Application Note on Remote Amplifier Powering

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Abbreviations in this article:
- dc: direct current
- LNA: Low Noise Amplifier
- LPC: LNA Power Coupler
- RF: Radio frequency
- TMA: Tower-Mounted Amplifier

1. Introduction

Amplifiers often are installed near an antenna to improve system noise figure or to compensate for coaxial cable transmission line (feedline) losses. The remote amplifier can be powered through the coaxial feedline or through a separate dedicated power cable. Using the coaxial feedline is more convenient – it requires only one cable run – but it requires a bias-tee arrangement. In this article I describe a bias-tee application and the solution to a problem I encountered using bias-tees under certain circumstances.

2. The bias-tee

A bias-tee is so named because of the way it looks in a schematic (figure 1). It usually consists of only two components, an inductor and a capacitor. The inductor passes direct current (dc) from the power supply through the dc port to the RF+dc port and blocks radio frequency (RF) currents to the power supply. The capacitor passes RF between the RF+dc and RF ports and blocks dc to the RF port. Working together, these two components isolate the dc and RF ports from each other. A typical application uses two bias-tees, one at each end of the feedline (figure 2).

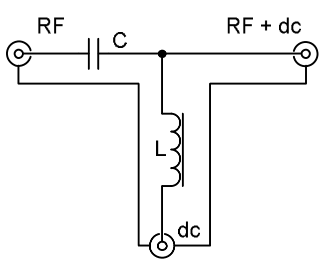

Figure 1 ~ Bias-tee schematic. The inductor L has high RF impedance and the capacitor C has low RF impedance in the desired frequency range. The center conductor of the coaxial cable is one conductor of the dc circuit and the shield is the return conductor. The inductor unavoidably has dc resistance thus imposing a slight voltage drop in the dc circuit. The RF impedance between the RF and RF+dc ports is low but still has measurable loss at operating frequencies, typically a few tenths of a dB.

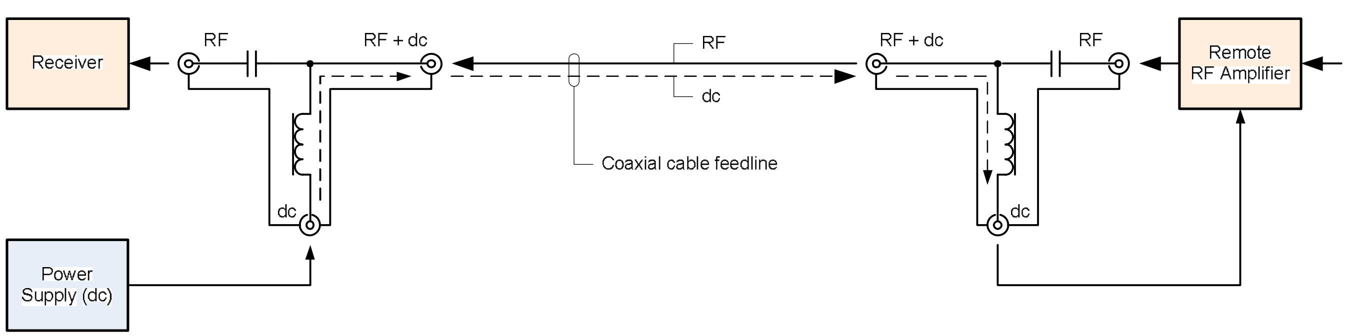

Figure 2 ~ Bias-tee application. The power supply is coupled to the feedline through the dc port of the bias-tee at the near end (left) and decoupled from the bias-tee at the remote end to power the amplifier (dashed line). Amplified RF from the remote amplifier is coupled to the feedline through the RF port and decoupled through the RF port at the near end for connection to a receiver or another amplifier.

3. Application

I use a remote low noise amplifier with my e-CALLISTO solar radio spectrometer. At the receiver end the setup has a low noise amplifier power coupler assembly (LPC) with a bias-tee and linear voltage regulator (figure 3) and at the remote end it has a tower-mounted amplifier (TMA) assembly with a bias-tee, low noise amplifier and linear voltage regulator (figure 4). The entire system is powered by a nominal 12 Vdc observatory power supply.

For the bias-tees, I use the Mini-Circuits ZFBT-4R2G+, which has 30 Vdc and 500 mA maximum voltage and current ratings. The low noise amplifier in the TMA is the Mini-Circuits ZX60-33LN+. Its normal operating voltage is between 3.3 and 5.0 V and it draws 80 mA. Because the performance of the amplifier somewhat depends on its supply voltage, I decided to use a regulated power supply in the TMA for the amplifier. To limit power dissipation and heat build-up in the TMA I used a 2-step powering scheme such that the LPC includes the first step down from 12 V to an intermediate voltage of 8.0 V. The second voltage step down is in the TMA where the voltage is reduced by another linear regulator to the amplifier voltage of 3.3 V (figure 5).

