

April 24, 1934.

L. HAMMOND

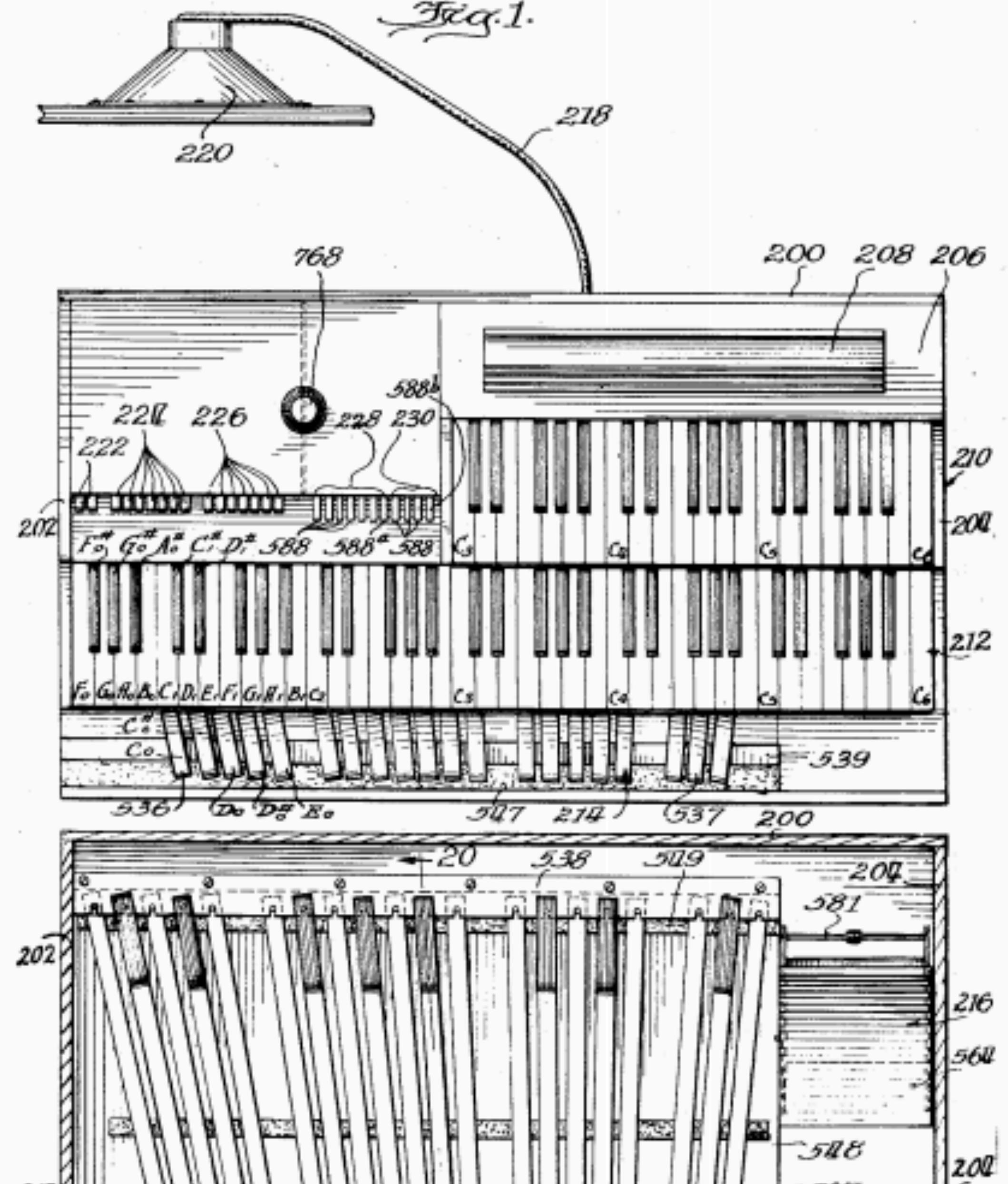
1,956,350

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934.

18 Sheets-Sheet 1

Fig. 1.



Hello

@pteichman





XIMIAN GNOME

The Complete Desktop Environment

Fv1.40601E

littl



fastly.[®]







GREEN ONIONS

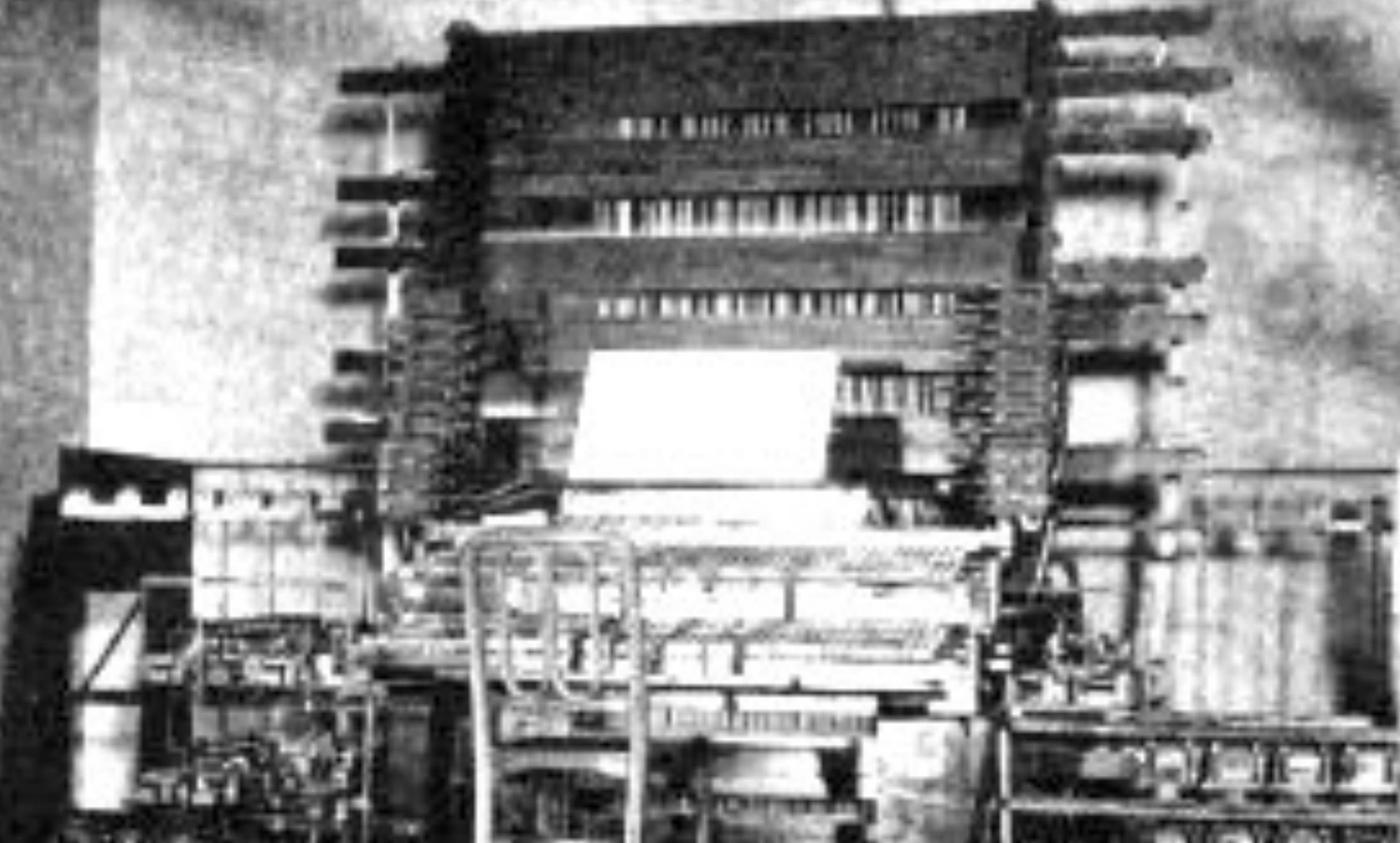
BOOKER T. & THE M.G.S



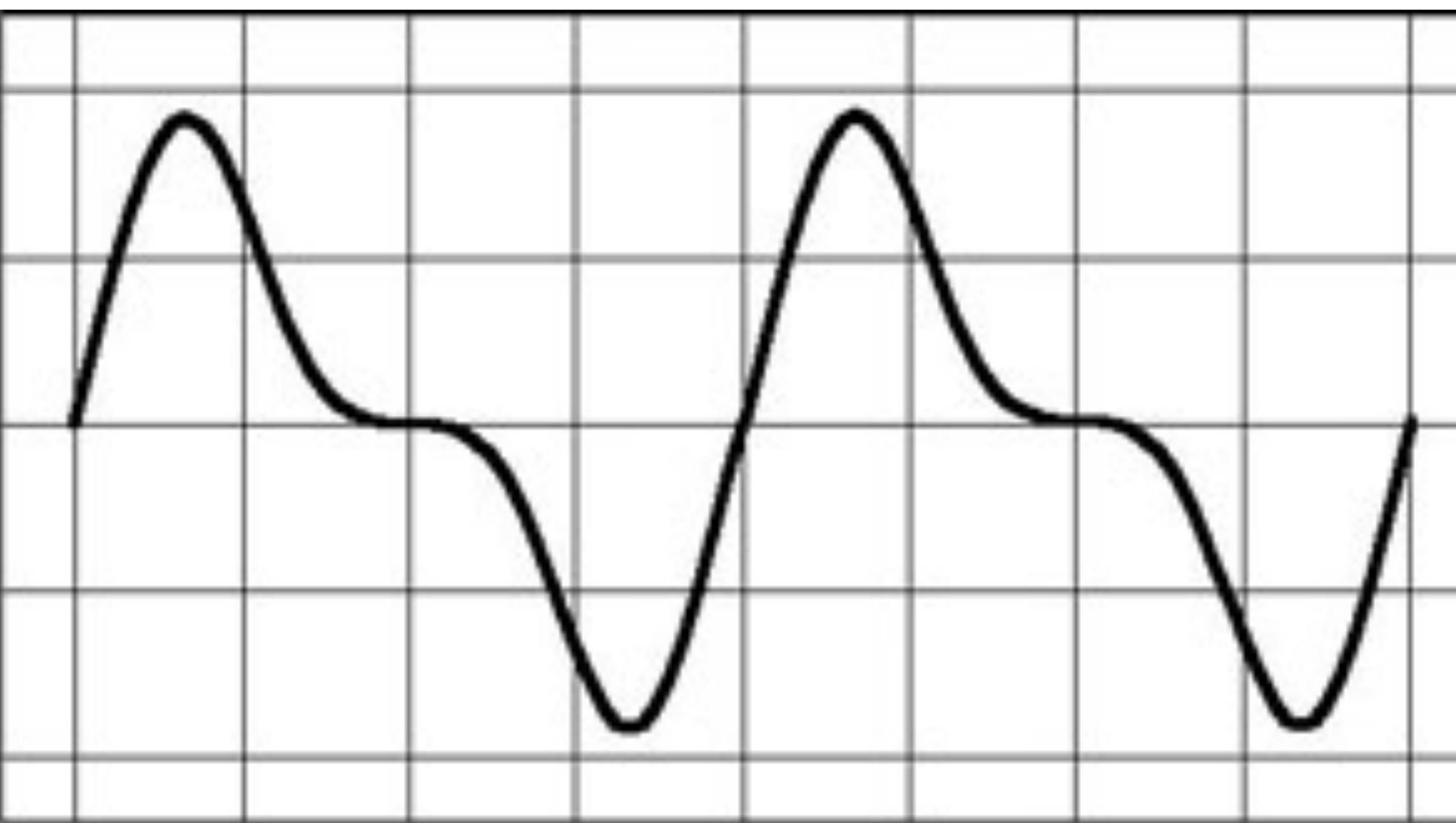
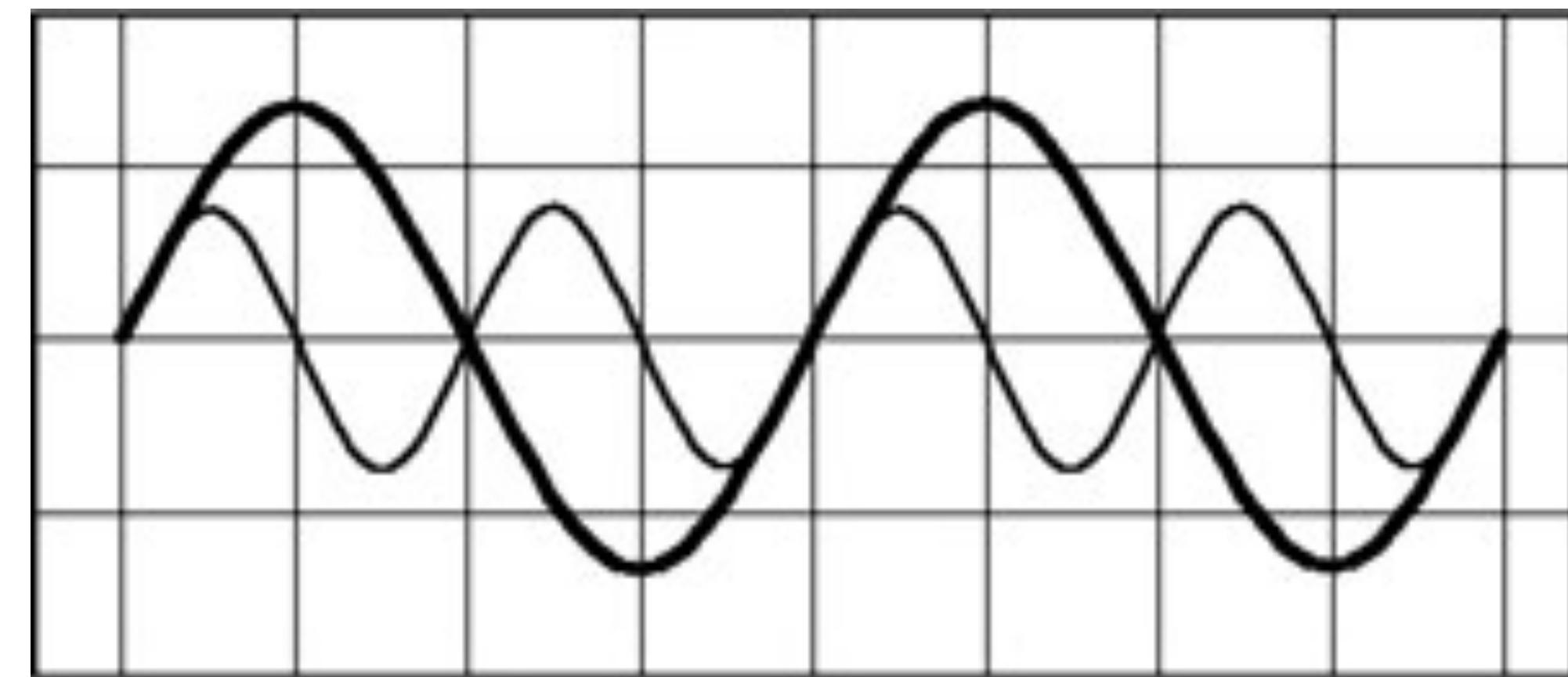
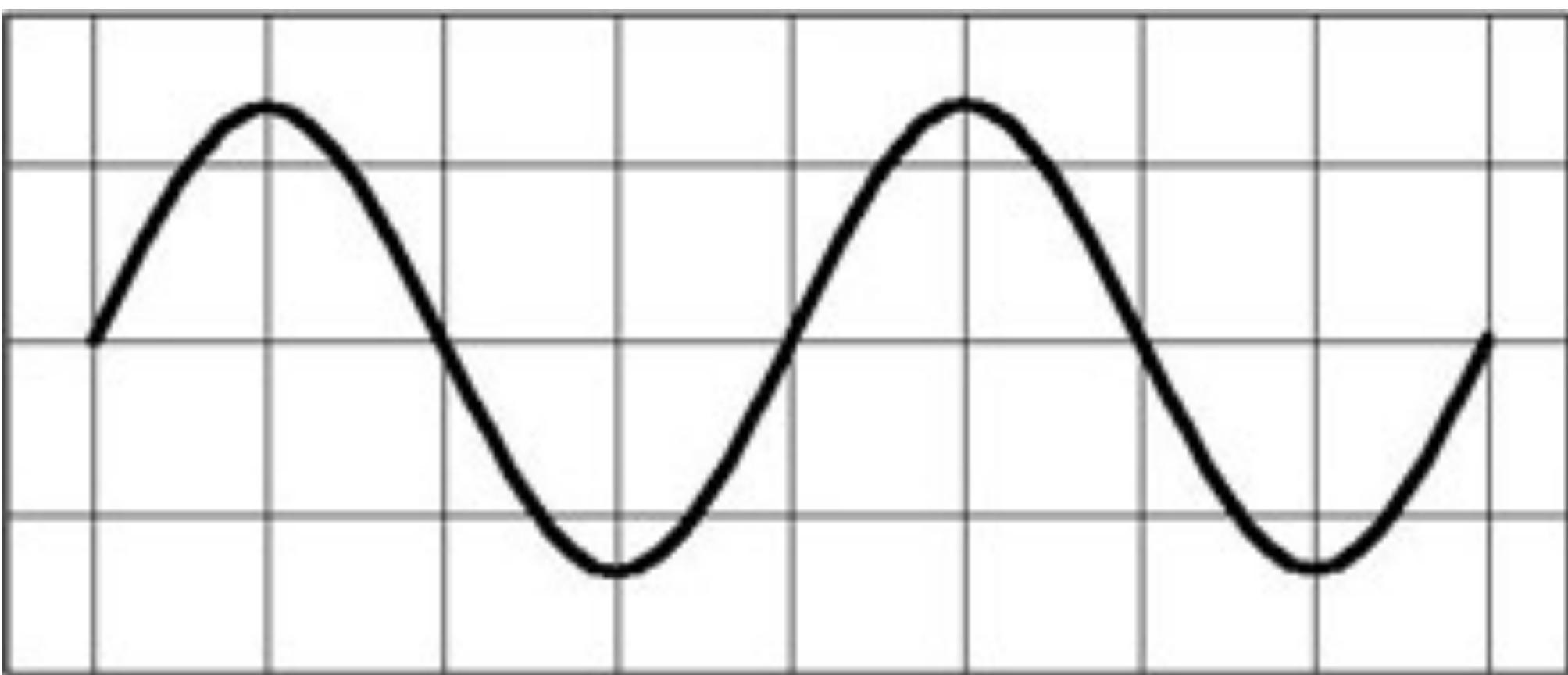
PRELUDE

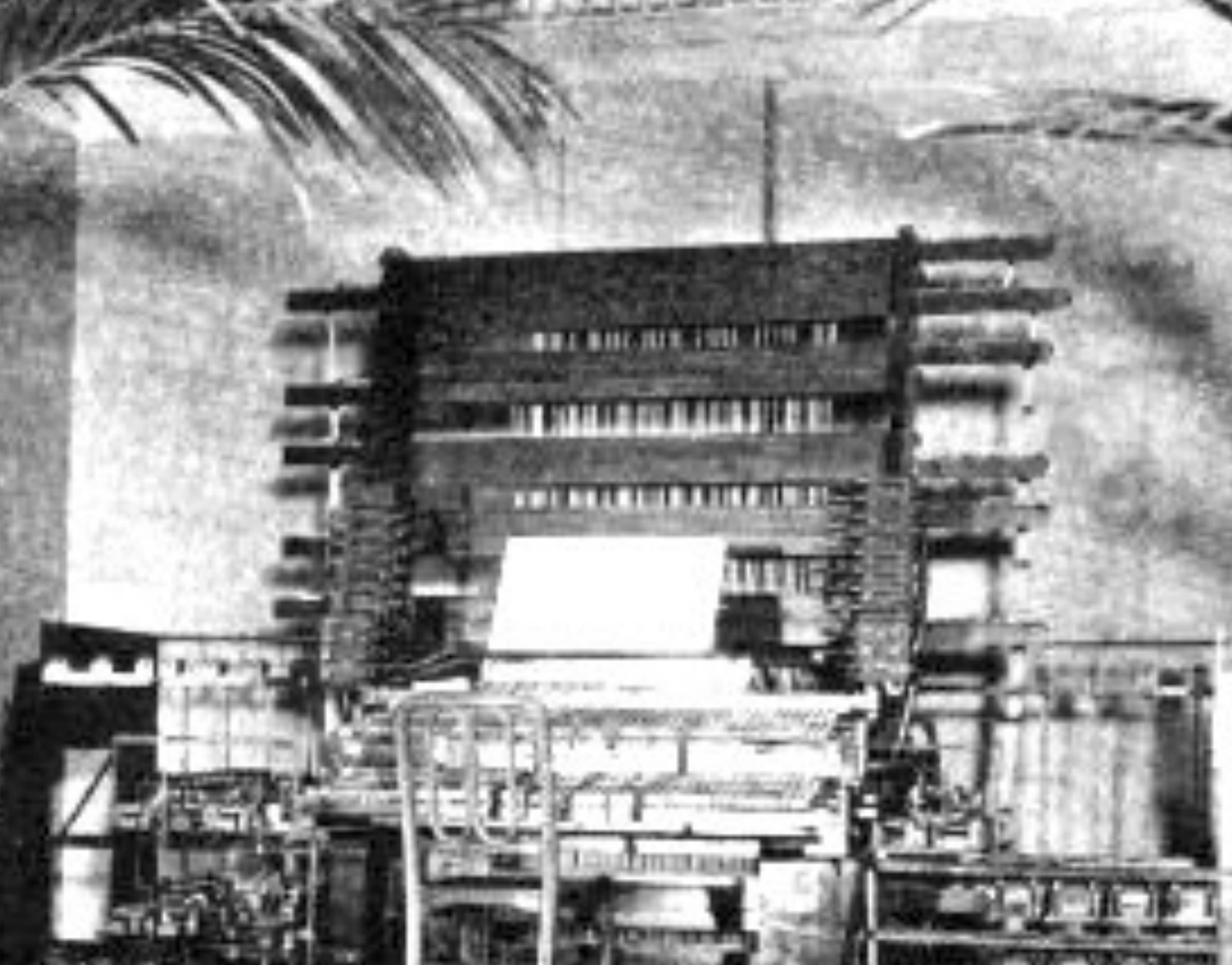
Super Heavy Organ

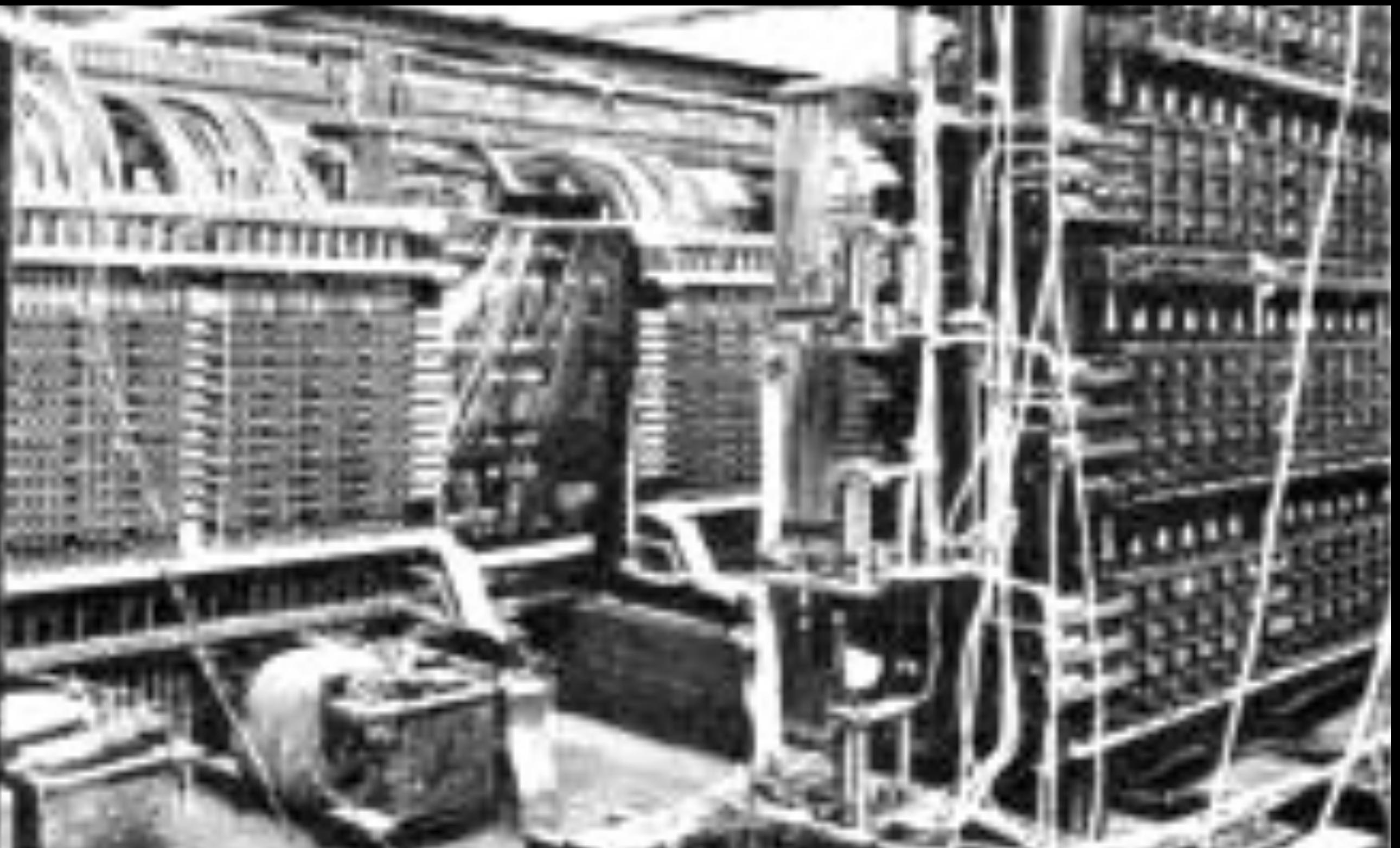
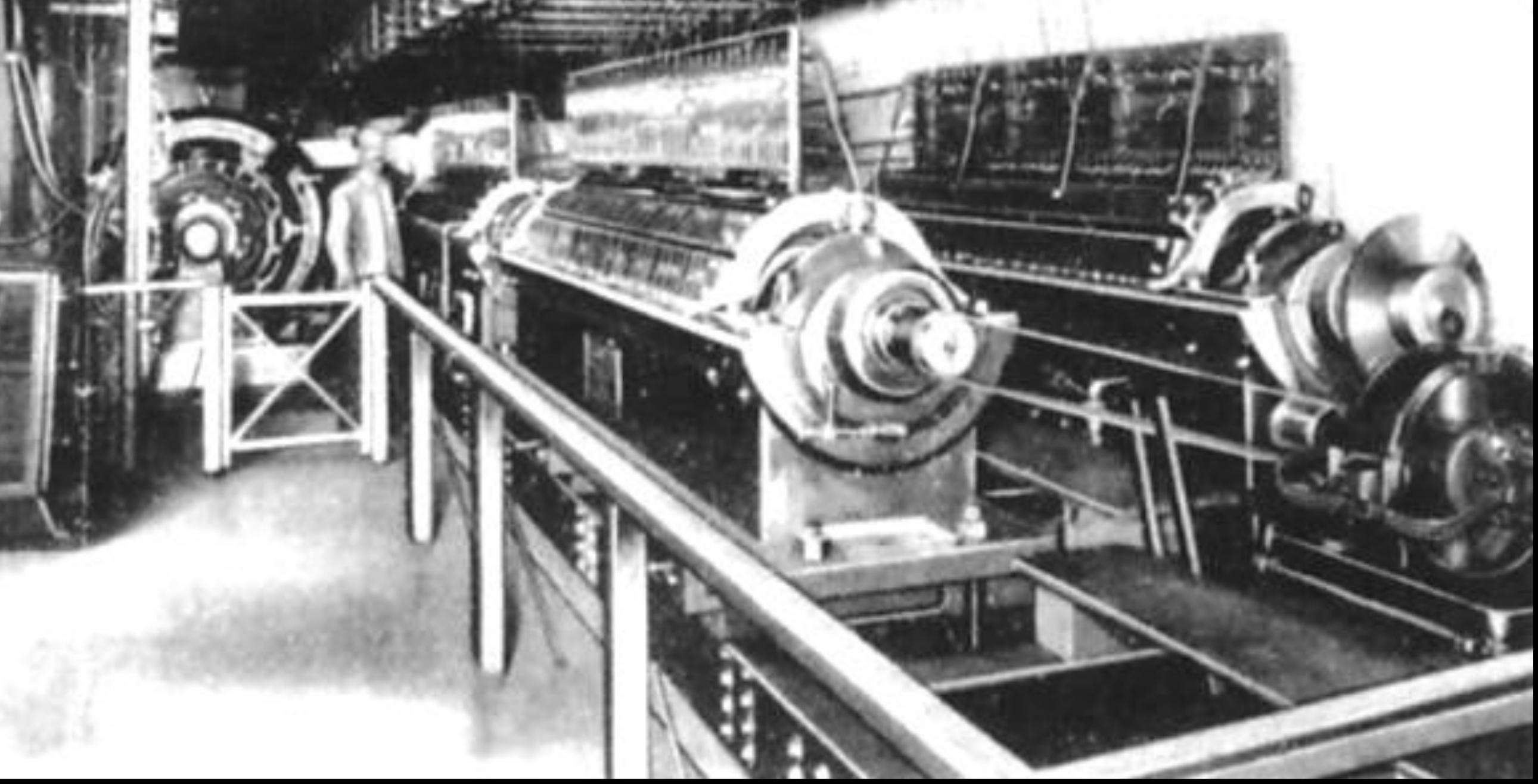
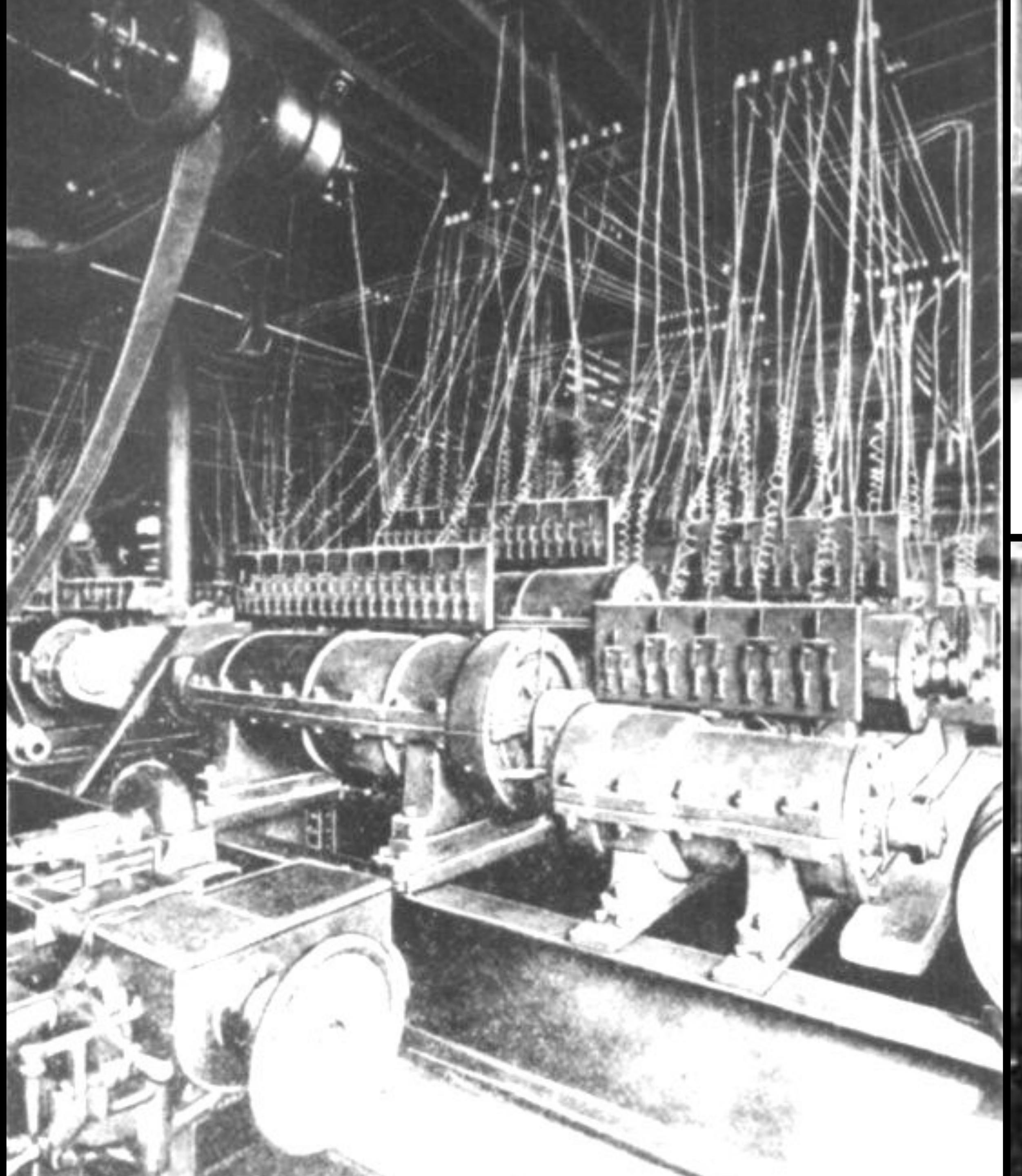
Telharmonium: 1906

