CSO YIG filter tuning performance

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1 Introduction

The CSO suite of new receivers will use a synthesized Local Oscillator (LO) scheme. The source for the LO will be a commercial synthesizer followed by a tunable YIG bandpass tracking filter[3]. The YIG filter will be integrated into a module which provides the following functions: (1) amplifies the signal from the synthesizer (Anritsu MG3690B); (2) actively controls the temperature of the YIG filter case; (3) provides a digital programming interface to the receiver control computer; (4) shields the nearby SIS receivers from the magnetic field originating from the YIG tuning coils; (5) provides a power detection circuit for monitoring and for computer closed loop control of the YIG programmed center frequency; and, (6) power splitting for two separate LO circuits downstream. See Figures 1 and 2. The typical power out of one the two output ports is depicted in Figure 3. The level of the output power meets or exceeds our design goals but it is important to keep the YIG bandpass centered on the synthesizer carrier frequency.

The YIG tracking filter is of the open-loop type[1] and our tests which build on previous work[2] found it required frequent updating of its tuning parameters to keep its bandpass properly centered.

Previous tests[2, 3] indicated that the YIG tracking filter would have better performance if its case temperature was stabilized by an external heater[4]. The case heater implementation and performance are described in Reference [4]. The external case heater was in addition to the internal YIG heater intrinsic to the unit. According to the manufacturer application note[5] the operating temperature of the YIG case should be 0 to 65 °C and with YIG spheres heated to 85°C by the intrinsic heater.

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[3]Micro Lambda, model number MLFP-41840RS, 18-40 GHz 4 Stage Bandpass Filter with remote serial driver.
[4]Case heater manufacturer: Micropac; model number 52416.

We tested the YIG tracking filter module[5] under 4 conditions:

1. YIG heater OFF. Case heater $\sim 58°$C.
2. YIG heater ON. Case heater $\sim 58°$C.
3. YIG heater OFF. Case heater $\sim 77°$C.
4. YIG heater ON. Case heater $\sim 77°$C.

As described below we found that the best performance of the YIG was filter was obtained under condition 4 even though the case operating temperature exceeded the manufacturer's recommendations[6].

2 Method

In our application the YIG tracking filter will be operated in the range from 20 to 35 GHz. We determined the YIG center frequency (CF or f_c) and passband at frequencies separated by approximately 1 GHz as described below:

1. Using old tuning parameters (or best guess), the YIG DC magnetic field was commanded to set the desired center frequency, say 20 GHz.
2. The Anritsu synthesizer was swept from a frequency lower than the commanded YIG center frequency to a higher frequency while the transmission through the YIG filter was monitored by a power meter. For example if the commanded YIG CF was 20 GHz we might command the Anritsu synthesizer to step sweep from 19.5 GHz to 20.5 GHz while sampling the power transmitted through the YIG filter.
3. The passband curve of the YIG filter was fit to a gaussian distribution to find the actual center frequency and passband full width at half the maximum amplitude (FWHM).

[5]The module will be packaged in a mu-metal enclosure not depicted in Figure 1. All our tests were performed without the enclosure.

[6]Micro Lambda stated that the best YIG stability would be obtained if the case temperature was maintained at $\sim 25°$C (Linda Crowley Dimmmers, email communication, 9-Dec-2010) but we did not try that temperature regime due to the practical difficulties of keeping the case temperature at a constant, cool temperature.

Figure 4 is an example of a YIG passband and the Gaussian fit. The commanded, nominal center frequency was 20 GHz. According to the Gaussian fit the center frequency was 19.9885 GHz, thus we would say that the residual error in the tuning was $19.9885 - 20.0 = -0.0115$ GHz or, rounding off, -12 MHz. Also according to this fit the FWHM of the YIG passband was 65MHz. As be can be seen from the fit, determining the best center frequency from a gaussian fit was an approximation as the YIG passband often had a more complicated structure.

The procedure to find the YIG center frequency was used in two test modes:

1. The YIG bandpass was sampled at 16 different frequencies starting at 20 GHz and ending at 35 GHz (1 GHz steps);

2. or, The YIG bandpass was repeatedly sampled at 20 GHz, and then switched to 35 GHz and sampled, with the cycle repeating at least once.

The first mode of testing was continually repeated overnight (or longer) to determine how stable the YIG tuning parameters were over time. The second mode of testing was used to determine how long one would have to wait (worst case) for YIG to stabilize after a big frequency switch.

The first mode of testing can be used to update the YIG tuning parameters since the integer command for the YIG control circuit can be tabulated against the actual YIG center frequency determined from Gaussian fitting to the YIG filter bandpass. The integer command ranges from about 6500 ($\sim$ 20 GHz) to 51000 ($\sim$ 35 GHz). For more details on a possible software implementation for the YIG filter control the reader might see Reference [6]. Our software implementation was slightly different.

