Beyond The Beep

The case for Calculator High Fidelity Audio Output

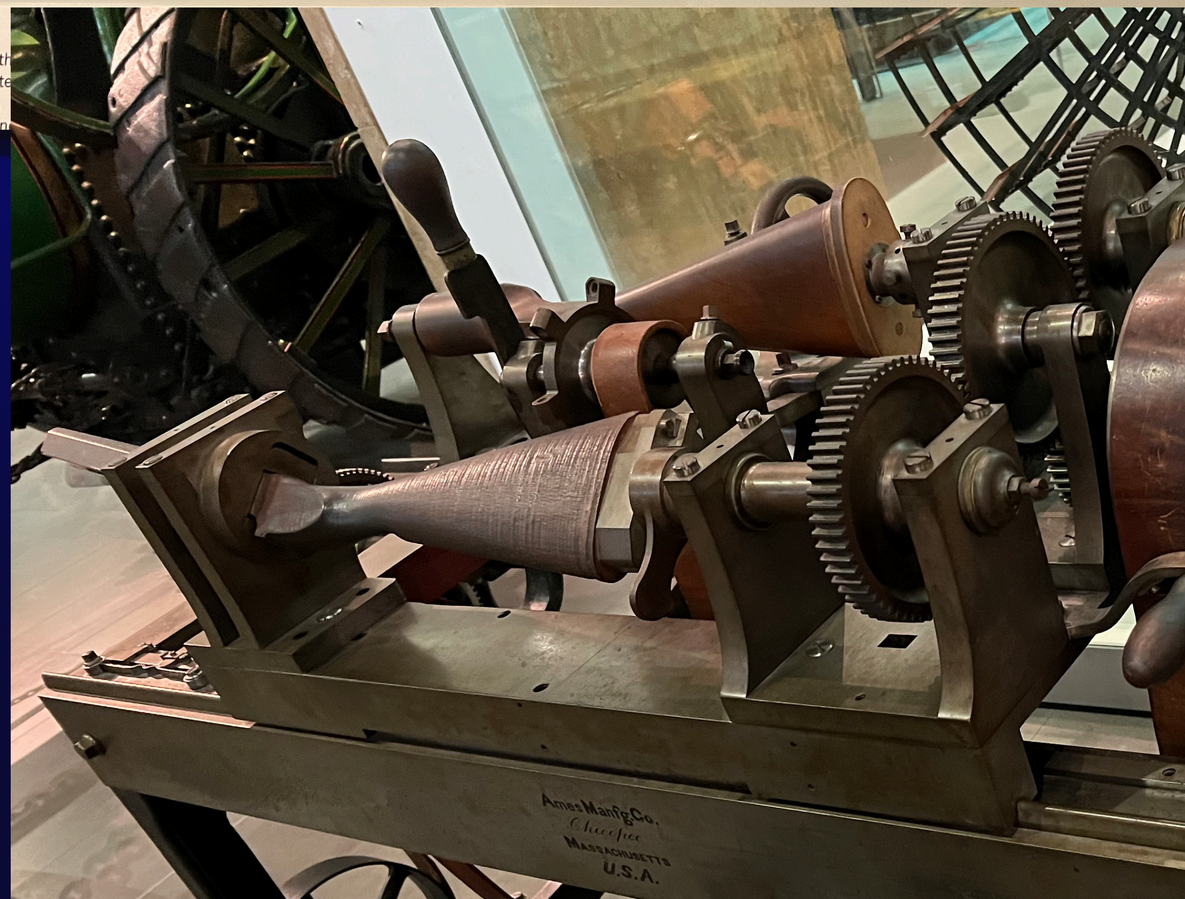
Robert Efroymson 23 October 2022

Another project

Bronzeartifacts.com


Burroughs
BURROUGHS


pilot
vodafone
11
13


Ames Manfg Co.
Chicopee
Massachusetts
U.S.A.

Setting Expectations

This will be a 30,000 foot view

I’m just getting started on a lot of the ideas here.

The talk will occasionally fly a bit closer to the ground

Please bear with me

It Should be done

- STEM is turning to STEAM: Art is joining Science Technology Engineering and Math
- Music has some mathematical character
- DSP is in high demand, and teaching it is valuable

Music and Math

Anyone remember “Gödel, Escher, Bach”?

