Packaging a Bias-Tee Module

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1. Introduction

Glossary of Abbreviations:
BOM: Bill Of Material
LED: Light Emitting Diode
PTC: Positive Temperature Coefficient
VNA: Vector Network Analyzer

This paper describes the installation of a bias-tee module in an aluminum enclosure to make it more convenient and safer to use. The packaged system eliminates flying leads and coaxial adapters. This is a simple construction project. The methods are similar to those I used to package a low noise amplifier module described in {Reeve15}. For the current project I used a Mini-Circuits bias-tee module because of its relatively low cost, wide frequency range and high performance. The packaging described here allows the external RF cables to be connected using type N connectors instead of the SMA connectors on the bias-tee module itself. Power is connected through a locking-type coaxial power plug and jack to a PTC resettable fuse, on-off switch and polarity guard diode. Capacitors and ferrite bead inductors are used to filter the power input.

A bias-tee may be built using passive components and just about any construction method (PCB, "dead bug" or "live bug") but there are advantages to using a commercial module including better and guaranteed performance and convenience. For example, the commercial bias-tee used here has a frequency range of 10 to 2800 MHz, > 40 dB isolation, 0.5 dB insertion loss at 1400 MHz, can handle up to 1.5 A at 30 Vdc and costs only 60 USD, characteristics that are very hard to beat in a shop-built unit. The overall project cost is < 100 USD and a few hours labor.

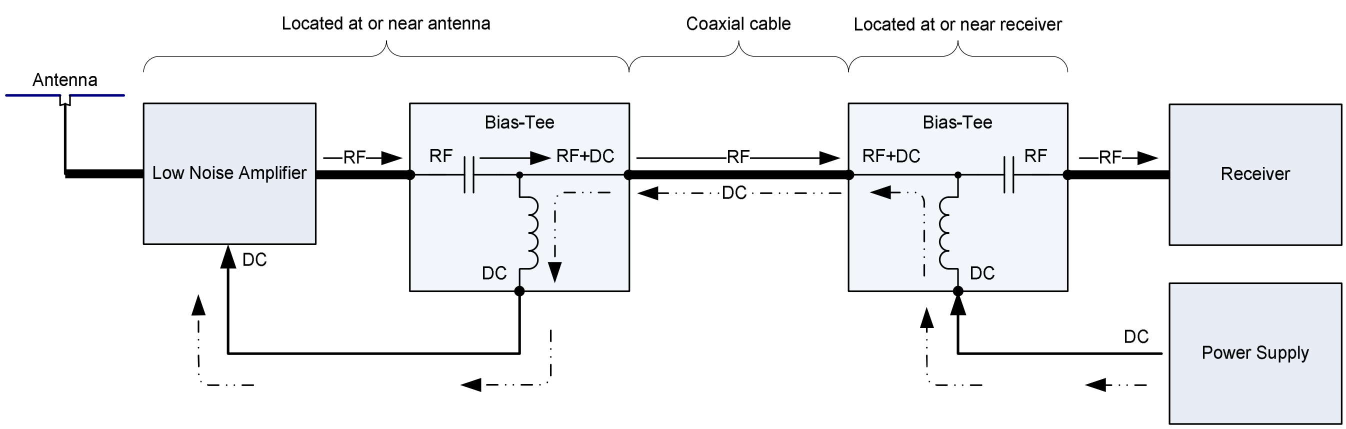

Figure 1 ~ Simplified diagram of a typical bias-tee application. Bias-tees are used in pairs, one to couple the power (shown by dashed lines) into the coaxial cable to the low noise amplifier or active antenna and another near the antenna to decouple the power for the electronics. The inductors in the bias-tee modules pass dc and block RF while the capacitors pass RF and block dc.

2. Bias-Tee Concepts

A bias-tee allows power to be fed to a dish-, tower- or mast-mounted low noise amplifier or active antenna using the same coaxial cable as the RF, thus simplifying the physical cabling (figure 1). The bias-tee isolates the

RF ports from the dc port so that RF is not coupled into the power supply and noise produced by the power supply is not coupled to the receiver and amplifier. The RF coupling is enabled by the capacitance between the RF and RF + dc ports and power supply noise coupling is blocked by the inductance between the RF and RF + dc ports and the dc port. The dc is coupled to the RF + dc port from the dc port by the low resistance of the inductor.

The simplified diagram of a bias-tee shows only a capacitor and inductor. Bias-tees designed for low frequency, narrow bandwidth applications can be that simple but are much more complicated when designed for higher frequencies and wider bandwidths. I used a Mini-Circuits ZFBT-282-1.5A+ bias-tee module (figure 2). A close examination of this unit shows a complicated design and layout (figure 3). Although bias-tees often are modules as shown here, the bias-tee at the amplifier end may be embedded with the amplifier itself (figure 4) and does not have to be a separate module.

