Academia Sinica, Institute of Astronomy & Astrophysics
SMA Project

Subject:
Temperature Stabilization of the Antenna YIG Oscillator Assemblies

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Introduction: The SMA telescope presently operates with four[1] sets of receiver inserts which provide routine observations in the 200 and 300 GHz bands, and to a lesser extent, in the 400 and 600 GHz[2] band. The final local oscillator (LO) frequencies generated within each antenna are derived from a YIG oscillator (6 to 8.5 GHz) which are phase locked to a set of coherent references. The YIG oscillator output is subsequently multiplied up in frequency via a cascaded sequence of a harmonic mixer, Gunn oscillator, and fixed multiplier. Typical final multiply ratios for the 230, 345, and 690 GHz observing frequencies are 32, 48, and 84, respectively. Thus, a seemingly innocuous YIG oscillator phase drift movement of 1 degree translates to a non-trivial 48 degrees at 345 GHz.

The largest contributor to the YIG oscillator phase instability is associated the temperature of the assembly. The phase to temperature coefficient has been measured to be roughly 0.1 degrees/degree C. This memo describes our approach and methodology to maintain the YIG oscillator assembly at a constant temperature.

Summary: We have identified three primary mechanisms which affect the antenna YIG oscillator assembly temperature which are as follows: a) cabin air temperature; b) cabin wall temperature; and c) YIG tuning voltage. Each of these temperature mechanisms and their associated solutions are described herein. Our goal is to maintain the YIG oscillator assembly variation to within 0.1 degrees C peak-to-peak over the duration of the observing period.

Cabin Air Temperature: Since the IF/LO enclosure resides within the antenna cabin its temperature is affected by the cabin air. In addition to the IF/LO enclosure, there are several temperature sensitive components within the antenna cabin which are directly exposed to the cabin air. These include the LO cables from the IF/LO enclosure to the Gunn DPLL, harmonic mixer, Gunn oscillator, and multiplier. The harmonic mixer, Gunn oscillator, DPLL and multiplier are mounted on a single modular LO plate assembly (one per receiver insert) which resides on the optics cage. We know that the LO plate is very sensitive to temperature, I.e., small variations cabin temperature result in noticeable changes in LO phase.

Stabilization of the cabin air temperature has been accomplished with use of a custom designed air handler system developed by the Cambridge Receiver Group. The air handlers have linear actuators which mix cooler outside air with the warmer inside air to maintain a constant cabin temperature. A linearly controlled heating element is used to provide additional heating during cold weather and the evening hours. These air handlers have been installed on all eight antennas.

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[1] As of this writing, four of the eight antennas have a 400 GHz insert installed.
[2] Operation of the 600 GHz insert is heavily weather dependent.

The upper and lower plots of *Figure 1* represent the ambient load temperatures and outside weather, respectively, over a period of four days. Both sets of the data are potted to the same scale for direct comparison. Diurnal variations are clearly evident on both plots where peak temperatures occur shortly after noon each day. Antenna 6 has the flattest response during the cooler periods. Further optimization is probably possible with judicious tweaking of the air handler parameters.

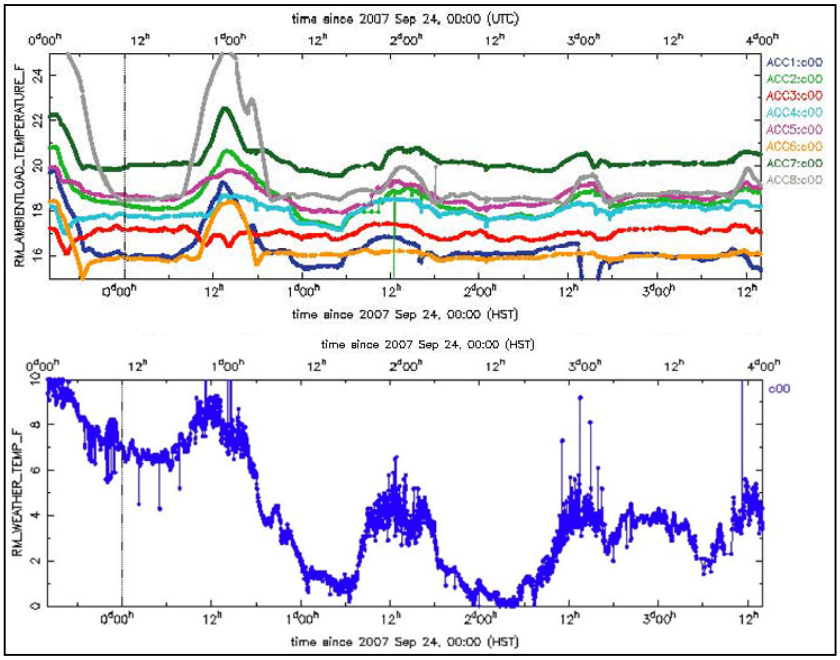

Figure 1 Comparisons of ambient load temperatures of eight antennas (top) to outside weather temperature (bottom).

