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THE ELECTRICAL DESIGN AND MUSICAL APPLICATIONS OF AN UNCONDITIONALLY STABLE COMBINATION VOLTAGE CONTROLLED HIGHPASS, BANDPASS, LOWPASS, BAND REJECT FILTER/RESONATOR.

INTRODUCTION

Since the acceptance of electronic music synthesizers in recording studios, bands, and educational institutions, the demand for a wider range of sound timbres has increased greatly. The filter to be described here was initially designed for use in the modular ARP * synthesizer, to extend the gamut of sound spectra available. The main design objectives were:

1). to achieve a very high but stable resonance factor ("Q")
2). to provide highpass, bandpass, and band reject (notch) capability as well as the already available lowpass function
3). to allow accurate and stable voltage control of both the center frequency (F_c) and Q in an exponential manner.

These goals have been achieved in what is called the ARP Module 1047 Multimode Filter/Resonator. In addition, many new applications have been realized, such as accurate real-time spectral analysis, biological signal processing, speech analysis and synthesis, and analog computation, to mention a few.

**ARP is a trademark of Tonus, Inc.*

BACKGROUND

Music synthesizers typically generate waveforms with rich but uniform harmonic structures, such as sawtooth or pulse waves. These are then fed into a filter, whose amplitude/frequency response modifies the amplitude relation of the harmonics, creating a change in the timbre ("tone") of the sound. Please refer to Figure 1.

Since the filter is the major timbre controlling element, it is obviously desirable to:

1). have a wide variety of frequency response shapes available,
2). be able to rapidly change the filter's parameters through voltage control; that is, to vary dynamically the timbre of the sound.

However, most synthesizers rely on a voltage controlled lowpass filter with relatively sharp (24 dB per octave) cutoff, and moderate resonance capability (20 dB peak, or a "Q" of 10). Although this response is certainly useful, most natural sounds do not resemble the harmonic structures attainable with this filter. Rather, they are the result of impressing a simple waveform from, for example, a reed, violin bow, or mechanical impulse, on a resonator which reinforces a region of the driving waveform's spectrum. Typical natural resonators are horns, strings, pipes, drums, and sounding boards. The 1047 filter's bandpass response is that of a natural acoustic resonator, namely single pole (6 dB per octave), and has a resonance factor voltage controllable from 0 dB to 54 dB; that is, a "Q" range of ½ (damped) to 512.

DESIGN

Please refer to Figure 2. The filter is basically an analog computing circuit consisting of summers and integrators, set up to solve a second order differential equation. The circuit is well known and documented in analog computer and servomechanism fields. What is unique, however, is that the parameters (K_1, K_2, K_3, and K_4) are voltage controlled by accurate temperature compensated exponential circuitry, (covered by U. S. Patent 3,444,362), driving wide range voltage controlled amplifiers.

As will be shown in the mathematical analysis, the four K parameters are scaled so as to:

1). provide independent control of center frequency and "Q"
2). normalize the response so that the four outputs have unity gain in their respective passbands.

MATHEMATICAL ANALYSIS

Please refer to Figures 2 and 3. The Laplace transform method will be used, so a few definitions are in order:

1). $s \equiv \sigma + jw$, where σ =damping factor (real axis) and w=angular frequency (imaginary axis)
2). $w \equiv 2\pi f$, where f=frequency in hertz.
3). Transfer function of an integrator $\equiv \frac{1}{s}$
4). $j \equiv \sqrt{-1}$

Proceeding to the analysis, then, let us assume an input signal E_1 (Figure 2), which according to Laplace is an impulse (a voltage that jumps to infinite amplitude and back in zero time) of area equal to E_1. (I offer my sincere apologies to mathematicians who do not accept impulse functions.) Let us also assume the Resonance Mode switch to be in the "NORMAL" position.

The output of the negative summer in E_H. $E_B = E_H(\frac{K_3}{s})$, $E_L = E_H(\frac{K_3}{s})(\frac{K_4}{s})$, so the summer's output $E_H = E_1 - E_L - K_2 E_B = E_1 - E_H(\frac{K_3 K_4}{s^2}) - E_H(\frac{K_2 K_3}{s})$. Multiplying by S^2 and rearranging terms, and letting $K_3 = K_4$, we arrive at:

$$E_H = E_1 \frac{s^2}{s^2 + K_2 K_3 S + K_3^2} = \text{Highpass response}$$

$$E_B = E_H(\frac{K_3}{s}) = E_1 \frac{K_3 S}{S^2 + K_2 K_3 S + K_3^2} = \text{Bandpass response}$$

$$E_L = E_H(\frac{K_3^2}{s^2}) = E_1 \frac{K_3^2}{S^2 + K_2 K_3 S + K_3^2} = \text{Lowpass response}$$

If we now set the denominators equal to zero, the solutions for S are the poles (Figure 3) of all three response functions:

$$s^2 + K_2 K_3 S + K_3^2 = 0,$$

$$s = \frac{-K_2 K_3}{2} \pm j K_3 \sqrt{1 - \frac{K_2^2}{4}} = \sigma_o \pm j w_o$$

The center frequency of the bandpass response, which will be called $w_c = \sqrt{\sigma_o + w_o^2} = K_3$

The resonance factor $(Q) = \frac{-wc}{2\sigma_o} = \frac{1}{K_2}$

K_3 and K_2 thus provide independent control of center frequency (F_C) and Q. Referring to Figure 2, the notch output is a weighted sum of the highpass and lowpass functions; that is,

$$E_N = \frac{aK_3^2 + (1-a)S^2}{S^2 + K_2 K_3 S + K_3^2} = \text{Notch Response}$$

Note that the notch response has the same poles as the other responses, but also has zeros at $S = \pm jK_3 \sqrt{\frac{a}{1-a}}$ which means that the notch frequency can be varied with respect to F_C.

If the Resonance Mode switch is in the "Limit" position, the four responses will be scaled by K_1,, which is made equal to K_2, resulting in a peak response of unity gain, regardless of Q.

RESULTS

Please refer to Figures 4, 5, and 6. What has been achieved is a highly resonant filter with voltage controlled frequency and resonance, that simultaneously provides highpass, bandpass, lowpass, and notch outputs. The filter is capable of providing a wide variety of formant shaping and tonal modulation. The bandpass response is that of a natural acoustic resonator, and is most useful in synthesizing instrumental timbres. In addition, the high degree of stable resonance and frequency tracking accuracy attainable enables the filter to perform precise, narrowband spectrum analysis of audio signals.

The center frequency of the bandpass output is the cutoff frequency of the highpass and lowpass outputs, and is referred to as "F_C". Fc may be set by the coarse and fine frequency knobs over the range of 16Hz to 16KHz. Control signals applied to any F_C input will change the center frequency from the knob setting by 1 octave per volt when the knob above the control input is at maximum. Control signals from the individual inputs are summed with the F_C knob controls, and may be positive, negative, or audio.

With the RESONANCE (Q) knob at minimum and the RESONANCE switch set to "Norm," the bandpass output has a gain of 0.5 at F_C and attenuates 6dB per octave above and below F_C. The lowpass output has unity gain from DG to F_C and attenuates 12dB per octave above F_C. The notch output has flat response everywhere except for a deep (40 dB) notch at a frequency determined by the $\frac{\text{NOTCH FREQ}}{F_C}$ knob. With this knob set to 1, the notch occurs at F_C. Note: the notch output is effective only at low Q.

As the RESONANCE (Q) knob is turned up, a resonant peak occurs at F_C in all four outputs, except in the notch output when the notch frequency is at F_C. The gain at this peak is numerically equal to the "Q", and the 3 dB bandwidth of this peak is equal to F_C/Q. Thus, as Q is varied from ½ to 512, the bandwidth varies from 2 F_C (2 octaves) to $F_C/512$, ($^1/_{32}$ of a semitone). When using high resonance, the audio input controls may have to be turned down to prevent overload. An overload light is provided for this purpose. The Q may be controlled by external signals. The Q control characteristic is exponential; that is, each volt applied to a "Q" input doubles the Q when the input knob is at maximum.

With the RESONANCE switch set to "Lim", the height of the resonant peak is limited to unity gain at F_C, and the response on either side falls off as the Q is increased. This mode is useful when tuning sharply about a strong fundamental or harmonic of the input signal, but will otherwise result in a very low output signal at high resonance. For most applications, this switch should be set to "Norm."

A low level signal such as an electric organ or guitar may be plugged into the front panel EXT INPUT, which is mixed with the lower matrix switch audio inputs.

Upper matrix switch inputs for audio, F_C, and Q are provided. The short arrows are independent, unattenuated inputs, while the long arrows marked 1, 5, and 9 are wired directly to the corresponding lower inputs for the purpose of attenuating upper matrix switch inputs.

Referring to Figure 7, another feature is keyboard percussion, which allows the filter to generate a wide variety of percussive tones from the keyboard. The keyboard gate and trigger outputs should be connected to the GATE and TRIGGER inputs at the upper right corner of the panel, and the keyboard control voltage applied to any one F_C input. With the KEYBOARD PERCUSSION switch on, striking a key produces a sharp percussive attack followed by a tone which varies from a slightly pitched click resembling a castanet clap (at low Q) to a slowly decaying sine tone at high Q. Upon releasing the key, the tone damps at a rate determined by the FINAL Q knob. The bandpass output gives the most natural percussive quality, although the highpass and lowpass outputs may be used. They give a sharper and a duller attack, respectively.

MUSICAL APPLICATIONS:SYNTHESIS

Since the 1047 filter has a linear PITCH vs. control voltage function (1 octave per volt), and precise control of resonance, the device will track a voltage controlled oscillator. Some examples of synthesis applications are:

1). Select any single harmonic up to at least the 30th from an oscillator, so that any note played will have this same harmonic emphasized.
2). Reject any harmonic in a likewise manner.
3). The filter may be controlled from a keyboard and fed from a FIXED oscillator, so that harmonics may be selected and played as a scale (just intonation).
4). The filter may be fed white or pink noise and be "played" on a keyboard, producing "pitched" noise. The degree of "pitched-ness," or "color" may be remotely controlled over a range from no pitch sensation to a slowly but randomly varying sine wave (depending on "Q").
5). "Phasing," or "flanging," may be simulated by listening to the notch output and sweeping the center frequency (F_C).
6). The simultaneous output capability permits the filter to be used as a voltage controlled electronic crossover network.

7). Several filters may be combined in parallel or cascade to yield all sorts of complex timbral modulations and/or impulse responses.

8). By applying negative voltage to the frequency control input, the center frequency may be driven down to at least 1Hz, permitting it to modify transients such as square waves for for envelope shaping applications.

MUSICAL APPLICATIONS : ANALYSIS

Please refer to Figure 8. The 1047 can be used with an oscilloscope and sweep source (simple sawtooth oscillator) to perform real-time spectrum analysis of virtually any kind of input signal. The exponential frequency control characteristic yields a plot that is amplitude vs. the logarithm of frequency, similar to conventional audio graph paper plots. By inserting a logarithmic converting circuit between the filter output and the oscilloscope vertical input, the plot will be directly calibrated in decibels vs. octaves.

MISCELLANEOUS APPLICATIONS:

The range of applications for any voltage controlled active filter is of course large, but in closing I would like to mention a few that are particularly pertinent to the capabilities of the 1047 filter:

1). Analog Computation. The filter is basically a voltage controlled analog oomputer, so it is useful in simulating and compensating feedback control systems.

2). Biological Data Processing. The filter can be used, for example, to isolate alpha waves from raw EEG outputs. For that matter, it can spectroanalyze the whole brain wave output in real time.

3). Seismic and vibration measurement.