3 Result

Figure 5 shows the result of the first test mode run overnight at two different case temperatues: $\sim 77°$C and $\sim 58°$C. The YIG filter center frequency clearly had less temporal drift when the case was kept at the warmer temperature (upper panel). Note that this result with the higher case temperature resulting in a greater stability contradicted our expectations based on the manufacturers application note[5] and email communications. Also of note, the manufacturer was shown the data in Figure 5, Lower Panel (Case temperature $\sim 58°C$) and they informed us that the the YIG filter was operating within its specification (Linda Crowley Dimmmers, email communication, 14-Dec-2010).

Using the YIG tuning parameters from a November 19, 2010 frequency sweep we also explored how the tuning parameters might drift over longer time periods, see Figure 6. In the Figure frequency sweeps acquired from November 19 to November 23 were tightly clustered. A week later, November 29 & 30 we observed a dramatic change in the residual error using the November 19 YIG tuning parameters. According to our records, the YIG case temperature was not cycled between November 23 and November 29.

Figure 7 displays the YIG bandpass filter Half Width at Half Maximum (HWHM) dependence on frequency. Comparison with Figure 6 shows that using 10 day old tuning parameters would put us on the edge of the YIG filter bandpass, see Figure 8. The data in these figures indicate that in our operational procedure we will want to check and update the YIG tuning parameters on a daily basis.

The individual 20 to 35 GHz frequency sweeps in Figure 6 took approximately 65 minutes. Could we shorten the time? In Figure 9 we attempted to address that question by alternating 65 minute frequency sweeps with 7 minute frequency sweeps. In the data of Figure 9 the maximum deviation between fast and slow sweeps was about 10 MHz at a YIG center frequency of 23 GHz. This amounts to ~ 30 % of the HWHM bandwidth.

Figure 10 shows the result of the second test mode run with the YIG case temperature maintained to $\sim 77°C$. The YIG filter clearly stabilizes faster when intrinsic YIG heater was turned ON (τ=2.5 min, Δ residual error $\sim$ 10 MHz). We therefore recommend that the YIG be operated in this mode. Table 1 summarizes the result.

The second test mode was also used with the YIG case temperature maintained at $\sim 58°C$, see Figure 11.

4 Conclusions

From these tests we form the following conclusions:

1. The YIG filter short term tuning parameter drift is less if case temperature is near 80°C. This result does not seem consistent with the manufacturer's recommendation that 0°C < case temperature < 65 °C

2. The YIG filter actual center frequency settled faster to its final value if the internal YIG heater was ON. If the case temperature was controlled to about $\sim 77°C$ and the internal YIG heater was ON, the time constant for the settling time was 155 seconds. Under the same conditions with the internal YIG heater OFF the time constant was about twice as long: 306 seconds.

3. Our observations indicated that there may be substantial drift in the YIG tuning parameters on the time scale of days. Micro-lambda confirmed that the drift we observed is consistent with their experience. Therefore, the YIG tuning curve should be checked at least daily and we should also employ a software algorithm to jiggle the YIG commanded center frequency around to make sure it is centered up on the synthesizer output.

4. A wait time of ~ 2.5 min should be enforced for large frequency jumps, perhaps defined as ≥ 5GHz. This wait time parameter could be fine tuned after the receivers are deployed to the CSO.

References

[1] . Microwave YIG filters. Application Note OFOISR App 06-S-1942, Teledyne Microwave.

[2] David A. Miller. Test results for the Micro Lambda MLFP-41804RS YIG filter and serial driver. Technical note, California Institute of Technology, 2010.

[3] Brian Force. YIG filter thermal characteristics. CSO technical memo, 2010, CSO.

[4] J. Kooi, D. Miller, R. Chamberlin, and B. Force. LO distribution box, YIG thermal stabilization. CSO receiver upgrade memo, Caltech, 2010. 18 Oct 2010.

[5] . Millimeter wave YIG bandpass filters. Web application note ., Micro Lambda Wireless, . http://www.microlambdawireless.com/YIG_Filters/Millimeter_Wave.htm.

[6] David A. Miller. Notes on micro lambda wireless YIG filter part number MLFP-41804RS. Technical note, California Institute of Technology, 2010.

