AN_6513_038

APPLICATION NOTE

JANUARY 2007

Harmonic Analysis with the TERIDIAN 71M6513

Teridian Semiconductor Corporation has developed a custom Compute Engine (CE) firmware to support energy metering with harmonic analysis.

Specification

The compute engine firmware was developed to provide the following capabilities:

1. Measurement of Wh, ISQh and VSQh information with harmonics and a separate Wh measurement register for the harmonic component. Two sets of registers are available simultaneously for meter harmonic analysis for Wh, current and voltage components.
    - The existing CE outputs, *WSUM_X* (0x42), *W0SUM_X* (0x43), *WSUM1_X* (0x44), and *WSUM2_X* (0x45) will be broadband Wh measurement registers
    - Four new output registers, *WSUM_H_X* (0x58), *W0SUM_H_X* (0x59), *W1SUM_H_X* (0x5A) and *W2SUM_H_X* (0x5B), will contain Wh information for the selected harmonic component.
    - Three new output registers, *I0SQSUM_H_X* (0x5C), *I1SQSUM_H_X* (0x5D) and *I2SQSUM_H_X* (0x5E), will contain ISQh information for the selected harmonic component.
    - Three new output registers, *V0SQSUM_H_X* (0x5f), *V1SQSUM_H_X* (0x60) and *V2SQSUM_H_X* (0x61), will contain VSQh information for the selected harmonic component.
2. A new register to select the desired harmonic component for measurement *NFREQ* (0x63) was added.
3. Only 3-phase 4-wire WYE (VA* IA + VB * IB + VC * IC) or 3-phase 3-wire (VA* IA + VB * IB) configurations are supported.
4. Only one pulse output, the WPULSE output, is supported.
    a. This pulse output can be configured for various pulse outputs through the *EXT_PULSE* register. Please refer to the 71M6513 data sheet or the 71M6513 Demo Board User Manual (DBUM) for further details.
    b. The Wh pulse generator, when in internal mode, will output broadband Wh.
    c. The maximum pulse rate is 1260Hz.
5. The neutral current measurement function is supported.
6. The voltage-to-voltage phase angle measurement is supported.
7. The line zero-crossing detection for RTC adjustment using the *MainEdgeCount* register is supported.
8. The SAG detection for early power-fail warning for each phase voltage is supported.
9. VARh information registers support broadband measurements only.

The upgrade procedure and results of performance tests will be demonstrated on the pages that follow.

Upgrading Meter Firmware

The following files are used to achieve the CE specifications listed above.

1. CE13B13b.ce
2. CE13B13b.dat
3. CE13B13b_ce.c
4. CE13B13b_dat.c

How to use these files:

One can easily upgrade the existing CE code to the new version by applying either of the following techniques:

1. Using the CE_MERGE utility to upgrade the current hexadecimal file. That is, the existing CE files (*.ce and *.dat) files will be updated to the new hex file without modifying the existing hex file as documented in the Demo Board Users Manual (DBUM).
2. Users of development systems (compiler, emulator) can include the files (*ce.c and *dat.c) and then rebuild the project in the compiler environment.

Caution: ***When upgrading to the new firmware, one should be cautious about the following:***

a. This CE firmware does not support VAR pulse output.

b. The pulse rate is limited to a maximum of 1260Hz.

c. The metering connections are limited to 3-phase 3-wire and 3-phase 4-wire WYE.

CE Code Details

In this section, the CE input and output registers used to control harmonics measurements are described.

Input Register *NFREQ* (0x63)

The Compute Engine measures harmonic contents on voltage and current signals using a tracking band-pass filter whose center frequency is programmable via the *NFREQ* (0x63) register. When *NFREQ* = -1, the CE tunes the band-pass filter to the fundamental frequency of measurement and provides the data for the fundamental component only. The CE provides Wh, ISQSUM and VSQSUM data utilizing the band-pass filters.

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

$$NFREQ = 2^{14}\sqrt{(2-\chi)(1-\cos(2\Pi\frac{f_{pk}}{f_s})}$$

where $\chi = 2^{-7}$

f_s = 32768/13 (sampling frequency)

f_{pk} = Center frequency

Overall, the CE code implements two meters:

- One meter is our standard 3-phase meter with VAR measurement.
- The other meter is a frequency-selectable meter that measures RMS values and Wh.

