University of Idaho

ECE 525

POWER SYSTEM PROTECTION AND RELAYING

SESSION no. 12

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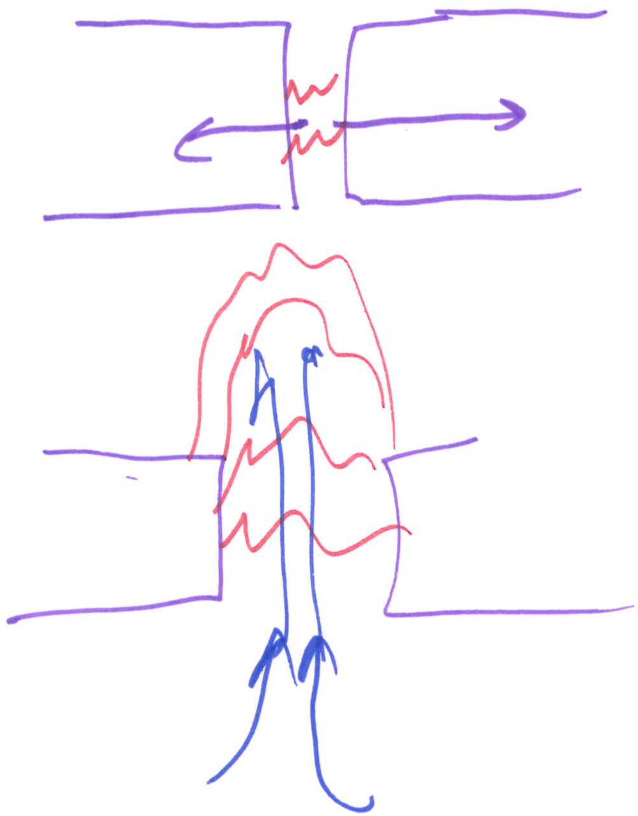

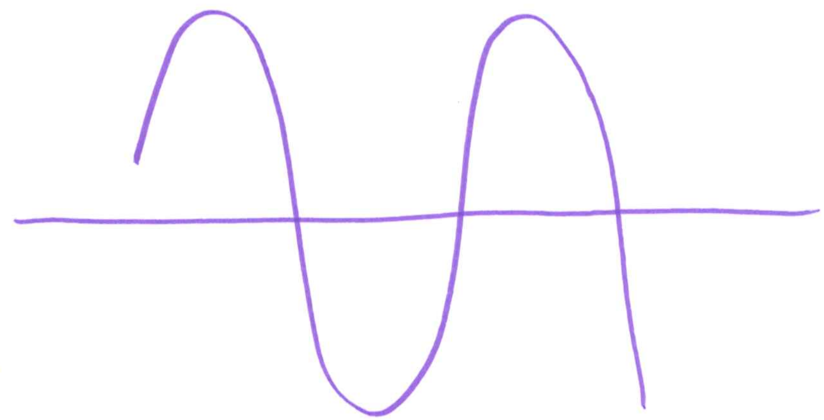

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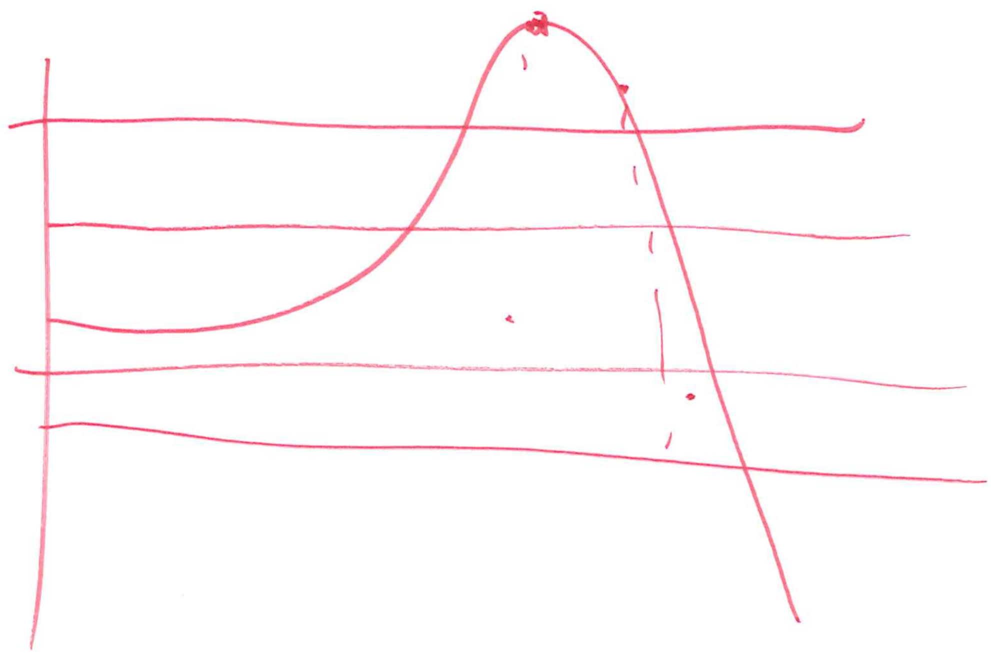
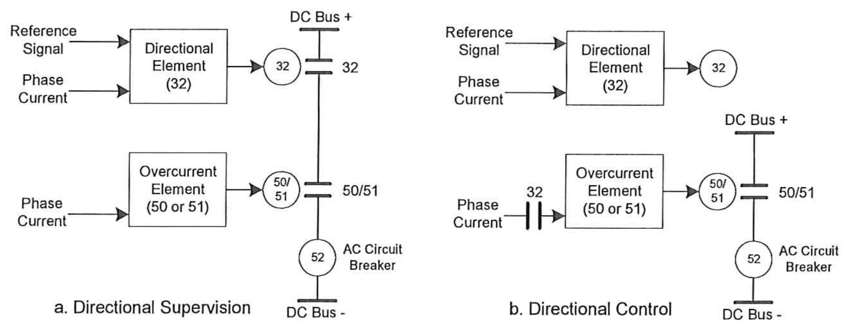


Directional Control vs Direction Supervision



Directional Step-Time Overcurrent (ANSI 67)

- The directional overcurrent relay can be perceived as a type 50 instantaneous element controlled by a type 32 directional element
- If the type 67 relay element is to provide backup protection, they use definite time delay for downstream coordination
- The 67 element requires more attention to detail for coordination than do type 51 relays
  - » The advantage that the stepped time has over the 51 is that the time steps are independently set.
  - » The disadvantage is that overreach errors have a more pronounced affect that often proves difficult to coordinate

