Oakley Sound Systems

5U Oakley Modular Series

RM4014 Ring Modulator

PCB Issue 3

Builder's Guide

V3.1

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Introduction

This is the Project Builder's Guide for the issue 3 RM4014 Ring Modulator 5U module from Oakley Sound. This document contains a basic introduction to the board, a full parts list for the components needed to populate the board, a circuit description, and a list of the various interconnections.

For the User Manual, which contains an overview of the operation of the unit and the calibration procedure, please visit the main project web page at:

http://www.oakleysound.com/ringmod.htm

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project webpage or http://www.oakleysound.com/parts.pdf.

For general information on how to build our modules, including circuit board population, mounting front panel components and making up board interconnects please see our generic Construction Guide at the project web page or http://www.oakleysound.com/construct.pdf.

The Issue 3 Ring Modulator PCB
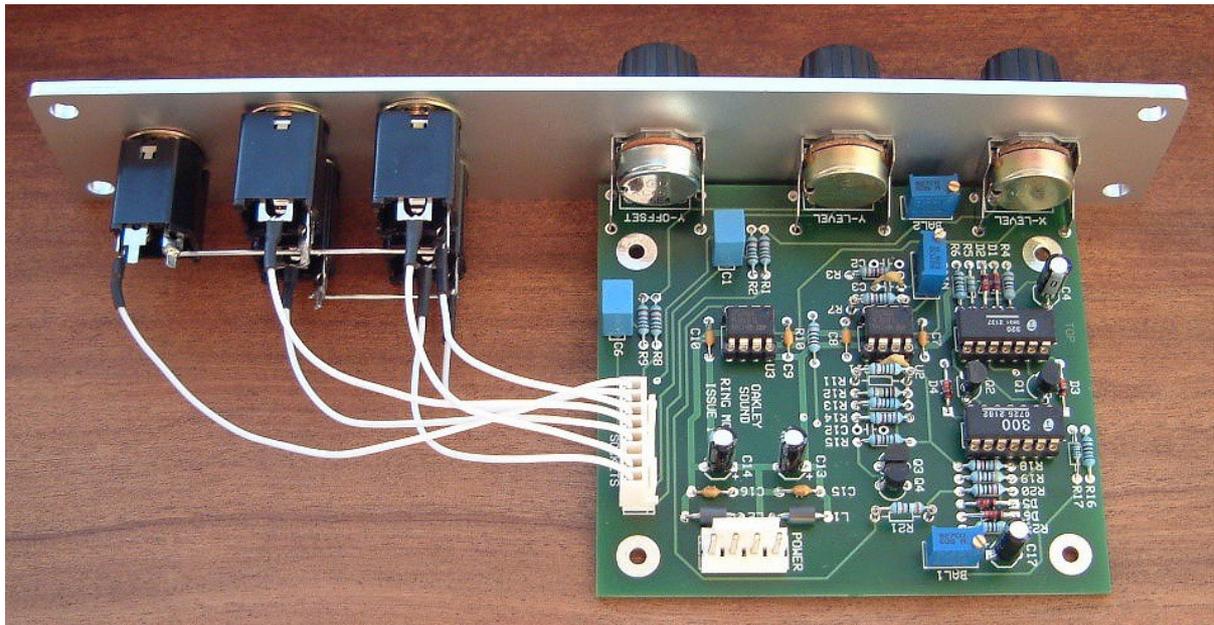
This is the prototype issue 1 Oakley RM4014 module behind a natural finish 1U wide Schaeffer panel. Issue 3 boards are similar but feature an optional MU power header and improved layout.

This is one of our smaller format PCBs. The module can be either built as a standard 5U Oakley panel design, or as a smaller 3U Frac sized panel. To allow this to happen the pots are Alpha/ALPS 16mm types with our special matching brackets. The pot spacing on this module is 36.8mm (1.45") instead of our usual 41.3mm (1.625"). Used in conjunction with smaller 20mm diameter knobs this still allows for an attractive module design and finger friendly tweaking.

The module requires plus and minus 15V supplies. The power supply should be adequately regulated. The current consumption is about +40mA and -35mA. Power is routed onto the main PCB by either our standard four way 0.156" MTA156 type connector or the special five way Synthesizers.com MTA100 header. The four pins are +15V, ground, earth/panel ground, -15V. The earth/panel connection allows you to connect the metal front panel to the power supply's ground without it sharing the modules' ground line. More about this later.

