71M6531

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APPLICATION NOTE

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CE31A06 - Harmonic Analysis

Introduction

Maxim is introducing a new compute engine (CE) code that supports measuring harmonics present on the voltage, current, and the power signals to use for analysis. The measurement functions are performed by a tracking band-pass filter whose center frequency is programmable. A broadband VARh calculation using a digital all-pass filter is utilized in this CE code to improve the frequency response of VARh measurements over the bilinear integrator used in standard CE codes for phase shift.

This CE code will support a single-phase meter using meter equations 0, 1, or 2 (*EQU* = 0, 1, or 2). This CE code contains all the other features of the standard CE code described in the 71M6531 data sheet. In addition, this CE code supports measuring the phase angle between phase A and phase B.

CE Variables

Table 1 and Table 2 show only the CE variables that were added.

Table 1: Harmonic Energy Transfer Variables

CE Address	Name	Description
0x9E	*W0SUM_H_X*	The sum of Wh samples from each wattmeter element through the tracking band pass filter (In_8 is the gain of 1 or 8 configured by the CE registers *IA_SHUNT* or *IB_SHUNT*). LSB = 6.6952×10^{-13} V*MAX IMAX/In_8* Wh.
0x9F	*W1SUM_H_X*	
0xA2	*I0SUM_H_X*	The sum of squared current samples from each element through the tracking band pass filter (In_8 is the gain of 1 or 8 configured by *IA_SHUNT* or *IB_SHUNT*). LSB = 6.6952×10^{-13} $IMAX^2/In\_8$ A^2h
0xA3	*I1SUM_H_X*	
0xA0	*V0SUM_H_X*	The sum of squared voltage samples from each element through the tracking band pass filter. LSB= 6.6952×10^{-13} $VMAX^2$ V^2h
0xA1	*V1SUM_H_X*	

Table 2: Phase Angle Variables

CE Address	Name	Default	Description
0xA9	*V_ANG_CNT*	1	This register allows the user to sum up the phase angle results over a number of accumulations (NACC) in order to increase accuracy. The final value has to be divided by *V_ANG_CNT* to get the result. The LSB value for *V_ANG_CNT* is stated in the data sheet for the 71M6531.
0x97	*PH_AtoB_X*	N/A	Phase Angle between phase A and phase B voltages. degrees=*PH_AtoB_X**360/(NACC**V_ANG_CNT*) - 3.63 NACC = *PRE_SAMPS***SUM_CYCLES*

Harmonic Analysis

Input and output registers are available from the Compute Engine to analyze harmonics present on the voltage and current inputs along with the power measurements are presented below.

Input Register *NFREQ* (0xA6)

The Compute Engine measures harmonic contents on voltage and current using tracking band-pass filter whose center frequency is programmable thru the *NFREQ* (0xA6) register. When *NFREQ* = -1 the compute engine tunes the band-pass filter to the fundamental frequency of measurement and provides the data for fundamental component only. The compute engine provides watt-hour, *ISQSUM* and *VSQSUM* data utilizing the band-pass filters.

Following is the formula for computing *NFREQ* register values for harmonic components.

Equation 1:

NFREQ=2^14 SQRT((2-gamma)(1-cos(2π fpk/fs)))*

Where

gamma=2^{-7}

fs=32768/13

fpk = Tracking frequency

Overall the CE code implements two independent meters:

- One is our standard single-phase meter with VARh capability.
- The other is a frequency selectable meter that measures RMS and Wh. This second meter can either be a tracking meter centered at the fundamental or a fixed frequency meter centered at a frequency programmed by the *NFREQ* register. When *NFREQ*<0, the meter is a tracking meter. When *NFREQ*>0, the meter is centered on Fpk (Hz) according to the above formula.

When *NFREQ*>0, the tracking filter, centered on Fpk, introduces a feedthrough component at the fundamental frequency, Fx(0). This feedthrough is the result from the gain attenuation of the filter. Table 3 and Table 4 show this attenuation of the fundamental frequency for 50Hz and 60Hz.

Table 3: Attenuation of the Fundamental Frequency – 50 Hz

Number of Harmonic	Fundamental Frequency	Frequency	*NFREQ*	Fundamental Attenuation Fx(0)
1	50	50	-1	1
2	50	100	4066	0.00044297
3	50	150	6079	$6.31484*10^{-05}$
4	50	200	8068	$1.82987*10^{-05}$
5	50	250	10026	$7.31792*10^{-06}$
6	50	300	11945	$3.54142*10^{-06}$
7	50	350	13818	$1.94802*10^{-06}$
8	50	400	15637	$1.17637*10^{-06}$
9	50	450	17396	$7.62935*10^{-07}$
10	50	500	19087	$5.23953*10^{-07}$
11	50	550	20704	$3.7716*10^{-07}$
12	50	600	22240	$2.82535*10^{-07}$
13	50	650	23690	$2.19018*10^{-07}$

14	50	700	25048	$1.74971*10^{-07}$
15	50	750	26309	$1.43582*10^{-07}$
16	50	800	27468	$1.20719*10^{-07}$
17	50	850	28520	$1.03786*10^{-07}$
18	50	900	29461	$9.10894*10^{-08}$
19	50	950	30288	$8.14987*10^{-08}$
20	50	1000	30998	$7.4254*10^{-08}$
21	50	1050	31587	$6.88465*10^{-08}$

Table 4: Attenuation of the Fundamental Frequency @ 60 Hz

Number of Harmonic	Fundamental Frequency	f (Hz)	*NFREQ*	Fundamental Attenuation Fx(0)
1	60	60	-1	1
2	60	120	4873	0.000308932
3	60	180	7276	$4.42594*10^{-05}$
4	60	240	9637	$1.29302*10^{-05}$
5	60	300	11945	$5.22452*10^{-06}$
6	60	360	14186	$2.56085*10^{-06}$
7	60	420	16348	$1.43032*10^{-06}$
8	60	480	18419	$8.79072*10^{-07}$
9	60	540	20386	$5.8198*10^{-07}$
10	60	600	22240	$4.08956*10^{-07}$
11	60	660	23969	$3.02094*10^{-07}$
12	60	720	25564	$2.32876*10^{-07}$
13	60	780	27017	$1.86317*10^{-07}$
14	60	840	28318	$1.54138*10^{-07}$
15	60	900	29461	$1.31424*10^{-07}$
16	60	960	30440	$1.15214*10^{-07}$
17	60	1020	31248	$1.03683*10^{-07}$
18	60	1080	31882	$9.56318*10^{-08}$
19	60	1140	32337	$9.03322*10^{-08}$
20	60	1200	32612	$8.73068*10^{-08}$
21	60	1260	32704	$8.6323*10^{-08}$

Note: Even though the *NFREQ* register data follows a formula for harmonic analysis, the MPU firmware should use a look-up table for feeding the desired harmonic component to the compute engine. The Fx(0) term shown in Table 3 and Table 4 is the residual amount of the fundamental frequency left in the measurement of the signal at the selected harmonic. The contribution due to the fundamental for measurement decreases with movement of the tracking filter away from the fundamental component.

Output Registers

When using the tracking filter centered on Fpk (*NFREQ*>0), the *WxSUM_X*, *IxSUM_X*, and *VxSUM_X* registers contain the wideband information. The *WxSUM_H_X*, *IxSUM_H_X*, and *VxSUM_H_X* registers contain narrowband information for the harmonic frequency based on *NFREQ* value.

If the tracking filter is centered on the fundamental frequency (*NFREQ*<0), the *WxSUM_X*, *IxSUM_X*, and *VxSUM_X* registers still contain the wideband information. However, the *WxSUM_H_X*, *IxSUM_H_X*, and *VxSUM_H_X* registers contain narrowband information for the fundamental frequency.

The RMS values can be computed by the MPU from the squared current and voltage samples as per the formulae for both broadband and at any desired harmonic frequency.

Equation 2:

$$Ix_{RMS} = \sqrt{\frac{\{IxSQSUM - (Fx(0) * IxSQSUM(0))\} * \cdot LSB \cdot 3600 \cdot F_S}{N_{ACC}}}$$

Where:

IxSQSUM measured at the selected harmonic

Fx(0) – Attenuation of fundamental component from the table

IxSQSUM(0) -- *IxSQSUM* measured at fundamental.

