NucleoSynth - Audio Synthesizer based on STM32 Nucleo-F446

Hardware DIY Construction Manual

 Status 21 November 2022

This is a DIY construction manual for a digital 10 voices polyphonic Audio Synthesizer based on the **STM32 Nucleo-F446** board which is plugged on a specific PCB.

First a complete version **with operator panel** is described. Preferably the ST-LINK part is cut off the Nucleo and completed with an 8MHz crystal oscillator. A corresponding firmware for an unmodified Nucleo is published, too.
At the bottom of this manual a **minimal hardware design without operator panel** and unmodified Nucleo module is described.

How to work with it and study firmware features, you are referred to the corresponding **Operating Manual**, see <www.midi-and-more.de/nucleosynth/nucleosynth-opman.pdf>.

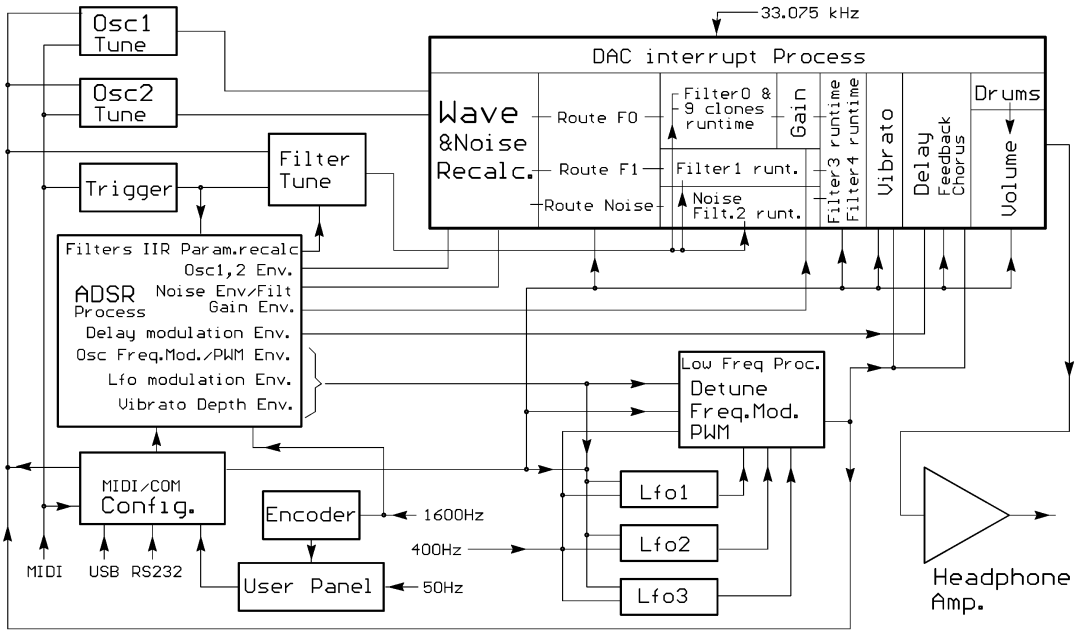
The synthesizer is controlled completely digitally. Digitally processed sound data are transformed to an **analog output signal using the internal 12 bit DAC** of the STM32F446 processor and finally amplified to headphone impedance with an audio amplifier IC. The audio generation is completely monaural.

Communication to play and configure the instrument is possible **via USB and USART**.
For details see the Operating Manual. For configuration and sound handling an Operator Panel is designed. MIDI and RS-232 modes are selectable with a DIP switch or with operator panel.

A design intention is to keep the additional hardware technology as low as possible. For most people, making a PCB is the biggest barrier. For this reason a completely Veroboard compatible design is proposed here. Though the wiring and solder process itself does not demand high skills, it takes much care and some experience to arrange all parts correctly. Alternatively it can be manufactured on single layer PCB material with simple technologies.

For the **Local Operator Panel** a minimal - but well useable design is proposed, built on Veroboard, too. It is equiped with a 2 lines/16 char. LCD display, 1 rotary encoder (with pushbutton) , 4 pushbuttons and 2 LEDs. It is connected with the main PCB by wires and connectors. This allows a flexible and low-tech construction in different kind of boxes.

