Construction and Adjustment Notes for the IG-18SL

The IG-18SL is an upgrade to the Heathkit IG-18 Audio Generator (also applicable to the IG-5218). This paper contains rough instructions for building the IG-18SL. Much is left to your skills however, so you need to be an experienced electronic project builder to complete this successfully. Assume that you are basically building it from scratch, using the schematic. These instructions just make it a bit easier. Note to international readers: *This modification cannot be used on 220V mains unless a 120V adapter is used*. It uses the 220V wiring on 120V, to get reduced PS voltage. Acknowledgment: This oscillator circuit is based-on the HP-339A. Its stellar performance is a testament to the greatness of HP (now Agilent) engineering.

Related documents:

- Schematic pages 1,2 Rev.6.
- Oscillator Board Pictorial Layout Rev.5, (normal and reversed)

Construction Tasks:

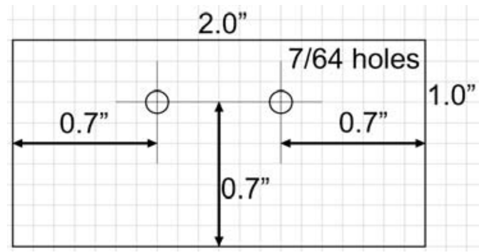
- Cut and drill the perfboard per the Pictorial.
- Wire the perfboard, leaving out the power supply (**hereafter "PS"**) jumpers.
- Cut and drill the heatsink. Assemble it to the regulators, insulating the 7915.
- Measure and sort caps to make the six precision values for the Multiplier switch.
- Modify (see below) and prewire the Multiplier switch.
- Fabricate and assemble the 15.8uF cap assembly and mount it on the back of the Multiplier Switch.
- Remove the existing oscillator board and Multiplier Switch.
- Install the new oscillator board and Multiplier Switch.
- Wire the oscillator board and Multiplier Switch into the system.
- **Rewire the transformer primary for 220V to get lower secondary voltage.**
- Test and debug the oscillator with an external, current-limited PS.
- Test and debug the internal PS. Install PS jumpers.

Oscillator Board Assembly

- The original PS and oscillator boards are not used. The new perf-board replaces the old oscillator board and includes the PS components. The original PS board can be left in place. The transformer leads must be extended (using heatshrink) to reach the new board.
- I generally tried to follow Heath's wire color coding for the notch filter and other circuits.
- Vector T68 press-in stakes (cut 1/8" below the board) were used to define external terminals and the PS jumpers on the board.
- In constructing the board, I followed the schematic, beginning at TP4, working my way left, both on the schematic and physically. Use the normal pictorial to place components and the reversed pictorial to connect wires under the board.
- Mount several components at a time and then wire them.
- Use IC sockets (without the IC's mounted) for construction.
- Some places the routing is tight. However, I did not route between leads which were spaced only 0.1". In two places, speghetti is needed to insure safe routing, though.
- I first built the oscillator section, then the square wave converter and finally the PS section.
- Grounding is critical to the performance of the oscillator. In the oscillator circuit, there are clean and dirty grounds which come together at the PS star ground. Separate routing to the star ground is important.
- The ground connection for the output attenuator and connector is returned to its

own special point on the clean ground.
- The ground connection for the square wave attenuator and connector is returned to its own special point on the dirty ground at the square wave converter.
- The AC mains ground connects to the chassis but not to any audio grounds, except through a 0.047uF cap on the new board. This is like Heath's circuit but remove the existing 0.047uF cap, under the chassis to control the connection point.
- Even if you choose to build the breadboard differently from the pictorial, I recommend that you layout U1 and the components around it (especially the bypass caps) exactly as shown in the pictorial.

Heatsink



- I used a strip of 1" x 0.08" aluminum bar stock available at Home Depot. Cut and drill as shown **at right**. The holes assume 4-40 mounting screws.
- Although painting it black would improve emissivity, I just finished it by sanding.
- When assembling to the TO-220 regulators, use heatsink grease. The 7915 regulator will need a mica insulator/bushing kit. Use grease on both sides of the insulator. The heatsink will be connected to ground by the tab of the 7815.

Modifying the Multiplier Switch

- The Mouser 690-C4D0604N-A six-pole, 4-position switch was one of the few such units I could find and it cost $16. It needed some modifications:
- Note that the end position is set by the position of a washer-tab on the shaft. It should be in the third slot counting CW from the left-most.
- The locator tab which is on the switch front housing should be broken off. It is intended to protrude into a hole in the front sub-panel to fix the orientation but we do not have such a hole.
- The D-shaft has a much shallower flat than the half-moon the Heath knobs require. I ground it with a grinding wheel which has a fairly sharp corner. Be careful, checking it with the knob and stopping short as you get close. Finish with a file. I went ~8mils too far and had to shim with thin metal.
- The units I received are way too hard to turn. To fix it, I drilled-out the two 1" rivets which hold it together. (To reassemble you will need 4-40 x 1.25" screws which are available from MSC.) It turned out that those screws are also needed to mount the cap board on the rear. Be careful not to lose the two ball-bearings which implement the detents. As shown **below right**, the front housing contains a spring (left) which is too stiff. I substituted the spring on the right but it needed mods, cutting off the top and bending the top spiral nearly flat. The result is a much nicer action.