Equation 3:

$$Vx_{RMS} = \sqrt{\frac{\{VxSQSUM - (Fx(0) * VxSQSUM(0))\} * \cdot LSB \cdot 3600 \cdot F_S}{N_{ACC}}}$$

Where:

VxSQSUM measured at the selected harmonic

Fx(0) – Attenuation of fundamental component from the table

VxSQSUM(0) -- *VxSQSUM* measured at fundamental.

Delay Compensation Gain Effects

This CE code uses internal delay compensation on the phase voltage signal path to align it with the associated phase current. This compensation introduces a slight gain (DCG) at Fpk as shown in the following tables.

Table 5: Delay Compensation Gain for 50 Hz Harmonic Components

Harmonic	f (Hz)	*NFREQ*	Delay Compensation Gain (dB)	$10^{(-DCG/20)}$
2	100	4066	0.026642472	0.996937
3	150	6079	0.036948138	0.995755
4	200	8068	0.048315538	0.994453
5	250	10026	0.05834708	0.993305
6	300	11945	0.064767297	0.992571
7	350	13818	0.065822255	0.992451
8	400	15637	0.060598035	0.993048
9	450	17396	0.049210995	0.994350
10	500	19087	0.032837207	0.996227
11	550	20704	0.01356497	0.998439
12	600	22240	-0.005923941	1.000682
13	650	23690	-0.022808671	1.002629
14	700	25048	-0.034648124	1.003997
15	750	26309	-0.039862451	1.004600
16	800	27468	-0.038065653	1.004392
17	850	28520	-0.030161492	1.003479
18	900	29461	-0.018170287	1.002094
19	950	30288	-0.004823105	1.000555
20	1000	30998	0.006983739	0.999196
21	1050	31587	0.014755255	0.998303

Table 6: Delay Compensation Gain for 60 Hz Components

Harmonic	f (Hz)	*NFREQ*	Delay Compensation Gain (dB)	$10^{(-DCG/20)}$
2	120	4873	0.030491546	0.996496
3	180	7276	0.043792782	0.994971
4	240	9637	0.056562008	0.993509
5	300	11945	0.064767297	0.992571
6	360	14186	0.065291553	0.992511
7	420	16348	0.056739887	0.993489
8	480	18419	0.039868949	0.995420
9	540	20386	0.01752776	0.997984
10	600	22240	-0.005923941	1.000682
11	660	23969	-0.025645833	1.002957
12	720	25564	-0.037579505	1.004336
13	780	27017	-0.039595976	1.004569
14	840	28318	-0.032147309	1.003708
15	900	29461	-0.018170287	1.002094
16	960	30440	-0.002249471	1.000259
17	1020	31248	0.010691029	0.998770
18	1080	31882	0.016761236	0.998072
19	1140	32337	0.014161211	0.998371
20	1200	32612	0.003660187	0.999579
21	1260	32704	-0.011607448	1.001337

This gain can be accounted for in RMS voltage values calculated in **Error! Reference source not found.** for instance applying a correction factor as shown in Equation 2 for RMS voltage.

Equation 2:

$$Vxc_{RMS} = SQRT(10^{-DCGFpk/20})*Vx_{RMS}$$

Where

DCG_{Fpk} = Delay Compensation Gain @ Fpk in dB

Vx_{RMS} = RMS voltage value from **Error! Reference source not found.**

As shown in the previous tables, values for DCG for different *NFREQ* selections could be stored in a lookup table in memory to be applied by the MPU.

Broadband VARh

The standard CE code shifts the fundamental and all harmonics for VARh measurement by 90 degrees, but exhibits a 1/f amplitude characteristic on harmonics. Specifically, the fundamental, regardless of frequency, is always shifted at unity gain. The third harmonic is attenuated by 3x, the fifth by 5x, etc.

The new code described in this Application Note utilizes a digital all-pass filter with exact unity gain at all frequencies and nearly 90º-phase shift from 40 Hz to 1220 Hz. The exact performance of this filter is as shown in Table 7.

Table 7: Filter Performance over Frequency

Frequency (Hz)	Phase Error (Deviation from 90 degrees)
40 to 1220	<3.7degrees
48.5 to 63	<0.05 degrees
50	<0.0002 degrees
60	<0.0005 degrees

The phase error introduced by this filter is digitally compensated.

CE Code Resources

This CE code is based on ce31a06

CE DRAM:

284 32-bit words (1136 bytes)

CE Program:

1281 16-bit words (2562 bytes)

CE Cycles:

1773

Upgrading Firmware

The following files can be used for the CE specifications described above:

1. ce31a06_CE.c
2. ce31a06_dat.c

How to use these files:

Upgrade the CE code to the new version by the following techniques:

1. If in the development stage, use the include files (*ce.c & *dat.c) for building project in the compiler environment.

Harmonics Analysis Test Results

The Fluke 6100A test system with phantom load and harmonic generation capability was used for verifying the performance. As per the IEC 62052/IEC 62053 and ANSI C12.20 metering standards, the voltage applied to the meter contained 10% of the fundamental voltage. The current applied to the meter contained 40% of the fundamental current fed to the meter.

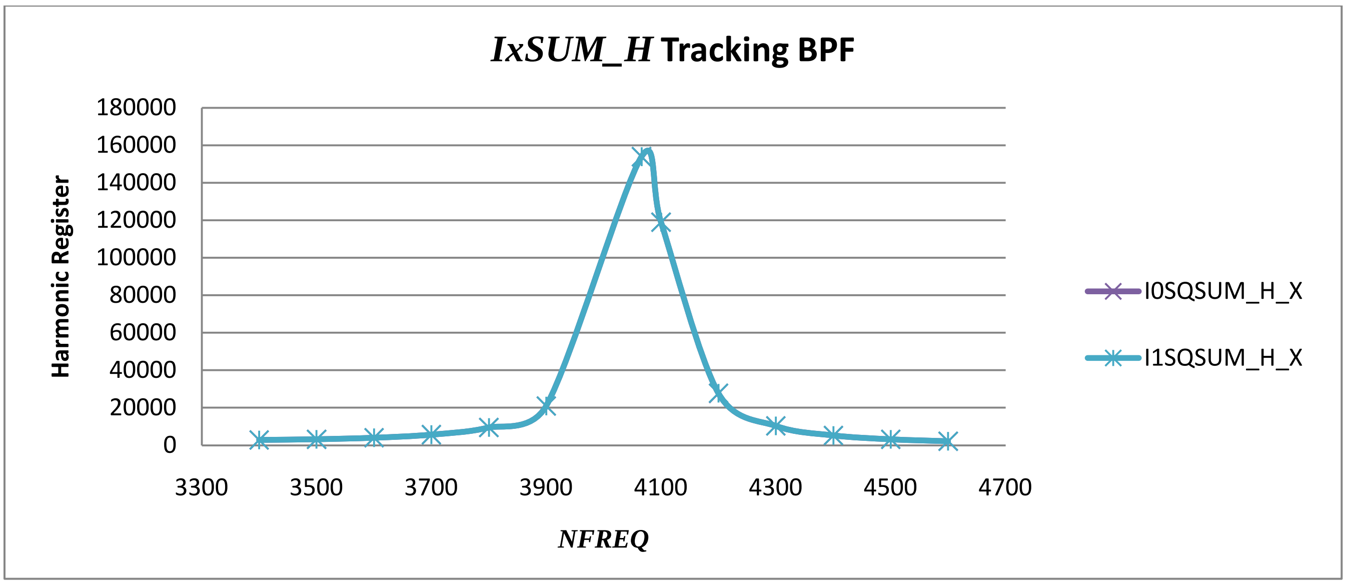
Please note that the harmonic performance of the measurement can be accurate from 1% of the fundamental component onwards.