Cabin Wall Temperature: Photos of the IF/LO enclosure are provided in *Figure 2*. The enclosure is located in the right rear corner of the antenna cabin and is secured to the cabin wall with four bolts. The enclosure contains two IF assemblies (left gray boxes), two YIG assemblies (right gray boxes), and an LO receiver plate (right side wall). The temperature of the enclosure is influenced by the temperature of the cabin wall which is coupled to the outside temperature.

In an attempt to decouple the enclosure temperature from the cabin wall we fabricated custom 2-inch aluminum stand-off spacers capable of supporting the weight (~135 LBS) of the enclosure. These spacers were installed on antennas 6 and 7.

Figure 2 Antenna IF/LO enclosure, 36 x 24 x 9 inches. Right photo – internal covers removed. Enclose weight is ~135 LBS.

The spacers are shown in photos of *Figure 3*. Note that in addition to the spacers, antenna 6 has a 2-inch sheet of closed cell foam installed between the enclosure and the cabin wall. Antenna 7 has a 2-inch air gap between the enclosure and the cabin wall. In addition, antenna 7 has four 3/16-inch wood insulators between the spacers and the enclosure.

The effect of the spacers are shown in *Figure 4*. Note the relatively similar behaviors for antennas 6[3] and 7. Antenna 6 operates hotter than the rest because the foam insulation restricts the radiation of heat from the rear of the enclosure.

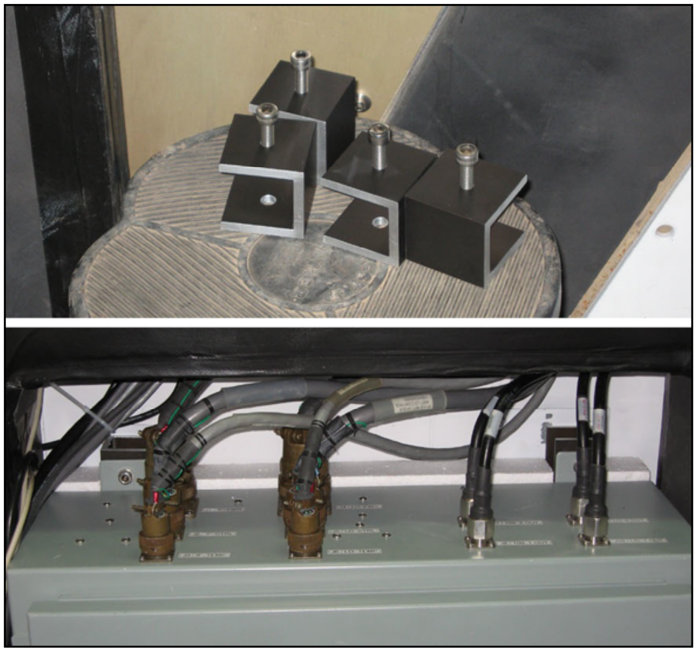

Figure 3 2-inch aluminum spacers (top), antenna 6 with spacers and foam insulation (bottom).

From this test it appears that the best performance is achieved by antenna 7 with the spacers plus the wood insulators. Antenna 7's diurnal variation for this particular period is ~1 degree C, still about a factor of ten larger than desired. Thus the passive insulation method alone does not appear to be sufficient for our stability goals. We discuss an active approach in the next section.