The second meter can either be a tracking meter centered at the fundamental frequency or a fixed-frequency meter centered at a frequency programmed by *NFREQ*. When *NFREQ* < 0, the meter is a tracking meter. When *NFREQ* > 0, the meter is centered on F_{pk} (Hz) according to the formula stated above.

Number of Harmonic	Frequency [Hz]	NFREQ Value
1	60	-1
2	120	4872
3	180	7274
4	240	9637
5	300	11945
6	360	14185
7	420	16347
8	480	18417
9	540	20385
10	600	22238
11	660	23967
12	720	25563
13	780	27016
14	840	28318
15	900	29460
16	960	30249
17	1020	31248
18	1080	31881
19	1140	32237
20	1200	32612

Number of Harmonic	Frequency [Hz]	NFREQ Value
1	50	-1
2	100	4063
3	150	6076
4	200	8065
5	250	10023
6	300	11942
7	350	11915
8	400	13818
9	450	15638
10	500	17397
11	550	19087
12	600	20703
13	650	22239
14	700	23698
15	750	23047
16	800	26308
17	850	27467
18	900	28520
19	950	29460
20	1000	30288
21	1050	30997
22	1100	31586

NFREQ Values for 60Hz (left) and for 50Hz (right)

Note that even though the *NFREQ* register data can be determined by the formula for harmonic analysis stated above, the MPU firmware should use a look-up table for feeding the desired harmonic component to the compute engine.

Compute Engine Output Registers

The integration time is 1 second. Additionally, the hardware will not permit output values to 'fold back' upon overflow.

CE Address	Name	Description
0x42	*WSUM_X*	The signed sum: *W0SUM_X+W1SUM_X+W2SUM_X*
0x43	*W0SUM_X*	The sum of Watt samples from each wattmeter element. LSB = $9.4045*10^{-13}$ *VMAX IMAX* / In_8 Wh.
0x44	*W1SUM_X*	
0x45	*W2SUM_X*	
0x46	*VARSUM_X*	The signed sum: *VAR0SUM_X+VAR1SUM_X+VAR2SUM_X*
0x47	*VAR0SUM_X*	The sum of VAR samples from each wattmeter element. LSB = $9.4045*10^{-13}$ *VMAX IMAX / In_8* VARh.
0x48	*VAR1SUM_X*	
0x49	*VAR2SUM_X*	

CE Address	Name	Description
0x33	*FREQSEL*	Selected phase for the frequency monitor **Phase A: 0 (default)** Phase B: 1 Phase C: 2
0x41	*FREQ_X*	Fundamental frequency. LSB $\equiv \frac{F_S}{2^{32}} \approx 0.587 \cdot 10^{-6}$ *Hz*
0x4A	*I0SQSUM_X*	The sum of squared current samples from each element. LSB = 9.4045*10^{-13} *IMAX*^{2} / *In_8*^{2} *A*^{2}*h*
0x4B	*I1SQSUM_X*	
0x4C	*I2SQSUM_X*	
0x4D	*INSQSUM_X*	The sum of squared current samples from the calculated neutral: $\sum (I_0 + I_1 + I_2)^2$. LSB=7.5236*10^{-12} IMAX^2 / *In_8*^{2} A^{2}h
0x4E	*V0SQSUM_X*	The sum of squared voltage samples from each element. LSB= 9.4045*10^{-13} VMAX^2 V^{2}h
0x4F	*V1SQSUM_X*	
0x50	*V2SQSUM_X*	

The RMS values can be computed by the MPU from the squared current and voltage samples as per the formulae:

$$Ix_{RMS} = \sqrt{\frac{IxSQSUM \cdot LSB \cdot 3600 \cdot F_S}{N_{ACC}}} \qquad Vx_{RMS} = \sqrt{\frac{VxSQSUM \cdot LSB \cdot 3600 \cdot F_S}{N_{ACC}}}$$

Other Measurement Parameters

PH_AtoB_X is the phase angle between phase A and phase B. *PH_AtoC_X* is the phase angle between phase A and phase C. These measurements can be used for phase sequencing and error detection. If the voltage at phase A is missing, the phase angle accuracy will be reduced.

MAINEDGE_X is useful for implementing a real-time clock based on the input AC signal. *MAINEDGE_X* is the number of half-cycles accounted for in the last accumulated interval for the AC signal of the phase specified in the *FREQSEL* register.

