Hammond® X-66

Renovating the

Scanner Recovery Preamps
&
Expression Preamps

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Binche / Belgium **May.2011**

TABLE OF CONTENTS

Renovating Scanner Recovery Preamps &
Expression Preamps on Hammond X-66.

Forewords – Purpose of this Project

When comparing the residual background noise level of the Hammond X-66 Console with today's keyboards and amplifiers, I stay under the feeling that the background noise level of the X-66 is much higher.

This can be easily demonstrated by pushing down the swell pedal without touching any key or pedal. Basically, you hear a mixture of multiple types of noises such as: hiss, digital noise, hum, buzz, whistling, etc.

The question was : ' Is there any possibility to alleviate this situation ? '.

The answer is YES but to a certain extend concerning the background hiss level.
As regarding the hum or buzz level, that's another difficult point that will be probably developed later on in another chapter.

When analysing the overall block-diagram of X-66, it appears that most important signals carrying notes are routed through the following sections :

- Dual 'Drawbar' scanner
- Dual 'Celeste' scanner
- 'Tab Voice' scanner
- Saturable Reactor Bass Vibrato

Inevitably, the signal losses generated by the three scanners must be re-amplified again by so-called **'Scanner Recovery Preamps'** board.

Ouptut signals from the above elements are all connected to the **'Expression Preamps'** board which drives in turn the output circuit.

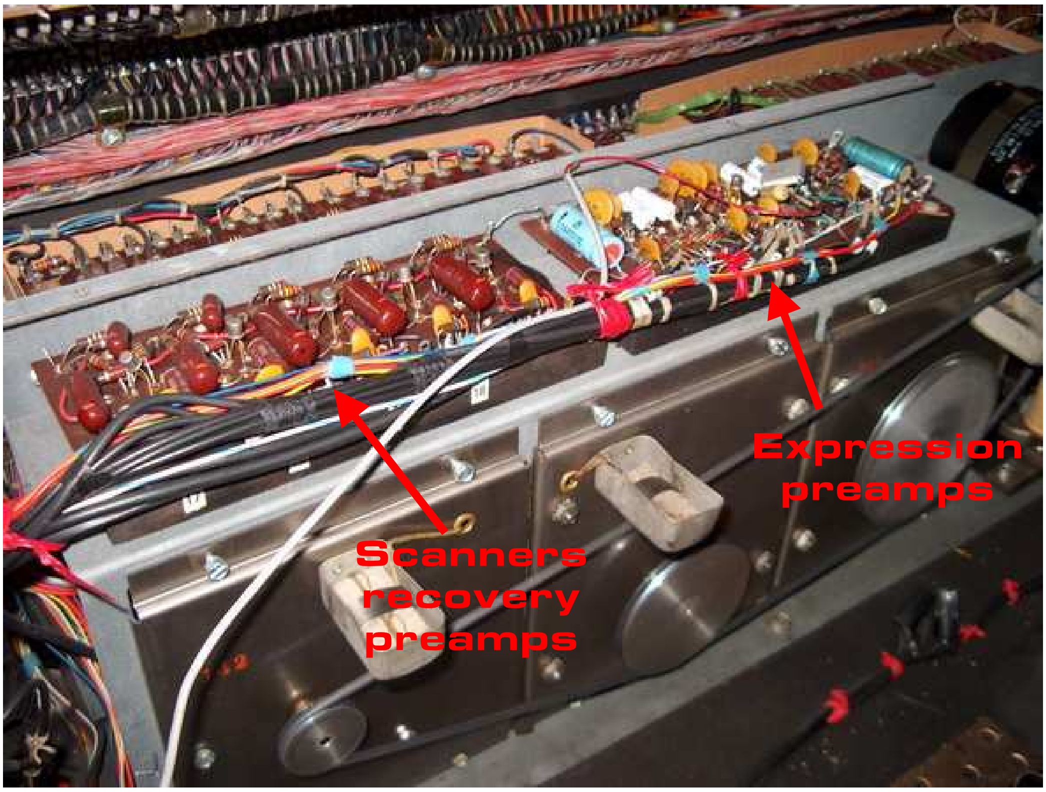
It's quite easy to conclude that the noise level of those two boards must be minimized at this " rallying area " and that is the main purpose of this chapter.

The other reason is purely a personal one. I don't like at all this engineering wiring concept of those two bakelite boards and others used in the X-66.
So, both boards have been entirely redesigned on conventional printed circuit boards (PCB) with updated today's components.

To my opinion, since final improvements were noticeable by ear, I found interesting to come up with those information.

General Description.

Original Scanner Recovery Preamp & Expression Preamp boards .