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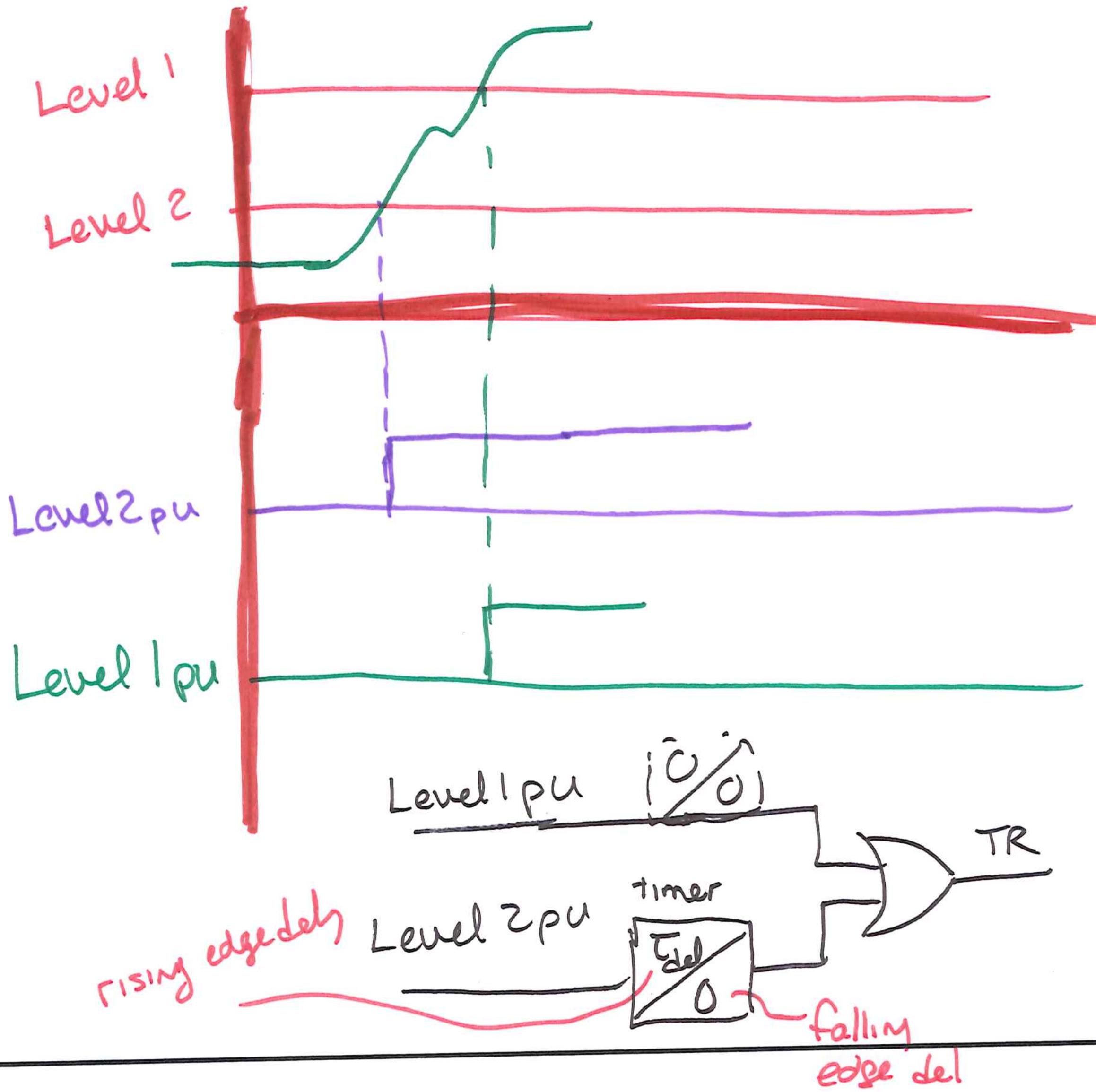
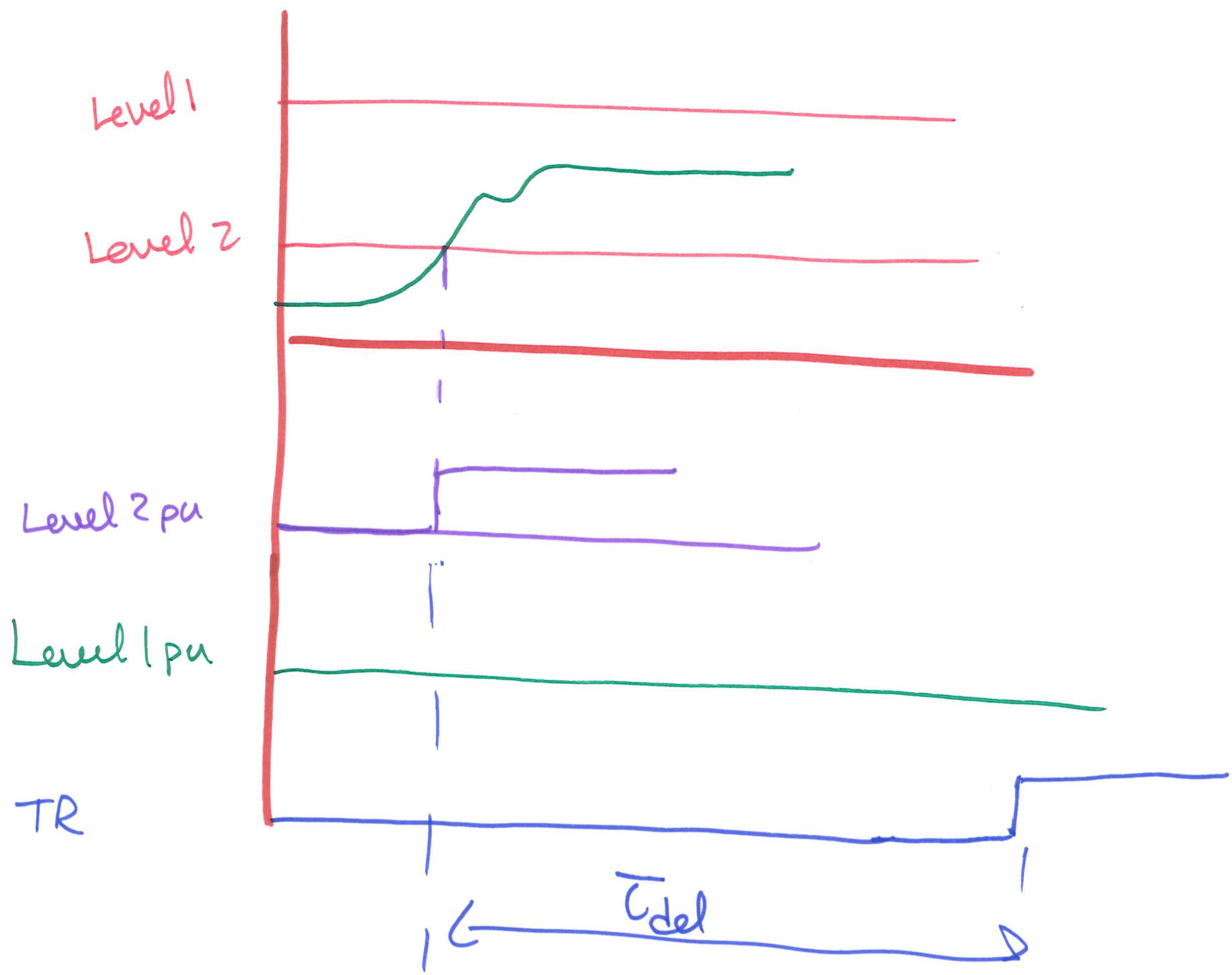
50 element




Level 1
Level 2
Level 2 pu
Level 1 pu
TR
τ_{del}

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Digital Filter Examples

- Define sampling rate per cycle

  $RS := 16$ — full cycle digital filter

- Define length of sample data set, in cycles

  $CY := 8$

- Total number of samples:

  $M := CY \cdot RS$

  $n := 0, 1 .. (M - 1)$

  $\Delta t := \dfrac{1}{RS \cdot 60Hz}$ $\quad \Delta t = 1.042\,ms$ $\quad t_n := 0, \Delta t .. n \cdot \Delta t$

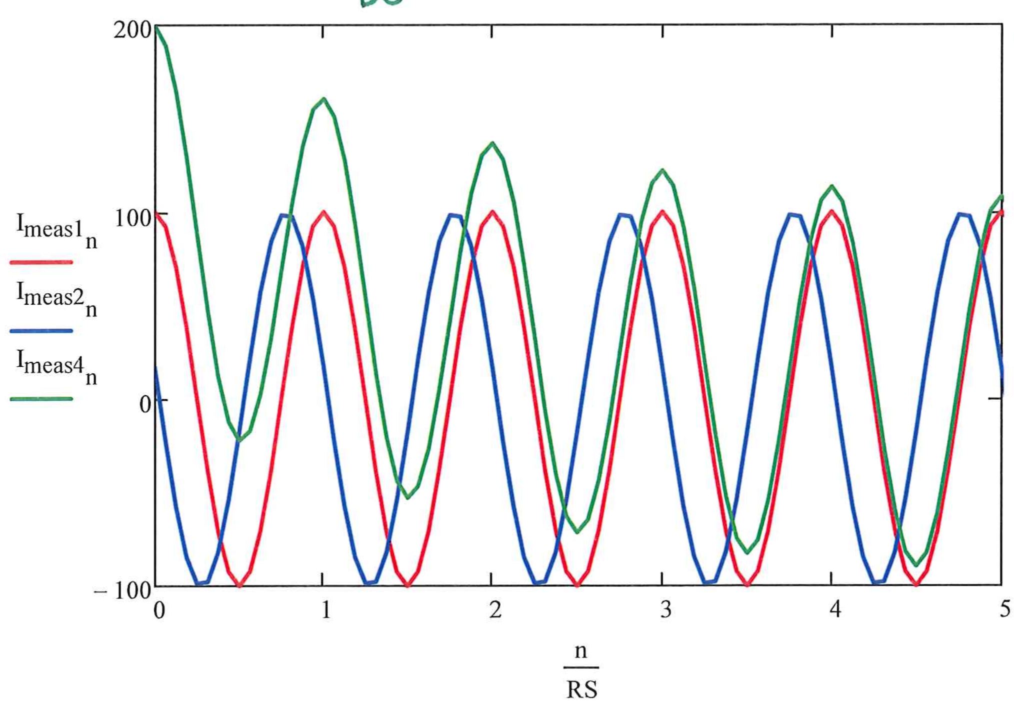
- Create input data signal, sampled at RS per cycle

