RF Seminar

PicoGPSDO

Eenvoudige GNSS gedisciplineerde referentieoscillator

Anthony Kok PE9K

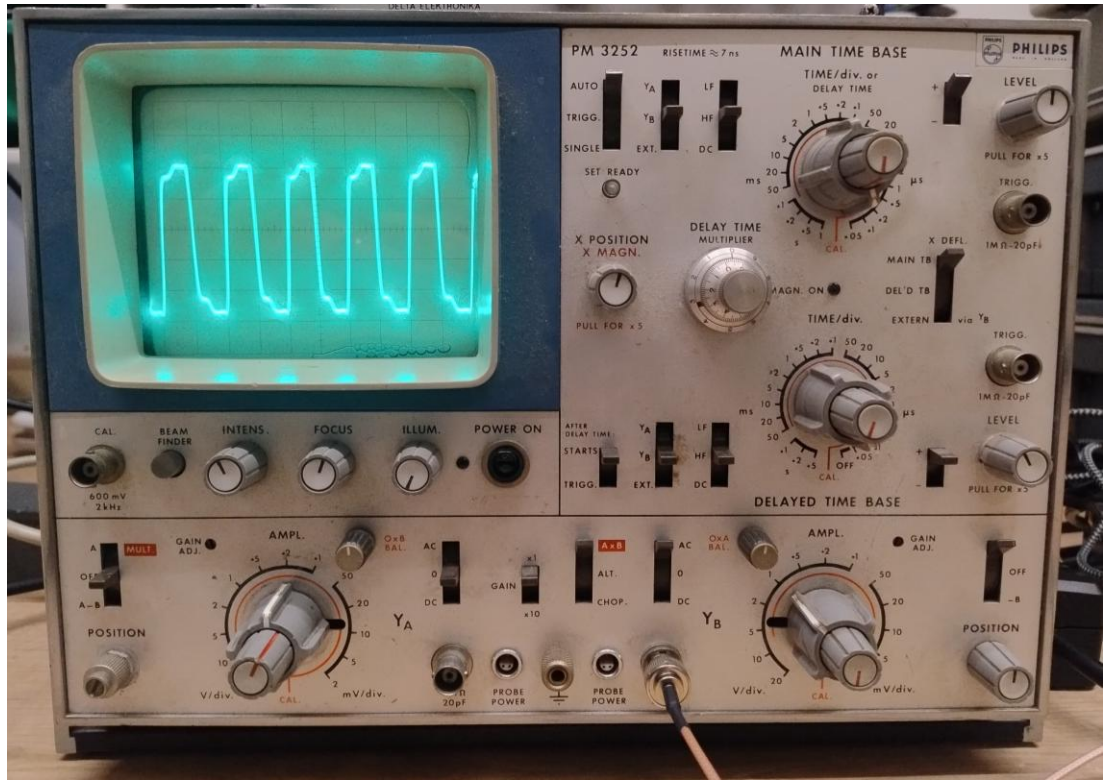
Introductie

- Anthony
- Ontwikkelaar van productieprocessen
- PE9K sinds augustus 2024

RF Seminar

Inhoud

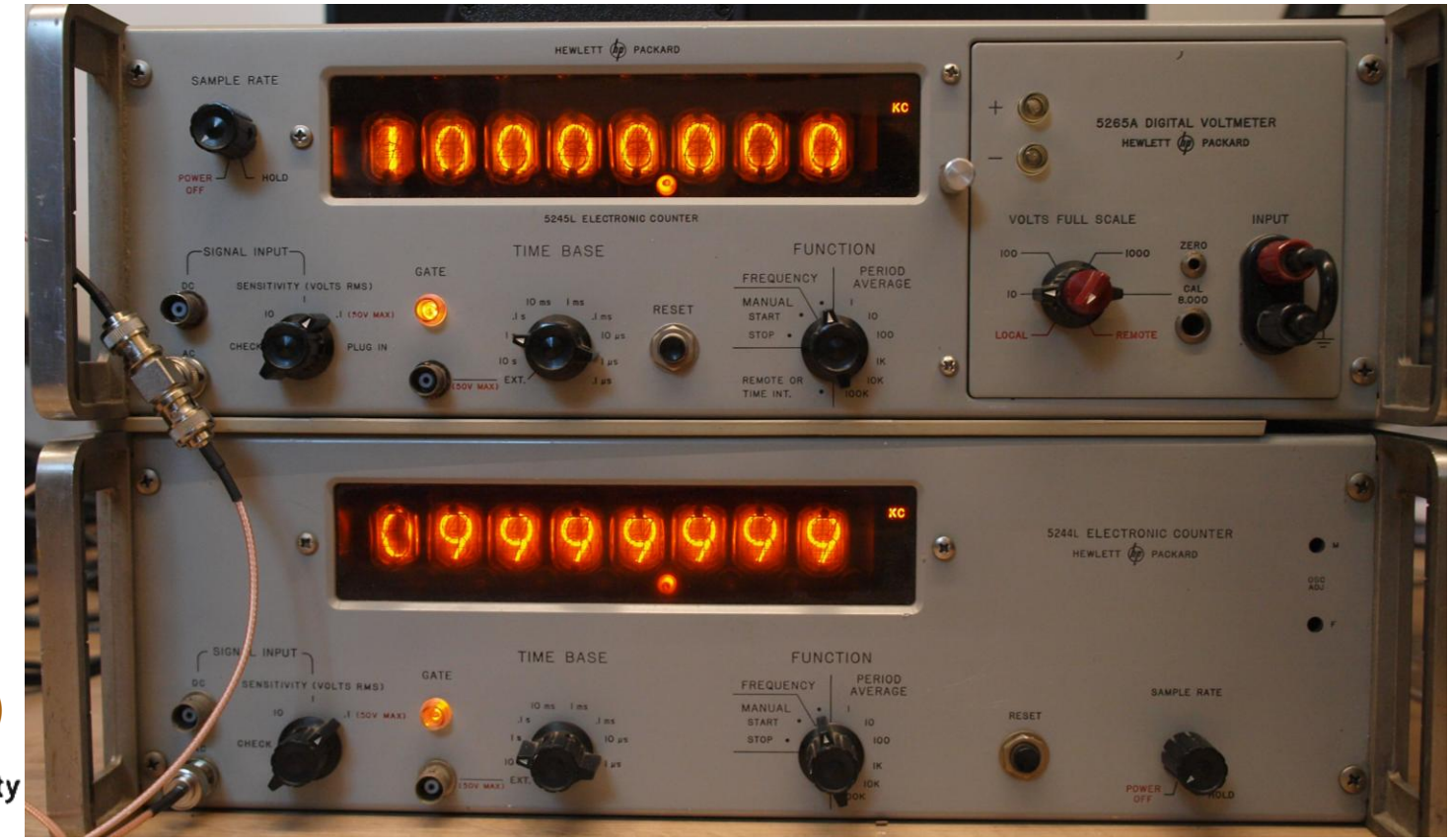
- Aanleiding
- Ontwerp
- Realisatie
- Meten
- Bevindingen
- Discussie



Aanleiding

- Eind 2024 kocht ik twee klassieke tellers
- HP 5245L (1965)
- HP 5244L (1967)

- Zijn ze OK?