The PCB has four mounting holes for M3 bolts, one near each corner. These are not required if you are using our specially made pot brackets. The size of the board is 96.5mm high by 86.4mm deep.

The input and output sockets are wired to the board via an eight way 0.1" Molex or MTA interconnect. This makes removing the board from the panel very easy. At the moment I have no plans to release a socket board that would fit the suggested panel design. However, it would be possible to utilise an Oakley Sock6 socket board with appropriate wiring and a different front panel design.

Ring Modulator issue 3 Parts List

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project web page or http://www.oakleysound.com/parts.pdf.

The components are grouped into values, the order of the component names is of no particular consequence.

A quick note on European part descriptions. R is shorthand for ohm. K is shorthand for kilo-ohm. R is shorthand for ohm. So 22R is 22 ohm, 1K5 is 1,500 ohms or 1.5 kilohms. For capacitors: 1uF = one microfarad = 1000nF = one thousand nanofarad.

To prevent loss of the small '.' as the decimal point, a convention of inserting the unit in its place is used. eg. 4R7 is a 4.7 ohm, 4K7 is a 4700 ohm resistor, 6n8 is a 6.8 nF capacitor.

Resistors

All resistors should be 1% 0.25W metal film resistors. R5 and R17 can be 5% metal film or carbon if you can't get 1% devices.

220R	R20
470R	R19
680R	R6, R16
1K	R10
4K7	R22, R4
10K	R9, R1, R2, R8
12K	R14
15K	R11
18K	R7, R15, R18
39K	R3, R21
56K	R13
1M	R12
2M2	R5, R17

Capacitors

Some capacitors are optional and are marked with a *. They were used in the original ARP-4014 module but are not recommended for this design.

12pF 2.5mm C0G ceramic	C11
47pF 2.5mm C0G ceramic	C3, C2*, C12*
100pF 2.5mm C0G ceramic	C5*
100nF axial multilayer ceramic	C7, C8, C9, C10, C15, C16
1.5uF, 63V polyester	C1, C6
2.2uF, 25V electrolytic	C4, C17, C13, C14

Discrete Semiconductors

1N4148 signal diode	D1, D2, D3, D4, D5, D6
BC550 NPN transistor	Q2, Q4
BC560 PNP transistor	Q1, Q3

Integrated Circuits

TL072 dual op-amp	U2, U3
THAT320P PNP array	U1
THAT300P NPN array	U4

Variable Resistors

50K or 100K multiturn trimmer	BAL1, BAL2, GAIN
100K linear Alpha 16mm pot	X-LEVEL, Y-LEVEL
50K linear Alpha 16mm pot	Y-OFFSET
Pot brackets	Three off

Miscellaneous

Leaded ferrite beads	L1, L2	
MTA156 4 way header	PSU	– Oakley/MOTM power supply
MTA100 6-way header	PWR	– Synthesizers.com power supply
0.1" 8-way Molex or MTA header	SOCKETS	– board mounted
0.1" 8-way Molex or MTA housing	SOCKETS	– wire harness
DIL14 pin IC sockets	Two off	
DIL 8 pin IC sockets	Two off	

LK is wire link and is fitted only if using Synthesizers.com power header, PWR.

Other Parts Required

Switchcraft 112APC 1/4" sockets	Five off mounted on panel

Three 20mm knobs.

Around 2m of insulated multistrand hook up wire for the socket connections.

Circuit description

A ring modulator is sometimes described as a four quadrant multiplier, and while this certainly sounds more grand, it also explains the action of the device in more detail. The four quadrants refer to the four quarters of a standard XY graph with the origin in the middle. The idea being that this device allows two inputs, we will call them X and Y, of either positive or negative voltage, to be multiplied together. The output is therefore either positive when both X and Y are the same polarity, or negative when they are different.

A standard voltage controlled amplifier (VCA) can be considered as two quadrant multiplier since one of its inputs can only be of a positive value. The two quadrants where Y is negative are not computed, and the output normally remains at zero when Y is not positive.

