MAX2771 broadband SDR: impact of low bit resolution and application to passive radar measurements

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`https://github.com/jmfriedt/NISAR_pbr`
`https://github.com/jmfriedt/max2771_fx2lp`

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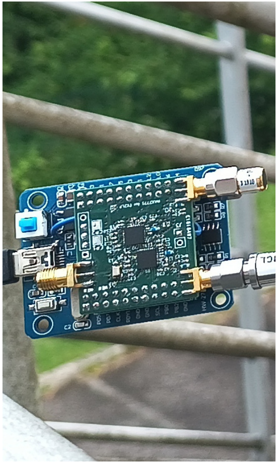


https://upload.wikimedia.org/wikipedia/commons/0/07/NISAR_spacecraft_model.png

Outline

1. Low-bit resolution ADCs (1 or 2 bits for MAX2771 [1]) and pulse-compression ratio
2. MAX2771 local oscillator phase drift: impact on passive radar and frequency stacking
3. Coherence loss from local oscillator phase fluctuation
4. L-band NISAR reception

[1] J.-M Friedt, *Broadband data transfer over USB for GNU/Linux: 1-2 GHz (L-band) SDR receiver dedicated to GNSS (and other) reception, interfacing with PocketSDR, GNU Radio and gnss-sdr*, FOSDEM 2025 at `https://archive.fosdem.org/2025/schedule/event/fosdem-2025-4150-broadband-data-transfer-over-usb-for-gnu-linux-1-2-ghz-l-band-sdr-receiver-dedicated-to-`

Low bit-resolution ADC

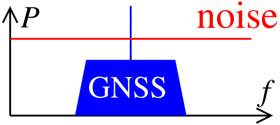
- fast (comparator), no successive approximation
- efficient communiaction & storage (packed bits)
- multiple receiving locations

GNSS

Signal: 50 W$=$ 47 dBm from 20000 km away $\Rightarrow$ FSPL $= 20\log_{10}(f) + 20\log_{10}(d) - 147.55 = 182$ dB at L1 $\Rightarrow$ received power$47-182 = -135$ dBm$+$antenna gains ($\simeq 13$ dB[a])

Noise: $k_B \cdot T = -174$ dBm/Hz $\times 2$ MHz (L1 bandwidth)$= -111$ dBm

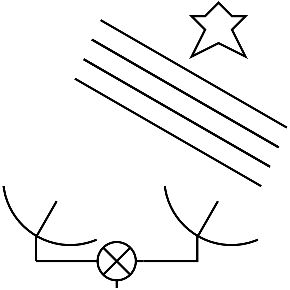
$\boxed{SNR = -11 \text{ dB}}$



[a] J.E. Donaldso *& al.*, *Characterization of On-Orbit GPS Transmit Antenna Patterns for Space*, NAVIGATION **67**(2) 411–438 (2020)

Radio-astronomy

Make an antenna believe it is as wide as the distance between receiver sites



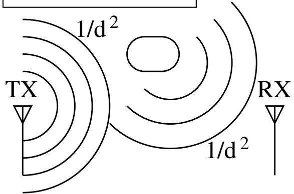
Short range RADAR

DVB-T: 25 kW$=$ 74 dBm illuminating a point-like target acting as a new source:

$1/d^4$ link budget$\Rightarrow$ FSPL $= 40\log_{10}(f) + 40\log_{10}(d) - 2 \times 147.55 = 200$ dB at 490 MHz and $d = 5$ km and received power is $74 - 200 = -126$ dBm

Noise: 8 MHz DVB-T bandwidth so $-174 + 69 = -105$ dBm

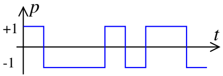
$\boxed{SNR = -21 \text{ dB}}$

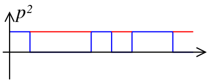


Using low-SNR signals

From <0 dB SNR to strong SNR: **cross-correlate** a known reference signal with the pattern buried in noise:

$$xcorr(p,s)_n=\sum_0^{N-1} p_k\cdot s^*_{k+n}$$





improves the SNR by 10 $\cdot\ \log_{10}(\mathbf{N})$

Case of a clean reference signal (GNSS, noise RADAR)

received signal $r(t)=A\cdot p(t)+n(t)$ with $p=\pm 1$

$$\Rightarrow xcorr(r,p)=\underbrace{A\sum p\cdot p}_{\langle\cdot\rangle=A\cdot N}+\underbrace{\sum p\cdot n}_{var=^{a}N\cdot\sigma^2}$$

$$\Rightarrow \frac{signal}{noise}(out)=\frac{(A\cdot N)^2}{\sigma^2\cdot N}=N\frac{A^2}{\sigma^2}\ \text{v.s.}\ \frac{signal}{noise}(in)=\frac{A^2}{\sigma^2}$$

gain by N

[a] since $p^2=1$ in both cases, $\langle p\cdot p\rangle$ and σ^2

Case of a noisy reference signal (passive RADAR)

received signal $r(t)=A\cdot p(t)+n(t)$ with $p=\pm 1$

$$\Rightarrow xcorr(r,p+n')=$$

$$\underbrace{A\sum p\cdot p}_{\langle\cdot\rangle=A\cdot N}+\underbrace{\sum p\cdot n}_{var=N\cdot 1^2\cdot\sigma^2}+\underbrace{A\sum p\cdot n'}_{var=A\cdot N\cdot\sigma'^2}+\underbrace{\sum n\cdot n'}_{var=^{a}N\cdot\sigma^2\cdot\sigma'^2}$$

$$\Rightarrow SNR(out)=\frac{(A\cdot N)^2}{N\cdot(\sigma^2+A\sigma'^2+\sigma^2\sigma'^2)}\propto N$$

output to input SNR ratio remains $\propto N$ but penalty from σ'^2

If $\sigma'=0$, returns to the previous case.

