

**synthesis  
technology**

**MOTM-420 Voltage-Controlled Filter  
Assembly Instructions & Owner's Manual**

Synthesis Technology  
6625 Quail Ridge Dr.  
Fort Worth, TX 76180  
(817) 281-7776  
[www.synthtech.com](http://www.synthtech.com)

July 26, 1999

# MOTM-420 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 15 parts:

|   |                            |
|---|----------------------------|
| 2ea 10mfd, 25V Electrolytic               | C14, C15                   |
| 1ea 3.3mfd, 50V non-polar Electrolytic    | C5                         |
| 1ea 33mfd, 35V low-leakage Electrolytic   | C12                        |
| 1ea 22pf (marked 220) ceramic axial       | C13                        |
| 2ea 2200pf axial polystyrene              | C10, C11                   |
| 1ea 1000pf yellow box (marked E102 or 1N) | C2                         |
| 7ea 0.1mfd (marked 104) ceramic axial     | C1, C3, C4, C6, C7, C8, C9 |

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

|   |                          |
|---|--------------------------|
| 6ea 10K (brown, black, orange)              | R17, 25, 26, 28, 29, R30 |
| 4ea 220 ohm (red, red, brown)               | R23, 24, 27, R31         |
| 4ea 100K 1% (brown, black, black, orange)   | R1, R2, R3, R10          |
| 3ea 100K (brown, black, yellow)             | R13, R20, R21            |
| 3ea 51K1 1% (green, brown, brown, red)      | R11, 12, 19              |
| 2ea 8K2 (gray, red, red)                    | R8, R14                  |
| 2ea 22K (red, red, orange)                  | R16, R32                 |
| 1ea 1K 1% 3W tempco (large, black)          | R4 (this mounts over Q1) |
| 1ea 44K2 1% (yellow, yellow, red, red)      | R5                       |
| 1ea 475K 1% (yellow, violet, green, orange) | R6                       |
| 1ea 4K7 (yellow, violet, red)               | R7                       |
| 1ea 221K 1% (red, red, brown, orange)       | R9                       |
| 1ea 2K7 (red, violet, red)                  | R15                      |
| 1ea 2K2 (red, red, red)                     | R18                      |
| 1ea 75K (violet, green, orange)             | R22                      |
| 1ea 82K (gray, red, orange)                 | R33                      |
| 1ea 12K (brown, red, orange)                | R34                      |
| 1ea 39K (orange, white, orange)             | R35                      |
| 1ea 510 ohms (green, brown, brown)          | R36                      |

**IC** bag, containing the following 12 parts:

|                                 |         |
|---------------------------------|---------|
| 1ea MXL1013CN8 precision op amp | U1      |
| 1ea TL072 dual op amp           | U2      |
| 1ea JRC4558 dual op amp         | U3      |
| 1ea JRC4556 dual op amp         | U4      |
| 1ea LM13600AN dual OTA          | U5      |
| 1ea SSM2220 dual matched PNP    | Q1      |
| 6ea 1N4148 diodes               | D1 – D6 |

- Misc #1 bag, containing the following 6 parts:**

2ea Axial ferrite beads (plain, gray things)L1, L2  
1ea MTA-156 power connector JP1  
1ea SPDT (ON-OFF-ON) toggle switch SW1  
1ea trimmer, 20K Bourns 3386P TP1  
1ea trimmer 2K Bourns 3386P TP2

- Knobs, 7ea, ALCO PKES90B1/4**

- Jacks, 7ea Switchcraft 112A**

- Pots, 7ea containing the following:**

1ea 100K cermet Spectrol 149 VR7  
3ea 100K conductive plastic Bourns 95A1 VR1, 2, 3  
3ea 100K log conductive plastic Spectrol 148 VR4, 5, 6