4). Speech Analysis and Synthesis. Formants may be accurately controlled in a speech simulator, for example.

5), Measurement. The filter can be used to measure frequency responses of circuits, loudspeakers, rooms, and anything that can be converted into an electrical signal.

6). Distortion analysis. The filter can either measure the amplitude of each distortion component (harmonic or sideband, etc.), or be used to notch out the fundamental sine wave and pass all the distortion at once.

7). Art. Figure 9 is a photograph of an oscilloscope which simply crossplotted the highpass and bandpass outputs of the filter, which was fed a mixture of square waves. The spirals are the polar equation of a damped sinusoid. The picture is merely an example of the infinite variety of "electronic art" that can be generated with the filter, an oscilloscope, and some experimentation.

8). Education. Music educators, physics instructors, psychoacoustic researchers; in short, anyone who can use an accurate, stable voltage controlled resonator will find this filter an extremely useful tool to both explore and advance the state of their art.

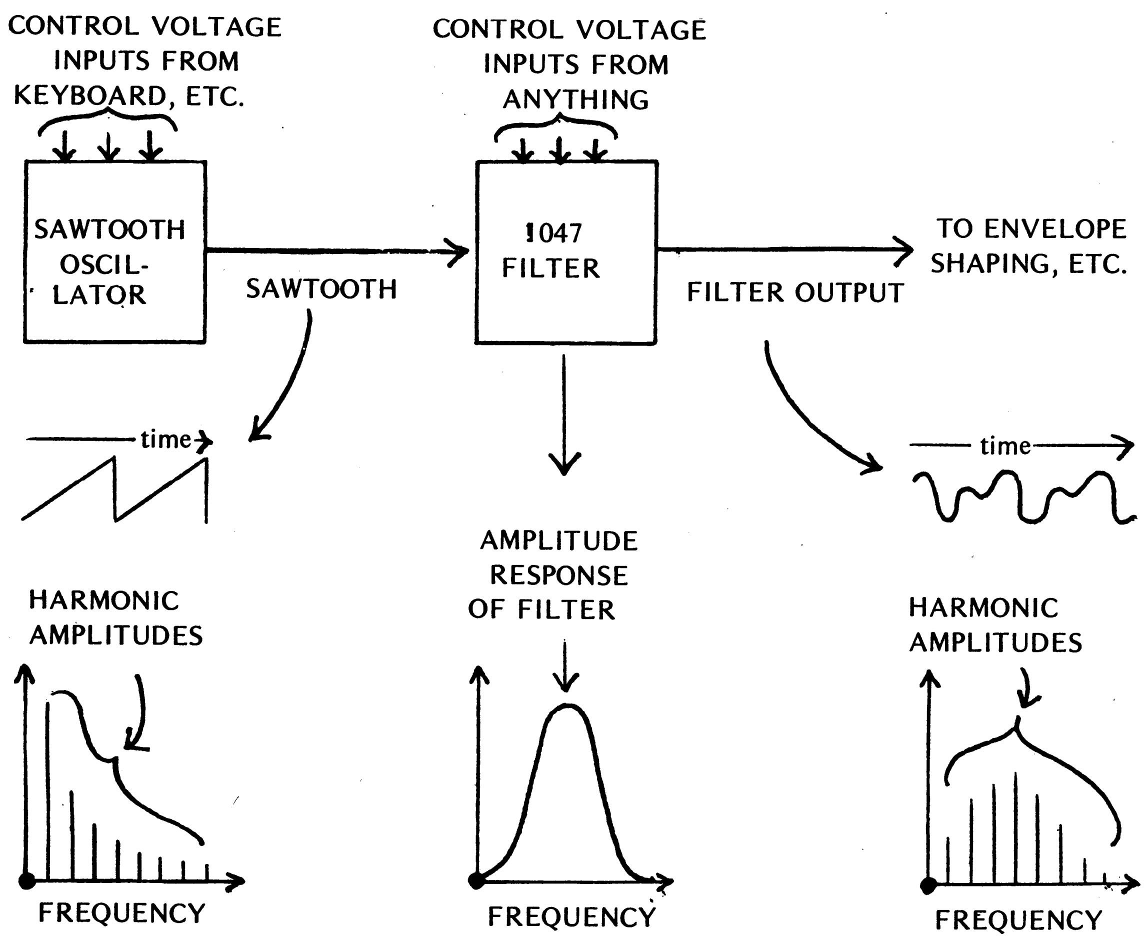
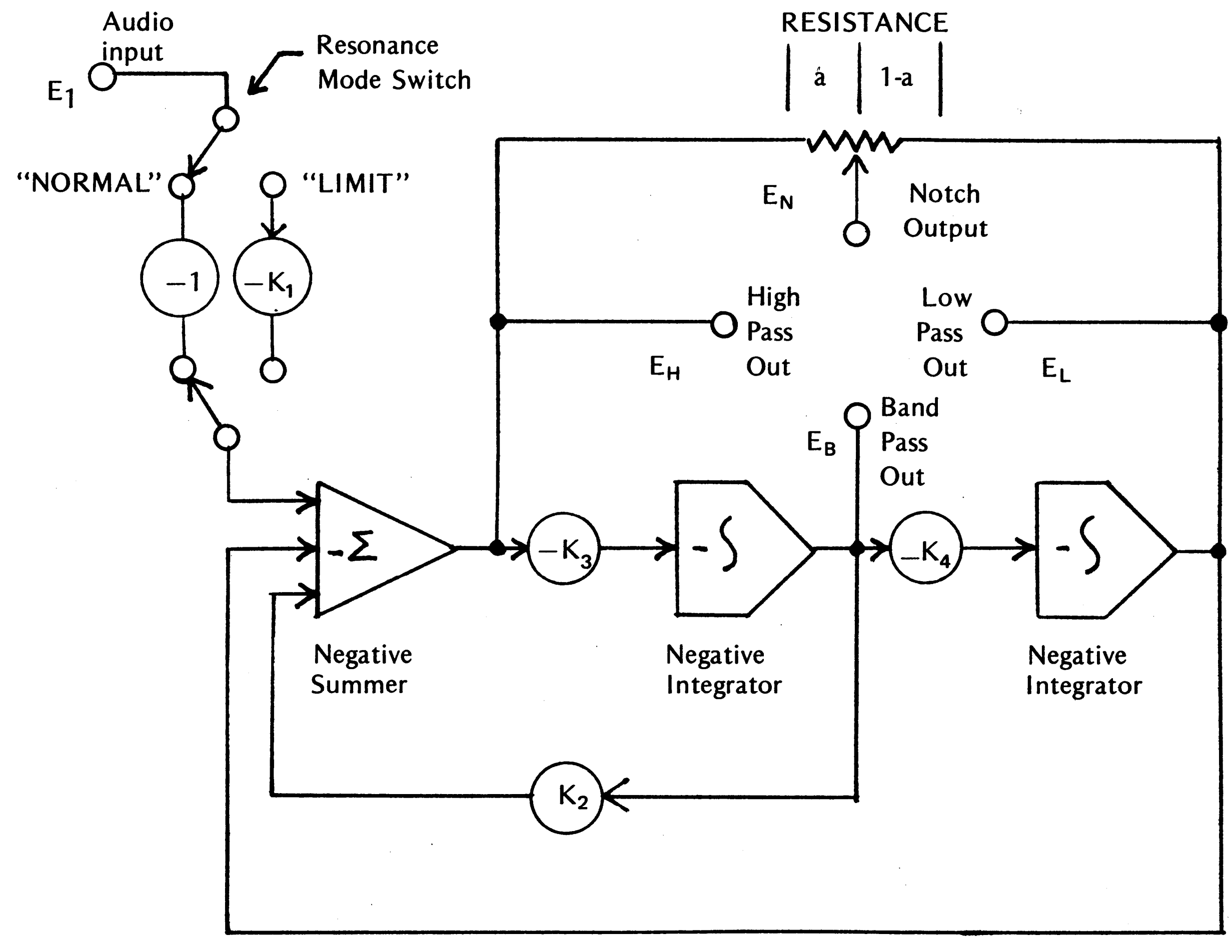