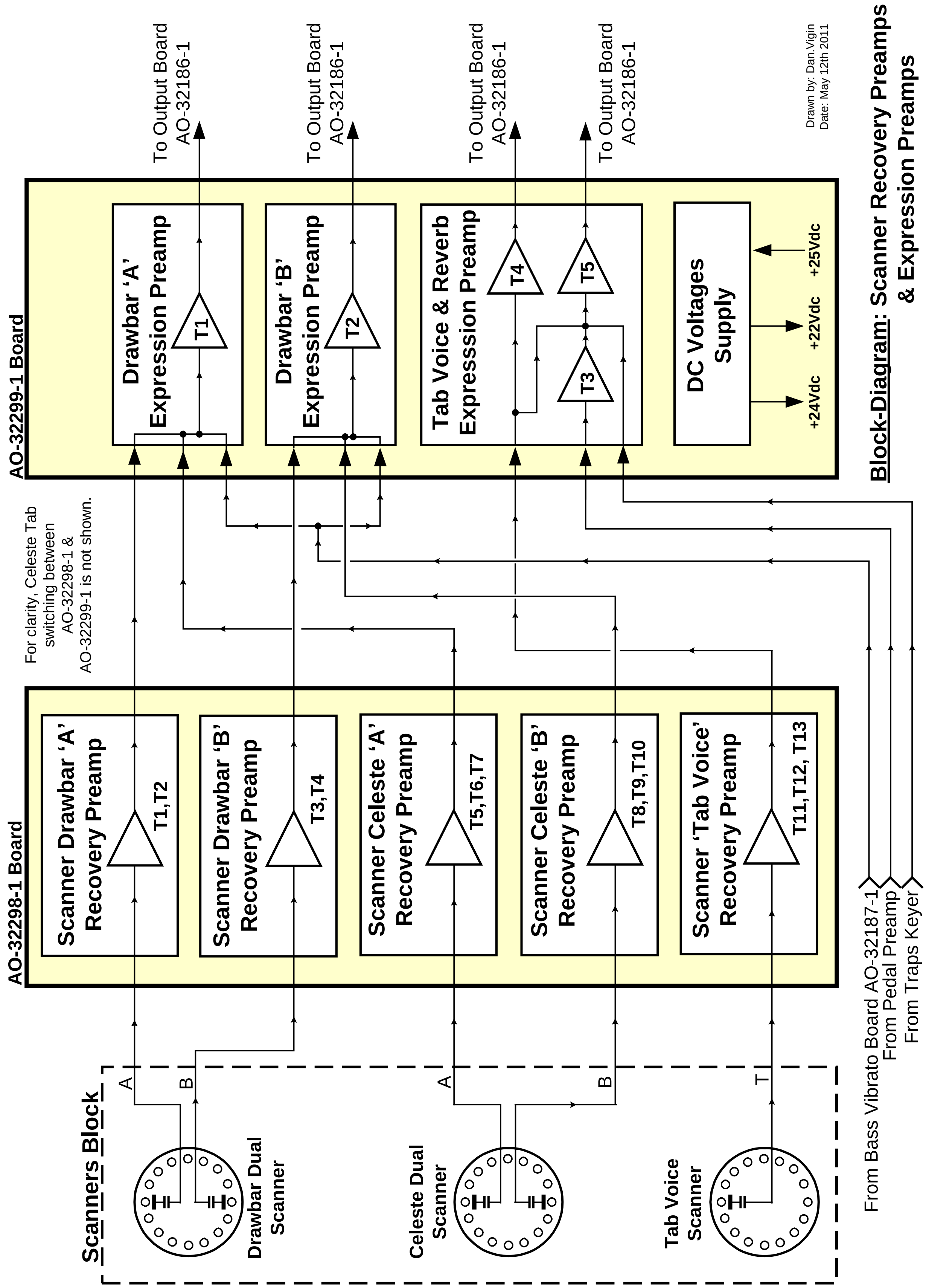


As shown on the above picture both original boards were installed on top of the scanner block.

This location is quite logical because the output impedance of the scanner is extremely high, then wiring has to be shielded and as short as possible. In addition to that, since the scanner block is a 'built-like-a-tank' all-steel chassis, it was also convenient to take also advantage of this assembly to add a metal shield on top of those two boards to prevent from undesirable interferences with other circuits.

Block-Diagram

A simplified block-diagram is shown on the next page. Both concerned boards are highlighted in yellow background. The output signals from each scanner are connected directly to the five 'Scanner Recovery Preamps' of board AO-32298-1. Those five Recovery Preamp's are almost identical. Details will be provide later on.


Block-Diagram: Scanner Recovery Preamps & Expression Preamps
Drawn by: Dan.Vigin
Date: May 12th 2011
AO-32299-1 Board
Drawbar 'A' Expression Preamp
T1
Drawbar 'B' Expression Preamp
T2
Tab Voice & Reverb Expresssion Preamp
T4
T5
T3
DC Voltages Supply
+24Vdc
+22Vdc
+25Vdc
To Output Board AO-32186-1
To Output Board AO-32186-1
To Output Board AO-32186-1
To Output Board AO-32186-1
For clarity, Celeste Tab switching between AO-32298-1 & AO-32299-1 is not shown.
AO-32298-1 Board
Scanner Drawbar 'A' Recovery Preamp
T1,T2
Scanner Drawbar 'B' Recovery Preamp
T3,T4
Scanner Celeste 'A' Recovery Preamp
T5,T6,T7
Scanner Celeste 'B' Recovery Preamp
T8,T9,T10
Scanner 'Tab Voice' Recovery Preamp
T11,T12, T13
From Bass Vibrato Board AO-32187-1
From Pedal Preamp
From Traps Keyer
Scanners Block
A
B
A
B
T
Drawbar Dual Scanner
Celeste Dual Scanner
Tab Voice Scanner

The output signals from those Recovery Preamps are connected to the Expression Preamp board AO-32299-1 which is in fact the most important 'rallying point' or connecting point in the organ.

However, for clarity purpose, the Celeste Tab switching between both boards is not drawn on this block-diagram.

The role of the Expression Preamp circuits is to collect signals mainly from the Scanner Recovery Preamps but also from other circuits of the organ and to adapt them to a steady level before reaching the output circuit board.

Drawbar 'A' & 'B' Expression Preamps are basic mixing voltage preamps.

Tab Voice & Reverb Expression Preamp is more complex since its function is collect and mix other signals before the output circuit board AO-32066-1.

DC voltage supplies located on the Expression Preamp board are feeding the Scanner Recovery Preamp board as well as the Expression Preamp board.

How to reduce the background noise ?

Easier to write than to do.

The Recovery Preamp board is composed of 13 transistors and 5 transistors for the Expression Preamp. Total 18 transistors.
Remember that each transistor generates a certain inherent noise level called Noise Figure (NF for short).

For instance, the old 2N3393 (2105 in Hammond parts list) has an NF of 5 db but its today equivalent BC548 has an NF of 1.2 dB. The least, the best. Quite a difference !
In addition to that, I have also noticed a certain trend that transistors become more and more noisy with aging.
Those two factors were sufficient for me to try to reduce this background noise level of my X-66 Console.

To be noticed that the background noise level is not only produce by active components such as transistors, diodes, IC's.. but also by passive components like old carbon resistors, tantalum capacitors... and also by cabling crosstalk, ground paths, leaks of magnetic fields, radio interferences, etc...

Taking the above points into consideration, both boards were redesigned and equipped with brand new active and passive components as described in the next pages.

Scanner Recovery Preamps - AO-32298-1.

As shown on the block-diagram, this board contains five preamps. In fact, the term 'Preamp' as used in the Hammond X-66 Service Manual is not adequate because those five boards are not amplifying anything.
The overall gain of those five stages is near " x 1 ", this means that the level of the input signal is identical than the level at its output !
Then, the next question is *' What the hell to have those five stages ? '.*
Pertinent question indeed.

In fact, the role of those five stages is to adapt the extremely high output impedance (about 220 Megohm as stated on Fig 5-7 of the X-66 Service Manual) of the signals coming out from the scanners to a normal output impedance in the range of 10 Kohm.
Refer to the schematic diagram on the next page.

Scan.Draw. 'A' & 'B' stages.

Both stages 'A' and 'B' are identical. First stage Draw.'A' is taken as reference.
Signal coming from the rotor plates via the stationary electrode of the scanner is connected directly via shielded cables to the input W4 and loaded by a resistor of 22 Megohm (quite high). This signal is driving the base of transistors T1 via a liaison capacitor of 10 nF. Transistor T1 is mounted in 'Emitter Follower' configuration (or also called 'Common Collector') offering so an high input impedance while its output impedance is low. Adequate counter-reaction is assured by 27 nF capacitor C3.