$I_{meas1_n} := 100 \cdot \cos\left(\dfrac{2 \cdot \pi \cdot n}{RS} + 0deg\right)$ "ωt"

$I_{meas2_n} := 100 \cdot \cos\left(\dfrac{2 \cdot \pi \cdot n}{RS} + 80deg\right)$

$I_{meas3_n} := 100 \cdot \cos\left(\dfrac{2 \cdot \pi \cdot n}{RS}\right) + 50$ DC offset

$I_{meas4_n} := 100 \cdot \left(\cos\left(\dfrac{2 \cdot \pi \cdot n}{RS} + 0deg\right) + e^{\frac{-n}{2RS}}\right)$ decaying dc offset



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- Lets look at the Cosine Filter Coefficients:

$k_4 := 0, 1 .. (4-1)$ $\quad$ $k_8 := 0, 1 .. (8-1)$ $\quad$ $k_{16} := 0, 1 .. (16-1)$ $\quad$ $k_{32} := 0, 1 .. (32-1)$

weighting coef

$$\cos_{coef}(k, RS) := \cos\left(\frac{2 \cdot \pi \cdot k}{RS}\right)$$

$\cos_{coef}(k_4, 4) =$

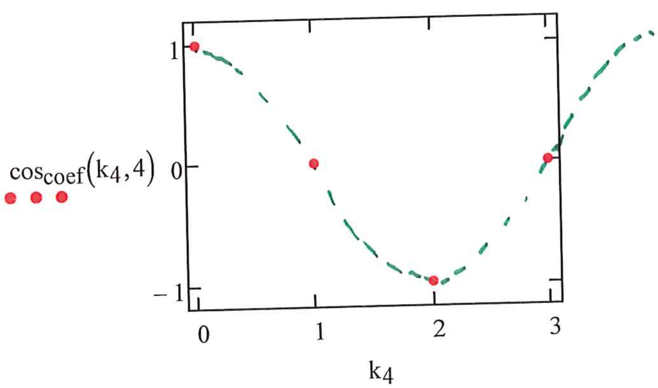
1
0
-1
0

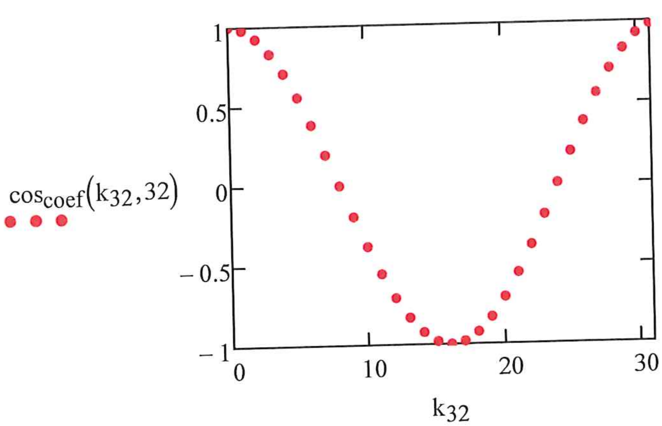
$\cos_{coef}(k_8, 8) =$

1
0.707
0
-0.707
-1
-0.707
0
0.707

$\cos_{coef}(k_{16}, 16) =$

1
0.924
0.707
0.383
0
-0.383
-0.707
-0.924
-1
-0.924
-0.707
-0.383
0
0.383
0.707
0.924





- Now lets look at the Sine Filter Coefficients:

$$\sin_{coef}(k, RS) := \sin\left(\frac{2 \cdot \pi \cdot k}{RS}\right)$$

$\sin_{coef}(k_4, 4) =$

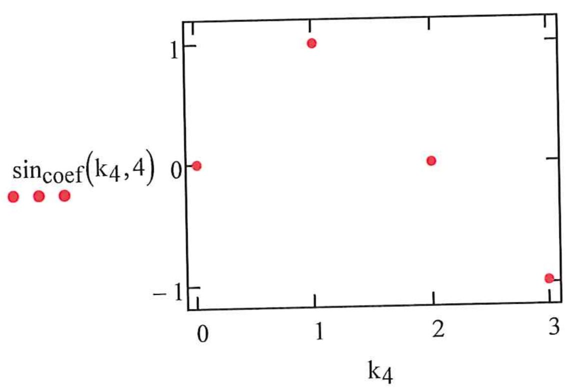
0
1
0
-1

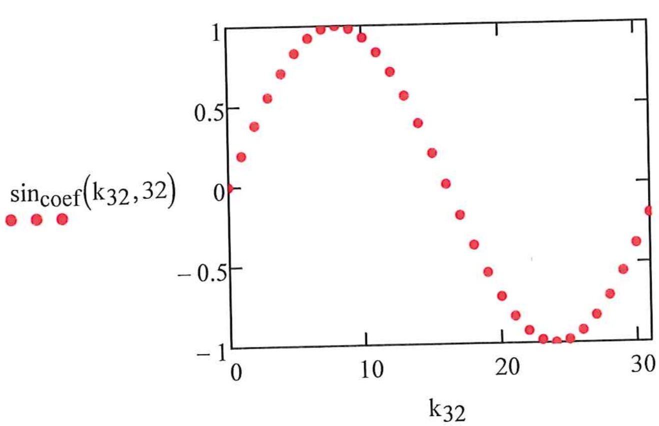
$\sin_{coef}(k_8, 8) =$

0
0.707
1
0.707
0
-0.707
-1
-0.707

$\sin_{coef}(k_{16}, 16) =$

0
0.383
0.707
0.924
1
0.924
0.707
0.383
0
-0.383
-0.707
-0.924
-1
-0.924
-0.707
-0.383





Be able to apply Eulers indentity to sampled waveform

cos + j sin

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Now define Cosine and Sine filters → moving window 1 cycle long

$$COSF(RS, A, q) := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[cos_{coef}(k, RS) \cdot A_{[q-(RS-1)]+k}\right]$$

waveform data; sample index

$$SINF(RS, A, q) := \frac{2}{RS} \cdot \sum_{k=0}^{RS-1} \left[sin_{coef}(k, RS) \cdot A_{[q-(RS-1)]+k}\right]$$

- Create a filter index, "i" (which includes RS samples of past history (so it starts at (RS - 1))

$i := (RS - 1) .. M - 1$

- Create a filter index, "v" (which includes RS/4 samples of past history for delaying cosine filter output put a quarter cycle (so it starts at (RS/4 - 1))