FIGURE 1

Typical filter application in sound synthesis



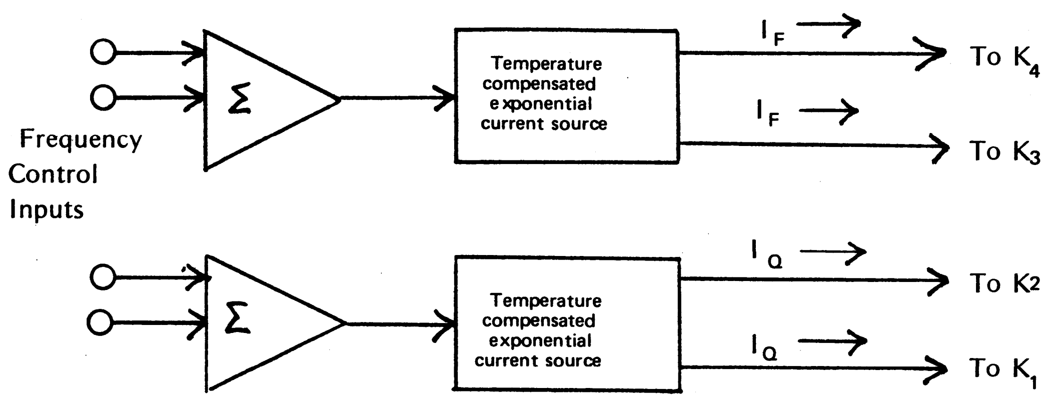


FIGURE 2
Filter Block Diagram

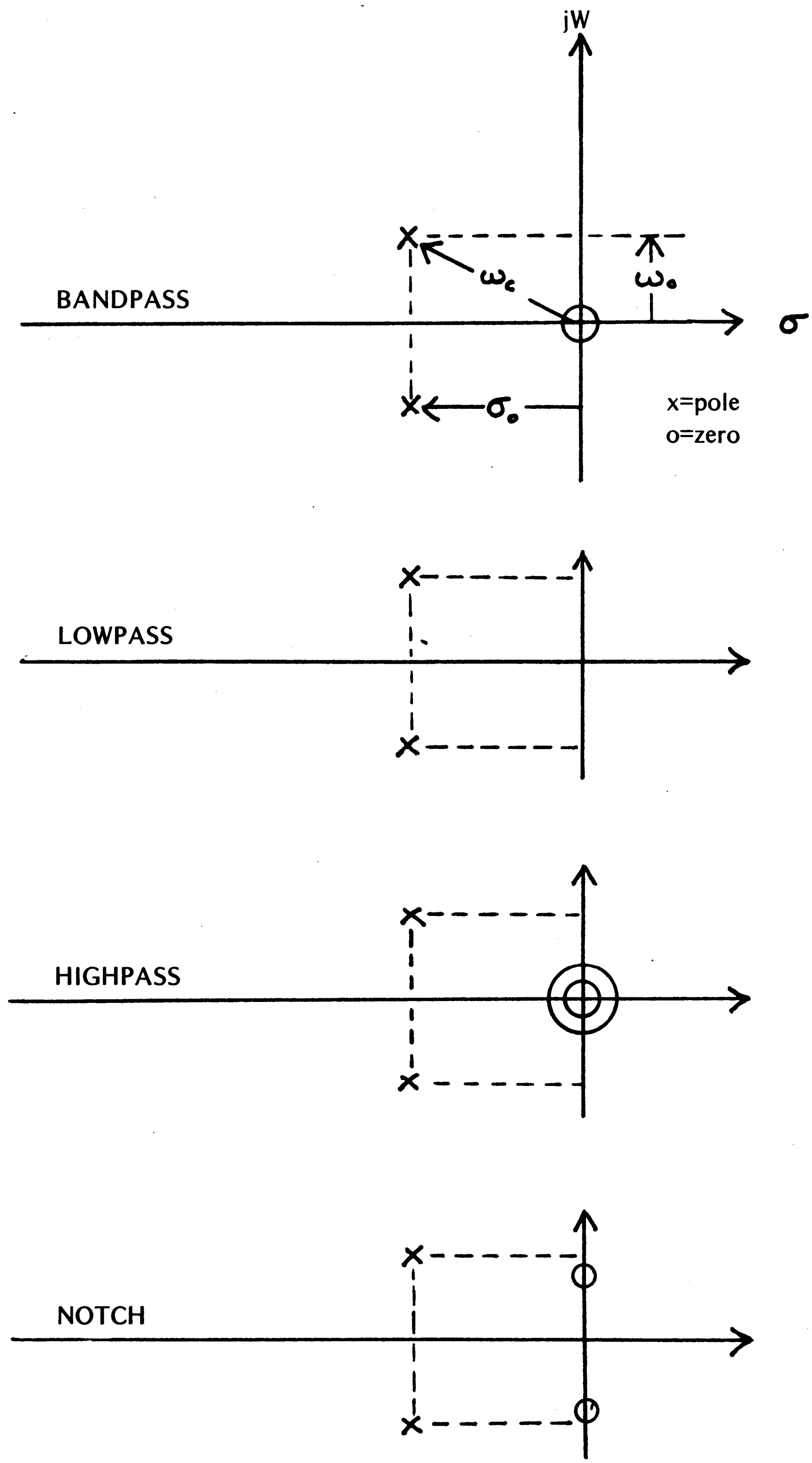


FIGURE 3

Pole-zero locations for mathematical analysis

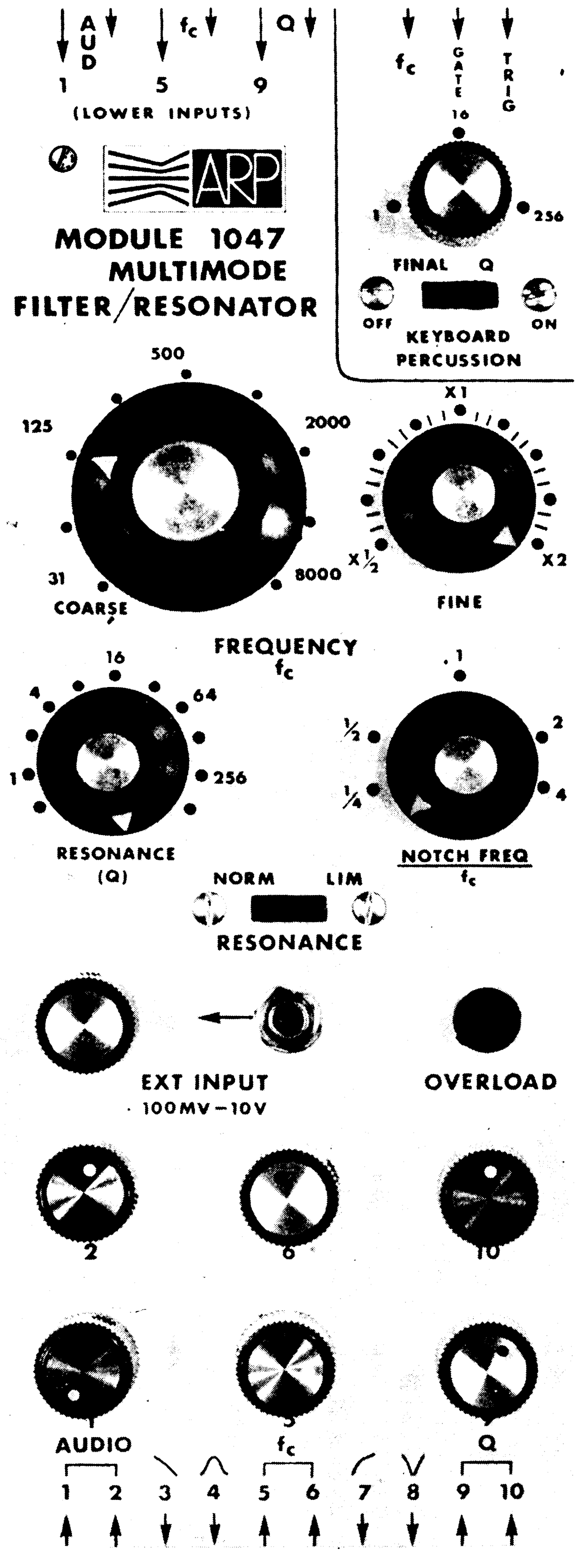
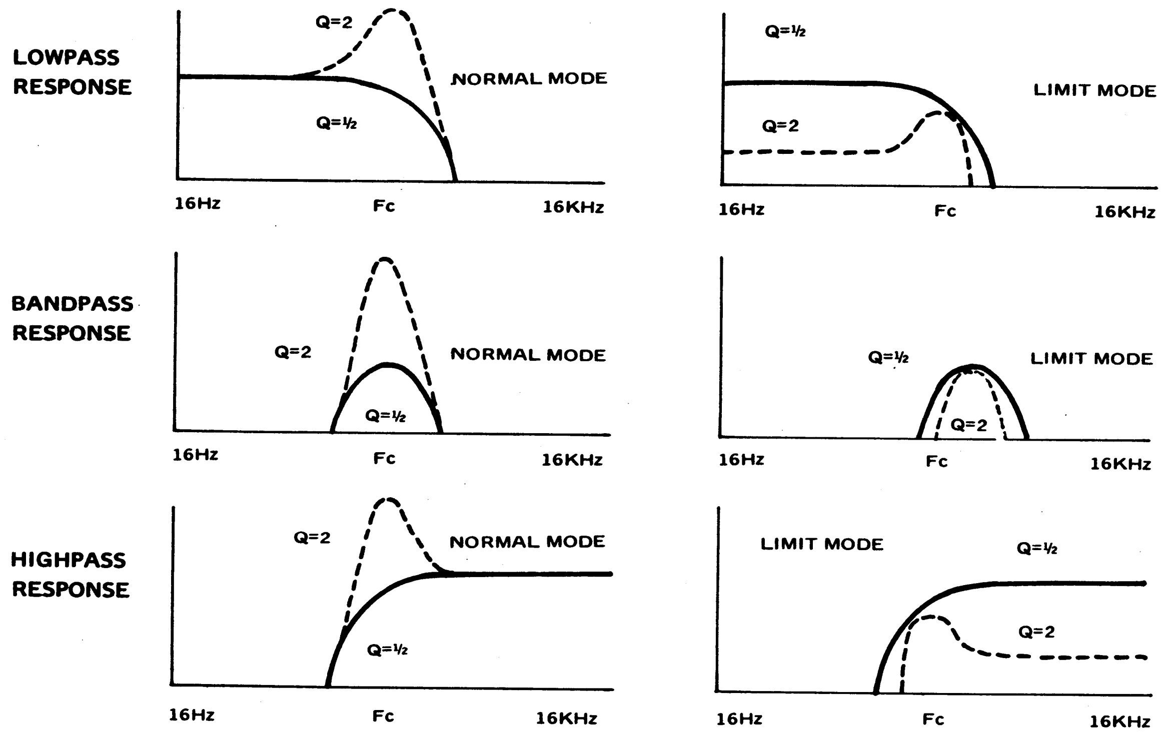


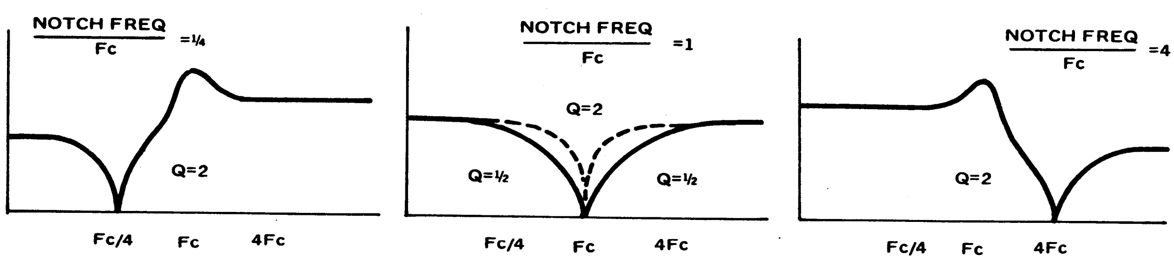
FIGURE 4 Filter Front Panel (actual size)

FIGURE 5

Frequency and Impulse Responses



NOTCH RESPONSES



PERCUSSIVE OUTPUT WAVEFORMS

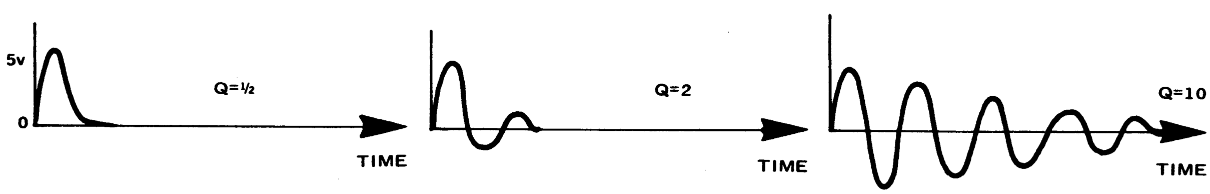


FIGURE 6

Electrical Specifications

ELECTRICAL SPECIFICATIONS

CENTER FREQUENCY (Fc):	16 Hz to 16 KHz, voltage controlled.
BANDPASS RESPONSE:	Single pole resonator, 6 db per octave.
RESONANCE (Q):	½ to 512 (0 to 54 db peaking at Fc), voltage controlled.
BANDWIDTH (3 db):	2 octaves to 1/32 semitone.
HIGHPASS AND LOWPASS RESPONSE:	12 db per octave cutoff at Fc, with same resonant peak at Fc as in Bandpass Response.
NOTCH RESPONSE:	Resonant peak at Fc as in Bandpass Response, plus notch at frequency determined by $\frac{\text{NOTCH FREQ}}{\text{Fc}}$ control. With this control at 1, response is flat except for notch at Fc.
NOTCH DEPTH:	$>$ 40 db.
NOTCH WIDTH (3 db):	2 octaves to 1 semitone.
CONTROL INPUT RANGE:	± 10v maximum.
INPUT IMPEDANCE:	50 K ohm minimum.
Fc CONTROL CHARACTERISTIC:	1 octave per volt; at OV, Fc is equal to the frequency knob setting.
Q CONTROL CHARACTERISTIC:	1 volt doubles Q; at OV, Q is equal to resonance (Q) knob setting.
AUDIO INPUT RANGE:	± 10 v maximum.
AUDIO INPUT IMPEDANCE:	50 Kohm minimum.
AUDIO OUTPUT IMPEDANCE:	1 Kohm.
OVERLOAD LIGHT:	Indicates excessive input level.
KEYBOARD PERCUSSION:	Applies pulse from keyboard to filter, which rings according to Q. Upon release of key, tone decays according to Final Q knob setting.
POWER REQUIREMENTS:	± 15 volts @ 60 mA, regulated to ±0.1%. +12 to +15 volts @ 30 mA, lamp supply.

