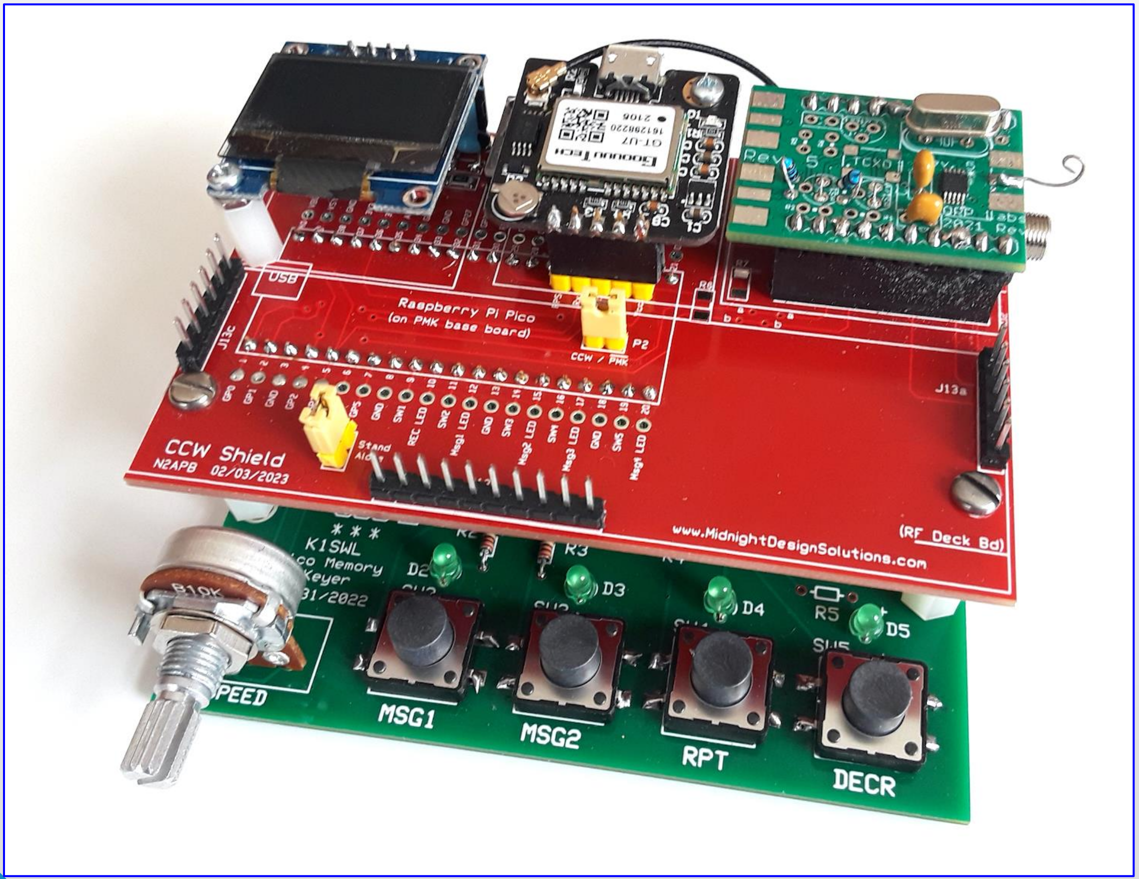
“How Low Can You Go?”

Design of a Modern Coherent CW Transceiver For Weak Signal Communications



FDIM 2023
Dayton, OH

George Heron (N2APB)
and Peter Eaton (WB9FLW)

Overview

- **Wait, WHAT??**
  - Copy a solid 599 signal when you hear nothing but the noise floor?
  - Gain a 20-30 dB signal path improvement over conventional CW rigs?
  - Turn your 5-watt QRP signal into the equivalent of more than 300 watts on the receive side?

- **YES! (Maybe.)** Using a modern approach to Coherent CW designs from 1970s:
  - Inexpensive Pico processor
  - GPS-timed transmission & reception
  - DSP processing of Rx signal within precisely maintained windows corresponding to 12wpm code speeds.

Background

- 20+ years ago co-author Peter Eaton WB9FLF and I explored what was then a technology born 20 years prior to THAT … back in the mid 70s
- Lots of experimental communications happening during mid-1970s
- **First CCW contact**: Ray Petit, W7GHM and Andrew McCaskey, WA7ZVC ➔ Sept 1975 QST.
- Elaborate frequency stabilization, WWV sync, sample & dump A/D circuits, phase shifting, …
- **Ade Weiss, W0RSP,** CQ 1977, and in The Milliwatt
- **Charles Woodson, W6NEY** , QST 1981.
- W6NEY conducted numerous successful CCW/QRPp tests on Japan-to-California path
- **CCW Newsletter** published for 6 years
- CCW disappeared in 1980s with morph into BPSK, WSJT and plethora digital modes

What is Coherent CW?

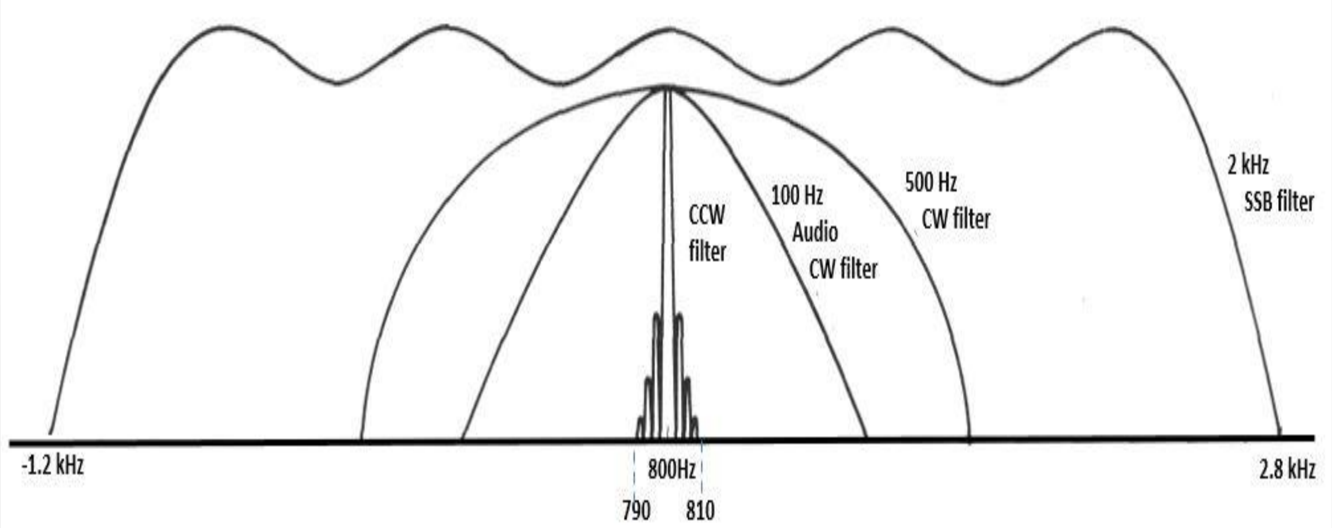
- **Chas Woodson, W6NEY, 1975**: *"The technique of sending and receiving information in binary (Morse) code in such a way that the **frequency**, **pulse length** and **pulse phase** are known and used in the demodulation of the information transmitted."*

- **The more we know about something, we seek, the easier it is to find.**

- ***Shannon-Hartley:*** *When we fit the narrowest bandwidth filter to the given information rate of a channel, the SNR skyrockets.*

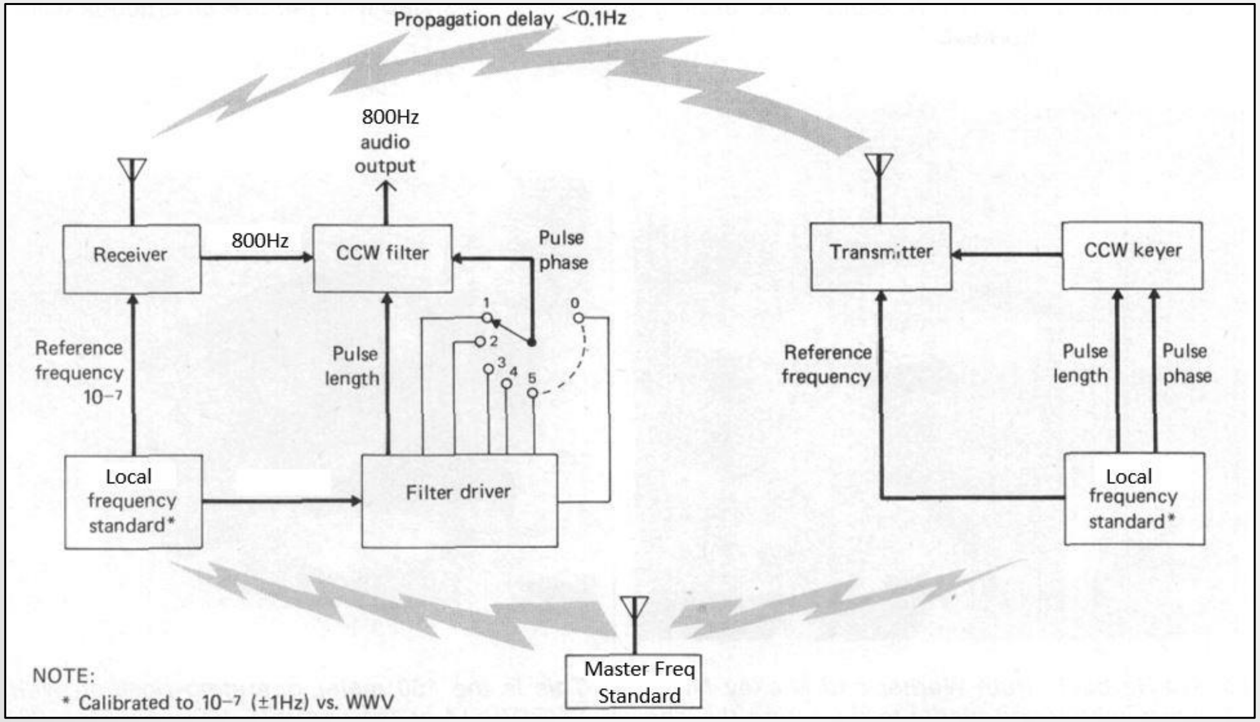
- ***What this means for CCW:***
  - ***12 wpm Morse code = Bandwidth of 10 Hz.*** *NO GOOD for conventional analog or digital filters ... GREAT for CCW!*
  - ***"SNR skyrockets" …*** *Like WSJT-X for digital modes, we can hear Morse code below the noise floor!*
  - ***CCW "re-creates" the audio tone*** *and reception is pure 599 with no background noise at all.*

Filter Comparisons



- The narrow 10 Hz CCW filter shown in the center is comparatively miniscule compared to traditional CW and SSB filters.
- One can envision the amount of QRM and QRN eliminated when using the CCW filter, and the correspondingly high SNR for the precisely tuned 800 Hz CCW signal being passed.