$$v := \left(RS + \frac{RS}{4} - 1\right) .. M - 1$$

¼ cycle (90°) offset

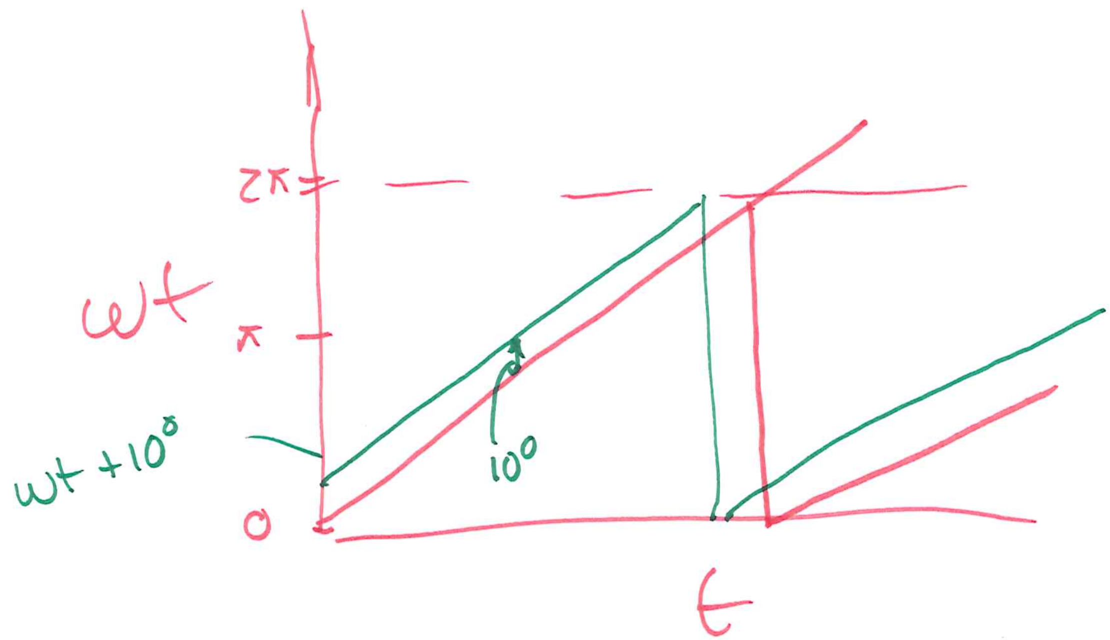
$COSF(RS, I_{meas1}, i) =$

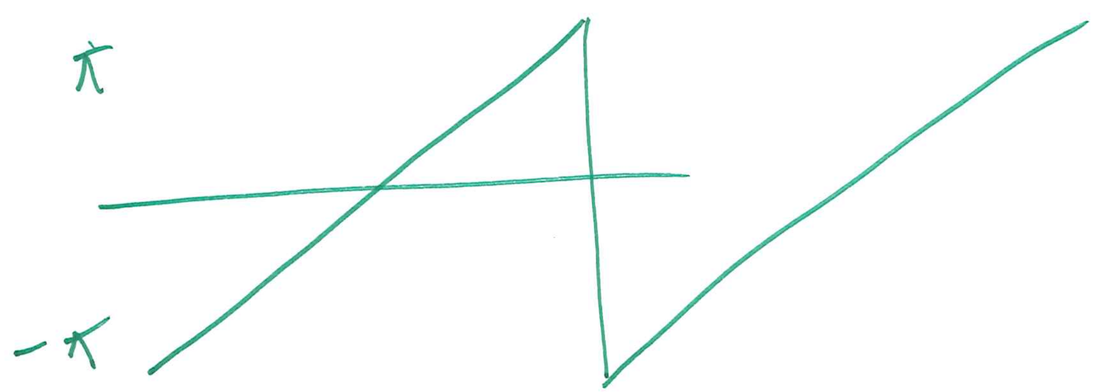
100
92.388
70.711
38.268
0
-38.268
-70.711
-92.388
-100
-92.388
-70.711
-38.268
0
38.268
70.711
...

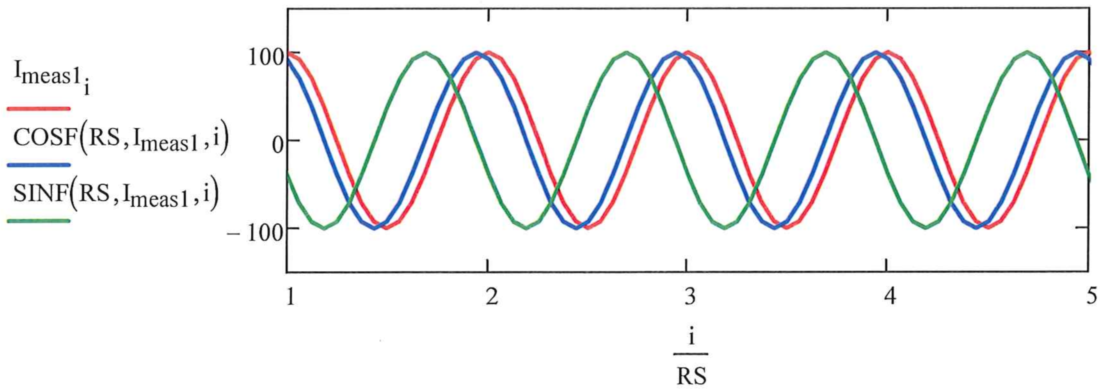
$SINF(RS, I_{meas1}, i) =$

0
-38.268
-70.711
-92.388
-100
-92.388
-70.711
-38.268
0
38.268
70.711
92.388
100
92.388
70.711
...

$\cos(\omega t)$ $\cos(\omega t + 10^\circ)$



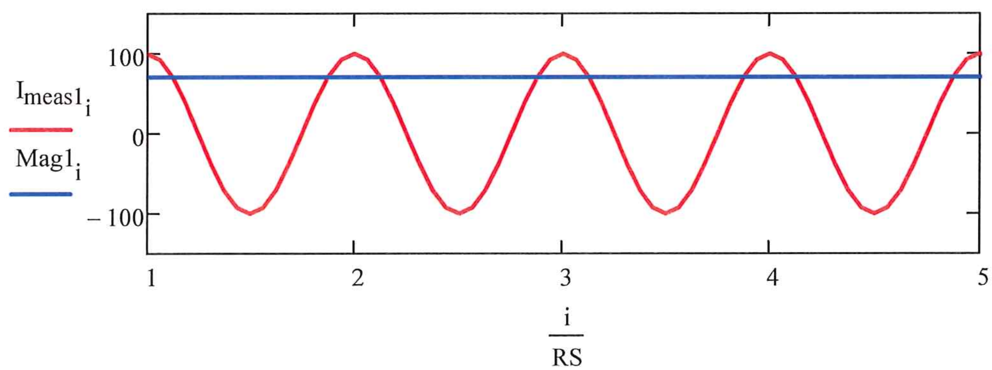


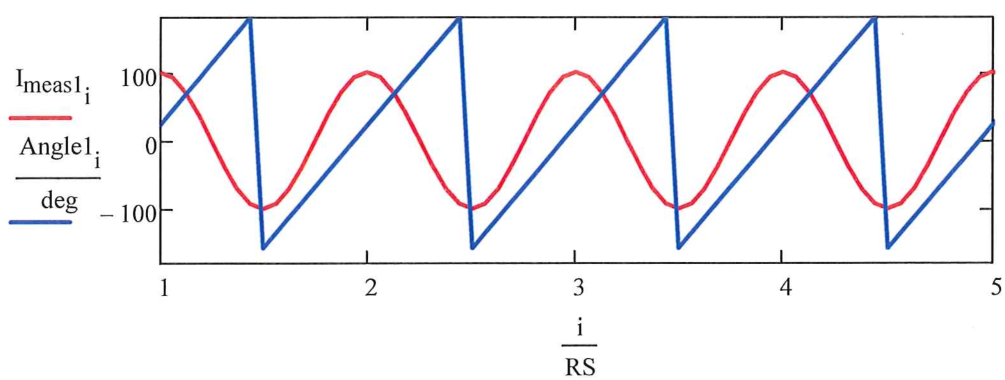


$$Phasor1_i := \frac{1}{\sqrt{2}}\left(COSF(RS, I_{meas1}, i) - j \cdot SINF(RS, I_{meas1}, i)\right)$$