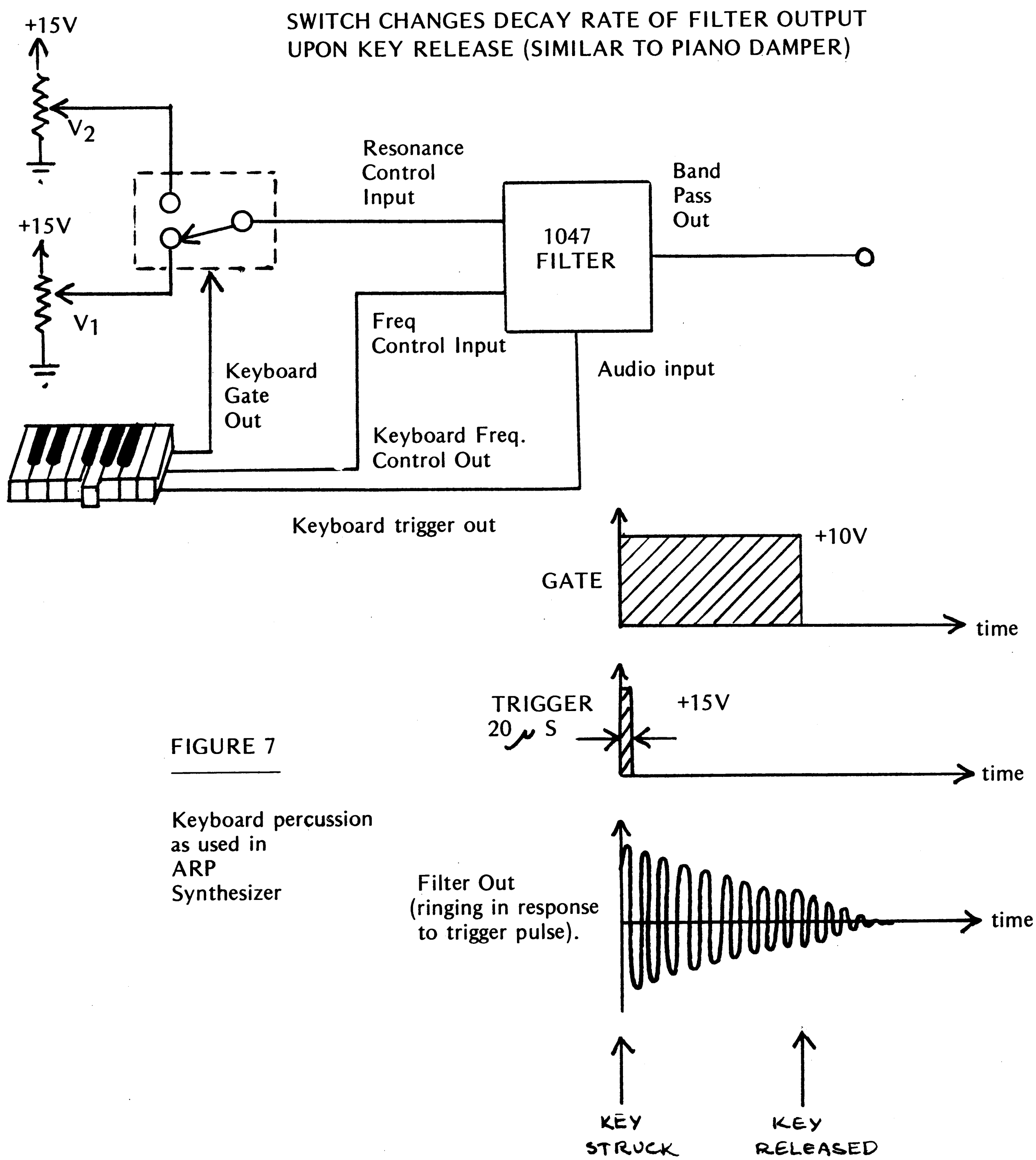


FIGURE 7

Keyboard percussion
as used in
ARP
Synthesizer

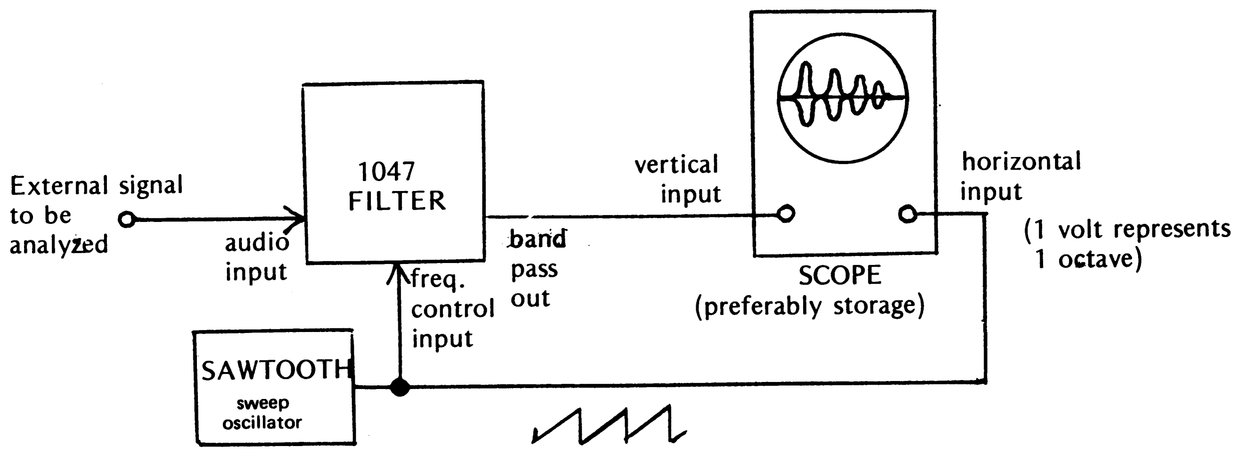


FIGURE 8

Typical filter application
in sound synthesis.
(spectrum analyzer)

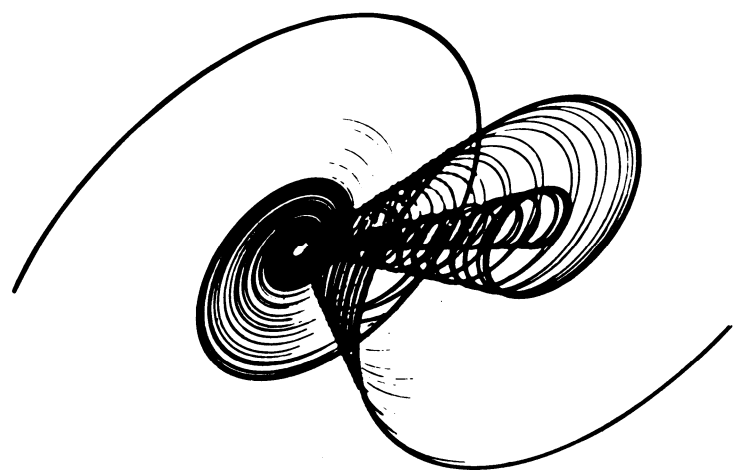
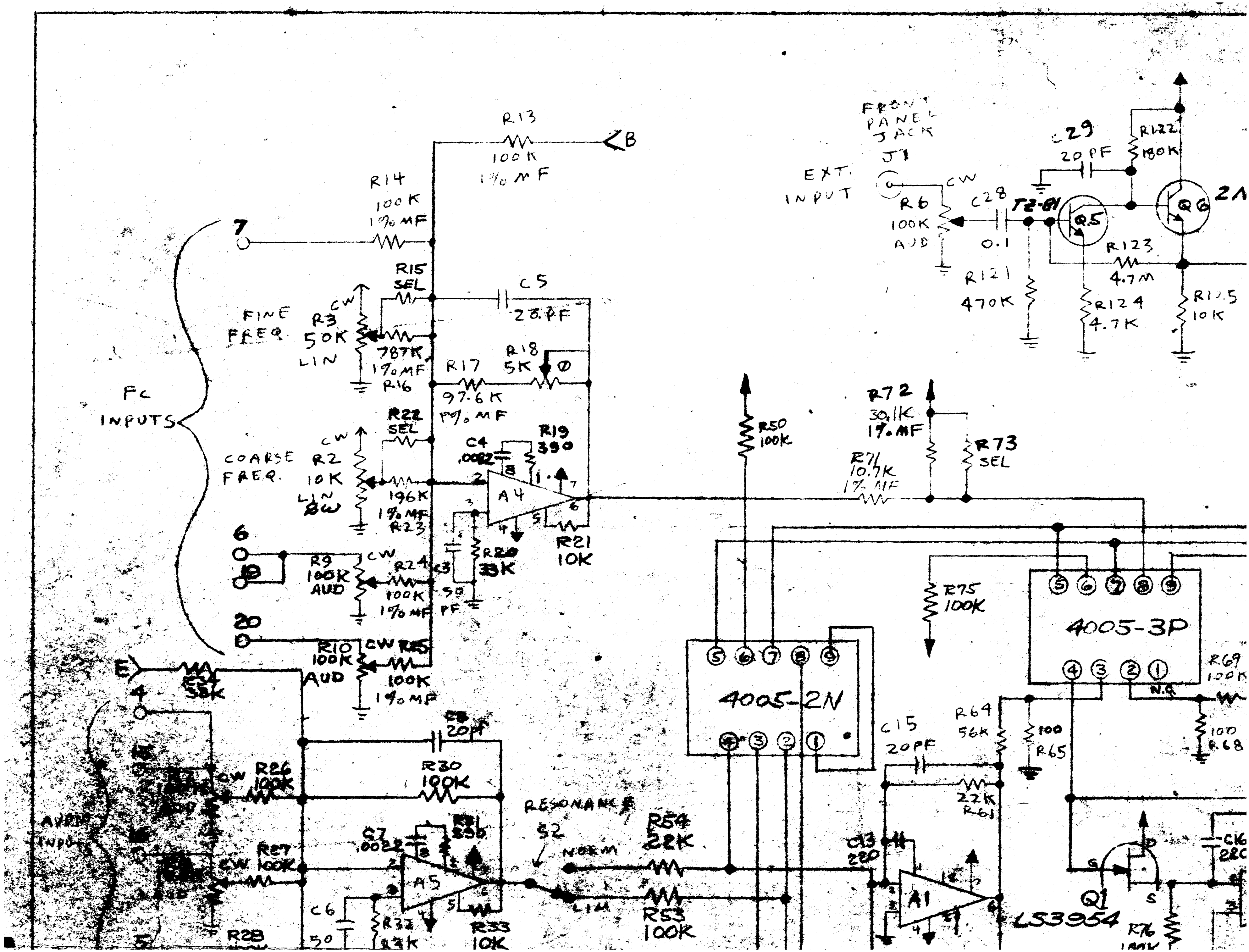


