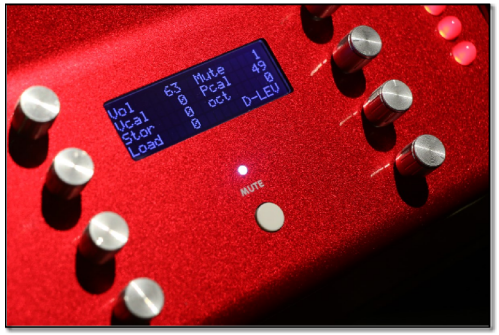
D-LEV
DIGITAL THEREMIN

August 17, 2025

Eric Wallin



About Me

- EE hobbyist, folk guitar since teens
- Variety of manufacturing and engineering adjacent jobs, unfortunately mostly mechanical
- BSEE & MSEE (UVA)
- Decade of Telecom FPGA digital design work
- Took a package / early retirement to work on my HIVE soft processor

FPGA

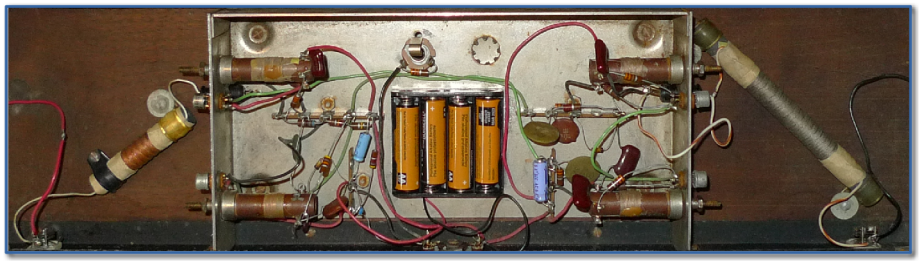
- Field Programmable Gate Array
- Sea of digital logic interconnected via switches
- Programmed using HDL (Hardware Description Language)
- Very tight pin timing ideal for digital oscillator use
- Slow & power hungry, often a solution in search of problem
- Good match w/ Theremin (accident waiting to happen)

The Theremin

- One of the very first electronic musical instruments
- Invented in 1919 by Leon Theremin
- Capacitive fields for pitch and volume, no physical contact
- Notoriously difficult to play
- Constrained by physics
- Originally “Etherphone” then “Termenvox”

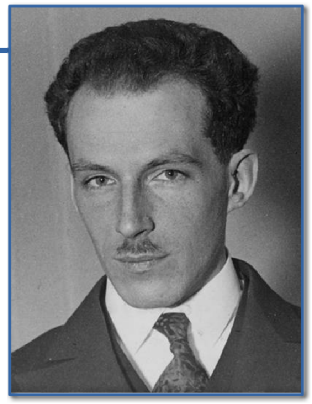
The Theremin

- Similar to some 1950's metal detectors
- Can be made from a handful of parts (e.g. Moog Melodia)



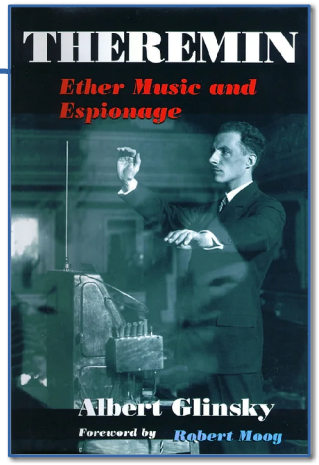
Leon Theremin

- Born *Lev Sergeyevich Termen* 1896 Russia
- Degree in physics / EE
- Conservatory trained cellist
- Demonstrated to Lenin in 1922
- Toured the world
- Played the Met in 1928, stayed in US
- Patented the Theremin in 1928
  - Sold rights to RCA, 500 units @ $3k
- Developed other instruments:
  - Terpsitone, Theremin Cello, Rhythmicon



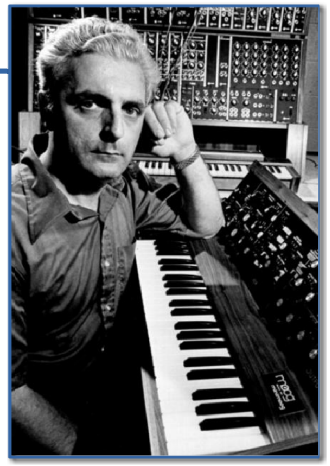
Leon Theremin

- Returned to the Soviet Union in 1938
- Debt, bad investments
- Stalinist purge, imprisoned until 1947
- Spy technology ("The Thing")
- Died 1993 (age 97) in Moscow
- *Theremin: An Electronic Odyssey*
- *Theremin: Ether Music and Espionage*