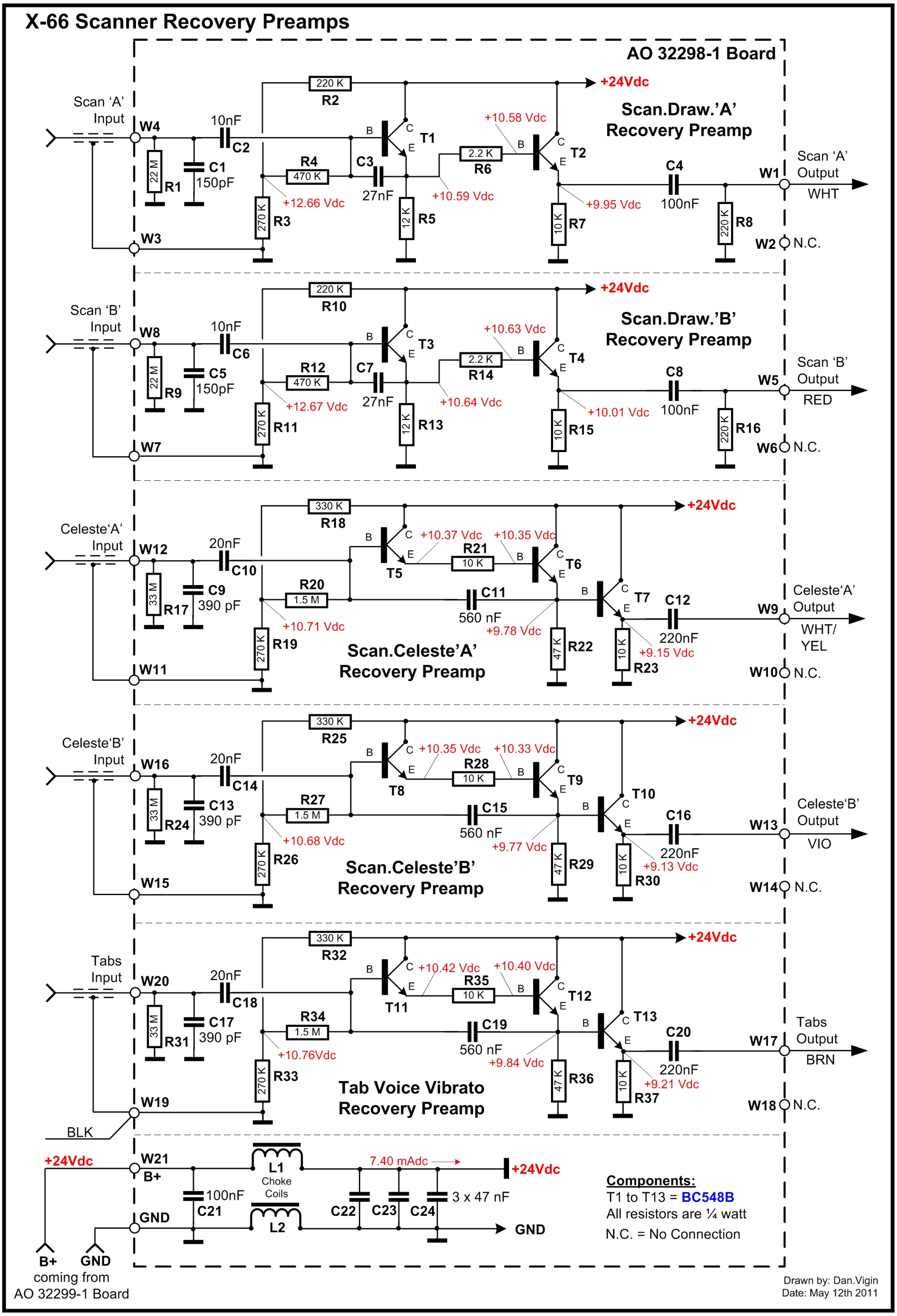
The second transistor T2 is also mounted in 'Emitter Follower' circuit and has a simple role of 'buffer stage' to improve and provide a total separation between the input signal from the scanner at W4 and the output signal available at W1.

The output capacitor C4 eliminates any DC component at output W1.

Measurements have been made thoroughly and it is confirmed that at 500Hz (taken as a reference frequency in this case), the gain is near ' x 1 ' .
See Response Curves graphs .

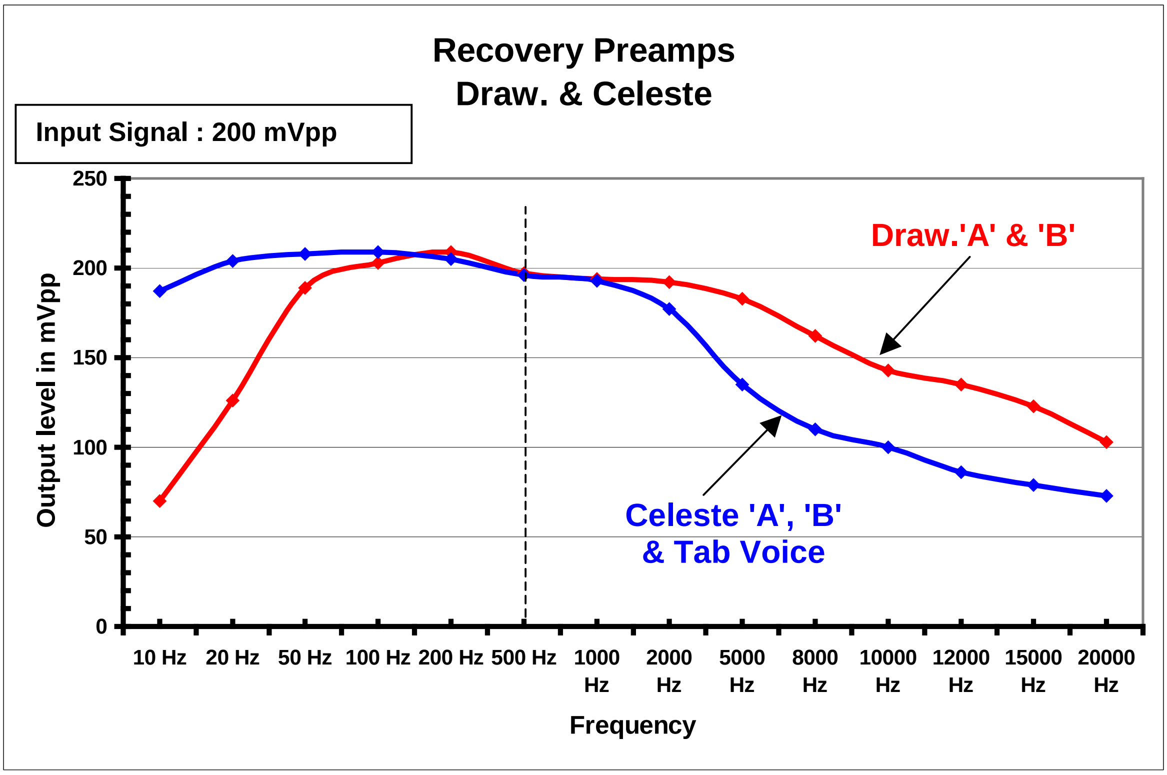
Scan. Celeste 'A', 'B' & Tab Voice stages.