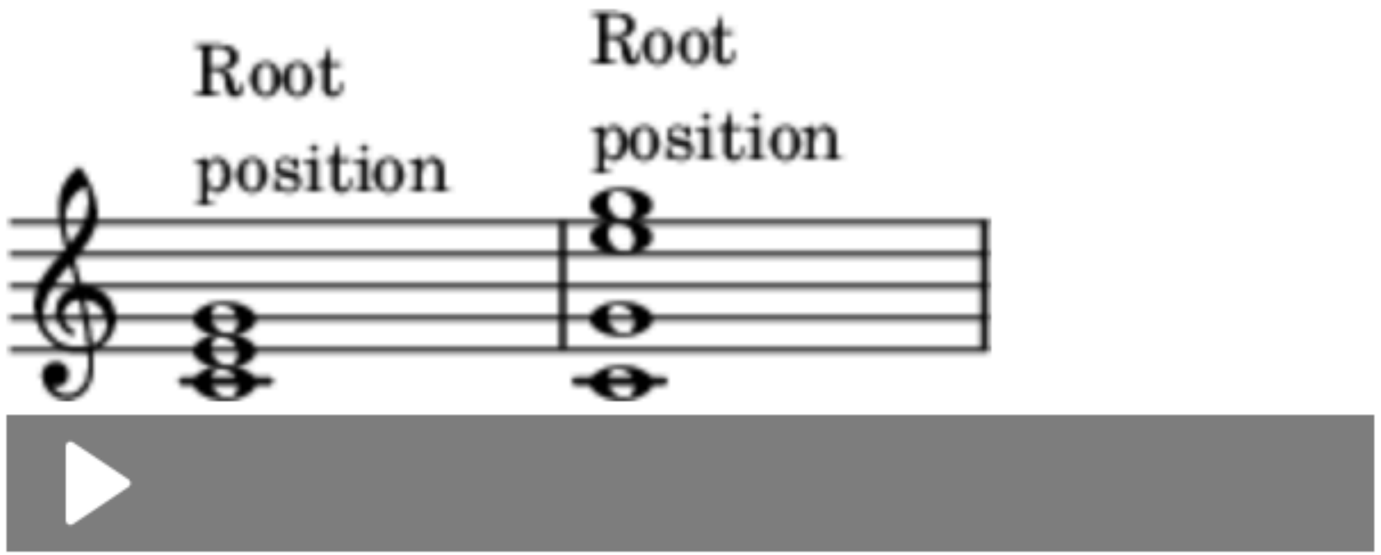
- There is a rich set of connections as described in that famous book
- More simply though, Transposition is addition
- Retrograde is list reversal,
- Inversion is a bit more complex