- Front panel**

- Mounting bracket**

- Wire bag, containing the following 12 wires:**

4ea RG-174 coax, 4 ½ inches  
1ea RG-174 coax, 7 inches  
3ea 3-wire set 22ga, 6 1/2 inches (white/red/black)  
2ea 2-wire set, 22ga, 7 inches (white/orange)  
1ea 3-wire set, 22ga, 4 inches (white/orange/gray)  
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)  
7ea small tie-wraps  
9ea small heat-shrink tubing

- Organic Solder**

- No-clean Solder**

- PC Board, MOTM-420**

**\*\*\* In addition, you will need a very small amount of silicone heat-sink compound. Available from Allied, Newark, Mouser, Maplin, and many others \*\*\***

## GENERAL INFORMATION

Thank you for purchasing the MOTM-420 Voltage-Controlled Filter (VCF). If you have any issues concerning the building or use of the kit, please contact us at (817) 281-7776 or by email: [syntht@yahoo.com](mailto:syntht@yahoo.com)

This kit should take the average builder between 3 to 4 hours. The VCF kit contains many different resistors and special parts. 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-420:

- \* Soldering iron, 50W max power
- \* A heat-shrink gun. (optional, but highly recommended)
- \* Needle-nose or chain-nose pliers
- \* Diagonal cutters
- \* Allen key set for securing the knobs (1/16" or 1.6mm)
- \* 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 trimmers
- \* Fingernail brush for washing off the organic flux
- \* Old towel for blotting dry pc board
- \* Heat-sink compound: this **is REQUIRED** for proper VCF operation. Available from Allied, Newark, Mouser, Radio Shack, Farnell, and most all electronic supply companies. (Postal regulations force us 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>.

You also may find it useful to purchase additional heat-shrink tubing (1/8" diameter, 2:1 shrink ratio) and solder. Just be sure it is NOT rosin-based flux!

## 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.

## 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-420 kit: standard 5%, 1/4W parts and special, precision parts. The precision parts use a slightly different color-coding scheme. If you are unsure of a resistor’s value, use your trusty DVM to measure it! Inserting the wrong resistor in the VCF kit will cause interesting behavior! And, it’s very hard to find the error!

Lastly, the large black “tempco” resistor is the **last** part soldered on the pc board. **DO NOT** solder it until told to do so!

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

- Find the **RESISTOR** bag.
- Find the MOTM-420 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

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.

Locate the 100K resistors (3) and solder into R13 (near C5), R20, and R21 (above R13).

- Locate the 4K7 resistor and solder into R7 (above TP1).
- Locate the 8K2 resistors (2) and solder into R8 (above R7) and R14 (by SW1).
- Locate the 2K7 resistor and solder into R15.
- Locate the 22K resistors (2) and solder into R16 and R32 (top right corner).
- Locate the 10K resistors (6) and solder into R17 (bottom right corner), R25, R26, R28, R29, and R30 (all are near U5).
- Locate the 2K2 resistor and solder into R18 (below TP2).
- Locate the 75K resistor and solder into R22 (by VR5).
- Locate the 4 220 ohm resistors and solder into R23, R24, R27, and R31 (all by U5).
- Locate the 82K resistor and solder into R33 (top right corner).
- Locate the 12K resistor and solder into R34 (below R18).
- Locate the 39K resistor and solder into R35.
- Locate the 510 ohm resistor and solder into R36.

## **PART #2: Precision Resistors EXCEPT R4**

***IMPORTANT NOTE! R4 is the last part soldered on the board! DO NOT SOLDER this part until told so. You have been warned!***

- Locate the 4ea 100K, 1% resistors and solder into R1, R2, R3, and R10 (all near U1).
- Locate the 44K2 1% resistor and solder into R5 (by TP1).
- Locate the 475K 1% resistor and solder into R6 (above U2 and C3).
- Locate the 221K 1% resistor and solder into R9.
- Locate the 3ea 51K1 1% resistors and solder into R11, R12, and R19 (all by U1).
- STOP! Save the big black tempco resistor for later. DON'T LOSE IT!

