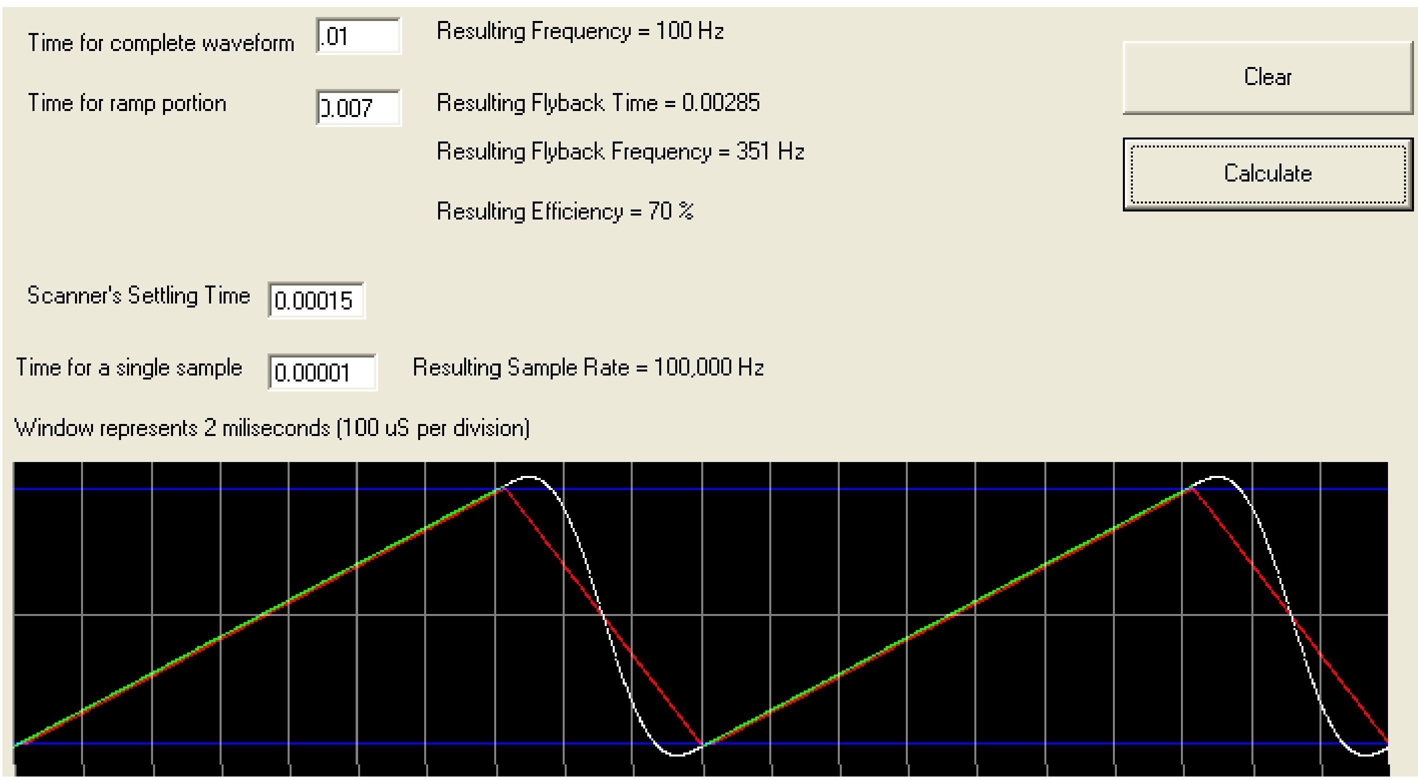
ScannerMAX Saturn 9B-56 scanning 16mm Y-axis mirror over wide angles with sawtooth and triangle waves

This is a test of the ScannerMAX Saturn 9B-56S scanner, with a 16mm Y-axis mirror. The Saturn 9B-56S scanner was driven with a ScannerMAX Mach-DSP servo driver having +/-24V rails. This servo driver is capable of driving two scanners (dual axis driver) and has a compact package. For convenience and for low heat dissipation by the servo driver, it is designed to have a single-ended power amplifier. This means that the power amplifier can only deliver approximately +/-21 volts to the galvo coils, but it also means that heat generated by the power amplifier is generally less than half of that of an H-bridge configuration.