In audio when an input signal is processed so that it changes from a positive value to a negative one we say it has been inverted, or that it is 180 degrees out of phase with the original. In this way, a ring modulator may be considered to change the phase of one of its inputs depending on the polarity of the other.

In a perfect ring modulator the inputs X and Y can be considered as having the same functions as each other.

ie. X x Y = output = Y x X

In our real life ring modulator this is not true. Imperfections in the circuit topology means that the output will sound different, or behave differently, depending on which signal you insert into X and which into Y. Generally, we will use X as our input signal (sometimes called the carrier), and Y as our modulator. That is, Y will shape X. In many applications it doesn't make too much difference which is which, so experimentation is the key here.

The Oakley Ring modulator is based around the old ARP module 4014. This was built on an incredibly tightly cramped circuit board which was then securely potted, with a very hard epoxy compound, into a small plastic box. The various interconnections were made to some thin gold plated legs that stuck out from the hard epoxy on the underside. It is almost impossible to remove the circuitry from its hard plastic shell and all encompassing resin. I suppose this was mostly down to Alan Pearlman's previous history in making op-amps for the aerospace industry – enclosing circuits like this would make them less likely to drift with temperature and be affected by surrounding humidity. However, one might also think that they did it to keep out the prying eyes of their competitors.

Later versions of the 4014 used soft and rubbery silicone to pot the circuitry into its shell with only a thin layer of epoxy on the underside to seal it all in. These are easier to repair since it is now possible, with great care, to remove the delicate circuitry from its shell and potting compound. Various folk have since reverse engineered this circuit and it can be found in various places on the internet.

The basic function of the 4014 is of two complementary VCA circuits, both controlled by a single driver, and each feeding a common current to voltage output stage. The driver features

a non linear gain that acts as a pre-distortion device which compensates for some of the non linearities in the VCA sections.
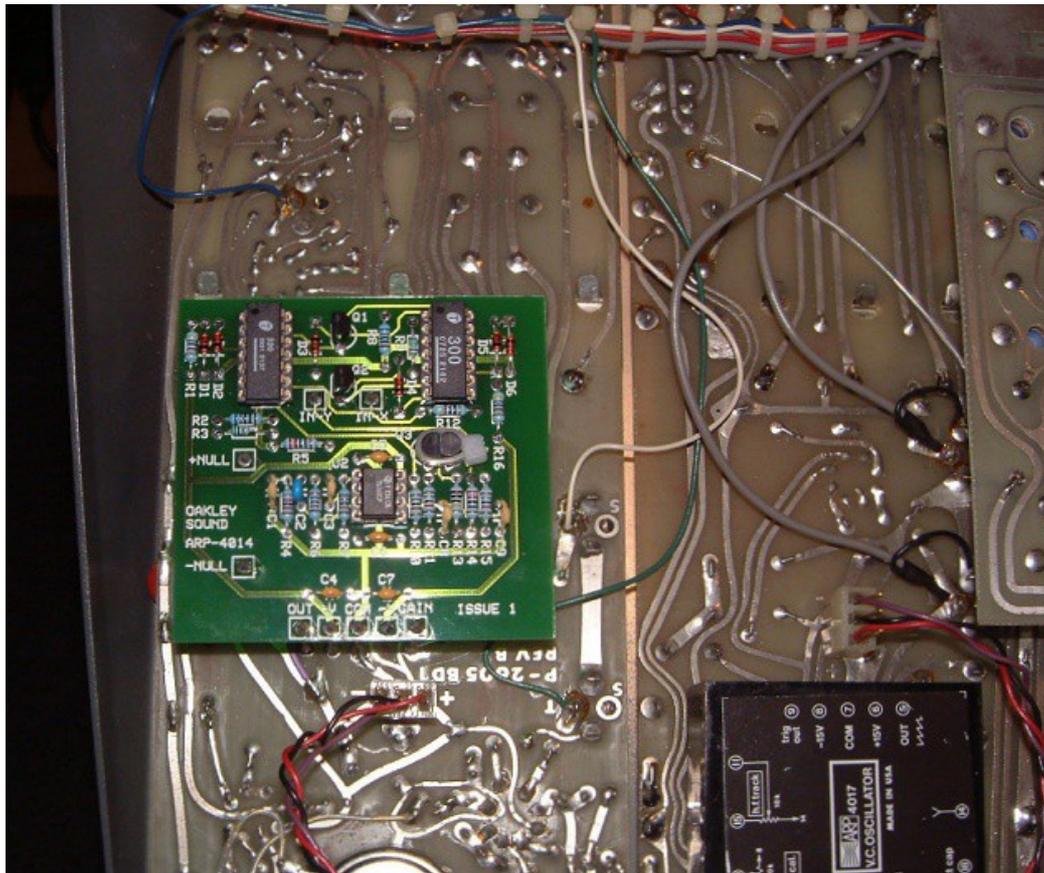
The very first Oakley ring modulator module built to replace a dead ARP-4014 module in an ARP2600 synthesiser. The Oakley RM4014 module borrows heavily from the design shown here.