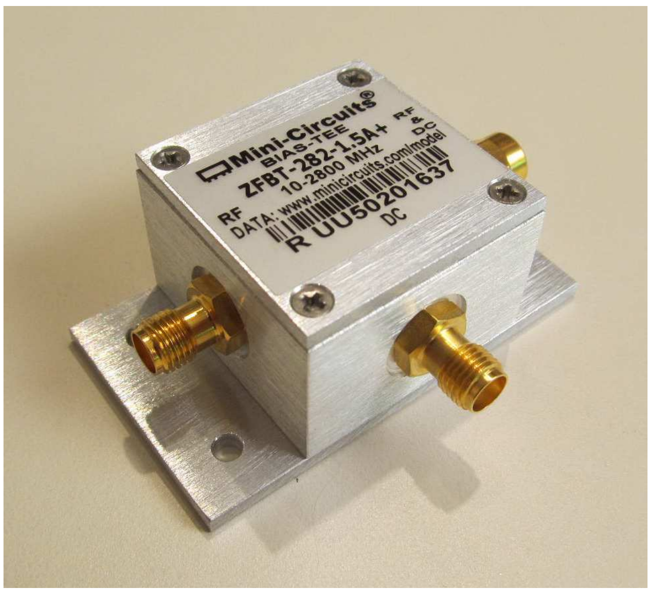

Figure 2 ~ Mini-Circuits ZFBT-282-1.5A+ bias-tee used in this project. Dimensions are approximately 56 x 32 x 24 mm, which includes the mounting bracket. The mounting bracket is 2.54 mm thick and provides a rigid mount. All connectors including the dc port use SMA connectors. The RF + dc port uses a male connector while the other two ports use female connectors. This prevents connecting it incorrectly, which could damage the equipment that is supposed to be on the RF port. Having an RF connector on the dc port simplifies connecting a shielded cable for the power feed. This bias-tee is rated 1.5 A at 30 Vdc.

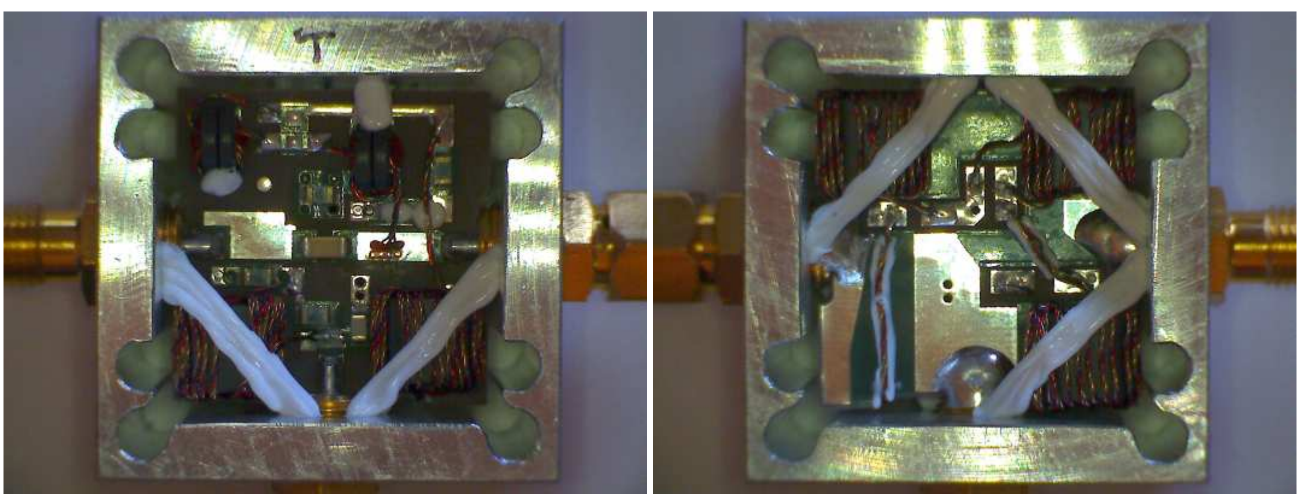

Figure 3 ~ Top (left) and bottom (right) magnified views of the Mini-Circuits ZFBT-282-1.5A+ bias-tee. Close examination reveals four separate trifilar wound transformers near the corners in the top section and three in the bottom section. These form the inductive circuit to the dc port at the bottom of each image. A rubber-like adhesive holds the inductors in place. The coupling capacitor (a surface mount device, SMD) is seen in the left image in the exact center of the printed circuit board between the two RF ports. Additional capacitors for filtering are visible on the printed circuit board in the top section. The RF + dc port is on the right side in the left image and left side in the right image. A thick machined aluminum enclosure provides a rigid platform for mounting the components.