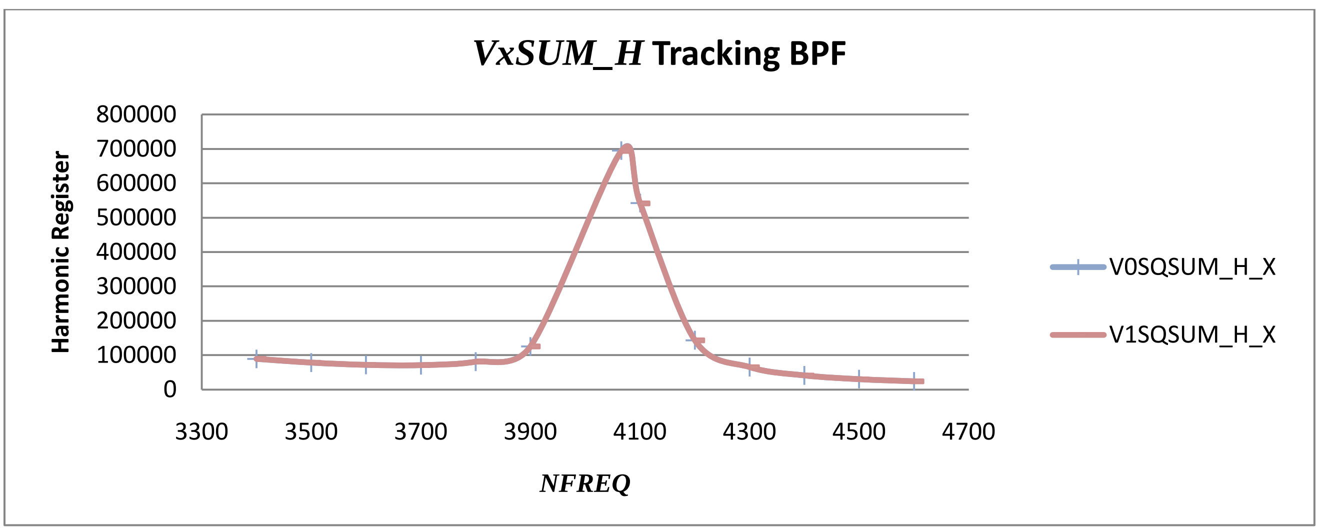
Tracking Band Pass Filter with Center @ Fpk

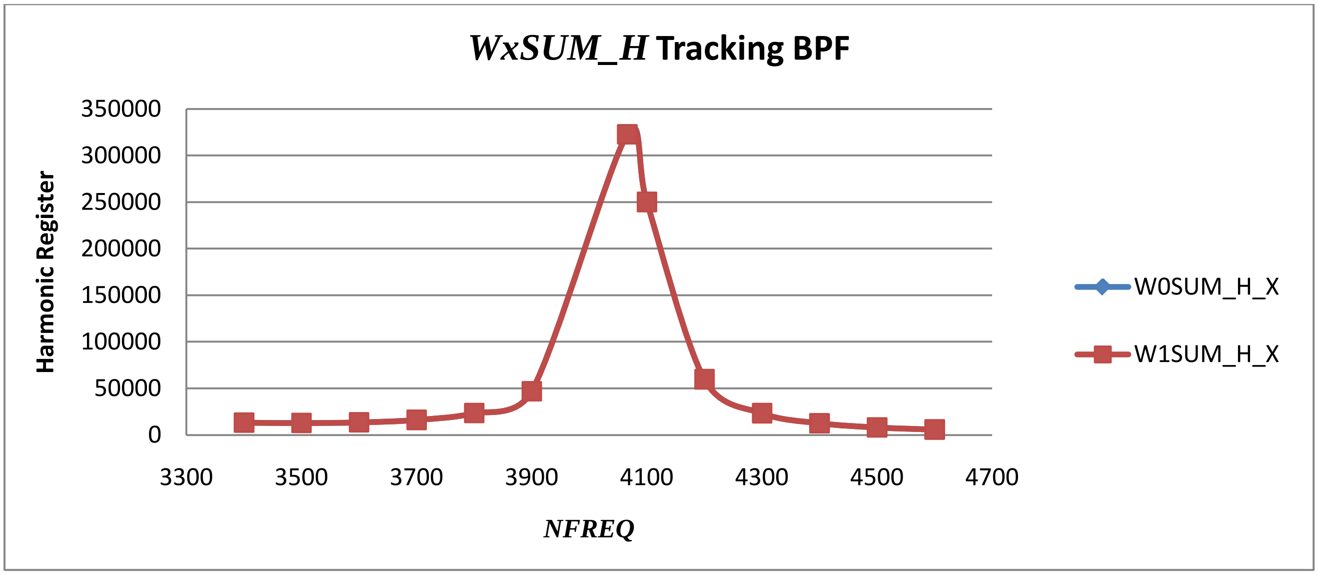
Recall that when using the tracking filter centered on Fpk (*NFREQ*>0), the *WxSUM_X*, *IxSUM_X*, and *VxSUM_X* registers contain the wideband information. The *WxSUM_H_X*, *IxSUM_H_X*, and *VxSUM_H_X* registers contain narrowband information for the harmonic frequency based on *NFREQ* value.

Filter Response

The following graphs show the response of the tracking band-pass filter for the case of 240 V, 10 A, 50 Hz, with 20% fundamental voltage component and 40% fundamental current component at the 2nd harmonic.






WxSUM_H Tracking BPF
Harmonic Register
350000
300000
250000
200000
150000
100000
50000
0
3300
3500
3700
3900
4100
4300
4500
4700
NFREQ
W0SUM_H_X
W1SUM_H_X

Tracking Band Pass Filter with Center @ Fpk (*NFREQ*>0)

W0SUM Using TBPF with *NFREQ*>0

Table 8 shows the results of the tracking filter at 240 V,10 A, 50 Hz, with 40% fundamental current component and 10% fundamental voltage component on the harmonics for Phase A.

The wideband ratio (WB Ratio) represents:

WB Ratio = *W0SUM_X_Fn*/(α**W0SUM_X_F0*)

Where:

Fn – Harmonic frequency

F0 – Fundamental frequency

W0SUM_X_Fn – Wideband with fundamental and harmonic frequency present

W0SUM_X_F0 – Wideband with fundamental frequency present

α - amplitude factor the includes the fundamental + harmonic component

WB Ratio shows how well the wideband register measures in the presence of harmonics. The amplitude factor α for this case is 1+0.1*0.4 = 1.04. The expected ratio is 1.0.

The narrowband ratio (NB Ratio) represents:

NB Ratio = *W0SUM_H_X_Fn*/*W0SUM_X_F0*

Where:

Fn – Harmonic frequency

F0 – Fundamental frequency

W0SUM_H_X_Fn – Narrowband with fundamental and harmonic frequency present

W0SUM_X_F0 – Wideband with fundamental frequency present only

NB Ratio shows how well the narrowband register rejects other frequencies Fpk. The ideal ratio is based on the amount of harmonic component present. In this case the expected ratio is 4% (0.1V*0.4V=0.04).

The NBc Ratio shows narrow band rejection after correcting for the Fx(0) attenuation and delay compensation gain.

Table 8: Tracking Filter Performance

W0SUM_X								
Harmonic	**f (Hz)**	*NFREQ*	**WB Ratio**	**NB Ratio**	**Fx(0)**	**Delay Compensation Gain (dB)**	**Correction**	**NBc Ratio**
2	100	+4066	1.000237	4.06%	0.00044297	0.026642472	0.9969	4.00%
3	150	+6079	1.000109	4.02%	6.31484E-05	0.036948138	0.9958	4.00%
4	200	+8068	1.000293	4.03%	1.82987E-05	0.048315538	0.9945	4.00%
5	250	+10026	1.000289	4.03%	7.31792E-06	0.05834708	0.9933	4.00%
6	300	+11945	1.000421	4.03%	3.54142E-06	0.064767297	0.9926	4.00%
7	350	+13818	1.000291	4.03%	1.94802E-06	0.065822255	0.9925	4.00%
8	400	+15637	1.000274	4.02%	1.17637E-06	0.060598035	0.9930	4.00%
9	450	+17396	0.999944	4.01%	7.62935E-07	0.049210995	0.9944	3.99%
10	500	+19087	1.000101	4.00%	5.23953E-07	0.032837207	0.9962	3.98%
11	550	+20704	1.000217	3.98%	3.7716E-07	0.01356497	0.9984	3.98%
12	600	+22240	1.000272	3.97%	2.82535E-07	-0.005923941	1.0007	3.97%
13	650	+23690	0.999416	3.96%	2.19018E-07	-0.022808671	1.0026	3.97%
14	700	+25048	0.999792	3.96%	1.74971E-07	-0.034648124	1.0040	3.98%
15	750	+26309	0.999986	3.98%	1.43582E-07	-0.039862451	1.0046	4.00%
16	800	+27468	1.000287	4.01%	1.20719E-07	-0.038065653	1.0044	4.03%
17	850	+28520	1.000863	4.05%	1.03786E-07	-0.030161492	1.0035	4.07%
18	900	+29461	1.001134	4.11%	9.10894E-08	-0.018170287	1.0021	4.12%
19	950	+30288	1.001631	4.14%	8.14987E-08	-0.004823105	1.0006	4.14%
20	1000	+30998	1.002368	4.16%	7.4254E-08	0.006983739	0.9992	4.15%
21	1050	+31587	1.000969	4.10%	6.88465E-08	0.014755255	0.9983	4.10%

