1) a) T

b) F

c) F

2) a) See next

b) 1.27 MHz

c) SNR 54.94 dB

SNDR 52.86 dB

ENOB 9.49 Bits

THD 0.196%

SFDR 54.57 dB

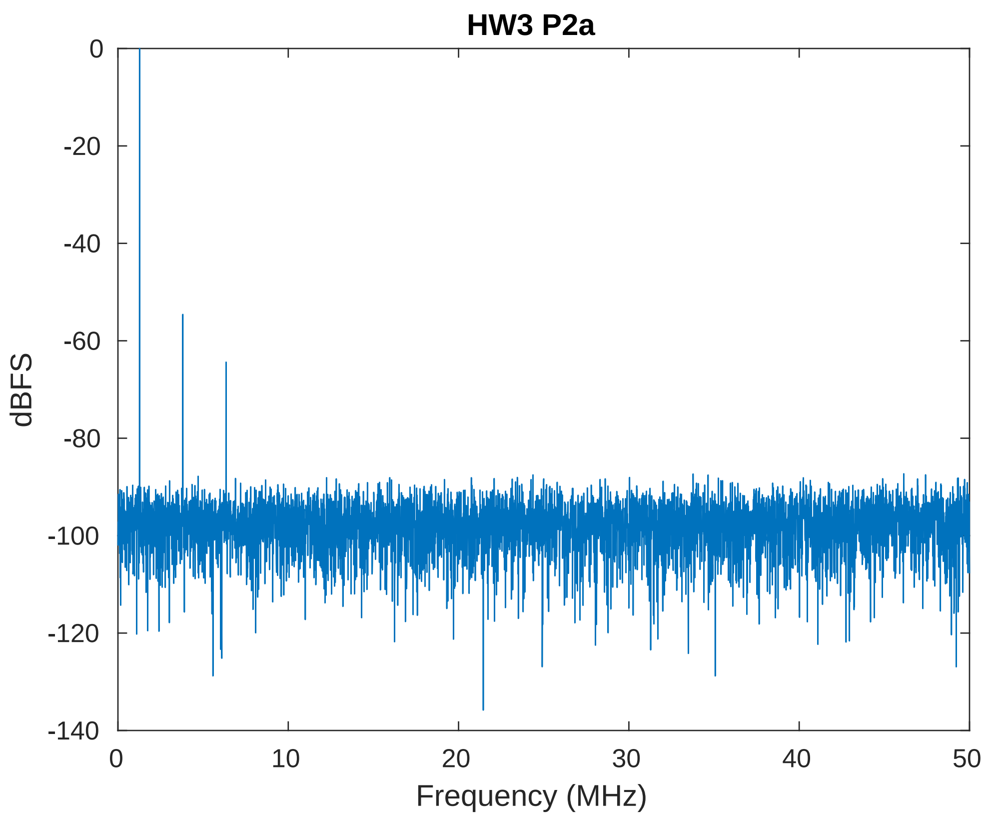
d) 3rd harmonic power

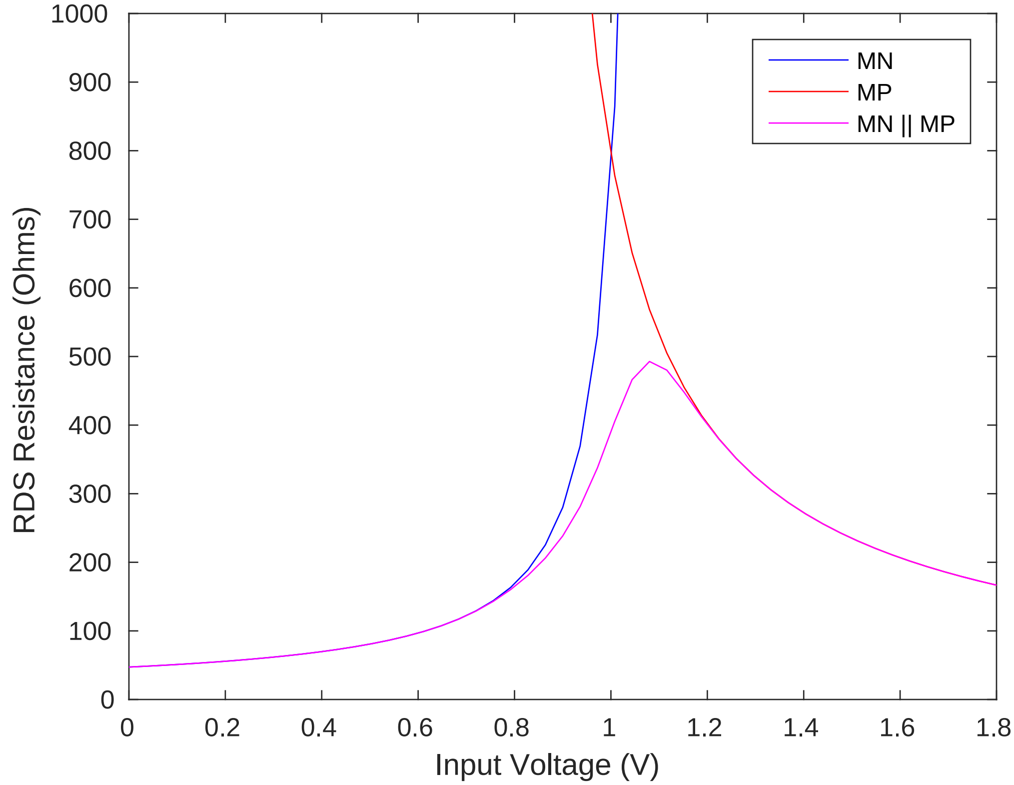
e)

