Notes on Touch Screen Project

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Insight Into Electronics Calibration:

When I set the voltage to the light emitting diodes to greater than about 1.2 volts, there exists illumination, because it is here I notice the voltage across the photodiodes have a range of positive values. As the negative biasing of the photodiodes is increased from around -.6 volts downwards to about -5 volts, the voltage across the photodiode goes through zero to negative values.

From this I have reasoned that the voltage across the photodiode was not enough to put them into reverse bias at low negative voltages, and hence when the light emitting diode was strong enough it caused them to generate a forward voltage from direct illumination. This forward voltage across the photodiode from direct illumination can be cancelled (as I did many times by design because I noticed it produced a definite signal) with a negative bias.

This means if I want the photodiodes in reverse bias I have to overcome the light emission by the light emitting diodes (smaller voltage to the light emitting diodes and higher reverse bias). However, there are two things to be taken into account. First, I cannot reverse bias them too much, or it will attenuate the signal beyond measurement range, and I cannot lower the voltage to the light emitting diodes too much, or else I face the same problem. This is also why approximately 2 volts on both worked marginally well.

The second problem, is that I have to compensate for the fluctuation in the signal (the sinusoidally varying part), both so that at the upper limit of voltage into the light emitting diodes does not force the photodiodes into forward conduction, and so that the lower limit still illuminates the photodiodes in a reverse bias regime.

The problem with tuning to zero bias is that both signs of the swings of the voltage are potentially effectively the same. They can be a forward biased voltage, which diminishes the negative signal in the forward voltage swing into the light emitting diodes, and a negatively biased voltage which is enhanced as a sinusoid when it goes negatively biased below this point. Hence one can see a negative signal that is of absolute value sign of a sinusoid. This would explain the mirroring.

Tuning the photodiodes to minimal reverse bias (-.620 volts), a forward bias signal appears at around: .918 volts into the light emitting diodes, indicating light reception by the photodiodes and a minimal voltage into the light emitting diodes. At maximum voltage into the photodiodes of: -5.032 volts, the forward biasing occurs at the lower limit of: 3.1 volts into the light emitting diodes, indicating a maximum voltage into the light emitting diodes. These two numbers indicate a scale and range, so that we may assume an added sinusoid of: +/- 1 volts on + 2 volts into the light emitting diodes for adequate light reception, and a reverse bias voltage of the full maximum.

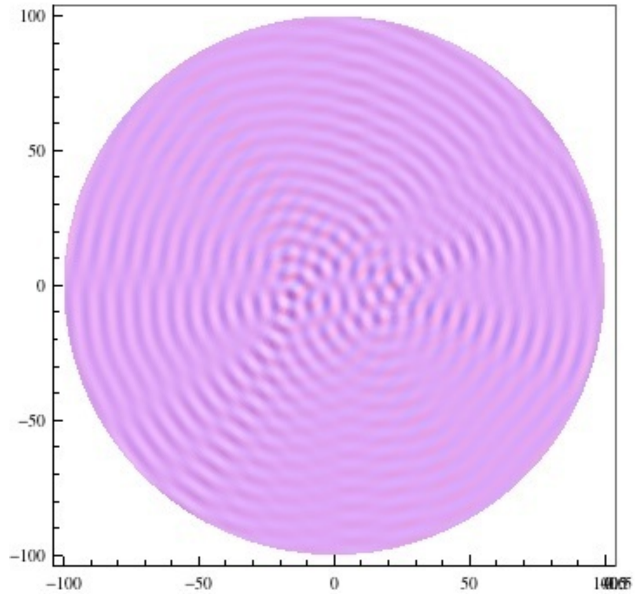
Intricacy:

It appears that tuning the coefficients does result in a satisfactory image of the ripples. However, secondary, 'detritus' does appear near the origin; anomalous peaks and dips associated with the press. These appear to vary as a function of the calibration.

It appears I will have to re-calibrate periodically. Such as waiting until a press dips below 1% of its value to determine it is 'removed' and waiting a certain time period (5 ms), and then re-calibrating in such a way there is a 'memory' for presses which already exist.

Over trials, I believe I can manage this with motion as well, by tracking points and returning to look for 'differences' between the interior 'model' of the presses, and new or removed or changed presses. This is perfectly compatible with the idea of superposition, and is a complex, yet terse, piece of code.

Look at the following image for an example:



There are two presses (actual) in the graph, around -15,-5 and -15,-10, from the ball and its cradle. The anomaly is near 25,0. But it does not produce a dip, instead it is a crest, so it can not be genuinely from a source, unless the two presses are constructively making it.

The final reason for the banding and the anomaly could very well be ellipsometry with respect to the vertical axis due to the placement of the LED's and PD's. This can be remedied in the same fashion as the tuning of a drum, where there is flatness or sharpness with respect to where you tap the head.

Finally, I have determined that 'down' in the image is the wire connection direction, and that there is no mirroring when I calibrate it properly. I used the calibration in the previous email. I presume that when I automate this process, and bring the two measurements together (calibration and object image) I will see much more accurate results.

I am sending this because for now it is the last step I am taking with manual measurements before attempting to program and automate the data-taking and processing.

It is invaluable to have some idea of what constraints need to be set in order to create a working program, without tremendously re-writing lots of code at each step in understanding. Lastly, I think you might take an interest in it because this is where I take a departure to software development, from the electronics.

Questions to Resolve:

Q1.) Is there a reason that the 180 degree phase shift is related to the 180 degree out of phase extra image of the source?

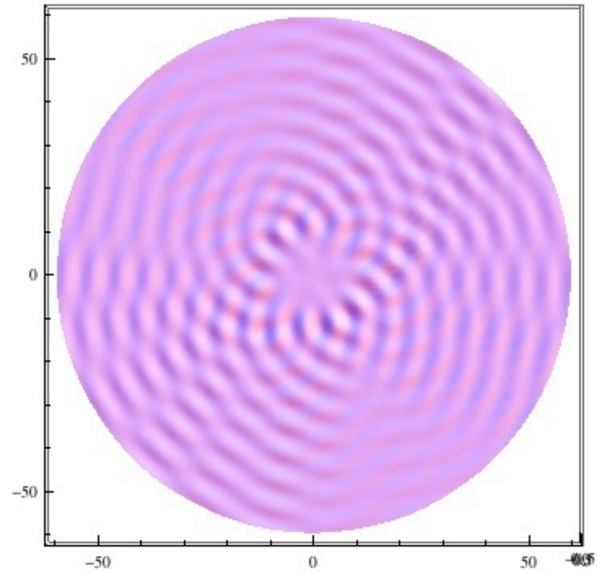
Q2.) What insures the crystals in series have harmonic overtones?

A1.) It is because the nodes from two 180 degree phase shifted frequencies place the nodes and antinodes twice as close together and hence the mathematical functions that map the region are frequency doubled in their geometric mapping relative to the natural modes given the coefficients they resolve from the measurement.