I0SUM_X & *V0SUM_X* Using TBPF with *NFREQ*>0

The description for WB Ratio and NB Ratio are the same for I0SUM and V0SUM except:

WB Ratio = *I0SUM_X_Fn/(*1.16**I0SUM_X_F0*)

WB Ratio = *V0SUM_X_Fn*/(1.04**V0SUM_X_F0*)

Expected Ratios:

I0SUM_X

WB Ratio = 1.0, NB Ratio = 16%

V0SUM_X

WB Ratio = 1.0, NB Ratio = 4%

The NBc Ratio shows narrow band rejection after correcting for the Fx(0) attenuation and delay compensation gain for V0SUM.

Table 9 and Table 10 show the results for *I0SUM_X* & *V0SUM_X* for the case of 240 V, 10 A, @ 50 Hz, with 40% fundamental current component and 10% fundamental voltage component on the harmonics for Phase A.

Table 9: *I0SQSUM_X* Performance

I0SQSUM_X				
Harmonic	f (Hz)	*NFREQ*	WB Ratio	NB Ratio
2	100	+4066	1.000418	16.07%
3	150	+6079	1.00022	16.02%
4	200	+8068	1.000265	16.02%
5	250	+10026	1.000092	16.02%
6	300	+11945	1.00033	16.02%
7	350	+13818	1.000127	16.02%
8	400	+15637	1.000422	15.99%
9	450	+17396	0.999582	15.98%
10	500	+19087	1.000062	15.97%
11	550	+20704	0.999779	15.99%
12	600	+22240	0.999498	15.98%
13	650	+23690	1.000078	15.94%
14	700	+25048	1.000008	15.96%
15	750	+26309	0.999522	15.95%
16	800	+27468	0.998981	15.92%
17	850	+28520	0.999395	15.92%
18	900	+29461	0.999326	15.90%
19	950	+30288	0.999474	15.89%
20	1000	+30998	0.999074	15.87%
21	1050	+31587	0.999585	15.88%

Table 10: *V0SQSUM_X* Performance

V0SQSUM_X								
Harmonic	f (Hz)	*NFREQ*	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Ideal Correction	NBc Ratio
2	100	+4066	0.971269	1.05%	0.00044297	0.026642472	0.9969	1.00%
3	150	+6079	0.971169	1.01%	6.31484E-05	0.036948138	0.9958	1.00%
4	200	+8068	0.971383	1.01%	1.82987E-05	0.048315538	0.9945	1.00%
5	250	+10026	0.971294	1.01%	7.31792E-06	0.05834708	0.9933	1.01%
6	300	+11945	0.971474	1.01%	3.54142E-06	0.064767297	0.9926	1.01%
7	350	+13818	0.971374	1.01%	1.94802E-06	0.065822255	0.9925	1.01%
8	400	+15637	0.971215	1.01%	1.17637E-06	0.060598035	0.9930	1.00%
9	450	+17396	0.971321	1.01%	7.62935E-07	0.049210995	0.9944	1.00%
10	500	+19087	0.971194	1.00%	5.23953E-07	0.032837207	0.9962	1.00%
11	550	+20704	0.97134	0.99%	3.7716E-07	0.01356497	0.9984	0.99%
12	600	+22240	0.971208	0.99%	2.82535E-07	-0.005923941	1.0007	0.99%
13	650	+23690	0.971094	0.98%	2.19018E-07	-0.022808671	1.0026	0.99%
14	700	+25048	0.971055	0.98%	1.74971E-07	-0.034648124	1.0040	0.99%

V0SQSUM_X								
Harmonic	f (Hz)	*NFREQ*	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Ideal Correction	NBc Ratio
15	750	+26309	0.97131	0.99%	1.43582E-07	-0.039862451	1.0046	1.00%
16	800	+27468	0.9712	1.01%	1.20719E-07	-0.038065653	1.0044	1.01%
17	850	+28520	0.971555	1.03%	1.03786E-07	-0.030161492	1.0035	1.04%
18	900	+29461	0.971892	1.07%	9.10894*10-08	-0.018170287	1.0021	1.07%
19	950	+30288	0.972274	1.11%	8.14987*10-08	-0.004823105	1.0006	1.11%
20	1000	+30998	0.97283	1.15%	7.4254*10-08	0.006983739	0.9992	1.15%
21	1050	+31587	0.973134	1.19%	6.88465*10-08	0.014755255	0.9983	1.19%

Appendix A shows the tracking filter results for Phase B @ 50Hz and all phases at 60Hz.

Tracking Band Pass Filter with Center @ Fundamental Frequency (NFREQ<0)

Recall that when using the tracking filter centered fundamental frequency (*NFREQ*<0), the WxSUM_X, *IxSUM_X*, and *VxSUM_X* registers contain the wideband information. The *WxSUM_H_X*, *IxSUM_H_X*, and *VxSUM_H_X* registers contain narrowband information for the information for the fundamental frequency.

W0SUM_X

Table 11 shows the results of the tracking filter (*NFREQ*<0) at 240 V,10 A, 50Hz with 40% fundamental current component and 10% fundamental voltage component on the harmonics.

The narrowband error (NB Ratio) represents the ratio of

NB Ratio = *W0SUM_H_X*/*W0SUM_X*

Where:

W0SUM_H_X – Narrowband with fundamental and harmonic frequency present

W0SUM_X – Wideband with fundamental frequency present only

Table 11 shows how well the narrowband register rejects the harmonic frequencies. The expected ratio is 1.0.

Table 11: Tracking Filter Performance for WnSUM_X

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***W0SUM_H***	***W1SUM_H***
2	100	-1	1.000219	1.000254
3	150	-1	0.999921	1.000016
4	200	-1	0.998959	0.999096
5	250	-1	0.999948	1.000041
6	300	-1	1.000058	0.999423
7	350	-1	0.999974	0.999961
8	400	-1	0.999229	0.999264
9	450	-1	0.999726	0.999956
10	500	-1	0.999313	0.999478
11	550	-1	1.000309	1.000325
12	600	-1	0.999898	0.999734
13	650	-1	0.999561	0.999874
14	700	-1	0.999681	1.000016
15	750	-1	1.000562	1.000377
16	800	-1	1.000011	0.999992
17	850	-1	1.000156	1.000197
18	900	-1	0.999722	0.999652
19	950	-1	0.999500	0.999702
20	1000	-1	1.000361	0.999838
21	1050	-1	0.998983	0.999250

I0SUM_X **and** ***V0SUM_X***

The description for NB Ratio is the same for *I0SUM_X* and *V0SUM_X* except

Table 12 and Table 13 show the results for *I0SUM_X* and *V0SUM_X* for the case of 240 V, 10 A, @ 50Hz, with 40% fundamental current component and 10% fundamental voltage component on the harmonics.