FIGURE 9

Filter-oscilloscope art

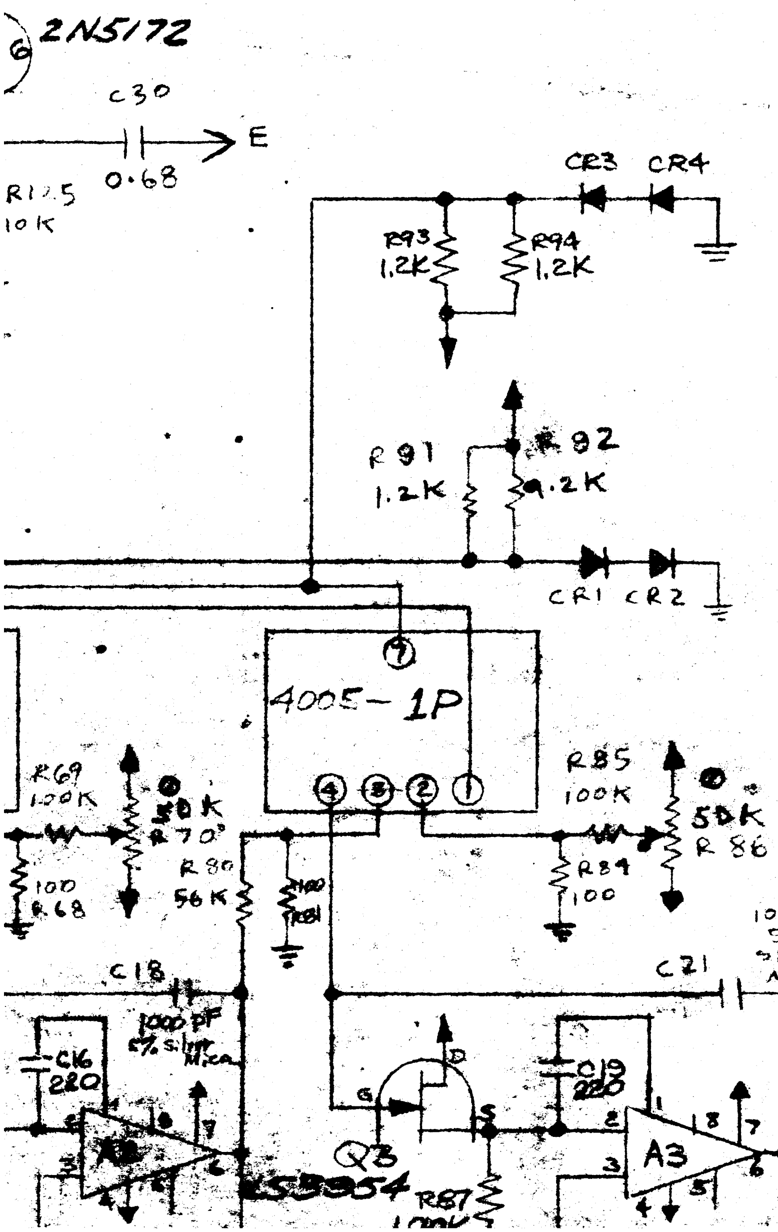


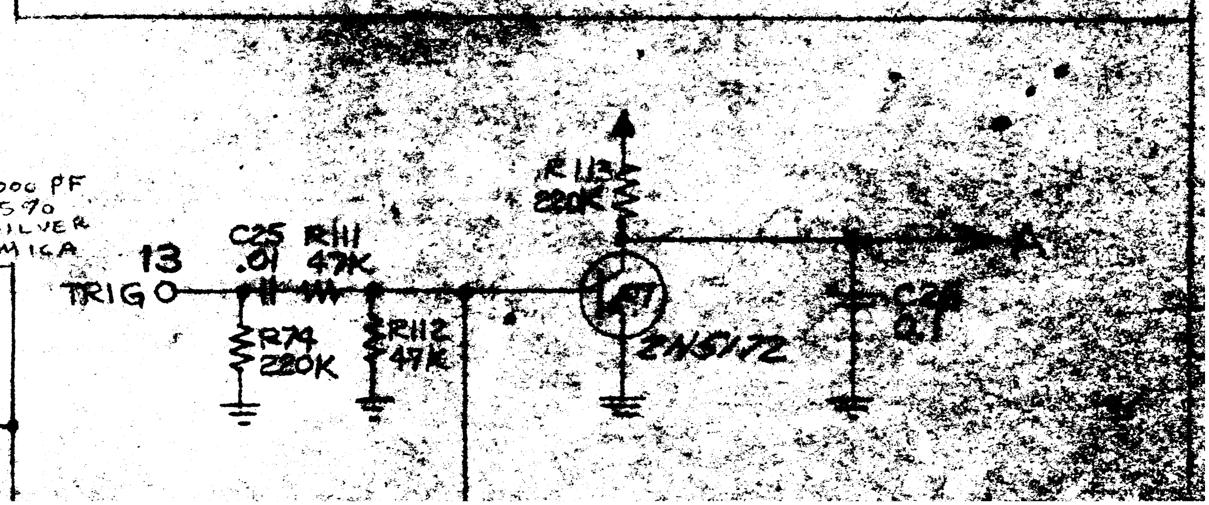
R13
100K
1% MF
B
R14
100K
1% MF
7
Fc
INPUTS
FINE
FREQ.
R3
50K
LIN
CW
R15
SEL
787K
1% MF
R16
C5
20 PF
R17
97.6K
1% MF
R18
5K
COARSE
FREQ.
R2
10K
LIN
R22
SEL
196K
1% MF
R23
C4
.0022
R19
390
A4
R20
33K
R21
10K
6
R9
100K
AUD
R24
100K
1% MF
50
PF
20
R10
100K
AUD
R25
100K
1% MF
E
R34
33K
4
R26
100K
R27
100K
R28
C8
20PF
R30
100K
C7
.0022
R31
390
A5
C6
50
R32
33K
R33
10K
RESONANCE
S2
NORM
LIN
R54
22K
R53
100K
R50
100K
4005-2N
R72
30.1K
1% MF
R71
10.7K
1% MF
R73
SEL
R75
100K
4005-3P
N.C.
R69
100K
R68
100
R64
56K
R65
100
C15
20PF
22K
R61
C13
220
A1
Q1
LS3954
R76
100K
C16
220
FRONT
PANEL
JACK
J1
EXT.
INPUT
R6
100K
AUD
C28
0.1
R121
470K
C29
20 PF
T2-01
Q5
R122
180K
Q6
R123
4.7M
R124
4.7K
R125
10K

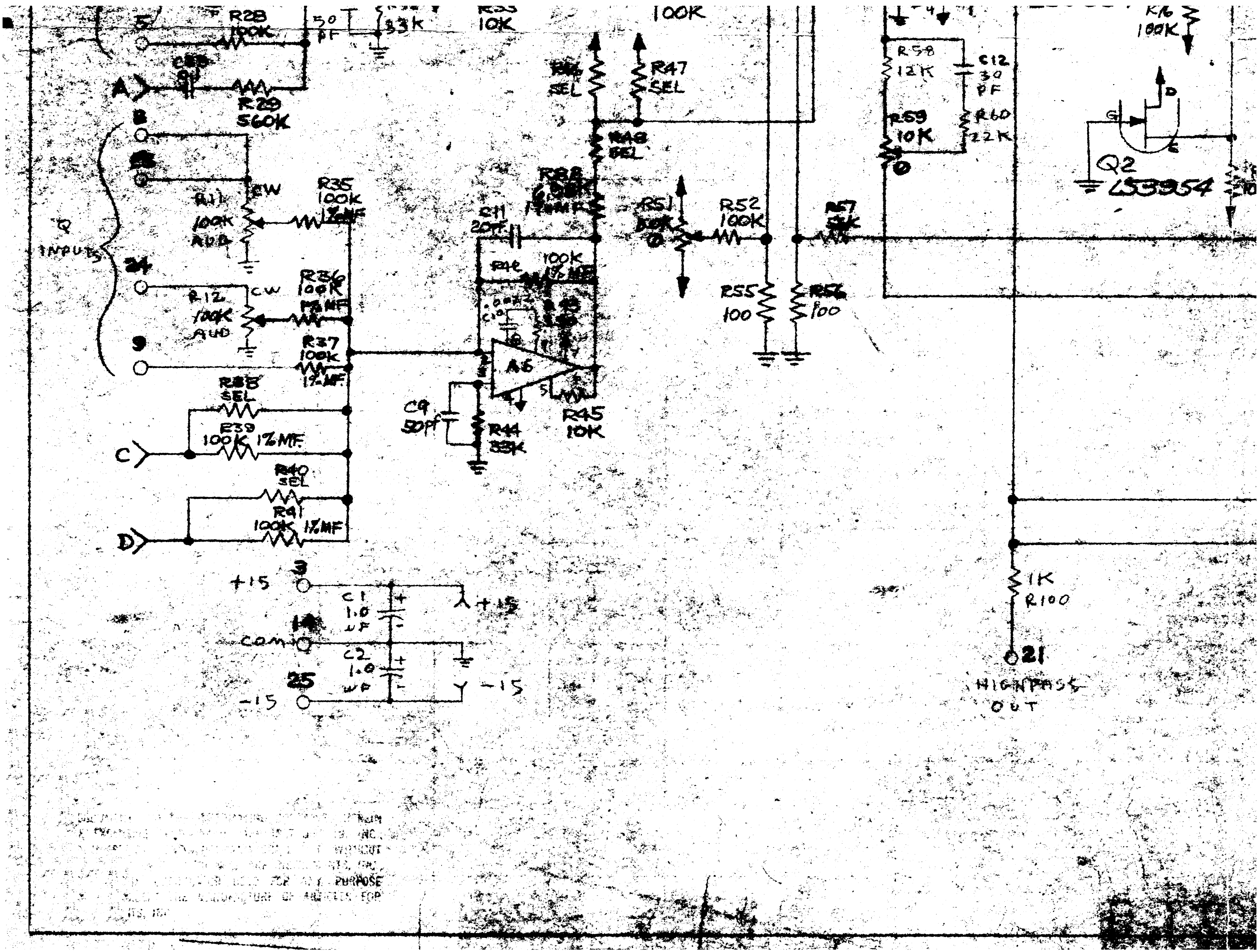
FOR ASSEM. SEE 72079
FOR PARTS LIST ~~SEE~~ PL7207901

NOTES:
UNLESS OTHERWISE SPECIFIED:
DIODES ARE IN914
RESISTORS ARE 1/4 WATT ±10%
S1 = DPDT SLIDE SWITCH
S2 = SPDT SLIDE SWITCH
PL1 = 12V LAMP

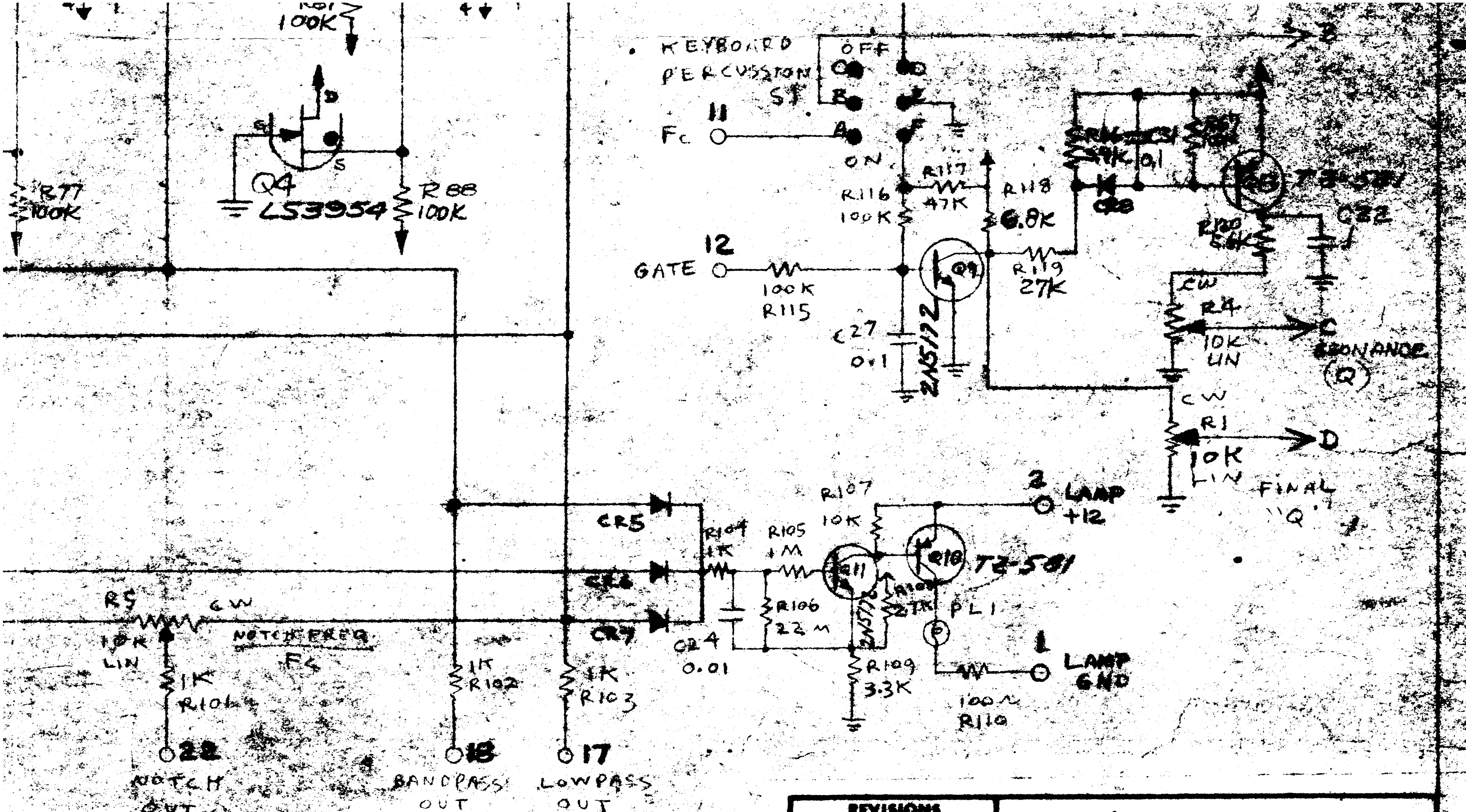
Q1 & Q2, Q3 & Q4 — LEDEL LS3954 MATCHED PAIR N-CHANNEL FET
Q5 — TZ-81 OR 2N5249
Q6,7,9,11 — 2N5172
Q8,10 — TZ-581 OR 2N5367
A1 THRU A3 — LM301A OP AMP
A4 THRU A6 — 1339 OP AMP
HIGHEST REF. DESIGNATION:
A6, C33, CR8, R125, Q11