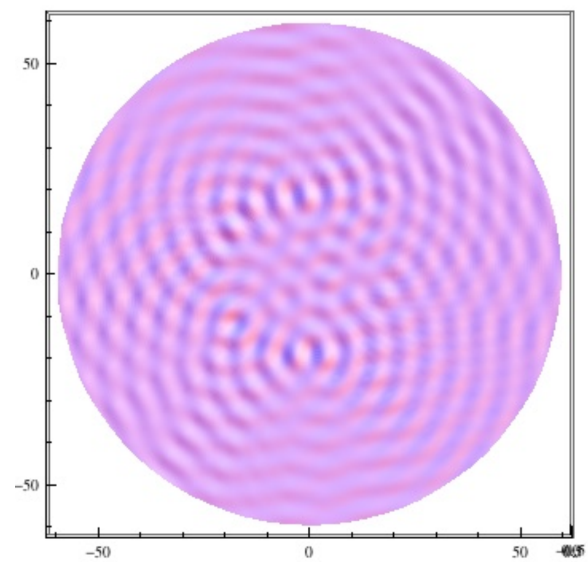
A2.) C is in series with the other C's and L is in series with the other L's, hence C -> C/n, and L-> L*n, so omega-> omega and the fundamental overtones of the crystal are the property that is in resonance, rather than just one overtone at n*f_D.

Inversion:

The current configuration, when ideally tuned to: 1.689 VDC on the light emitting diode input and -.923 VDC on the photodiode input, resulting in less than or equal to 40 mVDC on the photodiode results in rotated images, such as:



Where the image is 'rotated' by 180 degrees. But if one looks closely, one sees that the image is also inverted with respect to the rotated 'copy', with low becoming high, and high becoming low. This manifested earlier in an image test such as:

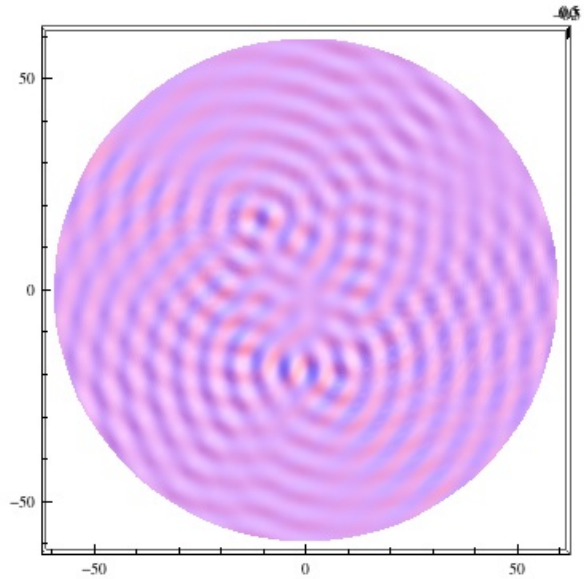


Q.) What reason do we have to believe that inserting an op-amp inverter in-line with the output will remove the secondary and 180 degree rotated image copy?

A.) Functionally, it appears this will accomplish nothing and that the mirror image is instrument (touchscreen) based. But as it turns out it is a matter of the mathematical interpretation of the series of geometric modes mismatching the actual modes. The actual modes are in fact only rotated by 180 degrees but with the correct geometry. Hence what needs to be changed is the phase as it associates with the mode number. It is for this reason that fixing the overall inversion of the output signal will fix the problem, because the manner in which the frequencies are compared will accord with the geometric interpretation of the modes, which is correct, but only yields inverted signals. It is also for this reason that a simple formula involving a phase rotation by 180 degrees will not work. It is in a way however analogous to counting from zero, versus counting from 180 degrees. This is basically what it will be doing when it functions with inversion, and is the reason the inverted signal produces two images copied and rotated by 180 degrees. The fact it is rotated by 180 degrees means there are two images out of 360 degrees. When it inverts the signal, it will properly measure the high as low and low as high, or in other words excitation with excitation and thus the correct interpretation of the geometry of the press will be rendered possible.

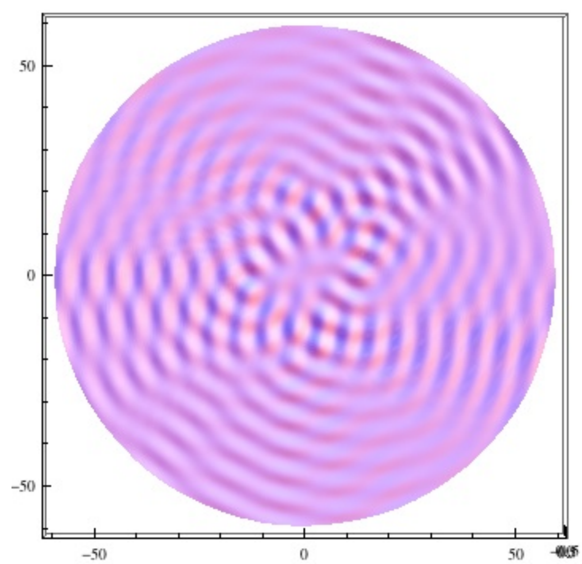
Hypothesis:
"The frequency inversion occurs with a negatively precessing phasor, hence what one sees is interference between the clockwise and counterclockwise rotating impedances of the complex filter that is the touchscreen, producing a 180 degree rotated copy."

Attempts at Image Acquisition:



This image was from test 58, after the introduction of the inverter. As one can see the pseudo image is less than 180 degrees out of phase with the touch (in the upper left). The calibration was as follows:

LED_IN: 1.266 VDC, LED: 1.069 VDC, PD_IN: -1.681 VDC, PD: -1.233 VDC, PD_OUT: -.119 VDC



This image was from test 62, after the introduction of the inverter and there is no pronounced image. The device was tuned with calibration:

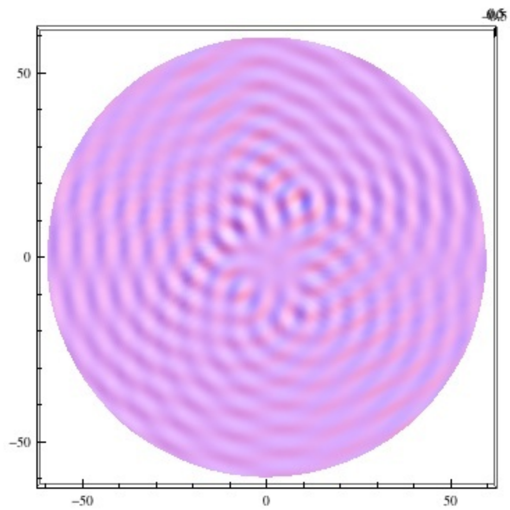
LED_IN: 1.565 VDC, LED: 1.102 VDC, PD_IN: -0.759 VDC, PD: 0 VDC, PD_OUT: -0.322 VDC

And was set so that PD_IN-PD_bias+LED_IN = 0 = PD. Although these two tests differ only in that PD was set 'low', another test was attempted, test 60 with the same condition, and higher voltages, and no valid image was produced. Another test was used to determine if PD-PD_bias+LED_IN = 0 is a valid condition, and there was no recognizable image produced.