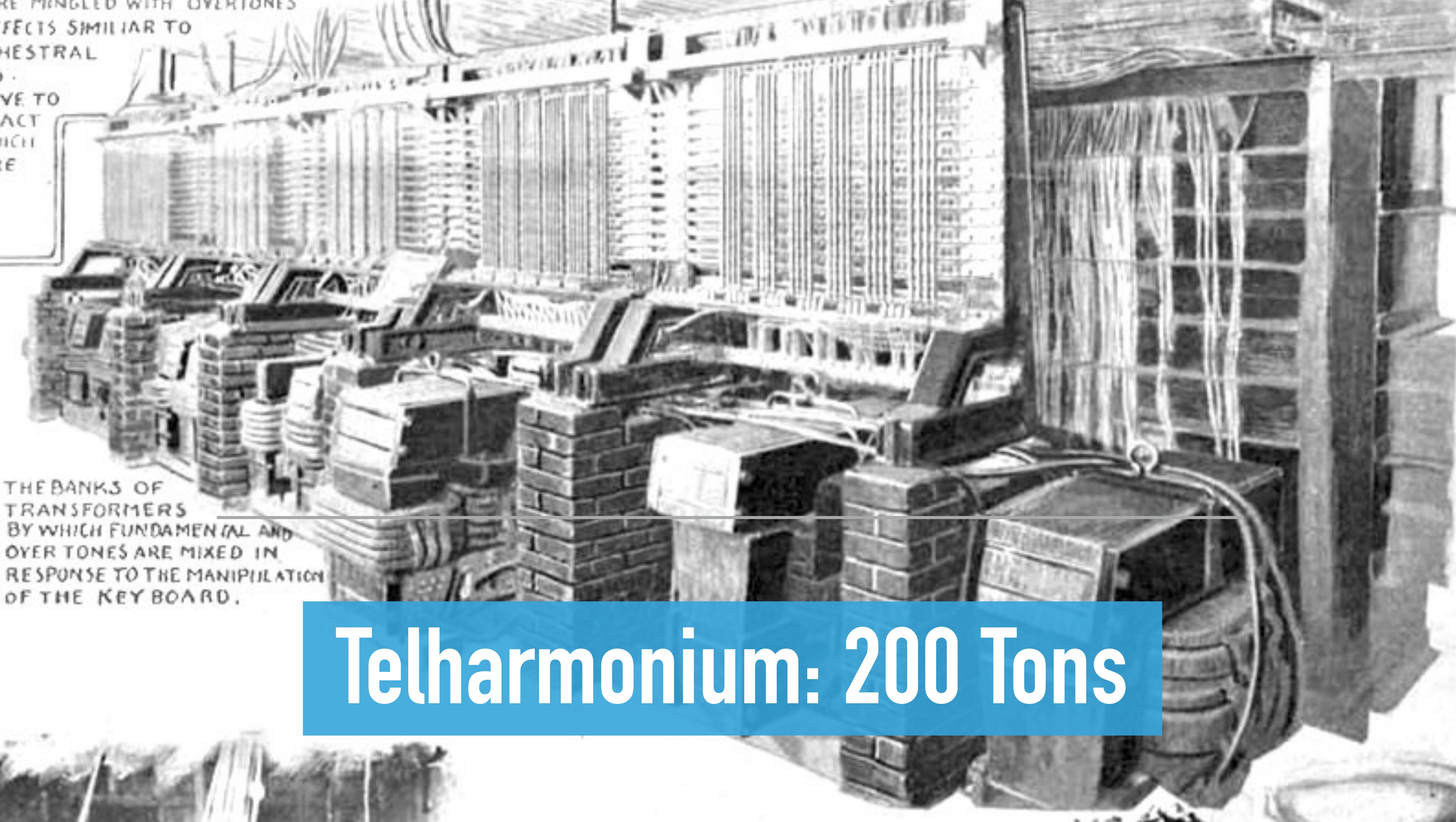












ARE MINGLED WITH OVERTONES
EFFECTS SIMILAR TO
CHESTRAL
...
IVE TO
ACT
NUCE
RE

THE BANKS OF
TRANSFORMERS
BY WHICH FUNDAMENTAL AND
OVERTONES ARE MIXED IN
RESPONSE TO THE MANIPULATION
OF THE KEY BOARD.

Telharmonium: 200 Tons





Hammond B-3: 420 lbs



Hammond B-3: 420 lbs
Leslie 122: 140 lbs

Roto



www.arduino.cc

Arduino
Duemilanove™

RESET

EFTDI

TX

RX

S1

00000000

SDSS

E01

103

102

102

SK1602

103

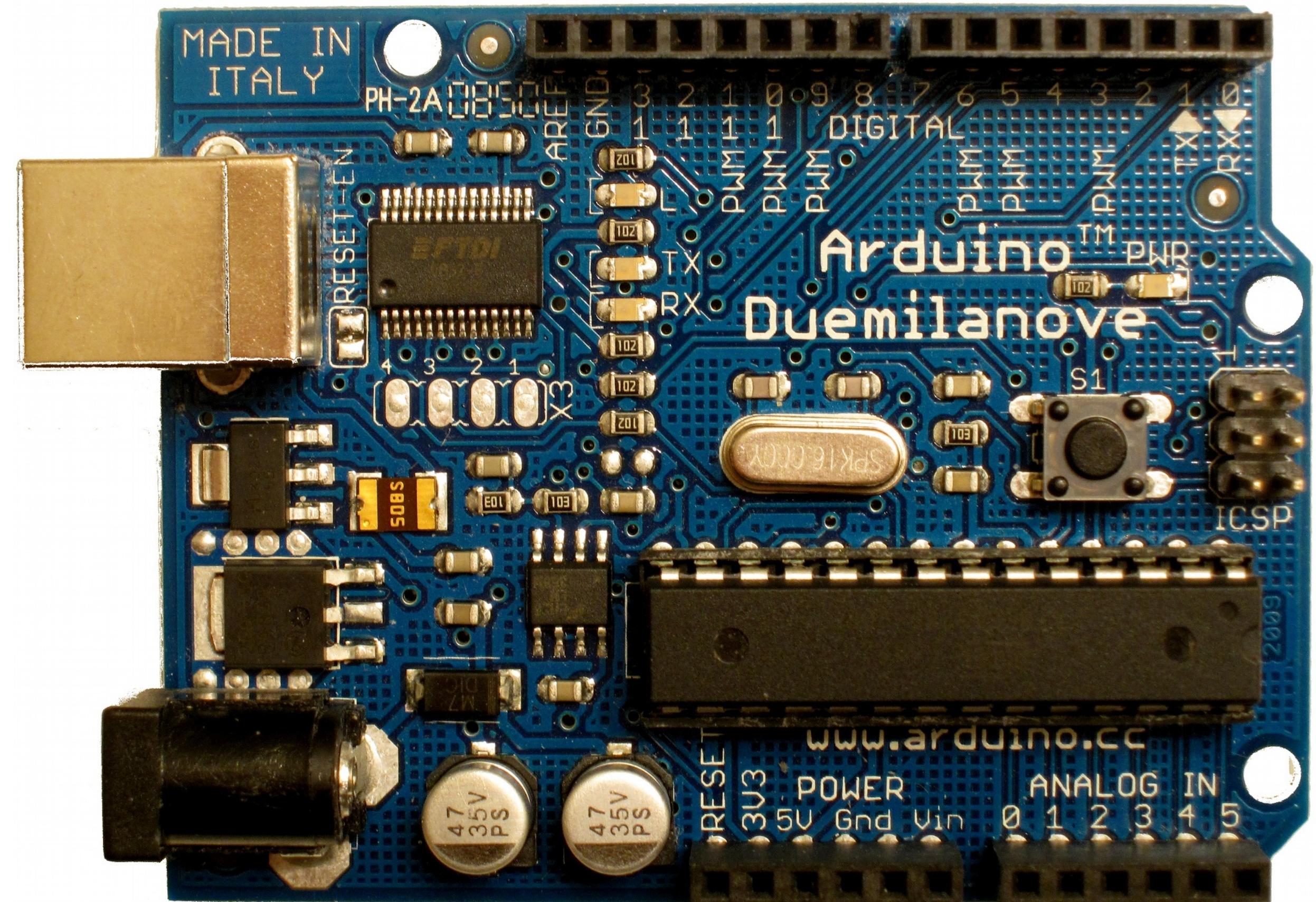
PWR

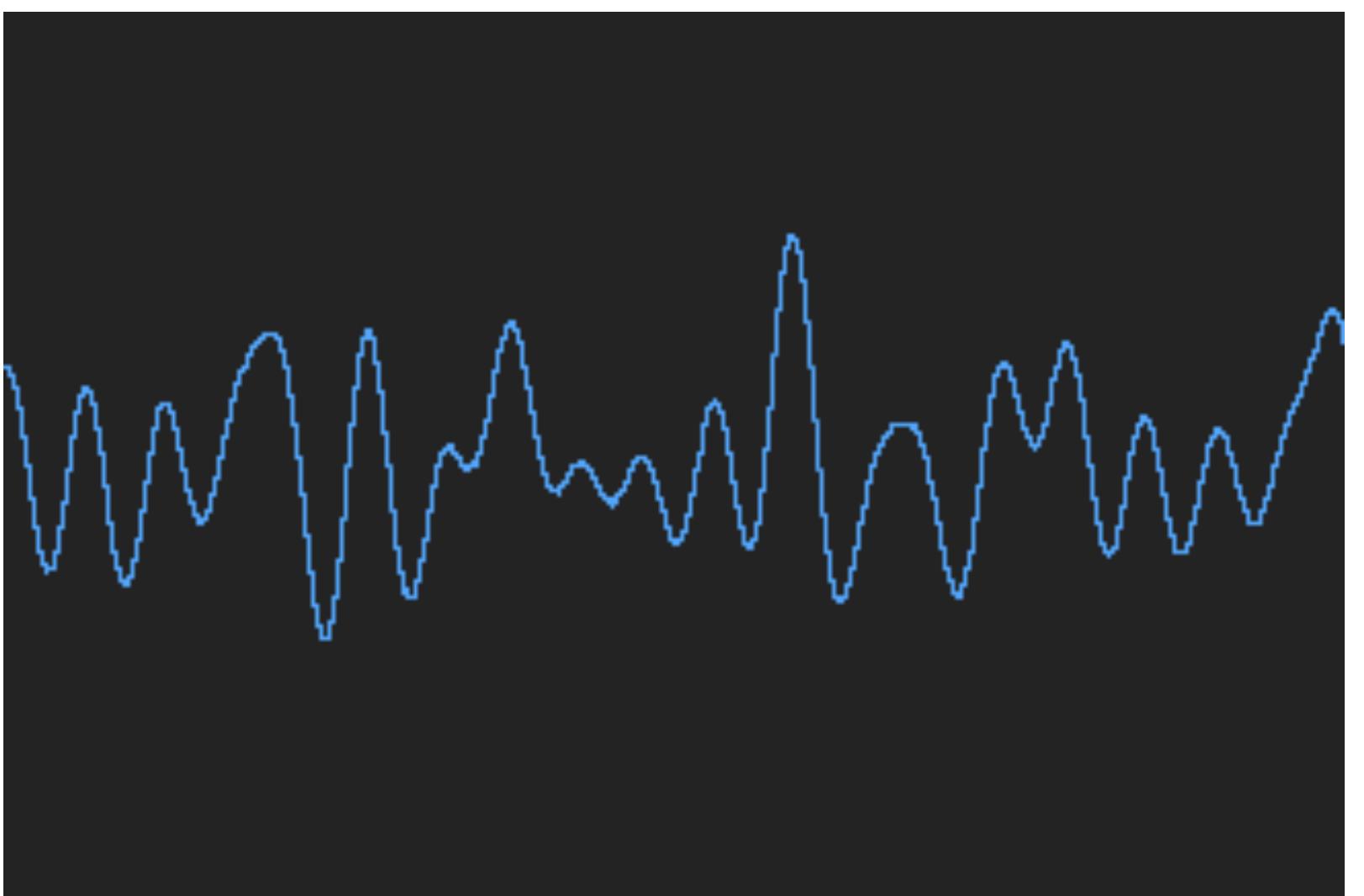
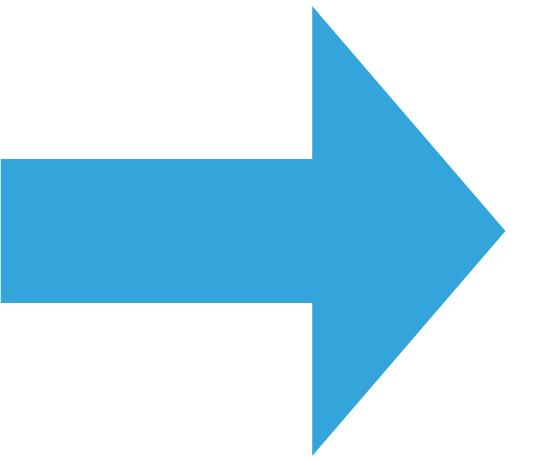
IC



“If you wish to make ‘Green Onions’ from scratch, you must first invent the universe”

CARL SAGAN





Arduino
Duemilanove

www.arduino.cc

RESET

EFTDI

TX

RX

TM

PWR

S1

SPK1600Y

SDOS

E01

103

102

102

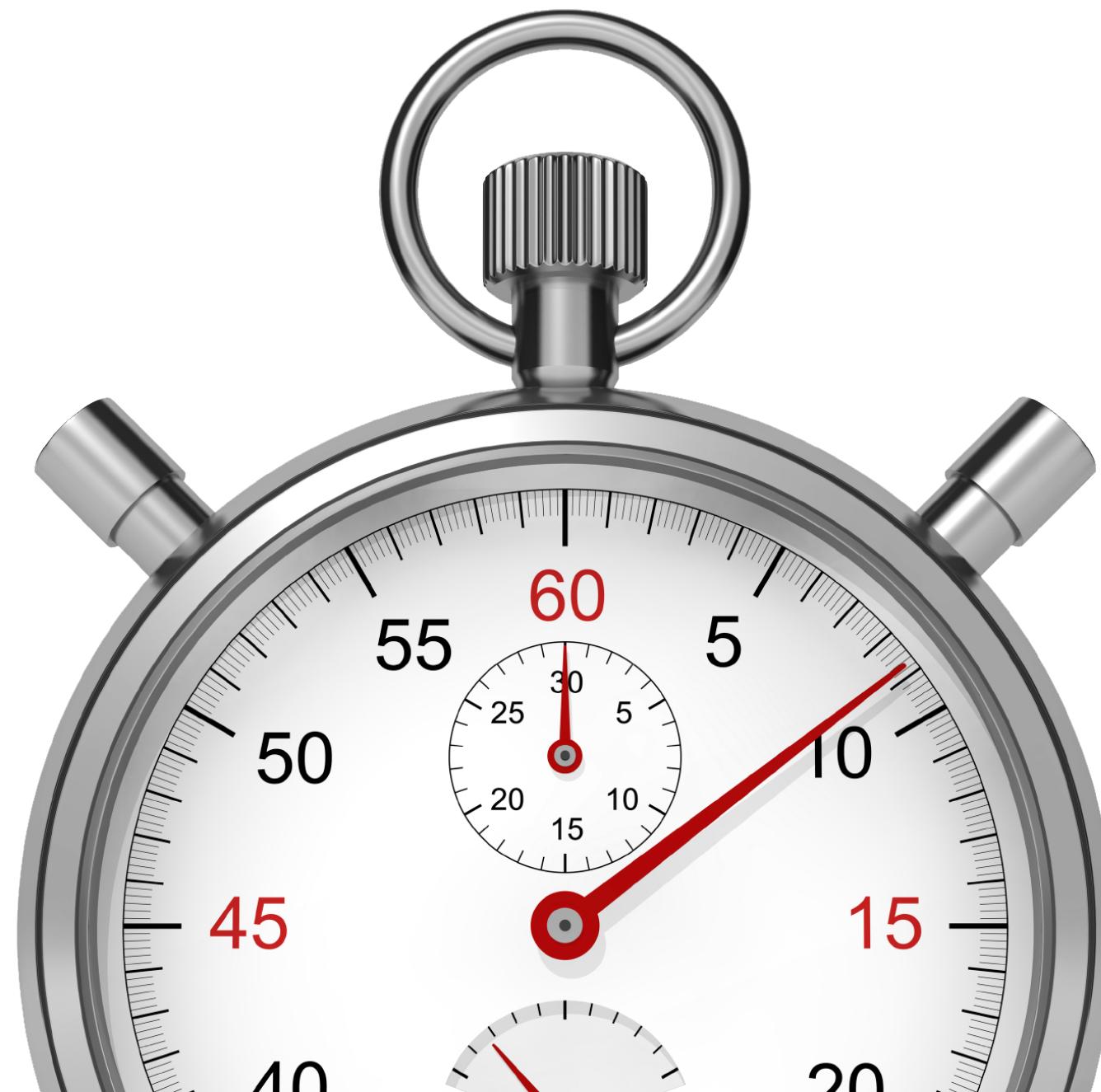
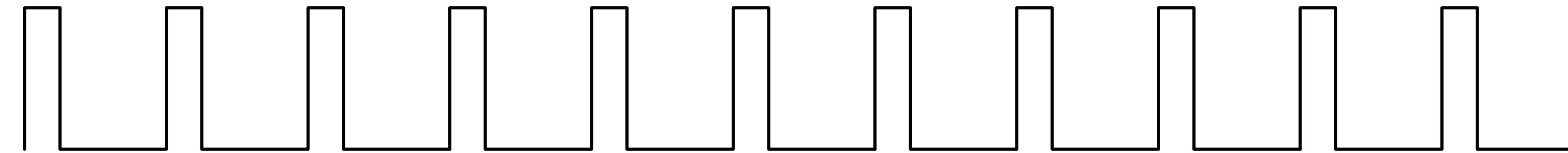
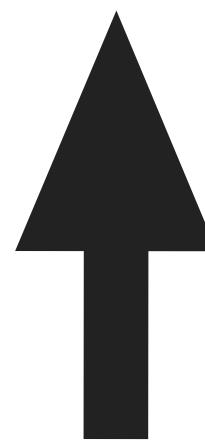
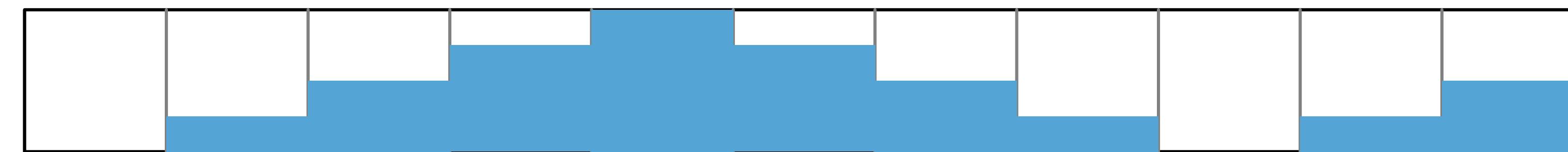
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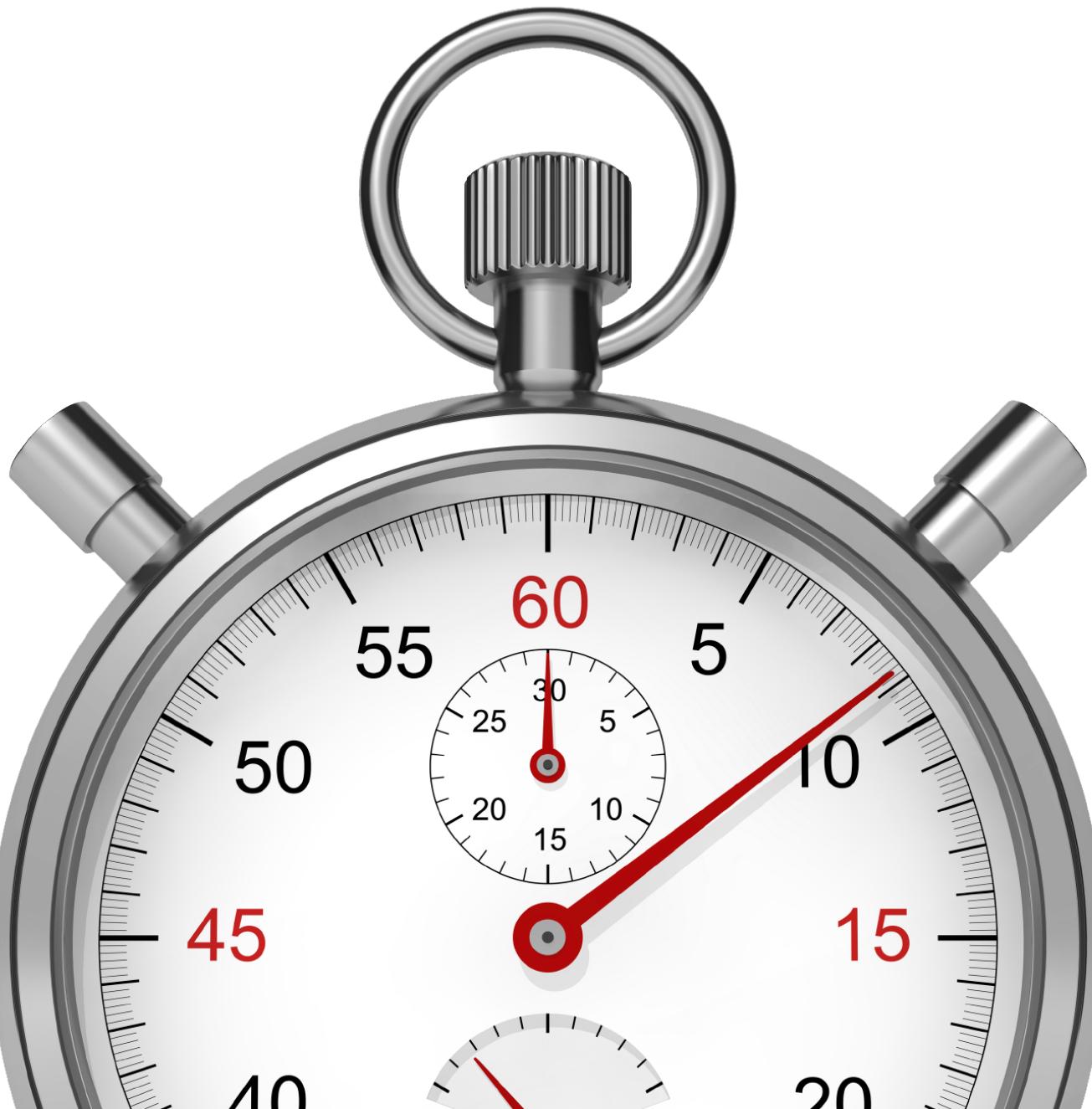
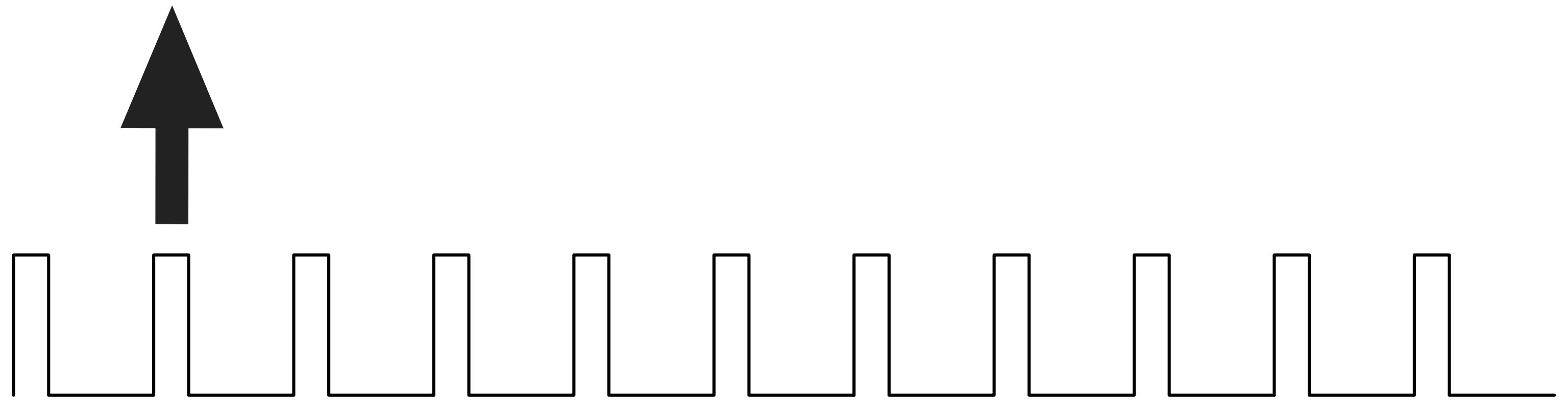
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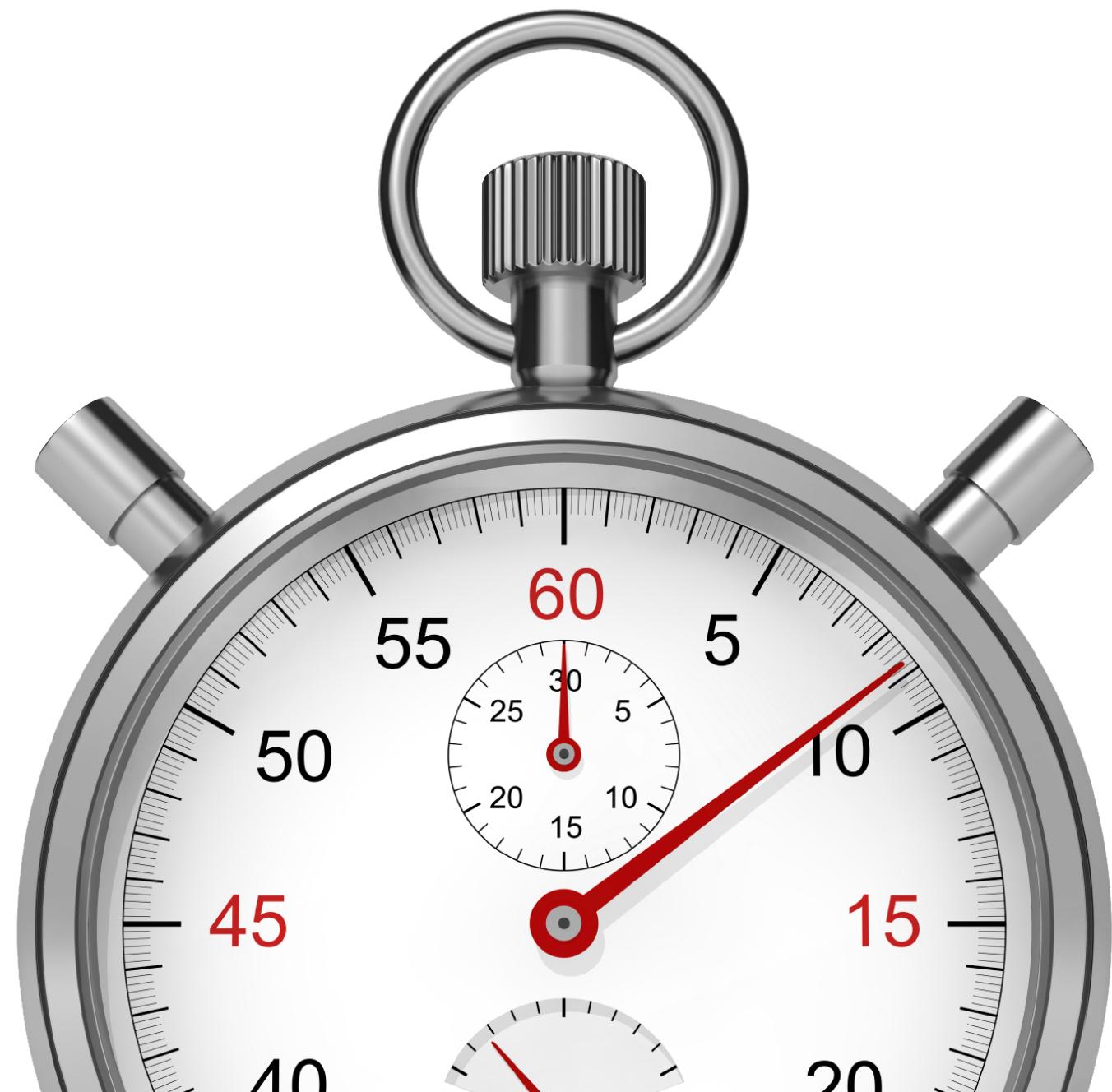
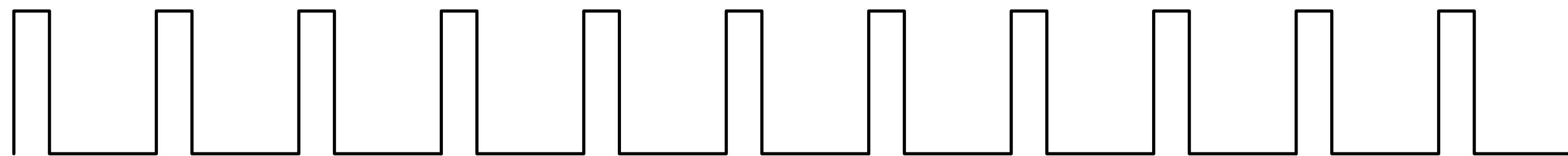
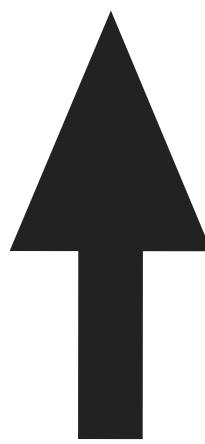
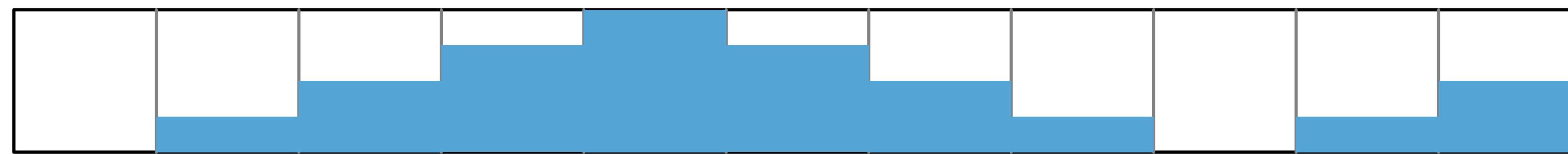
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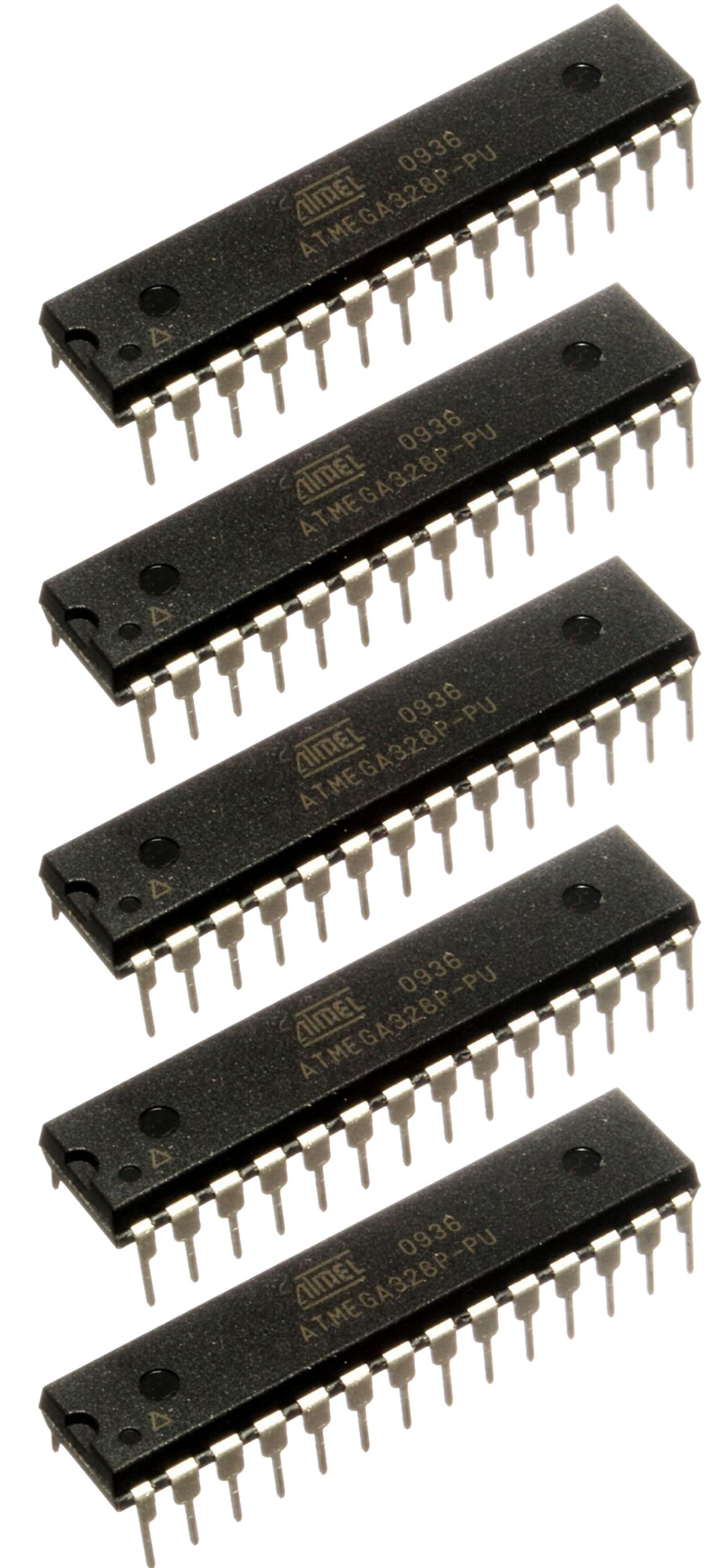
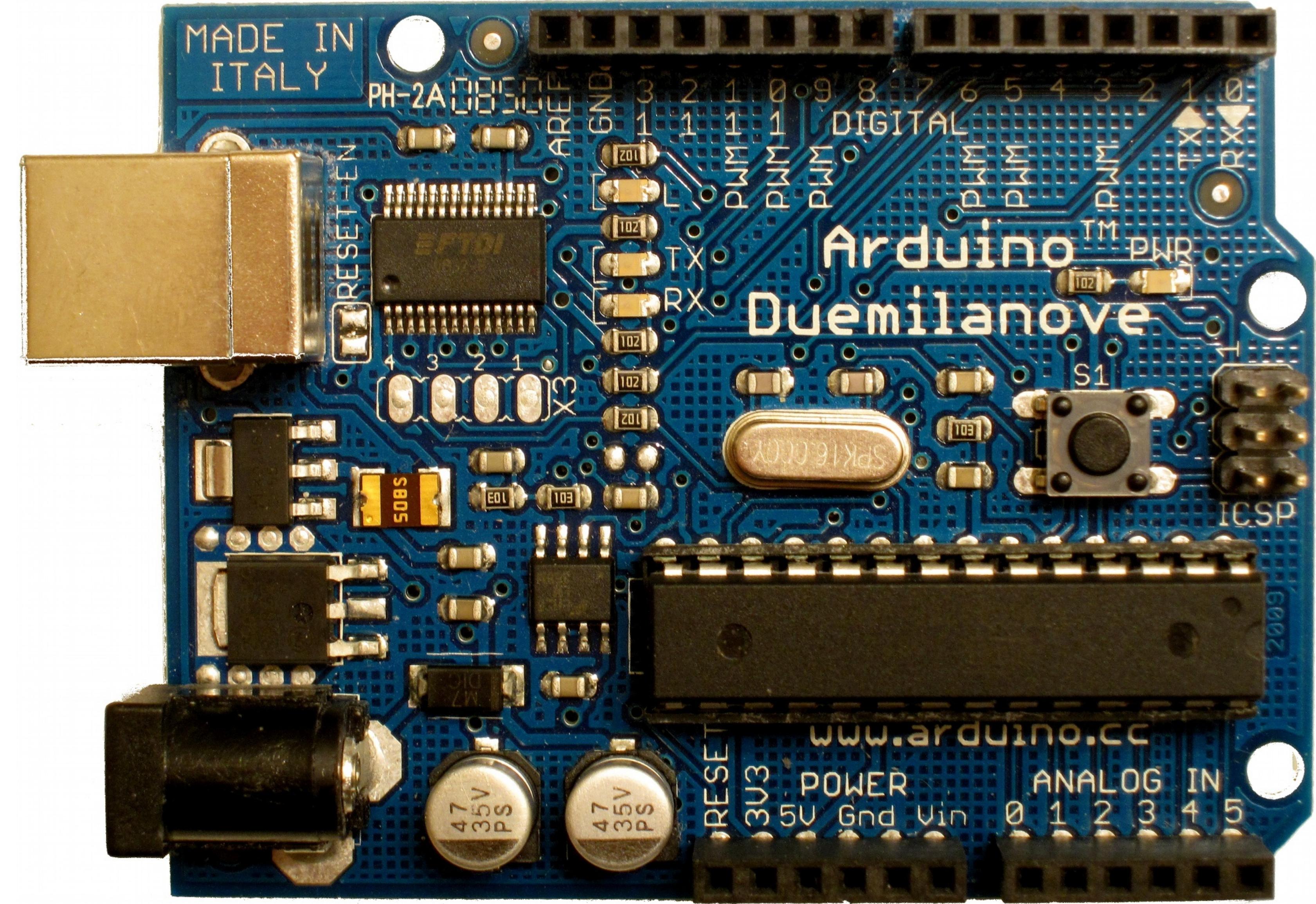
IC

