

Tests of an ATA amplifier and fiberoptic link

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This is a compendium of test results for a prototype ATA 'post amplifier module' (PAM s/n 3) and fiberoptic link (NEC NX8560LJ-CC laser, Discovery DSC50S photodiode). The goal was to assess their suitability for use with CARMA.

1. IF amplifier gain and return loss

As shown in Figure 1, the gain of the amplifier module is 48-53 dB between 500 MHz and 8 GHz. The dropoff in gain above 8 GHz is characteristic of the present batch of pre-production modules, although the gain was flat to 10 GHz on the prototype circuit. Since the ATA will operate up to 11 GHz, this defect will presumably be rectified before the modules go into production. The internal attenuators on the module can be set from 0-63 dB in 0.5 dB steps, but we were unable to test them since a computer interface is not yet complete.

The input and output return losses are shown in Figure 2.

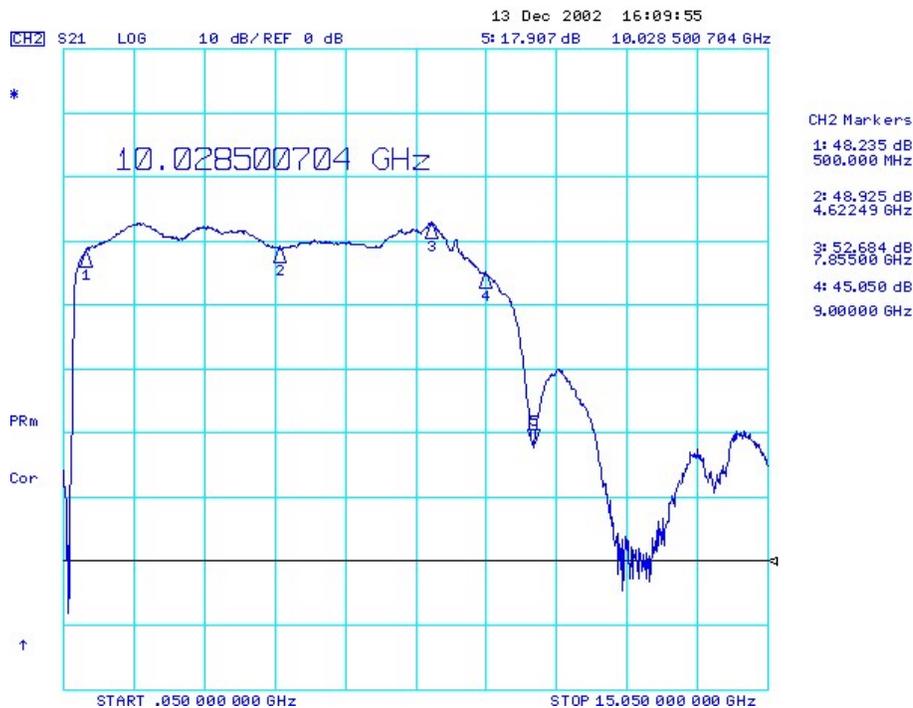


Figure 1. S21 of PAM s/n 3, measured with an 8722D network analyzer. The attenuators in the module were set to 0 dB for this measurement.

