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Application of Taguchi Method for Inverse Problems: Determination of Actual Parameters from Measured Data

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Overview

- Introduction
- Filter design
- Taguchi Method
- Use of taguchi in inverse problem: discussion of results
- Conclusions

Introduction

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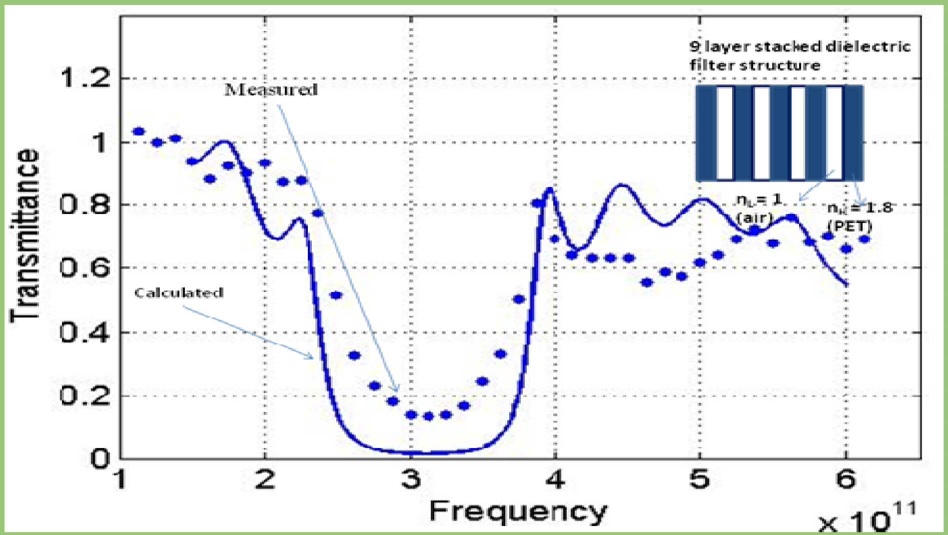
- Initial Object: to make cheap quasi-optic devices in the THz spectrum.
- Design of a quarter-wavelength stacked dielectric filter
- Assembled thin film structure from PET.
- Response not very good wrt simulation.
- Cause for deviations: layer thickness, warping, incidence angle etc.
- Use the Taguchi method in this inverse problem scenario: to predict the actual filter parameters from the measured results.
- Coupled Taguchi method and transfer matrix method for this inverse problem.
- Presented is an example of application of Taguchi method in an inverse problem for EM, for the first time(?) and which could be generalized.

Filter Design

- The basic photonic crystal is composed of stacked layers of alternate high and low dielectric constant materials. This gives a bandstop response.
- Response is determined by the periodicity of the dielectric variation, the thickness of the different high and low dielectric materials used in the stacked configuration.
- For stacked quarter-wave structures, the gap-midgap ratio is given by equation:

$$\Delta w / w_m = \left(\frac{4}{\pi}\right) \times \sin^{-1}\left(|n_1 - n_2| / |n_1 + n_2| \right)$$



Taguchi Method of Optimization

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- Decreases no. of tests required in an optimization process by use of orthogonal arrays

- Easy to code

Orthogonal arrays:

- Fractional factorial approach

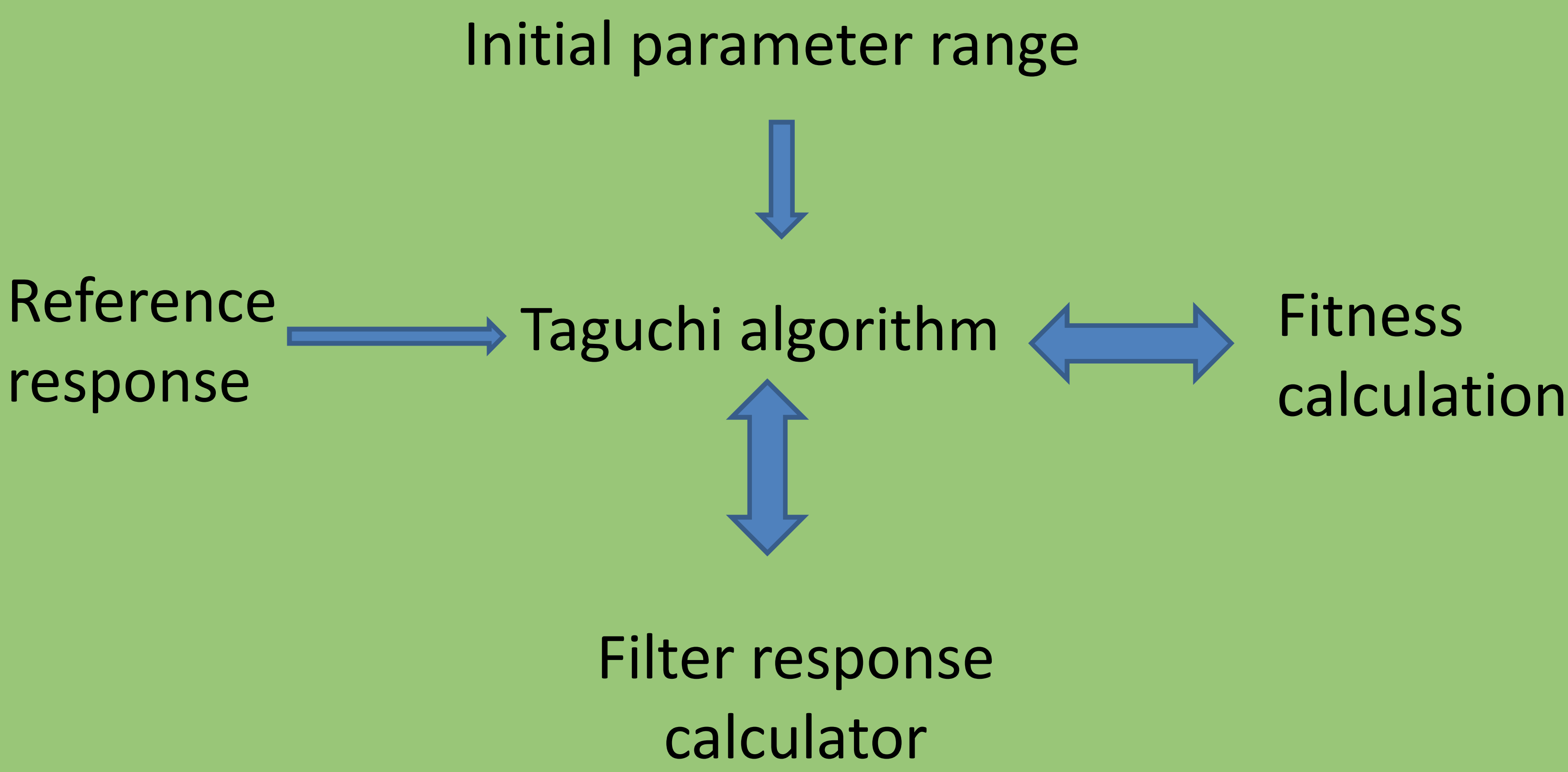
- Efficient way to determine control parameters with fewer no of experiments.

- Doesn't affect the accuracy of the results greatly compared to full factorial method.

Experiment \ Element	1	2	3	4	5	6	7	8	9	10	Fitness	S/N Ratio (dB)
1	1	1	1	1	1	1	1	1	1	1	5.153	-14.240
2	2	1	2	2	2	3	3	1	2	3	9.076	-19.157
3	3	1	3	3	3	2	2	1	3	2	9.578	-19.625
4	1	2	1	2	2	2	3	3	1	2	9.847	-19.866
5	2	2	2	3	3	1	2	3	2	1	6.821	-16.676
6	3	2	3	1	1	3	1	3	3	3	14.233	-23.066
7	1	3	1	3	3	3	2	2	1	3	12.898	-22.210
8	2	3	2	1	1	2	1	2	2	2	9.911	-19.922
9	3	3	3	2	2	1	3	2	3	1	9.073	-19.155
10	1	1	2	1	2	2	2	3	3	1	9.245	-19.319
11	2	1	3	2	3	1	1	3	1	3	14.696	-23.344
12	3	1	1	3	1	3	3	3	2	2	11.785	-21.427
13	1	2	2	2	3	3	1	2	3	2	7.690	-17.719
14	2	2	3	3	1	2	3	2	1	1	7.220	-17.171
15	3	2	1	1	2	1	2	2	2	3	11.447	-21.174
16	1	3	2	3	1	1	3	1	3	3	12.176	-21.710
17	2	3	3	1	2	3	2	1	1	2	7.716	-17.748
18	3	3	1	2	3	2	1	1	2	1	7.553	-17.563
19	1	1	3	1	3	3	3	2	2	1	10.495	-20.419
20	2	1	1	2	1	2	2	2	3	3	11.054	-20.871
21	3	1	2	3	2	1	1	2	1	2	12.142	-21.686
22	1	2	3	2	1	1	2	1	2	2	10.197	-20.169
23	2	2	1	3	2	3	1	1	3	1	11.646	-21.324
24	3	2	2	1	3	2	3	1	1	3	11.940	-21.540
25	1	3	3	3	2	2	1	3	2	3	11.702	-21.365
26	2	3	1	1	3	1	3	3	3	2	11.695	-21.360
27	3	3	2	2	1	3	2	3	1	1	9.354	-19.420

