

Compensation look-up-table (LUT) and How to Generate

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Description

The compensation look-up-table (LUT) contains frequency dependent phase and amplitude data. This is automatically applied to the "Image data" to maximize diffraction efficiency and improve the uniformity across the scan. The LUT is a fixed length file of 2047 points covering the full frequency range of the iMS4-L or -P. (12.5MHz - 200MHz).

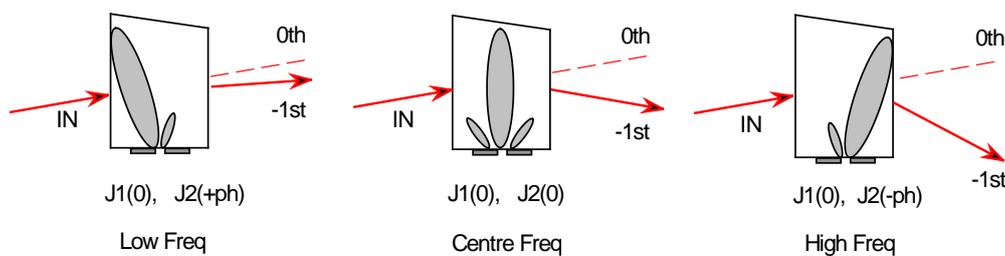
[The LUT can also be programmed with a user defined 12-bit data word. This is synchronously output on connector iMS4 connector J7 when the specified frequency(s) is called. It is an alternative to the point defined Synchronous data field programmed in the Image data].

Background Theory

Maximum diffraction efficiency exists when the laser beam and acoustic column in the AO crystal are at the Bragg angle. This angle is a function of the RF drive frequency and laser wavelength. In an AO deflector, the frequency defines the output scan angle. Consequently, when the scan angle is changed so too is the ideal input precise Bragg angle.

For optimum performance the Bragg angle needs to be readjusted according to the RF drive frequency (= scan angle). A fast and dynamic method to achieve this angle correction is to steer the acoustic beam in the crystal using a phased array transducer. Such transducers feature multiple RF inputs, driven with a progressive phase shift. The magnitude of this phase shift depends on the transducer geometry (constant) and the applied RF frequency (variable).

At the mid frequency, the phase difference between the two AOD inputs is zero. At all other frequencies, there is a positive (+ph) or negative phase (-ph) difference. At any given moment, the frequency and amplitude applied to each AOD has the same value. Only the phase is different between the two or more inputs of the AOD



LUT in summary:

Programming an incremental phase offset across the AO deflector RF inputs corrects for the input Bragg angle error. These phase values are appended to the downloaded Image file according to the channel number and frequency value of each image point.

Programming an amplitude factor corrects for frequency dependent amplitude variations due to conversion losses in the transducer, gain variations in the RF amplifier and coax cable characteristics. The LUT amplitude factor is multiplied with the Image file amplitude data, across all channels according to the point frequency.

The LUT is downloaded into the iMS4-P at start up by the user.

A default start-up LUT can also be programmed into non-volatile memory within the iMS4-L (or -P) Subsequently the LUT is automatically applied following DC power-on of the iMS4 (this function is not available via the GUI, see C++ SDK).

Basic LUT's.

Phase is calculated. The calculated values assume that the Bragg angle is adjusted at the AO geometric mean frequency. This is a near mid-frequency that will give a balanced positive and negative phase shift value at the min/max scan limits.

Phase calculation:

$$\varphi(f) = -180 \cdot \left[\frac{G \cdot \lambda_o \cdot 10^{-3}}{no} \cdot f^2 \cdot \left(1 - \frac{f1}{f} \right) \right]$$

where:

G	=	Device specific Geometric Constant
f	=	frequency (MHz)
f_c	=	AO device center frequency
$f1$	=	mean frequency for balanced +/- phase shift
	=	$f_c \times f_c^2 / [f_{max} \times f_{min}]$
λ_o	=	free space wavelength (nm)
no	=	refractive index

(Add 360 degrees to negative phase values).

The calculation of these theoretical phase values does not take account for errors introduced by the transducer matching network, RF amplifier and coax cable characteristics.