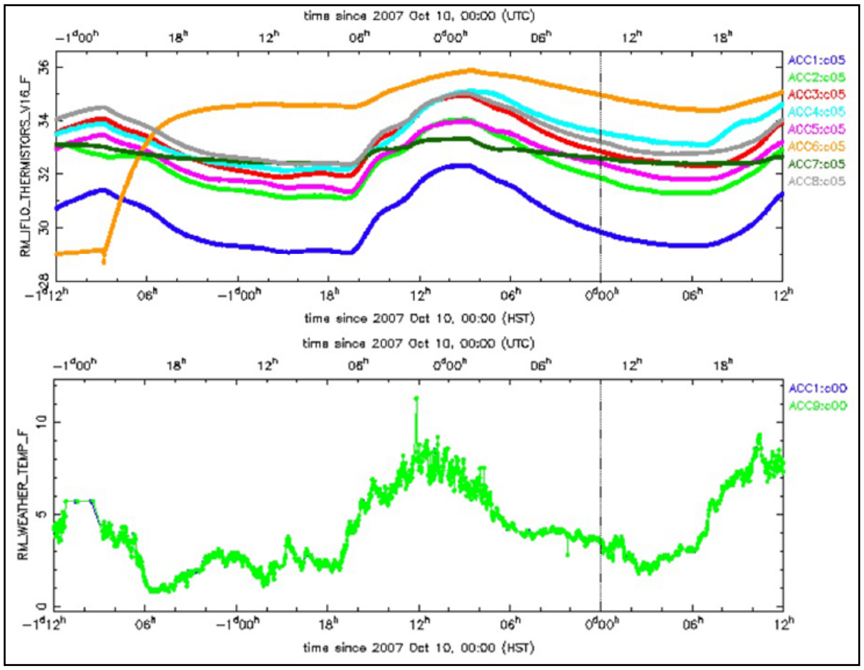

Figure 4 Comparison of enclosure center temperatures over 48 hours (top) to outside weather temperature (bottom).

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[3] Ignore the rapid rise in temperature between hours 03 through 06 (enclosure was being serviced).

<u>Fan Speed Controller</u>: To provide further improvement with the thermal stability we developed a fan speed controller which linearly servos the speed of a pair of fans to maintain a constant temperature of a thermistor. The assembly consists of two fans, a controller board, DC power supply, and an NTC thermistor. With the exception of the thermistor, the entire assembly is built into the removable cover for modularity. *Figure 5* shows a photo of the fan speed controller assembly.

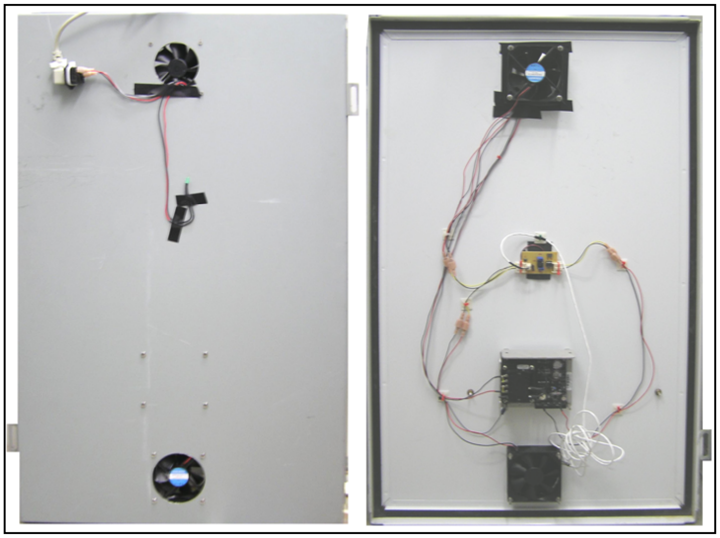

Figure 5 Photo of prototype fan speed controller mounted to the enclosure cover. Left – front view, right – rear view.

A prototype version of the fan speed controller was installed on antenna 6. The thermistor was installed onto the base plate of the enclosure near the center. The test was conducted with the 2-inch spacers and foam insulation in place.

Under normal static conditions with the cover closed, the two upper assemblies exhibit higher temperatures than the lower due to natural air convection within the enclosure. We attempted to counter this effect by orientating the fans to draw air in at the top and exhaust at the bottom.

Figure 6 shows the results in comparison to the other antennas. Note the drastic improvement for antenna 6.

