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Oct 30, 2015

PEM RF Sweep Report

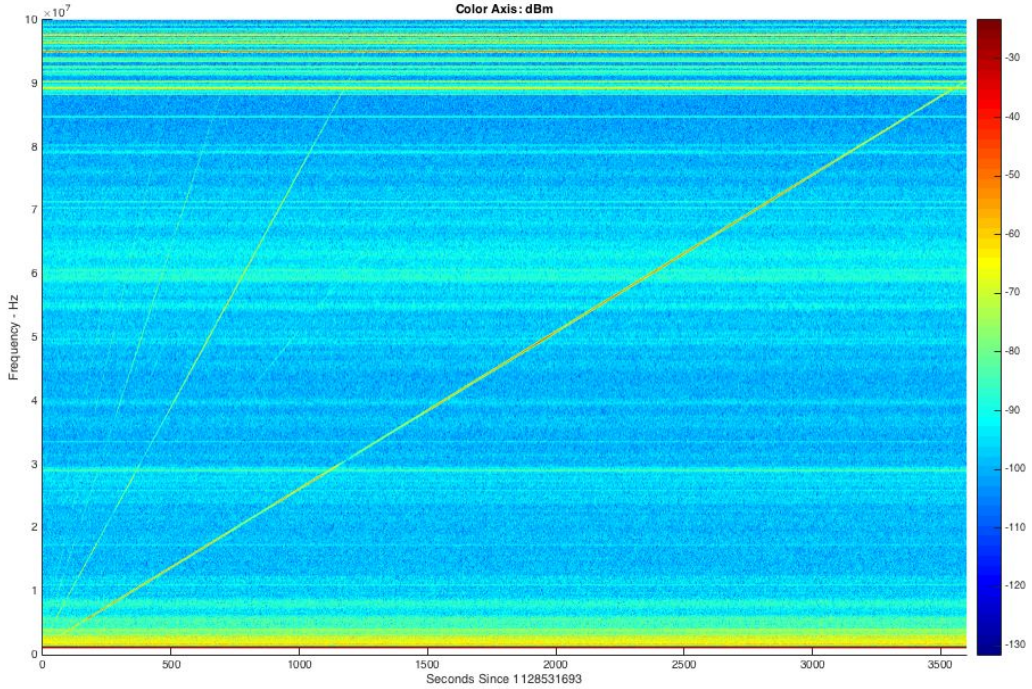
Background

In early September as part of the PEM injection set we injected RF at specific frequencies where coupling to the interferometer was thought possible. The injections were done using dipole antennas and RF amplifier located by the water tank on site. For those injections the 9 MHz and 45 MHz injections were picked up by the PEM radio channels in the corner station electronics bay ~1000x louder than the background. Of the 10 frequencies chosen only the 45MHz injection showed up in the gravitational wave channel, barely visible over the noise. Those results have shown that RF coupling to the interferometer is small at these frequencies where coupling might have been expected and additionally for the coupling at 45Mhz any RF signal would have to show up very strongly in our auxiliary channels before it shows up in the gravitational wave channel. In order to check for strong and unexpected couplings outside of these frequencies we injected a swept sine spanning a wide range of frequencies.