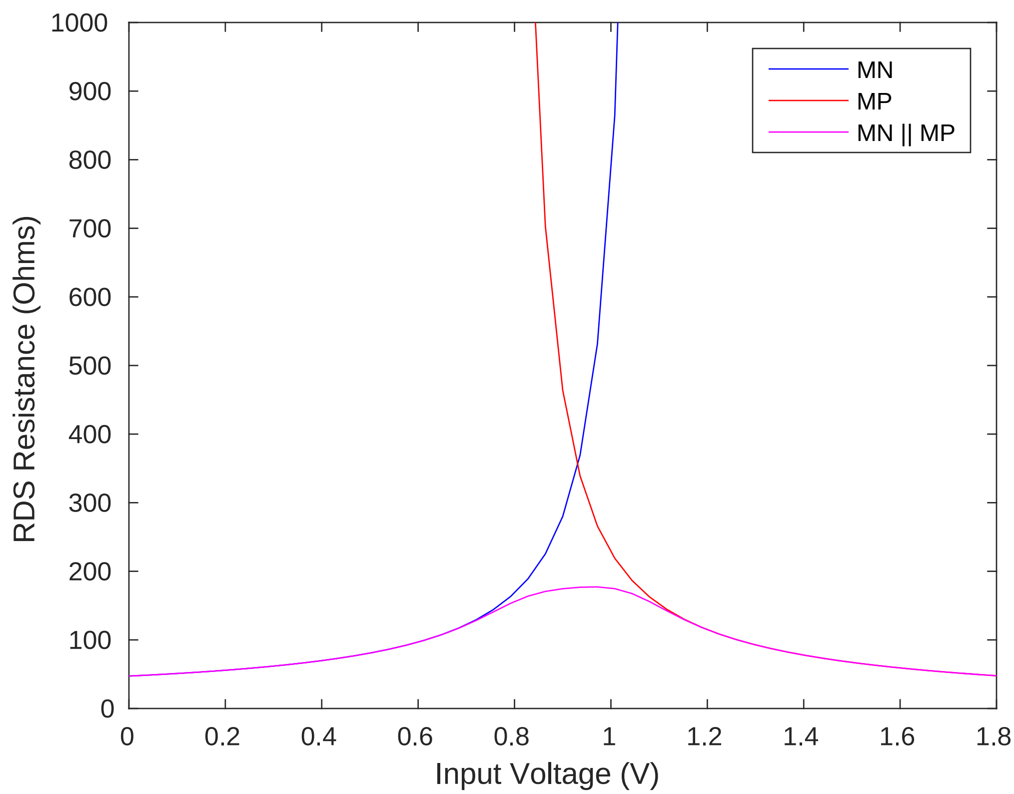
3) a) See next for plot

Vin	Device	Resistance
0	MN	47.26
0	MN‖MP	47.26
VDD	MP	166.68
VDD	MN‖MP	166.68
	max (MN‖MP)	492.74

b) $K = \frac{166.68}{47.26} = 3.52$


HW3 P2a
0
-20
-40
-60
-80
-100
-120
-140
dBFS
0
10
20
30
40
50
Frequency (MHz)


MN
MP
MN || MP
RDS Resistance (Ohms)
Input Voltage (V)
0
100
200
300
400
500
600
700
800
900
1000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8



MN
MP
MN || MP
RDS Resistance (Ohms)
Input Voltage (V)
0
100
200
300
400
500
600
700
800
900
1000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

3) c) $R_{per} = 177$ w/ 10μ Nmos 35.2μ pmos

$N = -\ln(0.1/100) = 6.9$

$N\tau = 5ns$ $\tau = RC$

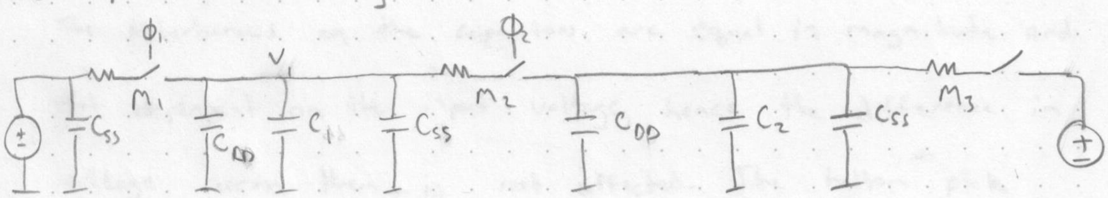
$NRC = 5ns$ $R = \frac{5ns}{N \cdot C} = \frac{5ns}{6.9 \cdot 1pF} = 724\Omega$

$width_N = 10\mu m \cdot \frac{177}{724} = 2.44\mu m$

$width_p = K \cdot width_N = 8.60\mu m$

4) $W = 10\mu m$ $L = 0.2\mu m$ $C_{ox} = 10fF/\mu m^2$ $V_t = 0.4$ $C_{OL} = 0.1fF/\mu m$

Clock period is long



a) $C_{SS} = C_{gs} + C_{sb}$ $C_{DD} = C_{gd} + C_{db}$ $C_{OL} = 10\mu m \cdot 0.1\frac{fF}{\mu m} = 1fF$

At t_1 and t_2 $V_g = 0$ for all Nmos → subthreshold

$C_{gs} = C_{OL}$ $C_{gd} = C_{OL}$

In subthreshold $1pF >> C_{DD} \parallel C_{SS}$ → ignore $C_{sb} = C_{jsb}$ $C_{db} = C_{jsb}$

C_{ol}

$\overline{V_n^2} = \frac{KT}{C_1} = 4141\mu V^2 = \boxed{64.4\mu V_{rms}}$

b) V_1 at t_1

before t_1, while Φ_1 is high, $V_1 = V_{in} = 1V$

when $\Phi_1\downarrow$ the charge of M_1 will be distributed into the source and into C_1, ~ 50/50

$Q_{channel} \doteq -WLC_{ox}(V_{dd} - V_{in} - V_t) = -20\mu m \cdot 0.2\mu m \cdot 10fF/\mu m\,(1.8 - 1.0 - 0.4)$

$Q_{ch} = -16fC$

$\boxed{V_{out} = V_{in} - \frac{Q_{ch}}{2C_1} = 0.992V \rightarrow 8mV \text{ offset}}$

c) $\boxed{V_{out} = V_{in} - V_{dd}\frac{C_{OV}}{C_{OL} + C_1} = 0.9982V \rightarrow 1.8mV \text{ offset}}$

5) $-403\,mdB$ gain at 400MHz

6) a) See next

bi) See next for plot

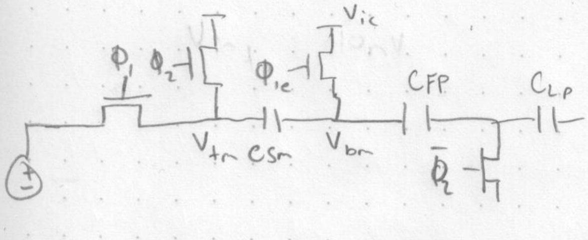
Immediately after Φ_1 rises, V_{cs} drop from 10mv to 9.386mV, an error of 0.614 mV

V_{cs} is computed as $V_{cs} = (V_{tm} - V_{bm}) - (V_{tp} - V_{bp})$

The disturbances on the capacitors are equal in magnitude and not dependent on the input voltage, hence the difference in voltage across them is not affected. The bottom plate sampling technique takes advantage of common mode rejection in the OTA combined with equal charge injection to null the resulting offset.

bii) See next.

biii) Charge injection error handcalc when Φ_{1e} opens



Φ_{1e} closed $\Rightarrow$ $V_{bm} = V_{iC} = 0.6V$

Φ_1 closed $\rightarrow$ $V_{tm} = V_{ic} + \frac{V_{id}}{2} = 0.605V$

Φ_{1e} mosfet channel = $30\mu/0.2\mu$ $Q_{ch} \approx -WLC_{ox}(V_{dd} - V_{in} - V_t) = 36fC$

$C_{sm} \parallel C_{FP} = 200fF$

$\Delta V = \frac{Q_{ch}}{2C} = \frac{36fF}{2 \cdot 200f} = \boxed{90.0mV}$ $\boxed{113mV \text{ observed}}$

