Frequency Response of HFD6180 (LC ROSA)

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June 9, 2014

Summary

The Finisar HFD6180 LC ROSA photodetector unit is used internally to offset-lock a pair of lasers by detecting and transmitting a beat-note signal from the incident beams. Though the unit is advertised as a 10Gbps/5GHz receiver, it does have a specified -3dB high frequency cutoff at 9 ± 3 GHz. Questions were raised about it's viability in the Li D1 offset range (10.4GHz). The unit has been tested previously and found to produce useable signals well above 10GHz, but no comprehensive data was ever collected or retained. Here, a pair of beams from the Ti:Sapphire laser are modulated and mixed : one fixed at $\sim$ 630 THz and the other scanned at offsets between 0 - 15 Ghz. The power of the beat-note fundamental at the output of the ROSA unit was recorded over this range. For successful operation, the new locking circuit anticipates a minimum input from the ROSA of -40 dBm. In the 10.4 GHz regime, the output power of the ROSA unit as a function of incident beat-note power was found to saturate at approximately -27.5 dBm. It's performance in locking electronics will be heavily dependent on incident beam power, as well as operating frequency.

Methodology

Using the Agilent E4407B (26.2 GHz) spectrum analyzer, the fundamental beat-note power was measured at the SMA output of the ROSA unit. The power of each constituent laser beam was measured with a power-meter, (beams were isolated by blocking one or the other with a thick paper card). Beams were coupled into a fiber splitter with one feeding the ROSA unit and the other end going to a power-meter or wav-emeter as necessary. It is useful to understand the power transfer as a function of incident beam power, so as to know minimum requirements for a particular setup. For these measurements. two beams were locked at $\sim$ 10.4GHz and their input power was varied by manipulating the fiber coupling optics, (not the laser cavities). There are a few specific points woth mentioning about the measurements:

- The coupling through the fiber splitter is not the same for both beams/destinations. There are 4 different coupling ratios from sources to destinations, which should remain the same if the fiber coupling itself is unchanged. These ratios were measured once at the start and end of the experiment and the data shown here is corrected accordingly.
- A particular configuration was considered mode-stable if the beat-note fundamental, as seen by the spectrum analyzer, was the only significant feature. Realistically there could be multiple side-bands present during every measurement, but any side-bands under -40 dBc were considered negligible and were ignored, (this is the condition for measurement consistency).
- The same power-meter was used for all power measurements. Furthermore, the spectrum analyzer was set to an attentuation of 0dB with a reference level of -10dB. To reduce sampling error, the bandwidth of the sweep was kept to within 1GHz of the beatnote fundamental.

The incident power of the beat-note as a function of the intensity of the two beams is obtained the usual way, (integrate the Poynting vector over one period and divide by the same period, assuming monochromatic light):

$$P_{beat} \propto |Ae^{i\omega_1 t} + Be^{i\omega_2 t}|^2 = A^2 + B^2 + 2AB\cos((\omega_1 - \omega_2)t) \tag{1}$$

$$P_{ROSA} = I_{ROSA}^2 \cdot R = I_{ROSA}^2 \cdot 50 \quad | \quad I_{ROSA} \propto P_{beat} \tag{2}$$

$$P_{R0SA} = (\alpha 2AB)^2 \cdot R \quad \rightarrow \quad \log|P_{ROSA}| = 2\log|A| + 2\log|B| + 2\log|2\alpha| + \log|50| \tag{3}$$

Where α is some parameter that defines the power transfer, and P,A,B are power, in watts. Presumably, α encapsulates both the *spectral responsivity* of the photodiode and the power transfer of the transimpedance amplifier present in HFD6180. The assumed current-incident power relationship is linear in the nonsaturation regime, as stated in (2). Presumably, the output power of the ROSA unit as a function of input Beam power should match the form of (3), with α to be deterimined.

Results / Discussion

Using the Agilent E4407B (26.2 GHz) spectrum analyzer, the fundamental beat-note power was measured at the SMA output of the ROSA unit. The power of each constituent laser beam was measured with a power-meter, (beams were isolated by blocking one or the other with a thick paper card). The error of the spectrum analyzer measurements was consistently in the ±0.1 dBm range, and is ignored here. Similarly, the incident laser beams were stable to within 5% of mean power and this variation is also ignored. The laser unit had a scanning bandwidth of around 10GHz and it was necessary to scan through two modes to obtain the results shown in **Figure 1**.