The LUT amplitude data is not so easy to estimate in advance and is generally set at a constant level. The value depends strongly on the frequency response of a specific RF amplifier model.

As you may conclude, the basic LUT is only an approximation and is unlikely to provide the best uniformity.

Creating a LUT.

For optimal performance the LUT generation should be undertaken during system integration. e.g. the laser beam characteristics and input angle to the AOD are unlikely to be identical to the Isomet test set-up.

A proficient C++ programmer will be able to develop an automatic calibration routine employing the ADC inputs of the iMS4-L (or-P).

Alternatively, the empirical method described below uses the Isomet GUI and Excel spreadsheet functions to create the LUT data.

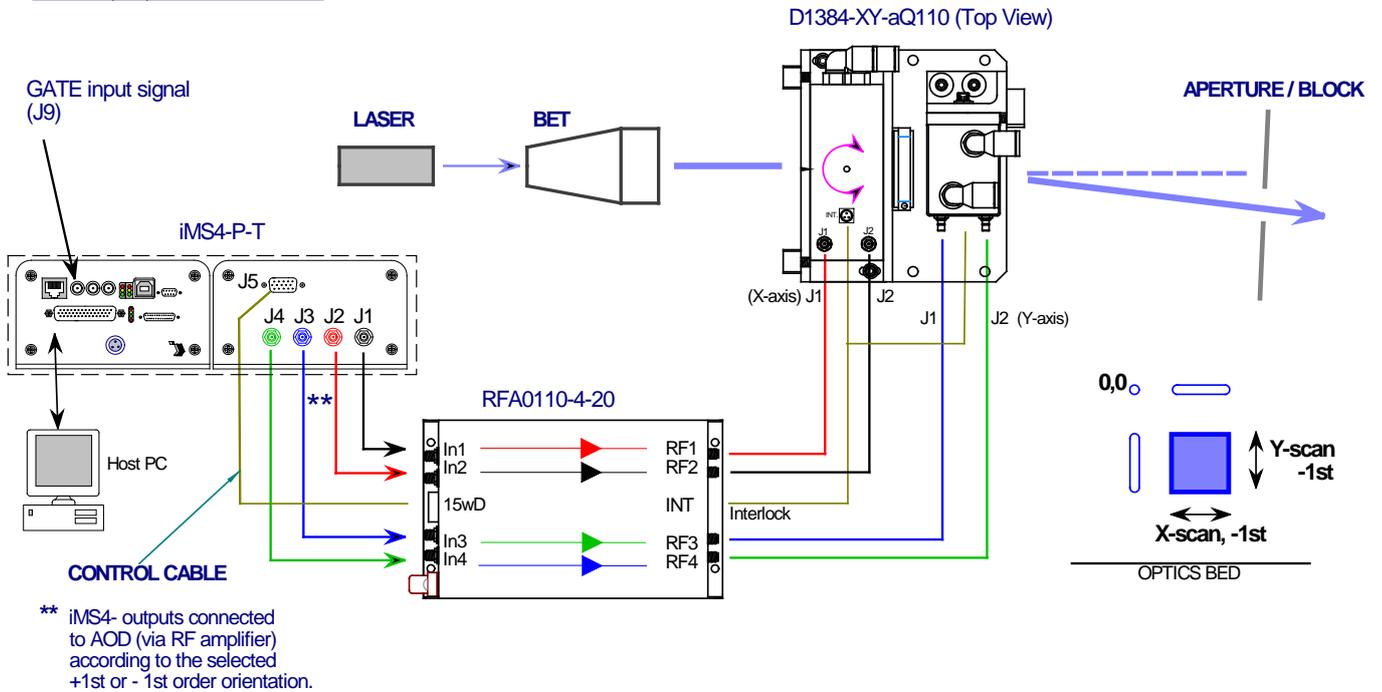
LUT Phase & Amplitude Determination

Please refer to the iMS4-L/-P manual and Isomet GUI Software Guides.