It appears the determining factor was that when PD voltage was set to 0 we saw a 180 rotation copy, and with PD voltage set to a nonzero value we see an image with less than a 180 degree rotation copy. It appears it is set functionally by the equation:

PD_IN/PD_bias*press_phi = image_phi

I do not as of yet know if this is true, or why it might be valid. But, if we take the measured value of PD_bias=0.573 VDC, then clearly the .6 estimate was leading to erroneous results. From test 58, This formula reads with press_phi approximately 125 degrees, and image_phi approximately 265 degrees, then the above formula leads to image_phi_predicted = -269 degrees in phase, with a press_phi of 125 degrees. Ironically, if PD/PD_bias = unity then this is similar if not identical to trying to measure when PD=0, although it differs by PD=0 having an extra reverse voltage for the incoming light and its associated produced signal. Using this we produce the following graph:



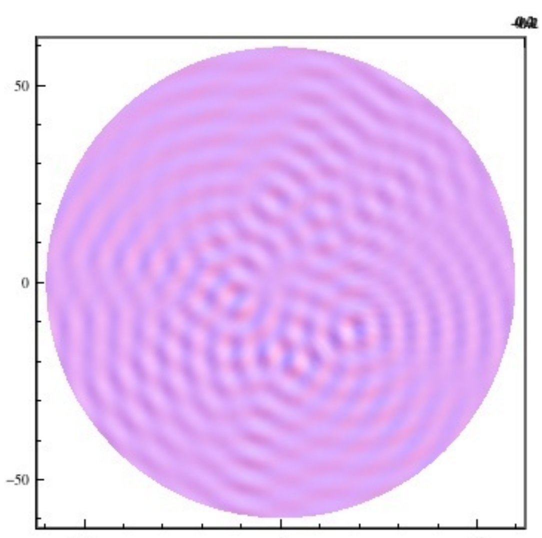
One thing is clear from this: |PD_IN| > |LED_IN| to ensure a signal, and that it is reverse biased.
It is also true that:

(PD_IN+LED_IN-PD_bias-PD_light)/PD_bias*120 degrees = 268.98 degrees

This gives a second way to calibrate the device, for we simply set:

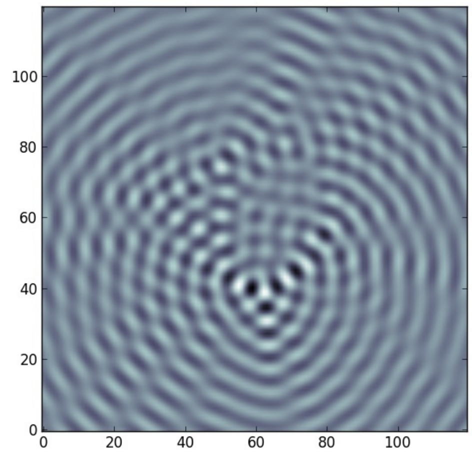
PD_IN+LED_IN=PD

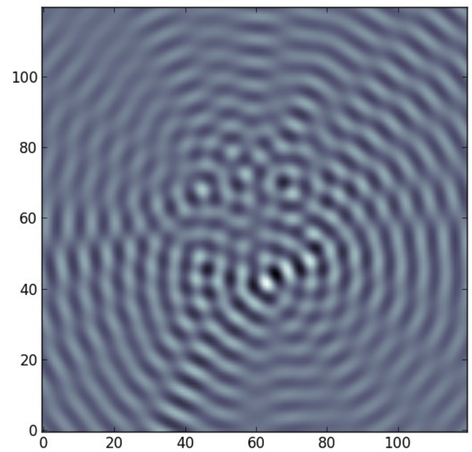
This produces:

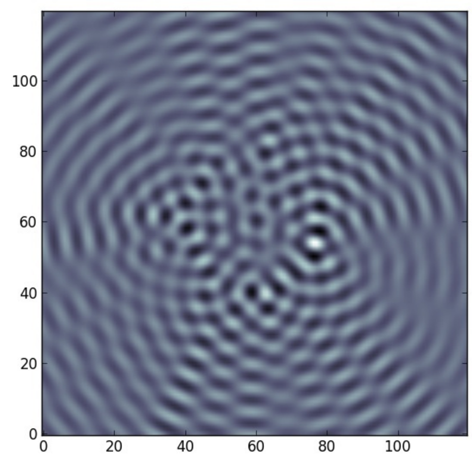


Reverse Bias with Python:

Although it was difficult starting to work on the project with Python, I quickly learned how to produce some images. From the calibration of test 58, the following images were produced:







Problems with Device:

Several problems exist with the electronics, forbidding a *completely* clear signal.

1.) The differential produced by the op-amp differs by a factor of 150 K ohms / 10 ohms = 15000. But this does not seem to matter, with the inverted configuration of the signal from the photodiodes in to the differentiator/high pass filter configured with the 10 ohms, and direct signal in to the 1.5 M ohm / 150 K ohm step down in amplitude by 10 amplifier. It would be interesting to see if there is a more ideal resistor network to be made.

Q.) Why does it not matter?

A.) It appears to not matter because the output is a 1.5 M ohm connected to ground (as a voltage divider) looking into the touchscreen photodiode output. This acts as a high pass filter with the capacitor of moderate frequency (100 pF, 1.5 M ohm). The direct signal is meanwhile taken to a 1.5 M ohm which is connected to the capacitor and op-amp in such a manner it is a high pass filter, since the other non-inverting input of the op-amp is connected to ground. It appears to matter little then that there be a difference in the feedback to the inverting input, because both inputs to the op amps act as genuine high pass filters.

2.) This problem is in the interrelationship between the high pass filter from the buffer amp output stage and the driving voltage of the sinusoid. It appears that the filter, when the LED goes into conductance produces with the voltage divider of 100 K ohm variable / 16 K ohm fixed, a 16 K ohm to 1 K ohm conversion (they are in parallel), lowering the first five frequencies to zero response, and creating a void in the center of the touchscreen. This is not a function of frequency but rather of the DC offset plus the sinusoid that varies, and adds a distortion in that the DC voltage sympathetically tracks the signal waveform and gets enhanced by an extra linear amount (16K->1K). A larger capacitor may remedy part of this problem, by requiring lower signal strengths to get a response, but there still exists the main issue of the voltage divider, which is the essential issue, for when the LED's conduct, they lower the resistance on the voltage divider substantially to ground, and hence the voltage in increases substantially. Because of the property of linear increase in the voltage out there is actually no effect on the coefficients in the series, because as output is compared to input, there exists no difference in the signal proportionality with this 'problem'.

Q.) What is the best way to solve this problem?