Figure 4 ~ Two low noise amplifier applications of bias-tees. The amplifier on the left is suitable for outdoor use and uses type N connectors for the RF. It has a built-in bias-tee so that power can be fed through the coaxial cable from the receiver end. It also has a BNC connector (seen between the two N connectors) so that power can be fed through a separate non-RF cable. The mast mounting brackets for this amplifier are shown in the foreground. The low noise amplifier on the right is not weatherproof and requires an external bias-tee. Power is fed through a dc coaxial jack and switch on the front panel. It also uses type N connectors for the RF. This amplifier is described in [Reeve15].

3. Bill of Materials

The bias-tee module and enclosure represent the majority of costs in the bill of material (BOM) (table 1). The power supply filter capacitors are not critical except they should have a voltage rating approximately twice the maximum supply voltage. An on-off switch and power indicating LED provide operating convenience. To help minimize the wiring, I used an LED with a built-in current limiting resistor for 12 V operation. Other operating voltages will require a different current limiting resistor value.

The current rating of all components, and especially the over-current protection, in this case a positive temperature coefficient (PTC) resettable fuse, must be coordinated so as not exceed the current rating of the bias-tee. Many bias-tee modules are rated 500 mA but the one used here is rated 1.5 A. The polarity guard diode should have a low forward voltage drop and usually is a Schottky diode. Its current rating should be approximately twice the fuse rating, and its reverse voltage rating should be approximately twice the maximum supply voltage. The fuse and diode shown in the BOM are rated 200 mA and 1 A, respectively, so there is no danger to the bias-tee. The fuse could be increased to 1.5 A if the diode is replaced with an SR240 or SR260 Schottky diode (rated 2 A at 40 V and 60 V, respectively).

All RF cables and the power cable connected to the bias-tee module use right-angle SMA connectors. For projects like this where economy is a first consideration, I use connectorized cables from a Chinese company called SuperBat RFSupplier {RFSupplier}. The cables cost a few dollars each (delivered), much cheaper than I can make them myself. I usually order custom length assemblies and have found their quality to be quite good. I also obtained the extruded aluminum enclosure from the same company. Where RF performance is a first consideration I use the considerably more expensive *Hand-Flex* connectorized cables from Mini-Circuits in the USA.

Table 1 ~ Bias-tee module bill of material. Substitutions may be made for most components.

Item	Qty	Desig.	P/N	Mfr or Vendor	Description
1	1		ZFBT-282-1.5A+	Mini-Circuits	Bias-tee module, 30 V, 1.5 A, 10 to 2800 MHz
2	1		AC-N01BO-S01RJ-316-11	RFSupplier	Coaxial cable, RG-316/U, SMA-F RA/N-F panel, 110 mm long
3	1		AC-N01BO-S01RA-316-13d5	RFSupplier	Coaxial cable, RG-316/U, SMA-M RA/N-F panel, 135 mm long
4	1		Generic	RFSupplier	Coaxial cable, RG-174, SMA-M RA/Blunt, 110 mm long
5	1		BOX-2427	RFSupplier	Enclosure, extruded aluminum, 110 x 80 x 36.5 mm
6	1	S1	317287	Jameco	Toggle switch, miniature, SPST
7	1	PJ1	767K	Switchcraft	DC coaxial power jack, extended barrel, 2.1 x 5.5 mm
8	1	PP1	L722A	Switchcraft	DC coaxial power plug, locking, 2.1 x 5.5 mm
9	1	C1001	545650	Jameco	Capacitor, 10 μF, 35 V, tantalum or electrolytic
10	1	C101	15229	Jameco	Capacitor, 10 nF, 50 V, MLCC
11	1	L1	Generic	Generic	Ferrite bead to fit diode leads
12	1	LED	637183	Jameco	LED, 12 V, Green, panel mount (with internal dropping resistor)
13	1	D1	1N5819	Generic	Schottky diode, 40 V, 1 A (see text)
14	1	F1	MFR-020	Bourns	PTC resettable fuse, 200 ma, 60 V (see text)
15	1		WH24-xx	NTE	Hookup wire, stranded 7x32, 24 AWG, 300 V PVC, red and black
16	2		91420A120	McMaster	Machine screw, phillips, flat head, M3 x 10 mm
17	2		91106A122	McMaster	Washer, internal star, 3 mm
18	2		90592A085	McMaster	Hex nut, M3
19	4		Generic	Generic	Rubber bumper feet, self-adhesive, 6 x 2 mm
20	1		7311	Keystone	Terminal lug, internal star, #4
21	1		1423A	Staffall/USECO	Terminal, double turret, internal thread, 4-40, or equivalent
22	1		N/A	Generic	Machine screw, phillips, pan head, 4-40 x 5/32 in (trim)
23	1		91772A833	McMaster	Machine screw, phillips, pan head, SS, 10-32 x 1 in
24	1		91841A195	McMaster	Hex nut, SS, 10-32
25	1		92146A550	McMaster	Washer, split lock, SS, #10
26	3		92141A011	McMaster	Washer, flat, SS, #10

