

Power Distribution Options for LWA Active-Antennas
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We examine a variety of power distribution methods for use in LWA-1 with an emphasis on determining whether a bias-T should be incorporated into future designs. We recommend that serious consideration be given to supplying power to the active baluns via bias-T units. If low level 60 Hz artifacts passing through the bias-T networks do not present an insurmountable receiver design problem, we would specifically recommend their use in distributing low voltage AC (e.g. 12.6 VAC) from a central transformer.

I. Introduction

The process of designing a second generation active-balun will give us an opportunity to address the shortcomings of the baseline design and explore power distribution options for the antenna stands.

This memo will focus on providing a list of ideas for supplying power to LWA active-antenna stands. We will discuss the baseline design and explore a variety of alternative power distribution options. We are not attempting to provide an exhaustive list of options - our goal is to provide a starting point for a system level discussion of this issue that will lead to design decisions.

Aspects of the LWA active balun will be contingent upon the method of power distribution. Decisions such as whether a bias-T will be used should be made early in the design of the next generation active balun.

II. LWA Baseline Design

The active balun presently in use in the LWDA was originally intended to be interfaced to a digital receiver co-located within the antenna stand. In this configuration, the balun is in close proximity to the receiver which was to provide regulated power through a bias-T (Fig. 1). Space constraints contributed to the decision not to incorporate a voltage regulator in the baseline balun design.

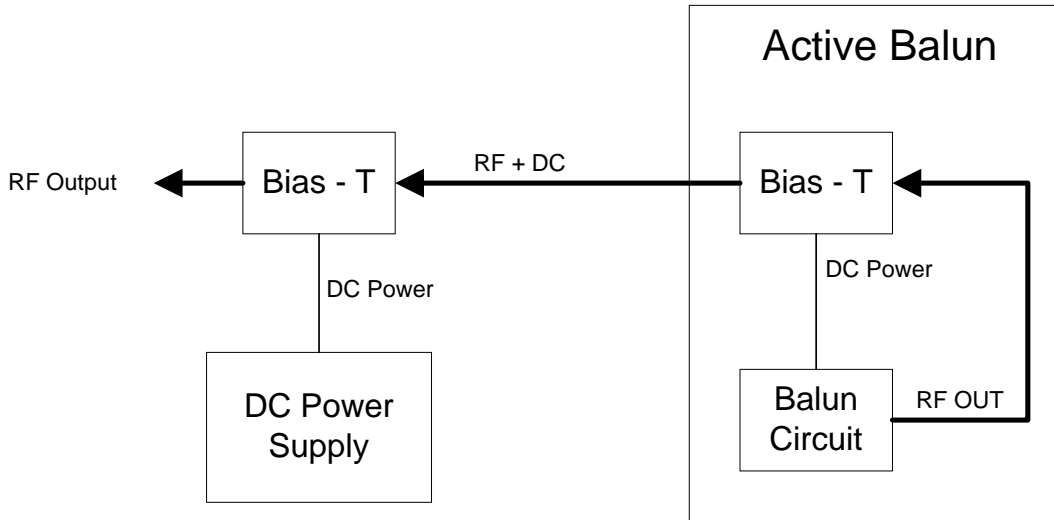


Figure 1 – Power distribution arrangement for baseline active-balun

When it was decided to move the LWDA receivers to a central location in a shielded environment, some deficiencies of the baseline balun design became obvious. For example, experimentation with the LWDA has established that it is essential that future active-balun designs include a local voltage regulator and provide additional gain to overcome cable losses (Fig. 2).