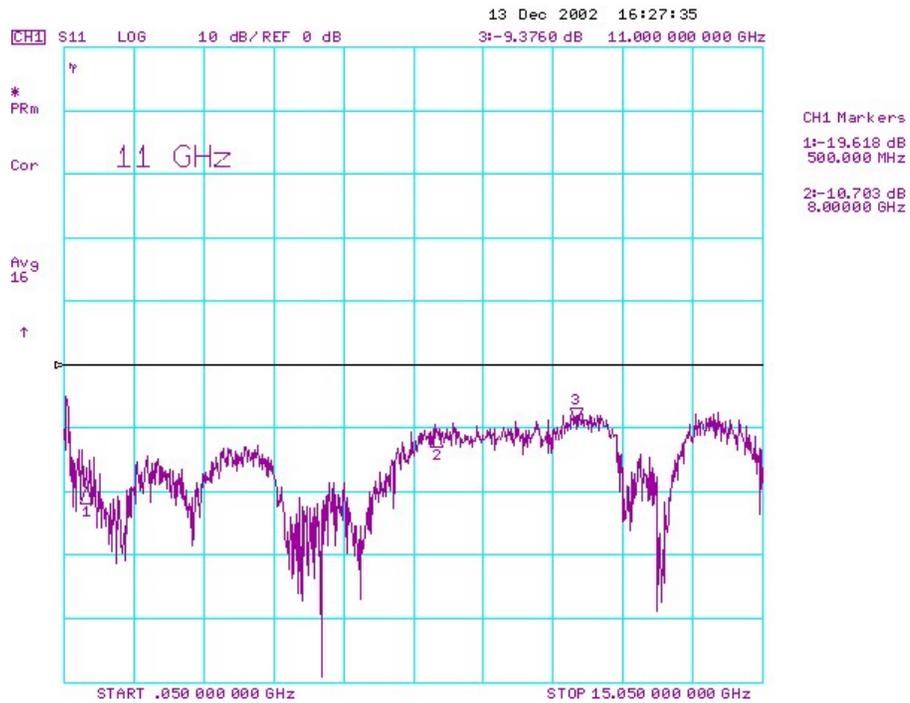
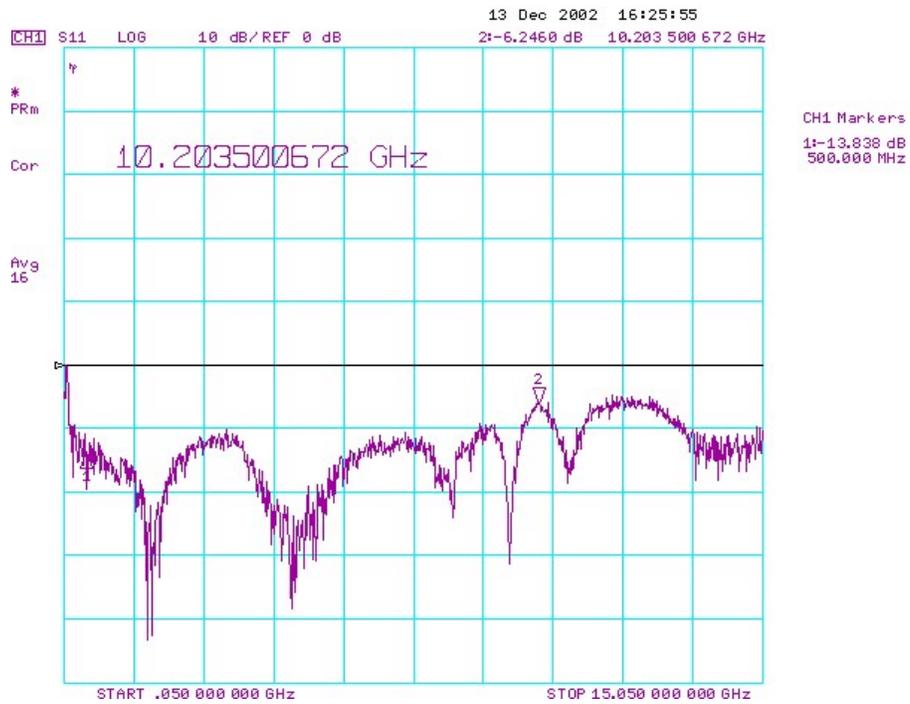


Figure 2. S11 (top) and S22 (bottom) for PAM s/n 3. The return loss is >10 dB from 0.5 to 9 GHz for both.

2. Amplifier noise temperature

An Agilent E4408B spectrum analyzer was used to measure the PAM output power with the input terminated with 295 K and 77 K loads. As shown in Figure 3, the Y-factor ($P_{\text{hot}}/P_{\text{cold}}$) decreases from ~ 0.78 dB at 1 GHz to ~ 0.72 dB at 8 GHz. A Y-factor of 0.75 dB corresponds to a noise temperature $T_n = (T_h - T_c)/(Y - 1) - T_c$ of ~ 1060 K.