Those next three stages are identical and almost similar than Scan.Draw 'A' & 'B' stages. However, the input impedance of these three stages is even greater than Scan. Draw 'A' & 'B' stages. Just have a look to the input resistor R17 of 33 Megohm !
An third 'Emitter Follower' stage has been added in this circuit again for better impedance adaptation between input and output.



X-66 Scanner Recovery Preamps
AO 32298-1 Board
Scan.Draw.'A' Recovery Preamp
Scan.Draw.'B' Recovery Preamp
Scan.Celeste'A' Recovery Preamp
Scan.Celeste'B' Recovery Preamp
Tab Voice Vibrato Recovery Preamp
Scan 'A' Input
Scan 'B' Input
Celeste'A' Input
Celeste'B' Input
Tabs Input
Scan 'A' Output WHT
Scan 'B' Output RED
Celeste'A' Output WHT/YEL
Celeste'B' Output VIO
Tabs Output BRN
BLK
+24Vdc
B+ GND coming from AO 32299-1 Board
L1 Choke Coils L2
7.40 mAdc
3 x 47 nF
Components:
T1 to T13 = BC548B
All resistors are ¼ watt
N.C. = No Connection
Drawn by: Dan.Vigin
Date: May 12th 2011

Response curves of Recovery Preamps.



It has to be noted that capacitors in series are of greater value that in the Scan.Draw.'A' & 'B' circuits. By its original X-66 design, this is quite normal because the treble notes (frequency number 45 up to 97) are passing through the Scanner Draw 'A' & 'B' while the bass notes (frequency number from 1 through 44) are passing through the two other scanners (i.e. Celeste and Tab Voice scanners) or also through the saturable reactor Bass Vibrato system.

As shown on the above Response Curves graphs, it is easy to conclude that Draw 'A' & 'B' Recovery Preamps are emphasizing the high-end part with a sharp decrease in the low-end area while Celeste & Tab Voice Recovery Preamps are more covering the low-end area with a slow decrease in the high-end region.

Full circuit description is available in Section II – Theory of Operation – of the X-66 Service Manual from page 2-1.

Additional measurements.

Max. output level Scan.Draw.'A' @ 500 Hz before clipping :	18.6 Vpp
Max. output level Scan.Draw.'B' @ 500 Hz before clipping :	18.8 Vpp
Max. output level Scan.Cel.'A' @ 500 Hz before clipping :	15.0 Vpp
Max. output level Scan.Cel.'B' @ 500 Hz before clipping :	15.1 Vpp
Max. output level Scan.'Tab Voice' @ 500 Hz before clipping:	14.8 Vpp

DC Supply.
DC voltage is supplied by adjacent board AO-32299-1. However, during tests on the bench, radio signals were detected ! Those radio interferences have been eliminated by adding decoupling capacitors C21 up to C24 and two choke coils L1/L2 on the new board. This point was mentioned earlier in the General Description part.

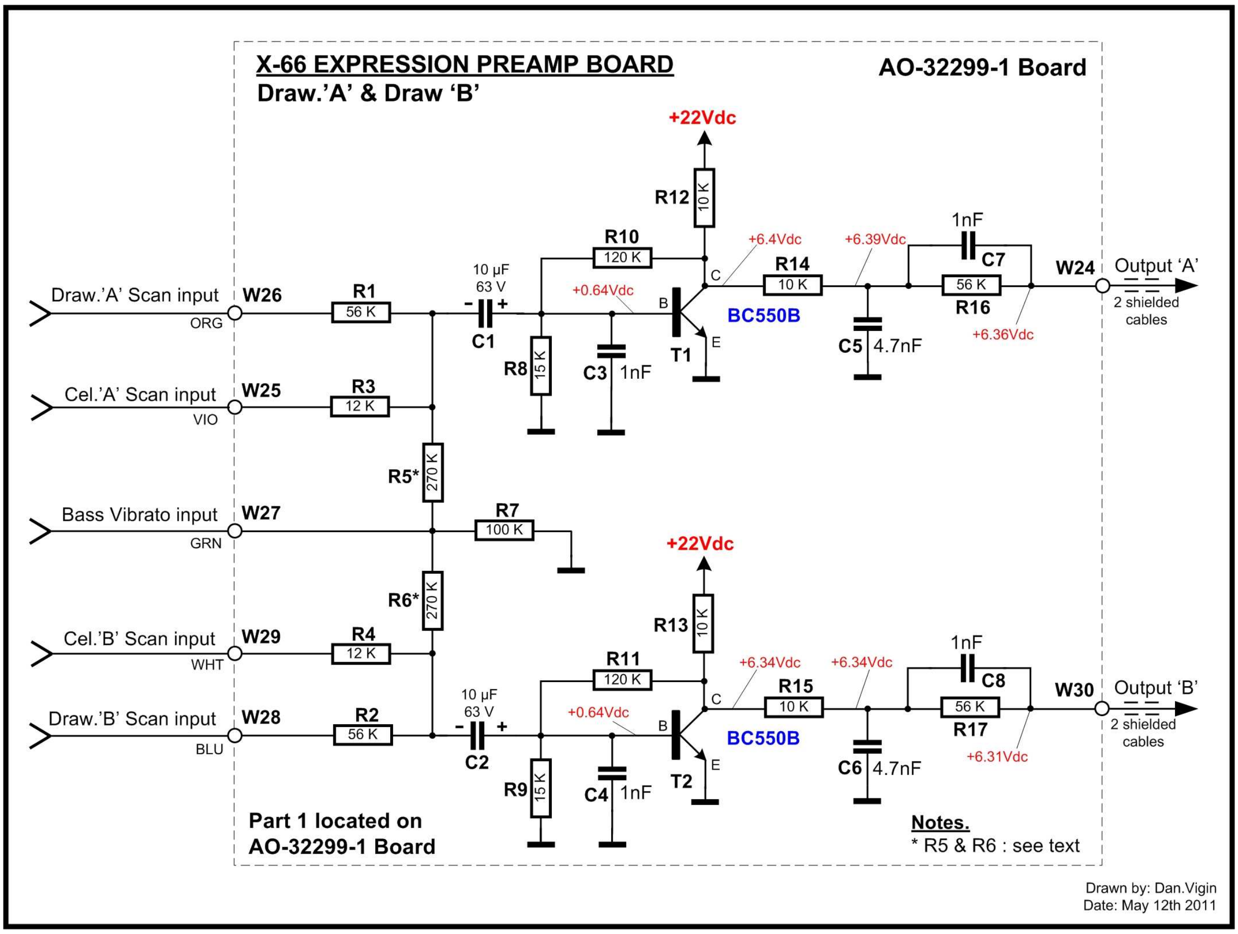
Expression Preamps board - AO-32299-1.