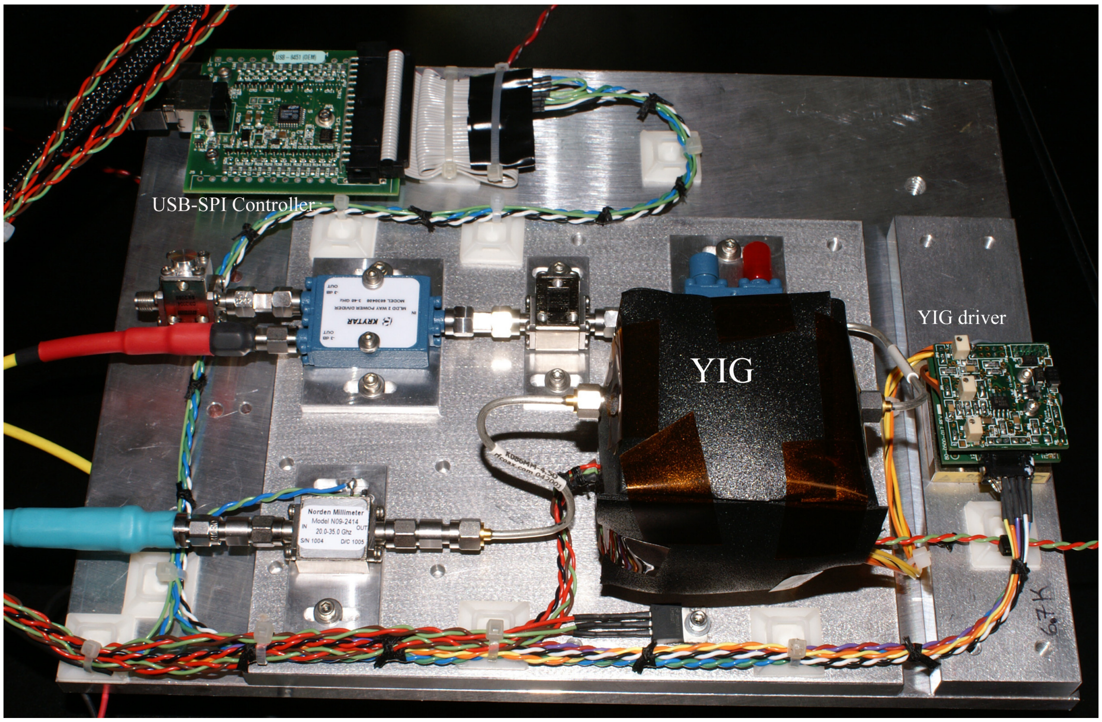

Figure 1: Photograph of the YIG tracking filter system we tested. Micro Lambda, model number MLFP-41840RS, 18-40 GHz 4 Stage Bandpass Filter with remote serial driver.

Table 1: Time constants from Figure 10. The YIG case temperature was actively controlled to about 77°C with a Micropac model number 52416 heater (18V, 9W).

	YIG heater	
20 - 35 GHz change (worst case)	ON	OFF
YIG Center Frequency time constant (sec)	155	306
Case heater time constant (sec)	571	583

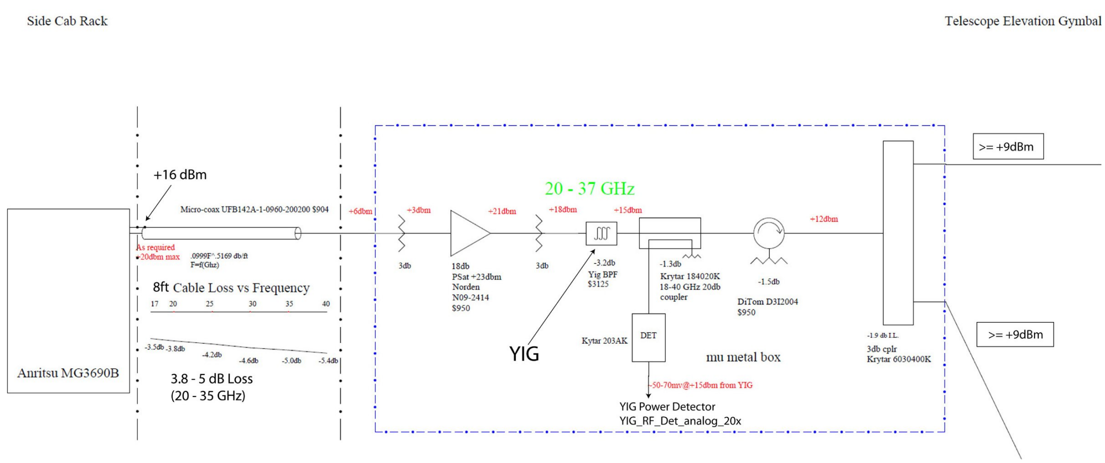

Figure 2: Block diagram of the YIG filter setup including the Anritsu synthesizer source. Filter implementation design and block diagram are by Brian Force.