R28 100K
R29 560K
50 PF
33K
R33 10K
100K
R47 SEL
R46 SEL
R48 SEL
R35 100K 1%MF
R36 100K 1%MF
R37 100K 1%MF
R38 SEL
R39 100K 1%MF
R40 SEL
R41 100K 1%MF
R11 100K AUD
R12 100K AUD
CW
INPUTS
C11 20PF
R45 10K
R44 33K
C9 50pf
A6
R51
R52 100K
R55 100
R56 100
R57
R58 12K
R59 10K
C12 30 PF
R60 22K
R16 100K
Q2
G
D
S
+15
COM
-15
C1 1.0 uF
C2 1.0 uF
1K
R100
21
HIGHPASS OUT



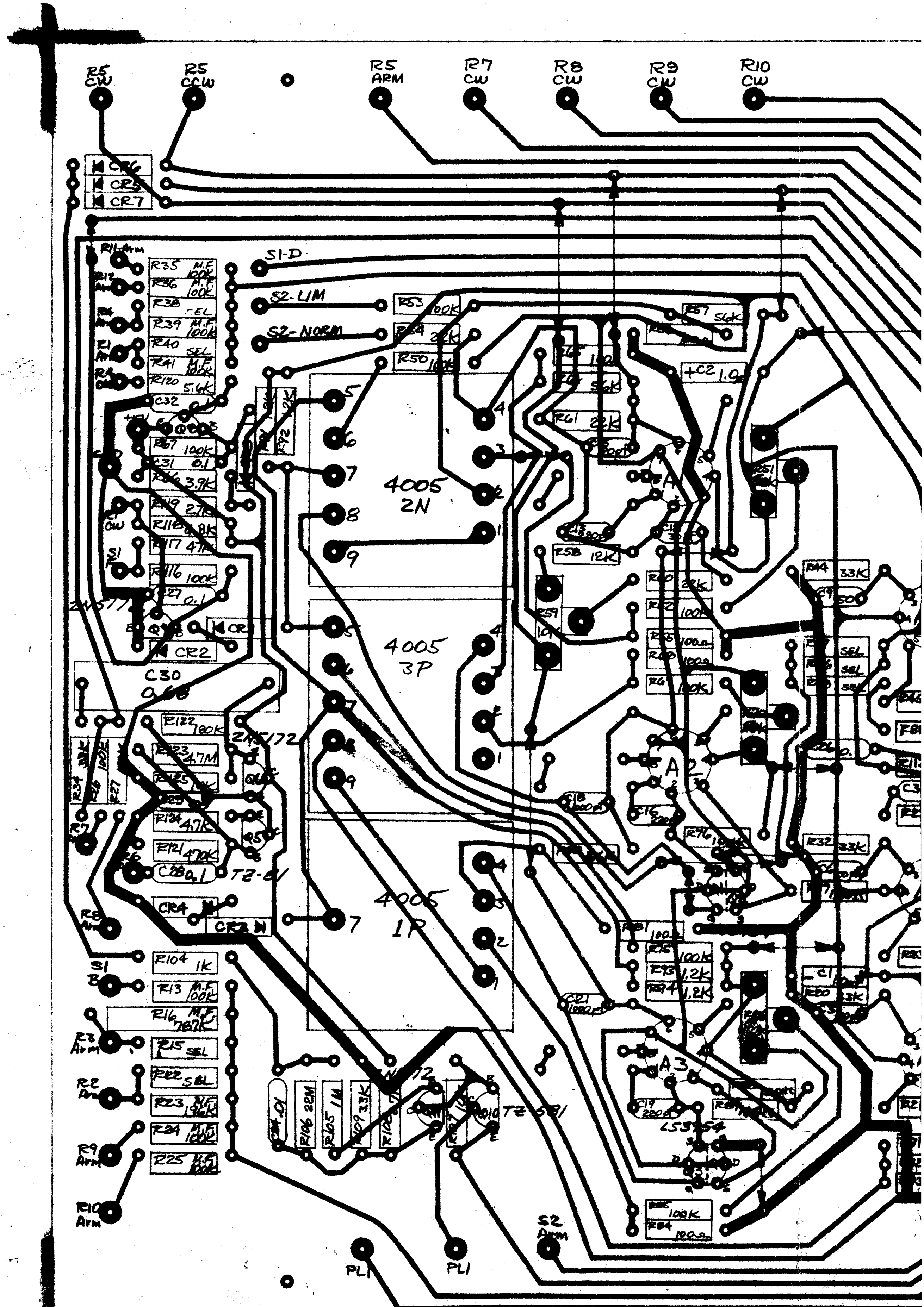
Changed R 76,77,87,88

REVISIONS		
NO.	DATE	BY
A	6-4-70	RDH
B	8-7-70	DPC
C	10-15-70	CW
D	ECO-0094 CBS	PB
E	ECO 0489 11/1/74	
F		

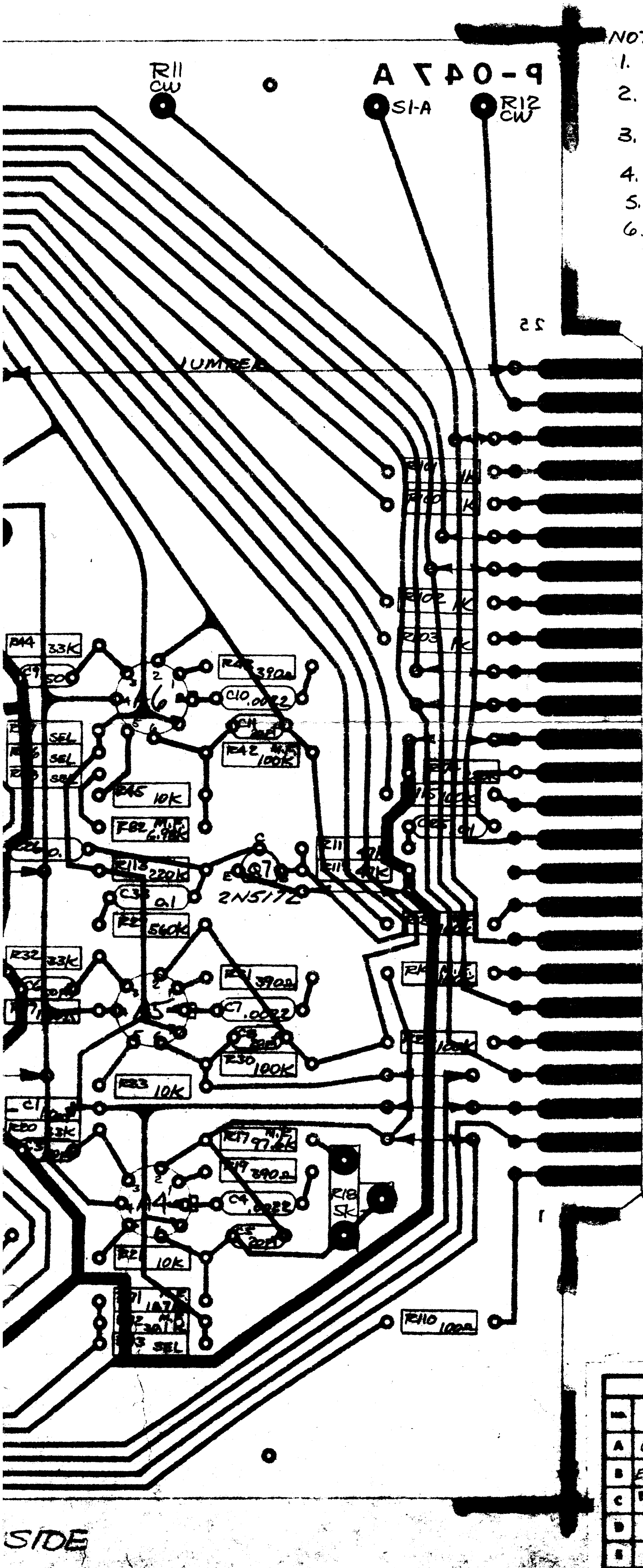
tonus, inc. 45 KENNETH STREET NEWTON HIGHLANDS MASSACHUSETTS 02161

SCHEMATIC
MULTIMODE FILTER/RESONATOR
MODULE 1047

DRAWN BY	SCALE	MATERIAL
D. COLIN		
CHK'D D Colin 6-8-70	DATE 4.17.70	
DRAWING NO. 77067	REV E	



COMPONENT SIDE



NOTES:
1. INSTALL 24 JUMPER WIRES AS SHOWN.
2. INSTALL TANTALUM CAP. C1 & C2 AND ALL DIODES WITH POLARITY AS SHOWN.
3. INSTALL A1 THRU A6 WITH TABS IN POSITION AS SHOWN.
4. ALL DIODES ARE IN914.
5. FOR SCHEMATIC SEE C-1047-003
6. FOR PARTS LIST SEE APL-1047-007

NOV 25 1974

REVISIONS		
NO.	DATE	BY
A	6.5.70	R.D.H.
B	ECO-0094	4/4/72
C	ECO 0489 11/1/74	11/1/74
D		
E		
F		

tonus, Inc.