A.) A new capacitor will not fix this, but will allow for lower driving strengths to make the low frequencies which are attenuated to a greater extent yield a greater response. The best way to fix this is to redesign the device such that only pure non-DC component sine wave signals are put in and out.

Steps to Mitigate Distortion:

A 820 pF capacitor and 10 K ohm potentiometer were purchased, to mitigate the following problems:

* 1.) The cutoff of the low frequencies.
* 2.) The consequent requirement of tuning voltage to high levels to obtain a visible signal.
3.) The crashing of the DDS-60 and or Arduino when the high frequencies (not attenuated) pass a large signal.
* 4.) The void region in the center from the truncation of low frequency terms in the series.
5.) The ripples from having an incomplete series.
\- 6.) The voltage amplification from having a large resistance to power in and low resistance on out.
* 7.) The banding seen where the impedance does match with respect to driving input and output.

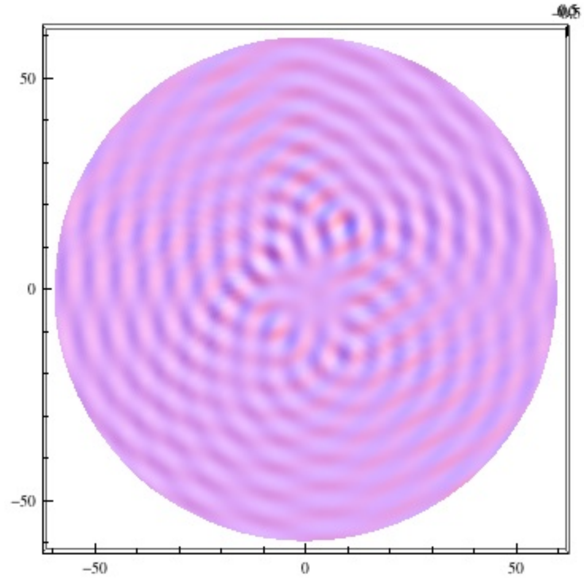
When these arrive, the following settings will be used from test 64:

LED_IN: 1.251 VDC
LED: -1.066 VDC

PD_IN: -0.922 VDC
PD: -0.573 VDC
PD_OUT: -0.123 VDC

With the idea to set PD = -0.573 VDC = PD_bias with LED_IN approximately 1.25 VDC

Before, these produced an image such as:



Fundamental Questions:

Q.) For what reason does PD/PD_bias relate to mirroring or its absence under reverse biasing, and how is this related to the complex impedance and generation of a negative frequency to the harmonics?

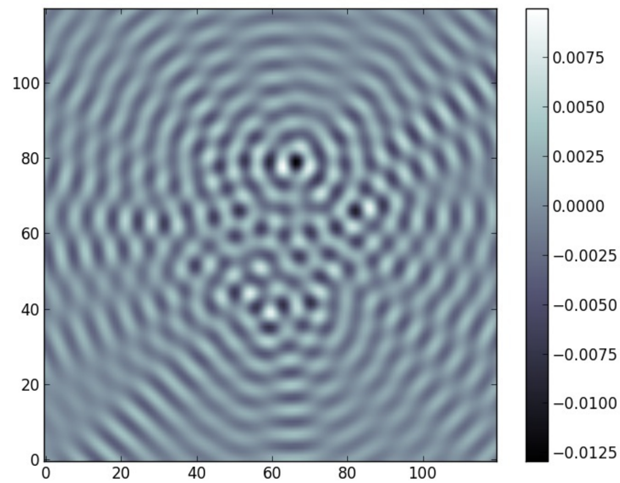
A.) When we set PD/PD_bias = 1, it is true that the pre-set voltage across the diode is 0 volts. This results in no mirroring because there is no mirror signal! It is also true that the diode is set to its minimal contribution from the resistor point, where the current is zero, the distortion introduced by the resistor is minimal as well, because the I-V curve for the resistor and photodiode or light emitting diode is exponential plus linear. The linear component is small in the case of the photodiode, but large for the light emitting diode, because the resistor for the light emitting diode is much smaller. If a similar idea applies to the light emitting diode, this should help determine ideal parameters for the voltage (DC and AC) into the light emitting diode. When PD=0, the bias is reversed, and therefore there is a complete mirror image, as was discovered with many tests. These two settings result in the two calibration curves, one with mirroring, and one without mirroring. The continuum in between results in images that have two points or more at angles between 0 and 180 degrees. The intersection of these two parabolas represent points of agreement, and hence one where the image cancels itself. Intermediate between these two points exists the point of zero slope, where there is no gain, because the light current is cancelled by the voltage sum of the photodiode and light emitting diode voltage. Hence admissible non mirrored configurations exist on one parabola where PD/PD_bias=1 at the intersection point with the light emitting diode configuration such that LED/LED_bias = 1 as well.

Q.) What is the interpretation of the device as an impedance as a function of frequency dependent variable amplitude and phase interaction device?

A.) First, one must ask the question as to what the interpretation of impedance is in this scenario. The geometry of the design is such that the boundary is in resonance with the region. And the impedance has a 'pole' wherever there exists a press. Thus the interpretation is that the geometry IS the impedance response, and it is a function of frequency. Thus the geometry of the interaction corresponds to a mapping of points of zero or non-zero impedance with respect to all frequencies. This can be derived from the fact that the LRC circuit that surrounds the region has poles within the region it encompasses where there exists constructive or deconstructive interference, or in a very valid sense, a type of resonance. This is the idea that a harmonic function evaluated over a boundary is equivalent to the derivative evaluated over the region it surrounds, which is the Fundamental Theorem of Calculus. Only in this case, the net integral is not what is evaluated, but instead the amplitude and phase response as a function of frequency over the boundary, which directly relates to the solution of the interior, and therefore has poles, which correspond to the presses, where the system finds resonance or loss of resonance, and with the property of analytic continuation from the boundary through its literal interpretation in terms of the separation of the Laplace equation, admits the solution of the differential relationship between boundary and region. Where, now the impedance has poles in the domain where there exist presses, and these correspond to a two dimensional impedance as a function of coordinate mapping.

