

# Loudspeaker Response Optimization with the aid of Impulse Response

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# Impulse

**Physics**

**Psychology**

**Economics**



# Impulse

**Physics**



# Impulse

## Physics

$$\mathbf{J} = \int_{t_1}^{t_2} \mathbf{F} dt$$



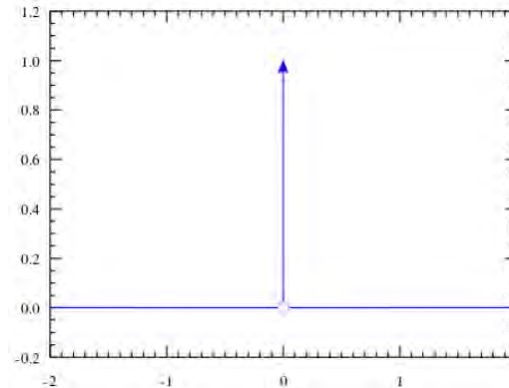
## Analytically

Dirac delta

$$\delta(x) = \begin{cases} +\infty, & x = 0 \\ 0, & x \neq 0 \end{cases}$$

also

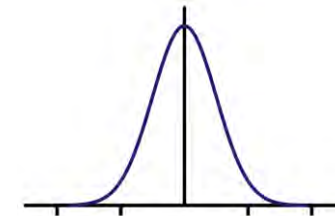
$$\int_{-\infty}^{\infty} \delta(x) dx = 1$$



## “Practically”

Gaussian

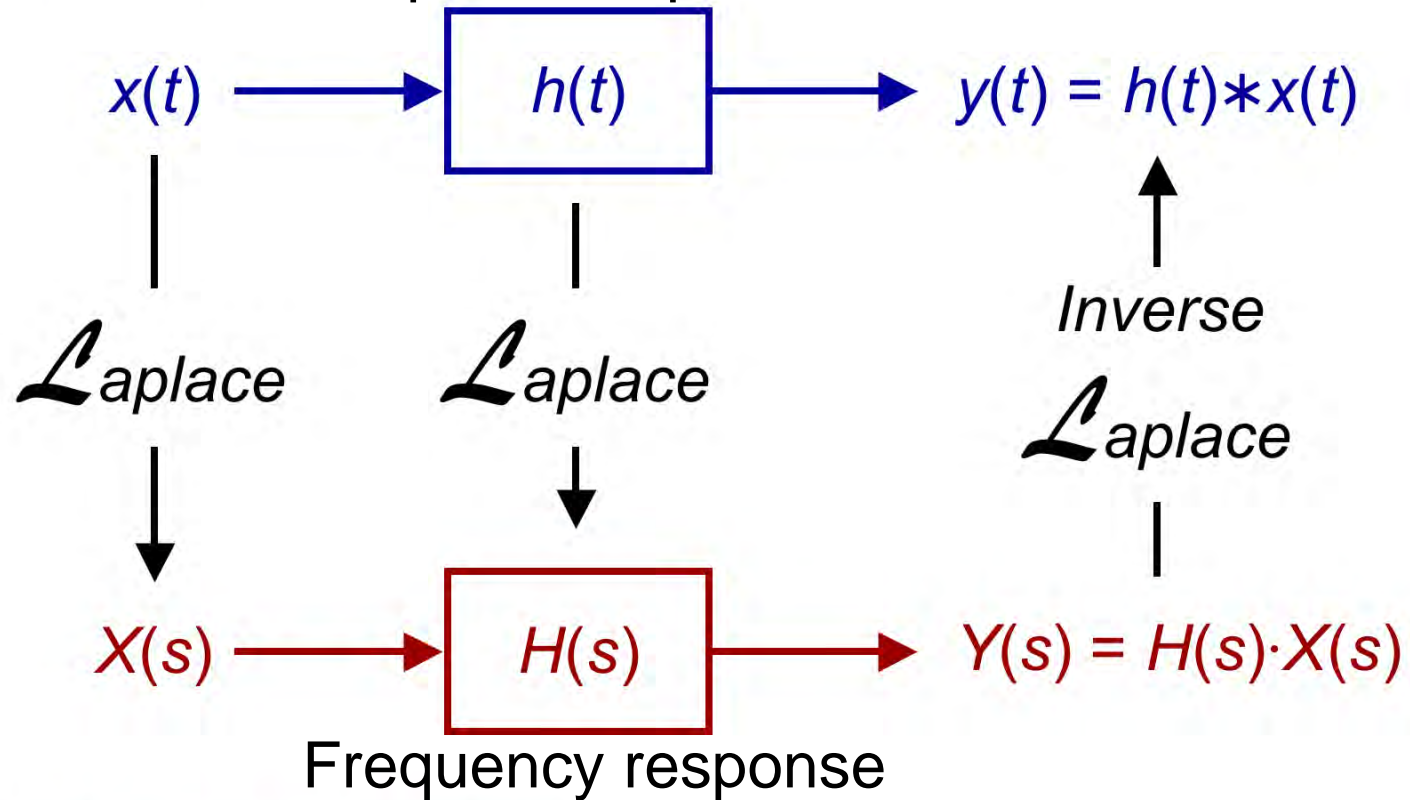
$$g(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{t^2}{2\sigma^2}}$$