Degrades as $\frac{A^2\cdot N}{\sigma^4}$ at low SNR ($A\ll\sigma$) if $\sigma\simeq\sigma'$

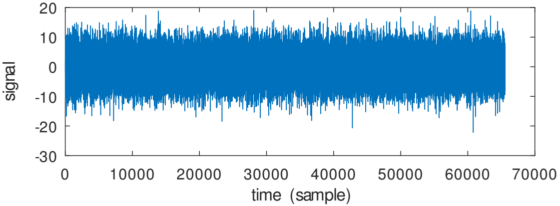
[a] E. Rubiola, *The Magic of Correlation Measurements*, p.19 at `rubiola.org/pdf-slides/2014T-IFCS--Cross-spectrum.pdf`

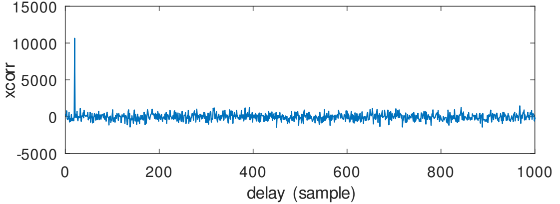
- **Hypothesis**: signal/scene/conditions remain stationary during processing duration
- Case of **moving targets**: compensate for frequency offset $xcorr(\tau,f)=\sum p_k\cdot s_{k+n}\exp(-j2\pi\cdot df\cdot k)$

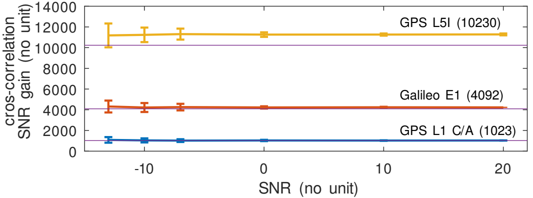
Pulse compression SNR gain: demonstration

```
pkg load signal
load codes_L1CA.mat;    % GPS L1 C/A: 1023 chips [1]
load codes_E1B.mat;     % Galileo E1: 4092 chips [1]
load codes_L5I.mat      % GPS L5I:   10230 chips [1]
pos=20; avg=100;        % time delay + num. of avg
Nsequence=[.01 .1 1 5 10 20]
for iter=1:3
 if (iter==1) x=codes_L1CA(:,1)';end
 if (iter==2) x=codes_E1B(:,1)' ;end
 if (iter==3) x=codes_L5I(:,1)' ;end
 x=x-mean(x);
 for N=Nsequence
  for iter=1:avg         % /!\ randn() and not rand()
   s=randn(1,65536); s=s-mean(s); s=s*sqrt(N);
   SNRbefore=var(x)/var(s); % ^amp*sqrt(N) => pow*N
   s(pos:pos+length(x)-1)=s(pos:pos+length(x)-1)+x;
   sol=(xcorr(s,x))(length(s):end);    % after xcorr
   signl=sol(pos).^2; % SNR=max(xcorr)^2/var(xcorr)
   noise=var(sol(pos+length(x)+10:end));
   SNRafter=signl/noise; % ^^^ xcorr bg noise power
   sm(iter)=(SNRafter/SNRbefore);
  end
 end
 errorbar(-10*log10(Nsequence),mean(sm),std(sm));
end
```

[1] GNSS codes from https://github.com/danipascual/GNSS-matlab







Low bit-resolution ADC impact on SNR

- high SNR signal[2]: quantization noise limited $\sigma_V^2 = V_q^2/12$,

$$SNR = 20 \times log_{10}(2) \times N + 20\log_{10}(\sqrt{3/2}) = 6.02 \times N + 1.76 \leq 8 \text{ dB if } N = 1$$

- few bits encode information in **time only**, not amplitude = 3 dB SNR loss (1/2 energy)
- better analysis[3][4]: SNR loss for Gaussian noise distribution[5] and **low SNR** ($\sigma_x \simeq \sigma_n$)

$$2/\pi = 1.96 \text{ dB}$$

- at low SNR, **cross correlation** (xcorr) extracts signal from noise
- xcorr to retrieve bit resolution (SNR improvement = pulse compression ration $B \times T$ = code length, e.g. 30 dB for GPS L1)
- dataflow: bits/s with accumulation of successive bits (bits * BW)

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[2] W. Kester, *Taking the Mystery out of the Infamous Formula, "SNR = 6.02N+1.76dB," and Why You Should Care* (2008) at `https://www.analog.com/media/en/training-seminars/tutorials/MT-001.pdf`

[3] M.S Stein & al., *Performance Analysis for Channel Estimation with 1-bit ADC and Unknown Quantization Threshold*, IEEE Transactions on Signal Processing **66**(10) 2557–2571 (2018) at arXiv:1703.02008v2

[4] J.H. Van Vleck & al., *The Spectrum of Clipped Noise*, Proc. IEEE **54**(1) 2–19 (Jan. 1966)

[5] $xcorr(x, sign(x)) = \langle|x|\rangle = \sqrt{2/\pi} \Rightarrow$power loss$= 2/\pi$: see "Bussgang Theorem": J.J. Bussgang, *Cross-correlation function of amplitude-distorted Gaussian signals* MIT Tech. Rep. **216** March 1952 at `https://dspace.mit.edu/handle/1721.1/4847`

MAX2771 based SDR receiver[6]

- Based on Tomoji Takasus's PocketSDR[a] with a firmware update to use exclusively opensource tools (`sdcc`)[b]
- Gain access to current GNSS constellation full bandwidth (up to 44 MS/s, maximum MAX2771 sampling rate accessed by USB2 FX2LP)
- LO$\in [1-2]$ GHz (L-band)
- MAX2771: 1 or 2-bit quantization (= 2 IQ streams on 8 bit FIFO)
- Common clock driving both chips

