Chopper motor control on MISM and NISM.

Background.

It was reported that the chopper on the MISM would fall out of lock (with its reference) over time, and it was suspected that this was due to changes in the temperature of the motor. Other unusual behavior was also reported such as only being able to achieve lock when the motor speed was increasing towards the desired value and not when a trying to reduce from one speed to another. It was reported that the chopper on the NISM had less problems and was more stable.

Circuit.

The chopper motor control circuit (drawing H-6172K2) is based upon a phase lock loop supplying the motor drive voltage to a brushless motor drive IC. The phase lock loop (PLL) compares the frequency of the chopper wheel measured by an opto-switch and that of a computer generated reference, the output of the PLL either increases or decreases motor drive voltage to remain in a phase locked condition. The key element in this is the loop filter which sets the response time of the loop and defines the loop stability.

The loop filter design is an adaptation of that in Unitrode application note U-113 from the 1990 Unitrode linear integrated circuits data and applications handbook. The filter consists of two elements, a low pass filter to attenuate the reference frequency, and the loop filter proper which supplies the necessary gain and phase response to the overall loop.

It was noted that both the MISM and the NISM had R21 as 180K rather than 1M as suggested by the design notes – this effectively reduces the loop filter gain from 14.6dB to 0dB.

Initial investigation of the MISM

It is time consuming to vary the temperature of the MISM by any significant amount so the initial investigation concentrated on examining the circuit operation and its ability to change lock-in frequency.

Two points in the circuit are indicative of circuit state, the output of the phase comparator, Vcomp (pin 13 of IC4) and the motor control voltage, Vmot (pin 4 of IC1).

When Vcomp was set to a 50% duty ratio 0-5V square wave with a reference frequency of 1KHz, it was noted that:

a/ Vmot was about 2.8V when locked, maximum Vmot about 4.8V.
b/ When locked a ripple of about 0.25V and 30Hz (roughly the rotation speed of the motor) is present on the 5V supply rail.
c/ While trying to achieve lock the noise on the 5V rail increases up to about 1V.
d/ When in an unlocked state Vmot is oscillating between 1v and 4.8V with a period roughly equal to the rotation period of the motor.
e/ The circuit will not operate on an extender card.
f/ The lowest reliable lock frequency was 960Hz, the highest 1080Hz.
g/ Lock in was easier to achieve when the motor speed was increasing, ie moving from a lower frequency to a higher frequency is more successful than the reverse.
h/ Small variations in Vmot result in a frequency change of about 400Hz/V which is similar to the 1000Hz/2.8V normal condition.

Confirmation of the role of the rotation speed of the motor can be seen by switching off the drive to the motor and watching Vcomp which displays a component that starts at about 30Hz and slowly reduces.
Initial conclusions from the MISM.

a/ Failure to achieve lock results from a resonance of the control circuit to the motor speed rather than from a lack of dynamic range in the phase comparator or in the voltage available to drive the motor (Vmot).

b/ The component of motor speed ripple on the 5V supply rails to the op amps is too large for reliable operation.

1st level circuit modifications.

The first modification required to the circuit is to decouple the motor and the op amps supply rails. Some experimentation was done with adding reservoir capacitors but the most satisfactory solution is to run the motor from a separate supply. Hence further testing was done with a separate 5V supply to Q2, with a 220uF capacitor local to the high side of Q2.

Although it is not considered that phase comparator dynamic range is a problem, it was noted that the output of the comparator is in tristate when phase lock is achieved, and that by having a pull down resistor but no pull up resistor on the output the circuit would be running 50% tristate and 50% high to get the desired 50% duty ratio square wave on the output – ie with a 180 degree phase difference between the signal and the reference, this effectively reduces the dynamic range of the comparator by two. Adding a 100K pull up resistor means that the output will sit at 2.5V when in lock with pulses up to 5V or down to 0V when out of lock – this is a far easier condition to judge accurately than a 50% duty ratio. The pull up resistor was added for all further tests.

With these modifications:

a/ Motor control becomes noticeably more stable, with the circuit offset voltage set for operation at 1kHz, lock can be reliably achieved from 900-1100Hz. Operation can be reliably switched from 950-1050Hz and back.

b/ The circuit will operate from an extender card.

c/ Failure to lock still results in a 30Hz oscillation of Vmot.

d/ No 30Hz ripple is observable of the 5V power.

e/ A 30Hz ripple can be seen on Vcomp when in lock, with half the rotation too fast and half too slow.

f/ Lock in was maintained for long periods (>12 hours) even at the frequencies which were difficult to lock originally.

g/ Motor current peaks at about 0.4A during start up and sits at about 0.15A at 1kHz.
h/ high frequency noise on Vmot, can be reduced by adding a 220UF cap to Pin 4 of IC1 – this does not influence the low frequency behavior of the loop.

Loop filter re-design.

The loop filter was redesigned, see attached scribble. Note that the component values are very different from the original and the reason for this has been highlighted in the scribble. Several filters were tried, at unity gain frequency at 4Hz and at unity gain at 30Hz (in an attempt to include the chopper wheel asymmetry within the loop).

Filter 1 – 4Hz, 3dB gain, original reference

a/ Lock in either direction from 920-1120 Hz

b/ 30Hz oscillation still cause of non-lock

Filter 2. – 4Hz, 3dB gain, modified reference filter

a/ Lock in range improved, 880-1150Hz
Filter 3. – 3db 30Hz filter, wider bandwidth, 34Hz ref filter
a/ Reliable lock in range 700-1250Hz
b/ Low frequency wobble on output, 30 Hz wobble on output more pronounced.