6) c)

i) Output referred differential noise

Ran out of time :(

ii) $11.7\ fV^2/Hz$

24.46% comes from OTA Balance ~75% from switches

6) d)

i) SDR = 85.4 dB

ii) SDR = 88.6 dB

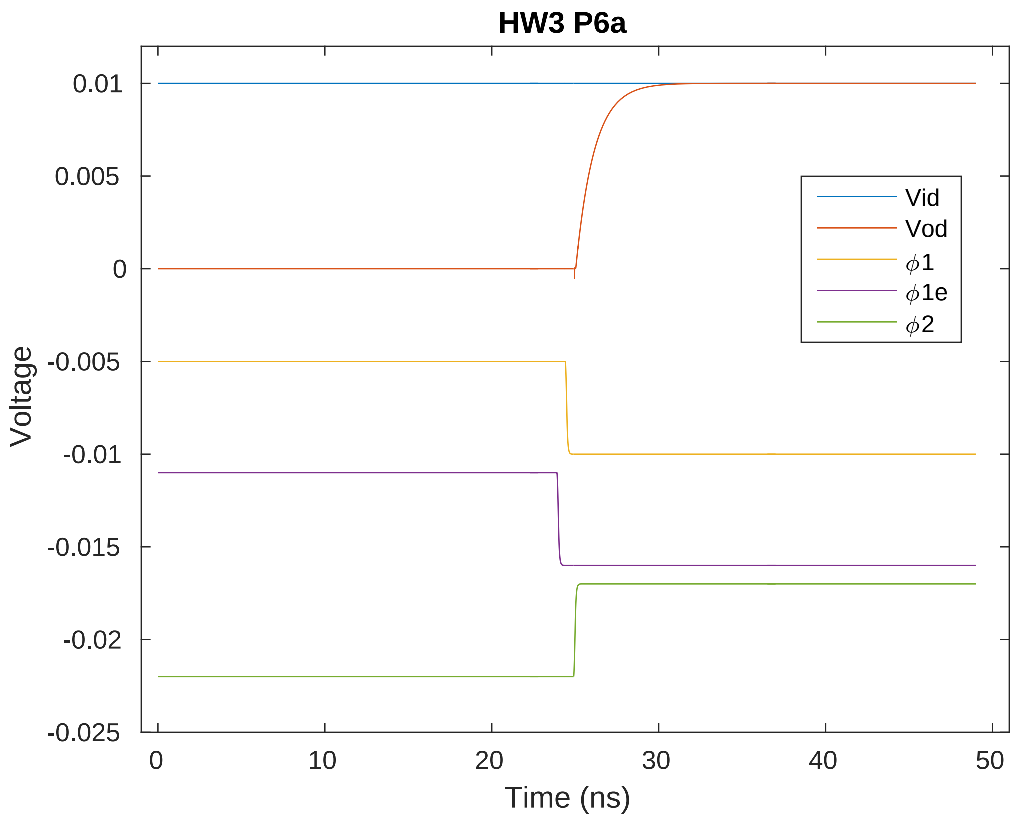
maxstep is the maximum timestep that the simulator solver will take when computing the node states of the circuit.

iii) SDR = 60.2 dB.

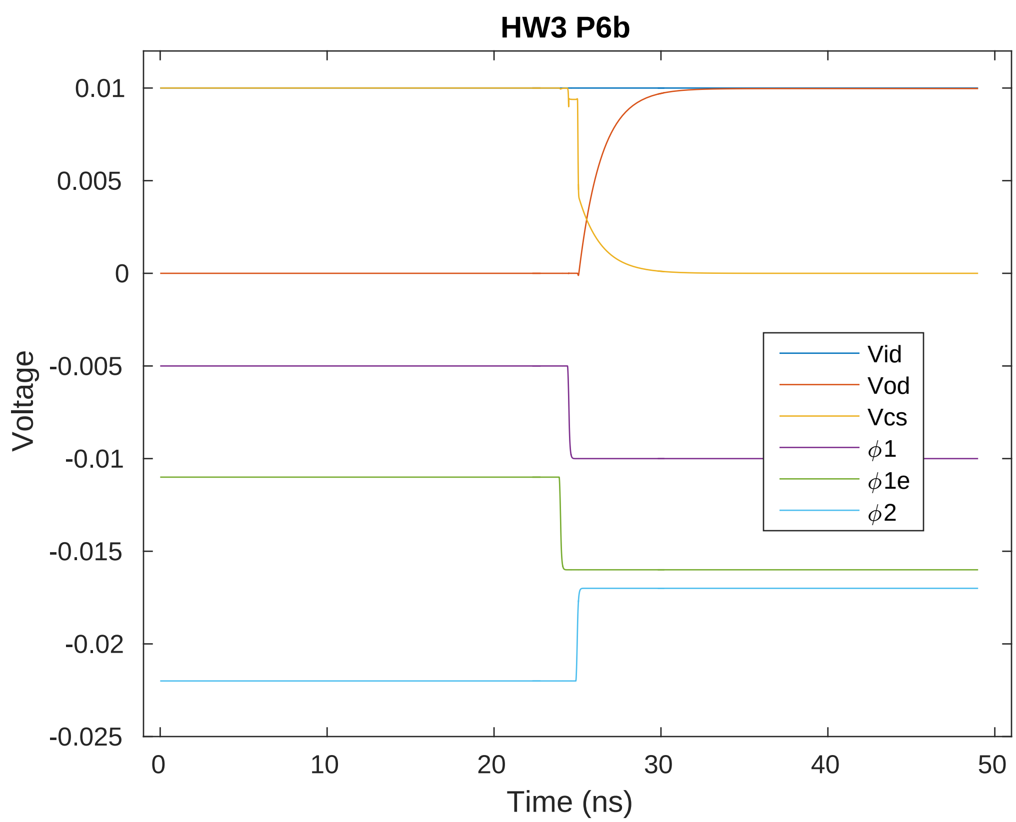
iv) SDR = 67.7 dB with ideal switches for Φ_{1e} and Φ_2

The effect is strong but it does not dominate.