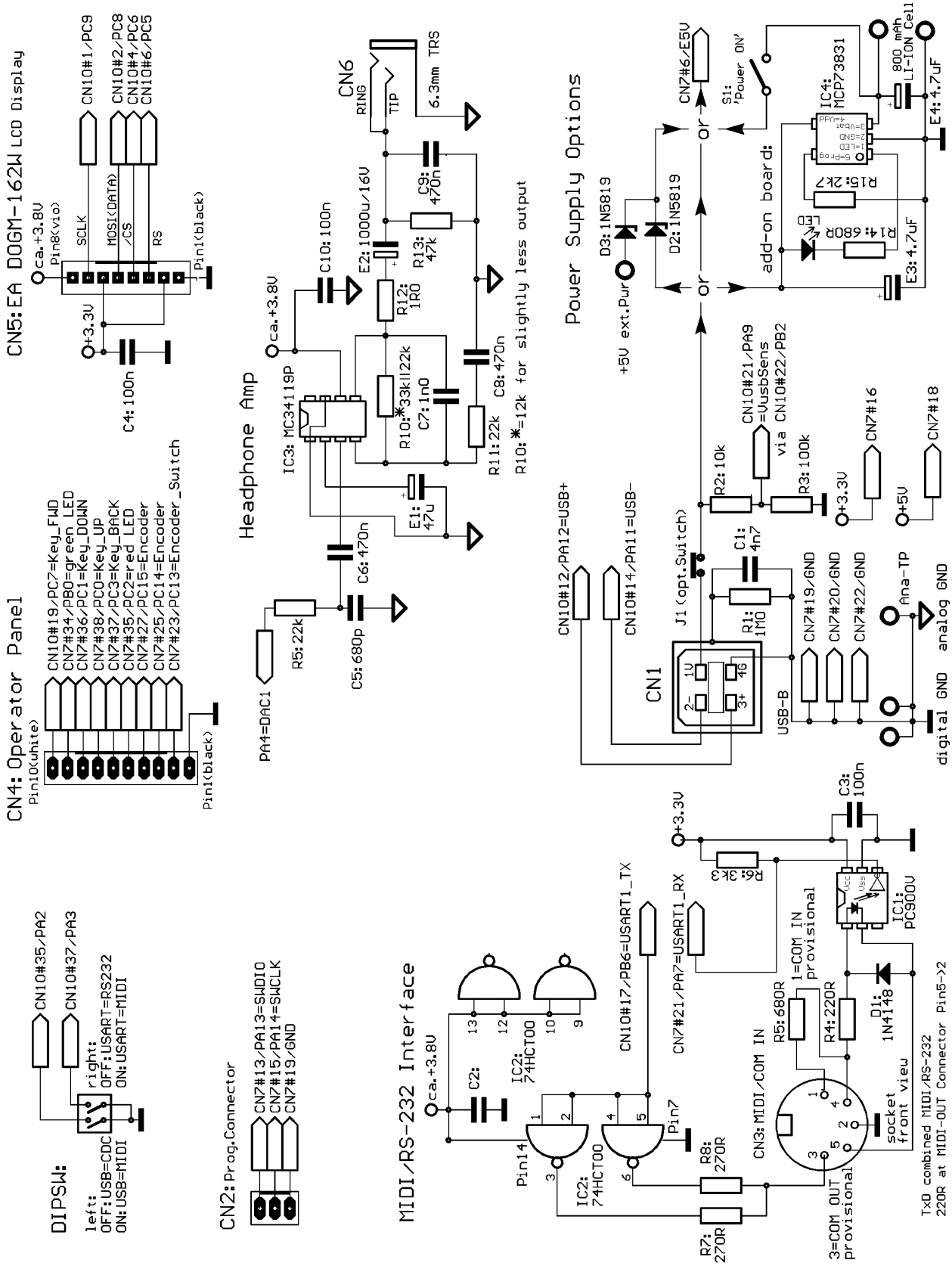
Simplified block diagram:



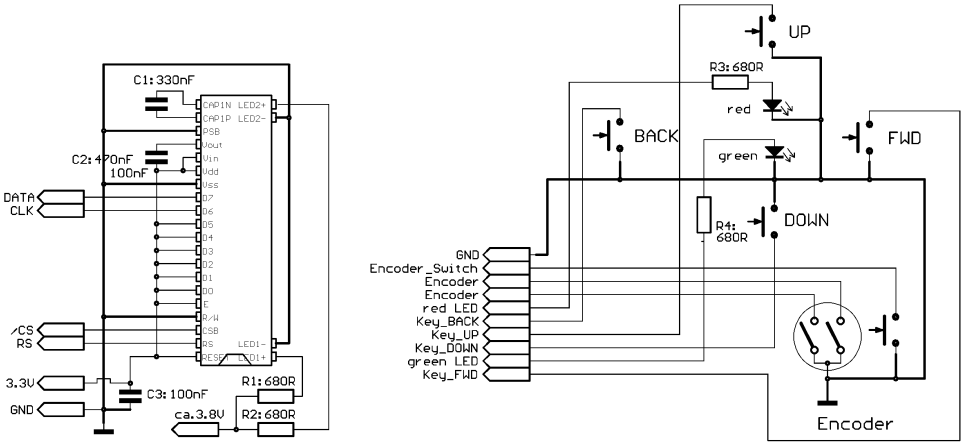
Hardware of the additional PCB

Schematic diagram:

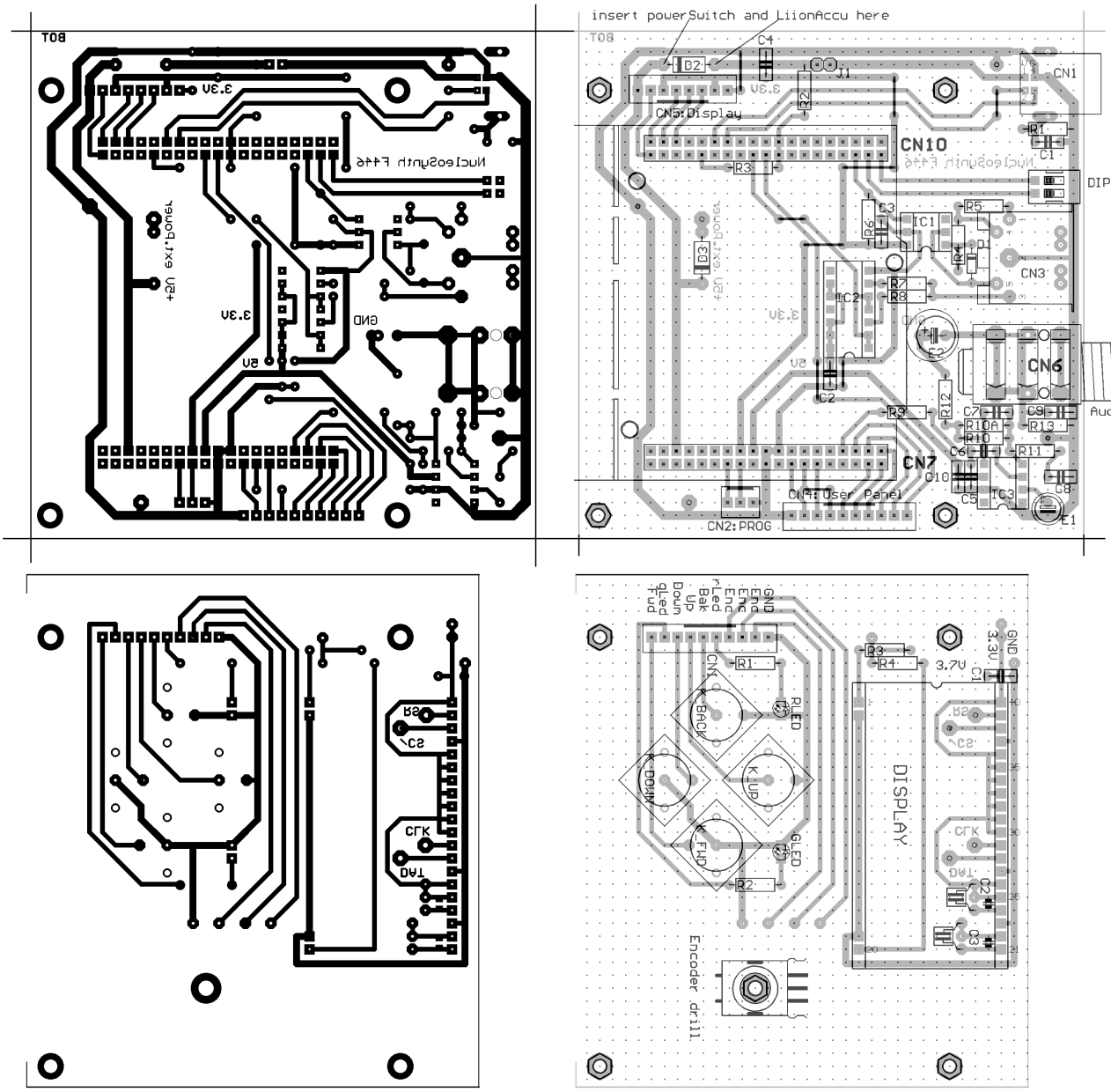
The connector CN7,CN10#pin numbers refer to the Nucleo board. For details see the Nucleo User Manual:



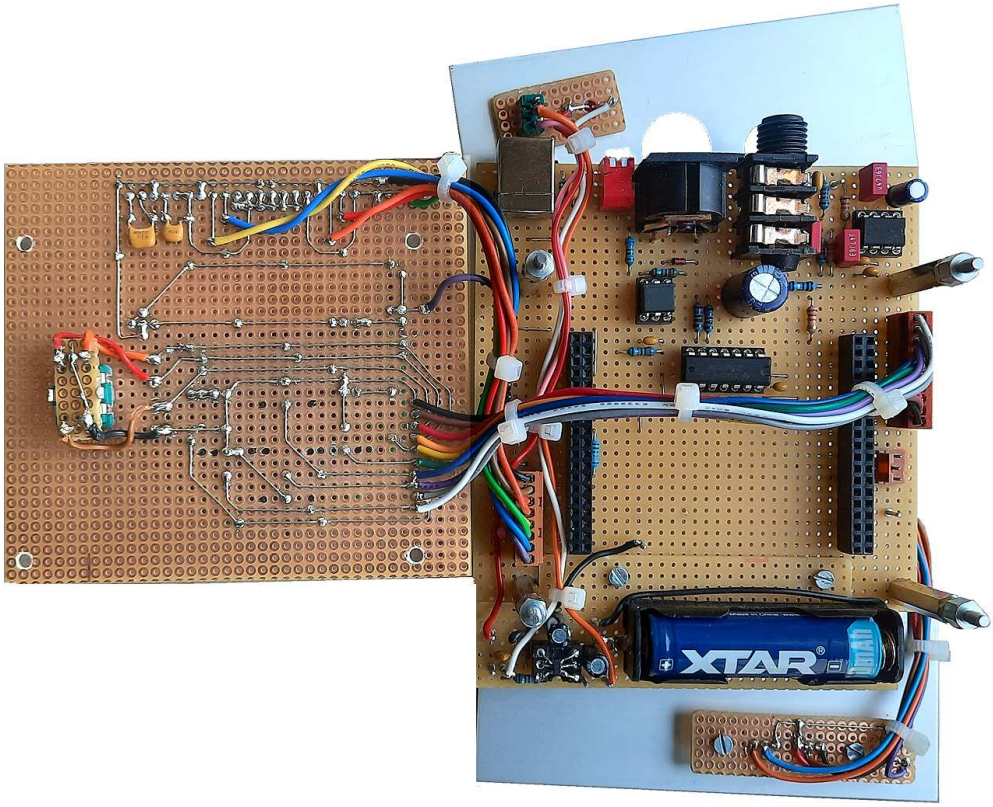
Operator panel schematic diagram



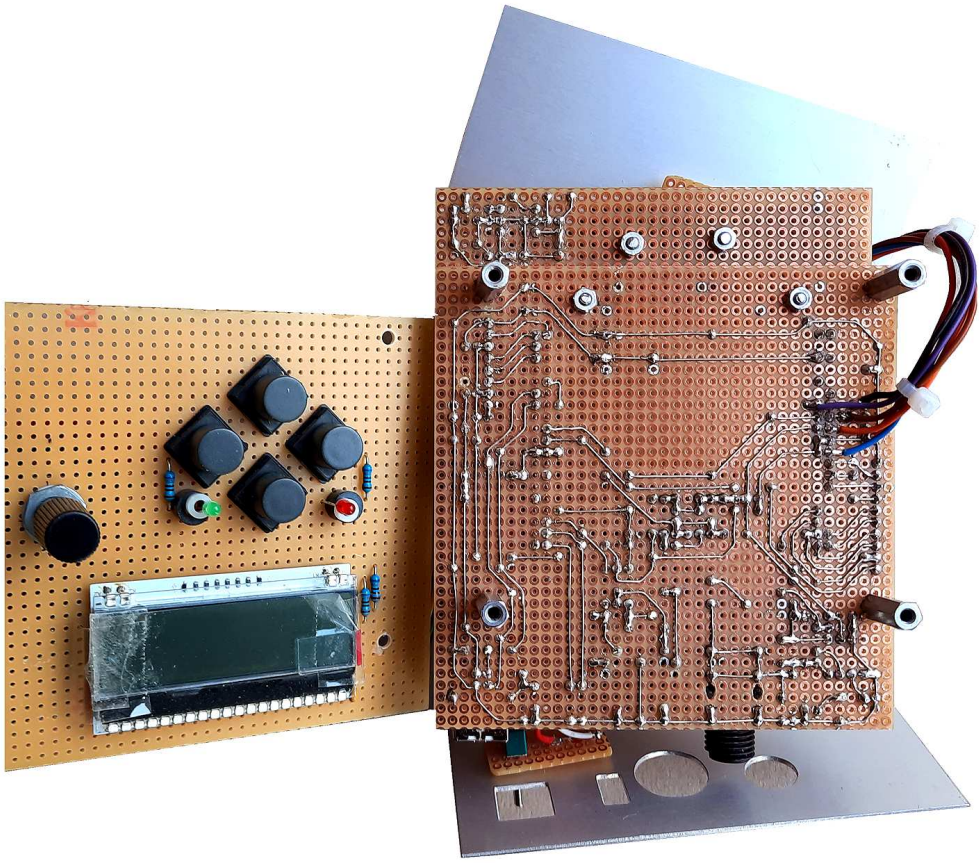
Assembly:



The complete synthesizer pulled out of its housing (Nucleo module removed):



Main board top, Operator Panel bottom. Rear panel with Power switch and charge LED,
Front panel with programmer connector, reset button expander and test pin (PA15, PB7) output for assistance of synthesiser firmware improvement while it is inside the housing. The accu+charger is provided as add-on board.



Main board bottom, Operator Panel top with front and rear panel

The prototype is built on a Veroboard with round copper pads in 2.54mm raster with 0.5mm silver plated copper wire directly soldered on. The Veroboard wiring diagram is given as single layer PCB design with min 0.8mm wires and the minimal distance of wires etc is 0.4mm. So it can be transferred to PCB material with most simple techniques like thermal transfer. Some of the jumper wires (surrounded with dotted lines in the assembly drawing) may be substituted with 1Ohm resistors for easier mounting.
Three options for power supply are proposed on the schematic diagram. Anyway, it is essential to prevent current flow from the module to the USB connector. Decouple with Schotty diodes if necessary. The **Li-Ion accumulator and charger is built on a separate Veroboard** and not necessary. DIY instruction see <www.midi-and-more.de/more/liion-charger.htm>