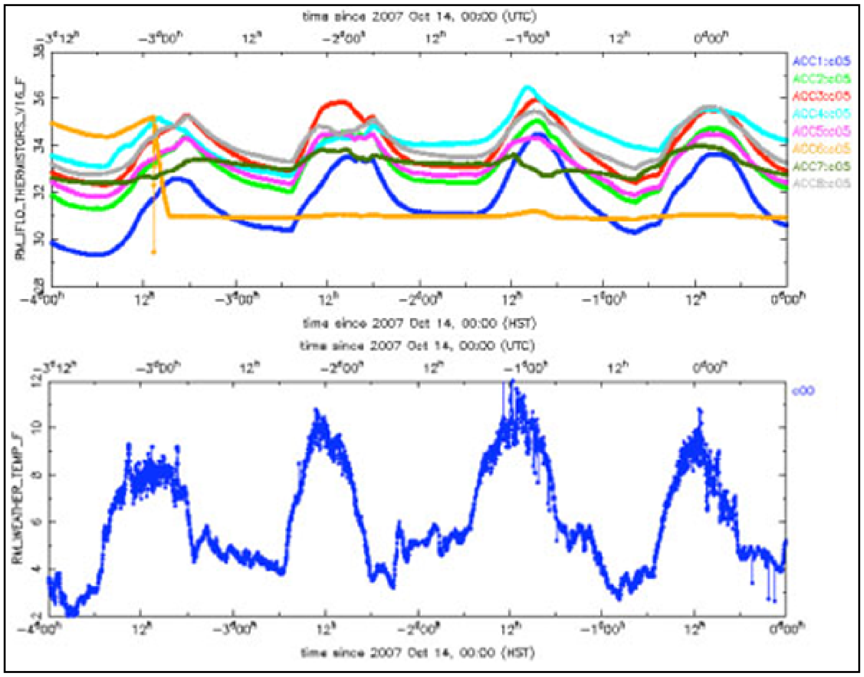

Figure 6 Comparison of enclosure center temperatures over 4 days (top) to outside weather temperature (bottom). Note the drastic improvement in antenna 6 after the addition of the fan speed controller shortly after hour 12.

Temperature stability issues were foreseen during the original design of the IF/LO hardware and as a result it was outfitted with twelve thermistors. *Figure 7* shows the locations for these sensors and *Figure 8* the resultant temperatures at these locations. Note the extreme stability with sensor c05 (enclosure center) due to this being the servo reference point. The two IF assemblies (upper left, lower left in *Figure 7*) provide identical functions and power dissipations, however, note that the lower assembly for antenna 6 is now operating ~3 degrees C warmer than the upper because of the direction of the fans. The same is not true for the YIG oscillator assemblies (upper right, lower right) because the actual power dissipation is dependent on the tuning frequency. Power dissipation versus tuning frequency will be discussed in the next section.

Although the enclosure center thermal response is extremely flat the same does not hold true for the four assemblies. This may in part be due to the thermal resistance between the assemblies and the enclosure base plate.