# Impulse

Time domain

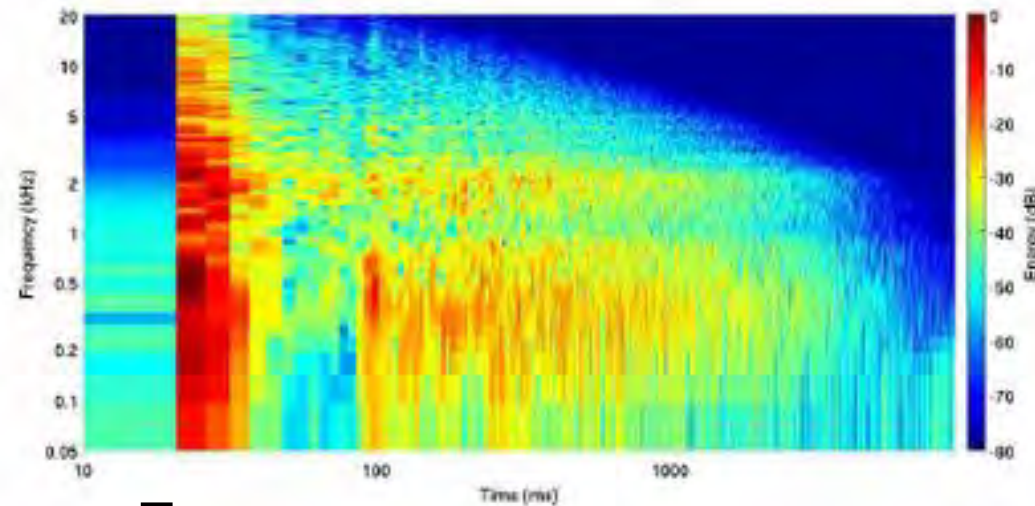
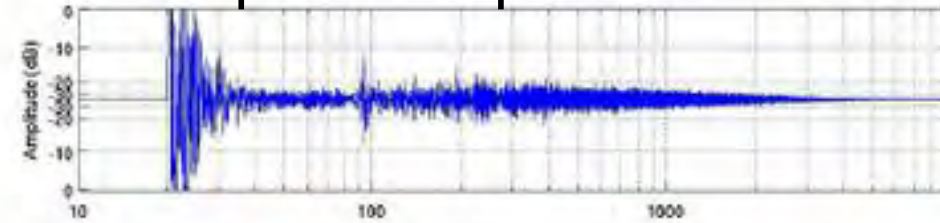
Impulse response