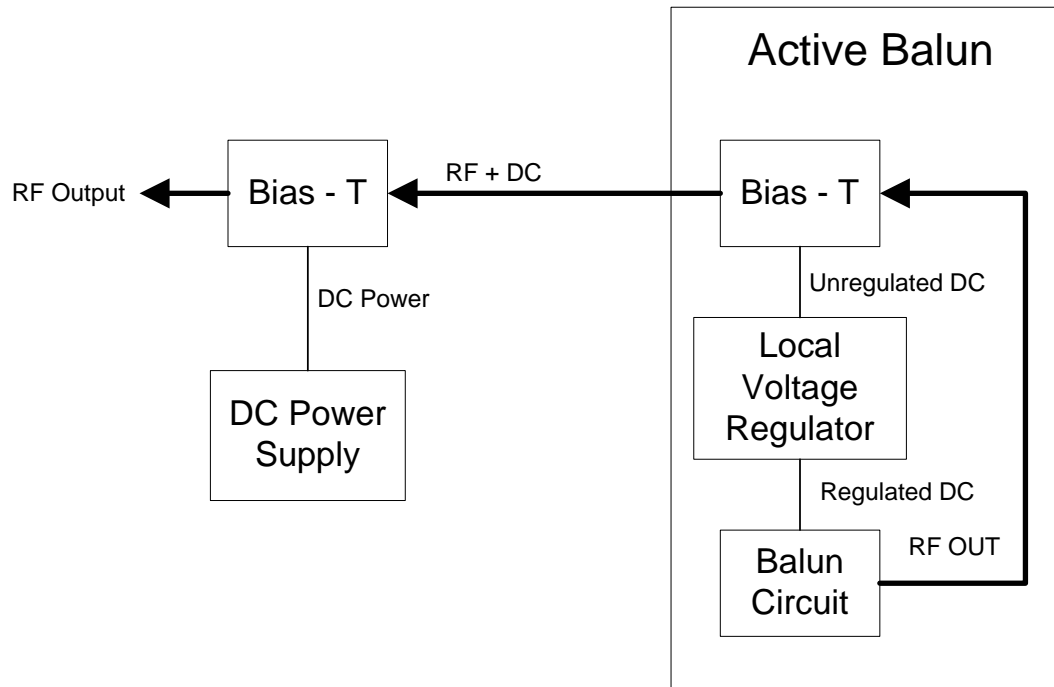


Figure 2 – Baseline Active Balun Design with Voltage Regulator Added

III. Possible Upgrades to LWA Baseline Balun Design

A. The Need for Voltage Regulation

Local voltage regulation will decouple power supply voltage levels and cable lengths that are different throughout a station.

Example 1 – Voltage drop over cable:

For 24 AWG copper wire the resistance per 1000 ft is 26.17 Ω . Assuming that the cable supplies one balun at 0.5 A (the baseline balun requires 330 mA), the resulting voltage drop going from the central supply to the balun would be:

0.65 Volts for 50 feet.
1.31 Volts for 100 feet.
2.62 Volts for 200 feet.
6.54 Volts for 500 feet.

Example 2 – Voltage drop over cable used in ETA:

The guidelines developed for construction of the Eight-meter-wavelength Transient Array (ETA) [1] stipulated that the voltage drop between the electronics building and the antenna stands would not be greater than 6 Volts over 500 feet of cable. The ETA specification called for a maximum current draw of 2.5A per antenna stand. The 12 gauge direct burial cable selected for this project easily meets the 6 Volt requirement – 2.5 A of current flowing through 500 feet of 12 AWG cable (1.619 Ω / 1000 feet) would produce a voltage drop of 1.5 Volts.

The gain, linearity, and noise performance of the active balun are all a function of the supply voltage. For best performance, the nominal supply voltage for the balun should be maintained with a local voltage regulator. A fixed linear voltage regulator will dissipate the difference between the input voltage and the fixed output voltage multiplied by the current supplied in Watts. For example: a 12 Volt regulator supplied with 15 Volts supplying the balun circuit with 0.5 Amps would dissipate 1.5W. This translates to 384 Watts in overhead for voltage regulation for a 256 element station.

Substantially increasing the wire gauge could theoretically eliminate the need for a regulator, but would require inexorably high cost cable. As the wire diameter decreases, the need for both higher supply voltages and a voltage regulator at each antenna stand increases proportionally.

B. Bias-T vs. Direct Connection

One of the fundamental decisions under consideration is whether a bias-T network will be used to supply power to the balun.

A bias-T is a simple network that allows power to be distributed over the same cable that returns the RF signal from an antenna stand (Fig. 3).

A separate bias-T network is required at each end of the RF cable - one to insert power at the receiving end and another to extract power at the balun end. Only one bias-T network located in each active balun is required to supply power to both polarizations of an antenna stand.