Example of an orthogonal array used in designing up a set of experiments in Taguchi

Taguchi Method of Optimization



Program Flow in Taguchi

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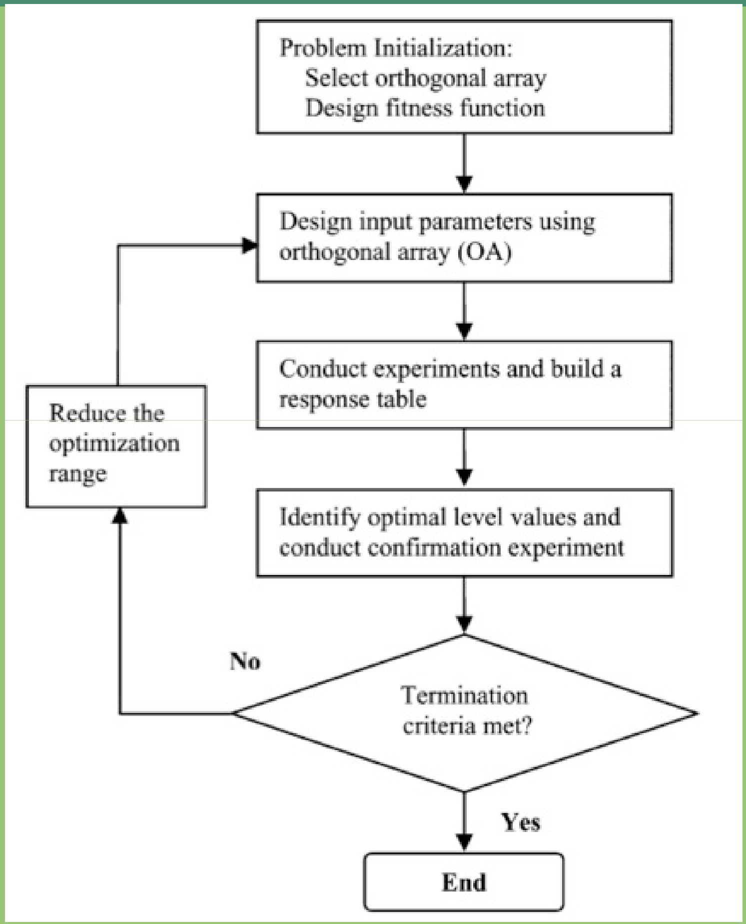
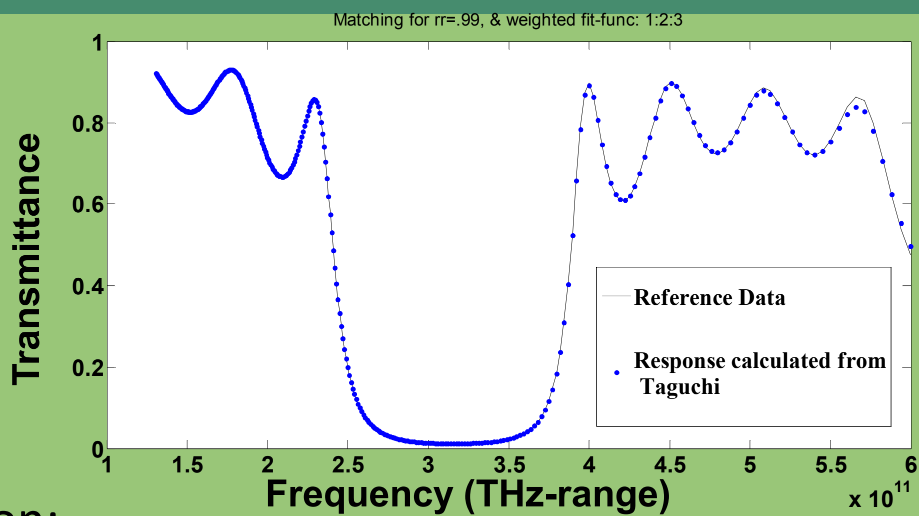
27	3	3	2	2	1	3	2	3	1	1	9.354	-19.420

Example of an orthogonal array used in setting up a set of experiments in Taguchi



Basic algorithm in Taguchi method

Verification in case of a rigid filter (without warping)