## **PART #3: 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 at least 15 minutes.
- Take a little break! You are about 1/3rd of the way finished.

## **PART #4: CAPACITORS EXCEPT C10 & C11 (polystyrene)/Board Wash #2**

- Locate the **CAPACITOR** bag. Set the polystyrene 2200pf caps (the big silvery ones with the long, thin leads) aside. ***THESE CAPS ARE SOLDERED IN AFTER THE ICs!***
- Locate the 22pf cap and solder into C13 (between R35 & R36).
- Locate the 1000pf yellow box cap and solder into C2 (next to U2).
- Locate the 0.1M caps (7). Solder into C1, C3, C4, C6, C7, C8, and C9.

- Locate the 3M3 non-polar electrolytic cap. Solder into C5.
- Locate the 33 $\mu$ fd cap. Note that it has a stripe on one side (the – terminal). Solder into C12 with the stripe **away** from the + pad.
- Locate the 10 $\mu$ fd electrolytics (2). Note that there is a stripe on the NEGATIVE terminal. The pc board has a + on the POSITIVE terminal. Carefully stick the capacitors into C14 and C15 with the stripe **away** from the + pad on the board.
- Wash the board again, gently scrubbing both sides. Use ONLY warm water!

## **PART #5: 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 (2). They are axial parts, gray colored with no markings. These are non-polar, and are soldered into L1 and L2 (by JP1).
- 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 MXL1013 op amp. Solder into U1. 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 bottom" on the pc board.
- Locate the TL072 op amp. Solder into U2.
- Locate the JRC4558 op amp. Solder into U3.
- Locate the JRC4556 op amp. Solder into U4.
- Locate the LM13600AN OTA. Solder into U5.
- Locate the SSM2220 (looks like an IC!). Solder into Q1, pointing down as the rest.
- Locate the diodes (6). 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 left. Solder into D1 – D6.

- Locate the blue trimmer pot marked P 202 on it's side. This is a 2K trimmer. Solder into TP2.
- Locate the trimmer pot marked P 203. This is a 20K trimmer. Solder into TP1.
- Locate the 2ea 2200pf polystyrene caps. Solder into C10 and C11.
- Being careful NOT to solder the 2 pads for R4, apply a small bit of solder to the via holes. These are the small pads that allow traces to "change sides" of the pc board. DO NOT SOLDER PADS FOR THE REMAINING COMPONENTS!!

## **PART #6: 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.**

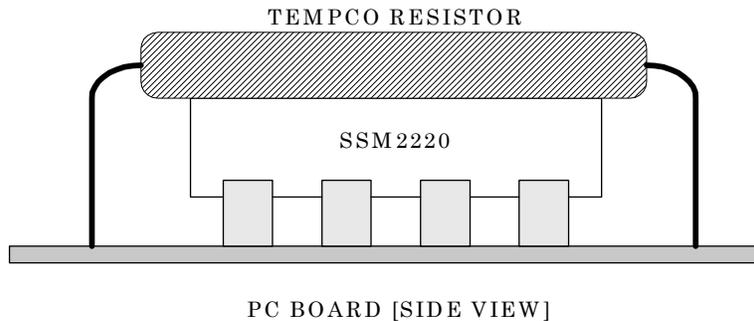
*You are now finished with the Organic flux solder. All soldering past this point is using the No-Clean solder. You do not have to wash the board anymore.*

## **PART #7: 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). There are 3 marked 148-9609-104. These 3 pots are soldered into VR4, VR5, and VR6. Be SURE the pots are sitting down all the way flat on the pc board with the shafts sticking straight out, square to the board. Solder the 100K linear pot (marked 149) into VR7.
- Locate the **Tempco resistor R4**. 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 Q1. Use just enough to cover the entire top *without* dripping down over the sides.
  - b) Bend the leads of R4 about 1/8<sup>th</sup> inch away from the body, at a 90 degree angle.
  - c) Insert the resistor into the 2 holes: one to the top of Q1 and one to the bottom of Q1.

