Stompboxology™

Volume 4, Number 4

Mo' Trem'lo

For a decades-old effect with six 'designer' models through our auspices alone, tremolo might seem at risk for depleting its options. In fact, tremolo remains king of the undiscovered effects precisely because it has yet to crowd the limit.

The pure sense of tremolo means rhythmic loudness change; but the sound that players associate with tremolo involves additional factors, such as distortion and altered frequency response. The following treatment splits tremolo into artificial categories, but ones useful to understand why various approaches sound different.

In this issue:

Tube-Amp Tremolo

The average player's exposure to tremolo comes not from stompboxes, but from hearing songs recorded through classic tube amps. Tube-amp tremolo is a varied effect, involving several mechanisms. The first is *bias modulation in the preamp*. Bias modulation means depriving the axe feed of headroom by shifting a triode's *operating point* (OP), the DC offset present at its output terminal, usually the plate. This shift subjects the signal to unipolar squashing that generates even harmonics of low order (Fig. 1). The quotient of distortion may vary audibly with each tremolo cycle, heard in Chet's cover of "If I Fell". The tremolo control voltage enters through the cathode in Fender® Bronco and Vibro-Champ amps; comes in through the grid in the mixer-based amps described below. Bias modulation in the preamp is accompanied by large feedthrough, incompletely suppressed by succeeding highpass couplers, but reduced in the output transformer. This type of tremolo tends to generate audible feedthrough. Early transistor amps used a similar mechanism but injected a greater quotient of high-order harmonics, because transistors tend to clip rather than squash.

The second mechanism entails *bias modulation in a push-pull output stage*, found in the Fender Vibrolux series and many Gibson® amps. The tremolo feed rides the grids' negative bias voltage (Fig. 4–3). This mechanism sounds distinct from preamp bias modulation because pentodes sound different than triodes, and because the signal being squashed has already undergone compression and distortion in the preamp. Negative feedback affects the sound, too. As a bonus, push-pull bias modulation cancels feedthrough.

A third method, the *nondistorting divider*, crops up in Ampeg® AC12 and G12 amps, and in Fender Deluxe Reverb and Super Reverb series. A voltage divider formed by an optocoupler is wired to act as a volume control (Fig. 4–2). This approach generates no harmonics and negligible feedthrough, but distorts the control envelope to an extent determined by the decay lag built into the optocoupler's photocell.

The *distorting divider* mechanism is found in tube amps that use a transistor tremolo modulator, notably the Rickenbacker® B-series of the mid-seventies. The effect on the waveform is closer to unipolar clipping than to squashing, making even harmonics of high order (Fig. 4–1). Feedthrough, in properly trimmed circuits, is negligible.

Finally, some amps achieve tremolo by *rhythmic mixing*, though this approach could just as easily be called vibrato (Fig. 2). The mechanism occurs in the Fender 6G7-A Bandmaster, 6G12-A Concert, and a few others. It works this way: The preamp output splits; one feed passes through a first-order highpass network with f_{-3} ~640 Hz. The other feed traverses a lowpass network whose f_{-3} is ~72 Hz. Each filtered signal enters one input of a voltage controlled mixer, driven by the tremolo oscillator. This approach generates a unique sound consisting of three elements:

- frequency-dependent amplitude modulation, due to rhythmic alternation between highpass and lowpass feeds
- phase change, for highpass (lead) and lowpass (lag) networks also shift phase, and do so in opposite directions; this endows the sound with an air of vibrato
- even-harmonic enrichment, because the mixer uses bias modulation as its gain-control mechanism

In addition, when the tremolo is 'off,' the network acts as a mid-cut EQ that reinforces the EQ found in the amp's tone control network. The circuit takes four or five triodes, and sounds as warm with bass as with guitar. The Vox® AC-15 tremolo/vibrato uses a similar mixer, but employs radically

Fig. 1. What happens in tube-amp tremolos that use bias modulation. Schematic shows typical triode inverting amplifier. When pot R1 is trimmed such that DC voltage present at plate is about 1/2V+, maximum headroom occurs. As operating point moves away from 1/2V+, loss of headroom subjects signal to unipolar squashing. In a tremolo circuit, voltage from oscillator modulates tube bias. This modulating voltage can also be applied through the cathode.

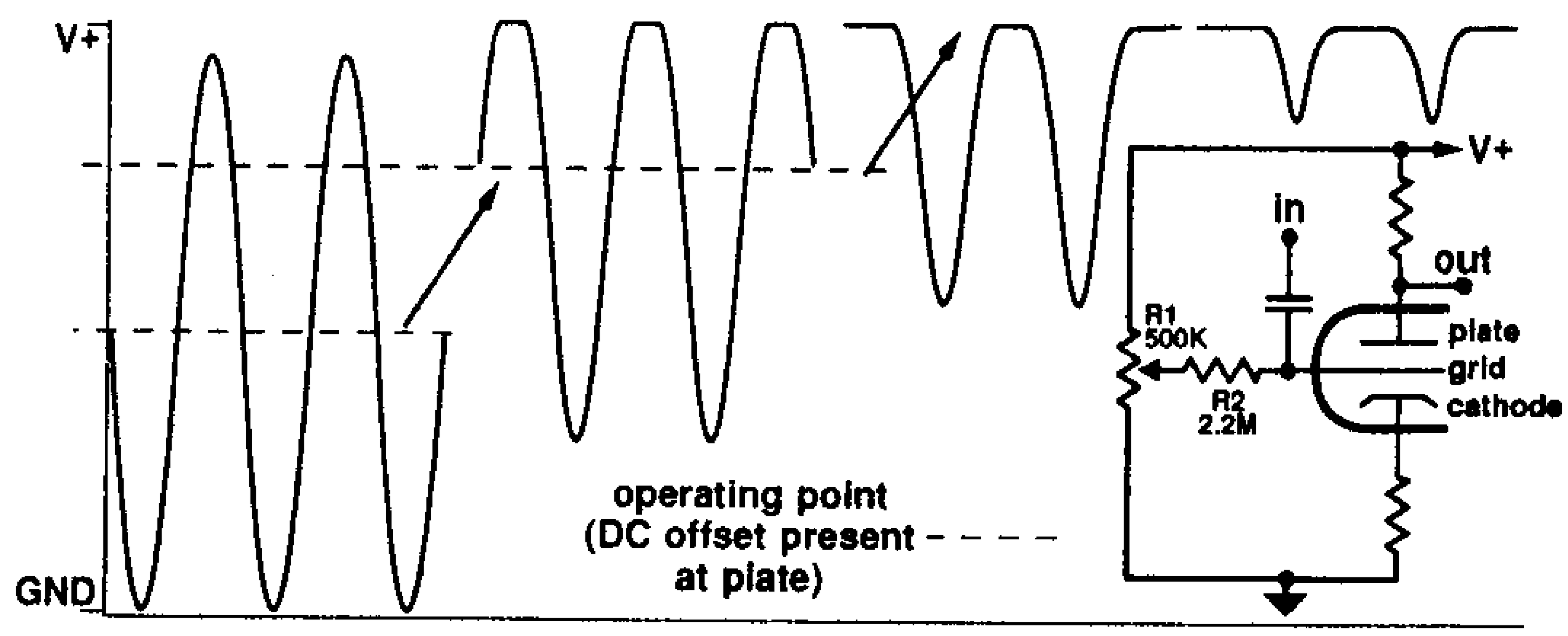


Fig. 2 (at right). 1—Basic circuit behind the 'mixer' variety of vibrato/tremolo in certain Fender amps. Preamp output feeds V1-a through lowpass network R1-C1; feeds V1-b through highpass network C2-R2. The modulation voltage is superimposed on the axe feeds entering each tube's grid; but when the control feed to V1-a is at maximum (squashing the signal), the control feed to V1-b is at minimum, allowing normal headroom. This state reverses with each oscillator cycle. 2—Block diagram of what's going on in circuit. 3—Graph of phase shift associated with each filter. 4—Rough plot of each filter's frequency response. Circuit combines elements of vibrato with tremolo, both effects varying with frequency; plus distortion introduced by unipolar squashing in the mixer.

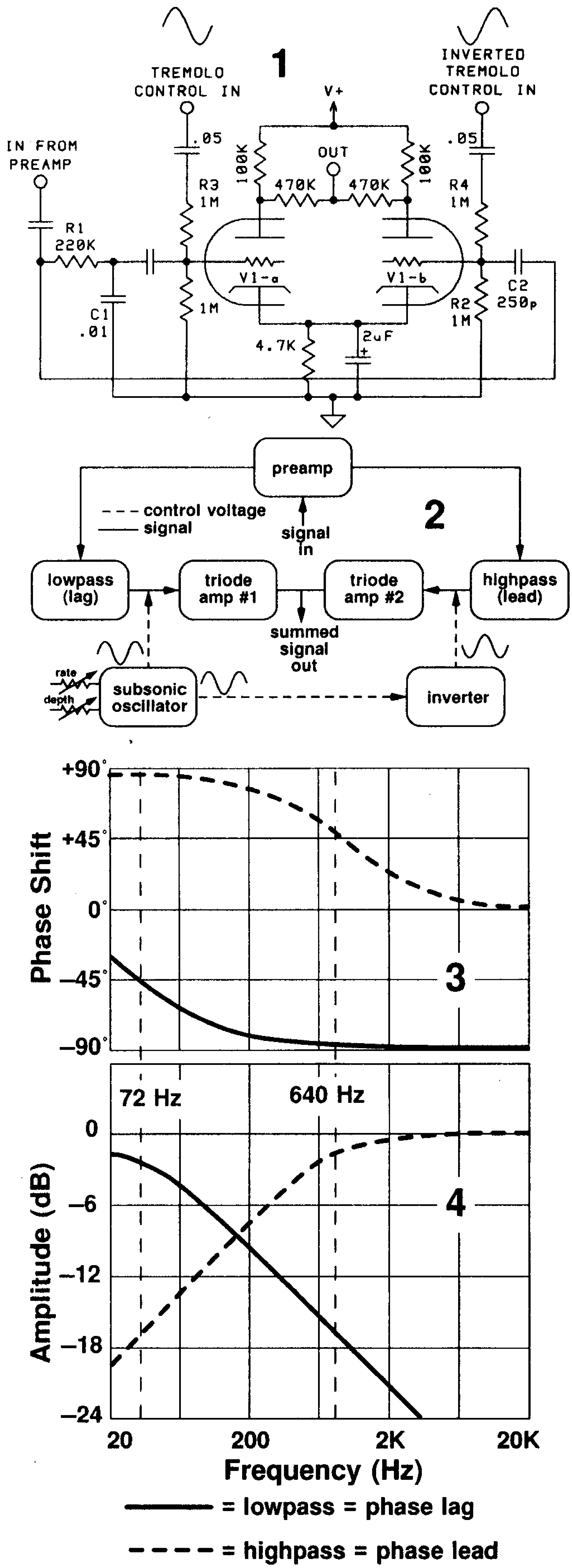
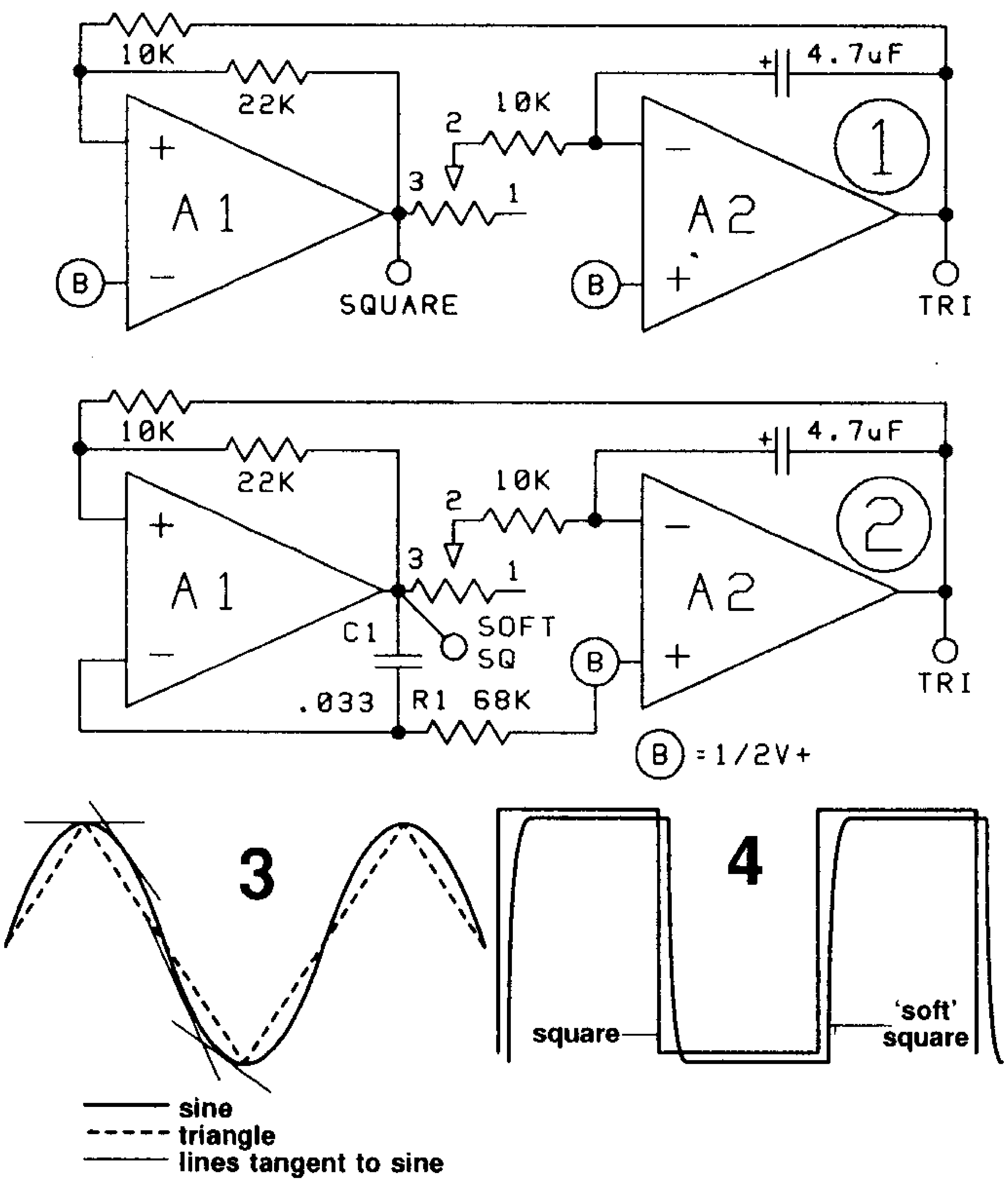


