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

Contents:

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).

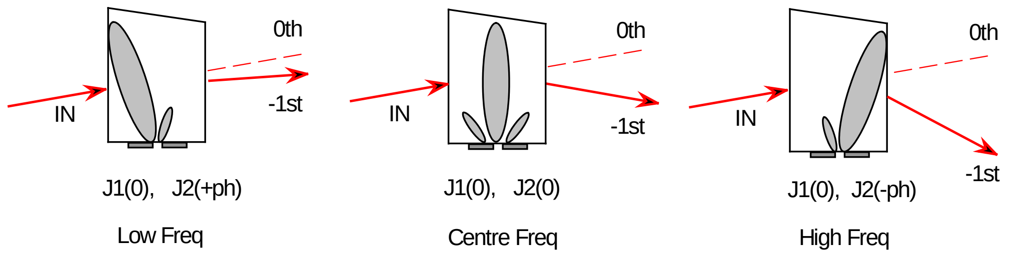
[The LUT can also be programmed with a user defined 12-bit data word. This is synchronously output on connector iMS4 connector J7 when the specified frequency(s) is called. It is an alternative to the point defined Synchronous data field programmed in the Image data].

Background Theory

Maximum diffraction efficiency exists when laser beam and acoustic column in the AO device 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 and so the precise Bragg angle is continuously changing.

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 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)
fc	=	AO device center frequency
f1	=	mean frequency for balanced +/- phase shift
	=	$fc \times fc^2 / [fmax \times fmin]$
λo	=	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 can 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).

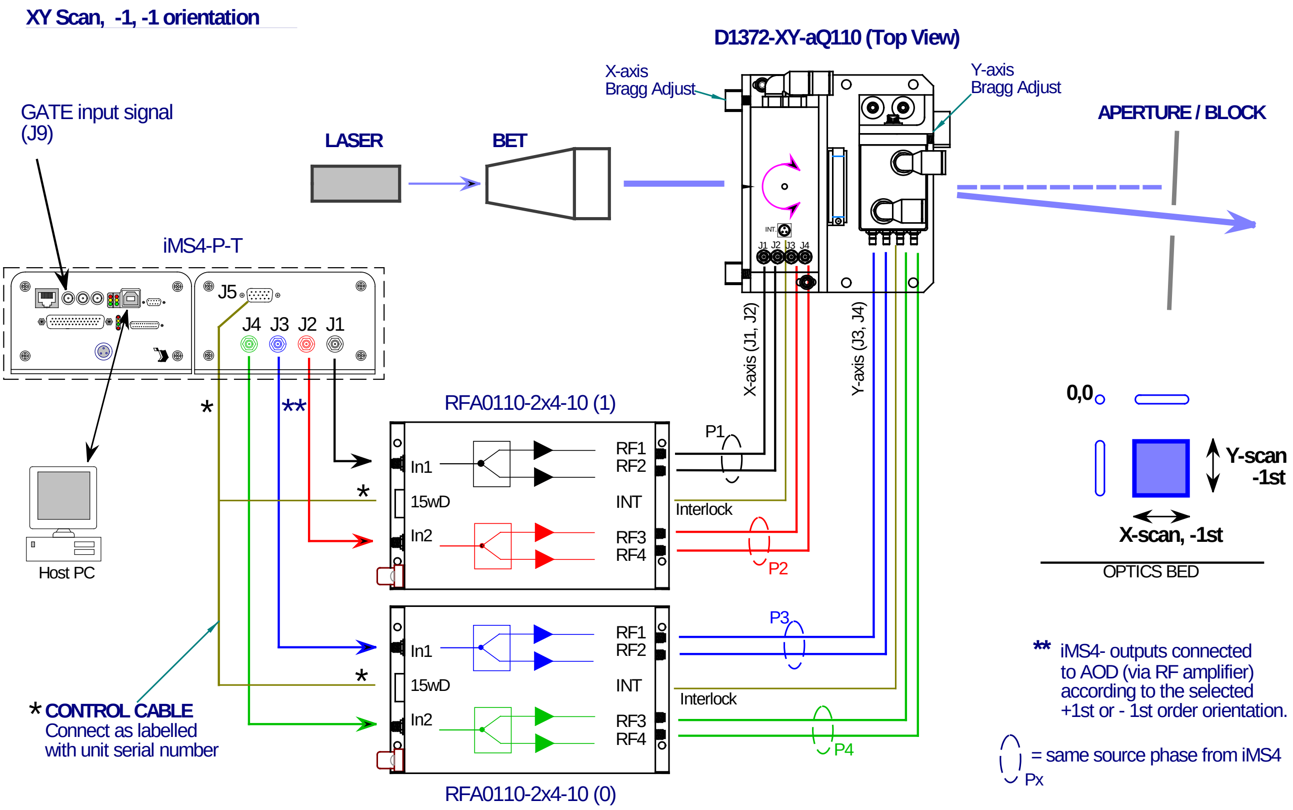
Alternatively the empirical method described below uses the Isomet GUI and Excel spreadsheet functions to create the LUT data.

