MOTM-310 Micro Voltage-Controlled Oscillator
Assembly Instructions & Owner's Manual

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MOTM-310 PARTS LIST

Please carefully check that all parts are in your kit. If you have a suspected shortage, please call or email. If you get free extra stuff, keep it for next time.

❒ **Capacitor** bag, containing the following 12 parts:

3ea 10mfd, 50V Electrolytic	C1, C2, C11
2ea 100pf (marked 101) ceramic axial	C7, C8
1ea 22pf (marked 220) ceramic axial	C4
1ea 4700pf axial polystyrene	C6
5ea 0.1mfd (marked 104) ceramic axial	C3, C5, C9, C10, C12

❒ **Resistor** bag, containing the following 36 parts:

6ea 1K5 1% (brown, green, black, brown)	R4, R5, R6, R25, R26, R30
4ea 10K (brown, black, orange)	R8, R12, R13, R29
3ea 1K (brown, black, red)	R11, R14, R27
3ea 100K 1% (brown, black, black, orange)	R2, R10, R31
2ea 47K (yellow, violet, orange)	R3, R33
2ea 1M (brown, black, green)	R9, R15
1ea 301K 1% (orange, black, brown, orange)	R1
1ea 3K9 (orange, white, red)	R7
1ea 100K 0.1% (marked 1003B)	R16
1ea 4.7M 1% (marked 4.7M 1%)	R17
1ea 205K 0.1% (marked 2053 BSCJ)	R18
1ea 51K1 1% (green, brown, brown, red)	R19
1ea 69K8 1% (marked 6982F)	R20
1ea 22K (red, red, orange)	R21
1ea 44K2 1% (marked 4422 FSCJ)	R22
1ea 1K 1% 3W tempco (large, black)	R23 (see instructions!)
1ea 22Ω (red, red, black)	R24
1ea 300Ω (orange, black, brown)	R28
1ea 2M2 (red, red, green)	R32
1ea 4K7 (yellow, violet, red)	R34
1ea 1M 1% (marked 1004F)	R35
1ea 1M8 (brown, gray, green)	R36

❒ **IC** bag, containing the following 10 parts:

1ea 2N4403 PNP TO-92 transistor	Q1
1ea LS3954A dual matched JFET	Q2
1ea MAT-02EH dual NPN	Q3
1ea TL074A quad op amp	U1
1ea MXL1013 (or LT1013) dual op amp	U2
1ea LM319N comparator	U3
1ea LM78L05 TO-92 voltage regulator	U4
3ea 1N4148 diodes (NOT in the black foam!)	D1-D3

❒ **Misc** #1 bag, containing the following 5 parts:

3ea Axial ferrite beads (plain, gray things)	L1, L2, L3
1ea MTA-156 power connector	JP1
1ea trimmer, 25-turn 20K Bourns 3296Y	TP1

❒ **Knobs**, 4ea, ALCO PKES90B1/4

❒ **Jacks**, 4ea Switchcraft 112A

❒ **Pots**, 4ea containing the following:

3ea 100K cermet Spectrol 149	VR1- VR3
1ea 100K cond. plastic Spectrol 148	VR4

❒ **Front panel**

❒ **Mounting bracket**

❒ **Wire** bag, containing the following 5 wires:

2ea RG-174 coax, 4 ½ inches
2ea 2-wire set, 22ga, 3 ½ inches (red/black)
1ea Power Cable, 20”

❒ **Hardware** bag, containing:

4ea #8-32 x 3/8 black screws (for mounting module to rack)
4ea #6-32 x 1/2 zinc screws (for attaching pc board to bracket)
4ea 1/4 inch aluminum spacers
6ea #6 KEPS nuts (2 for attaching bracket to front panel, 4 for pc board)
3ea small tie-wraps

❒ **Organic Solder**
❒ **No-clean Solder**
❒ **PC Board**, MOTM-310

GENERAL INFORMATION

Thank you for purchasing the MOTM-310 Micro Voltage-Controlled Oscillator (VCO). If you have any issues concerning the building or use of the kit, please contact us at (817) 281-7776 or by email: synth1@airmail.net.

This kit should take the average builder between 2 to 3 hours. The VCO kit contains many different resistors and special parts that require very accurate soldering skills. However, please remember this is NOT a speed contest; it is an accuracy contest. There is no rule that you have to complete the entire kit in one day (as long as you wash the flux off!).

Successful kit building relies on having the proper tools. Here is a list of what you will need to build your MOTM-310:

* Soldering iron, 50W max power
* Needle-nose or chain-nose pliers
* Diagonal cutters
* Allen key set for securing the knobs (1/16" or 1.58mm)
* Magnifying glass: to read the capacitor codes and to inspect solder joints
* Lead bending tool (optional, but makes the job go much faster)
* DVM (Digital Volt Meter) or oscilloscope (to check the output)
* #1 Philips screwdriver
* Small, flat screwdriver for adjusting the trimmer
* Fingernail brush for washing off the organic flux
* Old towel for blotting dry pc board
* Heat-sink compound: this ***is REQUIRED*** for proper VCO operation. Available from Allied, Newark, Mouser, Radio Shack, Farnell, and most all electronic supply companies. (Postal regulations force me not to include with the kit!)

For more information of tools used and suggestions, see the MOTM FAQ and Tutorial pages at http://www.synthtech.com.

HOW TO FOLLOW THE DIRECTIONS

Please read the entire instruction before proceeding. There may be valuable information at the end of the instruction. Each instruction has a check box ❒ next to it. After you complete the instruction, check the box. This way you can keep track of where you are in the process.

VERY IMPORTANT – PLEASE READ!

It is critical that you follow the steps exactly in order for proper operation. This kit contains expensive, hard-to-find parts! Please read ALL of an instruction before proceeding.

VERIFY THE PARTS LIST

❒ Verify that all of the parts are in the kit as shown on the parts list.

A WORD ON SOLDERING

There are 2 very different types of solder used in the kit. Most of the soldering uses 'Organic Flux' solder. ***This is strictly for use on the pc board, and is NOT to be used on the front panel wiring!***

In order for solder to 'stick' to the copper, a chemical called 'flux' is embedded in the solder. The flux leaves a residue on the pc board that should be cleaned with warm water. DO NOT USE SOAP OR OTHER CLEANSERS. Most of the parts in the kits are 'waterproof' and can be washed in the sink. The flux is OSHA approved for flushing down the drain, so don't worry about that! A soft brush is used to gently scrub the board. We recommend a 'fingernail brush', which is about 1" x 2" and can be found for about $1.