Frequency domain

# Impulse

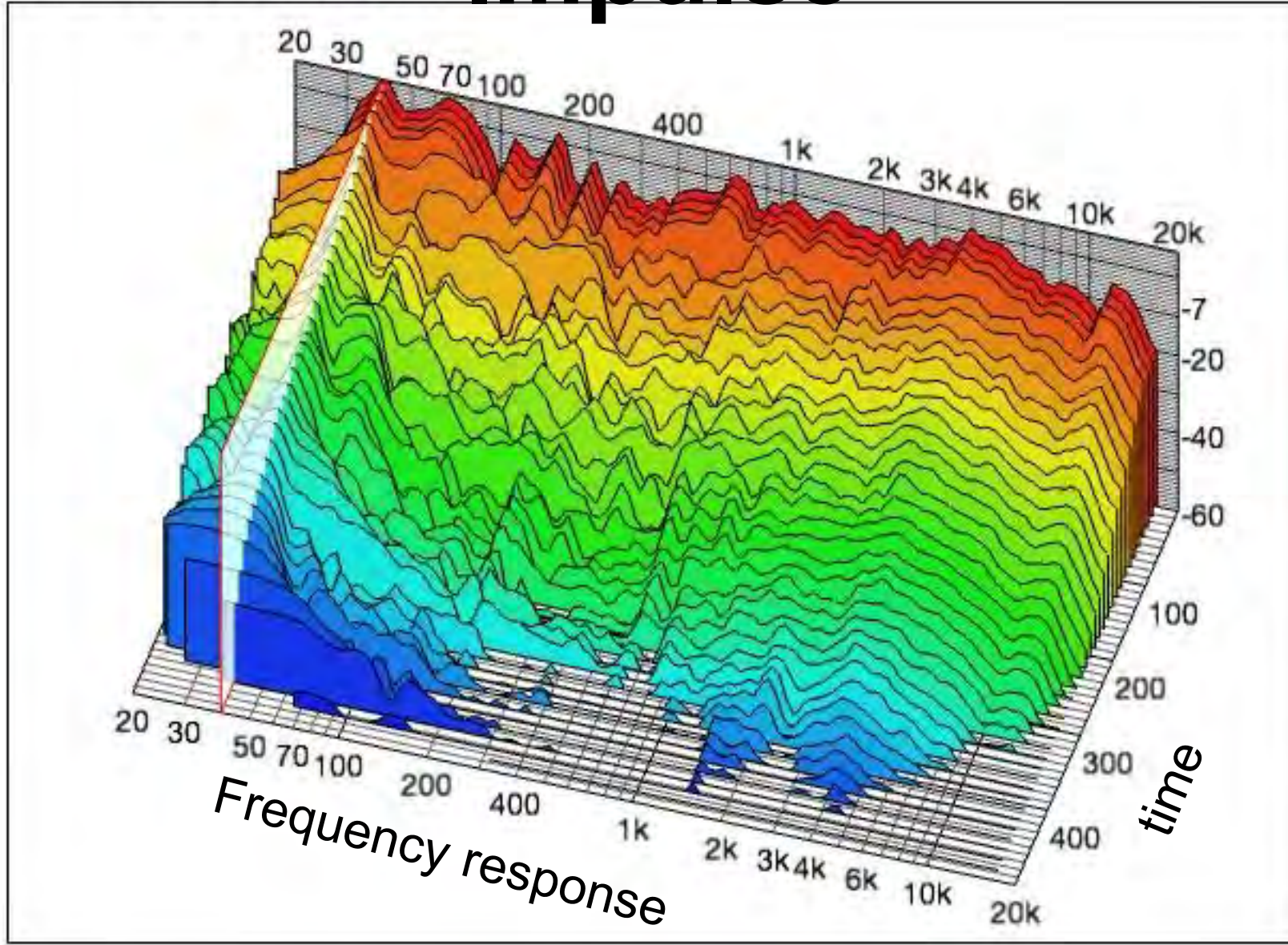
Impulse response

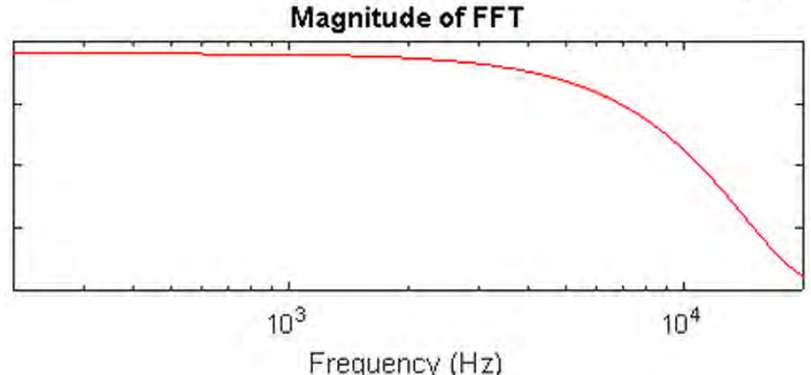
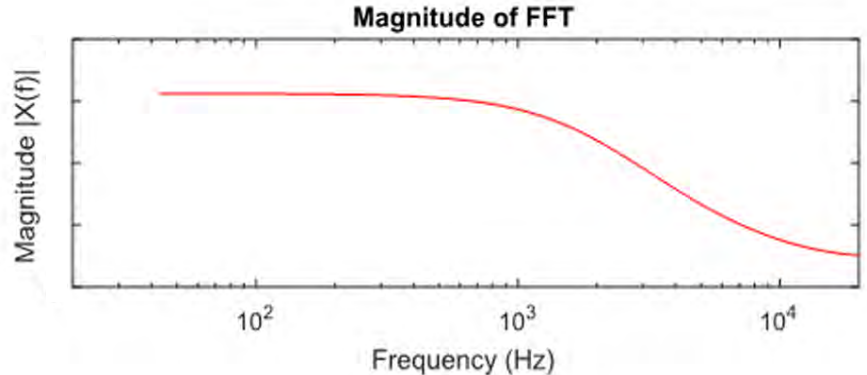
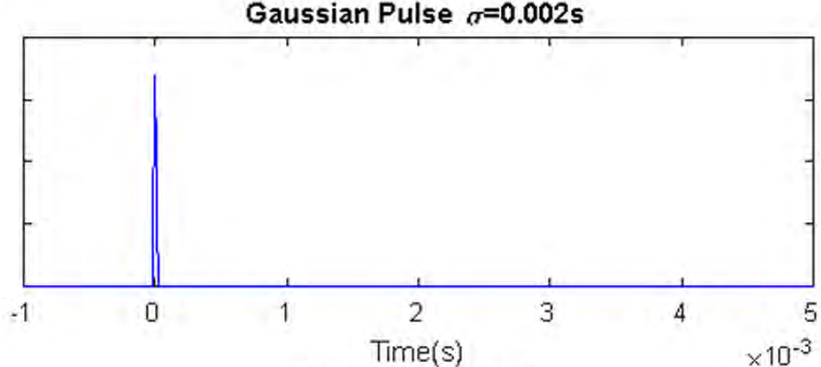
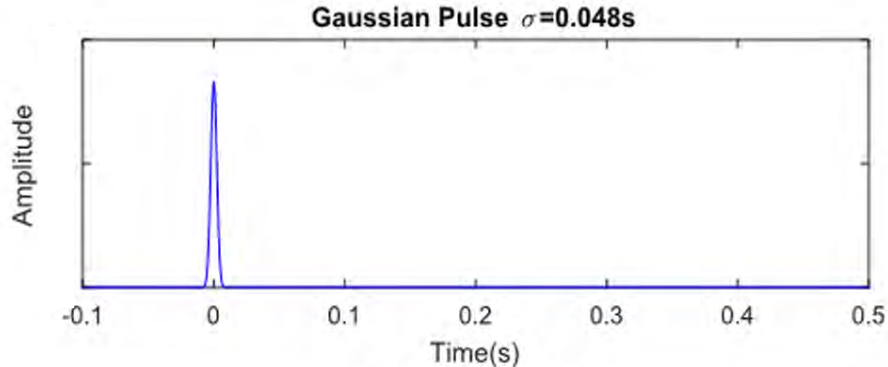