$$Mag1_i := \left|Phasor1_i\right|$$

$$Angle1_i := arg(Phasor1_i)$$

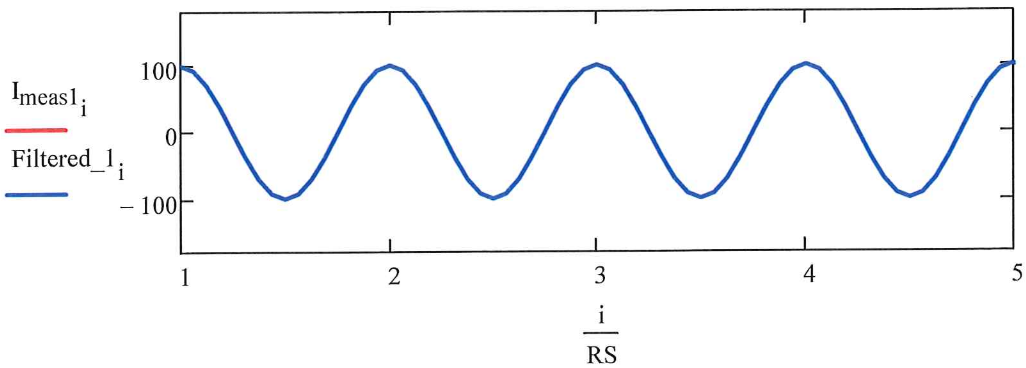




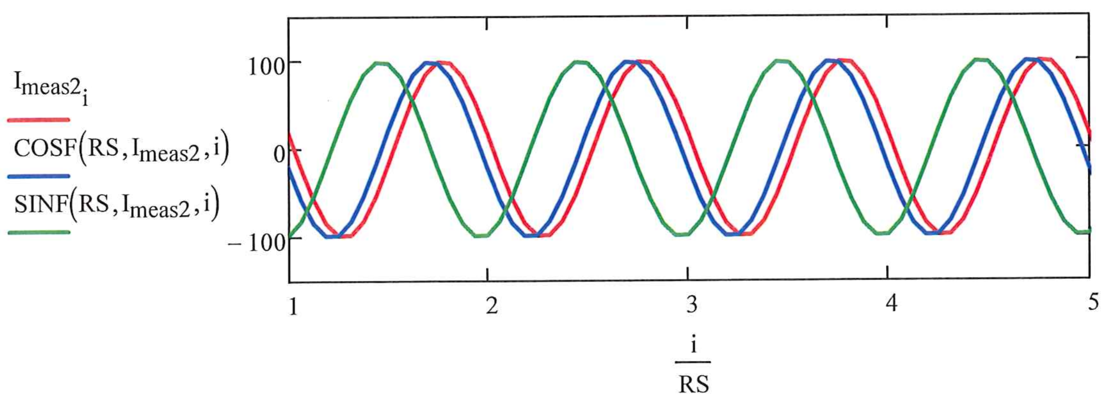
- So we need to compare this angle to a reference. In the case with only one measurement, we compare it to itself.

$$\theta 1_i := \text{Angle1}_i - \text{Angle1}_i$$

$$\text{Filtered\_1}_i := \sqrt{2}\cdot \text{Mag1}_i \cdot \cos\left[\left(\frac{2\cdot\pi\cdot i}{RS}\right) + \theta 1_i\right]$$



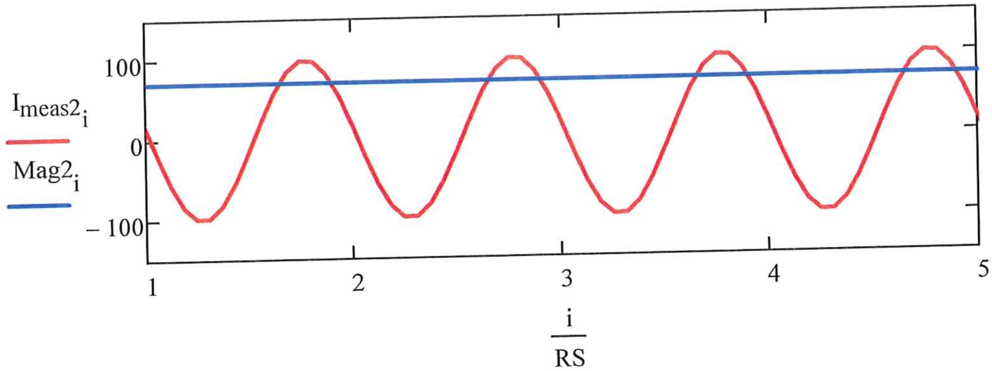
- Now repeat with the second signal, which is phase shifted

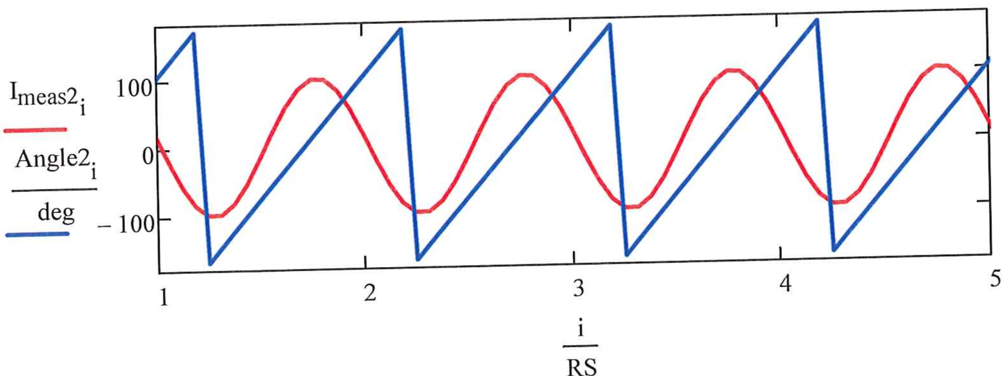


$$\text{Phasor2}_i := \frac{1}{\sqrt{2}}\left(\text{COSF}(RS, I_{meas2}, i) - j\cdot \text{SINF}(RS, I_{meas2}, i)\right)$$

$$\text{Mag2}_i := \left|\text{Phasor2}_i\right|$$

$$\text{Angle2}_i := \arg\left(\text{Phasor2}_i\right)$$



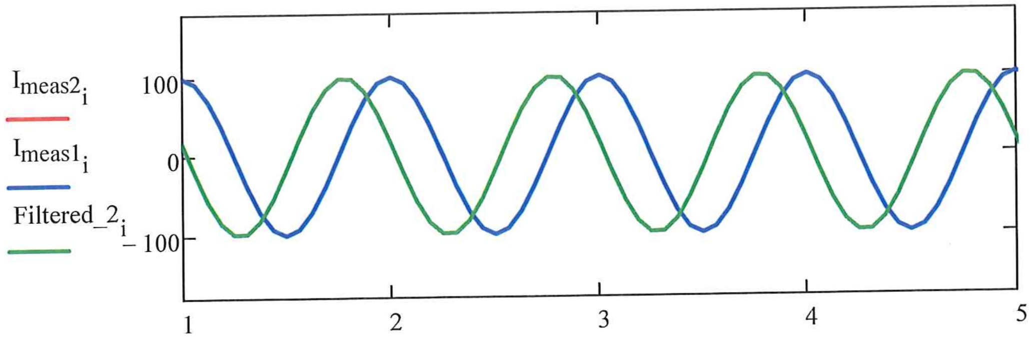


Tracks new angle

- So we need to compare this angle to a reference. In the case we'll use the first signal as a reference

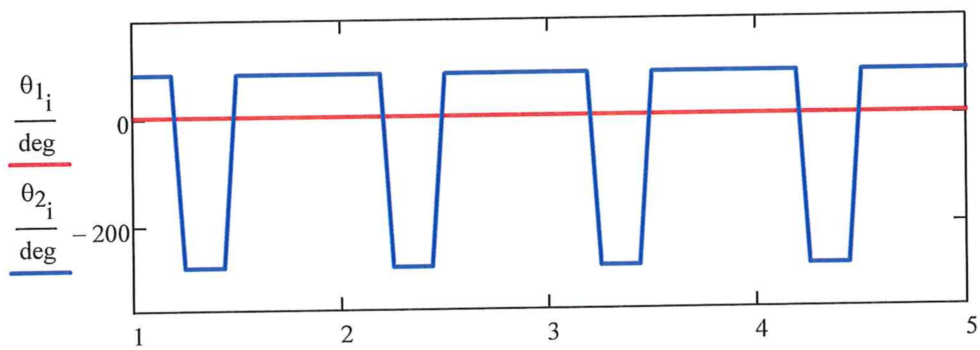
$$\theta 2_i := Angle2_i - Angle1_i$$

$$Filtered\_2_i := \sqrt{2} \cdot Mag2_i \cdot \cos\left[\left(\frac{2 \cdot \pi \cdot i}{RS}\right) + \theta 2_i\right]$$