Fig. 3 (below). 1—Ancient op-amp-based function generator creates triangle waves and squarewaves; tends to inject audible clicks when used in stompboxes in this form. 2—Addition of R1 and C1 softens rising and falling edges of squarewave enough to kill clicks in most boxes, with only minor effect on triangle amplitude and rate. 3—Graph illustrates why sinewave sounds slightly different than triangle when used as tremolo control voltage. A sinewave's slope changes constantly, while a triangle has only two slopes. The sonic differences tend to be more apparent at slow modulation rates, and in effects such as phase, rather than tremolo. 4—Graph illustrates the difference between a true squarewave and one whose rise and fall have been slowed (as by circuit #2).



different phase-shift networks. [*Vox's vibrato/tremolo is detailed in Vol. 5, No. 1—Ed.*]

Stompbox Tremolo

Stompbox tremolo can emulate all five tube-amp modes, but adds a sixth dimension: *VCA tremolo*, which resembles the nondistorting divider, except that the music envelope follows the control voltage perfectly. As the name implies, a voltage controlled amplifier serves as the modulation core, generating a sound free of distortion, frequency change, or phase shift. Three audibly distinct manifestations of tremolo result from setting the VCA's static gain at three distinct levels. One occurs with VCA gain at maximum; positive control pulses cannot further increase gain, negative control pulses reduce gain slightly. The resultant sound has a warm, shimmering quality. The second effect is achieved by setting VCA gain at about 60%, and using a modulation voltage that does not clip at either extreme. Tremolo depth deepens compared to the first setting. The third sound is attained by setting VCA static gain at 0; negative control pulses have no ef-

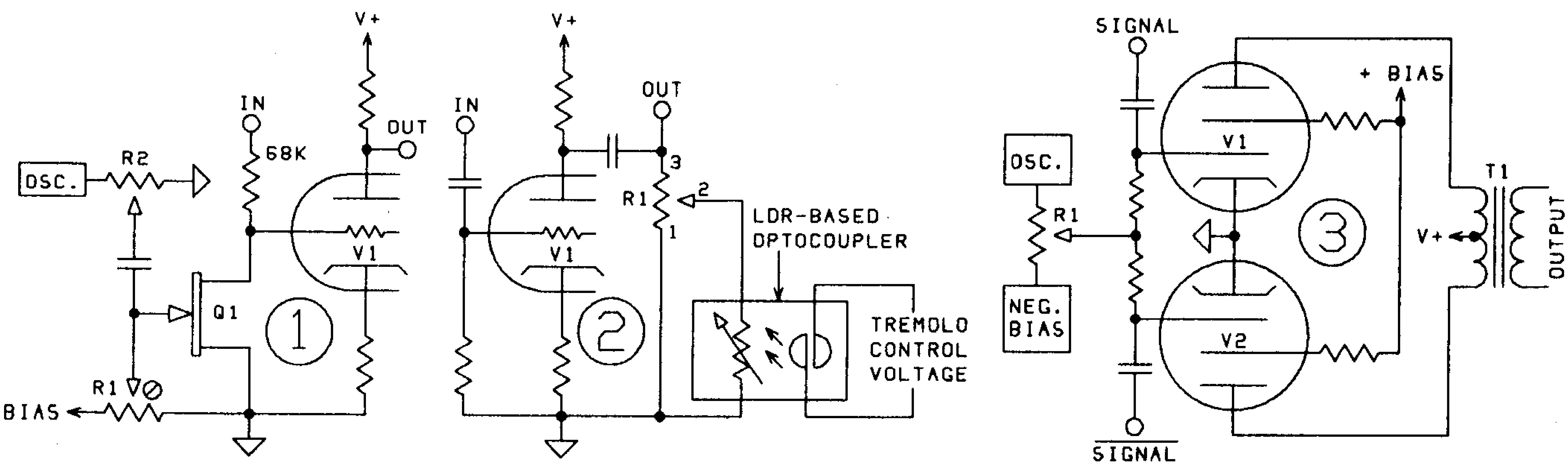


Fig. 4. Additional modulation modes found in tube-amp tremolos. 1—Distorting divider found in Rickenbacker B-series amps of the seventies; operates on axe feed before it reaches the first preamp tube. Trimpot R1 biases Q1 in an 'off' state sufficiently close to threshold to respond to control voltage whose amplitude is varied by R2. Key point is that divider action is not linear, but cuts off half the waveform first, generating even harmonics of higher order than those produced by squashing in a triode. 2—Mechanism typically found in Fender 'blackface' amps, and sometimes incorrectly labeled vibrato. Optocoupler is wired so as to act as a simple divider—a volume control, after one or two triode gain stages. Tremolo oscillator drives neon lamp, which alters photocell resistance. Unlike modes that vary depth by varying the tremolo control voltage, this one varies the extent of divider action in the circuit by a second divider, R1. 3—Tremolo can also be achieved by rhythmically altering the bias of a push-pull output stage. Many Gibson amps, and the Fender Tremolux 6G9 take this approach. Signal feeding each grid is inverted, but the tremolo control voltage is the same. The tremolo voltage alters the pentodes' operating point, squashing the signal in time with the oscillator; but because the push-pull stage is a differential amplifier, it ignores the same signal present at both inputs—the tremolo control voltage—while amplifying the axe feed, which presents at the inputs as a balanced signal. Result: feedthrough cancellation.

fect, positive pulses project sound from a background of silence. This gives the most dramatic effect.

Outboard tremolo also offers a wide range of control voltage shapes. These account for differences from subtle to dramatic. The differences between sine and triangle are difficult for untrained ears to hear, at least in tremolo. They're more audible at the very slow rates used in phase effects. A sinewave's slope changes constantly; a triangle wave has only two slopes. Given sine and triangle waves of equal amplitude, the sinewave has more area under the curve, giving deeper modulation.

Alternatives to sine/triangle include squarewaves, ramps, and negative ramps. True squarewave modulation is rare, because imposition of instantaneous rise and fall imparts a distinct sonic click, a useful special effect but troublesome to suppress between numbers. More often, slowing the rise and fall of a squarewave retains pulse-like modulation without introducing clicks. Summation of two independent control feeds, or multiplication of one feed against another (e.g., TM11), creates complex waveforms. Many of these are musically intriguing, while others suit special effects.

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Trem'lo Tips

Setting Sinewave Amplitude Without A Scope

Five of *The Stomp Box Cookbook*'s six tremolos used a sine oscillator adapted from a circuit that appeared in Ref. 1. Trouble is, proper amplitude trim requires access to an oscilloscope—or does it?

Common digital multimeters (DMMs) read average AC. This value represents (peak AC x 0.33). To set an oscillator's amplitude, turn rate up to maximum, read average AC using a meter and divide the value by 0.33. The figure is AC measured peak-to-peak.

'Clickless' Op-Amp Triangle Generator

Figure 3–1 shows one of the earliest function generator circuits based on op amps. It makes squarewaves and triangle waves. The circuit is simple, cheap, and easily tuned; and reasonably insensitive to changes in supply voltage.

But where function generators dote on true squarewaves—the faster the rise and fall the better—sharp edges generate clicks that are practically impossible to purge from the stompbox signal path.

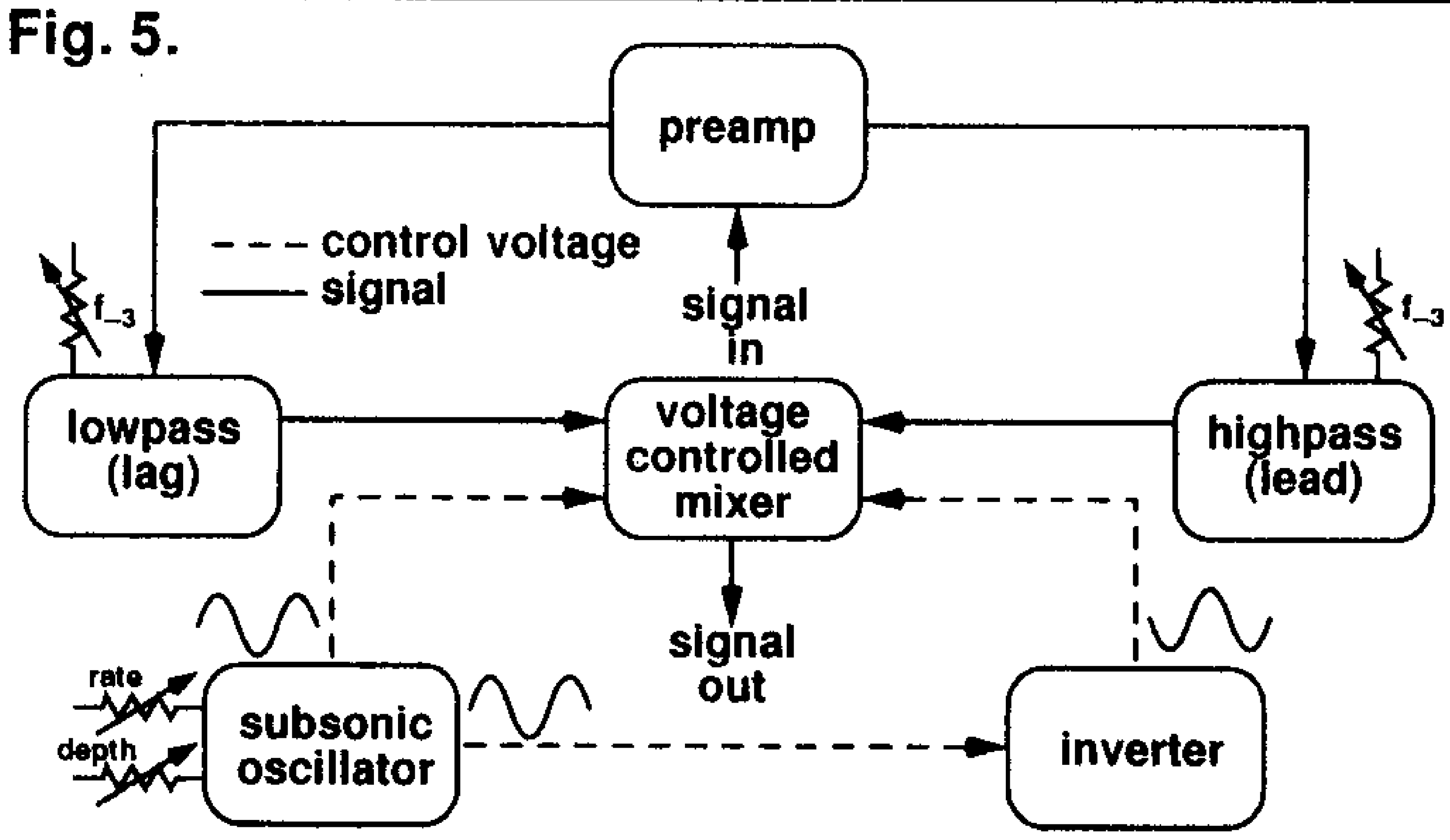
Addition of a resistor and a cap slows the rising and falling edges of the squarewave, preventing a click in most stompboxes (Fig. 3–2). This also blunts the tips of the triangle and slows the rate, returned to the desired range by choosing a new value for the cap in A2's feedback loop. [*This approach looks suspiciously like one found in the DOD® FX-64 chorus pedal—Ed.*]

Beginner's View

Q. Favor, dude?
A. Sure, dude.
Q. Explain to me in, like, exquisite detail, how TM10 works—then walk me through the assembly?
A. How the circuit works is shown in a block diagram (Fig. 5). Note the resemblance to the block diagram of Fender's circuit (Fig. 2–2), with two changes. First, we've made each filter's f_{-3} variable. Second, because our mixer does not superimpose the tremolo control voltage on the audio signal, the tremolo control voltages enter the mixer through their own control ports.
Q. What does 'f_{-3}' mean?
A. It means 'the frequency at which a filter's response has fallen by 3 decibels.' You may also see it referred to as 'f_C', the corner frequency.
Q. Okay, what about the schematic?
A. The schematic can be analyzed by identifying the parts that make up each block of the block diagram. Let's start with the power supply, which the block diagram doesn't show. We assume it to be a 9V battery. Power enters through the red (+) lead from the battery snap, then through rectifier diode D1.
Q. What's the purpose of D1?

(continued on page 14)

Fig. 5.



Project No. G51
Tremolo-Matic X

TM10 uses a voltage-controlled mixer to recreate the sound of the Fender three-tube vibrato/tremolo, but enhances the approach by making highpass and lowpass networks variable.

Circuit Function

Signal Path: Axe output couples through C7 to inverting preamp IC4-d, whose gain is fixed at ~6. Preamp output couples to variable lowpass network formed by R9, R24, C4, & IC4-b. Lowpass output couples through C3 to one input of IC3, an NE570 configured as a voltage controlled mixer.

Preamp output also couples to variable highpass network formed by R12, R23, C9, & IC4-c. Highpass output couples through C10 to IC3's second input. IC3 output exists as discrete currents at pins 5 and 12, summed and converted to a voltage by an internal inverting op amp. Output is taken off pin-7, coupled through C11 to R17; final output is taken at juncture of R16 with R17. Preamp gain coupled with divider action of R16-R17 achieves ~12 dB of quasi-companding. The net signal path is noninverting.

Control Path: IC2-b & -c form a soft triangle oscillator whose rate is controlled by R25, and whose output ties to depth control pot R22, whose wiper feeds inverting amp IC2-d through R1; IC2-d's output feeds unity-gain inverting buffer IC2-a. The result is to generate equal but inverted control voltages that couple through R5 and R18 to IC3's VCA control ports.