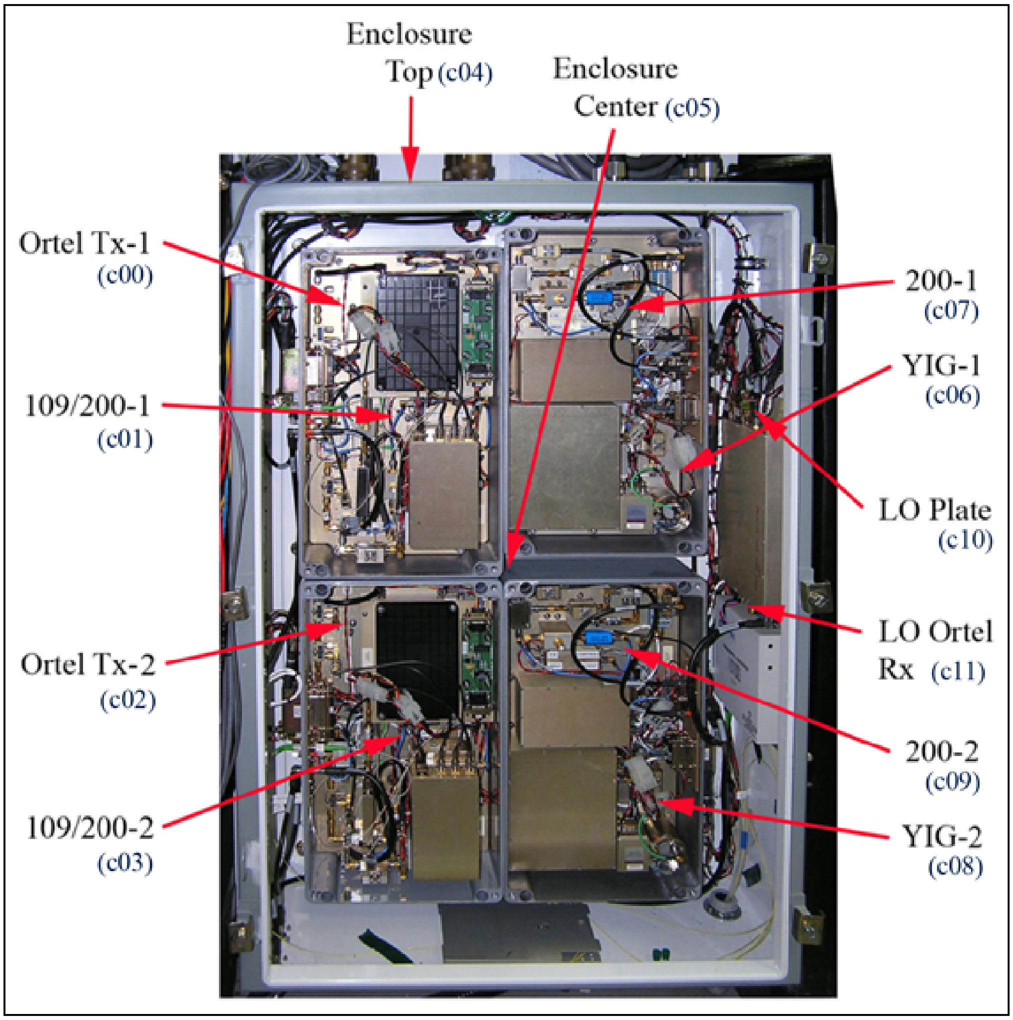

Figure 7 Temperature sensor locations within the IF/LO enclosure.

