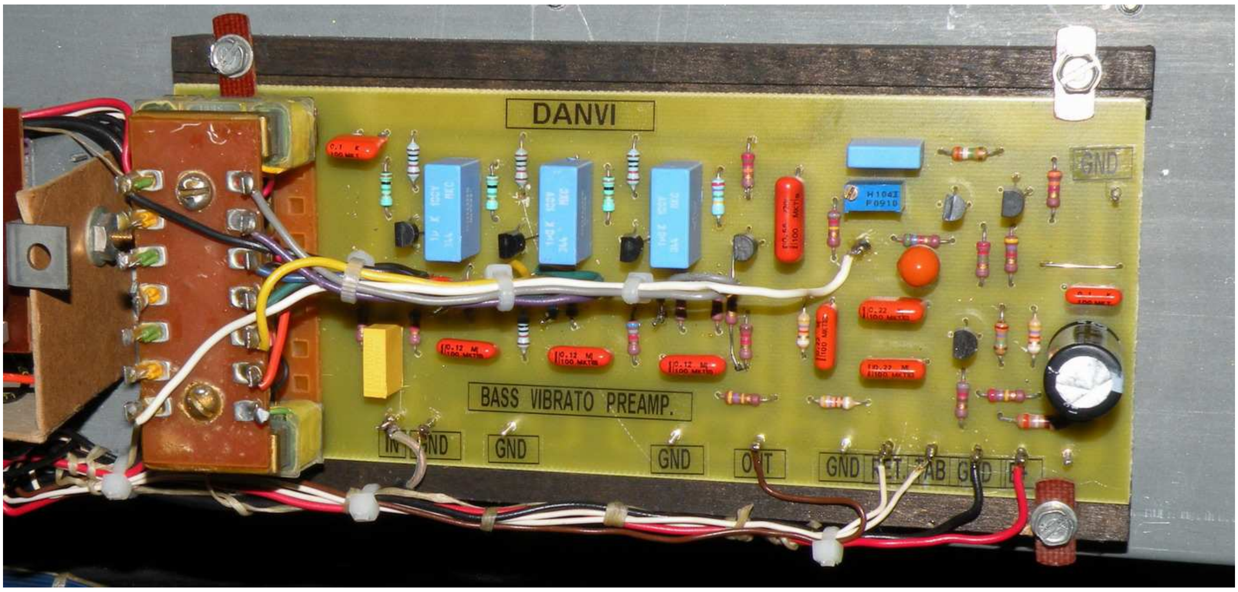
Hammond® **X-66**

Renovating the

Bass Vibrato Board

by Dan.Vigin



Binche / Belgium **June 2011**

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Renovating the X-66 Bass Vibrato board.

1. Forewords – Purpose of this Project

This chapter is simply the logical continuation of the previous project 'Renovating the Scanner Recovery Preamps & Expression Preamps' issued recently.

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 board

The three first sections were already covered beforehand while the Bass Vibrato board was left aside. However, this board is playing an extremely important role in the organ since whether or not the Bass Vibrato Tab is engaged, the whole low-end spectrum of the X-66 organ is routed through this board before reaching the Expression Preamp board.

In other terms, all notes from #1 up to #44 (half the organ !) are crossing by this Bass Vibrato board.

This board is also equipped with a lot of resistors of high values.
With aging, needless to say that their ohmic value has increased and hence the performances of the concerned circuit have been altered.
Also, the circuitry is composed of four amplifier stages in series with the first generation of silicon transistors which inherent noise may increase in function of the time. Other components like tantalum capacitors have to be replaced as well.
This problem is also known. To my opinion, it was time to renovate that board.

Also, a few weeks ago, I faced severe audible distortions in the low-end part of the keyboards under certain conditions. The fault was caused by the defective output transistor of this Bass Vibrato board. So, I had some doubts on the other stages.

The other reason is purely a personal one. I don't like at all this engineering wiring concept of those bakelite boards and others used in the X-66 console.

Then, it was decided to redesign this Bass Vibrato board on conventional printed circuit board (PCB) with today's components. Inevitably, circuits were reconditioned via computer with the aid of an electronic design simulator software while the original saturable reactor assembly was kept as such to avoid any original tonal modification.

Some improvements were noticed and are described in the following pages .