A CCW Communications System

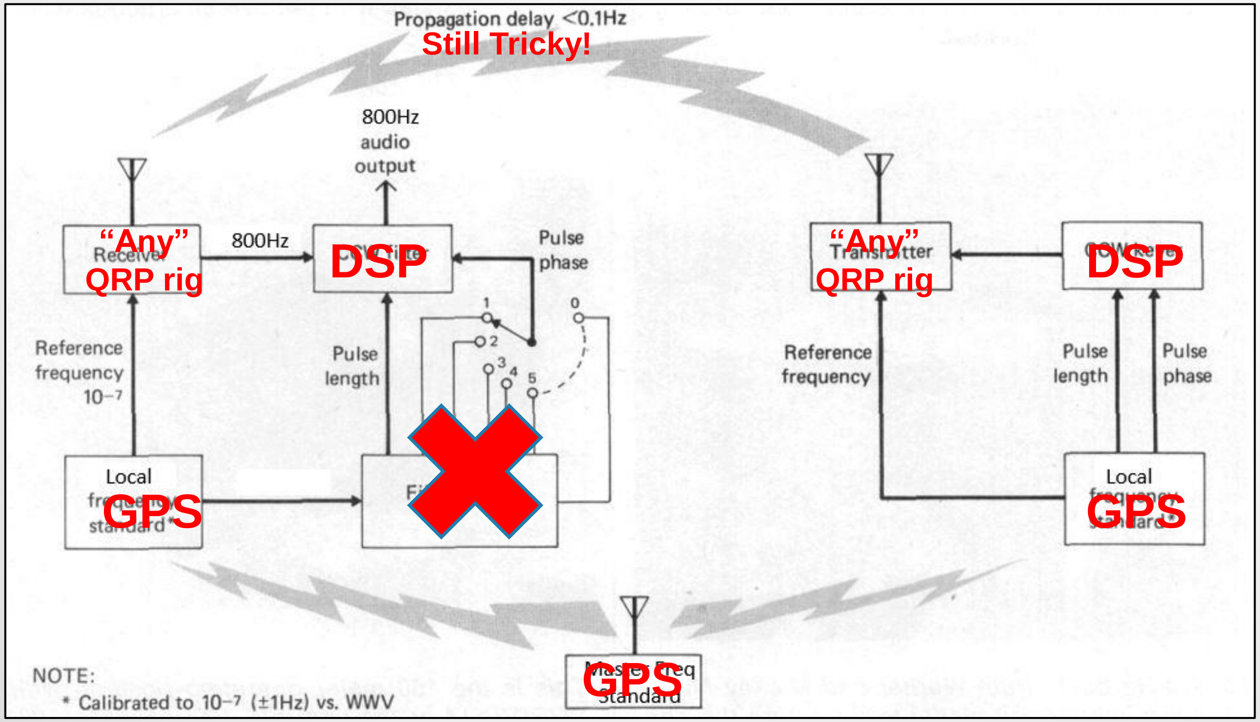


CQ Magazine June 1977, Ade Weis, W0RSP:
"Coherent C.W. – The C.W. Of The Future Part 1"]

A system **circa 1975** used **WWV** for the time sync, a **local oscillator** as the master frequency standard, and **filter driver for the phase adjust**.

MUCH Easier Today!

(… but still tricky.)



In the **circa 2023** system we can depend on GPS for both time sync and (global) frequency standard, and digital signal processing for CCW filtering.

N2APB + WB9FLW Demo CCW at FDIM 1998

R2/T2 + DSP56002EVM + DDS VFO (AD7008 – arrggh!)
+ VE2IQ's Sigma-Delta ADC board and "Coherent" PC app (whew!!)

How to extract a one-bit signal from that noise?

The noise is zero-mean.
The signal is a DC “bias” on the noise.

Use an
“integrate and dump filter.”
It’s a simple, special case of a “matched filter.”

(or call it a windowed Fourier transform, it’s the same thing)

11

Slide credit: Dave W8EDU

12 WPM Code has 100 ms Elements

100 ms elements=12 WPM code

That’s not blazingly fast CW, but it’s not bad, either.

Technician required 5 WPM, and that’s what is used in aviation.

General class was 13 WPM, Amateur Extra 20.

Current T license requires 20 WPM text,

16 WPM for 5 letter random code groups.

Slide credit: Dave W8EDU

Morse Code Reception is Hard to Automate

Morse *reception* is hard to automate! Problem: Morse is neither synchronous nor asynchronous:

1: You can’t tell code speed until you’ve heard some.

2:There are no start and stop bits.

3: Framing isn’t standardized

Old solution: Send a string of “V” (“ATTENTION”) characters to start a message. Modern term for that: “autobaud digital training sequence.”

Slide credit: Dave W8EDU

Standards for Morse Code

ITU-R M.1677-1 specifies:

2 Spacing and length of the signals

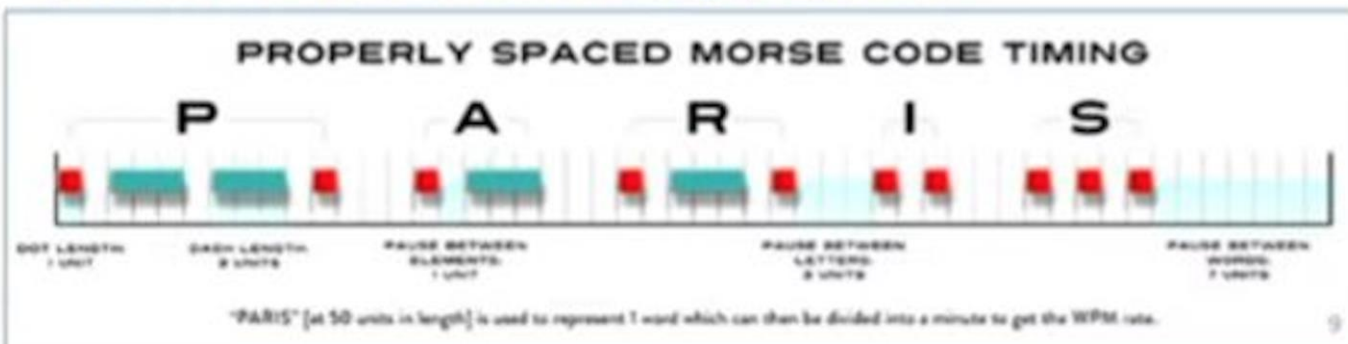
2.1 A dash is equal to three dots.

2.2 The space between the signals forming the same letter is equal to one dot.

2.3 The space between two letters is equal to three dots.

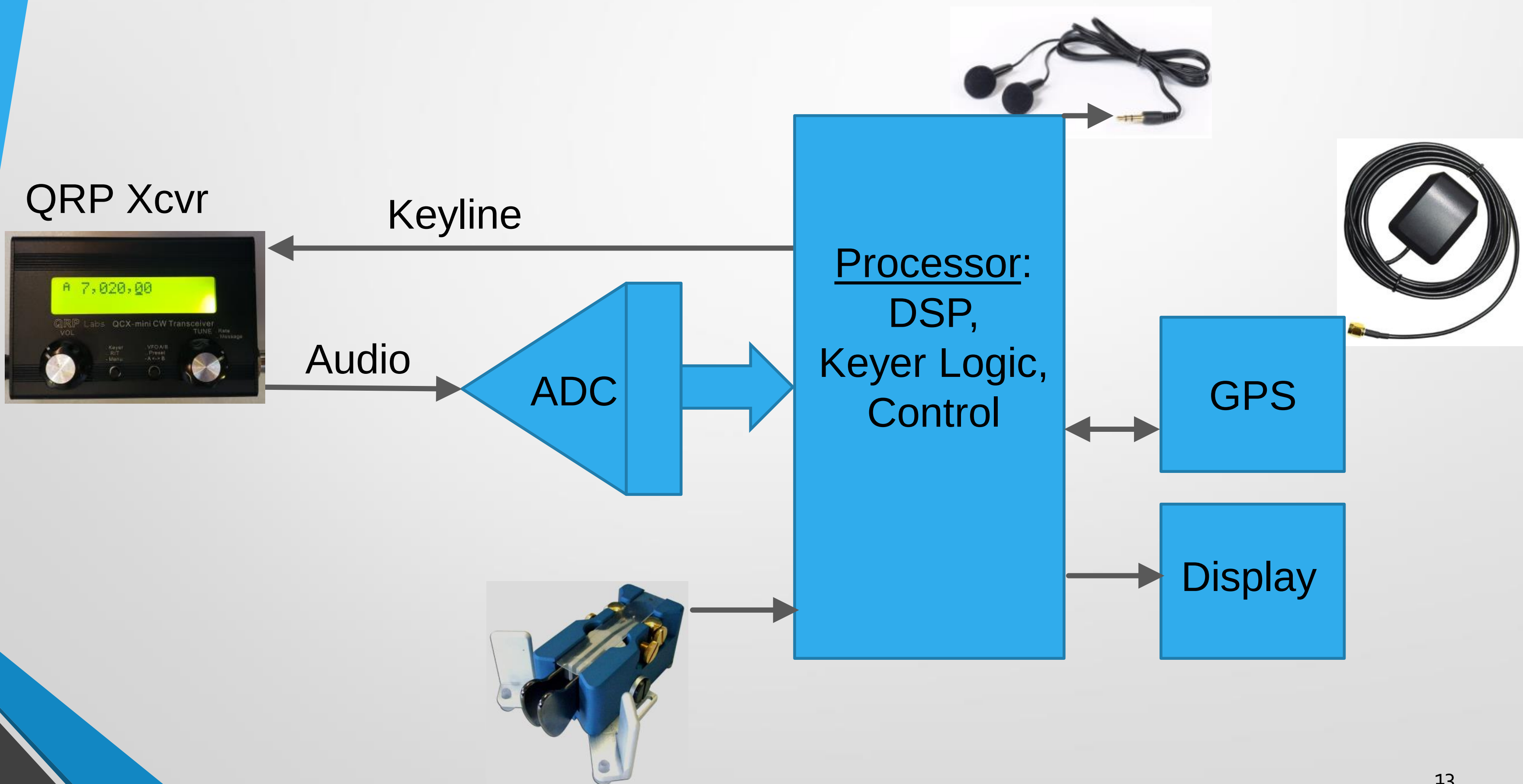
2.4 The space between two words is equal to seven dots.

Sending accurately *spaced* code isn't difficult and predates electronics. *Framing* is harder.

