System Level Design Review

PO9343 Microwave Data II

Joel Barry
Amanda Kristoff
Mia Mujezinovic
Michael Pecoraro
Meeting Purpose:

This meeting is to review the system and components to confirm it meets the Functionality, Engineering Specifications and Customer Needs of the P09343 Microwave Data II KGOCE MSD team.

Materials to be Reviewed:

- Project Overview (Rev. A)
- Customer Needs Chart (Rev. B)
- Customer Specifications Chart (Rev. B)
- Customer Needs to Specifications Chart (Rev. B)
- Concept Generation/System Level Design (Rev. A)
- Risk Assessment (Rev. A)
- Engineering Design Process (Rev. A)
- Component and System Progress Report (Rev. A)
- Two Quarter Schedule/Milestones (Rev. B)

Meeting Date: January 16, 2009

Meeting Location: 78-2150

Meeting time: 12:30 – 2 PM

Timeline:

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Topic of Review</th>
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<tbody>
<tr>
<td>12:30</td>
<td>Team Introductions</td>
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<tr>
<td>12:35</td>
<td>Project Overview</td>
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<td>12:40</td>
<td>Concept Generation/System Level Design</td>
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<tr>
<td>12:50</td>
<td>Risk Assessment</td>
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<tr>
<td>12:55</td>
<td>Engineering Design Process</td>
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<td>1:05</td>
<td>Component Progress: Branchline Hybrid</td>
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<td>1:10</td>
<td>Component Progress: Knochel Hybrid</td>
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<td>1:15</td>
<td>Component Progress: Schiffman Phase Shifter</td>
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<tr>
<td>1:20</td>
<td>System Progress: System A</td>
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<td>1:25</td>
<td>System Progress: System B</td>
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<td>1:30</td>
<td>Two Quarter Schedule</td>
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<td>1:40</td>
<td>Question</td>
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Introduction

Members:

- Mia Mujezinovic (Team Lead)
- Michael Pecoraro
- Amanda Kristoff
- Joel Barry

Breakdown of Roles/Tasks:

- **90 Degree Hybrid**: Michael Pecoraro
- **180 Degree Hybrid**: Joel Barry
- **Schiffman Phase Shifter**: Mia Mujezinovic
- **System A**: Mia Mujezinovic
- **System B**: Amanda Kristoff
- **Vertical Launch**: Anaren, Joel Barry, Michael Pecoraro
- **EDGE Updates**: Amanda Kristoff

Resources Utilized:

- Ansoft Designer
- Ansoft HFSS
- IEEE Xplorer Database
- Michael Enders (Anaren, customer)
Project Overview

Customer

- Michael Enders
  RF Engineer
  Anaren Microwave Incorporated
  Space and Defense Group

Menders@anaren.com 315-362-0273

Anaren®
What’ll we think of next?®

Project

- To design, build and verify the operation of two 4x4 Butler Matrices for use in antenna beamforming

![Block Diagrams of System A and System B](image)

Purpose

- Butler Matrices are networks that allow antenna beams to be electrically (as opposed to physically) steered. The necessary condition for electrically steering an antenna beam is that the antenna elements must be given different phase progressions. This is what a Butler Matrix does – depending on which input is used, a different phase progression is realized at the output.
- This project is more of a research type project for Anaren. They have two main goals that they would like us to attain:
  - Both Butler Matrices should be wideband – covering a bandwidth of 10-12GHz
  - Anaren has never used a Knöchel hybrid - they would like to see how it performs individually as well as in a system
Layout Stackup

The 120 mil stackup will be implemented in the Butler Matrix Designs for some key advantages:
- Thicker dielectric yields thicker traces for equal impedance lines which ensures traces will be greater than the minimum manufacturing tolerance of 10 mil
- Thicker traces are less susceptible to variation with the width tolerance of 0.5 mil