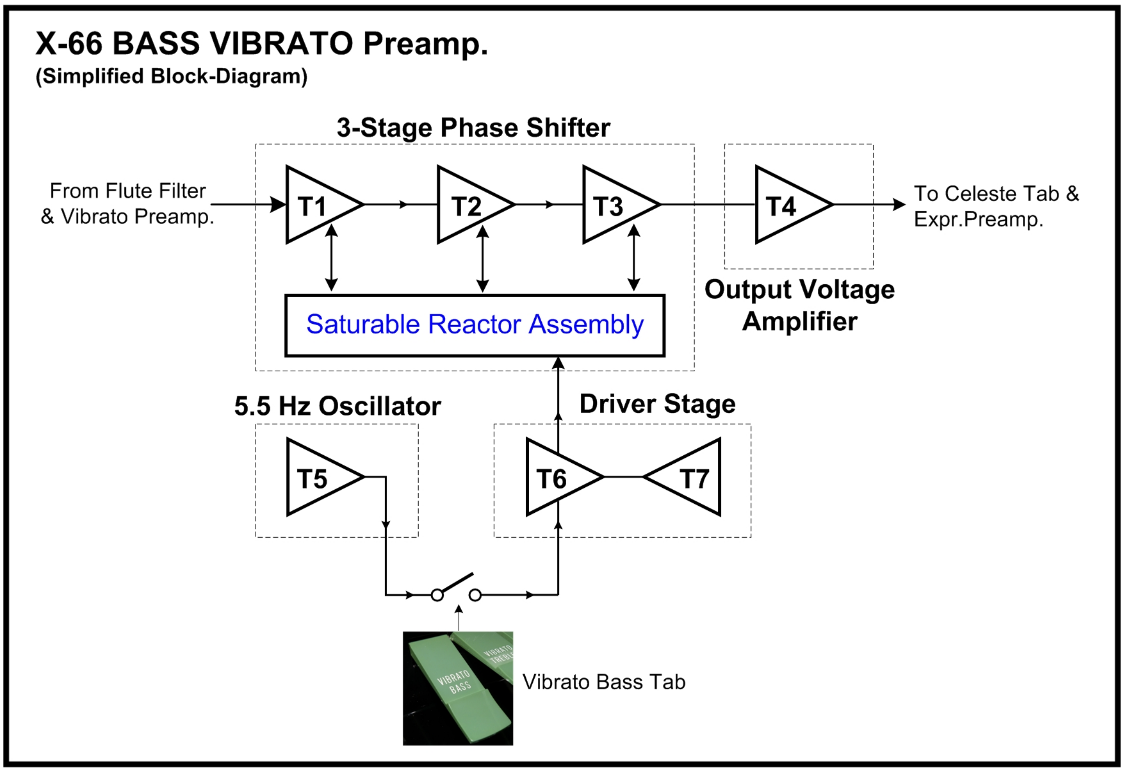
2. General Description.

The theory of operation of this Bass Vibrato board is detailed on Pt. 2-16 , Page 2-11 of the X-66 Service Manual.

For those who are interested to get further theories of operation on Hammond X-66 console, it is also advisable to have a look to the following website: http://www.nshos.com/X66Contents.htm

2.1. Block-Diagram

Nevertheless, the simplified block-diagram may offer a clearer view of operations.



Signals (notes # 1 to # 44) coming from the Flute Filters and pre-amplified by the Vibrato Preamp (refer to schematic diagram Fig 5-7 of the X-66 service manual) are reaching the three series-connected phase shifter stages (T1 to T3).

After being phase-modulated, signal losses are compensated by an output voltage amplifier (T4) in order to drive later on the Expression Preamp via the Celeste Tab switching.

The low frequency RC oscillator (T5) establishes the vibrato rate at 5.5 Hz.

With Bass Vibrato tab engaged, the driver stage (T6 & T7) supplies the pulses from the 5.5 Hz oscillator to the saturable reactor assembly which in turn provides the continuous phase shift to the signals played i.e. the Bass Vibrato effect.

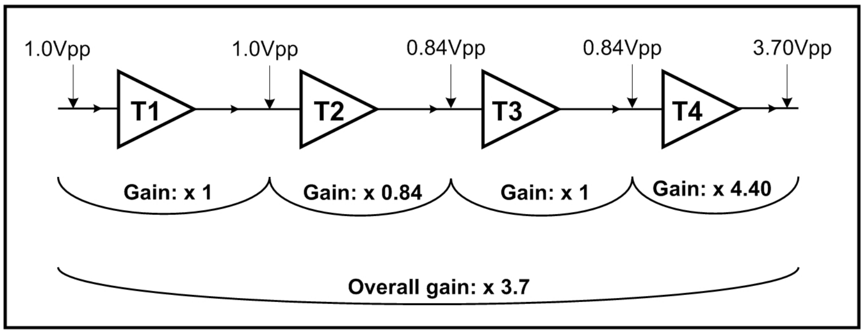
3. CIRCUITS DESCRIPTION.