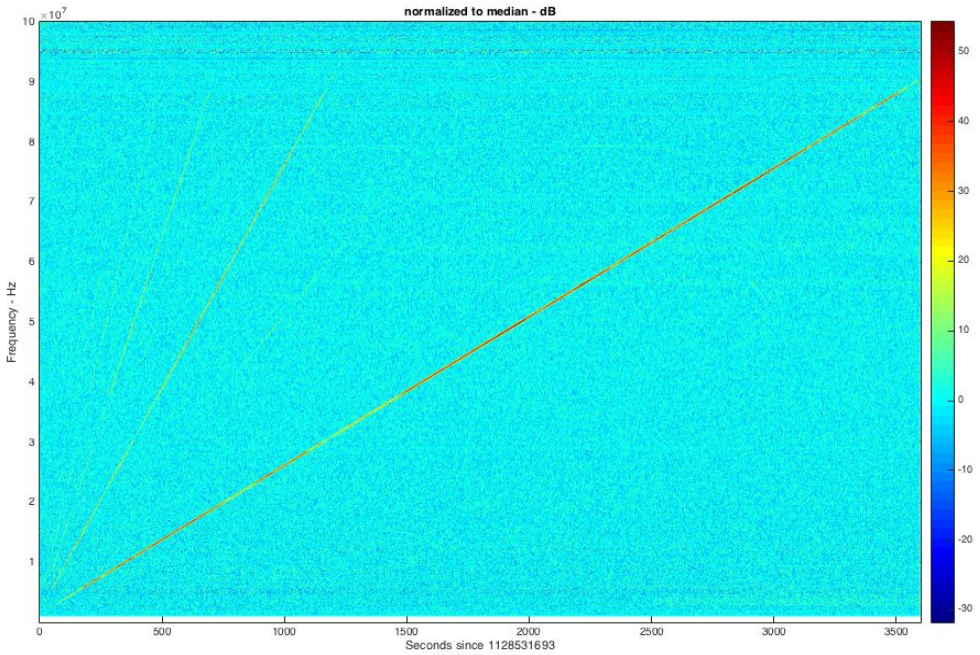
RF Sweep - monitoring the injection

The sweep was done using the same transmitting equipment as was used before except the Tektronix signal generator used earlier was replaced with an IFR. The frequency range extended from 9 kHz to 100 MHz with a linear step size of 5kHz and a step time of 200 ms. These parameters were chosen so that we could be sensitive enough to possible strong couplings without taking too much time (as this had to be done with the IFO locked but not in observation mode). This occurred on Oct 10th from 17:01 - 18:01 UTC. To monitor the radiated power we used a wideband antenna on the roof of the LVEA connected to a spectrum analyzer which is part of a new 'RF scanner' system to monitor RF activity on site.

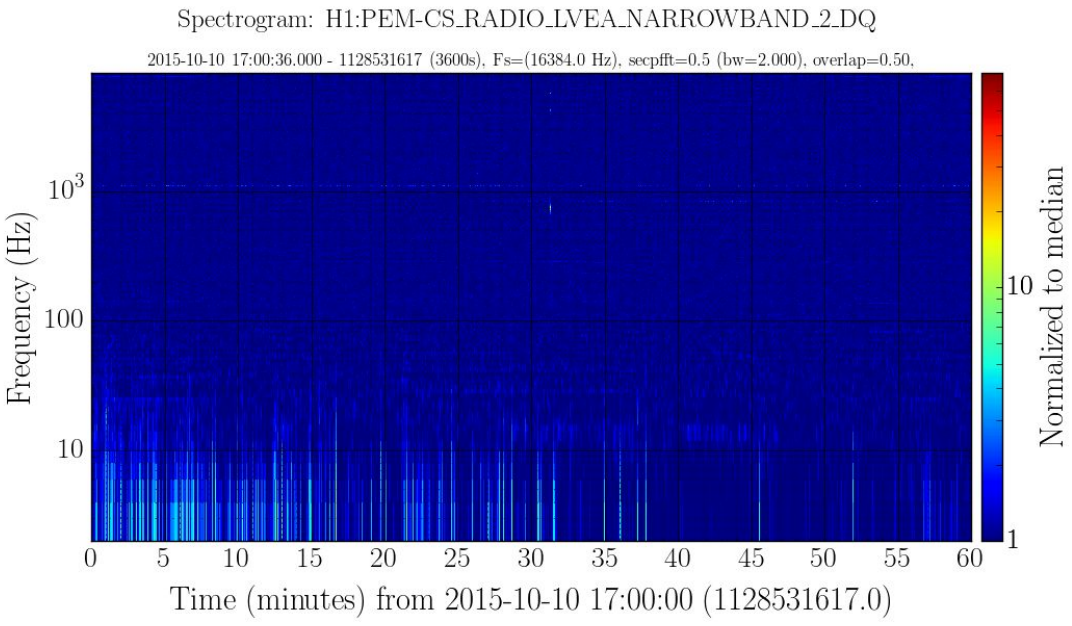
The following plots show the output of the scanner system, where the x axis is time, y is frequency and the color is received power. The zero of the time axis corresponds to gps time 1128531693 and goes for one hour. The first plot shows the power measured at the receiver in dBm. In the first plot you can see what the ambient RF background looks like up to 100 MHz. The loudest ambient signals are located in the FM radio band (from just below 9 MHz to just above 100 MHz). The FM radio band contains some signals that are comparable in strength to our injection. Other than those specific frequencies, our injection is at least 100x higher than all ambient signals.