U3, a dual op-amp, is configured as two voltage followers, one for each input. The signal level to each one is controlled via its own level pot. The source of the signal can come from either a direct coupled input via a single resistor, or AC coupled via a capacitor. The capacitor in conjunction with the resistor following it and the pot itself will act as a high pass filter. This will attenuate very low frequency signals with a -3dB point of around 1Hz. It is possible to use both the AC and DC inputs simultaneously thus creating a crude two channel mixer. However, although no harm to the unit will come about, it does cut down the overall signal level presented to the input level pot.

Both U3 halves act as protective buffers for the relatively high output impedance of the level pots. The lowish input resistances of the ring modulator input stages would otherwise detrimentally affect the pots' apparent taper, the cut-off frequency of the AC coupled input, and perhaps also the output stage of the connected modules.

The ring modulator core is built from two transconductance amplifiers that are complementary to one another. A transconductance amplifier is basically a 'voltage in, current out' device whose gain, in this case, is controlled by another modulating current. And complementary in this definition means identically opposite, mirrored if you like. In other words they behave mostly the same but one is modulated by positive currents from the driver, the other negative

currents. Since the driver is common to both of them and its own output is either positive or negative, only one of the transconductance stages is active at any one time.

I have tried to draw the schematic so you can see the two complementary halves of the core easily. Each one appears identical but for the type of transistors used. Where one uses a NPN, the other will use a PNP, and vice versa. Note too, that the X input is applied to different sides of the transconductance stages resulting in one of them being of opposite phase to the other. The left hand side deals with Y modulation signals that are positive in value. The right hand side deals with Y modulations that are negative in value.

Each transconductance amplifier is made from five transistors. Four are two sets of matched pairs. A matched pair is exactly that; two devices that share with almost identical characteristics. This cannot usually be obtained from simply buying two transistors of the same type, since in manufacturing there are small discrepancies that make every device slightly unique. In the original 4014 module, ARP would have hand selected their transistors by trying hundreds out and grouping them together into large bins with contained those devices with similar characteristics. Each pair would then be made by selecting two devices from the same bin. This would take too much time when you only want to build one or two Oakley Ring Modulators, so I have used pre-matched quad transistor arrays. The THAT300 is four matched NPN transistors, and the THAT320 is four matched PNP transistors. The electronic matching is near perfect and they are also made onto the same silicon die and in the same housing thus ensuring a good thermal matching too.

The voltage at the top of each transconductance stage is fixed by diodes to be 1.2V for the left hand side one and -1.2V for the right hand side. C4 and C17 provide some additional decoupling to reduce any noise or audio signal bleedthrough at these points. C4 and C17 were not in the original design, but I have added them here to reduce any chance of extraneous noise pick up.

The output of both transconductance stages go to the inverting input of the output op-amp, U2, pins 1, 2 and 3. This is wired as an inverting transimpedance amplifier, which is a 'current in, voltage out' device and essentially the opposite of a transconductance amplifier. A transconductance amplifier followed by a transimpedance amplifier make an amplifier, ie. 'voltage in, voltage out'.

To make sure the overall gain of the ring modulator is positive for Y being positive, we use the inverting outputs from each transconductance amplifier. These are found on the collector of the left hand transistor of the input pair, ie. U14, pin 14 and U1, pin 7.