A Bit more on Musical Inversion

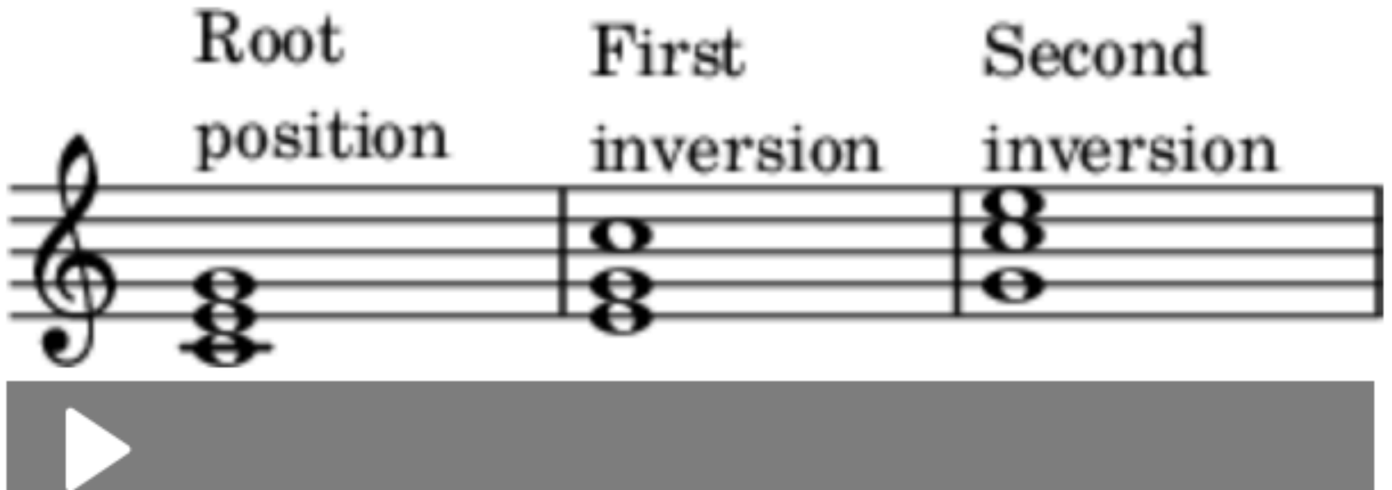
Not quite what you might think

- Different for Chords and Melodies. First Melodies
- Intuitively it means turning the notes “upside down”
- The start note is the same, but all the ‘moves’ go in the other direction
- Example: [5,7,7,9,8,6,6] starts at 1 then goes +2,+0,+2,-1,-2,-0
- Inverting that is -2,-0,-2,+1, +2, +0
- So: [5, 3,3,4,6,6]

bass into different octaves (here, the note E) and the doubling of notes (here, G), is known a
voicing, while the second is open.



In an inverted chord, the root is *not* the lowest note. The inversions are numbered in the ord



Reverse Polish Music

RPM Was skipped between RPN and RPL

- What is it?
- It is not Chopin played backward to reveal Satanic communication
- It is a set of functions that enable creating and modifying musical information
- Vertical and horizontal combinations to create polyphony or longer tune
- Transformations as indicated previously
- Others: Modal adjustments, tempi changes

There are issues

Design ongoing

- How to interpret number as a note
- Concept of Environment
- Rests vs Notes

Modes

Its not just Do Re Mi

- There are 12 notes in a traditional equal tempered Octave
- Do Re Mi Fa Sol Le Ti
- Did you count that? Only seven
- Same as White keys
- Modal transposition might make sense
- Numbers can be interpreted multiple ways

- 1 could be interpreted as Middle C, quarter note, 60 BPM, piano sound
- 2 could then be either D or C# depending
- [1,2,3,4,5,6,7] = Chromatic scale or major or minor or …

Environments can help

Examples:

- Defaults: C Major, quarter note, 4/4 Time, 60BPM, Piano sound
- All could be changed, some note by note, others by measure or line
- Leaving some fixed, and changing others might be educational
- Eg playing same sequence in Major, Minor, or Mixolydian modes
- Speeding up or slowing down
- Transposing by Octaves, or by smaller intervals
- Changing output type

[1 2 3 4] ⬆️ ⬆️ 3 T C ▶️

Set up “melody” of four ascending notes

Put on stack twice

Transpose second copy up by three semitones

Concatenate into 8 note melody

Play the melody

[5 7 9 11] ⬆️ ⬆️ ⬆️ 4 T C ← -2 T C ⬆️ ⇅ C ▶️

Exercise for the Student

Euclidean Rhythms

- Very interesting paper by Godfried Toussaint
- Relates a variety of World Rhythms from Fandango to Dave Brubeck
- His paper is worth looking up
- Relatively simple algorithm, surprisingly diverse outputs
- Basic idea, most even distribution of k points over n spaces