Frequency response



# Impulse







# Loudspeakers

**Electric Signal**



**Mechanical  
Displacement**



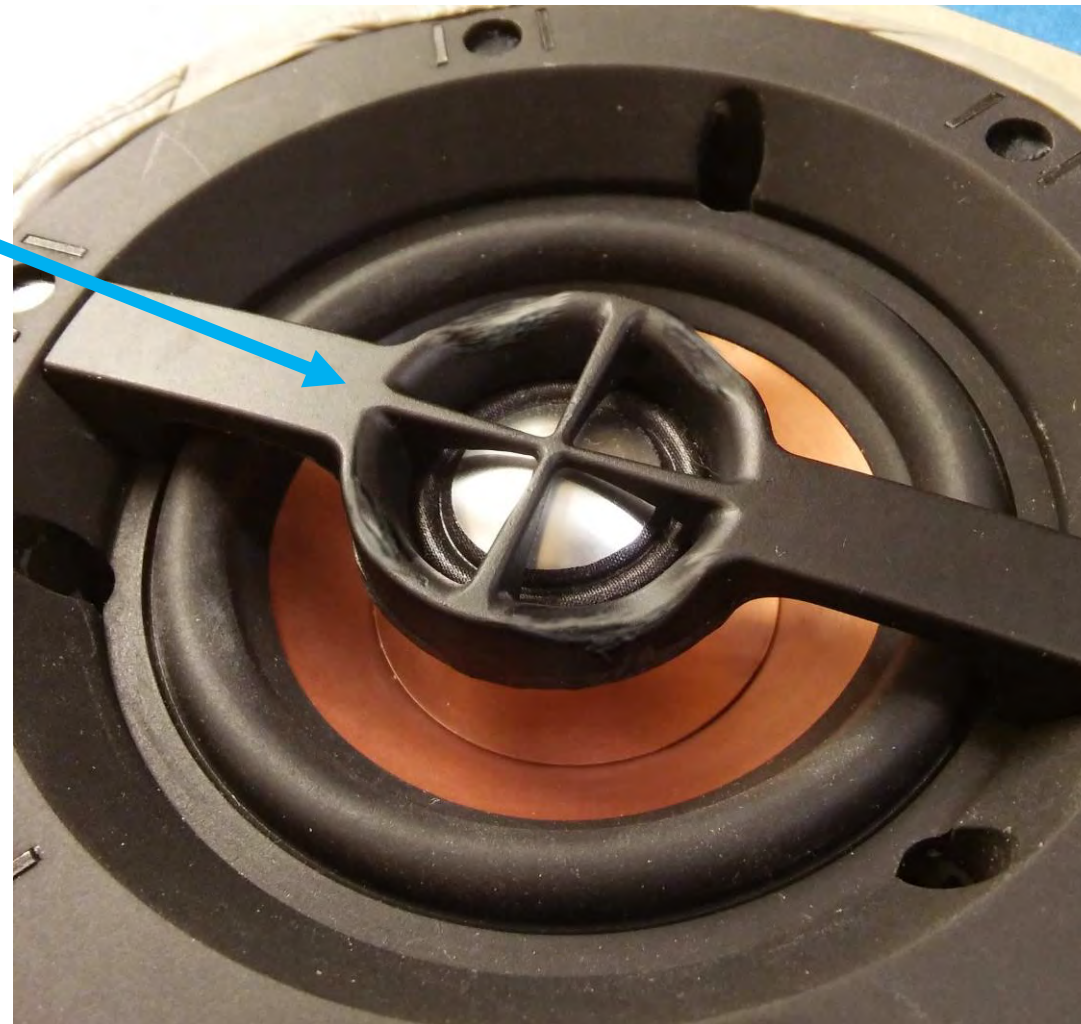
**Pressure  
Wave**



# Loudspeakers

**Tweeter**

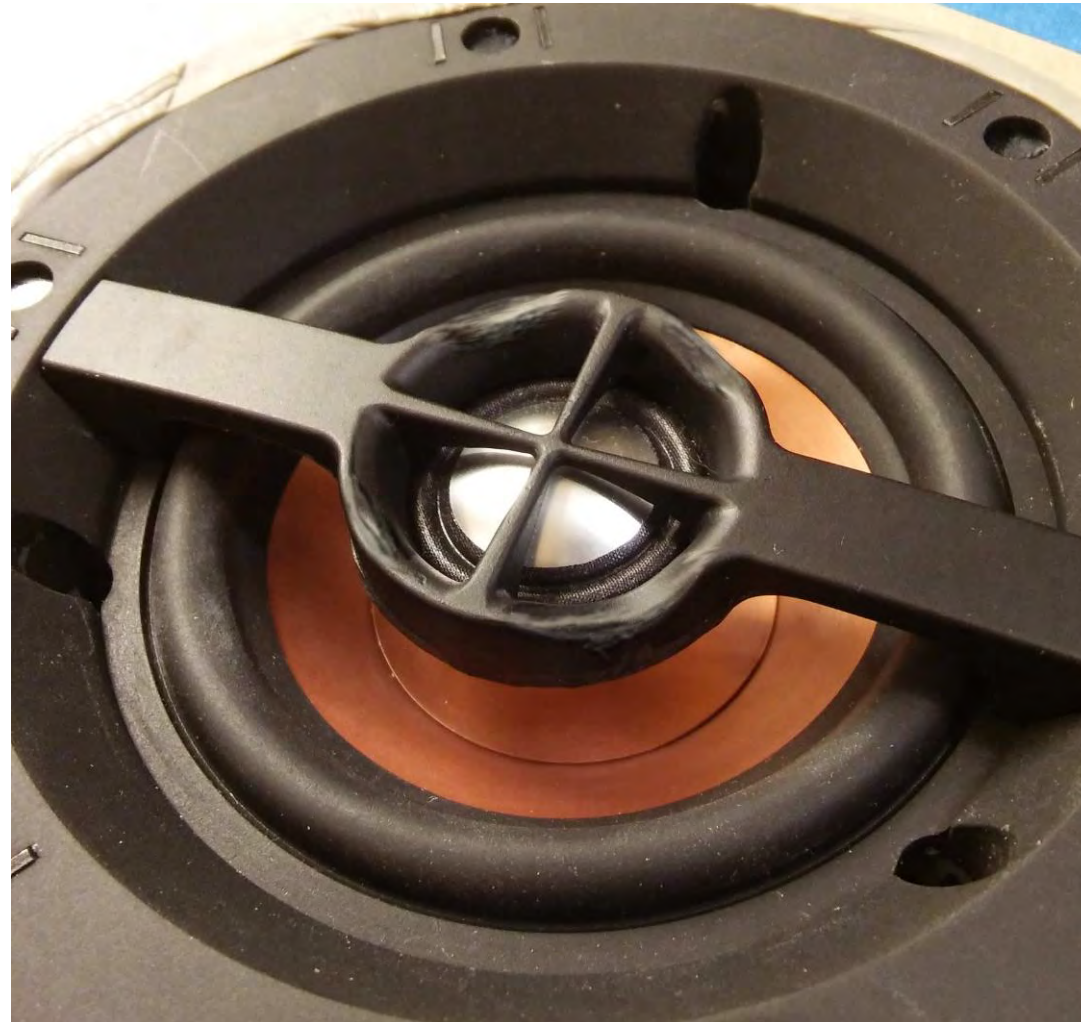
**2kHz-20kHz  
operating range**



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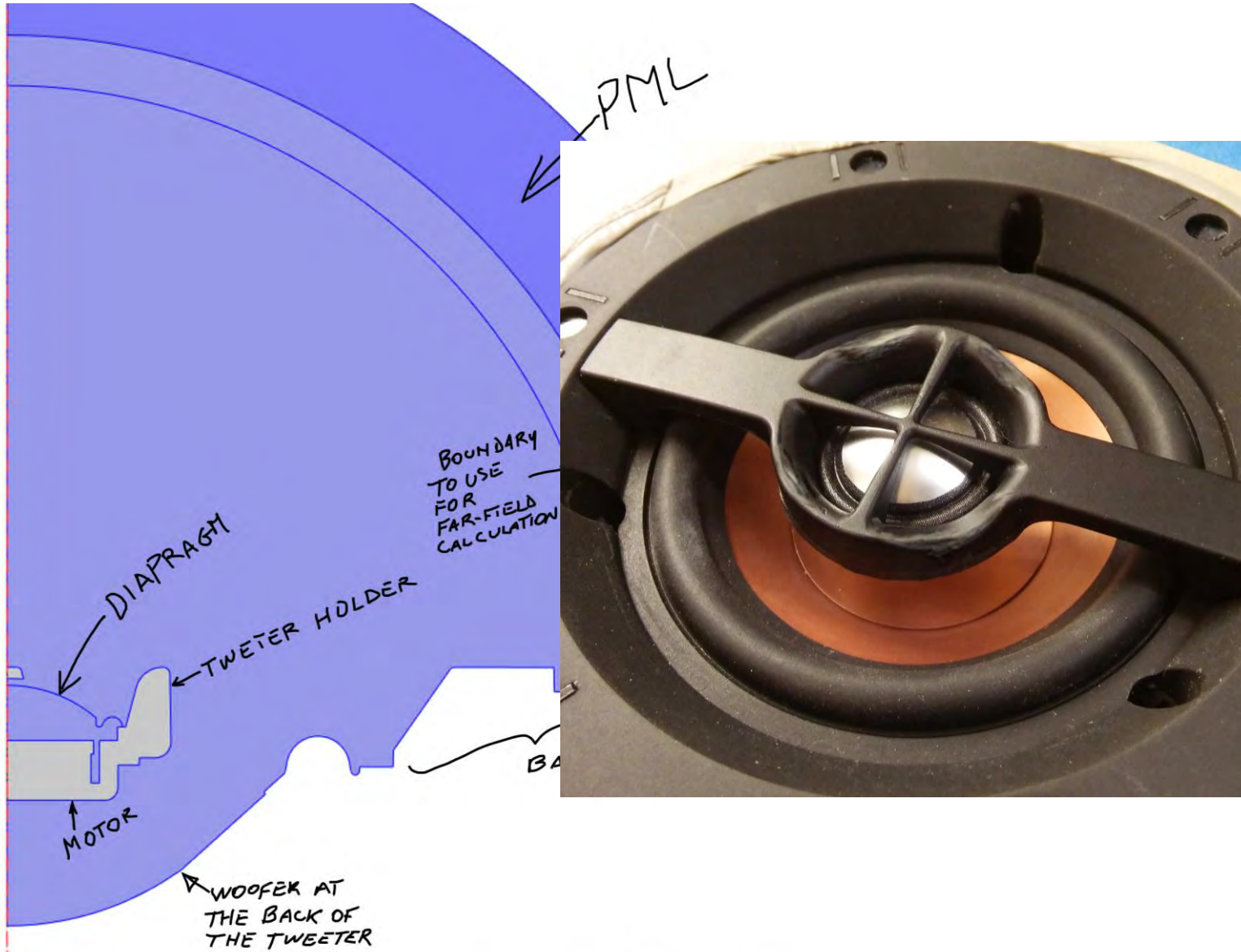
# Loudspeakers

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# Loudspeakers



loudspeaker\_Tweeter\_transi

The screenshot displays the COMSOL Multiphysics software interface. The top menu bar includes File, Home, Definitions, Geometry, Materials, Physics, Mesh, Study, Results, and Developer. The