This board is composed of two different circuits:
- Draw 'A' & Draw 'B' Preamps
- Tab Voice, Pedal & Traps Preamps

Draw 'A' & Draw 'B' Preamps.

Refer to the schematic diagram hereunder.
Only one channel will be covered since the second branch is identical.

Three types of signal are connected to the inputs of this Expression Preamp circuit:
- Draw 'A' coming from Draw.'A' Recovery Scanner Preamp
- Celeste 'A' coming from Celeste 'A' Recovery Scanner Preamp
- Bass Vibrato coming from Tab Voice Vibrato Recovery Preamp



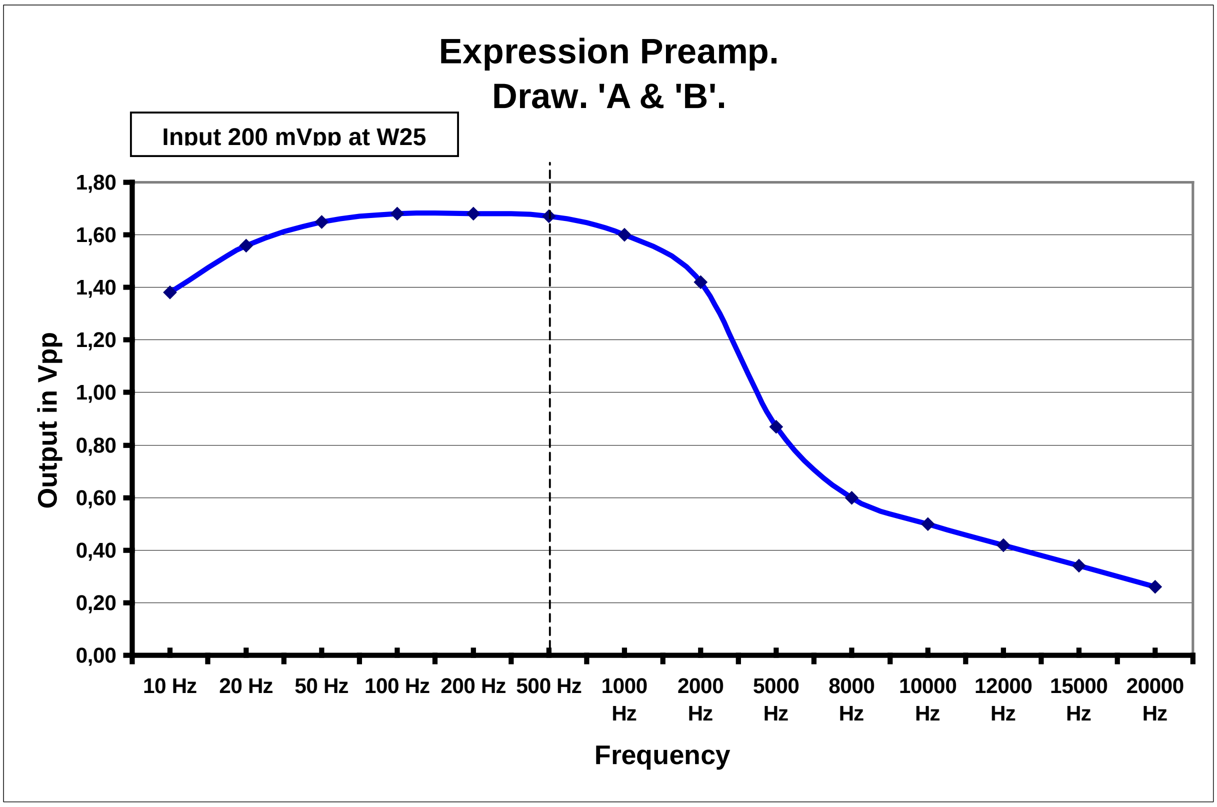
Signals reaching the inputs W25 up to W29 do have different levels and resistors R1 to R7 define the adequate levels. Original values can be found on schematic diagram of Fig.5-7 of the X-66 Service Manual.
However, in my case, resistors R5 and R6 have been decreased from 330 K to 270 K in order to provide some more 'groovy sound' in the low-end part of the audio spectrum. It's just a matter of personal taste.

The values of resistors R1 to R4 can be also modified to a certain extend but despite some trials, they have been left as such.

Afterwards, the incoming signals are routed through the 10µF capacitor directly linked to the base of transistor T1 mounted in common emitter configuration.
Some frequency corrections are applied via capacitors C3, C5 and C7.
Polarization of the base is assured by resistors R8, R10 and R12.

DC component of 6.3 Vdc is left as such at the output in order to drive later on the bases of the final transistors of the Expression Control board AO-32066-1.

Response curves of Expression Preamps Draw.'A' & 'B'.



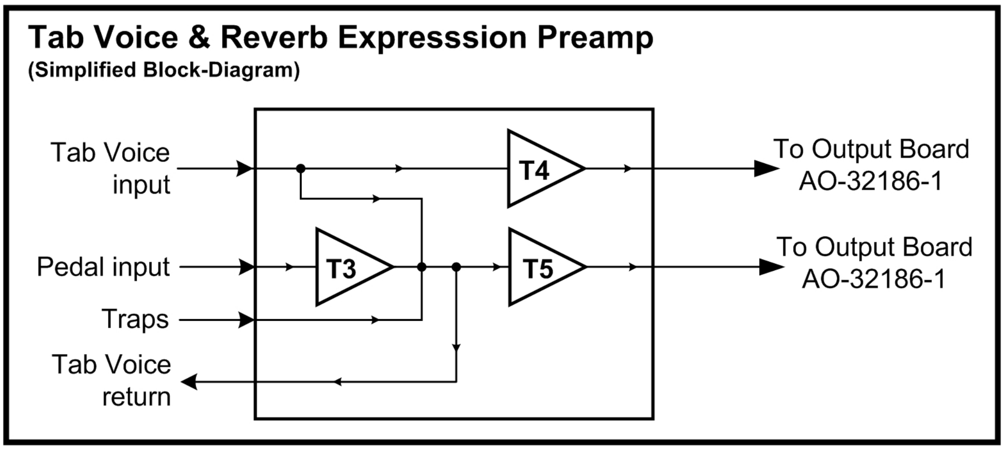
Here again, it's interesting to notice that the response curve is rather flat up to 2 KHz and then starts really to sharply fall down.

Additional measurements.

Gain @ 500 Hz (W25,W29) with 200 mVpp input :	x 8.35
Gain @ 500 Hz (W26,W28) with 200 mVpp input :	x 5.3
Gain @ 500 Hz (W27 only) with 200 mVpp input :	x 1.4
Max. output level @ 500 Hz before clipping :	11.7 Vpp

Tab Voice & Reverb Expression Preamp.

This preamp is composed of three transistors T3, T4 and T5 and can be compared to an audio mixing unit. See block-diagram hereunder.