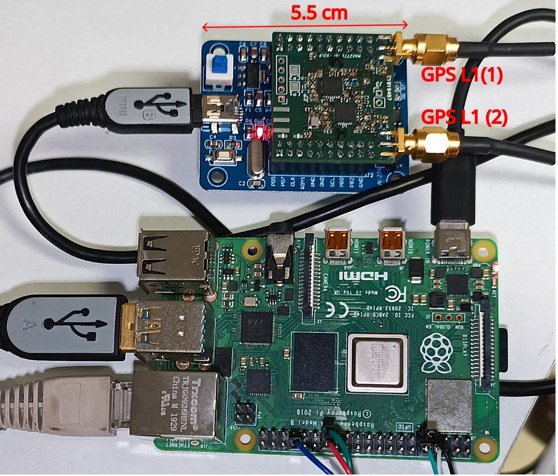
[a] `https://github.com/tomojitakasu/PocketSDR`
[b] `https://github.com/jmfriedt/max2771_fx2lp`

PocketSDR validation setup

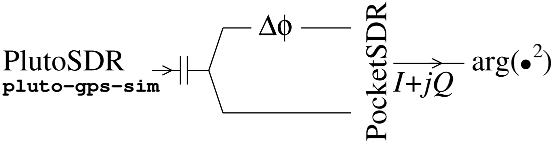
[6] J.-M Friedt, *Broadband data transfer over USB for GNU/Linux: 1-2 GHz (L-band) SDR receiver dedicated to GNSS (and other) reception, interfacing with PocketSDR, GNU Radio and gnss-sdr*, FOSDEM 2025 at `https://archive.fosdem.org/2025/schedule/event/fosdem-2025-4150-broadband-data-transfer-over-usb-for-gnu-linux-1-2-ghz-l-band-sdr-receiver-dedicated-to-`

Dual MAX2771 for GNSS spoofing detection and direction of arrival

- Low power, low cost GNSS spoofing detection, but too few bits for CRPA
- Codeless decoding for BPSK/BOC spoofing detection and direction of arrival measurement, but...
- ... DoA drift from PLL warming up[7]
- Oscillator drift measurement and **recalibration** (5th overtone of 312.5 MHz oscillator [8]) or stabilitization after some time [9]



Simulate direction of arrival (DoA) with phase shifter between the two antenna inputs



Codeless decoding: squaring the BPSK modulated signal removes spectrum spreading and acculates energy in a single spectral component at $2\delta f_{doppler}$

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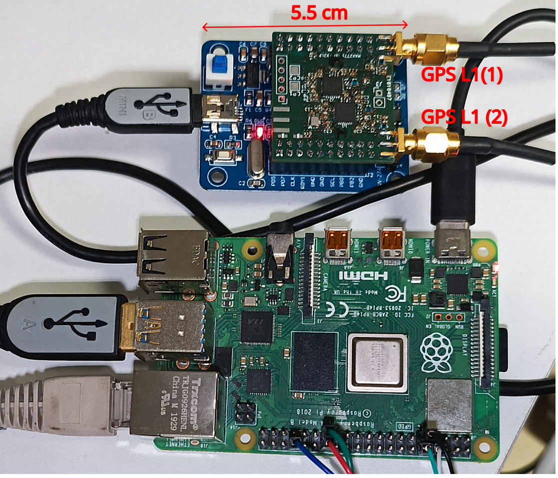

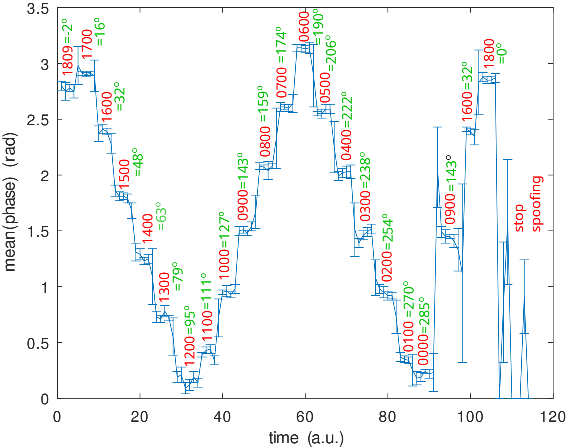

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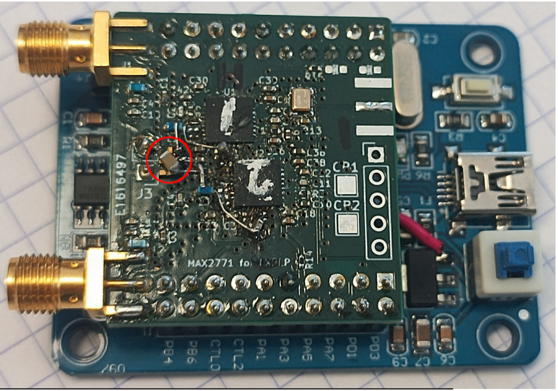
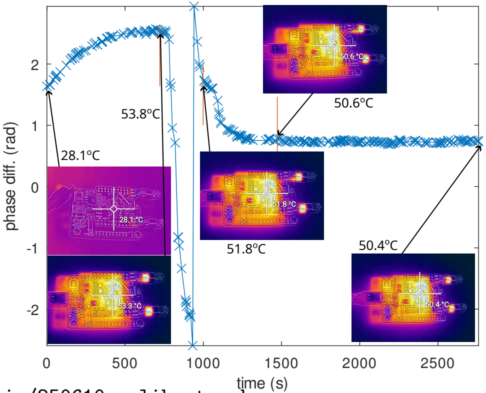
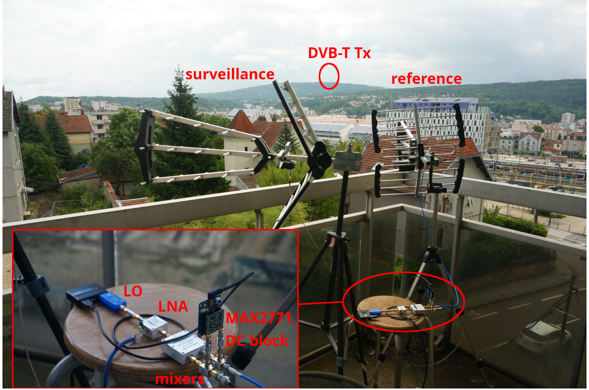