Table 12: *InSQSUM_X* Performance

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***I0SQSUM_H***	***I1SQSUM_H***
2	100	-1	1.000337	1.000260
3	150	-1	0.999518	0.999192
4	200	-1	0.999291	0.999289
5	250	-1	0.999743	0.999784
6	300	-1	0.998987	0.999277
7	350	-1	0.999797	0.999688
8	400	-1	1.000042	0.999701
9	450	-1	0.998812	0.998593
10	500	-1	0.998489	0.998234
11	550	-1	0.999573	0.999366
12	600	-1	1.000805	1.000393
13	650	-1	0.999971	0.999222
14	700	-1	0.998744	0.998250
15	750	-1	0.999683	1.000525
16	800	-1	1.000854	1.000379
17	850	-1	0.997832	0.998366
18	900	-1	0.999262	0.999516
19	950	-1	0.999549	0.999176
20	1000	-1	0.998879	1.000044
21	1050	-1	1.000583	0.999982

Table 13: *VnSQSUM_X* Performance

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***V0SQSUM_H***	***V1SQSUM_H***
2	100	-1	0.999449	0.999466
3	150	-1	0.999591	0.999638
4	200	-1	0.999746	0.999791
5	250	-1	0.999918	0.999981
6	300	-1	0.999683	0.999825
7	350	-1	0.999831	0.999871
8	400	-1	0.999690	0.999680
9	450	-1	0.999463	0.999454
10	500	-1	0.999817	0.999891
11	550	-1	0.999283	0.999287
12	600	-1	0.997724	0.997718
13	650	-1	0.999899	0.999931
14	700	-1	0.999569	0.999535
15	750	-1	0.999578	0.999546
16	800	-1	0.998427	0.998484
17	850	-1	0.999604	0.999705
18	900	-1	0.999596	0.999603
19	950	-1	0.999874	0.999945
20	1000	-1	0.998066	0.998080
21	1050	-1	1.000002	1.000032

Appendix B shows the tracking band pass filter with *NFREQ*<0 results for 60 Hz.

Testing with Lower Harmonic Percentages @ 50Hz, *NFREQ*<0

W0SUM_X

The narrowband ratio (NB Ratio) represents:

NB Ratio = (*W0SUM_X* - *W0SUM_H_X*)/*W0SUM_H_X*

Where:

W0SUM_H_X – Narrowband with fundamental and harmonic frequency present

W0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

Table 14: *W0SUM_X* and *W1SUM_X* Performance at Low Harmonic Levels

			NB Ratio		
Harmonic	VHarm (%)	IHarm (%)	Expected	*W0SUM*	*W1SUM*
3	1	1	0.010%	0.007%	0.007%
3	1	2	0.020%	0.011%	0.011%
3	2	2	0.040%	0.080%	0.077%
3	3	3	0.090%	0.093%	0.092%
3	4	4	0.160%	0.155%	0.160%
3	5	5	0.250%	0.247%	0.242%
3	8	8	0.640%	0.642%	0.637%
3	10	10	1.000%	0.995%	0.996%

I0SUM_X

The narrowband ratio (NB Ratio) represents:

NB Ratio = (*I0SUM_X* - *I0SUM_H_X*)/*I0SUM_H_X*

Where:

I0SUM_H_X – Narrowband with fundamental and harmonic frequency present

I0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

Table 15: *I0SQSUM_X* and *I1SQSUM_X* Performance at Low Harmonic Levels

			NB Ratio		
Harmonic	VHarm (%)	IHarm (%)	Expected	*I0SQSUM*	*I1SQSUM*
3	1	1	0.010%	0.029%	0.017%
3	1	2	0.040%	0.058%	0.052%
3	2	2	0.040%	0.047%	0.035%
3	3	3	0.090%	0.158%	0.142%
3	4	4	0.160%	0.190%	0.212%
3	5	5	0.250%	0.247%	0.251%
3	8	8	0.640%	0.660%	0.667%
3	10	10	1.000%	0.989%	1.003%

V0SUM_X

The narrowband ratio (NB Ratio) represents:

NB Ratio = (*V0SUM_X* - *V0SUM_H_X*)/*V0SUM_H_X*

Where:

V0SUM_H_X – Narrowband with fundamental and harmonic frequency present

V0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

Table 16: *V0SQSUM_X* and *V0SQSUM_X* Performance at Low Harmonic Levels

			NB Ratio		
Harmonic	VHarm (%)	IHarm (%)	Expected	*V0SQSUM*	*V1SQSUM*
3	1	1	0.010%	0.035%	0.043%
3	1	2	0.010%	0.020%	0.018%
3	2	2	0.040%	0.101%	0.098%
3	3	3	0.090%	0.124%	0.108%
3	4	4	0.160%	0.177%	0.178%
3	5	5	0.250%	0.257%	0.257%
3	8	8	0.640%	0.672%	0.654%
3	10	10	1.000%	1.016%	1.009%

Appendix C shows the *NFREQ*<0 testing with lower harmonic percentages @ 60Hz.

Testing with Larger Voltage Harmonic Percentages @ 50Hz, *NFREQ*<0

W0SUM_X

The narrowband ratio (NB Ratio) represents:

NB Ratio = (*W0SUM_X* - *W0SUM_H_X*)/*W0SUM_H_X*

Where:

W0SUM_H_X – Narrowband with fundamental and harmonic frequency present

W0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

Table 17: *W0SUM_X* and *W1SUM_X* Performance at High Harmonic Levels

				NB Ratio		
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	*W0SUM*	*W1SUM*
100	1	0	0	0.000%	0.018%	0.010%
100	2	40	40	16.000%	16.431%	16.400%
100	4	40	40	16.000%	16.385%	16.305%
100	4	50	40	20.000%	20.136%	20.030%
60	1	0	0	0.000%	0.208%	0.200%
60	4	50	40	20.000%	20.724%	20.623%
20	4	50	40	20.000%	23.827%	23.757%

I0SUM_X

The narrowband ratio (NB Ratio) represents:

NB Ratio = (*I0SUM_X* - *I0SUM_H_X*)/*I0SUM_H_X*

Where:

I0SUM_H_X – Narrowband with fundamental and harmonic frequency present

I0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

Table 18: *I0SQSUM_X* and *I1SQSUM_X* Performance at High Harmonic Levels

				NB Ratio		
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	*I0SQSUM*	*I1SQSUM*
100	1	0	0	0.000%	0.036%	0.040%
100	2	40	40	16.000%	16.370%	16.351%
100	4	40	40	16.000%	16.527%	16.517%
100	4	50	40	16.000%	16.152%	16.126%
60	1	0	0	0.000%	0.106%	0.103%
60	4	50	40	16.000%	16.596%	16.568%
20	4	50	40	16.000%	18.724%	18.664%

V0SUM_X

The narrowband ratio (NB Ratio) represents:

NB Ratio = (*V0SUM_X* - *V0SUM_H_X*)/*V0SUM_H_X*

Where:

V0SUM_H_X – Narrowband with fundamental and harmonic frequency present

V0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

Table 19: *V0SQSUM_X* and *V0SQSUM_X* Performance at Low Harmonic Levels

				NB Ratio		
Voltage (V)	**Harmonic**	**VHarm (%)**	**IHarm (%)**	**Expected**	***V0SQSUM***	***V1SQSUM***
100	1	0	0	0.000%	0.062%	0.048%
100	2	40	40	16.000%	16.239%	16.204%
100	4	40	40	16.000%	16.281%	16.118%
100	4	50	40	25.000%	25.660%	25.409%
60	1	0	0	0.000%	0.044%	0.037%
60	4	50	40	25.000%	25.627%	25.428%
20	4	50	40	25.000%	28.262%	27.999%

Appendix D shows the *NFREQ*<0 testing with larger harmonic percentages @ 60Hz.