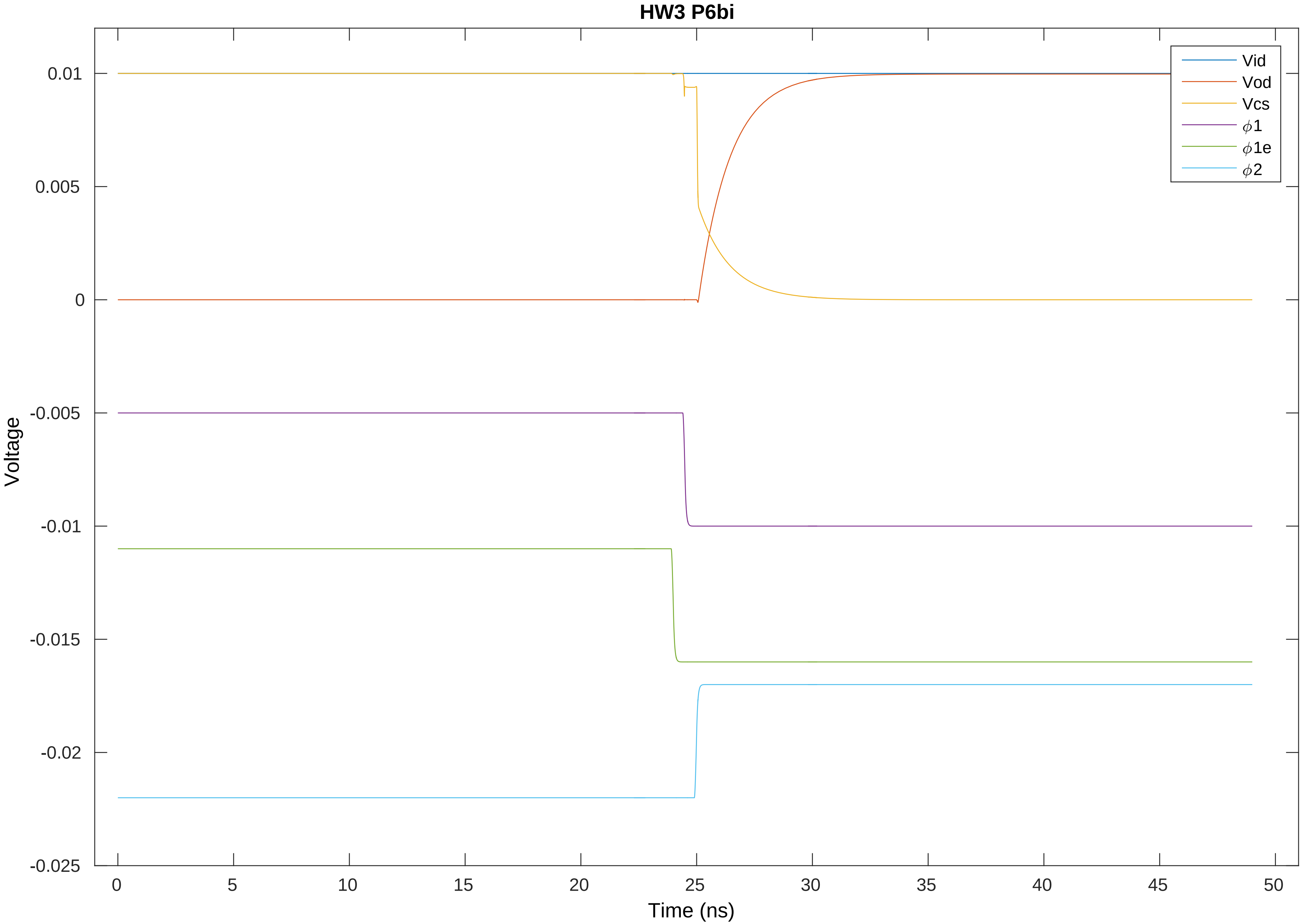
v) SDR = -1.11 dB - this doesnt make sense I think I messed something up.



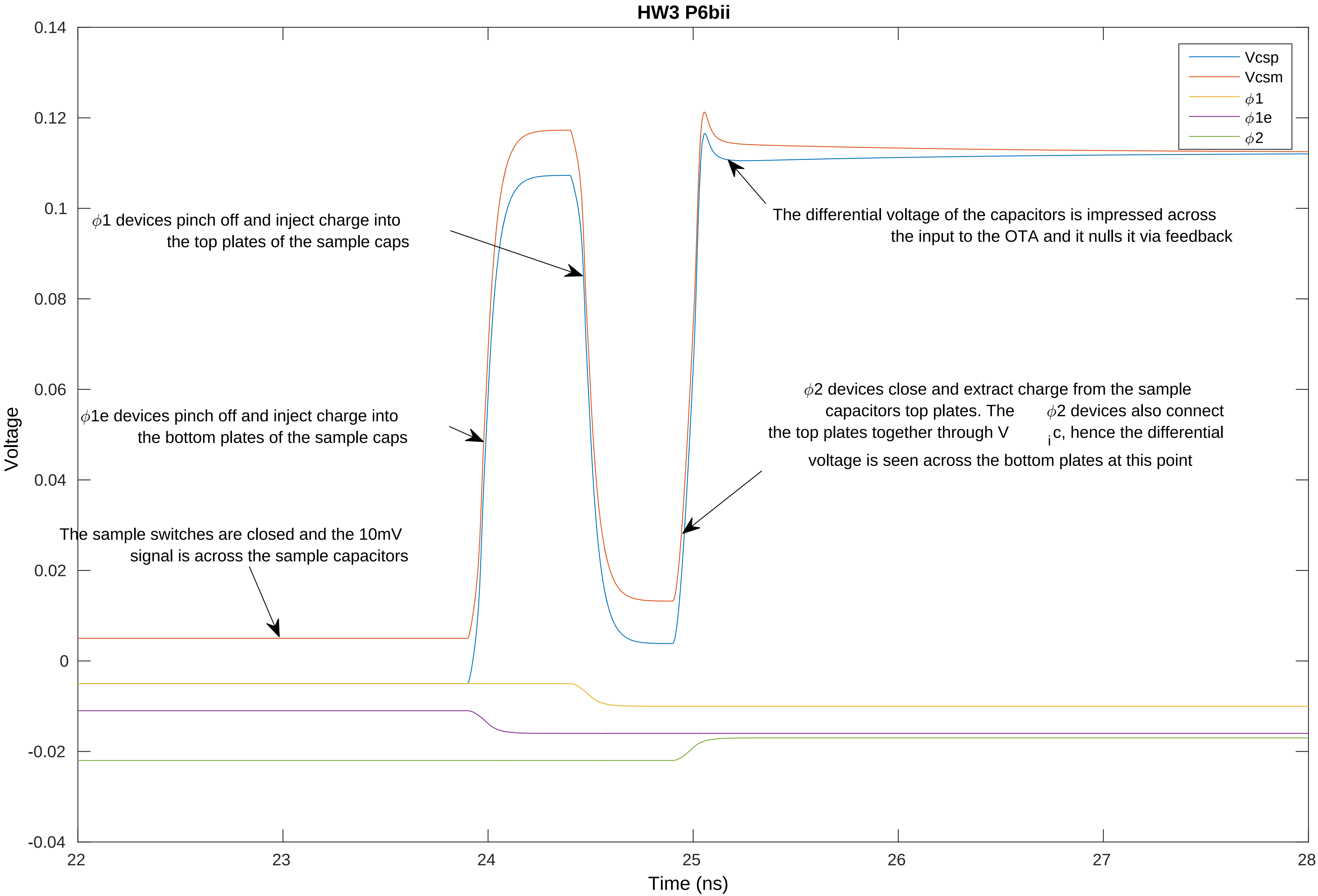
HW3 P6a
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
Voltage
0
10
20
30
40
50
Time (ns)
Vid
Vod
ϕ1
ϕ1e
ϕ2