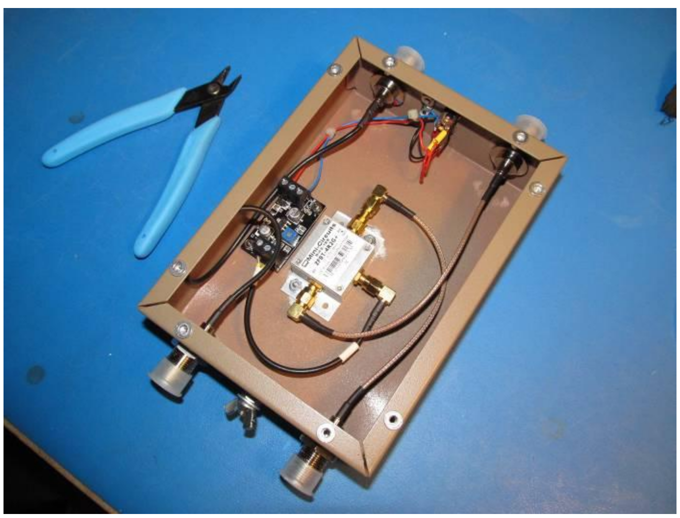

Figure 3 ~ Low noise amplifier power coupler assembly (LPC). The bias-tee is in the middle of the enclosure and the linear voltage regulator is to its left. The voltage regulator output is connected to the bias-tee through a coaxial cable and connector. Power input to the LPC is through a coaxial power jack at top. This LPC includes an additional set of RF connectors that bypass the bias-tee so that it can be used with a TMA that has two amplifiers (both amplifiers are powered through one set of bias-tees). The LPC shown here is a pre-production model.

Figure 4 ~ Tower-mounted low noise amplifier. The TMA shown is a prototype, which used an adjustable internal voltage regulator (middle-right). The bias-tee is at top and the LNA module is middle-left. The black object at bottom-left is a lightning arrestor.

