Ironwood ELECTRONICS

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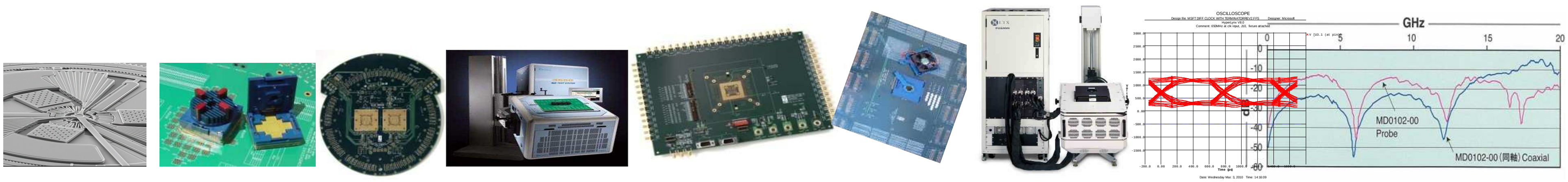


# Design of experiments using spring probe parameters for optimized socket bandwidth


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# Agenda

- Problem definition
- Seven principles of interconnect design for optimized insertion loss
- Key input variables and output variable
- Design of experiments
- Experimental results
- Analysis of results
- Optimized insertion loss model
- Confirmation run to verify model
- Conclusions

# Problem Definition

- There is no established relation between critical spring probe parameters and their influence on signal integrity.
- There is no baseline reference and a starting point for spring probe design which is an everyday need due to emerging new application requirements.

# Seven principles of interconnect design for optimized insertion loss

Eric Bogatin says:

1. Match characteristic impedance of socket to 50 Ohms
2. Keep the impedance constant through socket
3. Optimize (minimize) pad stack up capacitance
4. Keep socket short
5. Dielectric loss of socket not critical
6. Conductor loss of socket not critical
7. Contact resistance of socket not critical

# Key input variables and output variable

- Input variable
  - Spring pin length (1mm to 4mm)
  - Spring pin diameter (0.25mm to 0.35mm)
  - Ground pattern
    - C1 (G-S-G)
    - C2 $\begin{pmatrix} & G & \\ G- & S & -G \\ & G & \end{pmatrix}$
- Output variable
  - Bandwidth (GHz) at -1dB Insertion loss

# Design of experiments

| | |
|---|---|
| **Study Type** | **Factorial** |
| **Runs** | **8** |
| **Initial Design** | **2 Level Factorial** |
| **Blocks** | **No Blocks** |
| **Center Points** | **0** |
| **Design Model** | **3FI** |

| Name | Units | Type | Low Actual | High Actual | Low Coded | High Coded | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| Diameter | mm | Numeric | 0.25 | 0.35 | -1 | 1 | 0.3 | 0.05 |
| Length | mm | Numeric | 1 | 4 | -1 | 1 | 2.5 | 1.5 |
| Ground | | Categoric | C1 | C2 | | | Levels: | 2 |