Use

Pots & switch have these functions:

- **R22** tremolo/vibrato depth
- **R23** highpass corner
- **R24** lowpass corner
- **R25** tremolo/vibrato rate
- **S1** effect/bypass

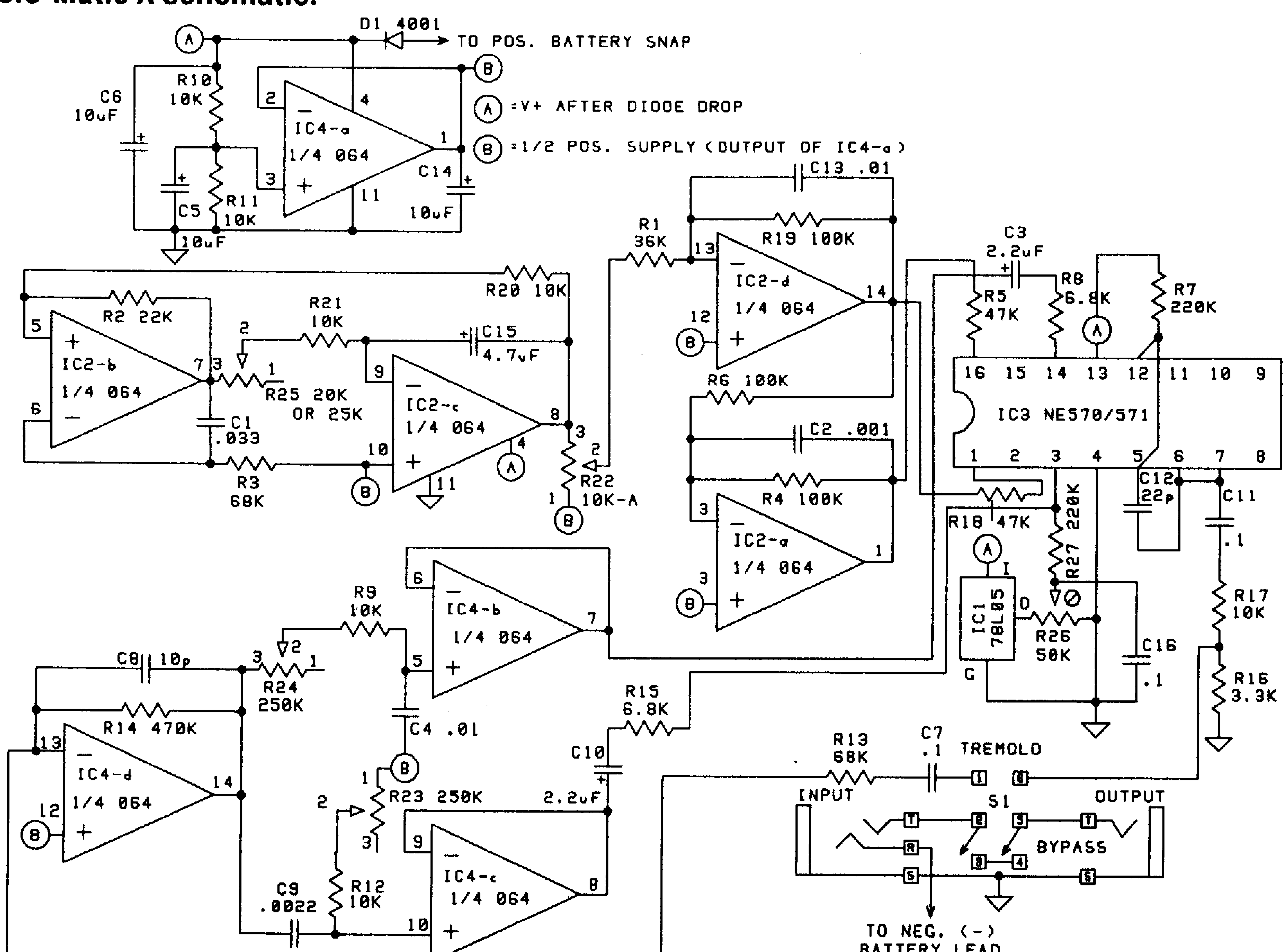
Initial settings: R22, fully CCW; R23, R24, R25 straight up. S1: effect in. In this state the box acts as a contoured preamp. Connect unit to axe and amp, establish desired listening level. Take lowpass control R24 and highpass control R23 through their ranges and note the effect on static tone. Next, turn R22 CW until modulation is heard. Take rate and depth controls through their ranges.

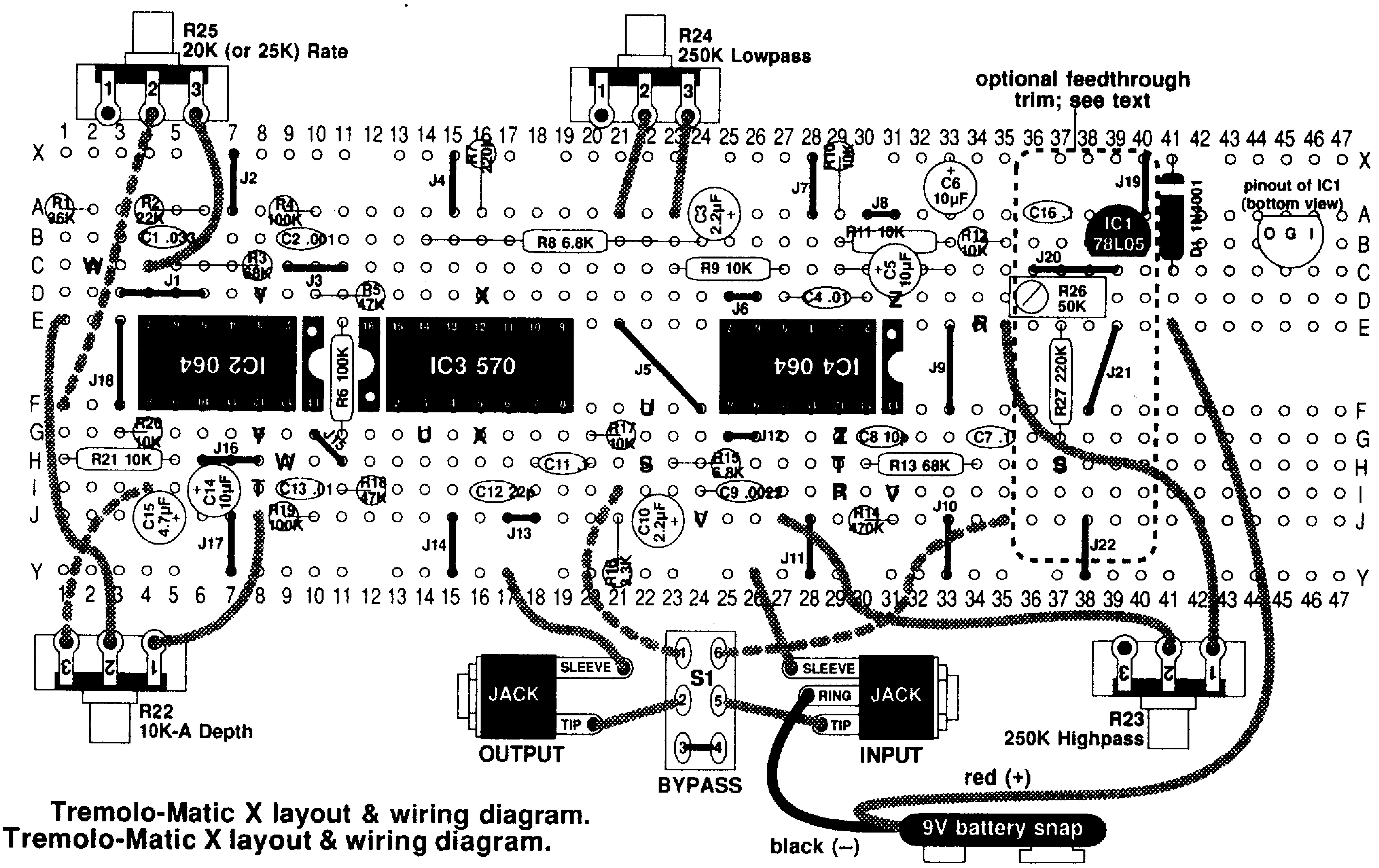
Notes

High-output axes will need reduced preamp gain, achieved by reducing the value of R14, or by replacing R14 with a 1M audio-taper pot to give variable gain.

With R24 at 9 o'clock and R23 at 11 o'clock, the filters closely duplicate the responses of those found in the Fender three-tube vibrato/tremolo. Turning R24 CCW lowers the lowpass corner; the control spans the approximate range 61–1600 Hz. Turning R23 CCW raises the highpass corner; the control spans the approximate range 280–7200 Hz.

Tremolo-Matic X schematic.





Tremolo-Matic X layout & wiring diagram.

Tremolo-Matic X layout & wiring diagram.

Parts List/Soldering Checklist

UCB Radio Shack p/n 276-170; Hosfelt p/n 42-183; or DC Electronics p/n J4-404

IC Sockets
- [ ] 14-pin for IC2; pin-1 goes in E10
- [ ] 16-pin for IC3; pin-1 goes in F12
- [ ] 14-pin for IC4; pin-1 goes in E31

Resistors
- [ ] R1 36K (org-blu-org) A1-A2
- [ ] R2 22K (red-red-org) A4-A6
- [ ] R3 68K (blu-gry-org) C5-C8
- [ ] R4 100K (brn-blk-yel) A9-A10
- [ ] R5 47K (yel-vio-org) D10-D12
- [ ] R6 100K (brn-blk-yel) D11-G11
- [ ] R7 220K (red-red-org) X16-A16
- [ ] R8 6.8K (blu-gry-red) B14-B24
- [ ] R9 10K (brn-blk-org) C23-C27
- [ ] R10 10K (brn-blk-org) X29-A29
- [ ] R11 10K (brn-blk-org) B29-B33
- [ ] R12 10K (brn-blk-org) B34-B35
- [ ] R13 68K (blu-gry-org) H30-H34
- [ ] R14 470K (yel-vio-yel) J30-J31
- [ ] R15 6.8K (blu-gry-red) H23-H25
- [ ] R16 3.3K (org-org-red) J21-Y21
- [ ] R17 10K (brn-blk-org) G20-G21
- [ ] R18 47K (yel-vio-org) I11-I12
- [ ] R19 100K (brn-blk-yel) J9-J10
- [ ] R20 10K (brn-blk-org) G3-G4
- [ ] R21 15K (brn-blk-org) H1-H5

Bare Wire Jumpers
- [ ] J1 D3-D6
- [ ] J2 X7-A7
- [ ] J3 C9-C11
- [ ] J4 X15-A15
- [ ] J5 E21-F24
- [ ] J6 D25-D26
- [ ] J7 X28-A28
- [ ] J8 A30-A31
- [ ] J9 E33-F33
- [ ] J10 J33-Y33
- [ ] J11 J28-Y28
- [ ] J12 G25-G26
- [ ] J13 J17-J18
- [ ] J14 J15-Y15
- [ ] J15 G10-H11
- [ ] J16 H6-H8
- [ ] J17 J7-Y7
- [ ] J18 E3-F3

Capacitors
- [ ] C1 0.033µF B4-B5
- [ ] C2 .001µF B9-B10
- [ ] C3 2.2µF A24-A25 ('+' lead to A25)
- [ ] C4 0.01µF D27-D30
- [ ] C5 10µF C29-C33 ('+' lead to C29)
- [ ] C6 10µF X33-A33 ('+' lead to X33)
- [ ] C7 0.1µF G34-G35
- [ ] C8 10pF G30-G31
- [ ] C9 0.0022µF I24-I27
- [ ] C10 2.2µF J22-J23 ('+' lead to J23)
- [ ] C11 .1µF H18-H20
- [ ] C12 22pF I16-I17
- [ ] C13 0.01µF I9-I10
- [ ] C14 10µF I6-I7 ('+' lead to I6)
- [ ] C15 4.7µF J4-J5 (polarity irrelevant)

Flying Jumpers (<u>insulated</u> wire)
- [ ] RR I29-E34
- [ ] TT I8-H29
- [ ] UU G14-F22
- [ ] VV J24-I31
- [ ] WW C2-H9
- [ ] XX D16-G16
- [ ] YY D8-G8
- [ ] ZZ G29-D31

Semiconductors
- [ ] D1 1N4001 X41-C41 (banded end goes in X41)
- [ ] IC2 TL064 quad op amp; pin-1 to E10
- [ ] IC3 NE570; pin1 to F12
- [ ] IC4 TL064 quad op amp; pin-1 to E31

Potentiometers (T=terminal; NC= no connection)
- [ ] R22 10K-A T1 to J8; T2 to E1; T3 to I4
- [ ] R23 250K T1 to E35; T2 to J27; T3 NC
- [ ] R24 250K T1 NC; T2 to A21; T3 to A23
- [ ] R25 20K (or 25K) T1 NC; T2 to C4; T3 to F1

Jacks (T=terminal)
- [ ] input jack (1/4", 3-terminal/stereo) tip to T5 of S1; sleeve to Y26; ring to negative ('–', black) lead of battery snap
- [ ] output jack (1/4", 2-terminal/mono): tip to T2 of S1; sleeve to Y17

Switches (T=terminal)
- [ ] S1 (DPDT stomp switch): T1 to I21; T2 ot tip of output jack; T3 to T4; T5 to tip of input jack; T6 to J35

Battery Leads
- [ ] negative (black, '–') to ring of input jack
- [ ] positive (red, '+') to E41

Parts & connections for optional feedthrough trim network:
- [ ] R26 50K multiturn trimpot wiper (center terminal) goes in D37; end terminals in D36 & D38
- [ ] R27 220K (red-red-yel) E37-G37
- [ ] C16 0.1µF A36-A37
- [ ] IC1 LM78L05 positive 5V regulator; output (O) goes in B38; ground (G) goes in B39; input (I) goes in B40; pinout appears on wiring diagram

Bare Wire Jumpers
- [ ] J19 X40-A40
- [ ] J20 C36-C39
- [ ] J21 E39-F38
- [ ] J22 J38-Y38

Flying Jumper
- [ ] SS H22-H37

Project No. G52
Tremolo-Matic XI

VCA-based tremolo whose rate varies rhythmically in response to a secondary oscillator.

Circuit Function

Signal Path: Instrument feed couples through C1 to inverting preamp IC1-a, whose gain is fixed at 10. Preamp output couples through C3-R3 to IC2, half an NE570 configured as a VCA whose gain varies 0–1, depending on control voltage present at pin-1. Output couples through C5 to R5; output is taken at the juncture of R5 & R7. The net signal path is noninverting, and incorporates about 15 dB of quasi-companding. IC5, R29-30, & C15 form an optional feedthrough trim network.

Control Path: (A) IC3 is the primary tremolo oscillator, an XR2206 configured as a voltage controlled triangle generator whose rate varies over the approximate range 1–8 Hz, depending on the voltage applied to R9. Because R26 varies the static DC offset at the output of IC4-c, it thus acts as the primary tremolo rate control. IC3 output couples to primary depth control pot R25, through R25's wiper to R24, to inverting amplifier IC1-b. The final tremolo control voltage couples through R22 to the VCA control port, pin-1 of IC2.

(B) The secondary oscillator consists of a triangle generator made up of IC4-a, -d, and associated components. Rate varies over the approximate range 0.5–10 Hz under control of R27. Output is taken off IC4-d and couples to secondary depth control R28, thence to inverting amp IC4-c, thence through R9 to the primary oscillator, IC3.

Use

Pots & switch have these functions:

R25 primary tremolo depth
R26 primary tremolo rate
R27 secondary tremolo rate (maximum rate occurs CCW)
R28 secondary tremolo depth
S1 effect/bypass

Initial settings: R25, R28 fully CCW; R26, R27 straight up; S1 effect in. In this state the box acts as a preamp with gain close to 1. Connect unit to axe and amp, establish desired listening level.

Turn primary depth control R25 clockwise and note increasing tremolo depth; take R26 through its range and note changes in rate. The box behaves as a conventional VCA-based tremolo.

Next, turn R25 fully CW, R26 straight up. Now slowly turn R28 CW, strum a chord and let it hang. Note that the tremolo rate varies rhythmically; R27 determines how fast this change occurs, R28 controls the extent of the change. Take R27 and R28 through their ranges and note the range of effects possible.