Topology Selection

- By unfolding the crossovers of the Butler Matrix A design, a single copper trace layer that mirrors the symmetry of the 90° coupler.
- Butler Matrix B is similarly unfolded to a single copper trace
- Vertical Mounting SMA connectors allow for access to all ports without implementation of crossover networks.
Risk Assessment

Amanda

Risks that have been addressed:

✓ Understanding the theory behind the components
✓ Understanding customer expectations/needs
✓ Learning HFSS
✓ Understanding ideal simulation tool in Ansoft Designer

Risks that still need to be addressed or considered:

 o Finalize and reevaluate specifications from Anaren
 o Vertical mount (receiving documentation from Anaren, designing and effects at system level needs to be considered)
 o Lead time on board manufacturing is 6 weeks
An extremely simplified process (or flow) by which we have been working to complete this project is seen below:

This process applies to each component and system that we will design. To explain the above process a bit further, read below:

- **Theory** - Everything begins with theory – there are textbook entries and papers written on each of the components that we are building (not necessarily the systems, but definitely on Butler Matrices in general). We read them, check them and fully understand them before getting started with any type of simulations. When we feel we are ready to start simulating, we go to the next level:

- **Ideal Simulations** - This type of simulation is done in Ansoft Designer using the special ‘ideal components.’ These components do not take into account any losses and show the absolute best case performance of your component or system. Impedance values, electrical lengths and frequencies are determined by the papers that were read (formulas would be given) and depending on the specific specifications for the project.

- **Designer Simulations** - Once the ideal simulations are completed, one can now include the substrate effects, discontinuities and other losses into the system using Ansoft Designer. These simulations will be, clearly, worse than the ideal simulations. The ideal simulation is, however, your goal; you always check back to see how well you can match it. Designer allows for many variables to be tuned in real time. Intelligent tuning, however, takes into account your ideal values and theoretical dependencies.

- **HFSS Simulations** - Once the designer simulation has been finished, the final step is tuning in HFSS. Using the theoretical dependencies and the ability of designer to see, magnitude-wise, how much these changes affect the output variables, the final tweaking is done.

Again, this process applies to both the component level and system level designs. This is the most efficient way of simulating – otherwise, you would have no real basis for what you are doing – you would be blindly tuning variables and hoping for the best.
Ideal values were obtained from the paper: *A Multisection Broadband Impedance Transforming Branch-Line Hybrid*; IEEE Transaction on Microwave Theory and Techniques. Formulas were given for theoretical values of impedances – these were solved for a line impedance of 50 ohms.

Results are as expected: over the entire bandwidth of 10-12GHz, there is equal power division between ports two and three and a 90 degree phase difference between ports two and three.
Component Progress - Branchline Hybrid

Michael

Designer (Initial 120mil)

Figure 9: Schematic View of Designer Hybrid

Figure 10: Layout View of Designer Hybrid

Figure 11: S-Parameters of Designer Hybrid

Figure 12: Output Phase Difference for Designer Hybrid

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- The tune feature was used to tune the lengths and widths of the transmission lines – the values seen in the table to the left were found to give the best performance.
- Although not as perfect as the ideal results, the simulated results are quite good – we have approximately equal power division between ports 2 and 3 and there is approximately a 90 degree phase difference between ports 2 and 3.
Quarter Wave Transformers (QWTs) were included at each of the four ports. These widths tuned, as well as the other lengths and widths to produce the table found to the left.

Transmission did not change much, neither did the phase. However, the return loss and isolations improved to approximately 22dB down.
The ‘Export to HFSS’ option in Ansoft Designer was used to create the HFSS model seen in Figure 12. This model, when simulated, has major problems. Figure 13 shows the power efficiency of this model – as can be seen, over half of power over the entire 10-12GHz bandwidth is being lost somewhere.

From the simulated S-Parameters we see that the transmission is no longer 50:50 and that the reflections and isolations have risen.