3.1. Preliminary : before redesigning this Bass Vibrato board the original board has been measured just to be sure at 100% that the new one will provide at least equivalent or better performances than the original one.

Criteria were mostly focused on :
- overall gain of the board with the same value of input signal
- max. headroom (i.e. distortions when reaching clipping)
- total harmonics distortion (or THD incl. noise level)

3.2. Gain structure.

This sketch provides the gain factors per stage. Under the same testing conditions, the overall gain of the original board was x 3.37 while the new board provides an overall gain of x 3.7. AC voltages are blue-coloured on the schematic diagram.



3.3. Three-Stage Phase Shifter.

Beside the substitution of the old transistors T1, T2 and T3, the basic circuit has been left as such to avoid any sound alteration from original.

- Replacement of active components : transistors T1 to T3 (21133 equivalent to 2N926). As a results of several tests and measurements, it appears that transistor BC547A was one of the most adequate substitute. The "Hfe parameter" is rather critical for those three transistors (red dot on original circuit).
The three transistors installed were carefully selected with an Hfe between 180 and 185. The Noise Figure (N.F.) of BC547 series is rather low, in the range of 2 dB, which suits with this type of circuits where three stages are in series.

- Replacement of passive components :

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

capacitors: while less relevant than transistors and carbon resistors, the 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.

3.4. Output Voltage Amplifier.

With the replacement of transistor T4 (2N3391A) by BC550B (with Hfe = 390), this output voltage stage has been also entirely redesigned. The other reason, - probably due to aging of components – it was noticed that the output signal was no more symmetrical and exhibits severe distortion before clipping level.

The original board provided a max. output voltage of 15.6 Vpp (at clipping with 1% THD) while the new one climbs up to 21.7 Vpp.

However, it is important to mention that supply voltage of +22Vdc (as stated on Fig.5-7 of X-66 service Manual) has been lifted up to +24 Vdc to gain more headroom.
With +24 Vdc, the headroom is so increased by 6.1 Vpp, not negligible.
The 500 µF filter capacitor has been replaced by 1000µF/35V (C9) with another 100nF decoupling capacitor (C10) for better DC voltage stability.

It has to be noted that when depressing two octaves simultaneously (i.e. 24 keys at the same time), it is quite easy to reach 5 to 6 Vpp at the input of the Bass Vibrato board. Then, if this input voltage is multiplied by its own overall gain of x 3.7, that means 20.2 Vpp, it is easy to conclude that we are very near the clipping level and hence audible distortion may appear ! Think to that !

With 1Vpp pure sinewave @ 392 Hz (Key #44 depressed and 16' drawbar at position 8 as stated in the X-66 service manual), the Total Harmonic Distortion (THD) remains below 0.1 %. The gain of this output voltage amplifier is x 4.40.

The new component values can be found on the schematic diagram. To be noted that one resistor of 560K (R17) has been added between base of transistor T4 and ground.

3.5. 5.5 Hz RC Vibrato Oscillator.

During measurements of the original board, it was also noticed that the lower half-wave was somewhat distorted (bottom clipping) with the transistor 2N3393.
So, this particular RC oscillator has been redesigned with a new transistor BC548B (Hfe of 250) in order to come up with a clean undistorted 5.5 Hz sinewave signal.
Like always, the RC-oscillator circuit was 'virtually' tested via computer circuit simulator and later on was 'physically' tested on the bench to confirm the results.
The outcome of this entails several minor values of components and a pure 5.5Hz sinewave of 18 Vpp, fully symmetrical now, was recorded without anymore visible distortion on the scope. To be noted that one resistor of 1K (R26) has been added in the emitter of transistor T5.