Robert Moog

- Towering figure in synth world
  - Modular, Mini-Moog, etc.
- Born in 1934 NYC
- BS, BSEE, PhD in EE & Physics
- Built first Theremin at age 14
- Designed & published his own in 1953
- Funded college selling kits & parts
- One patent (ladder filter)
- Died 2005 (age 71) leaving a vacuum



Moog Theremins

- Several early tube models
- Melodia 1961
- Big Briar 1991
- Etherwave 1996
- Ethervox 1998

Moog Etherwave Pro

- Bob's final design
- 2004 state of the art
- Good linearity
- No MIDI?
- Ergonomics?
- Fragile museum piece
- 1500 made, scarce, pricey

Antenna & Hand Capacitance

- The "capacity" to store energy in an electric field.
- C of one hand alone is ~10pF (with universe – self / intrinsic)
- C formed by two hands 20cm (8") apart is ~3pF (mutual)
- C formed by two hands 30cm (12") apart is ~2pF
- 1pF difference, need to measure ~1/1000 this – femto-Farads!
- Amazing that it works at all (i.e. stable & responsive)

Capacitance Sensing

– METHOD –

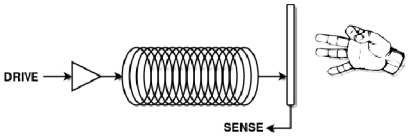
1. Make the capacitor (antenna) part of an oscillator
2. Hand varies the capacitance, changing the oscillation frequency
3. Measure frequency (digital) or use it directly (analog)

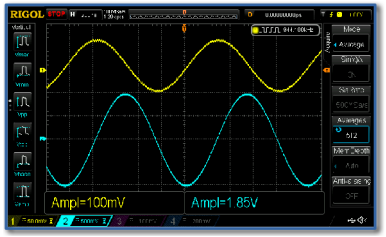
OSCILLATOR TYPES

- RC (Resistor / Capacitor) – most sensitive / least stable (e.g. Burns)
- Crystal – most stable / least sensitive (no e.g.)
- LC (Inductor / Capacitor) – "Goldilocks" sweet spot (e.g. most Theremins)

LC Oscillator & Coil Q

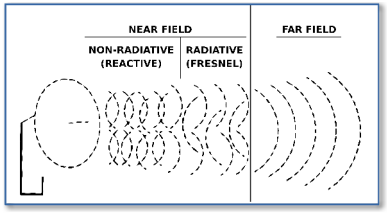
- LC oscillator good trade-off of sensitivity vs. stability
- Q = Quality factor
- Coil Q directly increases antenna voltage (heightens resonance peak)
- Coil Q directly increases frequency selectivity (narrows resonance peak)
- So high Q helps to swamp environmental interference





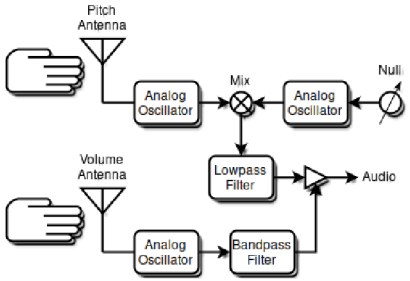
Theremin "Antennas"

- Usually < 1MHz operation (VLF radio band)
- Operate in *"Reactive Near Field"*
- "Antenna" very short for the wavelength => "electrode"
- Mostly "electro" and very little "magnetic" => weak emissions