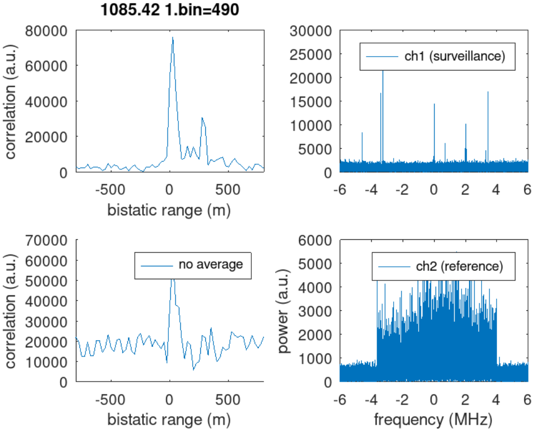


[7] https://github.com/jmfriedt/max2771_fx2lp/tree/main/250610_calibrate_phase
[8] https://www.mouser.fr/c/passive-components/frequency-control-timing-devices/oscillators/?frequency=312.5
[9] T. Takasu: https://ez.analog.com/rf/f/q-a/600152/phase-coherence-with-multiple-max2771-front-ends

Dual MAX2771 for passive radar

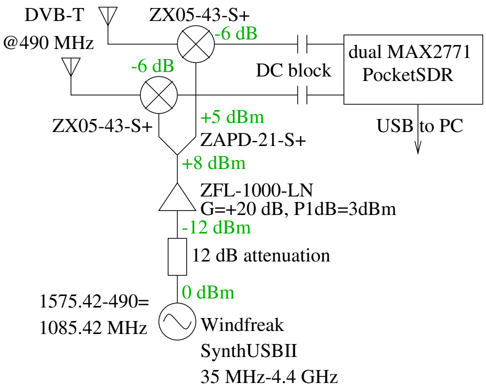
- passive radar using DVB-T signals of opportunity: external frequency transposition (mixer) from UHF to L-band[10]
- Range is a comparison of emitted and received at frequency offset inverse of time of flight
- Improve range resolution with frequency stacking: collecting from successive frequency bands assumes **stable phase** (time domain $\rightarrow$ FFT $\rightarrow$ stack spectra $\rightarrow \times^*$ (xcorr) $\rightarrow$ iFFT)
- SAR processing: iFT along the antenna position (azimuth) requires **stable phase** during acquisition

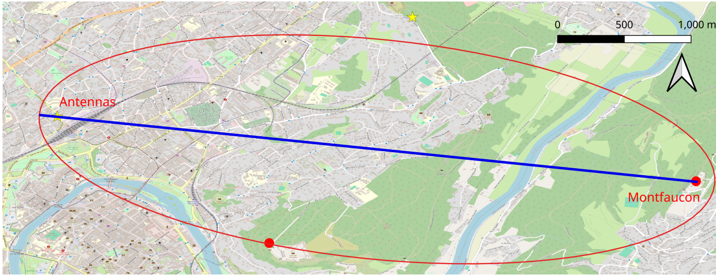




[10] https://github.com/jmfriedt/max2771_fx2lp/blob/main/250608_no_preamp/2_490MHz.png

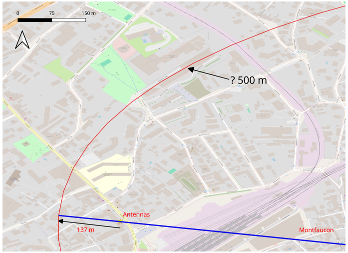
MAX2771 based passive RADAR





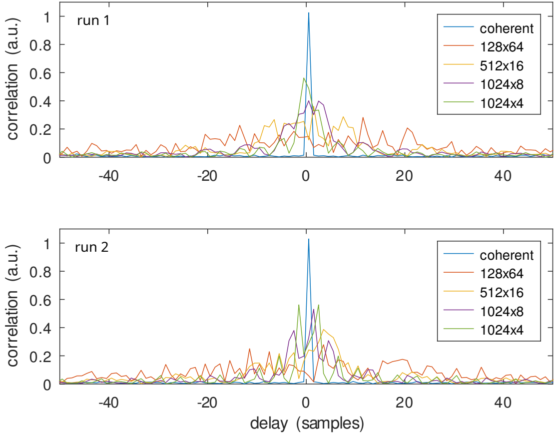
Polygon drawing in QGIS: ellipse through focal points and 1 target

- bistatic range analysis: transmitter at $(-L/2, 0)$ and receiver at $(L/2, 0)$
- transmitter-target-receiver time dt: $(R_T + R_R)/c$ v.s L/c direct signal
- $R_R + R_T = c \cdot dt + L = 2a$ constant is an ellipse x, y since $\sqrt{(-L/2-x)^2+y^2} + \sqrt{(L/2-x)^2+y^2} = 2a$