4. Construction

The construction shown here is based on an extruded aluminum clam-shell enclosure with sheet aluminum front and rear panels. I cut all holes after center-punching the locations marked on paper templates that I prepared in Visio software and printed on a LaserJet printer (figures 5 and 6). After cutting the holes (the holes for the RF connectors were pilot-drilled and then punched), washing off the cutting oil and cleaning with soap and hot water and 90% solution isopropyl alcohol, I applied the black-on-clear labels. The power section wiring is straight-forward (figures 7 and 8). I usually paint my project enclosures but in this case I left the enclosure in bare aluminum. The completed unit is compact but not crowded (figure 9).

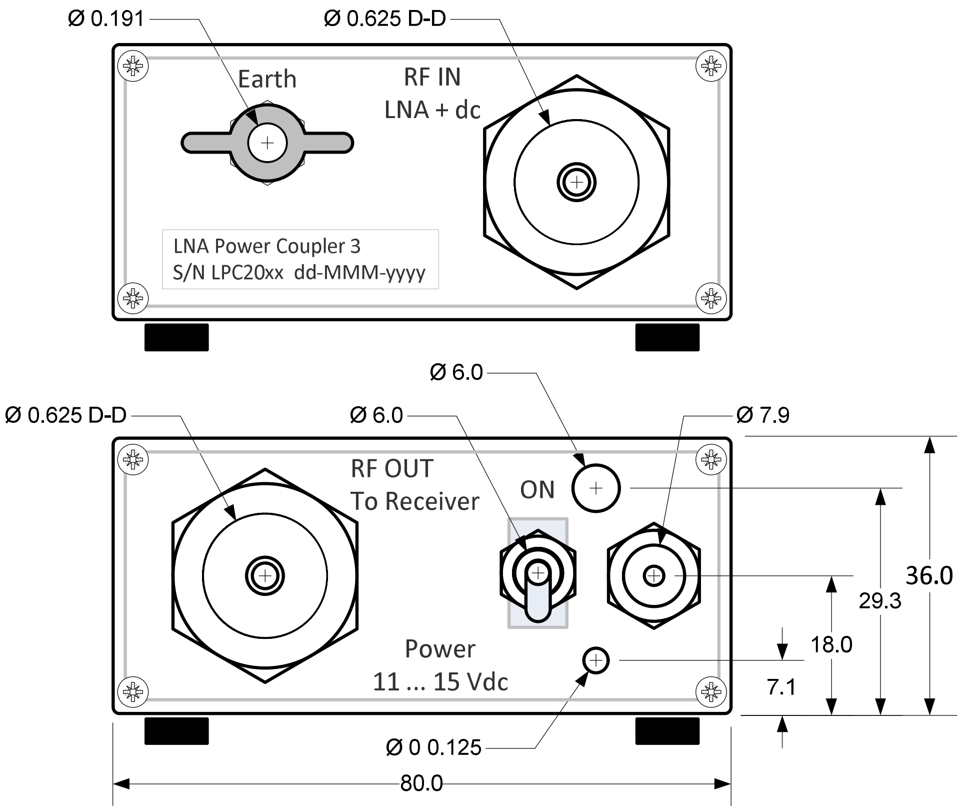

Figure 5 ~ Rear (top) and front panel layouts drawn with Visio software. Dimensions are in mm except some holes are in inches. I always use datasheet dimensions and sometimes these are given only in inches and sometimes only in mm. The power connector is middle-right on the front panel. The hole for the LED above the power connector and switch is shown undersize and is hand-reamed slightly to accommodate the press-fit LED shown in the material list. Bulkhead-mount type N connectors are shown but flange-mount may be used. A stud for earth bonding is on the left side of the rear panel.