The other type of solder is called 'No Clean Flux'; because as the name implies it does, not require washing. This solder is used for wiring the pots, switches, jacks, etc. This solder is harder to use on the pc board; because even when melted, it is not very fluid (about the consistency of toothpaste). We will use it VERY SPARINGLY on the pc board.

OK, let's get started on the board!

PART #1: SOLDERING THE RESISTORS

Since there are more resistors than anything else, we will start here. If you do not know the resistor color code, refer to the parts list. Resistors are not polarity sensitive, but the board will be easier to debug (and look nicer) if you point the first color band in the same direction for all the parts. The color code is also in the README FIRST document that every customer receives with his or her first order.

There are 2 types of resistors in the MOTM-310 kit: standard 5%, 1/4W parts and special, precision parts. The precision parts use a slightly different color-coding scheme or have the part value stamped on the resistor. If you are unsure of a resistor's value, use your trusty DVM to measure it! Inserting the wrong resistor in the VCO kit will cause interesting behavior! And, it's very hard to find the error.

You will start by soldering in ALL of the 5% resistors.

❒ Find the **RESISTOR** bag.

❒ Find the MOTM-310 blank pc board. There is a copy (larger than actual size) of the silkscreen which shows where the parts go at the end of this document. It will be useful if you locate the part on the print first, put the part in the board, then 'check off' the silkscreen. All parts are inserted from the side of the board with the white silkscreen (the "top" side).

❒ We will stuff the resistors by value to make things easier. The resistors (and other long-leaded parts) are inserted on a 0.4 inch spacing. The important thing is to be sure that the part is sitting all the way down on the board. Push the leads in the holes, push the part on the board, and then bend the leads on the bottom outwards to a 45 degree angle (roughly!). This is called 'cinching the leads': and keeps the part from falling out! From the bottom of the board, solder (using the organic flux), applying heat to the pad for about a half second first, then applying just enough solder to make a small puddle that looks like a tiny pyramid. Enough solder should flow in the hole such that on the top (component) side, a small amount is on the top pad as well. A ***SMALL AMOUNT***, not a blob!

The rule of soldering: don't use too much, you can always add more! Cut the leads flush with the top of the solder joint with your diagonal cutters.

This pc board has parts ***very close together***. It may not be clear where a certain resistor or capacitor is. We will try to give you a "hint" for the hard-to-find parts!

NOTE: you will need to save 2 of the resistor leads after you cut them! Don't forget!

❒ Locate the 10K resistors (4) and solder into R8 (left of U1), R12 (below C5), R13 (below R12), and R29 (above VR2).

❒ Locate the 1K resistors (3) and solder into R11 (Right of J3), R14 (above VR4) and R27 (below C9).

❒ Locate the 47K resistors (2) and solder into R3 (above VR3) and R33 (right of U2).

❒ Locate the 1M resistors (2) and solder into R9 (Left of U1) and R15 (right of VR4).

❒ Locate the 3K9 resistor and solder into R7 (below D1).

PART #2: BOARD WASH #1

❒ Verify all the resistors are in the correct position.

❒ Verify all the resistors are flat on the board. Correct if needed. Check solder joints.

❒ Wash the board in warm water, gently scrubbing *both* sides.

❒ Shake the board a couple of times, blot dry with an old towel (the leads will frazzle a good towel). Let dry about 15 minutes.

PART #3: Complete the 5% Resistors

❒ Locate the 22K resistor and solder into R21 (above C3).

❒ Locate the 22 ohm resistor and solder into R24 (below C9).

❒ Locate the 300 ohm resistor and solder into R28 (below R27).

❒ Locate the 2M2 resistor and solder into R32 (below D3).

❒ Locate the 4K7 resistor and solder into R34 (left of VR2).

❒ Locate the 1M8 resistor and solder into R36 (above D2).

❒ This completes the 5% resistors. Check your solder joints and wash the board again! Let dry 15 minutes. Take a little break!

PART #4: Precision Resistors EXCEPT R23

IMPORTANT NOTE! R23 is the last part soldered on the board! DO NOT SOLDER this part until told so. You have been warned!

In order to make debugging the board easier later on, be sure that you install the resistors which have printed values on them with ***the value facing up where you can read it***!

❒ Locate the 100K, 0.1% resistor and solder into R16 (above U1).

❒ Locate the 100K 1% resistors (3) and solder into R2 (below C3), R10 (below R11) and R31 (above C6).

❒ Locate the 301K 1% resistor and solder into R1 (below C3).

❒ Locate the 4M7 1% resistor and solder into R17 (by TP1).

❒ Locate the 205K 0.1% resistor and solder into R18 (below R17).

❒ Locate the 51K1 1% resistor and solder into R19 (below R18).

❒ Locate the 69K8 1% resistor and solder into R20 (below R19).

❒ Locate the 44K2 1% resistor and solder into R22 (below D2).

❒ Locate the 1M 1% resistor and solder to R35 (above R36)

❒ Locate the 1K5 resistors (6) and solder into R4, R5, R6, R25, R26 and R30.

❒ STOP! Save the big black tempco resistor for later. DON'T LOSE IT!

PART #5: BOARD WASH #3

❒ Verify all the resistors are in the correct position.

❒ Verify all the resistors are flat on the board. Correct if needed. Check solder joints.

❒ Wash the board in warm water, gently scrubbing *both* sides.

❒ Shake the board a couple of times and blot dry. Take another break or set the kit aside for later. You are about one-third finished at this point: this is a good stopping-point.

PART #6: CAPACITORS EXCEPT C6

❒ Locate the **CAPACITOR** bag. Set the polystyrene 4700pf cap (the big silvery one with the long, thin leads) aside. ***THIS CAP IS SOLDERED IN AFTER THE ICs!***

❒ Locate the 100pf ceramic axial caps (2). They are marked 101. Solder into C7 (by L2) and C8 (right of U2).

❒ Locate the 22pf cap and solder into C4 (by D1).

❒ Locate the 0.1M caps (5). These should be easy to find: they are all the ceramic caps left. Solder into C3, C5, C9, C10 and C12.

❒ Locate the 10µfd electrolytics (3). Note that there is a stripe on the NEGATIVE terminal. The pc board has a + on the POSITIVE terminal. Carefully stick the capacitors into C1, C2, and C11 with the stripe ***away*** from the + pad on the board.

❒ Wash the board again, gently scrubbing both sides. Use ONLY warm water!

PART #7: MISC and IC STUFF

Almost done with the parts on the pc board! This will finish up the soldering with the organic flux.

❒ Locate the **MISC #1** bag and the **IC** bag.

❐ Locate the ferrite beads (3). They are axial parts, gray colored with no markings. These are non-polar, and are soldered into L1, L2, and L3.