While evaluating the maximum scan amplitude and frequency for each waveform, it is important that this +/-21V rail voltage not be exceeded. To that end, several waveforms were tested, including “standard” triangle-wave and sawtooth waves from a function generator, as well as a rounded triangle-wave, and sawtooth with cycloid-type flyback. The latter two waveforms generally impart a modified sinewave onto the retrace portion of the waveform, instead of a simple linear ramp. This minimizes resonances, while also minimizing flyback time. To generate the cycloid-type flyback retrace waveforms, a custom program was written, which allows the user to specify the waveform “cycle time” as well as the “ramp time”. The program also allows the user to specify the scanner’s settling time, and will automatically increase the amplitude of the waveform to compensate for the natural low-pass-filter rolloff of a scanner/servo system. A picture of the program, and the cycloid-type flyback is shown below.



The Mach-DSP servo driver has accompanying Application Software that runs on a Windows-based PC. The software is capable of monitoring all parameters of the scanner during operation. The software also includes a built-in oscilloscope function. This comes in handy as it can be used to measure virtually any quantity of the overall scanning system.

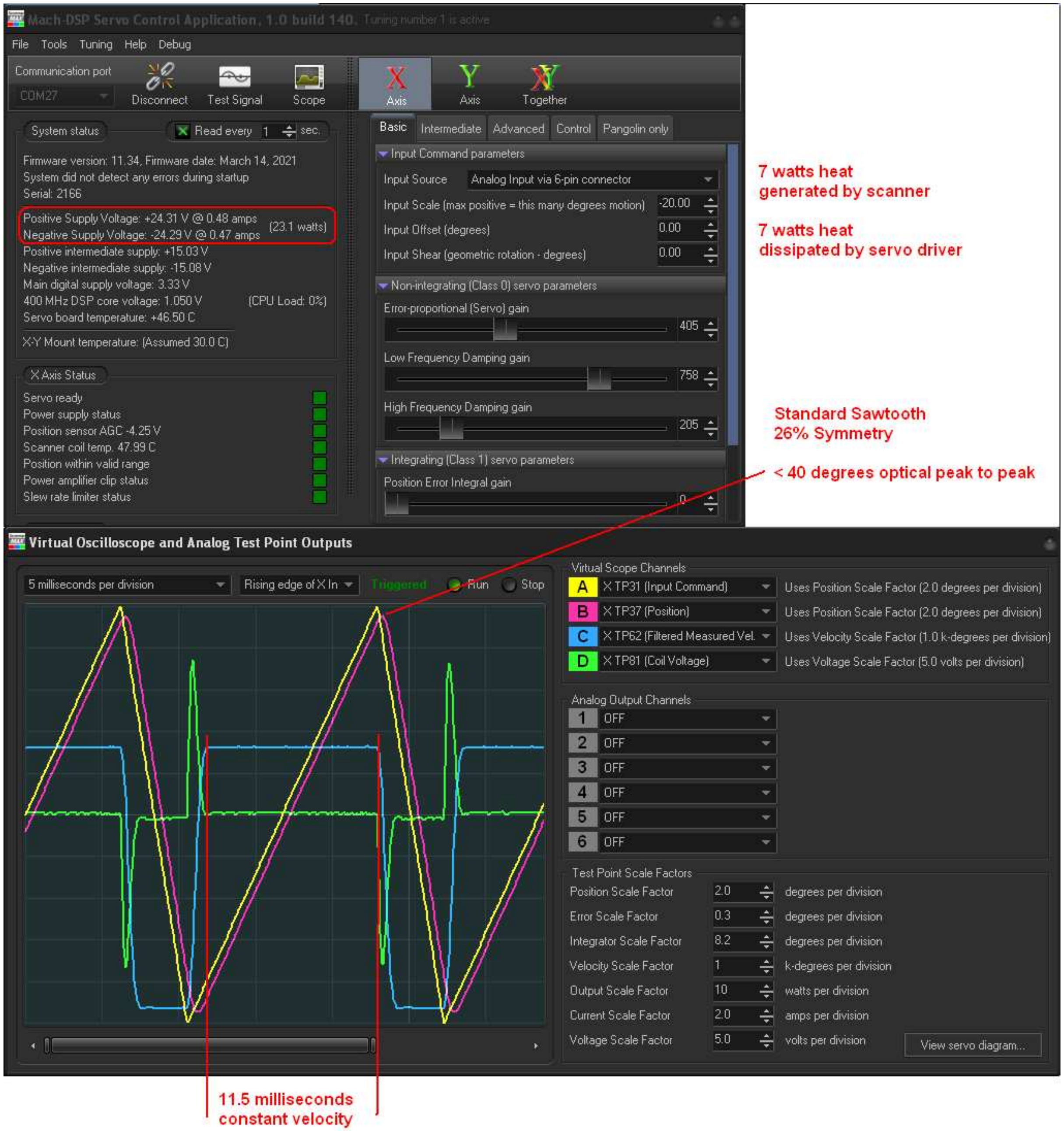
All screen shots that follow show four separate channels being measured. The yellow trace shows “Input command”. The pink trace shows “Position”. (Both Input and Position are in mechanical degrees, thus, optical scan angle is double that shown in the traces). The blue trace shows the “velocity” (first derivative of position). The green trace shows the coil voltage.