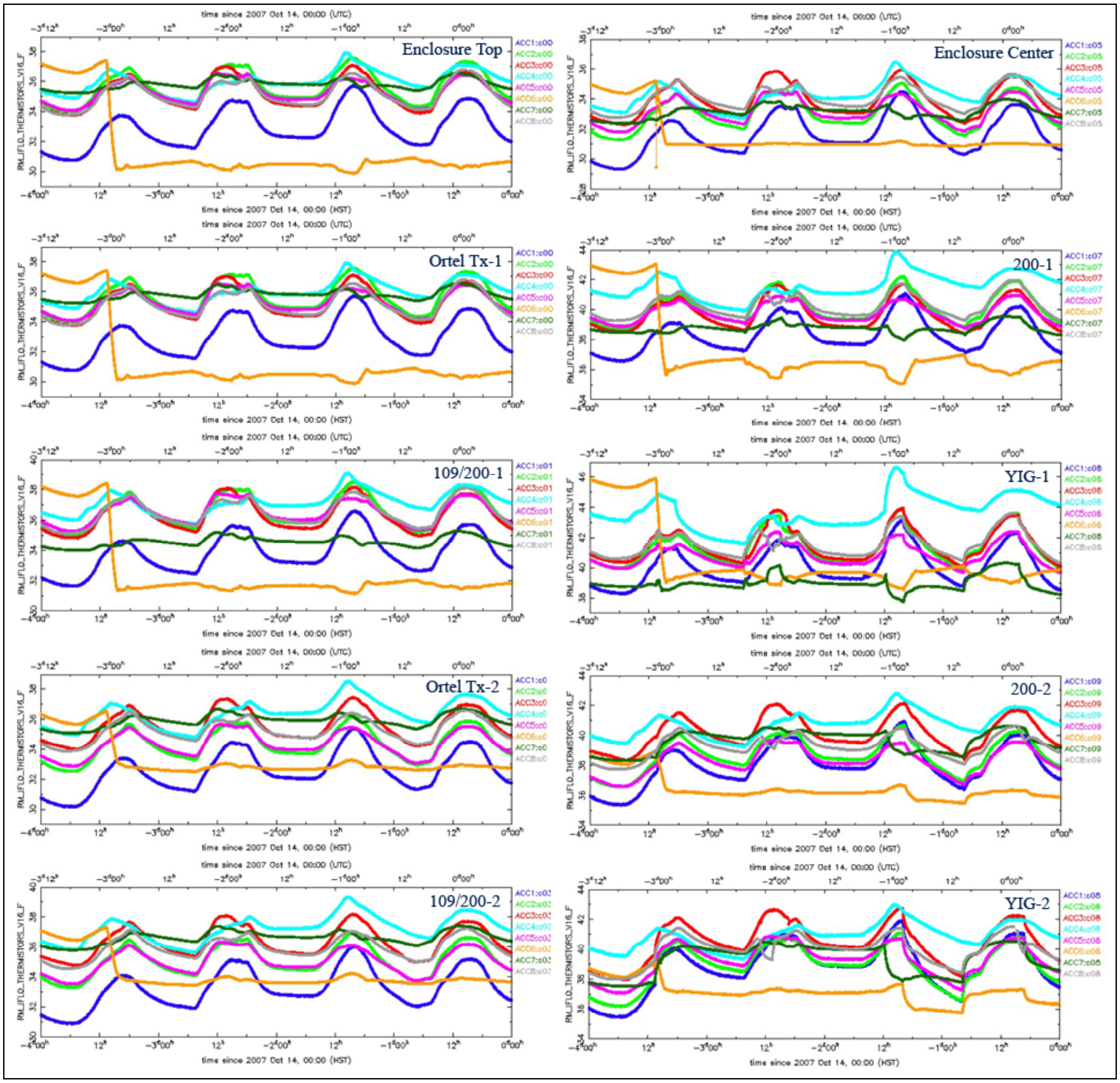

Figure 8 Sensor temperatures within the IF/LO enclosure over a 4 day interval. Note the blips in temperature for the YIG-1 and YIG-2 assemblies even though the enclosure center is flat.

YIG Coarse Tune Voltage: An interesting temperature signature became apparent after we removed some of the diurnal temperature variations. This is shown in *Figure 9* which represents the YIG-1 temperatures (upper plot) and tuning voltages (lower) for antennas 5 and 6 over a period of four days. Note the large variation of 4.5 degrees C as a function of YIG tuning voltage for both antennas. As the tuning voltage is increased the power dissipation of the YIG oscillator tuning coil increases with it.

There are two YIG oscillators to support two active receiver bands, however, some project tracks utilize only one receiver. During those single receiver projects the unused YIG oscillator is purposely tuned out-of-band so that it will not cause interference. An examination of *Figure 9* will reveal that the YIG oscillator operates coolest when a control voltage of 10V is issued which is contrary to what was described above. It turns out that 10V actually corresponds to -10V due to an overflow condition in 2's complement representation (9.9V does actually represent +9.9V). The intent is to push the YIG frequency to maximum[4] when not in use.

Figure 10 shows a closer in view of the antenna 6 YIG1 temperature over a 24 hour period. By design, all heat dissipating components within the YIG assembly are attached to a ¼ inch thick aluminum base plate for heat sinking and to increase its thermal time constant. Thus the time required to change by the full 4.5 degrees is almost 4 hours, with an associated time constant (time to change by 63% of its total swing) of ~48 minutes.

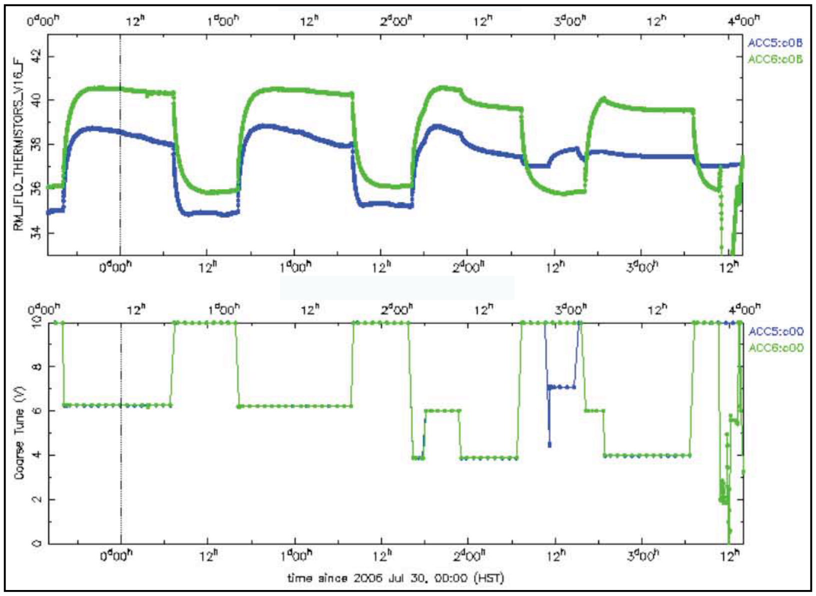

Figure 9 YIG-1 temperature (top) and control voltage (bottom) for antennas 5 and 6 over a 4 day interval.

