University of Idaho

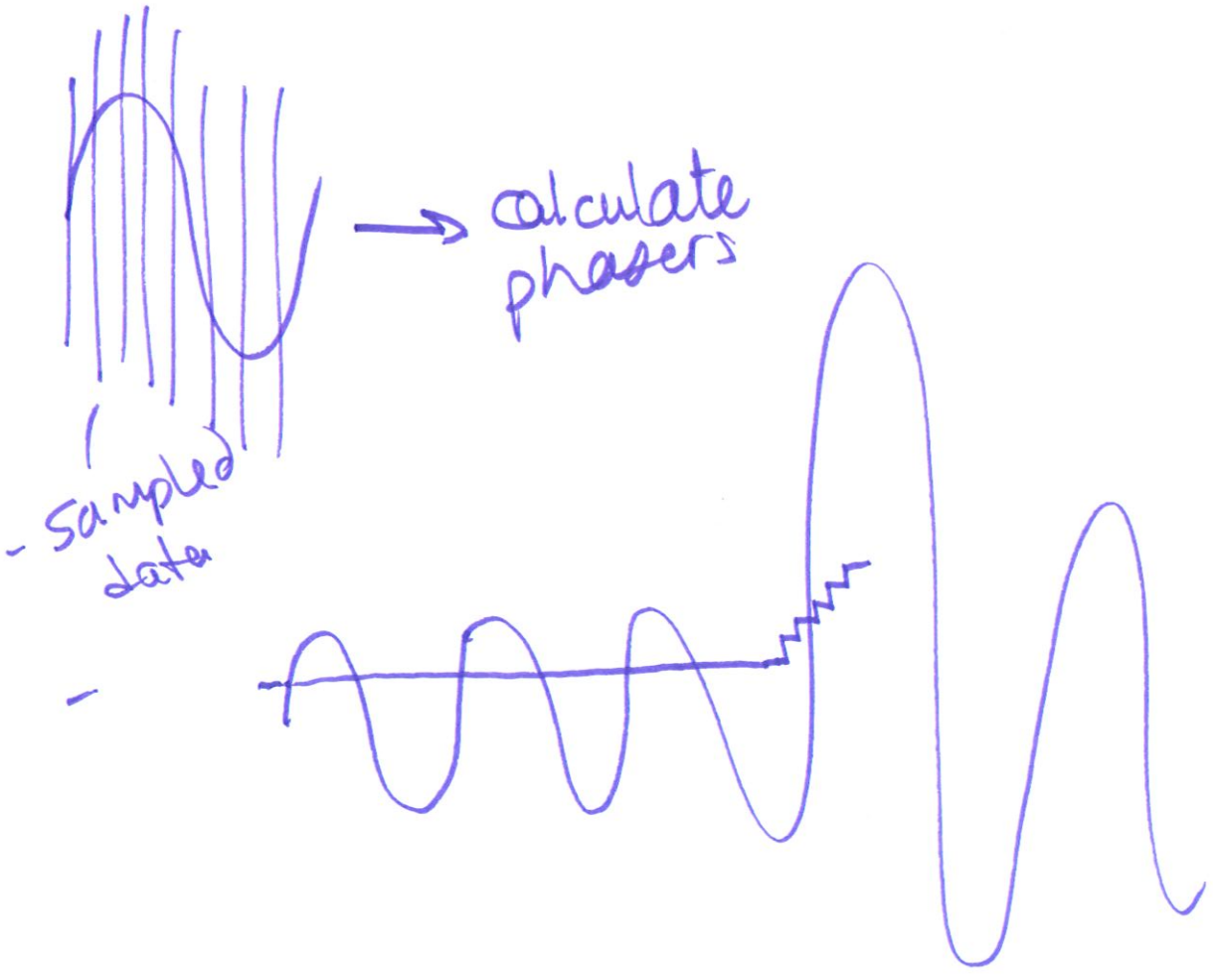
ECE 523
Symmetrical Components

Session 2

L2 1/29

U_I Off-Line Studies Versus Applying Measurements

- Normally applied using phasors
- Phasors have underlying assumption about frame of reference and frequency
- Measurement devices calculate RMS phasors and then transform
- Use of phasors only applies for quasi-steady-state analysis
- Some use of instantaneous terms, especially power electronic controls



LZ 2/20

Off-line applications of phasors & phasor calculations

- planning studies
  - power flow
  - stability
  - etc.
- fault studies
- Equipment rating
- setting protective devices
- post event analysis

LZ 3/20

measurements based applications

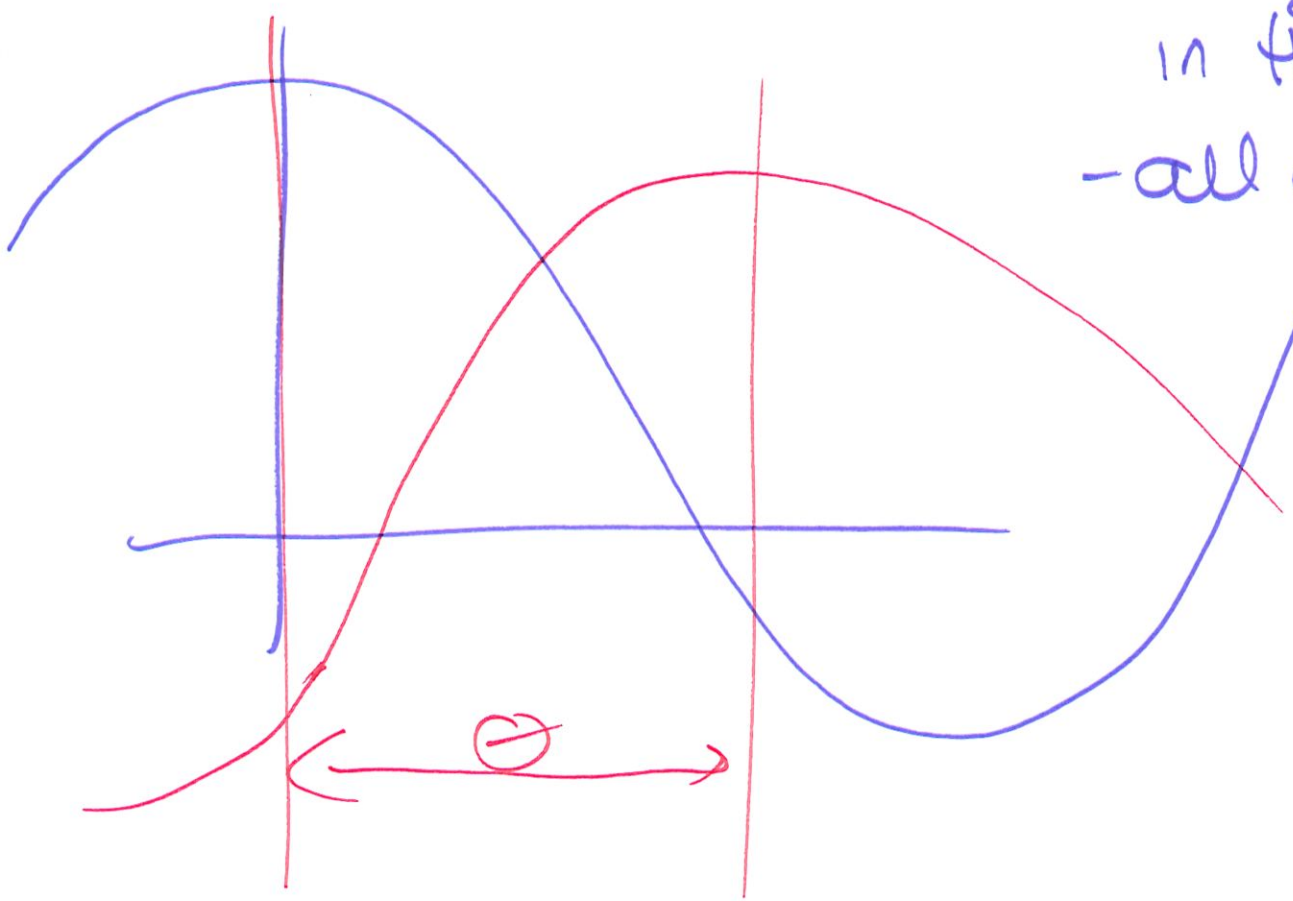
- real time control & protection
- event recording
- fault locations