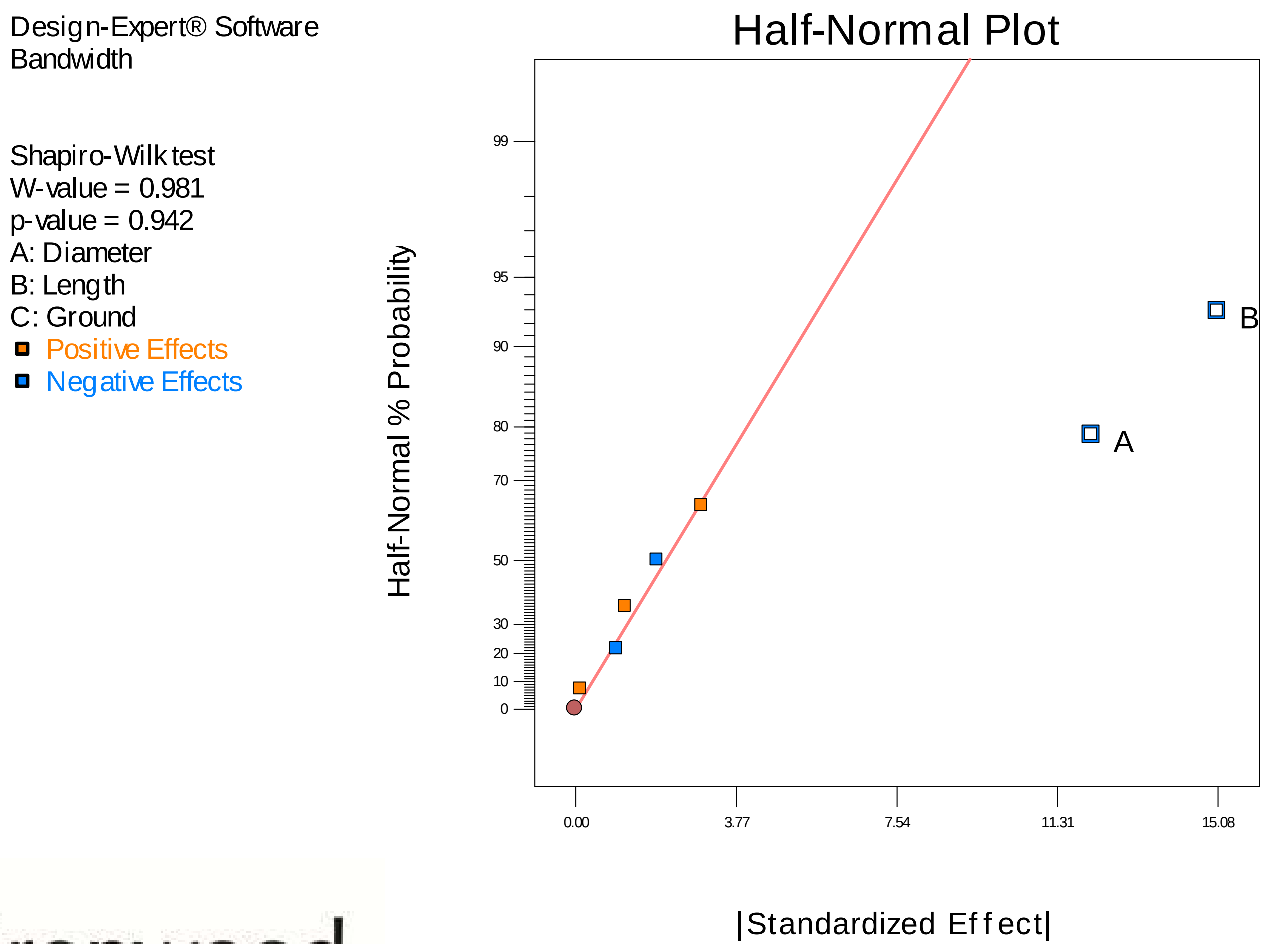
# Design of experiments

| Standard Order | Run Order | Block | Diameter (mm) | Length (mm) | Ground pattern | Bandwidth (GHz) |
|---|---|---|---|---|---|---|
| 7 | 1 | Block 1 | 0.25 | 4 | C2 | |
| 4 | 2 | Block 1 | 0.35 | 4 | C1 | |
| 3 | 3 | Block 1 | 0.25 | 4 | C1 | |
| 8 | 4 | Block 1 | 0.35 | 4 | C2 | |
| 5 | 5 | Block 1 | 0.25 | 1 | C2 | |
| 6 | 6 | Block 1 | 0.35 | 1 | C2 | |
| 2 | 7 | Block 1 | 0.35 | 1 | C1 | |
| 1 | 8 | Block 1 | 0.25 | 1 | C1 | |