Tracks the phase shift

Now plot the angle

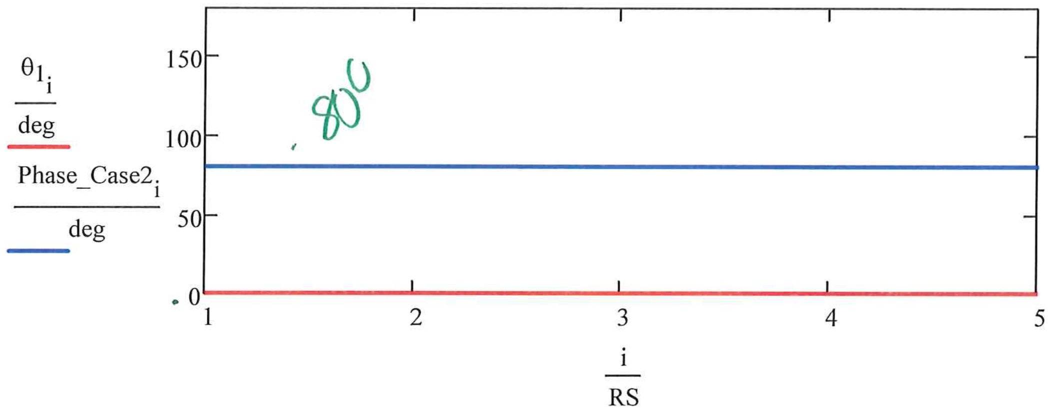


We have a problem in the angle due to the difference in reset times

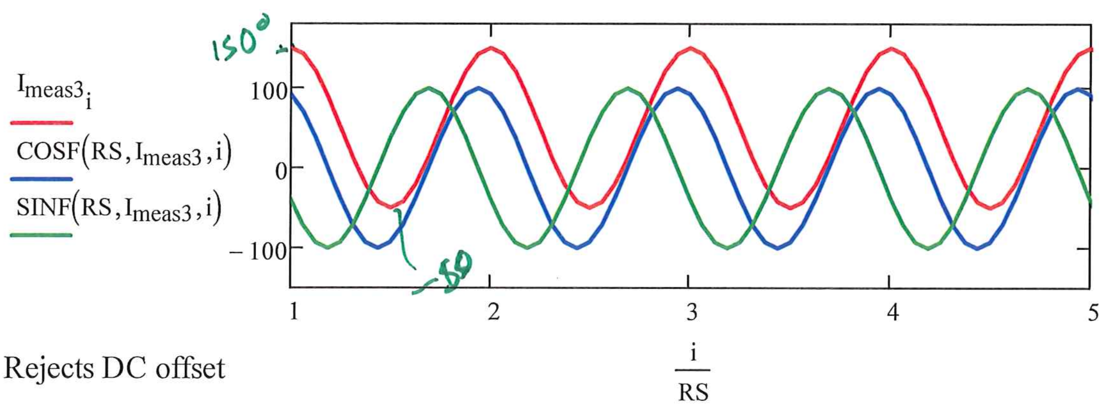
- Fix for the reset time issue:

$$Phase\_Case2_i := \begin{cases} Angle2_i - Angle1_i & \text{if } |Angle2_i - Angle1_i| < \pi \\ Angle2_i - Angle1_i - 2\cdot\pi & \text{if } (Angle2_i - Angle1_i) > \pi \\ Angle2_i - Angle1_i + 2\cdot\pi & \text{if } Angle2_i - Angle1_i < -(\pi) \end{cases}$$

If then else



- Now repeat with the third signal, which has a constant dc offset

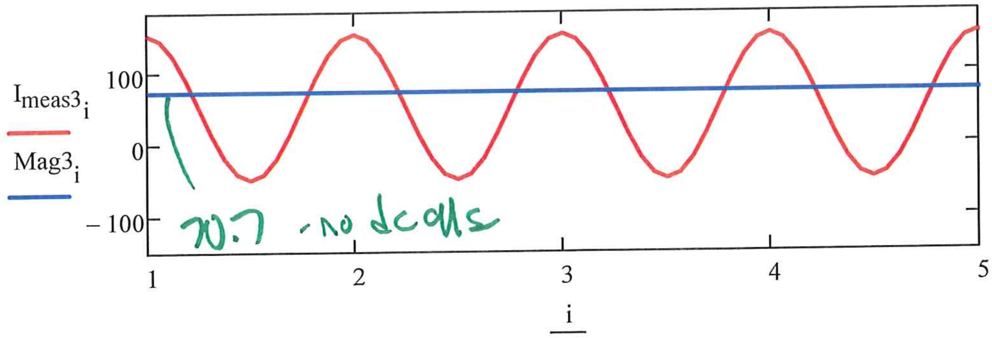


- Rejects DC offset

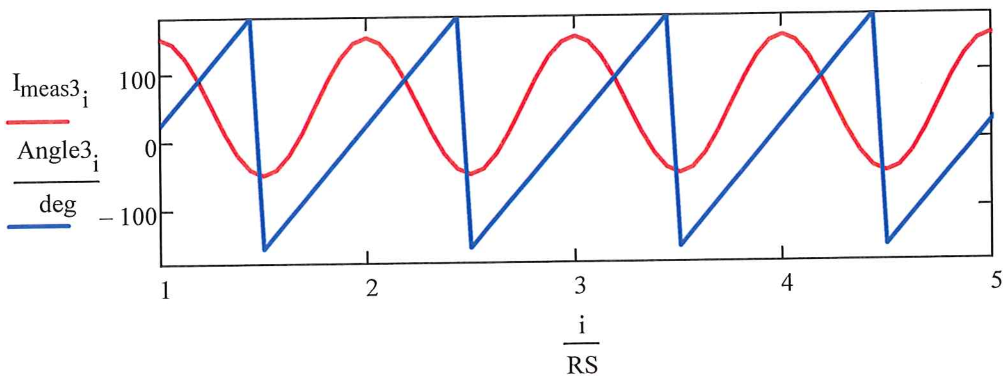
$$Phasor3_i := \frac{1}{\sqrt{2}}\left(COSF\left(RS, I_{meas3}, i\right) - j \cdot SINF\left(RS, I_{meas3}, i\right)\right)$$

$$Mag3_i := \left|Phasor3_i\right|$$

$$Angle3_i := arg\left(Phasor3_i\right)$$



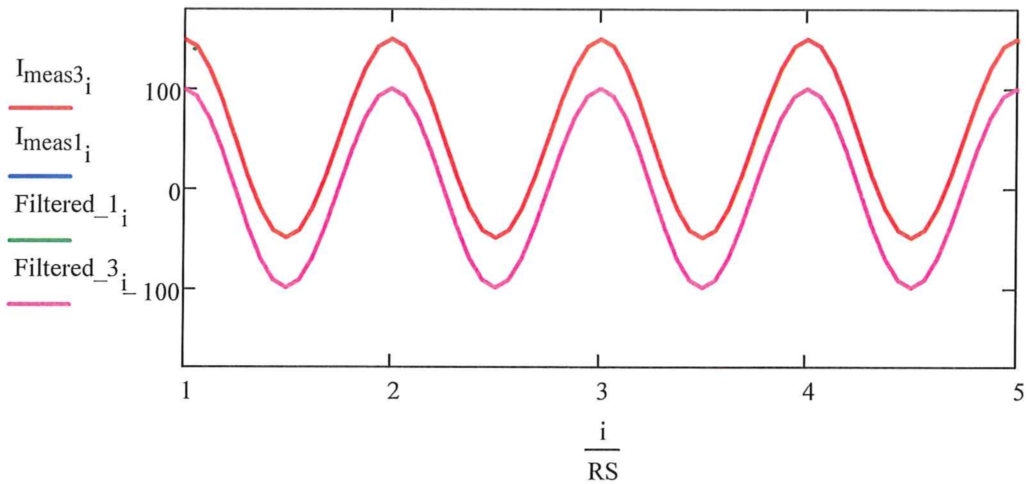
RMS magnitude of fundamental component



- Again need to compare this angle to a reference. In the case we'll use the first signal as a reference