The gain of the transconductance amplifiers is controlled by the driver circuit. The output of the driver circuit is converted to a current by R18 which in turn affects the current through the input pairs and hence the amplitude of the current output. However, the response of gain versus input current is not linear when the output of U2 is less than 0.6V for the left hand amplifier and above 0.6V for the right hand one. This is because to control the gain of the transconductance amplifiers the voltage at the bottom of R18 must be enough to overcome the inherent base-emitter voltage and turn on either of the input transistor pairs. This would give rise to a dead zone of operation if it were not for the deliberate non linearity introduced in the driver circuit.

Q3 and Q4 are wired as diodes in the feedback of the driver op-amp. This means for output voltages between -0.6V and +0.6V the gain of the op-amp is very high indeed as it is pretty much set solely by the ratio of R12 and R11. Thus even a small voltage on the Y input will lead to either +0.6V or -0.6V depending on the polarity of the input. Once this voltage has been achieved any increase in input voltage will decrease the gain as either Q3 or Q4 turns increasingly on. Eventually, the gain tends to the ratio of R15 and R11, a much smaller figure.

Unlike the original circuit application, the Oakley Ring Modulator allows you to add a positive offset voltage to the Y input voltage. Thus effectively increases the gain of the left hand transconductance amplifier thus allowing the non inverted X signal to pass through to the output even when no positive Y input is present.

Power is supplied via the usual four way 0.156" MTA or Molex connector or the special five way 0.1" Molex for MU based systems. As is the custom for Oakley modules, I have used ferrite beads to act as high frequency filters on the power lines. Decoupling at the point of entry is provided by C13 and C15 for the positive rail, and C14 and C16 for the negative rail. Additional decoupling is also provided elsewhere on the board by the other capacitors shown at the bottom of the schematic. All these capacitors keep the power supply clean of noise, and provide a reservoir for the little bursts of current that the circuit takes in normal operation.

Connections

Power connections – MOTM and Oakley

The PSU power socket is 0.156" Molex/MTA 4-way header. Friction lock types are recommended. This system is compatible with MOTM systems.

Power	*Pin number*
+15V	1
Module GND	2
Earth/PAN	3
-15V	4

Pin 1 on the I/O header has been provided to allow the ground tags of the jack sockets to be connected to the power supply ground without using the module's 0V supply. Earth loops cannot occur through patch leads this way, although screening is maintained.

It's worth filling the empty holes of the PWR pads with solder.

Power connections – Synthesizers.com

The PWR power socket is to be fitted if you are using the module with a Synthesizers.com system. In this case you should not fit the PSU header. The PWR header is a six way 0.1" MTA, but with the pin that is in location 2 removed. In this way location 3 is actually pin 2 on my schematic, location 4 is actually pin 5 and so on.

Power	*Location number*	*Schematic Pin number*
+15V	1	1
Missing Pin	2	
+5V	3	2
Module GND	4	3
-15V	5	4
Not connected	6	5

+5V is not used on this module, so location 3 (pin 2) is not actually connected to anything on the PCB.

If fitting the PWR header, you will also need to link out LK. This connects the panel ground with the module ground. Simply solder a solid wire hoop made from a resistor lead clipping to join the two pads of LK together.