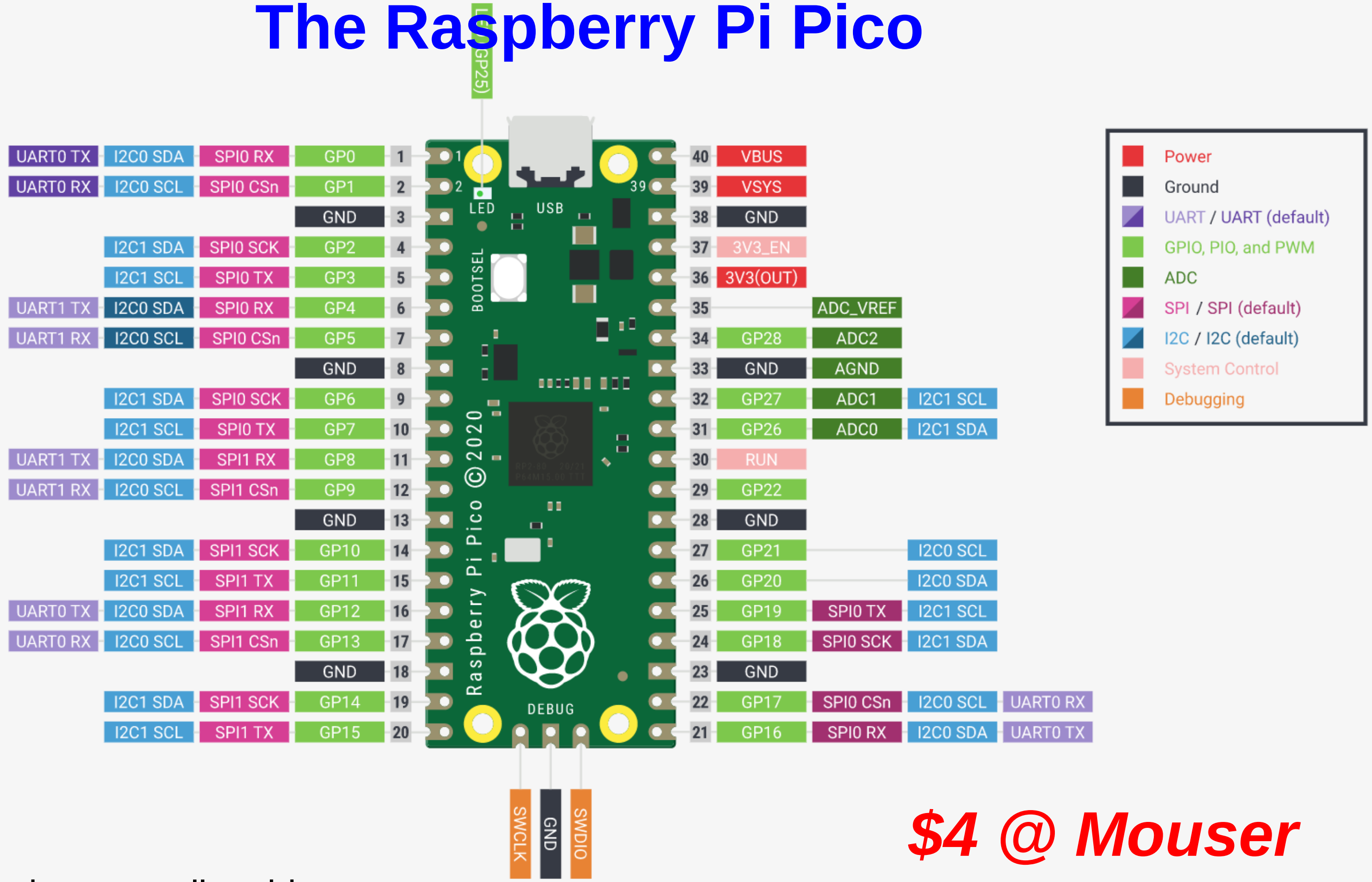


Slide credit: Dave W8EDU

A Modern Implementation of a CCW System



The Raspberry Pi Pico

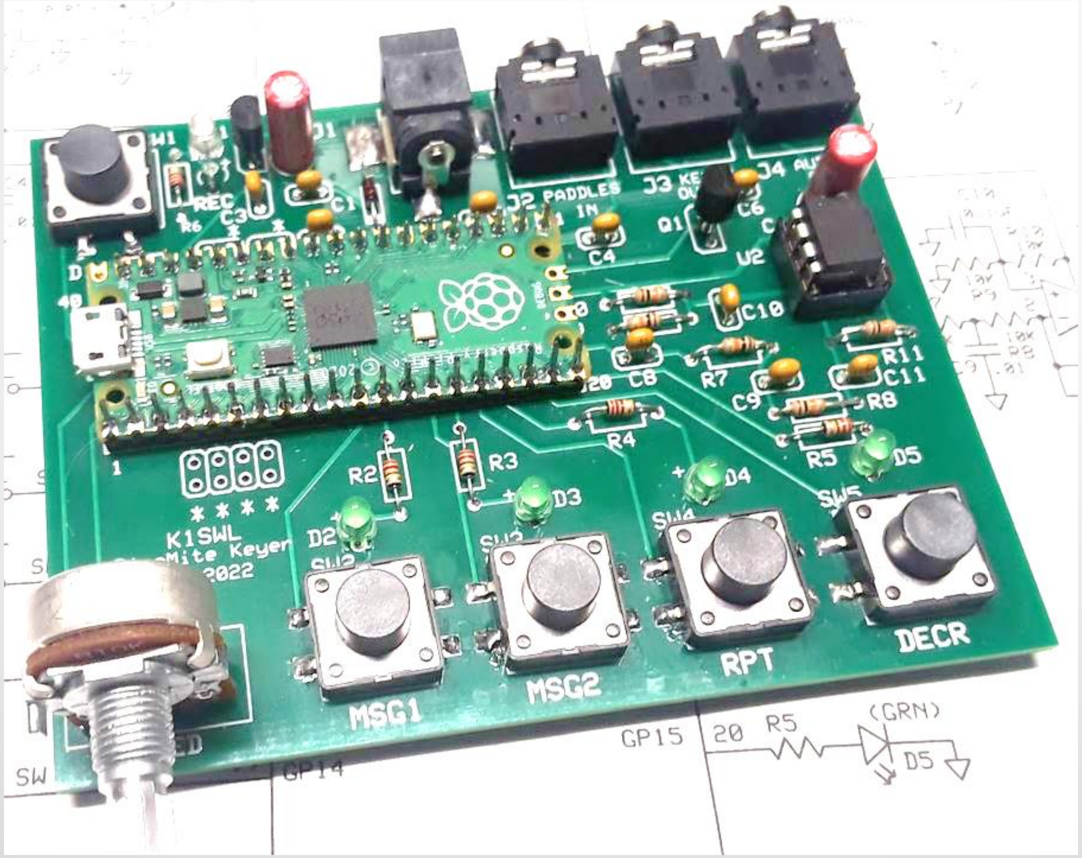


$4 @ Mouser
Qty's … LOTS!

- RP2040 microcontroller chip
- Dual-core Arm Cortex M0+ processor, 133/266 MHz
- 264kB of SRAM, and 2MB of on-board flash memory
- USB 1.1 with device and host support
- Low-power sleep and dormant modes
- Drag-and-drop programming

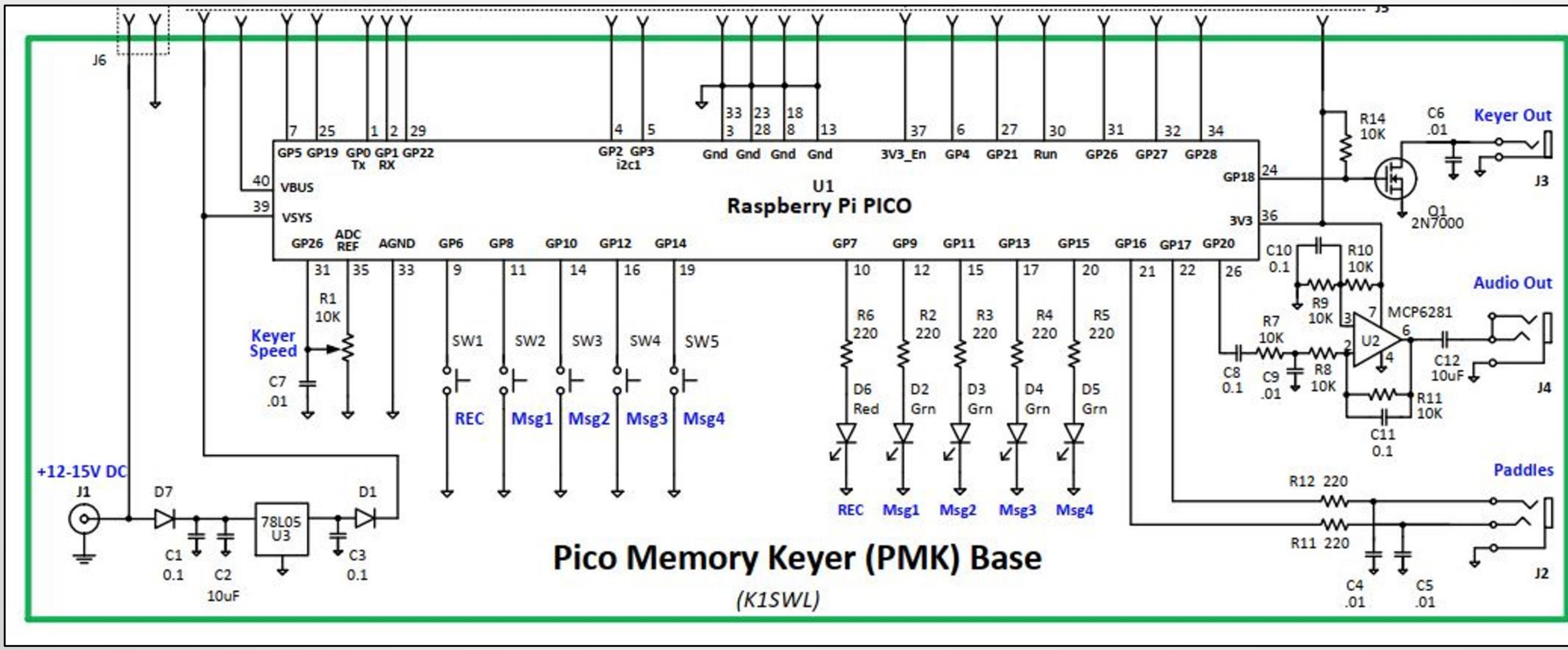
- 26 × multi-function GPIO pins
- 2 × SPI, 2 × I2C, 2 × UART, 3 × 12-bit ADC,
- 16 × controllable PWM channels
- Accurate clock and timer on-chip
- Temperature sensor
- Accelerated floating-point libraries on-chip
- 8 × Programmable I/O (PIO) state machines

The Computing Platform …
K1SWL "PicoMite Memory Keyer" (PMK)

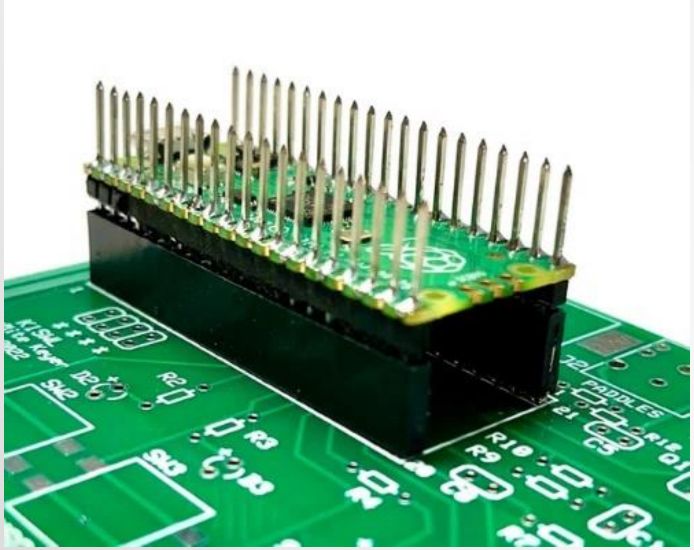


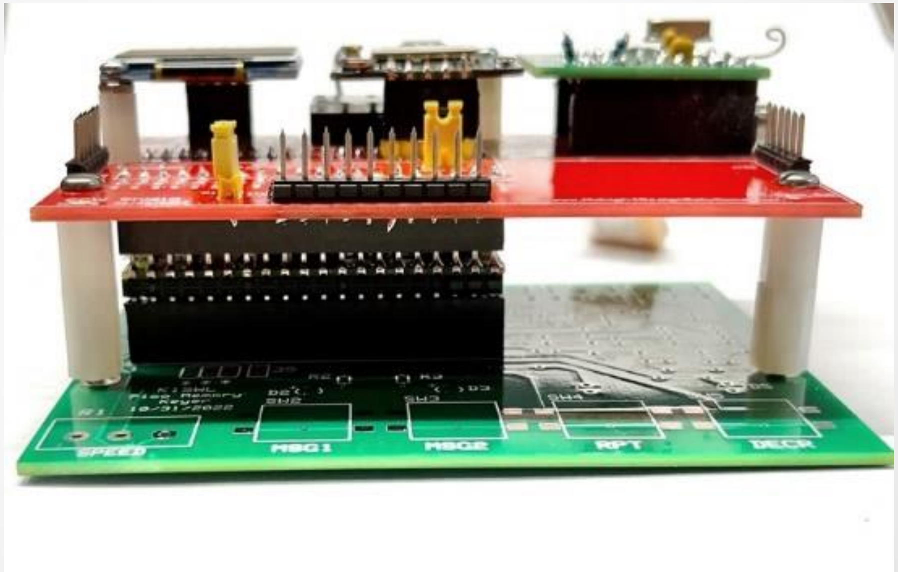
Dave Benson, K1SWL   QST for May 2023

PMK Schematic



Extending the PMK with “Shields”