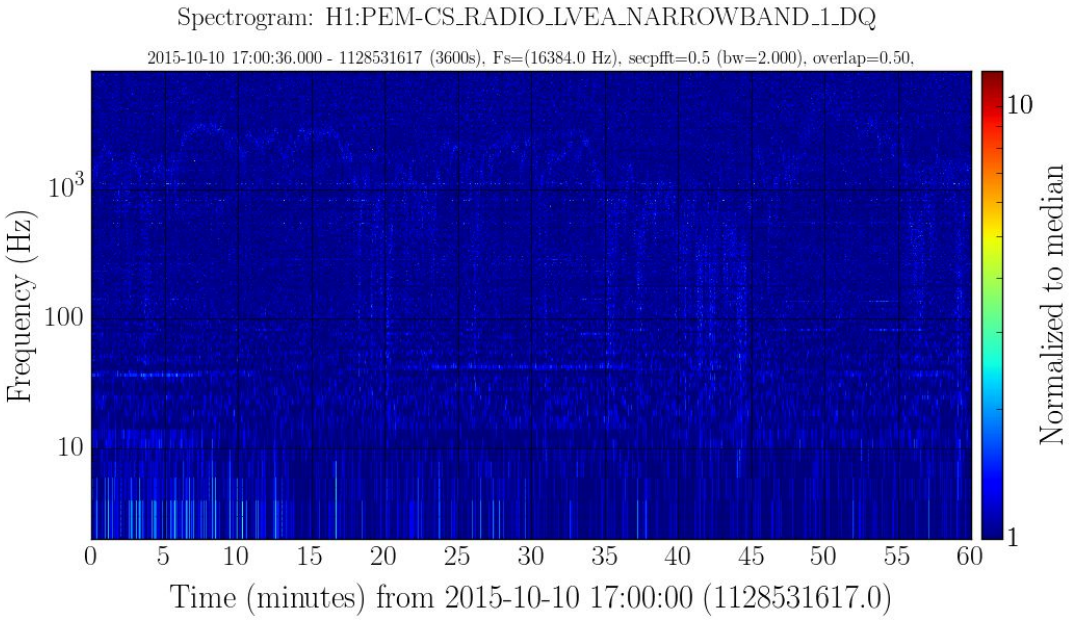


The plot below was made by calculating the median of each frequency bin over the whole time, then subtracting it from all times. Since the power was measured in dBm and the median was also in dBm, subtracting them gives dB relative to median. Looking at the color axis for anything that looks orange or darker we see that most of the sweep was picked up by the receiver at over 30 dB (1000 SNR). There were times that it dipped below that, notably at the extreme high and low ends of the frequency range where the background was higher. The higher slope lines that are visible likely correspond to higher harmonics of the intended injection frequency.



In addition to the broadband rf receiver, the PEM narrowband antennas in the LVEA and electronics bays were checked for a signal. These channels are dipole antennas demodulated at the 9 and 45 MHz modulation frequencies. With the aforementioned sweep parameters we only expect each channel to pick up a single 200 ms sinusoidal signal within its frequency range. These are barely visible in spectrograms of the channels during this hour. In the first plot (45 MHz) the sweep passes through the band at around 31 mins and 800 Hz. The second plot (9 MHz) has a small red dot around 7 mins 1100 Hz.





Links to all full size PEM antenna spectrograms for this hour:

- ➔ LVEA 9 MHz: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=102050
- ➔ EBAY 9 MHz: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=100666
- ➔ LVEA 45 MHz: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=102048
- ➔ EBAY 45 MHz: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=100668