Recommended drill diameters for etched PCB:
resistors, capacitors, diodes, ICs, jumper wires, DIPSW: 0.8mm; LED, connectors 1.0mm; USB socket 0.8mm/metal flag 2.0mm; Audio Out 1,5mm/fixture holes 2.0mm
For a **Veroboard construction**, the metal flags of the USB connector, the audio out TRS connector and mounting holes, additionally 2 pins of the recommended pushbuttons(keys) are out of the 2,54mm raster and must be drilled separately or expanded with jig saw.
A 1:1 TIF file with the PCB bottom layer is available for download at my webpage <www.midi-and-more.de/nucleosynth.htm>

Special parts: (cited suppliers are examples where private consumers can buy in Germany)
STM32 Nucleo-F446RG: sources Conrad, Reichelt, tme.eu, Mouser
LED: standard 3mm, 3mA through hole versions.
Optocoupler: PC900V; source Conrad 184098
LM34119P: source Reichelt
Connectors CN7,CN10 for Nucleo: source Reichelt MPE 094-2-50 - must be shortened
Programmer connector: source Reichelt PS 25/3G BR or Conrad 741221
Operator panel connectors: source Reichelt PS 25/8G BR, PS 25/10G BR Conrad 741256 & 741264
Audio Connnector: Neutrik Slim Series (15.88 mm wide) 6.35mm stereo, source e.g. Reichelt NR-J6HF
Encoders (at Operator Panel): Alps STEC11B13,source Reichelt et.al. Others may have different pulse sequence.
Pushbuttons (Keys): MTG1/2" 1241xxx (prod.Schurter) delivery: Reichelt TASTER 1032.6.
The left and right pins are not fully veroboard compatible, must be widened (1.5mm drill or jigsaw)
LCD (at Operator Panel):Reichelt: Electronic Assembly EA DOGM162W-A. A rather special part w.3.3VPWR+SPI
LCD LED backlight: Reichelt: Electronic Assembly EA LED55x31-W (white + translucent).
SPI communication. an adaptor circuit design to connect standard LCDs is available on request.

Hints for Veroboard assembly

It is useful to print a mirrored version of the placement drawing to get a view from bottom=solder side.

The diameter of the wire should be 0.5mm (min 0.4…max. 0.6 mm`) for easy bending and diagonal wiring between the neighboured copper dots. A set of "adjustment" pliers with small flat tips (or stable tweezers) is recommended for bending and positioning the wires. The correct positioning of parts is essential, because there is almost no reserve for alternative positioning. So it is recommended first to place all parts and solder them as slightly as possible only to fix them provisionally and cut longer wires about 1 mm above the Veroboard for later final soldering. At this stage, parts with more than two contacts like connectors should be soldered only at 2 diagonal edge pins. At the Nucleo connectors about 1/3 of all pins must be soldered, else it may deconstruct itself when the Nucleo module is pulled off.

Length and position of all wires (except USB data lines and parts around the headphone amp.) is uncritical. So if something goes wrong, forgotten or non-placeable wires can be put later directly with isolated wire.

Prototype Housing

The aluminium parts of the housing were available here, should be easy to use different sizes.

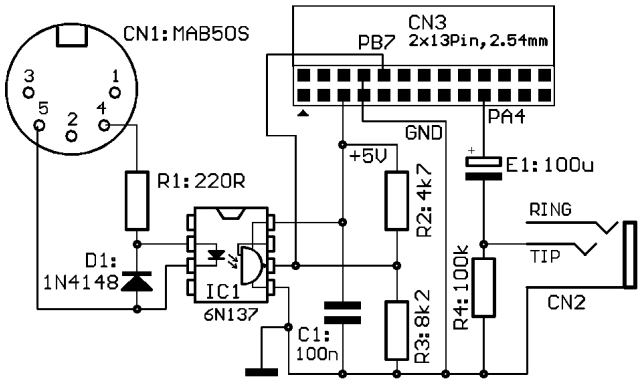
Test pins (PA15, PB7) are wired out to a 3 pin connector. Furhermore, the programming connector and reset button is extended to the front panel (for check of timing details and reprogramming while the housing is closed, not visible at this photo, bottom side of the operator panel). But this is not necessary for playing the instrument.