L2 4/20

Phasors in measurements

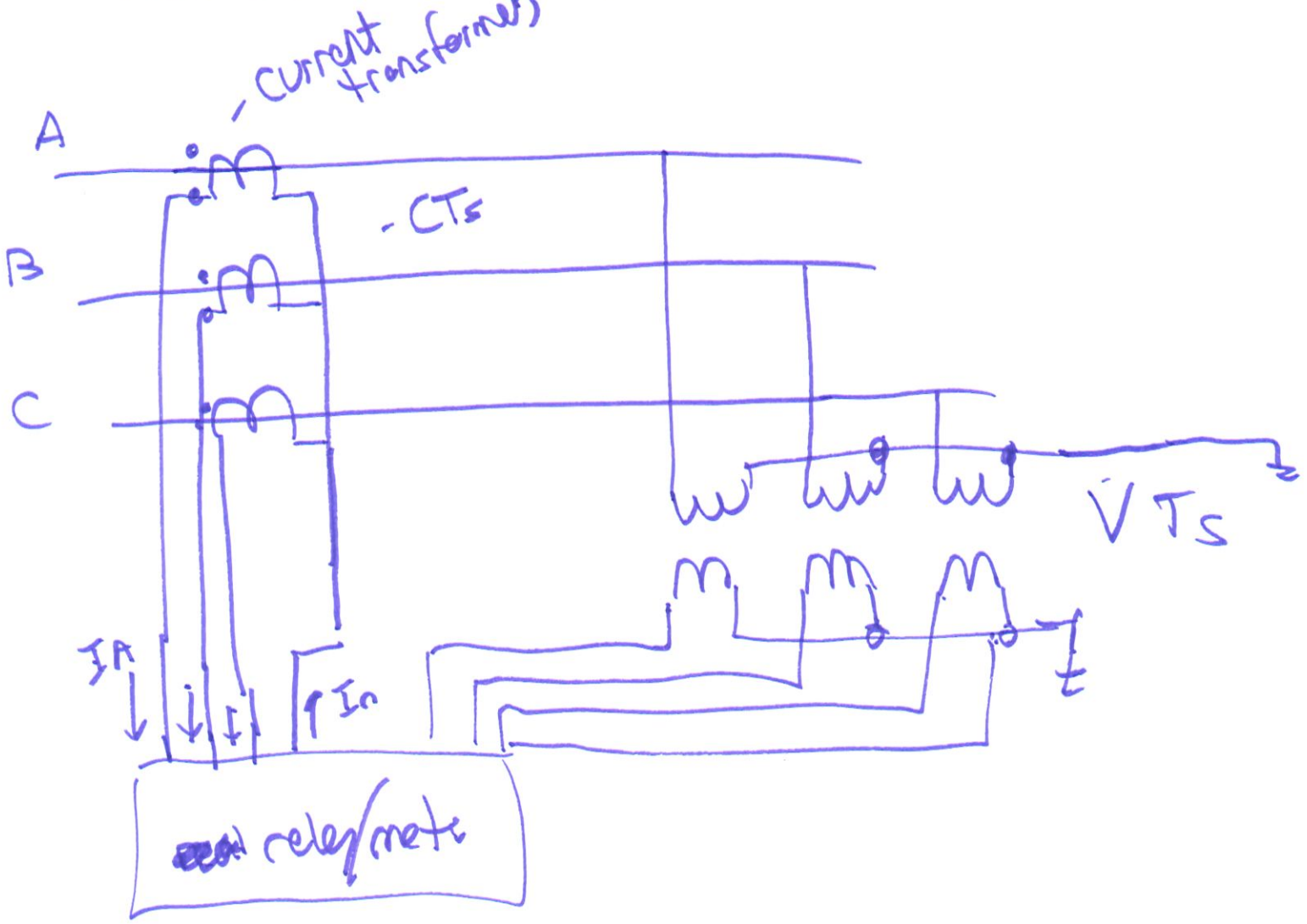
- Ayle reference?

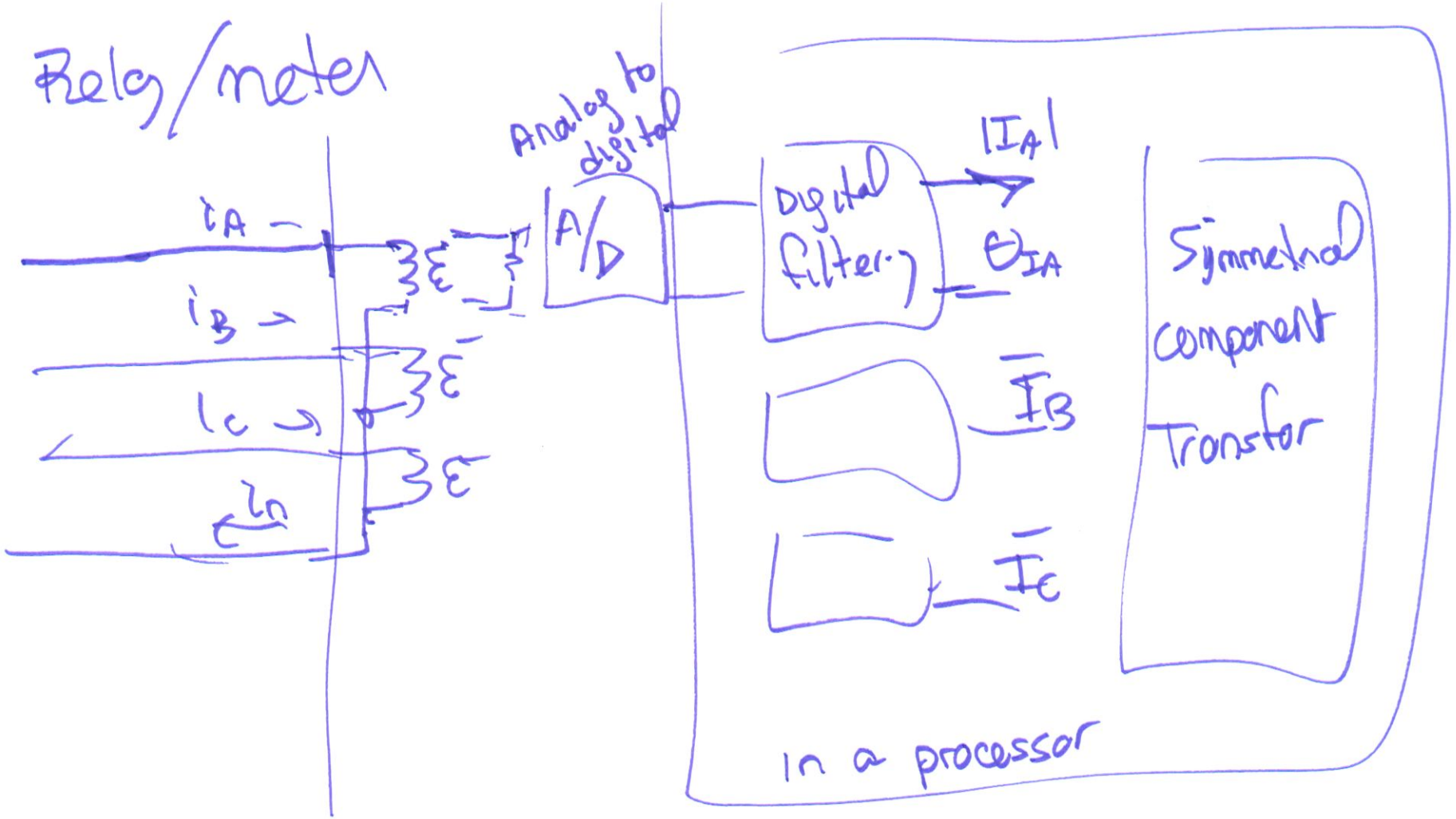
- voltage measurement in the metering device
- all phasors are relative to that voltage