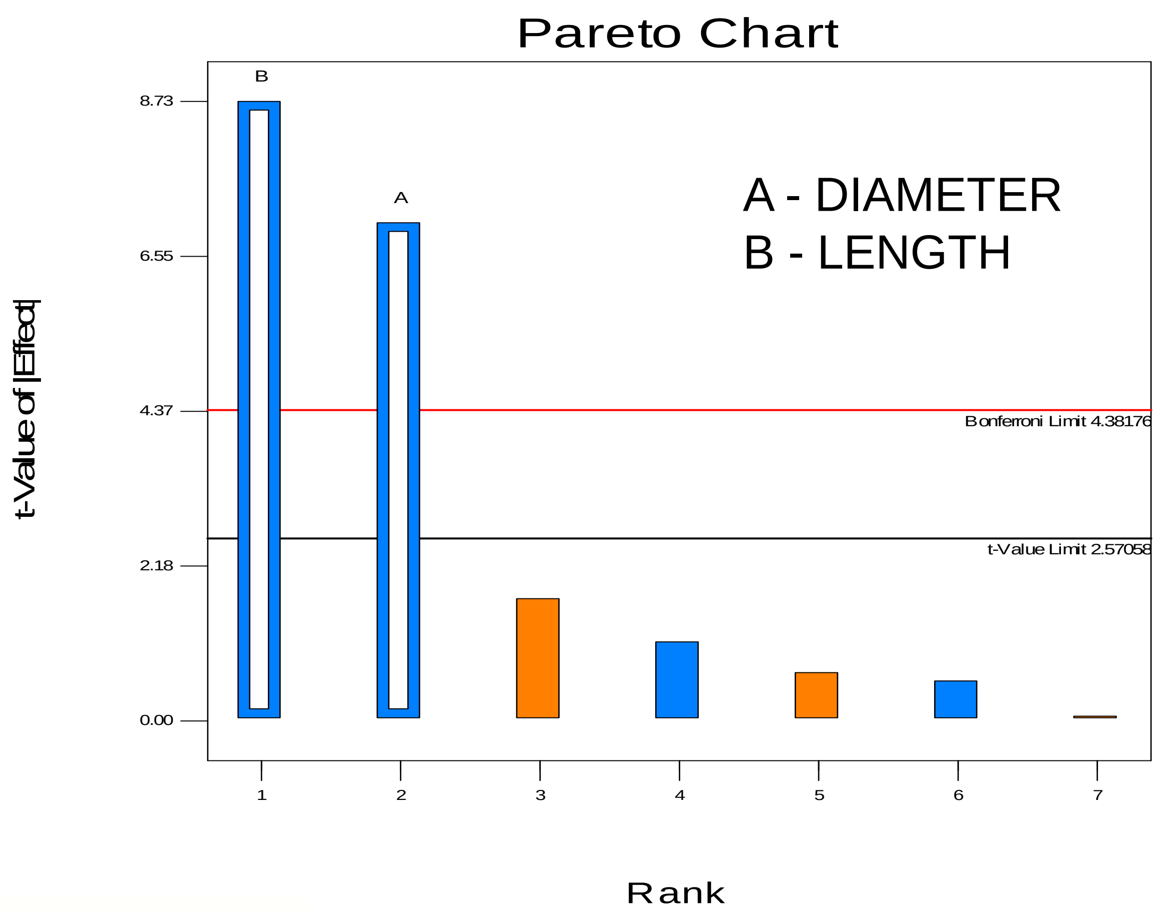
# Experimental results

| Standard Order | Run Order | Block | Diameter (mm) | Length (mm) | Ground pattern | Bandwidth (GHz) |
|---|---|---|---|---|---|---|
| 7 | 1 | Block 1 | 0.25 | 4 | C2 | 14 |
| 4 | 2 | Block 1 | 0.35 | 4 | C1 | 5.6 |
| 3 | 3 | Block 1 | 0.25 | 4 | C1 | 13.9 |
| 8 | 4 | Block 1 | 0.35 | 4 | C2 | 4 |
| 5 | 5 | Block 1 | 0.25 | 1 | C2 | 31 |
| 6 | 6 | Block 1 | 0.35 | 1 | C2 | 14.8 |
| 2 | 7 | Block 1 | 0.35 | 1 | C1 | 19 |
| 1 | 8 | Block 1 | 0.25 | 1 | C1 | 33 |

# Analysis of results



# Analysis of results



# Analysis of results

| | | | | | | |
|---|---|---|---|---|---|---|
| Response | Bandwidth | | | | | |
| ANOVA for selected factorial model | | | | | | |
| | | | | | | |
| Source | Sum of Squares | df | Mean Square | F Value | p-value, Prob > F | |
| Model | 748.5425 | 2 | 374.27125 | 62.78402181 | 0.0003 | significant |
| A-Diameter | 294.03125 | 1 | 294.03125 | 49.3237576 | 0.0009 | |
| B-Length | 454.51125 | 1 | 454.51125 | 76.24428601 | 0.0003 | |
| Residual | 29.80625 | 5 | 5.96125 | | | |
| Cor Total | 778.34875 | 7 | | | | |

The Model F-value of 62.78 implies the model is significant. There is only a 0.03% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant.
In this case A, B are significant model terms.
Values greater than 0.1000 indicate the model terms are not significant.

| | | | | |
|---|---|---|---|---|
| Std. Dev. | 2.4415671 | | R-Squared | 0.961705791 |
| Mean | 16.9125 | | Adj R-Squared | 0.946388107 |

