MEMO

Subject: Proposed ATA EMI guideline, and example of laserSETI camera
From: Franklin Antonio
Date: 5/15/2019

I've not seen any document which establishes EMI guidelines for equipment at ATA, ie limits on unintended emissions from equipment installed at the ATA site. I'm going to try to establish such a guideline here.

The trigger for this effort is the recent project to install the LaserSETI camera at ATA, and recent EMI tests of same by Eliot Gillum and Billy Barott. To understand the implications of those measurements, <u>one needs to have something to compare them against</u>.

Radio astronomy guidelines such as ITU-R RA.769-2 seem to be of limited help, because they address a scenario very different than narrowband SETI. I'll work the problem from scratch, supplying my own guesstimates for each parameter.

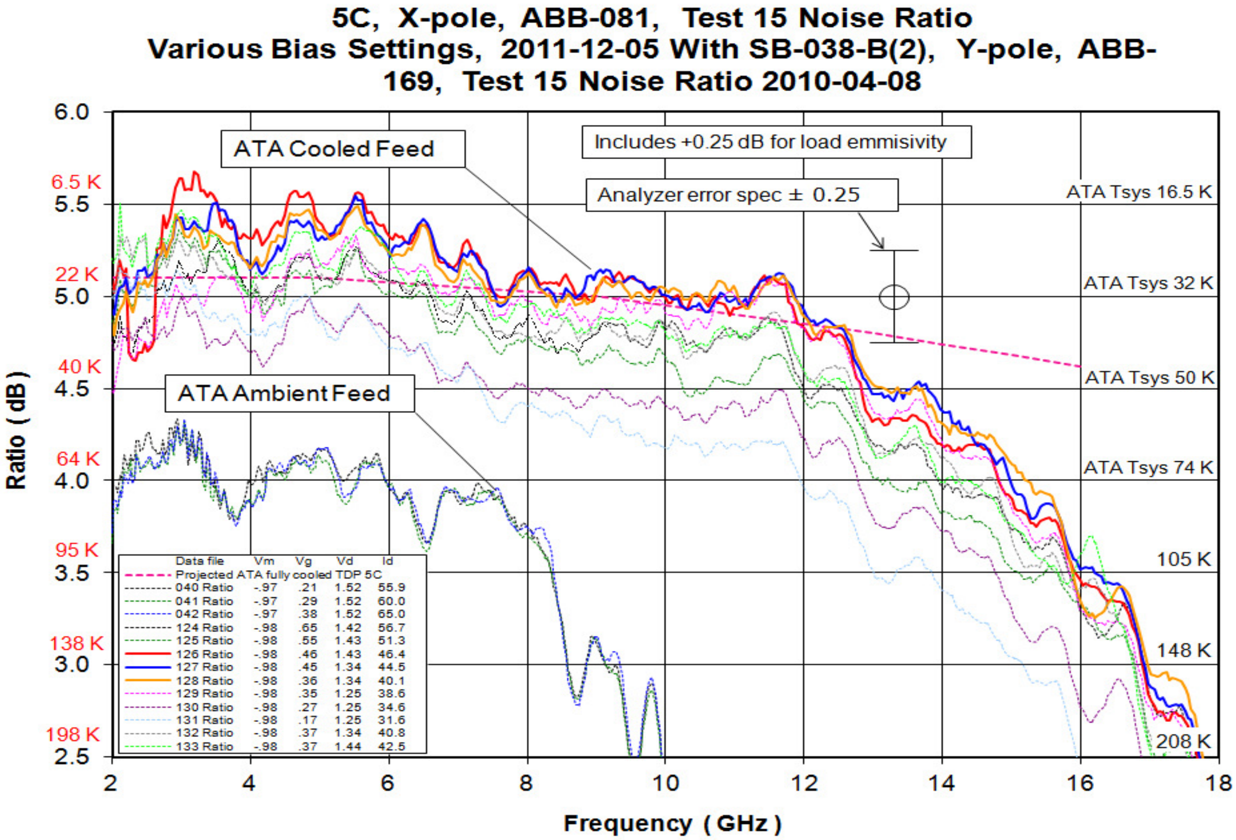
I'm going to keep this very simple. Do not take this as an indication that I object to refinements. I'm simply starting with the basics, which is appropriate given that we have nothing now. I'm going to use some guesses (WAGs) for various parameters. Do not take this as an indication that I would not like to have better numbers. You have to start somewhere. It is much less rigorous to operate with no guidelines at all, <u>as we have been doing</u>. The goal here is to establish a simple guideline which can be widely applied, easily, often.