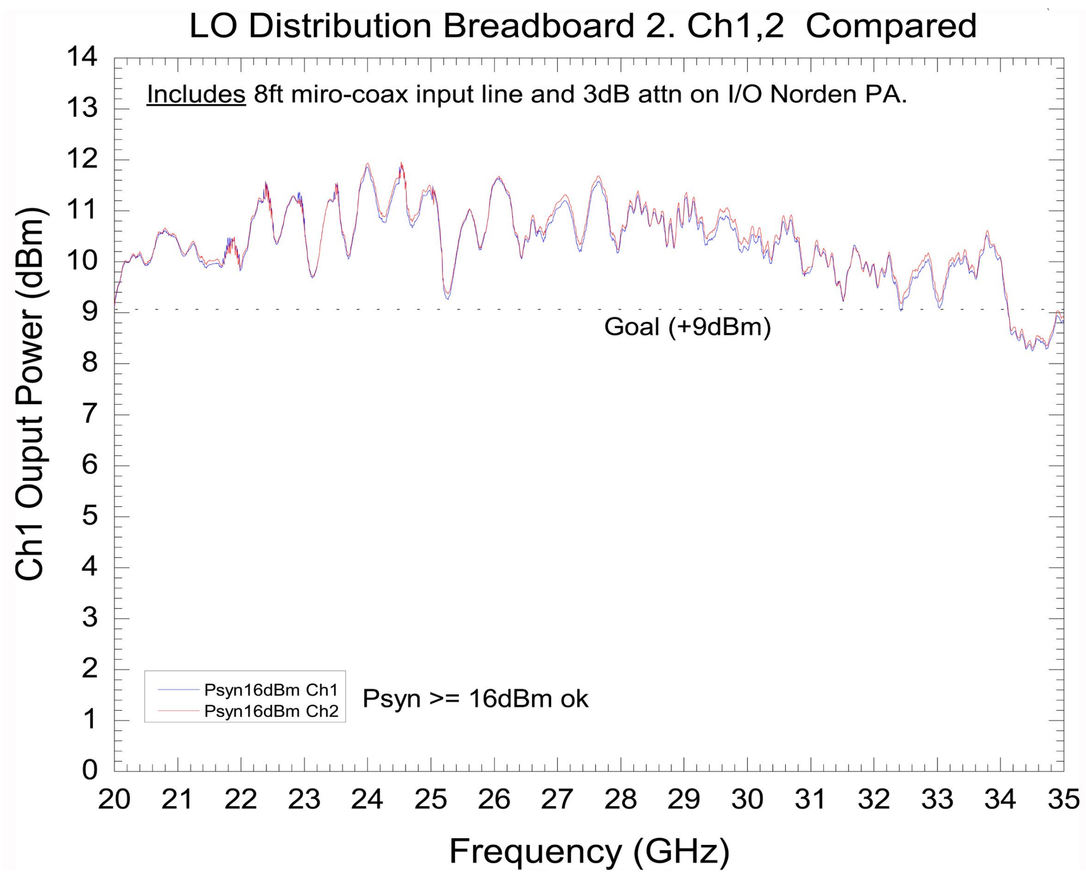

Figure 3: Measured output power, P_{out}, of Breadboard #2 depicted in Figures 1 and 2. The design goal is $P_{out} \geq 9$dBm.

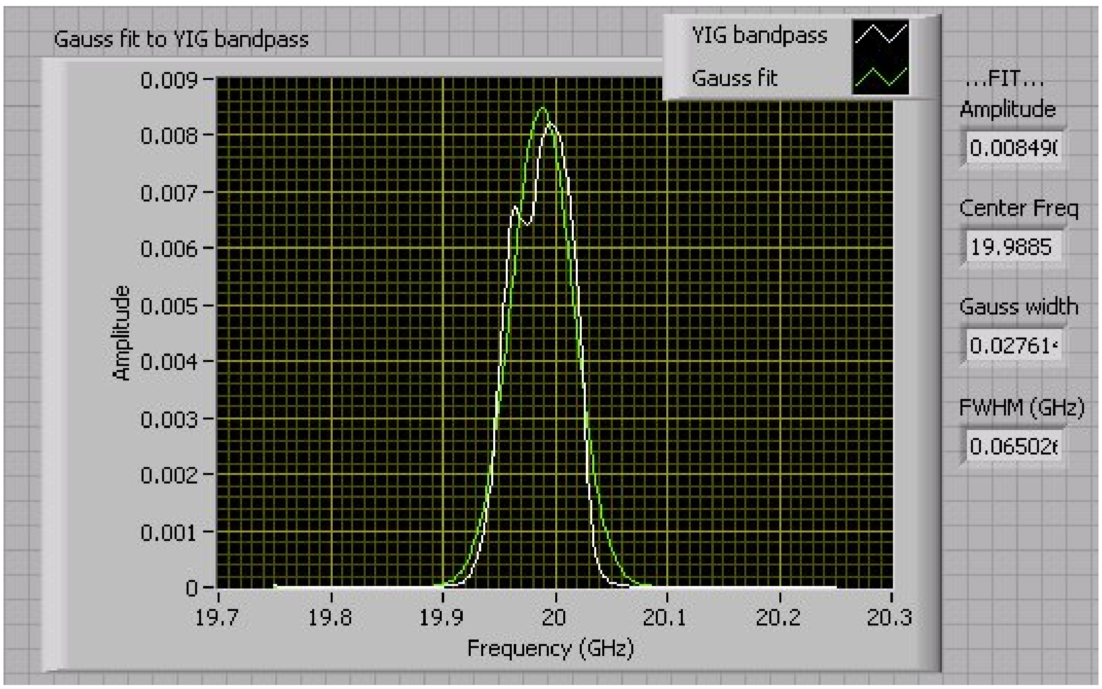

Figure 4: A screen shot of part of the LabView front panel for the YIG frequency sweep data acquisition program. FWHM: 65 MHz, f_c=19.9885 GHz. See text for explanation.