P.C. ASSEMBLY - MODULE 1047
MULTIMODE FILTER/RESONATOR

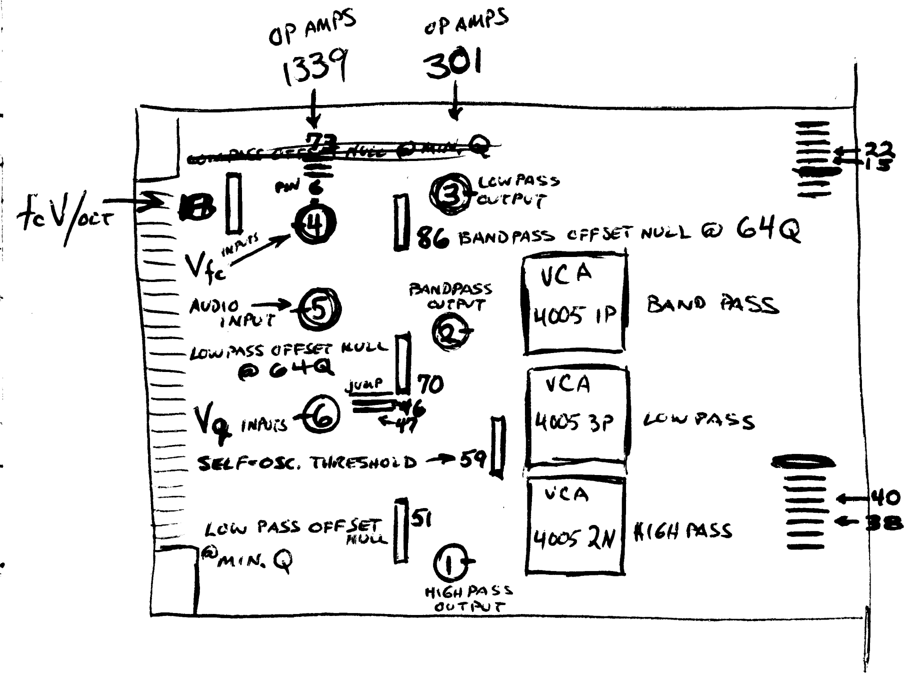
R. HALBACH | SCALE 2/1
6-3-70 | 6.5.70

CLARK FERGUSON

1047 MULTI-MODE FILTER/RESONATOR

PHYSICAL CHECK - +GND - CHECK ALL AUDIO ↶

#	FUNCTION	SET-UP	OUT	READ	TRIM
1.	PERC. RES. LIN.	PERC. OFF / FINAL Q ↶ / RES. [illegible] / SW NORM /	A6/6	-10.00	R38
2.	FINAL Q LIN.	PERC ON / FINAL Q ↷ / RES. ↶ / "	A6/6	-10.05	R40
3.	DIAL LIN.	PERC OFF / R18 CENTER / DIFF 2000/125 HZ	A4/6	DIFF 4.85	R28
4.	BAND PASS OFFSET 64 Q	fc 500 / fine x1 / RES. 64 /	BAND PASS	NULL 0v	R86
5.	LOW PASS OFFSET 64 Q	" " "	LOW PASS	NULL 0v	R70
6.	LOW PASS OFFSET <Q	[illegible] / " / RES. ↶ /	LOW PASS	NULL 0v	R51
7.	fc CAL.	AUDIO INPUT .2 ∿ 500 HZ / RES. 4 / fine x1 / fc TUNE MAX (TRIM for 500 SETTING)	BAND PASS	PEAK AT 500HZ	R73
8.	V OVERLOAD	RES. ↷ LAMP SHOULD LIGHT		21v	
9.	OVERSHOOT	500HZ ⊓ 1v AUDIO IN / RES. ↶ / fc 2KHZ / fine x1 /	LOW PASS	⊓	R46 or R47
10.	SELF OSC. THRESHOLD	NO INPUT / RES. ↷ / fc ↷ / CHANGE C12 IF NECESSARY 30-50	LOW PASS	OSC.	R59
11.	A.M. ✓	10VOLT 1HZ ⋀ Q INPUT / RES ↶ / (✓ALL Q INPUTS)	BAND PASS	AM	CHECK
12.	PERC V/OCT EXT. INPUT ✓	2KC EXT. INPUT / RES. ↶ / PERC ON / fine x1 / fc 2KC / FINAL Q 1	HIGH PASS	MAX. SIG.	CHECK
13.	PERC V/OCT ✓	+4.00v PERC. fc INPUT / " " " / fc 125HZ / "	HIGH PASS	MAX. SIG.	CHECK
14.	fc V/OCT ✓	REPEAT #12 + 13 WITH REMAINING fc INPUTS @ +4v	HIGH PASS	MAX. SIG.	CHECK
15.	LIM SW. ✓	AUDIO NO INPUT / RES. ↷ / fc ↷ / NOTCH f ↷ / SW LIM. /	LOW PASS	NO OSC.	CHECK
16.	PERC. TRIG. ✓	1HZ ⊓ 10v INTO TRIG / PERC ON / FINAL Q ↷ / fc ↷ / (PERC. OFF - NO SIG.)	BAND PASS	[waveform]	CHECK
17.	PERC. GATE ✓	10HZ ⊓ INTO GATE / PERC ON / (FINAL Q SHOULD CONTROL AMPLITUDE)	R40	⊓⊔	CHECK
18.	" ✓	" " (RES. " " ")	R38	⊓⊔	CHECK
19.	FINAL Q DECAY ✓	fc 500 / fine 1 / NOTCH 1 / RES. ↶ / 4HZ ⊓ 25% DUTY INTO GATE + TRIG / NOTE: CONTROL of FINAL Q + RES.	BAND PASS	[waveform]	CHECK



1047 TEST PROCEDURE
JAN-5-73 Updated 11/75

1. Test Equipment Required:
    1.1. Oscilliscope
    1.2. Digital Voltmeter
    1.3. 2500 Wing Cabinet
    1.4. Two Function generators

2. Applicable Documents
    2.1. C-1047-003 Rev. E (Schematic)
    2.2. C-1047-006 Rev. C (P.C. Layout)

3. Preliminary Set Up:
    3.1. Thoroughly inspect the module per the sample
    3.2. Measure the resistance between all five power supply inputs. It must be greater than 400Ω
    3.3. Check alignment of the knobs
    3.4. Turn all of the knobs counterclockwise and both switches to the left
    3.5. Adjust R59 fully clockwise(viewed from front)
    3.6. Plug the module into the wing cabinet using an extender cord
    3.7. Apply power

4. Q Control Voltage Adjustments:
    4.1. Resonance Adjustment
        4.1.1. Connect the DVM to A6 pin 6
        4.1.2. Turn the Resonance knob fully clockwise
        4.1.3. Trim R38 for -10.00V ± .05VDC on A6 pin 6
    4.2. Final Q Adjustment
        4.2.1. Switch the kybd. Percussion on
        4.2.2. Turn the Resonance knob fully counterclockwise
        4.2.3. Turn the Final Q knob fully clockwise
        4.2.4. Trim R40 for -10.00V ± .05VDC on A6 pin 6

5. Freq. Control Voltage Adjustments:
    5.1. Coarse Freq. Range Adjustment
        5.1.1. Switch off the kybd. Percussion
        5.1.2. Connect the DVM to A4 pin 6
        5.1.3. Set trimpot R18 to the center of its rotation
        5.1.4. Turn the fine freq. knob to 1
        5.1.5. Measure the voltages at A4 pin 6 with the coarse freq. knob at 2000HZ and at 125HZ
        5.1.6. Trim R22 so that the difference between these two voltage readings is 4.00V ± .05VDC
    5.2. Fine freq. range adjustment
        5.2.1. Set the course frequency knob to 500
        5.2.2. Measure the voltages at A4 pin 6 with the fine freq. knob at 1/2 and at 2
        5.2.3. Trim R15 so that the difference between these two voltage measurements is 2.00V ± .05VDC

6. VCA offset adjustments
    6.1. Bandpass Offset Adjustment
        6.1.1. Connect the DVM to the bandpass output
        6.1.2. Set the Coarse Frq. knob for 500
        6.1.3. Set the Fine Freq. knob for 1
        6.1.4. Adjust the Resonance knob to 64

6.1.5. Adjust the trimpot R86 for 0V ±.05VDC on the bandpass output

6.2 Lowpass offset adjustments

6.2.1. Connect the DVM to the lowpass output

6.2.2. Adjust R70 for 0V ±0.05VDC at the lowpass output

6.2.3. Adjust the Resonance knob fully counterclockwise

6.2.4. Adjust R51 for 0V ± 0.05VDC at the lowpass output

7. Coarse Freq. Knob Alignment

7.1 Adjust the Fine Freq. knob to 1

7.2 Adjust the Resonance knob to 4

7.3 Adjust the Notch Freq. knob to 1

7.4 Connect a 500 HZ sine wave at 0.2V P-P to the audio input located at lower 1

7.5 Adjust the audio input knob fully clockwise

7.6 Connect the scope to the bandpass output

7.7 Tune the Coarse Freq. Knob for a peak at the bandpass output

7.8 Trim R73 so that the signal peaks when the coarse freq. knob is at 500

8. Overload lamp test

8.1 Increase the resonance knob until the overload lamp lights(it may be necessary to increase the audio signal from .2V P-P)

8.2 The lamp should light at 21V±1V P-P

9. Notch Adjustment Test

9.1 Connect the scope to the notch output

9.2 With the module set up as in step 8.1 but not overloaded, tune the notch freq. knob for a null

9.3 The knob should be at approximately 1

10. Q control inputs test

10.1 Adjust the resonance knob fully counterclockwise

10.2 Connect the scope to the bandpass output

10.3 Connect a 1HZ sawtooth at 10V P-P to the Q control input located at upper 6[redacted] (500 Hz SINE WAVE STILL CONNECTED TO AUDIO INPUT)

[redacted]

10.4 The amplitude of the signal on the bandpass output should now be controlled by the 1HZ sawtooth

10.5 Repeat steps 10.1 thru 10.5 for each of the other three Q control inputs and check that the Q input knobs control the signals

11. Resonant Freq. Adjustment

11.1 Adjust the coarse freq. knob to 2000

11.2 Adjust the fine freq. knob to 1

11.3 Adjust the resonance knob fully counterclockwise

11.4 Adjust the notch freq. knob to 1

11.5 Adjust the final Q knob fully counterclockwise

11.6 Switch the kybd. percussion off

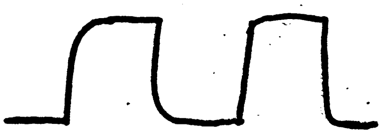
11.7 Connect a 500 HZ square wave at 1V P-P to an audio input

11.8 Adjust the audio input knob fully clockwise

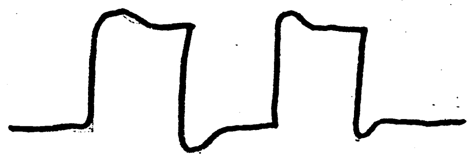
11.9 Connect the scope to the lowpass output

11.10 The output should have no overshoot (Fig. 11A) but should start to show overshoot when the resonance knob is turned clockwise (Fig.11B)

11.11 Trim R46 to meet these specifications
or R48



11A



11B

12. Filter control voltage inputs test:
    - 12.1 Connect a 2000HZ sine wave at 1V P-P to the external input (on front panel) + ADJUST EXT. INP. KNOB TO MIDRANGE
    - 12.2 Adjust the coarse freq. knob fully CCW
    - 12.3 Adjust the fine freq. knob fully CCW
    - 12.4 Adjust the Resonance knob fully CCW
    - 12.5 Connect a 1HZ sawtooth at 10V P-P to the Fc input located at upper 4
    - 12.6 Connect the scope to the lowpass output
    - 12.7 The signal on the lowpass output should be amplitude controlled by the 1HZ sawtooth
    - 12.8 Repeat steps 12.1 thru 12.7 for each of the other three fc inputs and check that the fc input knobs control the signals
    - 12.9 Switch the kybd. perc. to on
    - 12.10 Repeat steps 12.1 thru 12.8 for the kybd. perc. fc input