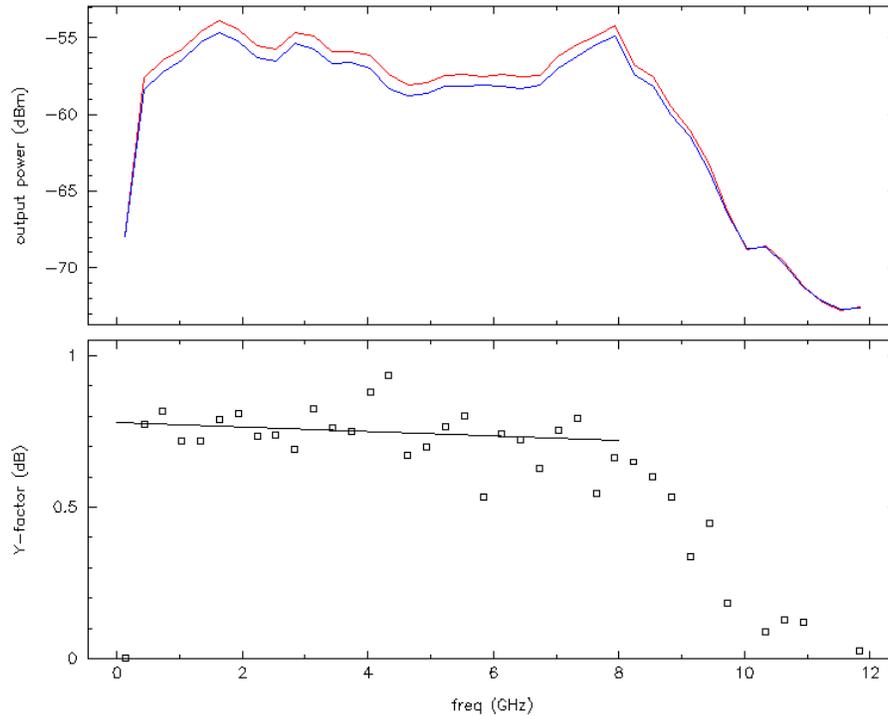


Figure 3. (top) Output power from PAM s/n 3 with its input terminated with 295 K and 77 K loads. The resolution bandwidth was 3 MHz. The spectrum analyzer noise floor is approximately -74 dBm. (bottom) The Y-factor derived from these measurements.

3. Amplifier detector response

Each PAM includes a total power detector which is coupled via a resistive voltage divider to the output of the last amplifier stage. To check the detector's frequency response, we recorded the (amplified) detector voltage while sweeping the PAM input from 0-12 GHz at a constant power level of -52 dBm. Figure 4 compares the detector response with the amplifier's gain curve – which of course is proportional to its output power. The ratio of the detector response to the amplifier output power has a ~ 2 GHz standing wave which merits further investigation.

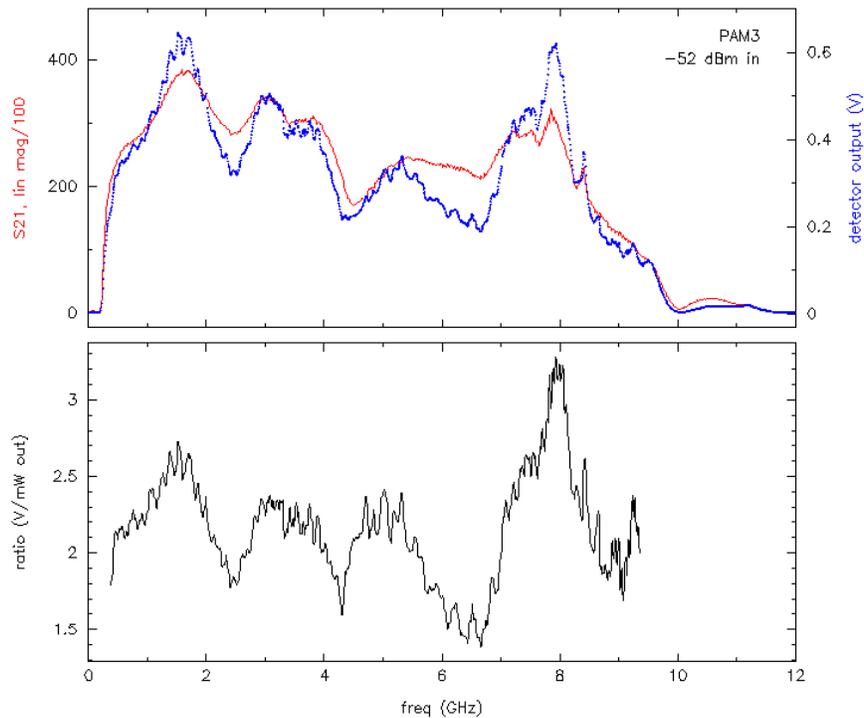


Figure 4. (top) Detector response (blue) and amplifier gain (red) for PAM s/n 3. An Agilent 83630L swept frequency generator provided the input to the amplifier at a constant power level of -52 dBm. The amplifier gain, shown here on a linear scale, was measured with an 8722D network analyzer, and includes loss in the coaxial cable used to connect the sweeper with the amplifier. (bottom) Ratio of the detector output voltage to amplifier output power.