❐ Locate the MTA-156 power connector. Solder into JP1. Note that the connector has a 'locking tab' on one side. This side is the "inside" facing relative to the pc board. Note the silkscreen symbol for JP1 has a line on one side, indicating this is the side where the locking tab goes.

❐ Locate the LM319 comparator. Solder into U3. Note that Pin #1 is the square pad. Pin #1 is the pin near the very small 'dimple' in the top of the part. All of the ICs point "to the top edge" on the pc board, when the board is in "landscape" orientation (JP1 at the upper right).

❐ Locate the TL074A. Solder into U1.

❐ Locate the 1013 op amp. Solder into U2.

❐ Locate the LM78L05. Look closely, it is marked on the "flat side" of the part. Note the hole pattern on the pc board has the middle lead slightly forward. Insert the 3 leads, with the bottom of the part about 1/8" from the pc board. DO NOT try to push the part all the way down on the board! Solder in U4.

❐ Locate the 2N4403 transistor. Solder into Q1.

❐ Locate the diodes (3). Note each has a dark band on one end on the body. This is the cathode and it must be placed in the holes with the band pointing to the right. Solder into D1 – D3.

❐ **The next 2 parts are the most difficult to insert and solder.** BE VERY PATIENT AND TAKE YOUR TIME! THESE PARTS ***ARE EXPENSIVE*** TO REPLACE IF DAMAGED BY HANDLING OR IMPROPER SOLDERING!

Locate MAT-02EH transistor Q3. Note that it has a small 'tab' sticking out sideways from the can. Also note that on the underside of the part is a ceramic spacer that is protruding slightly. Place the part carefully in the holes, so that the tab on the part is over the tab on the silkscreen (towards the upper left corner). Push the part gently down all the way on the pc board *until it touches the board.* Now solder the six leads**.** **IT IS VERY IMPORTANT FOR PROPER OPERATION THAT THE MAT-02 BE ALL THE WAY *FLAT AND LEVEL* ON THE PC BOARD!**

❐ Locate the LS3954A dual JFET. It goes into Q2. Note that it looks like a smaller version of Q3. However **DO NOT** PUSH THIS PART DOWN ALL THE WAY ON THE BOARD! You will find that the leads must be carefully and gently be bent into position in order for the part to go into the 6 closely spaced holes. ***BE PATIENT***! Again, look for the alignment tab on the part and solder Q2 in place (the tab points to the upper left). The 6 pads are VERY CLOSE TOGETHER AND VERY SMALL IN SIZE. Use a magnifying glass to examine your joints. BE VERY VERY CAREFUL THAT 2 ADJACENT PADS ARE NOT SHORTED BY SOLDER!

❐ Being careful NOT to solder the 2 pads for R23 and C6, apply a small bit of solder to the via holes. These are the small pads (no components go in them) that allow traces to "change sides" of the pc board. DO NOT SOLDER PADS FOR THE REMAINING COMPONENTS!! The via holes need a **VERY SMALL AMOUNT** of solder.

PART #8: FINAL BOARD WASH & INSPECTION

❐ Verify all the parts are in the correct locations. Make sure all of the ICs are pointing the same direction and that all of the diodes point to the left.

❐ Inspect the solder joints. Any solder shorts? Too much solder? Missing joints?

❐ Wash the board under warm water. Scrub gently. Dry.

THIS IS A GOOD STOPPING PLACE TO REST OR PUT THE KIT AWAY UNTIL LATER.

You are now finished with the Organic flux solder. All soldering past this point is using the No-Clean solder. You do not have to wash the board anymore.

PART #9: FINISHING THE PCB

You will now solder in the remaining parts on the pcb in preparation for wiring to the front panel. ***USE THE NO-CLEAN SOLDER. BE CAREFUL!***

❒ Locate the Spectrol pots (4). ***NOTE***: one of the pots is marked with a '148' part number. This pot is for VR4! **IMPORTANT**: in order for the pc board to properly align with the front panel, each pot must be ***absolutely flat*** on the pc board, with the shafts pointing away from the pc board. Solder the pots into VR1, VR2, VR3, and VR4 (the '148' marking).

❒ Locate the 4700pf polystyrene cap. Solder into C6. Be careful, the leads are quite thin.

❒ Locate the trimmer pot (has the small brass adjustment screw) and solder into TP1.

❒ Locate the **Tempco resistor R23.** This part is mounted in a special way: it goes on top of transistor Q1! Why? In order to compensate for the temperature drift of Q1, the resistor must be in good thermal contact. Refer to the illustration and be careful!

a) Apply a small amount of heat-sink compound to the top of Q3. Use just enough to cover the entire top without dripping down over the sides.
b) Bend the leads of R23 all the way against the resistor's body at a 90 degree angle.
c) Insert the resistor into the 2 holes: one to the left of Q3 and one to the right of Q3.
d) Push R23 all the way down so that the bottom of the resistor is sitting on top of Q3. The heat-sink compound will "squish out" from under R23. Wipe of any excess. WARNING! This stuff is next to impossible to wash out of blue jeans! DO NOT get any on your clothing!
e) Solder R23, making sure the resistor is level and TOUCHING Q3.

❒ Locate the 2 pieces of RG-174 black coax cable. Again, note that one end has longer wires stripped than the other. The short ends will go in the pc board in positions J3 and J4. Look at the pc board. Notice that in the coax positions, there is a large hole pad (lower pad) and a smaller pad (top hole). The braided wire is soldered into the larger hole. The smaller, inner conductor goes in the top hole. BE SURE THE SHORTER BRAIDED END GOES INTO THE PC BOARD.

Solder each coax cable into the holes. Attach a tie-wrap to secure the coax cable flush to the board. The tie-wrap goes down, into the left hole and up through the right hole. Secure and trim off any excess.

❒ Find the 2 red/black twisted pairs. They go into J1 and J2. Solder the black wire into the TOP (2) hole and the red wire into the BOTTOM (1) hole.

YOU ARE NOW FINISHED WITH THE PC BOARD WORK! BREAK TIME.

PART #10: FRONT PANEL PREPARATION

You will now attach components to the front panel. It is HIGHLY recommended that you use a set of hollow shaft nut drivers, NOT PLIERS, to tighten the nuts. This prevents scratching. NOTE: all references to part orientation is from the REAR of the panel.

❐ Locate the 4 Switchcraft jacks. Notice that from the rear, there is a beveled corner. This corner is ALWAYS CONNECTED TO GROUND, USUALLY WITH THE BRAIDED CONDUCTOR. Each jack has a flat washer, a lockwasher, and a ½" hex nut. Remove the nuts and washers from each jack. Place aside. Keep the lockwasher on the jacks.