Hand wiring the sockets
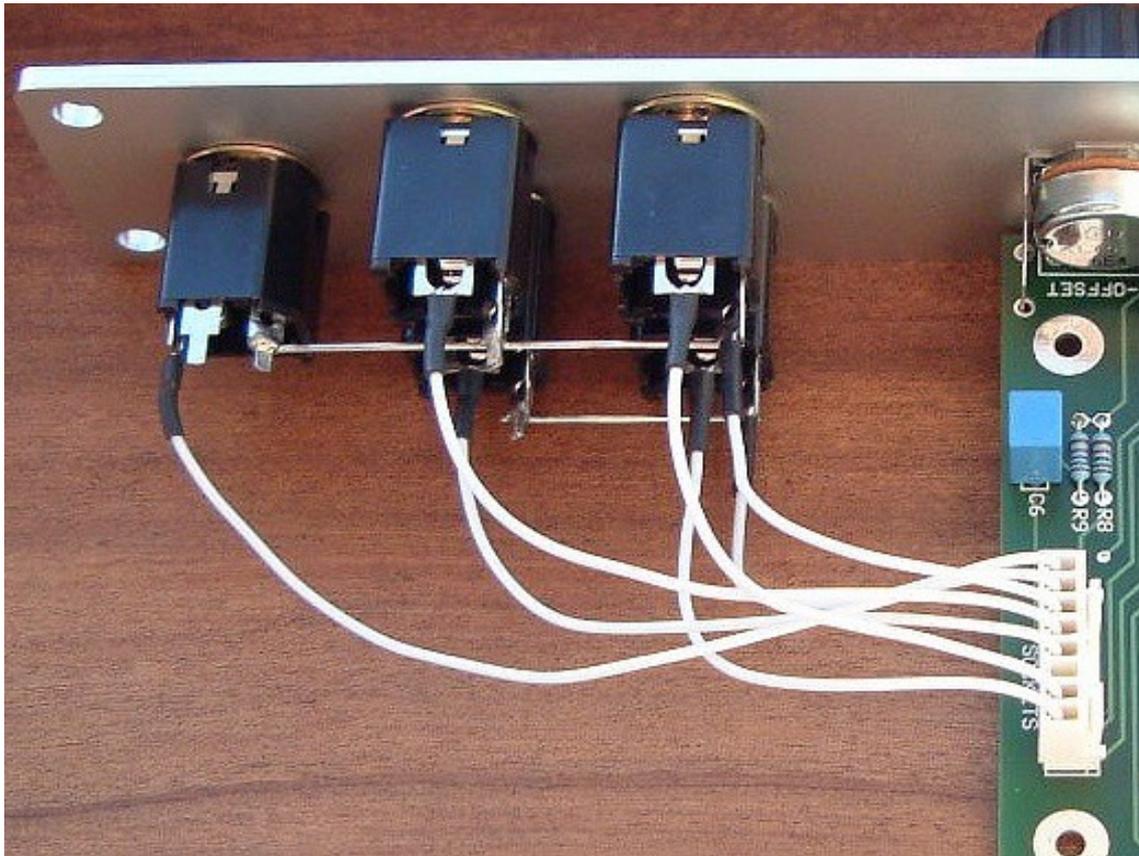
The prototype wired using Switchcraft 112APCX sockets showing the heatshrink around each solder tag.

How you wire your input and output sockets up will very much depend on your panel design and choice of sockets. I will only go into the details of wiring up the standard 5U high panel with the five 1/4" sockets underneath the PCB, but any Frac or Euro rack construction will be similar.

If you have used Switchcraft 112A or 112APC sockets you will see that they have three connections. One is the earth lug or ground tag, this is indicated by a bevel in the socket's housing. The second is the signal tag which will be connected to the tip of the jack plug when it is inserted. The third tag is the normalised tag, or NC (normally closed) lug. The NC lug is internally connected to the signal tag when a jack plug is not inserted. This connection is automatically broken when you insert a jack.

In this module we are going to 'common' the sockets' ground lugs. This means that the sockets' earth lugs are going to be joined together. I normally do this part of the wiring without the PCB or pots in place on the panel.

Fit the four input signal sockets onto the panel so that the bevel on the side of the socket is facing top right as you look at the rear of the panel. Then fit the output socket in the lowest hole, but attach it so that its bevel faces to the top left.

Now lay the panel on its side with the front panel facing away from you and the bottom of the panel to your right. The five sockets' pins should be facing you.

The first lugs we are connecting together will be the ground or earth tags on the two sockets on the top row, the two DC input sockets. I use 0.91mm diameter tinned copper wire for this job. Its nice and stiff, so retains its shape. Solder a length of this solid core wire right across the two earth tags on the top row. Trim off any excess that sticks out on either end.

Then do the same on the lower three sockets, that is the two AC inputs and the single output sockets. Because of the different orientation of the output socket you'll find that the output socket's earth tag lines up roughly with the other two's tags.

Fit the Ring-modulator PCB against the front panel if you haven't done so already.

I used Molex KK headers and housings to connect my ring modulator together. I also use the Switchcraft 112APCX sockets, and not the 112A that MOTM uses. These types are the ones that are designed to be soldered directly to a PCB, however, they also allow direct wiring and fitting of a heatshrink sleeving for strain resist.