Minimal Hardware design for unmodified Nucleo F446

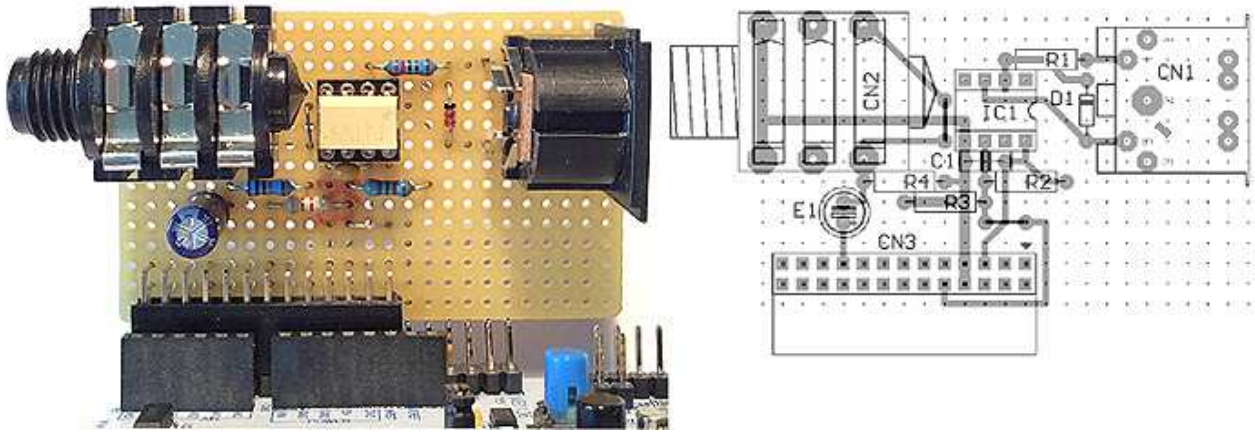
The STM32F446 onboard USB is not activated in this case. But STM32F446 USART2 is hardwired with the ST-LINK USB on the Nucleo board.
This way USART1 always works as legacy MIDI interface
and USART2 (via ST-LINK USB) is seen by the PC as virtual COM port. Inside the Nucleo board, USART2 always works with 115200 baud.

The hardware consists of two pieces: the output is simply the DAC, a.c. decoupled with an electrolytic capacitor without lowpass. The output impedance of the F446 internal DAC is specified with 5 kiloOhm. But at "TIP" after a.c. decoupling I have measured much lower values. Anyway, it seems not recommendable to connect a headphone directly there.

The other part is a conventional MIDI input with optocoupler.



This mechanical design is a proposal, the same result can be achieved many different ways:



The I/O ports for USART2 are specified 5 V tolerant, for this reason R3 is not absolutely necessary. CN 3 is plugged on Nucleo CN7, pins 13-38. In the schematic assemby drawing, CN3 seems wired mirrored at a first view. But in the photo you see: the upper wires of CN3 connect the even numbered pins of the Nucleo CN7. CN3: Reichelt order.no: BL 2x13W 2,54

With this minimal hardware, it is impossible to send SoundSet configurations as MIDI Dump. No MIDI OUT is supported by the firmware. Use the RS-232 connection instead.

Programming

With the unmodified STM32 Nucleo the onboard ST-LINK module can be used to program the STM32F446 processor. Follow the instructions in the Nucleo manual.
Programming the 'Minimal Hardware' or if the unmodified Nucleo is placed on the synthesizer PCB ('orig' firmware): **remove external power, place jumper J5 in U5V position**, power via ST-LINK.
But **for normal operation, the umodified Nucleo on the synthesizer PCB must be operated with J5 in E5V position and external power**.

Because the ST-LINK module of the original Nucleo module consumes place and current, it is advised to cut the ST-LINK part from the module and use it as a separate programmer to get a practically better useable Synthesizer. A corresponding ISP Connector is provided on the NucleoSynth PCB.