Appendix A – Tracking Band-Pass Filter with *NFREQ*>0 Results

Table 20: Phase B @ 50Hz, 10%V, 40%I

W1SUM_X								
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**	**Fx(0)**	**Delay Compensation Gain (dB)**	**Correction**	**NBc Ratio**
2	100	+4066	1.000464	4.05%	0.00044297	0.026642472	0.9969	4.00%
3	150	+6079	1.00015	4.01%	$6.31484*10^{-05}$	0.036948138	0.9958	3.99%
4	200	+8068	1.000355	4.00%	$1.82987*10^{-05}$	0.048315538	0.9945	3.98%
5	250	+10026	1.000313	4.00%	$7.31792*10^{-06}$	0.05834708	0.9933	3.97%
6	300	+11945	1.000378	4.00%	$3.54142*10^{-06}$	0.064767297	0.9926	3.97%
7	350	+13818	1.000085	3.99%	$1.94802*10^{-06}$	0.065822255	0.9925	3.96%
8	400	+15637	1.000154	3.99%	$1.17637*10^{-06}$	0.060598035	0.9930	3.96%
9	450	+17396	1.000127	3.99%	$7.62935*10^{-07}$	0.049210995	0.9944	3.96%
10	500	+19087	1.00007	3.98%	$5.23953*10^{-07}$	0.032837207	0.9962	3.96%
11	550	+20704	1.000362	3.97%	$3.7716*10^{-07}$	0.01356497	0.9984	3.96%
12	600	+22240	1.000409	3.97%	$2.82535*10^{-07}$	-0.005923941	1.0007	3.97%
13	650	+23690	0.999516	3.95%	$2.19018*10^{-07}$	-0.022808671	1.0026	3.96%
14	700	+25048	0.999642	3.94%	$1.74971*10^{-07}$	-0.034648124	1.0040	3.96%
15	750	+26309	0.99989	3.93%	$1.43582*10^{-07}$	-0.039862451	1.0046	3.95%
16	800	+27468	0.999834	3.92%	$1.20719*10^{-07}$	-0.038065653	1.0044	3.93%
17	850	+28520	0.999593	3.90%	$1.03786*10^{-07}$	-0.030161492	1.0035	3.92%
18	900	+29461	0.999143	3.88%	$9.10894*10^{-08}$	-0.018170287	1.0021	3.89%
19	950	+30288	0.999083	3.86%	$8.14987*10^{-08}$	-0.004823105	1.0006	3.86%
20	1000	+30998	0.998562	3.80%	$7.4254*10^{-08}$	0.006983739	0.9992	3.80%
21	1050	+31587	0.997536	3.68%	$6.88465*10^{-08}$	0.014755255	0.9983	3.67%

Table 21: Phase B @ 50Hz, 10%V, 40%I

I1SQSUM_X				
Harmonic	f (Hz)	*NFREQ*	WB Ratio	NB Ratio
2	100	+4066	1.000166	16.06%
3	150	+6079	0.999884	16.02%
4	200	+8068	1.000031	16.01%
5	250	+10026	0.999695	15.99%
6	300	+11945	0.999683	15.98%
7	350	+13818	0.999137	15.93%
8	400	+15637	0.99942	15.90%
9	450	+17396	0.998309	15.86%
10	500	+19087	0.998435	15.80%
11	550	+20704	0.997787	15.78%
12	600	+22240	0.997535	15.69%
13	650	+23690	0.996799	15.63%
14	700	+25048	0.996467	15.57%
15	750	+26309	0.995274	15.47%
16	800	+27468	0.994053	15.40%
17	850	+28520	0.994034	15.35%
18	900	+29461	0.993979	15.23%
19	950	+30288	0.992564	15.18%
20	1000	+30998	0.993191	15.11%
21	1050	+31587	0.991387	15.05%

Table 22: Phase B @ 50Hz, 10%V, 40%I

V1SQSUM_X								
Harmonic	f (Hz)	*NFREQ*	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	+4066	0.971258	1.05%	0.00044297	0.026642472	0.9969	1.00%
3	150	+6079	0.971074	1.01%	$6.31484 *10^{-5}$	0.036948138	0.9958	1.00%
4	200	+8068	0.971222	1.00%	$1.82987 *10^{-5}$	0.048315538	0.9945	0.99%
5	250	+10026	0.971193	1.00%	$7.31792 *10^{-6}$	0.05834708	0.9933	0.99%
6	300	+11945	0.971345	1.00%	$3.54142 *10^{-6}$	0.064767297	0.9926	0.99%
7	350	+13818	0.971248	1.00%	$1.94802 *10^{-6}$	0.065822255	0.9925	0.99%
8	400	+15637	0.971169	1.00%	$1.17637*10^{-6}$	0.060598035	0.9930	0.99%
9	450	+17396	0.97121	1.00%	$7.62935*10^{-7}$	0.049210995	0.9944	0.99%
10	500	+19087	0.971229	1.00%	$5.23953 *10^{-7}$	0.032837207	0.9962	1.00%
11	550	+20704	0.971297	1.00%	$3.7716 *10^{-7}$	0.01356497	0.9984	1.00%
12	600	+22240	0.971347	1.00%	$2.82535 *10^{-7}$	-0.005923941	1.0007	1.00%
13	650	+23690	0.971257	1.00%	$2.19018 *10^{-7}$	-0.022808671	1.0026	1.00%
14	700	+25048	0.971264	1.00%	$1.74971*10^{-7}$	-0.034648124	1.0040	1.00%

15	750	+26309	0.971317	1.00%	$1.43582*10^{-7}$	-0.039862451	1.0046	1.00%
16	800	+27468	0.971143	1.00%	$1.20719*10^{-7}$	-0.038065653	1.0044	1.00%
17	850	+28520	0.97111	1.00%	$1.03786*10^{-7}$	-0.030161492	1.0035	1.00%
18	900	+29461	0.971184	1.00%	$9.10894*10^{-08}$	-0.018170287	1.0021	1.00%
19	950	+30288	0.971144	0.99%	$8.14987*10^{-08}$	-0.004823105	1.0006	0.99%
20	1000	+30998	0.97126	0.99%	$7.4254*10^{-08}$	0.006983739	0.9992	0.99%
21	1050	+31587	0.971197	0.99%	$6.88465*10^{-08}$	0.014755255	0.9983	0.99%

Table 23: Phase A @ 60Hz, 10%V, 40%I

W0SUM_X								
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**	**Fx(0)**	**Delay Compensation Gain (dB)**	**Correction**	**NBc Ratio**
2	120	+4873	1.000073	4.04%	0.000308932	0.030491546	0.9965	4.00%
3	180	+7276	1.000139	4.02%	$4.42594 *10^{-5}$	0.043792782	0.9950	3.99%
4	240	+9637	1.000577	4.03%	$1.29302 *10^{-5}$	0.056562008	0.9935	4.00%
5	300	+11945	1.000235	4.03%	$5.22452 *10^{-6}$	0.064767297	0.9926	4.00%
6	360	+14186	1.000228	4.03%	$2.56085 *10^{-6}$	0.065291553	0.9925	4.00%
7	420	+16348	1.000005	4.02%	$1.43032 *10^{-6}$	0.056739887	0.9935	3.99%
8	480	+18419	1.000665	4.00%	$8.79072 *10^{-7}$	0.039868949	0.9954	3.99%
9	540	+20386	1.000301	3.98%	$5.8198 *10^{-7}$	0.01752776	0.9980	3.97%
10	600	+22240	0.999952	3.97%	$4.08956 *10^{-7}$	-0.005923941	1.0007	3.97%
11	660	+23969	1.000027	3.96%	$3.02094 *10^{-7}$	-0.025645833	1.0030	3.97%
12	720	+25564	0.999684	3.96%	$2.32876 *10^{-7}$	-0.037579505	1.0043	3.98%
13	780	+27017	1.000565	4.00%	$1.86317 *10^{-7}$	-0.039595976	1.0046	4.01%
14	840	+28318	1.000913	4.04%	$1.54138 *10^{-7}$	-0.032147309	1.0037	4.06%
15	900	+29461	1.000839	4.11%	$1.31424 *10^{-7}$	-0.018170287	1.0021	4.11%
16	960	+30440	1.001943	4.15%	$1.15214 *10^{-7}$	-0.002249471	1.0003	4.15%
17	1020	+31248	1.001335	4.14%	$1.03683 *10^{-7}$	0.010691029	0.9988	4.14%
18	1080	+31882	1.000407	4.02%	$9.56318 *10^{-8}$	0.016761236	0.9981	4.01%
19	1140	+32337	0.997961	3.73%	$9.03322 *10^{-8}$	0.016761236	0.9981	3.72%
20	1200	+32612	0.992659	3.03%	$8.73068 *10^{-8}$	0.016761236	0.9981	3.02%