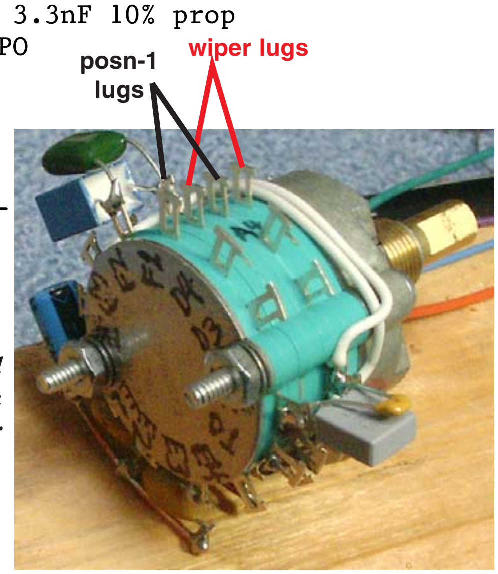
- Reassemble the switch with the 4-40 x 1.25" screws, lockwashers and nuts. The nut should be on the back side of the switch. NOTE: Before tightening the nuts, compare your switch to the photo on the next page. Set your switch to the leftmost position and orient the flat side of the shaft as in the picture. If you see wiper lugs at the same position as in the picture, the orientation of the wafers matches mine. If not, remove the nuts. Hold the switch, shaft-down, keeping the screws in-place. Pull the wafers off the screws, rotate them 180-deg, put them back on the screws and affix the nuts. The switch should now match the photo.

- Finally, to make the knob even with the others, you will need to put a nut and lockwasher on the shaft bushing before mounting the switch.

Multiplier Switch Capacitors

- Terminology note: I will say "cap value" to refer to a cap made up of multiple caps in parallel.
- Two classes of caps are used on the Multiplier switch: There are six, precision tuning cap values and then there are six control loop caps. The control loop caps do not require precision or linearity and can be polarized. They can be hi-K ceramic, tantalum, even aluminum. 10-20% accuracy would be nice for those, so aluminum may be a pushing it a bit. I used aluminum only for the 47uF.
- I used a Tenma 4-digit LCR meter to pick the tuning caps. Was easily able to get all values within one least-significant digit of the target "158" values.
- The LCR meter has a choice of test frequencies: 120Hz and 1kHz. I used 120Hz for the 15.8uF and 1kHz for the rest.
- For what it's worth, my frequencies tended to be 0.5% to 1% high.
- Use film (polypropylene preferred) or NPO ceramic types for the tuning values. *Unacceptable* types include: aluminum, tantalum and hi-K ceramics.
- The following table lists the values and the combos that I used for the tuning cap values. Notice that I was relying on the fact that they are typically a lot closer to nominal value than the specs state. (ester=polyester, prop=polypropylene)

Target Value	Capacitors Used
15.8uF	10uF 10% ester, 5.6uF 10% prop, 0.22uF 5% prop
1.58uF	1.5uF 5% ester, 0.047uF 10% ester
0.158uF	0.15uF 2% prop, 4.7nF 10% ester, 3.3nF 10% prop
0.0158uF	0.015uF 2% prop, 820pF 10% cer NPO
1.58nF	1.5nF 2% prop, 68pF 10% cer NPO
158pF	150pF 5% prop, 5-30pF trimmer



Partially wired multiplier switch in proper orientation.

- The following table lists the caps which I used for the control loop caps. These have to be physically small:

Value	Capacitor Used
47uF	47uF aluminum tol?
10uF	10uF tantalum 10%?
1.5uF	1.5uF tantalum 10%
1.0uF	1.0uF hi-K cer 20%?
0.33uF	0.33uF X7R cer 10%
0.15uF	0.15uF X7R cer 5%

How the Switch is Arranged

- A photo of the partially wired switch is shown **at right**. Refer also to the switch deck drawing on the Notch Filter page of the schematic.
- There are six poles and four positions. I have labeled the poles A,B,C,D,E,F and the positions 1,2,3,4. So D4 is the lug for the 4th position of pole D. Lug D0 is the wiper. You can see the markings for the rear deck in the photo.
- The lugs are on two decks, front and rear. But each deck has two levels of lugs. The front level has the wiper lugs, which are aligned with position-1 lugs on the other level.
- So there are twelve lug positions around the circle. The poles for one deck are represented by three groups of four lugs.