4. Fiberoptic link gain

The gain of a fiberoptic link with a short fiber connection is roughly -32 dB, as shown in Figure 5. The ~ 2 dB peak-peak ripples are attributable to mismatches in the 6 inch long SMA-GPO coax from the bias tee to the modulator input. Figure 6 shows that the RF input match to the laser's electroabsorption modulator is flat.

Inserting an additional 2.2 km spool of singlemode fiber plus a short fiber patchcord reduced the laser power by 1.2 dB, and the RF gain by ~ 3 dB. RF loss should be proportional to the square of the optical loss because the RF *voltage* is encoded by variations in the laser *power*. The extra 1.2 dB optical loss is very close to what we expect: $2.2 \text{ km} \times 0.22 \text{ dB/km}$ (at 1550 nm) + 2 additional connectors $\times 0.3 \text{ dB/connector}$ + 2 splices on spool $\times 0.1 \text{ dB/splice} = 1.3 \text{ dB}$.

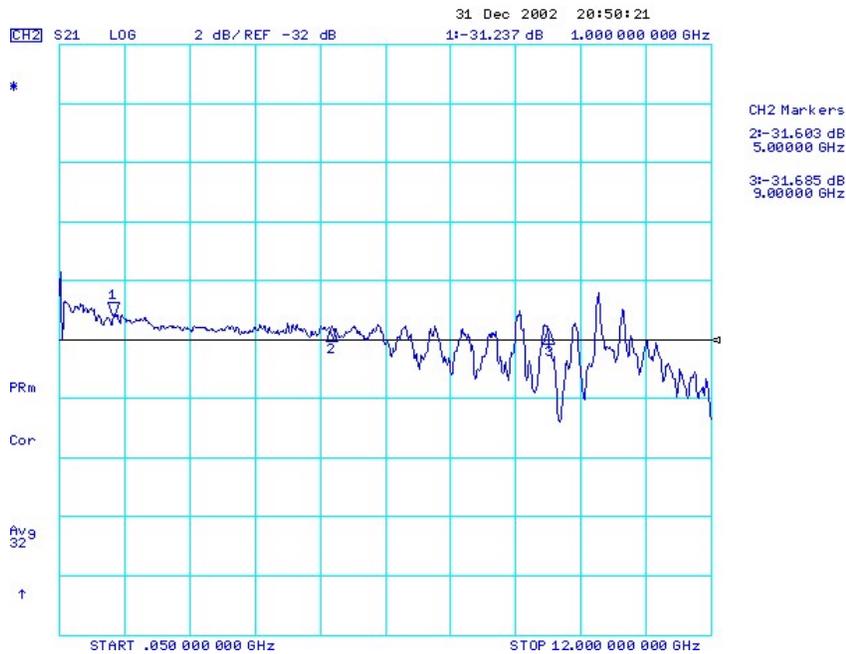


Figure 5. S21 for the fiberoptic link (NEC laser 0228Q002, Discovery photodiode DSC50S s/n 500213, connected via a few meters of singlemode fiber). A MiniCircuits bias tee (ZFBT-4R2G) was used to DC bias the electroabsorption modulator; losses in the bias tee were calibrated out. The input RF power was -10 dBm, the DC bias on the laser's electroabsorption modulator was -0.7 V, the optical power at the photodiode was 2.9 dBm, and the photocurrent was 1.2 mA.



Figure 6. S11 at the RF input (GPO connector) on the NEC laser module.

5. Fiberoptic link noise figure

The noise figure of the fiberoptic link was tested in two ways. First, as shown in Figure 7, we used a power meter to measure the link input and output power for several power levels. Fitting a straight line to the data, in Figure 8, one finds that the effective input noise (EIN) of the link is -30.6 dBm. The effective noise bandwidth, established by the gain rolloffs of the PAM and JCA amplifiers, is ~ 8 GHz. Thermal noise from a 290 K load for this bandwidth would be -174 dBm/Hz + 99 dB = -75 dBm, so the link noise figure is ~ 44 dB.