Notes

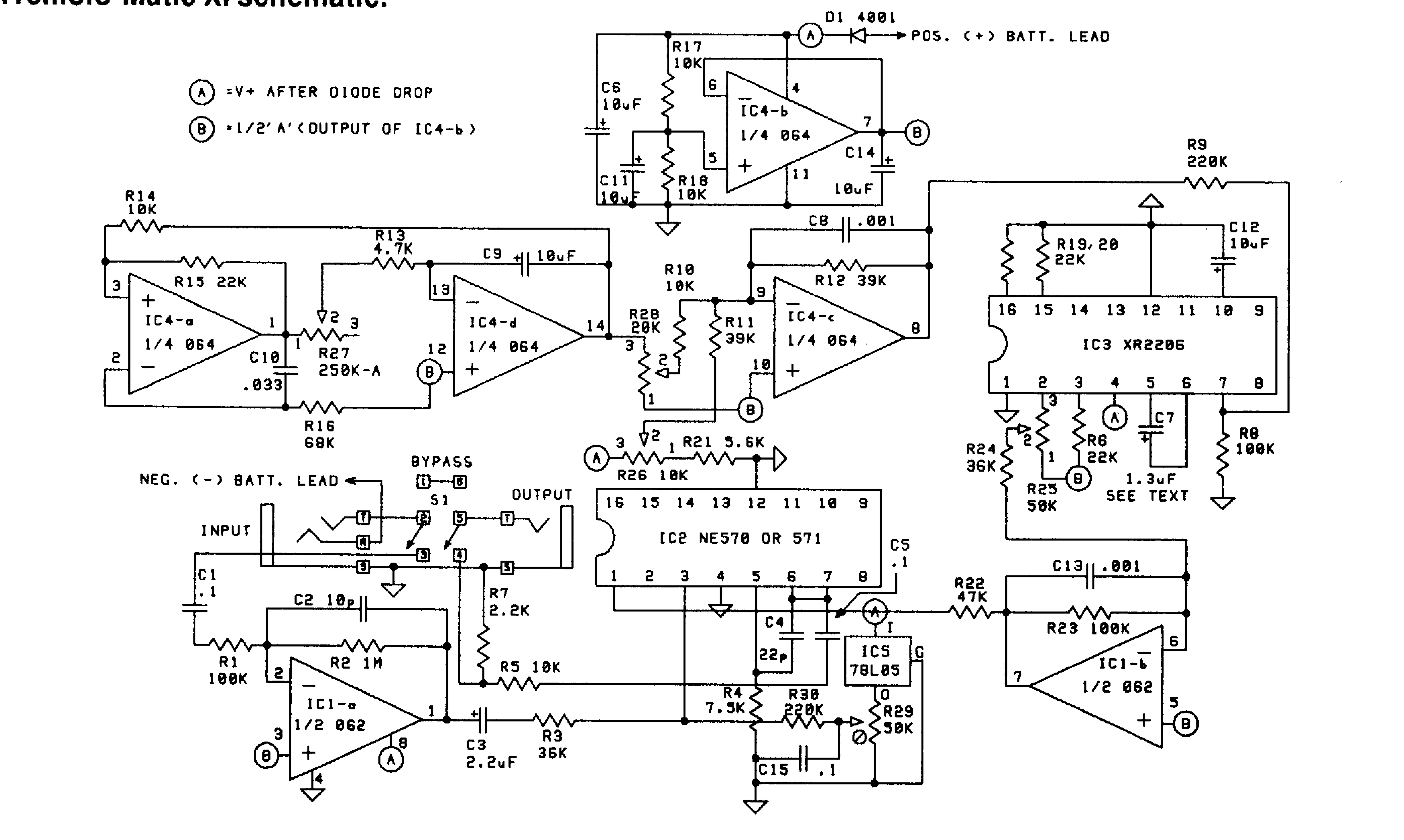
TM11 requires a pair of 9V batteries, because the 2206 needs at least 10V. The specified 1µF value of C7, which keeps tremolo rate in a "musical" range, measured 1.3µF. Thus, it may be necessary to select C7 by measuring samples, or to create the value by paralleling smaller caps. Significant departure from 1.3µF leads to unmusically fast or slow tremolo.

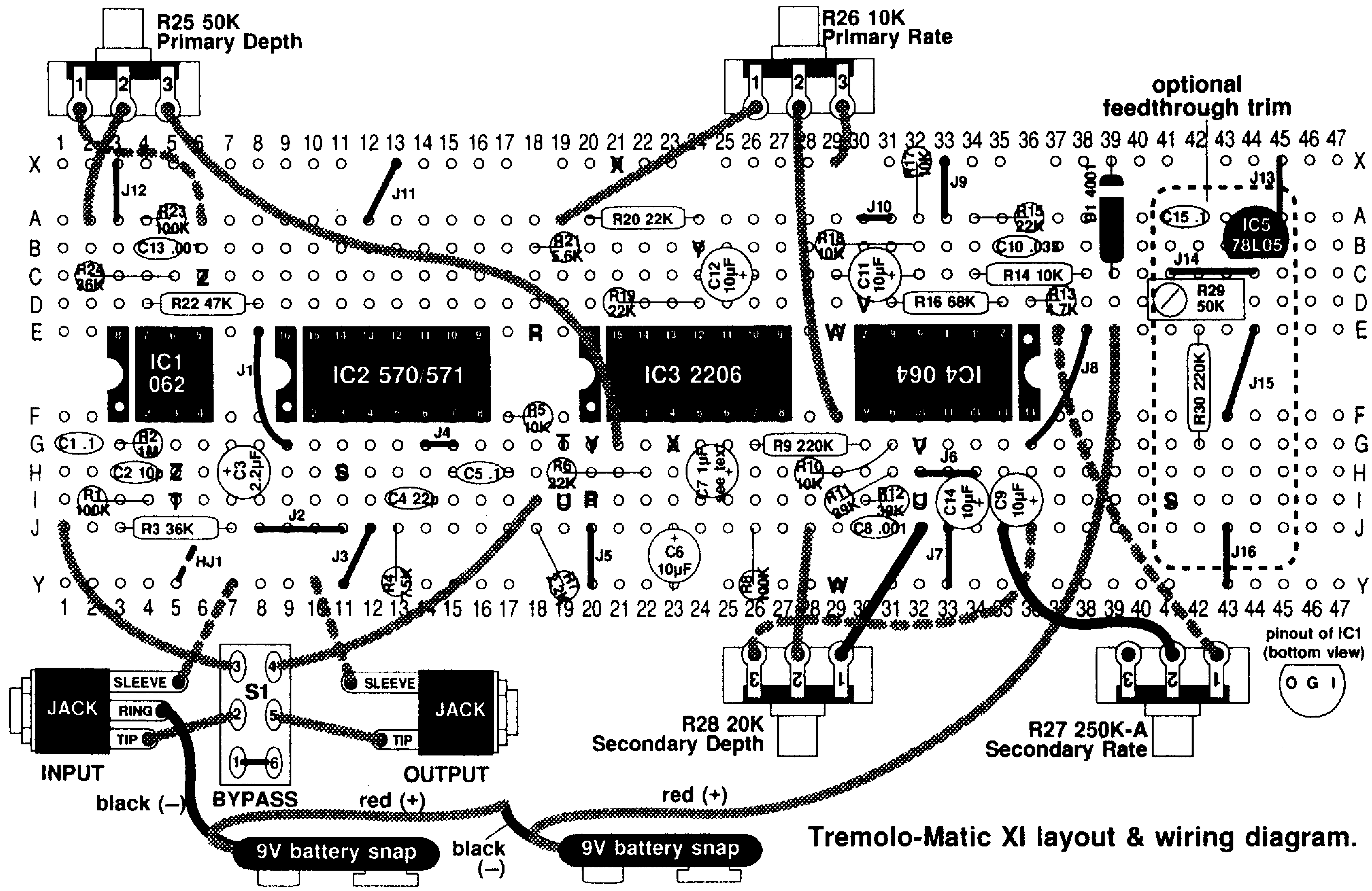
The preamp's fixed gain of 10 may have to be lowered to suit hot pickups. Replace R2 with a 1M pot for variable preamp gain.

If a 250K-RA pot can be had, use it for R27 and swap the end-terminal connection. Rate then increases when the pot is turned CW.

TM11 is a box for which patient, methodical experimentation pays off in spades. The sound doesn't always follow expectations, because it is possible to modulate the primary oscillator at a rate faster than its own, resulting in a net modulation rate slower than either oscillators'. Because "sweet spots" occur at so many and varied control settings, the most practical means to recall these settings is to provide numbered dials for the pots, and note the settings. Also, the most musically satisfying sounds tend to occur with the various functions set short of maximum.

Tremolo-Matic XI schematic.





Tremolo-Matic XI layout & wiring diagram.

Parts List/Soldering Checklist

UCB Radio Shack p/n 276-170; Hosfelt p/n 42-183; or DC Electronics p/n J4-404

IC Sockets

- [ ] 8-pin for IC1; pin-1 goes in F3
- [ ] 16-pin for IC2; pin-1 goes in F9
- [ ] 16-pin for IC3; pin-1 goes in F20
- [ ] 14-pin for IC4; pin-1 goes in E36

Resistors

- [ ] R1 100K (brn-blk-yel) I2-I4
- [ ] R2 1M (brn-blk-grn) G3-G4
- [ ] **install hidden jumper HJ1 [J6-Y5] <u>before</u> installing R3)**
- [ ] R3 36K (org-blu-org) J3-J7
- [ ] R4 7.5K (vio-grn-red) J13-Y13
- [ ] R5 6.8K (blu-gry-red) F17-F18
- [ ] R6 22K (red-red-org) H19-H22
- [ ] R7 1K (brn-blk-red) J18-Y19
- [ ] R8 100K (brn-blk-yel) J26-Y26
- [ ] R9 220K (red-red-yel) G26-G30
- [ ] R10 10K (brn-blk-org) H28-G31
- [ ] R11 39K (org-wht-org) I29-H31
- [ ] R12 39K (org-wht-org) I30-I31
- [ ] R13 4.7K (yel-vio-red) D36-D37
- [ ] R14 10K (brn-blk-org) C34-C38
- [ ] R15 22K (red-red-org) A34-A36
- [ ] R16 68K (blu-gry-org) D31-D35
- [ ] R17 10K (brn-blk-org) X32-A32
- [ ] R18 10K (brn-blk-org) B29-B32
- [ ] R19 22K (red-red-org) D21-D24
- [ ] R20 22K (red-red-org) A20-A24
- [ ] R21 5.6K (grn-blu-red) B18-B19
- [ ] R22 47K (yel-vio-org) D4-D8
- [ ] R23 100K (brn-blk-yel) A4-A5
- [ ] R24 36K (org-blu-org) C2-C5

Bare Wire Jumpers

- [ ] J1 E8-G9
- [ ] J2 J8-J11
- [ ] J3 J12-Y11
- [ ] J4 G14-G15
- [ ] J5 J20-Y20
- [ ] J6 H32-H34
- [ ] J7 J33-Y33
- [ ] J8 G36-E38
- [ ] J9 X33-A33
- [ ] J10 A30-A31
- [ ] J11 X13-A12
- [ ] J12 X3-A3

Capacitors

- [ ] C1 0.1 G1-G2
- [ ] C2 10pF H3-H4
- [ ] C3 2.2µF H7-H8 ("+" lead to H7)
- [ ] C4 22pF I13-I14
- [ ] C5 .1µF H15-H17 ('+' lead to H15)
- [ ] C6 10µF J23-Y23 ('+' lead to J23)
- [ ] C7 1µF H24-H25 (polarity irrelevant)
- [ ] C8 0.001 J30-J31
- [ ] C9 10µF I35-I36 (polarity irrelevant)
- [ ] C10 0.033 B35-B36
- [ ] C11 10µF C29-C32 ('+' lead to C32)
- [ ] C12 10µF C24-C26 ('+' lead to C26)
- [ ] C13 0.001µF B4-B5
- [ ] C14 10µF I33-I34 ('+' lead to I34)

Flying Jumpers (<u>insulated</u> wire)

- [ ] RR E18-I20
- [ ] TT I5-G19
- [ ] UU I19-I32
- [ ] VV D30-G32
- [ ] WW E29-Y29
- [ ] XX X21-G23
- [ ] YY G20-B24
- [ ] ZZ C6-H5

Semiconductors

- [ ] D1 1N4001 X39-C39 (banded end to X39)
- [ ] IC1 TL062 dual op amp; pin-1 to F3
- [ ] IC2 NE570; pin-1 to F9
- [ ] IC3 XR2206 VCO; pin-1 to F20
- [ ] IC4 TL064 quad op amp; pin-1 to E36

Potentiometers (T=terminal; NC= no connection)

- [ ] R25 50K T1 to A6; T2 to A2; T3 to G21
- [ ] R26 10K T1 to A19; T2 to F29; T3 to X29
- [ ] R27 250K-A T1 to E37; T2 to J35; T3 NC
- [ ] R28 20K T1 to J32; T2 to J28; T3 to J36

Jacks (T=terminal)

- [ ] input jack (1/4", 3-terminal/stereo): tip to T2 of S1; sleeve to Y7; ring to negative ('–', black) battery lead
- [ ] output jack (1/4", 2-terminal/mono) tip to T5 of S1; sleeve to Y10

Battery Leads (note: two 9V batteries in series)

- [ ] positive (red, '+') lead to E39
- [ ] negative (black, '–') lead to ring of input jack

Switches (T=terminal)

- [ ] S1 DPDT stomp switch: T3 to pad J1; T4 to I18; T1 to T6

Parts for optional feedthrough trim:

- [ ] R29 50K multiturn trimpot wiper (center lead) goes in D42; end leads in D41 & D43
- [ ] R30 220K (red-red-yel) E42-G42
- [ ] C15 0.1µF A41-A42
- [ ] IC5 LM78L05 5V pos. reg.; output (O) in B43; ground (G) in B44; input (I) in B45

Bare Wire Jumpers

- [ ] J13 X45-A45
- [ ] J14 C41-C44
- [ ] J15 E44-F43
- [ ] J16 J43-Y43

Flying Jumper

- [ ] SS H11-I41

Project No. G53
Tremolo-Matic XII

This specialty box gives the player access to a new category of sounds.

Circuit Function

Circuit functions identically to TM10, but that box's preamp, highpass, and lowpass networks have been replaced here by a pair of completely independent preamps, each of whose gain is variable from 0–10. Each preamp feeds one input of the voltage controlled mixer. TM12 rhythmically mixes any pair of signals.

Use

Pots and switch have these functions:

- **R20** input-2 preamp gain
- **R21** rate
- **R22** depth
- **R23** input-1 preamp gain
- **S1** effect/bypass

Initial settings: all pots fully CCW. Connect unit to two signal sources and amp, adjust R20 and R23 for desired listening level. In this state the box acts as a mixer in which signal predominance is determined by individual preamp gain. Slowly turn R22 CW and note that each signal's predominance alternates, as though a mixing pot were being rhythmically turned. Explore the sound of various rate and depth settings.