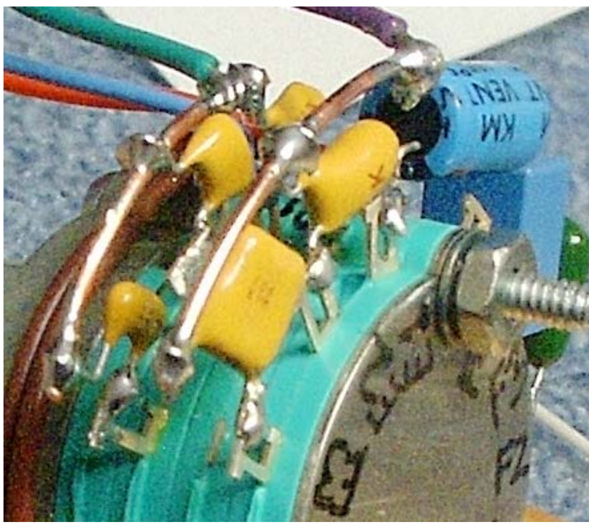
Building the Multiplier Switch

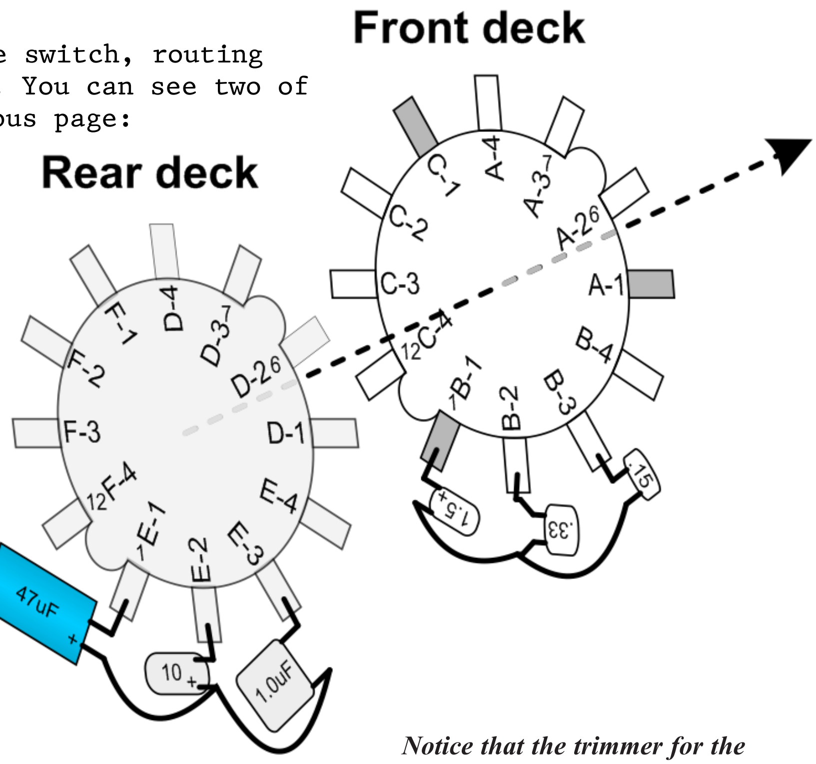
- Keep the caps as close to the switch as possible. Clearance is as low as 0.7".
- I arranged the poles so that the connections for each tuning cap are on the front and rear decks at the same compass position. For example, the 1.58uF cap value above goes from rear deck F2 to front deck C2. It's not there in the photo but the 158pf value will be from D4 to A4. (I slipped-in a label for A4 above.)

- I highly recommend that you label the rear as shown. Also slip-in labels for some of the other deck lugs.
- Here is the outline of the plan for building the switch:
  - Add internal wires.
  - Add control loop caps on B,E poles, with their rib-wires.
  - Add the 1.58uF,0.158uF, 0.0158uF, 1.58nF and 158pF tuning cap values.
  - Add leads to be used for external connections.
  - Assemble the rear cap board and attach it to the switch.
  - Mount the switch in the front panel.
  - Do all external connections.

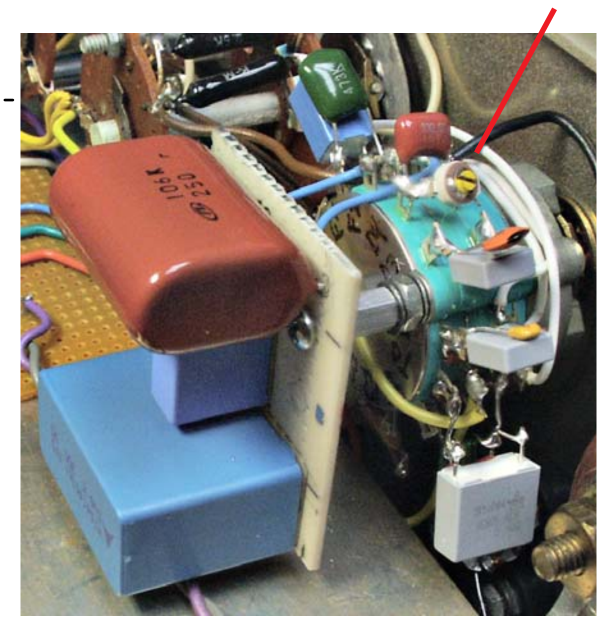
Internal Wires:

Add the four internal wires to the switch, routing them with clearance from the lugs. You can see two of the wires in the pic on the previous page:
- Wire A1-F3
- Wire A2-F4
- Wire C3-D1
- Wire C4-D2





Notice that the trimmer for the 158pF value should be oriented for convenient access.