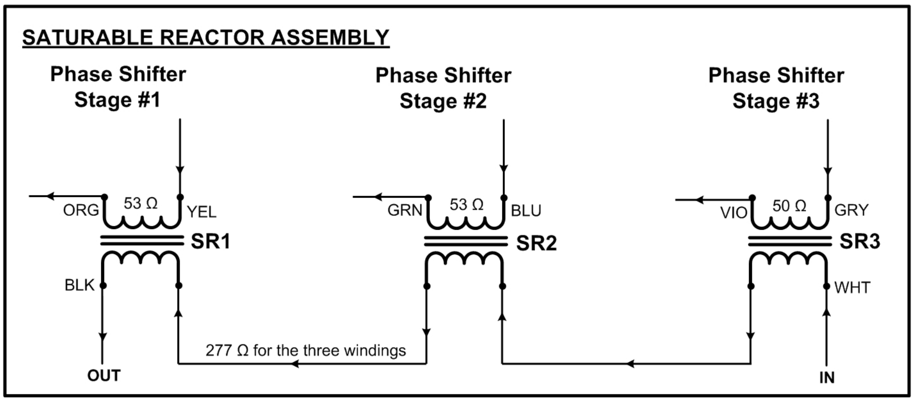
3.6. Saturable Reactor Driver stage.

Beside the replacement of both transistors 2N3391A by new BC550B (Hfe in the range of 300), this circuit has remained untouched. However, the adjustable potentiometer P1 has been replaced by a multi-turn cermet type. Signal strength has been adjusted for 600 mVpp at TP1 providing so an adequate frequency modulated signal.

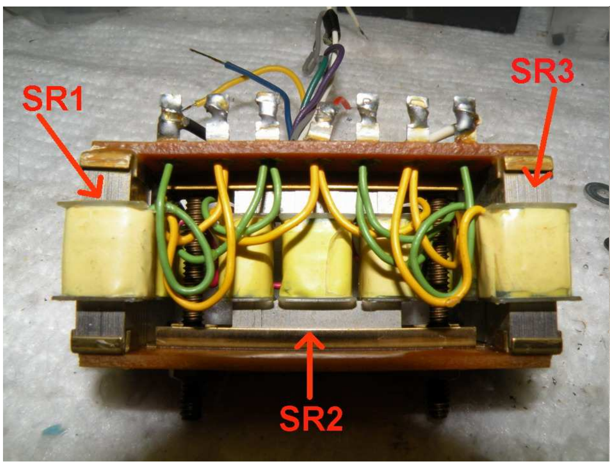
<u>About the Saturable Reactor Assembly.</u>

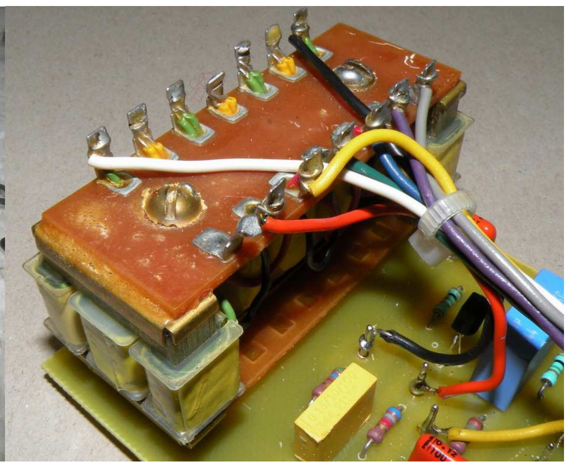
This special component is the result of intensive researches made by Hammond engineers. This type of saturable reactors can be found also in some Wurlitzer organs. For evident patents protection reasons, very few technical information is available. Nevertheless, an interesting description of this type of Saturable Reactor can be found on the following website : http://www.nshos.com/SReact.htm