With New Parts:

Although the calibration in terms of the DC voltages is unchanged (& I believe for an as of yet unexplained reason there is in fact no amplification by way of the voltage divider combined with a drop in resistance across the light emitting diode), and the range of values for the sinusoid coming in is about 1.5-2.0 times larger, and lowered in needed amount to get moderate signals at low frequencies, the overall process of calibration is still tricky and tight in ranges. Nevertheless the signal to noise ratio has increased from around 1.25 to 1.75 or 2.00, as the following image illustrates:



This used calibration settings of:

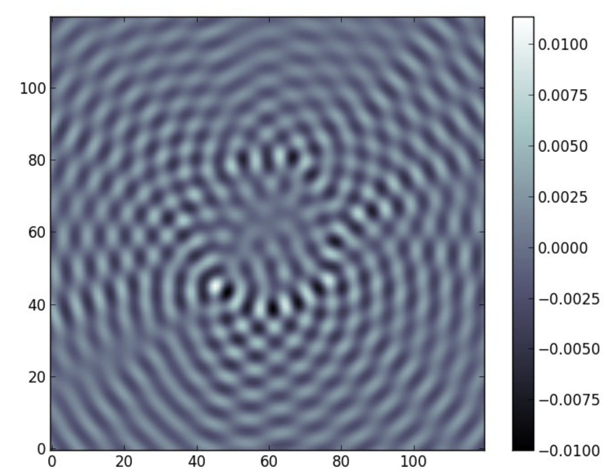
LED_IN: 1.269 VDC
PD_IN: -1.694 VDC
PD: -1.215 VDC

These calibration settings work in a sense, but produce a type of mirroring, at an intermediate angle. Next, we will attempt to find the curve of zero mirroring with:

PD = PD_bias

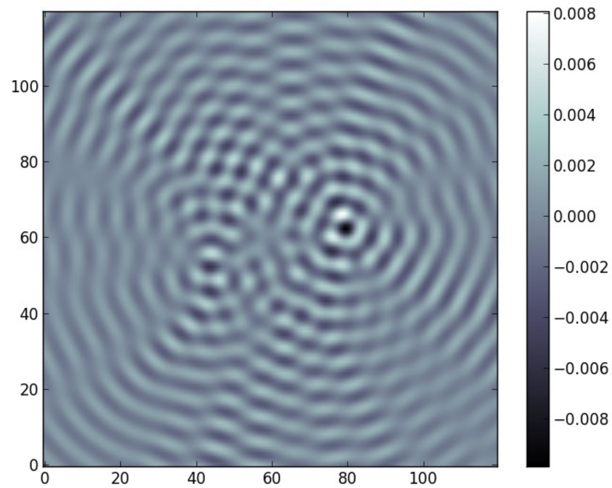
And test for multiple data points. After doing so, it is hypothesized an ideal image can be found where the two curves intersect. What is aimed at to be understood is the integration of this with the previous theory, explaining the why and how as to the behavior of the system, and the reason as to why these two curves appear, and what they represent electronically.

On a first trial test of the settings for Test 64 this produced the following image:



By further adjusting the voltage out of the sinusoid generator, the following image was produced:

LED_IN: 1.252 VDC
PD_IN: -1.001 VDC
PD: -0.579 VDC



It was then realized that the mirror image is a manifestation of impedance mismatch, in that it is literally producing a mirror image, and one that is attenuated by a factor of about 4 to 5 over the main signal. This can ideally be reduced to zero, and matches the 1 V max AC signal to 1.25 volts DC signal in to the LED's. It is their subtraction, and can be eliminated by adjusting the voltage of the DC signal down to whatever value the AC signal actually is.

In other words:

Amplitude_mirror/Amplitude_image = (LED_VDC-LED_VAC)/LED_VDC

This makes sense because when at the low point, we are a certain distance 'out' on the linear portion of the curve due to the resistor in series, and this manifests as a constant offset. Additionally, if LED_VAC exceeds LED_VDC then there appears a doubly inverted image, as was produced in this case. Given LED_VAC was set past the midpoint of 2 Vpp, it's amplitude probably exceeded by a portion of approximately 1.25 volts to 1.0 volts the LED_VDC, and this is approximately the amplitude ratio observed of the second image to the pre-image.

Also there is no amplification of the AC signal by the photodiode and resistor with the voltage divider, because to do so is to double count for the current going through it. Secondly, when the current goes down by a factor of 20 into each LED/resistor, it goes up by a factor of 20 in that there are 20 in parallel and the resistance is lowered by a factor of 20. Finally, they are equally scaled so remain of the same effective resistance as a function of voltage, because with more voltage, there is a greater current drop (exponential), but the resistor then accounts for more voltage drop (logarithmic in the diode as a function of voltage as a voltage divider), and the exponential increase in current flow is countered by a logarithmic voltage drop across the diode as a function of voltage supplied.

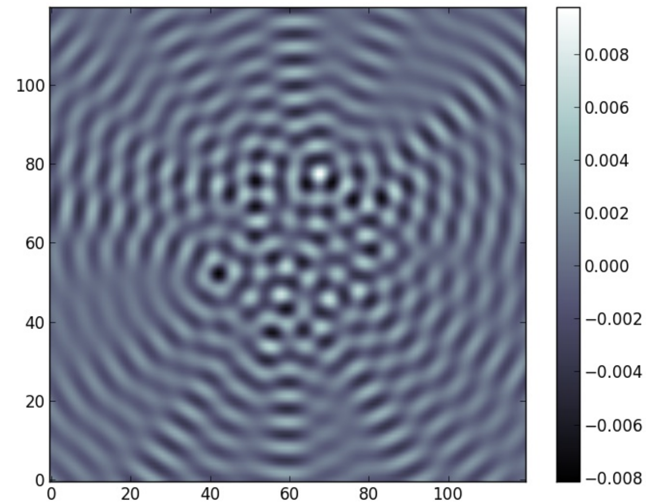
So the resistance of this combination remains the same, and there is no amplification of the AC signal by the voltage division past the point of the DC voltage plus AC voltage. Essentially, as the resistance of the resistor is fixed, and it in series with the diode acts as a voltage divider, the total resistance dependence of the diode is fixed, as a result of a logarithmic voltage drop across the resistor, and therefore an applied voltage minus a logarithmic voltage drop across the diode, with an exponential dependence on voltage, yields an exponential current to voltage relationship of the AC signal, with a total fixed resistance and therefore no amplification of the AC signal by the DC signal.

Finally, with an exponential current dependence to voltage across the LED, and logarithmic light intensity output, and linear to linear relationship of light intensity to voltage output on the photodiode, the signal is harmonic in the domain as a function of harmonic sinusoidal applied voltage.

Regaining Calibration:

The following calibration was used, with Vpp of the sinusoid at about 2 volts:

LED_IN: 1.254 VDC
PD_IN: -0.999 VDC
PD: -0.582 VDC



While not as clear as the previous test, the image is still recognizable, although there is a mirror image, and some noise. The mirror image in both images appears at an angle intermediate between 180 degrees and 0 degrees relative to the original image. It is also clear that the adjustment of the Vpp, which lead to this image, is partly the cause of the mirror image, both in its angle, because it appears at a different angle in each image, and with a different adjustment to begin with, and because it can tune the mirror image in terms of amplitude out of existence. One would think one could tune it to be higher or lower to either A: reduce the mirror image to zero amplitude, or B: admit the mirror image to the same position or 0 relative degrees to the 'actual' image.