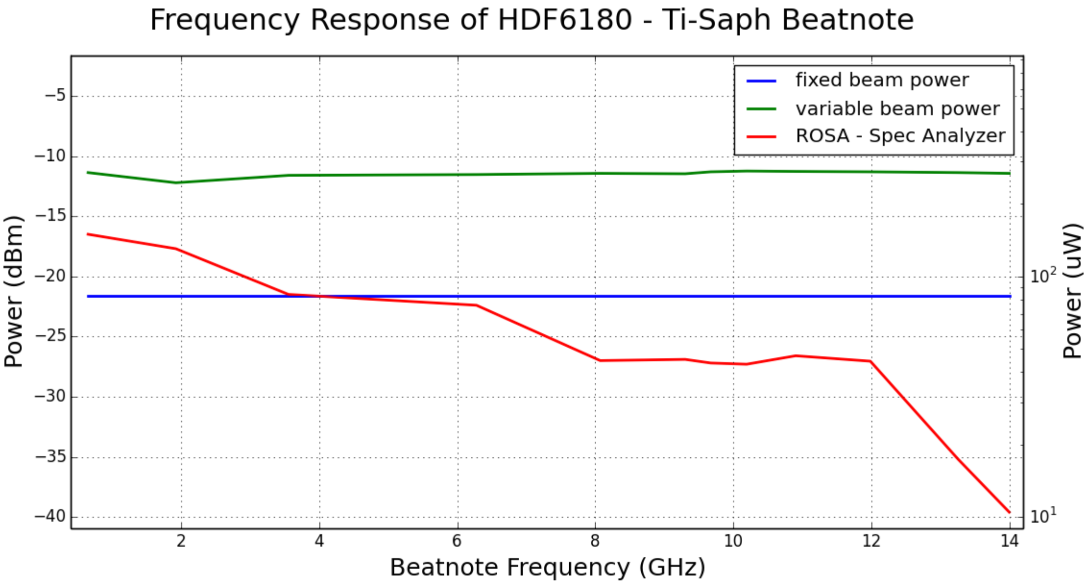

Figure 1: Input beam/ and output signal power, pre and post ROSA unit.

Occasionally, during scanning, some side-bands were observed, with amplitudes as high as -5 dBc to -10 dBc (approximately 50-30% of the carrier power) . Ideally, the lasers would be mode-stable during experiments and not exhibit the frequeny mode hopping that was sometimes observed. All reported measurements are averages of several samples (usually 5-10), and so the effect of these side bands is somewhat minimized.

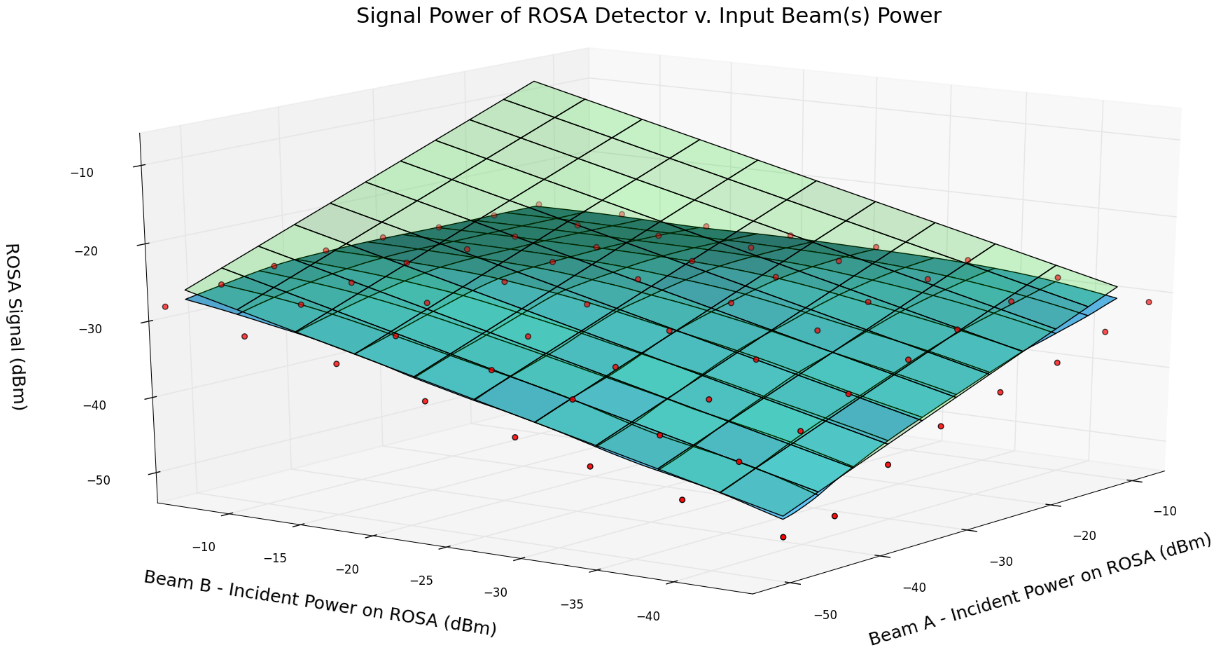

Figure 2: Power transfer results, shown in 3D for qualitative understanding, with the physical measurements shown as red dots. The interpolant, shown in blue, was used to generate the reference data in **Table 1**. The least squares fit for the presumed linear region, in transparent green, is for comparing the data to the form of (3).