DIGITAL
M7



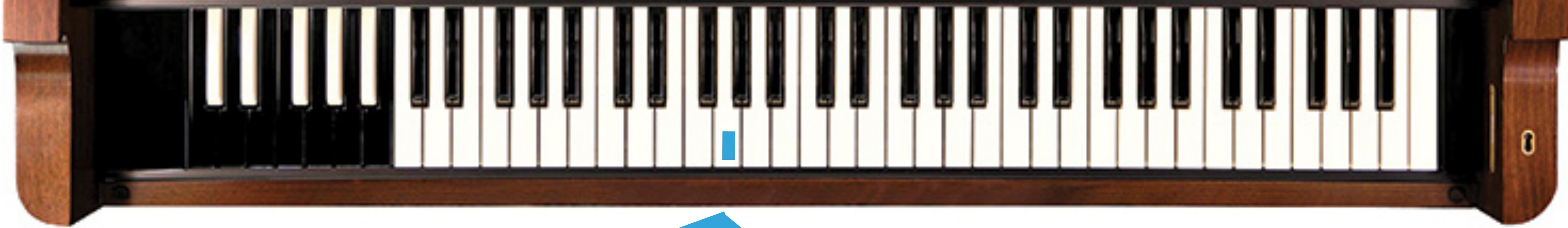








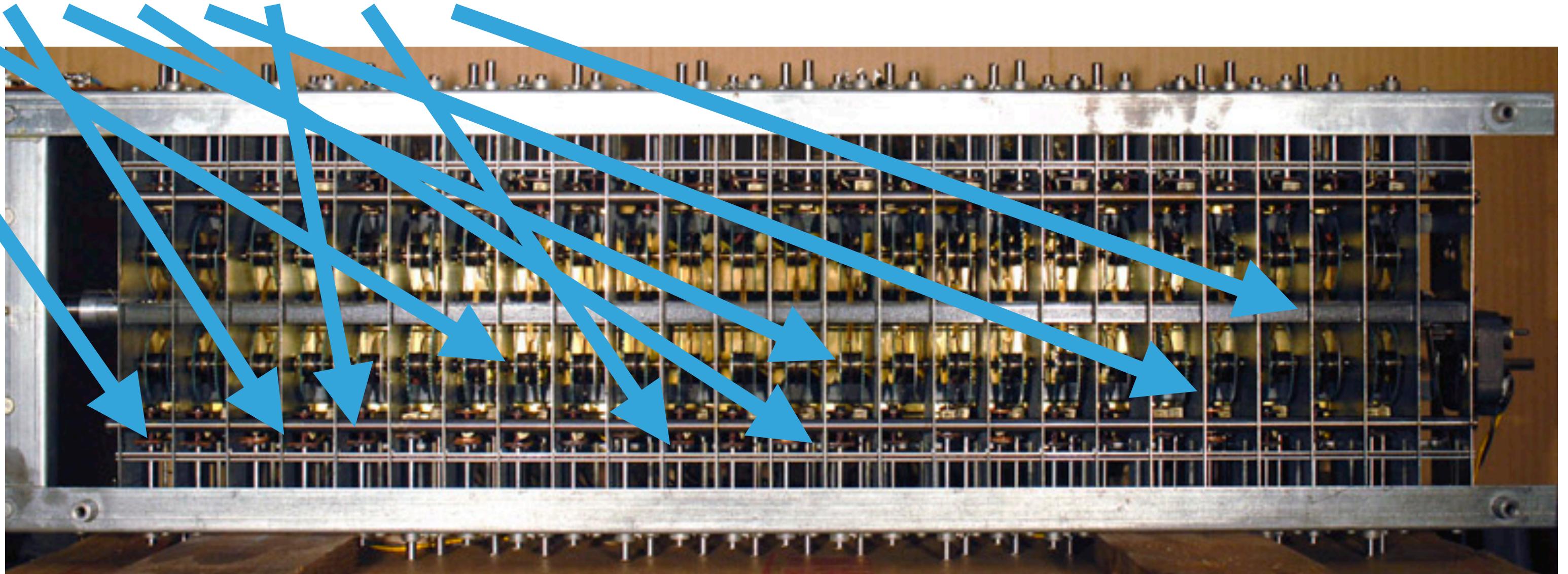
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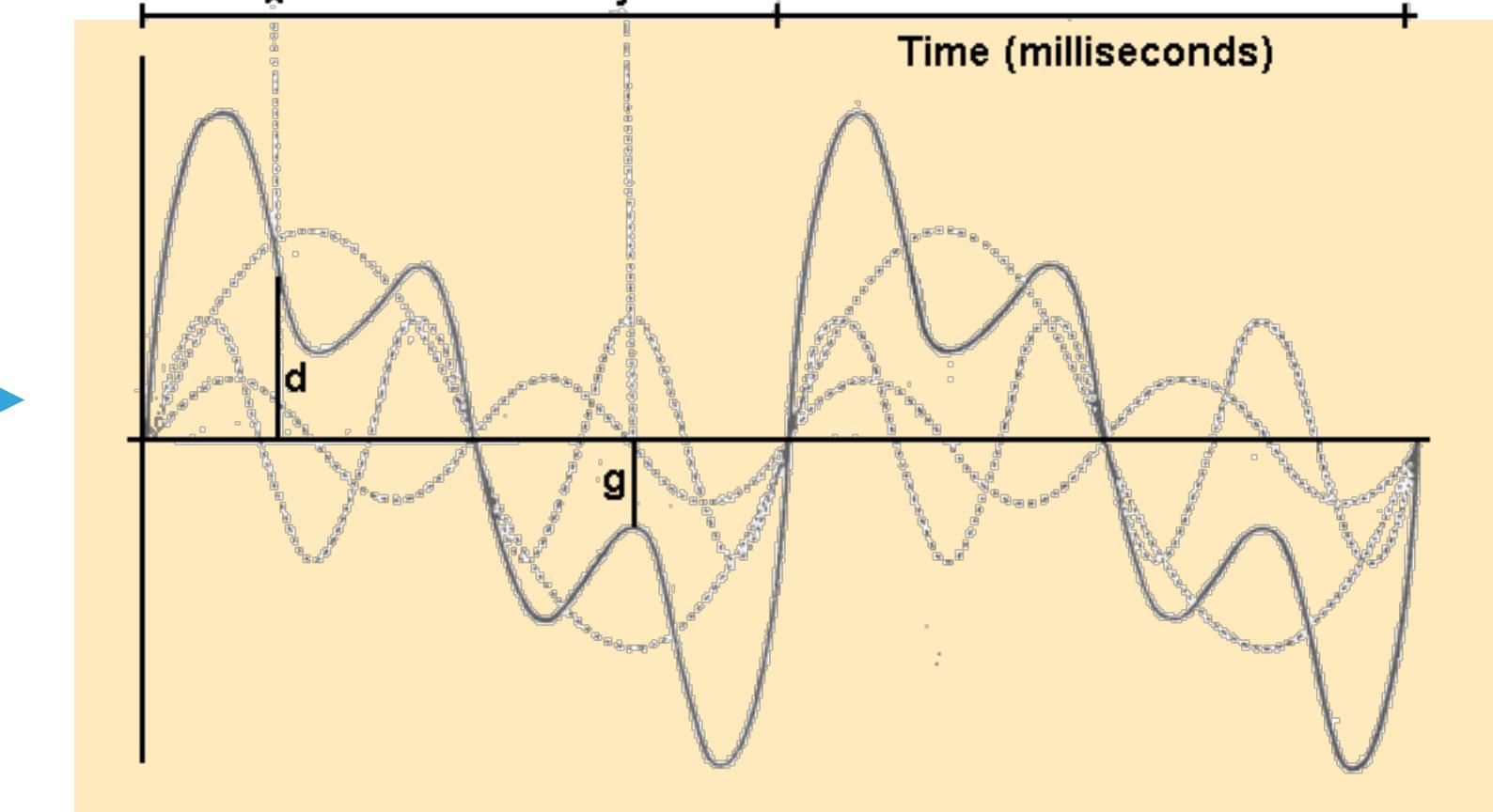
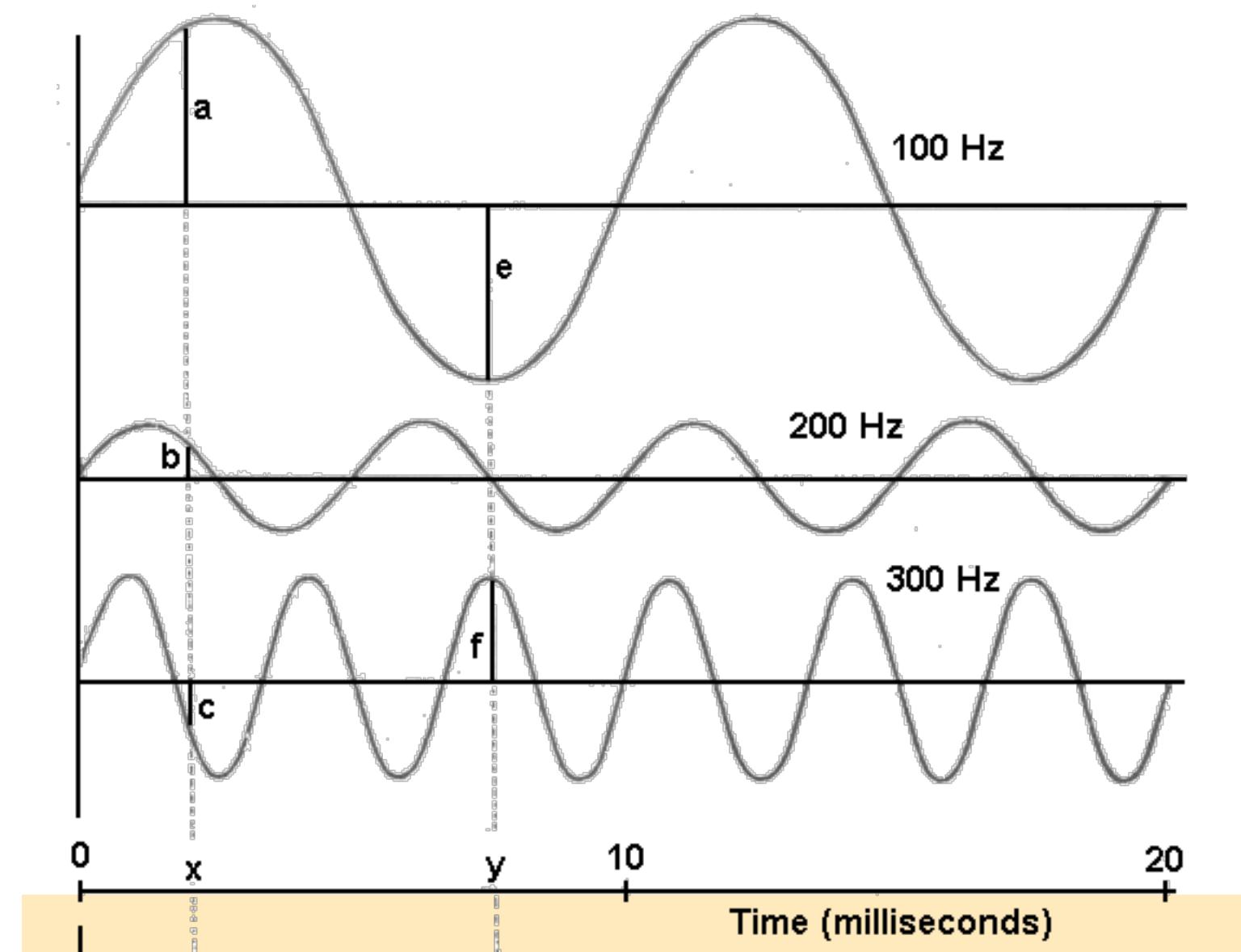


Drawbars



Tonewheel Oscillators





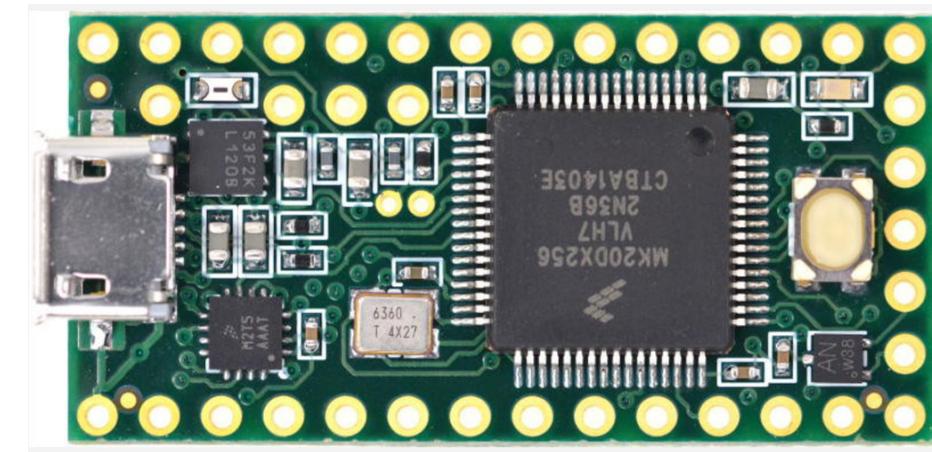
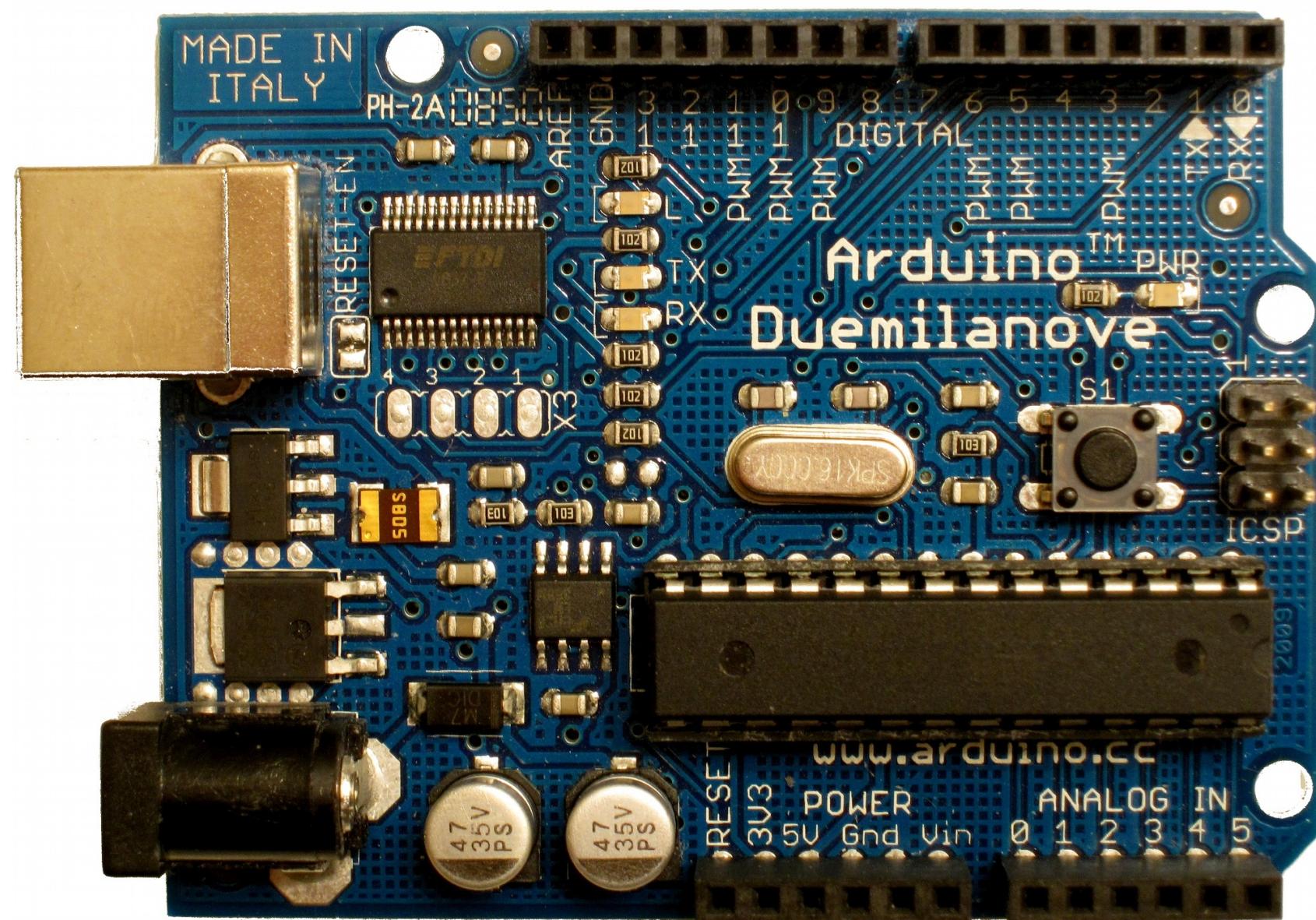