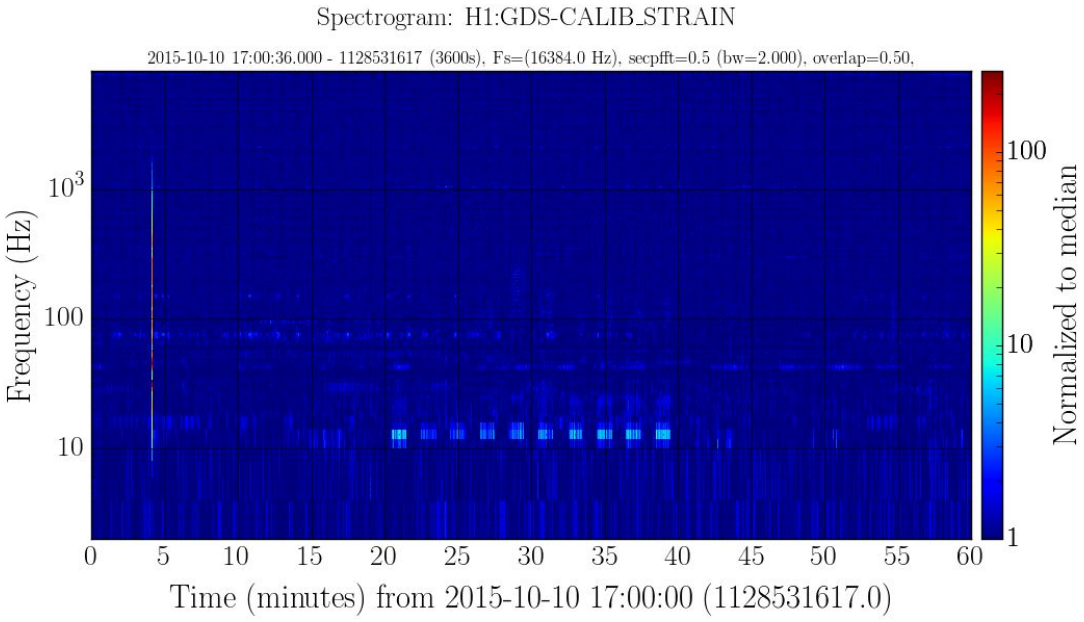
Since the sweep signal is so hard to see in the hour long spectrograms, we have checked omegascans of the PEM and DARM channels during this time:

- ➔ 45MHz:
  - Strain: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=101002
  - EBAY: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=101003
  - LVEA: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=101004
- ➔ 9MHz
  - Strain: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=100998&width=341
  - EBAY: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=101000
  - LVEA: https://ldvw.ligo.caltech.edu/ldvw/view?act=getImg&imgId=100999

In the omegascan of the PEM channels it is clear that the swept sine appears in the band for 200 ms, as expected.

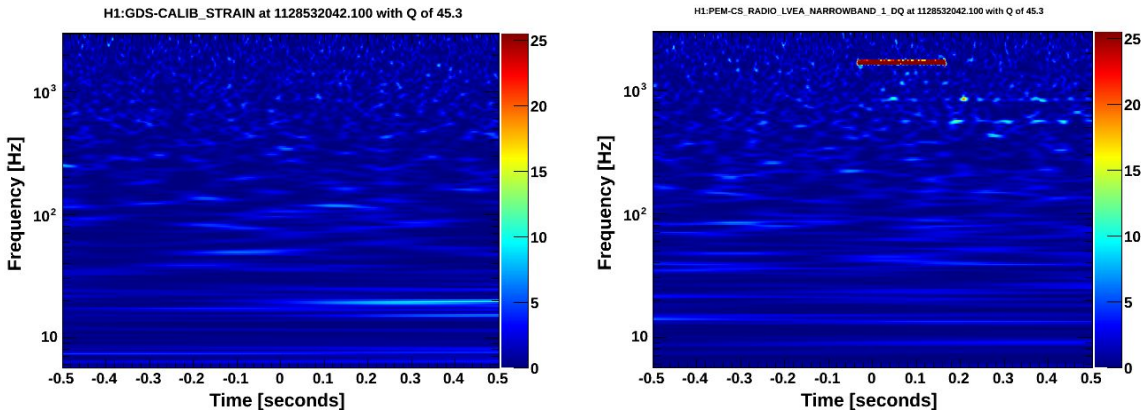
Checking for coupling to the gravitational wave channel

Any unexpected coupling to the interferometer could show up as a small dot in the spectrogram, just like it did on the auxiliary channels. The spectrogram below looks clean:



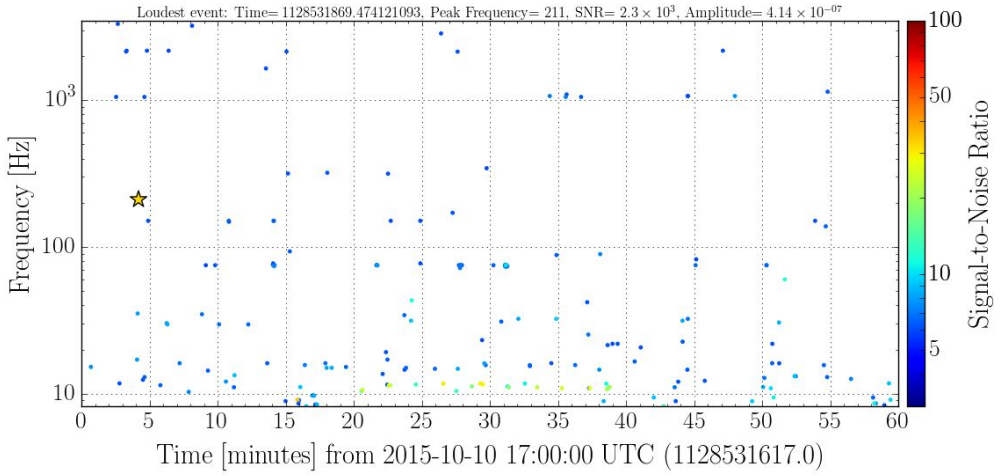
The only structure visible in the spectrogram is a large glitch at ~4 mins and unrelated PEM tamper injections above 10 Hz from 20 - 40 mins. Nothing that indicates coupling from the RF injection.

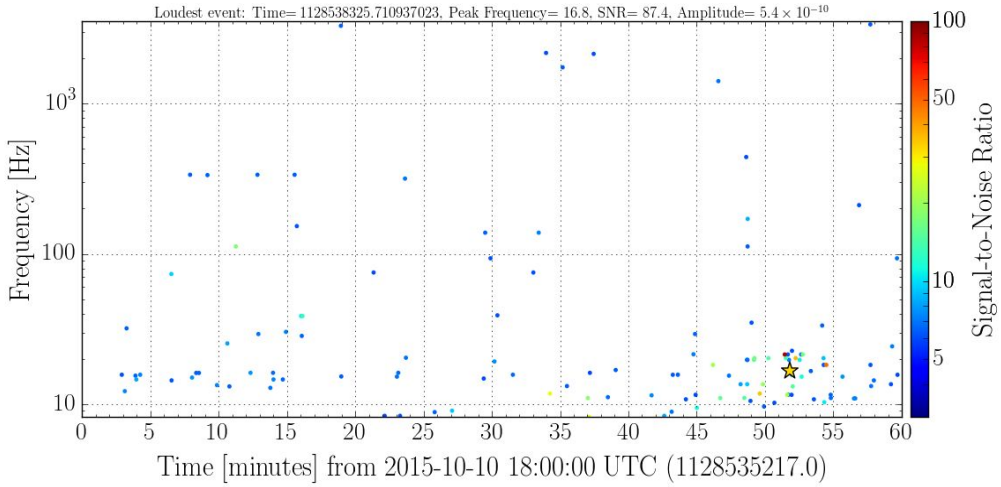
For a closer look we can compare the Omega spectrogram around the times where the sweep passes through the LVEA antenna band. On the left is GDS-CALIB_STRAIN and the right is the 45 MHz antenna in the LVEA. The gravitational wave channel is totally clean and the LVEA antenna shows a 200 ms stretch of excess power.



At the end of the previous section there were similar plots for 9 MHz and the EBAY antenna.

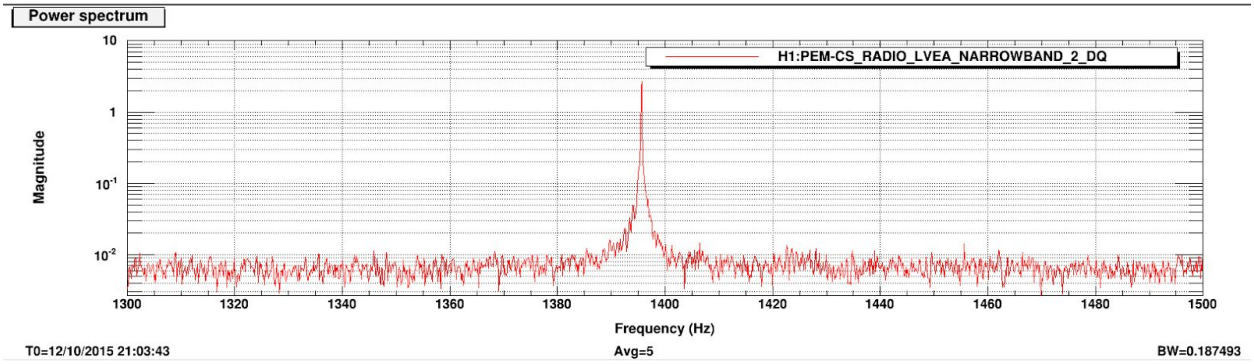
Finally, I plotted Omicron glitchgrams during the time of the injection and the subsequent hour. During the time of the sweep starting at 17:00 there were clearly stronger triggers associated with tamper injections that occurred, but otherwise no appreciable change in trigger rate:

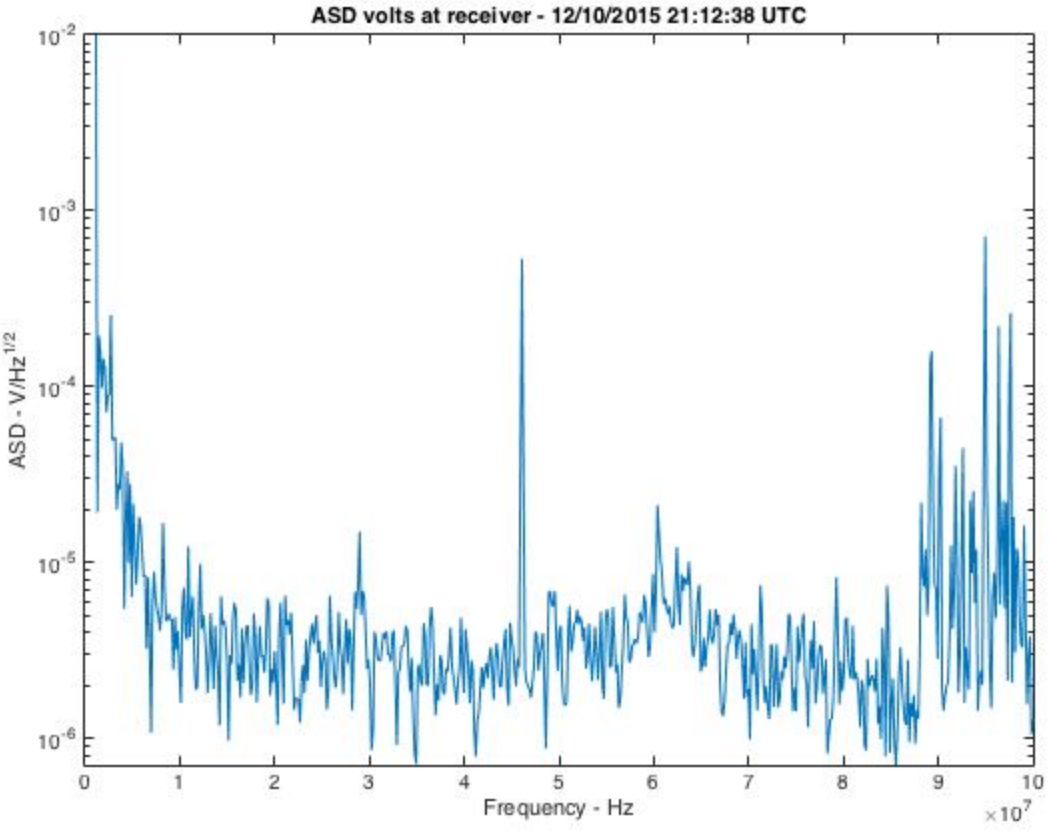




Comparison with earlier injections

To compare the sensitivity of the LVEA antenna used in the original PEM injections to the wideband scanner, we injected a continuous signal ~1400 Hz above the 45 MHz modulation frequency with the same power settings as the sweep. We see that the wideband scanner recovers the injection with a comparable SNR to the LVEA antenna.