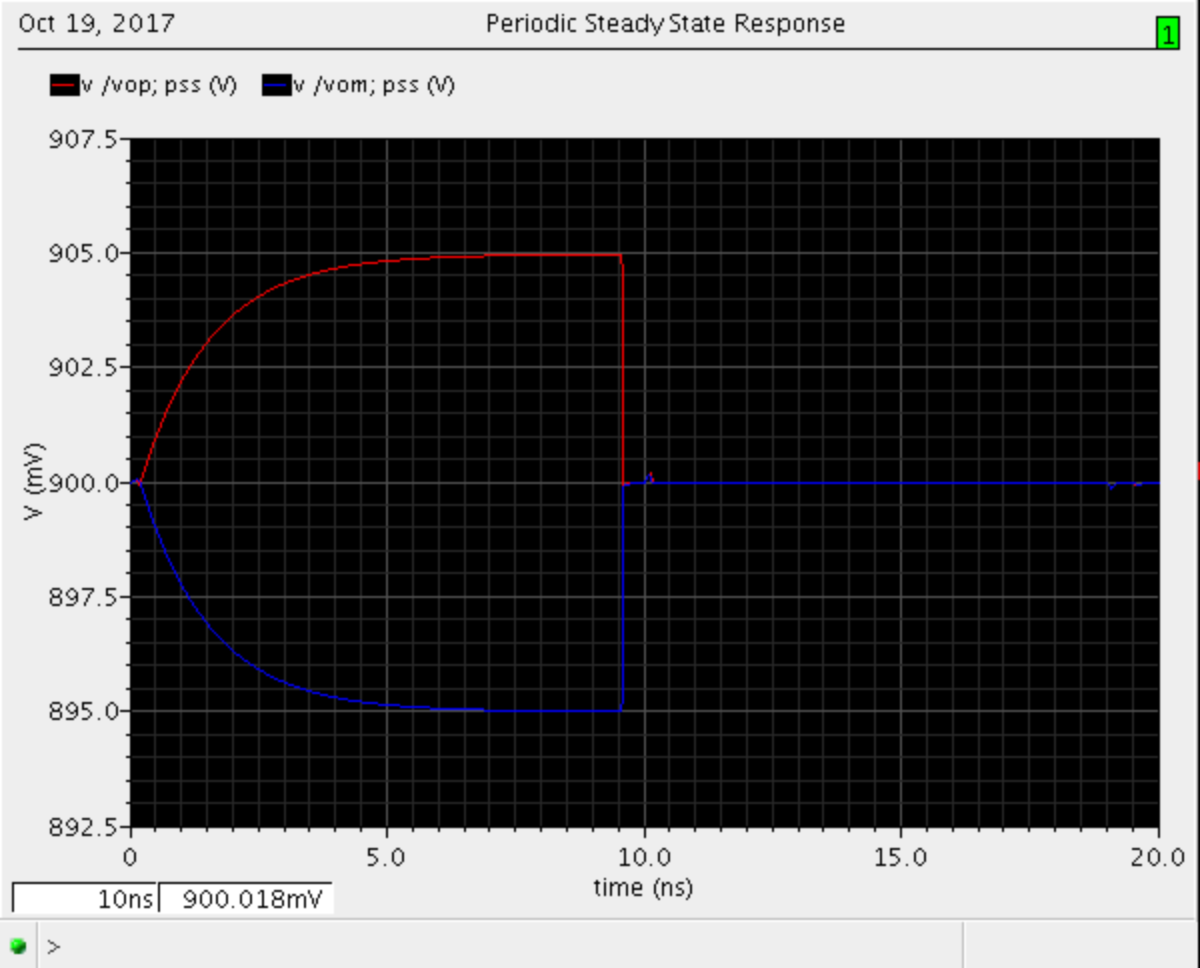


HW3 P6b
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
Voltage
0
10
20
30
40
50
Time (ns)
Vid
Vod
Vcs
ϕ1
ϕ1e
ϕ2



HW3 P6bi
Vid
Vod
Vcs
ϕ1
ϕ1e
ϕ2
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
Voltage
0
5
10
15
20
25
30
35
40
45
50
Time (ns)


HW3 P6bii
Vcsp
Vcsm
ϕ1
ϕ1e
ϕ2
ϕ1 devices pinch off and inject charge into the top plates of the sample caps
The differential voltage of the capacitors is impressed across the input to the OTA and it nulls it via feedback
ϕ2 devices close and extract charge from the sample capacitors top plates. The ϕ2 devices also connect the top plates together through V_ic, hence the differential voltage is seen across the bottom plates at this point
ϕ1e devices pinch off and inject charge into the bottom plates of the sample caps
The sample switches are closed and the 10mV signal is across the sample capacitors
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
22
23
24
25
26
27
28
Voltage
Time (ns)