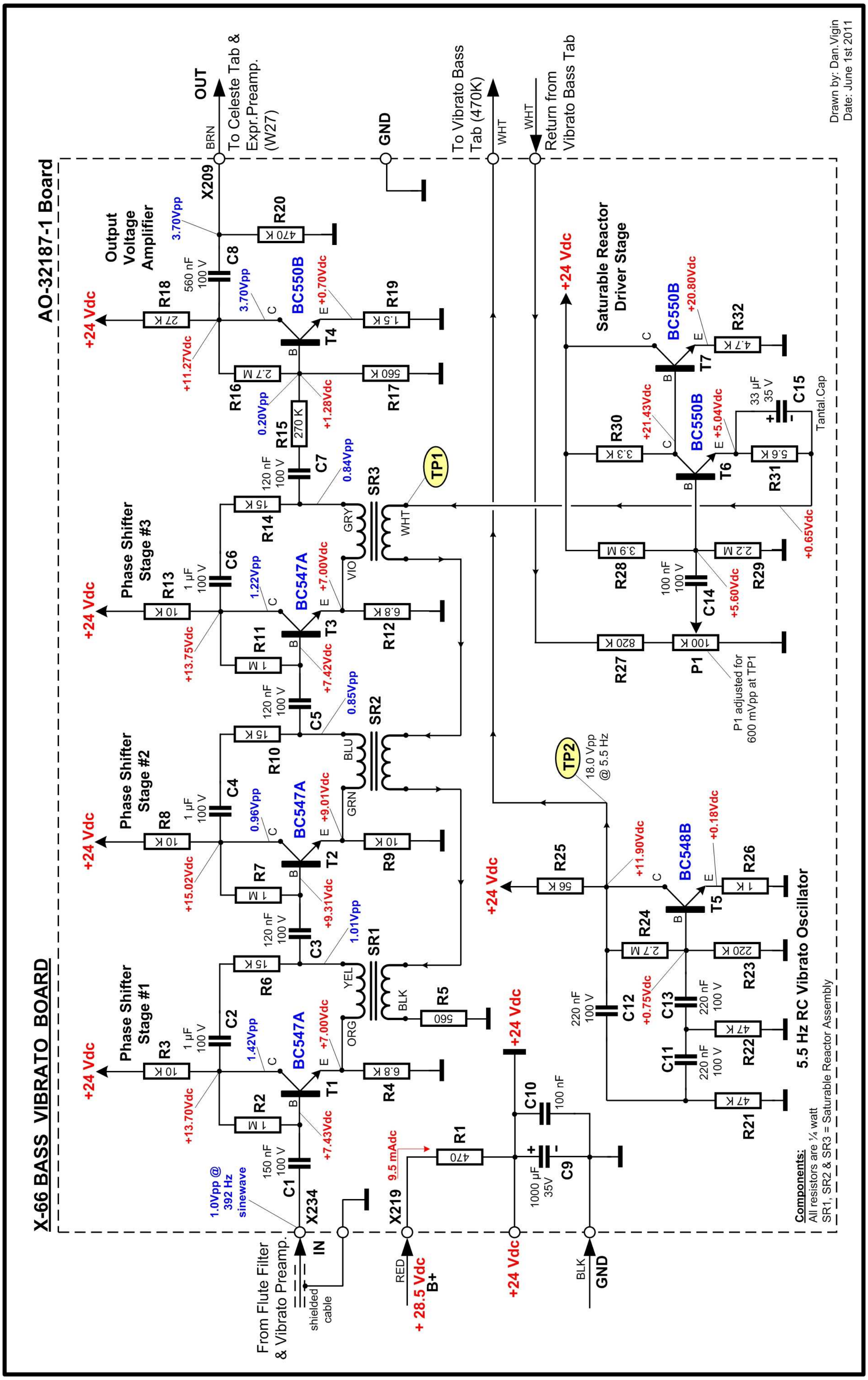
The drawing and pictures hereunder provide some practical details.



As shown on the next pictures, the Saturable Reactor Assembly is composed of three separate coils SR1, SR2 and SR3 that are mechanically integrated in one single unit.