For all of the testing, we drove the input command signal using either a standard function generator (for the simple waveforms) or the special program mentioned above (for cycloid waveforms).

Only a single tuning was used for all of the waveforms shown here. It is a simple PD tune with bandwidth of >600Hz, small-amplitude step time of 1.2 milliseconds, and 500 microsecond command-to-position (tracking) delay.

Although an integrator may seem intuitively desirable (i.e. the use of a PID or PDF control law), the PD tune is simple, robust and fault-tolerant. The 16mm Y-axis mirror is really very large and heavy compared to the Saturn 9 rotor inertia. This tuning provides an enormously high servo gain, which provides greater than 20 million dyne-centimeters of torque per radian of error. Given the very low friction of the bearings, and hysteresis compensation and other techniques employed within the digital Mach-DSP servo driver, positioning uncertainties are very small even without an integrator.

60 Hz Standard Sawtooth at 40 degrees optical



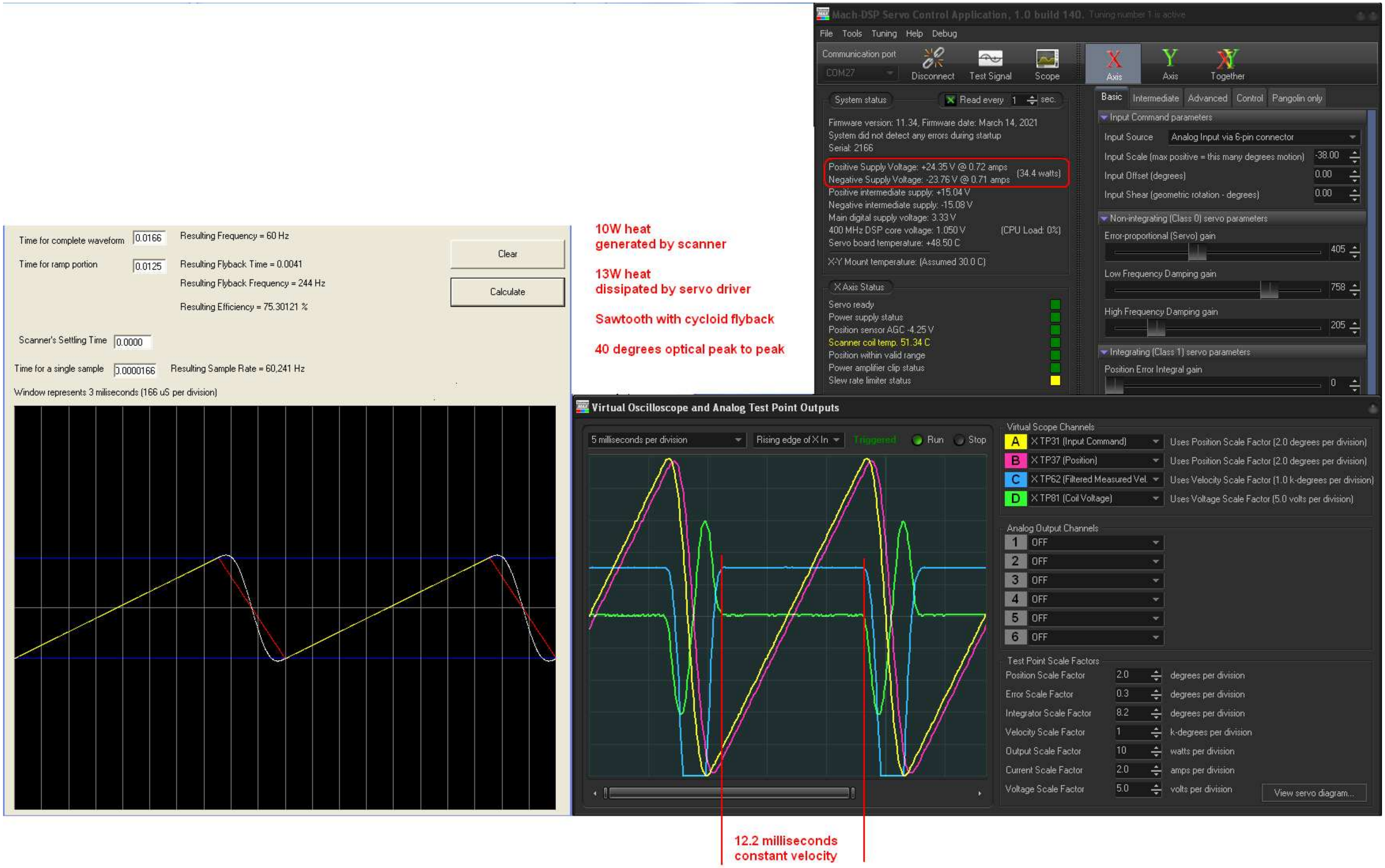
With a standard sawtooth waveform, symmetry must be set to 26% (4.3 millisecond flyback, 12.3 millisecond ramp).