CE Address	Name	Description
0x52	*PH_AtoB_X*	Phase lag from VA to VB. Angle in degrees is (0 to 360): *PH_AtoB_X* * 360/NACC + 2.4
0x53	*PH_AtoC_X*	Phase lag from VA to VC. Angle in degrees is (0 to 360): *PH_AtoC_X* * 360/NACC + 4.8
0x55	*MAINEDGE_X*	The number of edge crossings of the selected voltage in the previous accumulation interval. Edge crossings are either direction and are debounced.

Outputs from Harmonic Measurements

CE Address	Name	Description
0x58	*WSUM_H_X*	The signed sum: *W0SUM_X+W1SUM_X+W2SUM_X*
0x59	*W0SUM_H_X*	The sum of Watt samples from each wattmeter element. LSB = $9.4045*10^{-13}$ *VMAX IMAX* / In_8 Wh.
0x5a	*W1SUM_H_X*	
0x5b	*W2SUM_H_X*	

CE Address	Name	Description
0x5c	*I0SQSUM_H_X*	The sum of squared current samples from each element. LSB = $9.4045*10^{-13}$ *IMAX2 / In_8² A²h*
0x5d	*I1SQSUM_H_X*	
0x5e	*I2SQSUM_H_X*	
0x5f	*V0SQSUM_H_X*	The sum of squared voltage samples from each element. LSB= $9.4045*10^{-13}$ *VMAX2* V^2h
0x60	*V1SQSUM_H_X*	
0x61	*V2SQSUM_H_X*	

Performance of the New CE Firmware

Various signals were supplied to a meter that had been upgraded with the new CE firmware supporting harmonic measurements. In compliance with IEC 62052/ IEC 62053 and ANSI C12.20 metering standards, the voltage applied to the meter contained 20% of the fundamental harmonic components, and the current contained 40% of the fundamental harmonic components. The following tools were used to verify the performance:

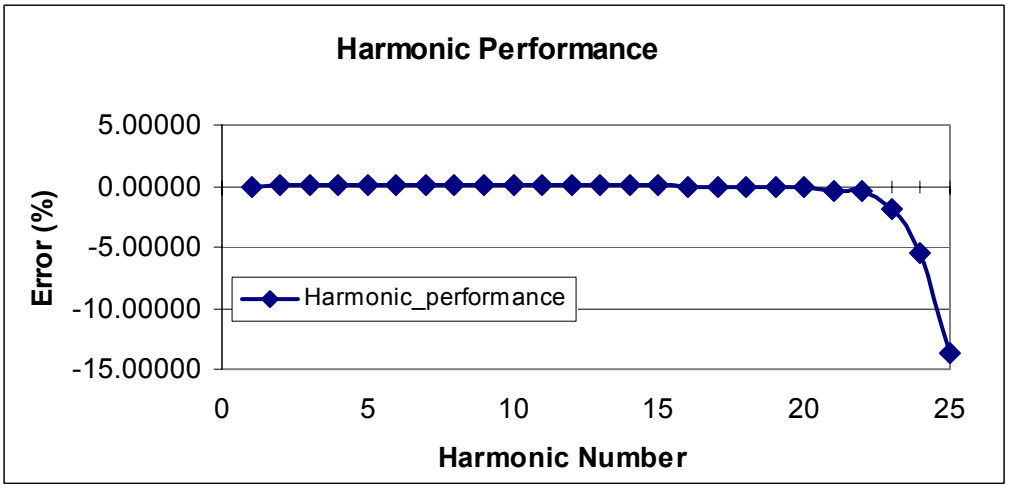
1. Fluke 6100A for phantom load with harmonic generation capability.
2. Fluke pulse input for capturing the pulse output from the meter under test.