Control Loop Caps

Add the control loop caps as shown **above right** and the photo **above left**. Note polarities. I used #12 house-wiring wire as the ribs which are the common terminal of each set of three. The rib is bent to match the curvature of the switch, about 1/2" above the lugs. Notice that you can lay the 47uF cap over the the F-4 position.

Tuning Caps

Add the five smaller tuning cap values to the switch. You can see them mounted across the top of the switch **at right**. Each value is made up of 2-3 caps. The connections for the caps are:
- 1.58uF C2-F2
- .158uF A1-D1
- 15.8nF A2-D2
- 1.58nF A3-D3
- 158pF A4-D4 (15.8uF is on the rear board. Will connect to C1-F1 later)

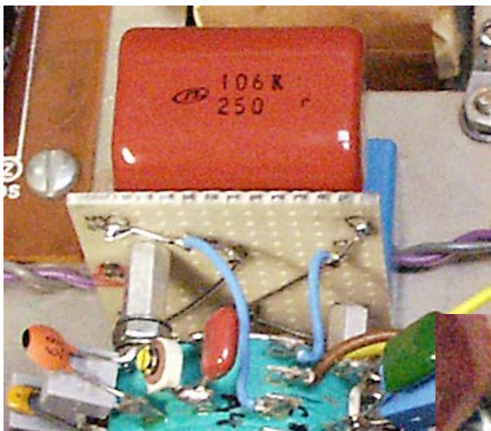
External Leads

Attach 9-inch wire leads which will be used for external connections to the switch. Temporarily route the leads out in the direction lug F-3 points. The lug connections, color and (future) external connections are below:

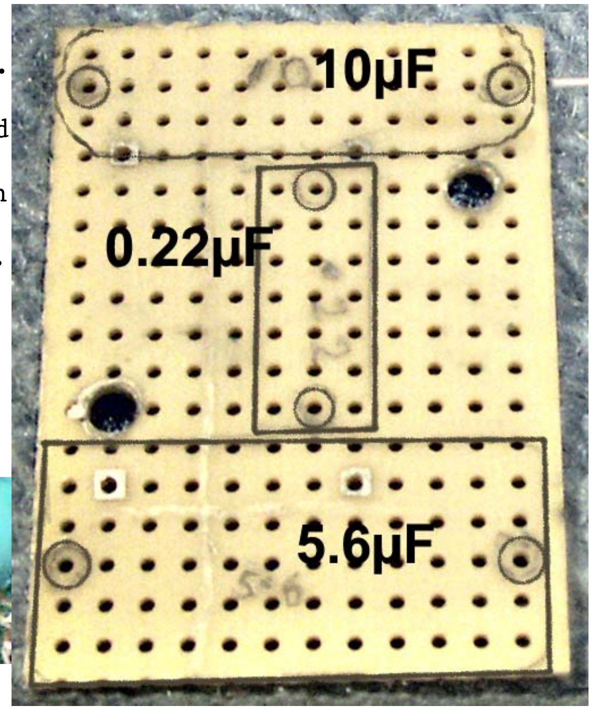
Lug Posn	Color	Extern Conn	Comment
A0	Wht	(K)	but connect to white wire terminal on 10's switch.
B0	Blu	(P)	
C0	Blk	(M)	
D0	Yel	(H)	Add TWO leads. Will go to yel 10's switch lug and R106.
E0	Org	(O)	
E-cap-cmn	Vio	(N)	"E-cap-cmn" is the common of the caps on E-pole.
B-cap-cmn	Grn	(L)	"B-cap-cmn" is the common of the caps on B-pole.
F0	Brn	(TT-Brn)	May use existing brn wire on 10's Freq switch.

Rear Cap Board

- Make the rear cap board as shown **at right**.
- Dimensions are 1.3 x 1.8".
- Insert the 10uF, 5.6uF and 0.22uF caps and wire them in parallel as seen in the photo **at left** and others.
- Add lockwashers and 3/8" 4-40 standoffs to the switch screws as shown **here**:



- Mount the rear cap board to the standoffs with two 4-40 x 1/4" screws.
- Connect the rear cap board to C1-F1.



Rear cap board; view from component side.