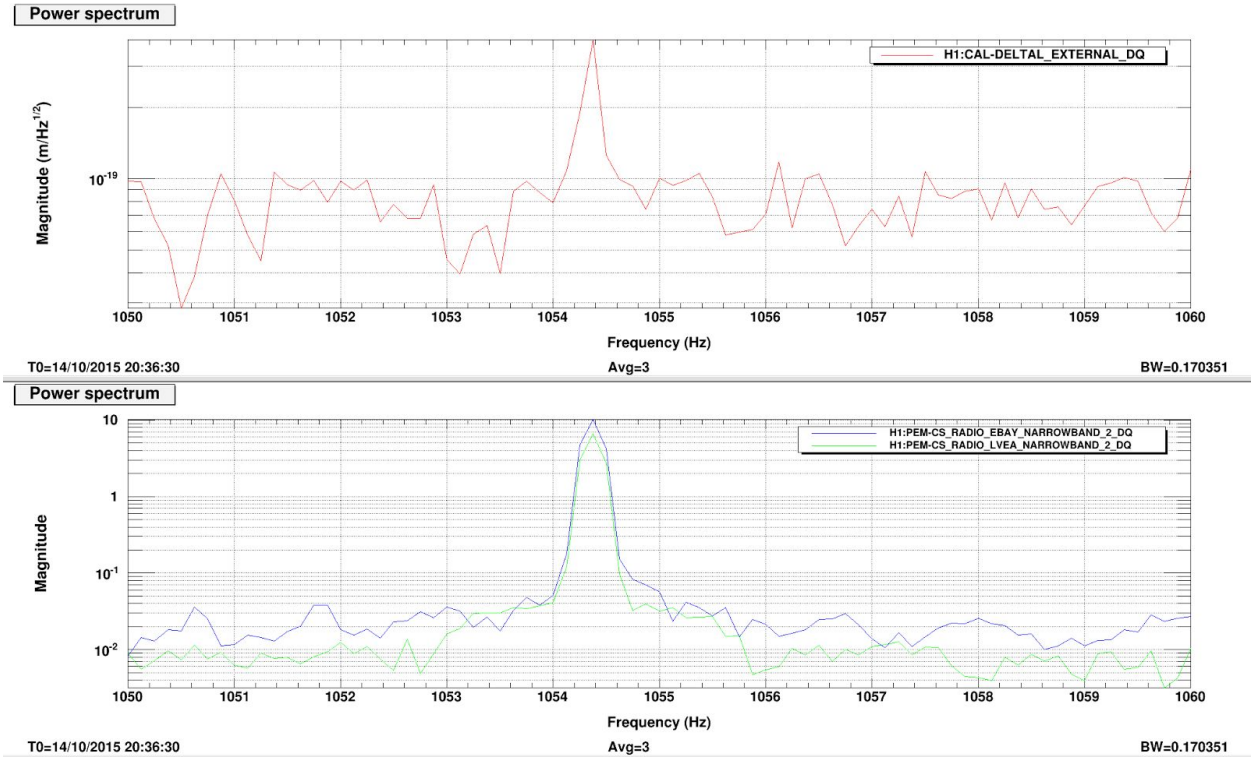




While the wideband scanner has good sensitivity and is able to cover a large range of over 100 MHz, it does suffer from a lack of time and frequency resolution, for this sweep it had a frequency resolution of ~100 kHz and took a spectrum measurement about once a second.

The sweep was performed at an amplitude comparable to the continuous injection that showed up in DARM at 45 MHz. The continuous injection had a PEM antenna SNR of ~1000 and made a small peak in darm with an SNR of ~4 when viewed at a ~0.1 Hz resolution. From this we can safely say that an SNR of at least 200 in the auxiliary channel would be necessary to produce an SNR of 1 in DARM. Furthermore, continuous injections at

other frequencies and similar power settings were unable to be recovered in DARM (including a recent injection at 9MHz using the IFR, for a narrow peak, and auxiliary channel SNRs of 1000).
(below is the continuous injection at 45MHz)



Based on our known coupling in the 45 MHz band and the fact that the sweep was in the band for only 200 ms it is not expected to have been visible in darm. If our signal had remained in the band for ~few seconds we would expect to see it in darm when it passed through 45MHz, however to scan the whole band at that speed would have taken many hours.

As it stands, we have no evidence for strong coupling to environmental RF signals. A more quantitative statement can be made based on the fact we saw no coupling in this sweep along with the measured auxiliary channel SNRs: for the band of the sweep we would have to see an SNR of at least 100 in the RF scanner before anything shows up in DARM. However that is a conservative estimate and I suspect the actual coupling to be lower. A much longer sweep could be done to check for smaller couplings. Also, an injection with higher power could be done to more accurately measure couplings (this would require an RF amplifier with higher power output). These are both things that the PEM team is looking into for future work.

Summary

We injected an rf sweep from 9 kHz to 100 MHz to check for coupling from environmental rf to the interferometer. We found no evidence for strong coupling at any frequency within the band. An initial upper limit for coupling is that a signal will need to show up with an SNR of 100 on the RF scanner to have an SNR of 1 in DARM, but further investigations may be able to lower that.