Model Builder on the left shows a tree view for the model 'loudspeaker\_Tweeter\_transient\_FFT\_4 adding...'. The Settings panel on the right is open to the Parameters section, displaying a table of parameters.

Name	Expression	Value	Description
f0	20000[Hz]	20000 Hz	Study frequency
T0	1/f0	5E-5 s	Period
c0	343[m/s]	343 m/s	Speed of sound in air
rho0	1.2[kg/m^3]	1.2 kg/m <sup>3</sup>	Density of air
M_MD	33.4[g]	0.0334 kg	Moving mass (voice coil and..
C_MS	1.18e-3[m/N]	0.00118 s <sup>2</sup> /kg	Suspension compliance
R_MS	1.85[N*s/m]	1.85 N-s/m	Suspension mechanical losses
BL	11.4[T*m]	11.4 Wb/m	Force factor, flux density (B) ti...
R_E	7[ohm]	7 Ω	Voice coil resistance
L_E	6.89[mH]	0.00689 H	Voice coil inductance (consta...
...	...	...	...



Model Builder

- loudspeaker\_Tweeter\_transient\_FFT\_
- Global Definitions
  - Parameters
  - Materials
- Component 1 (comp1)
  - Definitions
    - Analytic 1 (Vin)
    - Domain Point Probe 1
    - Domain Point Probe 2
    - Domain Point Probe 3
    - Domain Point Probe 4
    - Domain Point Probe 5
    - Domain Point Probe 6
    - Domain Point Probe 7
    - Domain Point Probe 8
    - Integration 1 (intop)
    - Speaker
    - Internal wall
  - Boundary System 1 (sys1)
  - Perfectly Matched Layer
  - Perfectly Matched Layer
  - View 1
  - Geometry 1
  - Materials
  - Pressure Acoustics, Transient