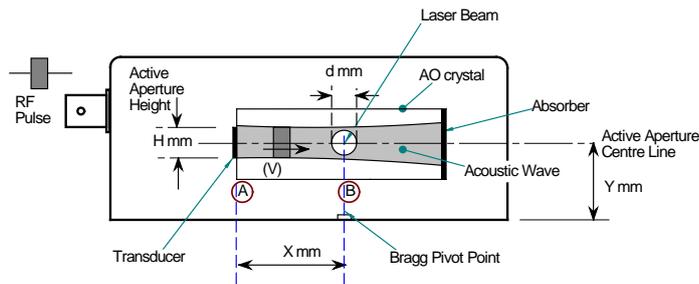
Download the *iMS LUT File Gen* folder from the Support page if the ISOMET web site

Figure 1 Typical X-Y set-up

XY Scan, -1, -1 orientation



It is assumed the laser beam is aligned centrally in the AO active aperture. This alignment is especially important if the beam diameter approaches the active aperture height dimension H



(refer app note: Optimizing Efficiency.pdf)

Method Overview

- Set the Bragg angles for the X-axis and Y-axis AODs in turn
- Step through the frequencies across the defined LUT range according to the spreadsheet template.
- At each point, adjust the Phase and then Amplitude to achieve a specified diffraction efficiency level = "LUT CAL level".(see Provisos below)
- Record the values into the spreadsheet template provided in (*.xls format).
- Use a Spline fit routine to extrapolate all LUT values of interest.
- Generate LUT file, using the executable file iMS4_LUT.exe.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	1	AOD	D1884														
3	2	Bragg Adj freq	114.000 MHz				Measured data points		8								
4	3	Geometric mid freq	114.583 MHz				Scan start		90.000								
5	4	RF centre freq	110 MHz				MHz per scope div		5.000	MHz							
6	5	Scan bandwidth	40 MHz														
7	6	LUT BW margin	10.00 %														
8	7	LUT start	88.00 MHz														
9	8	LUT stop	132.00 MHz				Point										
10	9	Out of BW Amplitude	0 %														
11	10	LUT Amplitude	"Spline" fit				pre										
12	11						0										
13	12	Wavelength	0.515 um				1										
14	13	Acoustic vel	5700 m/s				2										
15	14	Refractive index	1.55				3										
16	15	Geometric constant	1.8400				4										
17	16	Internal Bragg angle	2.91E-05 rad/MHz				5										
18	17						6										
19	18	** Using CAL slider on GUI to optimize AMPL and PHASE values					7										
20	19						8										
21	20	Spline fit software from www.srs1software.com					post										
22	21																

Provisos

1: The LUT CAL level should be set to avoid saturation in the AO deflector and/or RF power amplifier. The efficiency should be peaked using the phase (with amplitude set at a low level) and then the amplitude. Remember: Phase then Amplitude in that order.

Recommended 'LUT CAL' level = 75% diffraction efficiency (per axis).

Tip: It may be easier to place an optical power meter in the zero order beam path than the deflected 1st order. The zero order beam remains stationary. Provided the AOD is NOT overdriven, the first order diffraction efficiency (DE) equates to the zero order kick out (KO) efficiency. The power remaining in the zero order is thus 100%-DE%.

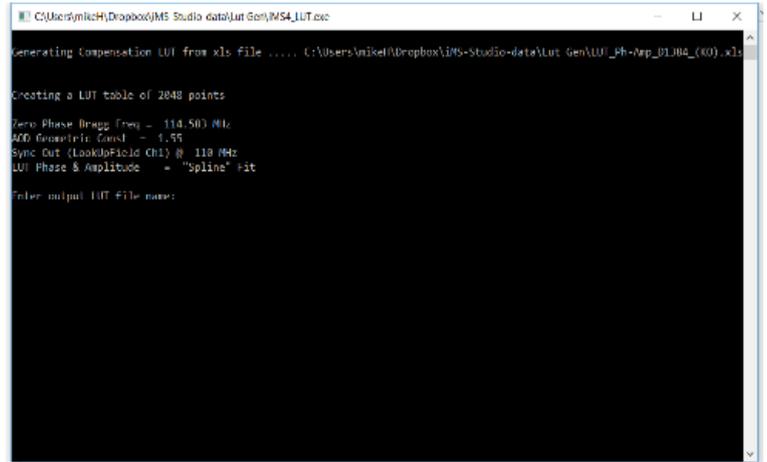
2: The spreadsheet uses a 'Spline fit' function to calculate and fill all 2047 entries required by the LUT table, spanning the full 12.5-200MHz range. To enable the Spline fit function in Excel, download and install SRS1 Cubic Spline for Excel 2.51 from www.srs1software.com Restart Excel to enable.

