Hammond® X-66

Notes and Frequencies

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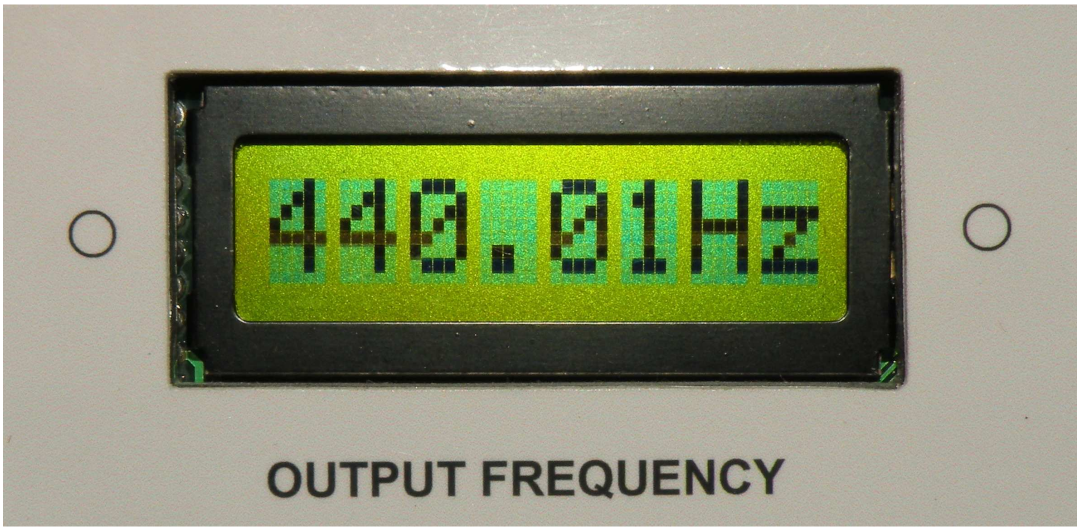

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X-66 Notes and Frequencies.

1. Forewords – Purpose of this Project

This article is mostly addressed to technicians or X-66 'fanatics' who want to understand better the connection between the Hammond 'Note numbers' and the effective tone frequency involved.

In the Hammond jargon, every note is defined by an abstract number which doesn't mean too much to any technician. In fact, this abstract number is an 'alias' of the frequency of the output signal of the concerned played key in function of the drawbar pulled out.

It is important to get a clear view of the following definitions:

1. **'Key Number'** : this number is assigned to the position of the key on the keyboard itself. For instance, C25 means the 'C' key in the middle of the keyboard (C of the third octave). There are max. 61 'Key Numbers'.

2. **'Note Number'** : this number implies the frequency of the output signal when depressing a certain 'Key Number' on the keyboard in function of the drawbar in use. In the X-66 console, there are a max. of 97 'Note Numbers'.

3. **'Frequency'** : this concept is not in common use in the Hammond service manuals and expresses in Hertz the effective sound output.
Since one 'Frequency' is assigned to the related 'Note Number', in the X-66 console, there are 97 'frequencies' available.

When working or repairing organs such as the X-66 console, it is my feeling that it is always easier to check and measure circuits while knowing the exact frequencies involved. i.s.o. abstract references such as " Note Numbers".

This point is particularly true when working with the frequency dividers boards as used in the X-66 notably.

In fact, as far as the relationship between 'Note Number' and 'Frequency', this article is not specific to the X-66 Console but is also applicable to other vintage Hammond organs such as models B3, C3, etc... The same Hammond nomenclature is used.

Questions like : *' What is the lowest and highest frequencies of this organ ? '*.
Most of players and technicians haven't got a clue of it.

The purpose of this article will fill this gap.

2. Fundamentals on X-66 Tone Frequencies.

The theory of operation concerning the tone-generation of the X-66 Console has been already developed in the main section " Restoring Part 2 " of the X-66 Hammond website. For more details, also refer to Annexes : "TWG Dividers" and "X-Tal Generator".

Like most of today's electronic keyboards, the X-66 Console is designed to reproduce the 'Equally-tempered musical scale' i.e. the only temperament available for such electronic instruments. Please, also visit : http://www.nshos.com/temperament.htm for those who wish to get more information on this point.

The Top-Octave frequencies are generated by one Tone-Wheel-Generator (TWG) driven by one self-starting synchronous motor.

The table hereunder shows the effective values measured at the output connector of TWG opposed to the ideal theoretical frequencies.
It is easy to deduct that the generated pitches do not correspond exactly to the perfect equally tempered scale.