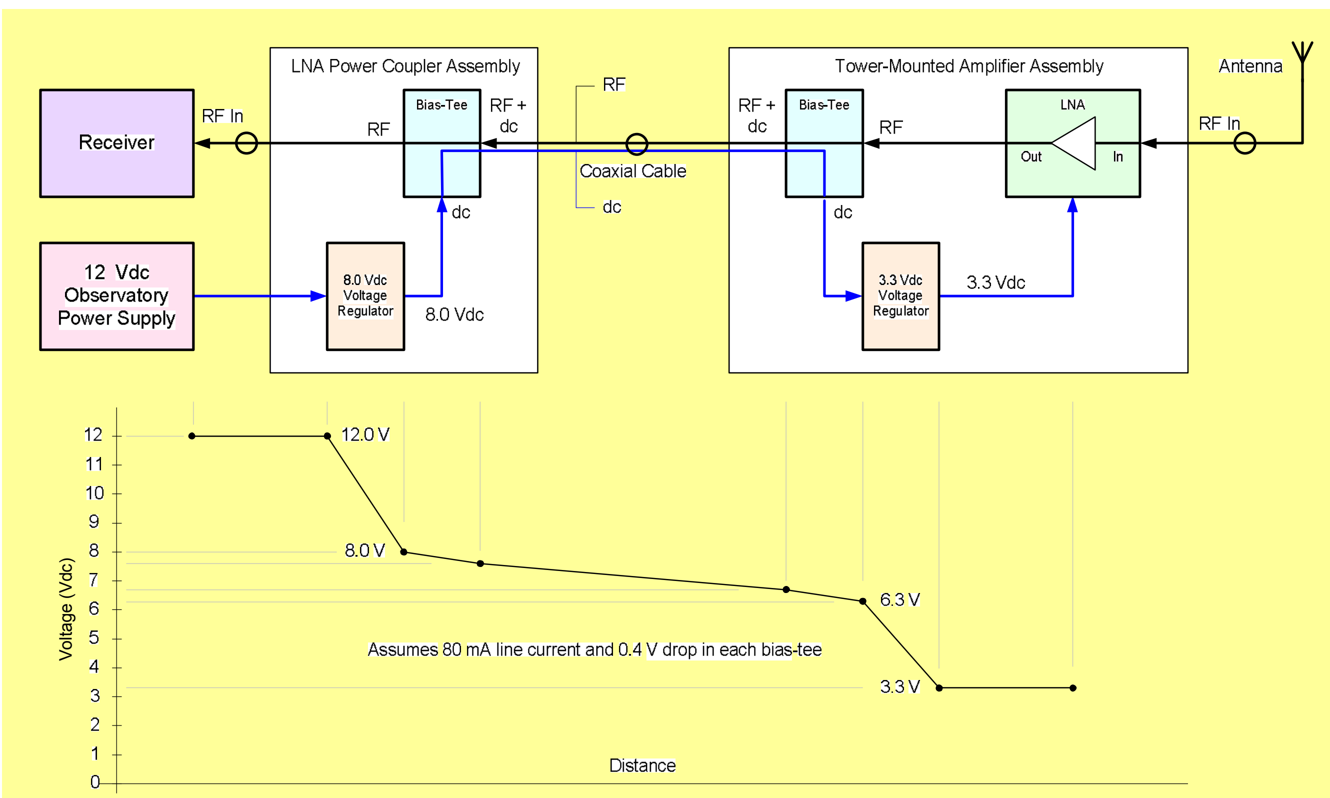

Figure 5 ~ TMA dc powering block diagram (upper) and voltage diagram showing voltage drop details (lower).

I arrived at the intermediate voltage of 8.0 V as follows: The linear voltage regulator integrated circuit (IC) that I originally used in the TMA required 3 V higher input than output, so the minimum voltage at the input to the TMA voltage regulator input would be 6.3 V. The dc resistance of each bias-tee is 4.5 ohms and the LNA load current is 80 mA, so the voltage drop attributable to each bias-tee would be approximately 0.4 V. Therefore, the input voltage at the TMA RF+dc port would need to be 6.7 V. To compensate for coaxial cable resistance voltage drop, I chose to set the LPC voltage regulator output 1.3 V higher to 8.0 V.

The feedline loop resistance (center conductor resistance + shield resistance) plus the bias-tee resistances must be taken into account. To achieve a minimum voltage at the TMA voltage regulator of 6.3 V, the maximum allowable voltage drop in the feedline is determined from

$$VD = V_{LPC} - VD_{LPC} - VD_{TMA} - V_{TMA} = 8.0 - 0.4 - 0.4 - 6.3 = 0.9 \text{ V}$$

where

V_D	= allowable voltage drop (V)
V_{LPC}	= LPC voltage regulator output voltage (V)
VD_{LPC}	= LPC bias-tee voltage drop (V)
VD_{TMA}	= TMA bias-tee voltage drop (V)
V_{TMA}	= minimum TMA voltage regulator input voltage (V)

For a load current of 80 mA, the maximum allowable feedline loop resistance works out to be 11.25 ohms. TWS-400 or LMR-400 (or equivalent) coaxial cable has a loop resistance of 1 ohm per 100 m at 20 °C, so its maximum allowable length in this design scenario is 1125 m, more than enough for all practical applications.

For completeness we should look at the case for a very short feedline (0 ohms dc resistance). The TMA input voltage at its RF+dc port would be 8.0 Vdc less the bias-tee voltage drop in the LPC, or 7.6 V. This would be reduced by the bias-tee in the TMA, and the input voltage at the TMA voltage regulator would be 7.2 V.

4. The problem with bias-tees

A problem can arise when supply voltage is first applied to a bias-tee. The bias-tee capacitor initially has no charge and momentarily is an electrical short circuit until it charges to the applied voltage. As the capacitor charges to the supply voltage it passes a voltage pulse from the power supply (dc port) to the RF side of the bias-tee (RF port). It may be that the pulse has high enough amplitude to damage the amplifier's RF output circuit. In fact, this was the case in my original design and I damaged two LNA modules before I figured out what was happening.

The first occurred in July 2011 while I was testing the TMA in my lab. The ZX60-33LN+ amplifier failed for no apparent reason. The amplifier was new and I attributed the failure to a simple early failure. Nevertheless, I contacted Mini-Circuits quality control department, and they asked me to send the amplifier for analysis. About a week later I received their report, which said "DC resistance test results indicate that the MMIC amplifier component is shorted on input and output."

The MMIC is a monolithic microwave integrated circuit, which is the central component in this low noise amplifier. I asked for clarification and was told "The amplifier was damaged electrically in use"; however, I failed to grasp the true problem. Mini-Circuits replaced the MMIC and returned the LNA to me. I did not think much about the problem until six months later when I had an in-service failure of exactly the same type. I again sent the amplifier to Mini-Circuits, which found the same problem as before. This time I scrutinized the setup and found that the bias-tee was coupling the full 8 V line powering voltage to the LNA module RF output (figure 6). According to the datasheet, the absolute maximum voltage rating of the module is 5.5 Vdc, but I was subjecting its output circuit to 8 V each time I applied power to the TMA. The reason for the two failures now was clear.