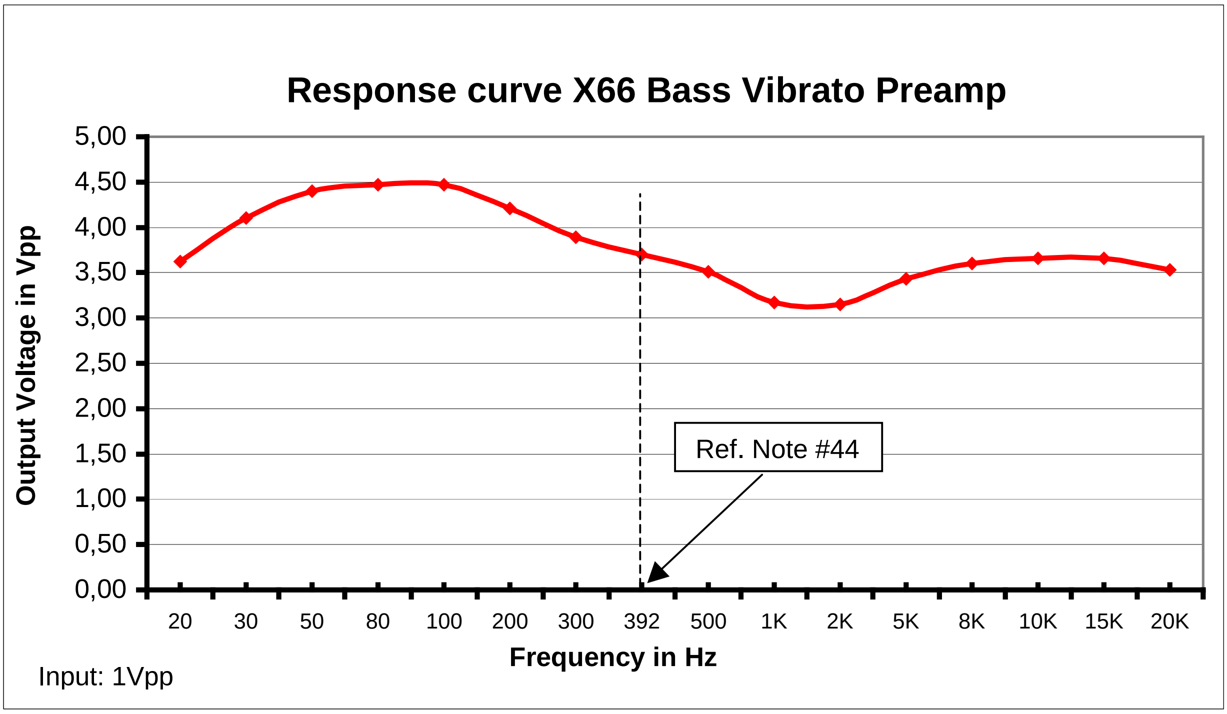





X-66 BASS VIBRATO BOARD
AO-32187-1 Board
From Flute Filter & Vibrato Preamp.
IN
shielded cable
X234
1.0Vpp @ 392 Hz sinewave
X219
RED
+ 28.5 Vdc
B+
9.5 mAdc
+24 Vdc
BLK
GND
Phase Shifter Stage #1
Phase Shifter Stage #2
Phase Shifter Stage #3
Output Voltage Amplifier
X209
BRN
OUT
To Celeste Tab & Expr.Preamp. (W27)
To Vibrato Bass Tab (470K)
WHT
Return from Vibrato Bass Tab
Saturable Reactor Driver Stage
5.5 Hz RC Vibrato Oscillator
TP1
TP2
18.0 Vpp @ 5.5 Hz
P1 adjusted for 600 mVpp at TP1
Tantal.Cap
Components:
All resistors are ¼ watt
SR1, SR2 & SR3 = Saturable Reactor Assembly
Drawn by: Dan.Vigin
Date: June 1st 2011

5. Tests and Measurements.

1. Frequency Response.



The above graphic depicts the frequency response of the Bass Vibrato circuit from the input up to the output. Since the highest concerned frequency is 392 Hz (note #44), it was expected to get a frequency roll-off from this point onwards.
In reality, it is not and frequency response above 2 KHz the remains almost constant up to 20 KHz. This was confirmed on both original and newly redesigned boards.

2. Overall Gain.

This performance was already mentioned in the Circuits Description section.
The IN/OUT overall gain is x 3.7 on the new board and was x 3.37 on the original one with a 1 Vpp @ 392 Hz sinewave input signal.

3. Headroom / Max. input Sensitivity.

The max. output level (for 1% THD) before clipping is now 21.7 Vpp with an 5.86 Vpp sinewave signal of 392 Hz at the input. Above this input level, clipping and distortion will severely climb up and will become very audible.