❐ Insert the 4 jacks/lockwashers, with the beveled corner in the ***upper right*** corner, into the 4 holes. Place the flat washer on the jack, then the hex nut. Hold the jack with one hand on the backside, keeping it 'square'. Tighten the hex nut with a nut driver. NOTE: when tight, not much of the exposed threads of the jack are exposed.

You are now ready to attach the pc board to the bracket and then wire up to the panel.

PART #11: ATTACH PC BOARD TO BRACKET/PANEL

❐ In the **HARDWARE** bag, locate 4 #6-32 x 3/8 screws, 6 #6 KEPS nuts, and 4 spacers.

❐ Locate the mounting bracket. The pc board attaches to the bracket, with the 4 screws threading from the top of the board, through the spacers, through the bracket, and then out the bottom of the bracket. The #6 KEPS nut attaches on the bottom of the bracket. Note the bracket has 2 long mounting flanges with a hole in each. These attach to the 2 threaded studs sticking out of the rear of the panel. The 4 pots each stick in its panel hole when the bracket is screwed down on the 2 threaded posts.

Attach the pc board to the bracket. The flanges will point upwards when the pc board is sitting on the bracket. Note that the bracket holes for the pc board are actually oblong. This is to allow adjustment for the pc board to firmly press up against the back of the panel. As a start, set the 4 screws ALL THE WAY TO THE LEFT of the oblong holes. ***Loosely*** tighten the 4 KEPS nuts on the bottom.

❐ THIS IS A VERY IMPORTANT STEP, SO PAY ATTENTION AND READ ALL OF IT BEFORE PROCEEDING!

Note that each of the 4 pots on the pc board have 2 hex nuts and a flat washer. Remove the first hex nut and the washer. Set aside.

What you will do now is adjust the remaining hex nuts so that when the bracket is all the way down on the panel's threaded studs, all the pot hex nuts touch the rear of the panel.

Screw (by hand) each hex nut on the pots so that it is all the way on (touching the face of the pot). Now, pick up the pc board/bracket assembly and carefully slide it over the 2 threaded studs, making sure the pots are aligned in the holes. Use 2 #6 KEPS nuts and tighten the bracket to the panel.

❒ Loosen the 4 KEPS nuts on the bottom of the bracket. Slide the pcb ALL THE WAY TO THE RIGHT AS FAR AS IT WILL GO, so that the 4 pot nuts are all pressing against the panel. By hand, put hex nuts on the outside threads of VR1 and VR4 to keep the pc board in place. Now, tighten the 4 KEPS nuts on the bracket. The pcb and bracket should be secure, with no gaps visible between the panel and the pot nuts. You may need to loosen the nuts on the pots, so that they are touching the back of the panel. Again, make sure each pot's nut is touching the back of the panel (no gaps!). There will be a gap from the edge of the *pc board* to the panel.

❒ Remove the hex nuts on VR1 & VR4. For all of the pots, first put on the flat washer, then the hex nut. Tighten with a ½" nut driver.

PART #12: FINISH WIRING TO THE PANEL

Please read the following instructions carefully. In order to neatly attach the many wires to the front panel components, the wires are soldered in a specific order. You may find, in some cases, easier to first remove a component from the panel and solder the wires, then reattaching to the panel.

❒ The first wire is the OUT coax on J4. Thread the coax down and in between the FM and OUT jacks. Solder the braid to the beveled lug on the OUT jack. Solder the inner conductor to the left lug. The top lug is open.

❒ Next find the red/black twisted pair in the FM holes. BUT, before you solder the wires, you will need to get one of the resistor leads you saved and solder a short jumper from the top lug of FM to the beveled lug. This will short the input to ground with nothing plugged in: this reduces stray pickup that causes the VCO to "wander". Since this jack is directly under the bracket, you may want to remove it first to attach this little wire. Once the shorting wire is soldered, locate the red/black twisted pair in the FM holes J2. Solder the RED wire to the left lug and the BLACK wire to the beveled lug.

❒ Solder the PWM coax in J3 to the PWM jack. Braid on the bevel, inner on the left.

❒ Prepare the 1V/OCT jack with the last resistor lead scrap. Solder the lead from the top lug to the beveled lug. Locate the red/black twisted pair in the 1V/OCT holes J1. Solder the RED wire to the left lug and the BLACK wire to the beveled lug.

❒ Rotate all of the front panel pots fully counter-clockwise. Locate the **KNOBS**. Notice each knob has a white line on it. Place the knob on the pot shaft, align the white line to the '0' tick mark, and tighten the hex screw. The silver part of the knob has a protective clear plastic overlay that can be removed if desired. Gently rub with your fingernail across it and it will peel off.

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CONGRATULATIONS! YOU HAVE FINISHED BUILDING THE MOTM-310!

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All that's left to do is test it! But before we do, please read the following Theory of Operation.

THEORY OF OPERATION

The MOTM-310 VCO has 4 basic sections: a voltage summing amplifier for the control voltages, an exponential voltage-to-current converter, a sawtooth oscillator, and a waveshaper. Each of these sections is covered below.

INPUT VOLTAGE SUMMER

Refer to the schematic page marked M310_2.SCH for the following discussion.

Since the '310 is in fact voltage-controlled, then one can assume one or more voltages set the operating frequency. Voltages come from 2 places: the initial frequency, which is set by the COARSE and FINE front panel pots, and the 32CV inputs. All of these are added together to make a combined control voltage.

The name of the game in VCO design is ***frequency stability.*** A major factor in maintaining long-term stability is careful design of the input summing amp. If this portion of the circuit drifts, then the entire VCO drifts as well.

It is also important that the main +/-15VDC power supply not drift as well (or be noisy or have any sort of signals imposed on the supply lines). This is why the MOTM-900 is highly recommended for powering the '310 VCOs, since it contains the LM723 voltage regulator.

The first critical part in the summer is the op-amp itself, U2A. This op amp is a LT/MXL1013, a low-offset and very low-drift DC accurate part. The critical parameter is choosing this part is the output offset voltage and the input bias current drift over temperature. Common op amps used in this application (like the TL072) have 10-20 times greater drift than the 1013. Remember, even the worst "trained" ear can hear the VCO drift out of tune if the voltage to the exponential generator is *more than 200µV*!

Having chosen the proper summing op amp, the next overlooked design decision is in picking the correct type of resistors in the summing circuitry. Most designs use standard 1% metal-film resistors. What is "standard" about them is the temperature coefficient of the resistance. Yes, resistors will change their value with temperature! The normal 1% resistor found in other VCOs drift 200ppm (parts per million) per degree C. A 1MΩ resistor drifts 200 Ω every 1 degree C the ambient temperature does up and down. A 15C temperature drift in a modular is not uncommon as the circuitry heats up and stabilizes.