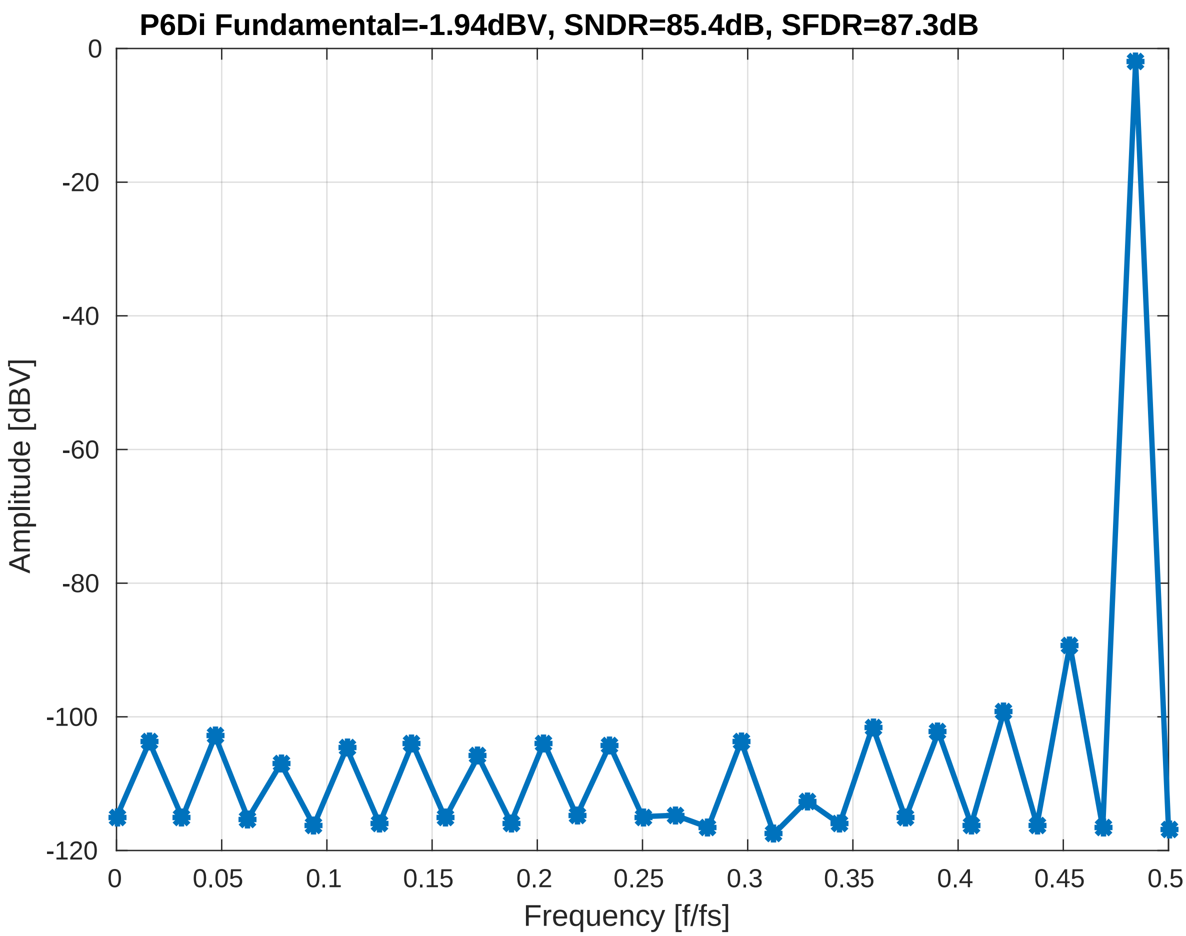

Oct 19, 2017
Periodic Steady State Response
1
v /vop; pss (V)
v /vom; pss (V)
907.5
905.0
902.5
900.0
897.5
895.0
892.5
V (mV)
0
5.0
10.0
15.0
20.0
time (ns)
10ns
900.018mV
>

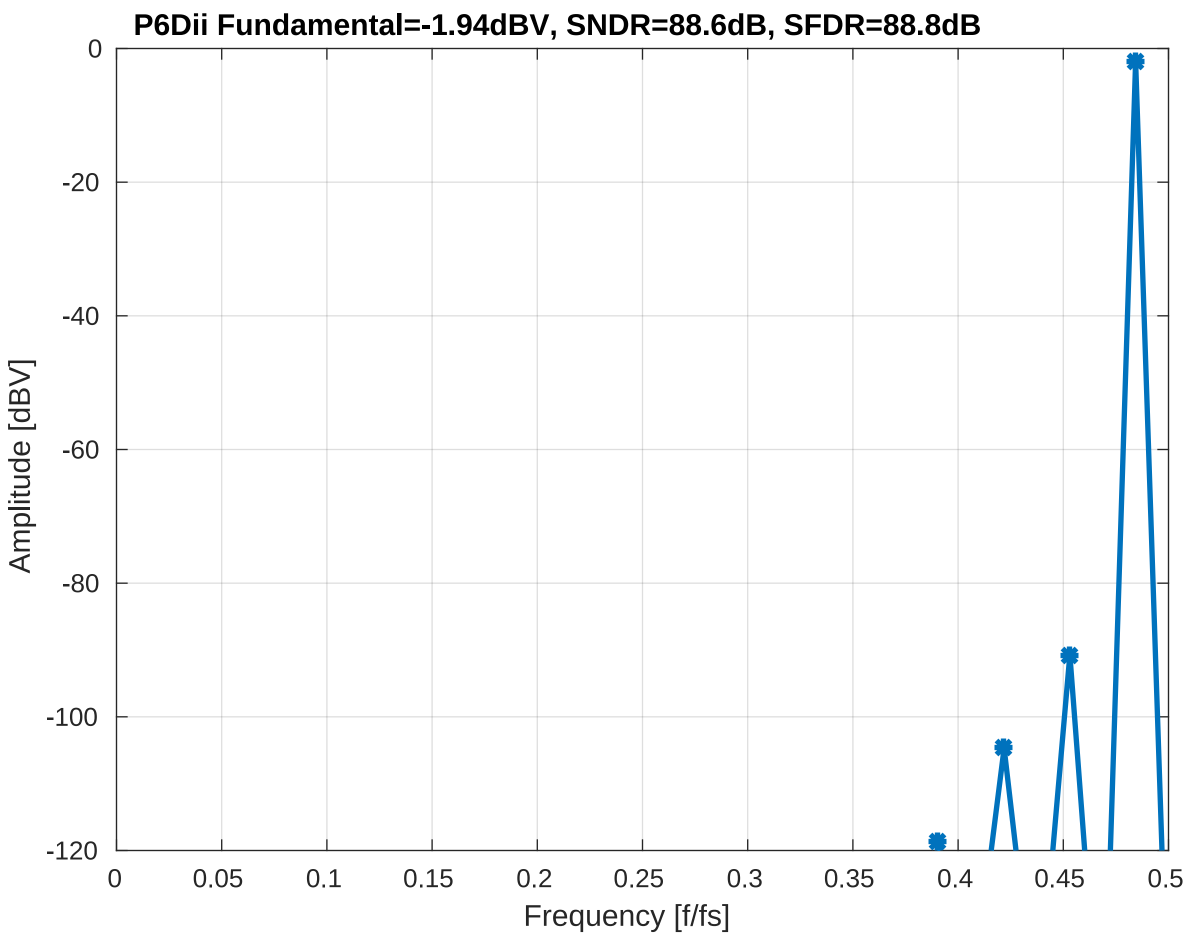
Window Expressions Info Help cadence

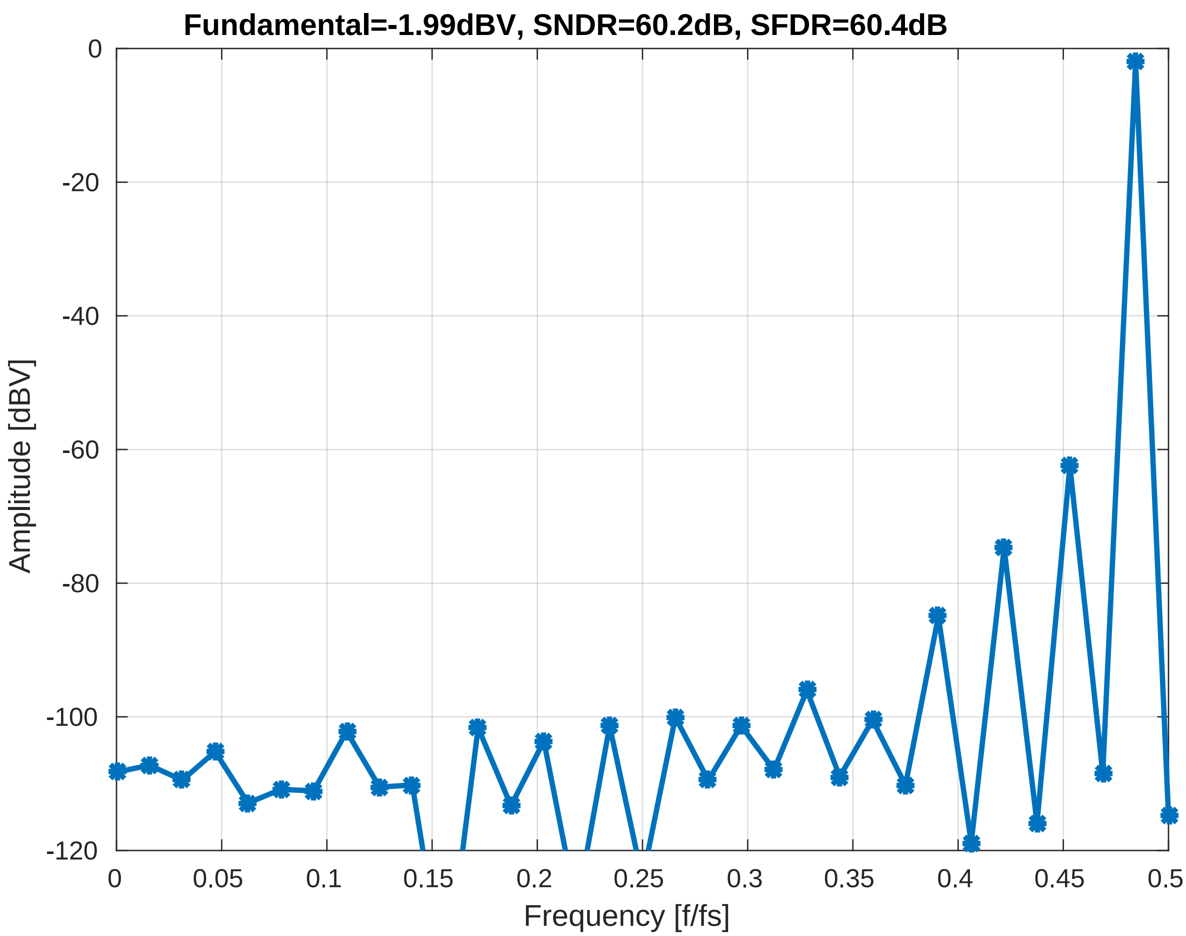
Device	Param	Noise Contribution	% Of Total
/I56/M0	id	4.21935e-15	35.86
/I54/M0	id	4.21601e-15	35.83
/I0/R2	rn	1.43879e-15	12.23
/I0/R0	rn	1.43879e-15	12.23
/I52/M0	id	1.91027e-16	1.62
/I57/M0	id	1.87769e-16	1.60
/I42/R2	rn	6.13282e-17	0.52
/I55/M0	id	6.43685e-18	0.05
/I53/M0	id	6.37452e-18	0.05