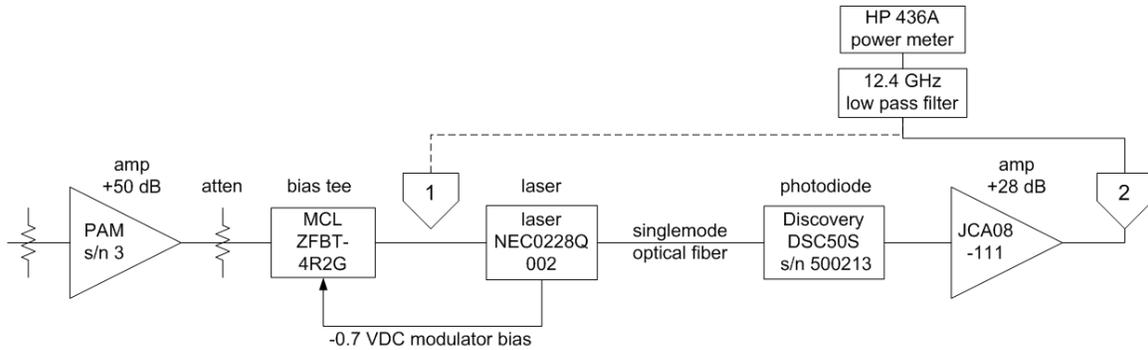


Figure 7. Test setup to measure the link noise figure. Wideband noise was generated in the PAM; attenuators were used to vary the link input power. Although a bias tee is built into the PAM, in this case it was necessary to provide a separate bias tee following these attenuators. The JCA amplifier following the link nearly cancels the 31 dB link loss. A 12.4 GHz low pass filter was included to exclude any (unexpected) contributions from out of band signals.

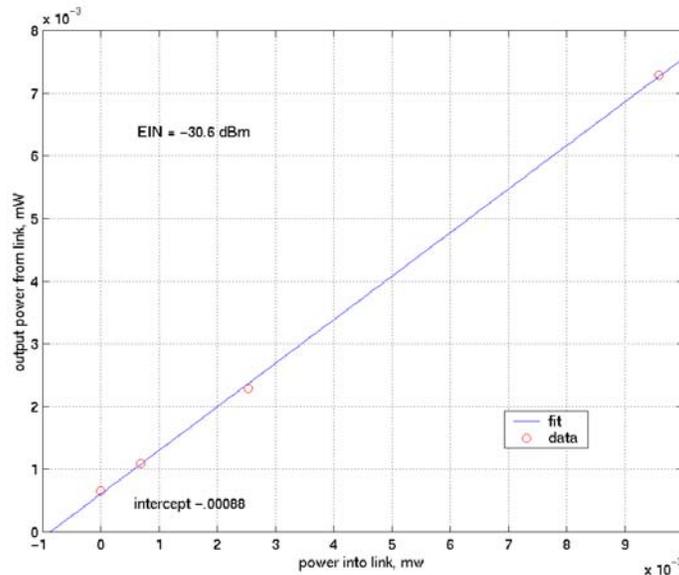


Figure 8. The magnitude of the x-intercept gives the effective input noise of the link, 0.88 microwatts, or -30.6 dBm.

To measure the noise figure as a function of frequency, we used the setup shown in Figure 9. The absolute noise power at the output of the JCA amplifier was measured with a spectrum analyzer; the data are shown in Figure 10. By measuring the gain through the system with a network analyzer, Figure 11, we converted from output noise to an effective input noise.