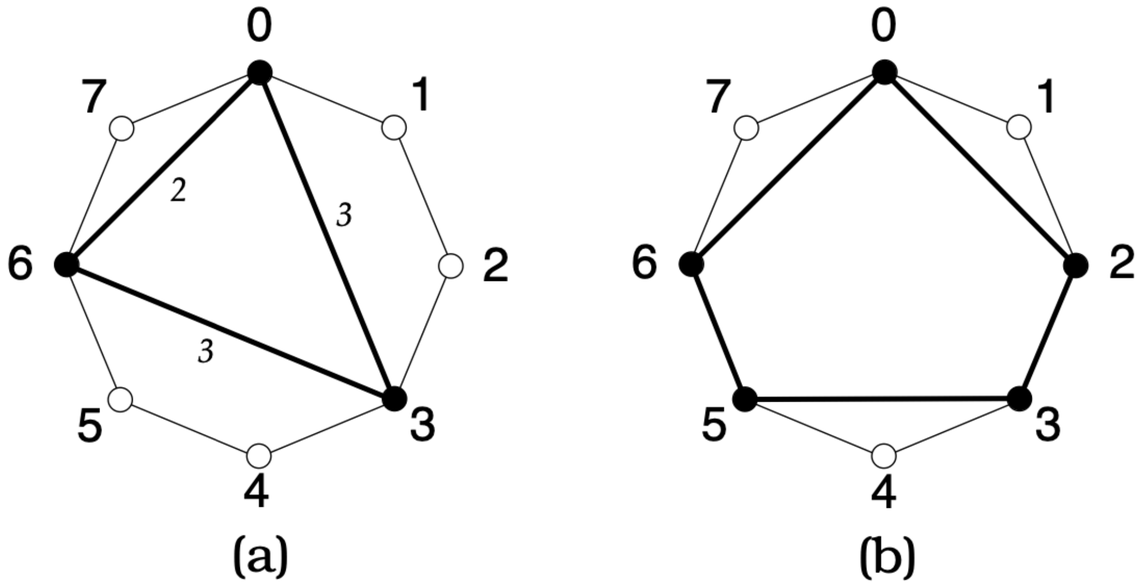
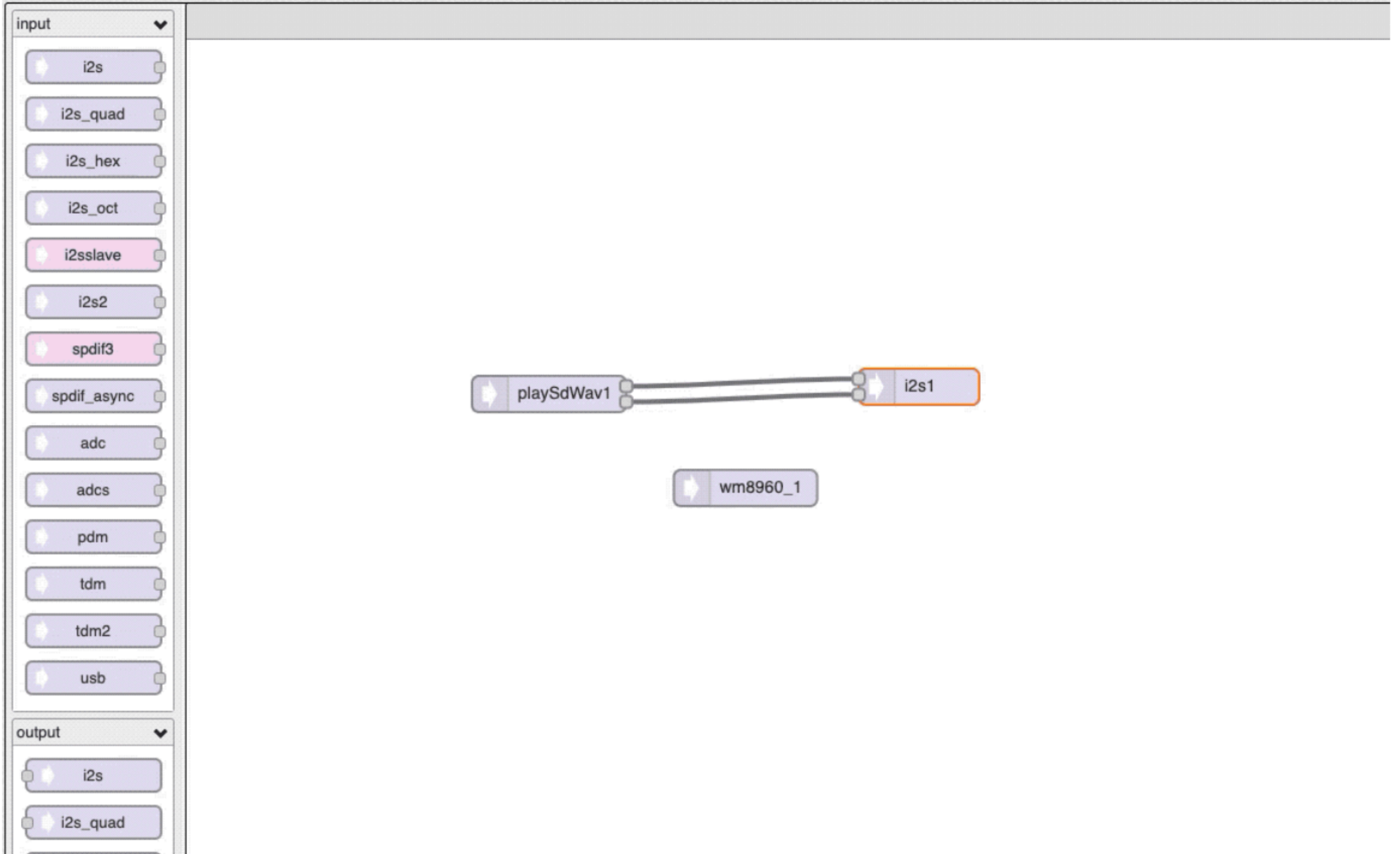


Figure 1: *(a) The Euclidean rhythm* $E(3, 8)$ *is the Cuban* tresillo, *(b) The Euclidean rhythm* $E(5, 8)$ *is the Cuban* cinquillo.