fully polyphonic



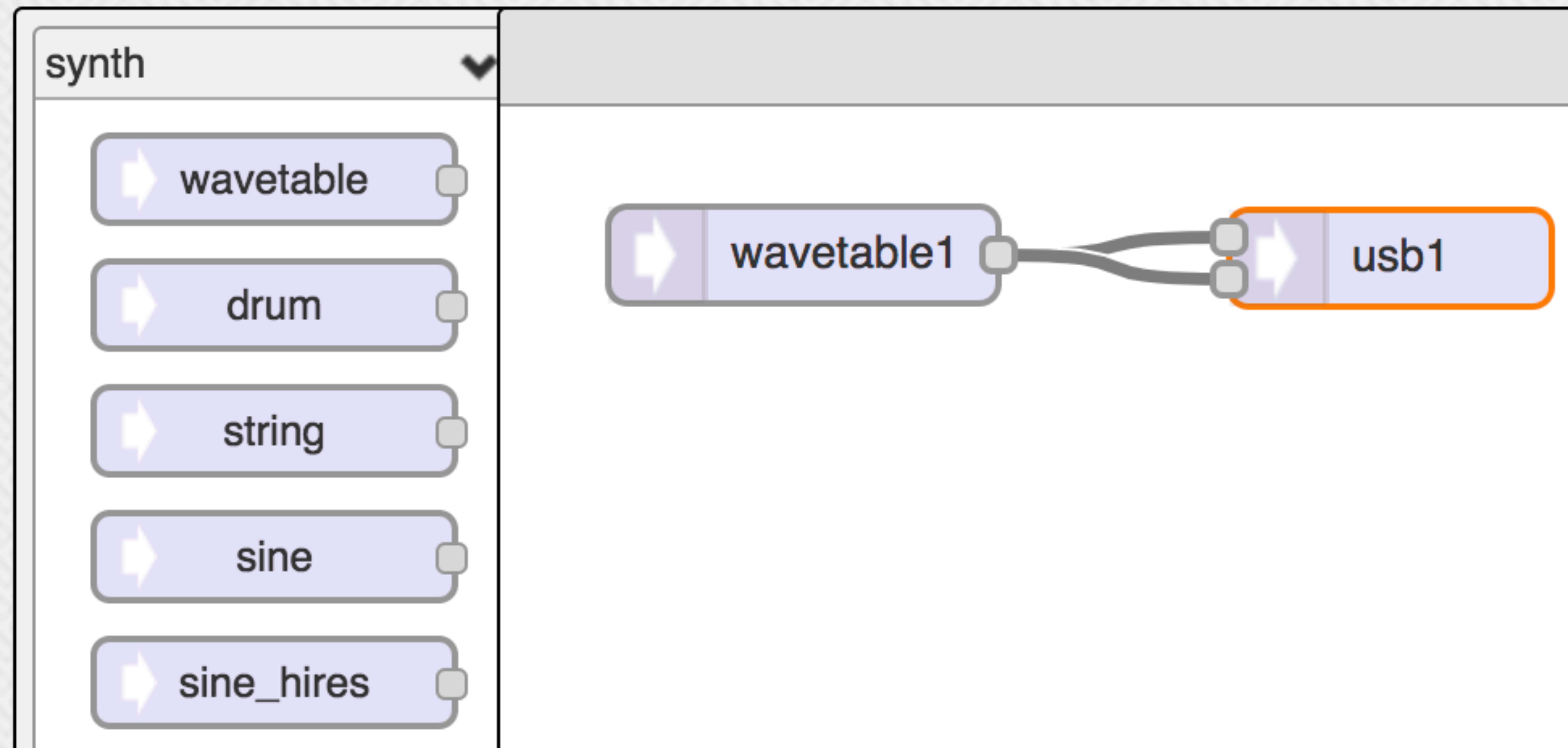
fully cacophonic

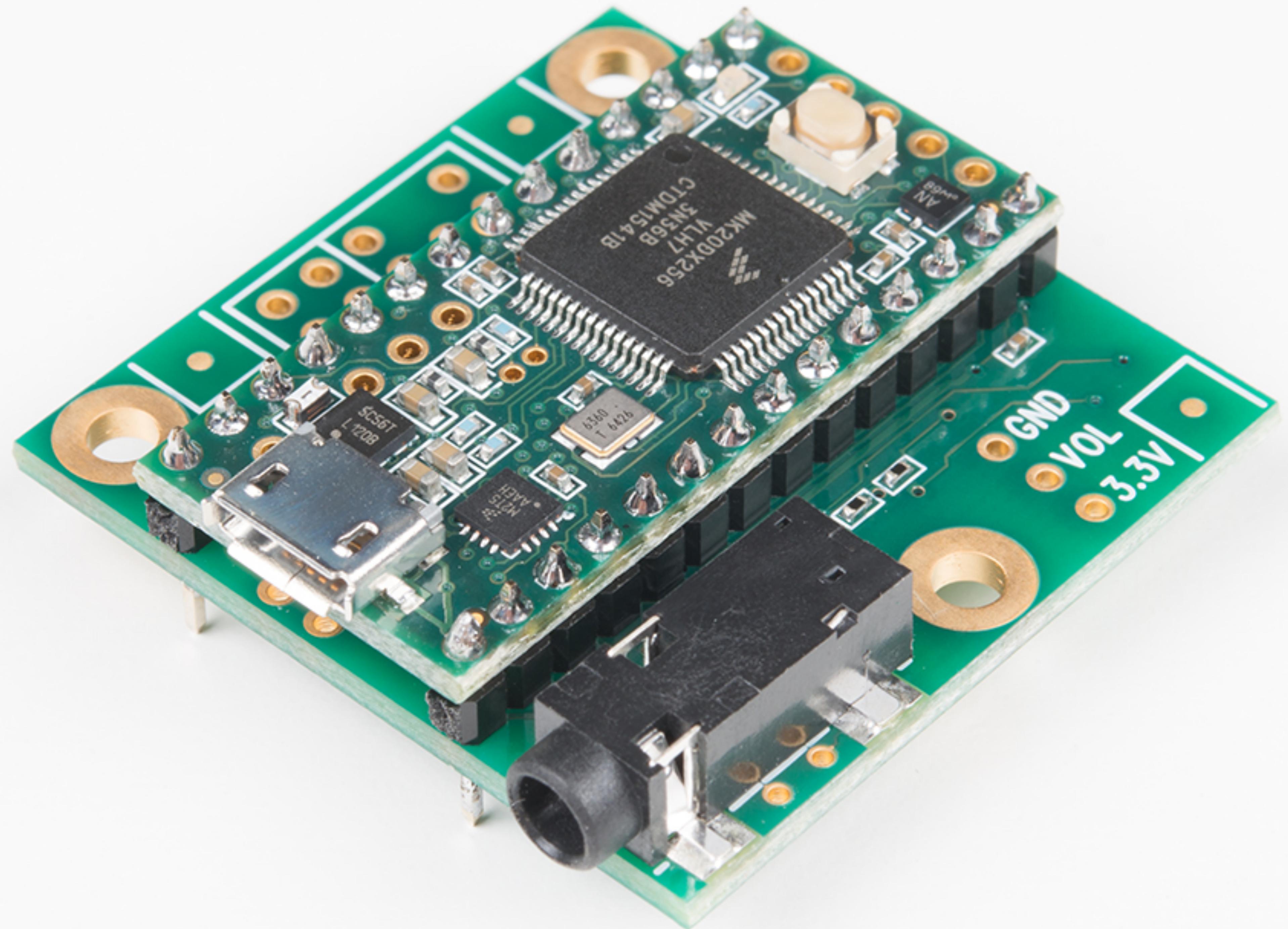


16 MHz
8 bit
USB Serial

72 MHz
32 bit
USB++

Audio System Design Tool for Teensy Audio Library





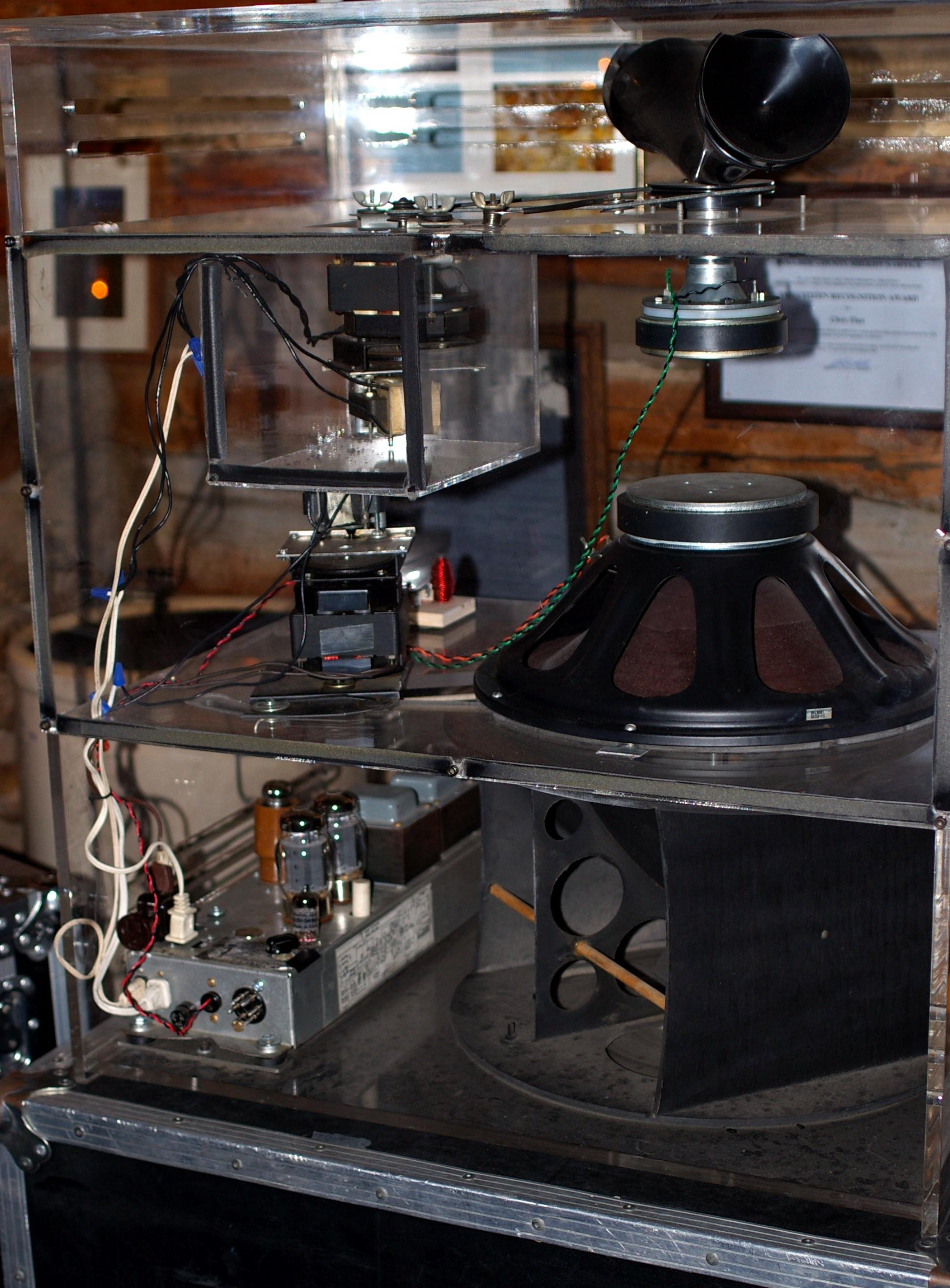
ROTO

Project Scope



Hammond B-3

Leslie 122



Jan. 9, 1951

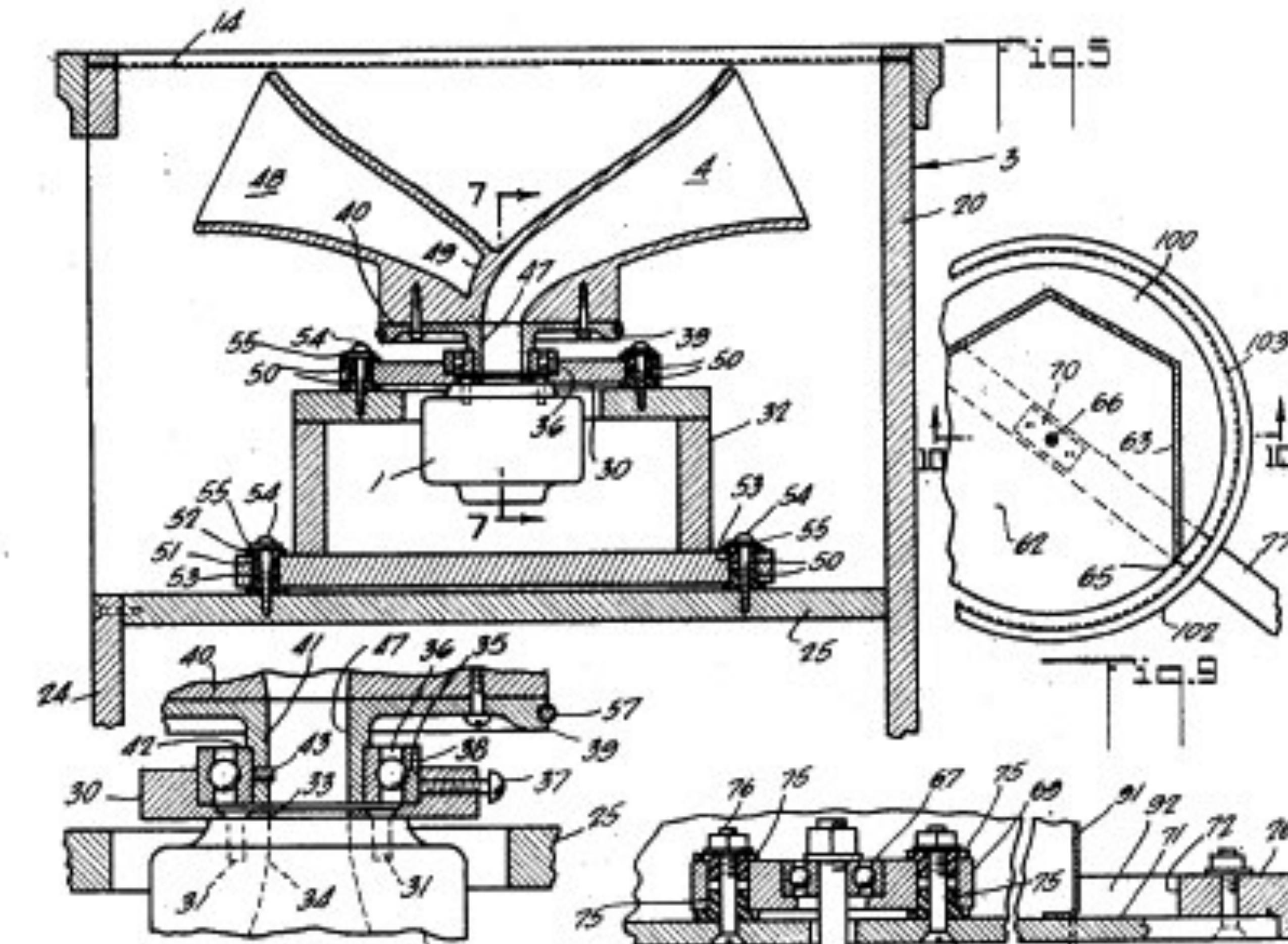
D. J. LESLIE

Re. 23,323

ROTATABLE TREMULANT SOUND PRODUCER

Original Filed July 9, 194

7 Sheets-Sheet 2



By Hustvedt - Own work, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=3472626>

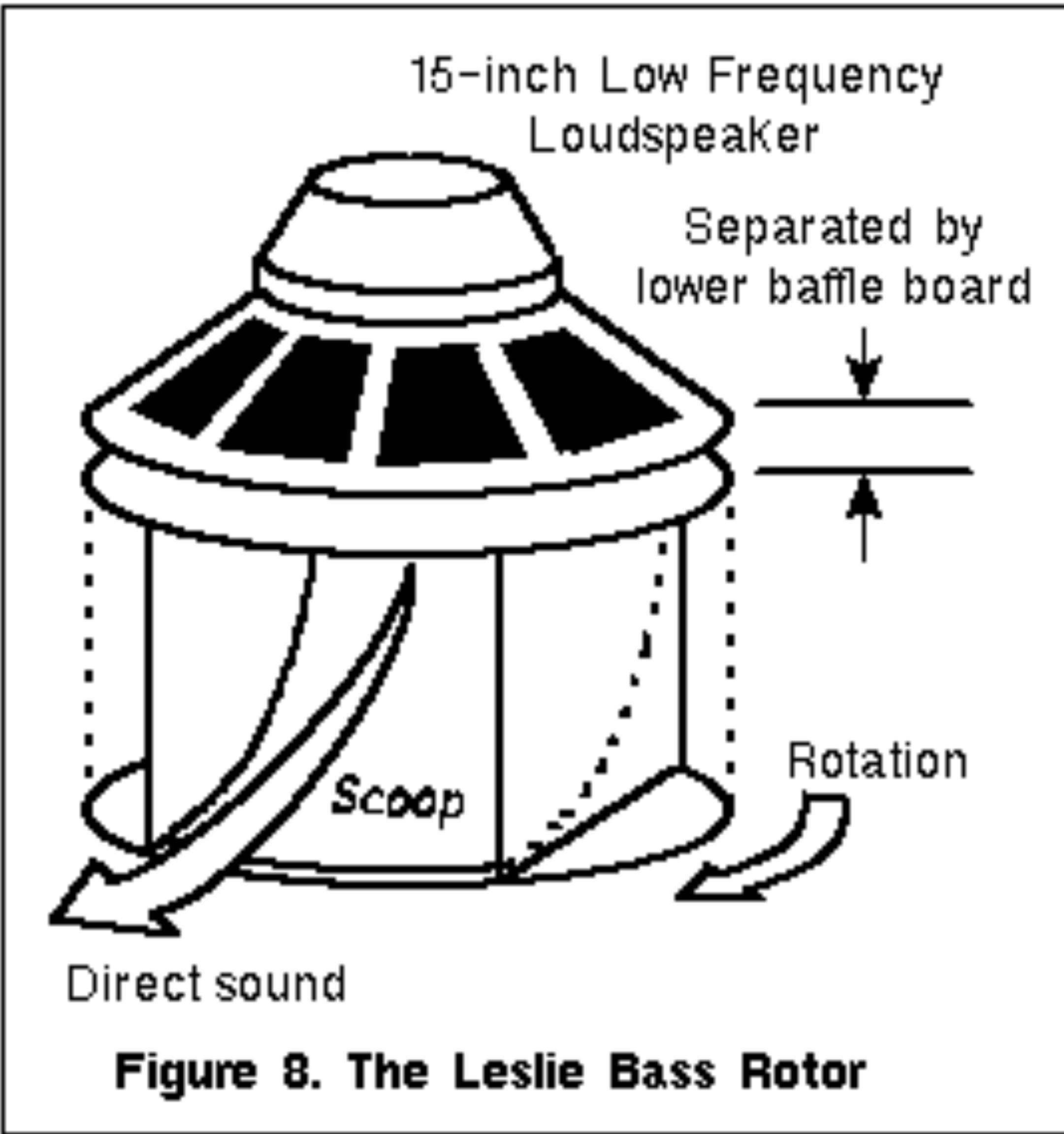
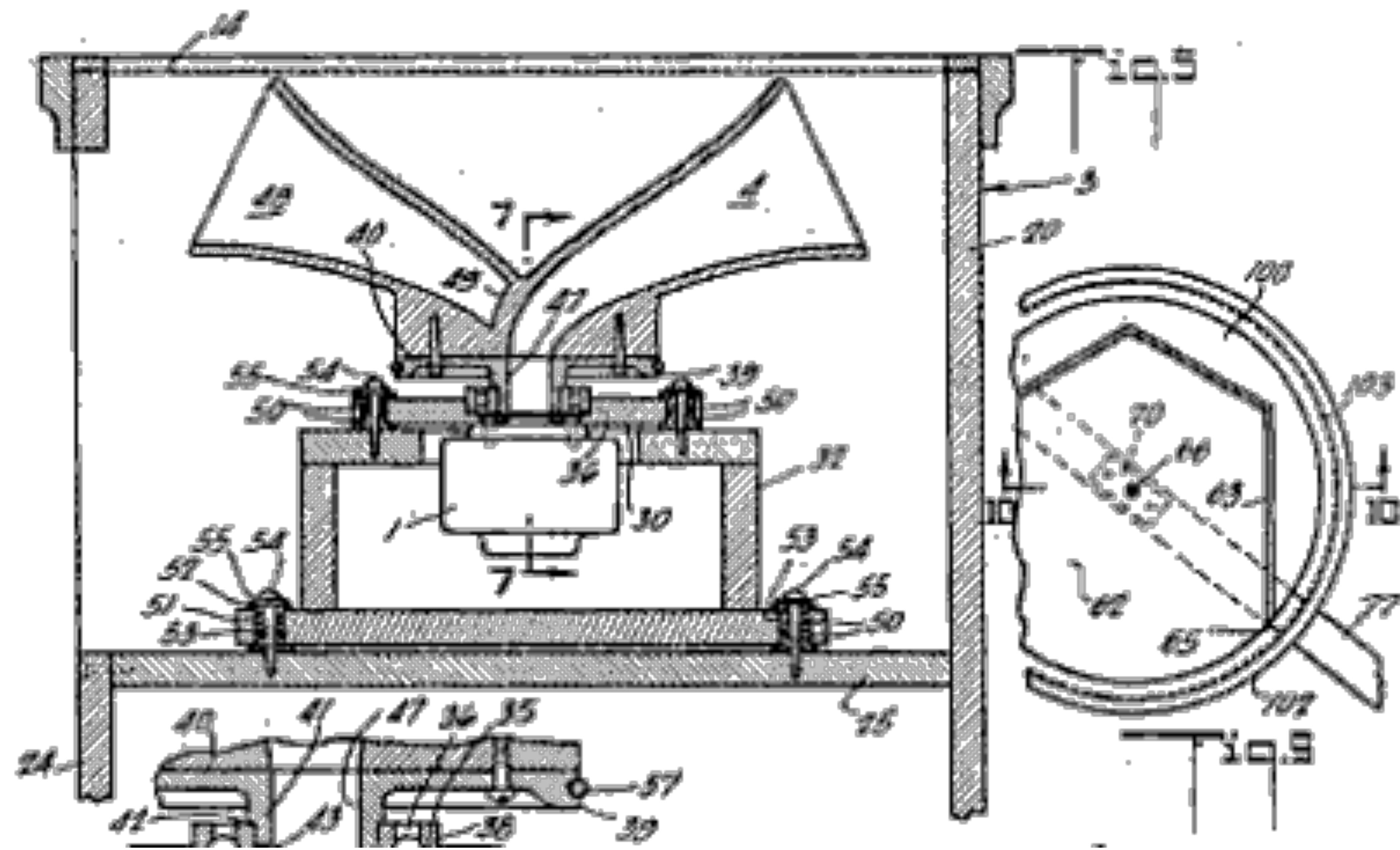


Figure 8. The Leslie Bass Rotor



MIDI

9V AC



POWER



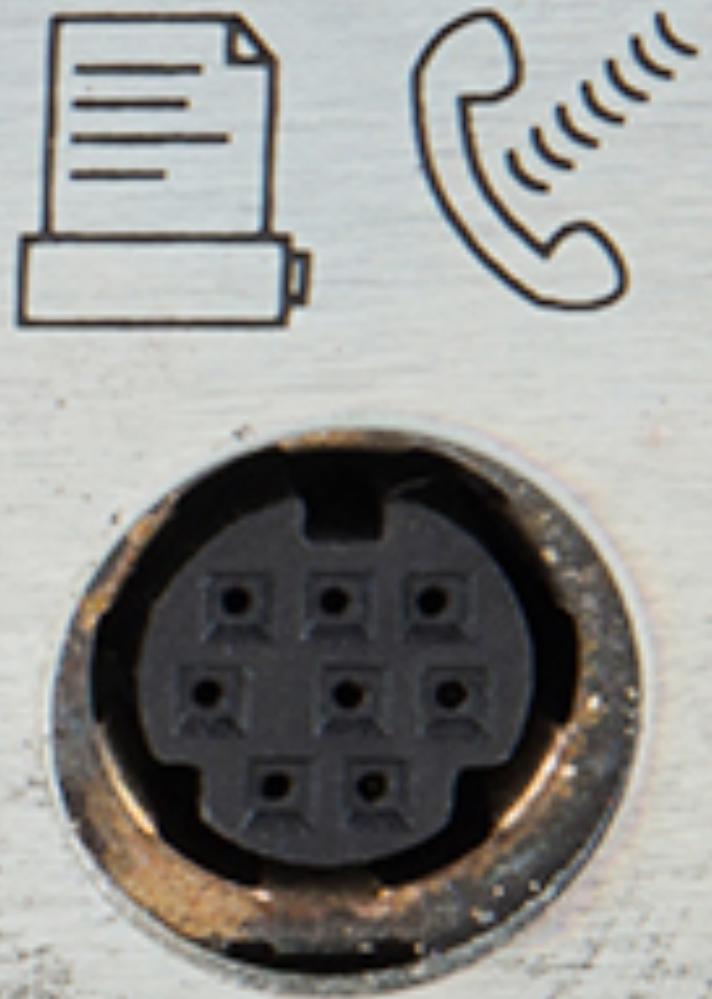
IN



OUT



THRU

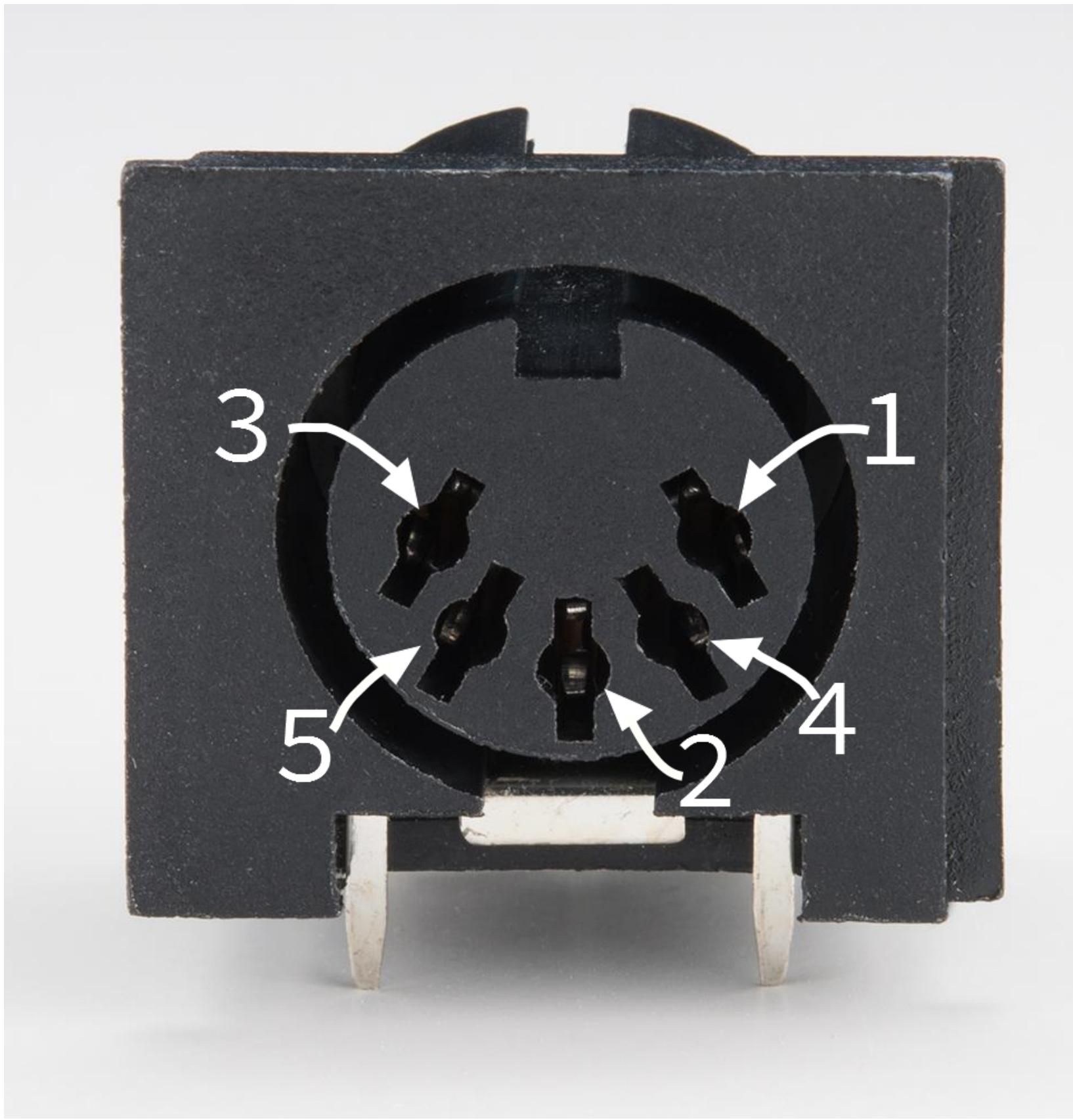


	byte 1	byte 2	byte 3
Note on	1001 CCCC	0NNNNNNN	0VVVVVVV
Note off	1000 CCCC	0NNNNNNN	0VVVVVVV
Control change	1011 CCCC	0NNNNNNN	0VVVVVVV
	4 bit channel	7 bit note	7 bit velocity