Table 24: Phase A @ 60Hz, 10%V, 40%I

I0SQSUM_X				
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**
2	120	+4873	0.999939	16.04%
3	180	+7276	0.999808	16.01%
4	240	+9637	1.000352	16.01%
5	300	+11945	0.999785	16.02%
6	360	+14186	0.999827	16.00%
7	420	+16348	0.999859	15.99%
8	480	+18419	0.999859	16.00%
9	540	+20386	1.000706	16.00%
10	600	+22240	1.000045	15.98%
11	660	+23969	1.000492	15.97%
12	720	+25564	1.000192	15.95%
13	780	+27017	0.999551	15.93%
14	840	+28318	0.999739	15.93%
15	900	+29461	0.999869	15.92%
16	960	+30440	0.999997	15.87%
17	1020	+31248	1.00001	15.88%
18	1080	+31882	0.999469	15.83%
19	1140	+32337	0.9985	15.86%
20	1200	+32612	0.996258	15.41%

Table 25: Phase A @ 60Hz, 10%V, 40%I

V0SQSUM_X								
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**	**Fx(0)**	**Delay Compensation Gain (dB)**	**Correction**	**NBc Ratio**
2	120	+4873	0.970975	1.04%	0.000308932	0.030491546	0.9965	1.00%
3	180	+7276	0.971094	1.01%	4.42594×10^{-5}	0.043792782	0.9950	1.00%
4	240	+9637	0.971121	1.01%	1.29302×10^{-5}	0.056562008	0.9935	1.01%
5	300	+11945	0.971208	1.01%	5.22452×10^{-6}	0.064767297	0.9926	1.01%
6	360	+14186	0.971218	1.01%	2.56085×10^{-6}	0.065291553	0.9925	1.01%
7	420	+16348	0.971317	1.01%	1.43032×10^{-6}	0.056739887	0.9935	1.00%
8	480	+18419	0.9713	1.00%	8.79072×10^{-7}	0.039868949	0.9954	1.00%
9	540	+20386	0.971118	0.99%	5.8198×10^{-7}	0.01752776	0.9980	0.99%
10	600	+22240	0.970998	0.99%	4.08956×10^{-7}	-0.005923941	1.0007	0.99%
11	660	+23969	0.971003	0.98%	3.02094×10^{-7}	-0.025645833	1.0030	0.98%
12	720	+25564	0.971178	0.99%	2.32876×10^{-7}	-0.037579505	1.0043	0.99%
13	780	+27017	0.97122	1.00%	1.86317×10^{-7}	-0.039595976	1.0046	1.01%
14	840	+28318	0.971525	1.03%	1.54138×10^{-7}	-0.032147309	1.0037	1.03%
15	900	+29461	0.971984	1.07%	1.31424×10^{-7}	-0.018170287	1.0021	1.07%

16	960	+30440	0.972468	1.12%	$1.15214 *10^{-7}$	-0.002249471	1.0003	1.12%
17	1020	+31248	0.972673	1.17%	$1.03683 *10^{-7}$	0.010691029	0.9988	1.16%
18	1080	+31882	0.973376	1.22%	$9.56318 *10^{-8}$	0.016761236	0.9981	1.21%
19	1140	+32337	0.973677	1.26%	$9.03322 *10^{-8}$	0.016761236	0.9981	1.26%
20	1200	+32612	0.971416	1.33%	$8.73068 *10^{-8}$	0.016761236	0.9981	1.33%

Table 26: Phase B @ 60Hz, 10%V, 40%I

W1SUM_X								
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**	**Fx(0)**	**Delay Compensation Gain (dB)**	**Correction**	**NBc Ratio**
2	120	+4873	0.999942	4.03%	0.000308932	0.030491546	0.9965	3.99%
3	180	+7276	0.999842	4.00%	$4.42594 *10^{-5}$	0.043792782	0.9950	3.98%
4	240	+9637	1.000201	4.00%	$1.29302 *10^{-5}$	0.056562008	0.9935	3.97%
5	300	+11945	0.999798	3.99%	$5.22452 *10^{-6}$	0.064767297	0.9926	3.96%
6	360	+14186	0.999848	3.99%	$2.56085 *10^{-6}$	0.065291553	0.9925	3.96%
7	420	+16348	0.999702	3.99%	$1.43032 *10^{-6}$	0.056739887	0.9935	3.96%
8	480	+18419	1.000298	3.98%	$8.79072 *10^{-7}$	0.039868949	0.9954	3.96%
9	540	+20386	0.999914	3.97%	$5.8198 *10^{-7}$	0.01752776	0.9980	3.96%
10	600	+22240	0.999632	3.96%	$4.08956 *10^{-7}$	-0.005923941	1.0007	3.97%
11	660	+23969	0.999553	3.95%	$3.02094 *10^{-7}$	-0.025645833	1.0030	3.96%
12	720	+25564	0.99968	3.93%	$2.32876 *10^{-7}$	-0.037579505	1.0043	3.95%
13	780	+27017	0.999743	3.92%	$1.86317 *10^{-7}$	-0.039595976	1.0046	3.94%
14	840	+28318	0.99951	3.91%	$1.54138 *10^{-7}$	-0.032147309	1.0037	3.92%
15	900	+29461	0.999045	3.88%	$1.31424 *10^{-7}$	-0.018170287	1.0021	3.89%
16	960	+30440	0.998314	3.85%	$1.15214 *10^{-7}$	-0.002249471	1.0003	3.85%
17	1020	+31248	0.997795	3.76%	$1.03683 *10^{-7}$	0.010691029	0.9988	3.75%
18	1080	+31882	0.995524	3.52%	$9.56318 *10^{-8}$	0.016761236	0.9981	3.52%
19	1140	+32337	0.989206	2.81%	$9.03322 *10^{-8}$	0.016761236	0.9981	2.81%
20	1200	+32612	0.967627	0.83%	$8.73068 *10^{-8}$	0.016761236	0.9981	0.83%

Table 27: Phase B @ 60Hz, 10%V, 40%I

I1SQSUM_X				
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**
2	120	+4873	0.999778	16.04%
3	180	+7276	0.999704	16.00%
4	240	+9637	0.999995	15.98%
5	300	+11945	0.999241	15.96%
6	360	+14186	0.999002	15.92%
7	420	+16348	0.998572	15.87%
8	480	+18419	0.998854	15.84%
9	540	+20386	0.99861	15.79%
10	600	+22240	0.997879	15.70%
11	660	+23969	0.997526	15.63%
12	720	+25564	0.996077	15.55%
13	780	+27017	0.995334	15.46%
14	840	+28318	0.994347	15.35%
15	900	+29461	0.993623	15.21%
16	960	+30440	0.994106	15.17%
17	1020	+31248	0.992188	15.07%
18	1080	+31882	0.991637	15.01%
19	1140	+32337	0.990072	14.91%
20	1200	+32612	0.996911	14.59%

Table 28: Phase B @ 60Hz, 10%V, 40%I

V1SQSUM_X								
Harmonic	**f (Hz)**	***NFREQ***	**WB Ratio**	**NB Ratio**	**Fx(0)**	**Delay Compensation Gain (dB)**	**Correction**	**NBc Ratio**
2	120	+4873	0.971012	1.03%	0.000308932	0.030491546	0.9965	1.00%
3	180	+7276	0.971036	1.00%	$4.42594 *10^{-5}$	0.043792782	0.9950	0.99%
4	240	+9637	0.971133	1.00%	$1.29302 *10^{-5}$	0.056562008	0.9935	0.99%
5	300	+11945	0.971085	1.00%	$5.22452 *10^{-6}$	0.064767297	0.9926	0.99%
6	360	+14186	0.971184	1.00%	$2.56085 *10^{-6}$	0.065291553	0.9925	0.99%
7	420	+16348	0.971282	1.00%	$1.43032 *10^{-6}$	0.056739887	0.9935	0.99%
8	480	+18419	0.971319	1.00%	$8.79072 *10^{-7}$	0.039868949	0.9954	1.00%
9	540	+20386	0.971247	1.00%	$5.8198 *10^{-7}$	0.01752776	0.9980	1.00%
10	600	+22240	0.97124	1.00%	$4.08956 *10^{-7}$	-0.005923941	1.0007	1.00%
11	660	+23969	0.971209	1.00%	$3.02094 *10^{-7}$	-0.025645833	1.0030	1.00%
12	720	+25564	0.971319	1.00%	$2.32876 *10^{-7}$	-0.037579505	1.0043	1.00%
13	780	+27017	0.971233	1.00%	$1.86317 *10^{-7}$	-0.039595976	1.0046	1.00%
14	840	+28318	0.971233	1.00%	$1.54138 *10^{-7}$	-0.032147309	1.0037	1.00%
15	900	+29461	0.971265	1.00%	$1.31424 *10^{-7}$	-0.018170287	1.0021	1.00%