Note that when using standard waveforms like this, the scanner itself does not completely track the incoming waveform. The scanner's position signal is rounded, although the incoming waveform is pointy. This rounded nature of the position signal makes it not quite achieve the 40 degree scan. If a 40-degree scan is desired, the amplitude of the incoming waveform would need to be increased somewhat.

Also note that although the waveform implies a 12.3 millisecond ramp portion, the scanner itself is only at constant velocity for around 11.5 milliseconds.

Power consumption is almost 0.5 amps from each of + and –24V power supply, or 23 watts of electrical power.
7 watts of heat is generated by the scanner while scanning.
7 watts of heat is also generated by the power amplifier portion of the servo driver.

60 Hz Sawtooth with cycloid flyback at 40 degrees optical



With a sawtooth waveform that has cycloid flyback, the program is set to generate a 4.1 millisecond flyback time, and 12.5 millisecond ramp portion.

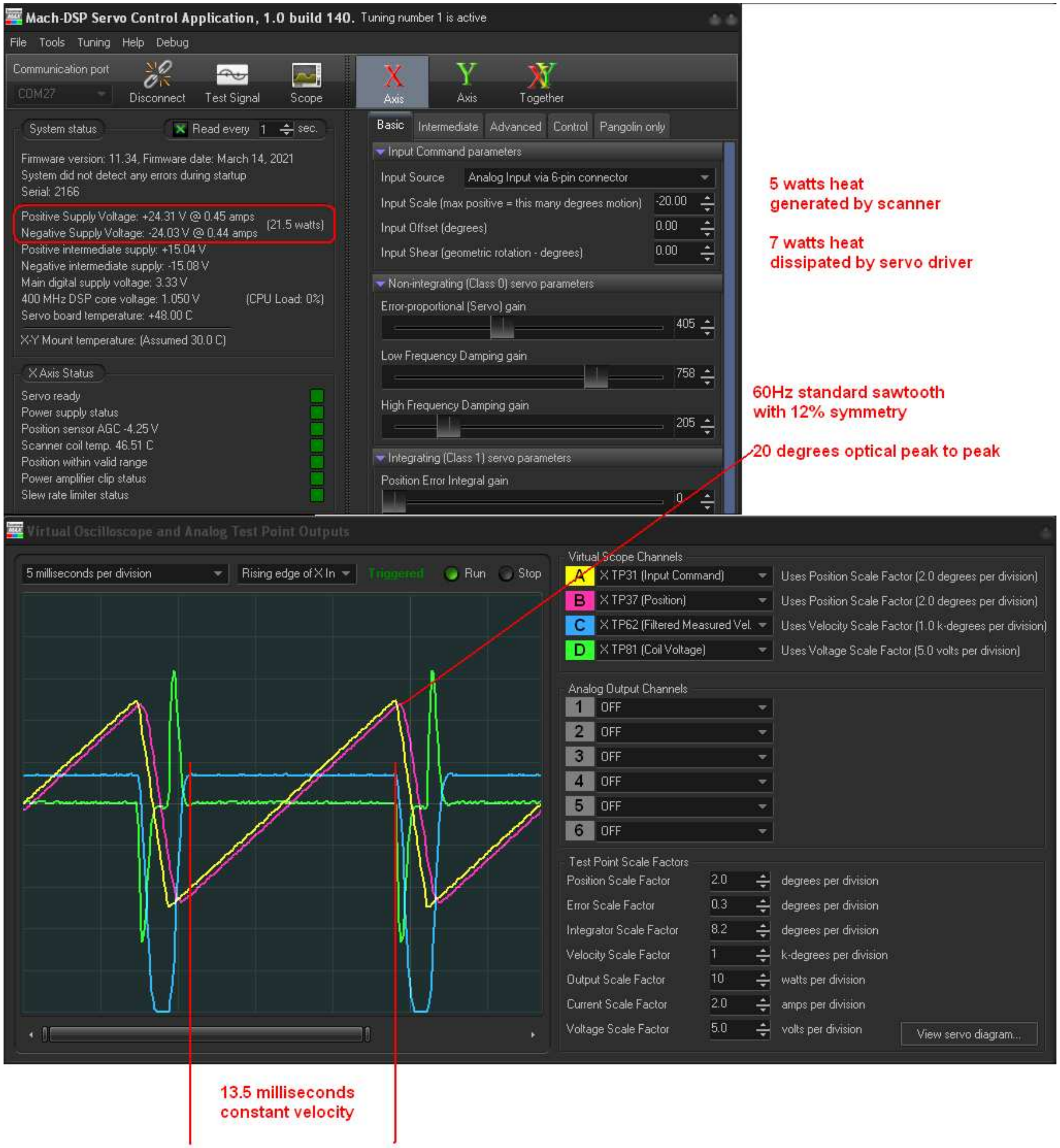
Note that when using cycloid waveforms, the scanner tracks the incoming waveform much more faithfully. The scanner's position signal is rounded, and the incoming waveform is also rounded. Given that the roundness of the waveforms approximately match, the position signal achieves the full 40 degree scan.