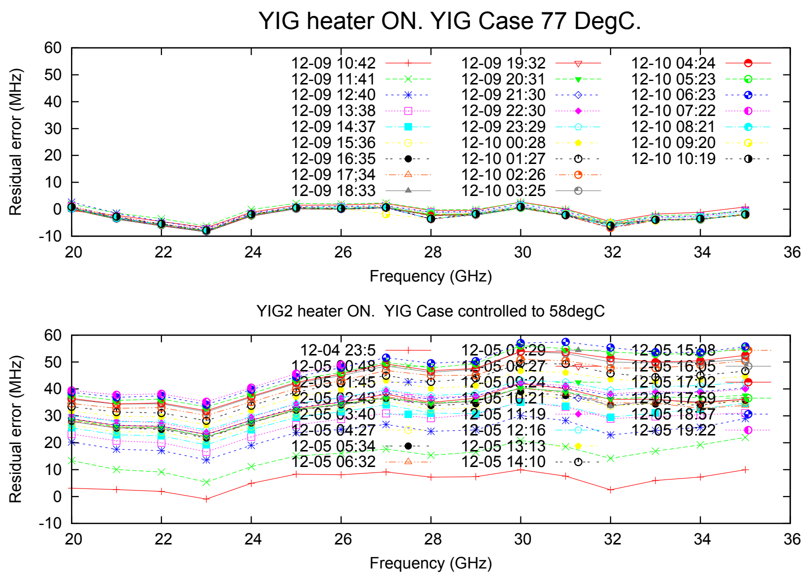

Figure 5: In the upper panel the YIG case temperature was actively controlled to about $\sim 77°C$ with a Micropac model number 52416 heater (18V, 9W). The elapsed time from the start to the end of the test was about 24 hours. In the lower panel the YIG case temperature was controlled to $\sim 58°C$. The elapsed time from start to end was about 20 hours. In both cases the YIG internal heater was ON. Clearly the residual tuning error was significantly reduced when the YIG case temperature was at $\sim 77°C$.

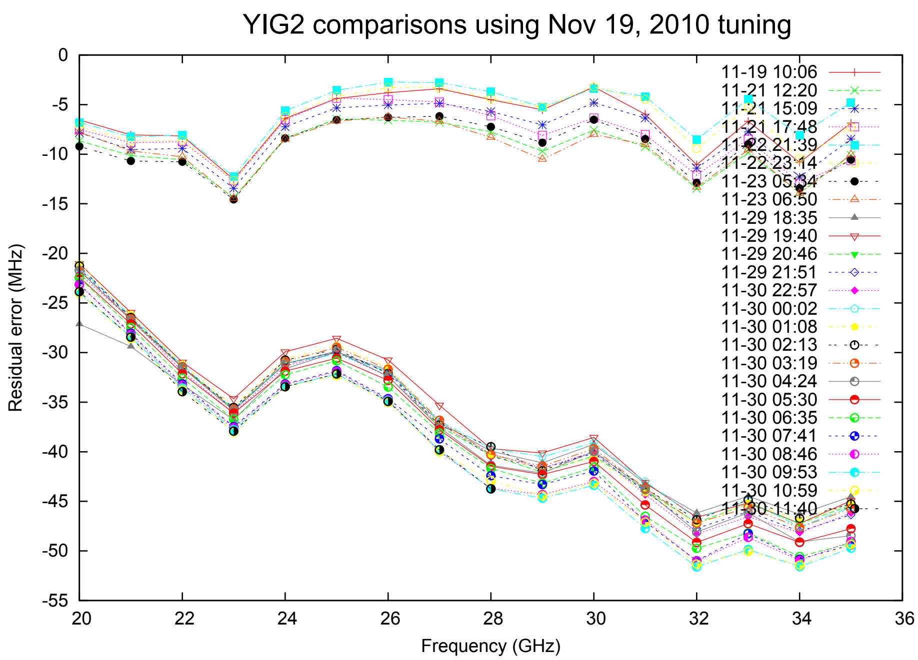

Figure 6: Comparisons using November 19, 2010 tuning. Each sweep from 20 GHz to 35 GHz was taken in a "slow" mode which required about 65 minutes. The top cluster of curves were acquired over about four days from November 19-23. Data taken about a week later later (lower cluster of curves, November 29, 30) indicated substantial drift in the YIG tuning parameters. The internal YIG heater was OFF. YIG case temperature at $\sim 80°$C.