Top Key Ref.	**Theoretical frequencies**	**Measured frequencies** *
C	4186,01 Hz	4185 Hz
C#	4434,92 Hz	4432 Hz
D	4698,64 Hz	4696 Hz
D#	4978,03 Hz	4977 Hz
E	5274,04 Hz	5272 Hz
F	5587,65 Hz	5587 Hz
F#	5919,91 Hz	5920 Hz
G	6271,93 Hz	6269 Hz
G#	6644,88 Hz	6643 Hz
A	7040,00 Hz	7041 Hz
A#	7458,62 Hz	7457 Hz
B	7902,13 Hz	7901 Hz

* Effective values measured at TWG output connector.

However, those little discrepancies in the top octave frequencies are negligible for the following reasons :

- The human ear is very sensitive to frequency variations in the range of 250Hz to 3 KHz. In this bandwidth, the human ear can detect a variation of frequency up to 0,06% ! To illustrate that, if one takes the 'A – 440,00 Hz' as reference, this means that the human ear is sensitive enough to detect a detuning frequency of 0,26 Hz, i.e. below 439,74 Hz and above 440,26 Hz (this means one beat every 4 seconds).
Above this frequency band, the human ear can only perceive a variation of frequency of 0,4 %. Just to give an idea, the variation of frequency of a vibrato violin is 0,5 % and increasing a note by one half-tone is 6 %.

- When looking to the 7041 Hz measured frequency column, we have to divide by 2 x 2 x 2 x 2 to obtain the A note which will become 440,062 Hz. This value is about 4 times below the threshold of detectable audible variation.

The generated pitches are close enough to give a very good sounding result.
See also : http://www.nshos.com/HammondX66-6.htm for further details.

Good to remember. When playing the A - 440 Hz, the upper octave of A 'key' will be 880 Hz while the lower octave of this A 'key' will be 220 Hz.
To get the lower octave of any note, the frequency has to be divided by 2.
To get the upper octave of any note, the frequency has to be multiplied by 2.

The conversion table on the next page depicts the existing relationships between the Hammond 'Note numbers' and the corresponding 'Frequencies'.
For instance, if you play the Note # 25 ('C' of the 3rd octave) in the middle of the keyboard with drawbar 16' pulled out, you will generate a tone frequency of 130,81 Hz in your speakers. However, if you keep depressing the same Note # 25 but with drawbar 8' pulled out, then the frequency heard will be doubled, this means 261,62 Hz.

When looking this conversion chart, this brings us to conclude that the lowest frequency of the Hammond X-66 is 32,7 Hz while the highest frequency is 8372 Hz.

By comparison, the highest note available on the legendary Hammond B3 is Note # 91 (i.e. 5919 Hz), so the Hammond X-66 provides a bandwidth that is 2453 Hz much higher than the B3. The lowest note C (Note # 1) is identical on both organs.

It is also interesting to notice that Hammond concert models such as RT-2 and RT-3 are featured with 32 pedal keys i.s.o. 25 pedal keys as on X-66, B3, etc...
The 32' Bourdon and 32' Bombarde available on those concert models are operating one octave lower than other organs. They are so-called 32-foot tones.
Frequencies are extremely low (see table hereunder) and provides very deep bass undulation when playing low in the first octave of the pedal. Those two 32-foot registers provide a "felt' effect but should be always used in conjunction with other higher pitched registers such as 16' or 8'.

32-foot tones (RT-2 & RT-3)

Hammond Note Nbr.	**'Key' Ref. Octave '0'**	**Frequency in Hz.**
Sub 1	C	16,3516
Sub 2	C#	17,3239
Sub 3	D	18,3540
Sub 4	D#	19,4454
Sub 5	E	20,6017
Sub 6	F	21,8268
Sub 7	F#	23,1247
Sub 8	G	24,4997
Sub 9	G#	25,9565
Sub 10	A	27,5000
Sub 11	A#	29,1352
Sub 12	B	30,8671