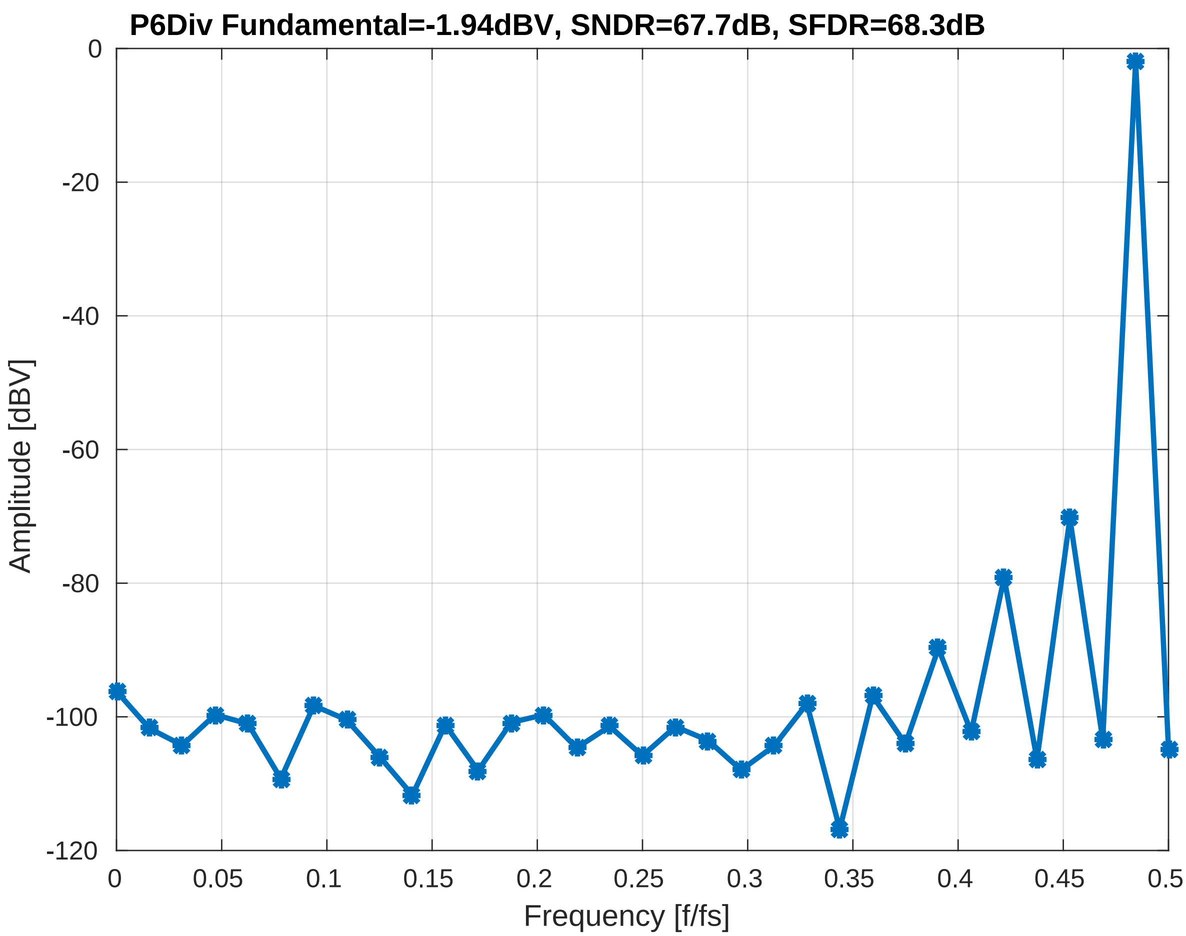
Spot Noise Summary (in V^2/Hz) at 1K Hz Sorted By Noise Contributors
Total Summarized Noise = 1.17659e-14
No input referred noise available
The above noise summary info is for pnoise_td data with timeindex = 9e-09