L 2 5/20

measurement sequence




Relay/meter
Analog to digital
i_A
i_B
i_C
i_n
A/D
Digital filtering
$|I_A|$
θ_{IA}
$\bar{I}_B$
$\bar{I}_C$
Symmetrical component Transfor
in a processor

- Lets look at the Cosine Filter Coefficients:

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

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

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

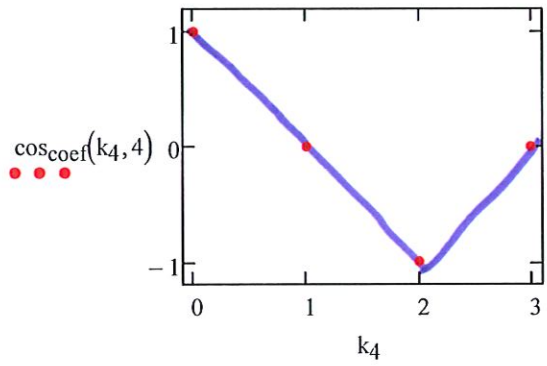
1
0
-1
0

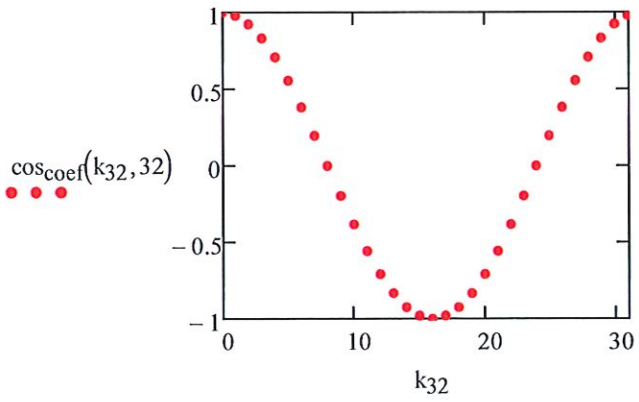
$\cos_{coef}(k_8, 8) =$

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





L2 8/29

Digital Filter Examples

- Define sampling rate per cycle

  $RS := 16$

- Define length of sample data set, in cycles

  $D := 8$

- Total number of samples:

  $M := D \cdot RS$

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

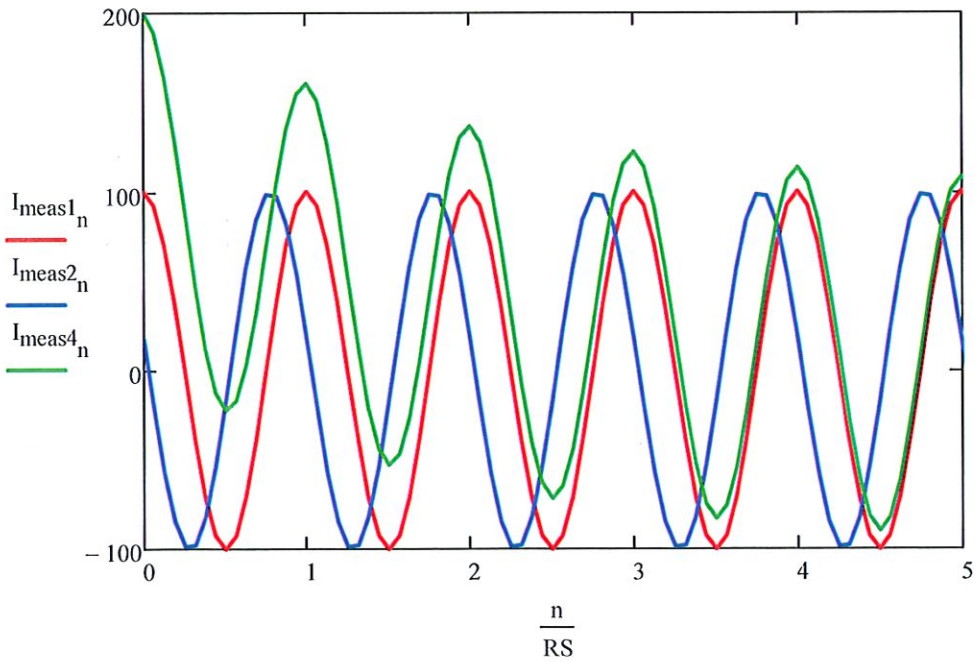
- Create input data signal, sampled at RS per cycle

$$I_{meas1_n} := 100 \cdot \cos\left(\frac{2 \cdot \pi \cdot n}{RS} + 0deg\right) \qquad I_{meas2_n} := 100 \cdot \cos\left(\frac{2 \cdot \pi \cdot n}{RS} + 80deg\right)$$

$$I_{meas3_n} := 100 \cdot \cos\left(\frac{2 \cdot \pi \cdot n}{RS}\right) + 50 \qquad I_{meas4_n} := 100 \cdot \left(\cos\left(\frac{2 \cdot \pi \cdot n}{RS} + 0deg\right) + e^{\frac{-n}{2RS}}\right)$$

constant offset

decaying dc offset



Now define Cosine and Sin filters

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

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

- 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))