Thermal noise (receiver, sky, ground) is fundamental. Emissions from electronic equipment on site are unwanted, and generally considered EMI. Thermal noise is broadband, whereas emissions from electronic equipment usually consist of a set of narrowband lines. This distinction of broad vs narrow is important. When one changes the bandwidth of a filter, the amount of power at the output will change if the source was broad (wider than the filters), for example thermal noise. However, the filter output will not change if the source is narrow (such as a harmonic of a clock in a digital circuit). This is of course the reason we use narrow filters in SETI receivers. Unfortunately, this property of filters applies to EMI signals as well as ET signals.

EMI specs are typically written in terms of flux, ie $W/m^2/Hz$. I will avoid that here. EMI tests are performed by measuring power out of a receive antenna, and that's the way the victim receiver operates as well, so for this memo I've simply skipped the step of converting to flux and then converting back to power.

The ATA receiver

See below feed temperature measurements from Jack Welch's ATA memo #90. The only important number is the ATA system temperature Tsys, of about 30 Kelvin. We'll use that number.



Thermal noise power = KTB, where
T = system noise temperature (ie antenna, sky, receiver) = 30 Kelvin
K = Boltzman's constant 1.38e-23 W/m^2/Hz/K
B = Bandwidth. I'll use 1 Hz, ie typical SETI measurement bandwidth

There have been recent discussions about Jack's 30K measurement and whether it was accurate, in light of recent antenna performance issues. I suspect that the discrepancy is largely due to EMI. This memo does not attempt to resolve that question. If you think the noise temp is higher, just substitute in a higher value.

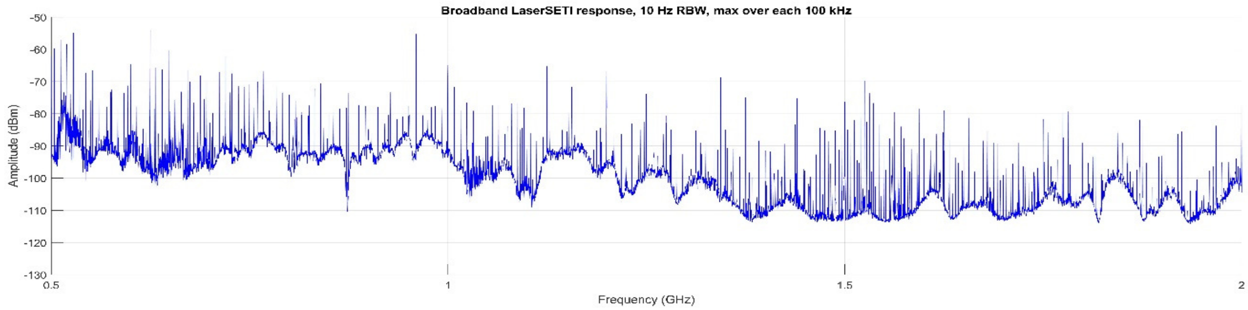
The above values produce thermal noise power in 1Hz = KTB = -184 dBm. I've rounded to the nearest 1 dB, because none of the inputs nor assumptions in this memo are as accurate as 1 dB.

Now that we know the thermal noise level we have to decide how large we will allow interfering signals to be relative to thermal noise. For example, if we choose to allow an interfering signal to be equal in size to thermal noise, then we degrade our sensitivity by 3dB. If you allow the receiver to be significantly degraded by EMI, one has to wonder why we spent all that effort and money on refrigerated front-ends! One can argue for more or less. It's a classic idealism vs pragmatism sort of choice.

For purposes of this discussion, I choose to allow EMI to degrade the receiver by 1 dB in a 1 Hz bandwidth. That requires that we keep the EMI >6dB below thermal noise. I'll refer to this later as the "protection ratio".

lasersETI EMI measurements

Recent laserSETI EMI tests by Billy & Eliot look like this.