The phase difference plot shows that the phase difference is approximately correct, but has worsened from the Designer simulation.
Ideal values were obtained from the paper: \textit{Broadband Printed Circuit 0°/180° Couplers and High Power Inphase Power Dividers}; IEEE Transaction on Microwave Theory and Techniques. Designer simulations were presented for a 50 ohm line impedance.

The results are as expected. Over the entire desired bandwidth of 10-12GHz, there is equal power division between ports two and three and a 180° phase difference between ports two and three when power is applied to port four.
Component Progress - Knöchel Hybrid

Designer (Initial 120 mil)

Figure 24: Schematic View of Designer Hybrid

Figure 25: Layout View of Designer Hybrid

Figure 26: S-Parameters of 180° Hybrid Coupler

Figure 27: Output Phase Difference for 180° Hybrid Coupler

<table>
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- The tune feature was used to tune the lengths and widths of the transmission lines – the values seen in the table to represent the widths of the different transmission lines based on the ideal impedances that will be tuned.
- With the addition of non-ideal corners, junctions and bends, the parasitic impedances of the lines have been changed, resulting in a shifted band of operation and relatively poor performance when compared to the ideal model.
Component Progress - Knöchel Hybrid

Designer (Second Cut 120 mil)

The tune feature was used to tune the lengths and widths of the transmission lines – the values seen in the table to the left were found to give the best performance.

- Although not as perfect as the ideal results, the simulated results are quite good relative to the initial trial – we have approximately equal power division between ports 2 and 3 and there is a normalized phase difference error of approximately +/- 0.4° between ports 2 and 3.

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The original Schiffman phase shifter design performed in Week 2 was scrapped completely and had to be redesign. There was a misunderstanding of the purpose of the phase shifter and how it functions within the entire circuit. After a meeting with Michael Enders at Anaren on 1/9/2009, the Schiffman phase shifter was re-designed from scratch.

Ideal

Figure 32: Schematic View of Ideal Schiffman Phase Shifter

The ideal model was developed using Schiffman’s original paper published in the IEEE Microwave Techniques Journal.


- The results are: Over 10 – 12GHz, the phase difference between the reference line and the Shiffman phase shifter is 45° flat, with a return loss of -34.88dB at best between Markers 1 and 3.
- From the ideal model, even and odd mode impedances are extracted to be used in the real model.

$Z_{oe} = 66\Omega$ and $Z_{oo} = 42\Omega$
Because of the nature of the Shiffman phase shifter, the design cannot be modeled in Designer and then verified in HFSS. Attempts to model the phase shifter in Designer first have lead to failures. After speaking with Michael Enders at Anaren, he suggested from his experience that the design be completed in HFSS, and Designer used to obtain starting values.

As a sanity check, the ideal model was converted to a physical model with the chosen substrate of 121.5mil.

From the figures above, it can be seen that the substrate does have some effect on the results. The phase difference is a bit flatter, and the return loss becomes a bit worse, with best case return loss of $-31.07$ dB. The results above are the best possible results, and the model will be exported to HFSS and modified.
The Schiffman phase shifter is designed primarily in HFSS. The ideal design does not take into account the thin strip of copper connecting the two coupled lines, and is nearly impossible to model in Designer. Also, port locations will become significant in the HFSS design. The design is still in progress, and results so far are unusable.

Figure 39: 3D view of the Schiffman phase shifter, with chamfered edges.
Ideal

Figure 40: Circuit layout of the ideal System A.

Figure 41: Transmission from Port 1 to all outputs.

Figure 42: Phase difference between output ports when Port 1 is input.
The above results are the best possible using all ideal components.

- The phase difference at the outputs when Port 1 is excited is 45° ±0.1°.
- The best possible return loss is -23.18dB. All four outputs have about -6dB ±0.3dB amplitude, meaning power is being split relatively equal between the four outputs, with each getting a quarter of the total input power.
Simulation results show that there is a large amount of reflection at S55 and S66, these require the 180 degree Hybrid Coupler to be readjusted. S78 also needs improved isolation, these will be re-evaluated after a new revision of the Hybrid Coupler is implemented.