LUT Phase & Amplitude Determination

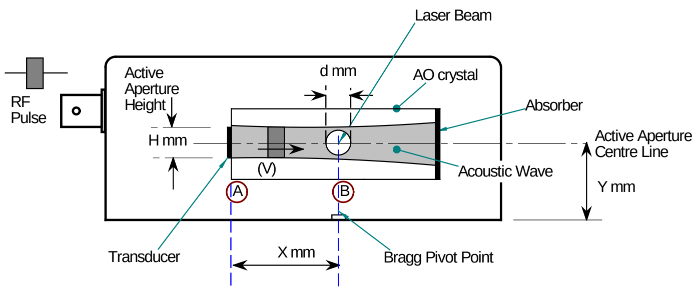
Please refer to the iMS4-L/-P manual and Isomet GUI Software Guides.

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

Figure 1 Typical X-Y set-up



It is assumed the laser beam is aligned centrally in the AO active aperture.



Method Overview

- Set the frequency to 1 of 11 values spaced across the desired scan.
- At each point, adjust the Phase and then Amplitude to achieve a specified diffraction efficiency level = "LUT goal 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.

	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	D1384				Measured data points		8								
3	2	Bragg Adj freq	114.000	MHz			Scan start		90.000								
4	3	Geometric mid freq	114.583	MHz					130.000								
5	4	RF centre freq	110	MHz			MHz per scope div		5.000	MHz				PHASE			
6	5	Scan bandwidth	40	MHz										GUIDE VALUES			
7	6	LUT BW margin	10.00	%													
8	7	LUT start	88.00	MHz				Freq	Ampl	Phase		Int Bragg	Phase	Phase Slider	Phase		Normalized
9	8	LUT stop	132.00	MHz			Point	Set	Adjusted	Adjusted		Calc	Theory	Theory	Adjusted		Ampli
10	9	Out of BW Amplitude	0	%				MHz	%	deg		rad	deg	deg	deg		
11	10	LUT Amplitude	"Spline"	fit			pre	85.00				8.45E-04	47.6	47.6	0.0		0.00
12	11						0	90.00				6.99E-04	41.7	41.7	0.0		0.00
13	12	Wavelength	0.515	um			1	95.00				5.54E-04	34.8	34.8	0.0		0.00
14	13	Acoustic vel	5700	m/s			2	100.00				4.08E-04	27.0	27.0	0.0		0.00
15	14	Refractive index	1.55				3	105.00				2.62E-04	18.2	18.2	0.0		0.00
16	15	Geometric constant	1.8400		-2BS		4	110.00	70	8.6		1.17E-04	8.5	8.5	8.6		0.70
17	16	Internal Bragg angle	2.91E-05	rad/MHz			5	115.00				-2.91E-05	-2.2	357.8	0.0		0.00
18	17						6	120.00				-1.75E-04	-13.9	346.1	0.0		0.00
19	18	** Using CAL slider on GUI to optimize AMPL and PHASE values					7	125.00				-3.21E-04	-26.5	333.5	0.0		0.00
20	19						8	130.00				-4.66E-04	-40.2	319.8	0.0		0.00
21	20	Spline fit sofware from www.srs1software.com					post	135.00				-6.12E-04	-54.7	305.3	0.0		0.00
22	21																

Provisos

1: The LUT goal 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 goal' level = 75% diffraction efficiency (per axis).