Theory Meets Practice:

The device, as it occurred to me, may be described as a pnp and npn transistor back to back, with a signal going 'through' and turned on or off by the external leads, as a form of feedback, with complex impedance. Thus there is the passing of a harmonic function through the np and pn junction of the photodiode and light emitting diode, that sets up a back to back single transistor as if it were of type pnnp, and the n zone is of a certain impedance dependent on the two dimensional region of the presses. Thus there exists a light signal on the n, going in and out, and the device can be seen to be a 'black box' two dimensional to one dimensional 'filter', as a function of frequency. Impedance is at the center of this 'black box', and thus is the 'valve' of light current from p to p, in an out of the region. Thus with reverse biasing there is a saturation back-to-back with respect to the two diodes back to back.

This means that 'saturation' with respect to the 'light junction' occurs at an intermediate point, where we are on the low point of the parabola for calibration, and the slope goes to zero. It is here we find that the signal is diminished, and no shapes can be discerned, or at least with an AC signal, they are minimal. Thus we can operate around this point and on the curve, and find that impedance mirroring occurs for a reason that is one to one with the existence of two calibration curves. This is roughly then a function of voltage level input to the light emitting diode and to the photodiode, with respect to their individual biases. The prediction is that when they are of the same ratio, the impedance should match, and the mirroring should be eliminated, which describes another curve.

The final problem is that if the VAC is set too high for a particular VDC, it results in clipping, and hence a partial mirror image, and a distorted output sinusoid. Hence in the test with the ideal image above, VAC was too high or low.

Design Theory

The mirroring, and the theory of the device being an impedance map, as well as the description in terms of pn and np junctions coupled by light, and the empirical observation of mirroring at intermediate angles have lead to one conclusion with regards to the device. There is as it seems a functional mapping of impedance as a function of voltage for input and output, which is not matched when there exists a mirrored image. This leads to two functions, one for the light emitting diode, and one for the photodiode, that are their 'gain', which act as leading to reflection and transmission coefficients internal to the electromagnetic functioning of the touchscreen. In a sense we know that first of all, the touch corresponds to a geometrically functional position which is an impedance as a function of position which attenuates the signal, and interferes with the light field of the 'junction', which is the interface between a pn and np junction (given the photodiode is reverse biased). The fact this is an impedance map is given by the fact that it is actually two things at once; for one, it is an impedance as a function of position, but two, it is also a frequency pole of resonance for the exterior circuit, or, attenuation, by the fundamental theorem of calculus. Given this, there exists an impedance or ratio of current to voltage, which is complex, meaning it phases and scales, which corresponds to the input and the output. The light is in a sense free as the response is not externally comparative in this circuit (via feedback between output and input), and all that matters is the ratio of the functions for gain given the harmonic light. If for example the sinusoid voltage in (which corresponds to a harmonic function so illuminated) does not correspond to the same tableau, or gradient as a vector in phase and amplitude to that of the input there WILL exist a phase and amplitude shift! This arises because there exists an impedance mismatch, which in this instance is a simple scalar of resistivity, or a ratio without complex component. However, the complex component of 'rotation' or phase does appear in the images so produced, and results because it acts as a filter. Thus, there is a rotation 'away' from the point of inflection or where the curves intersect, as a result of frequency response to voltage amplitude to phase rotation, because the device acts as a filter. For example, the circuit in advancing a slope difference determines the ratio of angular distortion, because the ratio of these two slopes determines the complex current to voltage phase difference by the fact that voltage in determining voltage also phases unless the slopes are identical. Thus, when the slopes are non identical, there exists a phase difference by the manner in which the impedance advances or lags the wave of a sinusoidal nature, the complex part would be purely imaginary were the device to be a simple capacitor or inductor, but this device relies upon an impedance map as a function of position, thus it is in a sense resonating with the partially mirrored function, because the two functions in relation to one another amount to an odd function as their ratio or difference. In simplistic terms, the impedance map of the device becomes mirrored in part, by this odd component, starting at 180 degrees, with the ratio away from this, the proportionality of the slopes in amplitude and phase. This is in loose terms described as the geometry of the space, illustrating an impedance reflection with respect to the difference in impedance accorded with the voltage weighted sinusoid reception and transmission curves, with respect to the boundary. Thus in other, simple terms, there appears a reflection because the surface IS an impedance map, and thus another pole appears around a circle (at the same radius), with amplitude the reflected amplitude, and a phase, a monotonic function of the phasing filter that constitutes the exterior, and because one function mapped to the other constitutes a rotation, it accords one to one with amplitude of this mirror image. Finally, because the exterior is a filter, and a set of oscillators, the complex coefficient that is the impedance, and the impedance ratio from pre-image to image, the reflected signal is rotated with respect to the original image, originating at 180 degrees (it is reflected), and carried to a lesser extreme because the device is linear in phase and amplitude (it is a closed loop). So it essentially rotates by its reflection, and if carrying another slope represents a different function of current to voltage, which is 'rotated' because the outside is harmonic. This harmonic nature means that phase of the outside corresponds to pure phasing as a function of impedance, because it is purely imaginary! The fact it is purely imaginary means that it is purely oscillatory, and the response to an impedance mismatch functionally is a phase proportional to the impedance mismatch, with the reflection (a 180 phase shift). The amplitude is proportional to this difference approximately because it corresponds to the midpoint or crossing point of the two curves of impedance magnitude as a function of voltage, and is realized in the device because at this point the imaginary components are the same, and the phase is coherent, or a relative phase of zero. Thus the amplitude is 1 minus this ratio, because it is the reflection component. Thus both the phase difference (which is functional), and the amplitude difference (which is roughly describable in terms of the midpoint of the functional crossing) between the actual image and pseudo image are explainable in terms of an impedance mismatch of the response curves of the two input and output voltages in the context of there being an impedance mapping of the device as a function of position with a pn and np junction with supplied voltages. These together describe a one dimensional manifold, or curve, for which there exist ideal settings, because there exists a continuous ratio of voltages function for which the impedance as a function of voltage (sinusoid) is a constant. Then, the system is described by two essential parameters of scale. One, the voltage offset (which determines both direct current voltages), and two the scale of the sinusoid (which now tracks both curves on input and output). This is made possible because the surface of the acrylic disc is flat, and hence it furnishes an impedance map which has globally flat coordinates. The device and its characterization is now nearly complete, and what one must do is locate the parametrization of this curve, and in any future design automate the process of calibration to fit this curve.

Design Theory II

The key to understanding this is that:

A:) Two current to voltage curves represent different impedance relationships as a function of voltage.
B:) Their slope difference represents geometrically a complex, imaginary rotation of the curves, and hence a phase difference from pure reflection (180 degrees).
C:) The impedance mismatch of the two curves at the center point determines the real part of the amplitude of the mirror image.

The key to designing the device is to set the direct current voltages such that they are proportionally the same to the two bias voltages. This ensures the two curves for gain are identical, and that they have identical slopes, assuming that they have the same junction type. If they do not have the same junction type then it is likely that setting the bias points proportional to the voltages in, should compensate for this.

The question is if it is:

LED_V/LED_BIAS = PD_V/PD_BIAS

Which sets the condition of impedance matching.