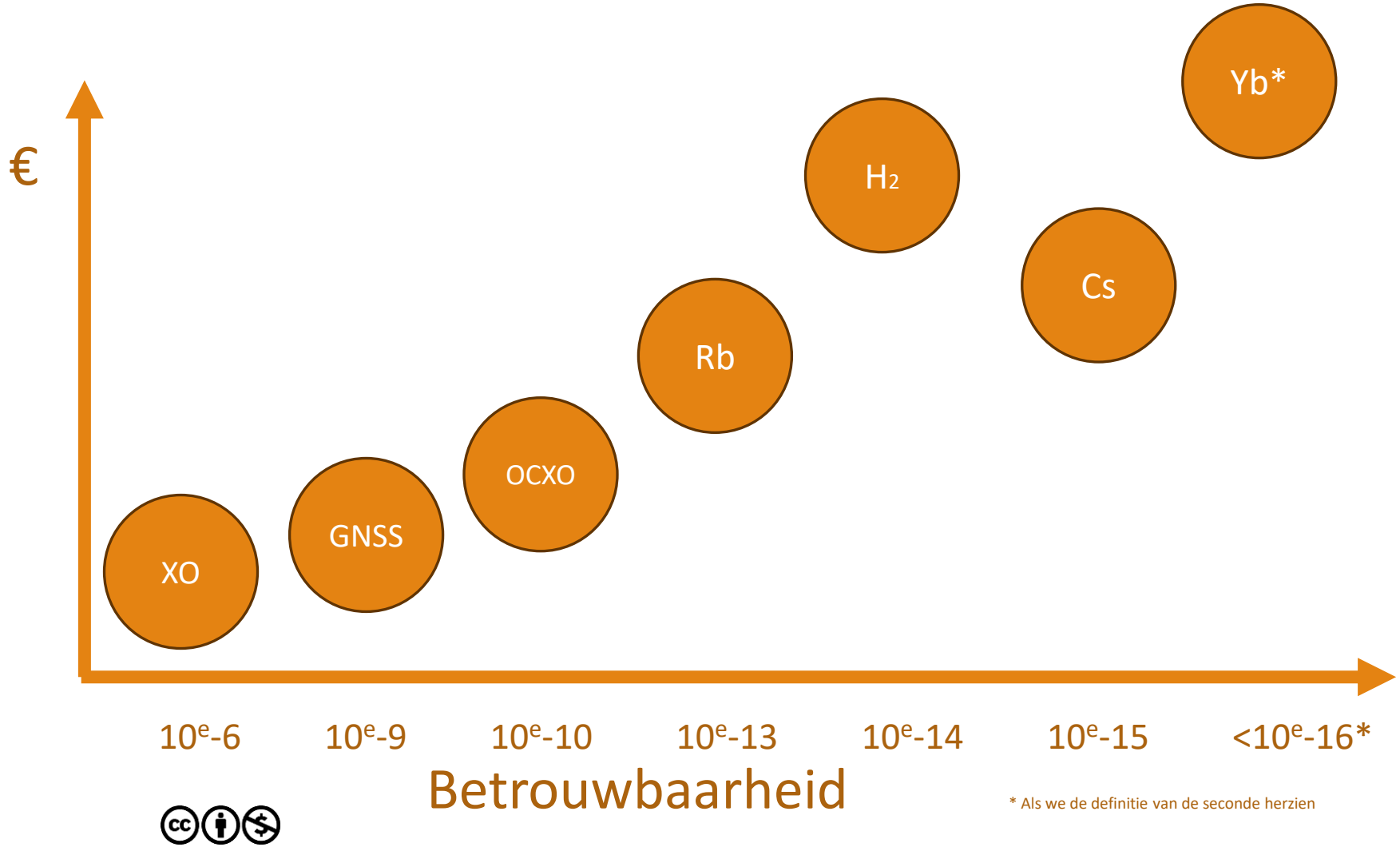


5245L ELECTRONIC COUNTER (1)

Compact 50 mc counter with 3 parts in 10' time base stability

Frequentiereferenties

Nauwkeurigheid: Δf/f @1s op willekeurig moment (2) (3) (4)



* Als we de definitie van de seconde herzien

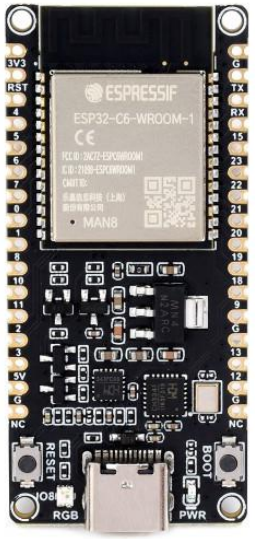
RF Seminar

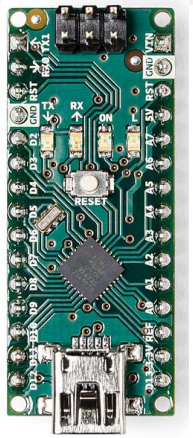
Ontwerp: Specificaties

- 1 MHz & 10 MHz uitgang.
- 1ppb stabiel & accuraat *(Δf / f: 10E-9@10S)*
- USB-C voeding
- Degelijke printplaat, alu doosje, minimum aan lampjes
- Microcontroller vogelt alles zelf uit (taal: C)
- Redelijke Kosten (€75,00)

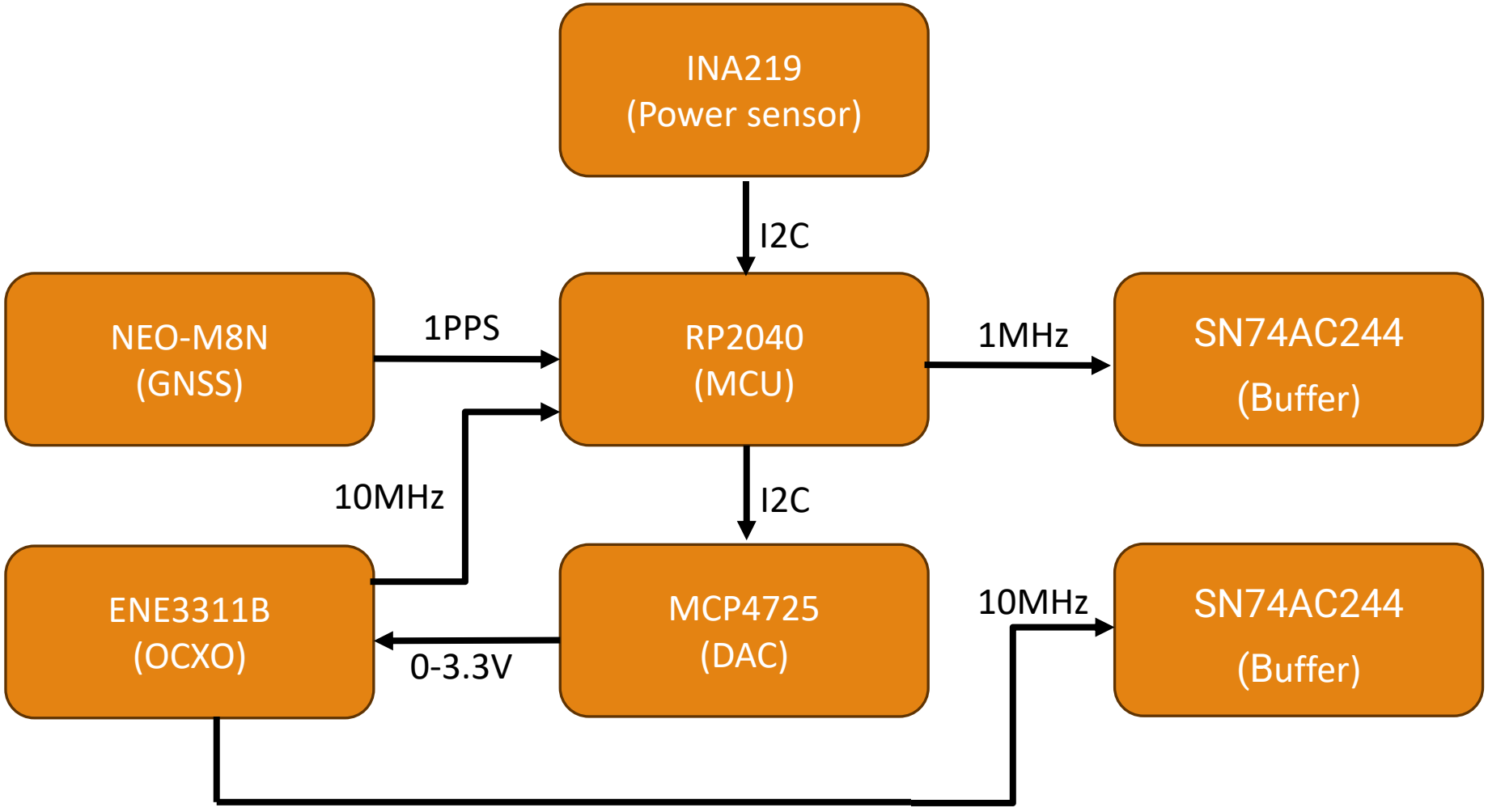
Microcontrollers

Platform	Teensy 4.0	ESP32	Pi Pico	Arduino Nano
Chip	IMXRT1062DVL6	ESP32-S3	RP 2040	ATmega32U4
Documentatie	+	-	+	++
Snelheid	600 MHz	40MHz – 160 MHz	133 MHz – 240 MHz	16MHz
Prijs *(5)*	€32,66	€8,82 – €22,99	€4,59 – €9,55	€16,34
Bekend *(Succesvol voltooide projecten)*	1	5	3	>10
Bijzonderheden	Zeer krachtig	Bluetooth + WiFi	PIO	Overzichtelijk





Blokschema V1.0



DAC

MICROCHIP

MCP4725

12-Bit Digital-to-Analog Converter with EEPROM Memory

- Span= Min. 20Hz
- Vref DAC = 3.3V
- Stapjes Min. 4 mHz
- Spec: <1ppb (10mHz @ 10MHz)