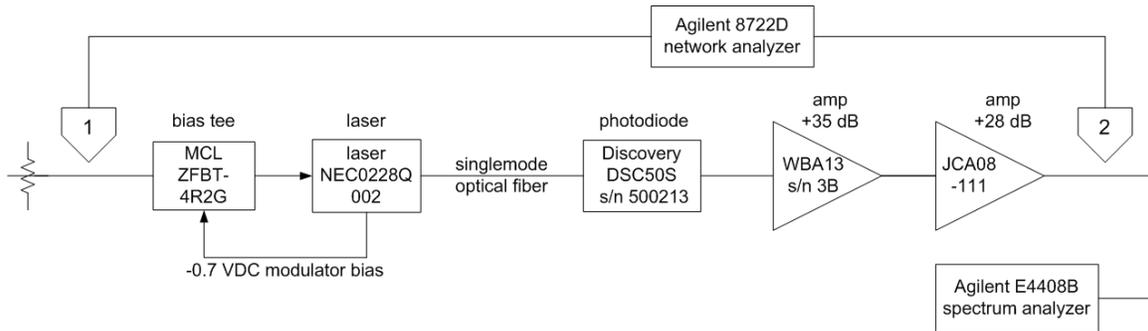


Figure 9. Test setup to measure the link noise temperature as a function of frequency. The WBA13 amplifier following the link has a very low noise temperature, about 50 K, so its contribution to the link noise figure is negligible. Two amplifiers follow the link to make sure that we are well above the spectrum analyzer noise floor.

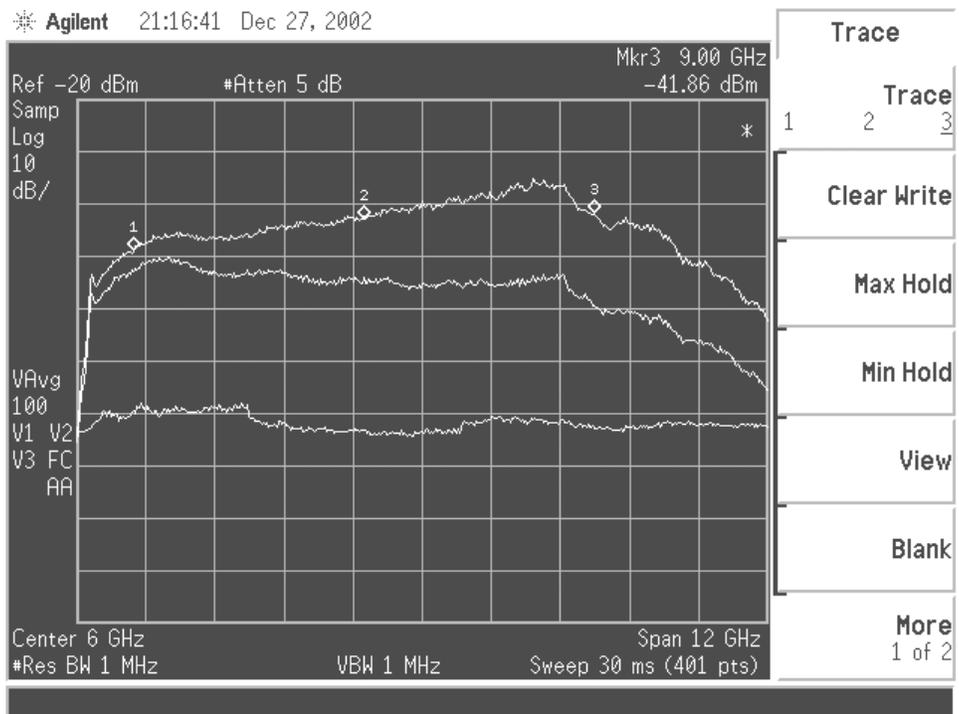


Figure 10. Noise power measurements with the E4408B spectrum analyzer. Top trace shows noise power with link on, middle trace shows power with link (laser and photodiode) off, bottom trace shows power with WBA13 amplifier off.