Notes

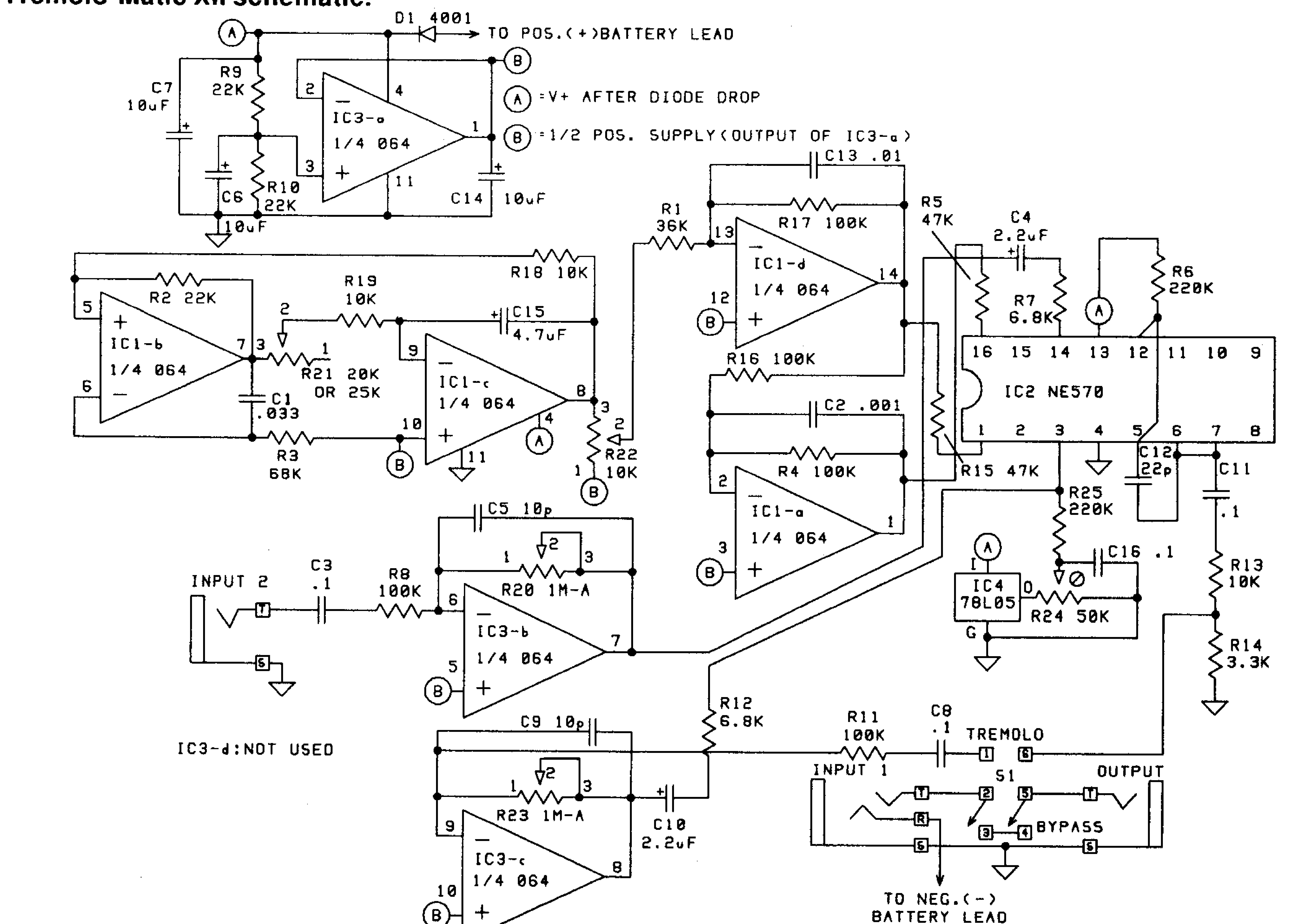
TM12 is a rhythmic, voltage-controlled mixer with variable rate and depth. The mixer is fed by independent, variable-gain preamps that can accommodate axe-level to line-level feeds. Here are a few possible connections:

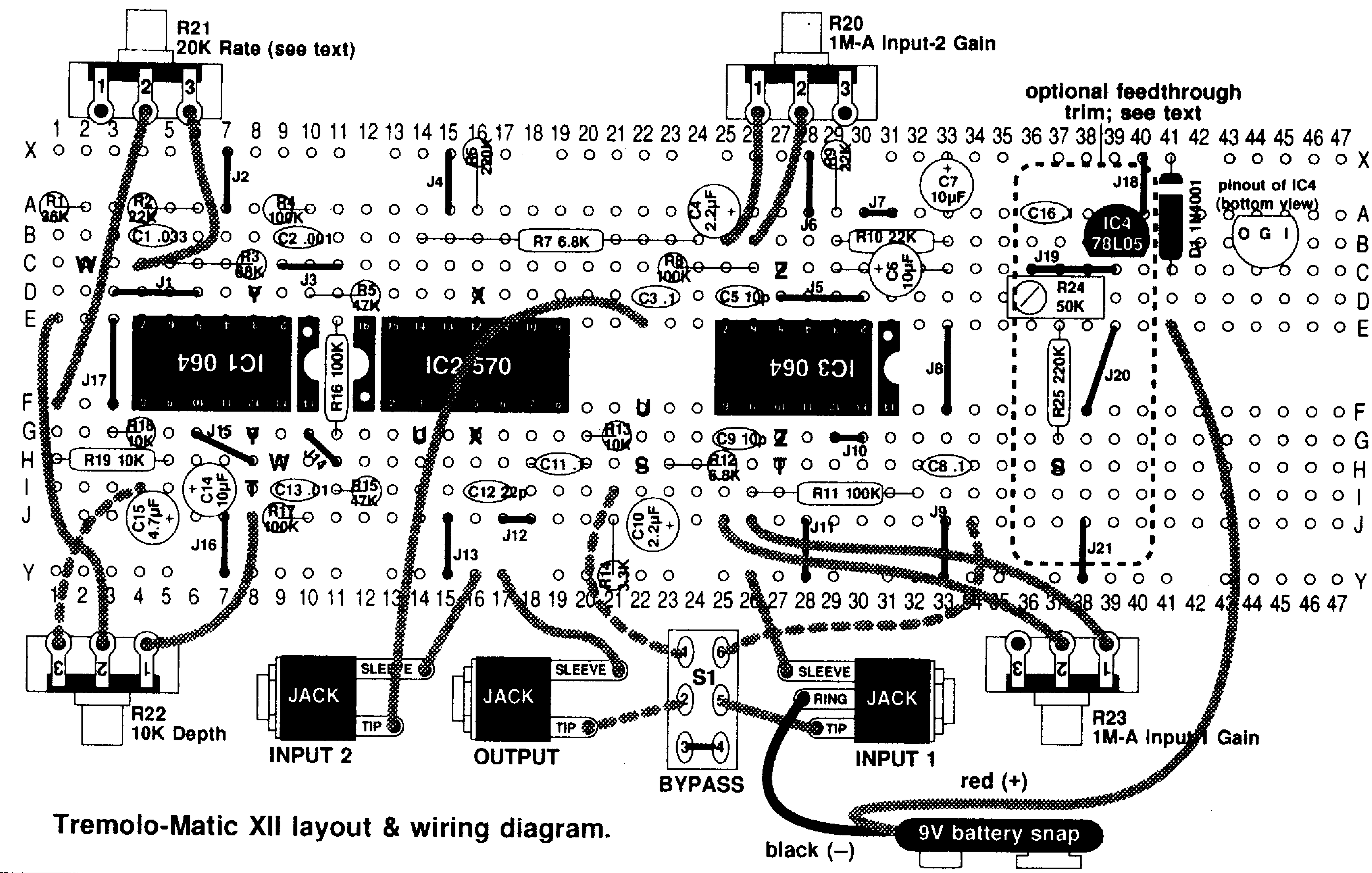
- raw axe feed to input-1; processed axe feed to input-2
- processed axe feed to input-1, another processed axe feed to input-2
- raw axe feed to input-1; some other signal source to input-2
- vocalist to input-1; second vocalist singing same (or different) lyrics to the same tune, to input-2
- two soloists playing same (or different) solos to the same rhythm track
- close-miked feed to input-1, room-miked feed to input-2
- live feed to input-1, recorded or programmed feed to input-2
- two different recorded or programmed feeds

And so forth. In the quest for new sound, TM12's potential is limited only by imagination.

The values of R21, R19, and C15 are nominal, giving the oscillator a range comparable to that of other rhythmic effects. The nature of TM12 may make slower rates desirable. To slow the entire control range, increase the value of C15; to enable a significantly slower rate without affecting maximum rate, change R21 to a 50K or 100K pot; a reverse-audio taper is ideal, but a linear taper gives acceptable results, with loss of fine control near maximum rate. Audio-taper pots can be used to regain fine control if the lead from pad C4 is moved from R21's terminal-3 to terminal-1. Maximum rate then occurs with the rate control turned fully CCW.

Tremolo-Matic XII schematic.





Tremolo-Matic XII layout & wiring diagram.

Parts List/Soldering Checklist

UCB Radio Shack p/n 276-170; Hosfelt p/n 42-183; or DC Electronics p/n J4-404

IC Sockets

- [ ] 14-pin for IC1; pin-1 goes in E10
- [ ] 16-pin for IC2; pin-1 goes in F12
- [ ] 14-pin for IC3; pin-1 goes in E31

Resistors

- [ ] R1 36K (org-blu-org) A1-A2
- [ ] R2 22K (red-red-org) A4-A6
- [ ] R3 68K (blu-gry-org) C5-C8
- [ ] R4 100K (brn-blk-yel) A9-A10
- [ ] R5 47K (yel-vio-org) D10-D12
- [ ] R6 220K (red-red-yel) X16-A16
- [ ] R7 6.8K (blu-gry-red) B14-B24
- [ ] R8 100K (brn-blk-yel) C23-C26
- [ ] R9 22K (red-red-org) X29-A29
- [ ] R10 22K (red-red-org) B29-B33
- [ ] R11 100K (brn-blk-yel) I26-I32
- [ ] R12 6.8K (blu-gry-red) H23-H25
- [ ] R13 10K (brn-blk-org) G20-G21
- [ ] R14 3.3K (org-org-red) J21-Y21
- [ ] R15 47K (yel-vio-org) I11-I12
- [ ] R16 100K (brn-blk-yel) E11-G11
- [ ] R17 100K (brn-blk-yel) J9-J10
- [ ] R18 10K (brn-blk-org) G3-G4
- [ ] R19 10K (brn-blk-org) H1-H5

Bare Wire Jumpers

- [ ] J1 D3-D6
- [ ] J2 X7-A7
- [ ] J3 C9-C11
- [ ] J4 X15-A15
- [ ] J5 D27-D30
- [ ] J6 X28-A28
- [ ] J7 A30-A31
- [ ] J8 E33-F33
- [ ] J9 J33-Y33
- [ ] J10 G29-G30
- [ ] J11 J28-Y28

redo the following jumpers:

- [ ] J12 J17-J18
- [ ] J13 J15-Y15
- [ ] J14 G10-H11
- [ ] J15 G6-H8
- [ ] J16 J7-Y7
- [ ] J17 E3-F3

Capacitors

- [ ] C1 .033µF B4-B5
- [ ] C2 .001µF B9-B10
- [ ] C3 .1µF D22-D23
- [ ] C4 2.2µF A24-A25 ('+' lead in A25)
- [ ] C5 10pF D25-D26
- [ ] C6 10µF C29-C33 ('+' lead in C29)
- [ ] C7 10µF X33-A33 ('+' lead in X33)
- [ ] C8 .1µF H32-H34
- [ ] C9 10pF G25-G26
- [ ] C10 2.2µF J22-J23 ('+' lead in J23)
- [ ] C11 .1µF H18-H20
- [ ] C12 22pF I16-I17
- [ ] C13 .01µF I9-I10
- [ ] C14 10µF I6-I7 ('+' lead in I6)
- [ ] C15 4.7µF J4-J5 (polarity irrelevant)

Flying Jumpers (<u>insulated</u> wire)

- [ ] TT I8-H27
- [ ] UU G14-F22
- [ ] WW C2-H9
- [ ] XX D16-G16
- [ ] YY D8-G8
- [ ] ZZ C27-G27

Semiconductors

- [ ] D1 1N4001 X41-C41 (banded end to X41)
- [ ] IC1 TL064 quad op amp; pin-1 to E10
- [ ] IC2 NE570; pin-1 to F12
- [ ] IC3 TL064 quad op amp; pin-1 to E31

Potentiometers (T=terminal; NC= no connection)

- [ ] R20 1M-A T1 to B25; T2 to B26; T3 NC
- [ ] R21 20K (see text) T2 to F1; T3 to C4; T1 NC
- [ ] R22 10K T1 to J8; T2 to E1; T3 to I4
- [ ] R23 1M-A T1 to J26; T2 to J25; T3 NC

Jacks (T=terminal)

- [ ] input-1 (1/4" 3-conductor/stereo) tip to T5 of S1; sleeve to Y26; ring to negative (black, '–') lead of battery snap
- [ ] output (1/4" 2-conductor/mono) tip to T2 of S1; sleeve to Y17
- [ ] input-2 (1/4" 2-conductor/mono) tip to E22; sleeve to Y16

Battery Leads

- [ ] positive (red, '+') lead to E41
- [ ] negative (black, '–') lead to ring terminal of input-1 jack

Switches (T=terminal)

- [ ] S1 (DPDT stomp switch): T1 to I21; T2 to tip of output jack; T3 to T4; T5 to tip of input-1 jack; T6 to J34

Parts & connections for optional feedthrough trim network:

- [ ] R24 50K multiturn trimpot wiper (center lead) goes in D37; end leads in D36 & D38
- [ ] R25 220K (red-red-yel) G41-G42
- [ ] C16 .1µF H42-H43
- [ ] IC4 LM78L05 5V pos. reg.; output (O) in B38; ground (G) in B39; input (I) in B40

Bare Wire Jumpers

- [ ] J18 X40-A40
- [ ] J19 C36-C39
- [ ] J20 E39-F38
- [ ] J21 J38-F38

Flying Jumper

- [ ] SS H22-H37

Project No. G54
Pan Tremolo-Matic (B-mod)

Pan Tremolo-Matic, simplified and adapted to an uncommitted circuit board.

Circuit Function

Signal path: Axe output couples through C10 to inverting preamp IC3-c, whose gain is fixed at ~6. Preamp output splits and feeds separate halves of IC3, each configured as a VCA; one signal couples through R13-C6; the other signal through R18-C12. The signal emerges from IC2 at pin-7 and couples through C13-R17-R16; output-1 is taken at juncture of R16-R17. Output-2 emerges from IC2 at pin-10 and couples to T1 of S2, and through C4-R7 to inverting buffer IC3-b, whose output ties to T3 of S2. S2's center terminal, T2, ties to C5; output-2 is taken at the juncture of R14-R15.