Similarly to Draw 'A' & 'B' preamps, those transistors are also mounted in 'Common Emitter' configuration. See schematic diagram on next page.

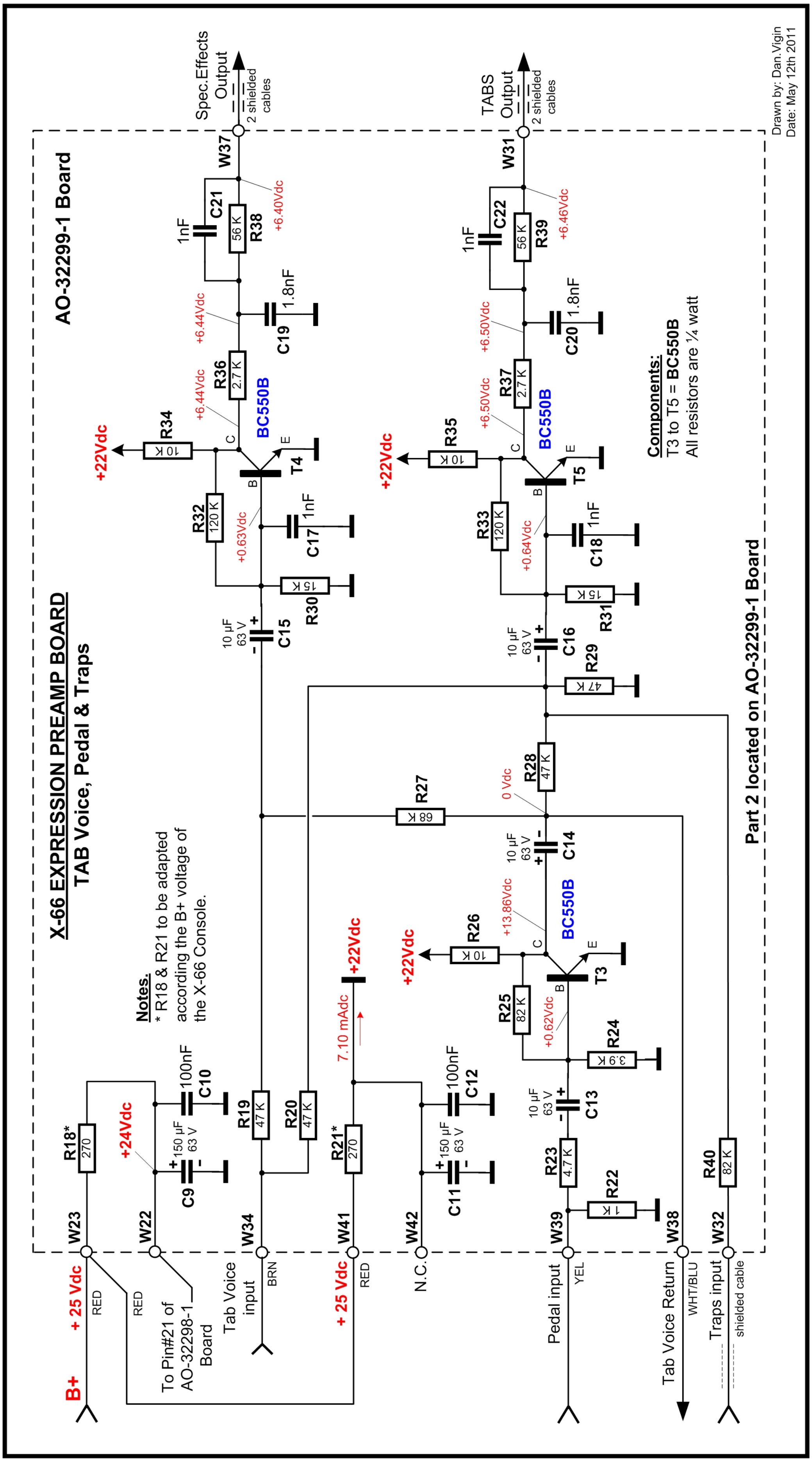
Tab Voice signal at W34 (from Scanner 'Tab Voice' Recovery Preamp) is driving equally T4 and T5 stages via resistors R19 and R20.
Then signals found at the outputs W31 and W37 are of same level.
Gain is around ' x 2 ' @ 500 Hz. Output signals available at W31 and W37 are routed directly to the Output Board AO-32186-1 keeping the DC component of +6.4 Vdc.
Max. input level @ 500 Hz at W34 is 5.2 Vpp before clipping.

Pedal signal at W39 requires some more level and is firstly pre-amplified by transistor T3. The output signal is forwarded to T4 stage via R27 (68K) on one end and via R28 (47K) to T5 stage. Since values of those resistors are different we can expect a lower level output at W37. This is demonstrated in the next Response Curves graphs.
Overall gain @ 500 Hz from W39 up to W31 is about ' x 30 ' while the gain from W39 up to W37 is about ' x 21 '.
Max. input levels before clipping are 0.4 Vpp and 0.6 Vpp respectively.

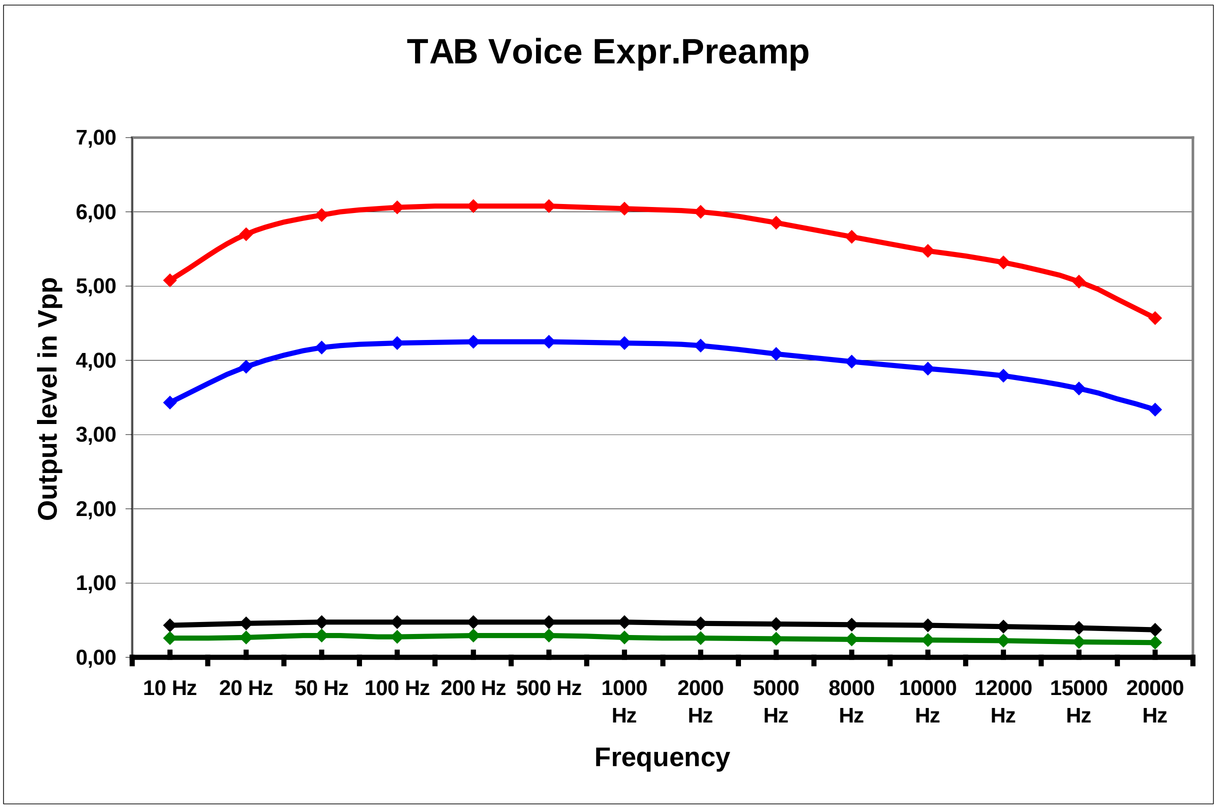
Traps signal at W32 is simply connected to T5 stage via one 82K resistor. Traps output signal is only available at W31. Overall gain @ 500 Hz from W32 up to W31 is about ' x 1.4 ' with a max. input level of 9.2 Vpp before clipping.
Modifying the value of this resistor R40 can increase or decrease the Traps output level as wished.