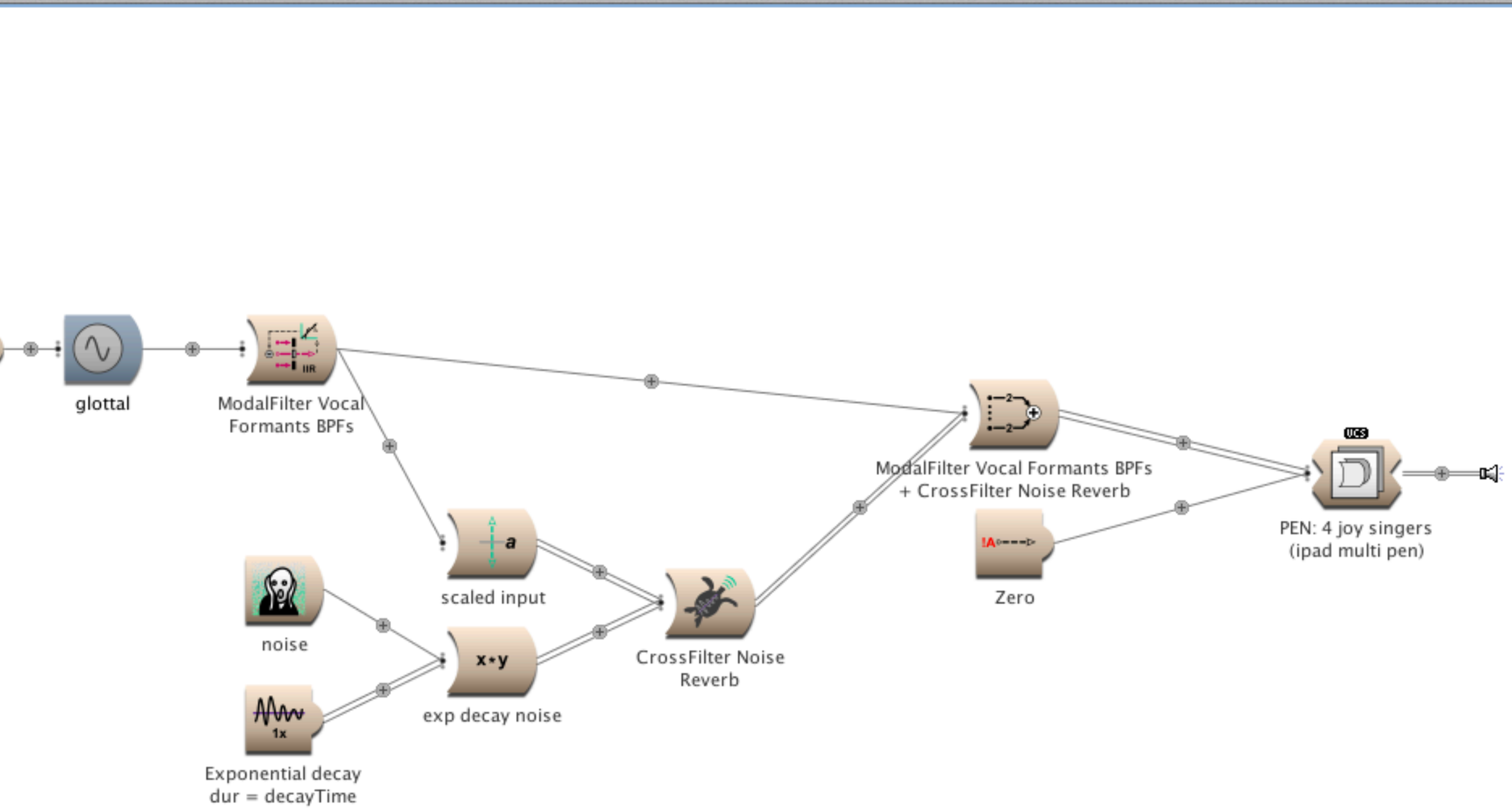
DSP

Digital Signal Processing

- Huge subject! From coding and compression to synthesis
  - Bit Crushing, distortion, filtering reverberation etc.
  - Synthesis: Analog Modeling, Physical Modeling, etc
- Can require substantial processing power
- Often best to code in low level language, C, C++ etc
- Can be done graphically if library and UI are built
  - Kyma
  - Teensy Audio Library