3: Find the executable program located in the downloaded folder, "iMS4_LUT.exe". This converts the appropriate spreadsheet column data into the defined LUT format.

DO NOT add or delete rows or column from the spreadsheet template.

To use, simply open Windows Explorer, browse to the appropriate folder(s) and drag and drop the *.xls file over the 'iMS4_LUT.exe' file name.

A command window will open, summarizing the LUT data and inviting the user to enter a LUT file name.



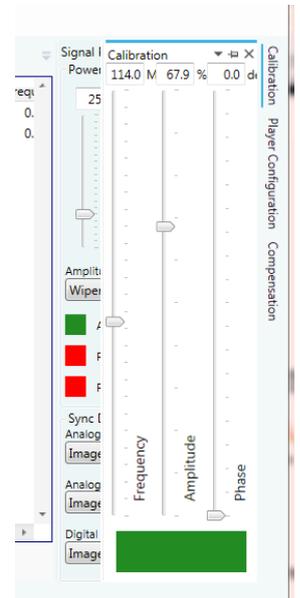
Taking Measurements

Refer to Figure 1 above. The following description will use the D1384XY-aQ110-7 and RFA0110-4-20 amplifier to illustrate the procedure.

- 1: Align the laser beam centrally in the AO active aperture.
For dual axis, check alignment is central to both deflectors.
- 2: Set the maximum RF power limit **

Select **Signal Path** panel and set the power control wiper values.
Amplitude Control Source: **Wiper 1**
Wiper 1 Power: **50% ***
DDS Power: **80% ***
- 3: Enable the RF power amplifier

Click on "Amplifier Enable Button:" **Green (On)**



* These values will depend on connected power amplifier and AO device.
e.g. for this example, Wiper1 level of 50% assumes a ~1m coax cable length from the PA to AOD.
For longer cable lengths, this value will need to be increased. (60% for 4m+)
Please contact Isomet, if uncertain.

** CAUTION: THERE IS A RISK OF SERIOUS DAMAGE TO THE AO DEVICES IF OPERATED AT EXCESSIVE (CW) RF POWERS.

For clarity, we will now define a common 'Frequency - Amplitude – Phase' adjustment sequence (or "FAPAS"). This sequence is described below and is referenced throughout the remainder of this document.

It uses the 3 sliders controls in the **Calibration panel** tab.
There are 5-steps to FAPAS.

- 1: Set the **Amplitude** slider to give **~40% efficiency**
(This reduced level ensures a non-saturated starting value)
- 2: Select the appropriate frequency
- 3: Peak the diffraction efficiency using the **PHASE** slider **ONLY**.
The actual peak efficiency at this stage may be less than 50%.
In most cases the calculated spread sheet value (col:N) is appropriate, and readjustment gives minimal improvement.

4: Now adjust the **AMPLITUDE** slider to achieve the LUT CAL level efficiency.
The recommended CAL level is ~75% efficiency per axis (60% overall for an XY AOD)**.

5: Record the new Amplitude and Phase values in to the spreadsheet table, col:I and col:J respectively.

** The final operating efficiency may be higher or lower than this level.
It will depend on the subsequent setting of the DDS and Wiper 1 (2) power control slides (**Signal Path** panel)
The main purpose of the LUT is to generate scan uniformity.

SETTING BRAGG ANGLES

X-axis

- 1: Drive X only
(Disconnect Ch3 and Ch4 outputs from the iMS4- to disable Y-axis drive).
 - Place a detector at X-axis first order beam position.
 - Tip: Check the detector position as the frequency (= scan angle) changes.

