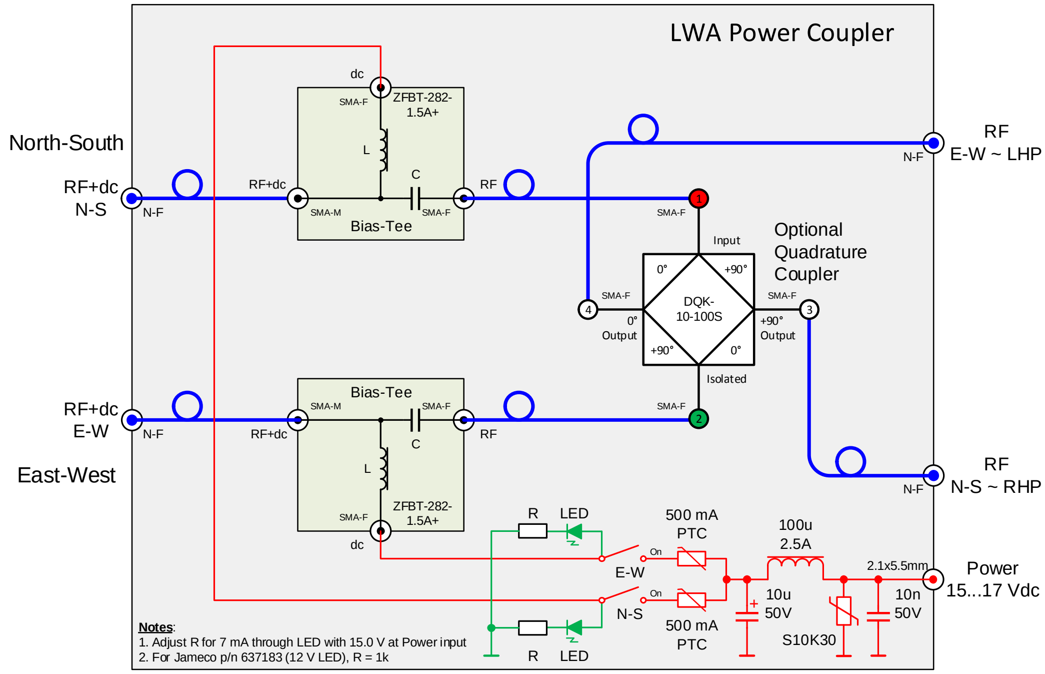

Figure 8 ~ LWA Power Coupler Schematic. The power coupler uses modular bias-tees and option quadrature coupler. If the coupler is not equipped, the bias-tee RF ports are cabled to the panel. The North American version of the LWAPC uses a 2.1 x 5.5 mm coaxial jack for power input. (Image © 2014 W. Reeve)

10. Power Supply

It is assumed that a single power supply will be used to feed the two source bias-tees. The power supply ripple should be very low (barely visible on an oscilloscope set to maximum gain). If a switched-mode power supply is used, it should be tested to ensure that conducted and radiated noise does not affect the LWA antenna system. Usually, conducted emissions are the worst, and both the input and output circuits should be measured and supplemental filtering added if necessary. Even if a linear power supply is used, additional filtering may be needed to minimize RF pick-up by input and output cables.

The conductors between the power supply and source bias-tee should be as short as possible and include at least two ferrite beads (solid or split), one close to the power supply and one close to the bias-tee. This will be most effective if the power supply output is grounded only at the bias-tee; that is, the grounding of the negative (–) power lead should be only through the dc connector shell on the bias-tee. It is desirable to wrap both power conductors bifilar (+ and – together) 2 or 3 turns through each bead (figure 8). Some experimentation may be necessary if the power supply is noisy. The power supply positive (+) polarity is connected to the feedline center conductor, and the negative (–) polarity is connected to the shield.

Figure 8 ~ Bifliar winding on clamshell noise suppression ferrite bead. Both positive and negative leads are wound side-by-side on the bead. (Image © 2014 W. Reeve)

11. Bonding and Grounding

All components with exposed conductive surfaces must be bonded to earth ground including the antenna center post (mast). If used, the lightning arrestors should be located as close as possible to the cable entrance and it must be solidly bonded to earth ground. The power supply ac input must be fed with a 3-wire cord and plug from a grounded electrical receptacle. The power supply dc output must be referenced to ground at the bias-tee dc connector or terminal, and the bias-tee enclosure or chassis must be bonded to earth ground.

12. References [ ] and Web Links { }

[LWA0135] Hicks, B. and Erickson, B., Bias-T Design Considerations for the LWA, LWA Memorandum #125, 2008

[LWA0190] Hicks, B., NRL Engineering Memo FEE0022, LWA FEE Version 1.7, part of Collected LWA Engineering Memos from the Development of the Front End Electronics (FEE), LWA Memorandom #190, 2008-2009

[ReeveLWAQC] Reeve, W., Antenna Application of the Quadrature Coupler, 2014

{RvLWA} http://www.reeve.com/RadioScience/Antennas/ActiveCrossed-Dipole/ActiveBalunOrderInfo.htm

Document information

Author: Whitham D. Reeve
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Revision:
- 0.0 (Original draft started, 28 Apr 2014)
- 0.1 (Numerous revisions and additions, 29 Apr 2014)
- 0.2 (Combined transmission with power, 1 May 2014)
- 0.3 (1st draft completed, 3 May 2014)
- 0.4 (Revised per comments, 24 May 2014)
- 0.5 (Updated and formatted, 29 Jun 2014)
- 1.0 (Distribution, 29 Jun 2014)
- 1.1 (Additional clarifications and added LWAPC, 10 Aug 2014)