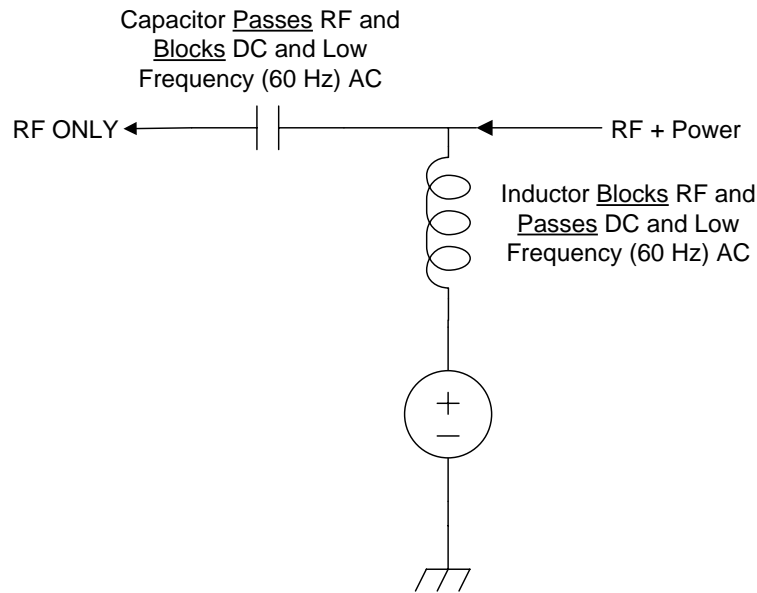


Figure 3 – Typical Bias-T Network

The alternative to supplying power over the RF cables with a bias-T is to provide a separate power distribution network with a direct power cable connection to each balun.

IV. Power Distribution Schemes Using a Bias-T

A. DC Distribution of Power throughout the Array Using Bias-T Networks

The most attractive aspect of distributing power with bias-Ts (shown in Fig. 2) is that this method completely eliminates the need for a separate power distribution network. Power is distributed over the same coaxial cable used to return RF signals from the antenna stands to a central hut.

B. AC Distribution throughout the Array Using Bias-T Networks

It is worth mentioning that at least one commercial antenna system we have studied (Lacrosse Model 'A' HDTV antenna) supplies AC power via a bias-T arrangement instead of DC (Fig. 4). One concern with this arrangement is that might prove difficult to adequately filter the 60 Hz component from the RF signal being passed to the receive chain.

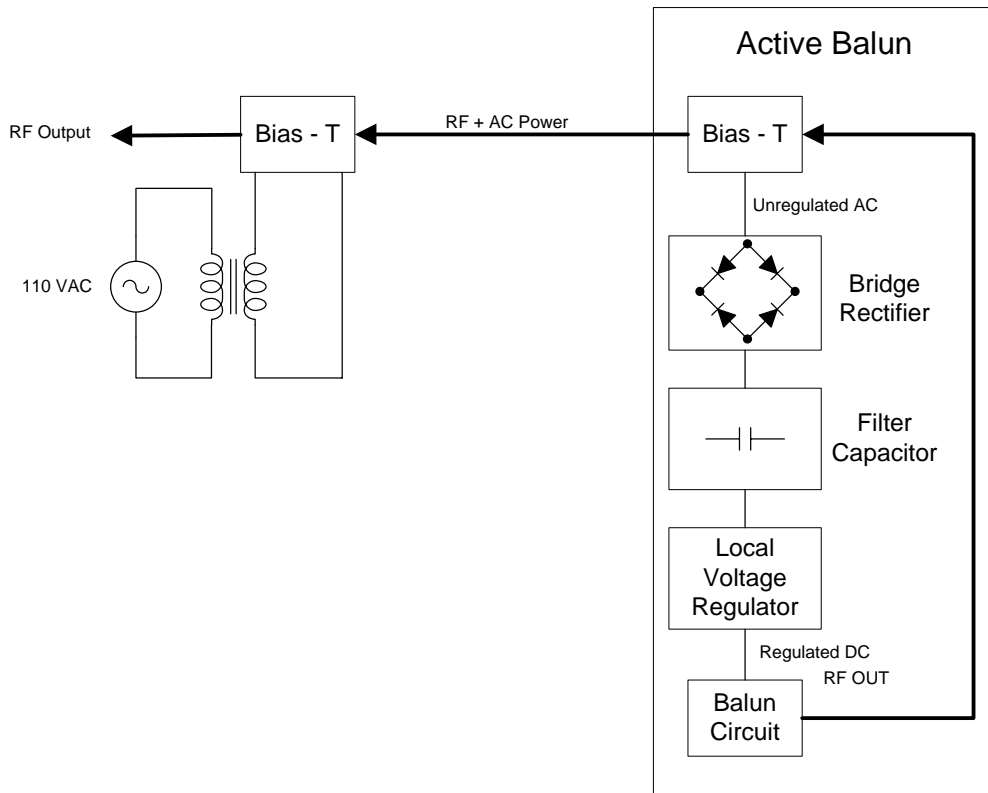


Figure 4 - AC Distribution Using a Bias-T

Advantages of Power Distribution Using Bias-T Networks:

1. The need for an extensive power distribution network is eliminated as power is supplied on the same co-axial cables returning RF signals from antenna stands.
2. The sourcing bias-T network would likely be incorporated onto the analog receiver circuit board, making it convenient to include a FET switch to selectively activate individual antennas.
3. The receiving bias-T is only present on one of the two balun outputs making the balun “virtually keyed” to prevent getting the polarizations switched at the output.
4. The coaxial cable used for the RF feeds is intrinsically shielded. This will help prevent unwanted signals from being introduced by the power connection.
5. Each antenna would have its direct own “home run” connection back to the central hut. This is potentially more reliable than a distributed multi-node network.

Disadvantages of Power Distribution Using Bias-T Networks:

1. The bias-T will only be present on one of the active-balun outputs. This will introduce a slight imbalance in the output impedance match. We are gaining direct experience with this method of distribution on the LWDA (Fig. 5).
2. In the case of AC power distribution with bias-T networks, 60 Hz artifacts could leak through to the receiver.

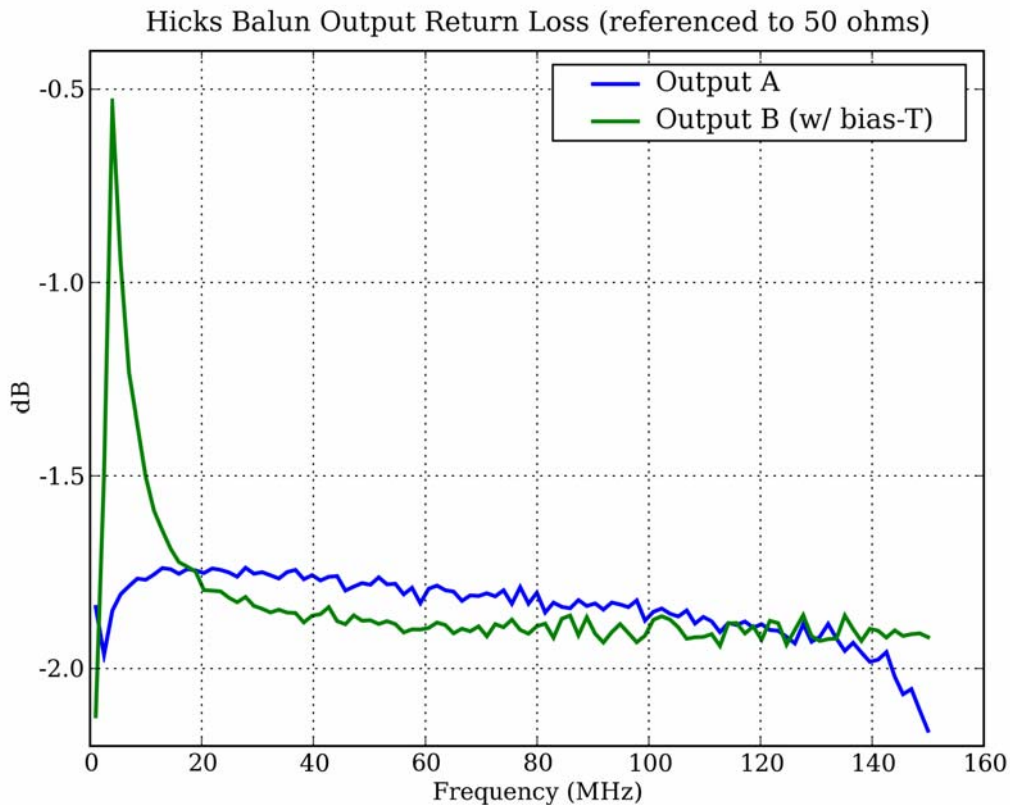


Figure 5 – Return Loss Difference between Balun Outputs With/Without Bias-T

V. Power Distribution Schemes without a Bias-T

A. DC Power Distributed from Central Hut

It is possible to locate banks of nominally regulated power supplies in the same location as the receive electronics and distribute power directly to the antenna stands with a network of dedicated shielded cables that connect directly the active baluns (Fig. 4).