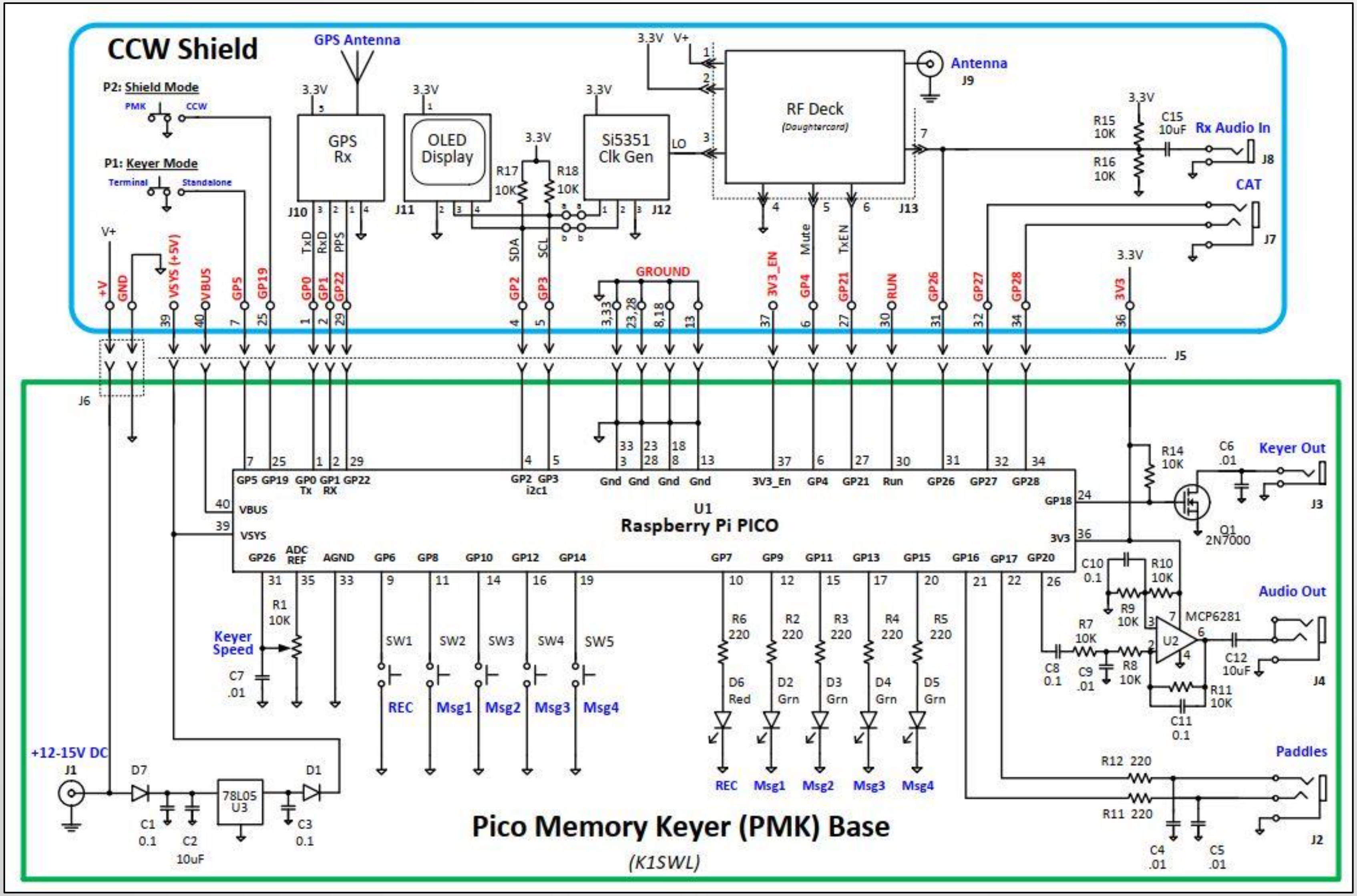




Double-ended, long pinheaders attach Pico to the PMK.

Shield plugs onto the Pico’s pinheaders.

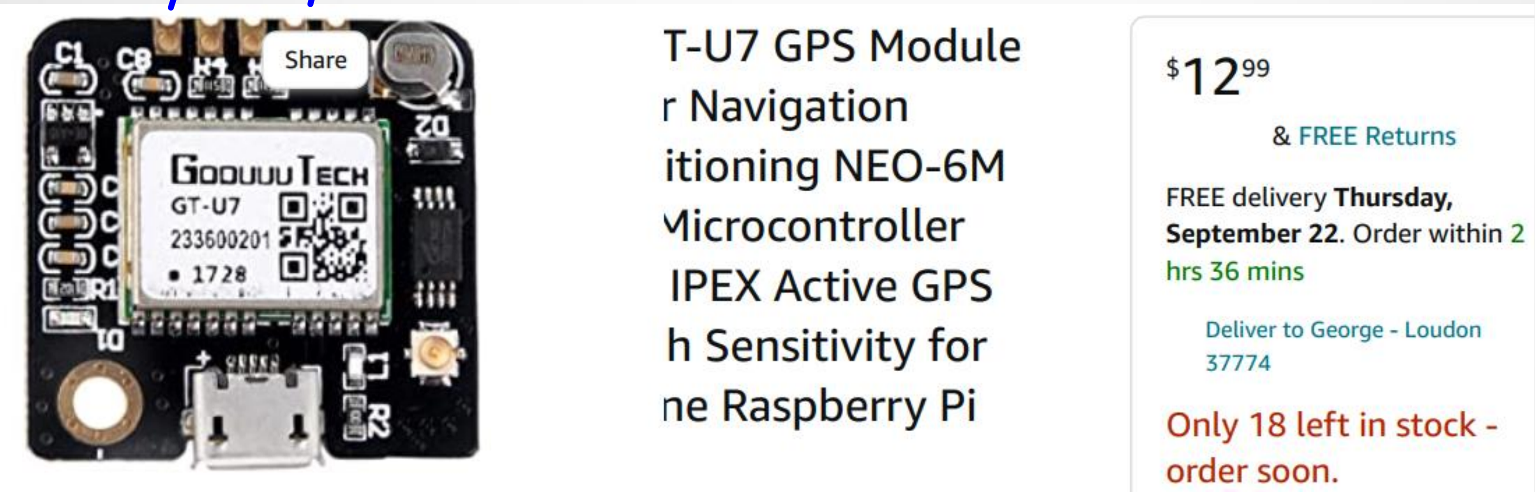
Full CCW Schematic: PMK + Shield



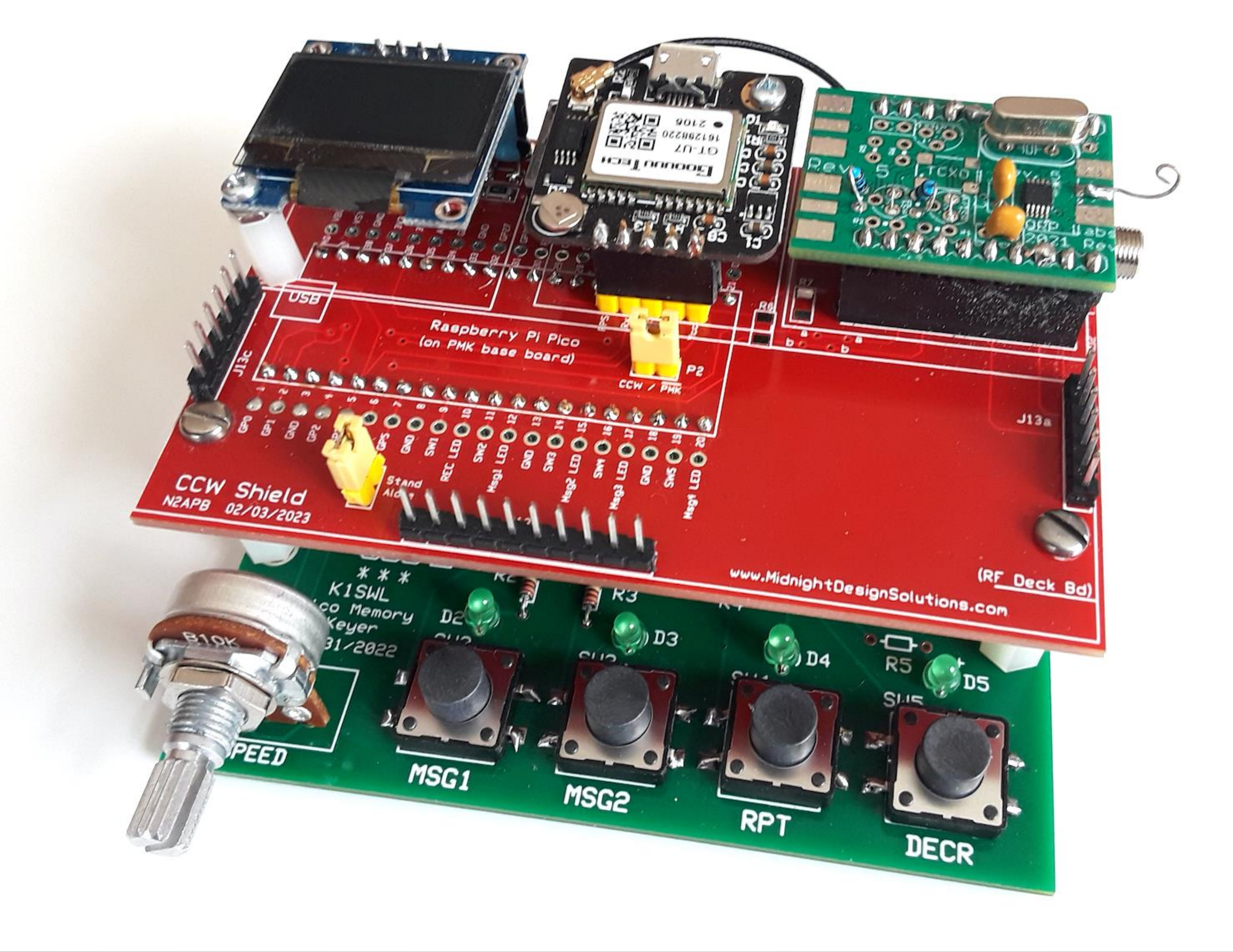
GPS = The Heart of the System

“TP1” delivers Cesium-based 100ms pulse train (10ns accuracy)