input
i2s
i2s_quad
i2s_hex
i2s_oct
i2sslave
i2s2
spdif3
spdif_async
adc
adcs
pdm
tdm
tdm2
usb
output
i2s
i2s_quad
playSdWav1
i2s1
wm8960_1

PEN: 4 joy singers (ipad multi pen)



- Oscillator Description
- *Envelope*
- *Reset*
- Modulation
- MaxMI
- *Frequency*

```
(!LogFreq nn) + ((16 * !X ) of: #(-12 0 1 4 5 7 8 11 1
19 20 24 25 )) smoothed nn
```

- *PitchBend*
- *Formant*
- Modulator

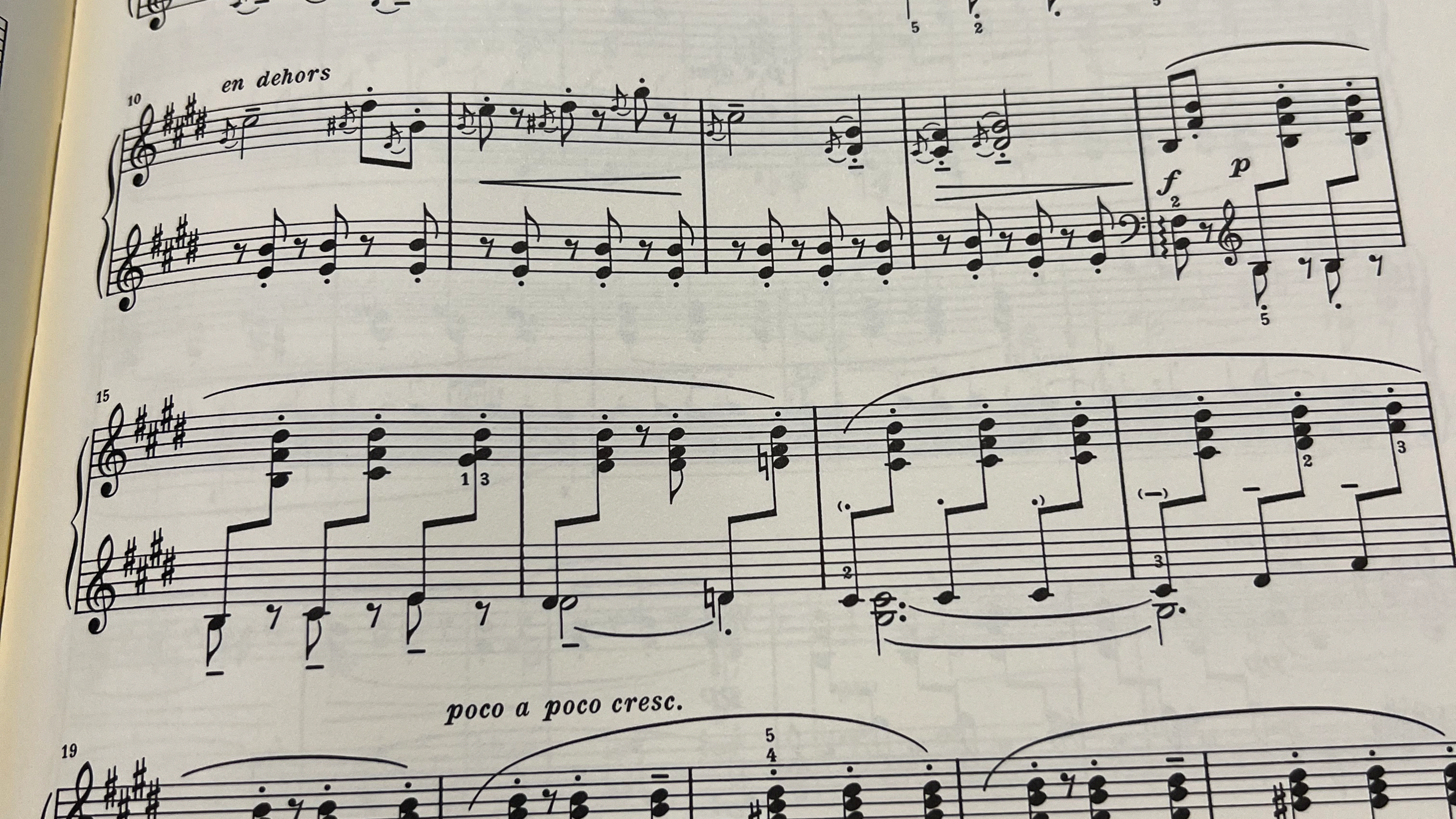
Constant

- Wavetable
- *Index*
- Interpolation
- FromMemoryWriter

Accept

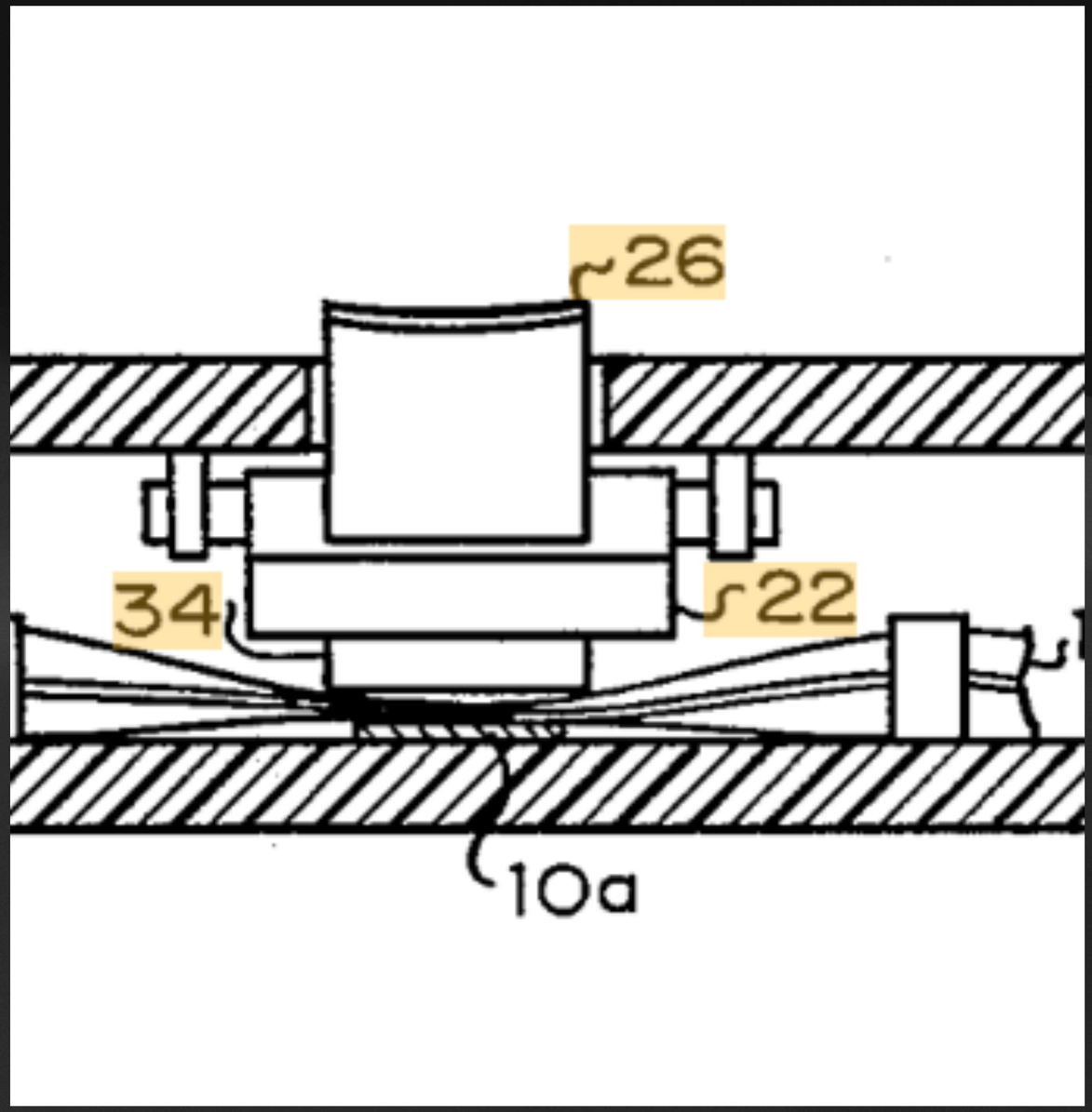
Other issues

- Music is not really just math
- Calculator UI lacks touch sensitivity, useful for Performance feel
  - This could be addressed with pressure sensors
  - A variety exist, including Roger Linn’s invention in the Linnstrument


en dehors
10
15
poco a poco cresc.
19
f
p

Keyboard with
Aftertouch??!?

- Diagram is from HP patent on key
- 10a is contact spring
- Could put pressure sensitive material under it, perhaps



It Can Be Done

- Capable Processors exist
- Lithium Batteries exist
- The SGTL5000 exists

Increasingly Capable Processors

ARM and other

- 2013 HP Prime had a 400 MHz ARM core
- 2018 revision: 528MHz A7
- This is an across the board trend
- Moore’s law may be running out of steam in HEDT and Server but
- “Small” processors continue to develop
- Besides ARM, there are ESP32, Core-V, etc