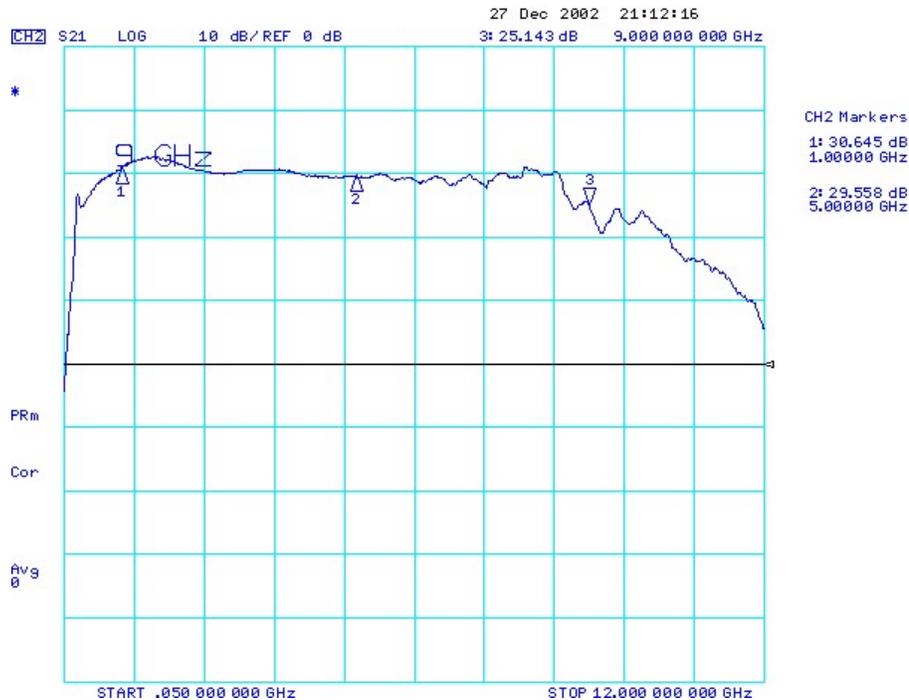


Figure 11. Network analyzer measurement of gain, S21, from point 1 to 2 in Figure 9. Losses in the bias tee were calibrated out in the network analyzer measurement, so this is the gain from the input of the laser to the output of the cable from the JCA amplifier.

As discussed in Agilent Application Notes 150 and 1303, the spectrum analyzer measurements *underestimate* the noise power density by 2 dB, owing to 3 effects:

1. The spectrum analyzer is a peak-responding voltmeter calibrated to indicate the rms value of a sine wave, whereas the amplitude of random Gaussian noise follows a Rayleigh distribution; this underestimates noise power by 1.05 dB.
2. By video filtering or averaging the output of a log amplifier, the spectrum analyzer compresses the noise peaks; this underestimates by another 1.45 dB.
3. But, the resolution bandwidth exceeds the equivalent noise bandwidth by ~ 0.5 dB, partially canceling the first two terms.

The E4408B has a ‘noise marker’ feature where firmware applies these corrections. With 1 MHz resolution bandwidth, the ‘raw’ reading from the spectrum analyzer at 5 GHz was -42.5 dBm; the ‘noise marker’ value at 5 GHz was -100.4 dBm/Hz, or -40.4 dBm/MHz, consistent with the expected 2 dB correction.

The effective input noise is then $EIN = P - G + 2$ dB, where P is noise power in dBm/MHz from Figure 10, G is the gain from Figure 11, and the 2 dB correction has been applied. The link noise figure is $NF = EIN + 114$ dBm/MHz, where 114 dBm/MHz is the noise power of a 290 K load. Figure 12 shows the result: the noise figure increases from 36 dB at 500 MHz to 49 dB at 8 GHz. The average value is roughly consistent with the 44 dB derived from the power meter data.

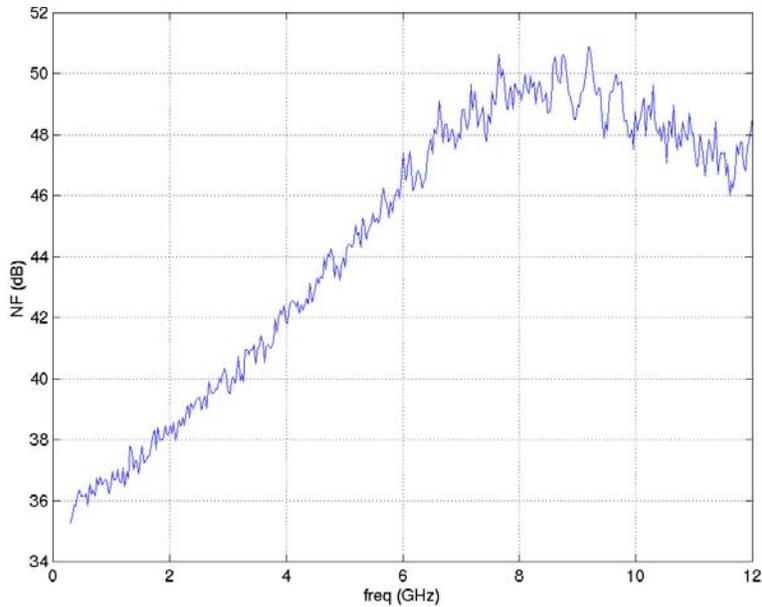


Figure 12. Link noise figure.