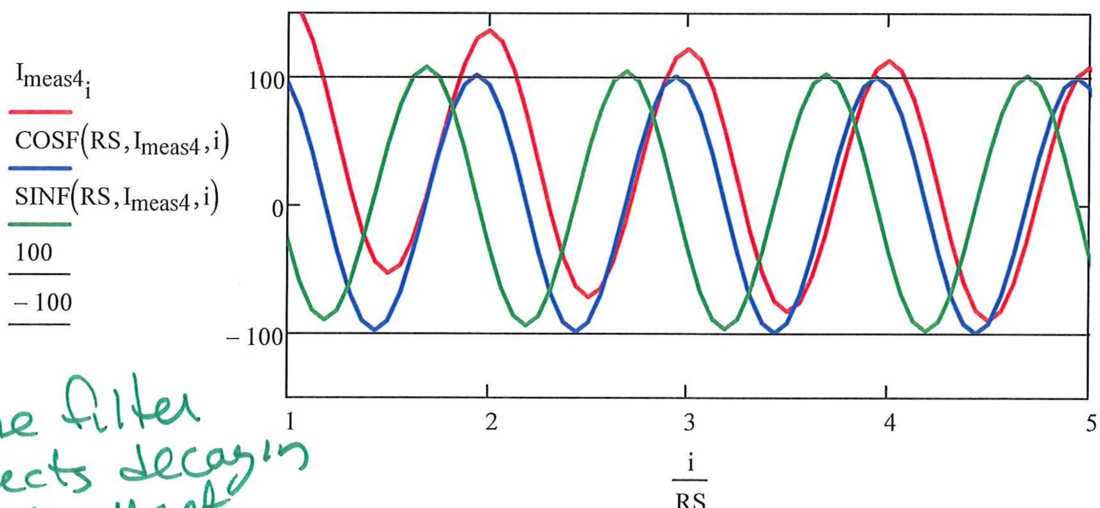
$$\theta 3_i := Angle3_i - Angle1_i$$

$$Filtered\_3_i := \sqrt{2} \cdot Mag3_i \cdot \cos\left[\left(\frac{2 \cdot \pi \cdot i}{RS}\right) + \theta 3_i\right]$$



Note the DC offset not in filtered results

- Now repeat with the fourth signal, which has a decaying DC offset.



cosine filter rejects decaying dc offset

Sine filer passing some (decaying) DC offset, but not cosine

$$Phasor4_i := \frac{1}{\sqrt{2}}\left(COSF\left(RS, I_{meas4}, i\right) - j \cdot SINF\left(RS, I_{meas4}, i\right)\right)$$

$$Mag4_i := \left|Phasor4_i\right|$$

$$Angle4_i := arg\left(Phasor4_i\right)$$

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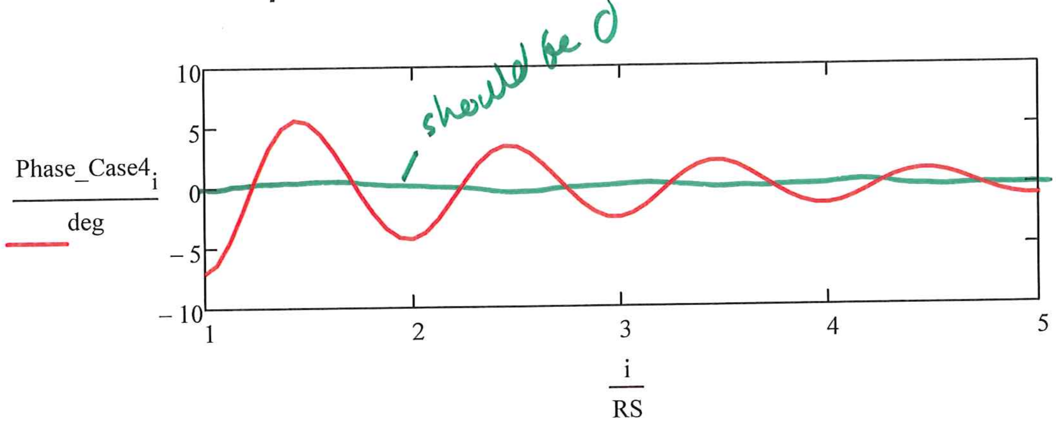
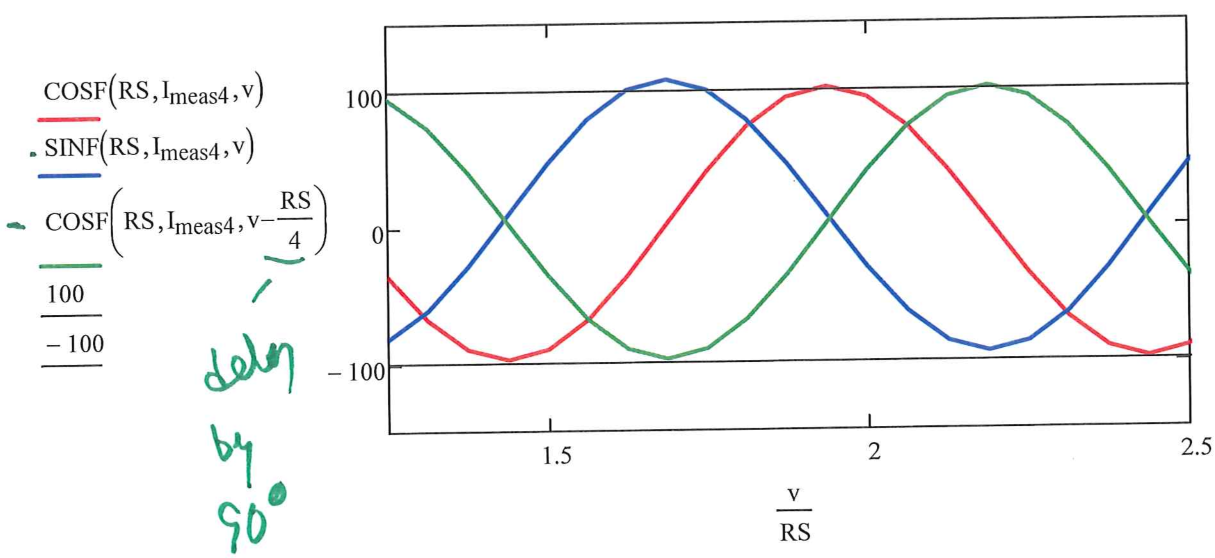
$$\text{Phase\_Case4}_i := \begin{cases} \text{Angle4}_i - \text{Angle1}_i & \text{if } \left|\text{Angle4}_i - \text{Angle1}_i\right| < \pi \\ \text{Angle4}_i - \text{Angle1}_i - 2\cdot\pi & \text{if } \left(\text{Angle4}_i - \text{Angle1}_i\right) > \pi \\ \text{Angle4}_i - \text{Angle1}_i + 2\cdot\pi & \text{if } \text{Angle4}_i - \text{Angle1}_i < -(\pi) \end{cases}$$



So still see decaying dc offset problem in angle calculation.

Alternative to using Sine Filter:

Note that delaying a cosine by 90 degrees (1/4 cycle) give a sine function

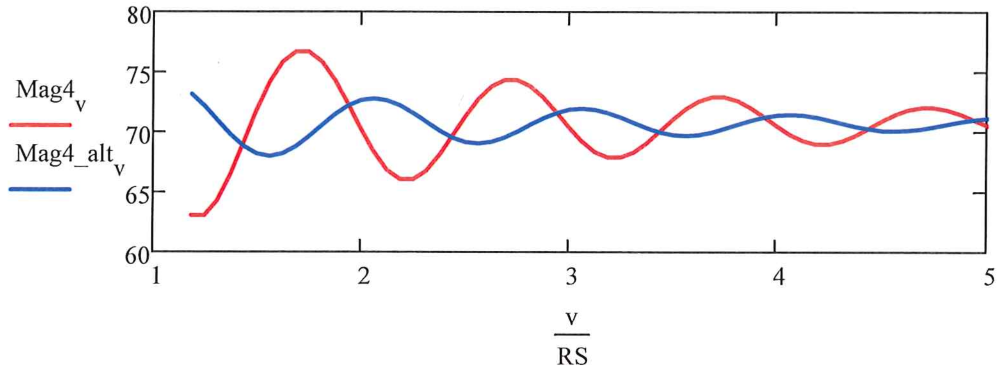


Note I'm changing index to "v" instead of "i" due to different starting point

$$\text{Phasor4\_alt}_v := \frac{1}{\sqrt{2}}\left(\text{COSF}\left(RS, I_{meas4}, v\right) + j\cdot\text{COSF}\left(RS, I_{meas4}, v - \frac{RS}{4}\right)\right)$$