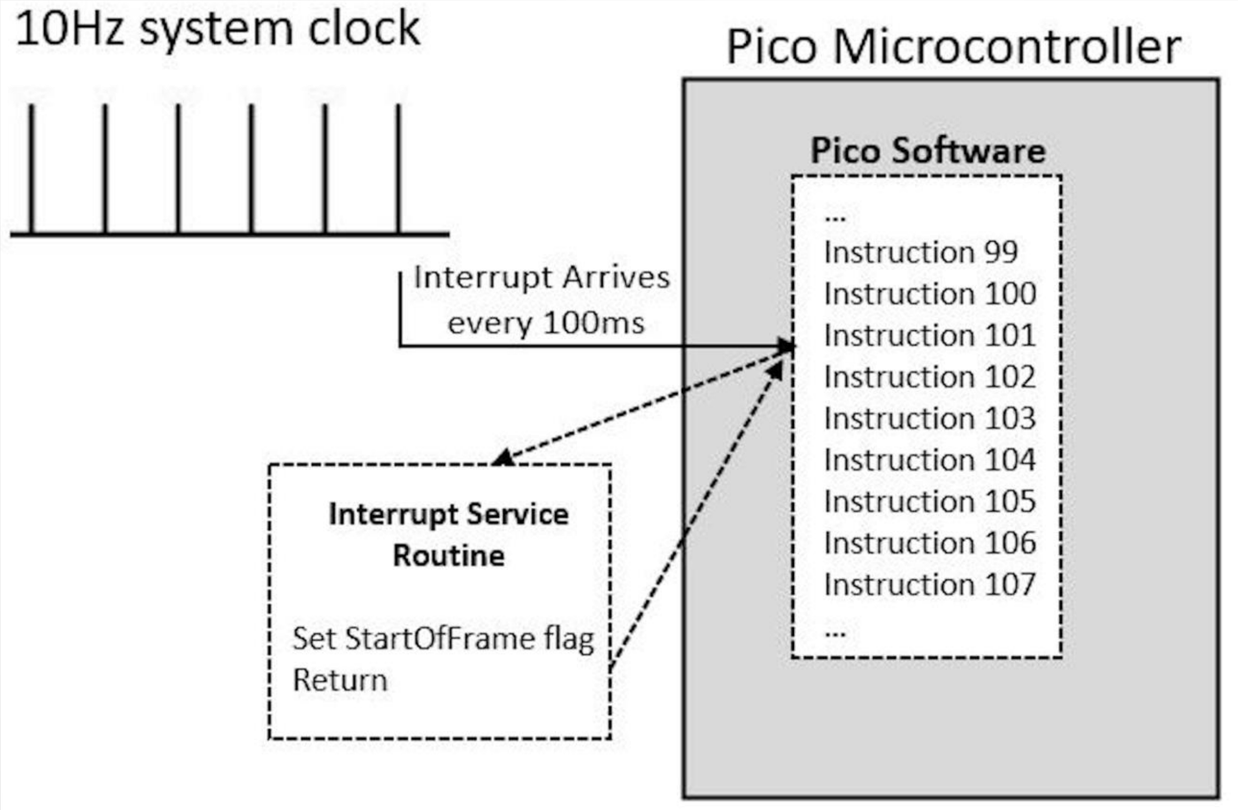
Date & Time @ 1-second intervals



Program for “TP1” to deliver 10 Hz clock

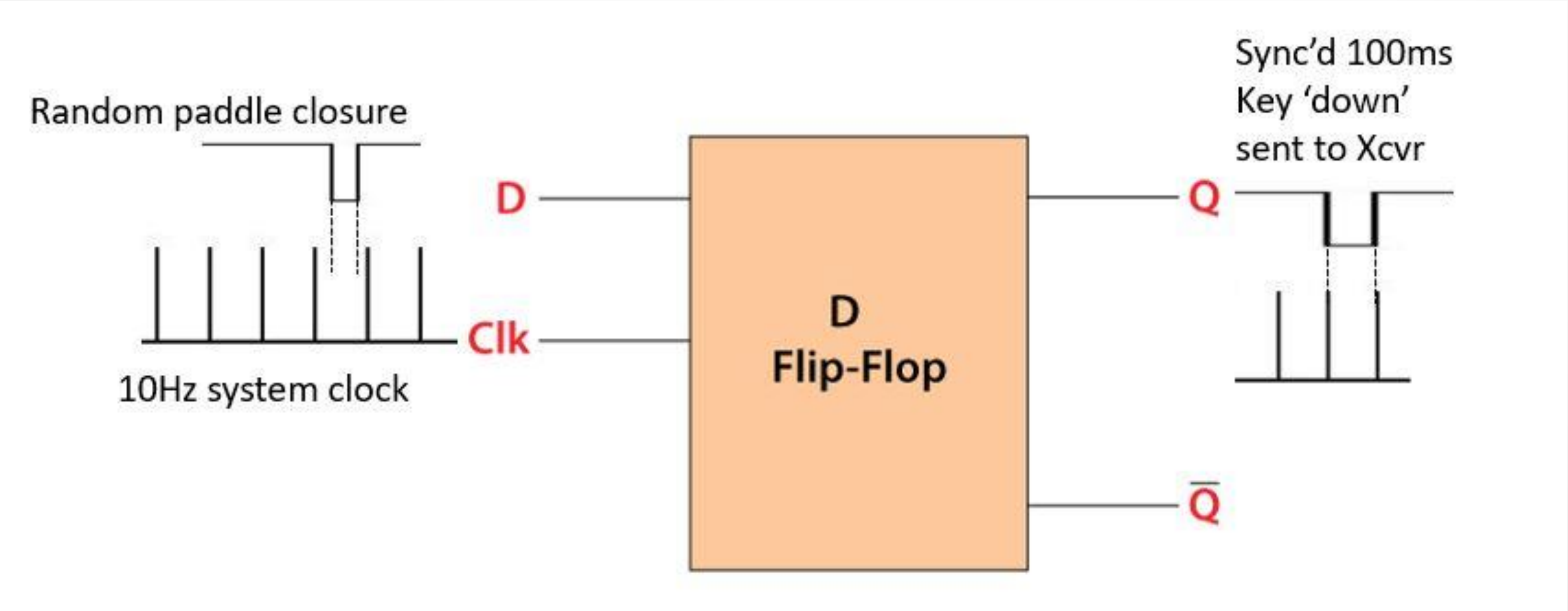

USB
J13c
Raspberry Pi Pico
(on PMK base board)
P2
CCW / PMK
J13a
CCW Shield
N2APB 02/03/2023
www.MidnightDesignSolutions.com
(RF Deck Bd)
K1SWL
D3
D4
D5
R3
R5
MSG1
MSG2
RPT
DECR

Time Synchronization



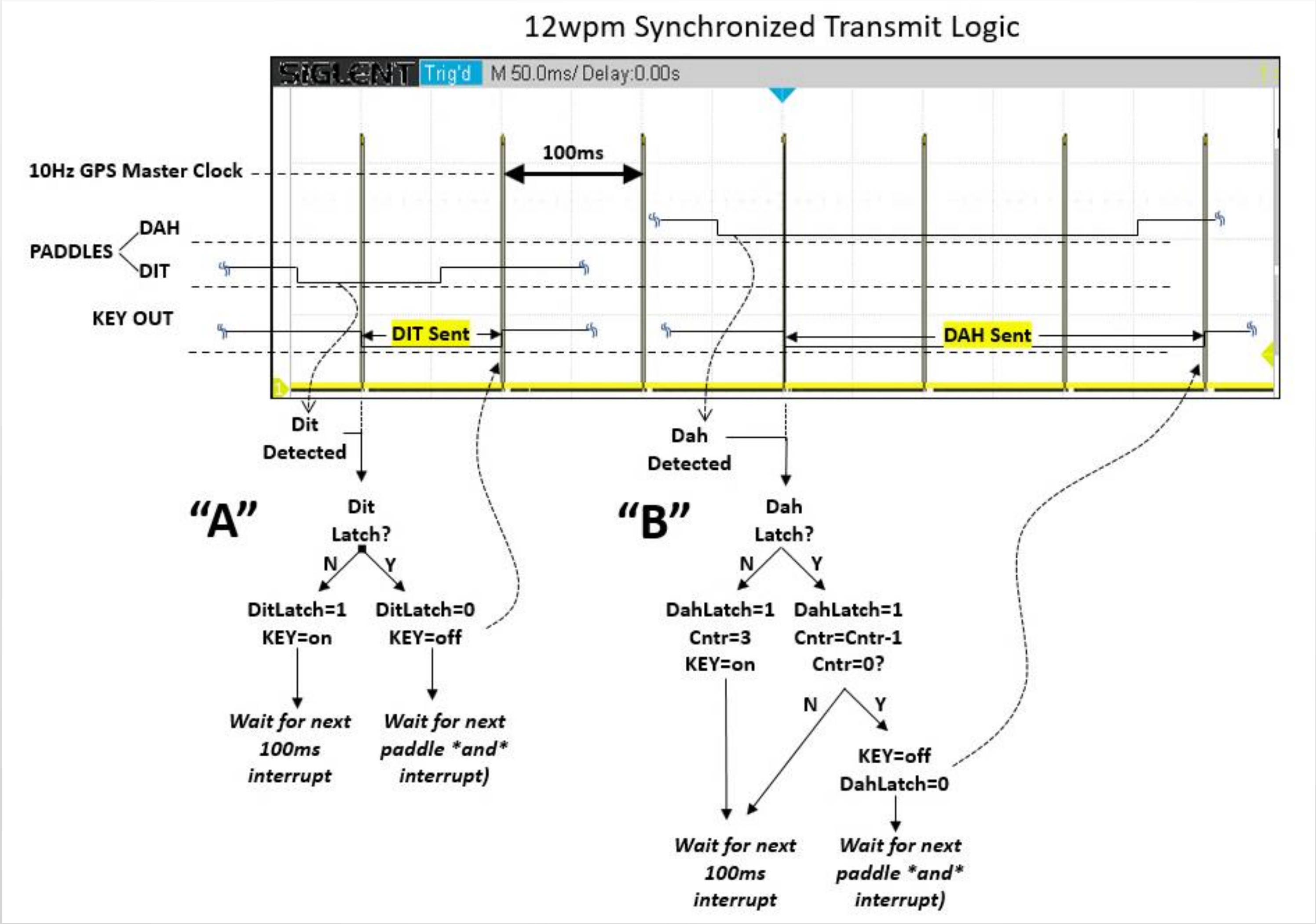
10HZ clock interrupts the Pico every 100ms.
This is the main heartbeat of the CCW system.

Synchronizing Morse Transmission to GPS Clock



Simple representation of a D-flipflop

Synchronizing Morse Transmission to GPS Clock

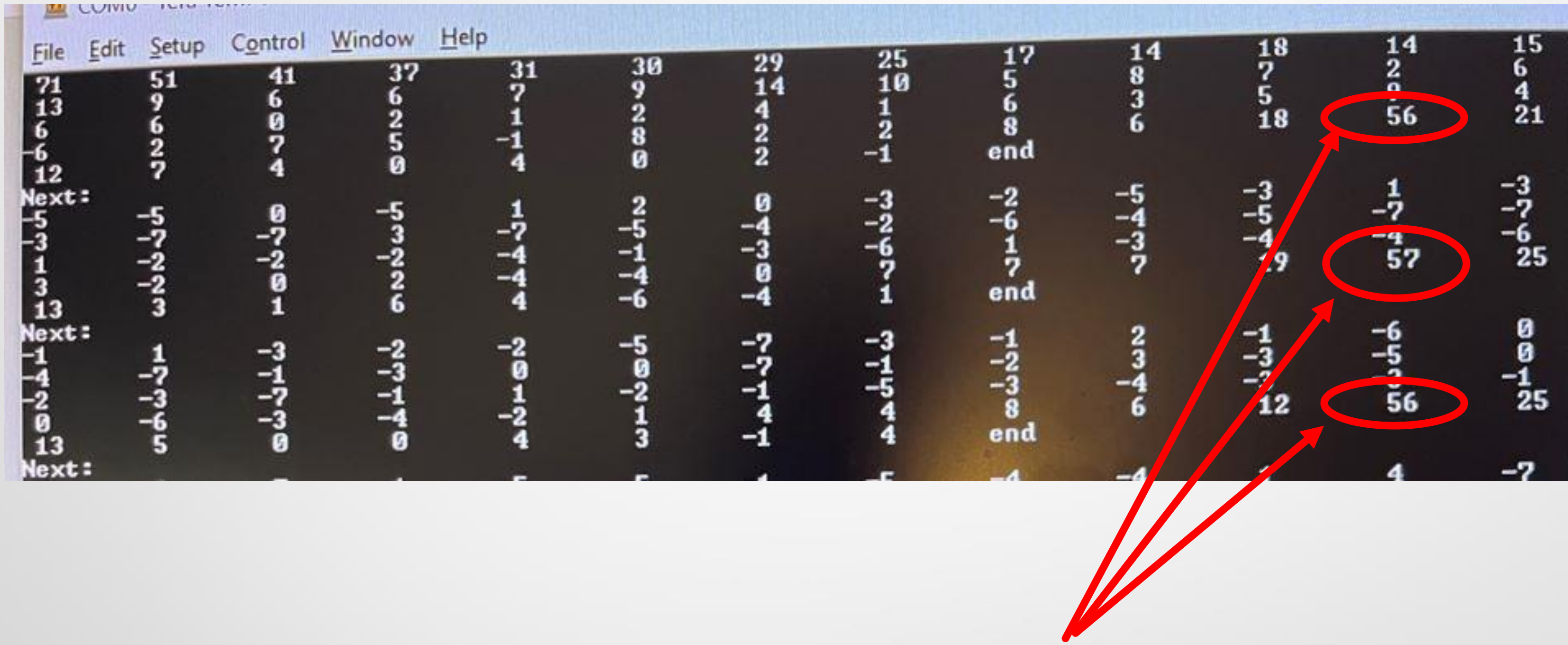


FFT Parameters → Frequency Resolution

Sampling & FFT Information			
ADC depth	12	bits	
Fs (max 500 kS/sec)	4000	Hz	
Samples	255		
Bin Res (Fs/Samples)	15.69	Hz	
Window (measured)	95	ms	
Bin (of 800 Hz tone)	51.00		
FFT Magnitude	(See display & data tables)		