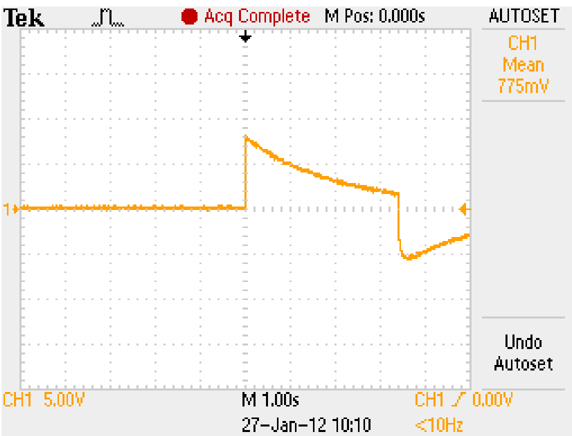

Figure 6 ~ Oscilloscope screen showing the dc voltage measured at the LNA module RF output port. In a normal operation, there would be only RF and no dc. However, the coupling capacitor in the bias-tee momentarily couples a pulse when voltage is applied to the TMA feedline. In this screenshot, the power was connected (center) and then disconnected about 3 s later resulting in an initial positive pulse of about 8 Vpk that decreases as the capacitor charged followed by a negative pulse when power was disconnected. Note the vertical amplitude scale is 5 V/division and the horizontal time scale is 1 s/division.

When discussing the failure with Mini-Circuits they suggested I use a voltage limiter on the LNA output, in particular their model VLM-33-S+ voltage limiter (figure 7). Of course, the problem with a limiting device is that it might also limit the amplifier's RF output to something below the maximum desired level. It turned out that the recommended device was matched quite well to my application. First, the limiter provides the necessary suppression of the powering voltage (figure 8). Second, although the maximum rated RF output of the amplifier is typically +17.5 dBm the limiter limits it to +11.5 dBm. Assuming an amplifier power gain of +21 dB, the corresponding input power at the LNA would be –9.5 dBm, which is considerably higher than the anticipated maximum input power of my solar radio spectrometer system even during strong solar radio flares. Finally, the voltage limiter frequency range is 30 to 3000 MHz, slightly wider than the TMA design range of 45 to 1000 MHz.

The actual installation of the voltage limiter was quite straight forward. It is equipped with type SMA-M and SMA-F connectors, allowing it to plug directly in series with LNA RF output port and the bias-tee RF port (figure 9).

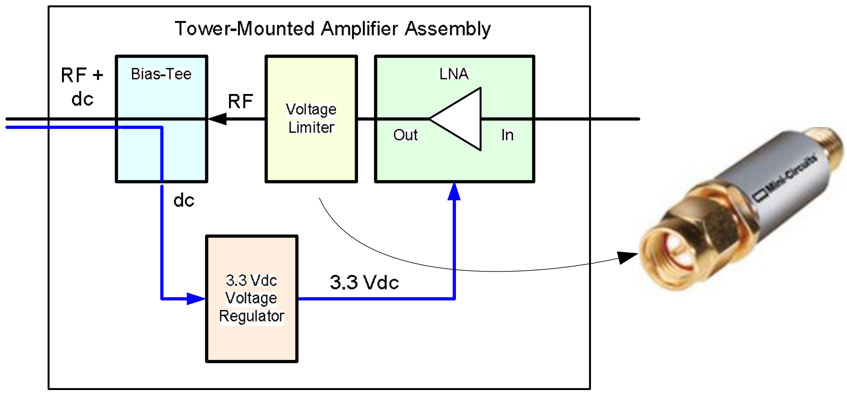

Figure 7 ~ Mini-Circuits VLM-33-S+ voltage limiter used to prevent over-voltage on the LNA module output circuit. The limiter is about 36 mm long and 10 mm diameter and has type SMA connectors. The limiter insertion loss is typically 0.23 dB.