Advantages of Direct DC Power Connection:

1. Power is supplied directly to the balun without the need for a bias-T enabling the output impedance as a function of frequency to be nearly identical for both outputs. When a bias-T is used, there is a slight imbalance in the output match.
2. DC power will likely be supplied from multiple units at a central location making it very straightforward to turn off power to sections of the array for testing and servicing.

Disadvantages of Direct DC Power Connection:

1. Requires a large amount of cable, connectors, and hardware that is not required when power is distributed by bias-Ts.
2. Centrally located DC power supplies will likely occupy a large amount of space.
3. Eliminating the heat generated by the centrally located supplies could prove challenging.
4. A set of connectors will be required for each antenna stand that would be unnecessary if a bias-T network were used instead.

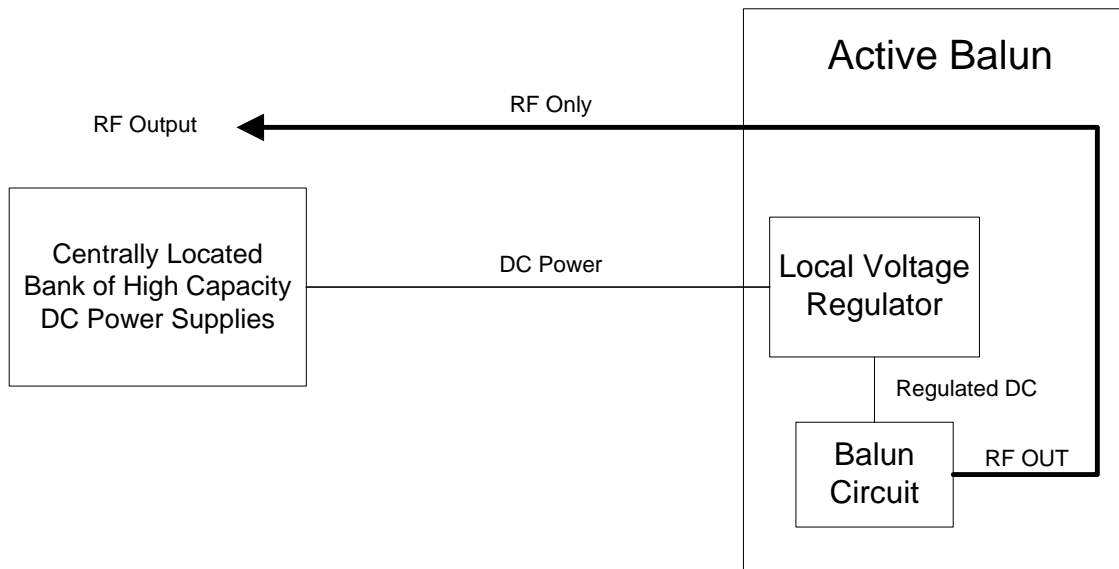


Figure 4 - Direct DC Power Distribution

B. AC Power Distributed from Central Hut Transformer

One alternative to using a bank of centrally located DC power supplies would be to use a centrally located step-down transformer and distribute either low voltage (for safety) or high-voltage (for lower distribution loss) AC throughout the array. In either case, a small transformer would be located at each antenna stand to step the voltage up or down. The case of a low voltage AC distribution network is depicted in Figure 5.

Advantages of AC Power Distribution with Central Transformer:

1. Since a central distribution transformer could likely be housed in a standard industrial transformer enclosure, space, cooling, and environmental constraints could likely be satisfied in an economical manner.
2. A low voltage distribution network would provide safety for maintenance personnel servicing antenna stands.

3. A higher voltage distribution network, such as that used on the Clarke Lake Array (~660 VAC), could reduce line loss and enable much less expensive low-gauge wire to be used.
4. Since each balun is essentially equipped with its own DC power supply, a large segment of the array would not become inactive as would be the case with the failure of a central DC supply sourcing many antenna stands.
5. Power is supplied directly to the balun without the need for a bias-T. When a bias-T is used, there is a slight imbalance in the output match.
6. Having 110 VAC distributed throughout the array would make it easy to provide power outlets throughout a station to power tools and lights for maintenance.