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

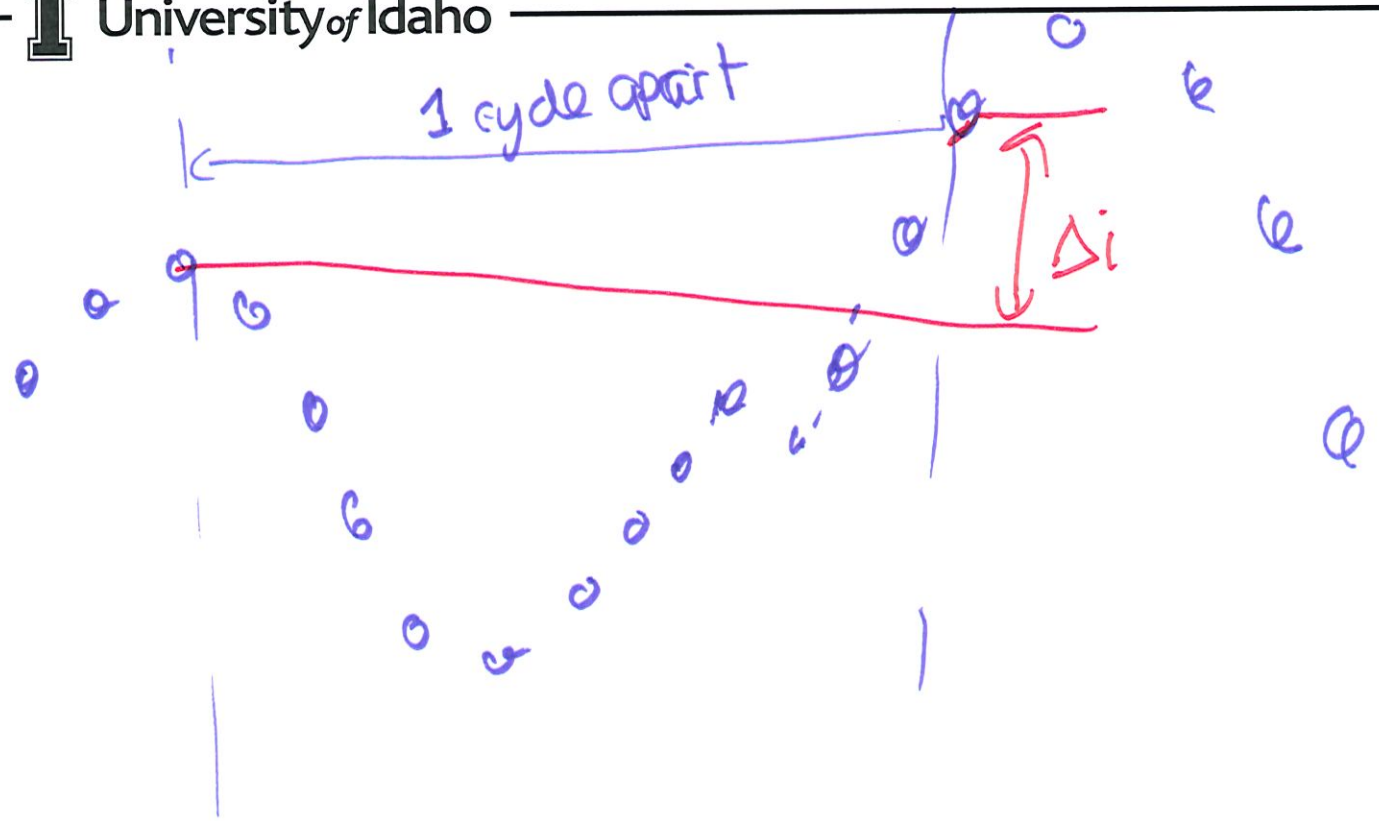
$COSF(RS, I_{meas1}, i) =$

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
...

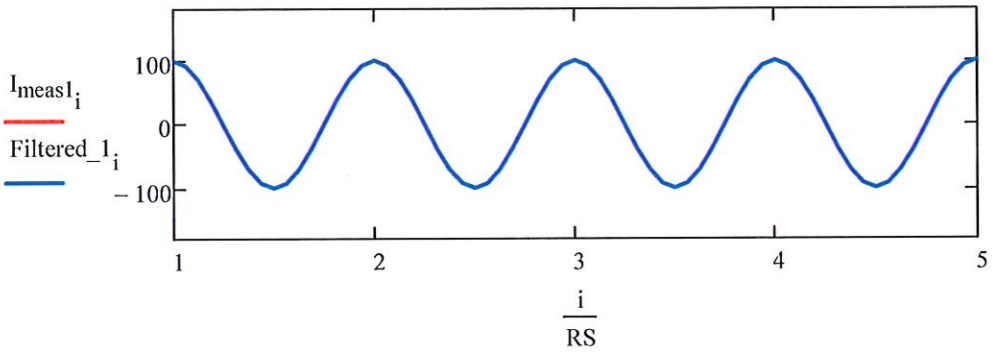
LZ 10/20



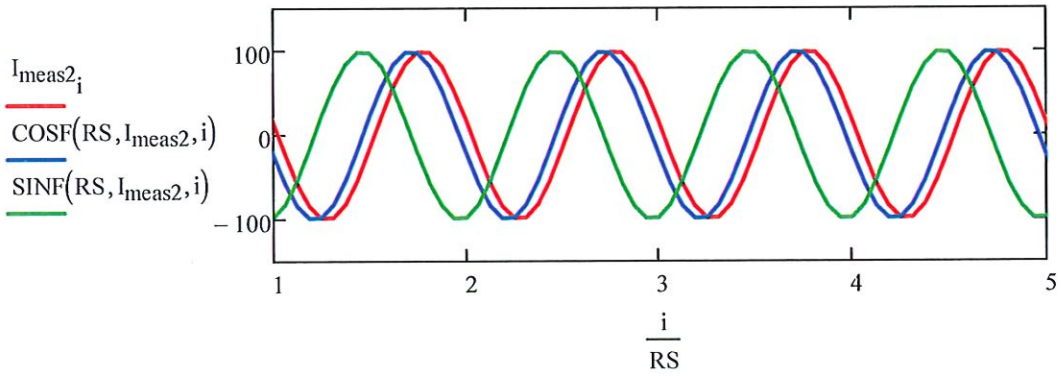
- So we need to compare this angle to a reference. In the case with only one measurement, we compare it to itself.

$$\theta 1_i := Angle1_i - Angle1_i$$

$$Filtered\_1_i := \sqrt{2} \cdot Mag1_i \cdot \cos\left[\left(\frac{2 \cdot \pi \cdot i}{RS}\right) + \theta 1_i\right]$$



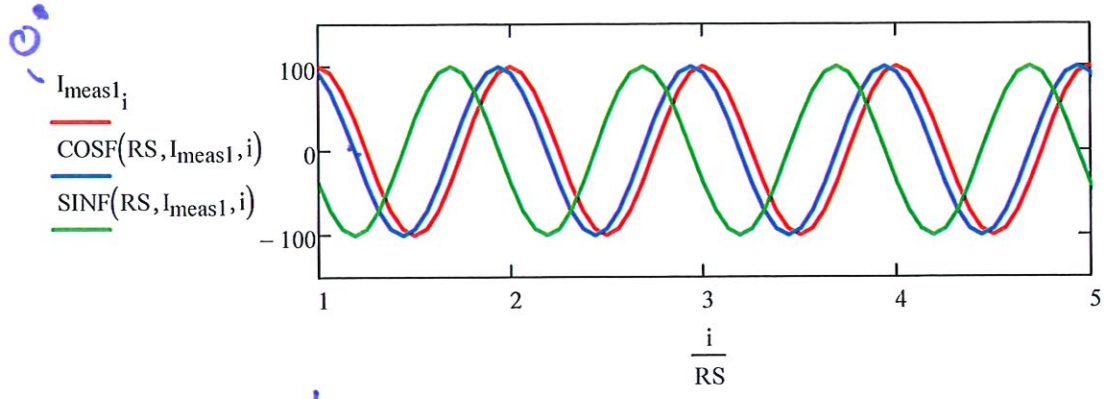
- Now repeat with the second signal, which is phase shifted



$$Phasor2_i := \frac{1}{\sqrt{2}}\left(COSF(RS, I_{meas2}, i) - j \cdot SINF(RS, I_{meas2}, i)\right)$$