An essential question which must be answered is as it pertains to the VAC signal. For it appears this does have an influence on the 'angle' of the reflected image, by way of its ratio or difference from the VDC signal. According to the above theory this parameter should be independent, because it is a constant angle. This can however be a prediction, and would be a linear increase in angle, given the exponential dependence of the signal voltage to current and hence of the impedance mismatch. Clearly, if the curves are the same, then it will not rotate to varying degrees with varying sinusoidal input, but will if the curves are mismatched. This is in fact one way to find the calibration corresponding to the curves, and would confirm one of the above calibration equations.

The fact that this 'bending' with different exponential functions, or an angle difference proportional to amplitude of the AC signal and the local slope difference as rates at the point of crossing, indicates that it only becomes independent when the curves are the same, and explains the observed data.

Secondly, the LED_BIAS is in fact a voltage drop, past the point of which the signal is observed as visible, or oscillating in the LRC circuit, so it is probable that it is in fact the first formula above. What we wish to do is say, that there exists a common curve, but since the curve is entire, and an offset does not matter, they never intersect unless their arguments behave differently. If the bias were not included there would be no multiplier, and with simple VDC, the identity must be that one curve must advance faster than the other curve and 'come from below' for a non-zero intersection, and of course, the resistors set an offset linear function.

Using our previous knowledge, that setting PD_V = PD_BIAS produces a mirror image, but clear images says one thing, but leaves empty the statement that we can use this as impedance matching, unless of course LED_V and LED_BIAS were recorded. They should be close to unity, or of course with the subtraction close to zero. But because of this degeneracy, they cannot inform a decision about which formula to use without further testing, unless of course it is based on the earlier theory, that it was the difference from unity which was producing the reflected signal. In this sense the formula should work, but it does appear that what is conclusive is that tuning PD_V to PD_BIAS was a solution (in part) because it reduced the reflection to nearly zero on one part of the signal (the input/output into/out from the photodiodes). This confirms that the general behavior without calibration is many reflected and retro-reflected signals leading to chaos, and that if and only if both reflection coefficients are set to zero is a non-mirrored stable image obtained. Finally, it explains the locking up of the device, for when both reflections lead to curves which substantially disagree it is possible that their reflections are large, leading to feedback in resonance, overloading the device.

Finally, what must be understood is merely if the bias point must be set to the voltage across for both photodiode and light emitting diode, and hence there is one condition of calibration, or if they may be proportional in general, and hence there is a curve of conditions leading to correct biasing. The remaining open question is if this curve is identical to the one so found.

New Calibration

The two bias voltages were measured with the device turned off and touchscreen connected, as:

LED_BIAS = 1.082 Volts
PD_BIAS = 0.582 Volts

Their ratio is:

LED_BIAS/PD_BIAS = 1.859

The calibration curve was estimated from two measurements which produced clear images by solving for alpha and beta in a quadratic curve passing through the origin of the nature of x = LED_VIN, y = PD_VIN and form y = alpha x + beta x^2. From these two measurements it was estimated that alpha is approximately: 3.666 and beta is approximately: 1.847. This beta is very close to the ratio of LED_BIAS/PD_BIAS above, and the question to be determined is if this curve determines the ratio equivalency of LED_V/PD_V = LED_BIAS/PD_BIAS.

Turning the device on and testing the points of the given test it is found that with a calibration not on the curve:

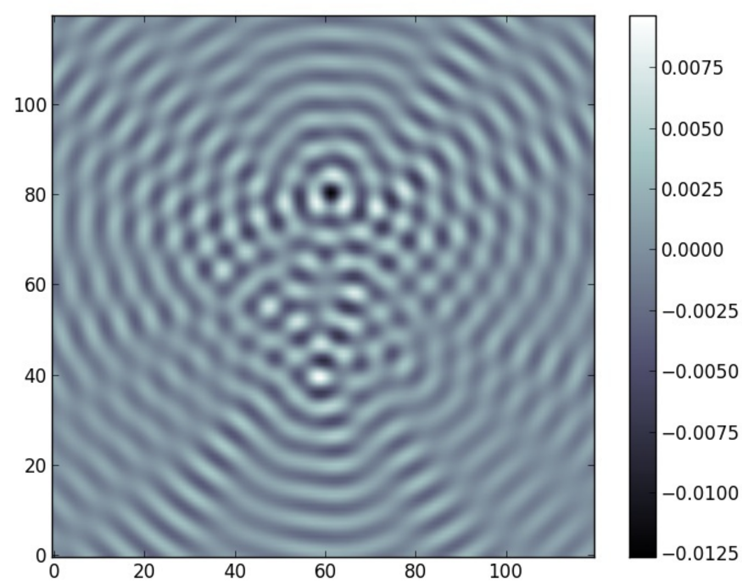
PD_VIN = -0.954 PD_V = -0.581 LED_VIN = 1.250 LED_V = 1.071

That LED_V/PD_V = 1.843

Seeming to indicate that from the test of at least one point of data, the setting of PD_V = PD_BIAS is also setting the ratio of LED_V/PD_V to equal LED_BIAS = PD_BIAS. We must however test another point to accurately assess this. For now, this produces an image such as before at similar settings. One can see that the remaining discrepancy comes from LED_V not matching LED_BIAS. Matching these should match impedances and produce an ideal image. So the system was adjusted to the following settings:

PD_VIN = -1.144 PD_V = -0.582 LED_VIN = 1.338 LED_V = 1.082

This is also not on the calibration curve, so the calibration curve sets something entirely different from the ratio so hypothesized, in generality. Nevertheless it is wise to stop here and test to see if it is capable of producing a valid image. An image produced after great adjustment of LED_VAC to about 2 Vpp was:



Further Characterization

To further characterize what must be analyzed is:

A:) Voltage IN to LED or photodiode voltage curves.
B:) Voltage IN curve such that voltage ratios are proportional to bias voltages.
C:) The property of the VAC signal IN. What settings are ideal, and does it lock up as a result of mismatch?

What needs to be designed if a curve is found, or even if not is auto adjustment of power levels to result in direct ratio equivalency, with an op-amp and voltage splitter mimicking the curve of response corresponding to the impedance map that is the device. With this, we should be finished.

To calibrate for the bias ratio the following settings were found before:

PD_VIN = -1.144 PD_V = -0.582 LED_VIN = 1.338 LED_V = 1.082

And new ones were found as:

PD_VIN = -1.732 PD_V = -0.597 LED_VIN = 1.645 LED_V = 1.111

Fitting these to a quadratic curve as before it was found the calibration curve is:

PD_VIN = alpha*LED_VIN + beta*LED_VIN^2 with alpha=.00741 and beta=-.64456

Two attempts were made here, one of which was to produce an image with these settings, but it was not found this to be a valid calibration curve for images. Even setting the calibration to the intersection of this curve with that of the 'old' calibration curve did not result in an adequate image, although the setting of LED_VAC was questionable.

Further Design

As it seems the resistors add an extra functional impedance relationship of a linear curve, and 1.5 M ohm / 20 = 75 k ohm, vs, the 1 k ohm of the output, this either does not contribute or if it does this means there is a point where the curves do minimally match in slope.