Test was performed in a screen room at Minex, using a broadband spiral receive antenna at 1m distance, with a 30dB amplifier between rx antenna and spectrum analyzer. I don't have gain data on the RX antenna, but given its similarity to other spiral antennas, I expect that its gain is between 0 and 2dBi at low frequencies, dipping to lower gain beginning somewhere around several GHz. For purposes of this memo, I'll call it 0dBi gain.

For the purposes of this memo, I'll presume that these tests were performed correctly and fairly represent the emissions from laserSETI.

I'd like to draw a line on that chart which sets a limit. No EMI above this line allowed. To do that we'll have to consider the expected distance between laserSETI and ATA dishes, and the expected antenna gain of ATA dishes in the direction of laserSETI.

laserSETI Location

Eliot provided me with two proposed locations. Here is the closest one...

It is 200m from the nearest ATA antenna (yellow line). At this increased distance, we would expect EMI to be 46 dB lower than the 1m measurement conditions (inverse square law). We'll apply that factor later.

We need an estimate of the gain of the ATA receive antennas in the direction of laserSETI. The proposed location is also lower than the ATA antennas, which is good, and I expect laserSETI to be mounted near ground level. I have never seen measurements of ATA dish sidelobes, so I have no measured data I can use for this estimate. I do know that generally, antennas designed to look at a cold sky must have very low gain pointed toward Earth, because Earth is hot. The offset-fed design of the ATA antennas would seem to meet this criteria. Therefore, I'm going to presume that the ATA antennas have a 0dBi gain in the direction of the proposed laserSETI site.

The ATA dishes have roughly 40 dBi to 60 dBi gain at center of their main beam over their operational frequency range, so 0 dBi may seem like an aggressive presumption. Given the limited data I could have just as easily accepted 10 dBi. If you disagree, produce your own number!

Putting it together

Now we have measured power levels received from the source at 1m into a 0 dBi antenna. We simply correct these measured levels for distance and receive antenna gain, and we'll have power at the output of the receive antenna. This requires many fewer steps than converting to flux and back to power.

I'm going to do the calculation in the reverse direction tho, starting at the receiver and working backwards. I'm doing this because I want to establish the emissions level which will produce a known EMI power in the receiver. Per my prior discussion...

Expected thermal noise in 1Hz	-184	dBm
Protection Ratio	-6	dB
Distance correction	+46	dB
Test antenna correction	0	dB
Victim antenna correction	0	dB
Total allowable aggressor power in 1 Hz	-144	dBm

Summary: If we keep all emissions from the aggressor below -144 dBm as measured by a 0 dBi antenna at 1m, we'll do no more than damage our sensitivity by 1 dB.

Before going back to the measured data chart, remember that that data was measured with a 30dB amplifier between the antenna and the spectrum analyzer. Therefore we need to add 30dB before comparing to the test data. In other words, on the chart this -144 dBm limit is shown at <u>-114 dBm</u>.

There's one other small point. Remember that I calculated expected thermal noise in a 1Hz bandwidth. I used this bandwidth because it is a typical SETI filter bandwidth. The EMI tests were done with the resolution bandwidth of the spectrum analyzer set to 10 Hz. One might expect that I would include a correction for this bandwidth ratio. I have not, and the reason is the nature of EMI from electronic equipment. As I described at the beginning of this memo, these emissions tend consist of narrowband lines, which unlike noise, do not change their amplitude as one changes the measurement bandwidth. (One narrow line in a 1Hz bandwidth filter vs a 10Hz filter produces same output power.) Therefore I've made the EMI emissions limit in a 10Hz bandwidth the same as the limit in a 1 Hz bandwidth.

<u>The allowable EMI limit therefore belongs at -114 dBm, as measured at the spectrum analyzer, and measured laserSETI emissions are almost everywhere above the limit</u>.

<u>LaserSETI needs considerable improvement almost everywhere below 2 GHz, and 50 dB improvement in some places</u>, to meet the criteria described in this memo.

Possible Refinements / Future Work

It would be nice to have more data. A good estimate of ATA dish gain off-axis, measurements of signal levels which cause the ATA preamp (LNA & PAX & fiber optic link) to saturate, etc.