Disadvantages of AC Power Distribution with Central Transformer:

1. Additional power connectors and an extensive shielded power distribution network are required that would not be necessary if bias-T networks were used.
2. A small transformer will be needed at each antenna stand.
3. If it isn't possible to encase the transformer local to the antenna stand in a part of the stand that is already weatherproof, an additional protective enclosure will be necessary.

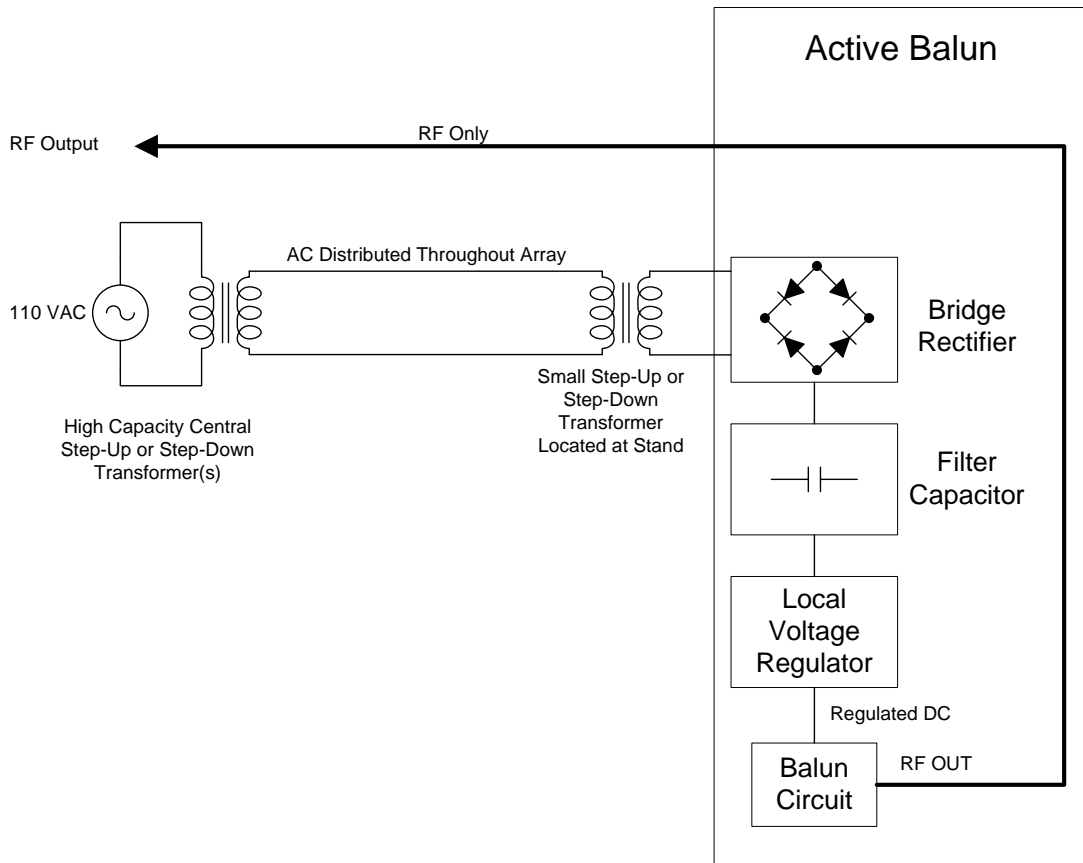


Figure 5 - Direct AC Power Distribution from Central Transformer

C. 110 VAC Power Throughout Array

It is also possible to distribute 110 V AC across the entire array and locate a small step-down transformer at each antenna stand (Fig. 6). The local step-down transformer could be housed in an enclosure to protect maintenance personnel from line voltage levels.