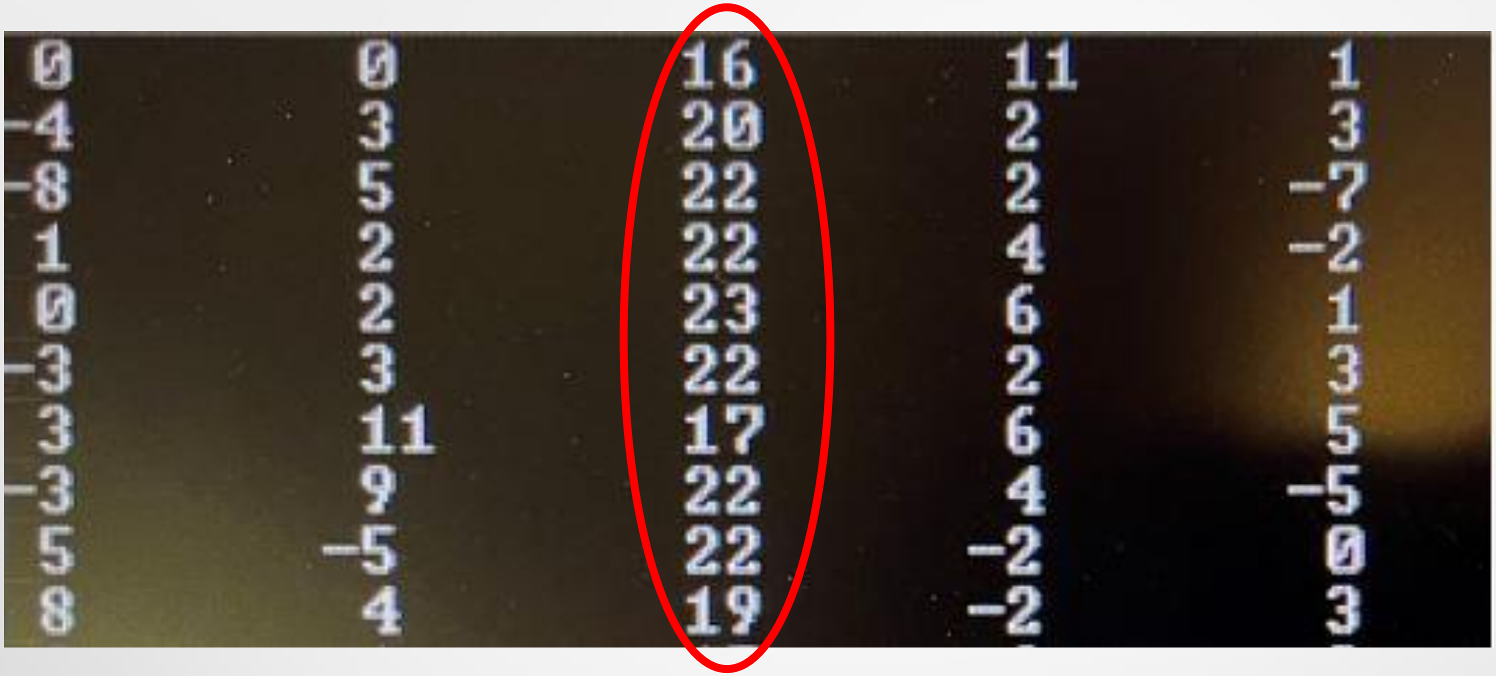
- "Frequency Resolution" (or filter bandwidth) of 15.7Hz.
- This is not as narrow as the 10Hz width of Petit's original CCW system, but it's pretty darned close, and still something far, far narrower than what could be achieved with electronics.

FFT Bin Counts for Bins 0-59



- “sweet spot” surrounding bin 51 representing 800Hz.
- <u>Big principle</u> enabling sampling and successful representation of a single frequency: ***“Zero-bias for noise, Signal for a constant signal”***

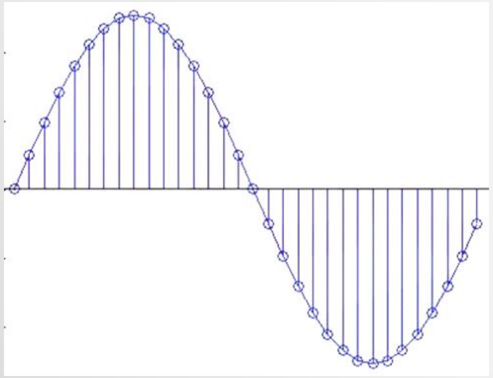
Man, What a Filter!

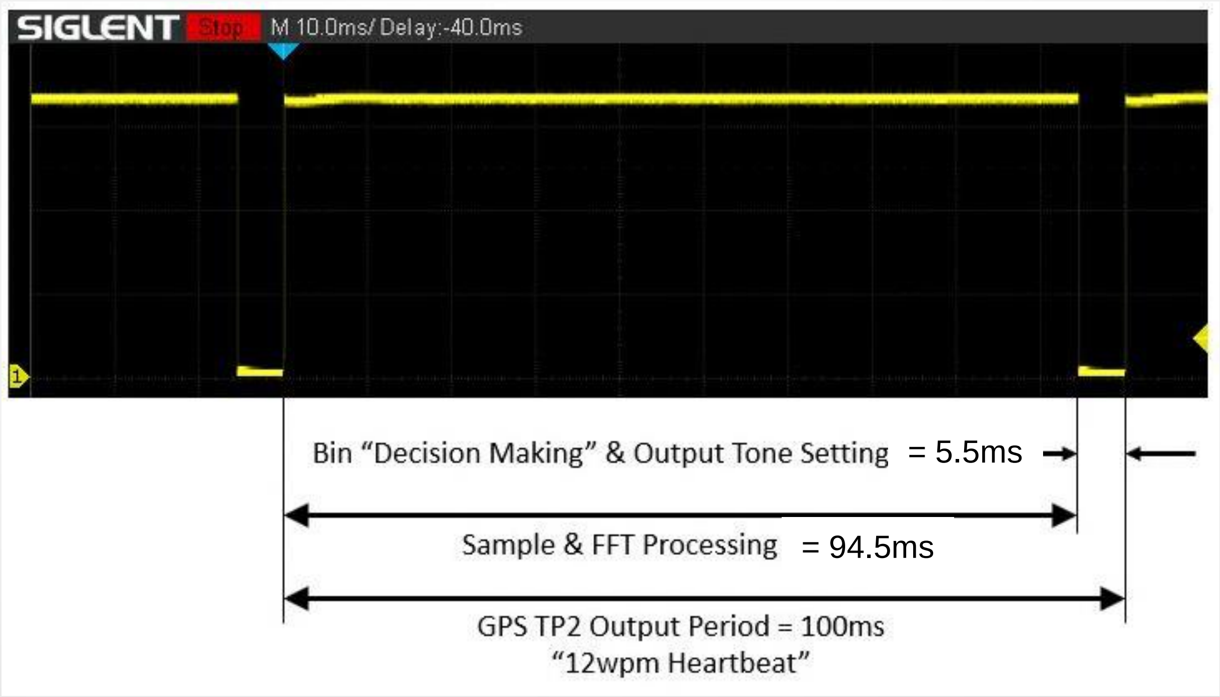


- Bins in/around those for **800Hz**
- ***This is why a CCW can be picked out of a "dead channel"***

Discrete sampling of a waveform by the Pico ADC

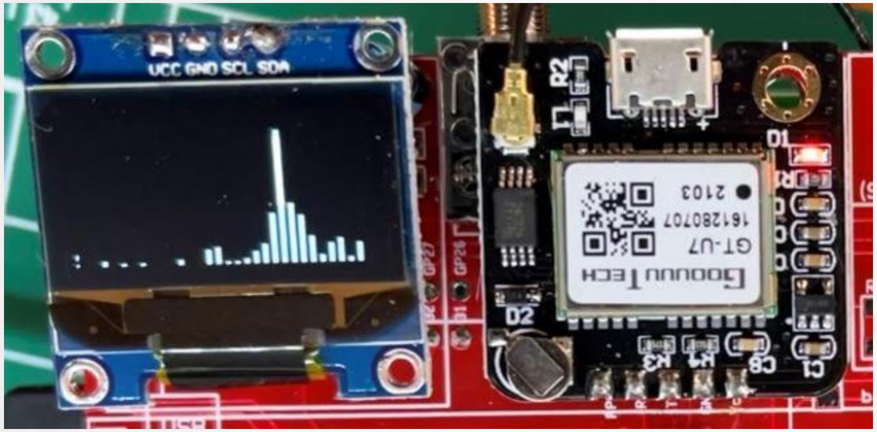
The software takes 255 samples and performs the FFT within a 94.5ms window.





- **100 ms element window**
- **94.5 ms FFT computational time**
- **5.5 ms remaining for mark/space decision making**
- **Plenty of time!**

Frequency domain of received signal after sampling and FFT processing



Note the frequency peaking at 800Hz

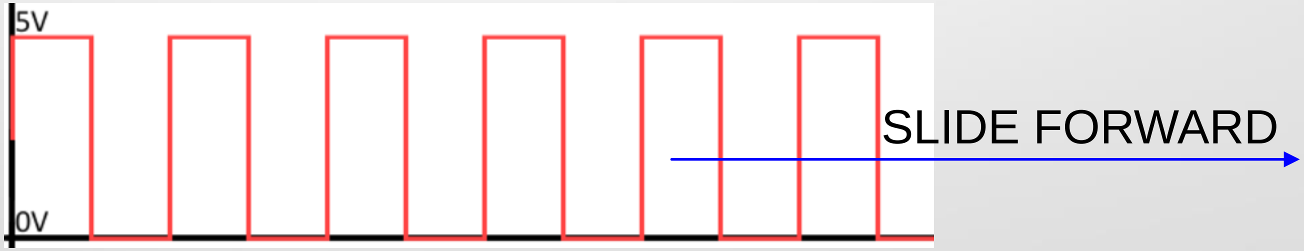
- It's at the 51st bin, which at 15.7Hz/bin yields the expected 800Hz value, which is also the value of the receive tone coming from the speaker.
- Elecraft K3 "Spot" function was a joy to use during development!

Transmission Synchronization

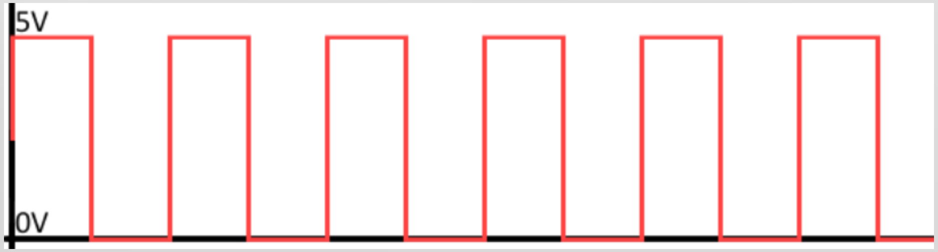
- "When" … Got this covered! (GPS date & time)
- "Speed" … This covered too! (Precisely 12 wpm)
- "Phase" … But this one is tricky, given RF path anomalies.

Solution: Send *dit* stream before initial transmission and <u>S L I D E</u> the master Rx GPS timing window to maximize the "800 Hz bin" size!