MAX2771 phase stability: generalization

- **DoA**
  phase drift so that the angle of arrival drifts
  $s_r(t)\cdot s_s^*(t) = \exp(j2\pi\delta f t + j\varphi_1)\cdot\exp(-j2\pi\delta f t + j\varphi_2) = \exp(j(\varphi_1 - \varphi_2)$
  with $\varphi_1 - \varphi_2 = \frac{2\pi}{\lambda}\sin\vartheta + \varphi_{12}(t)$
- **Frequency stacking** $\longrightarrow$
  $xcorr(s_r, s_s) = iFT(FT(s_r)\cdot FT(s_s)) \Rightarrow$ stack the narrowband spectra $FT(s)$ before performing the iFT on the broadband spectra
- **Synthetic Aperture RADAR (SAR)**
  iFT along the antenna motion since moving the RADAR by d constant adds at position nd a phase $\frac{2\pi}{\lambda}\cdot 2nd\cdot\sin(\varphi)$ at far field




```
for N=[128 512 1024 2048]
fcoh=[]; fincoh=[];
for k=1:floor(8192/N)
   sr=rand(N,1);   sr=sr-mean(sr);
   fsr=fftshift(fft(sr));
   fcoh=[fcoh ; fsr];
   ph=(rand(1)-0.5)*4*pi;
   fincoh=[fincoh ; fsr.*exp(j*ph)];
end
plot(tau,abs(fftshift(ifft(fftshift(fcoh.*conj(fcoh)))))/N)
plot(tau,abs(fftshift(ifft(fftshift(fincoh.*conj(fcoh)))))/N)
```

Coherence loss from phase noise during correlation

So far: impact of ADC resolution. Now: impact of **ADC clock instability**

- Correlation
$$\int_T s(t)\cdot c^*(t+\tau)\cdot dt$$
accumulates energy when c matches s delayed by τ
- Static phase: $\int_T s(t)\exp(j\varphi)\cdot c^*(t+\tau)\cdot dt = \exp(j\varphi)\cdot\int_T s(t)\cdot c^*(t+\tau)\cdot dt$ i.e. (GNSS PSK)
$$xcorr(s\cdot\exp(j\varphi),c)=\exp(j\varphi)\cdot xcorr(s,c)$$
- If some residual LO at df remains with respect to local copy of code/reference signal:
$$\int_T s(t)\exp(j2\pi\cdot df\cdot t)\cdot c^*(t+\tau)\cdot dt$$
vanishes unless $1/df \ll T$
- **What about** $\int_T s(t)\exp(j\varphi(t))\cdot c^*(t+\tau)\cdot dt$ **when** $\varphi(t)$ **random?**

Allan deviation to phase noise to jitter to coherence loss [12]

- Radio-astronomy: integration over seconds to hours $\Rightarrow$ coherence related to **Allan deviation** (long term oscillator characteristics $\sigma(\tau)$)
- Short range RADAR: time delays in the microsecond (300 m/μ) to ms range
- Short term oscillator characteristics: **phase noise measurement** $S_\varphi(f)=\sigma_\varphi^2/B$ (dBrad^2/Hz)[11]
- Phase noise $S_\varphi(f)\rightarrow$ Allan deviation $\sigma(\tau)$ in frequency offset range f **to** τ with $f\cdot\tau\simeq 0.45$ using the associated transfer function $H(f)$ (p.57):
$$\sigma_y^2(\tau)=\int S_y(f)\cdot|H(f)|^2\cdot df$$
with $S_y(f)=\frac{f^2}{\nu_0^2}S_\varphi(f)$ the fractional frequency spectral density
- $\sigma_{ADEV}(\tau)$: $$|H(f)|^2=2\frac{\sin^4(\pi\tau f)}{(\pi\tau f)^2}$$ maximum around $\tau\cdot f\simeq 0.45$
- $\sigma_{MDEV}(\tau)$: $$|H(f)|^2=2\frac{\sin^6(\pi\tau f)}{(\pi\tau f)^4}$$
- phase noise to jitter: $\varphi=2\pi\cdot\nu_0\cdot\tau\Rightarrow\sigma_\tau=\frac{1}{2\pi\nu_0}\sigma_\varphi=\frac{1}{2\pi\nu_0}\sqrt{\int_B S_\varphi(f)\cdot df}\simeq\frac{1}{2\pi\nu_0}\sqrt{B\times 10^{S_\varphi(dB)/10}}$

[11] dBrad^2/Hz=dBc/Hz+3 dB

[12] U.L. Rohde, E. Rubiola, J.C. Whitaker, *Microwave and Wireless Synthesizers 2nd Ed.*, Wiley (2021) p.57 at https://rubiola.org/pdf-lectures/Scient-Instrum-Files/Phase%20noise%20Wiley%2C%20Ch2%20updated%20draft.pdf

Rather than using analytical solutions, numerical integration:

- Numerical applications:
  $S_\varphi \rightarrow AVAR$ [13]
```
avar(m)=2*sum(Syint(1:end-1).*(fFint(2:end)-fFint(1:end-1)).*sin(pi*tau*fFint(1:end-1)).^4./(pi*tau*fFint(1:end-1)).^2);
mvar(m)=2*sum(Syint(1:end-1).*(fFint(2:end)-fFint(1:end-1)).*sin(pi*tau*fFint(1:end-1)).^6./(pi*tau*fFint(1:end-1)).^4);
```
- Numerical applications:
  $S_\varphi \rightarrow \sigma_T$
```
rad=sqrt(10.^(SdBrad(1:end-1)/10).*(fFint(2:end)-fFint(1:end-1))); % dBrad^2/Hz -> rad
res=rad/2/pi/fc;     % rad -> s
withweight=sqrt(sum((res.^2.*sin(2*pi*fFint(1:end-1)*1/2).^2)))
```
- Coherence time[14,15] T:

$$C(T) = \left| \frac{1}{T} \int_0^T \exp(j\varphi(t)) \cdot dt \right| \rightarrow \langle C^2(T) \rangle = \frac{1}{T^2} \int_0^T \int_0^T \langle \exp(j(\varphi(t) - \varphi(t'))) \rangle \cdot dt \cdot dt' = \ldots$$