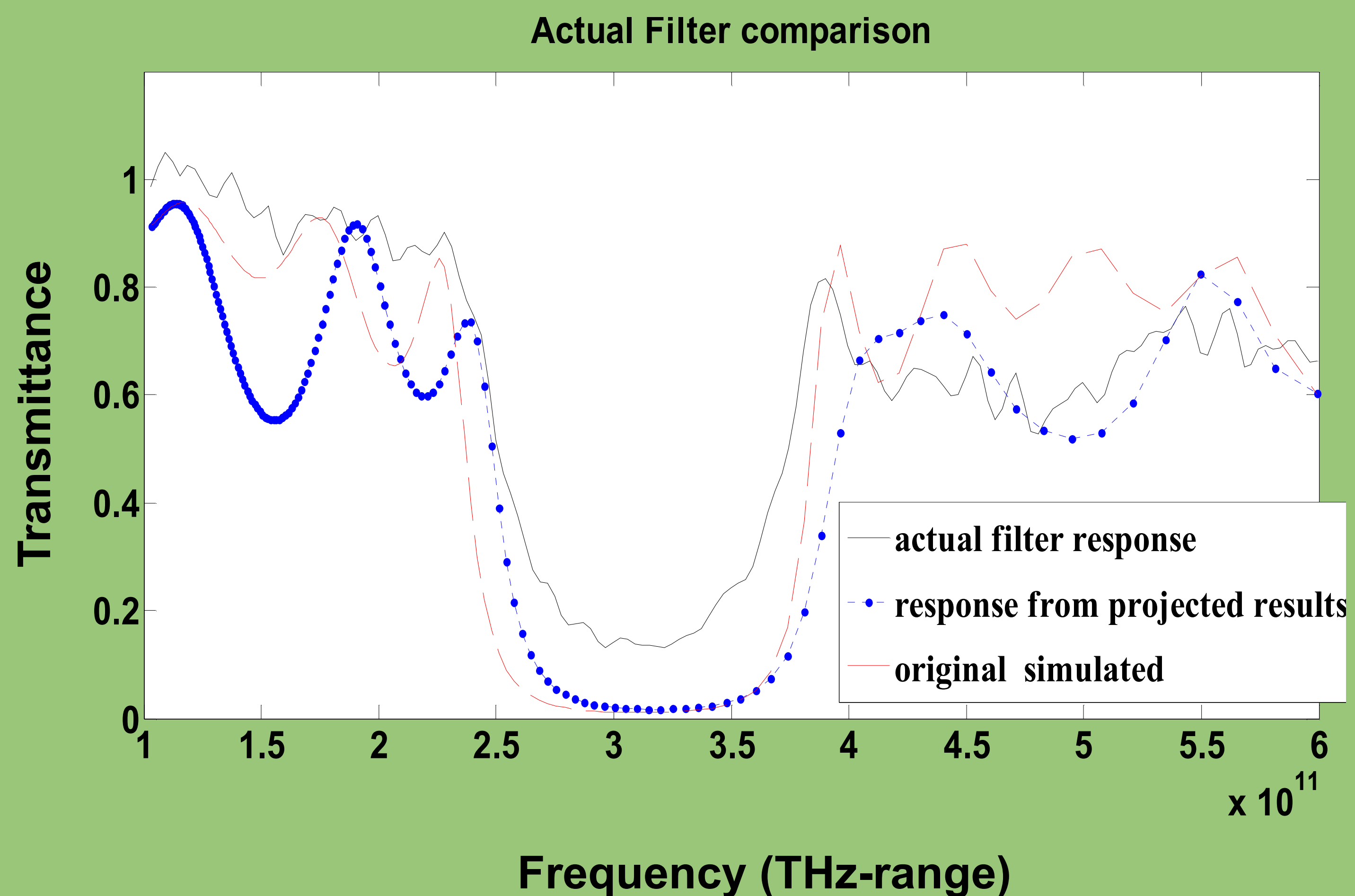
Layer thickness comparison:

Layer No in Filter-stack	1	2	3	4	5	6	7	8	9
Reference filter layer thicknesses(um)	120	260	120	260	120	260	120	260	120
Final predicted thicknesses(um)	121.10	258.38	124.88	250.52	124.42	253.9	124.19	255.34	123.62
Absolute error (%)	0.91	0.62	4.06	3.64	3.68	2.35	3.49	1.79	3.02

Average total error: 2.62%

No. of iterations: 918.

Direct application to actual PET-film bandstop filter

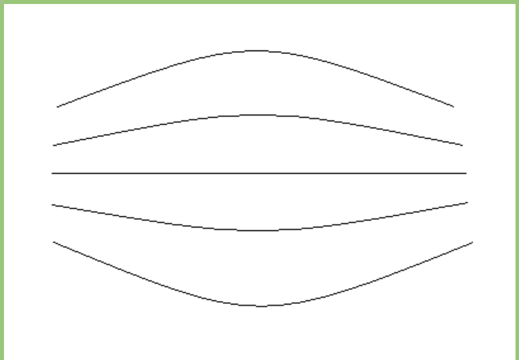


Modelling the filter warping

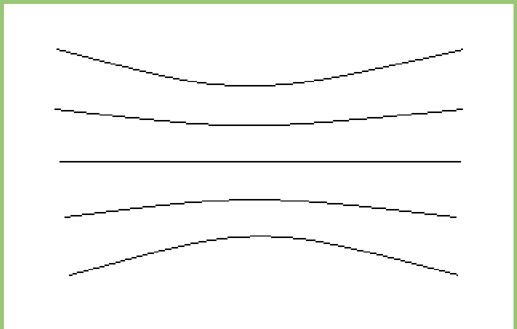
Approach1: Pixelating the filter to account for the warping.