- d) Push R4 all the way down so that the bottom of the resistor is sitting on top of Q1. The heat-sink compound will “squish out” from under R4. Wipe of any excess. **WARNING!** This stuff is next to impossible to wash out of blue jeans!
- e) Solder R4, making sure the resistor is level and **TOUCHING** Q1.



- Locate the 5 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 J1, J4 to J7. 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.**

The 1 **LONG** coax cable solders into J1 (1V/OCT IN). The 4 **SHORT** coax cables go into J4 – J7. 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 orange/white/gray twisted wire. This is soldered into SW1. Solder the Orange wire into the top #1 hole, the White wire into the middle #2 hole, and the gray wire into the bottom #3 hole.
- Find the 2 long orange/white twisted pairs. They go into J2 and J3. Solder the Orange wire into the **RIGHT** hole #2 and the White wire into the **LEFT** #1 hole.
- Find the 3 red/black/white twisted wires. They go into VR1, VR2 and VR3. In all cases, solder the White wire into the **LEFT** #1 hole, the Black wire into the **MIDDLE** #2 hole, and the Red wire into the **RIGHT** #3 hole. Be sure you solder the shorter conductor end into the pc board!

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

## PART #8: 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 7 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 7 jacks/lockwashers, with the beveled corner in the ***upper right*** corner, into the 7 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 #9: 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 VR7 and VR6 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 VR6 & VR7. For all of the pots, first put on the flat washer, then the hex nut. Tighten with a ½" nut driver.

## PART #10: 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.

- Find the SPDT toggle switch. These solder to the 3 wires in SW1 on the pc board. To make things go easier, first you will solder the wires to the component, then attach the component to the front panel. Solder the Gray wire to the TOP lug, the White wire to the MIDDLE lug, and the Orange wire to the Bottom lug (it doesn't matter **which** outside lug you call 'TOP'). Now, remove the outer hex nut. Place the switch through the small hole labeled **MODE** *with the Orange wire on the bottom*, near the phonejacks. Tighten the outside hex nut, but **DO NOT OVERTIGHTEN!!**
- Locate the 3 blue Bourns 91A panel pots. These solder to the 3 wires in VR1, VR2, and VR3. ***However, be careful because the ordering is different on the actual panel!***
- Each pot is soldered the same way. Facing the rear of the pot, you will see tiny indicators for each lug: 3 2 1 (lug #3 is to the left). First, slip a piece of the heat-shrink tubing over the wire (you may need to un-twist some first). Bend the wire into a small "J" shape and insert through the little slot in the lug. Solder the wire. Repeat for the other 2 wires. When all three wires are soldered, slide the heat-shrink over the lug/wire and apply heat (***a heat-shrink gun is highly recommended***).
- Solder the wires in VR1 to a pot: the Red wire goes to the LEFT #3 lug, the Black wire goes to the MIDDLE #2 lug, and the White wire goes to the RIGHT #1 lug (yes, I realize the pcb numbers don't match the pot numbers. Oh well.....). Don't forget the heat-shrink goes on first.! When you are finished soldering and the tubing is

shrunk on, insert the pot into the top panel hole (FREQ). Remove the outside hex nut and flat washer. **Place the pot in the hole with the 3 wires pointing down, towards the jacks.** Put the flat washer and hex nut back on the pot and tighten with a ½” nut driver.