[13] https://rubiola.org/pdf-lectures/Scientific%20Instruments%20L06-10,%20Oscillators.pdf

[14] A.R. Thompson *& al.*, *Interferometry and Synthesis in Radio Astronomy*, Springer Open (2017) p.434 at https://link.springer.com/book/10.1007/978-3-319-44431-4

[15] E.P. Boven *& al.*, *White Rabbit in radio interferometry*, Experimental Astronomy **61**(3) (2026)

Coherence loss from phase noise during correlation

$$\ldots = \frac{2}{T}\int_0^T \left(1-\frac{\tau}{T}\right)\exp\left[-2(\pi\nu_0\tau)^2\int S_y(f)H_I^2(f)\cdot df\right]d\tau \text{ with } H_I^2(f) = \left(\frac{\sin(\pi f\tau)}{\pi f\tau}\right)^2$$

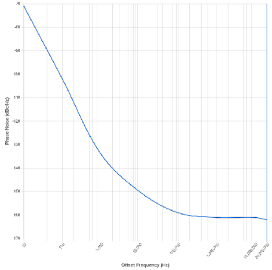
- "Since $S_y(f)$ is often not available, it is useful to relate $\langle C^2(T)\rangle$ to $\sigma_y^2(\tau)$" [16]… S_y is available to us !

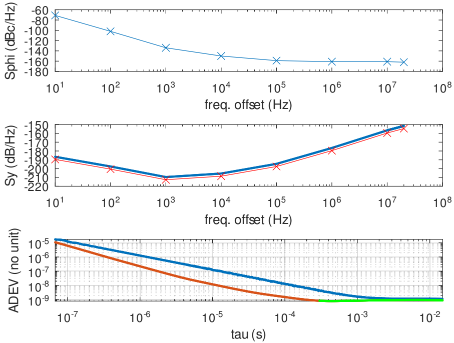
Abracon Phase Noise Plot

View ASA Series Information

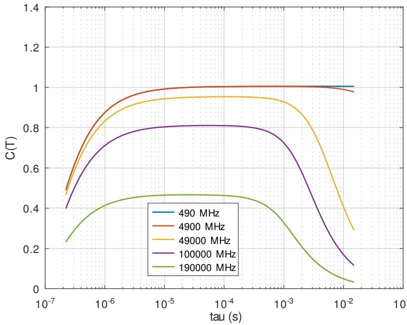
Series: XO
Product Type: ASA
Output Logic: CMOS
Carrier Frequency: 12
VDD: 1.8
Integration Bandwidth: 12 kHz to 20 MHz
Calculated RMS Phase Jitter: 736.4 fs
Calculated RMS Noise: 5.518e-5 rad

Offset Frequency (Hz)	Phase Noise (dBc/Hz)
10	-71.0
100	-102.0
1,000	-134.0
10,000	-150.0
100,000	-159.0
1,000,000	-161.0
10,000,000	-161.0
20,000,000	-162.0





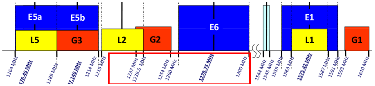
$S_\varphi \rightarrow S_y \rightarrow$ interpolated $S_y \rightarrow A(blue)/M(red)DEV$



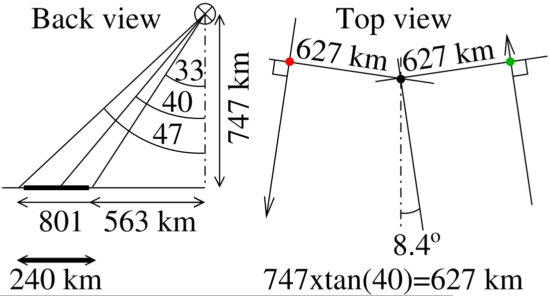
$S_y \rightarrow C(T)$

[16] A.R. Thompson *& al.*, *Interferometry and Synthesis in Radio Astronomy*, Springer Open (2017) at `https://link.springer.com/book/10.1007/978-3-319-44431-4`

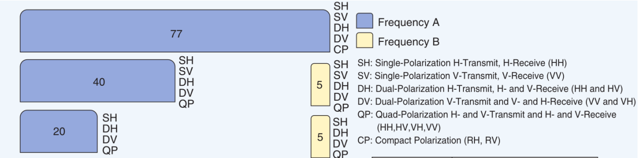
Receiving NISAR[18]: emission in L5/E6/G2 band



- NISAR is the **only spaceborne satellite looking left** (Antartica[17]) $\Rightarrow$ search for east ascending passes and west descending passes
- over Western Europe: L-band background land mode (L:DH:20M+05M:FS:B4:D01)



- NISAR: 1221.5 $\pm$ 2.5 MHz (NOT 1257.5$\pm \leq$ 42 MHz)