6. Gain compression

Gain compression for the PAM was measured with an 8 GHz CW signal. The gain as a function of *input* power is shown in Figure 13. The 1 dB gain compression point occurs at an input power level of roughly -45 dBm, which corresponds to a PAM output power of $+8$ dBm; the 1% gain compression point (0.044 dB) occurs for a PAM output power of roughly -2 dBm.



Figure 13. Gain of PAM s/n 2 at 8 GHz, vs. input power level, measured with the 8722D network analyzer.

To measure the gain compression of the link, the JCA amplifier and MiniCircuits bias tee were inserted between the network analyzer and the laser; an amplifier is required because the maximum output power from the network analyzer is -5 dBm. Allowing for the amplifier gain, 28 dB at 8 GHz, one finds from Figure 14 that the link's 1 dB gain compression point occurs at $+11.6$ dBm; the 1% compression point is at $+5$ dBm.



Figure 14. Gain of link alone, vs input power. The link was preceded by a JCA amplifier with 28 dB gain at 8 GHz, so the actual sweep range is -2 to $+13$ dBm.



Figure 15. Gain vs. input power for the PAM (s/n 2) + fiberoptic link.

The response of the PAM + link combination is shown in Figure 15. The 1 dB gain compression point is $\sim +8$ dBm (power level at PAM output); 1% gain compression occurs at about 0 dBm.

Finally, a check of the gain compression was made using wideband noise instead of a monochromatic signal. The JCA amplifier was used as the wideband noise source. This amplifier covers the 1-8.5 GHz band. With a 50 ohm termination on its input, it generates -43.7 dBm. Noise from the amplifier was fed into the PAM + fiberoptic link. The power level was adjusted in 3 dB steps by adding attenuators. An HP436A power meter was used to measure the noise at the input of the PAM and at the output of the link. The results, in Figure 16, indicate that the 1 dB gain compression point occurs at an input power of ~ -43 dBm, which corresponds to a PAM output power of $+7$ dBm.

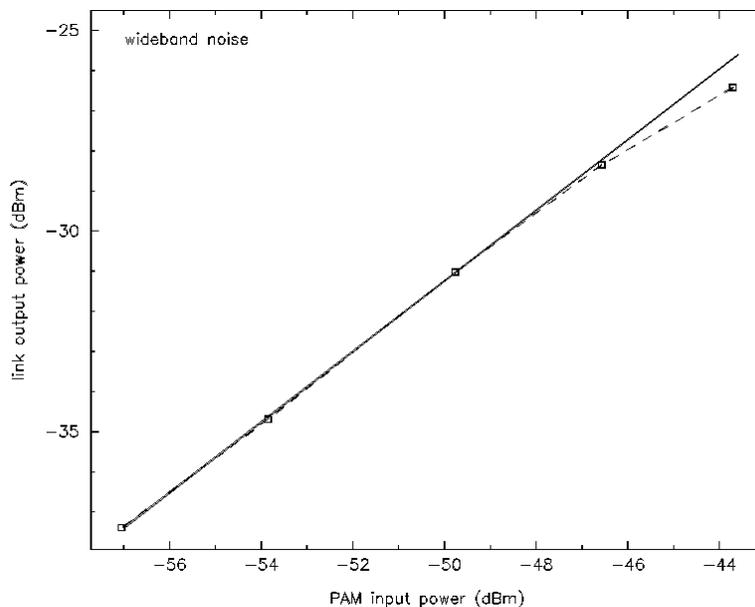


Figure 16. Output power from the PAM + link plotted vs input power, for wideband noise with an 8.5 GHz bandwidth.

References:

Agilent Application Note 150, 'Spectrum Analysis Basics,'
<http://cp.literature.agilent.com/litweb/pdf/5952-0292.pdf>, pp 33-35

Agilent Application Note 1303, 'Spectrum Analyzer Measurements and Noise,'
<http://cp.literature.agilent.com/litweb/pdf/5966-4008E.pdf>, pp. 6-9