ENE3311B

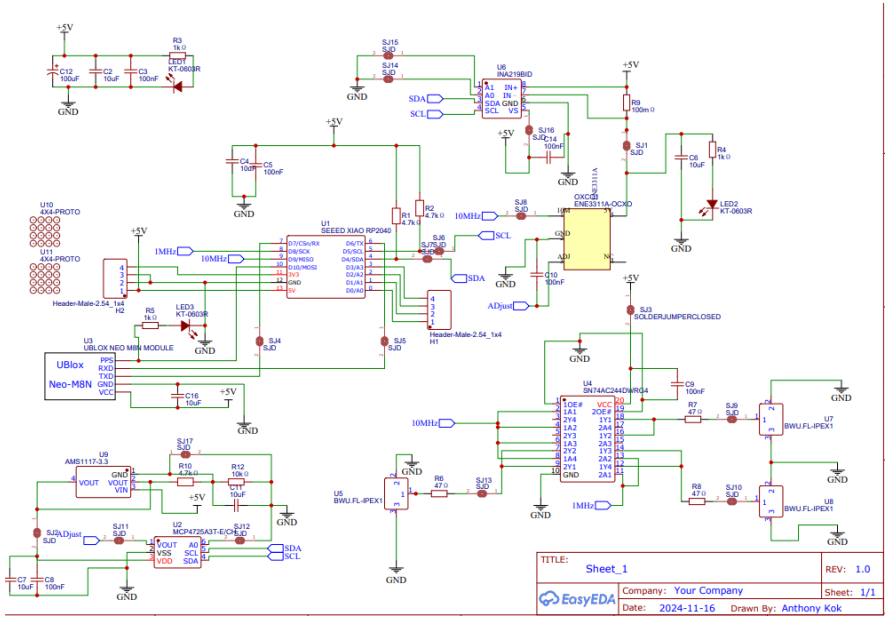
■ **Specifications**

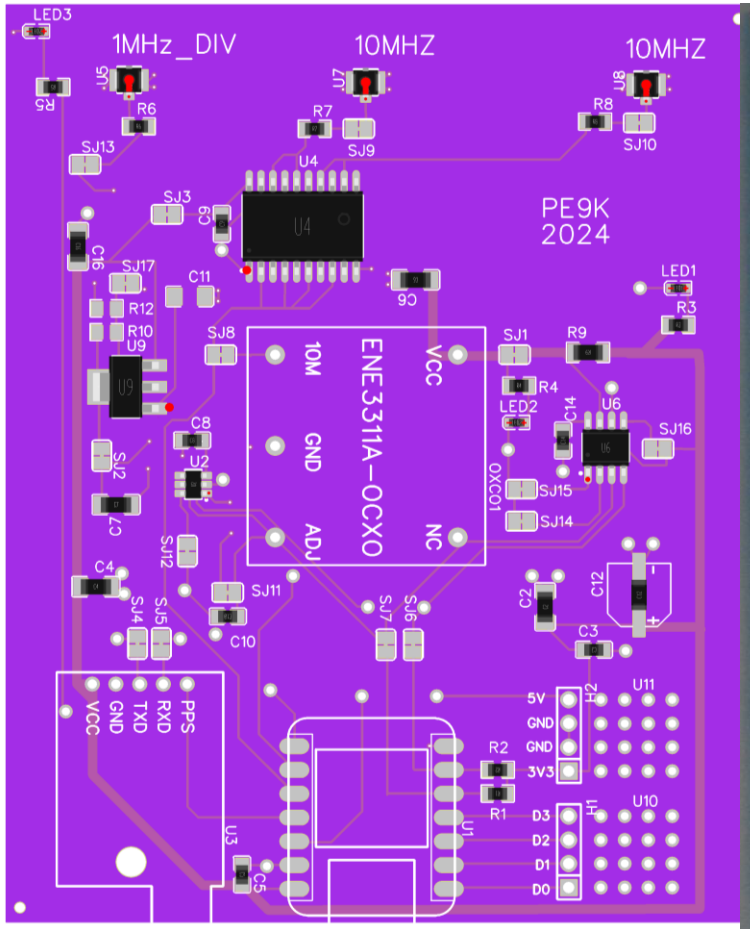
Item \ Model		NH26M26LC	
Nominal Frequency f_{nom} (MHz)		10	
Supply Voltage Vcc (V)		+5	
Load Impedance C_L (pF)		15	
Operating Temperature Range T_{opr} (°C)		–20 to + 70	–40 to + 85
Storage Temperature Range T_{str} (°C)		–40 to + 85	
Power Consumption P_{CC} (W)	at start	Max. 3.0	
	when stable, at +25 °C	Max. 1.3	
Frequency Tolerance $\Delta f/f_{nom}$	at +25°C, V_{cont} = Center, before shipment	Max. $\pm 200\times10^{-9}$	
Frequency/Temperature Characteristics Δf/f	at Operating Temperature Range	Max. $\pm 10\times10^{-9}$	
Frequency/Voltage Coefficient Δf/f	V_{CC} ± 5%	Max. $\pm 3\times10^{-9}$	
Long-term Frequency Stability Δf/f	Based on frequency after 30 days operation	Max. $\pm 2\times10^{-9}$ / day	
		Max. $\pm 50\times10^{-9}$ / year	
Stabilization Time (min.)	Time within specified frequency tolerance after power on at +25°C, based on frequency after 60minutes operation.	Max. 3 / within ± 50×10^{-9}	Max. 5 / within ± 50×10^{-9}
Frequency Control Range Δf/f		V_{cont}=+2V±2V	V_{cont}=+2V±2V
		Min. $\pm 1\times10^{-6}$	Min. $\pm 0.8\times10^{-6}$
Frequency Change Polarity		Positive	
Output Voltage		HCMOS V_{OL} : Max. +0.5 V V_{OH} : Min. +4.5 V	
Symmetry (%)	at (V_{OH} + V_{OL}) / 2	40 to 60	
Rise Time / Fall Time tr / tf (ns)		Max. 10	