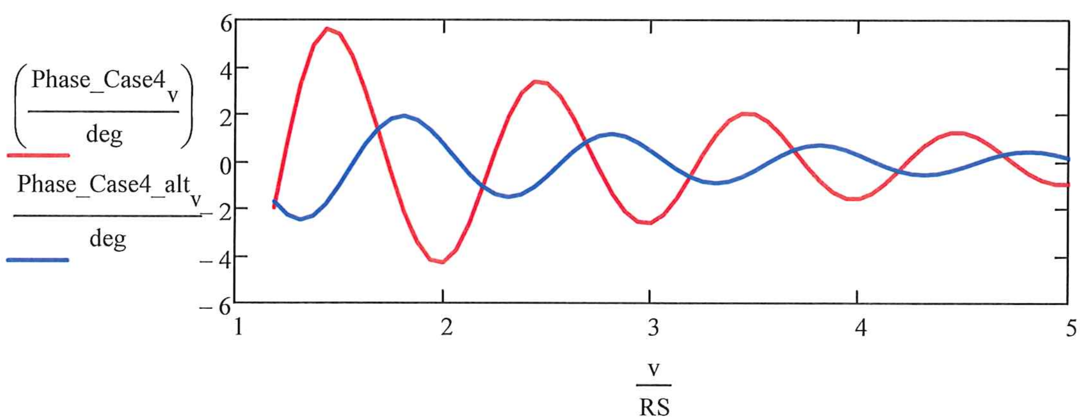
$$\text{Mag4\_alt}_v := \left|\text{Phasor4\_alt}_v\right|$$

$$\text{Angle4\_alt}_v := \arg\left(\text{Phasor4\_alt}_v\right)$$



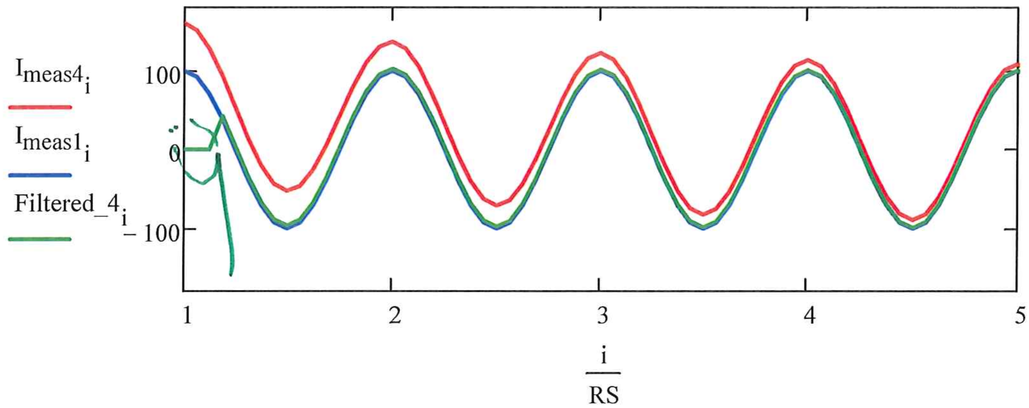
Magnitude has less error due to DC offset, but
cosine isn't perfect rejection either

$$\text{Phase\_Case4\_alt}_v := \begin{cases} \text{Angle4\_alt}_v - \text{Angle1}_v & \text{if } \left|\text{Angle4\_alt}_v - \text{Angle1}_v\right| < \pi \\ \text{Angle4\_alt}_v - \text{Angle1}_v - 2\cdot\pi & \text{if } \left(\text{Angle4\_alt}_v - \text{Angle1}_v\right) > \pi \\ \text{Angle4\_alt}_v - \text{Angle1}_v + 2\cdot\pi & \text{if } \text{Angle4\_alt}_v - \text{Angle1}_v < -(\pi) \end{cases}$$



Again, much better, but not perfect.

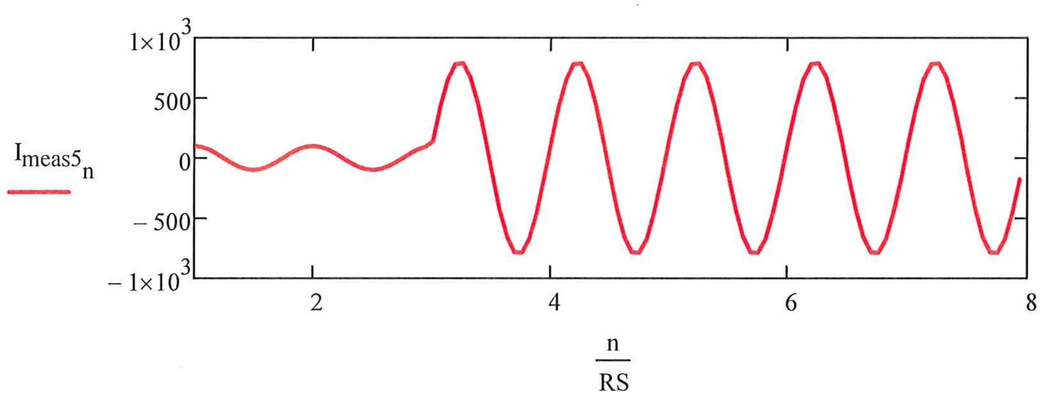
$$\text{Filtered\_4}_v := \sqrt{2}\cdot \text{Mag4\_alt}_v\cdot \cos\left[\left(\frac{2\cdot\pi\cdot v}{RS}\right) + \text{Phase\_Case4\_alt}_v\right]$$



DC offset largely removed, but not entirely

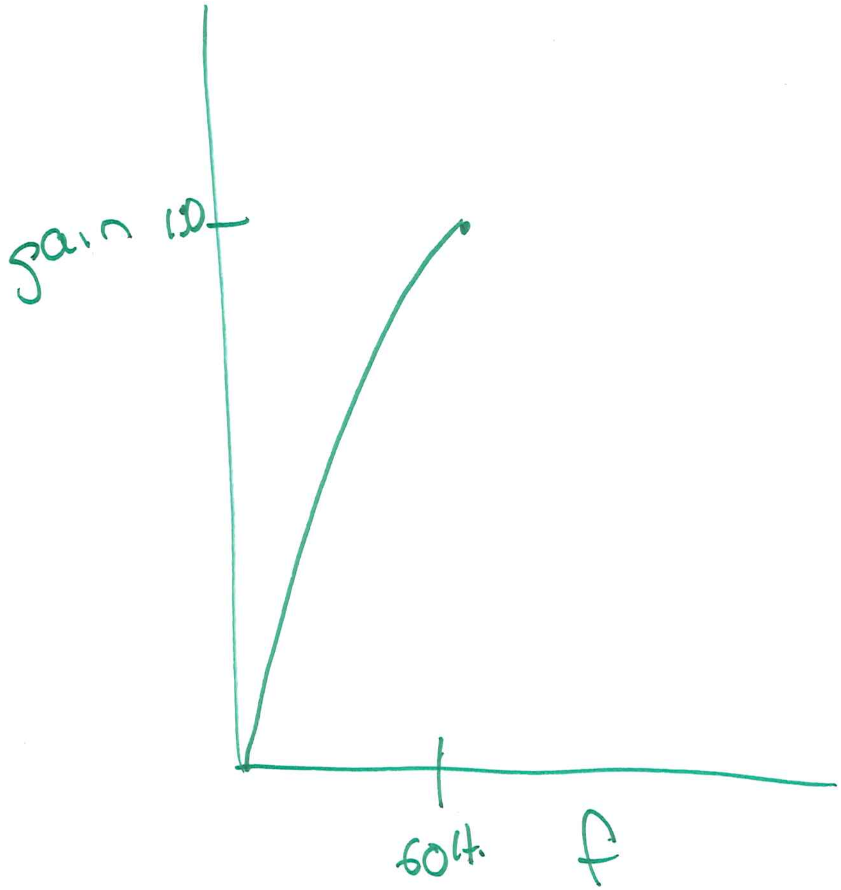
A few more cases:

$$I_{meas5_n} := \begin{cases} 100\cdot\cos\left(\frac{2\cdot\pi\cdot n}{RS} + 0\deg\right) & \text{if } 0 < n < 3\cdot RS \\ 800\cdot\cos\left[\frac{2\cdot\pi\cdot(n+2\cdot RS)}{RS} - 80\deg\right] & \text{otherwise} \end{cases}$$



$$\text{Phasor5}_v := \frac{1}{\sqrt{2}}\left(\text{COSF}\left(RS, I_{meas5}, v\right) + j\cdot\text{COSF}\left(RS, I_{meas5}, v - \frac{RS}{4}\right)\right)$$

$$\text{Mag5}_v := \left|\text{Phasor5}_v\right| \qquad \text{Angle5}_v := \arg\left(\text{Phasor5}_v\right)$$


gain
1.0
60Hz
f