Well, this is another small, but *easily corrected,* drift element. The ‘310 uses special, very low temperature drift resistors called RN55Es. These resistors drift *10 times less* than standard 1% resistors. A side benefit: no color bands to decode! The value is printed on the resistor body. Some resistors used are also a very tight 0.1% tolerance.

Lastly, the COARSE and FINE pots use very low drift cermet resistive material. This means when you set those front panel pots, the frequency does not drift because the resistance of the pots is changing with temperature.

There is a special, very important gain function required from the input voltages to the exponential converter: a 1 volt change in the input must appear as a 18.02mv change on the base of Q2 pin 2. This will be explained later on. The thing is, we need to attenuate so that this occurs.

This is done in 2 stages. The first stage is set by the trim pot TP1 in series with R20. The sum of these 2 resistors set the output voltage of U4B as:

V_{out} = - (TP1 + R20)/R16 <<<since R16 is our 1V/Oct input

TP1 sets the overall response to 1 volt/octave.

The voltage output from U2A then goes to a second, special voltage divider consisting of R22 and R23. Resistor R23 is a resistor that is actually touching transistor Q2 (assuming you built it correctly!). This resistor is made of special wire that changes its resistance +3500ppm. Hmmmm…didn’t we just say that the 200ppm of a 1% resistor was “too bad for MOTM”?

The reason R23 is “designed bad” on purpose is that the collector current of Q2 changes -3310ppm per degree C (in a negative direction). The Tempco resistor R23 makes the voltage divider alter its “division ratio” in a positive direction. Therefore, the intent of R23 is to cancel out the temperature drift of Q2. This temperature drift of collector current is the *main drift contributor* in the VCO.

The “nominal” voltage divider of R22 and R23 is:

V_{out} = R23 / (R23 + R22) or a ratio of 1:45.2

If the desired ratio is (1/.01802) or 1:55.494, then the input summer trimmer is set to “make up” the difference.

Let’s examine how the MOTM-310 is setup on the inputs. First, there is a dedicated 1V/Oct jack J1 that feeds R16 directly. The other input (FM1) is first attenuated and then fed not to a 100K resistor, but to a 51K1 resistor. This is so non-standard scales of older equipment can be used (most notably, the 1.21V/Oct of the EML 101). Also, the 51K1 allows wider modulation swings than the 1V/Oct input.

The initial frequency is set by the 2 panel pots COARSE (VR1) and FINE (VR2). Note the FINE resistor, R17, is a high value of 4M7Ω. This is how the voltage range is scaled to be narrower.

Lastly. resistor R21 is used to balance the input bias current flowing into U2A, which in turn reduces drift over temperature.

EXPONENTIAL CONVERTER/SAWTOOTH OSCILLATOR

The VCO works by applying a negative current to a capacitor. Why a current? Because a capacitor behaves according to the following relationship:

$$I_{cap} = C\ (dV/dt)$$

Where I_{cap} is the current in the cap and (dV/dt) is the rate of change of the voltage across the cap with time. The phrase "negative current" means we are pulling current *out* of a charged capacitor, thus *discharging* it.

So, the clever reader will note that if we have a constant C (capacitance value), then changing the current I_{cap} changes dV/dt in a linear fashion. And what exactly is dV/dt? Well, if the voltage change is constant (say 5 volts) then that means 1/dt changes and of course 1/dt is FREQUENCY! (You in the back of the class! Wake up!)

So here is how we make a VCO: you pick some cap C, pick some voltage to charge to (or in our case a voltage to discharge *from*) dV, and then feed it I_{cap} to change the frequency. What could be easier???

Well, the difficulty is that for a musical VCO, we want a doubling effect. See, the Western 12-note musical scale is arranged so that an octave is defined as a frequency doubling every 12 notes. If the note 'A' is set at 440Hz, 1 octave up is 880Hz and one octave down is 220Hz.

Our basic little VCO is linear: if the low A is 220Hz, the next A would be 440Hz but the NEXT one is 660Hz! WRONG!

What's a poor circuit designer to do?

Thankfully, Bob Moog already figured it out: you use the fact that the collector current of a transistor doubles every 18.02mv change of the base-emitter voltage. How does it do that? That's a long semiconductor device essay: there are plenty of books that derive this. Trust me.

Let's look back at the schematic. Our VCO is based around the humble, but loveable, capacitor C6. One end of C6 is tied to a reference voltage called VREF. Assume for now that VREF is +5V. The other end of the cap is tied to the collector of one half of dual transistor Q2.

Q2 is a very special device: without it our VCO would not be exponential. It is a dual transistor: there are 2 independent NPN transistors on the same die. Why? Because the transistors will drift with temperature and we want them to both drift the same amount (i.e. track each other over temperature). What exactly drifts? The collector current! The very thing that determines the frequency of our VCO! Therein lies the problem: the transistor gives us our desired doubling, but we pay the price of a rather large drift.

The cap in the ‘310 is not “charged” from ground to +5V. Rather, it is “discharged” from +5V to ground. In order to do this, we “suck” current out of the capacitor with Q2. The base of the first transistor is at ground. We then must change the voltage on the emitter to be below ground: that’s a ‘negative’ voltage. The other half of our dual op amp summer U2 is used for this.

The VCO has a ‘zero voltage’ frequency: this is the frequency when the output of the summing and is 0.0V. This is set by a reference current called IREF. The current is set by resistor R35, a 1.0M 1% low drift part. The current is derived from voltage source VX. Assume for the time being that VX = 5V. IREF is then:

IREF = 5/1M

Or 5µA. It is slightly less than this because the + input of the op amp is biased up to 310mv by resistor divider R32/R33. Why? This is to protect Q2 from having its base-emitter junction reverse biased.

Assuming a 5µA IREF and the base of BOTH transistors is 0V, then since the emitters are tied together, the collector currents are equal (5µA in both) and our frequency is:

F_{out} = (I/C) / 5V or about 200Hz.

This is simply a compromise to get the most useful part of the musical scale with positive-going control voltages (like from a MIDI-CV converter). Of course, the COARSE/FINE pots offset this point both up & down.

Looking back at the circuit: if IREF is a constant then the base-emitter voltage changes at Q2 pin 2 will cause current changes in the collector Q2 pin 6. Since C is fixed and our reset threshold is set at +0V (a dV of 5), a simple frequency equation is:

F_{out} = I / 2.35 x 10E-8

So if I gets bigger, F_{out} goes up. This makes sense: if we suck more current out of the cap, the faster it discharges towards 0V and, hence, the frequency increases. If I = 1ma, the VCO oscillates about 40kHz. Generally speaking, Q2 is operating with collector currents from 500nA to 500µA.