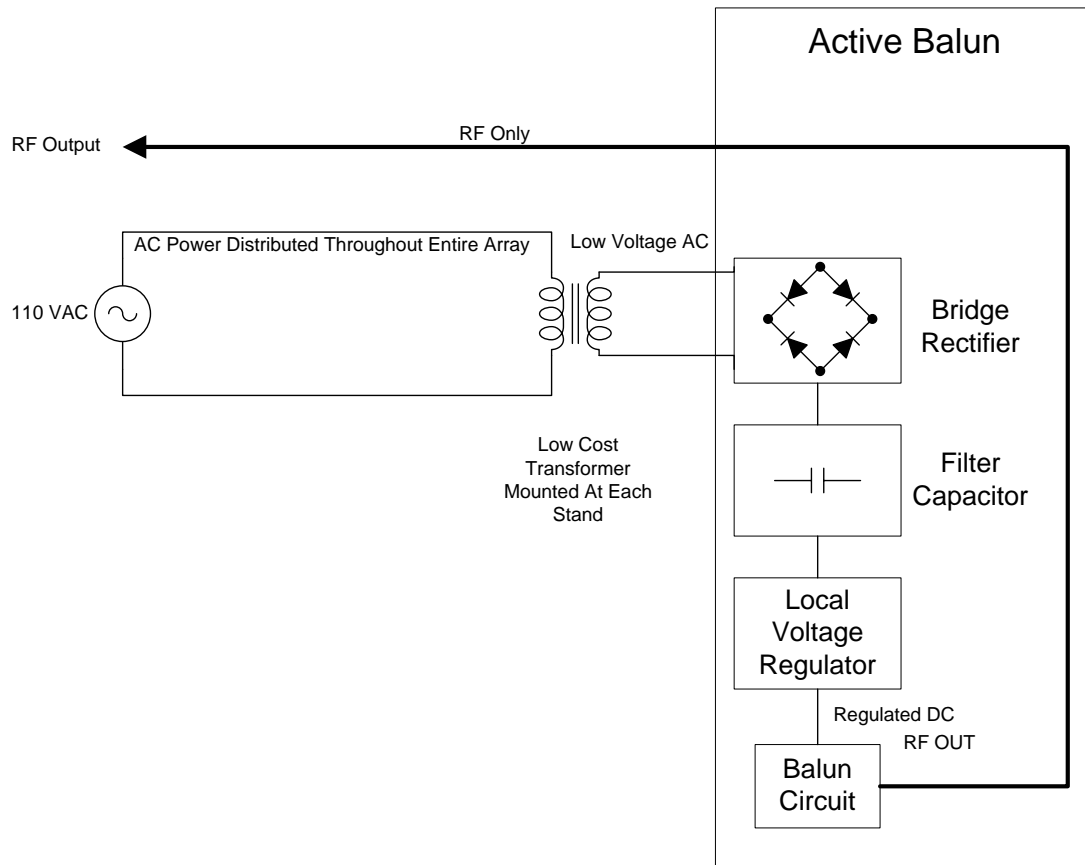


Figure 6 - Direct Distribution of 110V AC throughout the Entire Array

Advantages of Direct Distribution of 110 VAC Power Throughout Array:

1. Overall station reliability is increased since each stand is self-sufficient from a power standpoint.
2. Power supply cooling and space constraint concerns are eliminated.
3. Standard industrial 110V wiring hardware (junction boxes, fuse boxes, etc.) can be used throughout the entire distribution network.
4. The AC distribution network could be designed to enable the station array to be selectively powered for servicing and testing.
5. Power is supplied directly to the balun without the need for a bias-T. When a bias-T is used, there is a slight imbalance in the output match.
6. Power tools and test equipment could be powered at outlets placed at many or all of the antenna stands.

Disadvantages of Direct Distribution of 110 VAC Power Throughout Array:

1. Additional power connectors and an extensive shielded power distribution network are required that would not be necessary if bias-T networks were used.

VI. Cost Considerations

We include here some basic cost information to help enable cost comparisons of the various power distribution methods discussed in this report.

DC Bias-T:

The bias-T network used in the baseline balun design consists of one inductor and one capacitor. One such network must be present at the receiver side, and another included in the active balun unit.

Inductor Value: 4.7 uH
Manufacturer: JW Miller Magnetics
Manufacturer Part Number: 9230-36
Distributor: Digi-Key
Distributor's Part Number: M94R7-ND
Cost in Quantities > 500: \$0.46

Capacitor Value: 0.1 uF
Manufacturer: Panasonic
Manufacturer Part Number: ECJ-3VB1E104K
Distributor: Digi-Key
Distributor's Part Number: PCC1883CT-ND
Cost in Quantities > 500: \$0.08

The cost per bias-T network is, therefore, \$0.54 each.

High Capacity DC Power Supply:

A cursory survey of high capacity rack mount power supplies identified the Lambda model GEN 20-165 as a potential candidate for a central DC supply. It is capable of supplying 1 to 20 Volts at up 165 Amperes. Monitoring and control of this unit is possible via an RS-232 port.