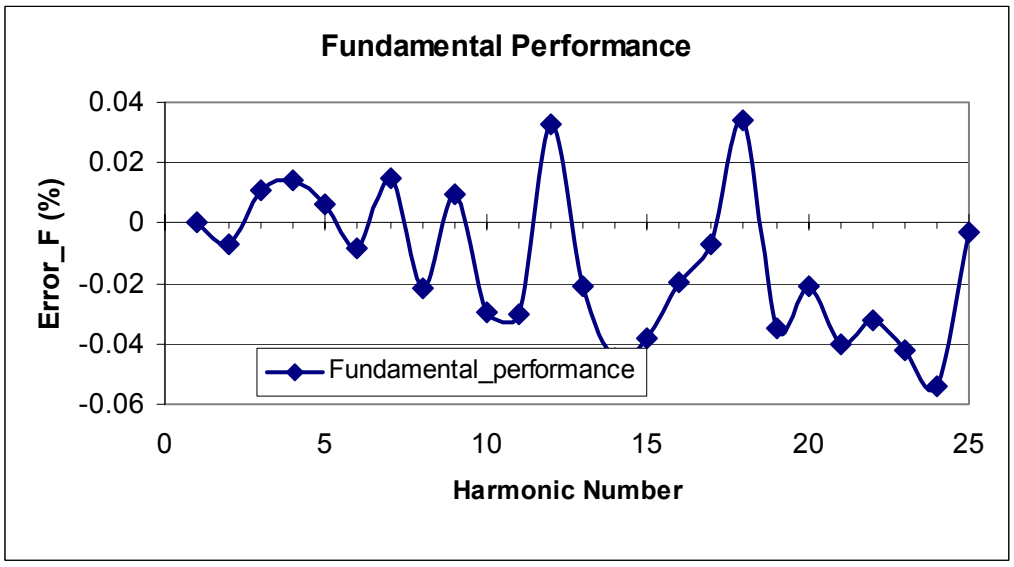
The following pages show measurement results obtained with the new CE code.

Harmonic Energy Measurement

Harmonic Number	Broadband Energy		Fundamental Energy	
	W0SUM_X	Error (%)	W0SUM_H	Error (%)
1	5979546	0.00000	5472809	0
2	5912313	0.00053	5472420	-0.0072
3	5911726	0.00053	5473392	0.0107
4	5911178	0.00053	5473581	0.0142
5	5911413	0.00053	5473147	0.0062
6	5911597	0.00053	5472356	-0.0083
7	5911510	0.00053	5473611	0.0147
8	5911021	0.00053	5471640	-0.0214
9	5911250	0.00053	5473323	0.0094
10	5911425	0.00153	5471206	-0.0293
11	5909891	0.00053	5471170	-0.03
12	5914076	0.00053	5474587	0.0325
13	5910360	0.00053	5471669	-0.0209
14	5910159	0.00053	5470360	-0.0448
15	5909132	0.00053	5470735	-0.0379
16	5910239	-0.02603	5471731	-0.0197
17	5908688	-0.08246	5472424	-0.0071
18	5910758	-0.08246	5474684	0.0343
19	5907648	-0.02603	5470912	-0.0347
20	5901486	-0.02603	5471672	-0.0208
21	5890318	-0.33144	5470620	-0.04
22	5873963	-0.41443	5471034	-0.0325
23	5808902	-1.90333	5470521	-0.0419
24	5610490	-5.52681	5469861	-0.0539
25	5162892	-13.70328	5472652	-0.0029

240V, 50Hz, 40% of Fundamental on Current, 20% of Fundamental on Voltage

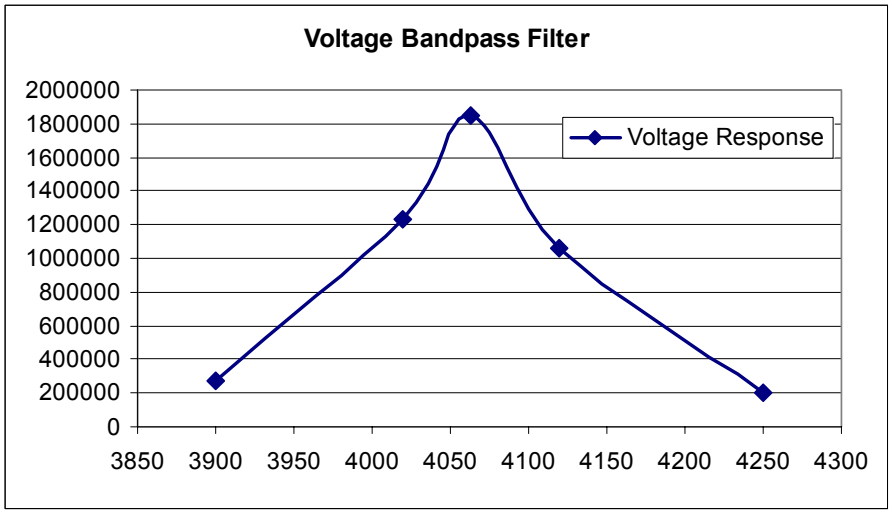

Harmonic Performance
5.00000
0.00000
-5.00000
-10.00000
-15.00000
Error (%)
Harmonic_performance
0
5
10
15
20
25
Harmonic Number

