APPLICATION NOTE

RTI Electronics

RTI Electronics AB, Sweden **Revision A, July 2007**

kVp measurements on GE AMX-4

A comparison between the Barracuda/Piranha, an invasive Voltage divider, and the Keithley Triad

Both the Barracuda and the Piranha have a correction algorithm enabling it to measure the tube voltage accurately on the AMX-4 mobile X-ray generator from GE Medical Systems. This note contains a description of the problem with the waveform from the AMX-4 and the verification of the correction by comparison between the Barracuda, an invasive voltage divider and the Keithley 35080 non-invasive divider with the Mobile Filter Pack GE recommends the latter device for calibrating the AMX-4).

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INTRODUCTION

Measuring the tube voltage on a GE AMX-4[1] non-invasively and accurately can be difficult and is a well-known and documented problem. It is hard for most non-invasive kVp-meters to follow the waveform correctly due to high kV ripple (20 kV of magnitude) at a frequency of 2 kHz. The Barracuda's (or Piranha's) normal sampling frequency is 2 kHz, hence, the Barracuda (or Piranha) needs a special correction when performing measurements on the AMX-4 to accurately determine the average of the peak kV.

The measurements performed with the Barracuda or Piranha using the correction algorithm agree closely with measurements made with the Keithley Triad System's 35080B non-invasive divider using the 37946C mobile filter pack[2] (50-135 kV) and with the results from a traceable high voltage divider with sufficient bandwidth to accurately follow the kV ripple from the AMX-4.

The IEC working group for the IEC 61676 standard has created a definition for kV with the unit PPV (Practical Peak Voltage). An independent study at PTB using the Barracuda MPD with the DC/HF waveform function for kV measurements has shown very good correlation with the new PPV unit. In practice however, kVp (measuring the average of the peaks of the waveform) is still the most commonly used way today to determine the tube voltage.

This application note illustrates how the Barracuda is enabled to give similar results as the Keithley 35080 non-invasive divider using the mobile filter pack as well as an invasive high voltage divider when measuring the tube voltage on the AMX-4/4+.

[1] The General Electric AMX-4 portable generator is the most popular mobile X-ray unit in the United States owning the largest share of the US market and it is becoming more and more popular throughout the world.

[2] The Triad's 35080B using the mobile filter pack is presently the only non-invasive kVp measuring device recommended by GE for measuring and calibrating the AMX-4/4+.

SETUP

The kV data from the AMX-4 was acquired simultaneously using the following three devices. The Barracuda MPD (Multipurpose Detector), The Radcal HV-1 invasive voltage divider connected to the Barracuda SEM (Signal Extension Module), and the Keithley Triad System model 10500AT consisting of the 35080B non-invasive divider using the 37946C mobile filter pack and the 35050A Dosimeter/kVp/Time readout device (fig. 1a and 1b).

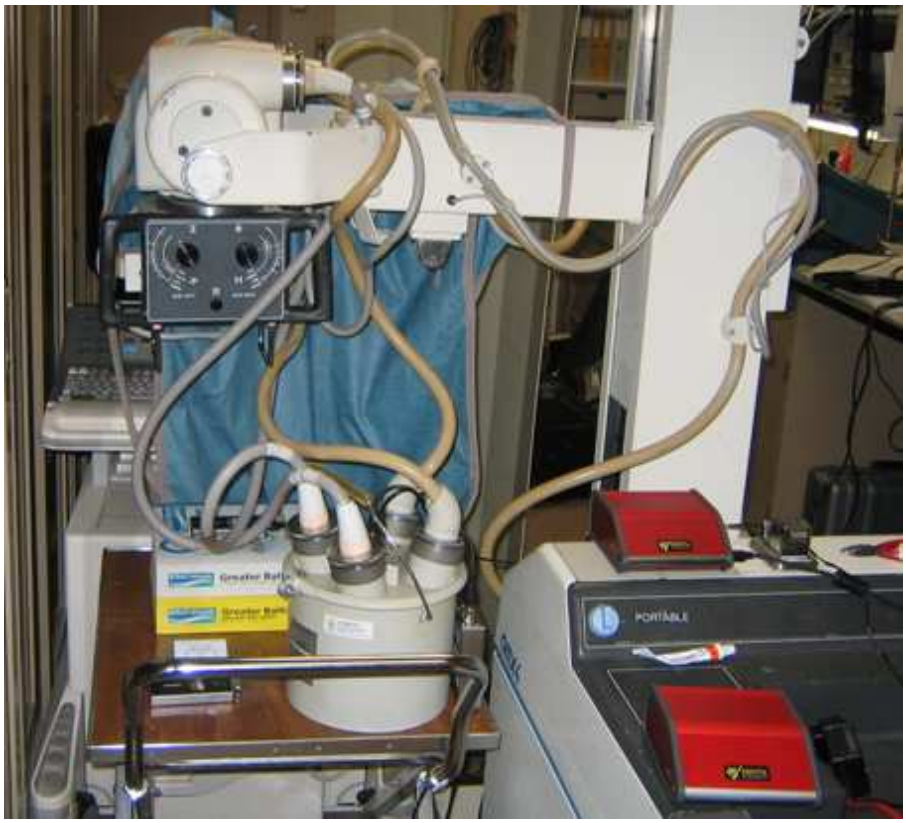


Figure 1a. The RadCal HV-1 invasive voltage divider connected to the Barracuda SEM module.

Figure 1b. The Barracuda MPD and the Triad System model 10500AT consisting of the 35080B non-invasive divider using the 37946C mobile filter pack. The 35080B sensor area was placed in the center of the field and 90º to the anode cathode in order to measure and display accurate results. The check filter of the MPD was used to correct any field symmetry problems in the ratio allowing the Barracuda to measure and display accurate results. This is an unique feature and advantage of the MPD.

CALIBRATION PROCEDURE

It is a well-known fact that the sampling frequency of the measuring instrument must be at least twice as fast as the output frequency it is being used to measure on in order to obtain an accurate measurement. As stated above, the AMX-4 has a waveform frequency of 2 kHz, which is the same as the normal sampling frequency of the Barracuda (or Piranha) using the DC/HF setting. This makes it very difficult for the Barracuda (or Piranha) to accurately sample and reproduce the waveform of the AMX-4. Furthermore, because there is a considerable amount of ripple in the kV waveform of the AMX-4 the Barracuda (or Piranha) displays a lower kV measurement (see the Barracuda measurements in the table 2).

However, the Barracuda also has a special high-speed mode built into the MPD where both the internal dose detector as well as an external signal from an analogue signal/source connected to the SEM (i.e. an invasive high voltage divider, a 35080B non-invasive divider, mA probe, dose probe etc.) can be measured simultaneously. Both of these signals have a selectable analogue bandwidth up to 100 kHz and a selectable digital sampling frequency up to 470 kHz. In this study we have selected an analogue bandwidth of 20 kHz with a digital sampling frequency of 120 kHz, which exceed the criteria for sampling correctly on the 2 kHz waveform of the AMX-4. This high-speed mode enables the detector to catch a large output variation in the AMX-4 kVp measurement.