Tab Voice return at W38. Small portion of Tab Voice and Pedal signals are returned to the Celeste Vibrato Drive amplifier AO-32297-1 to take benefit so of the 'slow scan' effect (0.6 Hz) of the Celeste scanner.

DC supplies have been adjusted accordingly with R18 and R21 to feed both boards with recommended DC voltages of +24 Vdc and +22 Vdc. It has been always a good engineering practice to shunt the 150 µF elco's by 100 nF capacitors (C10 & C12).


X-66 EXPRESSION PREAMP BOARD
TAB Voice, Pedal & Traps
AO-32299-1 Board
Notes:
* R18 & R21 to be adapted according the B+ voltage of the X-66 Console.
Components:
T3 to T5 = BC550B
All resistors are ¼ watt
Part 2 located on AO-32299-1 Board
Spec.Effects Output
TABS Output
2 shielded cables
Pedal input
Tab Voice input
Tab Voice Return
Traps input
To Pin#21 of AO-32298-1 Board
Drawn by: Dan.Vigin
Date: May 12th 2011

Response curves of Expression Preamps 'Tab Voice'.



The above Response Curves do merit some explanations as follows.

- Black curve at the bottom represents the frequency response curve with Tab Voice input signal at W34 and its corresponding outputs at both W31 and W37.

- Green curve is the frequency response of the Traps signal at W32 and its output at W31.

- Blue curve is the frequency response of the Pedal signal at W39 and its output at W37.

- Red curve is the frequency response of the Pedal signal at W39 and its output at W31.

Noise floor measurements.

As announced, both boards have been entirely redesigned with today's components.

Measurements are not easy to perform on the bench since ideally they should be done under interference free environment (Faraday cage).
Moreover, measured signals were very close the limits on my personal test-equipment.

Scanner Recovery Preamps.
With all inputs W4, W8, W12, W16 and W20 shorted to ground:

- average noise level at W1: ~1.8 mVpp (on scope), < 600 µVrms on HP-400E*
- average noise level at W5: ~1.8 mVpp (on scope), < 600 µVrms on HP-400E
- average noise level at W9: ~1.5 mVpp (on scope), < 500 µVrms on HP-400E
- average noise level at W13: ~1.5 mVpp (on scope), < 500 µVrms on HP-400E
- average noise level at W17: ~1.5 mVpp (on scope), < 500 µVrms on HP-400E

* unweighted with Hewlett-Packard millivoltmeter HP-400E

Expression Preamps
Draw.'A' & 'B', with inputs W25 and W29 shorted to ground:

- average noise level at W24: ~1.8 mVpp (on scope), < 600 µVrms on HP-400E
- average noise level at W30: ~1.8 mVpp (on scope), < 600 µVrms on HP-400E

Tab Voice Preamps, with inputs W32, W34 and W39 shorted to ground:

- average noise level at W37: ~1.5 mVpp (on scope), < 500 µVrms on HP-400E
- average noise level at W31: ~1.5 mVpp (on scope), < 500 µVrms on HP-400E

Realization

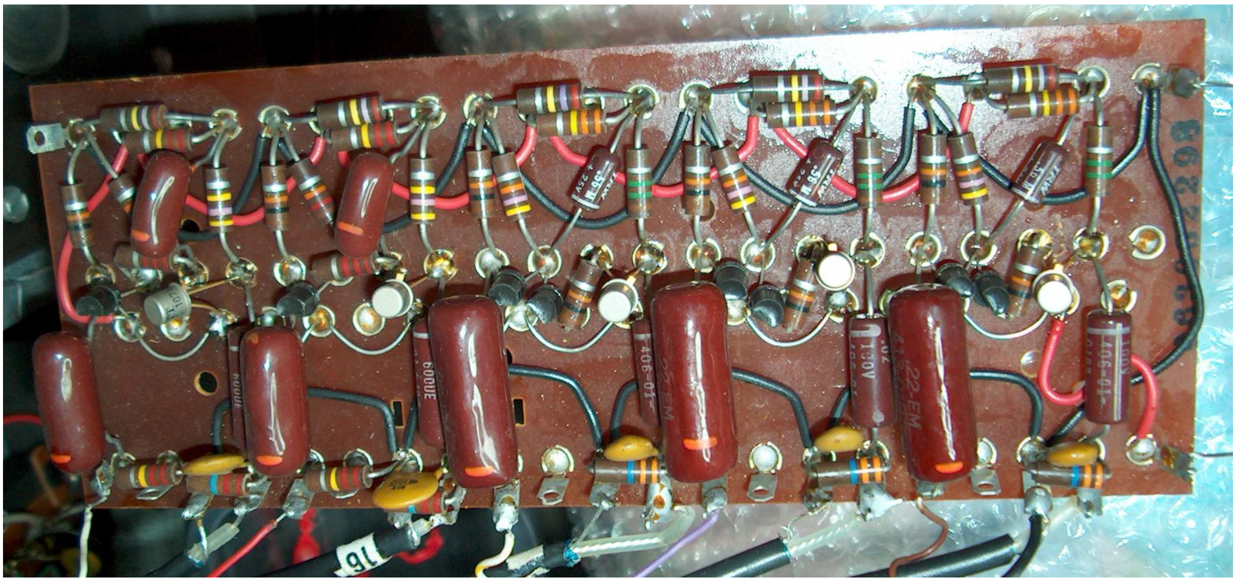
Replacement of transistors: tests and measurements were conducted firstly on the bench and transistors BC548B were installed on the Scanner Recovery Preamp board (13 in total) while BC550B were preferred on the Expression Preamp board (5 in total).
Selection of low-noise transistors is certainly the most relevant improvement.