$$Mag2_i := \left|Phasor2_i\right|$$

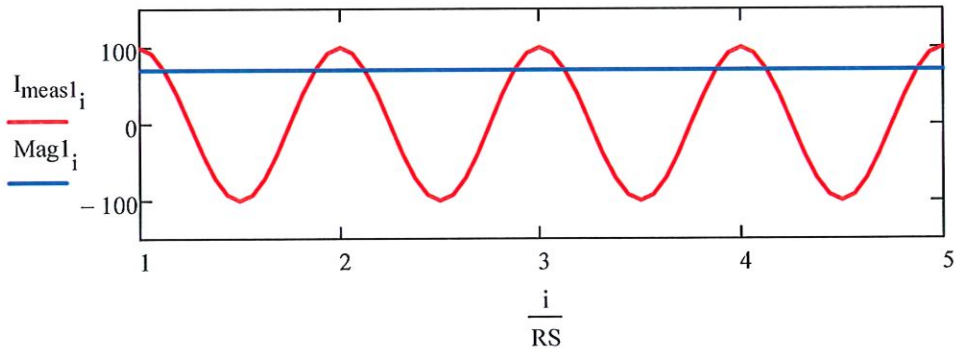
$$Angle2_i := \arg\left(Phasor2_i\right)$$

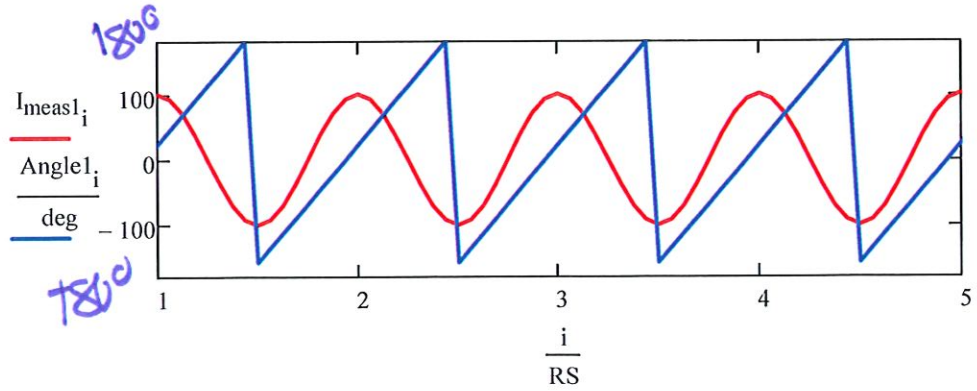


$$Phasor1_i := \frac{1}{\sqrt{2}}\left(COSF(RS, I_{meas1}, i) - j \cdot SINF(RS, I_{meas1}, i)\right)$$

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

$$Angle1_i := \arg\left(Phasor1_i\right)$$



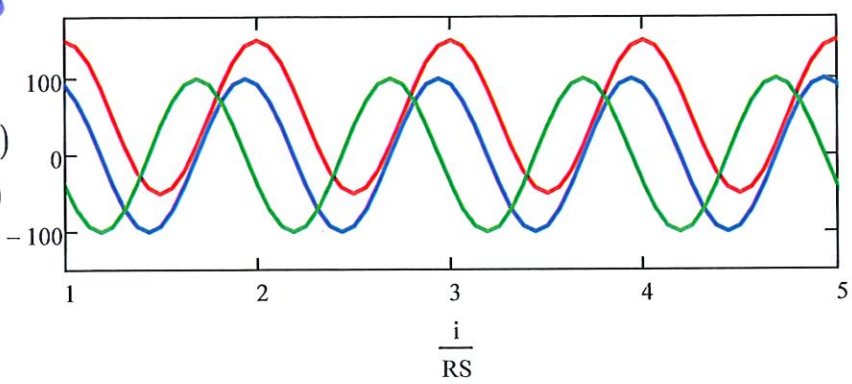


- Now repeat with the third signal, which has a constant dc offset

I_{meas3_i}

$COSF(RS, I_{meas3}, i)$

$SINF(RS, I_{meas3}, i)$

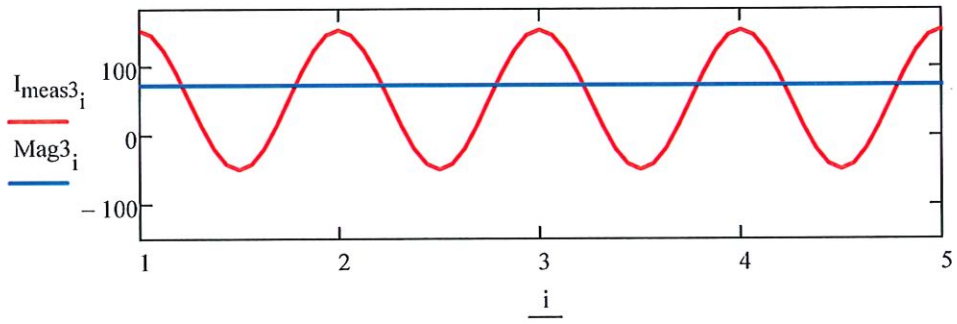


- Rejects DC offset

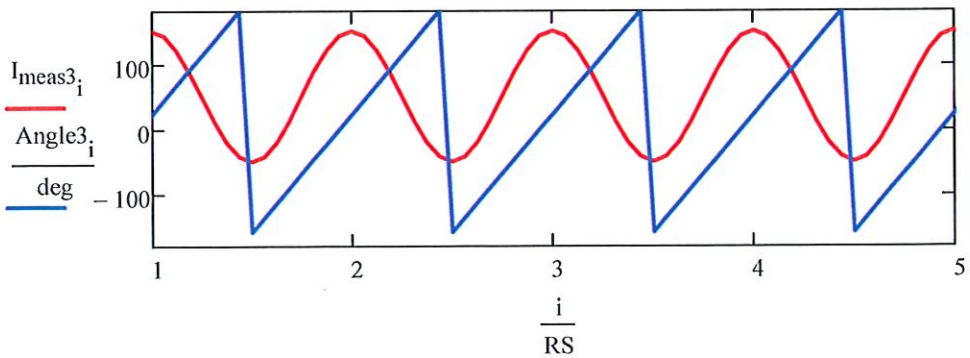
$$Phasor3_i := \frac{1}{\sqrt{2}}\left(COSF(RS, I_{meas3}, i) - j \cdot SINF(RS, I_{meas3}, i)\right)$$