Filter 4. 30Hz filter 40dB gain.
a/ Oscillates at rotation speed – probably positive feedback from phase delay in motor response

Most successful for MISM is filter 2.

**Temperature tests of MISM filter 2.**

The MISM was placed such that the external head piece of the instrument was in the freezer, this was then insulated from the detector side that remained outside. Temperature was monitored by a PRT in contact with the metal of the enclosure.

Filter offset adjusted at +20°C, when cooled to –60°C, loop stayed locked with detector output at 18% high at the –60°C point, no measurable change in motor voltage or current. Loop successfully re-acquired lock after power downs. Warmed back to +20°C, loop stayed lock and returned to the initial adjust position.

When the filter offset was adjusted at –60°C, and then the motor warmed back to 20°C, loop remained locked with detector output at 15% low at the 20°C point. Loop successfully re-acquired lock after power downs.

**Why was the original filter more successful on the NISM than the MISN.**

Calculation of the gain required for the NISM loop filter (in scribble page 7) gives a value of 21.3dB, some 14.8dB higher than that required for the MISM. Hence the same filter used for the MISM and NISM would be operating with far less relative gain in the case of NISM and would be less likely to oscillate with the rotation speed of the motor. Further more, the slower operating speed of the NISM and the lower moment of inertia of its chopper wheel means that the phase angle between the control and the motor wheel rotation would be less than in the case of MISM, adding to the stability.

Despite the two favorable factors above, perhaps the greatest single factor would be the relative balance of the two chopper blades – tests with the NISM show no detectable motor speed component on Vcomp.

**MISM Loop gain and stability.**

The higher the loop gain, the quicker the loop can respond to changes, however a high gain loop will be less stable. R3 can be selected to modify the gain the loop. For the chopper motor, response time is relatively un-important as external changes (such as temperature) are very slow – the exception to this being the initial time to lock from power on. Reducing the gain will also reduce the dynamic range of the loop.

Reducing the gain by modifying R3 decreases the motor speed ripple on Vmot and on Vcomp and hence the jitter in the locked frequency. The reduction of Vcomp jitter is evident but difficult to measure.

<table>
<thead>
<tr>
<th>R3</th>
<th>Gain</th>
<th>Initial time to lock</th>
<th>Vmot ripple</th>
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<tbody>
<tr>
<td>680K</td>
<td>3.6dB</td>
<td>12S</td>
<td>0.26V</td>
</tr>
<tr>
<td>434K</td>
<td>-0.3dB</td>
<td>14S</td>
<td>0.16V</td>
</tr>
<tr>
<td>307K</td>
<td>-3.3dB</td>
<td>16S</td>
<td>0.12V</td>
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</table>

The –3.3dB gain variant of the filter was also tested at varying motor temperatures.
Loop offset adjusted at 20°C, cooled to –60°C, motor stayed locked with detector output at 35% high at 60°C. Loop successfully regained lock after power downs. Loop offset adjusted to centre and then motor warmed to +20°C, motor stayed locked with detector output at 35% low back at 20°C. Loop successfully regained lock after power downs.

Note: Detector output at a higher mark/space ratio is to compensate for lower loop gain.

(Reference filter changed back to C1=47nF at this point).

**NISM.**

This filter (-3.3dB variant) worked ok the NISM although two problems were evident.

1. Under-damping
2. Large amounts of break through of the reference oscillator.

In the NISM case motor speed ripple was not detectable.

NB NISM runs at about 2V Vmot.

Adjusting the reference filter to

\[ C_1 = 47\text{nF} \]
\[ C_2 = 10\text{nF} \]

And increasing the Gain to 18dB by putting in the main filter

\[ R_1=600\text{K} \]
\[ R_2=68\text{K} \]
\[ R_3=1.5\text{M} \]
\[ C_1=188\text{nF} \]

Produced a stable and controllable filter, not temperature tested but confident it will work.

This filter achieved lock from 47Hz –237Hz, from a center frequency of 77Hz.

**Motor observations.**

During the cold testing in the fridge some odd properties of the chopper motor were noted. During cooling from 20°C the motor took more effort to spin until about –10°C, it then began to become progressively easier to spin with Vcomp at about –35°C being the same at 20°C, it continued to get easier to spin all the way to the coldest temperature reached at –60°C.

**New Circuit.**

Attached is the new circuit diagram, it uses a LM2575-5 5V switching power supply to generate 5V for both the motor voltage and for the TDA5141 chip. Expected efficiency is over 75% with a standby current of approx 100uA.

Filter component values are given in the table below.

**Conclusions.**

The main problem with the loop was noise on the Op amp power rails– supplying the motor with a separate supply to that of the Op amps eliminates this problem.
A component of motor speed is evident on the MISM control voltage – it is likely that this comes from an unbalanced load on the motor, when lock can not be achieved it is because the loop oscillates at the motor speed.

The NISM does not show a component of motor speed on the control voltage, however reference frequency breakthrough is apparent. When lock can not be achieved it was because the loop oscillated at the reference frequency.

Dynamic range available is more than adequate to control the motor from +20° to –60°C without adjustment to the filter offset.

With a separate motor power supply, the basic loop design is fine, optimisation of the design is a case of selecting component values.

The following table gives component values for the loop filter for the NISM and MISM, in both cases it gives the values that were best on actual test and the suggested values to use (not tested due to lack of components at time of writing).

<table>
<thead>
<tr>
<th></th>
<th>Nism tested</th>
<th>Nism suggested</th>
<th>Mism tested</th>
<th>Mism suggested</th>
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<tbody>
<tr>
<td>Reference</td>
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<tr>
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<td>172nF</td>
<td>66nF</td>
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Mike Rose 6/5/99