Control path: IC1-b, -c, and their associated components form a soft triangle oscillator whose rate is controlled by R26 and whose output couples to tremolo depth control pot R25, thence through R22 to inverting amp IC1-d. IC1-d's output feeds R20 to one VCA in IC2; also feeds inverting buffer IC1-a, whose output feeds through R5 to the other VCA in IC2. The result of the control path is for tremolo control pulses of equal amplitude but inverted polarity to feed two separate VCAs in IC2. This has the effect of rhythmically cross-fading the signal between the two VCA outputs.

Use

Pots & switches have these functions:

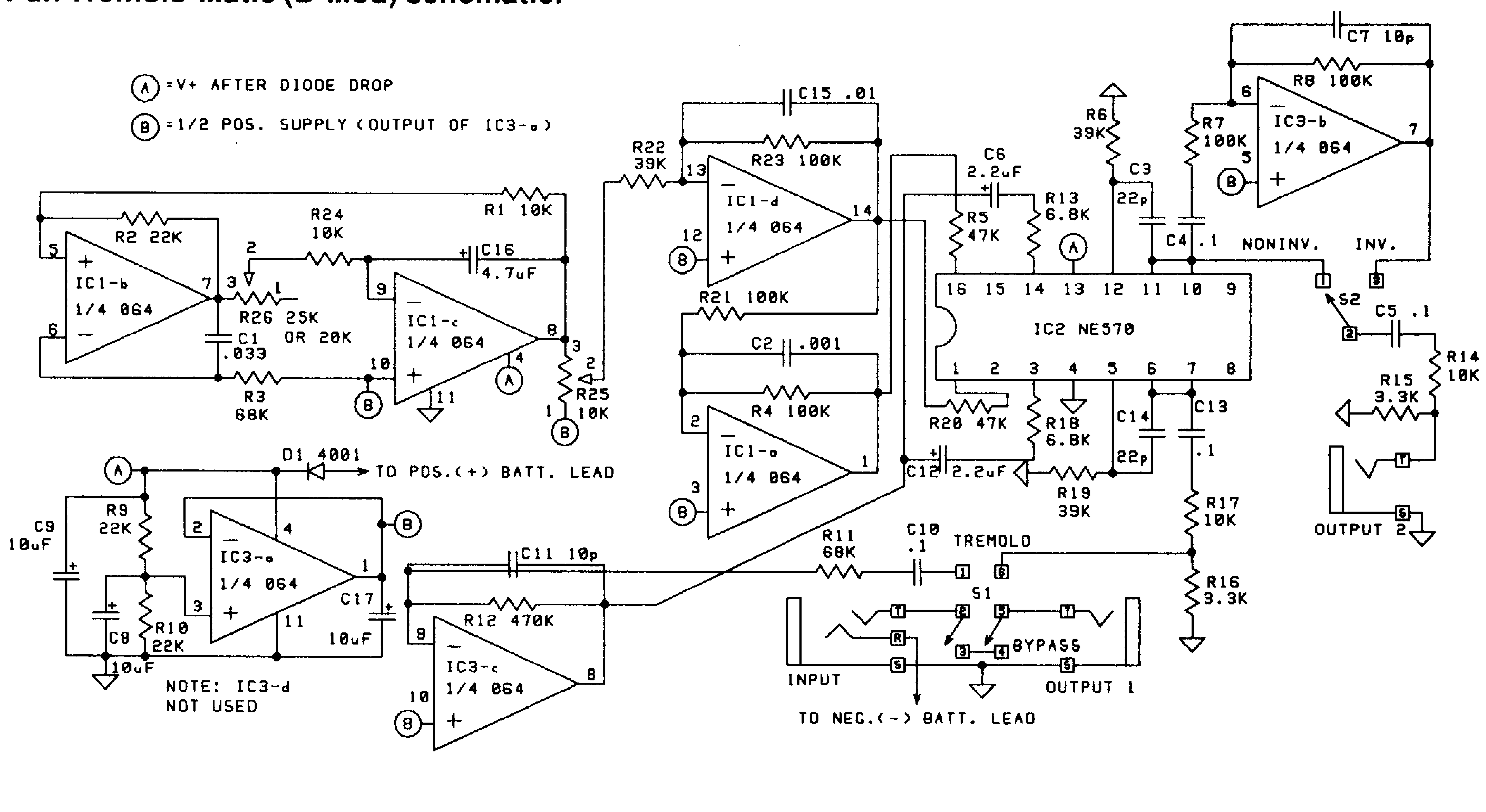
- **R25** tremolo depth
- **R26** tremolo rate
- **S1** effect/bypass
- **S2** output-2 inverted/noninverted select

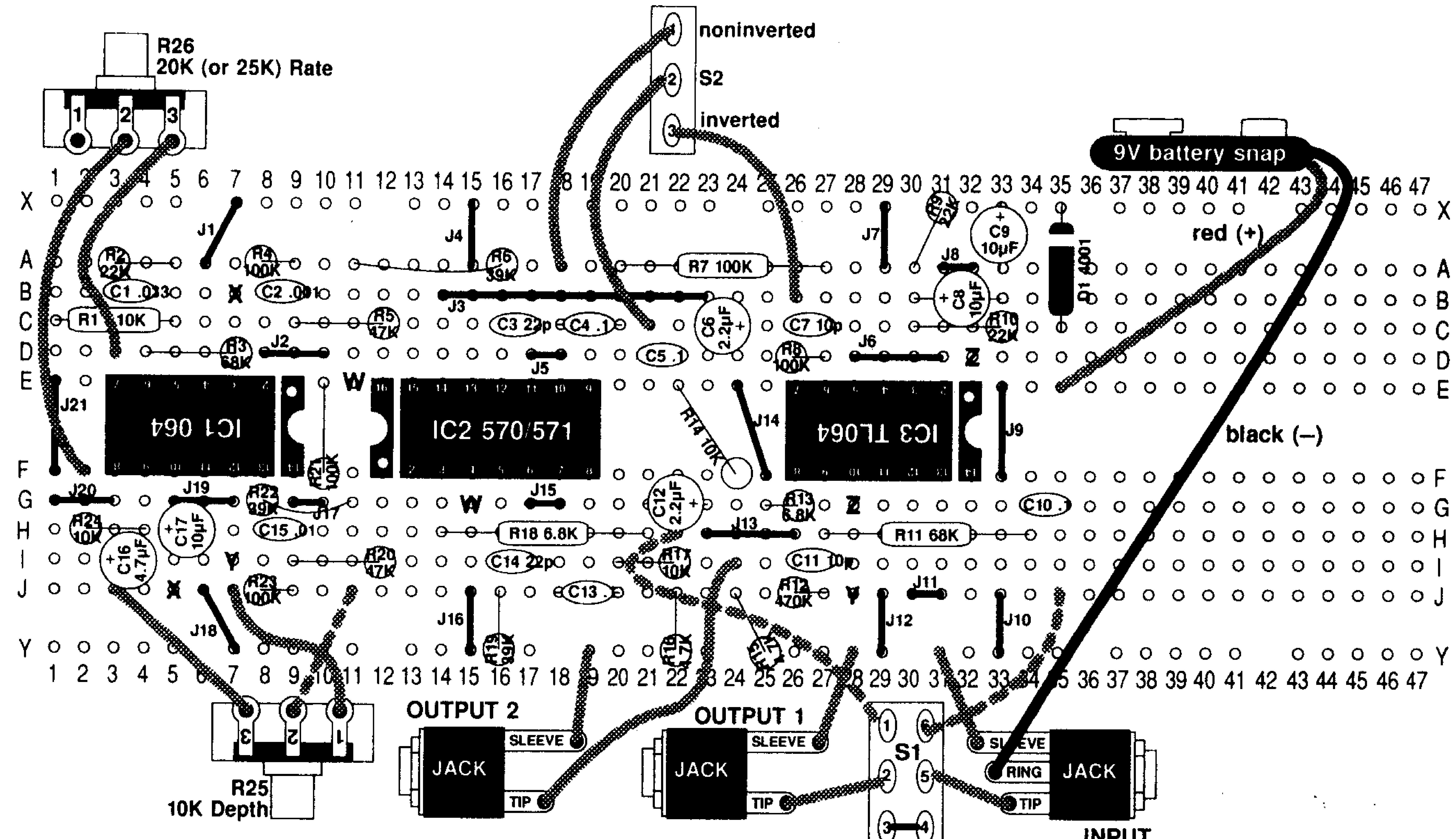
Initial settings: R25 fully CCW, R26 centered; S1 effect in; S2 noninverted. Connect unit to axe and two amps (or two channels of consumer stereo device). In this state the box acts as a signal splitter with equal levels feeding output-1 and output-2. Now turn R25 CW and note that the signal pans alternately between the two outputs; take rate control R26 through its range and note the effect; repeat the checkout sequence with S2 in 'inverted' position and note the phasey aspect of the sound.

Notes

High-output axes will need reduced preamp gain to avoid clipping, achieved by lowering the value of R12, or replacing it with a 1M-A pot for variable preamp gain.

Pan Tremolo-Matic (B-Mod) schematic.





Pan Tremolo-Matic (B-Mod) layout & wiring diagram.

Parts List/Soldering Checklist

UCB Radio Shack p/n 276-170; Hosfelt p/n 42-183; or DC Electronics p/n J4-404

IC Sockets

- [ ] 14-pin for IC1; pin-1 goes in E9
- [ ] 16-pin for IC2; pin-1 goes in F12
- [ ] 14-pin for IC3; pin-1 goes in E32

Resistors

- [ ] R1 10K (brn-blk-org) C1-C5
- [ ] R2 22K (red-red-org) A3-A5
- [ ] R3 68K (blu-gry-org) D4-D7
- [ ] R4 100K (brn-blk-yel) A8-A9
- [ ] R5 47K (yel-vio-org) C9-C12
- [ ] R6 39K (org-wht-org) A11-A16
- [ ] R7 100K (brn-blk-yel) A20-A27
- [ ] R8 100K (brn-blk-yel) D26-D27
- [ ] R9 22K (red-red-org) X31-A30
- [ ] R10 22K (red-red-org) C30-C33
- [ ] R11 68K (blu-gry-org) H27-H34
- [ ] R12 470K (yel-vio-yel) J26-J27
- [ ] R13 6.8K (blu-gry-red) G25-G26
- [ ] R14 10K (brn-blk-org) E22-F24
- [ ] R15 3.3K (org-org-red) J24-Y25
- [ ] R16 3.3K (org-org-red) J22-Y22
- [ ] R17 10K (brn-blk-org) I20-I22
- [ ] R18 6.8K (blu-gry-red) H14-H21
- [ ] R19 39K (org-wht-org) J16-Y16
- [ ] R20 47K (yel-vio-org) I9-I12
- [ ] R21 100K (brn-blk-yel) E10-F10
- [ ] R22 39K (org-wht-org) G8-G11
- [ ] R23 100K (brn-blk-yel) J8-J9
- [ ] R24 10K (brn-blk-org) H2-H4

Bare Wire Jumpers

- [ ] J1 A6-X7
- [ ] J2 D8-D10
- [ ] J3 B14-B23
- [ ] J4 X15-A15
- [ ] J5 D17-D18
- [ ] J6 D28-D31
- [ ] J7 X29-A29
- [ ] J8 A31-A32
- [ ] J9 E33-F33
- [ ] J10 J33-Y33
- [ ] J11 J30-J31
- [ ] J12 J29-Y29
- [ ] J13 H23-H26
- [ ] J14 E24-F25
- [ ] J15 G17-G18
- [ ] J16 J15-Y15
- [ ] J17 G9-G10
- [ ] J18 J6-Y7
- [ ] J19 G5-G7
- [ ] J20 G1-G3
- [ ] J21 E1-F1

Capacitors

- [ ] C1 .033µF B3-B4
- [ ] C2 .001µF B8-B9
- [ ] C3 22pF C16-C17
- [ ] C4 .1µF C18-C20
- [ ] C5 .1µF D21-D22
- [ ] C6 2.2µF C23-C24 ('+' to C24)
- [ ] C7 10pF C26-C27
- [ ] C8 10µF B30-B33 ('+' to B30)
- [ ] C9 10µF X33-A33 ('+' to X33)
- [ ] C10 .1µF G34-G35
- [ ] C11 10pF I26-I27
- [ ] C12 2.2µF G21-G23 ('+' to G23)
- [ ] C13 .1µF J18-J20
- [ ] C14 22pF I16-I17
- [ ] C15 .01µF H8-H9
- [ ] C16 4.7µF I3-I4 (polarity irrelevant)
- [ ] C17 10µF H5-H6 ('+' to H5)

Flying Jumpers (<u>insulated</u> wire)

- [ ] WW E11-G15
- [ ] XX J5-B7
- [ ] YY I7-J28
- [ ] ZZ G28-D32

Semiconductors

- [ ] D1 1N4001 X35-C35 (banded end to X35)
- [ ] IC1 TL064 quad op amp; pin-1 in E9
- [ ] IC2 NE570; pin-1 in F12
- [ ] IC3 TL064 quad op amp; pin-1 in E32

Potentiometers (T=terminal, NC=no connection)

- [ ] R25 10K T1 to J7; T2 to J11; T3 to J3
- [ ] R26 20K (or 25K) T1 NC; T2 to F2; T3 to D3

Switch (T=terminal)

- [ ] S1 DPDT stomp switch: T1 to H22; T2 to tip of output-1 jack; T3 to T4; T5 to tip of input jack; T6 to J35
- [ ] S2 SPDT inverted/noninverted select; T1 to A18; T2 to C21; T3 to B26

Jacks (T=terminal)

- [ ] input jack (1/4" 3-conductor/stereo): tip to T5 of S1; ring to negative battery lead; sleeve to Y31
- [ ] output-1 jack (1/4" 2-conductor/mono): tip to T2 of S1; sleeve to Y28
- [ ] output-2 jack (1/4" 2-conductor/mono): tip to I24; sleeve to Y19

Battery Leads

- [ ] negative (black, '–') to ring of input jack
- [ ] positive (red, '+') to E35

Project No. G55

Tremolo-Matic (B-mod)

Tremolo-Matic, the original pure-VCA tremolo, simplified and adapted to an uncommitted circuit board, and given a new wrinkle.

Circuit Function

Signal path: Axe output couples through C4 to inverting preamp IC3 whose gain is fixed at ~6. Preamp output couples through R7-C5 to IC2, half an NE570 configured as a voltage controlled amplifier whose gain varies 0–1, depending on the control voltage delivered through R14. VCA output couples through C6 to R10; output is taken at the juncture of R10 and R11. The net signal path is noninverting.

Control path: IC1-b, -c, and their associated components are configured as an oscillator that generates triangles waves, and squarewaves whose rise and fall are softened by the addition of C1 and R4 to an old op-amp function generator circuit. Switch S2 selects softened squarewaves or triangle waves to feed tremolo depth control pot R21, whose output feeds inverting amp IC1-d. The static DC offset present at IC1-d's output is controlled by R20; this voltage determines the VCA's static gain. The VCA control voltage couples through R14 to IC2.