# Optimized insertion loss model

***Bandwidth = +65.85000***
***-121.25000 * Diameter***
***-5.02500 * Length***

***Model valid within the following limits***

***Diameter: 0.25mm to 0.35mm***
***Length: 1mm to 4mm***

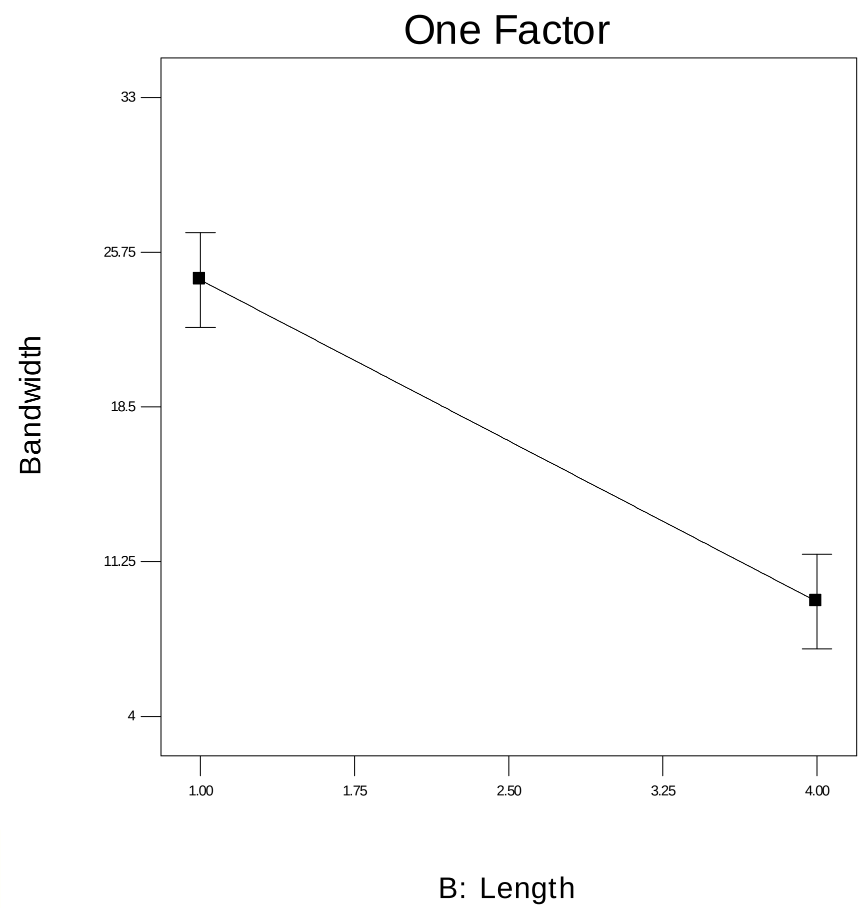
# Analysis of results

Design-Expert® Software

Bandwidth

X1 = B: Length

Actual Factors
A: Diameter = 0.30
C: Ground = C1



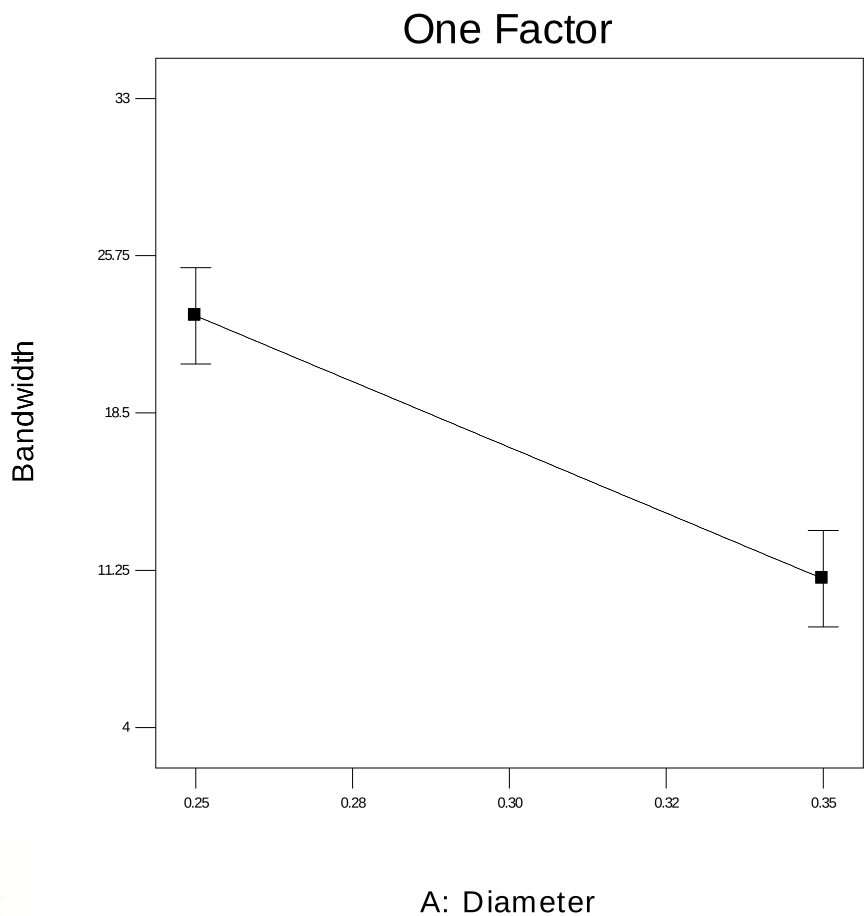
# Analysis of results

Design-Expert® Software

Bandwidth

X1 = A: Diameter

Actual Factors
B: Length = 2.50
C: Ground = C1



# Optimization of results

## To maximize Bandwidth:

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 Solutions found | | | | | | |
| Number | Diameter | Length | Ground* | Bandwidth | Desirability | |
| **1** | **0.25** | **1** | **C2** | **30.51248841** | **0.914223738** | **Selected** |
| 2 | 0.25 | 1 | C1 | 30.51248775 | 0.914223716 | |
| 3 | 0.25 | 1.03 | C2 | 30.36742561 | 0.909221573 | |
| 4 | 0.25 | 1.03 | C1 | 30.34746318 | 0.908533213 | |
| 5 | 0.25 | 1.18 | C2 | 29.6219383 | 0.883515114 | |
| | | | | | | |
| *Has no effect on optimization results. | | | | | | |