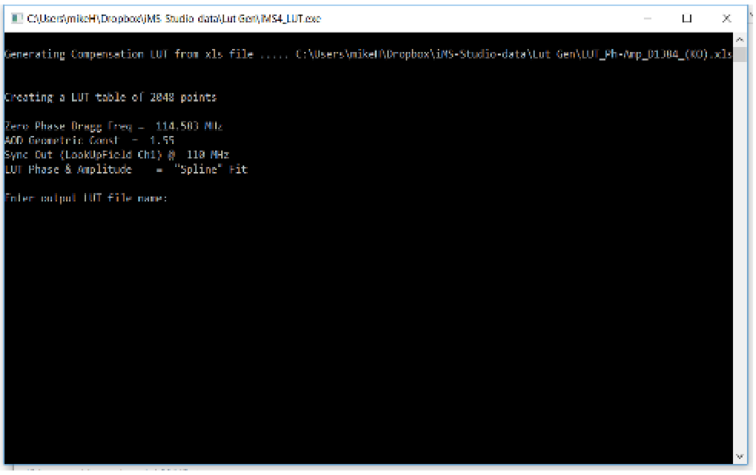
It may be easier to place an optical power meter in the zero order beam path than the deflected 1st order. To a very good approximation and provided the AOD is not overdriven, 75% first order diffraction efficiency (DE) equates to 75% kick out (KO) from the zero order, resulting in a residual 25% remaining in the zero order.

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.**srs1**software.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

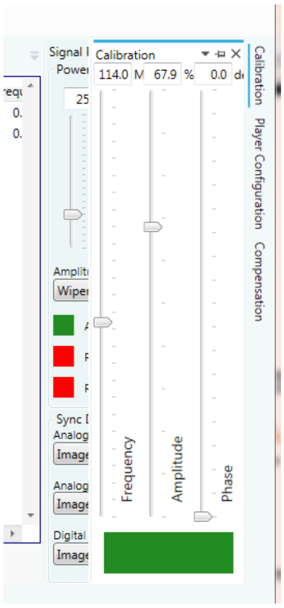
Refer to Figure 1 above. The following description will use the D1372XY-aQ110-7 as an example and assumes the laser power is recorded on the 0,0 beam i.e. a Kick-Out (KO) efficiency.

1: Drive the X-axis AOD only.

- Disconnect J3 and J4 from the iMS4-P.
- Place detector at beam position 0,0
- Align the laser beam centrally in the AO active aperture.
- (For dual axis, check alignment is also central to the following Y-axis aperture)

2: Select ***Signal Path*** panel and set wiper values

Amplitude Control Source: ***Wiper 1***
Wiper 1 Power: ***100%***
DDS Power: ***70%***
Amplifier Enable Button: ***Green*** (On)



FIND AND SET X-AXIS BRAGG ANGLE

3: Select ***Calibration panel*** tab

Frequency slider: **geometric *mean frequency,*** *(f1*=114MHz)
Amplitude slider: ***~50%*** *(starting value)*
Phase slider: ***zero degrees***

4: Adjust the X-axis AOD Bragg angle, beam height and beam location to find the peak efficiency. (refer app note: Optimizing Effiency.pdf)

5: Adjust the Amplitude slider, (***Calibration panel)*** to maximize efficiency. DO NOT overdrive. Better to be few % low than a few % over.

5: Record the efficiency, amplitude and frequency values. The KO efficiency at Bragg should exceed 80% (=< 20% residual in zero order).

6: Secure mechanical X-axis Bragg angle adjusters.

DETERMINE LUT VALUES

Start at the centre frequency and work outwards.
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.