Settings

Analytic

Plot Create Plot

Label: Analytic 1

Function name: Vin

Definition

Expression:  $1[\text{m/s}] * \exp(-\pi^2 * f_0^2 * (t - T_0)^2)$

Arguments: t

Derivatives: Automatic

Periodic Extension

Units

Arguments: s

Function: m/s

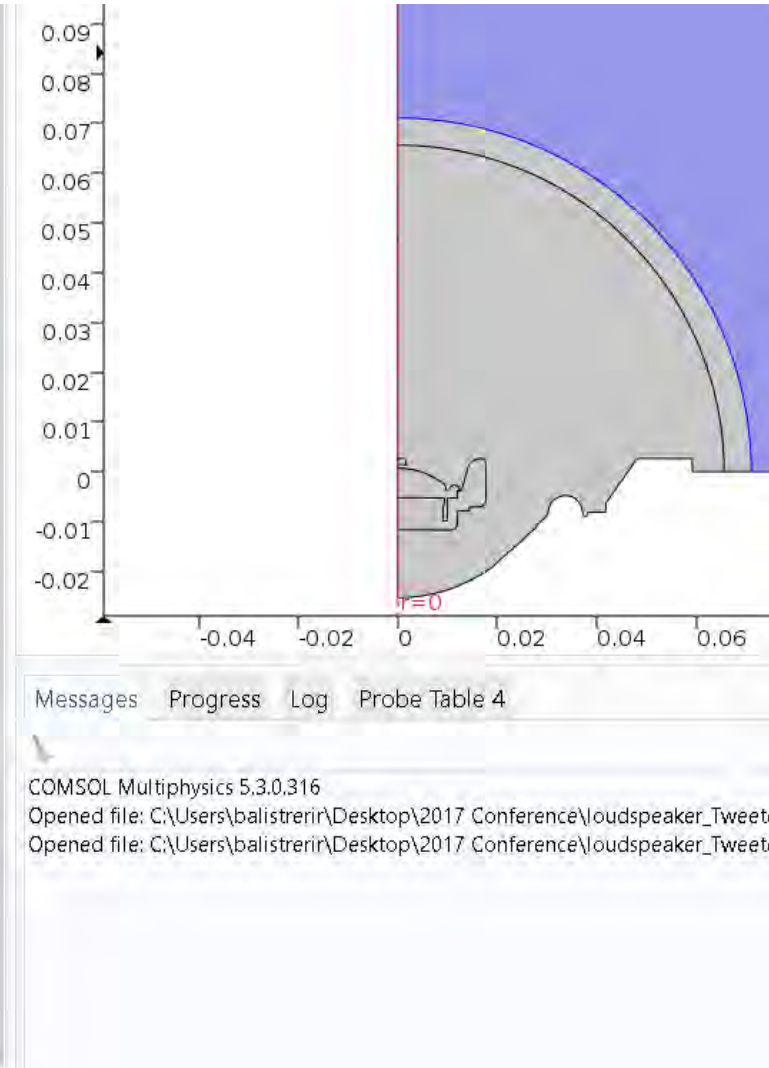
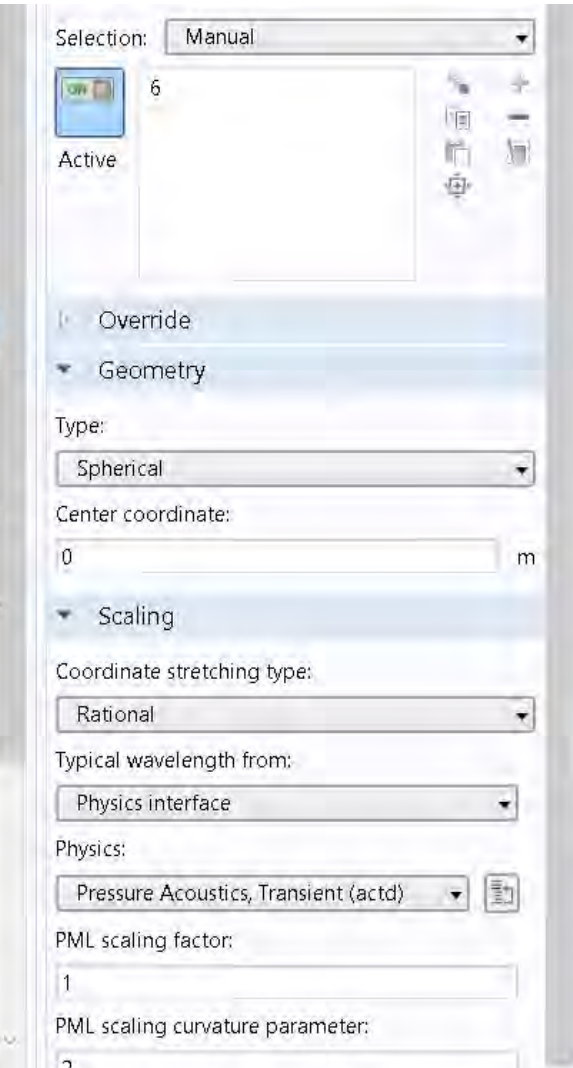
Advanced