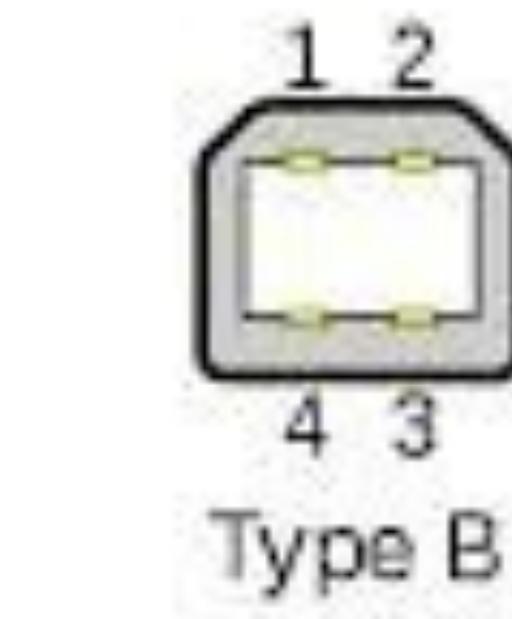
MIDI Messages

Standard MIDI ports

DIN

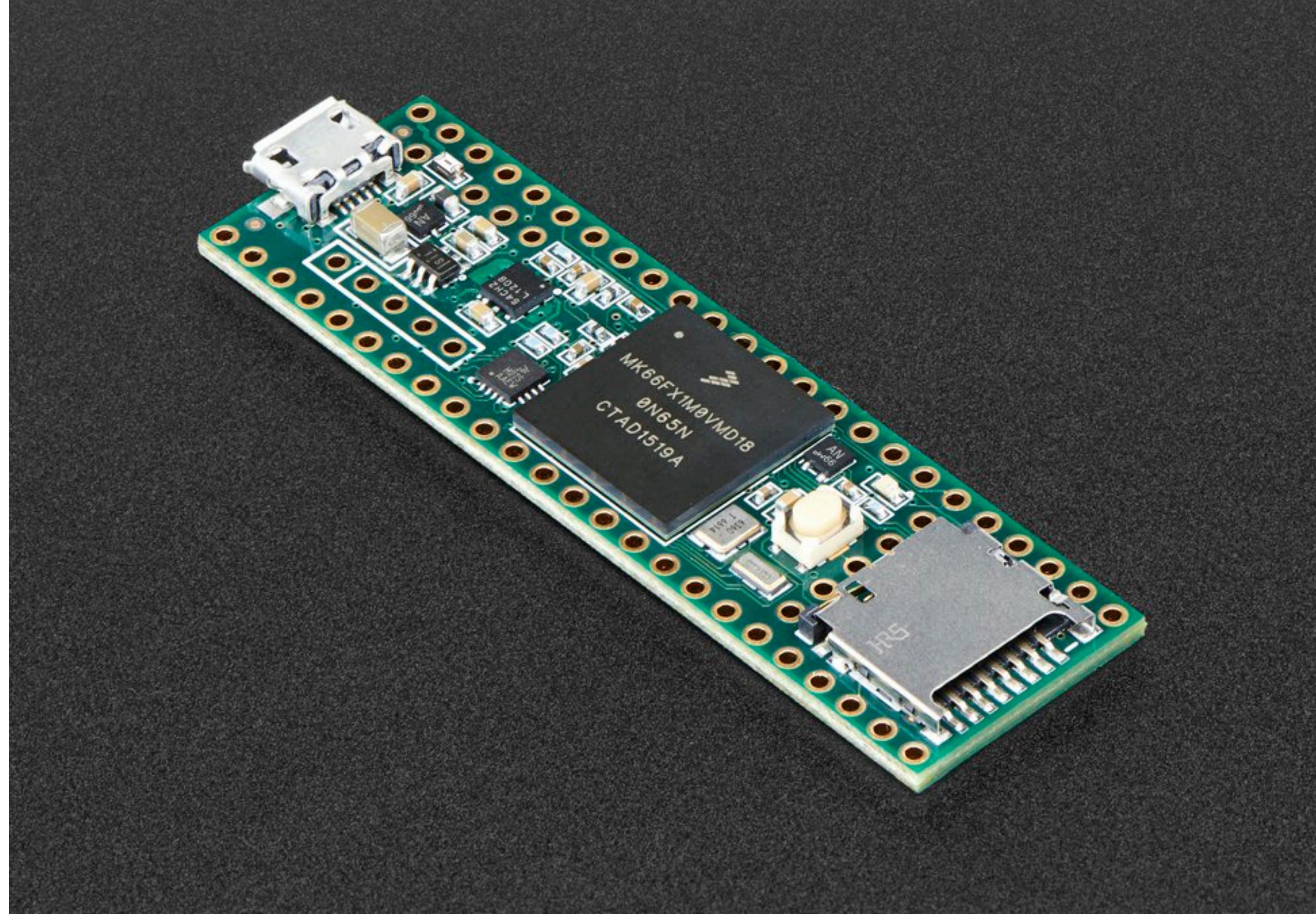


USB

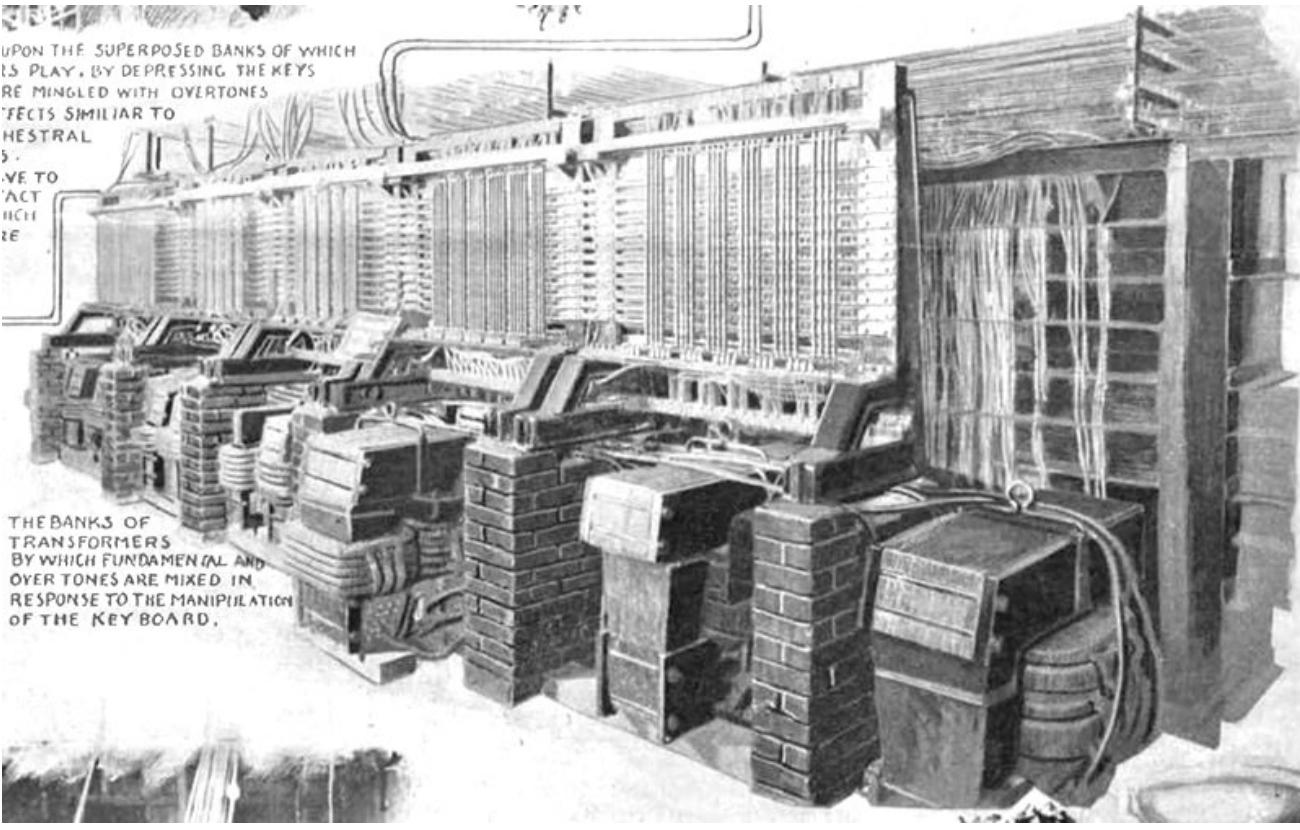


3.5mm





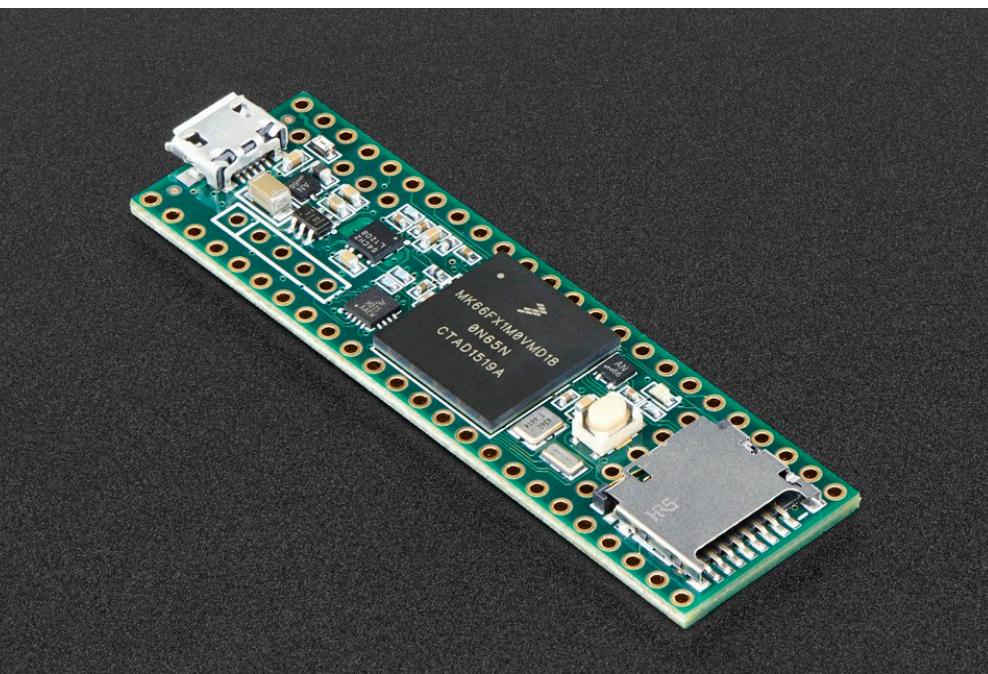
Teensy 3.6
44.1 kHz / 16 bit



181,000 kg



250 kg



0.003 kg

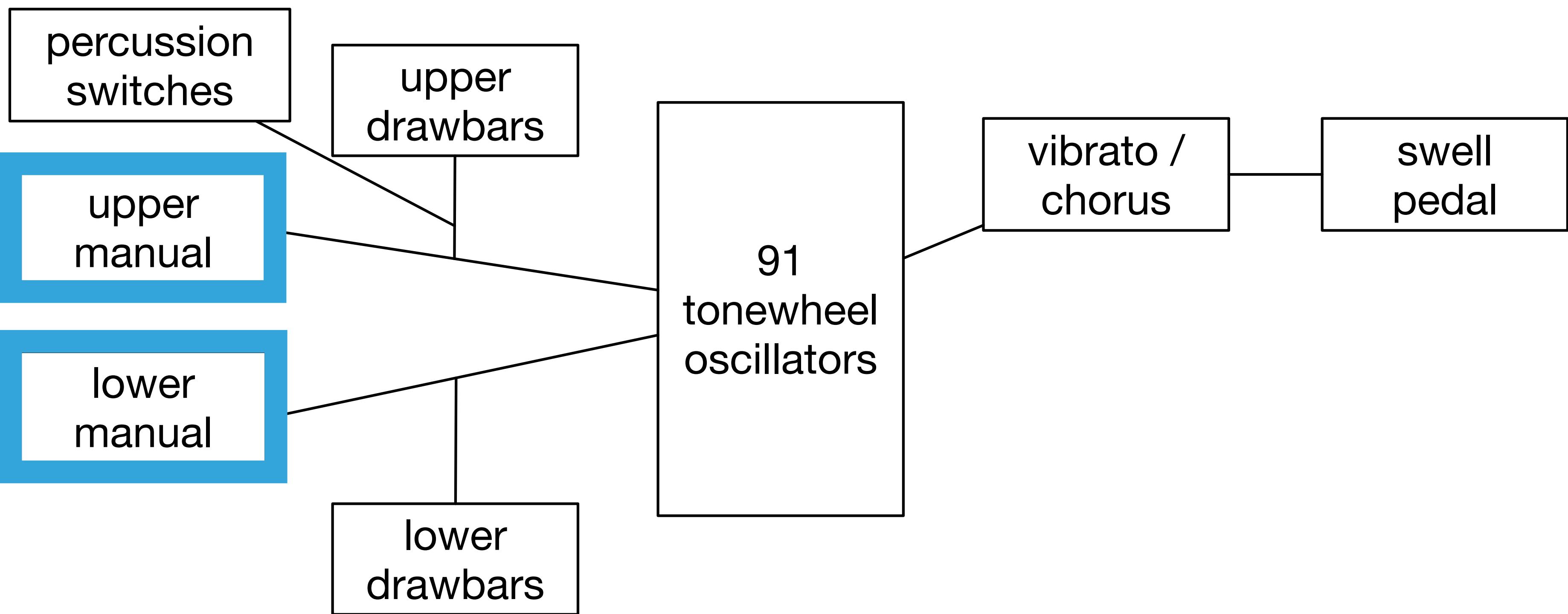
SINE OSCILLATOR
VIBRATO / CHORUS
PERCUSSION
SWELL

DISTORTION
TREMOLO / VIBRATO
2 ROTATING SPEAKERS
STEREO OUTPUT

TODO

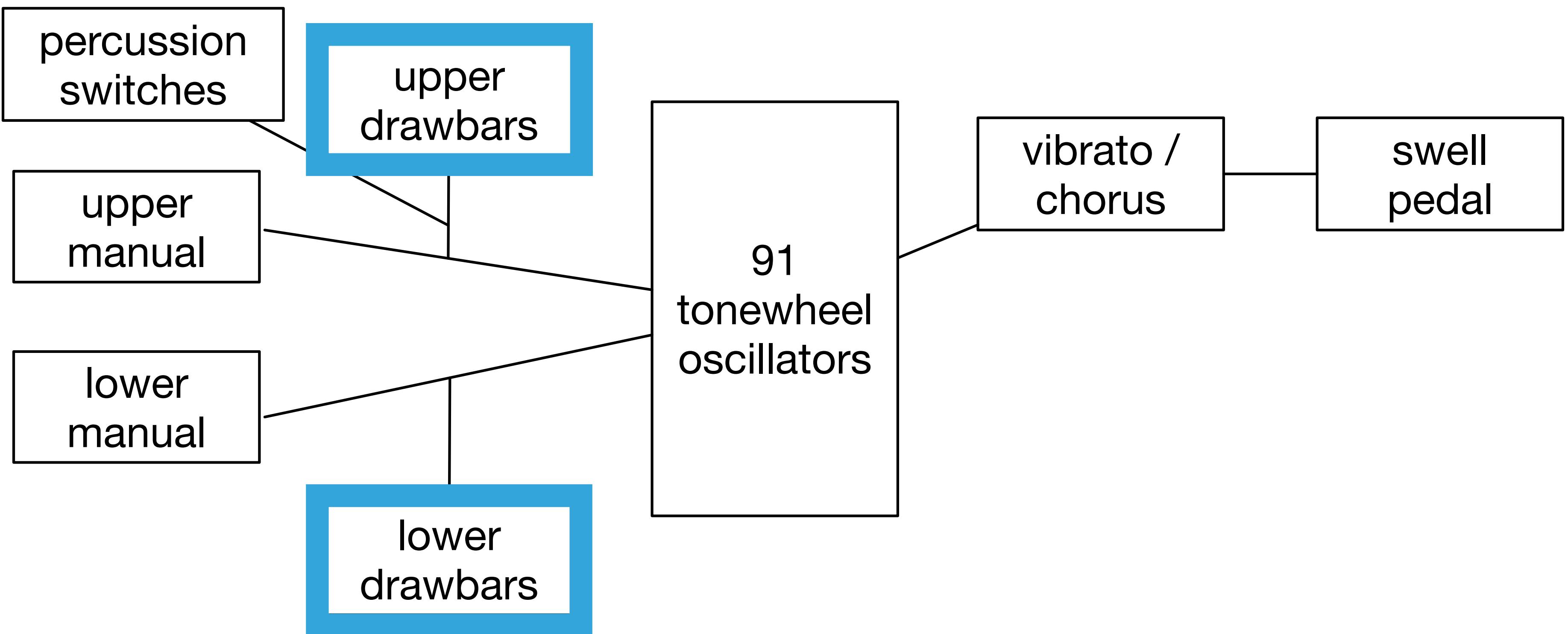
Hammond B-3

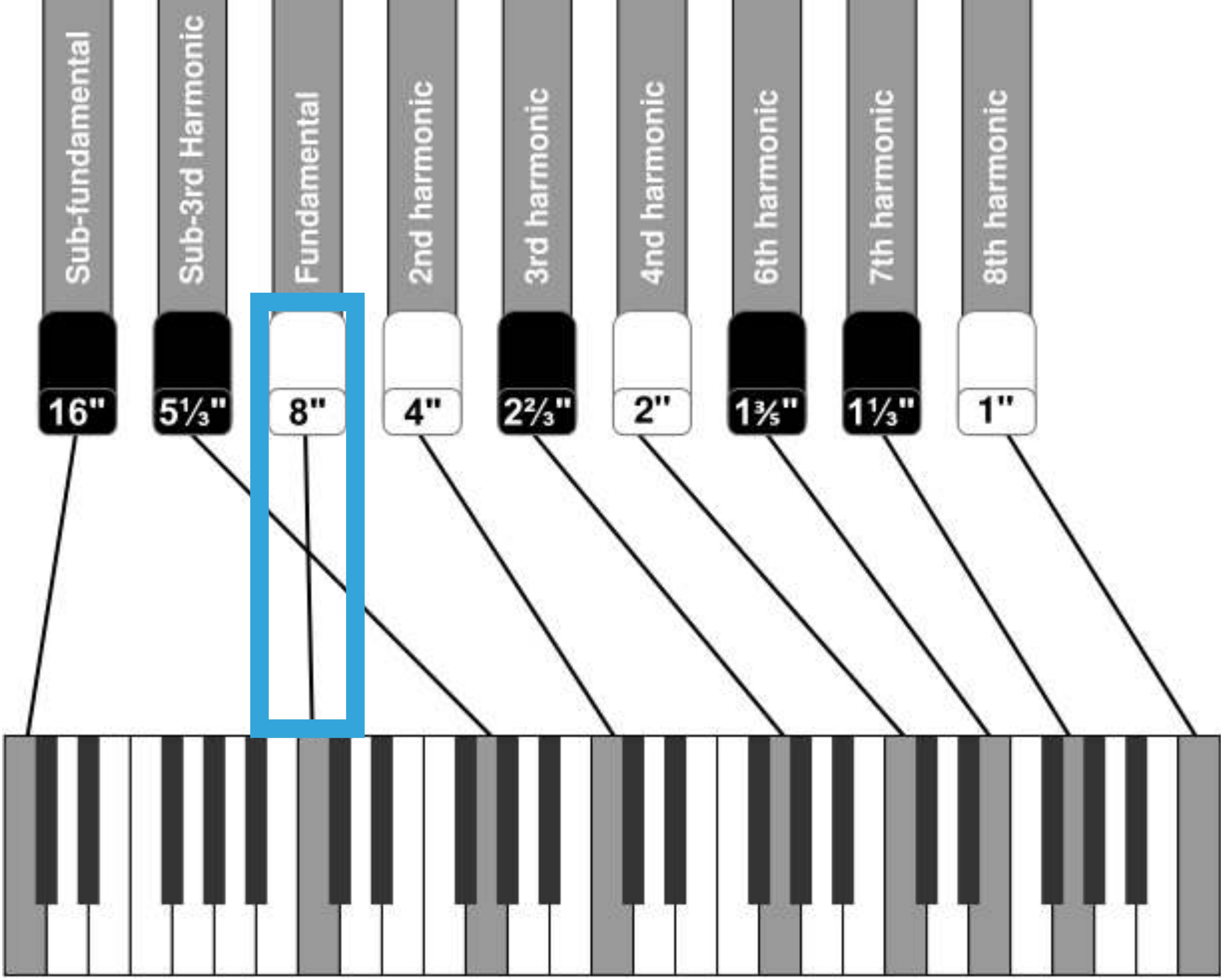


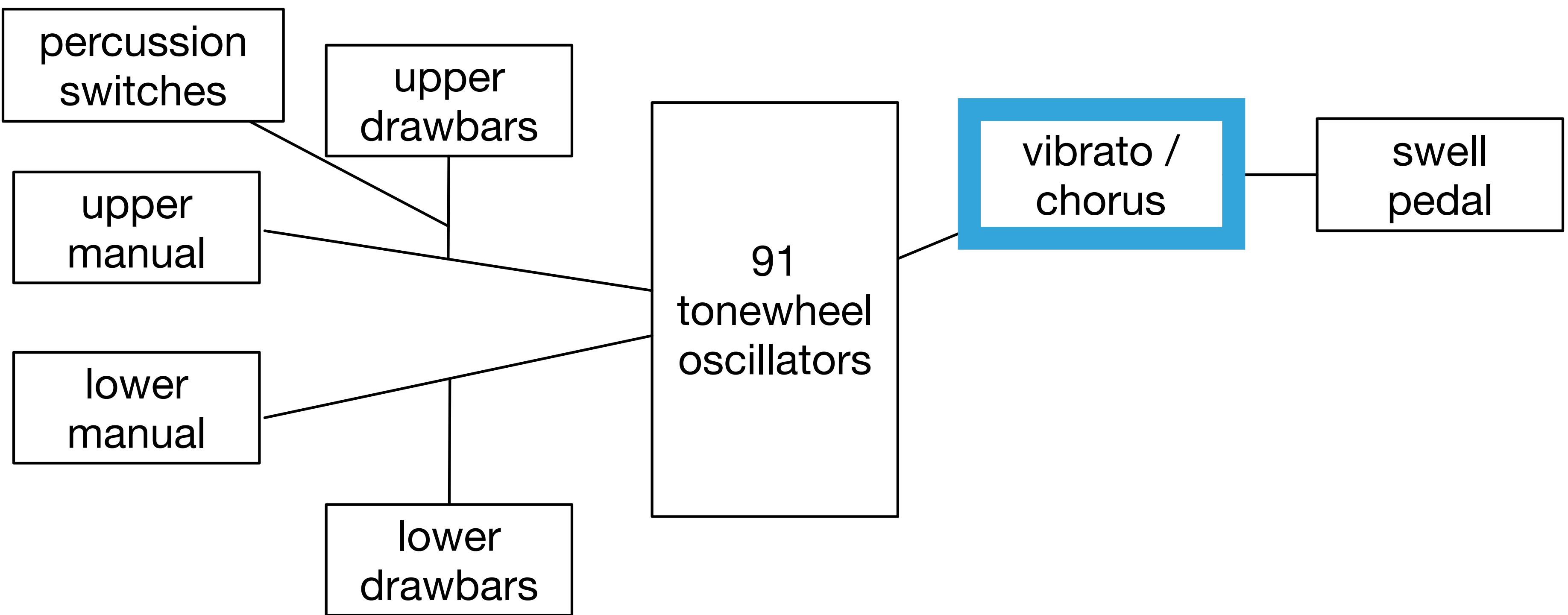


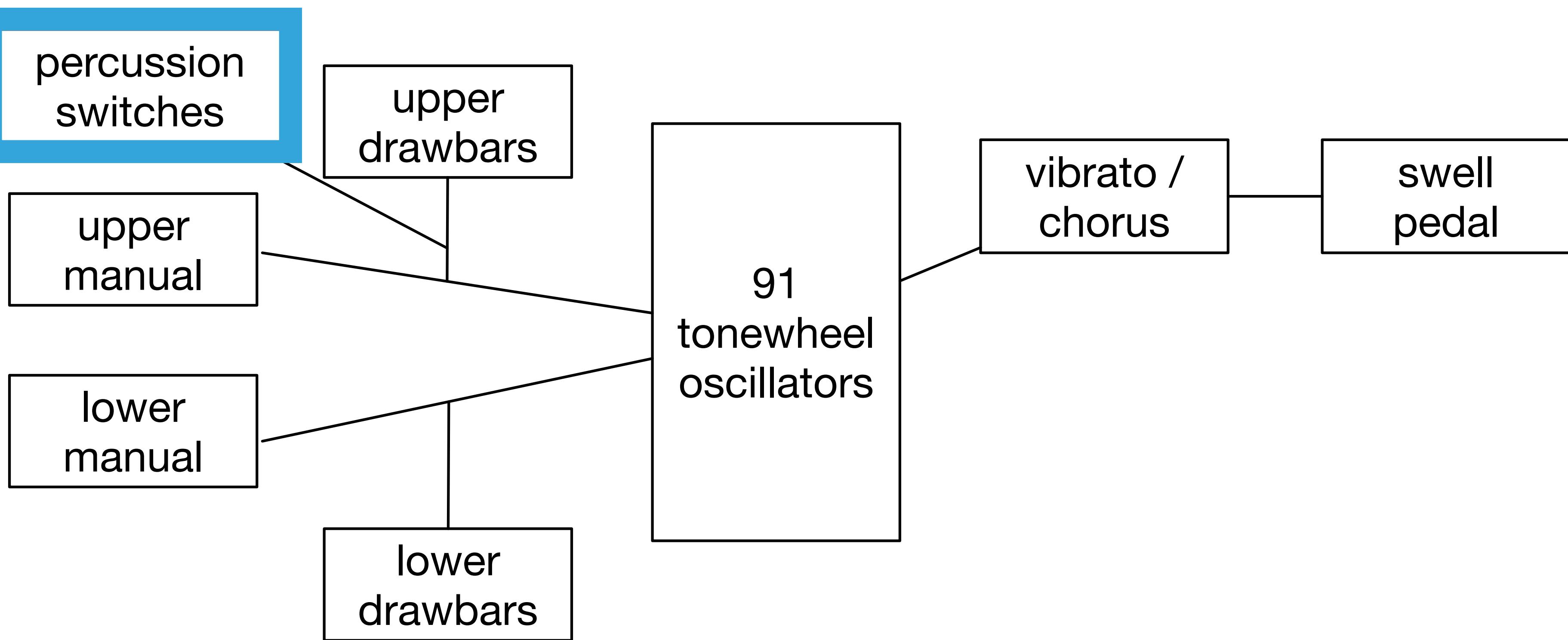


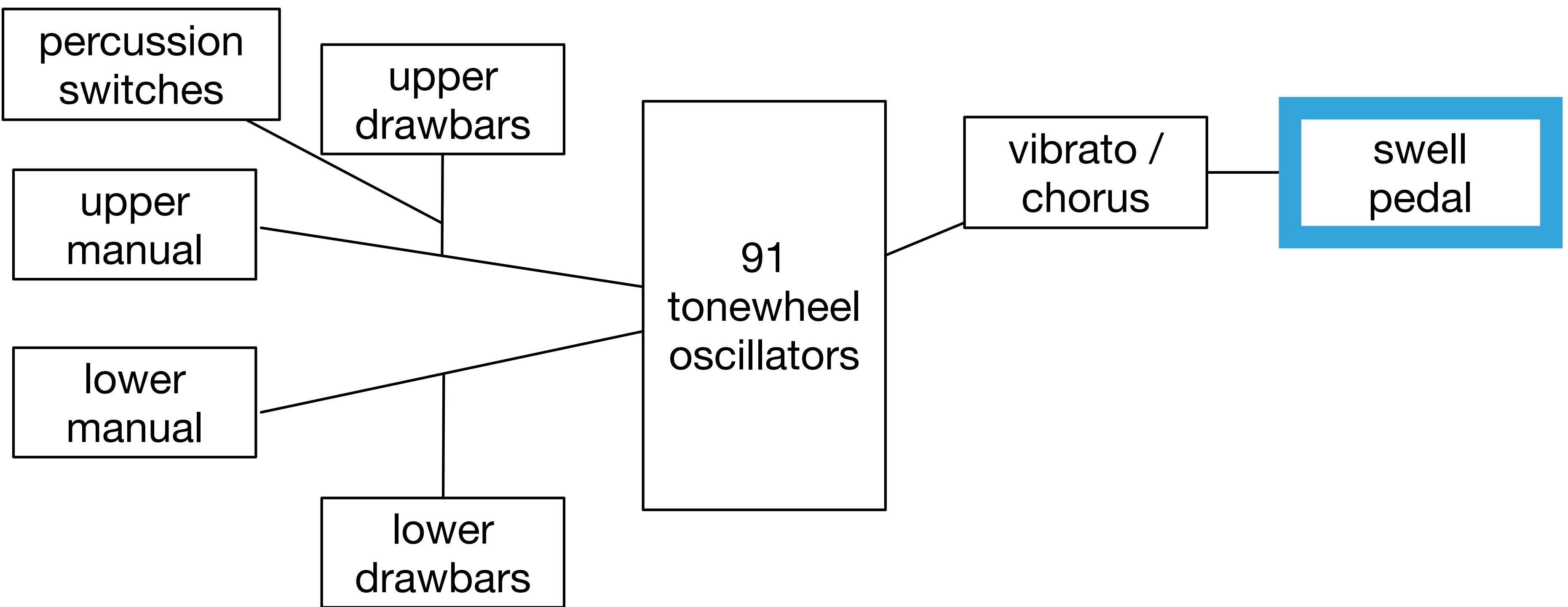
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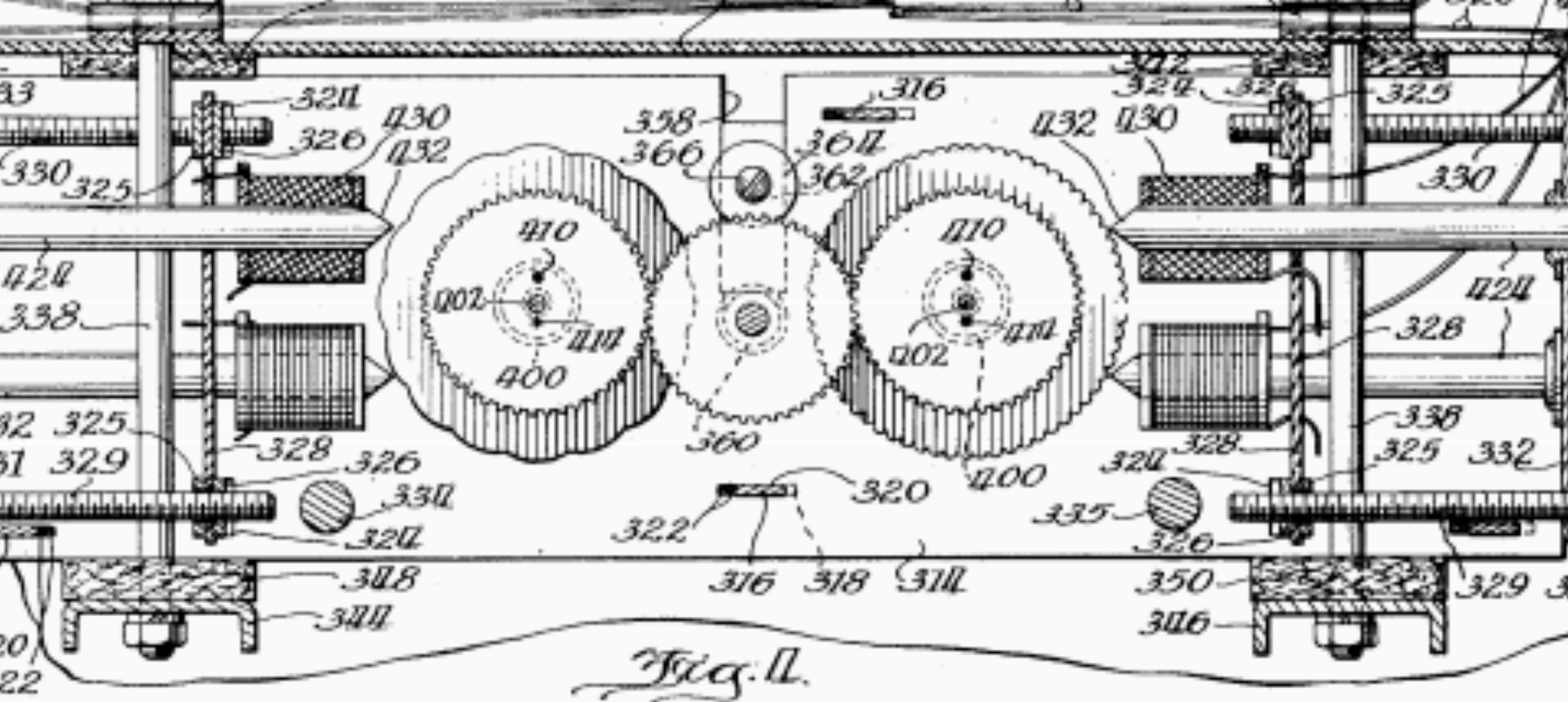