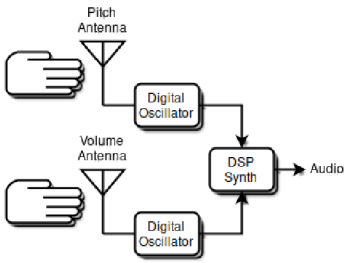


Analog vs. Digital

- Fields & audio generation are locked together



- Fields & audio generation are independent

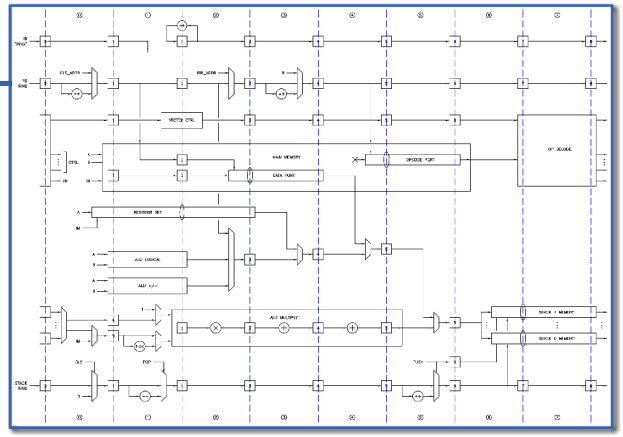


The D-Lev

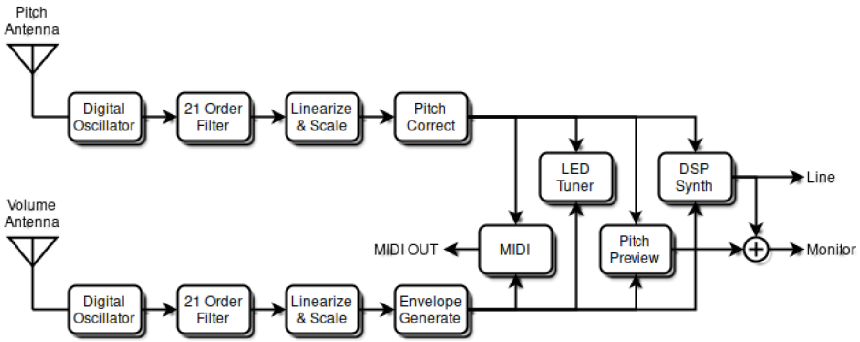
- D(igital)-Lev (Termen)
- 2012 (!) to present
- Linear / shaped fields
- Pitch & volume display
- Pitch correction
- Modal synthesis
- Hive soft processor
- FPGA hardware basis
- Open source

HIVE

- Barrel pipelined
- 8 threads
- 8 stack set / thread
- 32 bit / 180 MIPS
- 16kB memory
- Tooling:
  - Simulator
  - Assembler & language
  - Integer & float libraries
- Incredibly intense learning experience

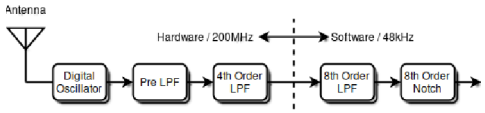


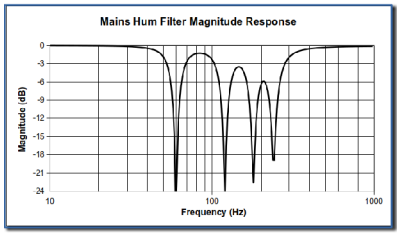
D-Lev Architecture



Fields Filtering

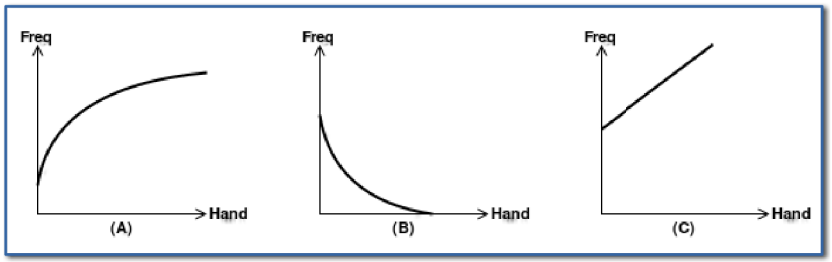
- 22nd order overall
- Pre LPF ½ rate
- 4th order LPF
- 8th order LPF (tracking for pitch side)
- 8th order notch
- Must be highly responsive with no lag (100Hz / 10ms)





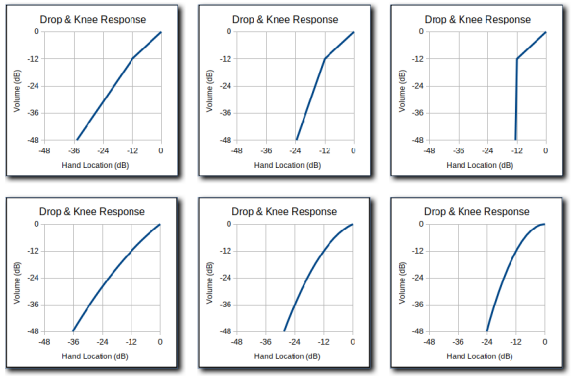
Fields Linearization

- Linear pitch field a holy grail
- Method stumbled upon by me in 2017
- A form of gamma correction: y = x^0.25