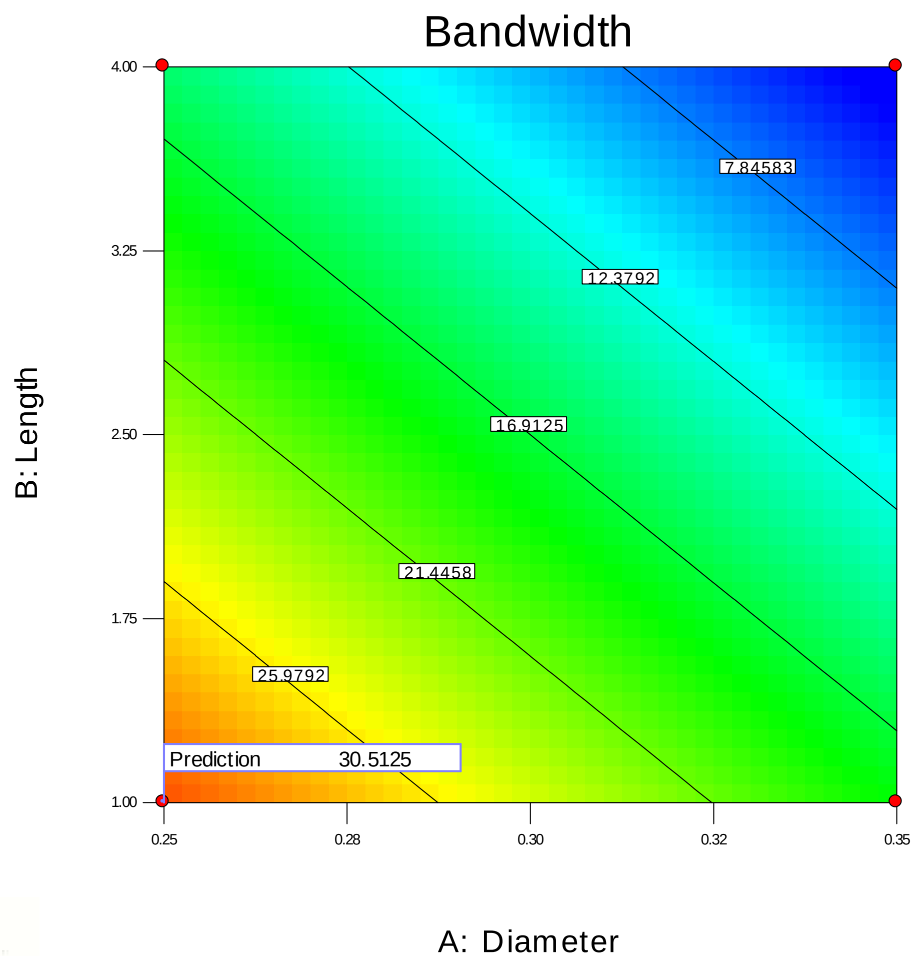
# Optimization of results

Design-Expert® Software

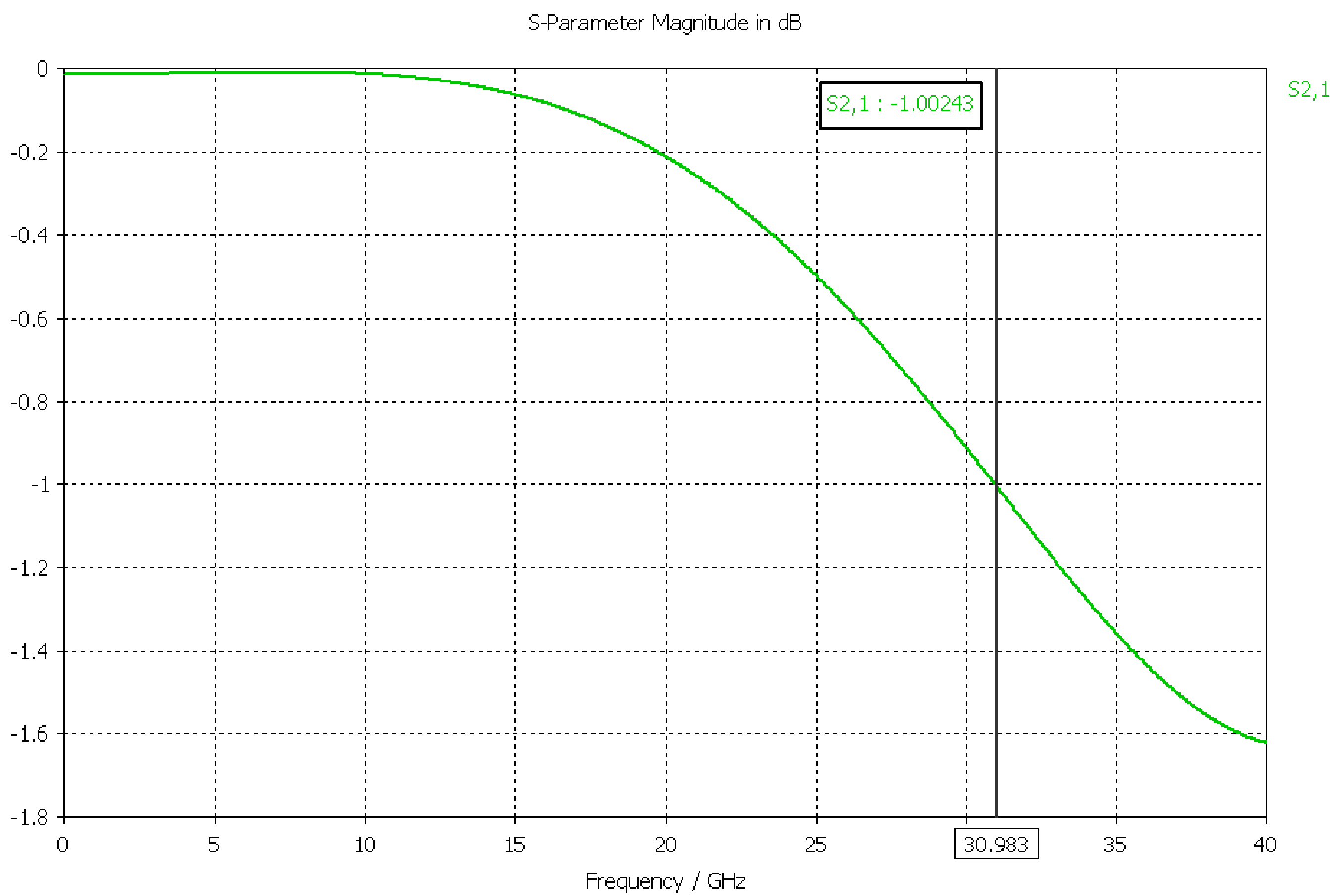
Bandwidth
● Design Points
33
4

X1 = A: Diameter
X2 = B: Length

Actual Factor
C: Ground = C2



# Confirmation run to verify model

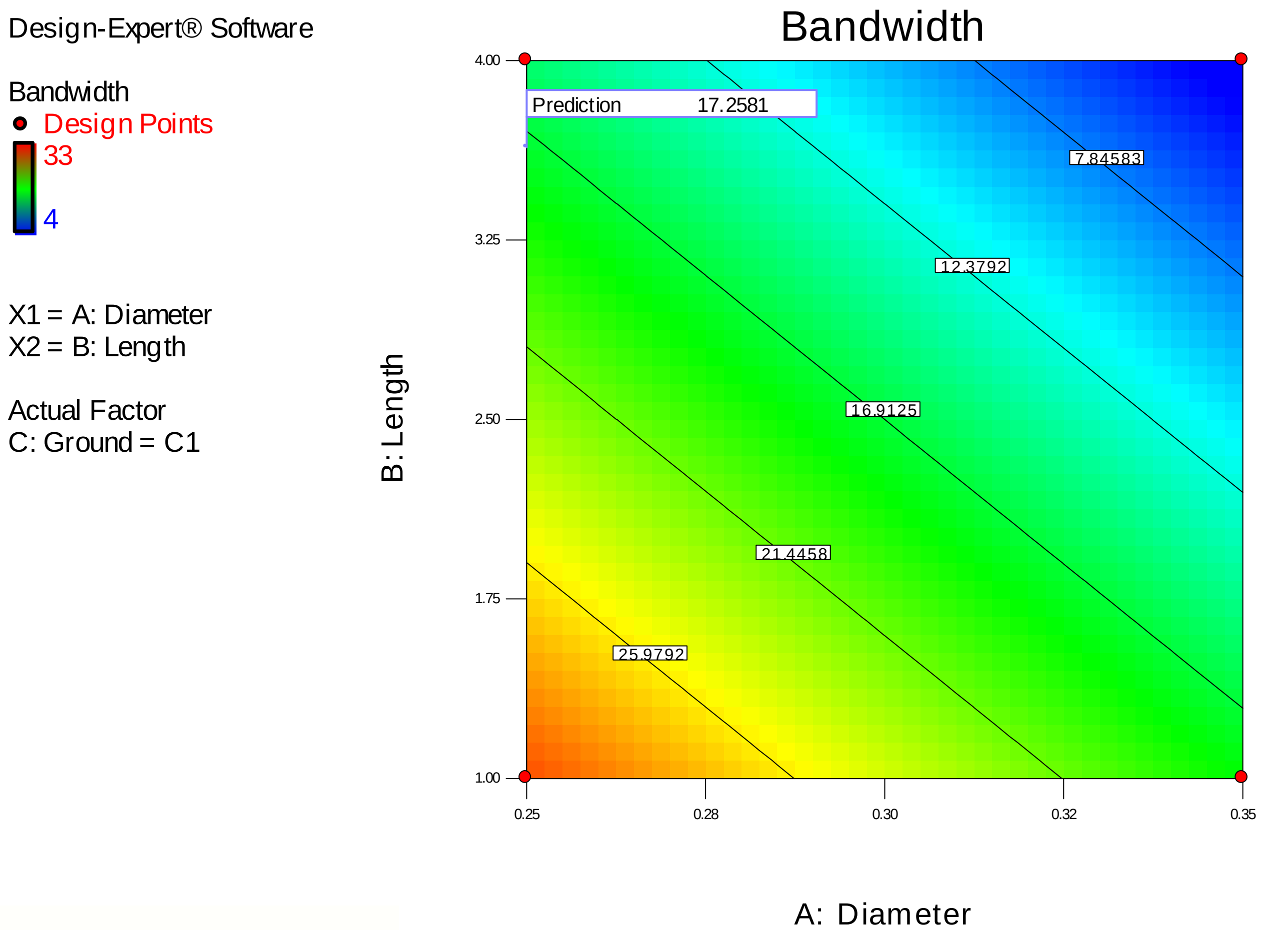


# Optimization of results

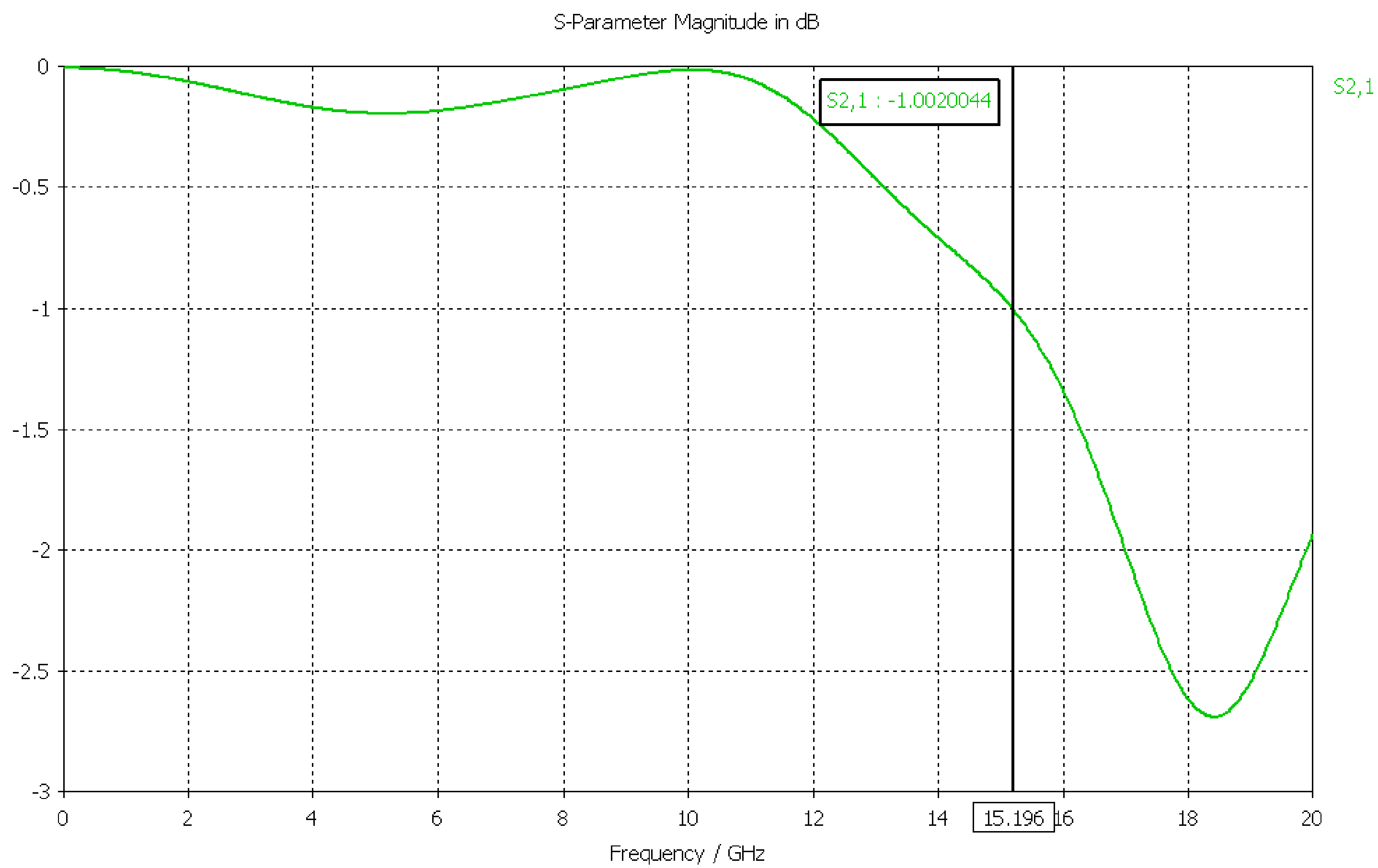
## To maximize Bandwidth and Length:

| 9 Solutions found | | | | | | |