$$Mag3_i := |Phasor3_i|$$

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



RMS magnitude of fundamental component

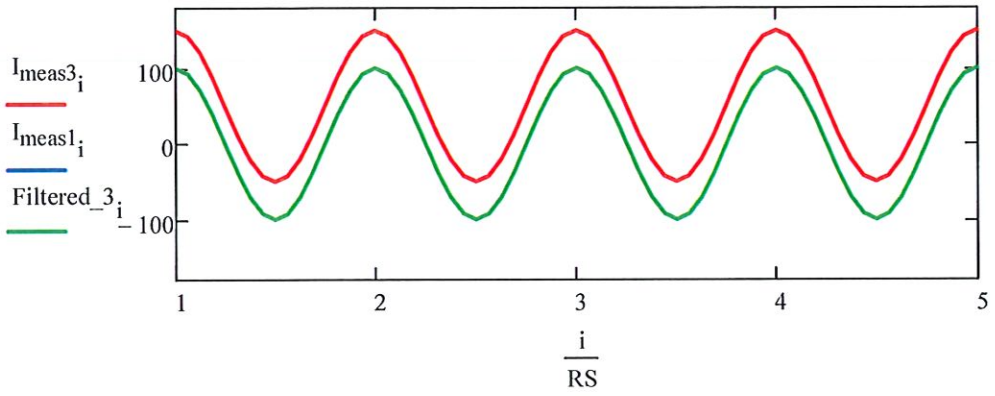


LZ 14/20

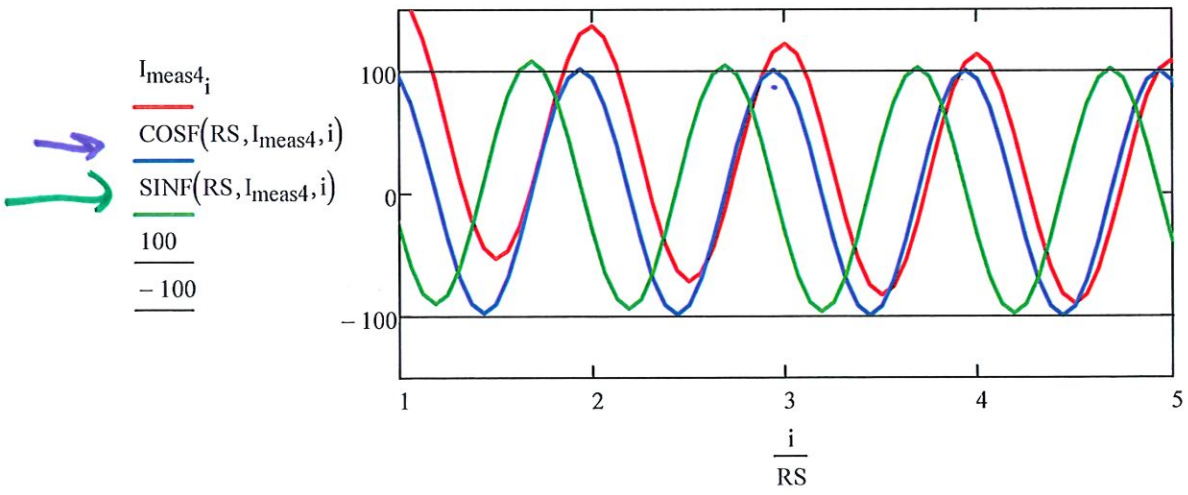
- So we need to compare this angle to a reference. In the case we'll use the first signal as a reference

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

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



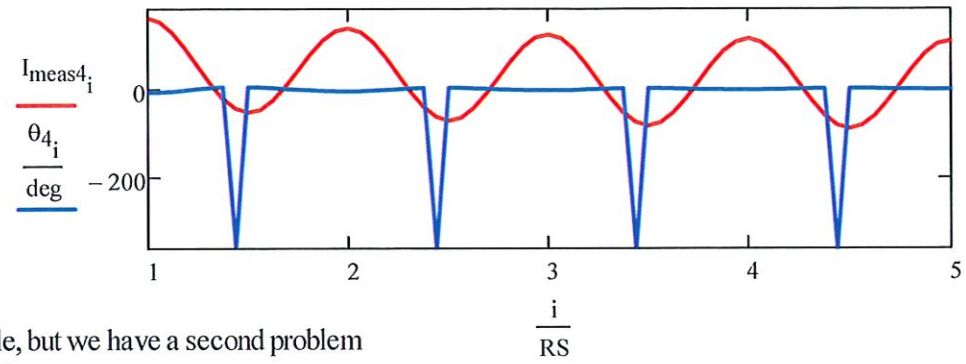
- Now repeat with the fourth signal, which has a decaying DC offset.



Sine filter passing some DC offset, but not cosine

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

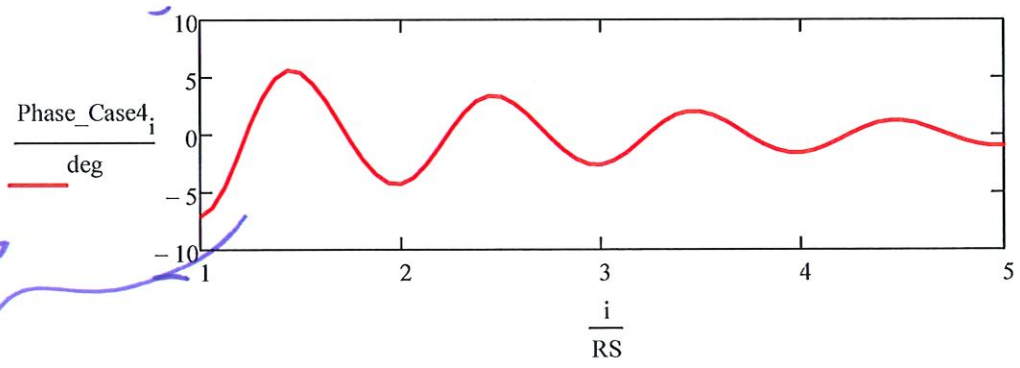
$\theta 4_i := Angle4_i - Angle1_i$



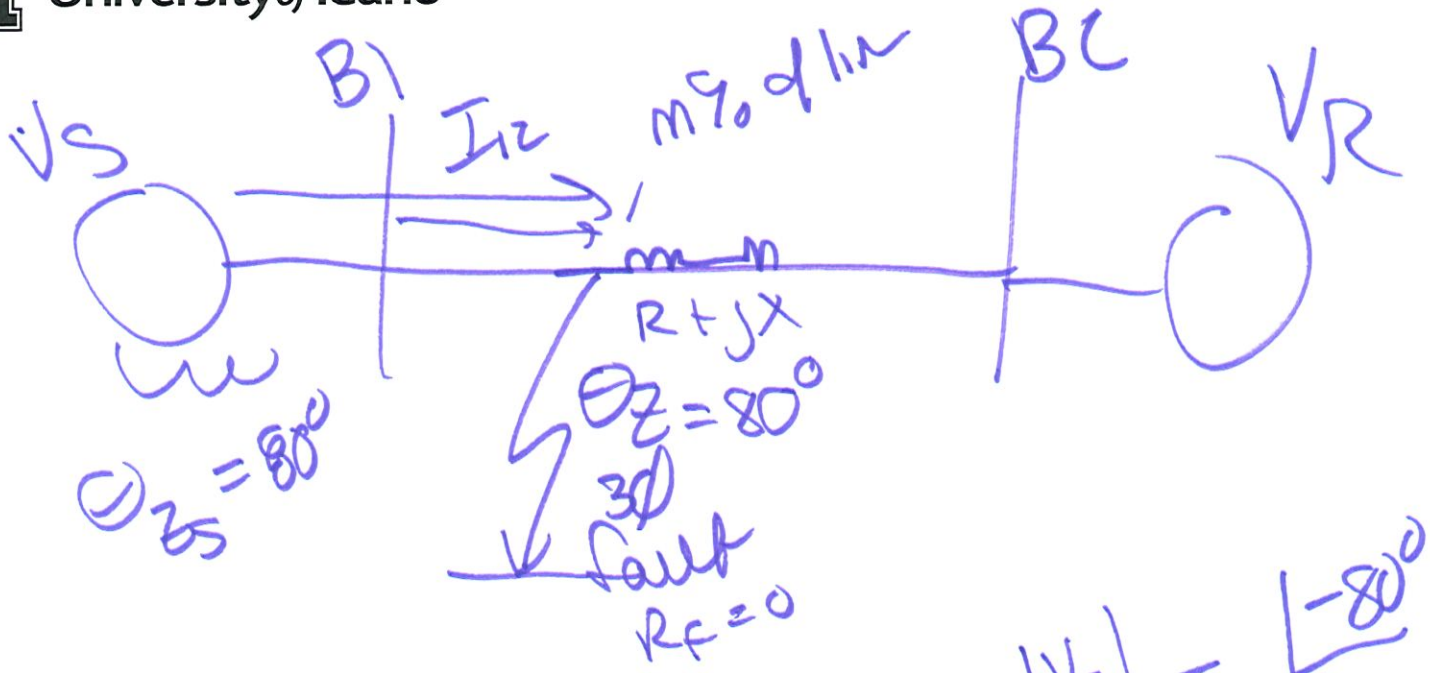
As does angle, but we have a second problem due to reset times