In fig. 2 and fig. 3, the difference between the Barracuda standard way of measuring kV and with the high speed mode is clearly displayed.

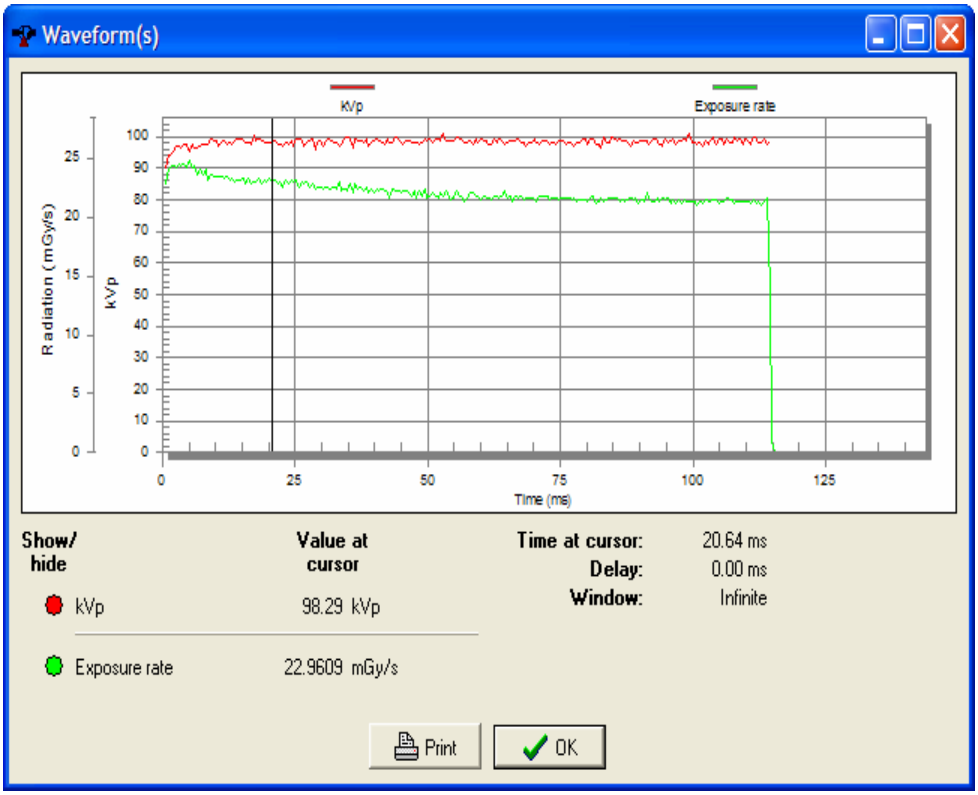


Figure 2. Tube voltage and exposure rate waveforms measured at 100 kV and 10 mAs with the Barracuda (80-155 kV filter) and the oRTIgo software. The Barracuda has a sampling rate of 2 kHz. Note how the exposure rate is greater in the beginning of the measurement. It is very advantageous to be able to study both the kV and the exposure rate waveform simultaneously. The Keithley Triad system is only capable of displaying the kV waveform.

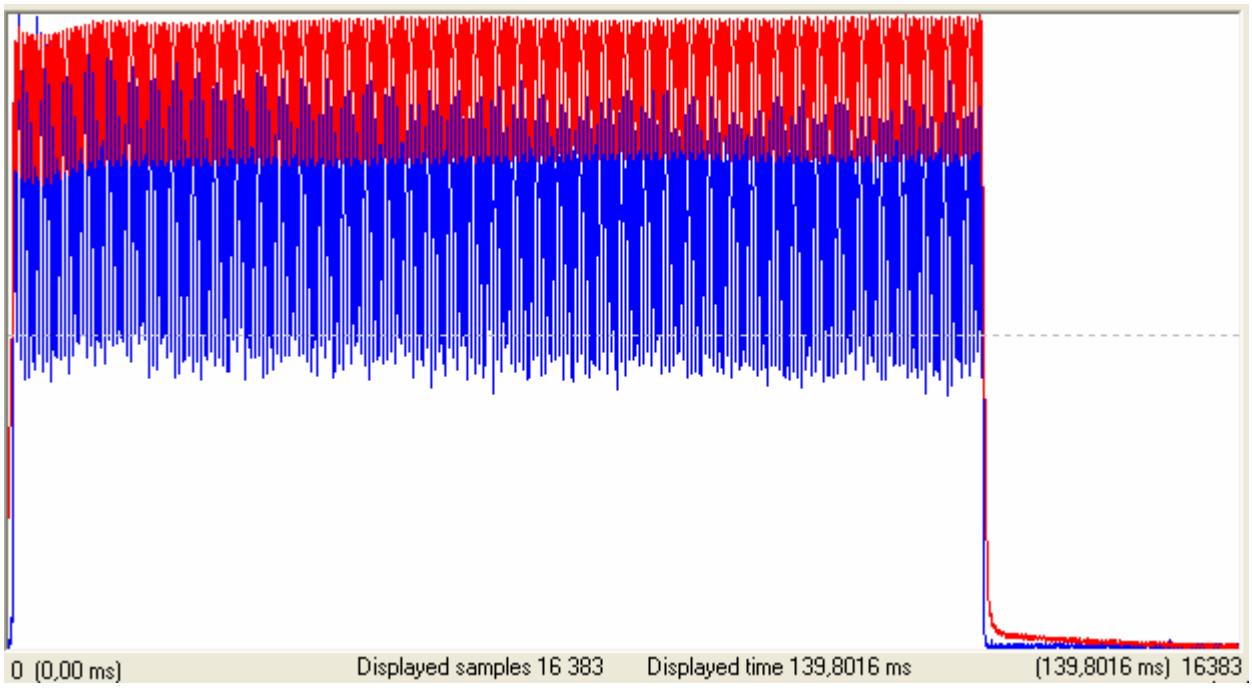


Figure 3. Tube voltage measured at 100 kV and 10 mAs with Barracuda (80-155 kV filter), and high speed mode. The variations in signal have a magnitude of approximately 20 kV. The red line represents the kV measured with the invasive high voltage divider. The blue line represents the exposure rate measured with MPD.

We analyzed the high voltage in range from 1mAS -100 mAs[3] (11 – 1100 ms) and found that the kV-waveform was stable and reproducible (fig. 3, 4 and 5). The calculations of the tube voltage was done at 10 mAs (fig. 3 and 6).