4. Total Harmonic Distortion (THD).

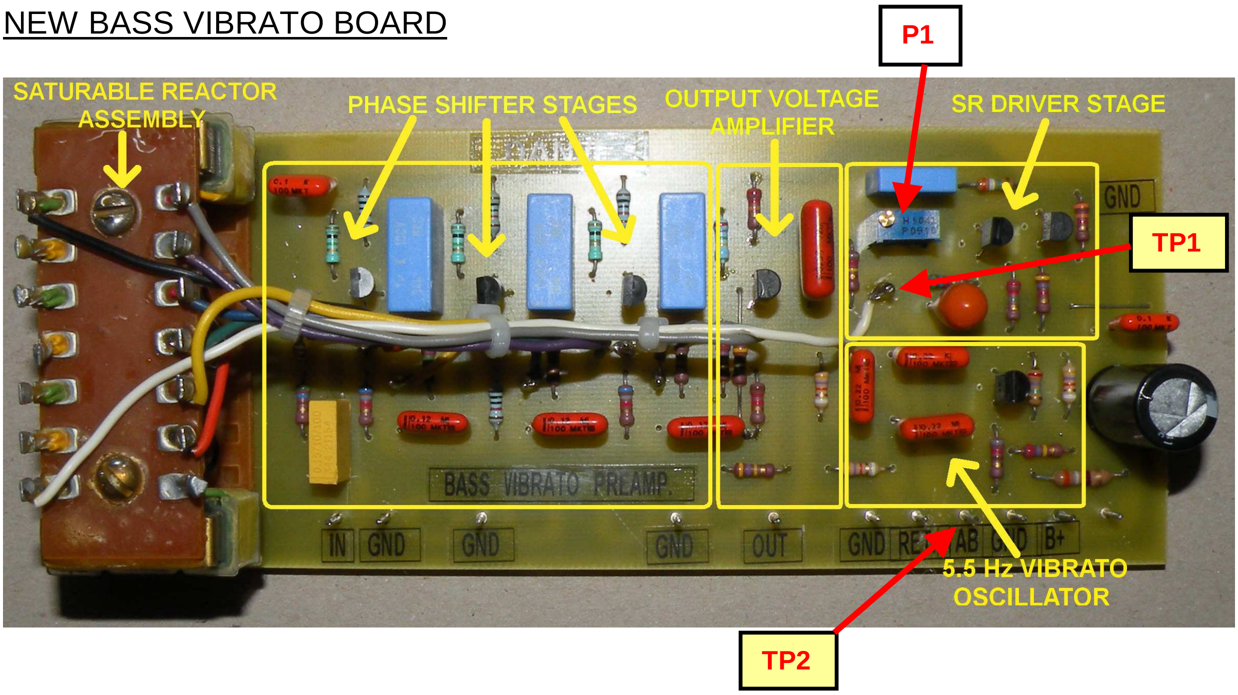
THD is below 0.1 % with 1Vpp input signal @ 392 Hz. With lower levels in the range of 100 mVpp, THD will drop to 0.06%.

6. Realization

There is not so much to write about the realization. Beside the saturable reactor assembly, all other active and passive components were replaced by new ones.

The picture hereunder shows the position of the different stages on board.

NEW BASS VIBRATO BOARD



The size of the new board is a replica of the original board and position of connecting points have been taken into consideration to avoid any wiring problem during installation.

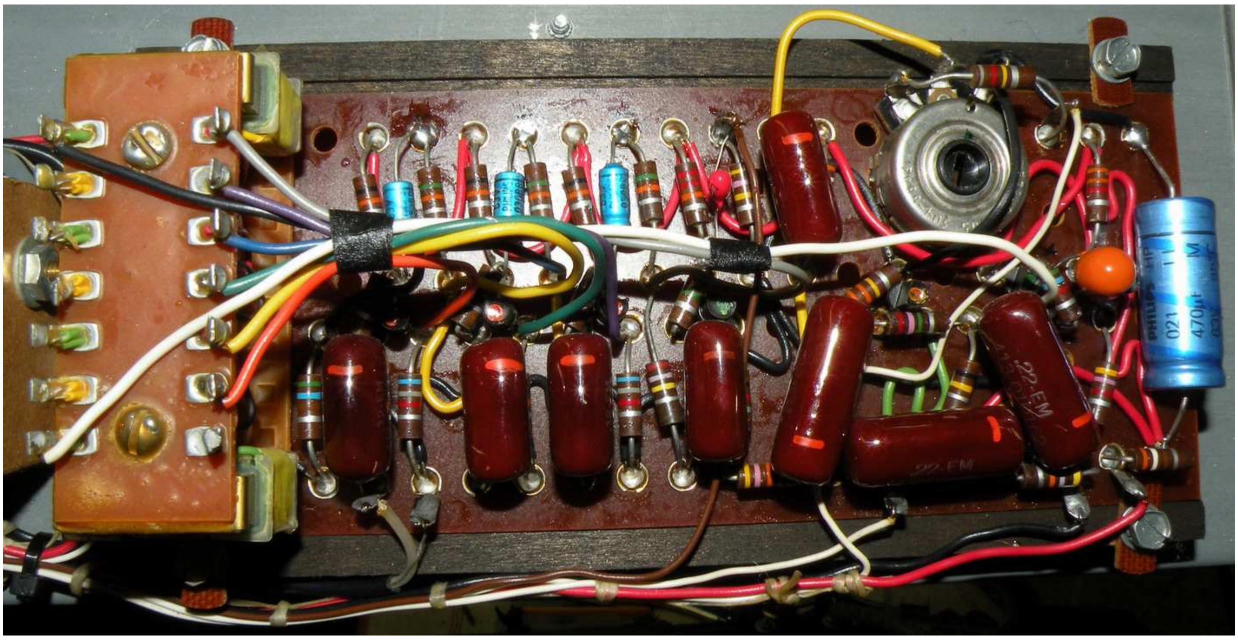
When the new board is installed, the only adjustment to be done is the level of phase shifting via the potentiometer P1. The probe of the scope has to be put on Test-Point TP1 and the level adjusted for 600 mVpp.
This level can be accommodated to your personal appreciation.