- Fix for the reset time issue:

$$Phase\_Case4_i := \begin{cases} Angle4_i - Angle1_i & \text{if } |Angle4_i - Angle1_i| < \pi \\ Angle4_i - Angle1_i - 2\cdot\pi & \text{if } (Angle4_i - Angle1_i) > \pi \\ Angle4_i - Angle1_i + 2\cdot\pi & \text{if } Angle4_i - Angle1_i < -(\pi) \end{cases}$$



So still see decaying dc offset problem in angle calculation.

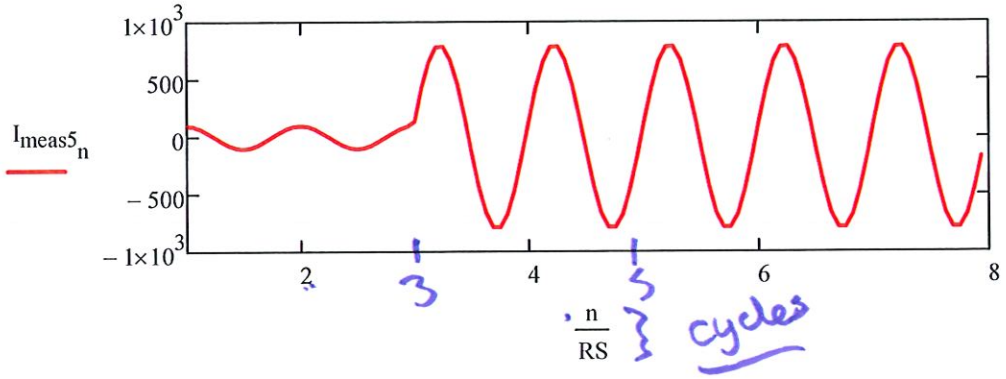


$$\bar{I}_{1f} = \frac{|V_S| \angle 0}{\bar{Z}_{S1} + m\bar{Z}_{L1}} = \frac{|V_S|}{|\bar{Z}_{S1} + m\bar{Z}_{L1}|} \angle -80°$$

$|Z_{S1}| \angle 80$ $\quad |Z_{L1}| \angle 80$

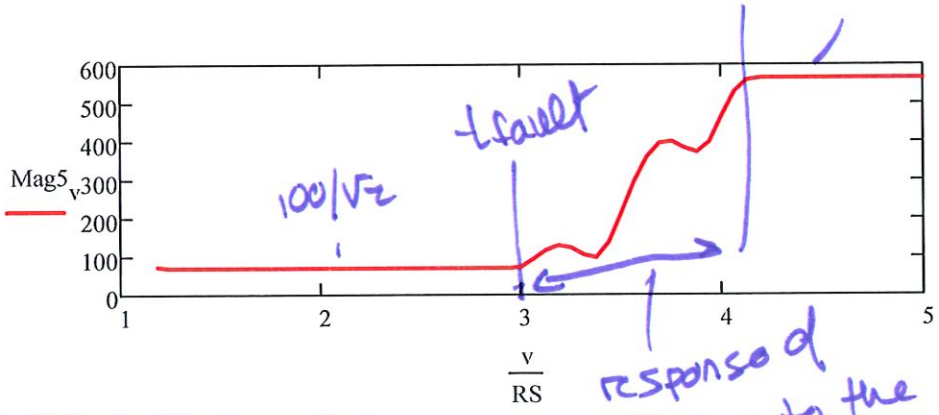
A few more cases:

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

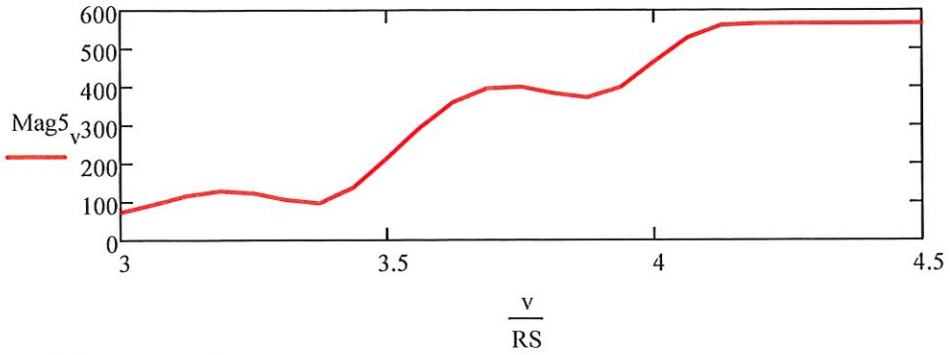


$$Phasor5_v := \frac{1}{\sqrt{2}}\left(COSF(RS, I_{meas5}, v) + j\cdot COSF\left(RS, I_{meas5}, v - \frac{RS}{4}\right)\right)$$