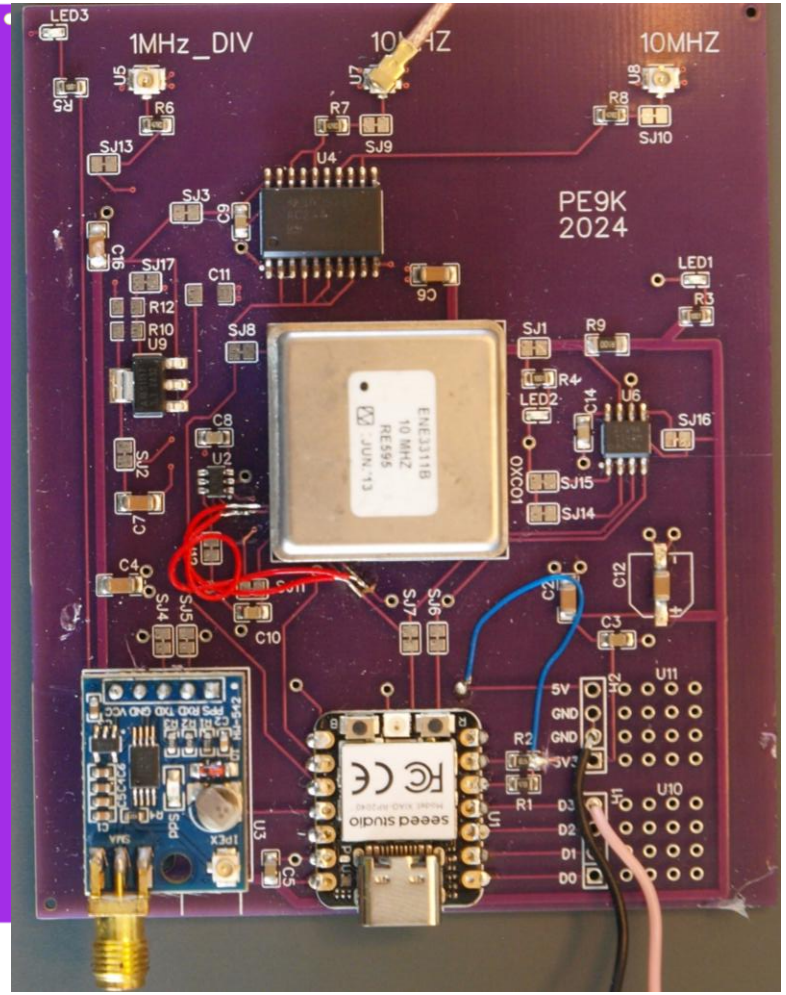
V_{cont}=+2V±2V

Min. $\pm 1\times10^{-6}$

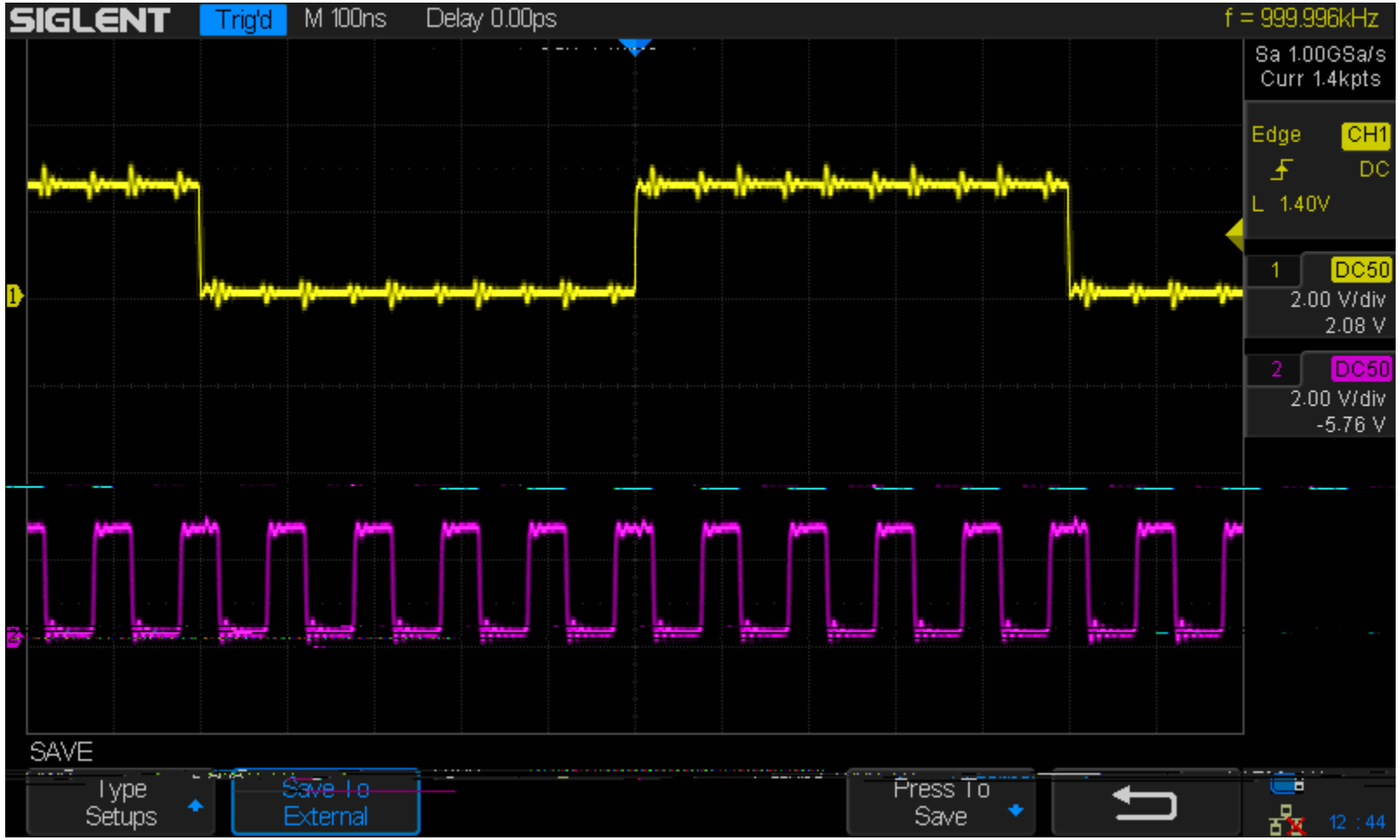
Realisatie


Sheet_1
Company: Your Company
Date: 2024-11-16
Drawn By: Anthony Kok
EasyEDA


1MHz_DIV
10MHZ
10MHZ
PE9K
2024
ENE3311A-OCXO
10M
GND
VCC
ADJ
NC

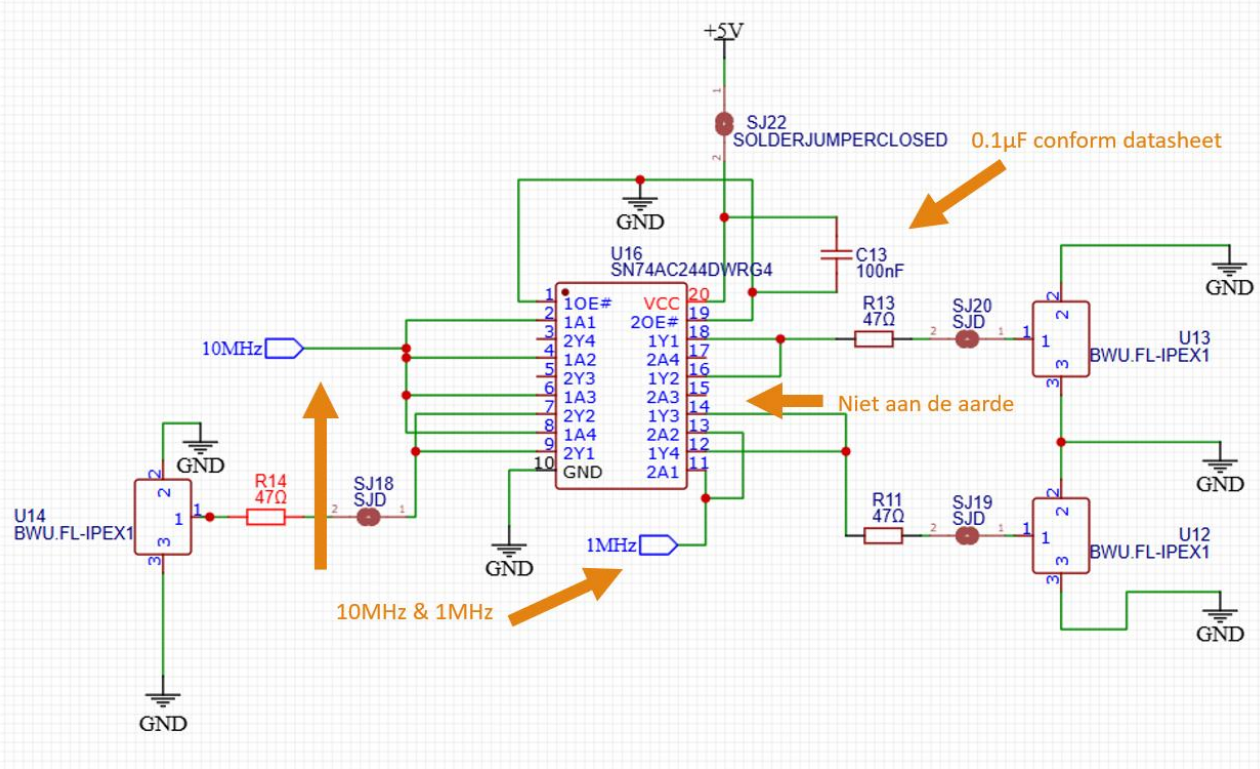

1MHz_DIV
10MHZ
PE9K
2024

Scopebeeld

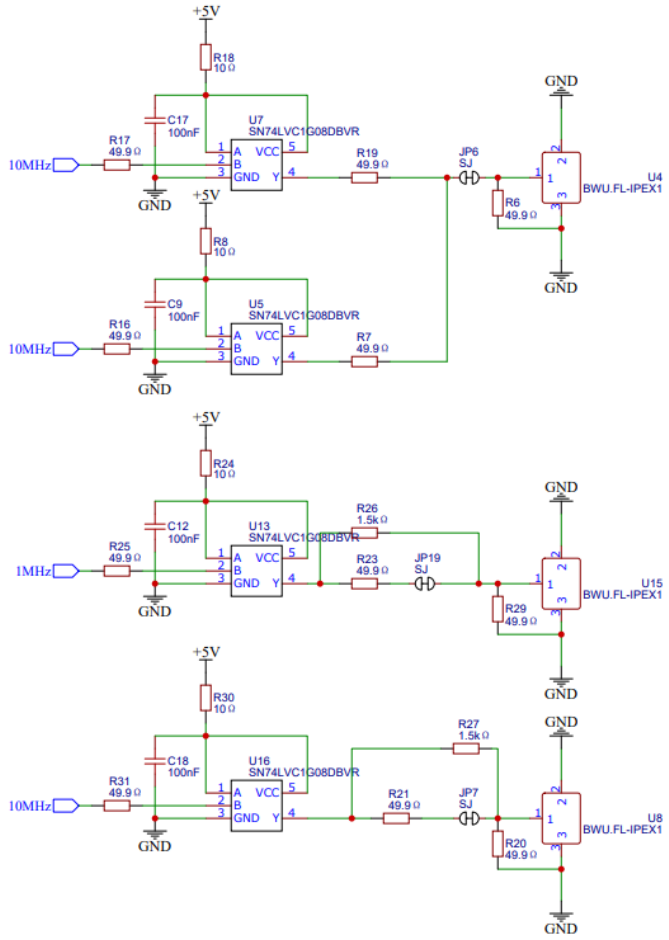

SIGLENT
Trig'd
M 100ns
Delay 0.00ps
f = 999.996kHz
Sa 1.00GSa/s
Curr 1.4kpts
Edge
CH1
DC
L 1.40V
1
DC50
2.00 V/div
2.08 V
2
DC50
2.00 V/div
-5.76 V
SAVE
Type
Setups
Save To
External
Press To
Save
12 : 44