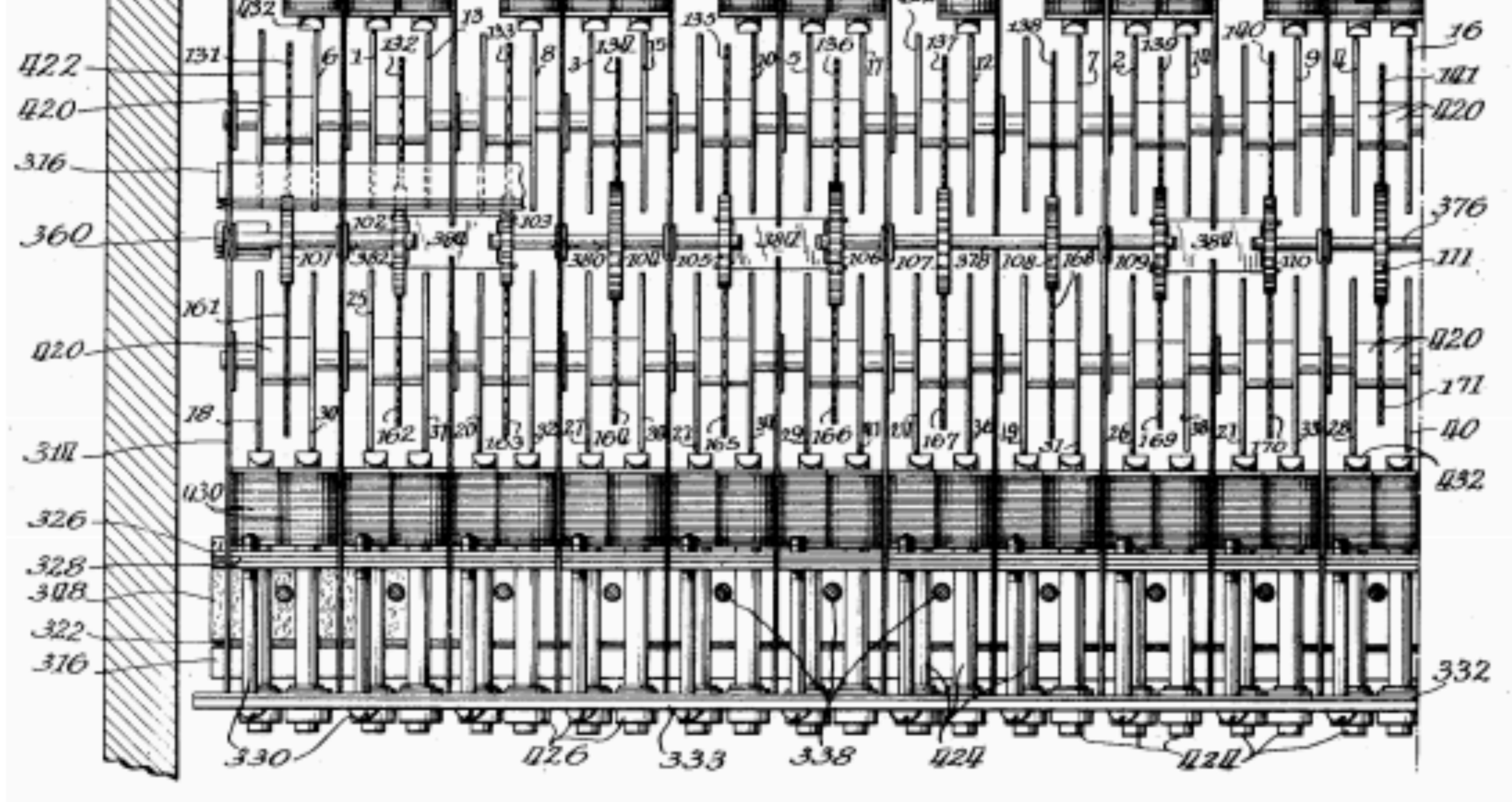


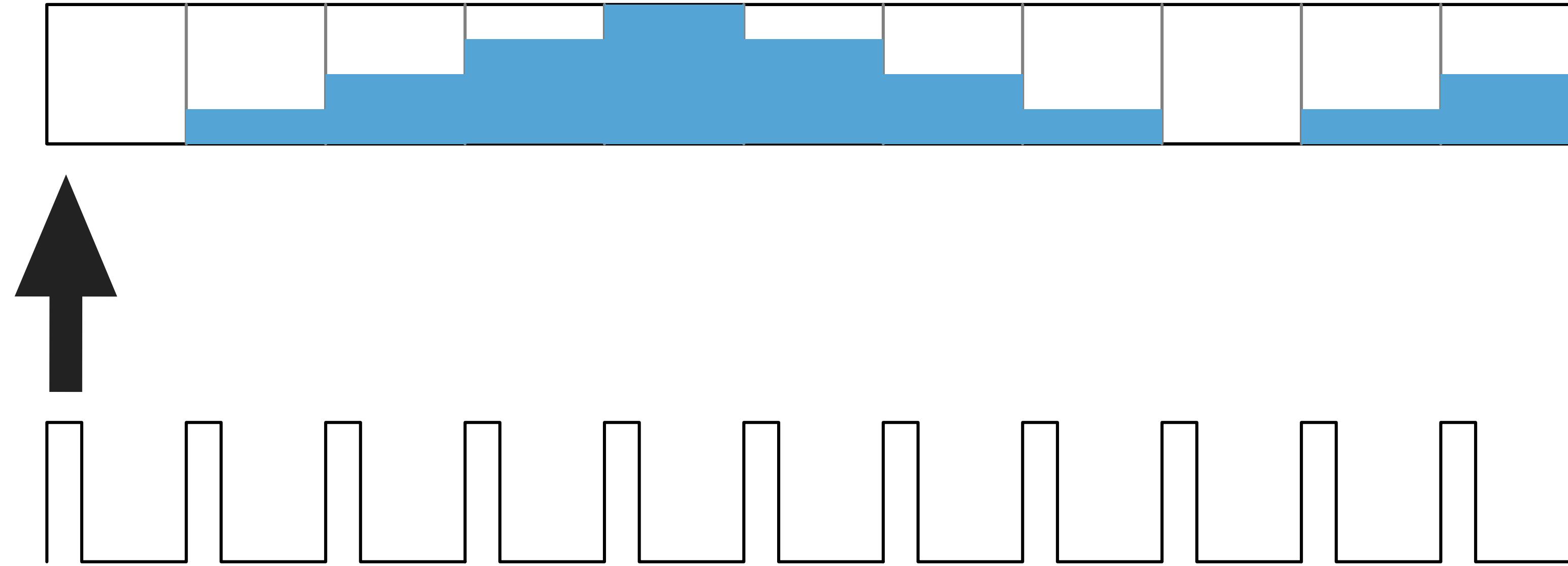
HAMMOND 1/7

91 Tonewheels



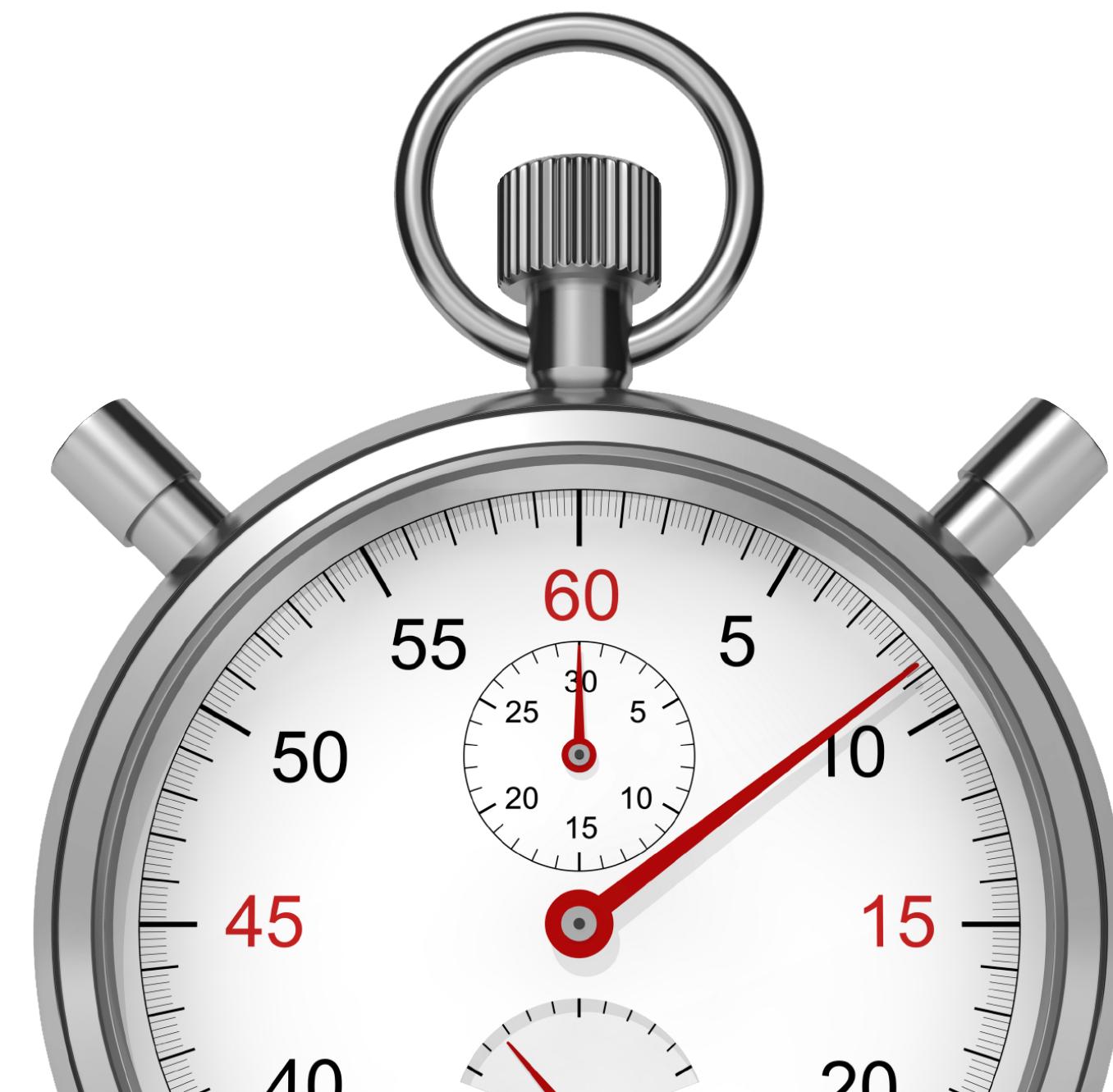
Tonewheels





44.1kHz means
22 μ s per sample

Tonewheels





Tonewheels

Kosovo-Serbia row makes Europe clocks go slow

⌚ 7 March 2018

TIME WARP —

Microwaves across Europe are 6 minutes slow due to a Serbia-Kosovo grid dispute

A connected grid offers a lot of efficiencies, but disputes can affect everyone.

European clocks lose six minutes after dispute saps power from electricity grid

A row between Kosovo and Serbia is draining energy from the continent's 25-nation system, causing electronic clocks to fall behind

Tonewheels

```
typedef struct audio_block_struct
{
    int16_t data[128];
    /* other stuff deleted */
} audio_block_t;
```

```
void transmit(
    audio_block_t *block,
    unsigned char index = 0);
```

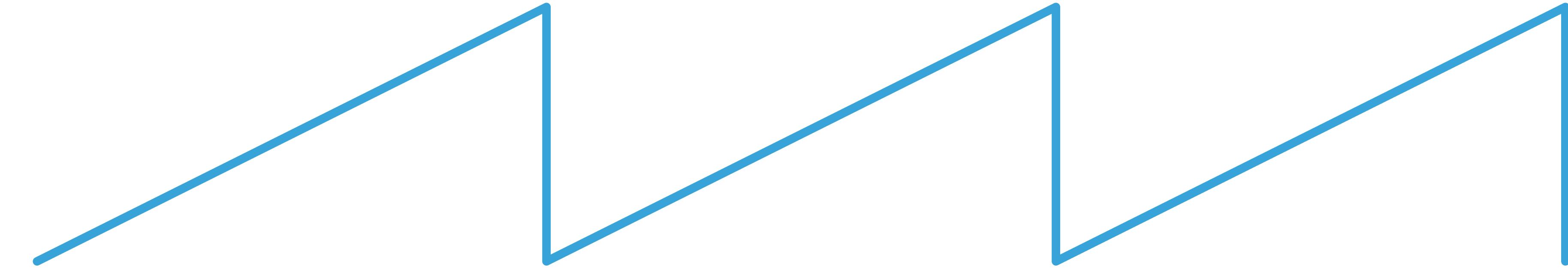
Tonewheels

HAMMOND 2/7

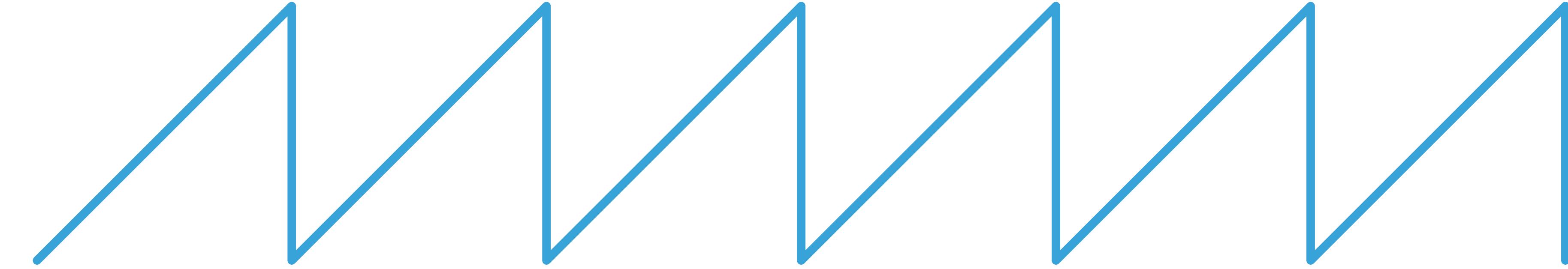
Direct Digital Synthesis

```
uint32_t counter = 0;
```

```
while (1) {  
    counter += 1;  
}
```



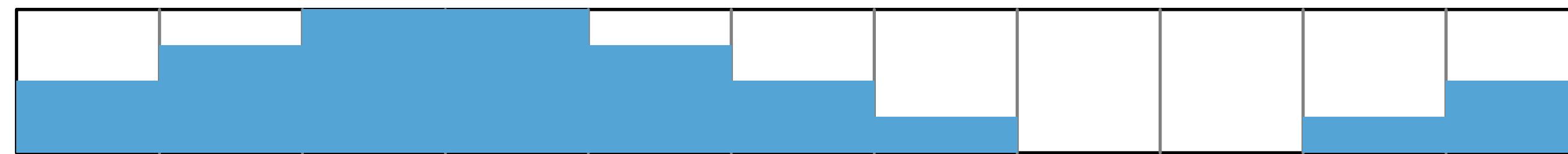
```
while (1) {  
    counter += 2;  
}
```



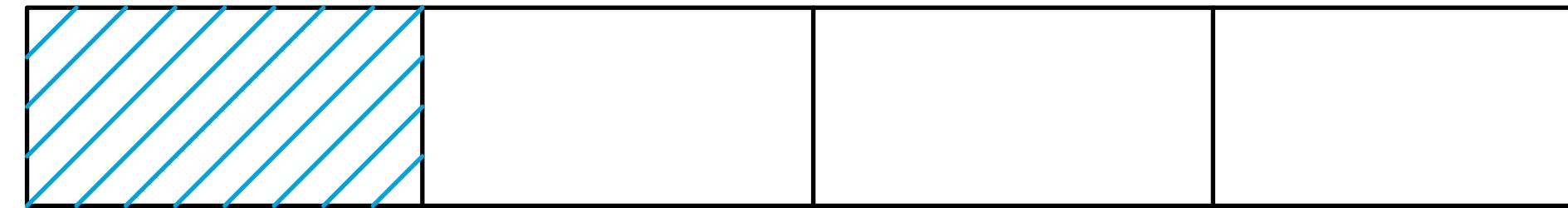
Direct Digital Synthesis

int16_t sine[256]

sine lookup table: 16 bit signed values, 256 elements



uint32_t counter



32

24

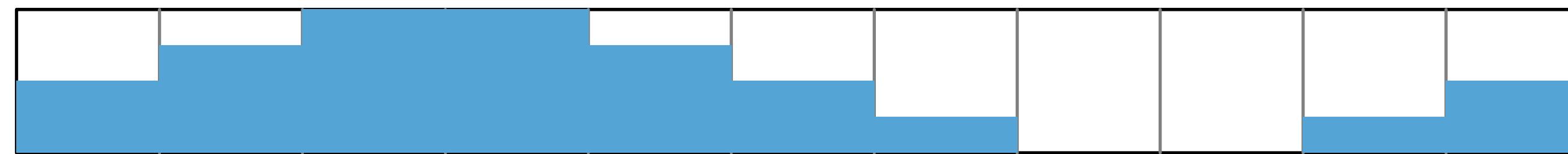
16

8

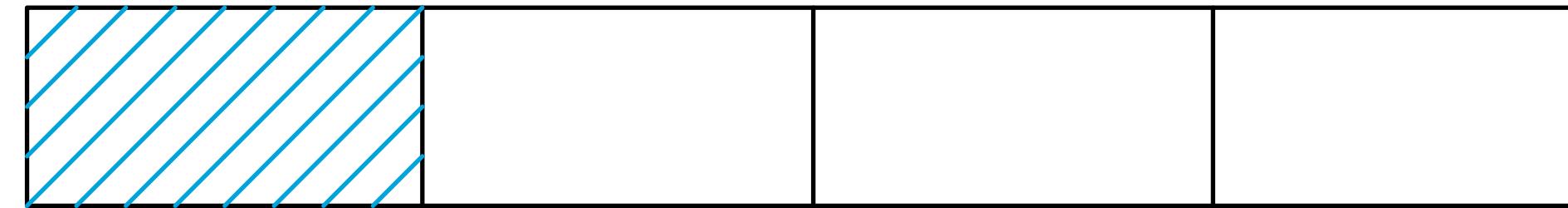
Direct Digital Synthesis

int16_t sine[256]

sine lookup table: 16 bit signed values, 256 elements



uint32_t counter



32

24

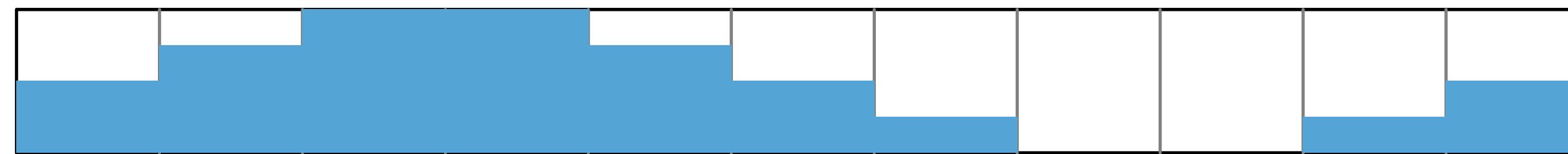
16

8

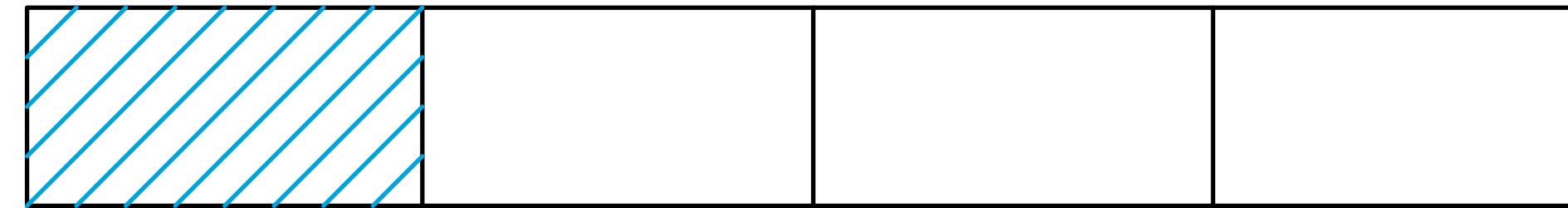
Direct Digital Synthesis

int16_t sine[256]

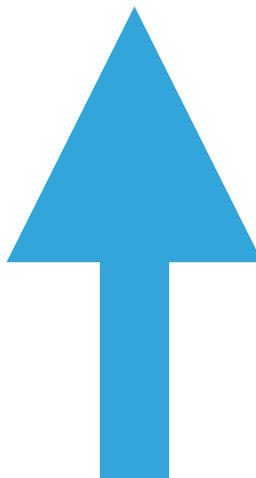
sine lookup table: 16 bit signed values, 256 elements



uint32_t counter



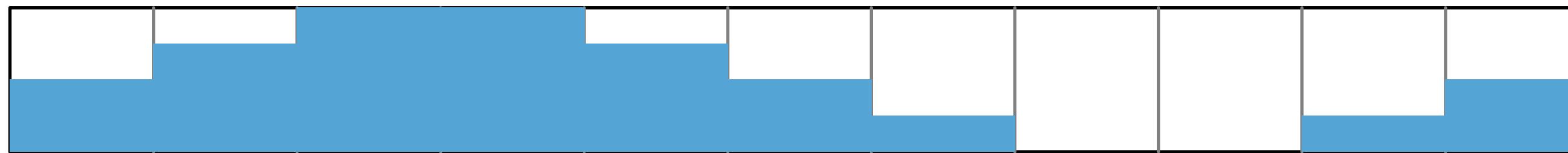
incr = 0000001 00000000 00000000 00000000



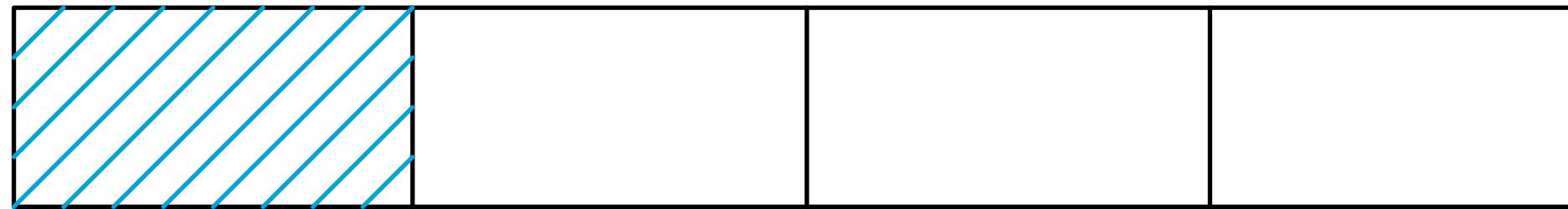
Direct Digital Synthesis

int16_t sine[256]

sine lookup table: 16 bit signed values, 256 elements



uint32_t counter



```
oscillator {
    uint32_t counter;
    uint32_t increment;
}
```

```
int16_t next() {
    counter += increment;
    index = counter >> 24;
    return sine[index];
}
```

Direct Digital Synthesis

```
oscillator {  
    uint32_t accumulator;  
    uint32_t increment;  
}
```

oscillator
position

frequency

Direct Digital Synthesis

HAMMOND 3/7

Setting Frequency

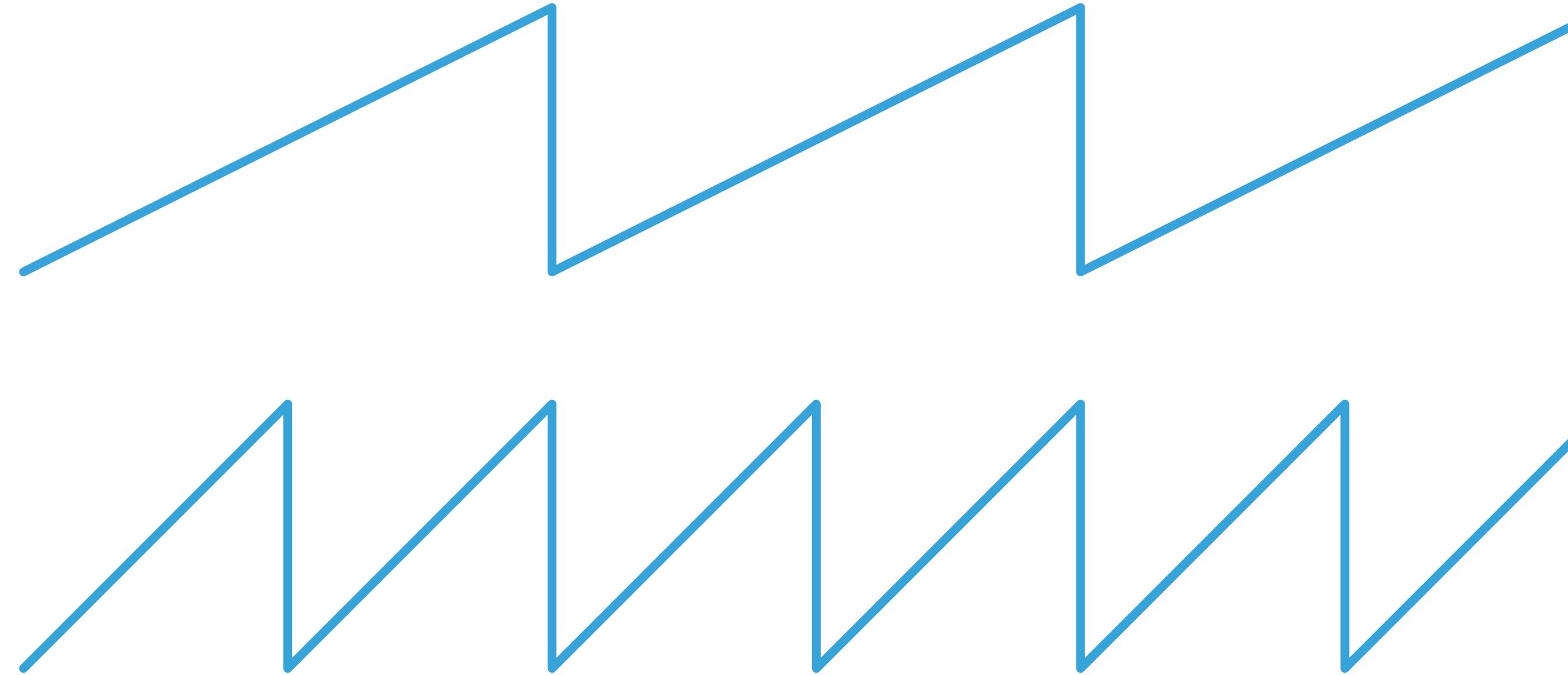
incr = 00000001 00000000 00000000 00000000

increment < 2²⁴?

frequency < 172Hz

increment > 2²⁴?

frequency > 172Hz



Setting Frequency

incr = 00000001 00000000 00000000 00000000

increment < 2^24?

frequency < 172Hz

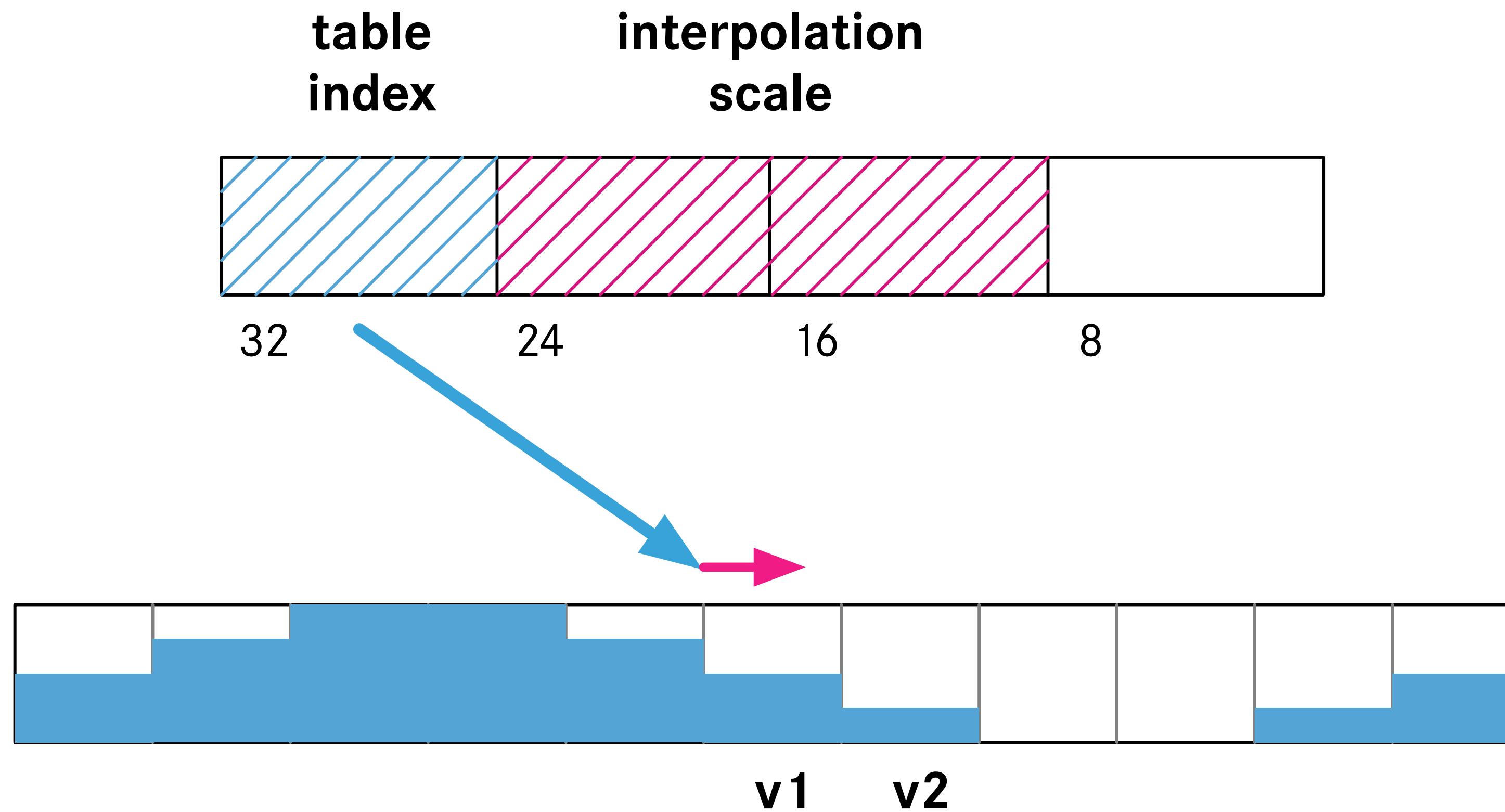
increment > 2^24?