3: Select **Calibration panel** tab

Set Frequency slider to the Geometric *Mean Frequency*, f_1 (114MHz) or the *Centre frequency* f_c (110MHz).
(Bragg at f_1 balances the magnitude of +ve / -ve beam steering angles as per Fig 1)

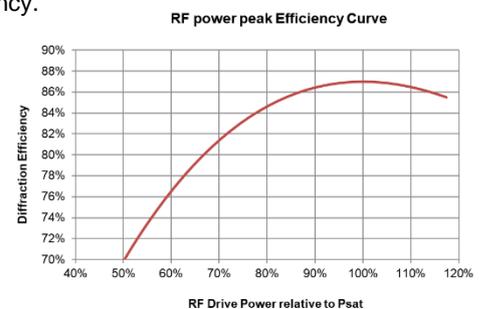
Follow the FAPAS sequence

- 4: Adjust the X-axis AOD Bragg angle to find the peak efficiency.
- 5: Adjust the Amplitude slider, (**Calibration panel**) to maximize efficiency.

Tip: DO NOT overdrive (exceed P_{sat}).
Better to be few % low than a few % over.

As noted from the curve, when operating near the peak, a small sacrifice in efficiency of ~1% will reduce RF drive by ~10%

- 5: Record the efficiency, amplitude and frequency values.
- 6: Secure mechanical X-axis Bragg angle adjusters.



Y-axis

- 1: Drive Y only
(Disconnect Ch1 and Ch2 outputs from the iMS4= to disable Y-axis drive).
 - Place a detector at Y-axis first order beam position.

Adjust the Y-axis AOD Bragg angle to find the peak efficiency.

It should not be necessary to adjust the Amplitude.
The same Amplitude slider controls the X and Y axis RF drivers.
Tip: If power adjustment is necessary, return to Step 2....7 and recheck X-axis

- 5: Record the efficiency, amplitude and frequency values.
The KO efficiency at Bragg should exceed 80%).
- 6: Secure mechanical Y-axis Bragg angle adjusters.

CHECK COMBINED X-Y BRAGG ANGLES

Typically a half wave plate is required between the X and Y axis. It will be necessary to check the rotation and align the polarization for the orthogonal Y axis

- 1: Drive both X and Y
 - Place a detector at XY first order beam position
- 5: Check orientation of the $\frac{1}{2}$ wave plate.
Loosen the lock or clamp screw and carefully rotate the $\frac{1}{2}$ waveplate ring for maximum efficiency.
- 4: Check Bragg alignment by carefully making minor adjustments to X or Y axis Bragg angle adjusters.

Record the efficiency, amplitude and frequency values.

The efficiency at Bragg should be the product of the X axis and Y-axis values

e.g. 85% x 85% = 72%

Typically, the efficiency at or near the centre frequency of the AO device is the high point.

Therefore, the target level for LUT calibration cannot exceed this value.

As a general rule set the LUT calibration level to 0.9 x efficiency at Bragg angle (= 60-65% XY efficiency)

DETERMINE LUT VALUES

A common LUT applies to both the X and Y channels.

One method to determine values is to calibrate along a diagonal line, driving both the X and Y axis simultaneously at the same frequency.

The CAL is to achieve the highest uniform efficiency at the lowest RF drive power.

Set an efficiency target for the calibration. This should be below the expected maximum XY efficiency

The recommended LUT CAL target level is ~75% per axis or 60% for the combined XY.

First step is to check that the target LIT CAL efficiency can be achieved at the extremes of the desired scan range.

A minor re-adjustment of the X or Y Bragg angles may help balance the RF powers required at the scan extremes. Imagine the sweep like a see-saw. Minor readjustment of the Bragg Pivot frequency can have a significant impact on the scan extremities.

The spreadsheet will calculate the theoretical phase value (col:N) for the frequency listed (col:H).

This phase should be used as a guide for the starting value.

Select **Calibration panel** tab

Frequency slider: **LUT frequency step**, (as listed in col:H)

Follow FAP sequence

Repeat steps 6: - 11: for all frequency steps as listed in col: H

- Sequence:
- a) Reduce Amplitude slider: **~40%** (starting value for each new freq' point)
 - b) Peak the efficiency using the **PHASE** slider
 - c) Set efficiency to LUT CAL level using the **AMPLITUDE** slider

It may not always be possible to achieve the LUT CAL level.

This is to be expected near the scan limits.

If necessary, reduce the LUT CAL level and repeat.