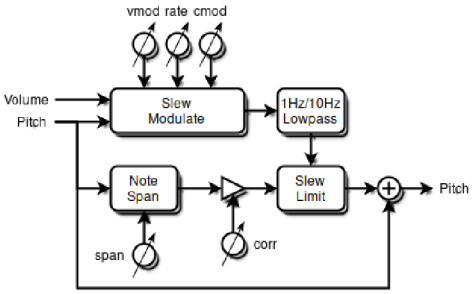
Volume Field Shaping

- Short shrift from designers
- Linear basis
- Linear response not desirable
- Knee: linear gain break
- Drop: 2nd order non-linear curve



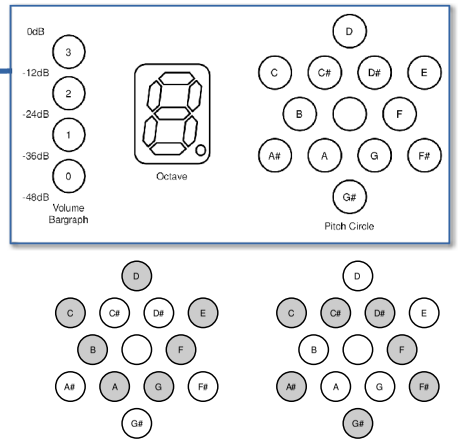
Pitch Correction

- Controversial – virtuosity lost with "Auto-Tune" overuse
- Theremin crying out for it
- 90% just slowed quantization
- Aggressive but unobtrusive
- Note center rate modulation
- Bi-modal filter for smooth glissando
- Volume rate modulation
- Chromatic only
- Requires absolute reference



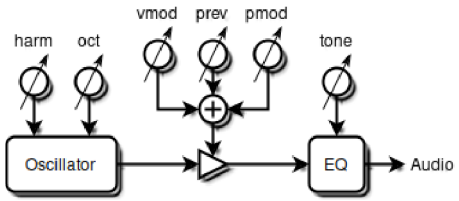
LED "Tuner"

- Responsive display of pitch & volume
- Real-time feedback
- Gray scales
- Come in on pitch after silence
- Patterns reveal key
  - *2 patterns + rotations*
  - *"Crown" & "House"*



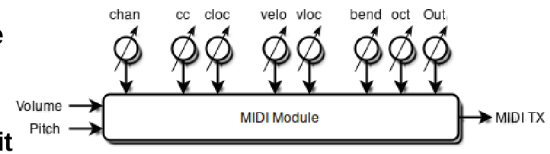
Pitch Preview

- Pro feature
- Player-only pitch monitor for silent "pitch fishing"
- Come in on-pitch after silence
- Employs "ducking"
- Can be unpleasant and disorienting
- Largely unnecessary when a responsive tuner is present
- 4th oscillator / DC stimulus when unused as preview



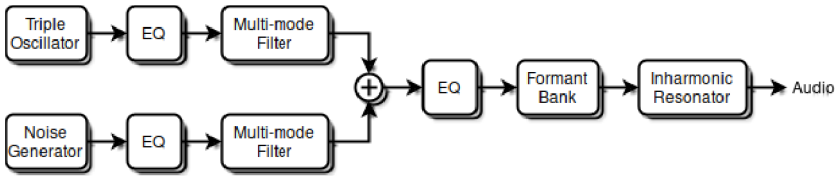
MIDI TX Module

- Musical Instrument Digital Interface (1983)
- Transmit only (no RX)
- Sends pitch & volume hand information to external synth
- Note on/off, velocity, pitchbend, CC, 7/14 bit
- More full-featured than most
- Can be used in tandem with D-Lev internal synth



D-Lev DSP Synthesizer

- VOCALS, strings, brass, woodwinds, bells, animals, UFOs, Theremins, etc.