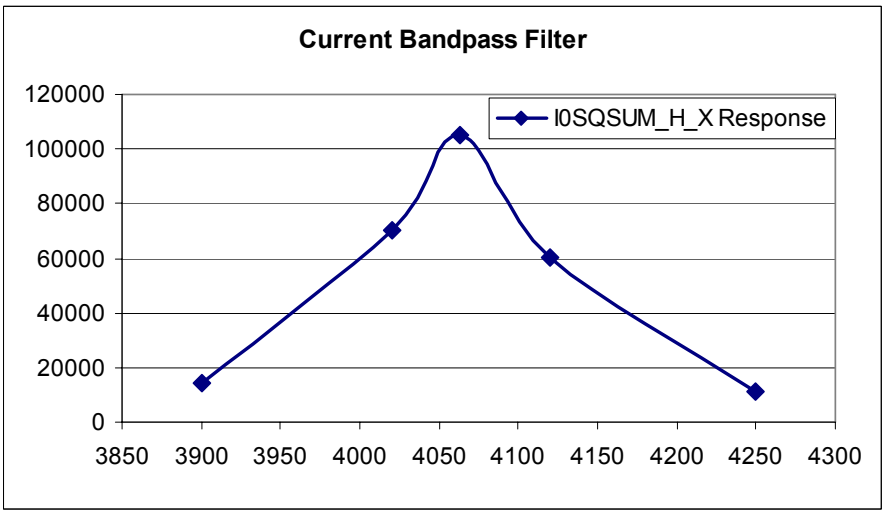

Fundamental Performance
0.04
0.02
0
-0.02
-0.04
-0.06
Error_F (%)
Fundamental_performance
0
5
10
15
20
25
Harmonic Number

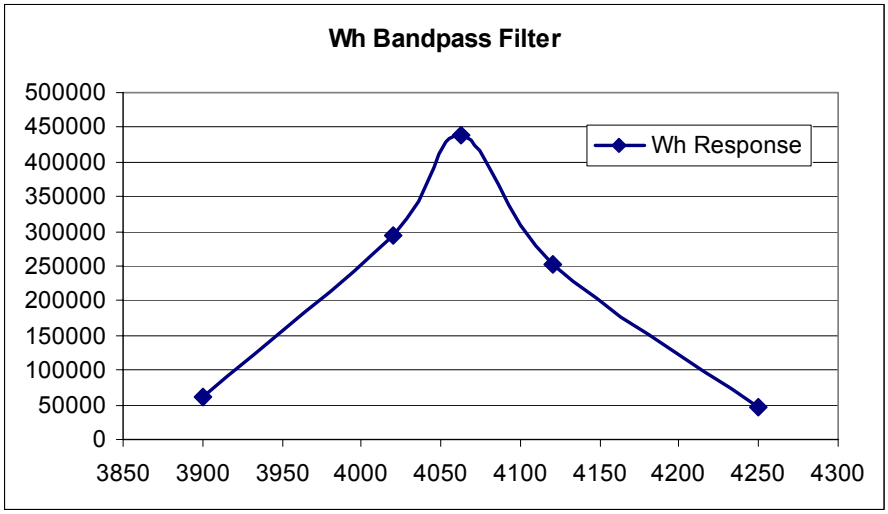
Tracking Band-Pass Filter Performance

Harmonic Number	*NFREQ*	W0SUM_H_X	I0SQSUM_H_X	V0SQSUM_H_X
2	3900	61552	14346	269401
2	4020	293865	70151	1236574
2	4063	439675	105076	1844368
2	4120	252933	60347	1064224
2	4250	46574	10914	202278