A completed table will look similar to that shown below

G	H	I	J	K	L	M	N	O	P	Q
6	7	8	9	10	11	12	13	14	15	16
Measured data points		8								
Scan start		90.000 130.000								
MHz per scope div		5.000 MHz								
Point	Freq Set	Ampl Adjusted	Phase Adjusted	Int Bragg Calc	Phase Theory	Phase Slider Theory	Phase Adjusted	Normalized Ampli		
pre	85.00	97	48.0	8.45E-04	47.6	47.6	48.0	0.97		
0	90.00	97	38.0	6.99E-04	41.7	41.7	38.0	0.97		
1	95.00	97	23.0	5.54E-04	34.8	34.8	23.0	0.97		
2	100.00	68	40.0	4.08E-04	27.0	27.0	40.0	0.68		
3	105.00	66	38.0	2.62E-04	18.2	18.2	38.0	0.66		
4	110.00	70	8.6	1.17E-04	8.5	8.5	8.6	0.70		
5	115.00	86	0.0	-2.91E-05	-2.2	357.8	0.0	0.86		
6	120.00	84	337.0	-1.75E-04	-13.9	346.1	-23.0	0.84		
7	125.00	78	345.0	-3.21E-04	-26.5	333.5	-15.0	0.78		
8	130.00	82	332.0	-4.66E-04	-40.2	319.8	-28.0	0.82		
post	135.00	100	311.0	-6.12E-04	-54.7	305.3	-49.0	1.00		

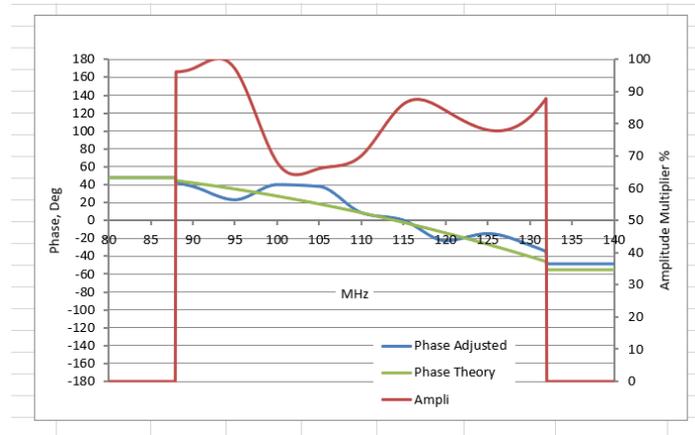
As will be noted from the data above, it is quite common for the most efficient scan (= frequency range) to be centred +/- 10% away from the nominal AO device centre frequency.

e.g. considering the D1384-aQ110 example above, the most efficient 40MHz scan extends from 95-135MHz, compared to the ideal design value of 90-130MHz.

The example above applies 11 equally spaced frequency steps that span approx. +/- 10% beyond the AO device specification. This can be changed if desired. Random frequency spacing could be also be used, provided these remain within +/- 20% of the AO device and RF amplifier bandwidths.

12: The spreadsheet will calculate the data sets required for the LUT (see Provisos) and generate a plot.