- Filter treated as a combination of pixels, each giving it's own response.
- Total response is an average of these pixel responses.
- Surface relief of the filter studied to determine distribution of warping within the layers
- Reflection intensity measured, correlated to surface warping.

Warp models for different surface profiles



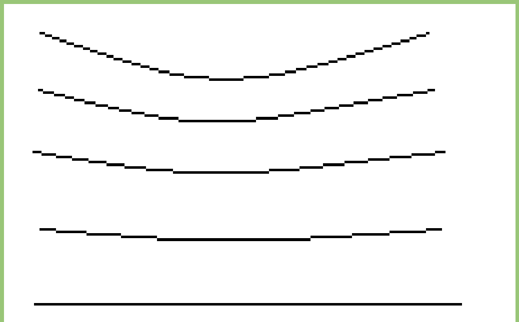
(a) Bulge-bulge



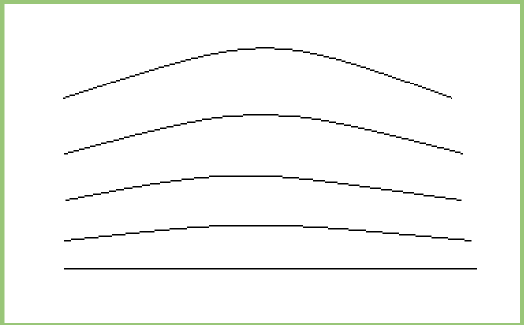
(b) Trough-trough

Warping of outer layers affect the distribution inside.

Some possible distributions shown here



(c) Trough-Plane



(d) Bulge-plane

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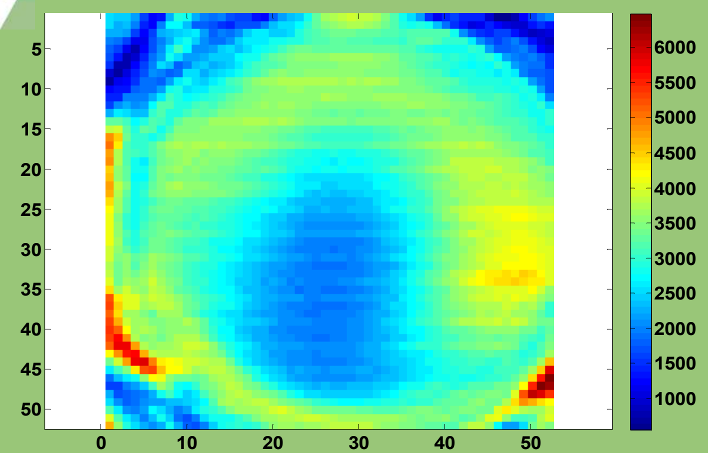
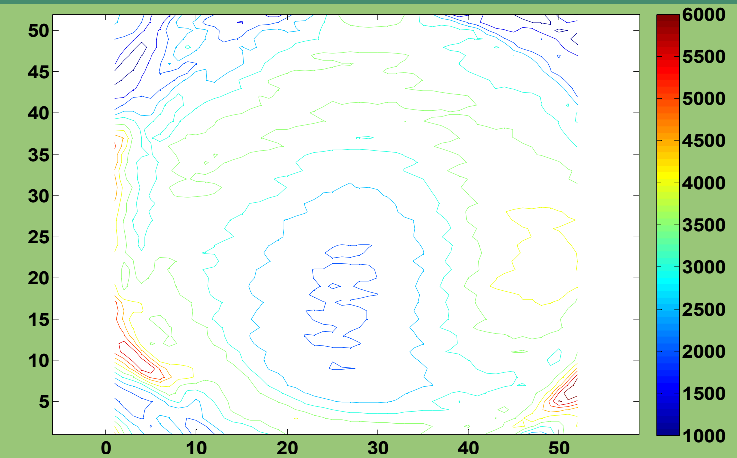
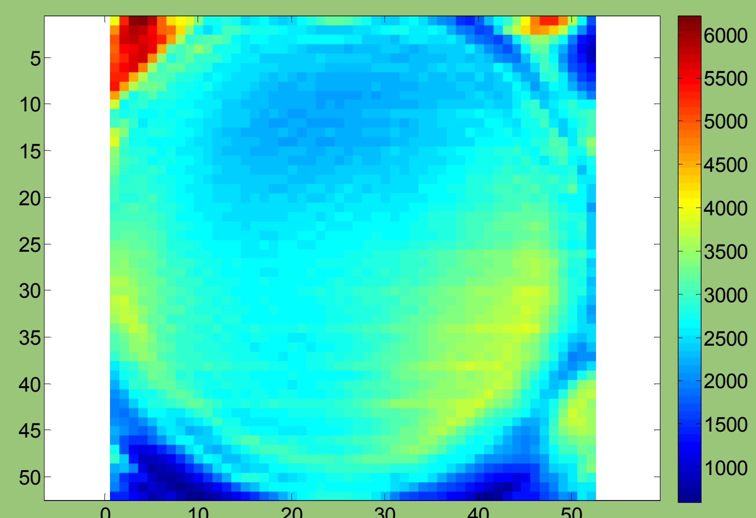
Surface profile of the filter