|---|---|---|---|---|---|---|
| Number | Diameter | Length | Ground* | Bandwidth | Desirability | |
| **1** | **0.25** | **3.64** | **C1** | **17.25805757** | **0.63400549** | **Selected** |
| 2 | 0.25 | 3.64 | C2 | 17.25776855 | 0.634005466 | |
| 3 | 0.25 | 3.65 | C2 | 17.19991881 | 0.63399974 | |
| 4 | 0.25 | 3.62 | C1 | 17.34746791 | 0.633989528 | |
| 5 | 0.25 | 3.66 | C1 | 17.13879092 | 0.633979894 | |
| 6 | 0.25 | 3.66 | C2 | 17.13074513 | 0.633977077 | |
| 7 | 0.25 | 3.61 | C1 | 17.41399089 | 0.633960073 | |
| 8 | 0.25 | 3.75 | C2 | 16.70416448 | 0.633454994 | |
| 9 | 0.25 | 3.1 | C2 | 19.96789457 | 0.620599198 | |
| | | | | | | |
| *Has no effect on optimization results. | | | | | | |

# Optimization of results



# Confirmation run to verify model



# Conclusions

- Key input variables of spring probe and output variable are identified
- A set of experiments were designed using Design Expert Statistical Software
- Experiments were conducted and results were analyzed using Design Expert Statistical Software
- A statistical model was developed that relates spring probe parameters to optimized signal bandwidth.
- A confirmation experiment was performed to verify the validity of model.