- In the exact same manner, attach the VR3 wires to a panel pot. This time, be SURE the pot goes into the second hole marked FM1. Secure to panel.
- In yet again the same exact manner, attach the VR2 wires to the remaining panel pot. This pot goes in the third hole marked FM2. The wires will “cross over” the FM1 wires. Secure to panel. Using a ty-wrap, bundle the 3 pot wires together.
- Now you will solder to the 7 jacks. Each jack has 3 lugs: from the rear we will refer to them as LEFT, TOP, and BEVELED. In all cases, there is nothing soldered to the TOP lug.
- Solder the AUDIO OUT coax in J7 to the OUT jack. For all coax connections to the jacks, the braid goes to the BEVELED lug, and the inner conductor goes to the LEFT lug.
- Solder the IN 3 coax in J6 to the IN 3 jack.
- Solder the IN 2 coax in J5 to the IN 2 jack.
- Solder the IN 1 coax in J4 to the IN 1 jack.
- Solder the orange/white wire in J2 to the FM2 jack. The white wire solders to the LEFT lug, and the orange wire to the BEVELED lug.
- Solder the orange/white wire in J3 to the FM 1 jack. White wire to LEFT, orange to BEVELED.
- Solder the 1V/OCT coax in J1 to the 1V/OCT jack. Use a ty-wrap to bundle the coax together. Trim the excess.
- 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.

\*\*\*\*\*  
**CONGRATULATIONS! YOU HAVE FINISHED BUILDING THE MOTM-420!**  
\*\*\*\*\*

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-420 VCF has 3 basic sections: a voltage summing amplifier for the control voltages, an exponential voltage-to-current converter, and 2 current-controlled integrators that form the actual filter.

### INPUT VOLTAGE SUMMER

Refer to the schematic page marked M420.SCH for the following discussion.

The precision DC op amp U1 sums the various sources of control voltage to feed the exponential converter. Op amp section U1A is an inverting summer. The 1V/OCT input is summed at unity gain (set by the ratio R2/R10). The filter's initial cutoff frequency is set by panel pot VR1 and gain resistor R9 (if you want to reduce the "spread" of the filter's range, increase R9 to like 390K – 470K). The filter has a variable FM2 input that due to the 51K1 gain set resistor, can achieve approximately 0.5V/OCT.

A second inverting stage U1B is used because the "sense" of the PNP exponential converter is such that positive control voltage inputs will increase the cutoff frequency.

We have added a special type of input circuit for FM1: it is called a reversing attenuator. Resistors R12 and R19 are "in-between" the panel pot VR3. Note carefully R19 goes to the input of the following inverter stage, while R12 goes back to the first stage. The reason is explained below.

If the pot is rotated all the way to the left (CCW), the wiper (connected to the input jack J3) is "all the way over" to the R19 side. Therefore, the voltage applied to J3 is split into two paths: one path has a gain of ~2 (the R1/R19 path) and the other has a gain of ~0.66 (the R2/(VR3 + R12) path). The net effect is of course  $(.66)(2) = 1.33$

Therefore, the FM1 input can be set to control the filter from  $-0.75\text{V/oct}$  to  $+0.75\text{V/oct}$ . This control range can be adjusted by changing R12 AND R19 (they both need to be 1% resistors of the same value).

### EXPONENTIAL CONVERTER

The voltage output of the summing amp U1B is divided by the ratio of  $R4/(R4+R5+TP1)$ . The reason is that the base-emitter junction of Q1A wants to see a 18.02mv change for each 1.00V change at the summer output. Also, the collector current of Q1 has a temperature dependence. This temperature coefficient is cancelled by R4. That is why R4 and Q4 must be in "thermal contact": they need to be as close as possible to the same temperature.

So, the desired attenuation ratio is 1V in = .01802V out or ~55.5:1. That is why R5 + TP1 value is close to 54K if TP1 is in the middle. Clever, yes??

Now we need a “reference current” for the VCF, which is what the current source supplies with 0.0V out of the summer. This current is set by R6, and is  $15V/475K$  or  $\sim 31.6\mu A$  (this same topology is used in the MOTM-300 VCO). Q1B is a “current mirror” that actually drives the 2 OTA stages. R7 & R8 are protection resistors, and C2 overdamps U2A (since it is operating open-loop). The “idle” cutoff frequency is  $\sim 250Hz$  (the exact value is left as an exercise for the reader).

## FILTER SECTION

The filter is based on the Korg MS-20 circuitry. The MS-20 used a custom OTA gain stage, and the MOTM-420 uses a LM13600AN OTA stage. “Vintage op amps” are used to duplicate the sonic characteristics of the MS-20 filter.