The components D2 and R36 set the ‘High Frequency Tracking’. At higher and higher current levels, the non-zero resistance of the emitters starts introducing errors. The VCO runs ‘flat’ because there is a slight error in the collector currents. The diode/resistor compensate for this by modulating the base current slightly

The voltage on C6 is first buffered by dual JFET Q3. The JFET is configured as a zero-offset follower. The FET Q3B is a constant current source that biases the other half Q3A. Since this is a monolithic, dual JFET , the V_{gs} voltages are matched and no offset voltage is present (in reality, the offset will be very small, on the order of 5µV). Since the cap voltage is “looking into” the gate of Q3A, the input impedance is very high: on the order of 500MΩ. This isolates the exponential converter control current from the comparator U3B. Why is this necessary? Because the LM319 comparator has a large input bias current that will vary over temperature.

The LM319 compares the sawtooth voltage to ground (as set by R30). Since it is an open-collector NPN output stage and we are controlling a PNP, the base of the PNP is biased by R27 & R29 to 6V. This is needed because the emitter of the PNP is at +5V (VREF) and in order to turn it off and on, we need to drive the base higher by at least a V_{be} drop (say 0.7V max).

WAVESHAPING

Once we have generated a negative slope sawtooth, the pulse waveform can be derived.

Since MOTM uses *de facto* +/-5V pk-pk waveforms, we need a level shift of the +5V – 0V sawtooth. Op amp U1B takes the sawtooth and via bias resistor R13 and shifts the waveform to +/-5V pk-pk.

The pulse is simply a comparison of the output sawtooth to a control voltage (the PWM input). Op amp U1A compares the sawtooth to the PWM input voltage on pin 2. Note that there is no input attentuator, or 'Initial Pulse Width' controls as in the MOTM-300. The normal Pulse is a square wave (50% duty cycle).

The single output is a "fade" between SAW and PULSE. VR4 is buffered by U1D, providing the fader function.

PRELIMINARY CHECK-OUT & CALIBRATION

The VCO needs one adjustment: the 1V/Oct tracking.

If you have access to an oscilloscope, this will *greatly reduce* your efforts, especially if you suspect the VCO is not operating properly. At the minimum, a good DVM is needed to check voltages at different points on the circuit if there is a problem.

SETTING THE 1V/OCT TRIMMER

First, apply power to the VCO and test the output for audio. Set the COARSE and FINE pots to center positions. If all is good, the VCO should oscillate at about 200Hz. Turning VR4 should modify the tone of the output. If you have a scope, examine the output for proper wave shape. WARNING! The output level of the '310 is about +24dBu. **DO NOT** plug it directly into an audio amplifier!

If you do not have any audio output, please proceed to the TROUBLESHOOTING section.

In order to properly set the tracking, you need a known, stable source of control voltages. Usually, these come from a MIDI-CV converter such as a Kenton Pro-2000. If you have a keyboard that outputs CV (such as a Roland SH-101), you can use that. Use a DVM to verify that your voltage source is accurately outputting 1V/Octave. DO NOT use a cheap analog meter for this!

Let the VCO stay powered up for 5 minutes before adjusting the trimmer. This lets the 5 separate temperature compensation loops stabilize.

In order to properly set the octave intervals, you have several options:

a) Use your wonderful sense of pitch.
b) Use a frequency counter, if available. Use the PULSE output to the counter.
c) Use another synth you think is in tune, and compare the pitches over speakers.
d) Use a good guitar tuner (Korg makes several nice ones).

In any case, the procedure is the same:

a) Set the COARSE and FINE pitches to a starting point. A440 is a good choice if you are using a freq. counter.
b) Play a note on the keyboard.
c) Play a note 1 octave higher.
d) Adjust the trimmer for the proper pitch. Keep playing/adjusting back and forth until this 1 octave is set.
e) Now play 4 or 5 octaves apart, without touching the COARSE/FINE pots. Readjust the trimmer if necessary.

That should do it! You may find that it will take several minutes to "zoom in" on the correct setting. If you cannot seem to get the VCO to set properly, see the TROUBLESHOOTING section.

TROUBLESHOOTING

If your MOTM-310 does not work, please verify ALL of the following before contacting us. The following reference directions assume that you are looking at the pc board with the panel to the right and the power connector to the left.

❒ All of the ICs are pointing the same way and all notches are 'up'. When the pcb is on the bracket, this can be called "the back edge".

❒ All of the diode's bands are to the "right" (or when mounted, "up").

❒ With a DVM, check the following DC voltages. This assumes the power supply is +/-15.0V and there are no external CV inputs plugged in.

a) Pin 8 of U1 is very close to +5.0V.
b) VX is close to +4.4V (left side of R35).
c) The right side of R35 is near +0.32V.
d) VREF is close to +5.0V (left side of C6).
e) With FINE set to the center position, pin 1 of U2 varies approx. from +6V to –6V as COARSE is rotated from end to end.
f) With FINE still at center, pin 7 of U2 varies approx. –0.3V to –3.8V as the COARSE pot is rotated end to end. Note this varies *exponentially*!

❒ All of the TO-92 packages all face the same direction.

❒ The braided wire on the coax goes to the beveled side of the jacks.

❒ The board has all the right parts in all the right places.

❒ No solder shorts or missing joints. BE SURE to carefully examined the pins on Q1 and Q2 for solder shorts.

If you still can not get the module to perform correctly, please contact us by phone/fax at (888)818-MOTM or by email to synth1@airmail.net

USE OF THE MOTM-310 VCO

A VCO is used to generate pitched waveforms (a “tone generator”). Different waveforms are simultaneously produced, because each waveform type has a unique sound. Why? The shape of the waveform is a by-product of the *harmonics* of the wave. A SINE wave has no harmonics: it is a “pure” tone. The TRIANGLE, SAW and PULSE each contain multiple harmonics of the fundamental. The relative strength and spacing of the harmonics is what causes the waveforms to have different shapes and sound different.

The “classic” synthesizer patch is as follows:

a) Your keyboard’s control voltage into the 1V/Oct input jack
b) An output waveform into the audio IN of a VCF
c) Output of the VCF into a VCA
d) 2 ADSR EGs triggered from the keyboard: one for the VCF and one for the VCA

Rather than explore how to patch the ‘310, we will instead go over what the ‘310 ***does***.

RULE #1 Voltage in = Frequency out

You change the frequency (hence, ‘pitch’) of the ‘310 with control voltages. These control voltages can be from a DC source (ie your MIDI-CV converter), a slowly-changing waveform

(LFO, S&H, sequencer) or audio (output from another MOTM-310). The 3 places you can stick a CV into the VCO are:

a) the 1V/OCT jack. This has no attenuator. It runs “straight in” to the summing amp.
b) The FM jack.. The FM pot attenuates the CV applied. Note that FM input is NOT 1V/Oct unless the pot is set just right. Rather, these are useful for frequency sweeps and effects. They have a wider range of modulation (for the same applied voltage) as the 1V/OCT input. FM1 can run up to 0.5V/Oct (double the range).