240V, 50Hz, 40% Fundamental on Current, 20% on Fundamental Voltage



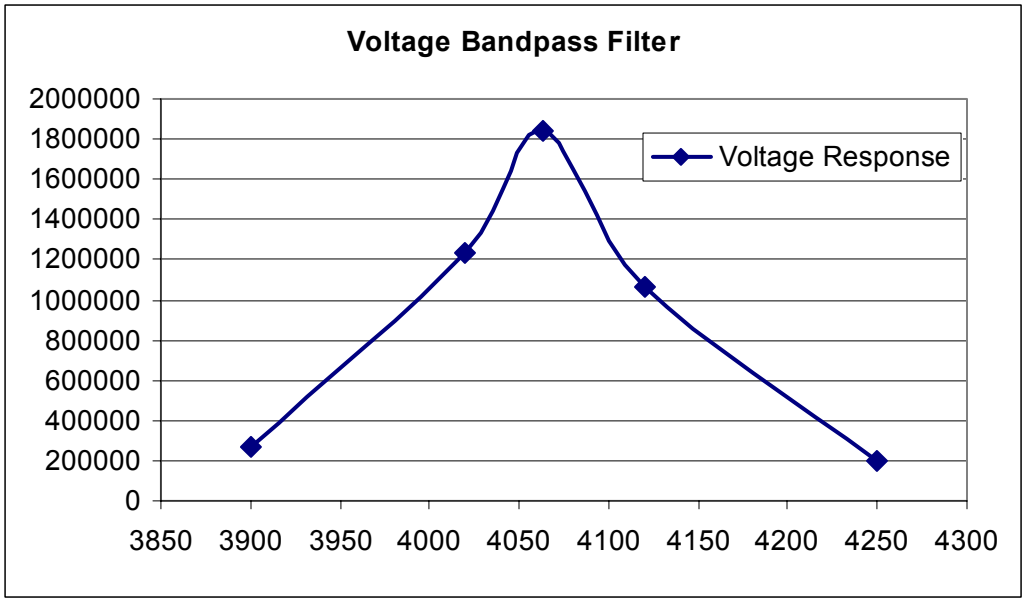


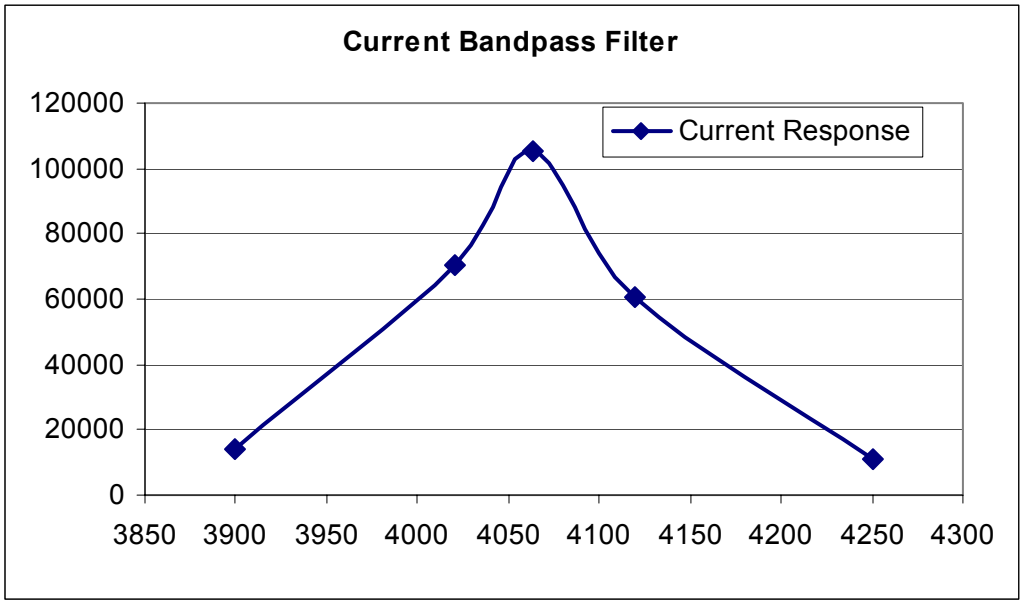

Wh Bandpass Filter
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
3850
3900
3950
4000
4050
4100
4150
4200
4250
4300
Wh Response