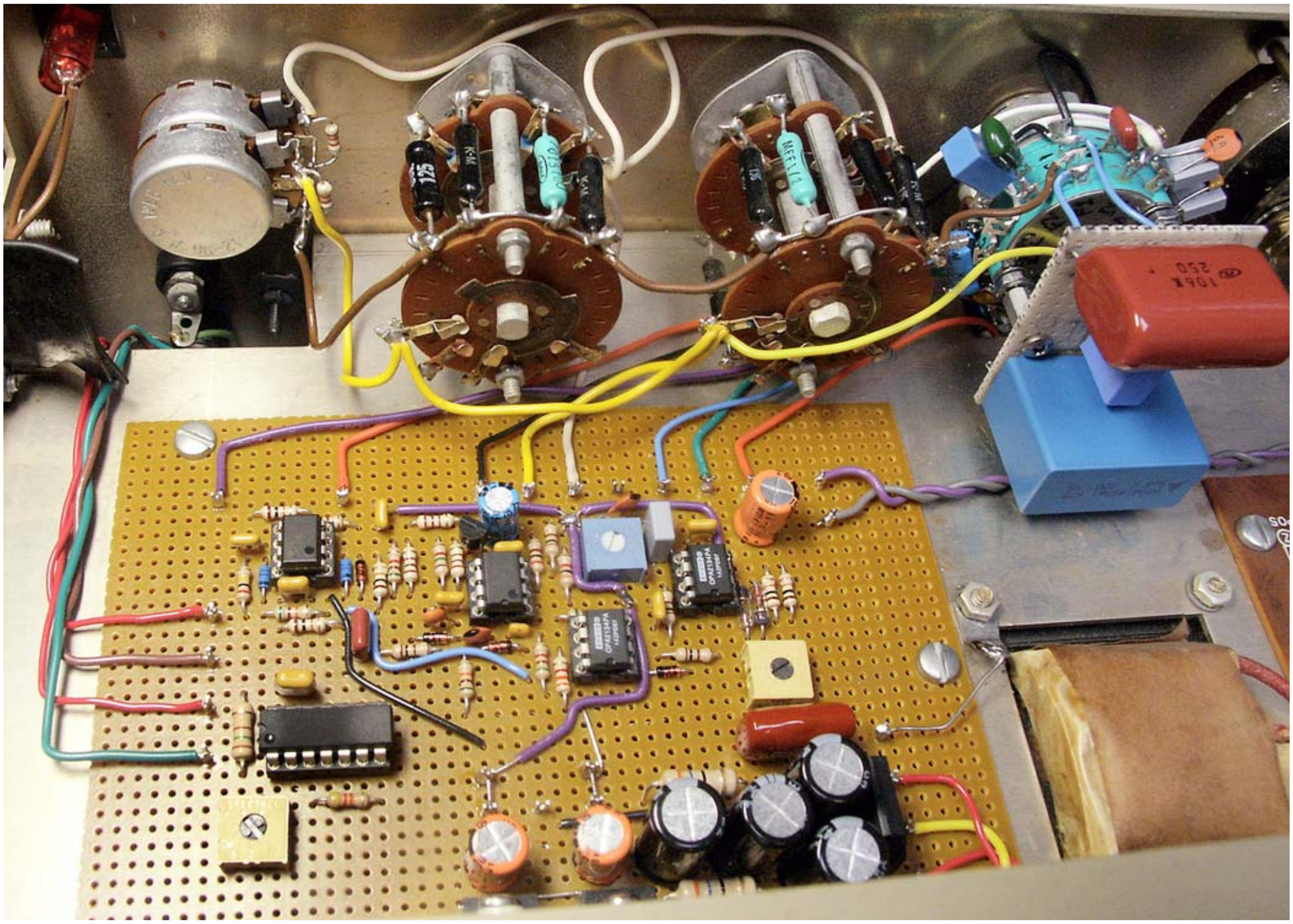
Mounting the Switch and Oscillator Board

- Disconnect and remove the old oscillator board. Bolt-in the new one.

- Disconnect the wires from the old Multiplier Switch and remove the switch. We can use the brown wire from the 10's switch but the white and yellow ones are probably too short to reach the proper terminals on the new switch. Remove those from the 10's switch but note where they go.

- Mount the switch to the front panel. You may need to put a 3/8" nut and a lockwasher on the bushing before mounting, to make the knob even with the rest. Use a 3/8" flatwasher and nut to secure the switch to the front panel but don't tighten yet. Place the knob on the switch and check whether its height matches the other knobs. If not, adjust the nut behind the panel. (No not *you* :)

- Once that is done, set the switch to X10 and adjust switch position so the knob pointer aligns with the front panel mark. Tighten.