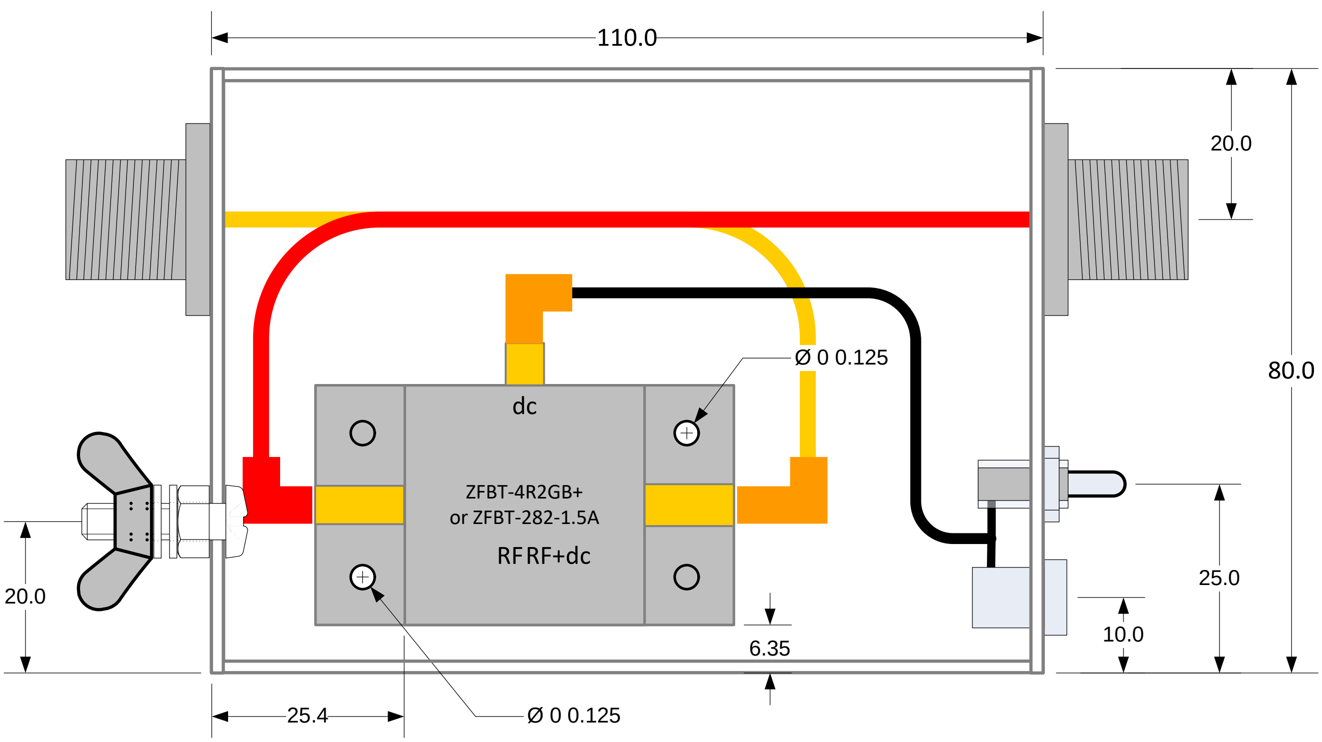

Figure 6 ~ Enclosure plan view as seen from the underside. It shows the layout of the bias-tee module and RF cabling (this drawing serves as a template for drilling the bias-tee bracket mounting holes and is taped to the outside of the enclosure prior to center punching and drilling). The bias-tee is offset to provide clearance for the power components on the front panel and for the RF connectors on the front and rear panels.

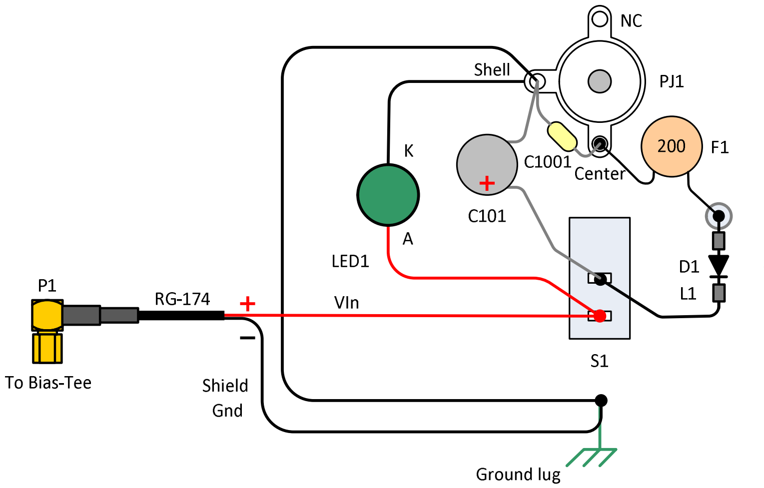

Figure 7 ~ Power wiring diagram with the center-positive coaxial power jack on the top-right. A current limiting resistor is not required if the specified LED is used with 12 Vdc supply voltage, thus simplifying the wiring. The PTC resettable fuse F1 connects to polarity guard diode D1 at the turret terminal. The fuse shown here is rated 200 mA; however, a current rating up to 1.5 A may be used with the ZFBT-282-1.5A+ bias-tee module. Two ferrite beads, indicated as L1, are slipped over the diode leads for filtering. The power input section connects to the bias-tee module via the connectorized RG-174 coaxial cable.