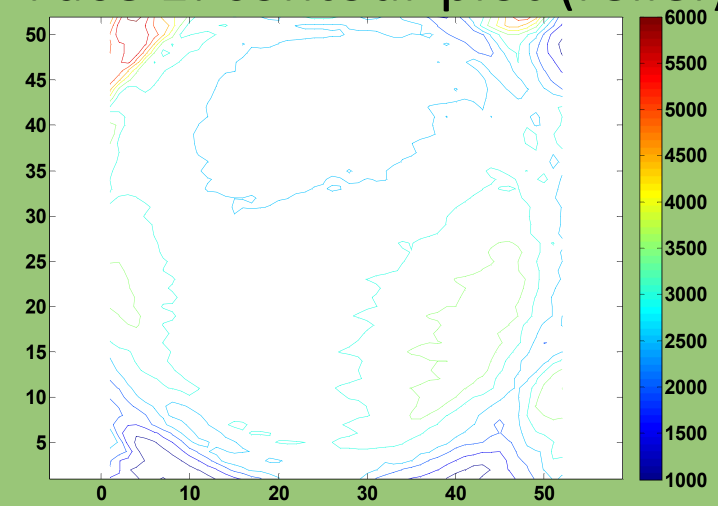
Face 1: intensity plot



Face 1: contour plot (relief)