Voltage Regulator:

Voltage Regulator: LM2940IMP-12 (12V, 1A)
Manufacturer: National Semiconductor
Manufacturer Part Number: LM2940IMP-12/NOPB

Distributor: Digi-Key
Distributor's Part Number: LM2940IMP-12CT-ND
Cost in Quantities > 250: \$0.93

Transformer for AC Distribution Methods:

Transformer Type: 115 VAC Primary, 12.6V Secondary @ 1.6A
Manufacturer: Signal Transformer
Manufacturer Part Number: 14A-20-12
Distributor: Digi-Key
Distributor's Part Number: 595-1003-ND
Cost in Quantities > 200: \$7.68

High-Capacity Transformer for Central AC Distribution Methods:

Transformer Type: Boost-Buck Transformer – 5kva
120 or 240 Volt Primary
12 or 24 Volt Secondary
Single Phase, 60 Hz

Manufacturer: TEMCo – Tower Electric Motor Co.
Manufacturer Part Number: TSB12N5F
Distributor: TEMCo
Single Unit Cost: \$840.00
Quote: #23501

This unit is capable of delivering 396A at 12.6 Volts and weighs 130 lbs.

Bridge Rectifier for AC Distribution Methods:

Bridge Rectifier: 50V @ 2A
Manufacturer: General Semiconductor
Manufacturer Part Number: 2KBP005M-E4/51
Distributor: Digi-Key
Distributor's Part Number: 2KBP005M-E4/51GI-ND
Cost in Quantities > 100: \$0.49

Direct Burial Shielded Cable for DC Distribution Methods:

Part Number: 451802SDB
Manufacturer: Paige Electric
Distributor: Direct from manufacturer
Description: 2 conductor, 18 AWG, shielded, waterblock direct burial cable
Price: \$160 per 1000 feet

Direct Burial Cable for AC Distribution Methods:

Part Number: 12-2 UF with Ground
Manufacturer: Essex Paranite
Distributor: Dean Bennett Supply
Description: 12 AWG, UF Direct Burial Cable with Ground
Price: \$1.08 per foot

Approximate cost of bias-T distribution for a station with 256 elements:

- | | |
|---|------------------|
| 1. 256 x 2 bias-T networks at \$0.54 each = | \$ 276.48 |
| 2. 1 Rack Mount DC Supply (GEN 20-165) = | \$2850.00 |
| 3. 256 Voltage Regulators at \$0.93 each = | <u>\$ 238.08</u> |
| Total = | \$3364.56 |

Approximate cost of DC distribution over a dedicated power cable for 256 elements:

- | | |
|--|--------------------|
| 1. Cable approximated at 100 ft./ant. = 25,600 feet * \$160/1000 ft. | = \$4096.00 |
| 2. 256 Voltage Regulators at \$0.93 each | = \$238.08 |
| 3. 1 Rack Mount DC Supply (GEN 20-165) | = <u>\$2850.00</u> |
| Total | = \$7184.00 |

Approximate cost of AC distribution over a dedicated power cable for 256 elements:

- | | |
|--|--------------------|
| 1. Cable approximated at 100 ft./ant. = 25,600 feet * \$1.08 / ft. | = \$ 27,648 |
| 2. 256 Voltage Regulators at \$0.93 each | = \$ 238.08 |
| 3. 256 Bridge Rectifiers at \$0.49 each | = <u>\$ 125.44</u> |
| Total | = \$ 28011.00 |

We did not conduct an exhaustive search for direct burial cable intended for 110 VAC system. We would like to invite comments on more reasonably priced alternatives to the type listed here.

Approximate cost of Central AC distribution over bias-T networks for 256 elements:

- | | |
|--|--------------------|
| 1. High Capacity Transformer 120/240VAC to 12/24 VAC | = \$ 840.00 |
| 2. 256 x 2 bias-T networks at \$0.54 each | = <u>\$ 276.00</u> |
| Total | = \$1116.00 |

VII. Summary and Recommendations

We recommend that serious consideration be given to supplying power to the active baluns via bias-T units. If low level 60 Hz artifacts passing through the bias-T networks do not present an insurmountable receiver design problem, we would specifically recommend their use in distributing AC from a high-capacity central transformer. The use of common 110 VAC wiring to all of the antenna stands should also be investigated.

VIII. References

- [1] “ETA Array Specification”, Steve Ellingson, August 21, 2005
http://www.ece.vt.edu/swe/eta/array/ArraySpec_050821.pdf