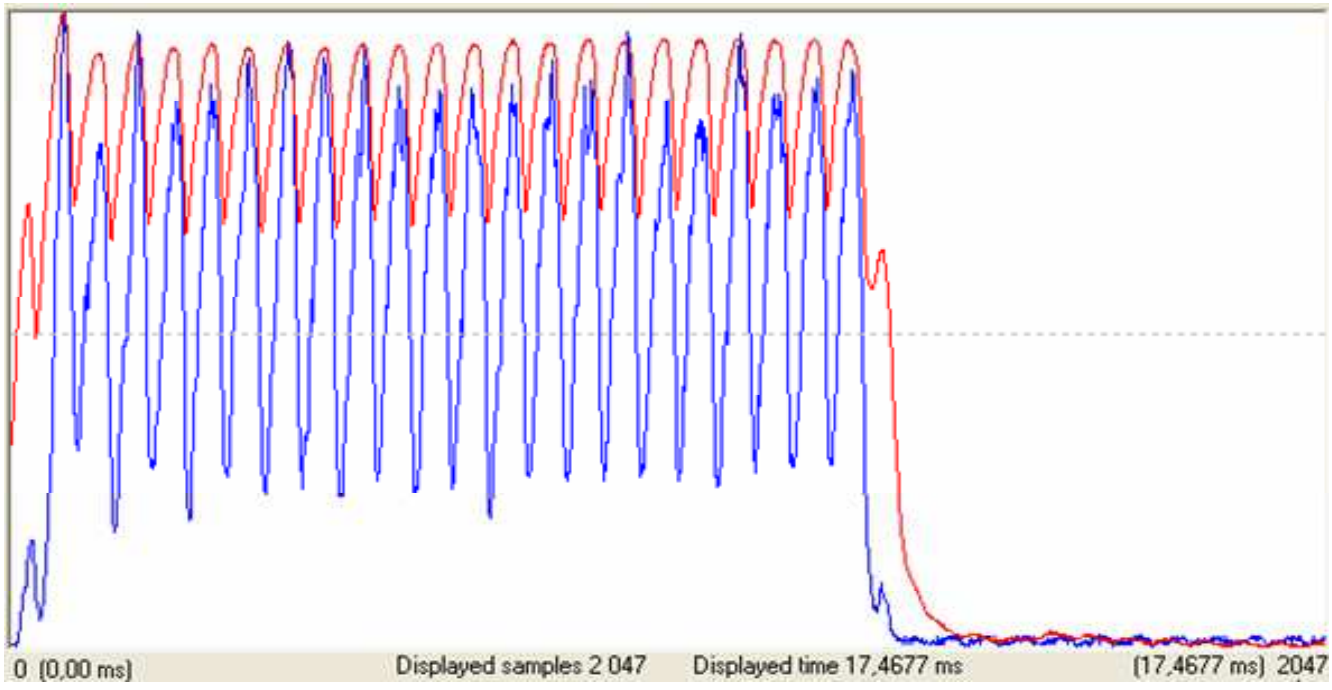


Figure 4. Tube voltage measured at 70 kV and 1 mAs with Barracuda (80-155 kV filter) and high speed mode. The red line represents the kV measured with the invasive high voltage divider. The blue line represents the exposure rate measured with MPD.

[3] The AMX-4 is a 100 mA generator thus only the time factor is changed when selecting different mAs settings.

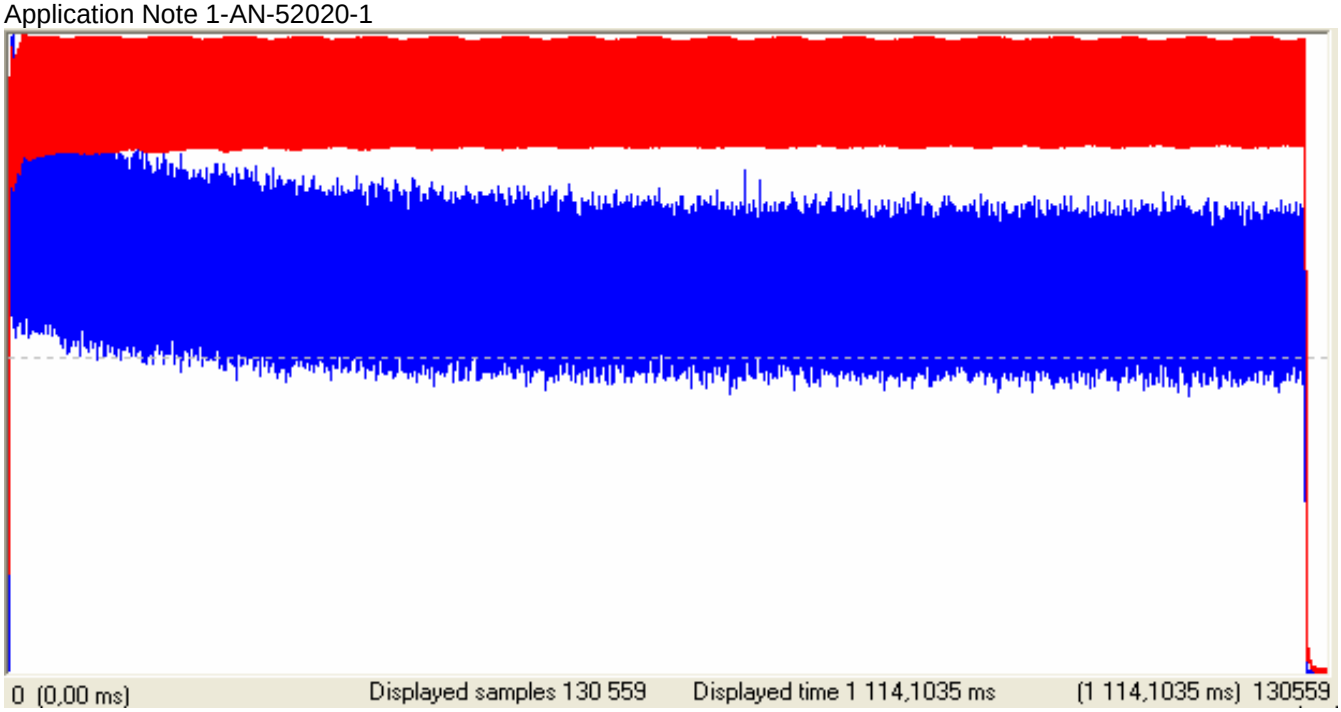


Figure 5. Tube voltage measured at 120 kV and 1000 mAs with Barracuda (80-155 kV filter) and high speed mode. The red line represents the kV measured with the invasive high voltage divider. The blue line represents the exposure rate measured with MPD. Altogether more than 130 000 data points were collected from both channels during little more than 1 s exposure time. Note that the kV waveform is quite stable but the level of the blue radiation waveform drops during the exposure.

The variations in the kV have a constant magnitude of approximately 20 kV and the calculated ripple can be greater than 35 % when measuring at a tube voltage of 50 kV (see table 1). The last part of the ripple in fig. 3 is enlarged in fig. 7.

Table 1. The ripple from the AMX-4, ranging from 14.6 to 35.1 %.

Ripple measurements

Set kV (kV)	Voltage divider (kVp)*	Voltage divider min (kV)	Ripple (kV)	Ripple (%)
50	53,6	34,8	18,8	35,1
52	55,3	36,0	19,3	34,9
60	62,0	42,5	19,5	31,5
64	64,4	45,3	19,1	29,7
70	70,6	51,5	19,1	27,1
80	80,6	61,0	19,6	24,3
85	85,0	64,0	21,0	24,7
90	90,5	70,0	20,5	22,7
100	101,6	81,0	20,6	20,3
110	112,1	92,0	20,1	17,9
120	120,4	101,5	18,9	15,7
125	125,3	107,0	18,3	14,6

* The value are based on the existing peak values from 500 sample points.