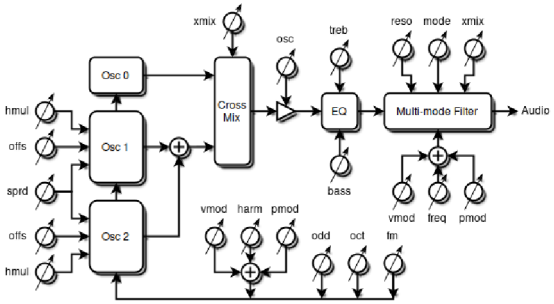


Modal Synthesis

- Simple excitation + a bunch of resonant filters
- Good at mimicking real-world sounds
- Classification of acoustic sources by resonances:
  - Horn: 1
  - Human vocals: 5 to 7
  - Violin / cello: 30 to 100
  - Cymbal: 1000
- D-Lev DSP synth has 8 formant filters
- Inharmonic Resonator upper fill

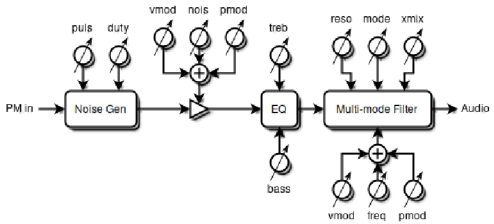
Triple Oscillator

- Center & two offset
- Reduced alias PM oscillator (1979)
- Patent: US4249447
- All / odd harmonic mix
- Brightness modulation
- FM (cross) & AM (ring) modulation
- EQ (bass & treble)
- Multi-mode filter



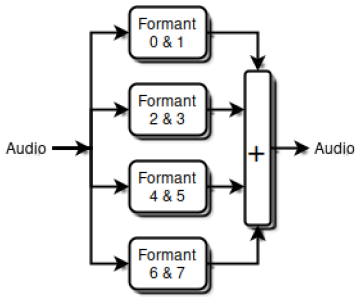
Noise Source

- Pink noise (1/f) better basis, easier to EQ than white
- AM “puffs” via Oscillator PM
- EQ (bass & treble)
- Multi-mode filter



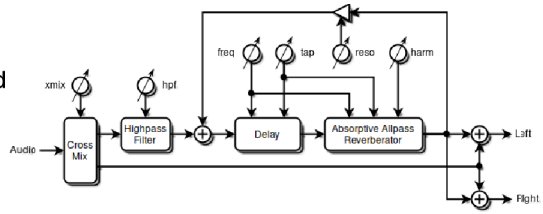
Formant Bank

- Eight 2nd order band-pass filters in parallel
- Chamberlin (1980)
- Independent
  - Fc (resonance frequency)
  - Level
- 4 pairs each share
  - Fc modulation
  - Q (resonance)

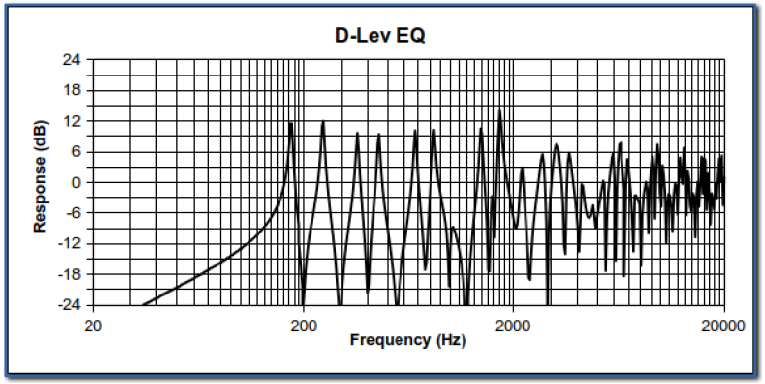


Inharmonic Resonator

- Delay-based filter
- Paper: Jae hyun Ahn & Richard Dudas
- Absorptive all-pass + simple delay, recirculated
- AP breaks up strict harmonic resonance locations
- String body resonances, drums, bells, gongs, human vocals
- Small room ambiance
- Pseudo stereo



Preset Example: Cello Synthesis

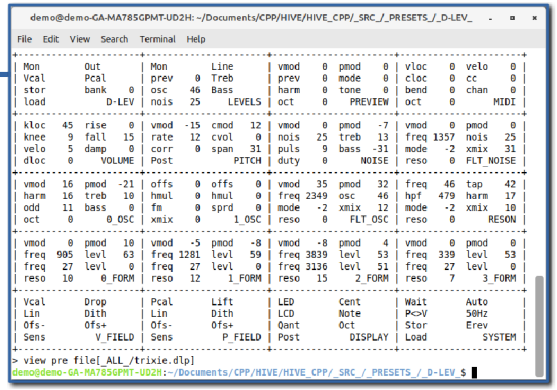


Presets

- Instantaneous setup of entire synth
- 250 preset slots, 6 system profile slots
- Long-term activity, integral to synth development
- Synths live & die by their factory presets
- Not a sample playback instrument
- Spectral analysis + research + mapping to synth = effort
- Discovering what makes an instrument “tick”
- Various timbres require different playing techniques to sound realistic – stretch exercise
- Users can create, modify, save, share presets

Librarian

- Manage presets
- Update software
- Remote control
- Command line interface (CLI)
- Open source
- Written in Go
- Win, Mac, Linux, Raspberry Pi, etc.