16	960	+30440	0.971269	1.00%	$1.15214 * 10^{-7}$	-0.002249471	1.0003	1.00%
17	1020	+31248	0.971128	0.99%	$1.03683 * 10^{-7}$	0.010691029	0.9988	0.99%
18	1080	+31882	0.971271	0.99%	$9.56318 * 10^{-8}$	0.016761236	0.9981	0.99%
19	1140	+32337	0.971237	0.99%	$9.03322 * 10^{-8}$	0.016761236	0.9981	0.99%
20	1200	+32612	0.970995	1.08%	$8.73068 * 10^{-8}$	0.016761236	0.9981	1.08%

Appendix B – Tracking Band Pass Filter with *NFREQ*<0 Results for 60Hz

Table 29: *W0SUM_X* and *W1SUM_X*

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***W0SUM_H***	***W1SUM_H***
2	120	-1	1.000314	1.000208
3	180	-1	1.000134	1.000052
4	240	-1	1.000490	1.000269
5	300	-1	0.999882	0.999974
6	360	-1	0.999421	0.999430
7	420	-1	1.000201	1.000093
8	480	-1	1.000510	1.000139
9	540	-1	1.000589	1.000427
10	600	-1	1.000407	1.000524
11	660	-1	1.000770	1.000290
12	720	-1	1.000656	1.000671
13	780	-1	0.999964	0.999891
14	840	-1	0.999160	0.999411
15	900	-1	1.000868	1.000251
16	960	-1	0.999763	1.000023
17	1020	-1	1.000109	0.999913
18	1080	-1	1.000047	1.000526
19	1140	-1	1.000742	1.000022
20	1200	-1	1.001000	1.002169

Table 30: *I0SQSUM_H* and *I1SQSUM_H*

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***I0SQSUM_H***	***I1SQSUM_H***
2	120	-1	0.999823	0.999773
3	180	-1	1.000168	1.000062
4	240	-1	1.000448	1.000511
5	300	-1	1.000018	0.999598
6	360	-1	0.999602	0.999445
7	420	-1	1.000412	1.000355
8	480	-1	0.999867	1.000163
9	540	-1	1.000181	1.000162
10	600	-1	0.997289	0.997344
11	660	-1	1.000862	1.001102
12	720	-1	0.998657	0.998819
13	780	-1	1.000606	1.000557
14	840	-1	0.999664	0.999268
15	900	-1	0.998913	0.999890
16	960	-1	1.000178	0.999607
17	1020	-1	1.000093	1.000240

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***I0SQSUM_H***	***I1SQSUM_H***
18	1080	-1	0.999124	0.998230
19	1140	-1	0.998679	0.999661
20	1200	-1	0.999958	0.996604

Table 31: *V0SQSUM_H_X* and *V1SQSUM_H_X*

			NB Ratio	
Harmonic	**f (Hz)**	***NFREQ***	***V0SQSUM_H***	***V1SQSUM_H***
2	120	-1	0.999963	1.000066
3	180	-1	0.999316	0.999349
4	240	-1	0.999948	0.999840
5	300	-1	0.999387	0.999750
6	360	-1	1.000062	1.000117
7	420	-1	0.999915	1.000002
8	480	-1	0.999207	0.999198
9	540	-1	0.999977	1.000001
10	600	-1	0.999815	0.999883
11	660	-1	1.000061	1.000029
12	720	-1	0.999494	0.999511
13	780	-1	0.999827	0.999911
14	840	-1	0.999947	1.000054
15	900	-1	0.999885	0.999963
16	960	-1	1.000260	1.000289
17	1020	-1	1.000101	1.000071
18	1080	-1	0.999813	0.999844
19	1140	-1	0.999957	1.000012
20	1200	-1	1.001034	1.000395

Appendix C - Testing with Lower Harmonic Percentages @ 60Hz, *NFREQ* <0.

Table 32: ***W0SUM_X*** **and** ***W1SUM_X***

			NB Ratio		
Harmonic	VHarm (%)	IHarm (%)	Expected	*W0SUM*	*W1SUM*
3	1	1	0.010%	0.029%	0.019%
3	1	2	0.020%	0.008%	0.020%
3	2	2	0.040%	0.107%	0.108%
3	3	3	0.090%	0.080%	0.096%
3	4	4	0.160%	0.211%	0.208%
3	5	5	0.250%	0.248%	0.245%
3	8	8	0.640%	0.700%	0.712%
3	10	10	1.000%	1.006%	0.998%

Table 33: ***I0SQSUM*** **and** ***I1SQSUM***

			NB Ratio		
Harmonic	VHarm (%)	IHarm (%)	Expected	*I0SQSUM*	*I1SQSUM*
3	1	1	0.010%	0.023%	0.008%
3	1	2	0.040%	0.051%	0.051%
3	2	2	0.040%	0.093%	0.092%
3	3	3	0.090%	0.191%	0.187%
3	4	4	0.160%	0.160%	0.176%
3	5	5	0.250%	0.264%	0.273%
3	8	8	0.640%	0.723%	0.744%
3	10	10	1.000%	1.013%	1.025%

Table 34: ***V0SQSUM_X*** **and** ***V1SQSUM_X***

			NB Ratio		
Harmonic	VHarm (%)	IHarm (%)	Expected	*V0SQSUM*	*V1SQSUM*
3	1	1	0.010%	0.031%	0.030%
3	1	2	0.010%	0.078%	0.084%
3	2	2	0.040%	0.057%	0.058%
3	3	3	0.090%	0.109%	0.089%
3	4	4	0.160%	0.171%	0.174%
3	5	5	0.250%	0.262%	0.269%
3	8	8	0.640%	0.641%	0.647%
3	10	10	1.000%	1.021%	1.003%

Appendix D - Testing with Larger Harmonic Percentages @ 60Hz, *NFREQ*<0.

Table 35: *W0SUM_X* and *W1SUM_X*

				NB Ratio		
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	*W0SUM*	*W1SUM*
100	1	0	0	0.000%	0.007%	-0.010%
100	2	40	40	16.000%	16.383%	16.339%
100	4	40	40	16.000%	16.337%	16.235%
100	4	50	40	20.000%	20.151%	20.007%
60	1	0	0	0.000%	0.149%	0.143%
60	4	50	40	20.000%	20.223%	20.122%
20	4	50	40	20.000%	20.194%	20.119%

Table 36: *I0SQSUM_X* and *I1SQSUM_X*

				NB Ratio		
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	*I0SQSUM*	*I1SQSUM*
100	1	0	0	0.000%	0.004%	0.000%
100	2	40	40	16.000%	16.426%	16.390%
100	4	40	40	16.000%	16.095%	16.064%
100	4	50	40	16.000%	16.135%	16.117%
60	1	0	0	0.000%	0.111%	0.113%
60	4	50	40	16.000%	16.108%	16.089%
20	4	50	40	16.000%	16.963%	16.959%

Table 37: *V0SQSUM_X* and *V1SQSUM_X*

				NB Ratio		
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	*V0SQSUM*	*V1SQSUM*
100	1	0	0	0.000%	-0.002%	0.014%
100	2	40	40	16.000%	16.329%	16.271%
100	4	40	40	16.000%	16.297%	16.106%
100	4	50	40	25.000%	25.765%	25.460%
60	1	0	0	0.000%	0.150%	0.136%
60	4	50	40	25.000%	25.724%	25.433%
20	4	50	40	25.000%	26.348%	26.065%

Revision History

Revision	Date	Description
Rev. 1.0	03/04/11	First publication.