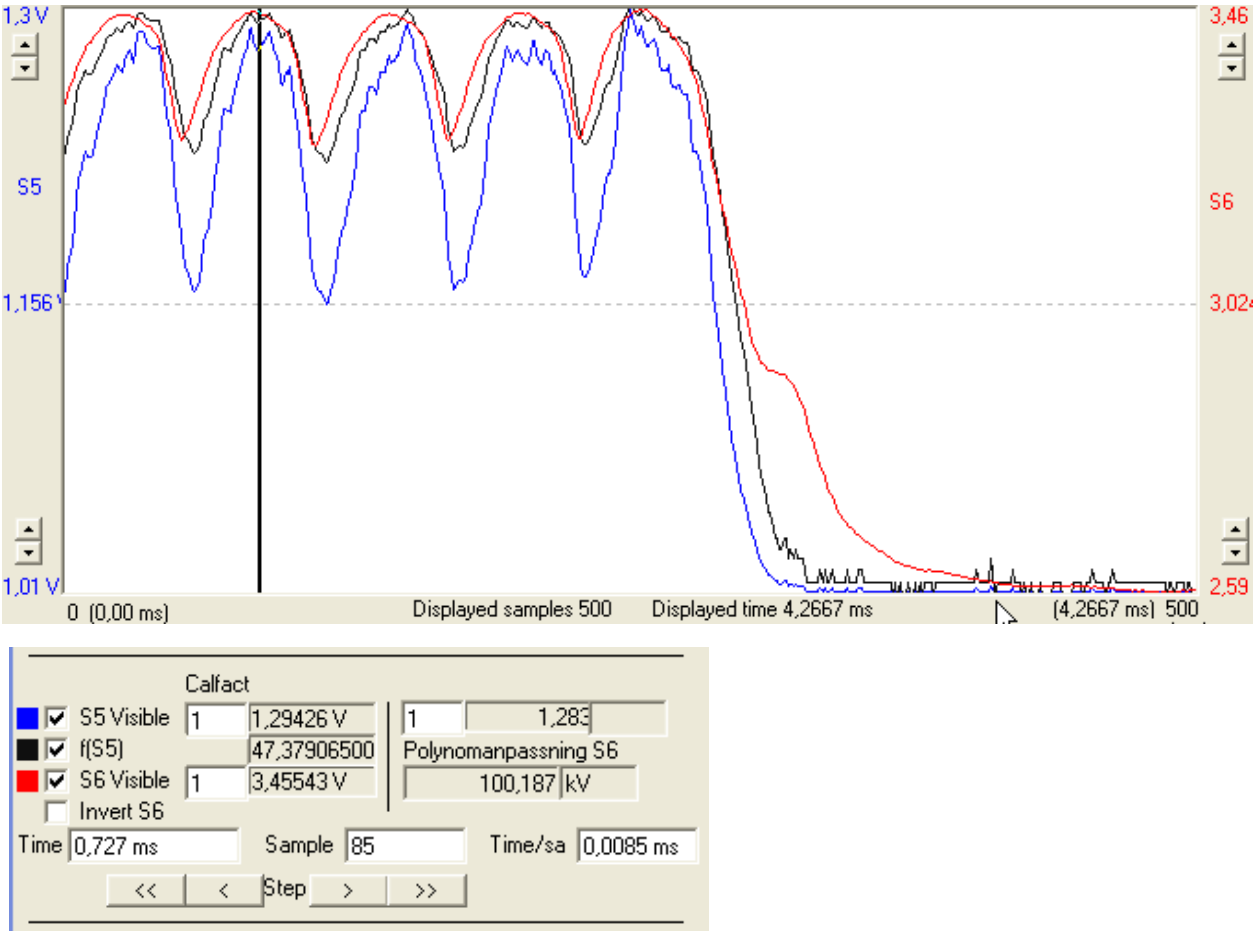


Figure 7. An enlargement from fig. 3 of the last 500 samples of the AMX-4 output measured with the Barracuda in high-speed mode. One period is equal to 0.5 ms. The red line represents the kV measured with the invasive high voltage divider. The blue line represents the exposure rate measured with MPD and the black line represents the kV-waveform estimation based on the measured exposure rate from the MPD. The peaks were read by use of the cursor and the average of the kV peaks has been used to determine the kVp value from the high voltage waveform. The kV measurement at this specific peak is 100,2 kV and is shown in the added window. The small variations of the exposure rate signal arises from the detector noise at this high bandwidth which is added to the waveform.

The results of the measurements on AMX-4 at a distance of 56 cm are presented in table 2.

Table 2. Measurement data from AMX-4 using oRTIgo and dynamic export to Excel.

Measurements made using oRTIgo and dynamic export to Excel:

Set kV (kV)	Barracuda filter	Set mAs (mAs)	Exp time (ms)	Total filtration (mm Al)	HVL (mm Al)	Dose (mGy)	Voltage divider (kVp)*	Barracuda waveform DC/HF (kV)	Keithley mobile pack (kV)
50	35-75 kV	10,0	109,9	3,0	1,8	0,57	53,6	51,6	
52	35-75 kV		119,9	3,0	1,9	0,62	55,3	53,0	56,4
60	35-75 kV		105,3	3,0	2,1	0,82	62,0	58,8	
64	35-75 kV		99,3	3,0	2,2	0,92	64,4	61,4	65,6
70	35-75 kV		100,8	3,0	2,4	1,15	70,6	66,9	71,7
80	55-105 kV		124,0	3,1	2,9	1,57	80,6	77,1	
85	55-105 kV		123,0	3,1	3,1	1,75	85,0	81,0	86,3
90	55-105 kV		107,9	3,1	3,4	2,01	90,5	86,4	
100	55-105 kV		115,4	3,1	3,8	2,54	101,6	97,4	
110	80-155 kV		110,4	3,0	4,1	3,09	112,1	109,0	
120	80-155 kV		116,4	3,0	4,3	3,58	120,4	117,1	121,4
125	80-155 kV		122,5	3,0	-	3,85	125,3	122,1	

* The value are based on the existing peak values from 500 sample points.

RESULTS

To be able to make the corrections for the kV results when measuring with DC/HF waveform, some type of algorithm was needed (based on the measured data from table 2). A linear dependence was found between the voltage divider and the Barracuda kV value (fig. 8).