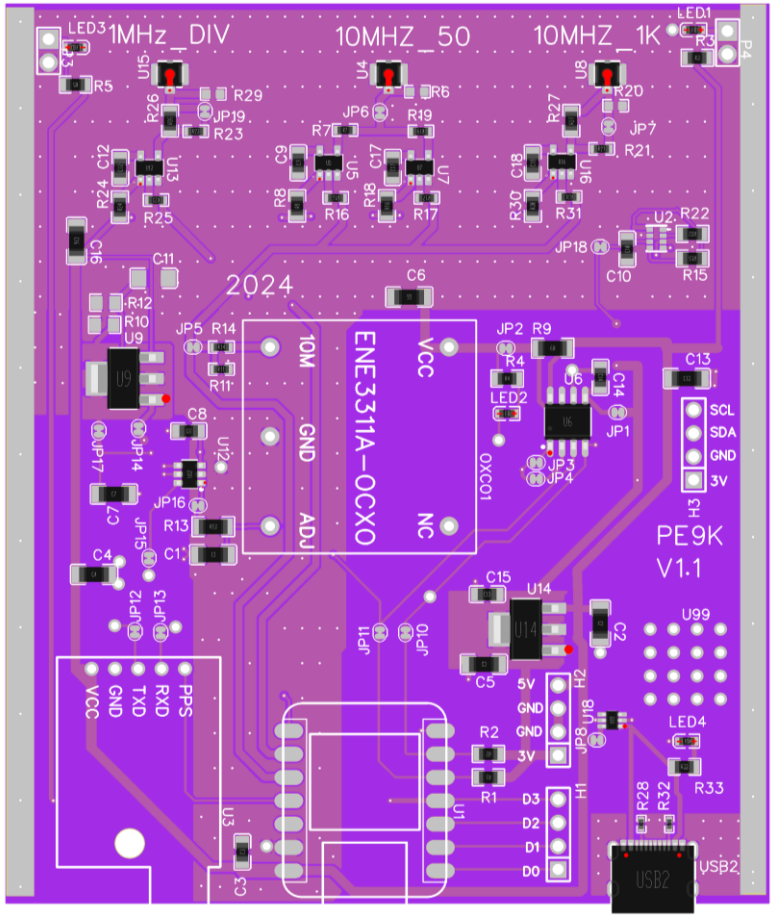
Wat moet er anders?

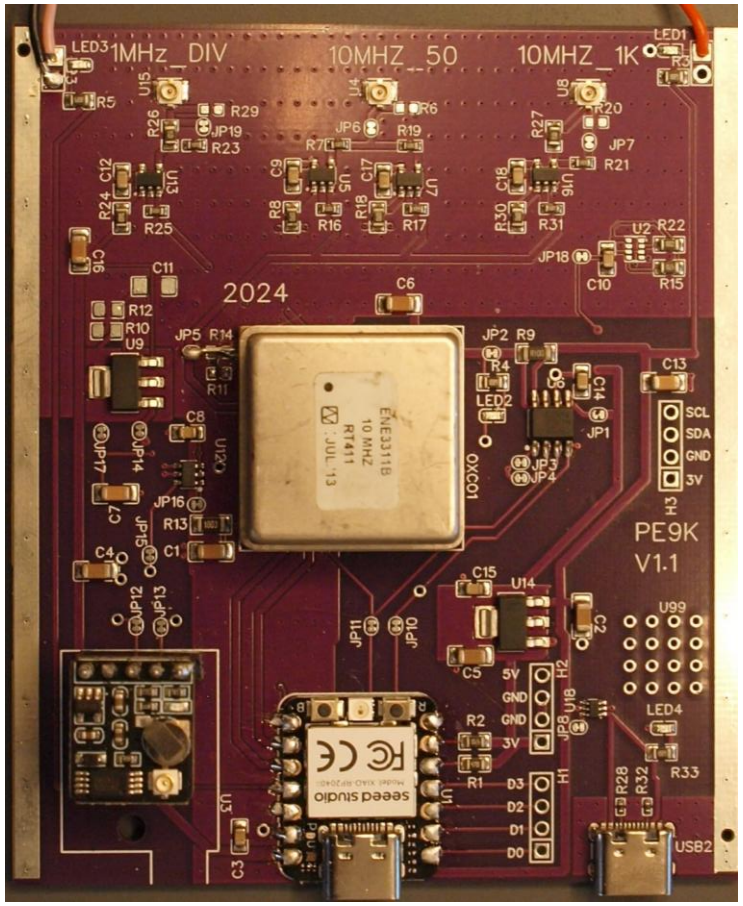
- Uitgangsimpedantie: niet optimaal voor tellers
- Ontkoppeling buffer NOK
- Ongebruikte ingang “zweeft”
- Impedantie sporen: twijfelachtig
- Omwisselen van SDA & SCL op DAC
- 3.3V ipv 5V op I2C pull-up
- USB-C voeding los van computer
- Andere GNSS ontvanger



Opnieuw

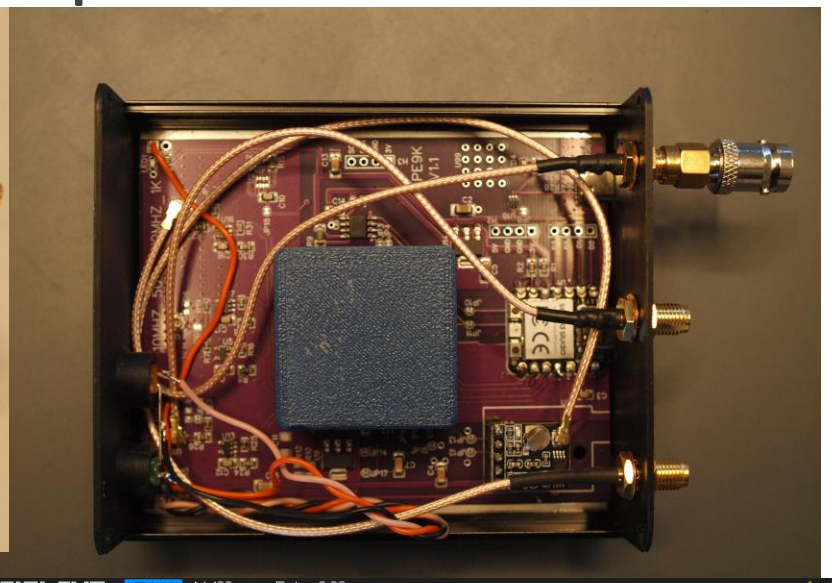

+5V
R18
10Ω
C17
100nF
U7
SN74LVC1G08DBVR
R17
49.9Ω
10MHz
GND
R19
49.9Ω
JP6
SJ
R6
49.9Ω
U4
BWU.FL-IPEX1
R8
10Ω
C9
100nF
U5
R16
49.9Ω
R7
49.9Ω
R24
10Ω
C12
100nF
U13
R26
1.5kΩ
R25
49.9Ω
1MHz
R23
49.9Ω
JP19
SJ
R29
49.9Ω
U15
R30
10Ω
C18
100nF
U16
R27
1.5kΩ
R31
49.9Ω
R21
49.9Ω
JP7
SJ
R20
49.9Ω
U8


1MHz_DIV
10MHZ_50
10MHZ_1K
2024
ENE3311A-OCXO
10M
GND
ADJ
VCC
NC
OXCO1
PE9K
V1.1
SCL
SDA
GND
3V
VCC
GND
TXD
RXD
PPS
5V
GND
GND
3V
D3
D2
D1
D0
USB2