OTA stands for Operational Transconductance Amplifier. The “gain” of the OTA is:

$$I_{out} = 19.2 * V_{diff} * I_{control}$$

Where  $V_{diff}$  is the differential voltage between the + and – input pins and  $I_{control}$  is a control current fed into the ABI pin. So, an OTA has a Current Out/Voltage In transfer, hence the term “transconductance” (note a ‘standard’ op-amp is Voltage Out/Voltage In).

As every good EE knows, the simplest low-pass filter is a series resistor and a cap to ground. The “corner frequency” is the familiar:

$$F = 1/(2)(\pi)RC$$

Since a variable C is hard to make, most filters use a variable R(esistance) to make a variable filter. Now, the clever reader will also recall Ohm’s Law:

$$I = V/R$$

Which can be re-written

$$R = V/I$$

Hmmmm.....if an OTA has a I/V function, and since the R for our simple low-pass is in the denominator (ie  $1/R$  factor) AND since  $1/R$  is  $I/V$ ....HEY! the OTA is a *variable resistor*, whose “value” is set by the control current  $I_{control}$ . We got ourselves a VCF!!

Note: the following discussion skips tons and tons of college-level calculus and complex arithmetic. Sorry!

The MOTM-420 uses 2 filter sections: U5A + C10 and U5B + C11. These sections form the variable “RC” sections of the filter. As stated earlier, the ‘R’ is really set by the control current from the summing amp/exponential converter. The OTA’s output current is the product of the audio signal (the  $V_{diff}$  part) and the current into the ABI pins.

In order to “peak” the filter at the cutoff frequency (called Resonance), we take a portion of the filter output and feed it back into the input. This is the function of U4A. Panel pot VR7

is a simple voltage divider. U4A is a non-inverting amp whose gain is set by the combination of R18 and trim pot TP2 (the MAX Q trim). R32 is a 'trick' to get a log-like response from linear pot VR7.

The 6 diodes across the opamp is a voltage limiter. Each diode has a 0.6V drop, so 3 diodes in series is a ~1.8V limiter.

The 3 audio inputs are summed by U3A. The individual gains for each stage is 75K/100K or 0.75. Since we have 3 inputs, and each can be connected to say a VCO output at +-5V pk-pk, the input summer will start to clip at some point. This is just a compromise between pot settings on the front panel versus all 3 inputs going full blast. You can adjust R22 up or down in value to suit.

The filter output is amplified by U4B. It's gain is 39K/12K or about 3.25. Therefore, the "end-to-end" gain on a single signal is  $(.75)(3.25) = 2.4$  which duplicates the MS-20 characteristic.

Note that the MOTM-420 can be used with ANY input levels, not just the +-5V pk-pk "standard" MOTM levels. This makes the MOTM-420 ideal for processing just about any audio signal in your studio!

The filter sections can be switched to form a lowpass filter, a highpass filter, or a notch filter. Switch SW1 does this by selectively grounding audio signals to the 2 filter sections. The theory behind this is beyond the scope of this discussion (entire books have been written on this subject. I like "Analog Filter Design" by M.E. Van Valkenburg).

## PRELIMINARY CHECK-OUT & CALIBRATION

The VCF needs two adjustments: the 1V/Oct tracking and the maximum Q trim.

Both of these trims are done "by ear", so an oscilloscope is not required. However, hours of enjoyment can be had watching the VCF output waveforms.

## SETTING THE MAX Q TRIMMER

The MAX Q TRIM sets the point on the dial for the RESONANCE pot that causes the filter to *self-oscillate*.