Also note that although the waveform implies a 12.5 millisecond ramp portion, the scanner itself is only at constant velocity for around 12.2 milliseconds, which is 6% better than the 11.5 millisecond achievable with the standard sawtooth waveform.

Given that the coil voltage seen above is only around +/-15V, it is possible that the flyback time may have been decreased slightly, and ramp portion may have been increased slightly, thereby providing even higher efficiency.

Power consumption is around 0.72 amps from each of + and –24V power supply, or 35 watts of electrical power.
10 watts of heat is generated by the scanner while scanning.
13 watts of heat is also generated by the power amplifier portion of the servo driver.

60 Hz Standard Sawtooth at 20 degrees optical



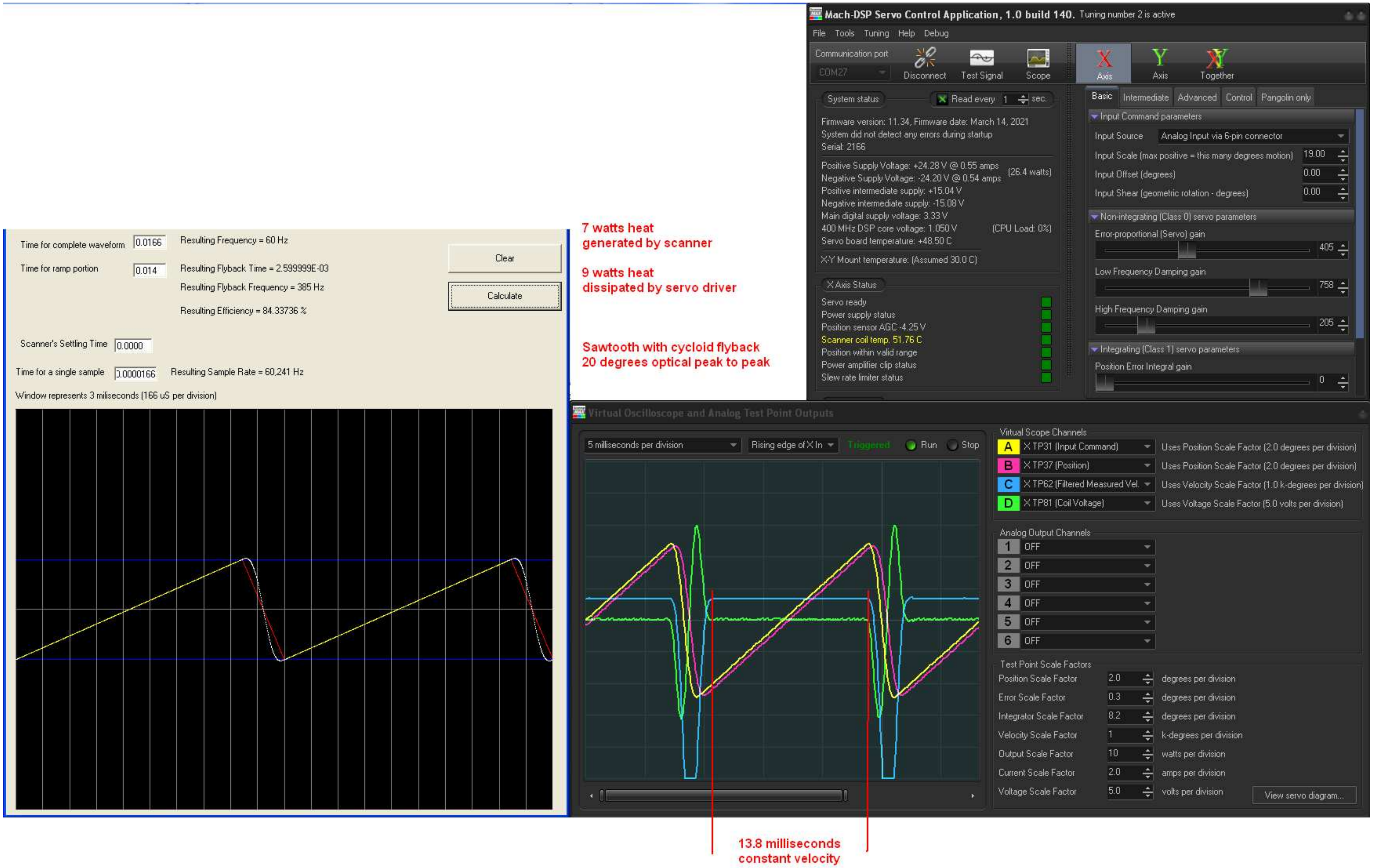
With a standard sawtooth waveform, symmetry must be set to 12% (2 millisecond flyback, 14.7 millisecond ramp).