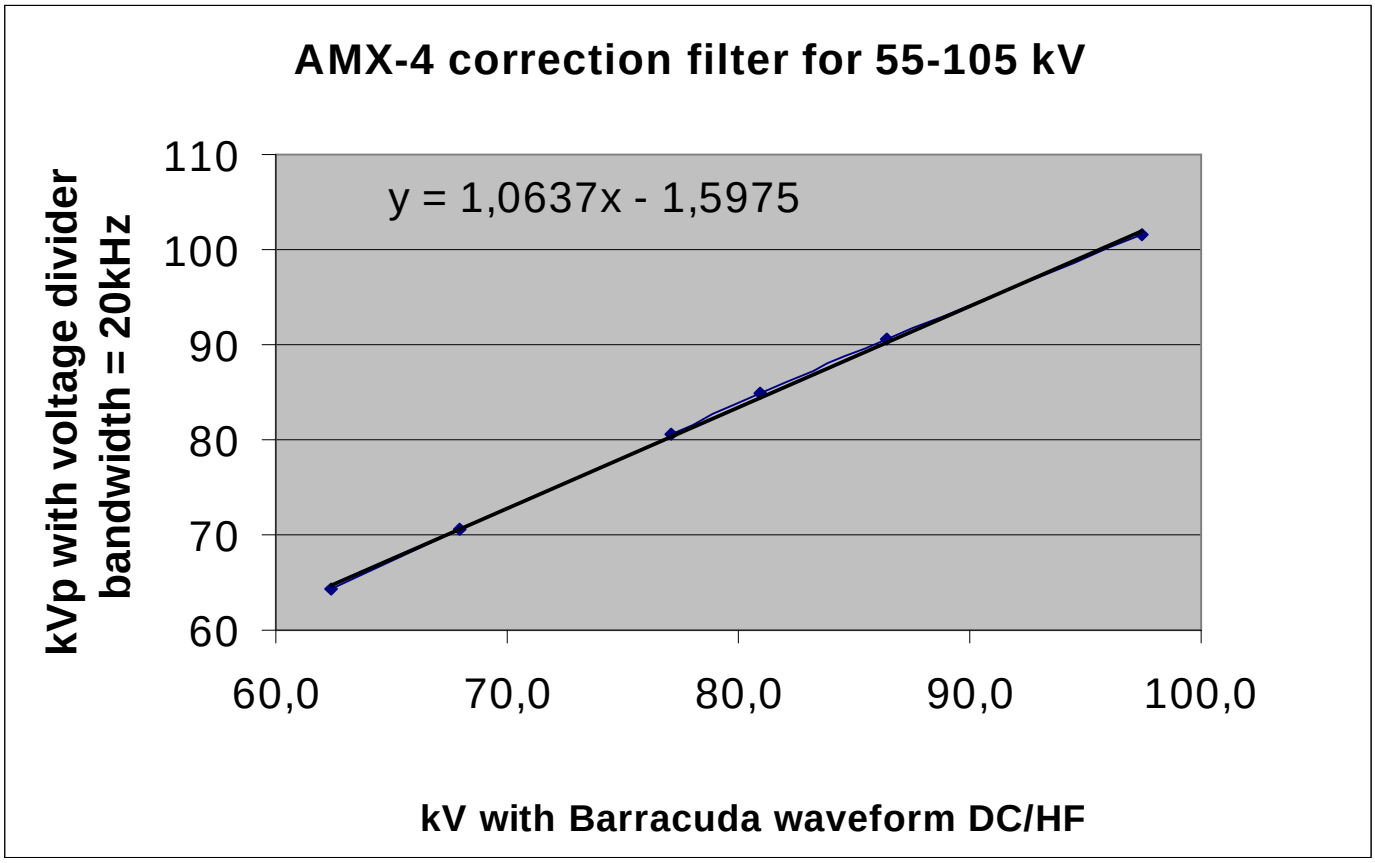


Figure 8. The graph demonstrates the linear dependence between the kV from the voltage divider and the Barracuda using the DC/HF waveform.

35-75 kV	y = 1,1036x - 3,2316
55-105 kV	y = 1,0637x - 1,5975
80-155 kV	y = 0,9948x + 3,7939

x is the tube voltage value with waveform DC/HF
y is the corrected value

An example using filter 55-105 kV
x = 81,0 kV
The corrected value is y = 1,0637 * 81,0 - 1,5975 = 84,6 kV

The linear equations for correction

Using the linear equation, the tube voltage measured with the DC/HF waveform mode can be corrected. The corrected values are consistent with those from the same measurements using the invasive voltage divider. The correction also provides an agreement with the measurements made with the Keithley Triad System's 35080B using the 37946C mobile filter pack (50-135 kV) (see table 3). A new column with a heading titled "Barracuda waveform AMX-4" has been added showing these new values.

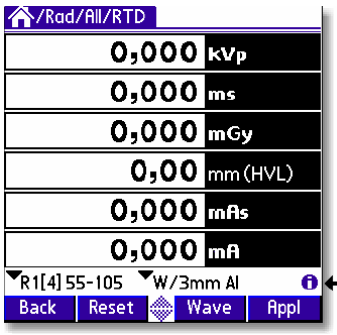
Table 3. A new comparison displaying the tube voltage results between the different measuring devices. The Barracuda's results using the new AMX-4 correction algorithm compares very closely to both the reference high voltage divider's results as well as the Keithley Triad's results using the mobile filter pack.

Set kV (kV)	Barracuda waveform DC/HF (kV)	Voltage divider (kVp)*	Keithley mobile pack (kV)	Barracuda waveform AMX-4 (kV)	Ratio Voltage divider and waveform AMX-4	Ratio Voltage divider and Keithley
50	51,6	53,6		53,7	1,00	
52	53,0	55,3	56,4	55,3	1,00	0,98
60	58,8	62,0		61,7	1,01	
64	61,4	64,4	65,6	64,5	1,00	0,98
70	66,9	70,6	71,7	70,6	1,00	0,98
80	77,1	80,6		80,4	1,00	
85	81,0	85,0	86,3	84,6	1,01	0,98
90	86,4	90,5		90,3	1,00	
100	97,4	101,6		102,0	1,00	
110	109,0	112,1		112,3	1,00	
120	117,1	120,4	121,4	120,3	1,00	0,99
125	122,1	125,3		125,3	1,00	

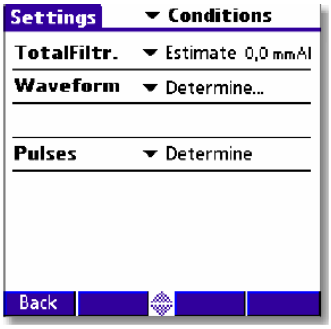
* The measurements are based on 500 samples from the HV kV waveform.

TEST OF THE NEW AMX-4 CORRECTION

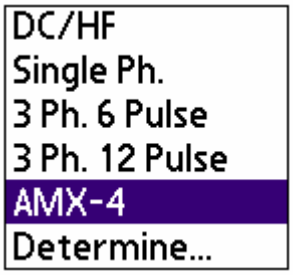
The correction algorithm for the AMX-4 has been implemented in the QABrowser and oRTIgo software. When using the QABrowser it is found in the “extended setting” menu, see below.