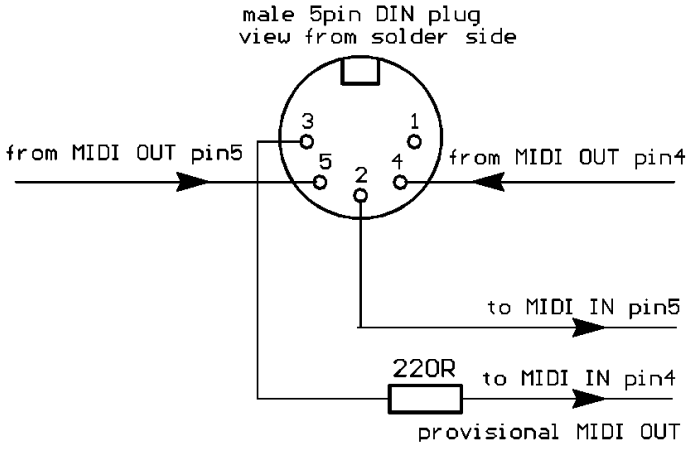
How to program external parts with the cut-off Nucleo ST-LINK module, read the Nucleo manual. **After the ST-LINK part is cut off, the 8Mhz oscillator on the Nucleo kernel board must be completed.** For this task a small solder pen for soldering 0603 SMD parts and filll some jumper pads is required. R35,R37 are 0Ohm jumpers. It is not absolutely necessary to unsolder any SMD parts, but it is strongly recommended to remove SB50, SB54 and SB55.

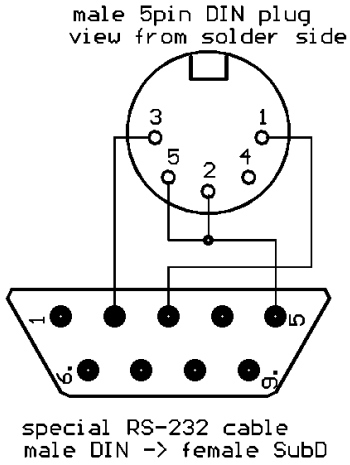
If the programmer is cut off and used standalone, the programming software possibly sends a problem like "no target voltage". Then connect the 3.3V output (pin next to text U1) of the regulator (5 pins) on the ST-LINK part with R23 (4.7 kOhm, pad directed towards the SWD connector) to pretend a supply voltage of the programmed device. A reset wire, as is provided in other DIY instructions, is not necessary. But if programmed by ST-LINK standalone, it is necessary to push the onboard reset button while ST_LINK is made "connected".

If the Nucleo board was already used for another project, it is highly recommended to perform a full "chip erase". At least it is necessary to **erase "Sector7"**, because the user created SoundSets and Waveforms are stored there. If this sector is virgin or erased, the NucleoSynth will start with default configuration as described in the operation manual. With incompatible data from older firmware, the NucleoSynth may hang at system start.

Build a programmer adaptor:
--- connect the 2nd pin of the Nucleo SWD connector (counted from the side towards the Mini USB connector) with pin PA14 of the microcontroller on the remaining Nucleo board.
--- connect the 3rd pin with Ground.
--- connect the 4th pin with pin PA13 of the microcontroller
These pins are broken out on the "base board" PCB as **ISP Connector**. (PA13 leftmost, see assembly drawing above).
---if a development environment or IDE like EmBitz (I am working with), True Studio or similar is used, programming may be offered directly from the IDE.
--- but I have made better experience simply to program the hex code without programming environment, especially if the "Release" code is programmed. Start the ST-LINK software. Hold the reset button pressed, click item "Connect" of the "Target" menue, release the reset button after ca.0.2..0,5 seconds. When you are connected, select "Program&Verify" from the "Target" menue, check "Browse" and upload the hex code.

How to connect the onboard MIDI connector with legacy MIDI and RS-232:
Usually in MIDI cables pins 1 and 3 are not connected, so normally there is no risk of wrong wiring when operating in MIDI mode.
The DIN socket on the PCB provides a **standard MDI IN**.
A provisional MIDI OUT can be installed with a split cable adaptor. Because the drive level is somewhat less than standard 5V and a 130 Ohm series resistor is already built on the board, the standard two 220 Ohm resistors are replaced by a single 220 Ohm. Because the only implemented MIDI OUT feature is dump of SoundSets, this option is less recommended.
For the **special RS-232 cable** use a simple shielded audio cable with 2 isolated wires, length max 5 meter. Ground = shield.





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