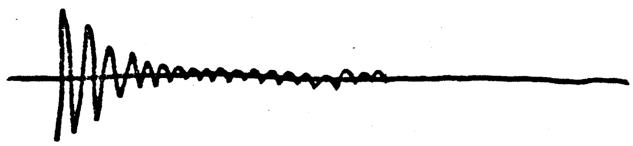
13. Audio inputs test:
    - 13.1 Connect a 10V P-P 500 HZ sine wave to the audio input located at upper 2
    - 13.2 Adjust the coarse freq. knob fully CW
    - 13.3 Connect the scope to the lowpass output [redacted]
    - 13.4 CONFIRM PRESENCE OF OUTPUT SIGNAL
    - 13.5 Repeat steps 13.1 thru 13.4 for the other three audio inputs and check that their amplitude is controlled by their respective input knob

14. Resonance limiting adjustment
    - 14.1 Turn all of the input knobs CCW
    - 14.2 Adjust the coarse freq. knob fully CW + SWITCH KBD. PERC. OFF
    - 14.3 Adjust the fine freq. knob fully CW
    - 14.4 Adjust the resonance knob fully CW
    - 14.5 Adjust the notch freq. knob to 1
    - 14.6 Connect the scope to the lowpass output
    - 14.7 Slowly turn trimpot R59 CCW (viewed from front) until the lowpass output breaks into oscillation
    - 14.8 If the lowpass output oscillates while R59 is fully CW, increase the value of C12 until it stops oscillating then repeat step 14.7
    - 14.9 Switch resonance to LIM
    - 14.10 The oscillations should disappear
    - 14.11 SWITCH RESONANCE TO NORM

15. Keyboard Percussion test:

15.1 Kybd. perc. trig input test

15.1.1. Adjust the coarse freq. knob MIDRANGE
15.1.2. Adjust the resonance knob fully CW
15.1.3. Switch the kybd. percussion to ON
15.1.4. Adjust the final Q knob fully CW
15.1.5. Connect a 1HZ square wave at 10V P-P to the kybd. perc. trig input located at upper 10
15.1.6. Connect the scope to the bandpass output
15.1.7. The signal shown in fig. 15.1A should be on the bandpass output
15.1.8. Switch off the kybd. percussion
15.1.9. The signal at the bandpass output should disappear



15.2 Kybd. Perc. Gate input test:

15.2.1. Adjust the Resonance knob fully CCW + TURN ON KBD. PERC. SWITCH
15.2.1. Connect a 10V P-P 10HZ square wave to the gate input located at upper 9
15.2.2. Connect the scope to A6 pin 6
15.2.3. Verify the 10HZ square wave is on A6 pin 6 and that it is controlled by the final Q knob

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TITLE P.C. ASSY - MULTI MODE FILTER/RESONATOR MODULE 1047 VERSION 1

DWN BY R.D.H. 5-18-72

Rev	By	Date
A	DPC	[illegible]
B	ECO 0074	2/4/72
C	ECO 0238	2-8-73

DWG NO. APL1047-007 B

SHEET 1 OF 6

ITEM	REF	DESCRIPTION OF PART	VENDOR	VENDOR PART NO.	TONUS PART NO.	QUANTITY REQUIRED
1	R55,56,65,68, R81,R4,110	100 Ω, 1/4 W, 10%, Carbon Comp Resistor	AB	CB1011		7
2	R19,31,43	390 Ω	↓	CB3911		3
3	R100 thru 104	1 K Ω	↓	CB1021		5
4	R91,92,93,94	1.2K Ω	↓	CB1221		4
4a	R114	2.2K Ω	↓	CB2221		1
5	R108	2.7K Ω	↓	CB2721		1
6	R109	3.3K Ω	↓	CB3321		1
7	R66	3.9K Ω	↓	CB3921		1
8	R124	4.7K Ω	↓	CB4721		1
9	R120	5.6K Ω	↓	CB5621		1
10	R118	6.8K Ω	↓	CB6821		1
11	R21,33,45, 63 — 79, 90, 107, 125	10K Ω	↓	CB1031		9
12	R58	12K Ω	↓	CB1231		1

NOV 7 1975

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DRAWN BY E.D.H 5-18-70

Rev	By	Date
D	ECO 0376	KBA [illegible]
E	ECO 0489	TJN/EW 11/25/74
F	ECO 0530	TJN/EW 1/29/75

DWG. N APL1047-007 F

SHEET 2 OF 6

TITLE P.C. ASSY -MULTIMODE FILTER/RESONATOR MODULE 1047 VERSION 1

ITEM	REF	DESCRIPTION OF PART	VENDOR	VENDOR PART NO.	TONUS PART NO.	QUANTITY REQUIRED
13	R54,60,61	22K Ω, 1/4 W, 10%, Carbon Comp. Resistor	AB	CB2231		3
14	R119	27K Ω	↓	CB2731		1
15	R20,32,34,44	33K Ω	↓	CB3331		4
16	R112,117,111	47K Ω	↓	CB4731		3
17	R57,64,80	56K Ω	↓	CB5631		3
18	R26,27,28,30, 50,52,53,67,69, 75,85,77,115,116, 76,87,98	100K Ω	↓	CB1041		17
19	R122	180K Ω	↓	CB1841		1
20	R74,113	220K Ω	↓	CB2241		2
21	R121	470K Ω	↓	CB4741		1
21a	R29	560K Ω	↓	CB5641		1
22	R105	1 MEG Ω	↓	CB1051		1
23	R123	4.7 MEG Ω	↓	CB4751		1
24	R106	22 MEG Ω	↓	CB2261		1

NOV 7 1975

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DRAWN BY E.D.H. 5-18-70	Rev	By	Date	DWG. NO. APL1047-007 F
TITLE P.C. ASSY - MULTIMODE FILTER/RESONATOR MODULE 1047 VERSION 1				SHEET 3 OF 6

ITEM	REF	DESCRIPTION OF PART	VENDOR	VENDOR PART NO.	TONUS PART NO.	QUANTITY REQUIRED
25	R15,22,38,40,46, 47,48,73,96	SELECT, 1/4 W, ±10%, Carbon Comp. Resistor	AB			9
26	R82	6.98KΩ, ±1%, Metal Film, RN55C, Resistor	Mepco			1
27	R71	10.7KΩ				1
28	R72	301KΩ				1
29	R17	97.6KΩ				1
30	R13,14,35,36,37, [illegible],41,42,75,	100KΩ				10
31	R23	196KΩ				1
32	R16	787KΩ, ±1%, Metal Film, RN65D, Res.				1
33	R18	5KΩ Potentiometer (trimmer)	CTS	X201R502B		1
34	R59	10KΩ	CTS	X201R103B		1
35	R51,70,86	50KΩ	CTS	X201R503B		3
36						

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tonus, inc. 45 Kenneth Street, Newton Highlands, Massachusetts 02161

DRAWN BY R.D.H 5-18-70 | Rev | By | Date

DWG. NO. APL1047-007 F
SHEET 4 OF 6

TITLE P.C. ASSY-MULTIMODE FILTER/RESONATOR MODULE 1047 VERSION 1

ITEM	REF	DESCRIPTION OF PART	VENDOR	VENDOR PART NO.	TONUS PART NO.	QUANTITY REQUIRED
37						
38						
39						
40	C5,8,11,15,29	20 pf Capacitor, ceramic disc 20% 50V	ACI	AC-1		6
41	C12	30 pf	"	AC-1		1
42	C3,6,9	50 pf	"	AC-2	NOV 7 1975	3
43	C18,21	1000 pf Capacitor ±5%, Silver Mica				2
44	C4,7,10	.0022 µf Capacitor, ceramic disc	Erie	811-000-X5F0-222K		3
45	C24,25	.01 µf	Erie	811-000Z5U0103M		2
46	C26 C31,[illegible]27,28	0.1 µf	Erie	5815-000-Y5M0-1047		6
47	C1,2	1.0 µf Capacitor, Tantalum, 35V	Sprague	150D105X9035A		2
48	C30	0.68 µf Capacitor ±10%, 50V	G.E.	75F6R5A684		1
48a	C13,16,19	220 pf Capacitor, ceramic disc	ACI	AC-1		3

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DRAWN BY R.D.H. 5-18-70

Rev	By	Date

DWG. NO. APL1047-007 F

SHEET 5 OF 6

TITLE P.C. ASSY - MULTI MODE FILTER/RESONATOR MODULE 1047 VERSION 1

ITEM	REF	DESCRIPTION OF PART	VENDOR	VENDOR PART NO.	TONUS PART NO.	QUANTITY REQUIRED
49	CR1 thru CR8	IN914 DIODE				8
50	Q1,2,3,4	CEDEL LS3954 Transistor MATCHED PAIR N-CHANNEL FET		LS3954		2
51	Q5	TZ-81 OR 2N5249				1
52	Q6,7,9,11	2N5172				4
53	Q8,10	TZ-581 OR 2N5367				2
54	A1 thru A6	1339 I.C. Op Amp	TELEDYNE	1339		3
54a	A1, A2, A3	LM301A I.C. Op Amp	National Semiconductor	LM301A		3
55		VCA MODULE	ARP		APL4005-005D	1
56		VCA MODULE	ARP		APL4005-007D	1
57		VCA MODULE	ARP		APL4005-009D	1
58						
59						
60						

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TITLE P.C. ASSY -MULTIMODE FILTER/RESONATOR MODULE 1047 VERSION 1

DRAWN BY R.D.H 5-18-72

Rev	By	Date

DWG. NO. APL1047-007 E

SHEET 6 OF 6

ITEM	REF	DESCRIPTION OF PART	VENDOR	VENDOR PART NO.	TONUS PART NO.	QUANTITY REQUIRED
61						
62		Printed Circuit Board	ARP		C1047-005C	1
63						
64						
65		ASSEMBLY	ARP		C-1047-006C	REF
66		SCHEMATIC	ARP		C-1047-003E	REF
67						
68						
69						
70						
71						
72						

NOV 7 1975

ARP engineering change order

number 0489
sheet 1 of 1

DATE 10/24/74 BY KC Effectivity E

product/subassembly changed 10 47 MODULE

REASON FOR CHANGE

PER ECR 1279

DETAILS OF CHANGE

APL 1047-007

1) ITEM 10; CHANGED PART NO. FROM CB6921 TO CB6821
2) ADDED PART NO'S TO ITEMS 33, 34, 35, 44, 46, 48, 48A + 50
3) ITEMS 55, 56 + 57; RAISED REV FROM B TO C
4) ITEMS 65 & 66: RAISE P/N REVS RESPECTIVELY FROM B TO C & D TO E

APL 1047-013

1) ITEM 22; RAISED REV FROM D TO E
2) ITEM 4: RAISE P/N REV FROM D TO E
3) ITEM 31; CHANGED PART NO FROM PK-70B TO PKB-70B
4) ADDED ITEMS 24, 39, 40, 41, 42, 43 & 44

C1047-003 & 006

CHANGE R118 FROM 6.9K TO 6.8K

NOV 25 1974

APPROVALS		Initial/date	Distribution	DRAWINGS AFFECTED			
				Type	Dwg No.	From	To
Eng Mgr	☐			PL	APL 1047-007	D	E
Proj Eng	☐			PL	APL 1047-013	A	B
Drafting	☐	Raleigh	10/29/74	SCHEM	C1047-003	D	E
Prod Eng	☒	PCM 11-1-74		P.C. ASSY	C1047-006	B	C
Prod Mgr	☐						
Purchasing	☒	WEH 11/1/74					
Mat'l Ctrl		[illegible]					
INV Ctr'L		[illegible] 11-15-4					
		J. F. [illegible] 11/15/74					
		[illegible] 11-15-4		Comp By/Date: TJN/EW 11/25/74			