External Switch Connections

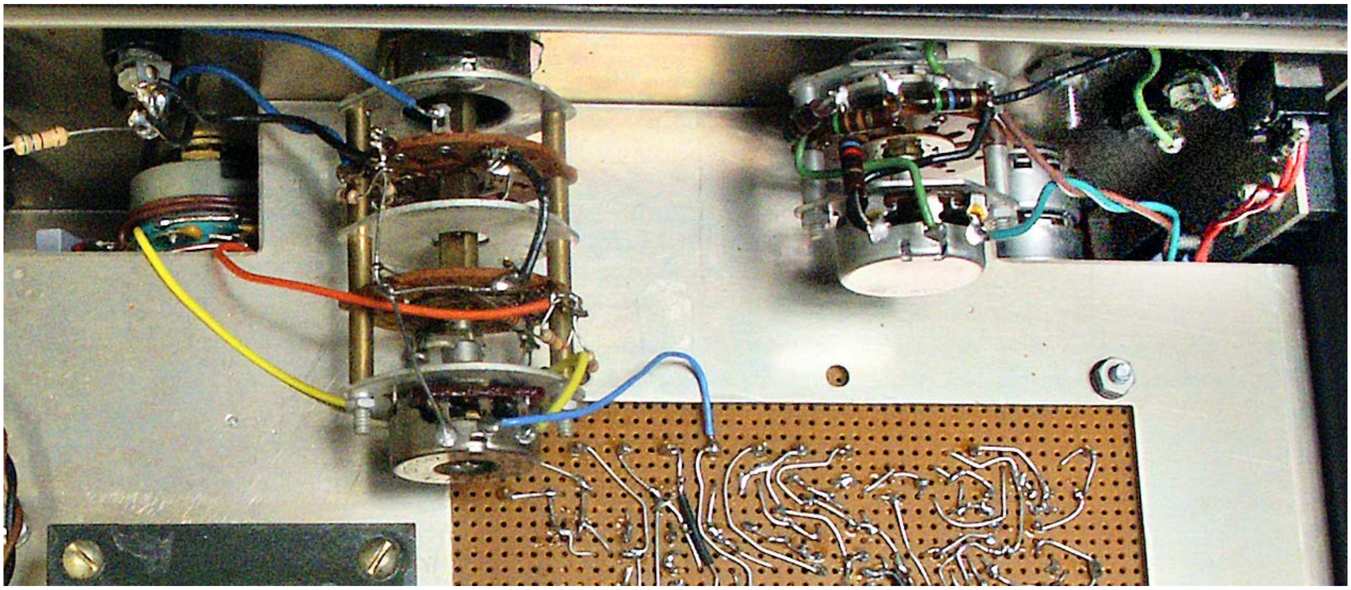
- Refer to the table on the previous page and the **photo above** for guidance on connecting and routing the wires from the Multiplier Switch to the rest of the circuits.
- Connect the brown wire from the 10's switch to F0 (remembering that the "0" indicates the wiper lug).
- The white lead from A0 goes to the terminal on the 10's switch where other white wires are connected. Try to keep this wire from getting too close to metal and especially from getting near the yellow wires.
- One yellow lead from D0 goes to the terminal on the 10's switch where other yellow wires go. Try to keep this wire from getting near the white wires. The other yellow wire from D0 goes down into the lower chassis, to the Amplitude pot, R106 (CW lug). Keep it away from the transformer. See photo on next page.
- The other wires from the switch go to the terminals on the oscillator board. Note that there are two orange wires used, so check the signal letters on those.

This completes the Multiplier Switch.

Wiring the Rest of the System

- Only one wire will be connected to the bottom of the new oscillator board. All other connections go to the terminals on top.
- There was a ground lug mounted below the chassis on one of the oscillator board screws. Move it above the chassis to the transformer screw shown above and connect it to terminal (S).
- Connect the existing purple (pos)and gray (neg) leads from the meter to (D) and (E), respectively.

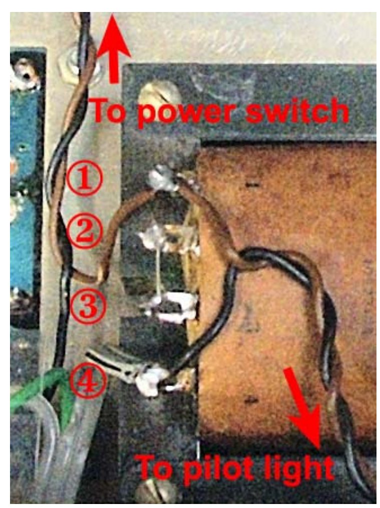
- Unsolder the transformer leads from the old power supply board and extend them about seven inches, insulating with heatshrink. Connect the yellow/red lead to (T) and the red leads to (U) and (V).
- Now refer to the bottom chassis wiring **photo below**. Connect the wiper of the Amplitude pot to terminal (G). This will be the only connection to the bottom of the board. I left a little extra wire to allow the board to be tilted up from the top side while still connected.



- Connect an orange wire from the shown point on the attenuator switch [there is only a 2.4K resistor there] to terminal (F) on top of the board. Keep the yellow and orange wires apart.
- Connect green and brown wires from the square wave fine control CW terminal and attenuator ground to terminals (B) and (C) on the topside of the board. Twist the pair about 1-2 turns per inch. Bend the leads so they make minimal contact with the sharp edge of the chassis.

- You can see the back of the new Square Wave On/off switch in the upper right corner above, and from the front, in the photo at left. Drill a hole and mount the switch. For frequencies above 5kHz, turning off the square wave does reduce distortion.

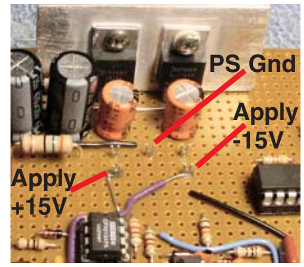
Connect it with red leads to terminals (A) and (Q) on the topside of the board. Order doesn't matter. You can twist the leads for neatness. Bend the leads so they make minimal contact with the sharp edge of the chassis.