7: Select ***Calibration panel*** tab and set -

Frequency slider: ***desired frequency,*** e.g. 110MHz
Amplitude slider: ***~40%*** *(starting value)*
Phase slider: ***calculated degrees*** *(see starting value in col:N)*

8: **Step 1**
Peak the efficiency by adjusting the phase slider value.
(In most cases the calculated value is appropriate, and readjustment gives minimal improvement).

9: **Step 2**
Adjust the amplitude slider value to achieve the desired LUT goal level.
The recommended goal level is a KO efficiency of 75%. (or 25% residual in the 0,0 order)

10: RECORD the amplitude and phase values in the spreadsheet (cells I16-J16)

11: Repeat steps 6: - 11: for all 5MHz spaced 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 goal level using the ***AMPLITUDE*** slider

It may not always be possible to achieve the LUT goal level.
This is to be expected near the scan limits.
If necessary, reduce the goal LUT level and repeat.

A completed table will look similar to that shown below

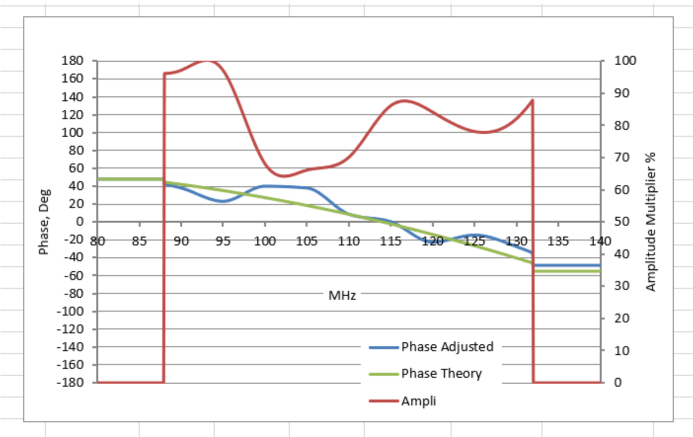
G	H	I	J	K	L	M	N	O	P	Q
6	7	8	9	10	11	12	13	14	15	16
Measured data points		8								
Scan start		90.000								
		130.000								
MHz per scope div		5.000	MHz							
	Freq	Ampl	Phase		Int Bragg	Phase	Phase Slider	Phase		Normalized
Point	Set	Adjusted	Adjusted		Calc	Theory	Theory	Adjusted		Ampli
	MHz	%	deg		rad	deg	deg	deg		
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 D1372-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

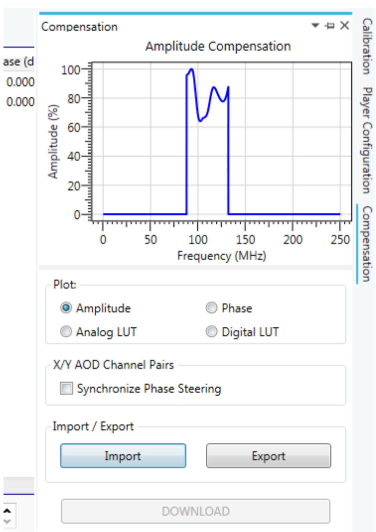


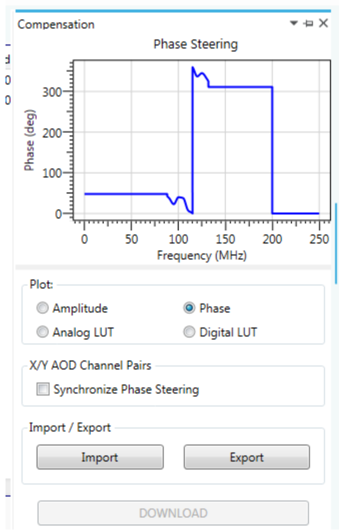
13: To create the *.LUT file, drag the *.xls file over the iMS4_LUT.exe in Windows explorer or type the *.xls file name after the iMS4_LUT.exe and run.