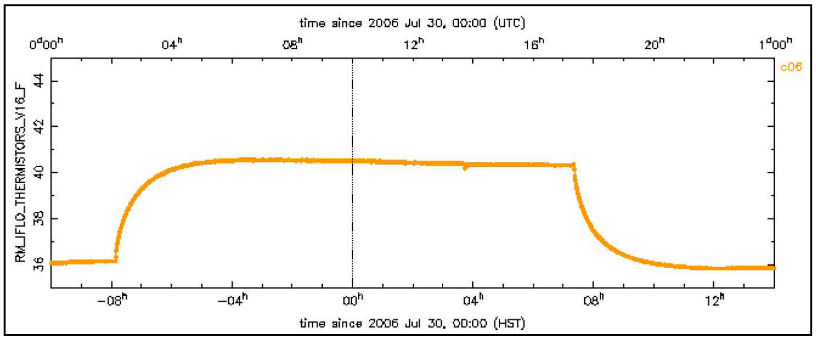

Figure 10 Close in view of YIG1 temperature over 24 hours

We currently do not understand the actual mechanism which causes the ~0.1 degree phase/degree C movement. The temperature change refers to the overall YIG assembly, not just the YIG oscillator device itself. It is therefore difficult to predict the overall phase drift effect caused by the heating of the YIG oscillator device. In actual practice the YIG oscillators are locked to the project frequency during priming which is usually a minimum of one hour prior to the science track. By the time the track has begun the YIG oscillator device is probably 80% to 90% of its final tuning related temperature.

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[4] The YIG oscillator accepts a coarse voltage of 0 to 10V with a corresponding frequency output of 5.5 to 9.5 GHz.

During normal observations calibration on an astronomical source is performed at intervals of approximately 20 minutes. This calibration, when applied to the data, should in principle be capable of removing much of the phase drift effects caused by the YIG oscillator. We are, however, still motivated to reduce the source of this phase drift for a number of reasons. One is that the calibration removes phase drift effects from a multitude of other sources in the system and it is thought best to keep the number of phase drift sources to a minimum. Another compelling reason is that there are not many astronomical sources available in the 600 GHz band. This limitation is combined with the larger multiply ratios for 600 GHz LO chain.

John Test of the Cambridge IF/LO Group developed a temperature compensation circuit which provided a complementary heat load (power transistor and resistor) attached to the base plate adjacent to the YIG oscillator component where the total power dissipation of the YIG plus load was held constant. Both the power transistor (MJE3055) and 25 Ohm power resistor are TO-220 case styles and are screwed directly to the base plate. Maximum heating of ~6.0W to the base plate occurs when the YIG control is at -10V, and correspondingly no heating occurs when the YIG control is +9.9V.

This circuit was installed into YIG-1 of antenna 6 prior to the installation of the fan speed controller. *Figure 11* shows the YIG-1 temperature plot (upper graph) and its associated control voltage (lower) after its installation. Note the significant improvement in comparison to the upper green trace shown in *Figure 10*. Ignoring the spikes for this comparison, the peak-to-peak temperature variation reduced from ~4.5 to ~1.5 degrees, both taken over a 4 day interval.

The temperature spikes in the compensated circuit are a result of the fast response of the heater. I.e., when the control voltage abruptly drops to -10V (10V on the graph) the auxiliary heater immediately begins to add heat to a still warm YIG assembly causing an upward spike in temperature. Similarly, when the control voltage abruptly moves from -10V to 4V the circuit immediately removes the auxiliary heat to a still cool YIG assembly causing a downward spike.