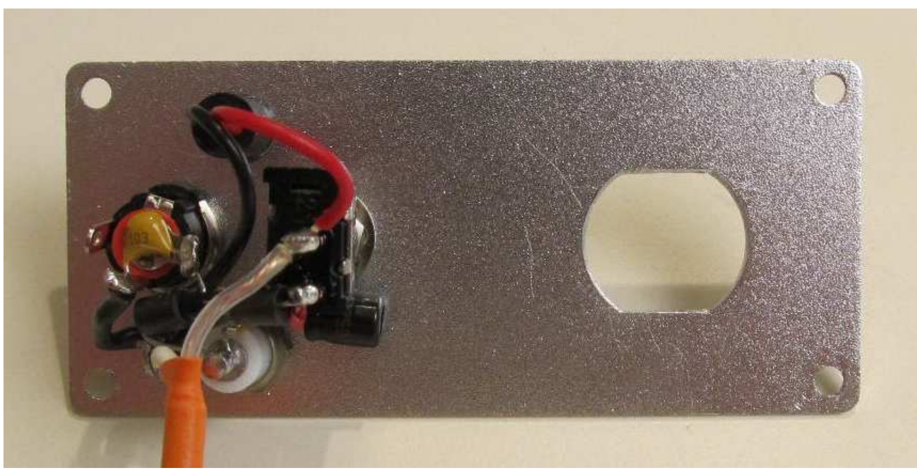

Figure 8 ~ Close-up of the inside front panel showing the power input components. The turret terminal can be seen at lower-left and the coaxial cable for the dc feed to the bias-tee is seen dropping downward at left. All connections are kept short to minimize the chance for a short circuit. A custom-made punch was used to cut the double-D hole on the right for the type N connector.