Note that when using standard waveforms like this, the scanner itself does not completely track the incoming waveform. The scanner's position signal is rounded, albeit not as much as it was for the 40-degree waveform. Nevertheless, the position does achieve approximately the full 20 degree scan.

Also note that although the waveform implies a 14.7 millisecond ramp portion, the scanner itself is only at constant velocity for around 13.5 milliseconds.

Power consumption is almost 0.45 amps from each of + and –24V power supply, or 21.5 watts of electrical power.
5 watts of heat is generated by the scanner while scanning.
7 watts of heat is also generated by the power amplifier portion of the servo driver.

60 Hz Sawtooth with cycloid flyback at 20 degrees optical



With a sawtooth waveform that has cycloid flyback, the program is set to generate a 2.6 millisecond flyback time, and 14 millisecond ramp portion.

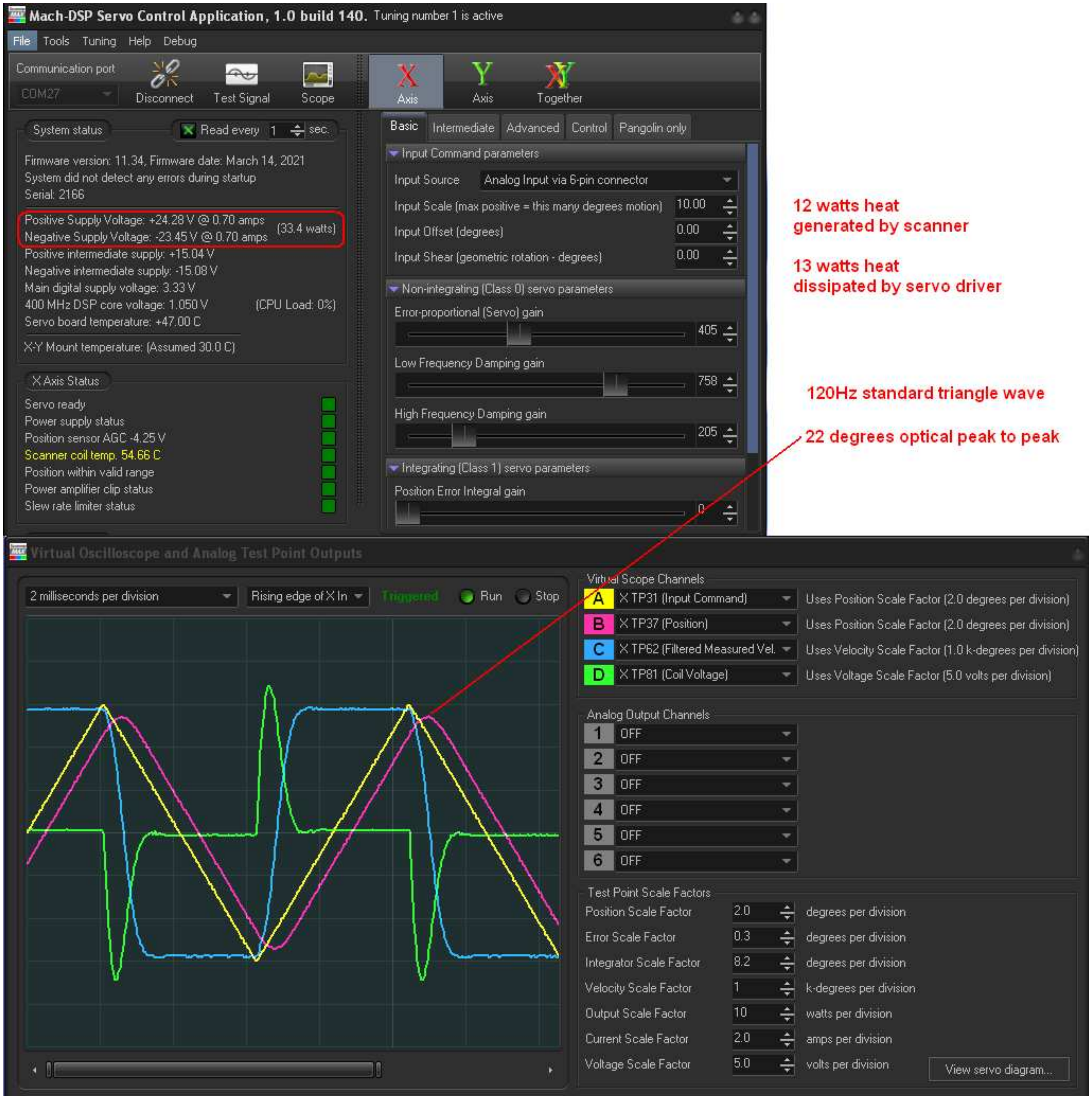
Note that when using cycloid waveforms, the scanner tracks the incoming waveform much more faithfully. The scanner's position signal is rounded, and the incoming waveform is also rounded. Given that the roundness of the waveforms approximately match, the position signal achieves the full 20 degree scan.