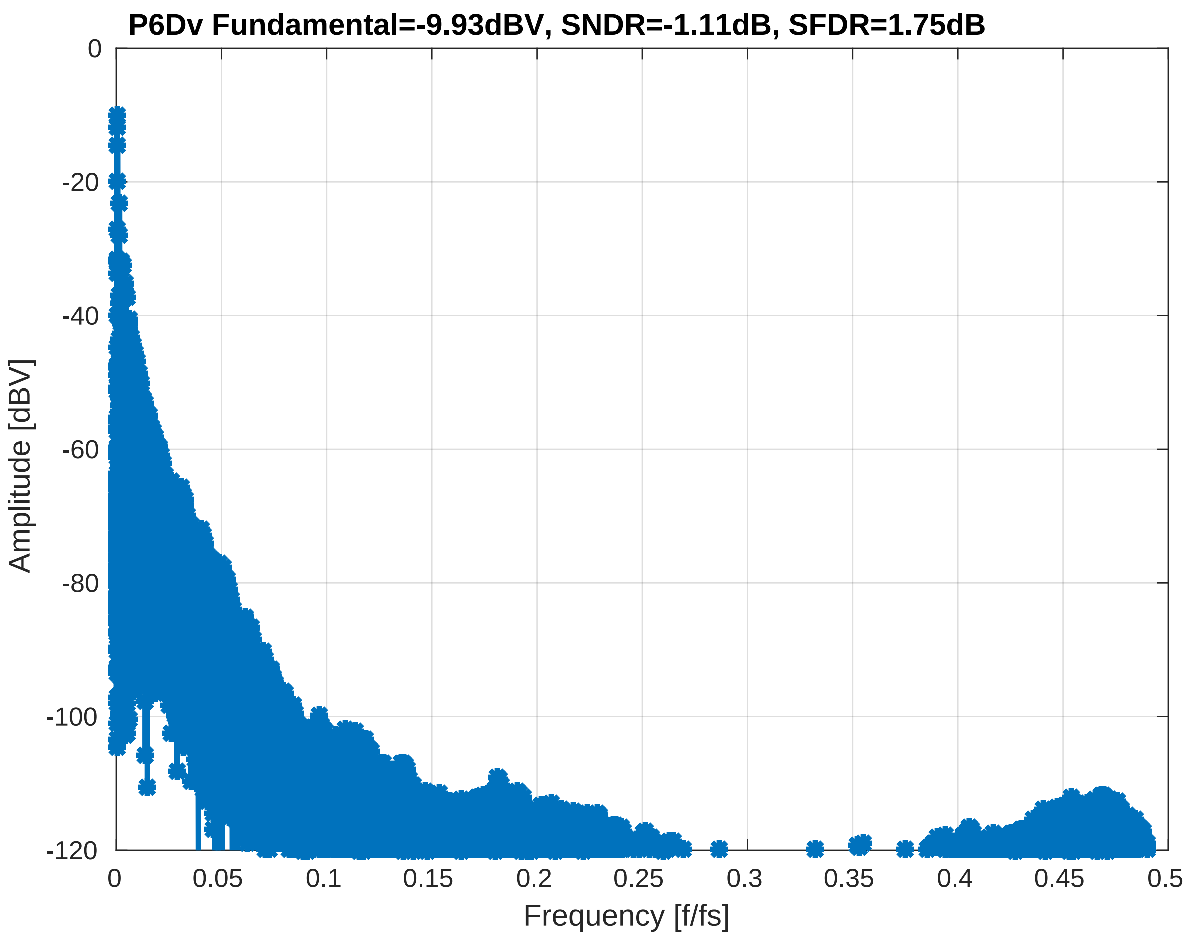
11


P6Di Fundamental=-1.94dBV, SNDR=85.4dB, SFDR=87.3dB
Amplitude [dBV]
0
-20
-40
-60
-80
-100
-120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency [f/fs]


P6Dii Fundamental=-1.94dBV, SNDR=88.6dB, SFDR=88.8dB
Amplitude [dBV]
0
-20
-40
-60
-80
-100
-120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency [f/fs]


Fundamental=-1.99dBV, SNDR=60.2dB, SFDR=60.4dB
Amplitude [dBV]
Frequency [f/fs]
0
-20
-40
-60
-80
-100
-120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


P6Div Fundamental=-1.94dBV, SNDR=67.7dB, SFDR=68.3dB
0
-20
-40
-60
-80
-100
-120
Amplitude [dBV]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency [f/fs]


P6Dv Fundamental=-9.93dBV, SNDR=-1.11dB, SFDR=1.75dB
Amplitude [dBV]
0
-20
-40
-60
-80
-100
-120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency [f/fs]

```
function enob = my_enob(x, fs)
  % inputs
  % x - signal (vector)
  % fs - sample frequency (scalar)

  enob = (my_snr(x, fs, 6) - 1.76) / 6.02;
end
```

```
function r = my_sfdr(x, fs, n_harm)
  % inputs
  % x - signal (vector)
  % fs - sample frequency (scalar)
  % n_harm - number of harmonics to remove

  % calculate fft in decibels from signal
  N = length(x);

  % calculate the psd with a rectangular window
  [psd, f] = periodogram(x, rectwin(N), N, fs);

  % find the fundamental
  [~, f_idx] = max(psd);
  fundamental_freq = f(f_idx);

  % calculate the power of the fundamental and n harmonics
  for harmonic = 1:n_harm
    h_idx = harmonic * f_idx;
    p_h(harmonic) = bandpower(psd, f, [f(h_idx-harmonic) f(h_idx+harmonic)], 'psd');
  end

  r = 10*log10(p_h(1) / max(p_h(2:end)));

end
```

```
function r = my_sndr(x, fs)
  % inputs
  % x - signal (vector)
  % fs - sample frequency (scalar)

  % calculate fft in decibels from signal
  N = length(x);

  % window function to use - matlab uses hamming by default
  window = hamming(N);
  %window = rectwin(N);

  % calculate the psd with a rectangular window
  [psd, f] = periodogram(x, window, N, fs);

  % find the fundamental
  [~, f_idx] = max(psd);
  fundamental_freq = f(f_idx);

  % remove the fundamental
  psdn = psd;
  for i = f_idx-1:f_idx+1
    psdn(i) = median(psd);
  end

  %psd_db = 10*log10(psd);
  %psdn_db = 10*log10(psdn);

  sig_pwr = bandpower(psd, f, 'psd');
  noise_pwr = bandpower(psdn, f, 'psd');
  r = 10*log10(sig_pwr / noise_pwr);

end
```

```
function r = my_snr(x, fs, n_harm)
  % inputs
  % x - signal (vector)
  % fs - sample frequency (scalar)
  % n_harm - number of harmonics to remove

  % calculate fft in decibels from signal
  N = length(x);

  % calculate the psd with a rectangular window
  [psd, f] = periodogram(x, rectwin(N), N, fs);

  % find the fundamental
  [~, f_idx] = max(psd);
  fundamental_freq = f(f_idx);


  % remove the fundamental an n harmonics
  psdn = psd;
  for harmonic = 1:n_harm
    harm_f = harmonic * fundamental_freq;
    harm_idx = harmonic * f_idx;
    for i = harm_idx-harmonic:harm_idx+harmonic
      psdn(i) = median(psd);
    end
  end

  %psd_db = 10*log10(psd);
  %psdn_db = 10*log10(psdn);

  sig_pwr = bandpower(psd, f, 'psd');
  noise_pwr = bandpower(psdn, f, 'psd');
  r = 10*log10(sig_pwr / noise_pwr);

end
```

```
function r = my_thd(x, fs, n_harm)
  % inputs
  % x - signal (vector)
  % fs - sample frequency (scalar)
  % n_harm - number of harmonics to remove

  % calculate fft in decibels from signal
  N = length(x);

  % calculate the psd with a rectangular window
  [psd, f] = periodogram(x, rectwin(N), N, fs);

  % find the fundamental
  [~, f_idx] = max(psd);
  fundamental_freq = f(f_idx);

  % calculate the power of the fundamental and n harmonics
  for harmonic = 1:n_harm
    h_idx = harmonic * f_idx;
    p_h(harmonic) = bandpower(psd, f, [f(h_idx-harmonic) f(h_idx+harmonic)], 'psd');
  end

  r = 100 * sqrt(sum(p_h(2:end)) / p_h(1));
end
```