A typical phase and amplitude LUT plot is shown below

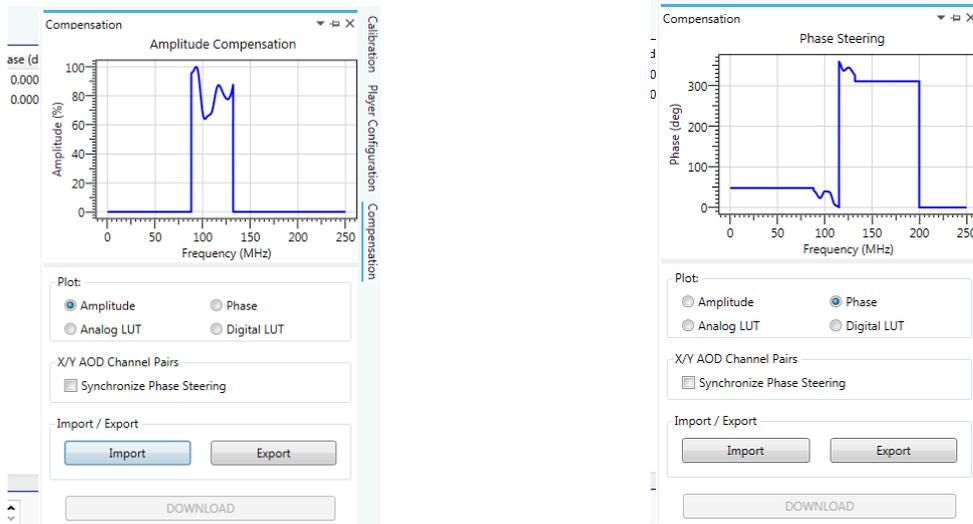


13: To create the *.LUT file, drag the *.xls file over the iMS4_LUT.exe in Windows explorer or type the *.xls file name after the iMS4_LUT.exe and run.

Using the LUT

1: Import and then Download the new compensation table into the iMS4 using GUI Compensation tab.

e.g. Isomet GUI Compensation panel screen shots; Amplitude and Phase



2: Run the desired Image file and record the scanned detector output for the X-Axis.

If undesirable variations still exist, then by comparison with Excel LUT plot, you can make appropriate changes to the Spreadsheet data and repeat steps 10: 12:, 13:

3: Adjust the global power level to reach the desired efficiency.
i.e. Select **Signal Path** panel and readjust the **DDS Power** and/or **Wiper 1** levels.

Take care not to apply excessive RF.

Good efficiency sweep should be witnessed with the following wiper levels.

DDS level = 80%

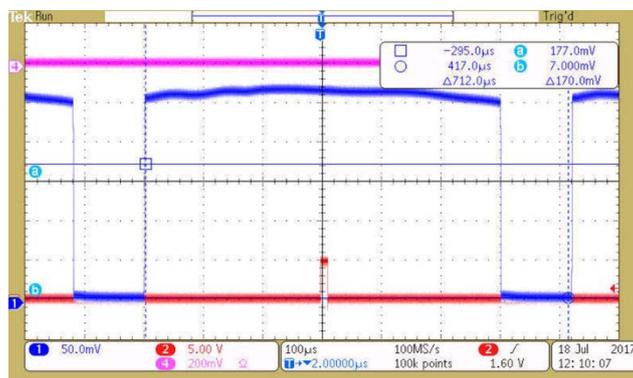
Wiper 1 = 50%

Example of a single axis scan,
532nm, 40MHz sweep

Trace 4: = 100% efficiency level

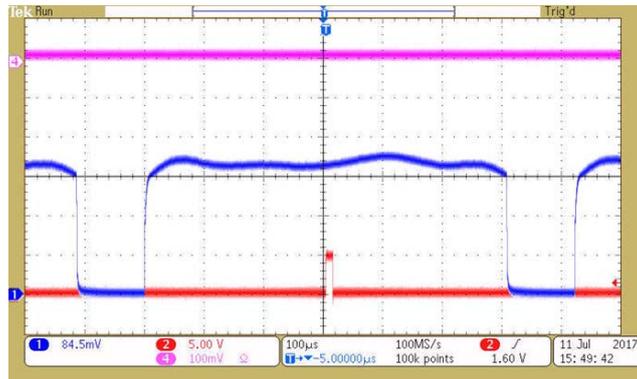
Trace 2: = 0% efficiency level
(and sync pulse)

Trace 1: = detector output



A good LUT will also give a uniform response at lower RF powers
 e.g. reduce the DDS level to (say) 40%

Trace 4: = 100% efficiency level
 Trace 2: = 0% efficiency level
 (and sync pulse)
 Trace 1: = detector output



Concluding Comments

There are currently limitations using the existing iMS4-P synthesizer design with dual axis AOD's

- A single LUT applies to both the X and Y axis.
 For optimum efficiency, separate LUTs would be needed for the X and Y axis.
- The global RF power control (Wiper 1 or Wiper 2) applies to all four channels.
 For optimum control, Wiper 1 should apply to channel 1 and 2, Wiper 2 to channel 3 and 4.

These changes are planned for the next hardware revision of the iMS4- series.

However the variation between the two deflectors of an X-Y set should be minimal especially if the operating scan bandwidth is less than maximum range.