At any instant in time, **both of these inputs are ADDED to the COARSE and FINE settings** to produce the output frequency.

RULE #2 Different waveforms sound….. different

The 2 waveforms produced by the VCO each are useful in different ways.. SAWtooth and PULSE waves are “raspy” and “buzzier/reedy” due to very strong harmonics. Use the SHAPE control to obtain mixtures of these, for rich harmonic content.

PWM is loads of fun! Be sure to freely use all sorts of wacky CV signals to modulate it. Note that you can use audio frequencies to modulate Pulse width. The input range is –5V to +5V. You will most likely need to first use a mixer (such as the MOTM-850) to first attenuate the PWM controlling signal. With no signal connected to the PWM jack, the Pulse is actually a Square wave.

There is no set ‘rule’ that relates a desired sound to a certain waveform. All we can suggest is: experiment!!

RULE #3 You *can* use audio signals to FM modulate

The controlling signals (1V/OCT and FM) are NOT limited to DC voltages. You can use audio signals as well. This can generate bell tones and other harmonically rich timbres. Lastly, you can also feedback the output of a VCO back into itself! This is called a chaos patch. Very strange and bizarre sounds can be generated by “cross modulation” of VCOs.

SPECIFICATIONS
MOTM-310 Voltage-Controlled Oscillator

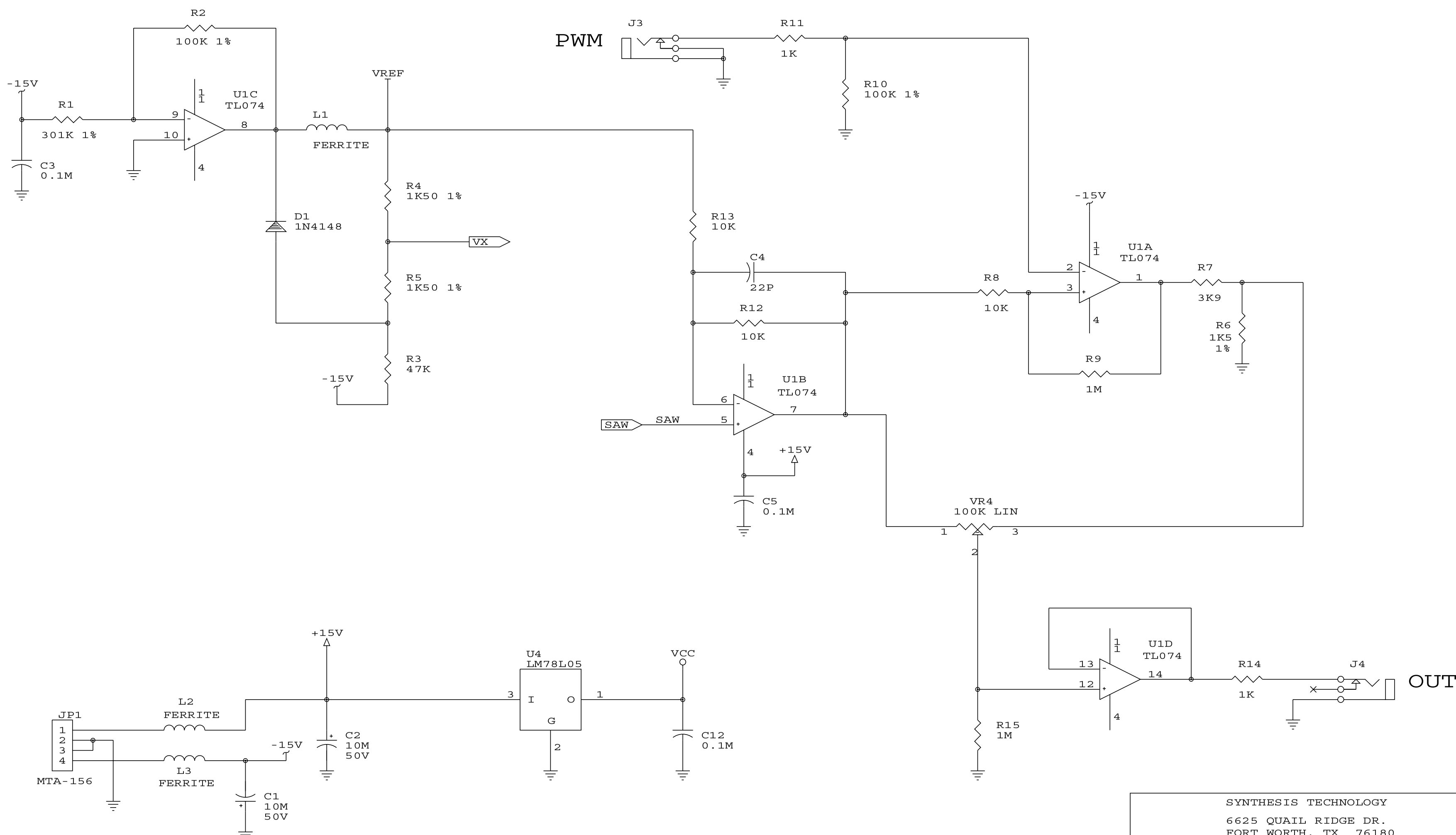
Voltage input levels	-7.5V to +7.5V
Waveform output level	10V pk-pk nom.
Output impedance	1000 ohms, nom.
Frequency Range	0.1Hz – 30Khz, nom.
Frequency stability	Less than 0.1% error @4Khz in 24 hours

CONTROLS

COARSE	sets VCO initial frequency over 20 octaves
FINE	sets VCO initial frequency over 1 octave
FM	attenuates the CV applied to FM1 jack
SHAPE	controls output waveshape (SAW to PULSE)

GENERAL

Power Supply	-15VDC @ 25 ma +15VDC @ 25 ma
Size	1U x 5U 1.72” x 8.72” 44mm x 221.5mm
Depth behind panel	2.5 inches (63mm)