- a) a suggested point on the dial for self-oscillation is the '8' or '9' tick mark. Set the RES pot to the desired point on the dial.
- b) Set the MODE switch to LP
- c) Set the FREQ knob to 5 (straight up)
- d) Plug an audio mixer or preamp into the OUT jack. Be sure your amp is not set too loud! The '420 can pop a tweeter without any problems. Apply NO audio inputs to the '420.
- e) Apply power to the '420. Slowly adjust the trimmer until you hear the filter oscillate. The waveform is very close to a sine wave (it's not perfect due to the capacitors not being the exact same value and the OTA's current outputs not exactly the same).

## SETTING THE 1V/OCT TRIMMER

First, apply power to the VCF and wait for 10 minutes. This allows the Q1/R4 temperature to stabilize to operating point.

Although the purpose of the trimmer is to set the filter's cutoff frequency to double for each volt applied (ie 1V = 200Hz, 2V = 400Hz, 3V = 800Hz, etc) the easiest way is to set this is use the VCF as a VCO!

From the above MAX Q procedure, the VCF will oscillate and act as a VCO over a limited range of control voltage. This is because the exponential converter is not as precise as those in VCOs (although the MOTM-420's exponential converter is better than any VCF ever made!).

The best way is to "beat" the output of the VCF with a VCO or synth that is in tune. Or, if you have good pitch you can just set it by ear!

- a) plug a source of accurate 1V/OCT into the jack (ie a Kenton Pro-2000)
- b) set the MODE switch on LP
- c) set the FREQ to about 6
- d) set the RES to 9.
- e) Set the 1V/OCT ADJUST pot to the center position.

You should now be able to play the VCF as a VCO. Now adjust the trimmer for the best tracking. The tracking is not that great, but over a 3-4 octave range you should get fairly close. Remember, the exact cutoff frequency is not that important as it is for a VCO!

## TROUBLESHOOTING

If your MOTM-420 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 'down'.
- All of the diode's bands are to the "left".
- The braided wire on the coax goes to the beveled side of the jacks.
- The parts in the the right places, and the panel pots/switch is wired correctly.
- No solder shorts or missing joints. BE SURE to carefully examine the pins on Q1 for solder shorts.

## USE OF THE MOTM-420 VCF

The MOTM-420 is a “stand alone” module that can be used for filtering just about any audio source (you can’t plug a guitar or mic directly into it, but use a ‘direct box’ or preamp first!).

The important thing to remember is the top row of jacks is for *control voltages*, and the bottom row is for *audio inputs*. You can use audio signals to modulate the filter.

The filter has three modes: LP (low-pass), HP (high-pass) and NF (Notch filter).

A low-pass filter is like a BASS tone control. It passes lower frequency and attenuates higher frequencies. The point where this starts is called the *cutoff frequency*. Frequencies below the cutoff “pass through”, while frequencies above cutoff get reduced in volume.

A hi-pass filter is like a TREBLE control: again higher frequencies “pass through” and lower frequencies are attenuated.

A notch filter has a ‘dip’ at the cutoff frequency: if the signal is above OR below cutoff, it passes through. At the cutoff frequency, it is attenuated.

Note that as a “side effect”, the phase of the output signal gets shifted relative to the input. This can also add new sounds!

## FILTER SLOPES AND RESONANCE

The amount the frequencies get attenuated relative to the cutoff is called the filter’s *slope*. The MOTM-420 in LP and HP modes have a 12dB/oct slope (12dB is about 1/4<sup>th</sup>). For example: if the LP filter has a 500Hz cutoff, a 1Khz sine wave is attenuated 12dB at 1Khz, 24dB at 2Khz, etc. The Notch filter, due to the circuitry used, has only a 6dB/oct slope. If you are in NF mode, and the filter is set to 500Hz, then a 500Hz sine wave is attenuated 6dB at 500Hz (about half). Note these are ‘ideal’ figures and the actual filter will have slightly less attenuation.

You can get “sharper” slopes by daisy-chaining MOTM-420s. If you have 2, then take the OUT of the first one into the IN 1 of the second one. If both filters are set to the same **FREQ**, **RES**, and **MODE** settings, the slopes will be twice normal (24dB/oct for LP/HP and 12dB/oct for Notch).