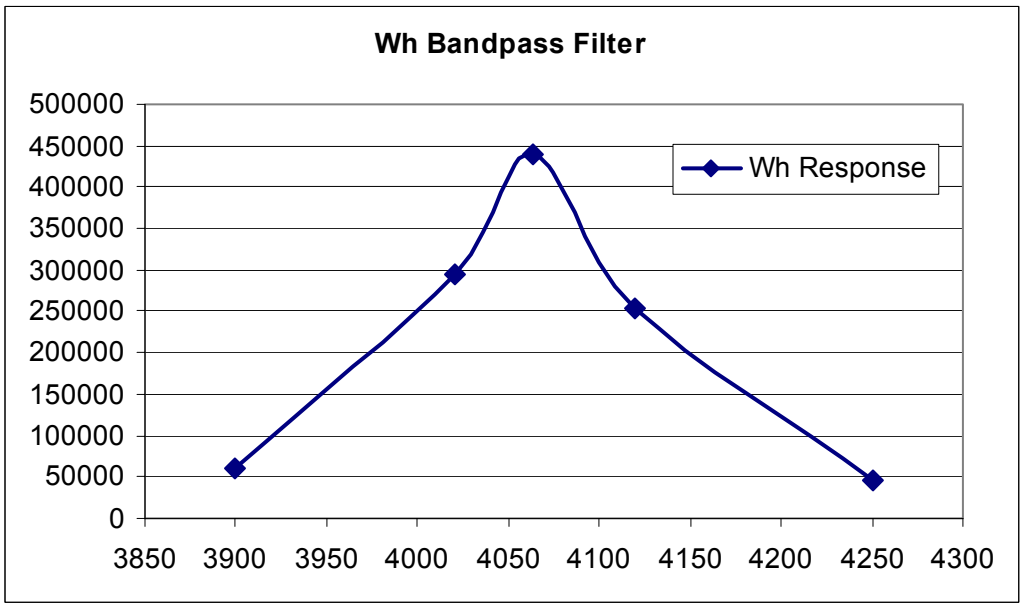
50Hz Harmonic Analysis Using Adjustable Band-Pass Filter

Harmonic Number	*NFREQ*	W0SUM_H_X	I0SQSUM_H_X	V0SQSUM_H_X
2	4063	437675	105076	1844368
3	6076	437613	104765	1829630
4	8065	437543	104627	1821313
5	10023	437054	104726	1823699
6	11942	436731	104708	1823224
7	13818	437713	104853	1831252
8	15638	437498	104789	1820321
9	17397	437225	104598	1824496
10	19087	437273	104723	1822552
11	20703	437427	104810	1825207
12	22239	437634	104889	1825814
13	23698	437036	104524	1826959
14	23047	436780	104789	1820417
15	26308	436245	104662	1818437
16	27467	435531	104405	1820050
17	28520	435000	104134	1812279
18	29460	433967	104070	1813743
19	30288	431994	104376	1812542
20	30997	427998	104223	1805564
21	31586	419405	104374	1802009