The blue interpolant from **Figure 3** was sampled at some reference values to provide a convenient look-up table for experimental use (**Table 1**). Half the table could be thought to be redundant, but there is a slight variation. As the table is generated automatically by a scipt, the values are included for reference.

Table 1: Lookup table for matching input beam powers (in uW and dBm) to ROSA signal output power (dBm only). Numerical values below are from interpolant shown in **Figure 3**

			Beam A									
	-	(dBm)	-40.00	-36.67	-33.33	-30.00	-26.67	-23.33	-20.00	-16.67	-13.33	-10.00
	(dBm)	**(uW)**	**10.00**	**14.68**	**21.54**	**31.62**	**46.42**	**68.13**	**100.00**	**146.78**	**215.44**	**316.23**
Beam B	-40.00	**10.00**	-42.87	-41.18	-39.52	-37.80	-36.29	-35.06	-33.72	-32.48	-31.26	-30.38
	-36.67	**14.68**	-41.55	-39.97	-38.20	-36.28	-34.76	-33.61	-32.52	-31.34	-30.25	-29.49
	-33.33	**21.54**	-39.56	-38.07	-36.66	-34.82	-33.28	-32.12	-31.10	-30.08	-29.18	-28.71
	-30.00	**31.62**	-37.90	-36.58	-35.28	-33.51	-32.05	-30.95	-30.01	-29.15	-28.49	-28.17
	-26.67	**46.42**	-36.32	-34.99	-33.73	-32.03	-30.67	-29.82	-29.13	-28.49	-28.01	-27.87
	-23.33	**68.13**	-34.74	-33.47	-32.18	-30.71	-29.49	-28.87	-28.43	-28.03	-27.79	-27.73
	-20.00	**100.00**	-33.28	-32.09	-30.90	-29.60	-28.69	-28.23	-28.02	-27.83	-27.70	-27.68
	-16.67	**146.78**	-31.72	-30.68	-29.73	-28.80	-28.13	-27.88	-27.79	-27.70	-27.62	-27.62
	-13.33	**215.44**	-30.59	-29.68	-28.93	-28.25	-27.85	-27.71	-27.68	-27.63	-27.59	-27.58
	-10.00	**316.23**	-29.62	-28.88	-28.29	-27.83	-27.65	-27.55	-27.57	-27.60	-27.60	-27.59

A rather surprising result from this test is that the data in the nonsaturation region does not seem to follow the form of (3). The plane equation determined by the least squares solver for the data in the nonsaturation region is:

$$Z = 0.473 \cdot X + 0.466 \cdot Y - 5.438 \tag{4}$$

For the fitting, all data was in units of dBm. Stating (3) with original measurement units:

$$P = 0.473 \cdot \log_{10} |A^2 * 1000| + 0.466 \cdot \log_{10} |B^2 * 1000| - 5.438$$

$$\therefore P = 0.946 \log_{10} |A| + 0.932 \log_{10} |B| - 2.620$$

Where P is in dBm and A^2, B^2 are in μW. Note that the plotted points are the measured power in dBm which is proportional to the square of the intensies, A, B. This gives a value of 6.57 mA/μW for α, which sounds reasonable. However, the validity of this model is called into question given that the slope of the plane in each dimension is far from 2, as stated in (3). In fact, the plane fitted to the data seems to suggest that $P_{ROSA} \propto (AB)$, and it is not apparent why this should be.

Conclusion

The locking circuit for the Li D1 system, which is to be extended to the Rb85/87 systems in the future, was designed with a minimum input power requirement of -40 dBm. For a 10GHz input, the HFD6180 was shown to output a ~ -30 dBm signal. The HFD6180 will be retained for use in the D1 locking electronics, and extended to the Rb87/85 locking electronics as well. Usage in regimes higher than 12-14 GHz, and below an input beam power of -35 dBm (17.8 μW) is not recommended without significant amplification. Linear relationships between incident and output power, even below the measured saturation limit, should not be assumed.