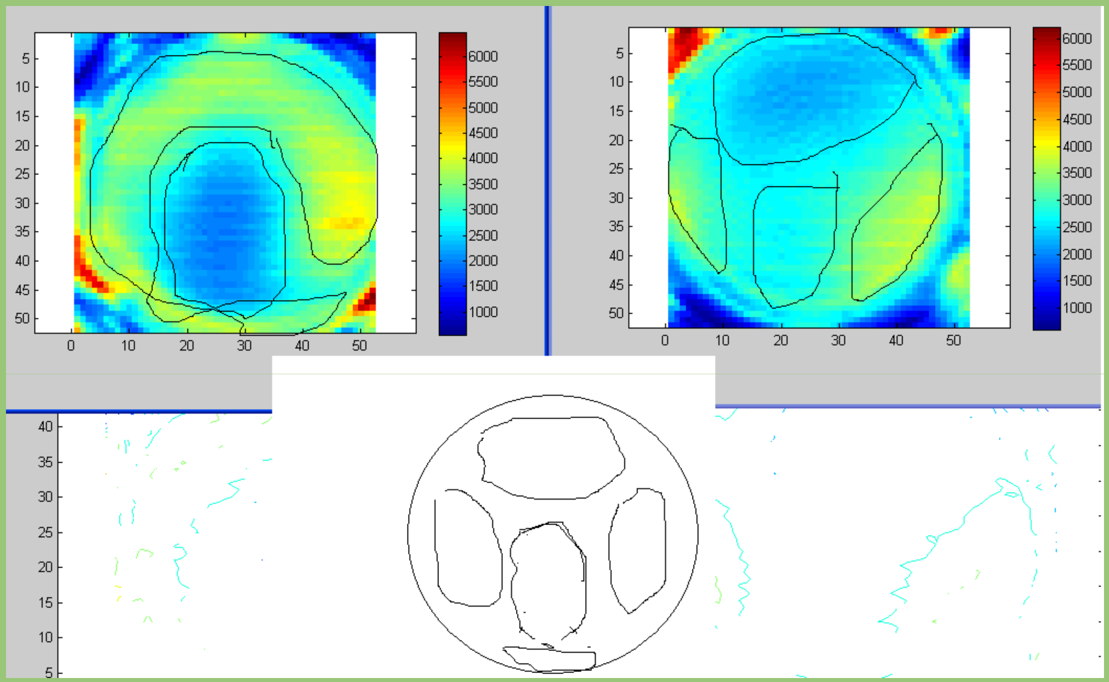


Face 2: intensity plot



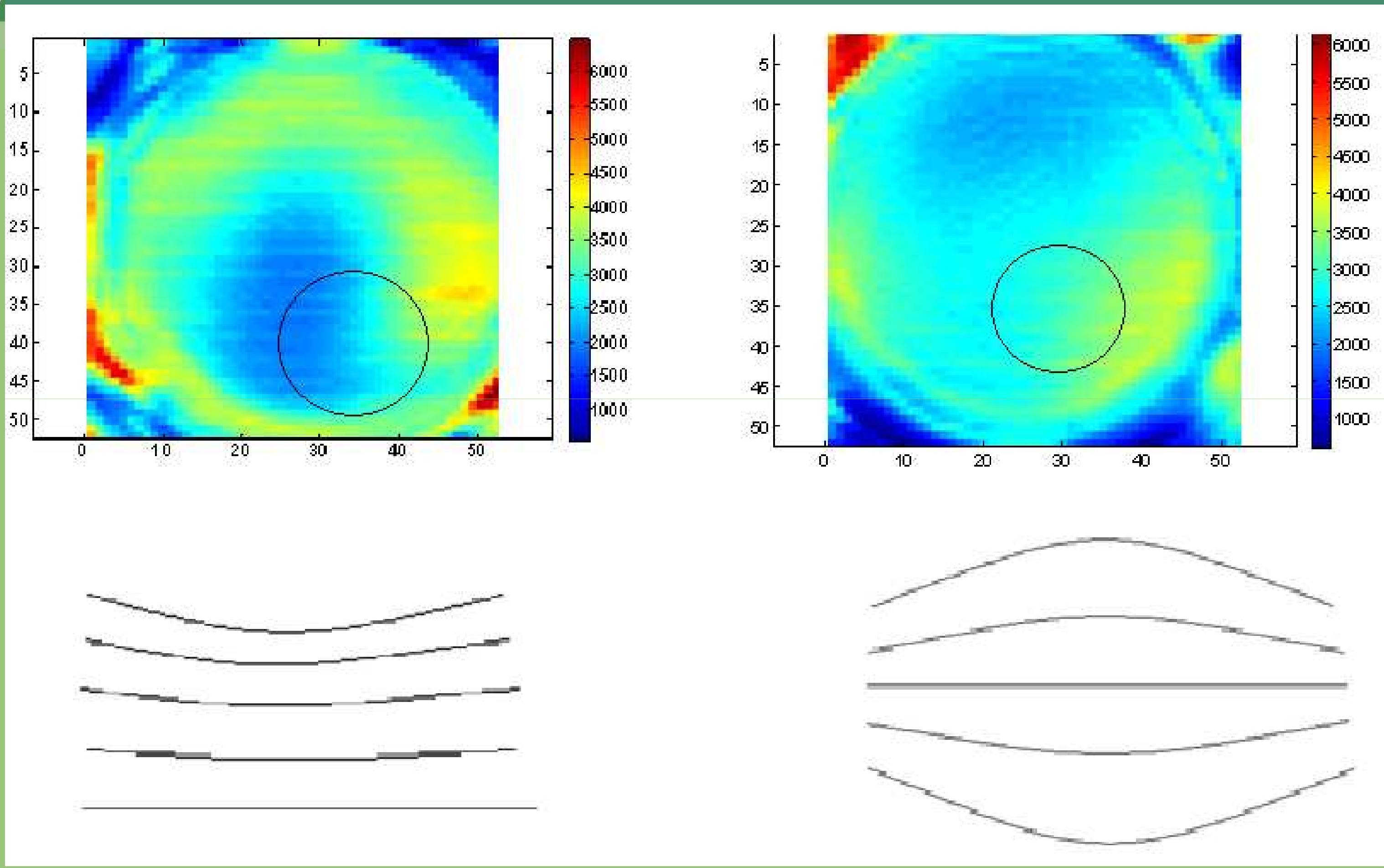
Face 2: contour plot (relief)

Surface profile of the filter



- Selecting the pixels and their warp models
- Based on the regions where the THz beam passes
- Entire filter area is not active