240V, 50Hz, 40% fundamental on Current, 20% on Fundamental Voltage



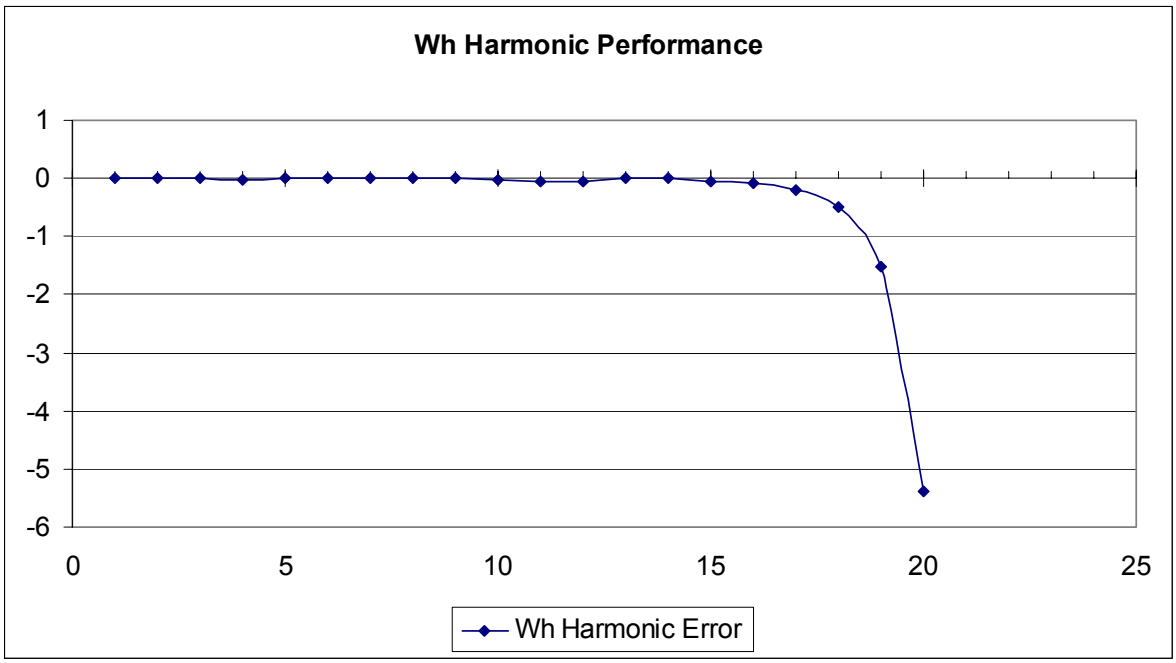

Current Bandpass Filter
120000
100000
80000
60000
40000
20000
0
3850
3900
3950
4000
4050
4100
4150
4200
4250
4300
Current Response


Wh Bandpass Filter
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
3850
3900
3950
4000
4050
4100
4150
4200
4250
4300
Wh Response

60Hz Harmonic Analysis Using Adjustable Band-Pass Filter

Harmonic Number	Fre-quency [Hz]	NFREQ	Broadband Error (%)	W0SUM_X	I0SQSUM_X	V0SQSUM_X	W0SUM_H_X	I0SQSUM_H_X	V0SQSUM_H_X
1	60	-1	0	5474411	655597	45666678	5471867	645797	45665250
2	120	4872	-0.00054443	5913079	761554	47492350	439171	105013	1839817
3	180	7274	-0.00054443	5912911	760687	47493132	438829	106950	1825692
4	240	9637	-0.01216334	5910778	760944	47494198	437903	104686	1827530
5	300	11945	-0.00054443	5909416	760587	47492390	437928	104974	1826674
6	360	14185	0.00111542	5910758	760833	47496724	438141	105041	1827224
7	420	16347	-0.00054443	5911642	761017	47494463	438226	105173	1825642
8	480	18417	-0.00054443	5912330	761234	47496080	437658	104574	1825704
9	540	20385	-0.00054443	5908736	760366	47495023	437369	104784	1825249
10	600	22238	-0.02710194	5908837	760700	47491731	437366	104279	1822395
11	660	23967	-0.04536024	5911602	761144	47489700	436399	104654	1819534
12	720	25563	-0.04536024	5907808	760405	47489254	436714	104658	1818809
13	780	27016	-0.00054443	5914180	761875	47494446	436674	104889	1818529
14	840	28318	-0.00054443	5909402	760745	47492121	435282	104559	1814518
15	900	29460	-0.0553193	5906832	760518	47486973	434411	104712	1810556
16	960	30439	-0.08353666	5906532	760856	47487200	431457	104618	1808274
17	1020	31248	-0.19474626	5903815	761503	47482258	425749	104482	1804357
18	1080	31881	-0.49849784	5882538	760535	47482809	409341	104581	1802138
19	1140	32337	-1.51100311	5832230	761696	47479345	356189	103799	1762907
20	1200	32612	-5.37678143	5629504	766460	47662626	137486	104233	1842821

240V, 60Hz, 40% fundamental on Current, 20% on Fundamental Voltage



Applied 240V, 60Hz, 40% Fundamental on Current, 20% on Fundamental Voltage

From the above table it can be seen that the *W0SUM_H_X* at harmonic #2 is about 8% of the fundamental energy (439171/5474411, or 8.02%). Also, one can see that the sum of the harmonic current and the fundamental current is equivalent to the broadband current (*I0SQSUM_H_X* + *I0SQSUM_F* = *I0SQSUM_X*). Similar considerations apply for the voltage measurements.

Summary

The capability of the 71M6513 with the new CE code for broadband and fundamental watt-hour measurement and individual harmonic component measurement capability for operation at 50Hz and 60Hz and their harmonics has been demonstrated.

Requests for further details can be sent to:

meter.support@teridian.com

TERIDIAN Semiconductor Corp., 6440 Oak Canyon Rd., Irvine, CA 92618

TEL (714) 508-8800, FAX (714) 508-8877, http://www.teridian.com