100 ms Window
(Rx GPS)



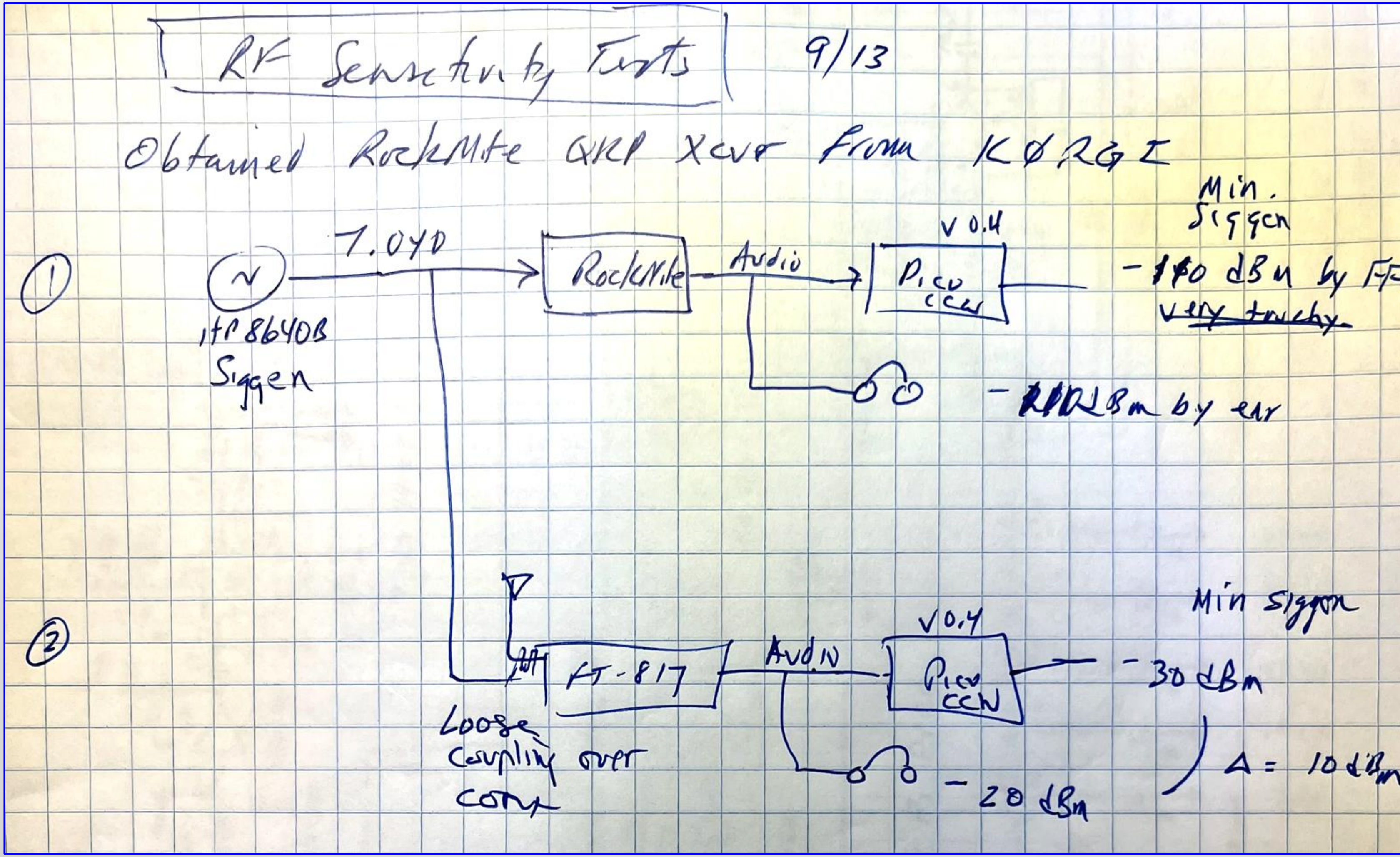
CCW Detector
Output



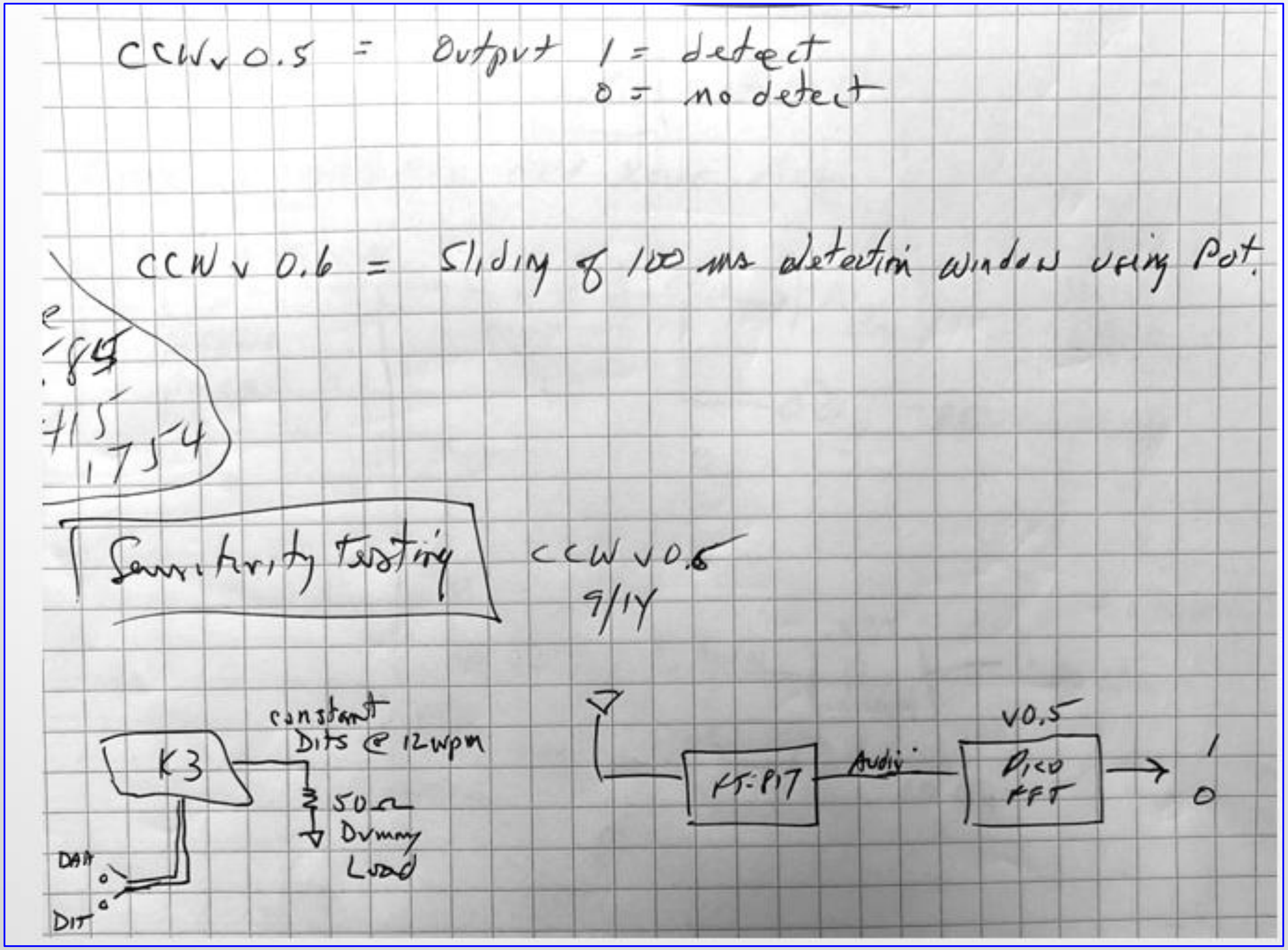
Software

- **The Pi Pico** = Amazing Development Platform!
- **Suported Languages:** Arduino C, C++, MicroPython, CircuitPython, Assembly Language, Scratch, HTML5, JavaScript, JQuery, Java, Perl, Erlang
- **Even in Basic …** K1SWL and I both used MMBASIC

Bench Measurements



FFT Sync Development & Experiments
9/14/2022



Field Testing

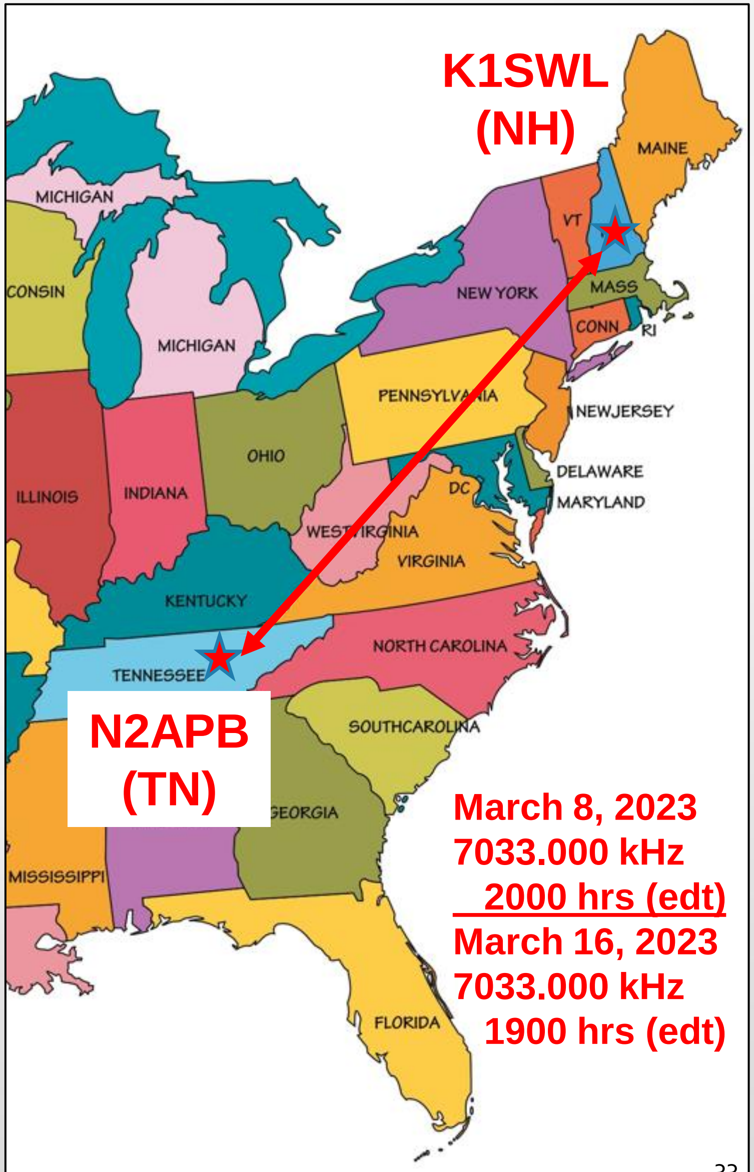
Dave

- KX3 @ 12W
- EFHW
- S7 Noise
- Rx just above the noise

George

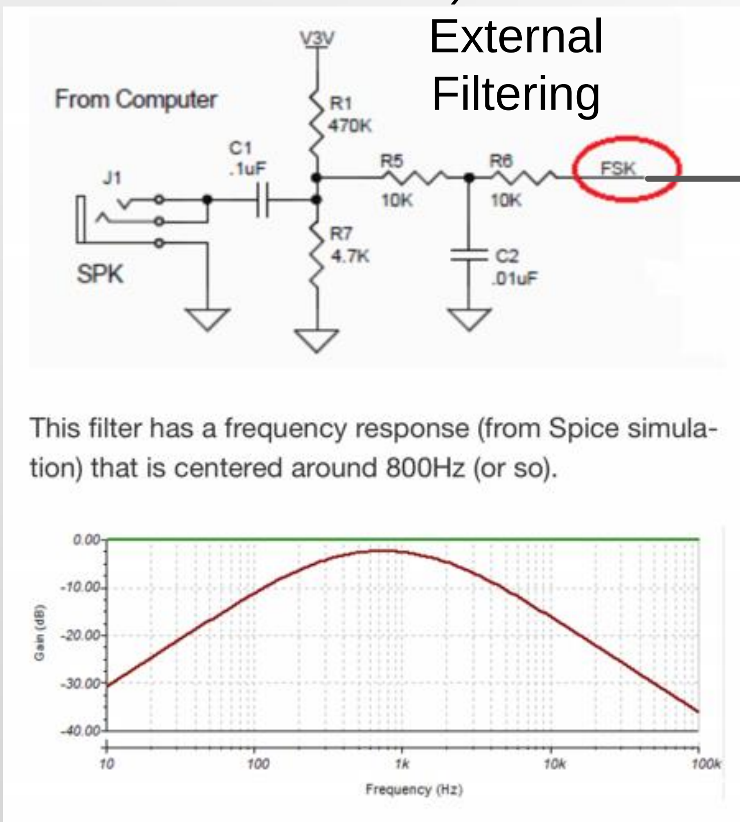
- K3@10W
- Hustler 5BTV
- S7 Noise
- 1 S-unit above noise