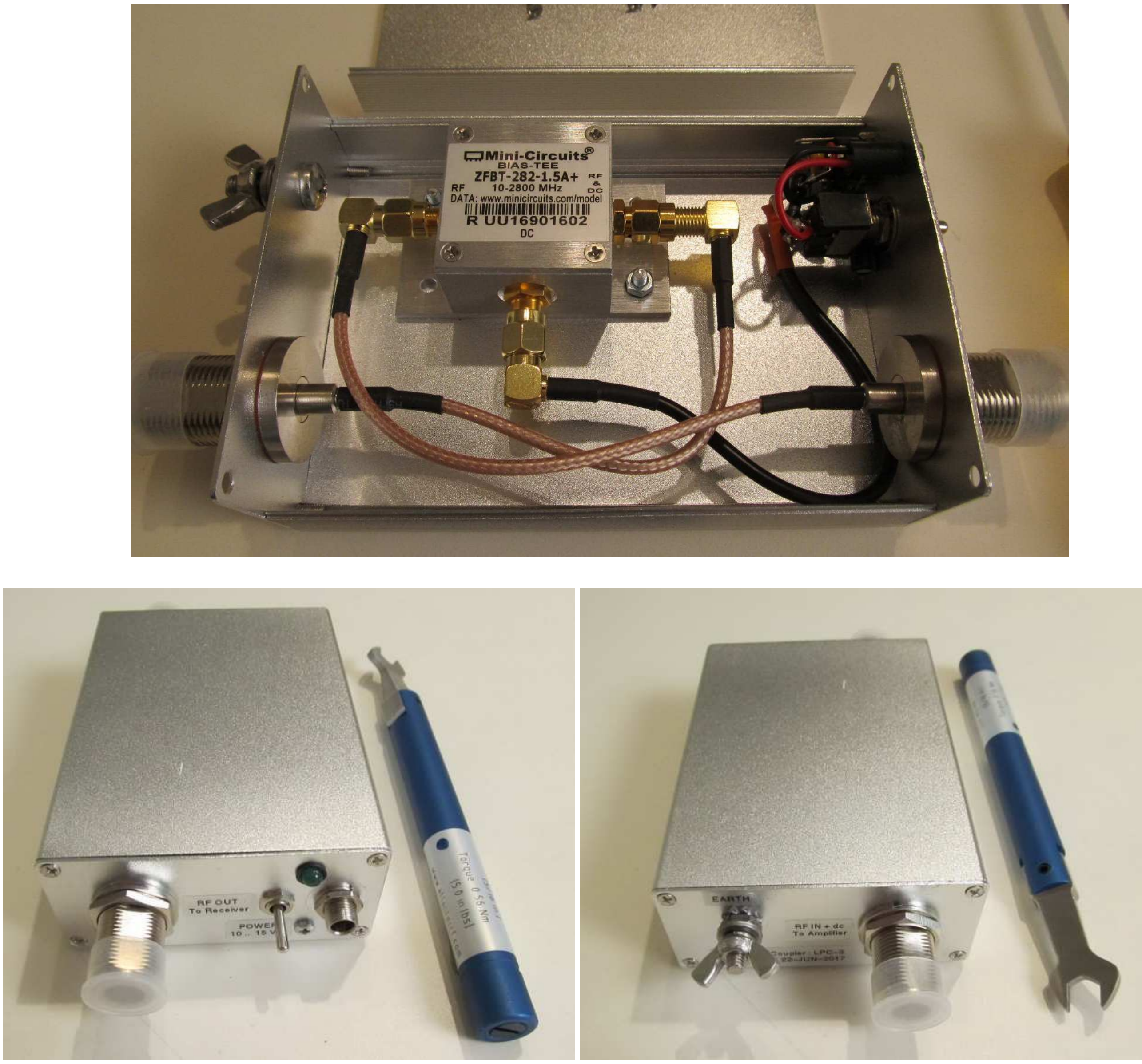

Figure 9 ~ Three views of the completed bias-tee package: Upper: The inside view shows all components and cabling in place. Lower: Bias-tee assembly with cover in place. The wrench is an 8 mm (5/16 in) torque wrench for the SMA connectors. The type N connectors are shown with protective caps.

5. Measurements

I measured the input reflection coefficient and insertion loss of the completed bias-tee assembly with a Keysight N9923A FieldFox vector network analyzer (VNA) (figures 10 and 11). The analyzer was calibrated with an HP 85032B 50 ohm Type-N Calibration Kit through the full frequency range of 2 to 6000 MHz, but the measurements shown here are limited to 2 to 3000 MHz. These measurements are primarily made to verify operation of the RF cables, connectors and bias-tee module.

I was not sure how to do the bias-tee isolation measurements so I contacted the manufacturer (Mini-Circuits). I discovered they use two reference bias-tees plus the one under test, all connected in a certain way and to a 3-

port vector network analyzer. I could duplicate the setup and make suitable measurements with my 2-port VNA by substituting 50 ohm terminations on the third port and swapping port connections around for each measurement. However, I decided to not measure isolation and assumed it is not seriously corrupted by my implementation. It should be noted that the factory isolation measurements are on the basis of 50 ohms impedance even on the dc port. In actual use the dc port is terminated in very low power supply impedances that are unpredictively reactive at radio frequencies and nowhere near 50 ohms.

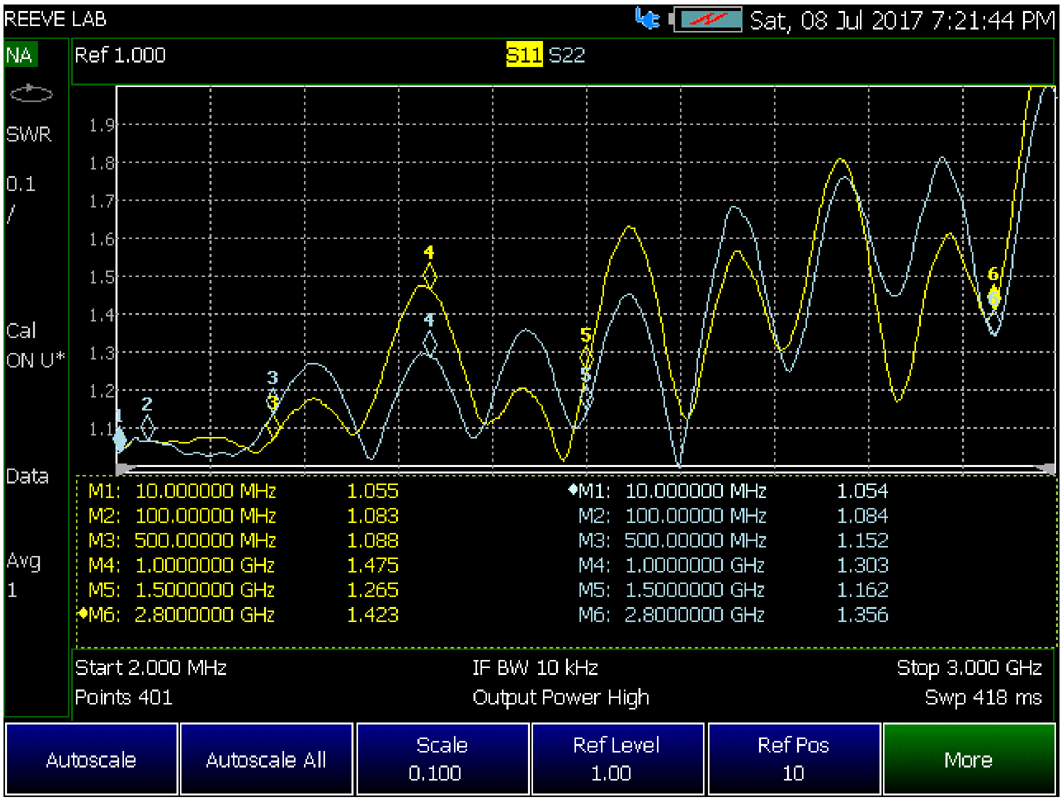

Figure 10 ~ S11 and S22 scattering parameters from 2 to 3000 MHz. The marker table below the traces shows measured values at selected frequencies. S11 (yellow trace) and S22 (blue trace) are in terms of VSWR. The scale factor is 0.1/div, which provides a magnified view. S11 and S22, indicate the degree of impedance matching of the two RF ports. The actual measurements are reflection coefficients, which are converted to VSWR for display. The lower the VSWR, the better (1.0:1 is ideal). These measurements indicate that VSWR is better than about 1.8:1 across the entire band. A 1.8 VSWR is equivalent to a reflection coefficient of 0.29 and return loss of 10.9 dB. The wavy nature of the traces is magnified by the narrow scale and indicates resonances, most likely in the internal cabling.