Tap this symbol to open the screen with *Settings* for the Barracuda and the various detectors

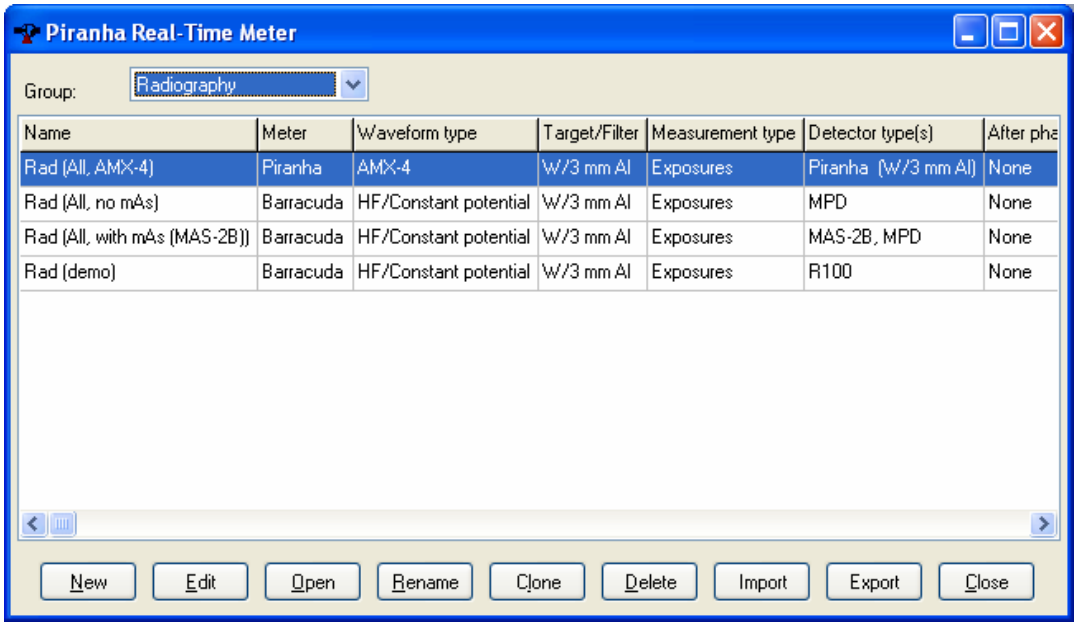


Tap Determine to open the list of possible waveforms. Select AMX-4

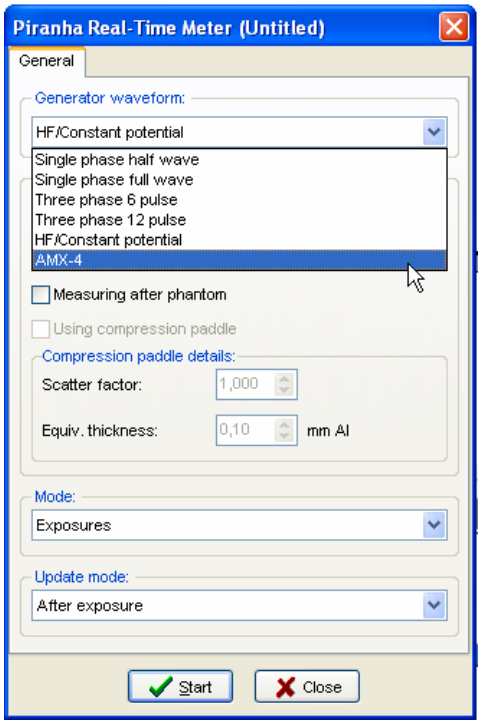


In oRTIgo the setting is found in the real-time meter under “generator waveform” and in the database part when selecting a room and generator in a template in the oRTIgo database. See pictures below:

Real-time meter:



Select New



Open the list under Generator waveform and tab AMX-4

Open the list under Generator waveform and tab AMX-4

oRTIgo database part:

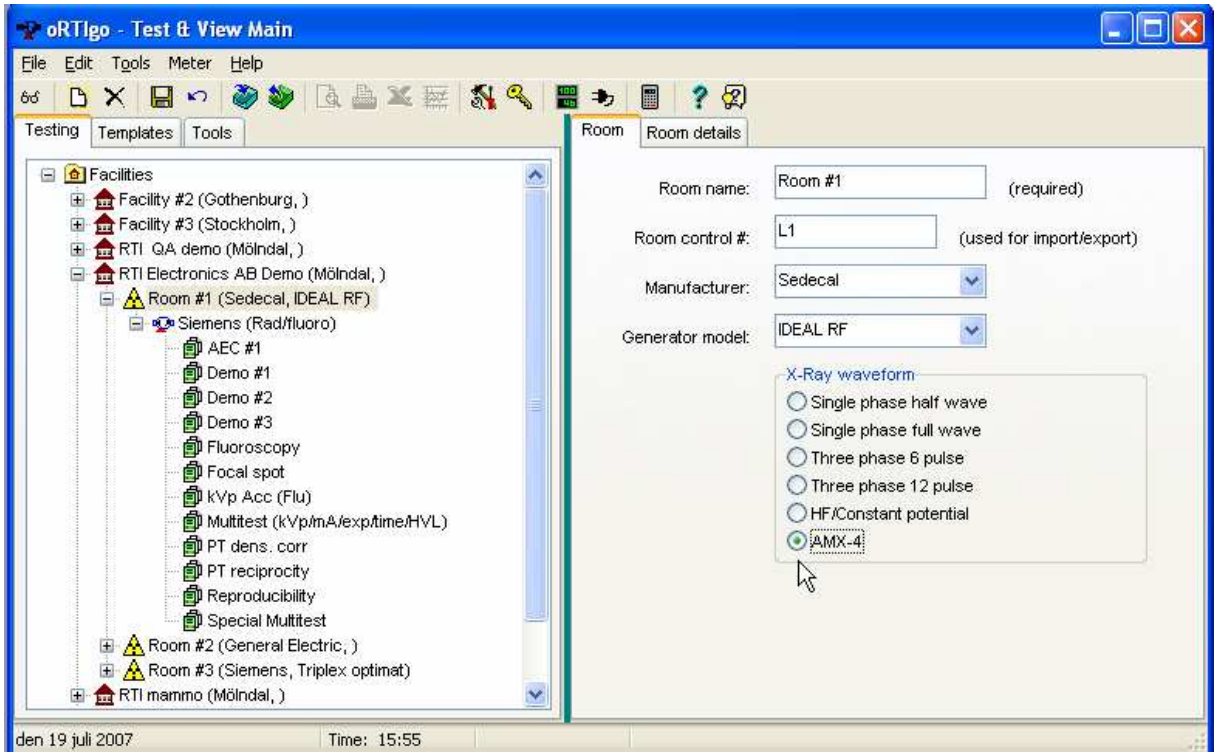


Figure 9. The settings in oRTIgo database part. Fill in AMX-4 under the room details.

APPENDIX A - Other Barracuda-Keithley comparisons

Table 4 shows a comparison of measurements between the Keithley Triad using the two different filter packs (37617C Wide Range “standard” filter pack and 37946C mobile filter pack) and the Barracuda MPD using the DC/HF waveform setting. The first two sets of data are measured with an inherent filtration of 3.5 mm Al in the tube. The second two sets show the effect when additional filtration is added to the beam. Figure 10 shows the kV accuracy verses the filtration.