- Just BTW, ARM is British, originally was: Acorn RISC Machine

How powerful is powerful enough

Hint: we are there already

- There are many synthesizer modules running on similar CPUs
- Mutable Instruments has open source specs, you can see the ARM cores they use
- The Teensy is used in other instruments
- DSP of course is far more compute intensive than some of the other music related functions

- Mutable Plaits uses a STM32F373CCT6 which is a 72MHz CPU
- DIY Neutron Orgone Accumulator uses a Teensy 3.1, similar
- Both are highly regarded instruments but
- Note: They are tightly coded and only run synth code

Lithium batteries are awesome

Need I say more?

- First small data point
- HP Prime G1: 1500 mAh battery
- HP Prime G2: 2000 mAh
- Not like Moore’s law, but improvements likely to continue
- Second data point
- How long can you listen to music on your phone?

The SGTL5000

Exists, and maybe is awesome

- Includes Audio codec and headphone amp
- One chip solution
- Widely used in many product categories
- Tens of thousands in stock
- About $3 in quantity

The SGTL5000 is a Low Power Stereo Codec with Headphone Amp from NXP, and is designed to provide a complete audio solution for products needing LINEIN, MIC_IN, LINEOUT, headphone-out, and digital I/O. Deriving it's architecture from best in class, NXP integrated products that are currently on the market. The SGTL5000 is able to achieve