Use multistrand hook up wire to connect each socket lug to the relevant pin on the header. Keep your wires short but not too short and you can use as many different colour wires as you can – although I tend to use one colour because I'm a minimalist. There is absolutely no need to use screened cable for such short runs.

The connections of the lugs of the CV and audio output sockets that go directly to the PCB are summarised in the table below. They are given in the order in which I would recommend that they be soldered.

Socket Name	Lug type	Header Pin number
IN X (DC)	Earth	8
IN X (DC)	Signal	1
IN Y (DC)	Signal	4
X x Y	Signal	7
IN X (AC)	Earth	6
IN Y (AC)	Signal	5
IN X (AC)	Signal	2

NB. Pin 3 is not used.

Once that is done, your module is ready for testing and calibration.

Testing, testing, 1, 2, 3...

Apply power to the unit making sure you are applying the power correctly. Check that no device is running hot. Any sign of smoke or strange smells turn off the power immediately and recheck the polarity of the power supply, and the direction of the ICs in their sockets.

Assuming everything is OK so far, it is time to apply an audio input. Use a signal like a triangle output from a VCO. Middle A, 440Hz is a good note to use. Turn down all the pots to their minimum setting and insert your triangle wave signal into IN X (AC). Listen to the output signal from the ring modulator module. For the moment you should hear nothing.

Turn up the X LEVEL pot to full. Again, you shouldn't hear anything, but maybe you will hear a little triangle wave bleedthrough. Now slowly turn up the Y OFFSET pot. If all is well this should behave like a volume control, increasing the level of the triangle wave as it is turned up.

Ensure that altering Y LEVEL should have no effect on the sound, but that X LEVEL behaves also like a volume control. It should seem that both X LEVEL and Y OFFSET do the same thing. They do not of course, since X LEVEL is altering the signal level going into the ring modulator circuit, and Y OFFSET is adjusting the gain of the amplification within the ring modulator.

Swap the input signal over to the IN X (DC) input. This should have no apparent effect on the sound.

There is a very good chance your circuit is working correctly if you have got this far with no problems. However, we still need to check a few other things and you'll need another signal source to do this. Connect a LFO or VC-LFO to the IN Y (DC) input. Use a sine or triangle wave signal at a lowish frequency, say 1Hz or so.

Turn the Y OFFSET down and the X LEVEL up. Now slowly turn the Y LEVEL up and listen to the resultant sound. It should be the triangle wave you can hear again, but it will pulse up and down with LFO signal. You should hear it go up and down in volume twice for every cycle of the LFO, ie. at 2Hz if you have set your LFO to 1Hz. This is because, unlike an ordinary VCA, the triangle wave is being multiplied by both the positive and negative parts of the LFO's waveform. Thus you get a rise in volume with increasing positive voltages and a rise volume with increasing negative ones.

If you increase the Y OFFSET pot to its maximum value, you should find that you now have only one cycle of volume change per LFO cycle. The offset pot has added a positive voltage to the Y input thus making it solely positive in value.

If all is well, then you have a working ring modulator module.

Final Comments

If you have any problems with the module, an excellent source of support is the Oakley Sound Forum at Muffwiggler.com. I am on this group, as well as many other users and builders of Oakley modules.

I'd love to hear about what you have done with your module. Please do post pictures of your finished module at the Oakley Sound forum on Muffwiggler.

If you are in the EU and can't get your project to work, then Oakley Sound Systems are able to offer a 'get you working' service. If you wish to take up this service please e-mail me at my contact e-mail address found on the website. I can service either fully populated PCBs or whole modules. You will be charged for all postage costs, any parts used and my time at 25GBP per hour. Most faults can be found and fixed within one hour, and I normally return modules within a week. The minimum charge is 25GBP plus return postage costs.

If you have a comment about this user guide, or have a found a mistake in it, then please do let me know. But please do not contact me directly with questions about sourcing components or general fault finding. Honestly, I would love to help but I do not have the time to help everyone individually by e-mail. The forum is the best place to ask these sorts of questions.

Last but not least, can I say a big thank you to all of you who helped and inspired me. Thanks especially to all those nice people on Muff's Forum and the SynthDIY and Analogue Heaven mailing lists.

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