frequency > 172Hz

$$incr = \frac{2^{32}}{44100} * freq$$

Setting Frequency

uint32_t counter



Setting Frequency

HAMMOND 4/7

Setting Volume

```
oscillator {  
    uint32_t accumulator;  
    uint32_t increment;  
    uint16_t volume;  
}
```

```
int16_t next() {  
    accumulator += increment;  
    index = accumulator >> 24;  
    scale = (accumulator >> 8) & 0xFFFF;  
    sample = interpolate(sine[index], sine[index+1], scale);  
    return (sample * volume) >> 16;  
}
```

top 8
bits

next 16
bits

apply
volume

Setting Volume

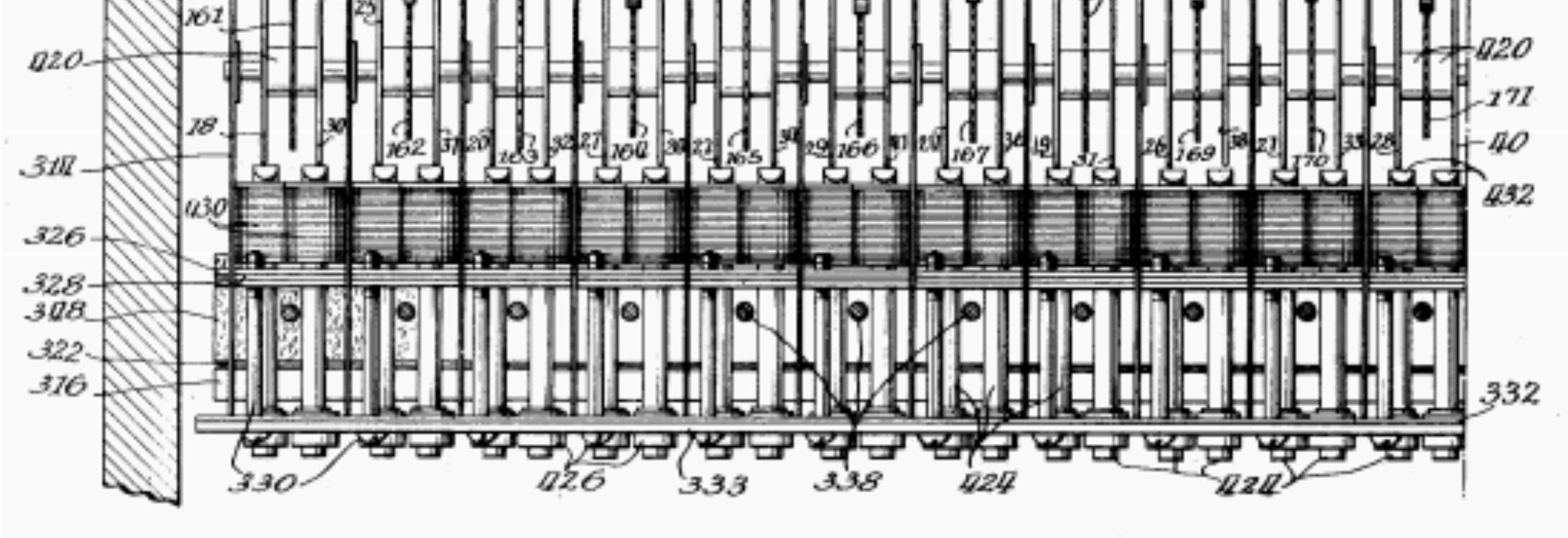
```
int16 sample;  
int16 volume;
```

```
int16 result = (sample * volume) >> 16;
```

(N bits) * (M bits) = N+M bits

(N bits) + (M bits) = (max(N, M) + 1) bits

Setting Volume



```
oscillator {  
    uint32_t accumulator[91];  
    uint32_t increment[91];  
    uint16_t volume[91];  
}
```

Setting Volume



Fully cacophonic

HAMMOND 5/7

Vibrato / Chorus

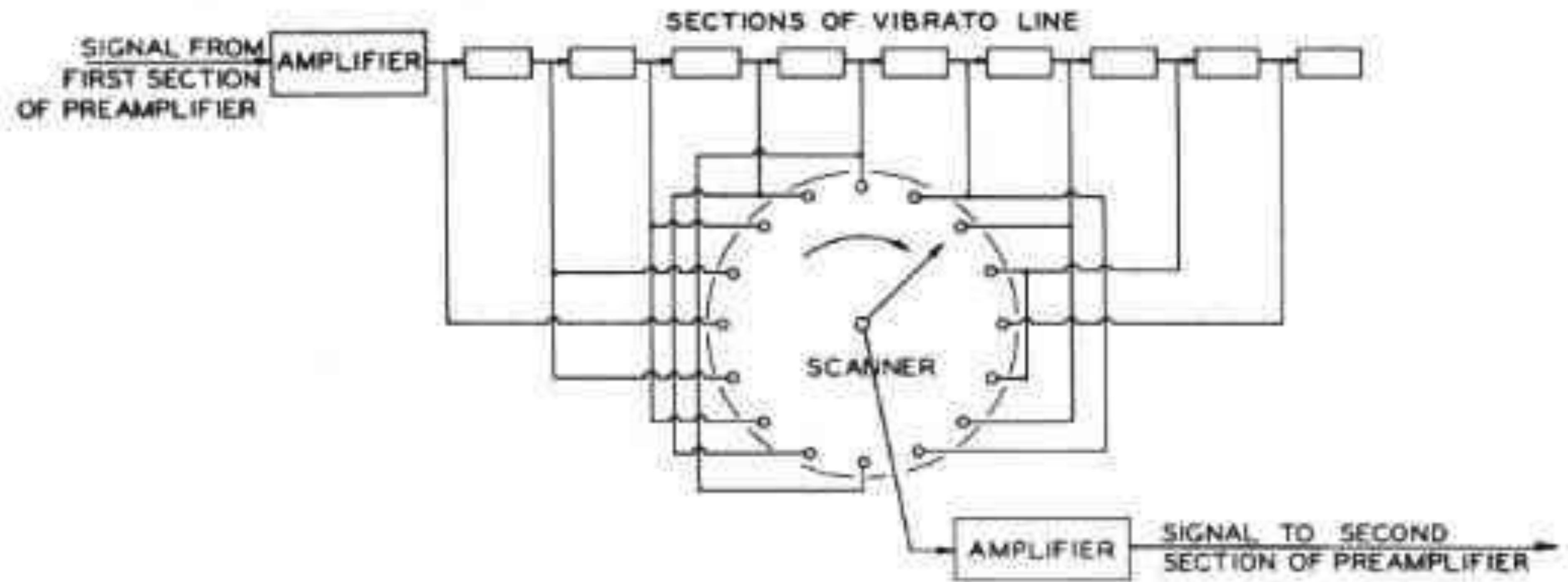


Fig. 1 - FUNDAMENTAL DIAGRAM OF VIBRATO EQUIPMENT.

Vibrato / Chorus

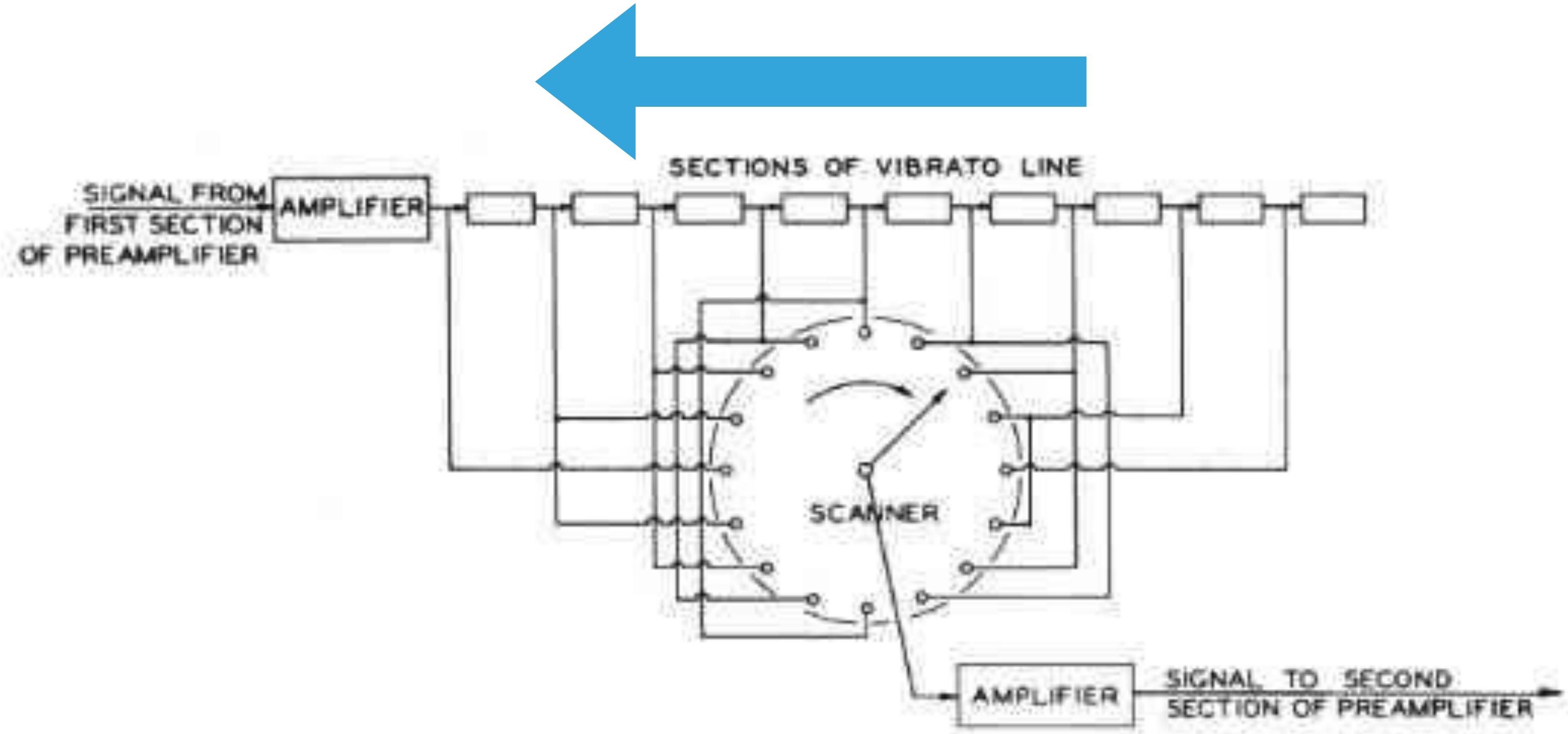
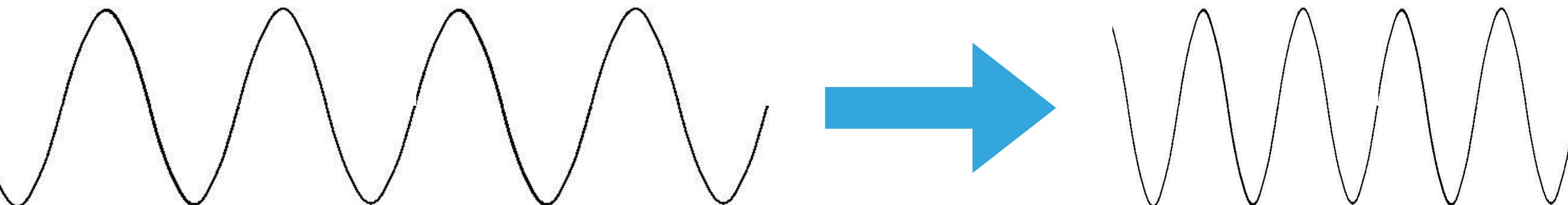


Fig. 1 - FUNDAMENTAL DIAGRAM OF VIBRATO EQUIPMENT.



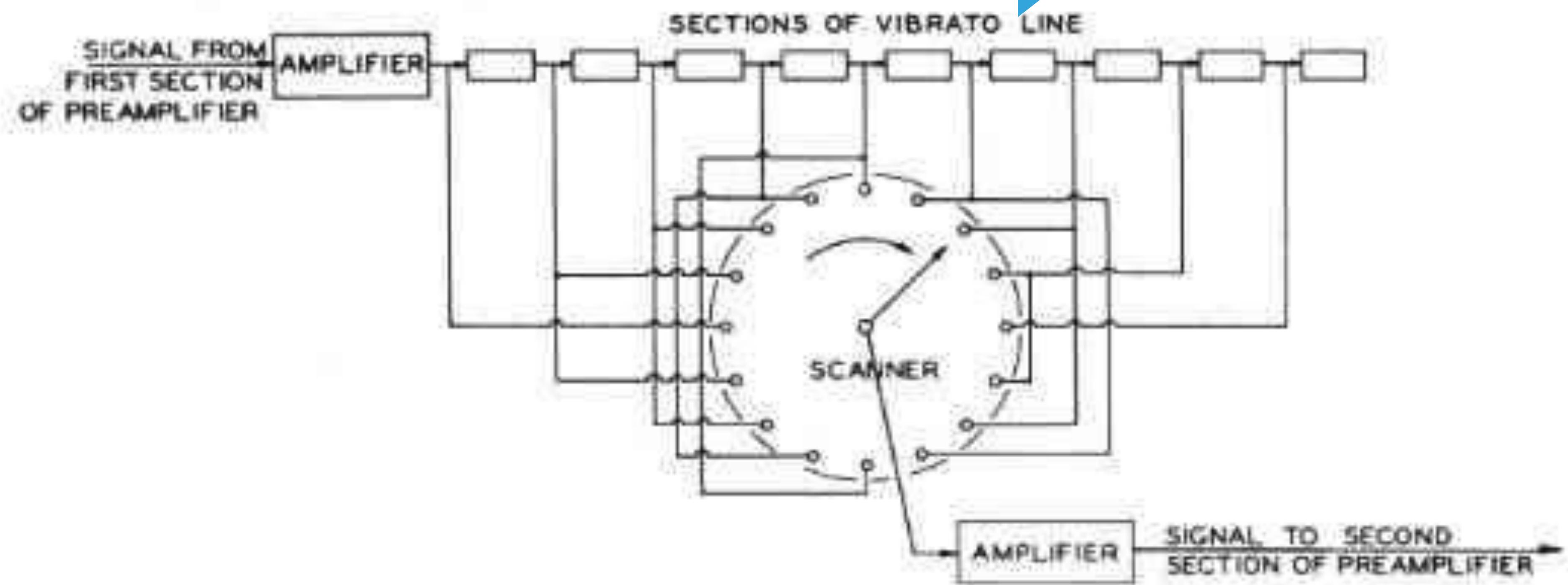
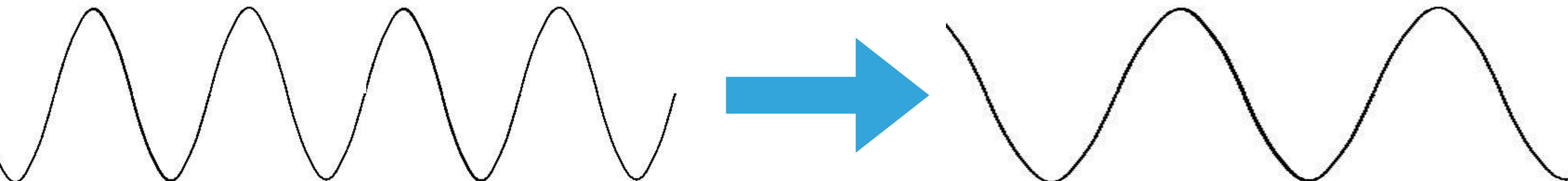


Fig. 1 - FUNDAMENTAL DIAGRAM OF VIBRATO EQUIPMENT.



VIBRATO
AND
CHORUS



C-2

V-3

C-3

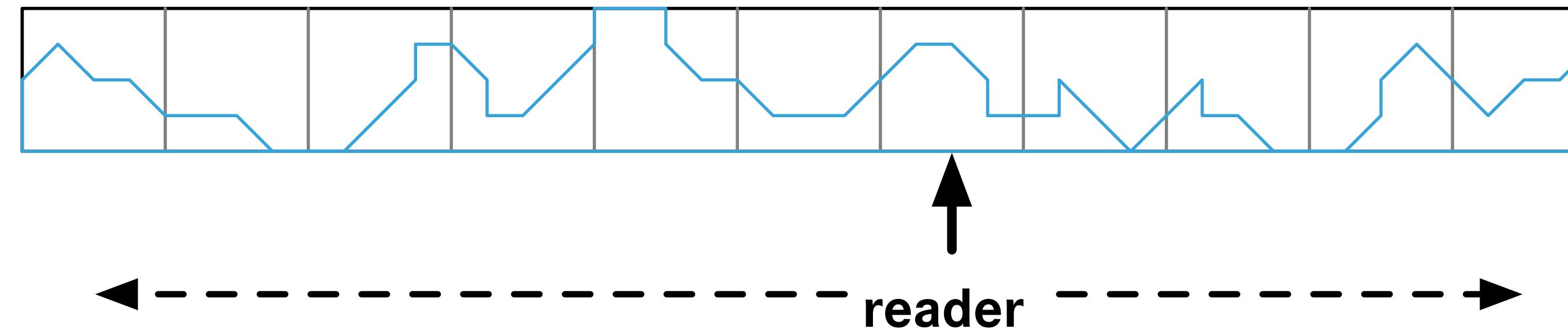
VIBRATO
AND
CHORUS

V-2

V-1

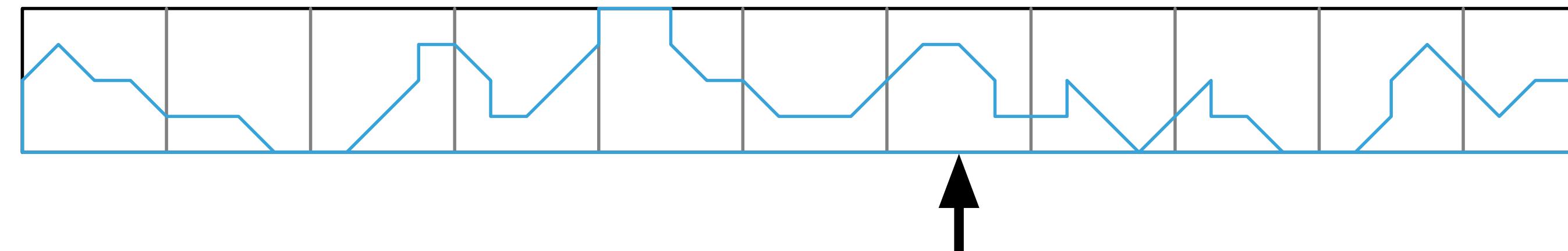
C-1

writer →

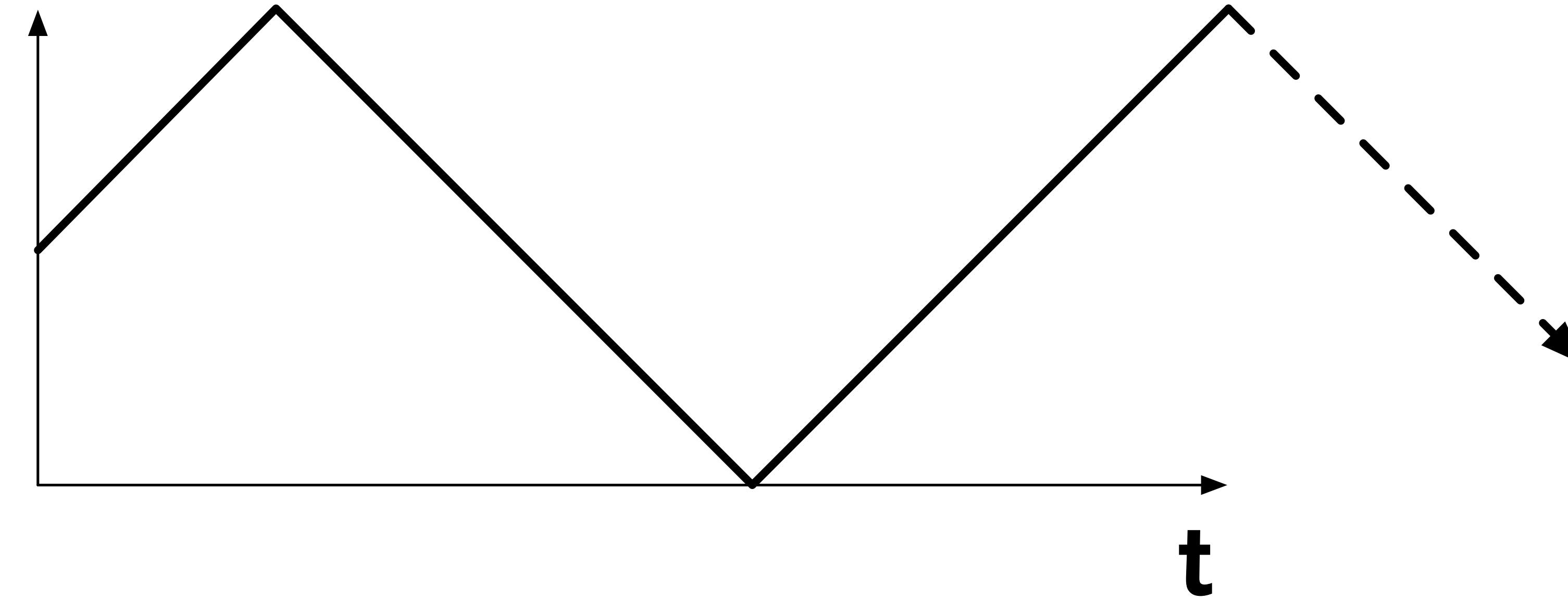


Vibrato / Chorus

writer →



**read
offset
from
writer**



Vibrato / Chorus

```
int16_t triangle[256];
```

```
oscillator {  
    uint32_t accumulator;  
    uint32_t increment;  
    uint16_t depth;  
}
```

oscillator
position

frequency
(7Hz)

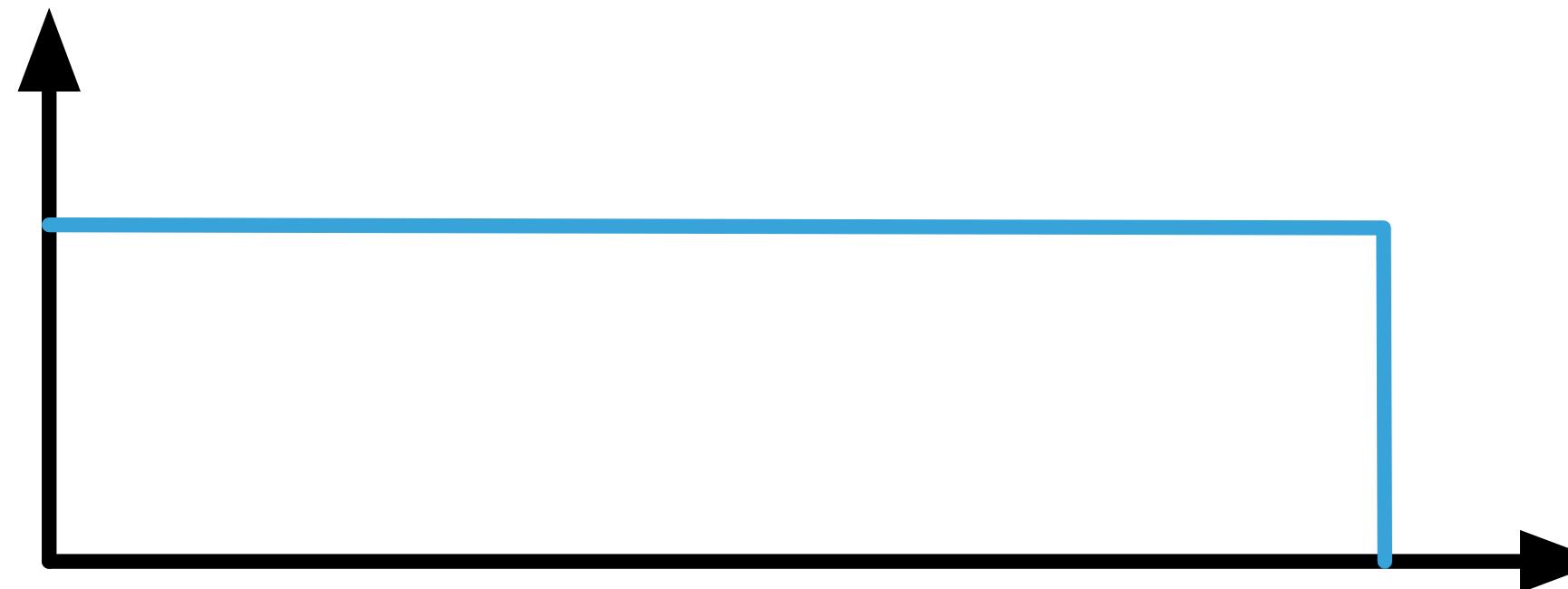
vibrato
depth

Vibrato / Chorus

HAMMOND 6/7

Percussion

Volume



held
notes

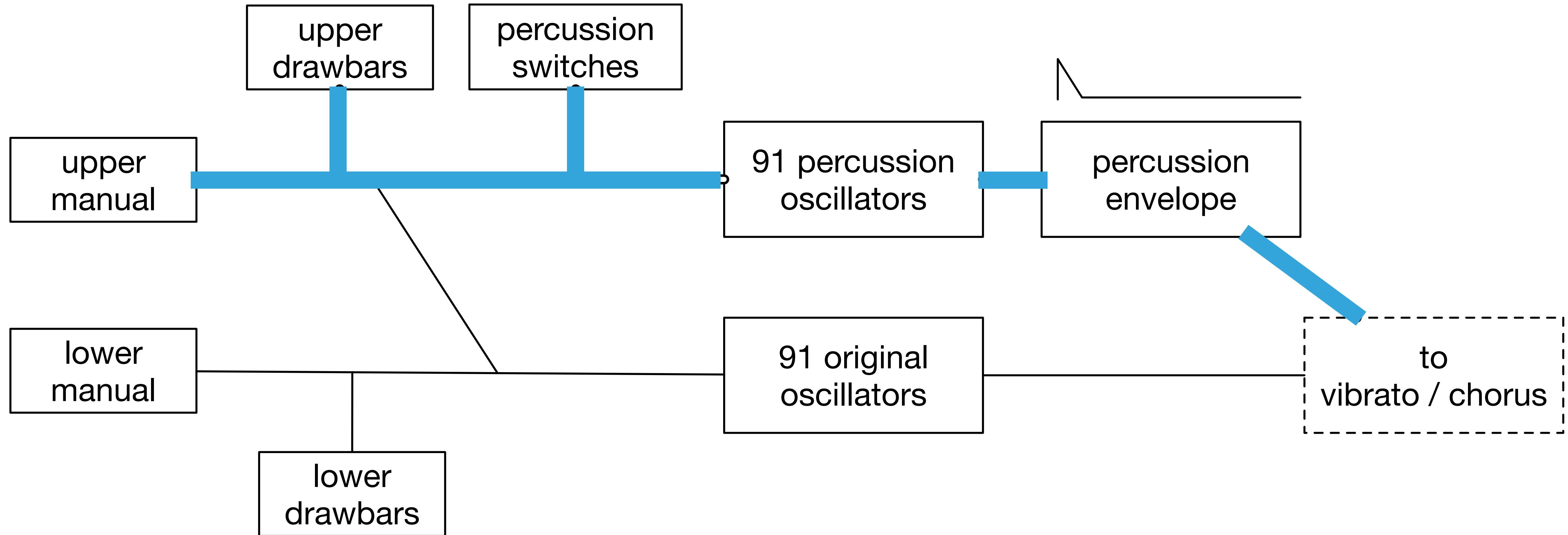


percussion
chirp

key down

key up

Percussion



Percussion



HAMMOND 7/7

Swell

SINE OSCILLATOR
VIBRATO / CHORUS
PERCUSSION
SWELL

B-3 Reprise

Bridge





“I never intended for my organ to sound that way.”

Laurens Hammond



“I never intended for my organ to sound that way.”

Laurens Hammond



"I was amazed at all the publicity Hammond created for me by their continuous bad-mouthing of my product. This word-of-mouth advertising was so good that from the start until the company was sold to CBS in 1965, no advertising was ever needed and my problem has always been keeping up production to match sales."