ultra low power with very high performance and functionality, all in one of the smallest footprints available. Target markets include media players, navigation devices, smart phones, tablets, medical equipment, exercise equipment, consumer audio equipment, etc. Features such as capless headphone design and an internal PLL help lower overall system cost.

Features

Analog Inputs

- Stereo LINEIN - Support for external analog input
- Stereo LINEIN - Codec bypass for low power
- MIC bias provided
- Programmable MIC gain
- ADC - 85 dB SNR (-60 dB input) and -73 dB THD+N (VDDA = 1.8 V)

Analog Outputs

- HP Output - Capless design
- HP Output - 62.5 mW max, 1.02 kHz sine into 16 Ω load at 3.3 V
- HP Output - 100 dB SNR (-60 dB input) and -80 dB THD+N (V_{DDA} = 1.8 V, 16 Ω load, DAC to headphone)
- LINEOUT - 100 dB SNR (-60 dB input) and -85 dB THD+N

Other Audio Output Solutions
exist

- USB-C
  - Capable of multi channel high bit rate audio
- Bluetooth
  - Really? You can use Bluetooth for audio?
- Speaker
  - Maybe suitable not for educational use, kids being what they are

It Must Be Done

In Fact, it kinda already has been done

And I don’t mean the HP-48

- Trackers
  - Dirtywave M8
  - 1010 Music Blackbox
- Teenage Engineering projects
  - Pocket Operators
  - OP-Z


TOP BOT
BEND RND
ACC LEVEL
TEMPO
x2 INT
REAL-SYN
TOP
OFF
BOT
TRIG
PITCH-SUS
VOLUME
MOVEMENT
ACCENT
RES-GO