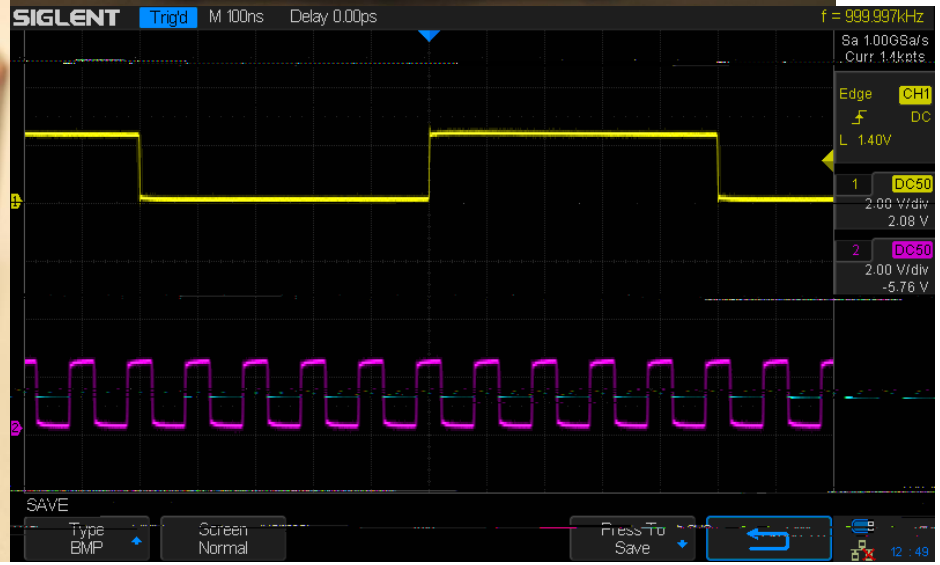

1MHz_DIV
10MHZ_50
10MHZ_1K
2024
PE9K
V1.1
USB2

Opbouwen

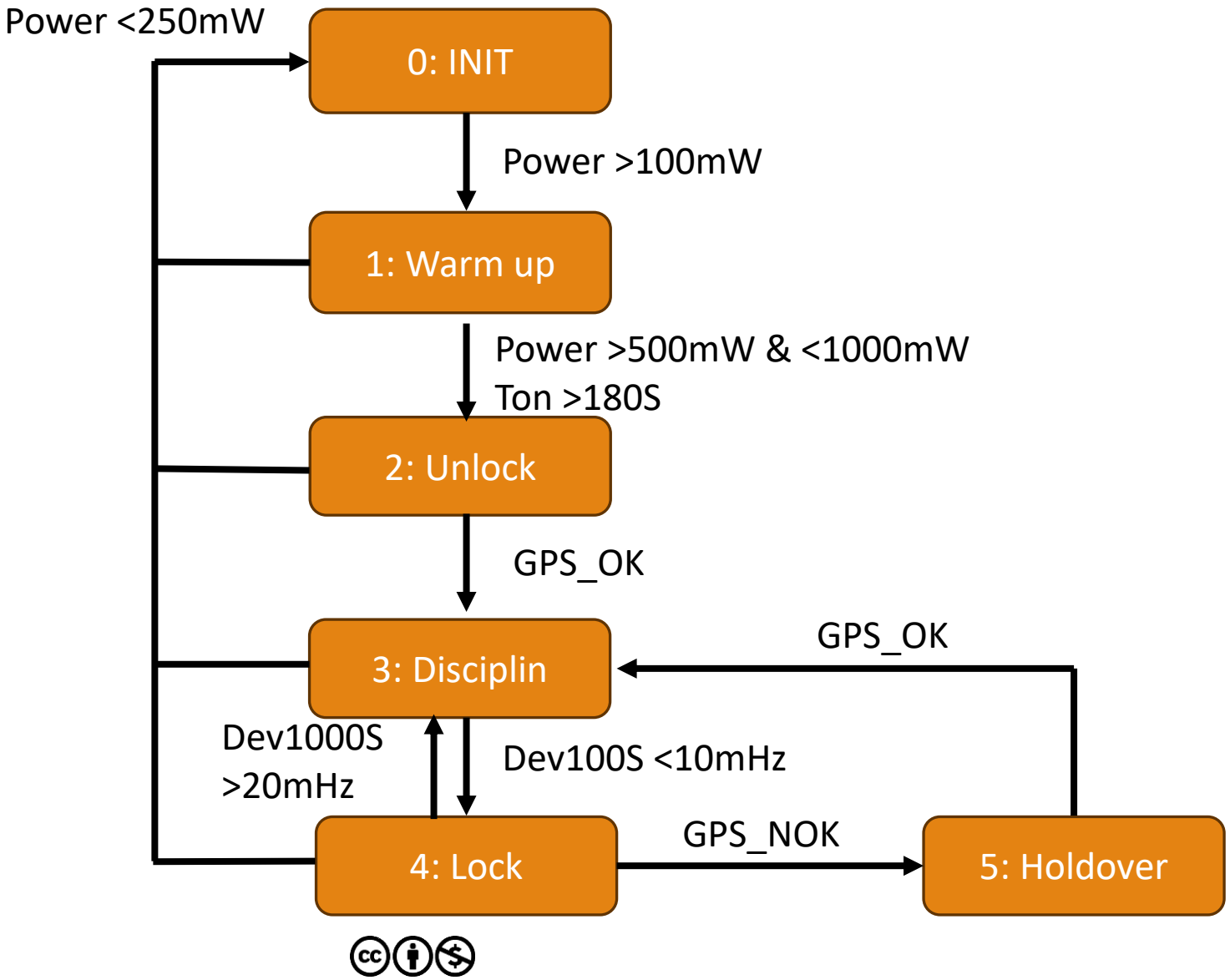

V1.1 CC1
GPS
1MHz
10MHz
Data+Power
Power




Status Power

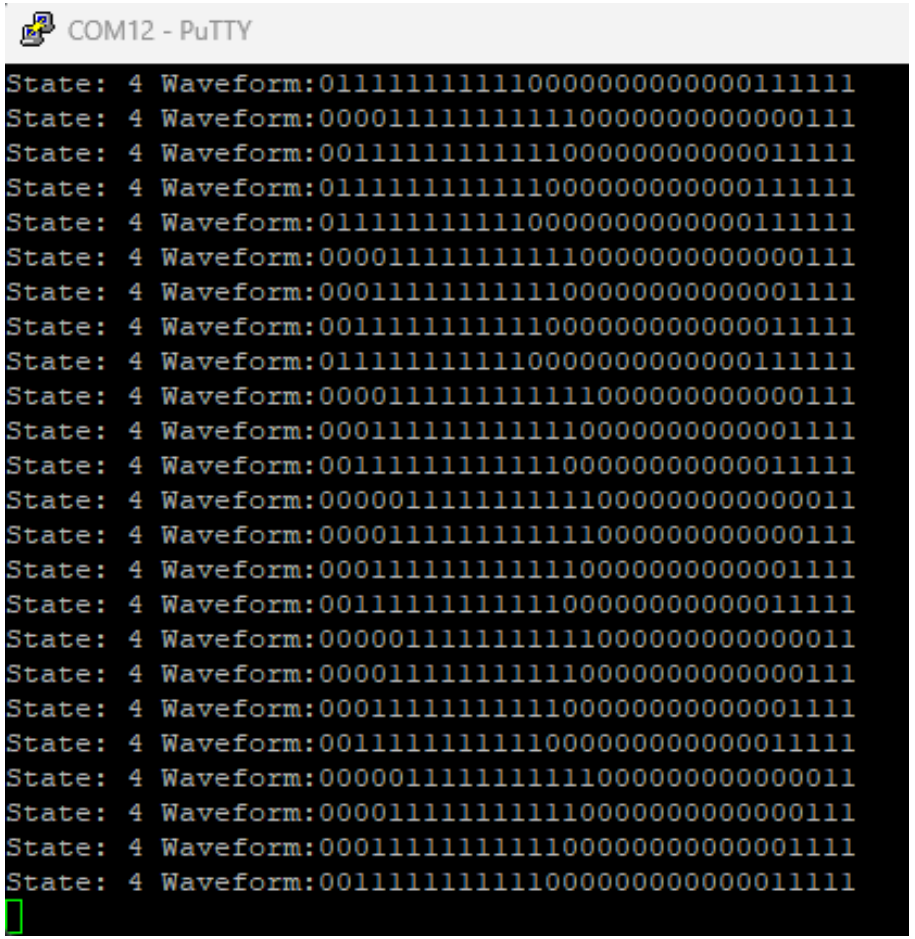

SIGLENT
Trig'd
M 100ns
Delay 0.00ps
f = 999.997kHz
Sa 1.00GSa/s
Curr 1.4kpts
Edge
CH1
DC
L 1.40V
1
DC50
2.08 V
2
DC50
2.00 V/div
-5.76 V
SAVE
Type
BMP
Screen
Normal
Press To
Save

Software


Power <250mW
0: INIT
Power >100mW
1: Warm up
Power >500mW & <1000mW
Ton >180S
2: Unlock
GPS_OK
3: Disciplin
GPS_OK
Dev1000S
>20mHz
Dev100S <10mHz
GPS_NOK
4: Lock
5: Holdover

Software 2

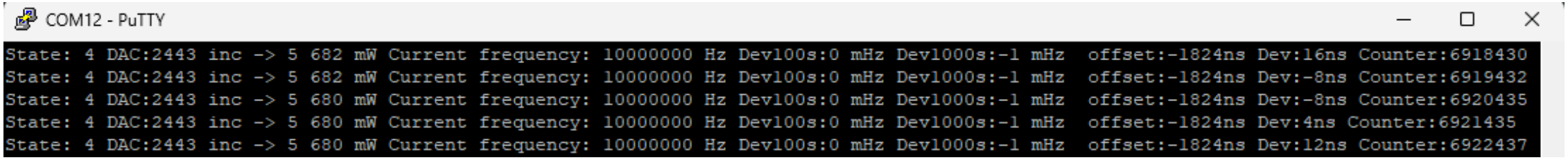
- Logicanalyzer triggert op “GNSS PPS”
- Signaal is blokgolf van OCXO
- Ieder punt is +/- 4ns
- Gat van 4ns tussen bit 15 en 16
- Zaagtand gps zichtbaar? (16ns)
- Begin van een PLL