Don Leslie

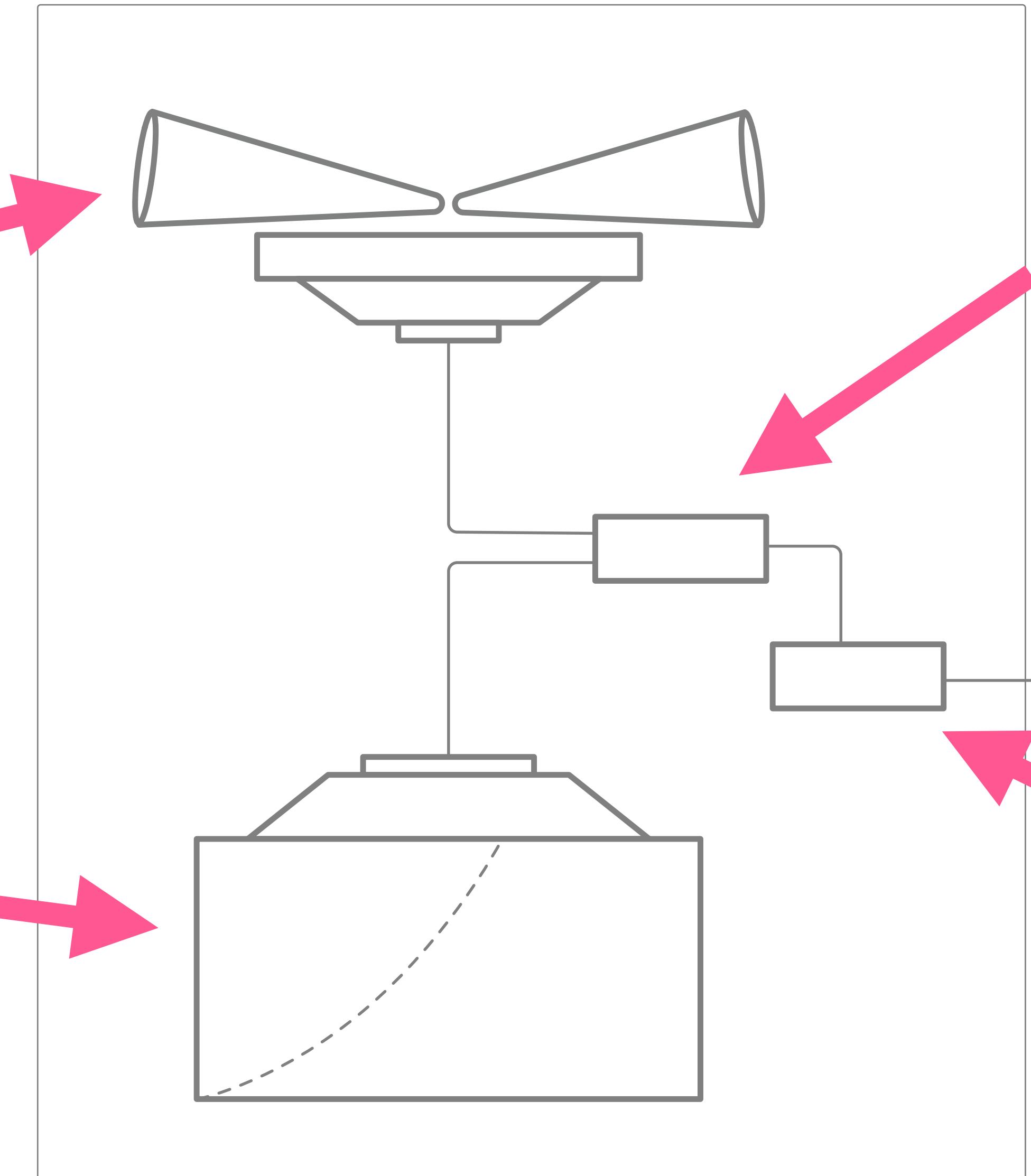
Leslie 122

treble
rotor

bass
rotor

800Hz
crossover

tube
amplifier

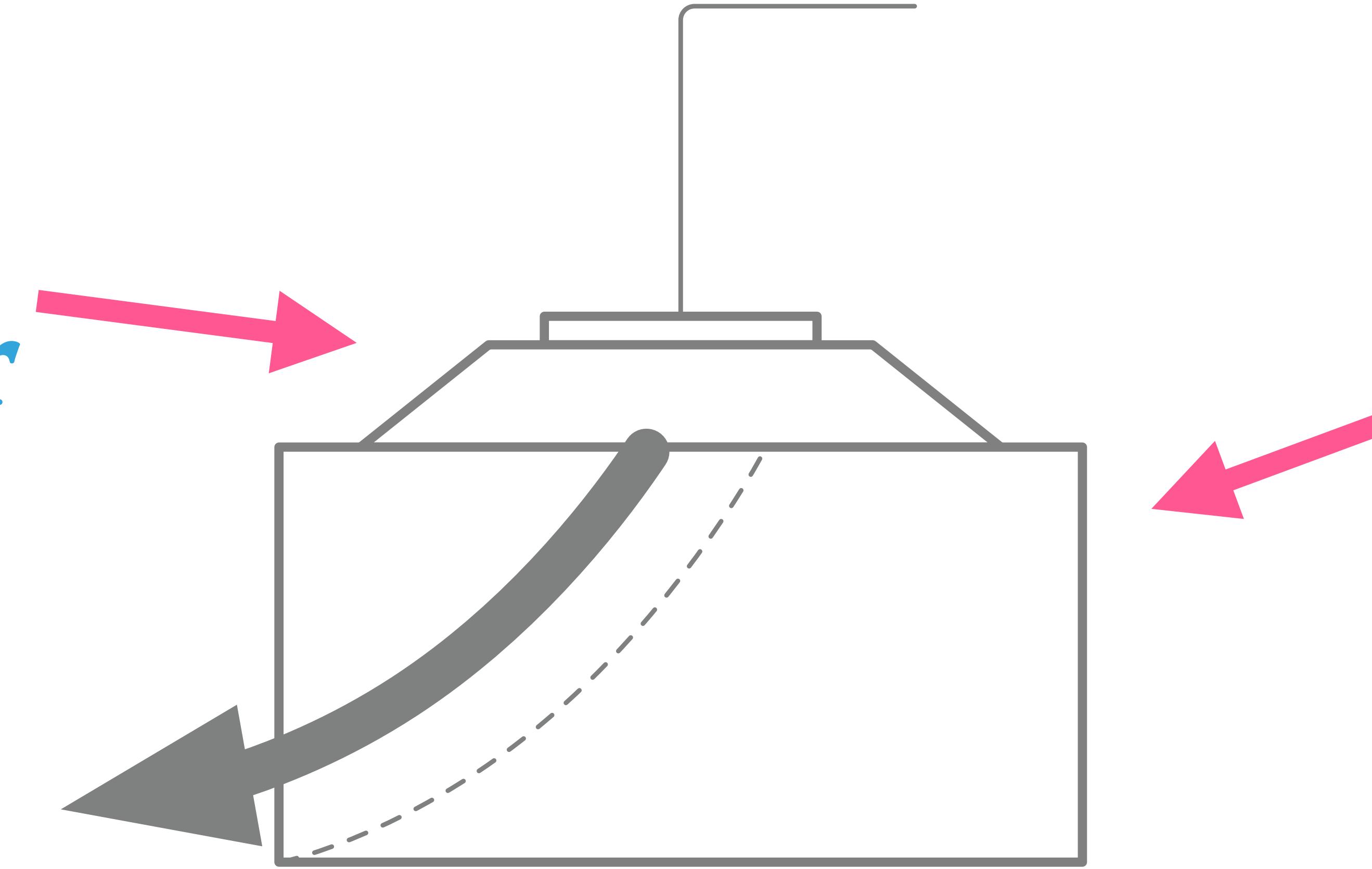


Leslie 122

LESLIE 1/4

Bass

bass
speaker



Bass rotor

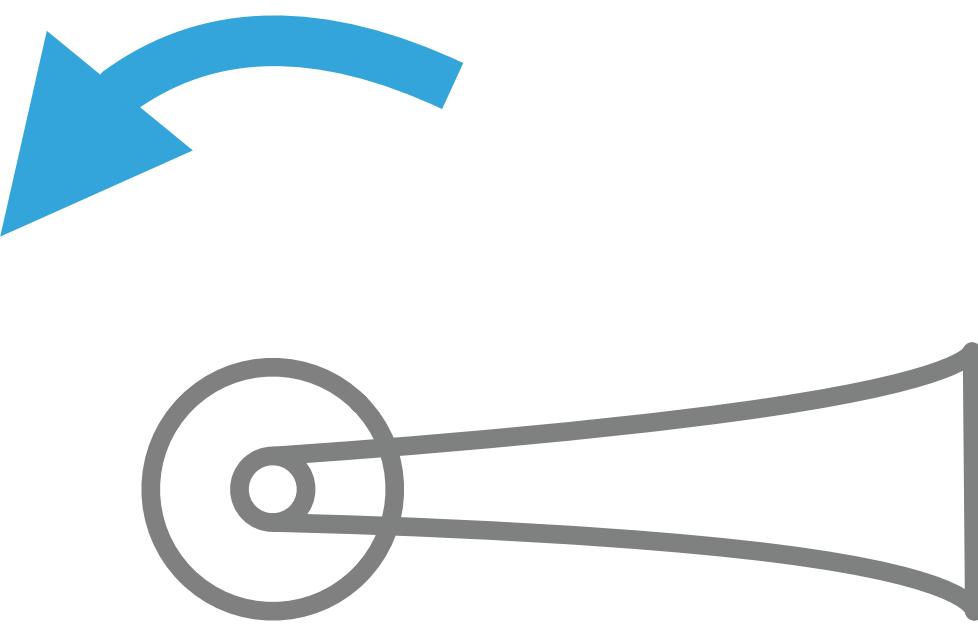


LESLIE 2/4

Treble

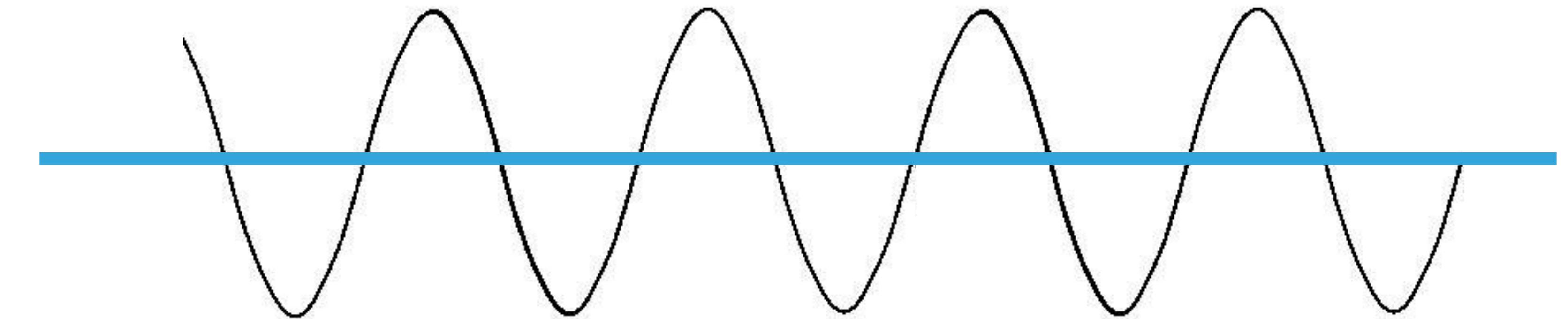


Treble horn



real pitch

perceived increase



perceived decrease

Treble horn

```
amfm {  
    int16 ringbuf[];  
    uint32 accumulator;  
    uint32 increment;  
    uint16 read_shift[256];  
    uint16 volume[256];  
}
```

sawtooth
oscillator

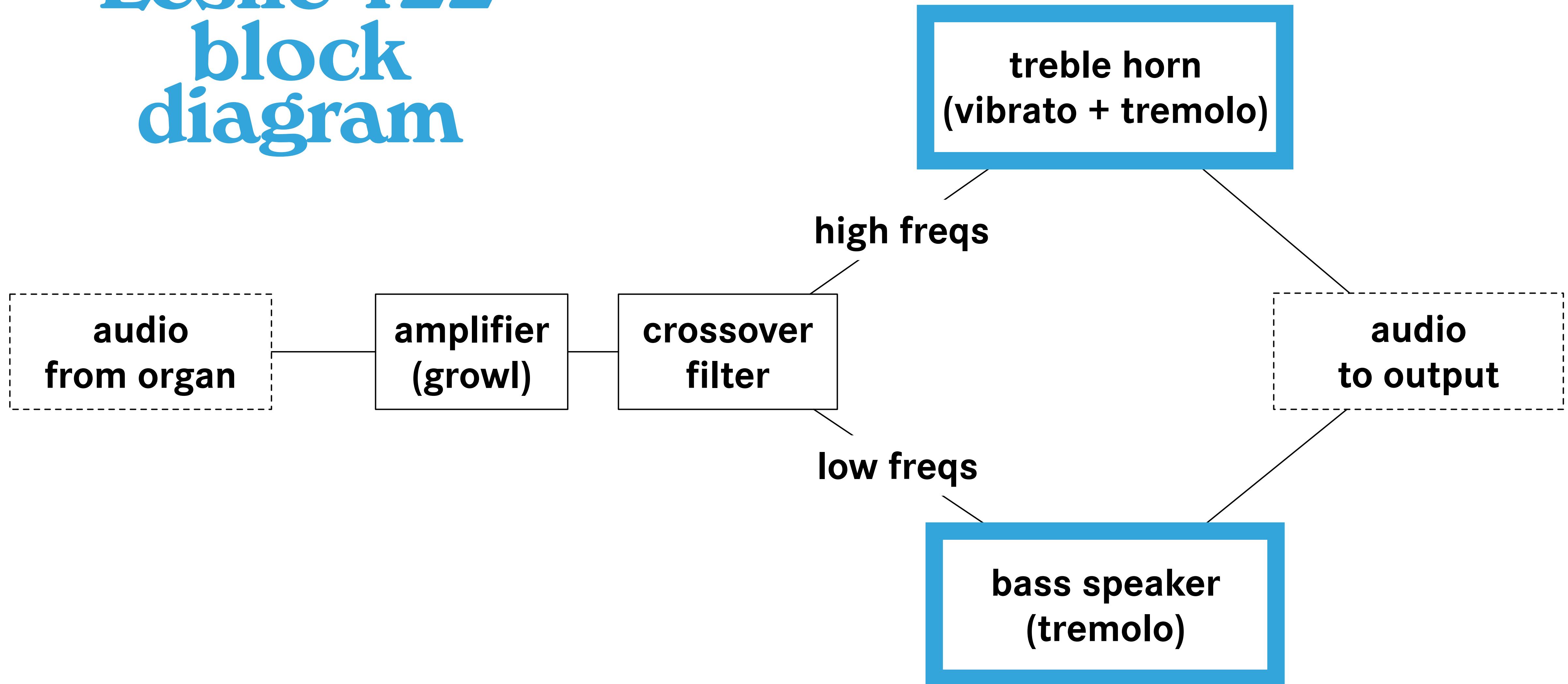
frequency
control

vibrato

tremelo

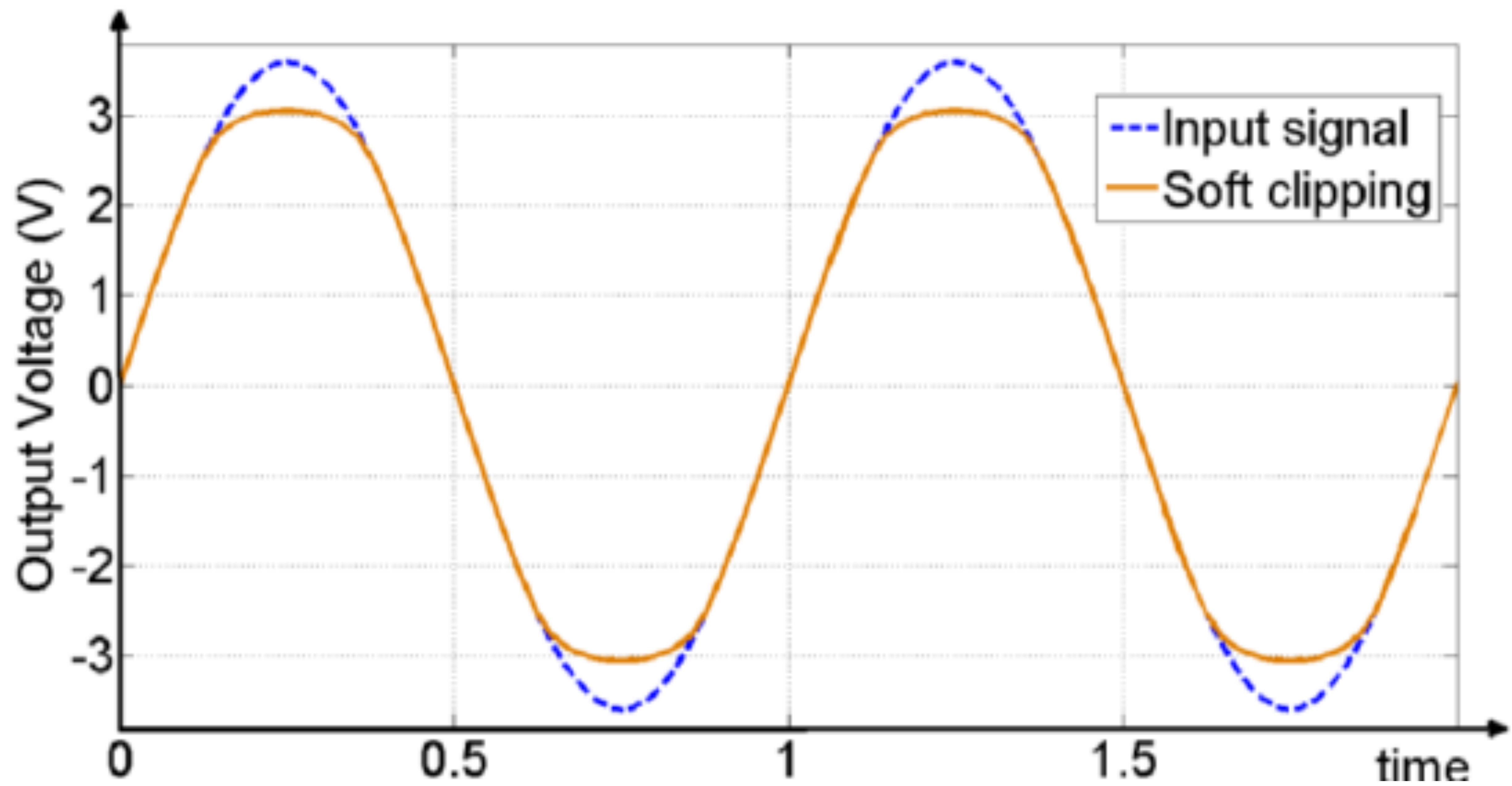
Treble horn

Leslie 122 block diagram



LESLIE 3/4

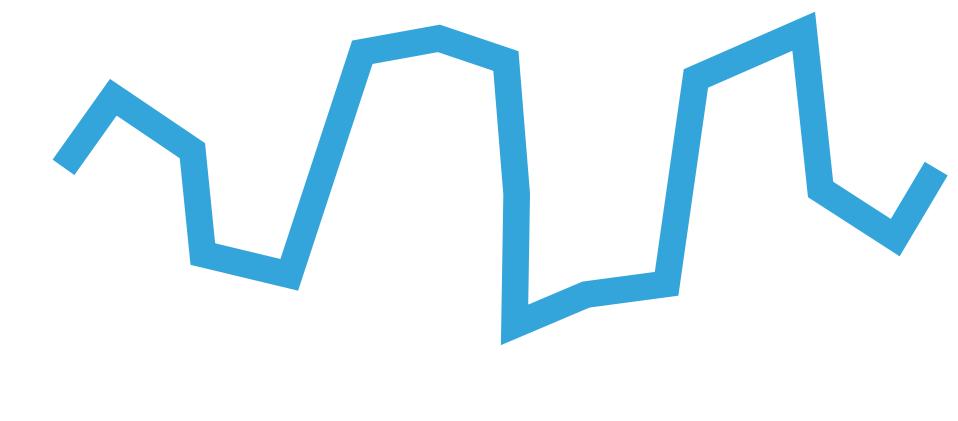
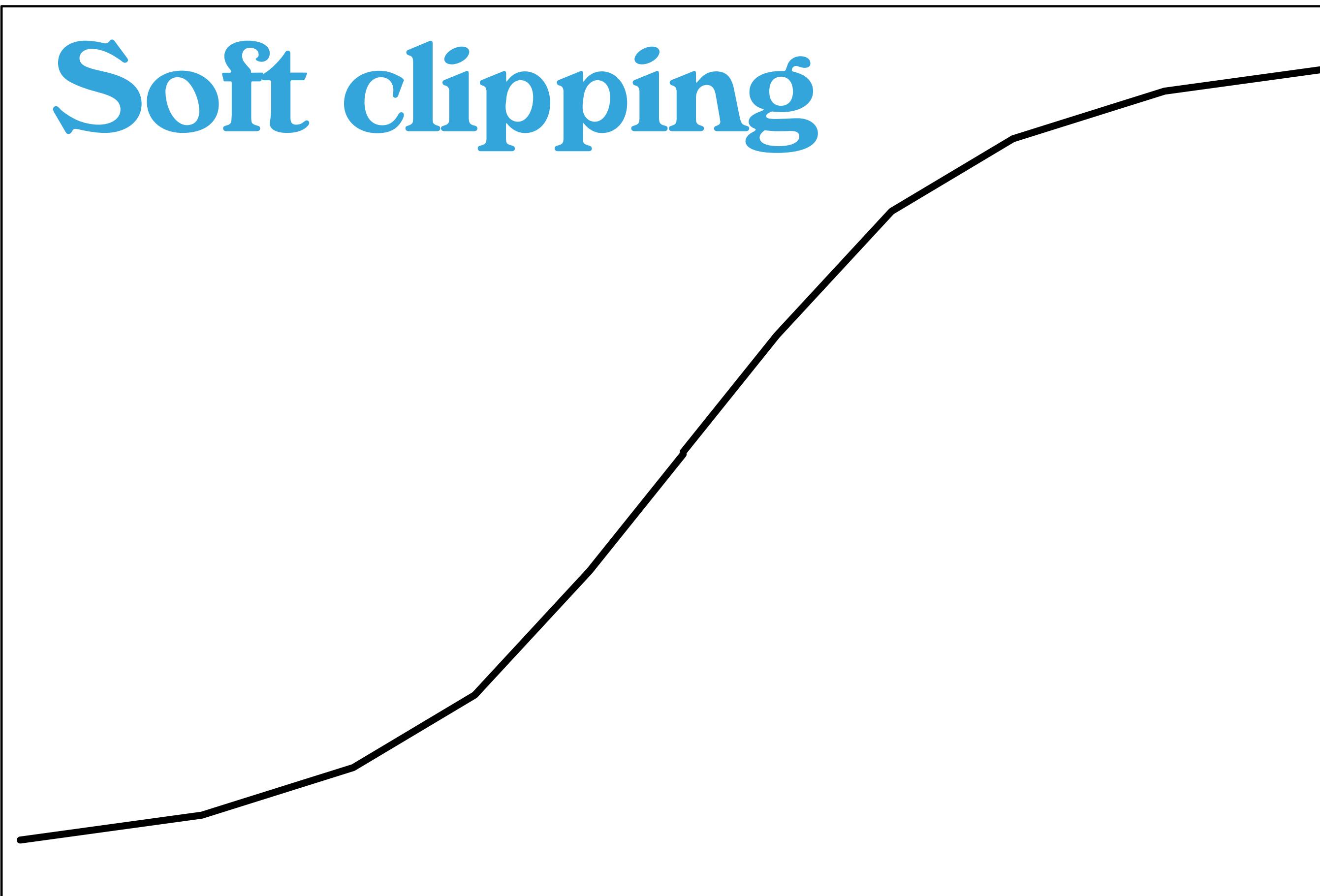
Growl



zero
↓

16-bit signed
lookup table

Soft clipping



Growl

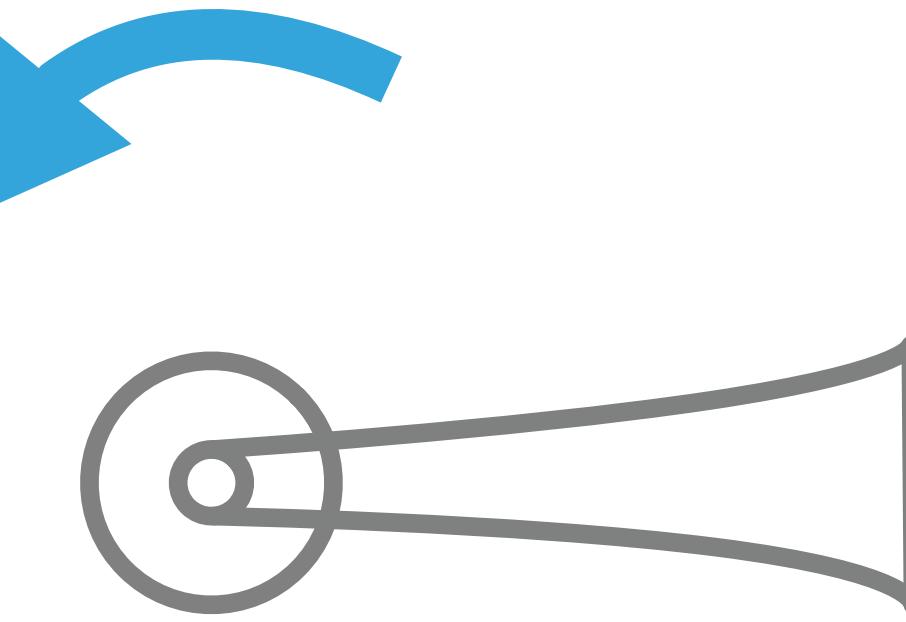
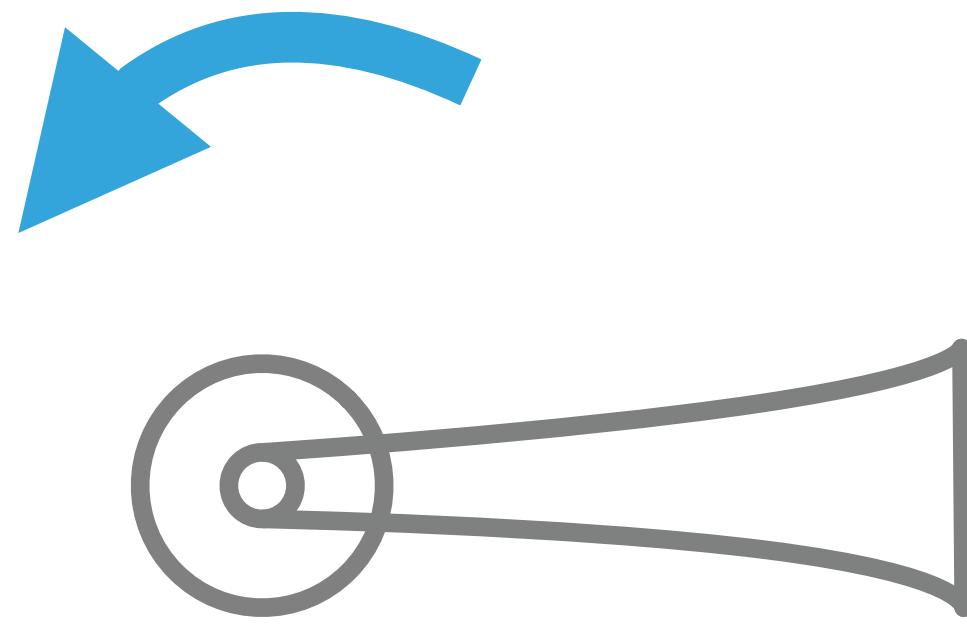
LESLIE 4/4

Stereo

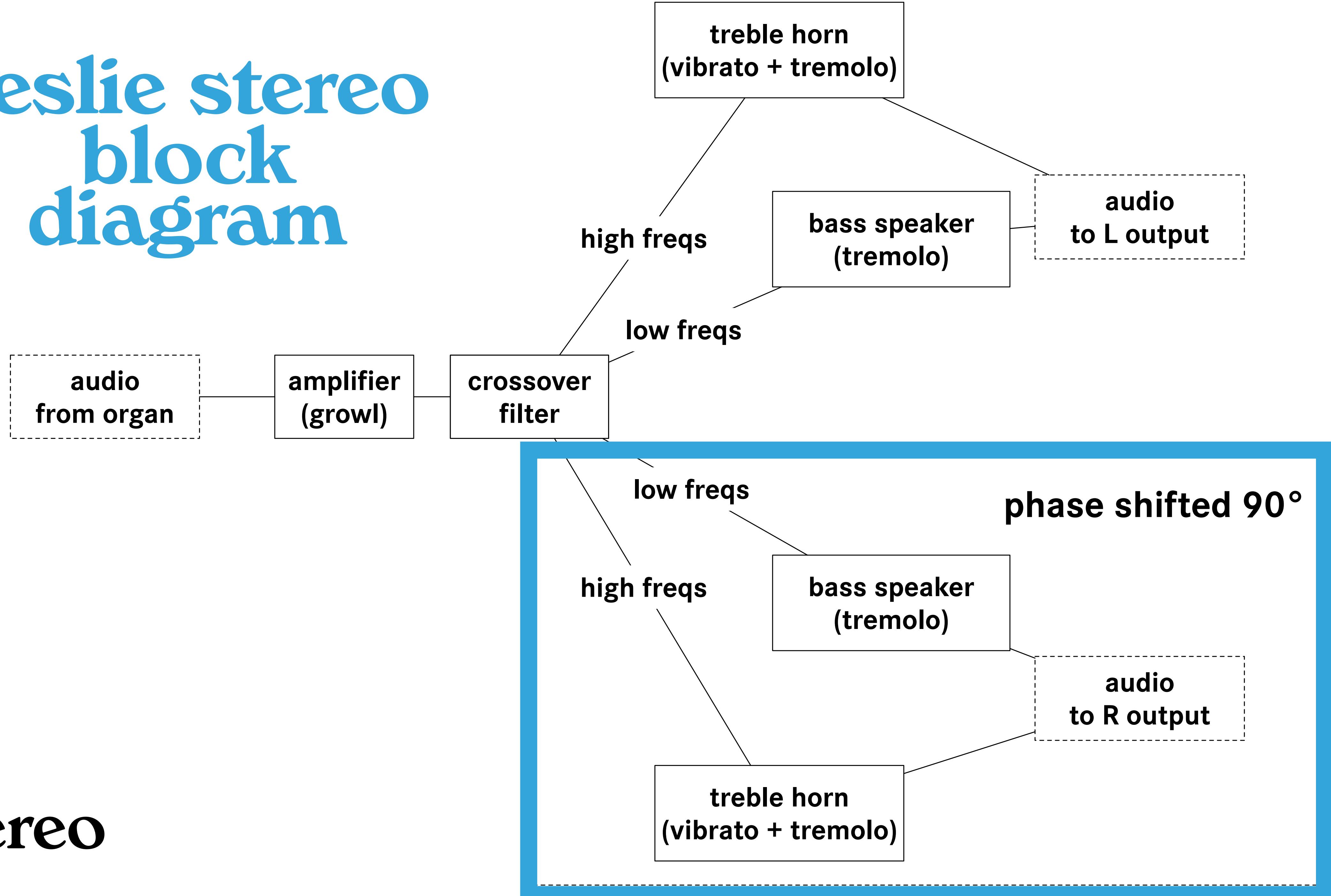
Stereo



Stereo



Leslie stereo block diagram



Stereo

DISTORTION
TREMOLO / VIBRATO
2 ROTATING SPEAKERS
STEREO OUTPUT

Leslie Reprise

Coda

[github.com/
pteichman/roto](https://github.com/pteichman/roto)

[github.com/
pteichman/roto](https://github.com/pteichman/roto)