Use

Pots & switches have these functions:

- **R19** feedthrough trim
- **R20** VCA static gain
- **R21** tremolo depth
- **R22** tremolo rate
- **S1** effect/bypass
- **S2** waveform select triangle/soft square

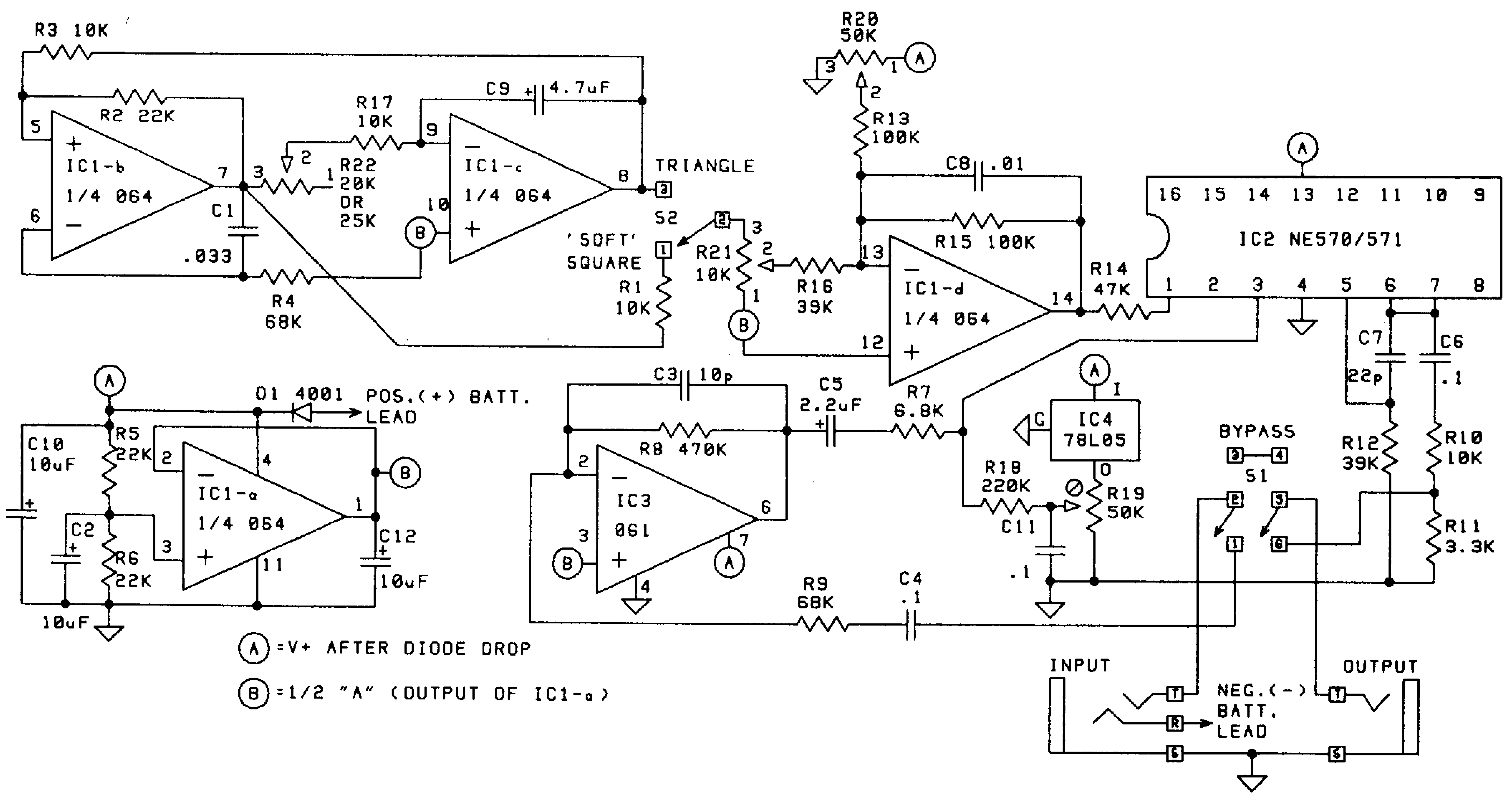
Initial settings: R20 centered; R21, R22 fully CW; S1 effect in; S2 soft square. Connect unit to axe, and to an amp whose volume is turned *all the way down.* Slowly advance amp's volume level until feedthrough pulses are heard. Trim R19 for minimum feedthrough.

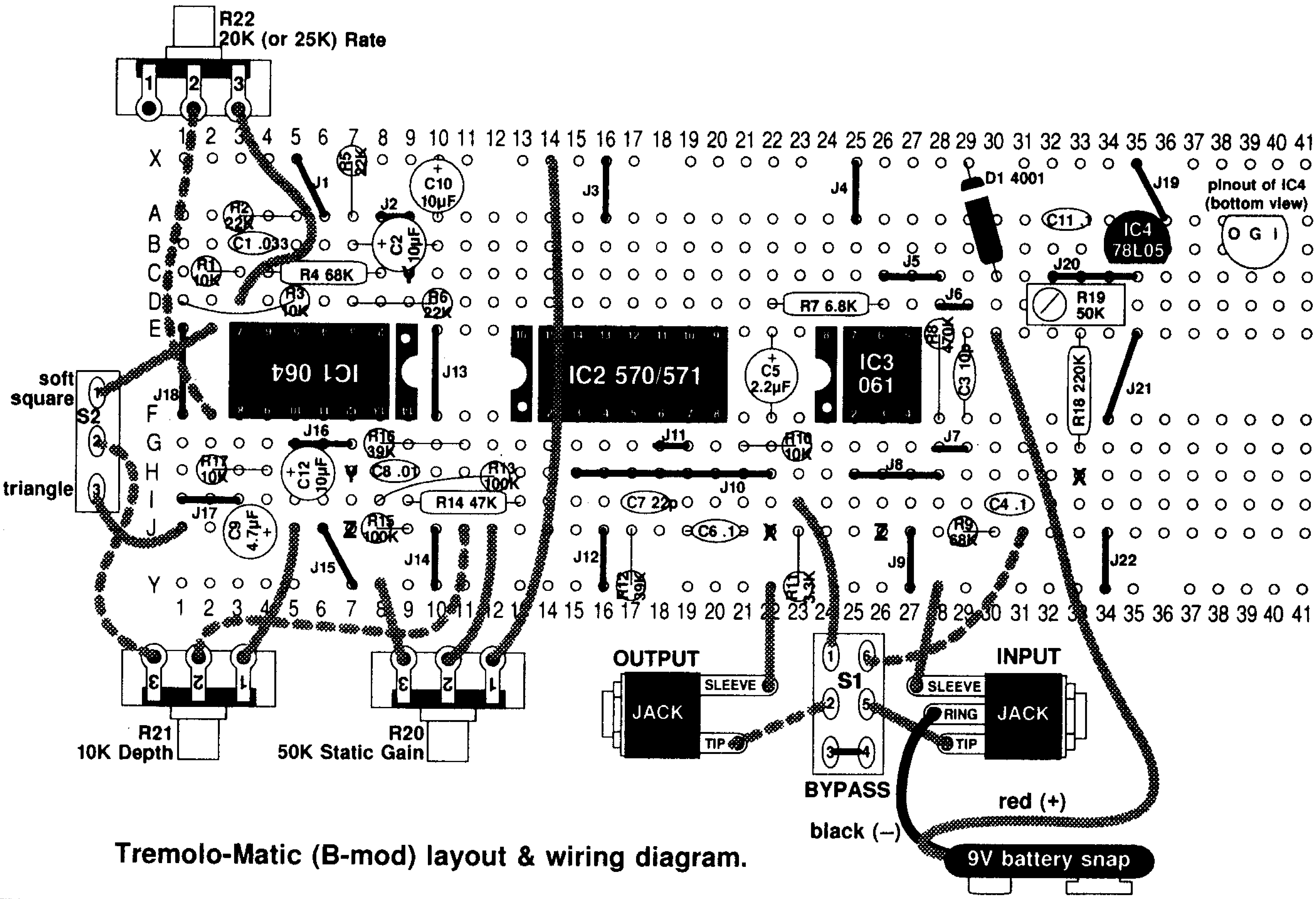
Now turn axe volume all the way up; adjust amp volume for desired listening level. Take R20, R21, & R22 through their ranges and note the effect on sound. Toggle S2 between triangle and soft square and note the effect on sound.

Notes

This revision of the classic VCA tremolo eliminates the need for oscillator trim, simplifies the signal path, and adds a selectable soft squarewave to the control path (making feedthrough trim mandatory). TM creates three distinct forms of tremolo, depending on static VCA gain. With VCA gain near maximum, each control pulse can only reduce volume, giving a mild form of tremolo. With VCA gain at ~60%, each control pulse increases and decreases gain relative to the static point. With VCA gain at 0, each control pulse brings the sound out of a background of silence, producing a percussive air.

Tremolo-Matic (B-mod) schematic.





Tremolo-Matic (B-mod) layout & wiring diagram.

Parts List/Soldering Checklist

UCB Radio Shack p/n 276-170; Hosfelt p/n 42-183; or DC Electronics p/n J4-404

IC Sockets
- [ ] 14-pin for IC1; pin-1 goes in E9
- [ ] 16-pin for IC2; pin-1 goes in F13
- [ ] 8-pin for IC3; pin-1 goes in F24

Resistors
- [ ] R1 10K (brn-blk-org) C2-C3
- [ ] R2 22K (red-red-org) A3-A5
- [ ] R3 10K (brn-blk-org) D1-D5
- [ ] R4 68K (blu-gry-org) C4-C8
- [ ] R5 22K (red-red-org) X7-A7
- [ ] R6 22K (red-red-org) D7-D10
- [ ] R7 6.8K (blu-gry-red) D22-D26
- [ ] R8 470K (yel-vio-yel) E28-F28
- [ ] R9 68K (blu-gry-org) J29-J30
- [ ] R10 10K (brn-blk-org) G21-G23
- [ ] R11 3.3K (org-org-red) J23-Y23
- [ ] R12 39K (org-wht-org) J17-Y17
- [ ] R13 100K (brn-blk-yel) I8-H12
- [ ] R14 47K (yel-vio-org) I9-I13
- [ ] R15 100K (brn-blk-yel) J8-J9
- [ ] R16 39K (org-wht-org) G8-G11
- [ ] R17 10K (brn-blk-org) H2-H4
- [ ] R18 220K (red-red-yel) E33-G33

Bare Wire Jumpers
- [ ] J1 X5-A6
- [ ] J2 A8-A9
- [ ] J3 X16-A16
- [ ] J4 X25-A25
- [ ] J5 C26-C28
- [ ] J6 D28-D29
- [ ] J7 G28-G29
- [ ] J8 H25-H28
- [ ] J9 J27-Y27
- [ ] J10 H15-H22
- [ ] J11 G18-G19
- [ ] J12 J16-Y16
- [ ] J13 E10-F10
- [ ] J14 J10-Y10
- [ ] J15 J6-Y7
- [ ] J16 G5-G7
- [ ] J17 I1-I3
- [ ] J18 E1-F1
- [ ] J19 X35-A36
- [ ] J20 C32-C35
- [ ] J21 F34-E35
- [ ] J22 J34-Y34

Capacitors
- [ ] C1 .033µF B3-B4
- [ ] C2 10µF B7-B10 ('+' lead to B7)
- [ ] C3 10pF E29-F29
- [ ] C4 .1µF I30-I31
- [ ] C5 2.2µF E22-F22 ('+' lead to E22)
- [ ] C6 .1µF J19-J21
- [ ] C7 22pF I17-I18
- [ ] C8 .01µF H8-H9
- [ ] C9 4.7µF J3-J4 (polarity irrelevant)
- [ ] C10 10µF X10-A10 ('+' lead to X10)
- [ ] C11 .1µF A32-A33
- [ ] C12 10µF H5-H6 ('+' lead to H5)

Flying Jumpers (<u>insulated</u> wire)
- [ ] XX J22-H33
- [ ] YY C9-H7
- [ ] ZZ J7-J26

Semiconductors
- [ ] D1 1N4001 X29-C30 (banded end to X29)
- [ ] IC1 TL064 quad op amp; pin-1 goes in E9
- [ ] IC2 NE570; pin-1 goes in F13
- [ ] IC3 TL061 op amp; pin-1 goes in F24
- [ ] IC4 LM78L05 5V regulator; output (O) goes in B34; ground (G) goes in B35; input (I) goes in B36

Potentiometers & trimpots (T=terminal; NC=no connection
- [ ] R19 50K multiturn trimpot; center terminal (wiper) goes in D33; the two end-terminals go in D32 and D34
- [ ] R20 50K T1 to X14; T2 to pad J12; T3 to Y8
- [ ] R21 10K T1 to J5; T2 to pad J11; T3 to center terminal (T2) of S2
- [ ] R22 20K or 25K; T1 NC; T2 to F2; T3 to D3

Switches (T=terminal)
- [ ] S1 DPDT stomp switch; T1 to I23; T2 to tip of output jack; T3 to T4; T5 to tip of input jack; T6 to pad J31
- [ ] S2 SPDT square/triangle select switch; T1 to E2; T2 to terminal 3 of R21; T3 to hole J1

Jacks (T=terminal)
- [ ] input jack (1/4" 3-terminal/stereo jack); tip to T5 of S1; ring to negative ('–') battery lead; sleeve to Y28
- [ ] output jack (1/4" 2-terminal/mono jack); tip to T2 of S1; sleeve to Y22

Battery Leads
- [ ] negative (black, '–') lead to ring of input jack
- [ ] positive (red, '+') lead to E30

Beginner's View

(continued from page 3)

A. D1 conducts current only in one direction. If you were using a battery snap that didn't have color-coded leads, and if you accidentally reversed the polarity of the power connection, no significant current would flow through D1; the circuit wouldn't suffer damage. Without D1, reversed supply polarity could destroy several components and possibly start a fire. The drawback of using D1 is that you lose about 0.6V of battery voltage; but since this box functions down to 6V, no problem.

Q. What's going on with IC4-a, and this 'A' and 'B' inside circles?

A. We use symbols to keep the schematic simple. 'A' inside a circle is simply the positive battery voltage after it gets through D1. 'B' inside a circle is the circuit's 'artificial ground', about half of 'A'. Op amps need this reference voltage to function.

Q. What about the input jack?

A. As you know from using commercial stompboxes, the input jack acts as the power switch. Plug in the axe and the box turns on. The negative battery lead ties to the input jack's ring terminal. When no plug is inserted in the jack, no power flows because battery negative does not contact circuit ground—the downward-pointing triangle symbol on the schematic. When you insert the axe plug, the sleeve of the plug shorts the jack's ring terminal to its sleeve terminal, tying battery '–' to circuit ground. Current flows; the circuit turns on.