Table 4. Measurements done with the mobile filter pack, the standard filter pack (50-150 kV) and the Barracuda using the DC/HF waveform mode. Note that the Barracuda using DC/HF waveform mode was slightly more accurate than the 35080B using the standard filter pack at certain kV settings. The measured results from the 35080B using the standard filter pack (50-150 kV) show why GE recommends using the Mobile filter pack for AMX-4 measurements.

Barracuda filter	Set mAs (mAs)	Set kV (kV)	Barracuda waveform DC/HF (kVp)	Exp time (ms)	Total filtration (mm Al)	HVL (mm Al)	Dose (mGy)	Keithley Triad (kV)	Exp time (ms)	Keithley filter pack
35-75 kV	20	52	52,6	236,9	3,4	2,0	1,29	56,4	235,6	Mobile pack
35-75 kV	20	64	60,8	234,4	3,4	2,4	1,95	65,6	233,5	Mobile pack
55-105 kV	20	85	79,8	250,99	3,4	3,2	3,68	86,3	249,8	Mobile pack
80-155 kV	20	120	117,1	238,39	3,7	4,7	7,64	121,4	237,1	Mobile pack
35-75 kV	20	52	52,6	243,94	3,5	2,1	1,29	58,5	242,5	Standard pack
35-75 kV	20	64	60,9	237,39	3,5	2,4	1,94	60,5	236	Standard pack
55-105 kV	20	85	80,1	252,98	3,5	3,3	3,68	79,3	251,9	Standard pack
80-155 kV	20	120	117,2	238,9	3,5	4,6	7,62	116,2	238,1	Standard pack
55-105 kV	10	64	62,3	115,92	7,5	3,6	0,29	68,2	115,5	Mobile pack
55-105 kV	10	64	62,8	116,43	11,4	4,4	0,13	70	115,9	Mobile pack
55-105 kV	10	85	80,2	121,97	3,5	3,3	1,83	86,1	120,7	Mobile pack
55-105 kV	10	85	80,6	122,97	8,5	5,0	0,72	89,8	121,8	Mobile pack
55-105 kV	10	85	80,9	121,97	12,8	6,1	0,38	92,2	121,1	Mobile pack
55-105 kV	10	64	62,2	115,42	7,6	3,6	0,29	62,1	115,1	Standard pack
55-105 kV	10	85	80,0	121,97	3,5	3,3	1,84	80,1	120,9	Standard pack
55-105 kV	10	85	80,5	121,97	8,5	5,0	0,72	81,6	120,9	Standard pack

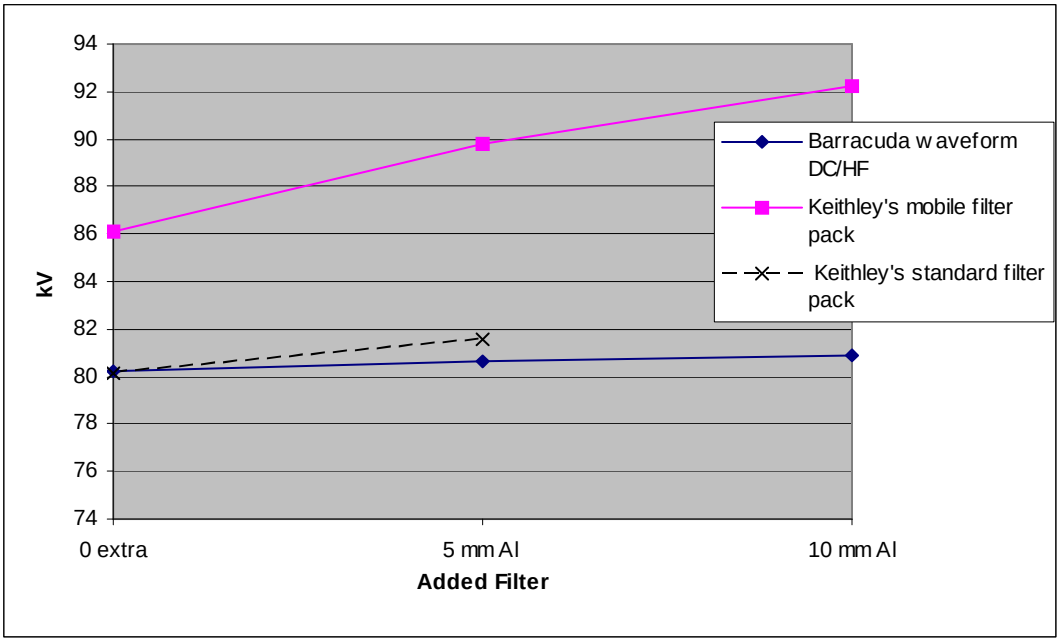


Figure 10. This graph shows how the kV measurements of the 35080B using the two different filter packs and the Barracuda with the MPD are effected by filtration. The 35080B using the standard filter pack shows a change of > 0.3 kV/mm Al (from 3.5 to 12.8 mm Al total filtration) while using the mobile filter pack shows an even greater change of > 0.6 kV/mm Al. In contrast the Barracuda MPD, using a superior measurement design, automatically corrects for the measured kVp by always measuring the total filtration and thus the Barracuda only shows a change of < 0.08 kV/mm Al. The filtration measurement capability coupled with the new correction algorithm for the AMX-4 waveform make the Barracuda a more accurate non-invasive device for measuring and calibrating AMX-4/4+.

In table 4 there is one other discrepancy that should be noted. When using the 35080B with the standard filter pack at the set kV of 52 kV, the measured value was 58.8 kV. At the set value of 64 kV the measured value was 60.5 kV. There was a difference of 12 kV between the two set values but only a difference of 6.5 kV between the two measurements. Using the mobile filter pack, there was a difference of 9.2 kV between the two measured values. The reason for this discrepancy can be attributed to at least two hardware limitations, the standard pack's filter thickness and the logarithmic pre-amplifier. These together create a deformed and inaccurate kV waveform. Fig. 11 and 12 show the waveform differences between the standard and the mobile filter packs.