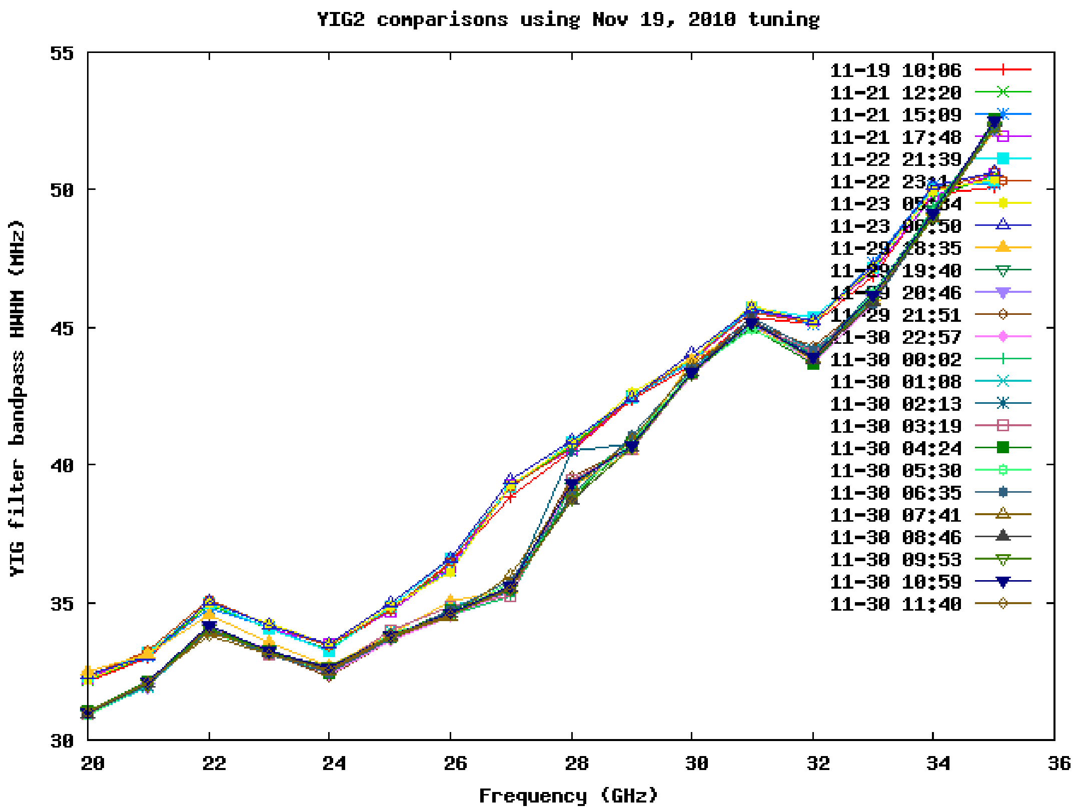

Figure 7: The YIG bandpass Half Width at Half Max (HWHM) versus frequency using the data that were the source of the previous figure. Comparison with Figure 6 shows that using 10 day old tuning parameters would put us on the edge of the YIG filter bandpass: see the next figure.