Q. What is 'S1'?

A. The stomp switch. When you switch the effect out, it bypasses the circuit with straight wire.

Q. So we've got power, and we can switch the circuit in or out of the signal path. Now what?

A. We follow the signal through the system. Your axe feed comes in through the tip terminal of the input jack, through S1, to C7 and R13 to the inverting input of preamp IC4-d.

Q. What do you mean, 'IC4-d'?

A. IC4 is a quad op amp, meaning it contains four independent operational amplifiers. On schematics these are conventionally labeled with letters a-b-c-d. The 'a' op amp uses pins 1-2-3; the 'b' op amp refers to pins 7-6-5; 'c' uses 8-9-10; and 'd' uses 14-13-12. Pins 4 and 11 are power pins. Pin 4 receives the positive voltage, pin-11 receives the negative voltage. This arrangement shows why most quad op amps have to be plugged in 'upside down' relative to chips that receive their positive voltage along the top margin.

Q. Okay, I've got the chip layout. But why did you call IC4-d an 'inverting preamp'?

A. Because of the way it's configured: the input comes through R13 to the inverting ('–') input; and a resistor, R14, is wired between the '–' input and the output. This causes the output signal to be inverted. The '+' terminal ties to the voltage reference, 'B'.

Q. Why do we need C7? Why not couple the axe feed directly?

A. C7 acts as a DC blocking cap: it lets through audio from your axe, but blocks direct current.

Q. My axe doesn't generate any direct current, dude.

A. True, but your axe can be considered a resistance of about 10K ohms when the volume control is turned all the way up. Without C7, R13 would tie to ground through this path, causing the output of IC4-d to swing to its positive limit, effectively blocking the audio signal.

Q. What's the preamp gain?

A. Gain equals (R14 ÷ R13) = (470K ÷ 68K), or 6.9; a little less in practice because the axe resistance adds to R13; call voltage gain about 6.

Q. Why use an inverting preamp? I thought the ideal stompbox didn't invert the signal.

A. Correct. But the signal is going to pass through an inverting op amp inside IC3, so use of an inverting preamp makes the net signal path noninverting.

Q. What's the purpose of C8?

A. C8 and C12 are very low-value caps wired in the feedback loops of op amps. This helps stabilize the amps by reducing their gain at high frequencies. In all likelihood we could have omitted them, but veteran builders usually include them because they make op-amp instability unlikely as a cause of malfunction.

Q. What do you mean 'feedback loop of an op amp'?

A. The path between an op amp's output and its '–' input is commonly called 'the feedback loop,' or, more properly, 'the negative feedback loop.'

Q. Okay, we've got the boosted axe feed coming out of the preamp. What next?

A. The signal splits, flowing into two separate paths. One path is a variable lowpass filter made up of R24, R9, C4, and IC4-b. The other path is a variable highpass filter made up of C9, R23, R12, and IC4-c.

Q. What do you mean, 'variable lowpass (or highpass) filter'?

A. Using resistors and capacitors, the simplest filter that it's possible to make. In the case of a lowpass filter, the capacitor on the end of a resistor shunts high frequencies to ground. The frequency at which this shunting action becomes noticeable—the f_{-3}—depends on the relative values of the resistor and the capacitor.

The same applies to the highpass filter, only the relative positions of the resistor and the cap are reversed. The signal traverses the capacitor, while the resistor on the end acts as a shunt for low frequencies.

Q. What do IC4-b and IC4-c do? Looks like their outputs are connected to their '–' inputs.

A. They are. This configuration is known as a voltage follower. Whatever voltage appears at the '+' input of the op amp also appears at its output terminal; hence the name.

Q. What's the point? Why not connect the filters directly to the inputs of IC3, without putting these voltage followers in the way?

A. The voltage followers act as buffers. A *buffer* is a circuit that has extremely high input impedance, very low output impedance. The point is to prevent loss of signal due to divider action.

Q. 'Divider action,' dude?

A. Divider action, dude. Anytime you have two resistors wired in series, you have a divider, more properly called a voltage divider. In this case, when R24 is at maximum, the impedance at the juncture of R9 and C4 is about 260,000 ohms; if that were tied directly to R8 (which is in series with a 20K resistor inside the 570 at pin-14) it would see an impedance of only ~27,000 ohms. Divider action would cause voltage loss equal to (27,000 ÷ 287,000). We'd lose over 90% of the signal. Using the buffer, the 260,000-ohm impedance sees an essentially infinite impedance at the '+' terminal of IC4-b, so no signal loss occurs at that point. Each buffer's output impedance is 200 ohms or less; that forms a voltage divider with 27,000 ohms, losing less than 0.02V going into IC3.

Q. What's the point of splitting the signal and feeding it through a couple of filters?

A. Remember the purpose of the box: to duplicate what goes on inside the Fender 3-tube tremolo/vibrato.

Q. Okay, we've split the signal into two paths. One path is a variable highpass filter, the other path is a variable lowpass filter. What happens to these two signals?

A. Each one enters an input of IC3, which is an NE570 configured as a voltage controlled mixer.

Q. You want to 'splain that, dude?

A. The 570 contains two independent voltage controlled amplifiers, or VCAs. The signals enter pins 3 and 14; they emerge at pins 12 and 5. But at the outputs, the signals exist as current, which we have to convert back to voltage to be useful. The tool that does this is an op amp inside the 570; but a useful feature of current is that we can add the two currents and use a single current-to-voltage converter for both. This turns a pair of independent VCAs into one voltage controlled mixer.

Q. How do we control the mixer?

A. With a pair of control voltages. Here's how we get them: The basic oscillator consists of IC2-b and IC2-c; plus R2, 20, 21, 25; and C13; R25 varies the rate. This circuit is as old as operational amplifiers, and generates triangle waves at the output of IC2-c; squarewaves at the output of IC2-b. But because squarewaves generated anywhere inside a stompbox tend to cause clicks in the signal path, the circuit adds C1 and R3 to slow the rising and falling edges of the squarewave to the point that they don't click.

The triangle wave output (IC2-c, pin-8) ties to R22, a potentiometer (volume control) that varies the signal feeding R1 from 0 to 100%. The signal is inverted, and boosted by a factor of ~2.8 inside IC2-d. The output of IC2-d is the primary control voltage. To get the second voltage, we feed the primary control voltage through R6 to IC2-a. This inverts it, so that, when one control voltage goes high, the other goes low.

These triangle waves control the two separate VCAs inside IC3. One control voltage ties through R5 to one VCA control port, IC3 pin-16; the other control voltage ties through R18 to the second VCA control port, IC3 pin-1. When the control voltage at pin-16 is at its positive limit, the gain of that VCA is ~1; at the same instant, the control voltage at pin-1 is at its negative limit, so the gain of the second VCA is essentially 0. Both VCA outputs add. When pin-16 is fully positive, the VCA output consists only of the output of the lowpass filter; when pin-1 is fully positive, the net output consists entirely of the output of the highpass filter. When the control voltages are somewhere between their limits, the output consists of a mixture of the two input signals.

Q. What does R27 do?

A. Keeps the resting DC offset at IC3 pin-7 near 1/2V+, giving maximum headroom.

Q. What does 'resting DC offset' mean?

A. 'Resting DC offset' means 'voltage measured in the absence of an audio signal.'

Q. Hold it, dude. There's a voltage divider made up of R16 and R17 on the output. Looks like that divider is reducing the output signal by a factor of (3300 ÷ 13,300), or about 4.

A. The preamp boosted the input signal by a factor of 6. That output network reduces it, so we've returned the output signal near its original level, to avoid an abrupt change in volume when switching the effect out of the signal path. The point of doing this is that electronic noise from the preamp, and especially from IC3, gets reduced as well. So do feedthrough impulses coming out of IC3. This technique of boosting the signal at the input and reducing it at the output is called *quasi-companding*. It's a common and very effective means to reduce noise in pedals.

Q. Why'd you choose these particular op amps?

A. The 064 is a low-voltage, low-current type that's cheap and widely available. Its high noise voltage does not intrude in this arrangement.

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Q. Okay, dude, I understand how it works. Now show me how to build it.

A. First a warning. I'm assuming that you can solder, wire, and perform the other necessary tasks competently and safely. If you can't, or if you have any doubts about your constructional skills, don't try to build the project.

Q. Got it.

A. First, gather all the parts.

Q. Where's the parts list?

A. The soldering checklist is also the parts list. The resistor on the schematic has the same number on the wiring diagram and on the soldering checklist. You can photocopy the soldering checklist to avoid marking up the original.

Q. Where do I start?

A. First some general principles. Since you're building a device from scratch, fixing errors becomes a matter of prevention, or what I call anticipatory troubleshooting. Build the box correctly, even if you have to work at a snail's pace. Time spent checking the work as you go is time you won't have to spend troubleshooting.

That said, install the sockets that will hold the integrated circuits. The end of each socket has a notch, known as a 'key,' which correlates with the notch on the chip that goes in the socket. Orient the socket so the key occupies the same end that the notch on the IC will occupy. This acts as a reminder of how to insert the chip.

Next, solder each resistor one at a time; let the resistor cool, then clip the leads close to the board. Examine the board through a magnifier after each one is done.

Once the resistors are installed, use their clipped leads as bare-wire jumpers. Install each jumper one at a time; double-check the hole coordinates before you solder.

Next, install the capacitors.

Q. Why does capacitor polarity matter?

A. Polarized caps are designed to function in the presence of a DC voltage difference between their leads. The '+' terminal must tie to the circuit point having the higher voltage.

When used for bypass (i.e., tied directly across the power supply; C6 in this case), subjecting a capacitor to reversed polarity causes heating, which could destroy the cap or cause it to burst.

Polarized caps in the signal path also have to be oriented correctly. For example, the resting DC offset at the filter buffers' outputs is close to 1/2V+, or about 4V with a typical 9V battery. The voltage at pins 3 and 14 of IC3 is near 1.8V. Therefore, the coupling caps' (C3, C10) '+' leads have to face the filter buffers.

Q. Why not use nonpolar capacitors, so you don't have to worry about polarity?

A. You could use them; they'd work fine. But nonpolar caps cost a lot more than polarized ones, so most builders, and practically all commercial manufacturers, use polarized caps.

Q. How do I identify the '+' lead? There's no '+' marking on any of my caps; only a '–' sign down one side.

A. If one side is '–' the other side must be '+'. Another key is that the longer of a capacitor's two leads is the positive lead. This practice of labeling the '–' lead on the cap but showing the '+' lead on the schematic is an ancient convention.

Q. How do I identify the disc capacitors? None of mine are marked '0.0022µF' or '22 picofarads.'

A. Most disc caps use a three-digit code. The first two digits give the value; the final (rightmost) digit is a multiplier. For example, C1 might be labeled '333'. The first two digits tell you '33 picofarads'; the final digit (3) means 'multiply times 1000'. So, 33 picofarads times 1000 gives 33,000 picofarads; to convert that to microfarads, divide by a million, giving 0.033µF. C9 is probably labeled '222', C4 & C13 '103', C7 & C16 '104', C2 '101'. C8 and C12 are probably labeled '10' and '22', respectively; their numbers may be underlined to indicate that no multiplier is involved.

Some caps' labeling may not follow this convention, making them difficult or impossible to identify. In those cases, whip out your DMM and measure the capacitance.

A. Next, install the flying jumpers. For this you'll need 24- or 26-gauge, insulated copper wire, preferably stranded. Several jumpers (e.g., XX, YY, ZZ) pass over chips. You have to leave enough slack in these jumpers to allow socketing and desocketing the chips.

Next, install D1, then socket the chips IC2, IC3, and IC4. If you're using virgin chips, you'll find that the leads have to be bent inward a bit to get them into the socket holes. Identify pin-1 of each chip by the notch, pit, or white stripe on one end.

Before pressing the chip into the socket, make certain that you have it correctly oriented; note that IC2 and IC4 are upside down compared to IC3. Also, look closely to see that each pin goes in a socket hole and does not straddle the inner or outer lip. It's possible to insert the chip and have one or more pins bend under or outside their holes.

If you have to desocket a chip, never use your bare fingers. You'll probably wind up with a sliced finger and badly bent pins on the chip. To desocket, insert the tip of a small, flat-blade screwdriver under one end of the chip; rotate the screwdriver so that the end of the chip lifts slightly; repeat this procedure on the other end of the chip; then again on the first end, gently raising the chip until it lifts free.

With all chips socketed, we can perform a key preliminary troubleshooting step: measure the resistance across the board's power leads. Set your meter to read ohms, on a 10,000- or 20,000-ohm scale; clip the meter's red ('+') lead to ground (such as J10); the black ('–') lead to the positive power bus (such as J7). If no reading appears, reverse the meter leads. You'll probably get a reading in the thousands of ohms—my prototype read about 2000 ohms—but in no case less than 1000 ohms. A lower reading, especially less than 500 ohms, indicates a serious problem that you must correct before powering up the circuit.

If the board passes the ohmmeter test, install the jacks, pots, stomp switch S1, and 9V battery snap.

Q. How long should I make the lead wires for pots and jacks?

A. It's not critical at this stage; say 5–7". You'll probably want to trim them when you install the board in a stompbox enclosure.

Q. My input jack isn't labeled, dude. How do I identify its tip-ring-sleeve terminals?

A. Good question, dude, since most jacks aren't labeled. The quick way requires a 3-conductor (stereo) plug. Remove the cover from the plug to expose its three terminals. Using your meter set for low-ohms reading, identify the plug terminals that tie to sleeve, ring, and tip. Label the three terminals.

Next, insert the plug into the jack. Clip one meter lead on the plug's sleeve terminal; touch the other meter lead to the three jack terminals; the one that reads 0 or very low resistance is the jack's sleeve terminal; the other two terminals should read as open circuits. Next, move the meter lead to the plug's tip terminal; repeat the procedure to identify the jack's tip; then on to the ring terminal. Now label the jack terminals T-R-S. Don't trust your memory. Also, never assume that a plug or jack made by another manufacturer follows the same pinout; always confirm by measuring.

Q. What's next?

A. At this point we have an assembled board that should be functional. We're going to check it out before mounting it in a case. If something is wrong, a free board makes troubleshooting easier.

The first time you power up, stand ready to unsnap the battery immediately should you note smoking, hissing, hot chips or wires. If you connect the battery and nothing happens, insert the axe plug. If no signs of malfunction appear, turn to the 'initial settings' on page 4 and follow the checkout procedure.

Q. Why didn't we install the feedthrough trim network? Also, dude, it looks like you forgot to include a feedthrough trim for the second channel—and not just in this box, but TM12, too.

A. The 12 dB of quasi-companding and the highpass action of C11 attenuate feedthrough enough that this box doesn't really need it. As for the box needing two trims, one of the 570's magical properties is that, in this configuration, a single trim kills feedthrough for both VCAs.

Q. What, exactly, is 'feedthrough'?

A. The percentage of the control voltage that appears at the output of a voltage-controlled block along with the audio signal.

Q. Dude! This box sounds fantastic!

A. Thank Leo. He thought up the mechanism.

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