LINK
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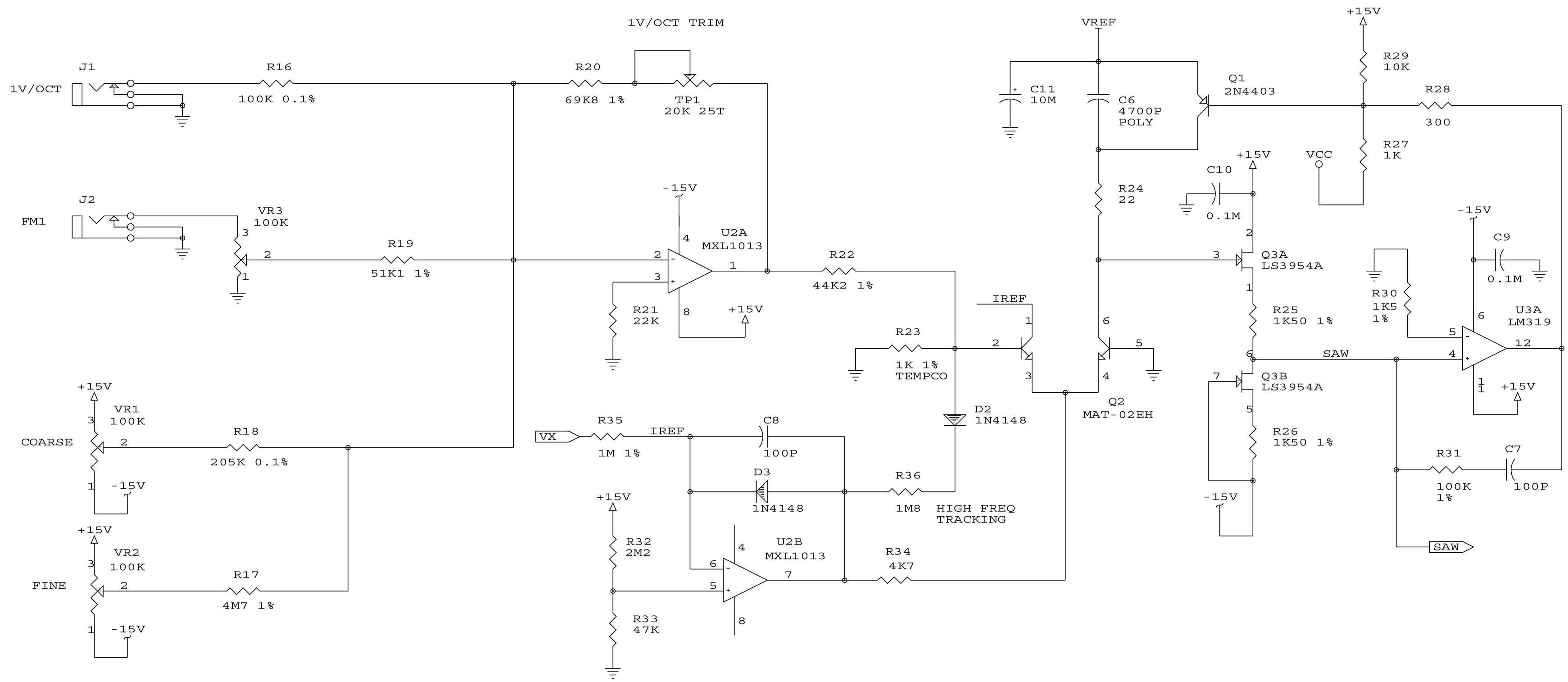

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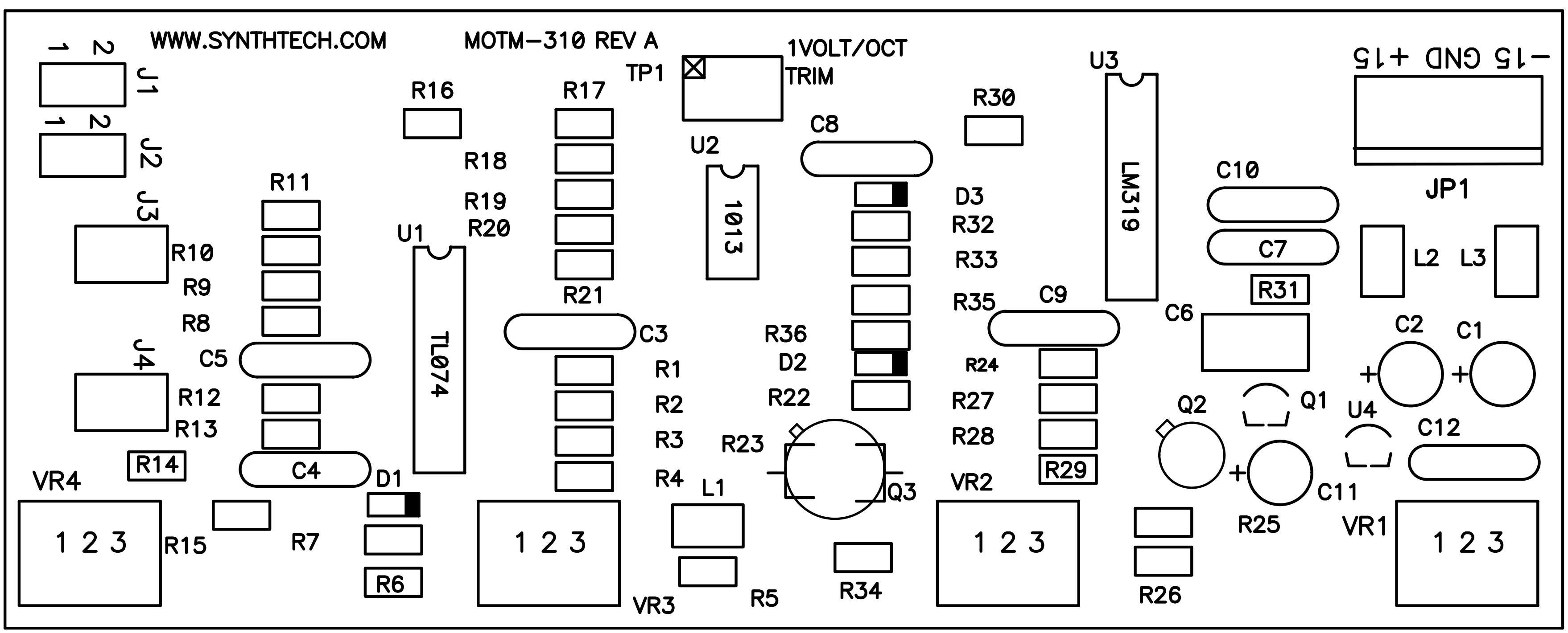

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MOTM-310 REV A
1VOLT/OCT
TRIM
TP1
J1
J2
J3
J4
R1
R2
R3
R4
R5
R6
R7
R8
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R36
U1
TL074
U2
1013
U3
LM319
U4
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
D1
D2
D3
L1
L2
L3
Q1
Q2
Q3
VR1
VR2
VR3
VR4
JP1
-15 GND +15