The amplitude and frequency of the 5.5 Hz vibrato oscillator can be checked also at Test-Point TP2 with the scope. The amplitude should be near 18 Vpp.

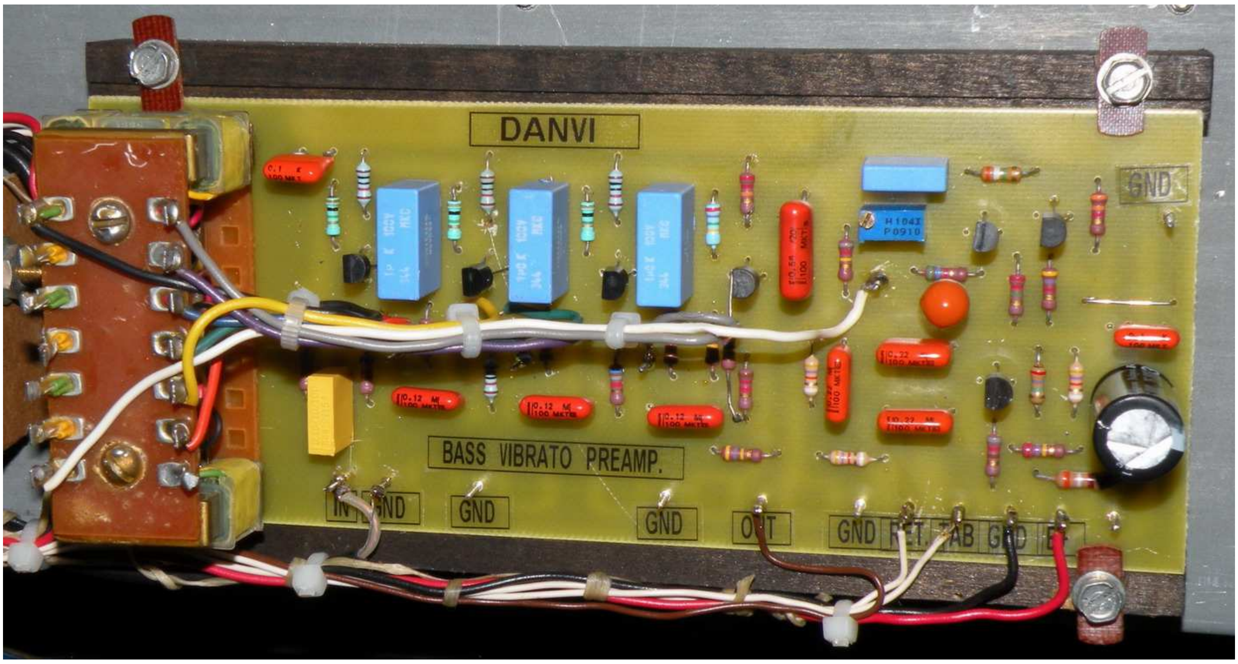
Both views of components side and copper side of the printed circuit board are provided in Appendix #1.

7. Bass Vibrato board – AO-32187-1

Before



After



8. Conclusions.

When playing, it seems to me that the sound of my X-66 is "cleaner" than before,
I would mean more "transparent" whether one note is played at a time or chords.

However, we all know that sound reproduction is rather subjective topic and depends from individuals. Difficult to say also since human ear does have very bad memory.

As far as the residual 'noise level', some slight improvements were noticed with the use of low-noise transistors T1 to T4 but again it is not easy to express in which ratio this inherent noise has been reduced since this depends of so many other parameters.

To my opinion, the major improvement remains the additional 25% headroom granted with the modifications of the Voltage Output Stage.

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.

In my case, no doubt that the new Bass Vibrato board will stay operating in my X-66 Console.

Trust having been of some help,

Dan Vigin

APPENDIX #1 – Printed Circuit Board.