Rewiring the Transformer
- The new power supply requires a lower secondary voltage from the transformer. We get that by wiring the primary for 220V operation (but operate it on 120V).
- Refer to the transformer photo **at right**. Remove the existing jumpers: lug-1 to lug-2 and lug-3 to lug-4.
- Move the brown pilot light wire from lug-2 to lug-1.
- Add a jumper from lug-2 to lug-3.

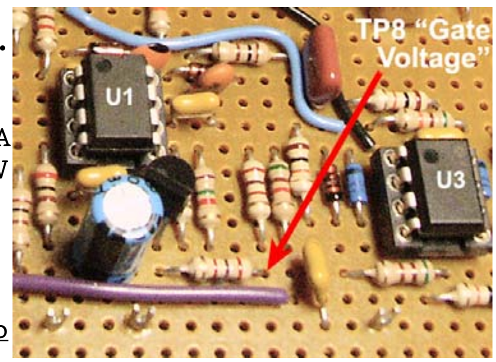
That completes the construction of the IG-18SL!

Final Tests and Adjustments



Initial Checkout

- Preset the three pots to their center positions.
- We assume that you implemented the power supply jumpers JP1,2 and that those are open, breaking the connections between the ±15V supplies and the oscillator. *If you don't have the oscillator isolated from its power supply components, do not connect an external supply.*
- Adjust a dual lab power supply (PS) for ±15V and 70mA current limit.
- Turn it off and connect it to the oscillator side of the PS jumpers (JP1,2) and to the PS ground terminal, as shown **above right**.
- Set the IG-18SL for 1kHz, max amplitude. Attach an oscilloscope (**hereafter "scope"**) to the output of the unit. Turn on the lab supplies. You should see a sinewave of about 20V peak-to-peak (**hereafter "Vpp"**). If not, try adjusting R30.
- Note that R30 can force it to oscillate even when the control loop is not working. Normally, the unit will show stable 20Vpp amplitude over a wide range of R30 settings. If it does not, investigate the problem. (Sorry that troubleshooting is beyond the scope of these instructions.)
- Temporarily set R30 for -1.0VDC on TP8 (**at right**). It should typically adjust from a positive value (stay away from that) to -3.3VDC.



- Check the +15V current drain. It is typically 47mA with the square wave on and 32mA with it off. -15V current drain is about 28mA.
- If it looks okay, remove the lab supply. With JP1,2 still open, connect the IG-18 to AC power and switch it on. Verify that the voltages on the supply side of JP1,2 are about ±15V. Voltages into the regulators with no load are typically ±29VDC.
- Passing that test, unplug the unit and solder the JP1,2 connections.

Operating Point Adjustment

- Power it back up and set frequency for 10 X100. Adjust Operating Point, R30, for a "Gate Voltage" of -1.0VDC on TP8. Leaving the 10's frequency control on 10, check the gate voltage on the other Multiplier ranges. Ideally, it will stay between -0.5V and -2.0V. If it goes more positive than -0.5V, adjust R30 so that it does not do so. Check some other frequency control settings to make sure that it stays more negative than -0.5V.

Meter Adjustment

- Turn the variable amplitude control all the way down and zero the meter using its mechanical zero screw.
- Set frequency for 1kHz and monitor the sinewave output voltage with a DVM. Set the amplitude and attenuator for a maximum, even value, such as 6.4Vrms. Adjust Meter Cal, R21, so that the meter indicates that value.

Square Wave Symmetry

- (Still at 1kHz) Connect a scope to the square wave output and set the output controls for maximum.
- Adjust the scope for the widest possible display of three transitions (e.g. low-high, high-low, low-high). Use horizontal position to center the middle transition in the graticule. Adjust symmetry, R6, until the high period is the same as the low period.

Final Tests

- Assemble the top and bottom covers to the unit.
- Check frequency across the band, using a frequency counter. My unit was typically 0.5 to 1% high. However when the 10's frequency switch is set to 30, it can be 2% high. (The standard resistor value used is a bit off the mark.)
- Check amplitude flatness across the band. My unit is typically ±0.01dB from 10Hz to 40kHz. From 20-20kHz, the built-in meter should settle back on the same hair-

line, as the Multiplier switch is advanced.
- Check distortion. Mine reads 0.0014% at 1kHz on an HP-8903A. That value is attributable to the analyzer itself.

Congratulations! This completes the IG-18SL Audio Generator project.

Detailed test results

- Accuracy, flatness and distortion are shown **at right**.

- Settling: Generally 250-500ms. 1-sec max on all ranges.
  - No ringing on envelope.
  (Freq switches at 10 or more.)

- Max sine level: 6.56Vrms

- Max square wave pos level: 8.56V.

- Square wave neg level: <1mV.

- Rise/fall time: 14ns/11ns.

- Square wave quality: no significant overshoot, ringing or aberrations.