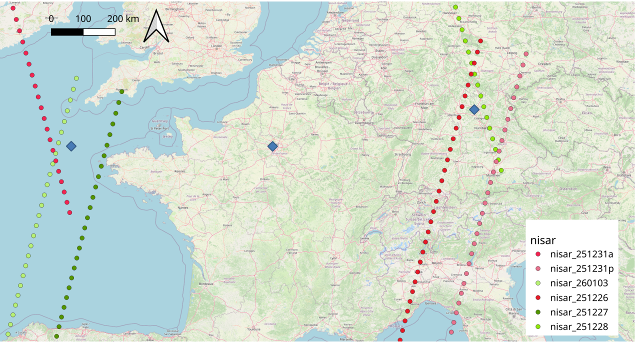
L-Band Mode Bandwidth [MHz]	Center Frequency [MHz]	
	Frequency A	Frequency B
77	1,257.5	N/A
40 + 5	1,239	1,293.5
20 + 5	1,229	1,293.5
20 + 20	1,229	1,286
5 + 5	1,221.5	1,236.5

FIGURE 16. A schematic representation of the L-SAR bandwidths used by NISAR, some of which are split bands. The pulsewidth associated with each bandwidth generally corresponds to a chirp rate of 1 MHz/ms, though other pulsewidth/bandwidth combinations are possible.

[17] A. Witze, *Arctic scientists iced out by radar mission*, Nature **566** (7 Feb. 2019) "Most other SAR missions are right-looking [... but...] NISAR science team decided to make its satellite left-looking for its entire primary mission" and `https://science.nasa.gov/mission/nisar/observation-strategy/`: As NISAR will be only left-looking – a change in observation tactics since the early planning stages – the mission will rely on data from the international constellation of SAR satellites to supplement its coverage around the Arctic pole... (last updated Jul 23, 2025)

[18] P.A. Rosen *& al.*, *The NASA-ISRO SAR Mission – a summary*, IEEE Geoscience & Remote Sensing Mag. (June 2025)

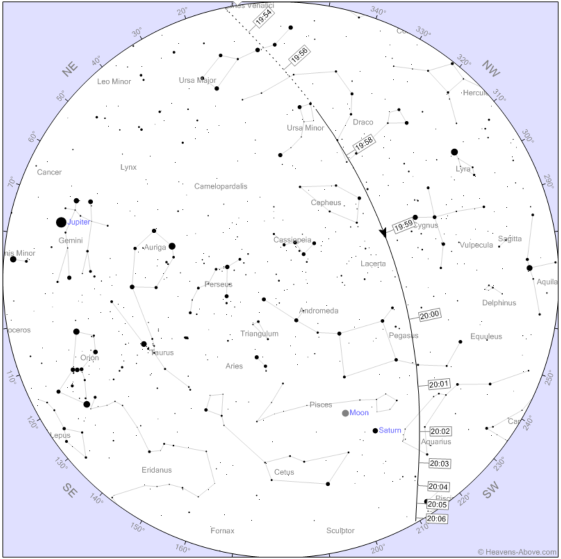
- Download NORAD's TLE from Celestrak
- Predict pass according to beam geometry and altitude
- Check ascending/descending pass & verify on Heavens Above→



Date: 27 December 2025

Orbit: 749 x 751 km, 98.4° (Epoch: 24 December)

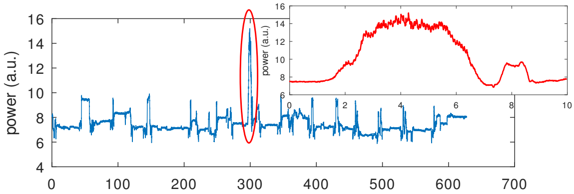
Event	Time	Altitude	Azimuth	Distance (km)	Brightness	Sun altitude
Rises	19:51:51	0°	10° (N)	3,211	-	-26.9°
Reaches altitude 10°	19:54:12	10°	6° (N)	2,282	-	-27.3°
Exits shadow	19:57:09	34°	348° (NNW)	1,235	?	-27.8°
Maximum altitude	19:59:04	53°	291° (WNW)	918	?	-28.1°
Drops below altitude 10°	20:03:55	10°	215° (SW)	2,267	?	-28.9°
Sets	20:06:14	0°	211° (SSW)	3,187	?	-29.3°

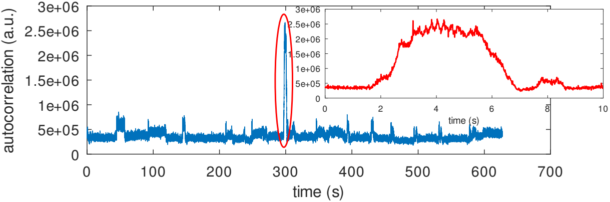


https://github.com/jmfriedt/NISAR_pbr

NISAR: results[19] Dec. 27, 2025 (B210, 8 bits)

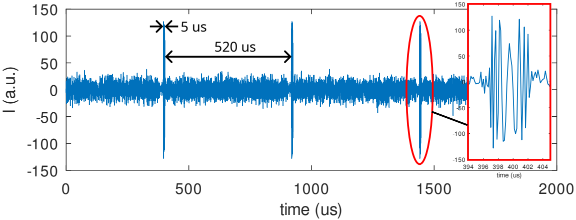
Top: signal power

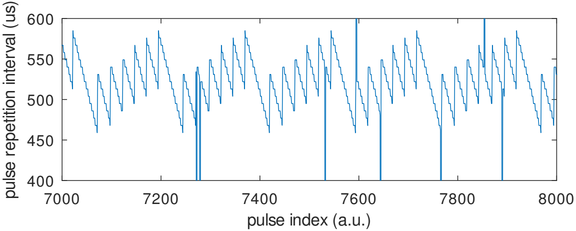




Bottom: signal off-center auto-correlation

Top: real part of received signal (demonstrating chirped pulse: red rectangle)