I note that Billy charted the maximum value within each 100kHz. He was forced to reduce the data in some way in order to present a huge amount of data. However, it is likely that only a small fraction of the 10Hz bins in each 100kHz were near the max value. In SETI we can afford to have a small fraction of frequency bins jammed by EMI, because we use EMI excision algorithms which can easily handle a small fraction of jammed frequencies. So instead of "maximum", perhaps something like "99 percentile" would have been a better choice, because we can probably allow 1% of frequencies to be jammed. Of course there also needs to be a limit which these exceptions are not allowed to cross, so that one or more very strong spectral lines don't saturate the ATA preamp.

For future EMI measurements, it would be nice to have a calibrated test antenna, and the screen room at Minex probably ought to have maintenance to refurbish its isolation. These items are however lower priority than a great many other needs. We have facilities today which allows us to perform reasonable informative tests.

Although some might argue that the level of scrutiny described here has not been applied to other equipment at the ATA site, that is a situation that we hope to improve. For example, we've recently diagnosed (and hopefully fixed) several EMI sources in the new feed control box. I look forward to a site EMI survey in the coming months. Hopefully this effort will eventually result in system performance which is more commensurate with Jack's feed performance test data.

There is a near infinity of additional refinements one could make to this approach. One could consider the impact on sensitivity of further signal processing after filtering, ie noncoherent combining, etc. I argue for simplicity, so have left out that sort of thing.

I should note that for most equipment at the ATA site, the distance from aggressor to victim is much less than laserSETI, so the required levels are correspondingly lower.

Appendix – Proposed ATA EMI Guideline

[This is simply a formalization of the calculations I've described above.]

Devices installed at ATA should have emissions below a limit set by the following.

EMI Limit = $N_B + C + G_1 + G_2 - G_3 + P$ dBm

as measured at the input of a spectrum analyzer.

Test setup: Broadband antenna of gain G_1 dBi at 1 meter (or such distance as is practical), connected thru a path (ie amplifier and cable loss) of gain G_2, and then a spectrum analyzer. Spectrum analyzer should be set to a resolution bandwidth as low as practical, ideally at the operational measurement bandwidth B (probably 1 Hz).

Parameters:

N_B = Expected noise power in bandwidth B = $10 \log_{10}(KTB)$

K = Boltzman's constant 1.38×10^{-23} Joules / degree Kelvin

T = Effective system noise temperature of ATA receiver. I've presumed 30 Kelvin.

B = bandwidth (in Hz) of measurements made during normal operation. I've presumed 1 Hz (ie typical SETI).

C = distance correction = $20 \log_{10}(D_2/D_1)$ This is 20 log rather than 10 log because signal falls as inverse square of distance.

D_1 = aggressor to antenna distance in measurement setup. Probably 1 meter.

D_2 = aggressor to victim distance, ie distance from aggressor to nearest ATA antenna. Probably many meters.

G_1 = Gain of test antenna. Probably near 0 dBi. Note: May be a function of frequency.

G_2 = Gain of path between test antenna and spectrum analyzer. Include any amplifier and subtract cable losses. Cable losses are probably significant only above 1 GHz. Note: May be a function of frequency.

G_3 = Presumed gain of victim (ATA antenna) in direction of aggressor. In most cases this will be a sidelobe. I've presumed 0 dBi. Note: May be a function of frequency.

P = Protection ratio. This is the allowed ratio of interfering signal power to noise power within bandwidth B. I propose that we use -6 dB. For fine power measurements in non-SETI radio astronomy, an even smaller value may be appropriate, but in this case a larger B would probably apply.

Finally, I propose that a small fraction of B Hz bins be allowed to rise above this spec limit. Perhaps 1% of the B Hz bins could be allowed to go 20 dB higher than the EMI limit. Those polluted frequencies would be treated by EMI excision in later processing stages.

Note: Testing at these low signal levels is challenging. For example, a screen room used for testing may not block out local TV, radio, etc signals well enough to produce levels below the limit everywhere, even when the device-under-test is powered down. For this reason, I suggest that you always record results with the device-under-test both powered off and on, so you can tell which bumps are the local environment leaking into the screen room.