To finalize the design, however, what must be understood is how the original signal coming in of DC nature contributes in summation to the total voltage across the photodiode. It is clear that the light emitting diode voltage likely does not depart from the 'biasing', because it should not absorb light. However, this is possible, so it is not known.

The manner in which to do this is to momentarily disconnect the LED voltage and measure the photodiode voltage as a function of applied voltage. However, this disconnects the LED, and may change the relationship of these two voltages, such that when the device is in operation it is not know what actual DC bias apart from light reception the photodiode is receiving.

This extra contribution is the primary contributor to either a mirrored image, due to a lack of impedance matching functionally, and feedback, leading to breakdown, and clipping, if the impedance mismatch acts such that it generates functionally many reflected images.

It is hypothesized that LED_BIAS/PD_BIAS=beta, the coefficient of the quadratic curve so found for ideal, but non biased images. Perhaps this curve and the knowledge of what it implies could be used to properly calibrate the device with biasing in the so integrated circuit, with both voltages applied, for it describes the DC to DC signal in and out.

Finally, this modification should be the final modification such and so as to obtain a clear image with but one ripple formation, minimal noise, and no mirrored image. The related problem is how to adjust the VAC on the LED, for this has tight constraints to produce viable image acquisition, and it was noted that this changes the bias voltage so measured, although of course not that of the built in voltage drop across the diodes. This can be remedied tuning VAC to zero and measuring, for the AC component admittedly should not be a part of the bias as measured, which it is because a multimeter is used.

Calibration Revisited:

The calibration found so far as a quadratic curve simply represents the linear relationship from the exponential of a log or a log of an exponential on the two light sensors, the light emitting diode and the photodiode. It is the product, and is therefore possible to separate into the DC component (by varying this an taking measurements) and the actual built in voltage drop. With this it is possible to calibrate ideally such that a new curve is found for equivalent voltage drops strictly from the voltage sources proportionally to the built in voltage drops, so as to reduce the coefficient of reflection from impedance mismatch to zero. This should eliminate retroflection in the optical to the electronic circuit, thus eliminating the phenomenon of chaos in this circuit as well a (predominant) mirror image. This should manifest as an 'extra' linear dependence to the constituent curves, and its zero point is therefore interpolatable from the data.

Finally, it was determined that the theoretical model for the curve for which:

LED_V/LED_BIAS = PD_V/PD_BIAS

Is in fact very close to the measured curve for which we saw coherent images before, and is not set by the curve for which these values are the strict unity between the sides of this equation, as when it departs from this calibration point, the DC component of the illumination creates an offset to the curve and hence the coefficients.

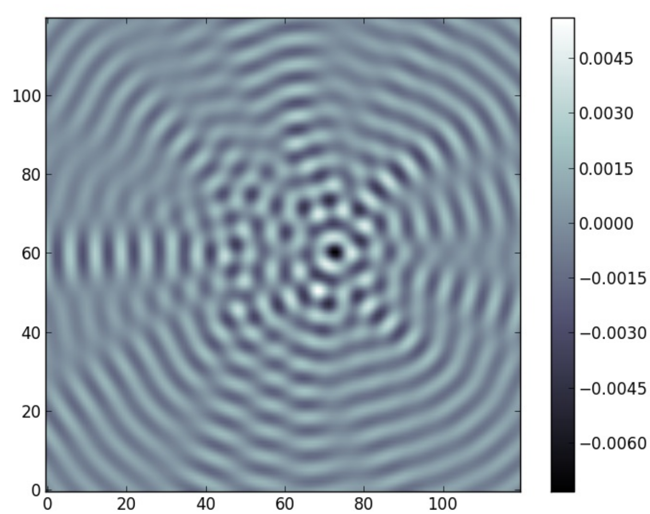
The curve is modeled as: PD_VIN = alpha*LED_VIN + beta*LED_VIN^2

In theory alpha = alpha_1/alpha_2 where these are the pre factors of the exponential dependence of voltage drop to current, and beta = LED_BIAS/PD_BIAS. It is natural to arrive at this when it is considered the light going in and then out scales up and down the alpha dependence on a separated linear relationship from the quadratic.

The measured values are:	alpha = 3.666	and	beta = 1.847
The theoretical values are:	alpha = 3.685	and	beta = 1.859

These are very close, and could differ for two reasons. .26 was used in the denominator of the exponential argument when it may be closer to .27, and this would alter the alpha, and secondly, the measurements were taken from non ideal but visually good images, which always had mirror images.

The bottom line is it is clear that there is a correspondence to be found and that this quadratic closely approximates the ideal image curve for which the voltages supplied are proportional to their bias voltages. Secondly, all that remains to be done is to interpolate real data and find an empirical match, or test with the theoretical settings and use theory to obtain the best possible images. For this, the data sheets would be helpful. Here is an image with the improved calibration;



Final Calibration:

The calibration proceeded under finding the solution such that the slope and offset of the two functions for the light emitting diode and photodiode were the same. This proceeds under the guidelines before, that first of all the two devices are modeled as lines, and their product is formative of a common relationship based on the equivalence:

LED_V/LED_BIAS = PD_V/PD_BIAS

This relationship is at the heart of the relationship between the curves, and what is found is that the curve of PD_VIN to LED_VIN is of the form of:

$y = \alpha x + \beta x^2$

As it is found this reduces to:

$y = \alpha x * (1+\beta/\alpha x)$

beta/alpha was found as LED_BIAS/PD_BIAS earlier, and alpha is found by matching the slopes.

To find alpha requires the 'direct gain' to be found as a relationship between the input and output, and is as a given found from the relationship of the slopes.

Setting the slopes equivalent requires taking the differential of the voltage to current curve for a diode as:

partial_Vd of $I_0*(e^{(Vd/Vt)}-1)$

And equating the functions. When 1.082 and .582 are substituted into the two curves as the voltage it is found that the equation that results produces a gamma=1/Vt for both devices in its relationship to alpha given by I_E/I_C as modeled in a transistor of:

alpha = 1+gamma

This is the gain factor, and is entirely analogous to a transistor functionally and operationally.

With this $f_1*f_2=f$ is y, and the two functions can be explained as:

f_1 = alpha x

Which is the direct gain of the VIN for the LED scaled to the PD direct output.

And,

f_2 = (1+beta/alpha x)

As the excess from reverse biasing (which accounts for 1 appearing), and the reverse of the light from voltage to voltage from light, which accounts for the alpha in the denominator, and beta, which is the strict prefactor proportionality such that the curves in slope be scaled the same amount for all values of VIN to the LED.

As a final note, the gain is non-unity and the same for both devices, such that the impedance matches (which was the assumption with respect to the differential above), and yet the gain is not unity!

With this, the device is genuinely a "Light Interactive Field Effect Transistor".

With this in addition: alpha=3.6835 and beta=1.8591