A popular filter effect is to add *resonance* to the cutoff frequency. Resonance is just adding additional gain right at the cutoff frequency. The effect is that the filter sounds “brighter” or “squeakier”. If you add too much resonance, the filter will self-oscillate.

## USING YOUR MOTM-420 WITH OTHER MOTM MODULES

### 1) The basic patch

The most basic synth patch is as follows:

- a) VCO outputs into the filter IN jacks
- b) Keyboard voltage into the 1V/OCT jack
- c) MOTM-800 EG + output into the FM1 jack
- d) OUT of the '420 into a mixer/amplifier

90% of synth sounds are tweaking this one set-up (can you say Minimoog??!?) Set MODE to LP, set RES to 4, and start turning up the FREQ. Adjusting the FM1 pot set the amount of filter “sweep”, and with the reversing feature you can sweep “up” or “down”!

Experiment with different VCO waveforms, adding noise, and filtering the output of a MOTM-120.

### 2) Using 2 MOTM-420s

You can get **very** complex and interesting sounds by using 2 MOTM-420s.

- a) Sweep one filter up while the other sweeps down. This is effective in NF mode to get phasing effects. Use a LFO (or MOTM-300 in low-speed) and the FM1 pots to set the relative sweeps. Use 2 different sweep rates to get even more lush effects (this is the basic premise used in the MOTM-410 filter)
- b) Emulate the MS-20 by setting one filter to HP and one to LP
- c) Audio inputs plugging into the first filter will get attenuated differently than audio inputs plugging into the second filter! This can make for some bizarre stuff.
- d) You DO NOT have to use the keyboard CV into the filters. You can use FM1 or FM2 instead to have “variable tracking” (the Minimoog has switched tracking intervals). The net effect of not tracking is the timbre will change as you play up and down the keyboard. This may be a good thing!

## USING THE MOTM-420 WITH OTHER GEAR

You can patch into the audio inputs from just about anything. The only thing to remember is the “end-to-end” gain (at zero resonance) is about 2.4X. Of course, this is with the IN pot at 10. The built-in audio mixer of the '420 comes in very handy for adjusting gains.

Unlike other MOTM modules, there is no real “minimum” voltage input requirement. The limiting factor is the noise floor of the op amps. These op amps used in the '420 are older bipolar types and not as “clean” as the OP-275s used in other modules. Why are they there? To get that MS-20 sound!

Experiment! You can spend hour and hours playing with all the possible settings and audio inputs.

# SPECIFICATIONS

## MOTM-420 Voltage-Controlled Filter

|                              |   |
|------------------------------|---|
| Control Voltage input levels | -13V to +13V                            |
| Cutoff frequency range       | 1Hz to 28Khz                            |
| Output impedance             | 1000 ohms, nom.                         |
| Filter modes                 | LP and HP @ 12dB/oct, Notch @6dB/oct    |
| Audio input level            | 50mv pk-pk min, 12V pk-pk max           |
| Filter gain                  | 2.4 nominal @ RES = 0, Input level @ 10 |

### CONTROLS

|            |                                      |
|------------|--------------------------------------|
| FREQ       | sets VCF initial cutoff frequency    |
| RES        | resonance (gain) at filter cutoff    |
| FM1        | level set for FM1 control voltage    |
| FM2        | level set for FM2 control voltage    |
| IN 1, 2, 3 | level set for audio input IN 1, 2, 3 |
| MODE       | selects filter mode (HP, LP, NF)     |

### GENERAL

|                    |  |
|--------------------|--|
| Power Supply       | -15VDC @ 18 ma<br>+15VDC @ 18 ma             |
| Size               | 2U x 5U<br>3.47" x 8.72"<br>88.1mm x 221.5mm |
| Depth behind panel | 4.375 inches (111mm)                         |



SYNTHESIS TECHNOLOGY  
MOTM-420 FILTER  
WWW.SYNTHTECH.COM