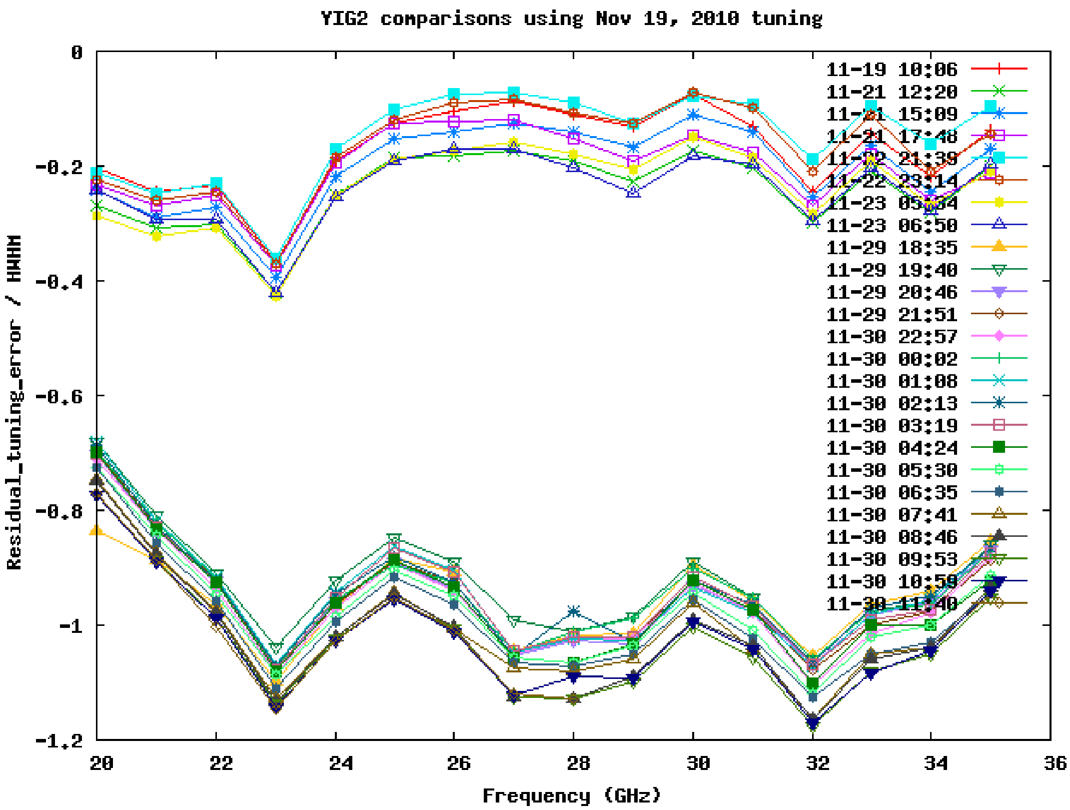

Figure 8: The residual tuning error of Figure 6 is divided by the YIG bandpass HWHM of Figure 7. If this fraction is greater than 1.0 or less than -1.0 then the YIG bandpass filter was very badly centered on the programmed synthesizer frequency and the tone from the synthesizer was attenuated by more than 3dB. As in Figure 6 the plots are clustered by acquisition date. Using 10 day old tuning parameters put us on the edge of the YIG filter bandpass. It should be noted that in actual operation only a $\sim$ 1dB drop in power at the 20-35 GHz operating band edges, and a $\sim$ 2dB at the band center may be tolerated, see Figure 3. Thus $Residual\_tuning\_error/HWHM < \pm 0.5$ under all circumstances. This condition will require daily checks on the YIG tuning parameters (e.g. see Figure 9) and may also require small dithering of the the programmed YIG center frequency around the nominal value to peak up its output.

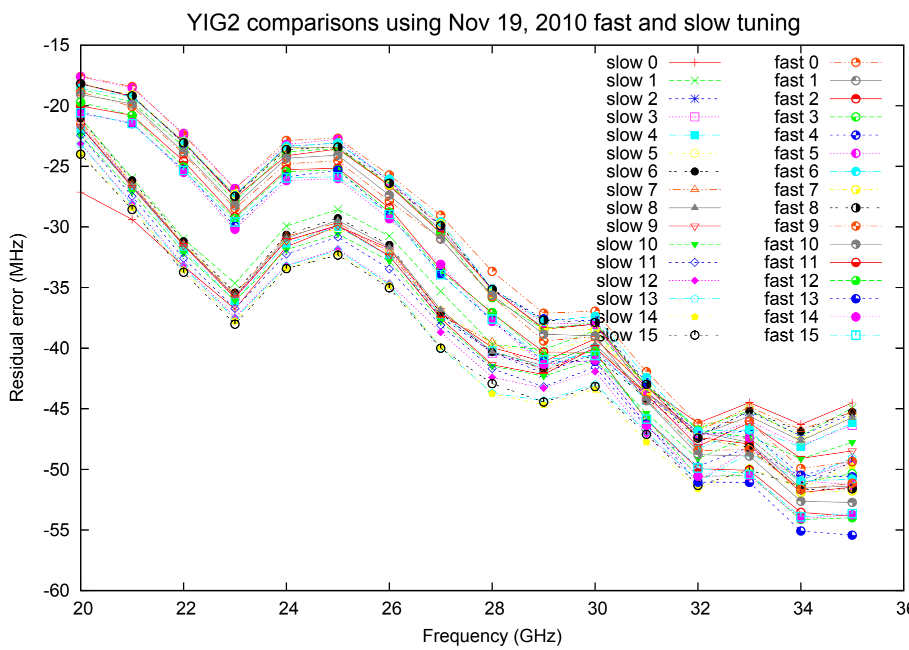

Figure 9: Comparisons using November 19, 2010 tuning. Each sweep from 20 GHz to 35 GHz was taken in a "slow" mode which required about 65 minutes. "Fast" sweeps took about 7 minutes and were alternated with the slow sweeps. The point of this test was to see how much error we might get if YIG filter tuning parameters were based on fast sweep data. We saw about a 10 MHz deviation at 23 GHz and somewhat less at higher frequencies. The internal YIG heater was OFF.