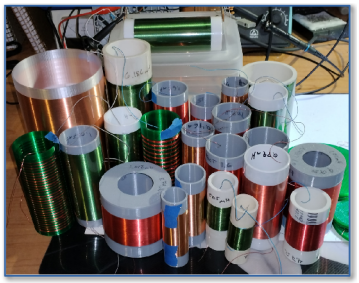


Opportunities / Future Directions?

- Reversed volume field with shaping & velocity
- Looser pitch field
- Plates rather than rods
- Interactive tuner use
- Pitch correction
- More robust fields
- Better ergonomics
- Delay & Reverb built-in
- Third field for modulation / dynamics?

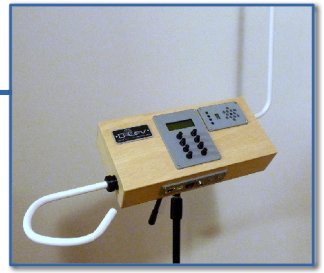
Project History

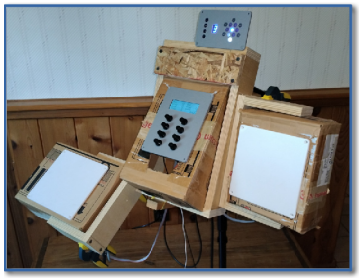
- 2012 : Pitch only FPGA proof of concept
- 2013 : Solenoids, tuners, analog oscillators, mixing, plate antennas
- 2014 : Hand/antenna C measured and simulated, Hive math package
- 2015 : Assembly language, interfaces, parsing
- 2016 : Functional prototype, Hive sim re-write
- 2017 : Synthesis & documentation, linearity solved
- 2018 : Refinements, presets, cabinetry
- 2019 : 3D printing, presets, pitch correction
- 2020 : Clarabox kit, videos
- 2021 : New librarian, user manual
- 2022 : Volume response, R&D
- 2023 : More R&D, open source
- 2024 : Coil experiments, regrouping



My D-Lev Builds

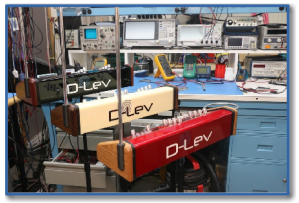
- "Tupperware Party", Lab unit, D-Lev *Tour*

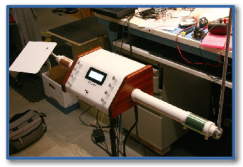


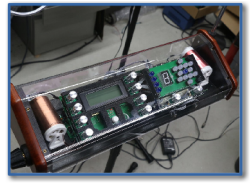


Roger Hess's Builds

- P1, Pro, P3







Scratch Builds

- Evan Kahn & Eli Silver
- Len Sherman
- André Amyot

The D-Lev Kit

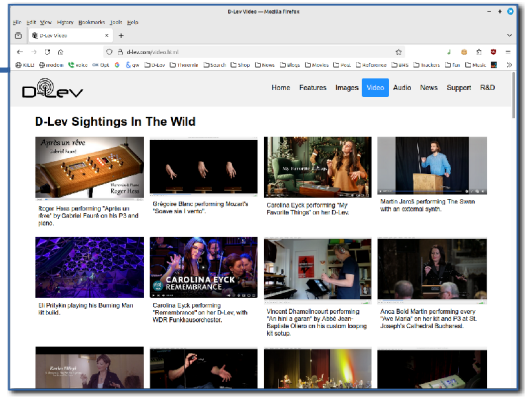
- Get design out, feedback from builders & players
- Social phase of project
- 50 made, sent all over the world
- Users supply cabinet & antennas
- 1 week to 3D print & build, $250 parts, 4lbs to ship
- Profit / loss neutral
- Open source

Kit Builds

Kit Builds

Thank You!

More info:

d-lev.com

thereminworld.com