3. Conversion table 'X-66 Hammond Keys' to 'Frequencies'.

Hammond Note Nbr.	'Key' Ref. 1st octave	Frequency in Hz.	Hammond Note Nbr.	'Key' Ref. 2nd octave	Frequency in Hz.	Hammond Note Nbr.	'Key' Ref. 3rd octave	Frequency in Hz.	Hammond Note Nbr.	'Key' Ref. 4th octave	Frequency in Hz.
1	C	32,7032	13	C	65,4064	25	C	130,813	37	C	261,626
2	C#	34,6478	14	C#	69,2957	26	C#	138,591	38	C#	277,183
3	D	36,7081	15	D	73,4162	27	D	146,832	39	D	293,665
4	D#	38,8909	16	D#	77,7817	28	D#	155,563	40	D#	311,127
5	E	41,2034	17	E	82,4069	29	E	164,814	41	E	329,628
6	F	43,6536	18	F	83,3071	30	F	174,614	42	F	349,228
7	F#	46,2493	19	F#	92,4986	31	F#	184,997	43	F#	369,994
8	G	48,9994	20	G	97,9989	32	G	195,998	44	G	391,995
9	G#	51,9131	21	G#	103,826	33	G#	207,652	45	G#	415,305
10	A	55,0000	22	A	110,000	34	A	220,000	**46**	**A**	**440,000**
11	A#	58,2705	23	A#	116,541	35	A#	233,082	47	A#	466,164
12	B	63,7354	24	B	123,471	36	B	246,942	48	B	493,883
Hammond	'Key' Ref.	Frequency	Hammond	'Key' Ref.	Frequency	Hammond	'Key' Ref.	Frequency	Hammond	'Key' Ref.	Frequency
Note Nbr.	5th octave	in Hz.	Note Nbr.	6th octave	in Hz.	Note Nbr.	7th octave	in Hz.	Note Nbr.	8th octave	in Hz.
49	C	523,251	61	C	1.046,50	73	C	2.093,00	85	C	4.186,01
50	C#	554,365	62	C#	1.108,73	74	C#	2.217,46	86	C#	4.434,92
51	D	587,330	63	D	1.174,66	75	D	2.349,32	87	D	4.698,64
52	D#	622,254	64	D#	1.244,51	76	D#	2.489,02	88	D#	4.978,03
53	E	659,255	65	E	1.318,51	77	E	2.637,02	89	E	5.274,04
54	F	698,456	66	F	1.396,91	78	F	2.793,83	90	F	5.587,65
55	F#	739,989	67	F#	1.479,98	79	F#	2.959,96	91	F#	5.919,91
56	G	783,991	68	G	1.567,98	80	G	3.135,96	92	G	6.271,93
57	G#	830,609	69	G#	1.661,22	81	G#	3.322,44	93	G#	6.644,88
58	A	880,000	70	A	1.760,00	82	A	3.520,00	94	A	7.040,00
59	A#	932,328	71	A#	1.864,66	83	A#	3.729,31	95	A#	7.458,62
60	B	987,767	72	B	1.975,53	84	B	3.951,07	96	B	7.902,13
									97	**C**	**8.372,02**

4. Note # 97 on Hammond X-66.

When analysing the table of frequencies (page 4), it appears that the highest frequency available from the TWG is Note # 96 (7902 Hz).
Then, Note # 97 (highest C, red coloured on the table) is not issued by the TWG and another solution has to be found.

In fact, the Note # 97 is generated by Note # 78. The square wave signal is extracted from the 'F' divider board AO-28967-3 at Pt. D5-78.
Square wave signals provide uneven harmonics (i.e. 3rd, 5th, 7th..).

Now, we know that Note # 78 is rated at 2793,83 Hz.
By applying this frequency into a band-pass filter sharply tuned to the third harmonic(1), the other components of this signal will be suppressed and only this frequency multiplied by a factor of 3 will go through. So 2793,83 Hz x 3 = 8.381,49 Hz.

The result is a frequency of 9 Hz higher that the theoretical frequency of 8372,02 Hz. No problem for the ear since this discrepancy is only 0,11 % and we have previously seen that above 3 KHz, the human ear can only detect frequency variations of 0,4 %. So, it's about four times lower, no real problem.

To be noted that after filtering out of this band-pass filter, this new frequency is purely a 'sine wave' signal and not more 'square-wave'.

(1) technique currently used by radio-ham's.

5. X-66 Wiring charts

It is interesting to establish a close correlation between the Conversion Table of Page 6 and the wiring charts Fig. 4-3 and Fig. 4-4 of the X-66 service manual.

Two examples:

- Bottom row (Spring row #1) of this wiring chart – Sub Fundamental or 16' drawbar :
    - First Note Number is 1 and last Note Number is 61.
    - When depressing Key # 1 (first row on top of the chart), you get 32,7 Hz output
    - When depressing Key # 61, you get 1046,5 Hz output.

- Third row (Spring row #3) – Fundamental or 8' drawbar :
    - First Note Number is 13 and last Note number is 73
    - When depressing Key # 1 (first row on top of the chart), you get 65,4 Hz (i.e. 2 x 32,7 Hz)
    - When depressing Key # 61, you get 2093 Hz (i.e. 2 x 1046,5 Hz).

6. Conclusions

Based on my personal experience on Hammond organs, I was considering to write something about the relationship between Hammond Note Numbers, Keys Numbers, Frequencies... since I was confused myself at certain moment with those different definitions while restoring or repairing organs.

To my opinion, the conversion table provided on Page 6 associated with the wiring chart Fig. 4-3 & Fig. 4-4 of the X-66 service manual should clarify this situation and can be also applied to other vintage Hammond organs.

Trust having been of some help with those information.

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