Pixel Selection in the filter



Region1- Trough-Plane

Region2- Bulge-Bulge

Comparison between Pixelled & Non-Pixelled Filter Data

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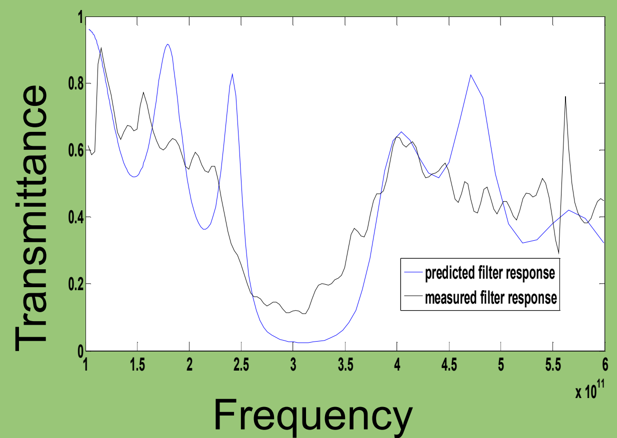
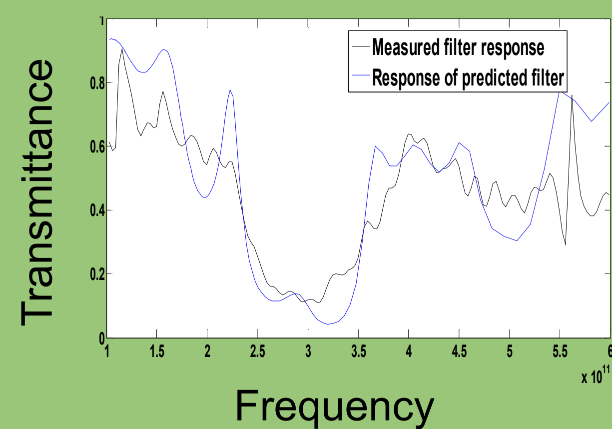
Without pixellation



Layer No	Thickness (μm)
1	130
2	191
3	120
4	260
5	120
6	191
7	130
8	318
9	130

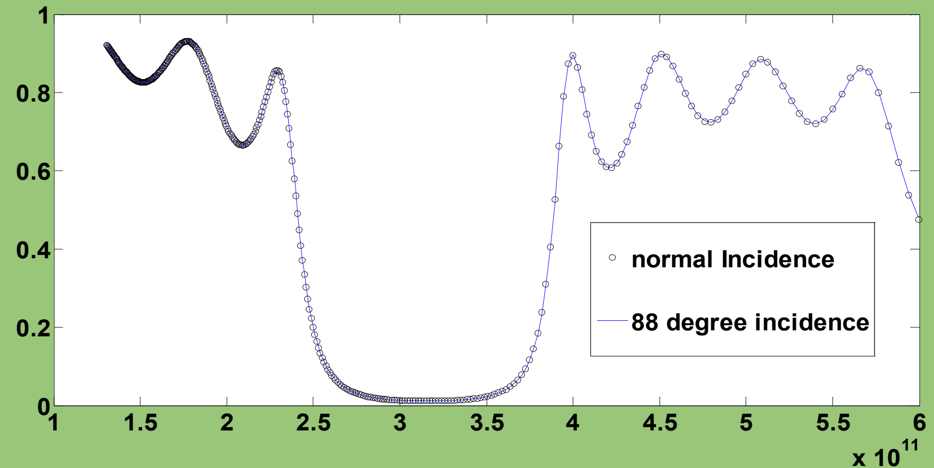
With pixellation



Layer No	Thickness in region 1 (μm)	Thickness in region 2 (μm)
1	130	130
2	317	143
3	130	130
4	314.3	146.84
5	130	130
6	175.3	146.84
7	130	130
8	314.32	146.84
9	130	130

Approach 2: Effect of Incidence Angle

- Warping and undulating surface implies non-normal incidence angle at different regions of the filter.
- Attempt was made to take this into account.



- Effective variation in response is minimal (for maximum range)
- Hence not a key detrimental factor.

Conclusions

- Demonstration of Taguchi method being used in Inverse electromagnetic problem.
- A new approach of pixellating structure-dependent components (stacked filter in this case) to analyze actual parameters.
- Future work: Surface imperfections via RCWA.

References

- Weng et al, **"OPTIMIZATION USING TAGUCHI METHOD FOR ELECTROMAGNETIC APPLICATIONS",** *Proc. 'EuCAP 2006', Nice, France, November 2006.*
- Weng et al,"**Linear Antenna Array Synthesis Using Taguchi's Method: A Novel Optimization Technique in Electromagnetics**", *IEEE Transactions on Antennas and Propagation, VOL. 55, NO. 3, MARCH 2007.*
- *C.Rao," **Factorial Experiments Derivable from Combinatorial Arrangements of Arrays**", Supplement to Journal of Royal Statistical Society,Vol.9,No.1,1947(pp.128-139).*
- Joannapoulos et al, "**Photonic Crystals: Molding the Flow of Light**", *Princeton University Press(2008), pp. 6-65.*
- *J.Lekner,"Theory of Reflection",Springer (1987).*