Software 3

- Statemachine
- DAC waarde
- DAC PWM bits (-tot +7)
- OCXO vermogen
- Ingebouwde counter

- Berekende deviatie in laatste 100s
- Berekende deviatie in laatste 1000s
- Verloop sinds in state 4 (in 100en ns)
- Gemeten deviatie in laatste 100s volgens PLL
- Counter in ms sinds start



RF Seminar

Check de speclijst

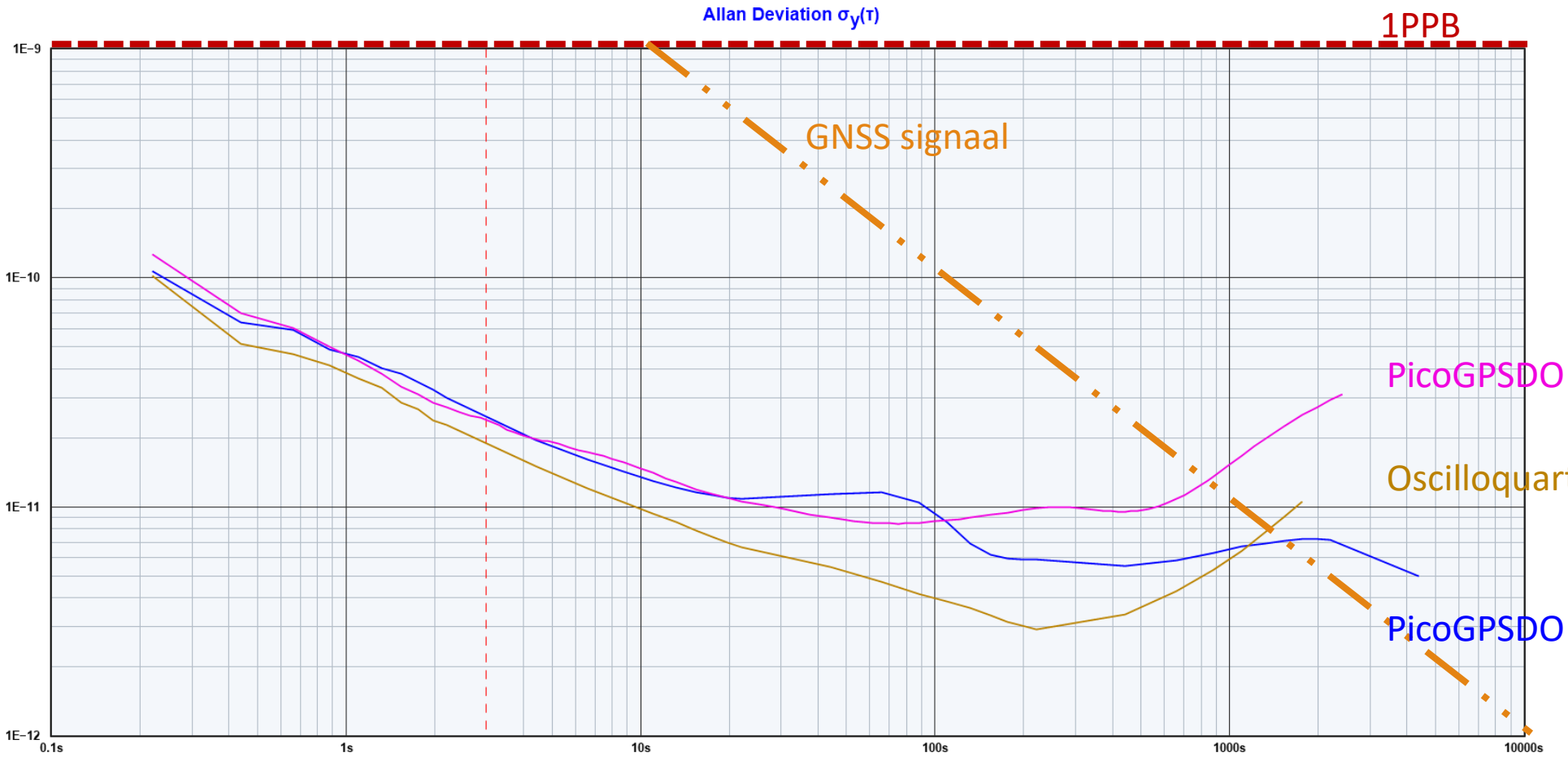
- ✓1 MHz & 10 MHz uitgang.
- ❑1ppb stabiel & accuraat *(Δf / f: 10E-9@10S)*
- ✓USB-C voeding
- ✓Degelijke printplaat, alu doosje, minimum aan lampjes
- ✓Microcontroller vogelt alles zelf uit (taal: C)
- ✓Redelijke Kosten (€75,00)

Meten

Tau	Sigma(Tau)
1s	3.98E−10
2s	2.83E−10
4s	2.02E−10
8s	1.48E−10
10s	1.37E−10
20s	1.20E−10
40s	9.80E−11
80s	7.14E−11
100s	6.68E−11
200s	6.22E−11
400s	3.20E−11
800s	2.36E−11
1000s	2.13E−11

Trace	Notes	Input Freq	Sample Interval	ADEV at 100s	Duration	Elapsed	Acquired	Instrument
PicoGPSDO V1.1 001 PDS		10 MHz	0.220 s		1h 22m 30s	1h 22m 30s	22500 pts	BG7TBL + Rb
PicoGPSDO V1.1 004		10 MHz	0.220 s		2h 55m 5s	2h 55m 5s	47750 pts	BG7TBL + Rb
GPSDO V1.1 001 1MHz		1000 kHz	0.220 s	6.68E−11	2h 8m 58s	2h 8m 58s	35171 pts	BG7TBL + Rb
HP 5245L		1000 kHz	0.240 s	4.72E−11	2h 14m 0s	2h 14m 0s	33500 pts	BG7TBL + Rb
PicoGPSDO V1.1 005		10 MHz	0.220 s		10h 4m 32s	10h 4m 32s	164874 pts	BG7TBL + Rb
Oscilloquartz 8663 B6SC MY3537		10 MHz	0.220 s		2h 8m 20s	2h 8m 20s	35000 pts	BG7TBL + Rb

Meten



Trace	Notes	Input Freq	Sample Interval	ADEV at 3s	Duration	Elapsed	Acquired	Instrument
PicoGPSDO V1.1 001 PLL		10 MHz	0.220 s	2.47E−11	4h 54m 26s	4h 54m 26s	80300 pts	BG7TBL + Rb
PicoGPSDO V1.1 004		10 MHz	0.220 s	2.39E−11	2h 55m 5s	2h 55m 5s	47750 pts	BG7TBL + Rb
GPSDO V1.1 001 1MHz		1000 kHz	0.220 s		2h 8m 58s	2h 8m 58s	35171 pts	BG7TBL + Rb
HP 5245L		1000 kHz	0.240 s		2h 14m 0s	2h 14m 0s	33500 pts	BG7TBL + Rb
PicoGPSDO V1.0 001 Holdover		10 MHz	0.220 s		55m 0s	55m 0s	15000 pts	BG7TBL + Rb
Oscilloquartz 8863 B6SG MY3537		10 MHz	0.220 s	1.89E−11	2h 8m 20s	2h 8m 20s	35000 pts	BG7TBL + Rb

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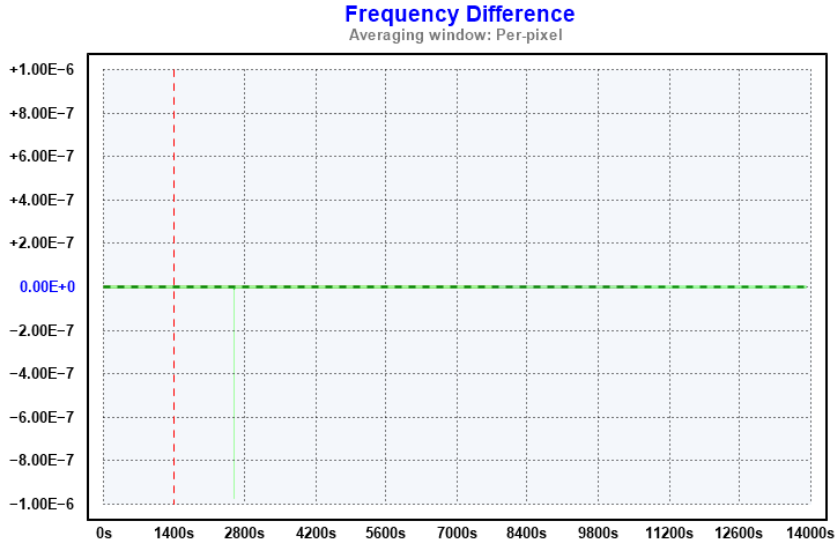
- ✓Microcontroller vogelt alles zelf uit (taal: C)
- ✓Redelijke Kosten (€75,00)