Also note that although the waveform implies a 14 millisecond ramp portion, the scanner itself is only at constant velocity for around 13.8 milliseconds, which is 2% better than the 13.5 millisecond achievable with the standard sawtooth waveform.

Given that the coil voltage seen above is only around +/-15V, it is possible that the flyback time may have been decreased slightly, and ramp portion may have been increased slightly, thereby providing even higher efficiency.

Power consumption is around 0.55 amps from each of + and –24V power supply, or 26.5 watts of electrical power.
7 watts of heat is generated by the scanner while scanning.
9 watts of heat is also generated by the power amplifier portion of the servo driver.

120 Hz Triangle Wave at 22 degrees optical



12 watts heat
generated by scanner

13 watts heat
dissipated by servo driver

120Hz standard triangle wave

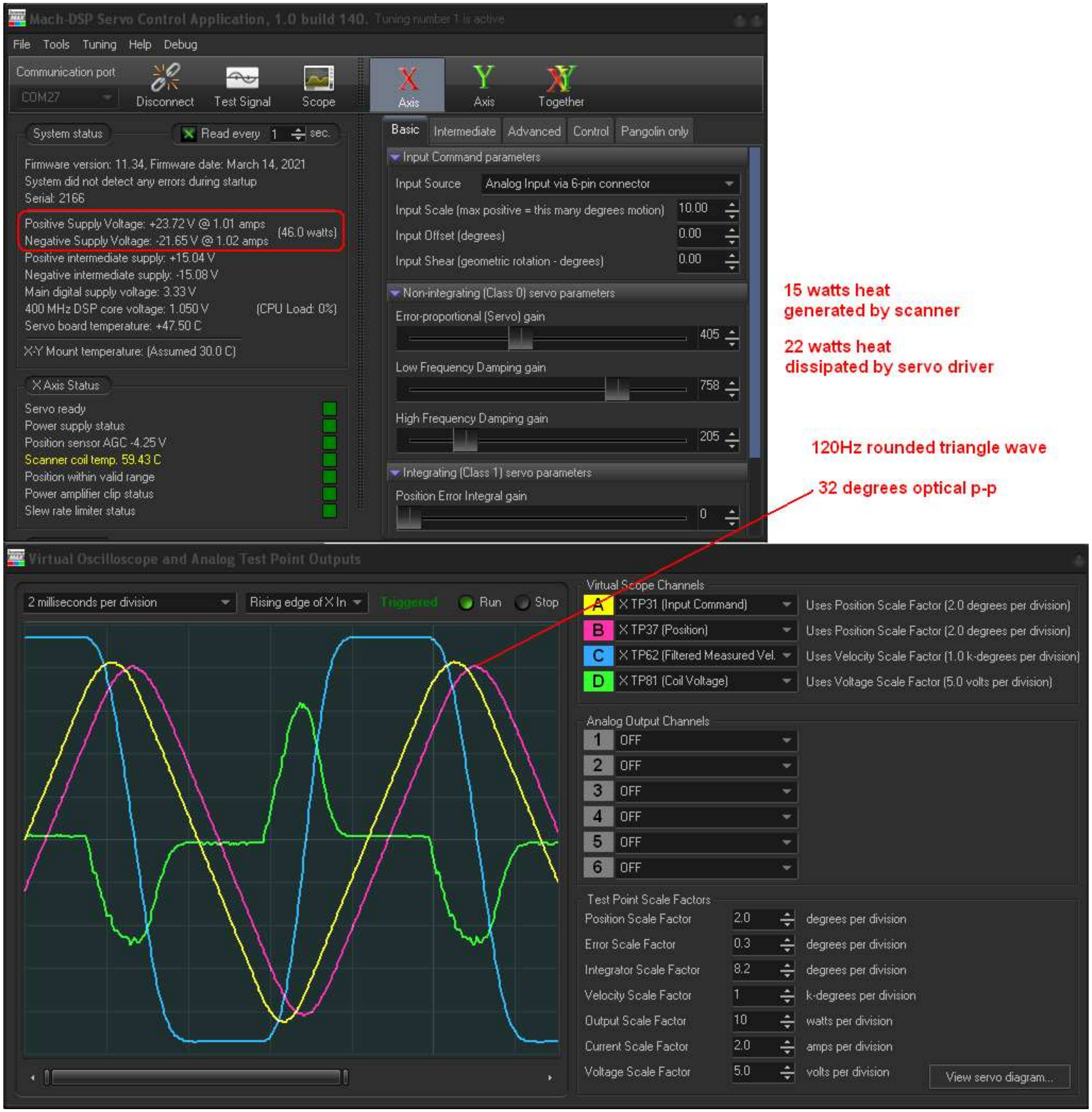
22 degrees optical peak to peak

With a standard triangle waveform, the greatest amplitude that can be scanned at 120Hz is 22 degrees optical peak to peak. This is because a higher amplitude triangle wave would exceed the maximum coil voltage that could be supplied by this particular servo driver power amplifier configuration.

Note that when using standard waveforms like this, the scanner itself does not completely track the incoming waveform. The scanner's position signal is rounded, although the incoming waveform is pointy. Here we can see that the incoming waveform amplitude commands 24 degrees optical peak to peak, although the position only achieves around a 22 degree scan angle.

Power consumption is around 0.7 amps from each of + and –24V power supply, or 33.4 watts of electrical power.
12 watts of heat is generated by the scanner while scanning.
13 watts of heat is also generated by the power amplifier portion of the servo driver.

120 Hz Rounded Triangle Wave at 32 degrees optical



15 watts heat
generated by scanner

22 watts heat
dissipated by servo driver