Replacement of carbon resistors: the resistors made of carbon composition as used in the " sixties " were rather noisy. The highest value the worst because the thermal noise generated in each resistor is directly proportional to the resistor value.
Unfortunately, in those two concerned preamps, resistors of very high value are found.
All those old carbon resistors were replaced by Metal Film resistors.

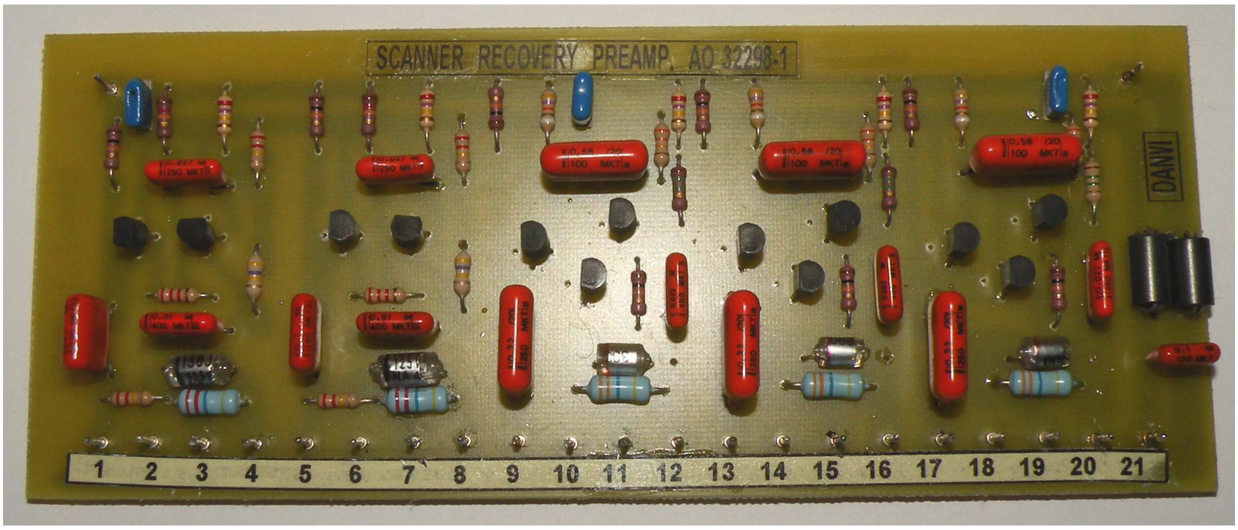
Replacement of capacitors: while less relevant than transistors and carbon resistors, Sprague capacitors used in the X-66 are quite stable and do not suffer of aging but those capacitors are rather bulky and were also replaced by Metallized Polyester Film capacitors (MKT from Vishay).
Nowadays, such type of capacitors are mostly used in low-noise Hi-Fi amplifiers.
Ceramic capacitors C1,C5,C9,C13 and C17 at the input of the Scan.Recovery Preamp board were also replaced by Styroflex type capacitors.
Other ceramic capacitors of 1 nF on the Expression Preamp board were also replaced by new one of same type with correct value.

Scanner Recovery Preamps board – AO-32298-1

Before



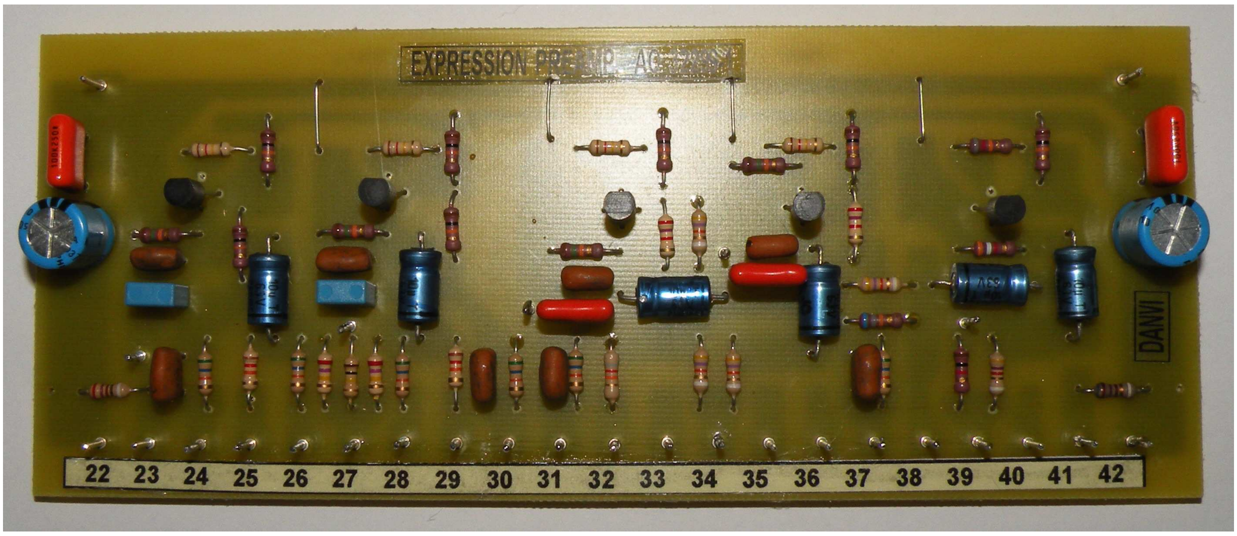
After



Expression Preamps board – AO-32299-1

Before

After



Printed Circuit Boards

Both typons (negative) and components side drawings are provided in attachment for those who are interested to realize those two PBC's.

Conclusions.

As a conclusion, I have to recognize that during numerous tests and measurements on the bench, I was not really convinced by the real need of doing all that work simply because it is not easy to measure 'noise level', which was the objective, whenever the circuits are not connected to each other in their original conditions as in the X-66 Console.

I mean by that correct input and output impedances (very important in this particular case), adequate signal levels, proper metal shielding of preamps, cabling, DC voltages, etc...

However, at the end, we all know that the human ear always remains the final decision-maker and will confirm whether or not it was worthwhile to do it.
After extensive listening tests, while not perfect, indeed, I found a substantial noise level reduction notably in the mid and high-end range of the audio spectrum as expected.

The remaining hum or buzz level (low-end part) needs also some improvements and will be probably the object of another chapter in the future.

Trust having been of some help,

Dan Vigin