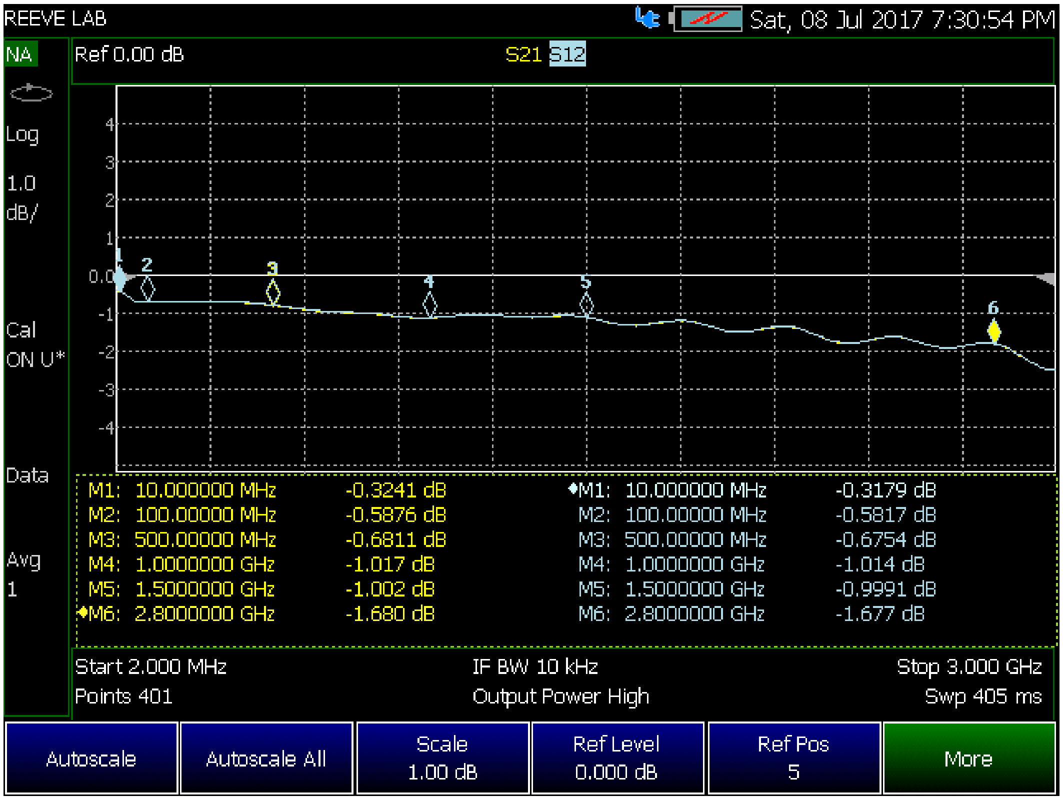

Figure 11 ~ S21 and S12 scattering parameters from 2 to 3000 MHz. S21 (yellow trace) and S12 (blue trace) are insertion losses in terms of dB reduction from zero with scale factor of 1 dB/div. The two traces are almost indistinguishable. S21 measures the loss from the RF+dc port to RF port and S12 is the reverse direction. The more positive the insertion loss value, the better (0.0 dB is ideal). These measurements indicate the insertion loss increases steadily as frequency increases but is less than 1.7 dB at 2800 MHz.

6. Discussion

The performance of this bias-tee assembly appears to be quite good. There is not much to go wrong. The typical insertion loss of the ZFBT-282-1.5A+ bias-tee module by itself is about 1.4 dB at 2800 MHz. The cables in the assembly introduce some additional losses (called *implementation losses*) but the measurements show these to be < 0.3 dB at 2800 MHz. Similarly, the typical maximum VSWR of the standalone module is on the order of 1.2:1 or 1.3:1 at 2800 MHz whereas the measurements of the assembly show slightly worse at 1.8:1. The measured VSWR is better than 1.5:1 to 1500 MHz, equivalent to a return loss of 14 dB.

7. References

[Reeve15] Reeve, W., Packaging a Low Noise RF Amplifier Module, Society of Amateur Radio Astronomers, September-October 2015 (paper available at: http://www.reeve.com/Documents/Articles%20Papers/Reeve_LNA-Package.pdf

{RFSupplier} http://rfsupplier.com/

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