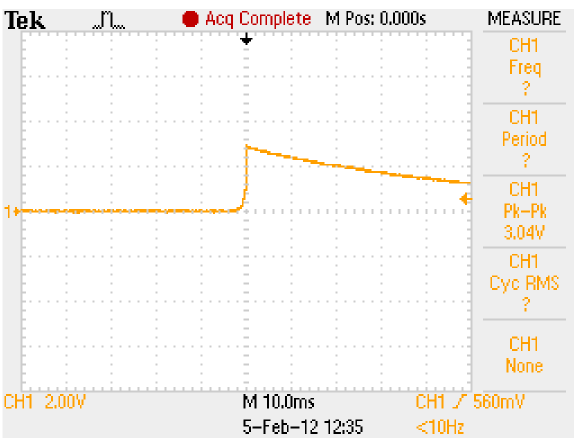

Figure 8 ~ Oscilloscope screen showing the dc voltage measured at the LNA module RF output port with the VLM-33+ limiter installed on the LNA module output. As seen, the voltage pulse upon application of TMA power is about 3 Vpk. Note that the amplitude scale is 2 V/division and the time scale is 10 ms/division.

Figure 9 ~ Physical installation of the VLM-33+ voltage limiter in the TMA. It is connected directly to the LNA module RF output port shown left of middle. The TMA shown here is a production model that is equipped with a fixed low-voltage dropout linear regulator and an optional FM broadcast bandstop filter.

5. Redesign for cost saving

The datasheet for the ZX60-33LN low noise amplifier used in my TMA shows performance figures for 3.3 and 5.0 V input voltages. The gain is slightly lower and noise figure slightly higher at 3.3 V input. This indicates that the internal amplifier voltage is not tightly regulated. I chose to operate the LNA at 3.3 V and to use a voltage regulator in the TMA to reduce performance variations.

A low dropout (LDO) voltage regulator may provide some advantages over the older technology linear regulator used in the original TMA design. LDO regulators typically require 1.2 to 1.3 V higher input than output, in this case 4.6 V input for 3.3 V output. An example of a suitable LDO is the LM1117-3.3 regulator by Texas Instruments. The voltage drop in the TMA bias-tee would be about 0.4 V thus raising the required voltage at the TMA RF+dc port to 5.0 V. If the feedline length is limited to, say, 100 m of LMR-400, TWS-400 or equivalent coaxial cable, the maximum voltage drop in the cable would be

$$VD_{feedline} = 100\ \mathrm{m} \cdot 1\ \Omega/100\ \mathrm{m} \cdot 0.08\ \mathrm{A} \approx 0.1\mathrm{V}$$

In this design, the output voltage at the LPC RF+dc port could be set to 5.1 V. For pulse voltage analysis the worst-case situation would be zero length feedline, in which case the maximum pulse voltage applied by the bias-tee to the amplifier output would be 5.1 V, providing a slightly reduced margin of 8% margin compared to 10% for the original design previously described. In the new scenario the maximum rating of the LNA module is not exceeded and it could be safely operated without a limiter. Eliminating the voltage limiter would save about US$50.

6. High and low temperatures

The above analysis does not take into account operation of the bias-tees and feedline at high ambient temperatures. A coaxial feedline exposed to the direct Sun where the ambient temperature is above 35 or 40 °C can easily reach 140 °C, raising its dc resistance by about 5% compared to its resistance at 20 °C. This could be handled by raising the voltage at the LPC RF+dc port to compensate but such action would raise the pulse voltage at the LNA module RF output port and eliminate almost all the margin. An alternative would be to use a high performance LDO voltage regulator that requires a lower differential voltage between input and output. An example that may work in this application is the TI LP3990MF-3.3 LDO with a differential of 200 mV or theTPS72733 with a differential of around 65 mV.

There also is the question of low temperature operation. At lower temperatures, the feedline loop resistance and TMA bias-tee resistance would become lower. However, we already considered a worst-case in which the feedline had zero length (and zero resistance), so low temperatures would have no significant effect.

7. Conclusions

A remote low noise amplifier can be used to improve radio telescope performance. The amplifier may be powered through the coaxial cable feedline or a separate power cable. The feedline powering method requires a bias-tee arrangement to isolate the RF and dc powering ports from each other and is more convenient from an installation perspective. However, care must be taken that the voltage momentarily coupled to the RF port during power application and removal does not exceed the amplifier's voltage rating. If it does, a voltage limiter may be used on the bias-tee RF port.

8. References and further reading

e-CALLISTO Tower-mounted amplifier: http://www.reeve.com/Solar/e-CALLISTO/e-callistoTMA.htm
Mini-Circuits ZX60-33LN low noise amplifier datasheet: http://www.minicircuits.com/pdfs/ZX60-33LN+.pdf
Mini-Circuits VLM-33-S+ voltage limiter datasheet: http://www.minicircuits.com/pdfs/VLM-33+.pdf