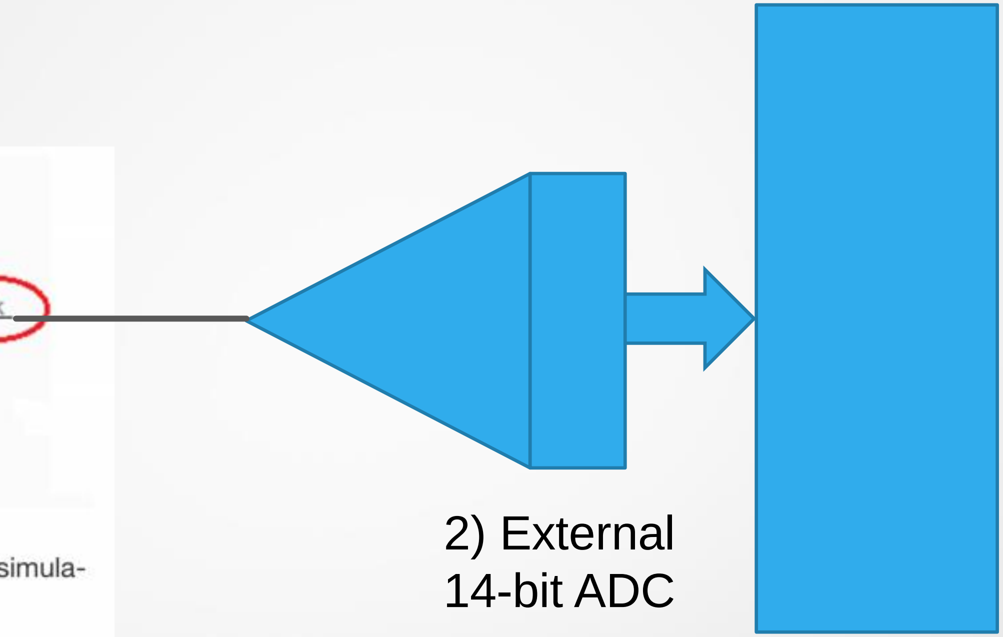
“Dit Stream QSO”
75% copy – *“Eh”*



Likely Refinements

1) Better External Filtering





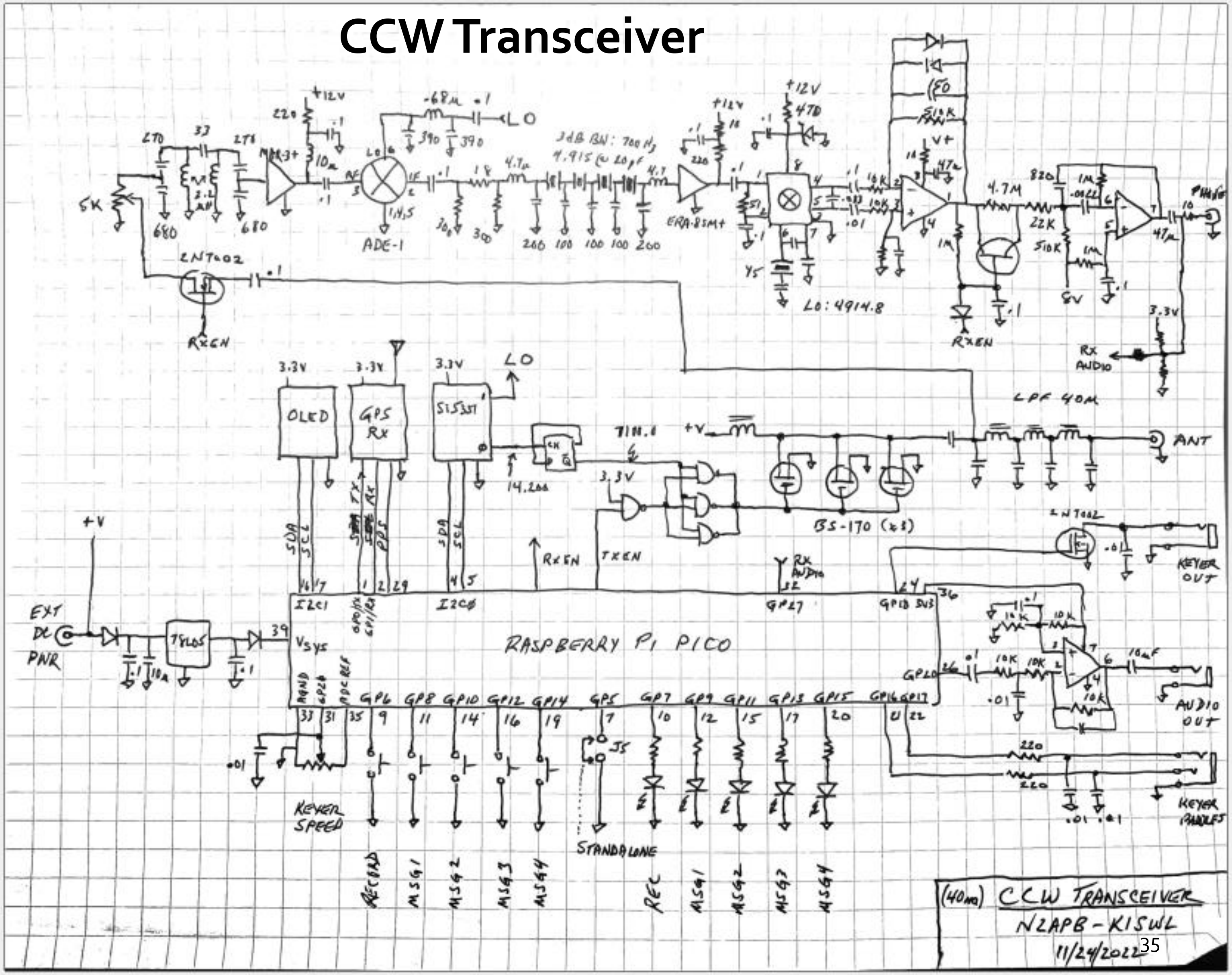
2) External 14-bit ADC

3) Teensy Processor

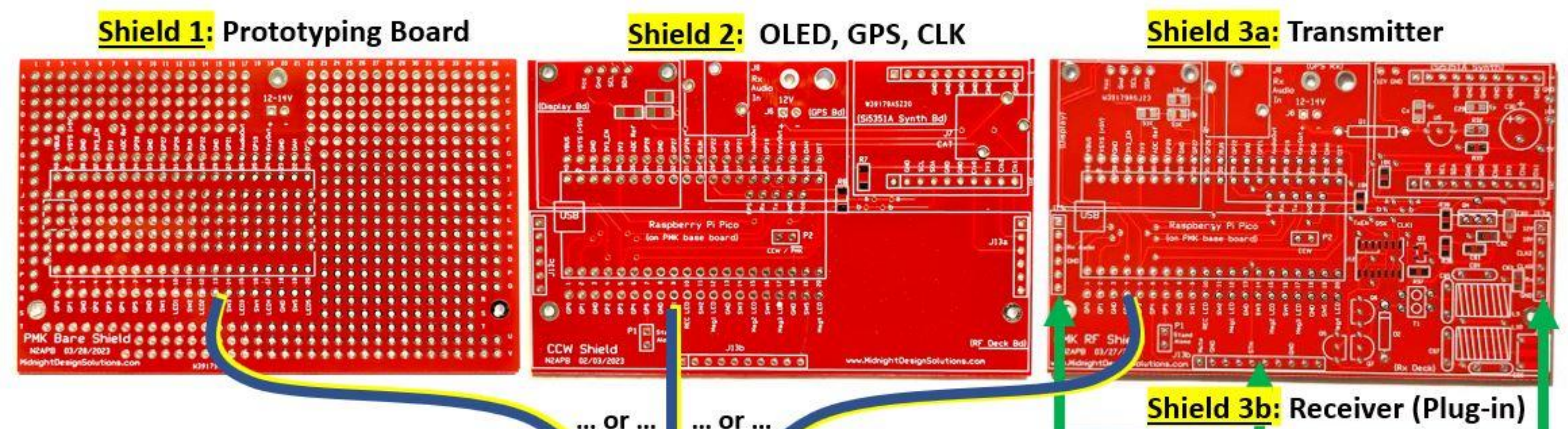
4) Improved frequency peaking by bin interpolation
5) Automated synchronization protocol
6) Keyboard Send / Morse Decode?
… ***NO!!***

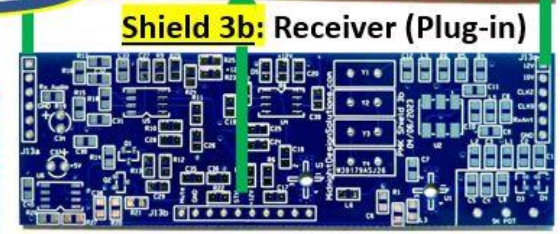
What in the Pipeline at Midnight Design?

CCW Transceiver



CCW Transceiver Shields





Plug any of these Shields on top the PMK's microcontroller to extend its hardware capabilities, as desired.

To use and build upon the Open Source software provided with K1SWL's Pico Micro Controller MMBasic libraries ... or to develop your own applications using Arduino C/C++, MicroPython, and other languages using readily available device libraries!

Shield 3b hardware will be available first as a 40-meter add-on to the PMK in time for the FDIM Seminar and the Dayton Hamvention.

... n2apb

Is CCW in Your Future?

- The quest for QRPppp … WAS @ 1mW, etc?
- Balloons
- Space Comms & Research
- Specialized Ham Gear

Students at Case Western Reserve University:

W8EDU and CCW

Thanks to a grant from the Amateur Radio Digital Communications Foundation, two senior electrical engineering project groups at CWRU are working on a modern implementation, supervised by the hams of W8EDU.

Current plan: Adafruit GPS and Teensy controller for laptop console or by-ear use. Strict GPS-controlled CCW timing.

Future: Automated signal-to-noise reading between Morse elements, for HamSCI data collection. Maybe time-of-flight and Doppler data.

A parallel WWVB monitoring project will share some code. Join us in the 2024 Eclipse QSO Party and in general CW operating. This should be fun!

The CCW Archives

MidnightDesignSolutions.com/ccw

Maintained by ...
George Heron, N2APB
Peter Eaton, WB9FLW

CCW Compendium -- *by George Heron, N2APB and Peter Eaton, WB9FLW.* This is a bibliography of over 400 pages of CCW literature, projects, historical happenings, technology evolution, and more. Some of the references have been mentioned in recent feedback (e.g., QST articles)
CCW - The More You Know About a Signal, The Easier It Is To Copy -- *by George Heron, N2APB and Peter Eaton, WB9FLW.* George and Peter wrote a paper concerning CCW that was ultimately presented as two speaking sessions at the 1998 FDIM session at Dayton. Peter overviewed the rich and colorful history evolution of this low bandwidth communications mode brought about by some ham pioneering giants, and I reviewed the technology and a practical homebrew CCW rig and station. (Partial article ... never finished and not used in FDIM.)

Stealth CW -- *by Stan Wilson AK0B, St. Louis QRP Society Peanut Whistle January 1995.* Stan's article is a wonderful 2-3 page detailed overview of the technology. (At the moment I can't find the electronic version of his piece, but I do have permission from Stan to post it.)
BPSK Basics

BPSK article in QRPp **--** by Vic Black, AB6SO in QRPp for Vic clearly and succinctly overviews the evolution and current state of the technology, and gives some additional references.

COHERENT CW - AMATEUR RADIO'S NEW STATE OF THE ART?, by Raymond C. Petit W7GHM, QST September 1975.

COHERENT C.W. - THE C.W. OF THE FUTURE PART I, *by Adrian Weiss K8EEG/0, CQ June 1977.*

COHERENT C.W. - THE C.W. OF THE FUTURE PART II, by *Adrian Weiss K8EEG/0, CQ July 1977.*
PRECISION CW HANDBOOK, *by Peter Lumb G3IRM*
PCW NOTES, *by Peter Lumb G3IRM*

COHERENT CW PART 1 - THE CONCEPT, by *Charles Woodson W6NEY, QST May 1981.*

COHERENT CW PART 2 - THE PRACTICAL ASPECTS, *by Charles Woodson W6NEY, QST June 1981.*

COHERENT CW, Chapter 21 (Special Modulation Techniques), from the ARRL Handbook 1985.

A DSP Version of COHERENT CW (CCW), *by Bill de Carle VE2IQ, QEX February 1994*
Coherent CW for VHF - will it work?, *by Don H. Gross W3QVC and Bert C. De Kat VE3DPB*
CCW Newsletter -- over 100 separate issues!

Credits

Massive credit goes out to all the aforementioned authors, experimenters and pioneers listed on the previous CCW Archives page, upon whose collective shoulders we both stand in our own research.

But **SPECIAL KUDOS** and **THANKS** go to one in our own QRP community, **ADE WEISS, W0RSP**, who helped in that experimentation almost 50 years ago with article publications and promotion of this amazing technology.

Those interested in copies of W0RSP's excellent technical detailing of Coherent CW principles and operation should contact us for copies of his 1977 articles from CQ Magazine.

Thank You!