IG-18SL audio generator results

Freq	Act Freq	Ampl (dB)	Dist (%)	Comment
1Hz	0.9995	+1.40		
3	3.018	+0.44		
10	10.033	+0.09		
15	15.06	-0.01		
20	19.98	0.00	0.0014	(test eqmt)
50	50.23	0.00	0.0014	(test eqmt)
100	100.76	0.00	0.0014	(test eqmt)
1K	1011.7	0.00	0.0014	(test eqmt)
5K	5032.9	0.00	0.0015	(test eqmt)
10K	10074	0.00	0.0021	on X100 range
10K	10055	0.00	0.0063	on X1000 range
20K	20006	-0.01	0.0050	
40K	40191	-0.01	0.0066	
70K	70615	-0.02	0.0190	
100K	99300	-0.02	0.0350	
110K	110330	-0.02	0.0460	

- 100kHz square wave duty cycle error read less than 0.02%. (Test eqmt probably not that accurate.)

- Lowest square wave operating freq: 0.14Hz (setting was 0.2Hz). Duty Cycle err: 1.1%

- DC offset at output: 1-10kHz: -2.14mV, 50kHz: -2.85mV, 100kHz: -4.97mV.

- PS current: +15V: 47mA, -15V: 28mA. (with square wave on)

- Meter accuracy: Set at 6.5V, reads dead-on at 2V and within the pointer width at 1V. Over 20Hz to 20kHz, remains dead-on. The new smoothing cap keeps readings rock steady down to 10Hz, slight quiver at 5Hz, moderate quiver at 2Hz. At 1Hz, it doesn't bang the rails.

- Effect of turning square wave on/off: None at 1kHz but at 20kHz, distortion changes 0.0048% to 0.0056% with the square wave.

IG-18SL parts list

Rev. 2, 9/22/17

Qty	Refs	Value	Description
1	U1	HA3-2625-5	100MHz opamp
2	U2,4	OPA2134	low dist opamp
1	U3	TL082	GP jfet opamp
1	U5	74C14B	CMOS hex Schmitt inverter equiv to CD40106B
1	U6	7815	Pos 15V TO-220 regulator
1	U7	7915	Neg 15V TO-220 regulator
1	Q2	2N4092	JFET
2	CR2,4	1N5711	Schottky diode
2	CR5,6		Germanium diode
4	CR3,7,8,14	1N4148	GP diode
1	CR9	3N259	Bridge rect 2A, 1000V 2KBP-10M
1	S1	C4D0604N-A	6P4T rotary switch, Electroswitch
1	S2	SPST	Mini toggle switch
1	C91	15.8uF	Precision cap pack film
1	C92	1.58uF	Precision cap pack film
1	C93	0.158uF	Precision cap pack film
1	C94	0.0158uF	Precision cap pack film
1	C95	1.58nF	Precision cap pack film, cer
1	C96	158pF	Precision cap pack, cer, trimmer
7	C9,10,11,12,13,14,29	0.1uF	Ceramic cap
4	C1,2,3,4	470uF	Alum cap 35V
1	C33	0.047uF	Film cap 600V
3	C5,6,7	100uF	Alum cap 50V
2	C25,30	47uF	Alum cap 50V
2	C8,27	1uF	Ceramic cap
1	C26	10uF	Tant cap 25V
1	C21	1.5uF	Tant cap 25V
1	C22	0.33uF	Ceramic cap
1	C23	0.15uF	Ceramic cap
2	C32,45	27pF	NPO ceramic cap
1	C48	510pF	(sub 560pF) NPO ceramic cap
1	C46	620pF	(sub 680pF) NPO ceramic cap
1	C44	3pF	NPO ceramic cap
1	C24	0.015uF	Film cap
1	R6	20K	Pot, single turn
1	R21	10K	Pot, single turn
1	R30	2K	Pot, single turn
2	R1,2	36	Resistor, 1W, 5%
1	R7	150	Resistor, 1/2W, 5%
5	R24,25,42,43,45	10K	Resistor, 1/4W, 5%
4	R3,29,37,52	100	Resistor, 1/4W, 5%
3	R28,50,51	2.7K	Resistor, 1/4W, 5%
2	R4,41	51K	Resistor, 1/4W, 5%
1	R27	7.5K	Resistor, 1/4W, 5%
1	R31	3K	Resistor, 1/4W, 5%
1	R53	200	Resistor, 1/4W, 5%
2	R35,48	5.1K	Resistor, 1/4W, 5%
1	R5	43K	Resistor, 1/4W, 5%
1	R44	510	Resistor, 1/4W, 5%
1	R40	200K	Resistor, 1/4W, 5%
1	R34	3.3K	Resistor, 1/4W, 5%
1	R36	5.1M	Resistor, 1/4W, 5%

4		8-pin Minidip socket, machined
1		14-pin dip socket, machined
1	2" x 1" x 0.08"	alum bar
1		TO-220 mica heatsink kit
2	4-40x3/8	screw for heatsink
2	4-40x1.25	screw for S1
2	4-40x3/8	standoffs for rear cap board
1	3/8	nut for shimming S1
1	3/8	lockwasher for shimming S1
6	4-40	lockwasher
4	4-40	nut
24	T68	terminal stake
1	5.4 x 4.1"	perfboard, main board
1	1.3 x 1.8"	perfboard, rear cap board