$$Mag5_v := |Phasor5_v| \qquad Angle5_v := \arg(Phasor5_v)$$

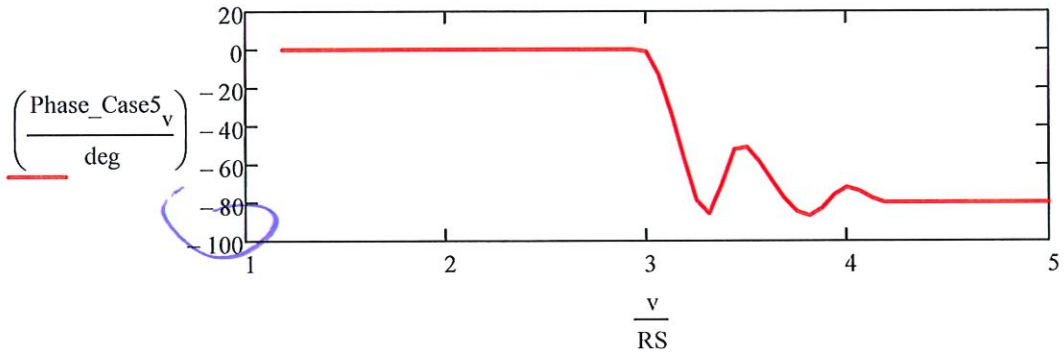


- Notice the filter response time

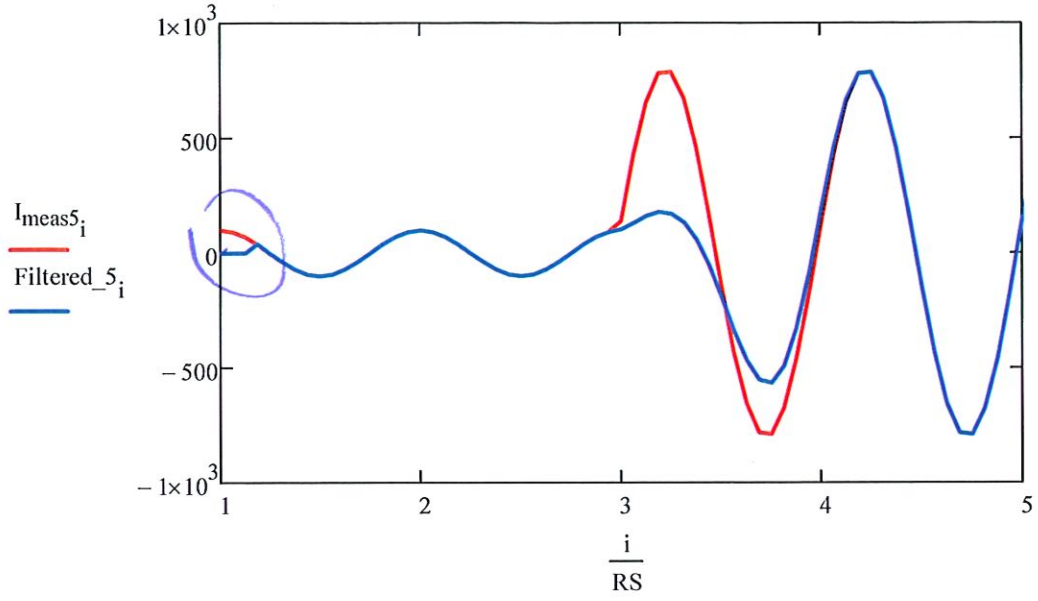


Takes a little over a cycle

$$\text{Phase\_Case5}_v := \begin{cases} \text{Angle5}_v - \text{Angle1}_v & \text{if } \left|\text{Angle5}_v - \text{Angle1}_v\right| < \pi \\ \text{Angle5}_v - \text{Angle1}_v - 2\cdot\pi & \text{if } \left(\text{Angle5}_v - \text{Angle1}_v\right) > \pi \\ \text{Angle5}_v - \text{Angle1}_v + 2\cdot\pi & \text{if } \text{Angle5}_v - \text{Angle1}_v < -(\pi) \end{cases}$$



$$\text{Filtered\_5}_v := \sqrt{2}\cdot \text{Mag5}_v \cdot \cos\left[\left(\frac{2\cdot\pi\cdot v}{RS}\right) + \text{Phase\_Case5}_v\right]$$

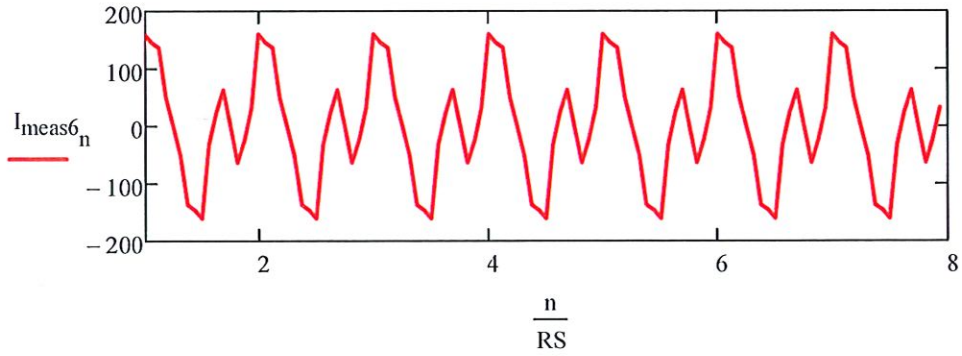


Notice delay in filter response

- Now add some harmonics.

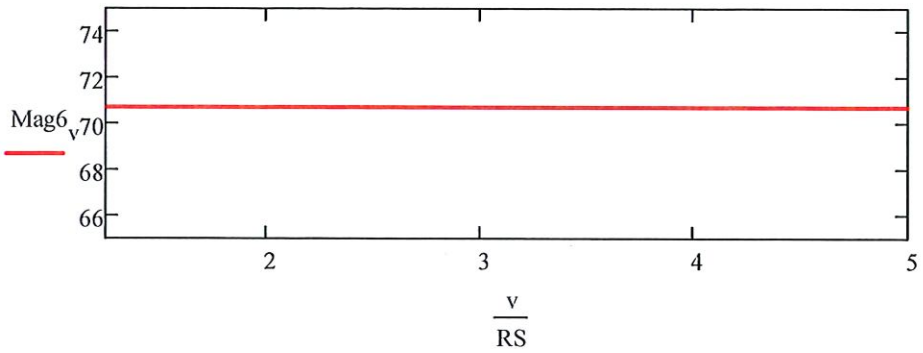
First, integer harmonics

$$I_{meas6_n} := 100\cdot\cos\left(\frac{2\cdot\pi\cdot n}{RS}\right) + 80\cdot\sin\left[2\left(\frac{2\cdot\pi\cdot n}{RS}\right)\right] + 40\cdot\cos\left[3\left(\frac{2\cdot\pi\cdot n}{RS}\right)\right] + 20\cdot\cos\left[7\left(\frac{2\cdot\pi\cdot n}{RS}\right)\right]$$

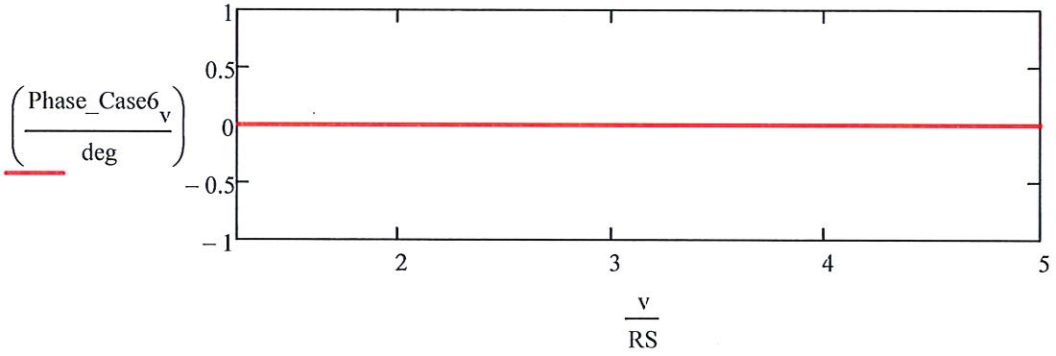


$$Phasor6_v := \frac{1}{\sqrt{2}}\left(COSF\left(RS, I_{meas6}, v\right) + j\cdot COSF\left(RS, I_{meas6}, v - \frac{RS}{4}\right)\right)$$

$Mag6_V := |Phasor6_V|$ $Angle6_V := \arg(Phasor6_V)$



$$Phase\_Case6_V := \begin{cases} Angle6_V - Angle1_V & \text{if } |Angle6_V - Angle1_V| < \pi \\ Angle6_V - Angle1_V - 2\cdot\pi & \text{if } (Angle6_V - Angle1_V) > \pi \\ Angle6_V - Angle1_V + 2\cdot\pi & \text{if } Angle6_V - Angle1_V < -(\pi) \end{cases}$$



$$Filtered\_6_V := \sqrt{2}\cdot Mag6_V \cdot \cos\left[\left(\frac{2\cdot\pi\cdot v}{RS}\right) + Phase\_Case6_V\right]$$