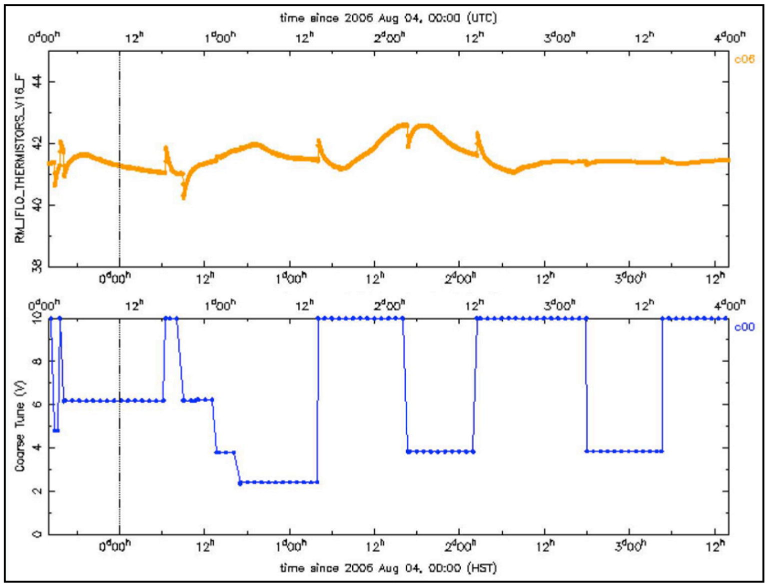

Figure 11 YIG1 temperature (top) and control voltage (bottom) for antenna 6 after installation of John Test's heater circuit, 4 day interval.

We modified the compensation circuit to slow down the heating and cooling time constant with the use of active RC circuits. *Figure 12* shows a comparison of YIG1 for antennas 5 and 6 over a 48 hour interval. Note the marked reduction in temperature spikes which was obtained with a power time constant of ~3.3 minutes. Also note from the plot that this RC value is still slightly too large based on the downward and upward spikes when the YIG is abruptly turned off (+10V on Coarse Tune graph) and on.

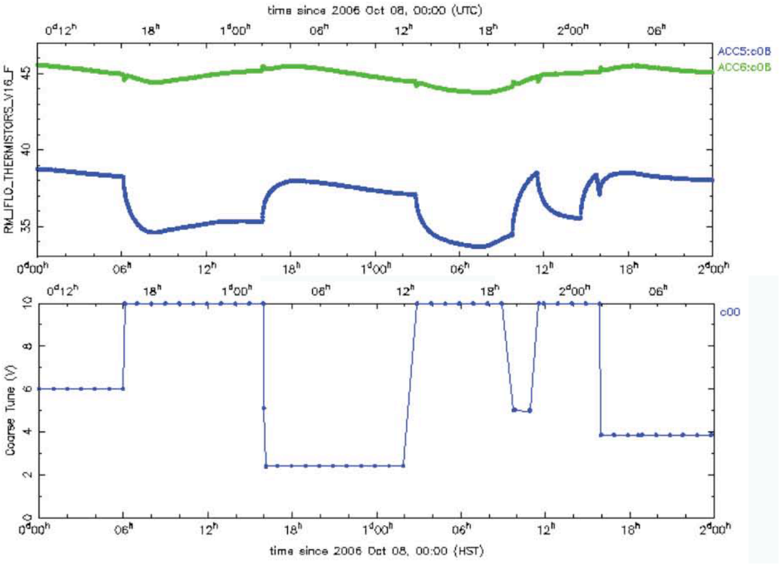

Figure 12 YIG-1 temperature (top) and control voltage (bottom) for antennas 5 and 6 over a 48 hour interval. Antenna 6 trace (green) has RC compensated heater circuit.

Conclusions & Recommendations: The results of the prototype fan speed controller in stabilizing the IF/LO enclosure temperature were very encouraging. This test was conducted on an enclosure which was spaced and insulated from the cabin wall. We've recently repeated this test on antenna 2's enclosure which is mounted directly to the cabin wall with the results being almost as good. The final solution will probably utilize small 3/8 inch insulating shims instead of the large 2 inch aluminum spacers. This insulation in conjunction with the use of the fan speed controller should ensure a stable operating temperature at the enclosure center. These modifications are not invasive and are easy to implement.

We've identified that the YIG oscillator device power dissipation is a function of its tuning voltage. One solution which we have shown to work is to add a complementary heater (described in the previous section) to each of the 16 YIG oscillator assemblies. This solution is somewhat labor intensive and involves some technical risk. A second alternate solution would be to coarse tune the YIG oscillators to the evening's project frequency as early as practical so that the hardware has time to reach thermal equilibrium prior to the science track. Say by 3 or 4 PM in the afternoon. This might be particularly useful for projects which rely on a high degree of phase stability such as with the phase transfer project.

As a final note it is reiterated that the stability of the final LO to the SIS mixer relies on the stability of not only the YIG oscillator assembly but also on the stability of the cables and the LO plate assemblies located in the open air environment of the cabin. Optimization of the air handler performance would likely be a worthwhile endeavor.

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