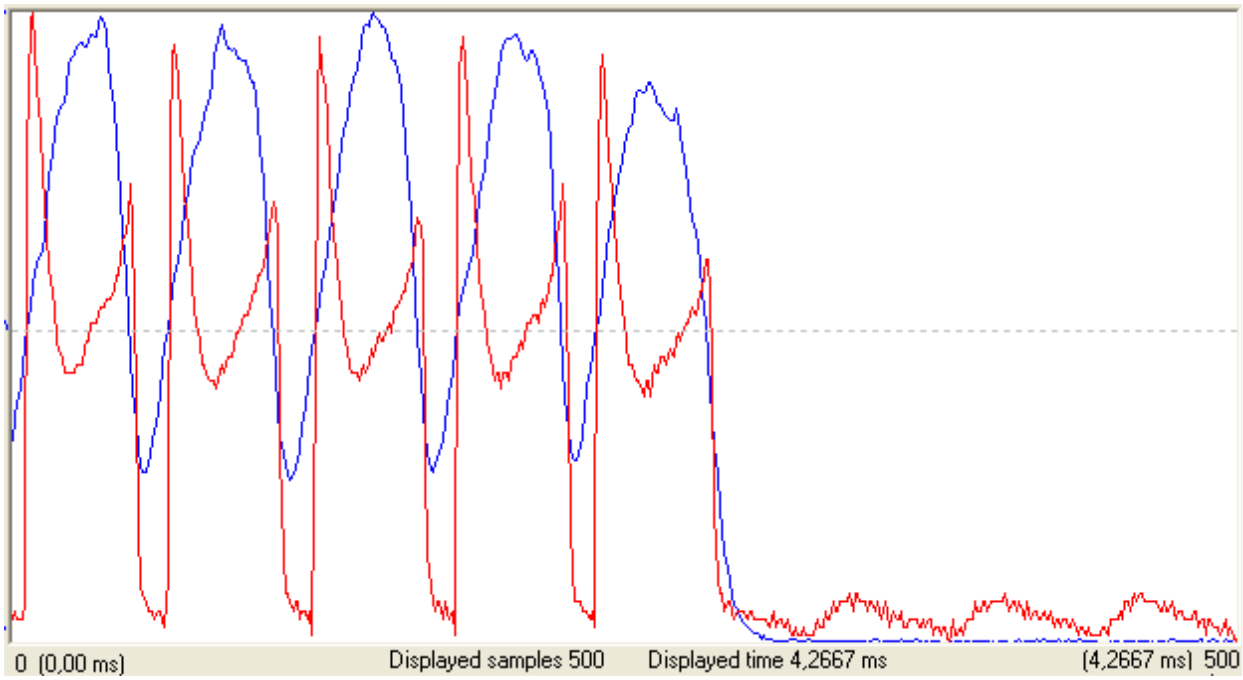


Figure 11. The 35080B using the standard filter pack was connected to the SEM on the Barracuda and the high-speed sampling capability was used. The blue line is the exposure rate measured with Barracuda MPD and the red line is kV measured with Keithley standard filter pack. The generator settings were 52 kV at 10 mAs. It is obvious that the kV waveform created by the 35080B's analogue ratio circuit is incorrectly displayed since the maximum kV is not related in any way to the radiation waveform's maximum dose rate output.

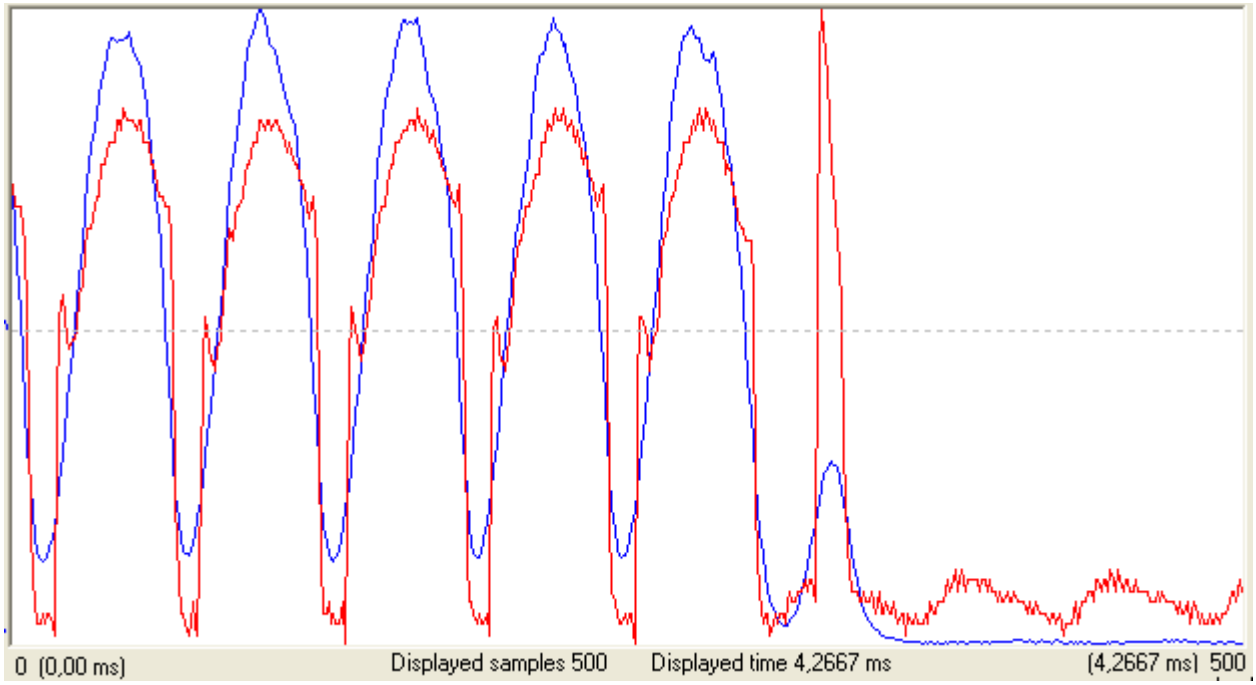


Figure 12. These waveforms were produced using the same generator settings as in fig. 12 using the mobile filter pack. This shows why it is important to use the mobile filter pack with the 35080B when calibrating or measuring on the GE AMX-4. One final thing to note: The last kV pulse displayed by the 35080B is erroneous compared to the true radiation output from the Barracuda. This reinforces the advantage of the Barracuda and its ability to show the radiation waveform. It also has the potential to cause an incorrect result from the measurement by the 35080B.

APPENDIX B - The effect of the load of the voltage divider

In the following table it is shown how much the Voltage divider itself affects the loading of the X-ray generator. Measurements were done with the Barracuda MPD using the same kV setting with and without the High Voltage divider in the field to see the kind of change there would be in the kV related to whether the high voltage divider is in or out of the circuit.

Table 5. The effect of the Voltage divider load on the X-ray generator.

T=Keithley Triad system
B=RTI Barracuda system with meaurements recalculated with AMX-4 correction

With Voltage divider				**Without Voltage divider**					
Set mAs	Set kV	kVp (B)	kVp (T)	Set mAs	Set kV	kVp (B)	kV (T)	Diff (B)	Diff (T)
20	52	54,8	56,4	20	52	57,0	57,8	-4,2%	-2,7%
20	64	63,9	65,6	20	64	65,2	66,8	-2,0%	-1,9%
10	70	70,1	71,7	10	70	71,6	72,9	-2,1%	-1,7%
20	85	83,3	86,3	20	85	84,7	87	-1,6%	-0,8%
20	120	120,3	121,4	20	120	121,1	122,7	-0,7%	-1,1%

Typically the kV drops 2 percent with the high voltage probe connected in the circuit. However, the accuracy in our correction algorithm is not compromised because the calibration was made with all three probes (HV-1 high voltage divider, the Barracuda MPD and the Keithley Triad) in the field simultaneously.

We would like to thank Bill Tyler and staff at the VA Medical Centre in Baltimore, Maryland as well as Rob Morrison at FBA and individuals from GE in Sweden for allowing us to perform and acquire the data that enabled us to create this correction algorithm for the Barracuda.

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