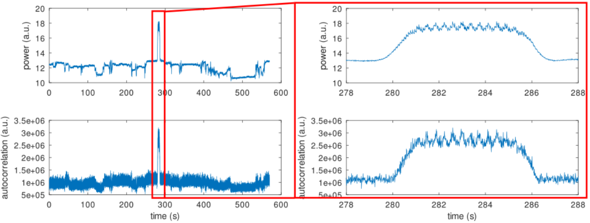
Bottom: Pulse Repetition Interval (PRI)

Predicted elevation maximum: 19:59:04, **observed** peak power: 19:59:01.6±2 s

[19] `https://github.com/jmfriedt/NISAR_pbr`

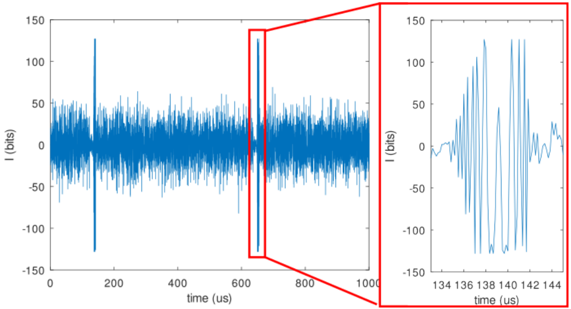
NISAR: results[20] Jan. 3, 2026 (B210, 8 bits)

Top: signal power



Bottom: signal off-center auto-correlation

Top: real part of received signal (demonstrating chirped pulse: red rectangle)



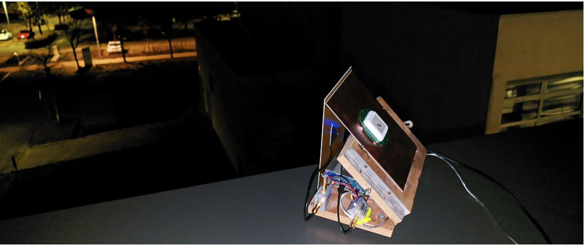
Predicted elevation maximum: 20:07:16, **observed** peak power: 20:07:14.7±2 s

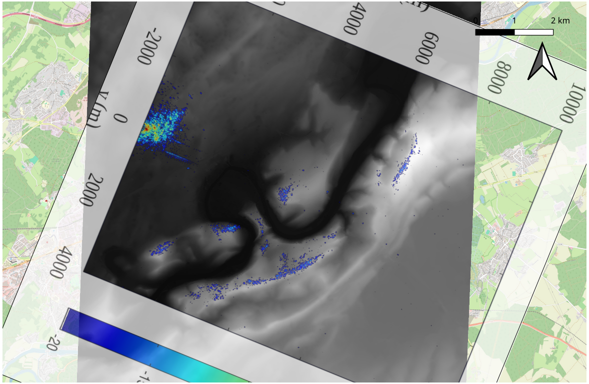
⇒ no need to record 10 min of data, a few seconds around the predicted maximum elevation is enough

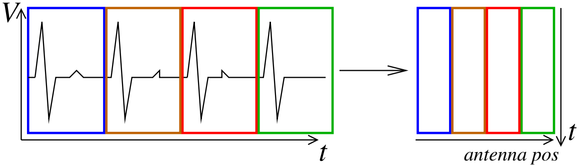
[20] `https://github.com/jmfriedt/NISAR_pbr`

NISAR passive RADAR imaging

- One multiband GNSS antenna facing the sky (reference antenna)
- One multiband GNSS antenna facing the opposite direction (surveillance)
- Record both **coherently** (same LO)
- Cross-correlate for range compression
- Inverse Fourier transform along satellite position (pulse index) for azimuth compression
- Image formation by converting range R-wavevector $\sin(\vartheta)$ to polar coordinates (R, ϑ)





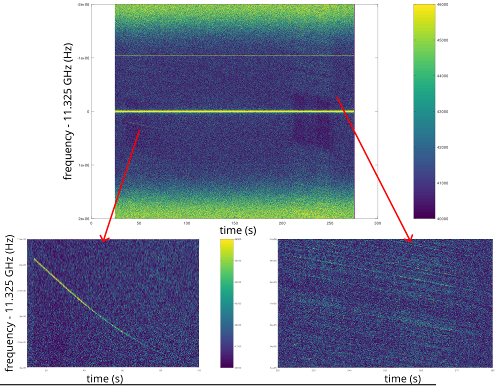


Conclusion & perspectives: receiving other satellite signals

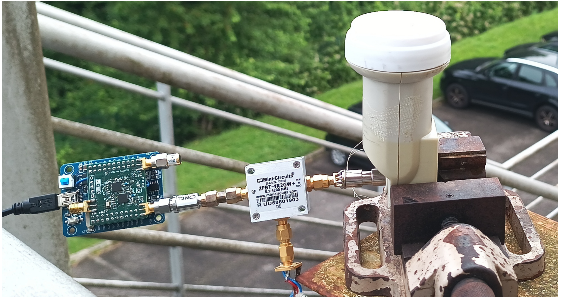
- Addressed the impact of low bit resolution ADC
- Addressed the impact of clock jitter
- Demonstrated NISAR reception and passive RADAR using DVB-T signal of opportunity

...using the low cost dual-MAX2771 PocketSDR clone.

Project at `https://github.com/jmfriedt/max2771_fx2lp/`



All references from Anna's Archive and Sci Hub



Using an LNB[a] to convert Ku to L-band:

- Starlink 11.325 GHz beacon$-$9.75 GHz LNB$=$ 1.575 GHz within upper L band (L1) !
- Telstar 11N TWSTFT signal[21] is within lower L band (L2) after transposition: 10953.95 $-$ 9750 $= 1204 \in [1160 : 1290]$ MHz

[a] 12-14 V supply voltage through bias T

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[21] `https://webtai.bipm.org/ftp/pub/tai/data/2025/time_transfer/twstft/op/twop60.677`