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:

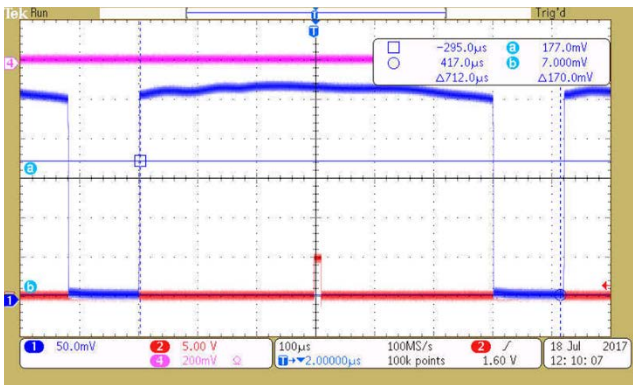
3: Adjust the global power level to reach the desired efficiency.
i.e. Select ***Signal Path*** panel and readjust the ***DDS Power*** and/or ***Wiper 1*** levels.

Take care not to apply excessive RF.
Good efficiency sweep should be witnessed with the following wiper levels.

DDS level = 75%
Wiper 1 = 100%

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

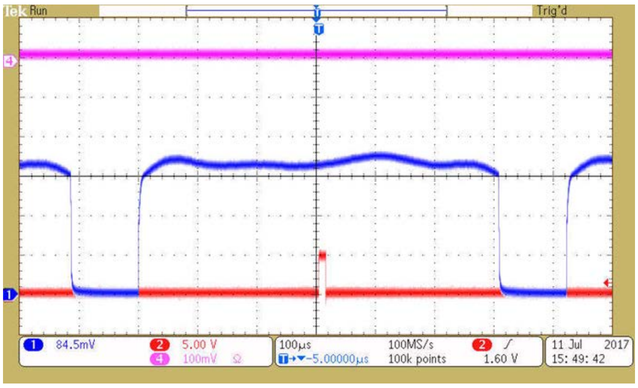
Trace 4: = 100% efficiency level
Trace 2: = 0% efficiency level
(and sync pulse)
Trace 1: = detector output



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



Subsequent steps for dual axis X-Y AO deflectors

- Setting the half waveplate rotation
- Setting the Y-axis Bragg angle

1: Drive both the X-axis and Y-axis at the Bragg frequency of 114MHz.

- Reconnect J3 and J4 to the iMS4-P.
- Place detector at beam position 0,0
- Check alignment of the laser beam is central within the AO active aperture

Fasteners securing the Y-axis assembly to the base plate can be loosened to allow minor adjustment of the Y-axis mount with respect to the X-axis.

2: Select ***Signal Path*** panel and set wiper values

Amplitude Control Source: ***Wiper 1***
Wiper 1 Power: ***100%***
DDS Power: ***50%***
Amplifier Enable Button: ***Green*** (On)

FIND AND SET Y-AXIS BRAGG ANGLE

3: Select ***Calibration panel*** tab

Frequency slider: **geometric *mean frequency,*** *(f1* =114MHz)
Amplitude slider: ***~50%*** *(starting value)*
Phase slider: ***zero degrees***

4: Adjust the Y-axis AO device Bragg angle, beam height and location to find the peak efficiency relative to the first order output beam from the X-axis. DO NOT increase the amplitude at this stage.

The overall efficiency will be the product of the individual AOD efficiencies. So for 70% X-axis and 70% Y-axis the overall dual axis efficiency will be 49%.

5: Check orientation of the ½ wave plate.
Loosen the lock or clamp screw and carefully rotate the ½ waveplate ring for maximum efficiency.

6: Adjust the Amplitude slider, (***Calibration panel)*** to maximize X-Y efficiency.
DO NOT overdrive. Better to be few % low than a few % over.

7: Record the efficiency, amplitude and frequency values.
The KO efficiency at Bragg should exceed 60% (~80% per AOD).

8: Secure mechanical Bragg angle adjusters and waveplate clamp

9: Run an X-Y image. Fine adjustment of the Y-axis Bragg angle may help to improve overall uniformity.

To check the Y-axis without X-axis scanning, load an Image file with the X-axis at constant fixed frequency (114MHz) on channel 1 and 2 (assuming connected as Figure1) and run the frequency sweep data on channels 3 and 4. Remember the Y-axis scan efficiency will be reduced by the efficiency of the X-axis at its spot frequency.

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.

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