Bevindingen

- Een goede meting te voltooien is lastig
- Systeem is *meestal* stabiel
- Voldoet voor doelstelling



Origin	Drift (per sec)	Drift (per hr)
+9.15E−10	−5.76E−16	−2.07E−12
+1.36E−10	−1.70E−14	−6.12E−11
+5.75E−10	+8.47E−15	+3.05E−11
+6.71E−13	−1.86E−16	−6.69E−13

Avg Time (s)	Freq (Hz) at 13903s	Error
0.1	10 000 000.002 696 088	+2.70E−10
0.3	10 000 000.000 672 137	+6.72E−11
1	10 000 000.001 066 180	+1.07E−10
3	10 000 000.000 519 264	+5.19E−11
10	10 000 000.000 431 130	+4.31E−11
30	10 000 000.000 406 239	+4.06E−11
100	10 000 000.000 530 791	+5.31E−11
300	10 000 000.000 411 848	+4.12E−11
1 000	10 000 000.000 430 450	+4.30E−11
3 000	10 000 000.000 293 728	+2.94E−11
10 000	9 999 999.999 944 719	−5.53E−12

Trace	Notes	Input Freq	Sample Interval	Freq at 1400s	Duration	Elapsed	Acquired	Instrument
PicoGPSDO V1.1 001 PDS		10 MHz	0.220 s	10 000 000.008 Hz	1h 22m 30s	1h 22m 30s	22500 pts	BG7TBL + Rb
PicoGPSDO V1.1 004		10 MHz	0.220 s	10 000 000 Hz	2h 55m 5s	2h 55m 5s	47750 pts	BG7TBL + Rb
GPSDO V1.1 001 1MHz		1000 kHz	0.220 s		2h 8m 38s	2h 8m 38s	35171 pts	BG7TBL + Rb
HP 5245L		1000 kHz	0.240 s		2h 14m 0s	2h 14m 0s	33500 pts	BG7TBL + Rb
PicoGPSDO V1.1 005		10 MHz	0.220 s		10h 4m 32s	10h 4m 32s	164874 pts	BG7TBL + Rb
Oscilloquartz 8863 B6SG MY3537		10 MHz	0.220 s	10 000 000.005 Hz	2h 8m 20s	2h 8m 20s	35000 pts	BG7TBL + Rb
PicoGPSDO V1.1 004		10 MHz	0.100 s	10 000 000 Hz	3h 51m 43s	3h 51m 43s	139026 pts	BG7TBL + Rb

ToDo

- Goede implementatie PLL schrijven
- EMI Immuniteit van het geheel
- Filtering signalen met bijv Kalman filters
- Documentatie compleet maken
- Meten, testen, simuleren

PicoGPSDOV1_1_PM.ino | Counter.pio.h | Div.pio.h | Pds.pio-BU.h | Pds.pio.h | UI.h | pps.pio.h

```
418         PDS_0 = bitRead(Phase_0, i);
419         if( PDS_0 == 1){PDS_wave [i] = 49;}
420         if( PDS_0 == 0){PDS_wave [i] = 48;}
421         if (PDS_0 == 1 and PDS_1 == 0 and PDS_one != 0){PDS_two = i;}
422         if (PDS_0 == 1 and PDS_1 == 0 and PDS_one == 0){PDS_one = i;}
423
424         PDS_1 = PDS_0;
425       }
426
427       //convert to ns
428       if (PDS_one >= 0 && PDS_one <= 15 ){PDS_now = PDS_one* 4;}
429       if (PDS_one >= 16 && PDS_one <= 31 ){PDS_now =(PDS_one+4)* 4;}
430
431       //see change from previous value and unwrap
432
433
434       if  (PDS_now <= 25 && PDS_last > 75 ){PDS_diff=  (100 - PDS_last ) + PDS_now;  } //(75->25 = 50)
435       else if  (PDS_now >= 75 && PDS_last < 25 ){PDS_diff=  (PDS_now - 100 - PDS_last);}   //(25->75 = -50)
436       else {PDS_diff=  (PDS_now -  PDS_last);}
437       //write previous value as last
438       PDS_last = PDS_now;
439
440       //calculate direction over 100 samples
441       phase_index = phase_index + 1;
442       if (phase_index> 200){phase_index =0;}
443       phase_dir [phase_index] = PDS_diff;
444
445       PDS_d0 =0;
446       for (int i= 0; i < 200; i++){
447       PDS_d0 = phase_dir [i] + PDS_d0;
448       }
```

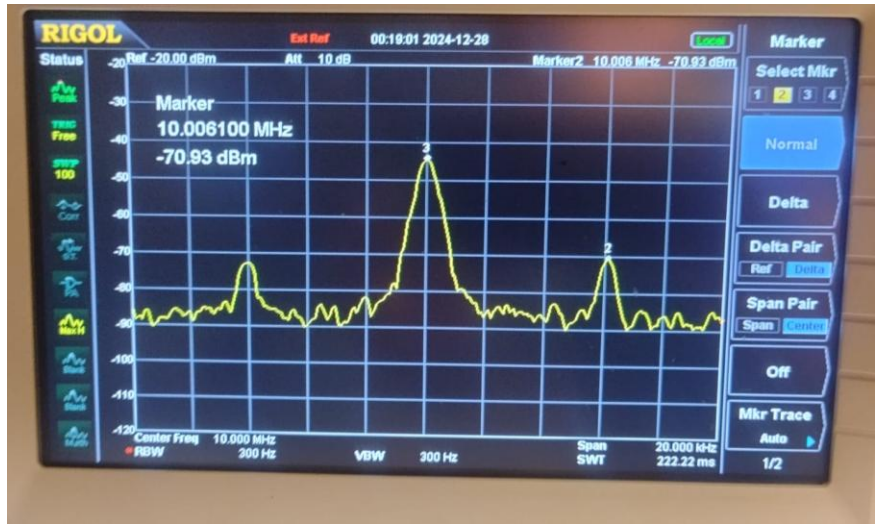
Discussie

Is het niet al lang goed genoeg?

Waar ligt de grens van deze hardware?

Nauwkeurigheid, Stabiliteit, Faseruis hoeveel van elk?

Is de OCXO wel de juiste oscillator?



(10)

RF Seminar

Bedankt

Ernst PA1EJO

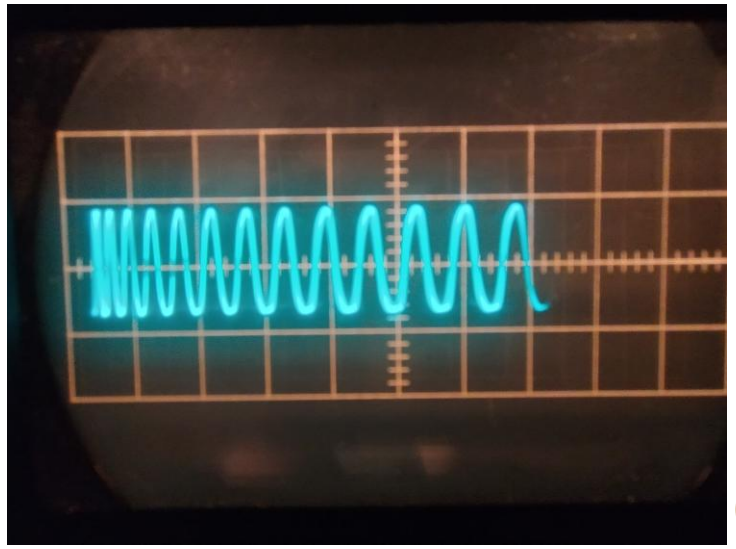
Henk PA0HPV

John PE1GHG

Bas PH0BAS

Bronnen

1. HP 1965 catalogus [http://hparchive.com/Catalogs/HP-Catalog-1965.pdf]
2. Rf seminar 22 december 2024: Erik Kaashoek PD0EK [https://www.rfseminar.nl/cms/wp-content/uploads/2024/12/Erik-Kaashoek-PD0EK-Ontwerp-simulatie-en-verificatie-van-een-GPSDO.pdf]
3. THE Yb OPTICAL LATTICE CLOCK https://tf.nist.gov/general/pdf/2339.pdf
4. NPL Caesium fountain [NPL Cs fountain]
5. Prijzen 13-4-2025 [https://www.kiwi-electronics.com/]
6. Fragment code PicoGPSDOV1_1PM 250421; Fasedetectie, “unwrappen” & bufferen
7. 9280399.9 kHz gemeten met HP 5245L Counter+ HP5257A Transferoscilator + PicoGPSDO
8. 10MHz gemeten met een Tektronix 545A (inclusief defect in horizontale versterker)
9. PM3252 geleend van Quint
10. PicoGPSDO V1.0 op een SA



(8)