120Hz rounded triangle wave

32 degrees optical p-p

Just as rounding the sawtooth waveform using a cycloid technique results in more faithful tracking of sawtooth waveforms, this same trick can be used with triangle-waves. In essence, “rounding” can be imparted onto the tips of the triangle waveform, which reduces the coil voltage requirement and allows greater scan amplitude.

With the rounded triangle wave above, the greatest amplitude that can be scanned at 120Hz is 32 degrees optical peak to peak. If the waveform is rounded more, then an even greater amplitude triangle wave could be achieved.

Power consumption is around 1 amp from each of + and –24V power supply, or 46 watts of electrical power.
15 watts of heat is generated by the scanner while scanning.
22 watts of heat is also generated by the power amplifier portion of the servo driver.

Conclusion:

This test generally shows how the Saturn 9B can be used to scan 16mm Y-axis mirrors over wide angles with sawtooth and triangle waveforms, for imaging applications such as scanning microscopes. The mirror used is capable of projecting a 16-mm beam through a 40 degree optical angle, and given that it is a Y-axis mirror, it has the capability of receiving the 16mm beam from a separate scanner such as a separate galvo or polygon.

Given the power requirements and heat generated by both the scanner and servo driver, all of these waveforms could be scanned for a virtually indefinite period.

While a simple function generator can be used to generate the triangle-waves and sawtooth waves, a waveform that incorporates cycloid motion makes better use of the power capacity of the scanner and servo driver, and ultimately provides greater light throughput due to shorter flyback times. Cycloid waveforms also will not excite extraneous resonances, which are not present in this particular scanning system itself, but it also reduces vibration conveyed from the scanner to other components that might reside in the optical compartment.