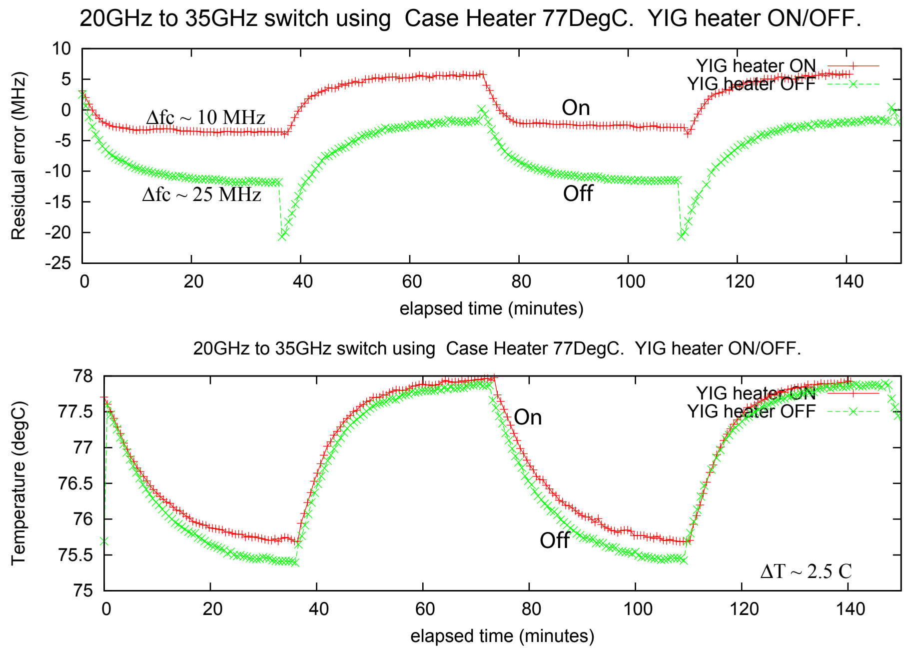

Figure 10: The YIG case heater was controlled to $\sim 77°$C. The commanded YIG center frequency was alternated between 20 and 35 GHz with about 38 minutes on each commanded frequency before switching to the other. Each data point in the upper panel is the result of a single frequency sweep around the commanded center frequency to determine the actual center frequency. The difference between the commanded and the actual center frequency is represented as "Residual error (MHz)". The lower panel depicts the YIG case temperature as a function of time. These data were acquired in two modes: With the internal YIG heater ON and with it OFF. The purpose of the measurement was to determine if the internal YIG heater was effective. From these data we found that using the internal YIG heater decreases the required settling time by about a factor of two, see Table 1, to a τ $\sim$2.5 min. Taking into account the overshoot in the residual error in the OFF case, the residual error in center frequency was reduced by a factor of $\sim$ 2.5. with the case heater ON.

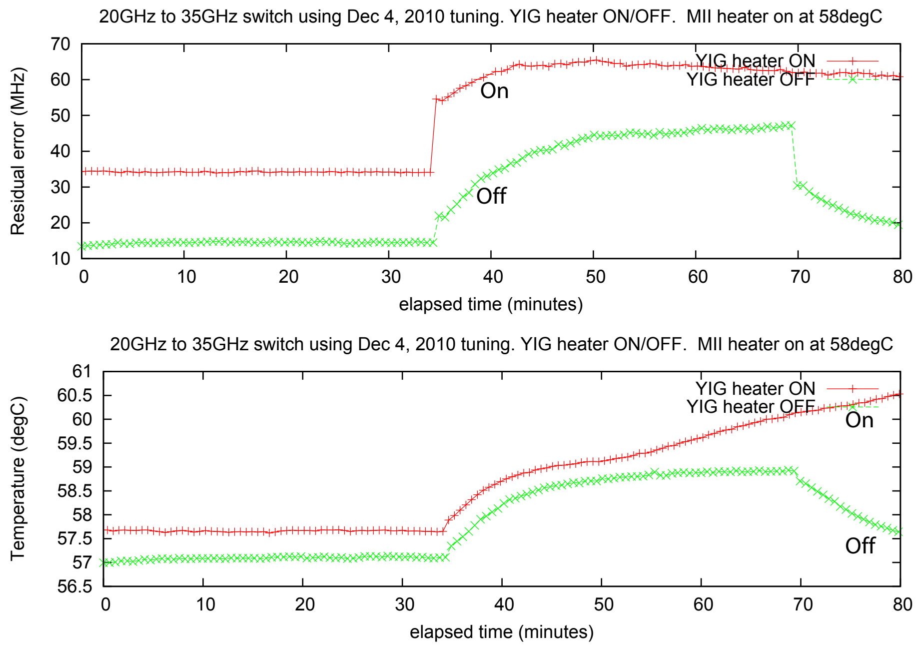

Figure 11: This figure is like the preceding one except that the case heater was controlled to $\sim 58°C$. As as in the preceding figure these data showed that YIG center frequency settled to its final value at a faster rate if the internal YIG heater was ON.