Plot Parameters

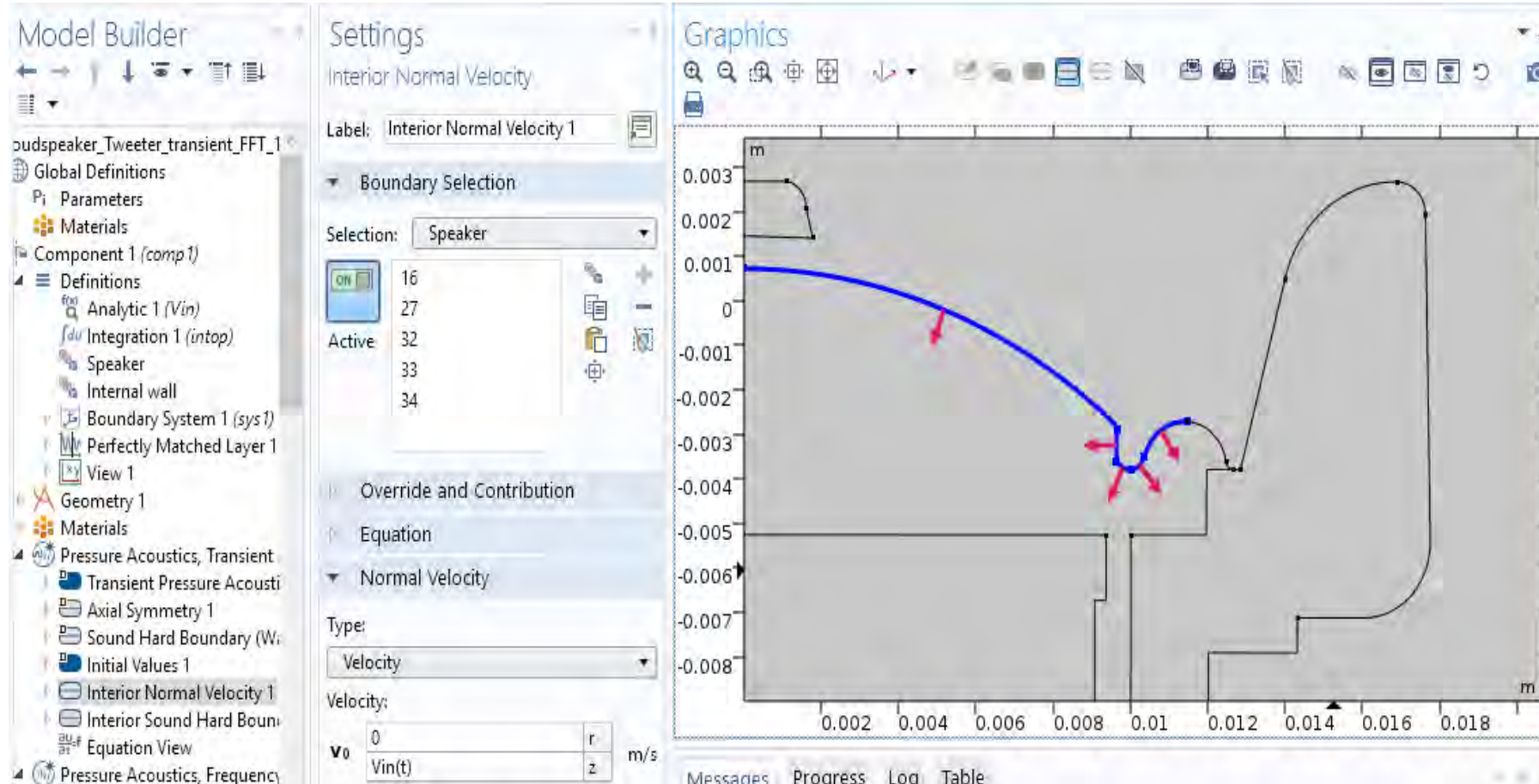
Argument	Lower limit	Upper limit
t	0	2*T0



# PML



# Diaphragm Velocity





# Meshing

loudspeaker\_Tweeter\_transient\_FFT\_3 PLA

- Global Definitions
  - Parameters
  - Materials
- Component 1 (comp1)
  - Definitions
  - Geometry 1
  - Materials
  - Pressure Acoustics, Transient (actd)
    - Transient Pressure Acoustics M
    - Axial Symmetry 1
    - Sound Hard Boundary (Wall) 1
    - Initial Values 1
    - Interior Normal Velocity 1
    - Interior Sound Hard Boundary
    - Equation View
  - Pressure Acoustics, Frequency Dom
  - Mesh 1
    - Size
      - Free Triangular 1
      - Mapped 1
        - Distribution 1
      - Boundary Layers 1
        - Boundary Layer Properties
  - Study 1 - Transient + FFT
  - Study 2 - Mapping to Frequency Dom
  - Results
    - Data Sets
    - Views
    - Derived Values
    - Tables
    - Acoustic Pressure
    - Pressure: p(t)
    - ACTD Pressure FFT
    - SPL FFT 1
    - Pressure FFT 1

Size

Build Selected Build All

Label: Size

Element Size

Calibrate for:  
General physics

Predefined Normal

Custom

Element Size Parameters

Maximum element size:  
(c0\*T0)/5 m

Minimum element size:  
(c0\*T0)/9 m

Maximum element growth rate:  
1.3

Curvature factor:  
0.3

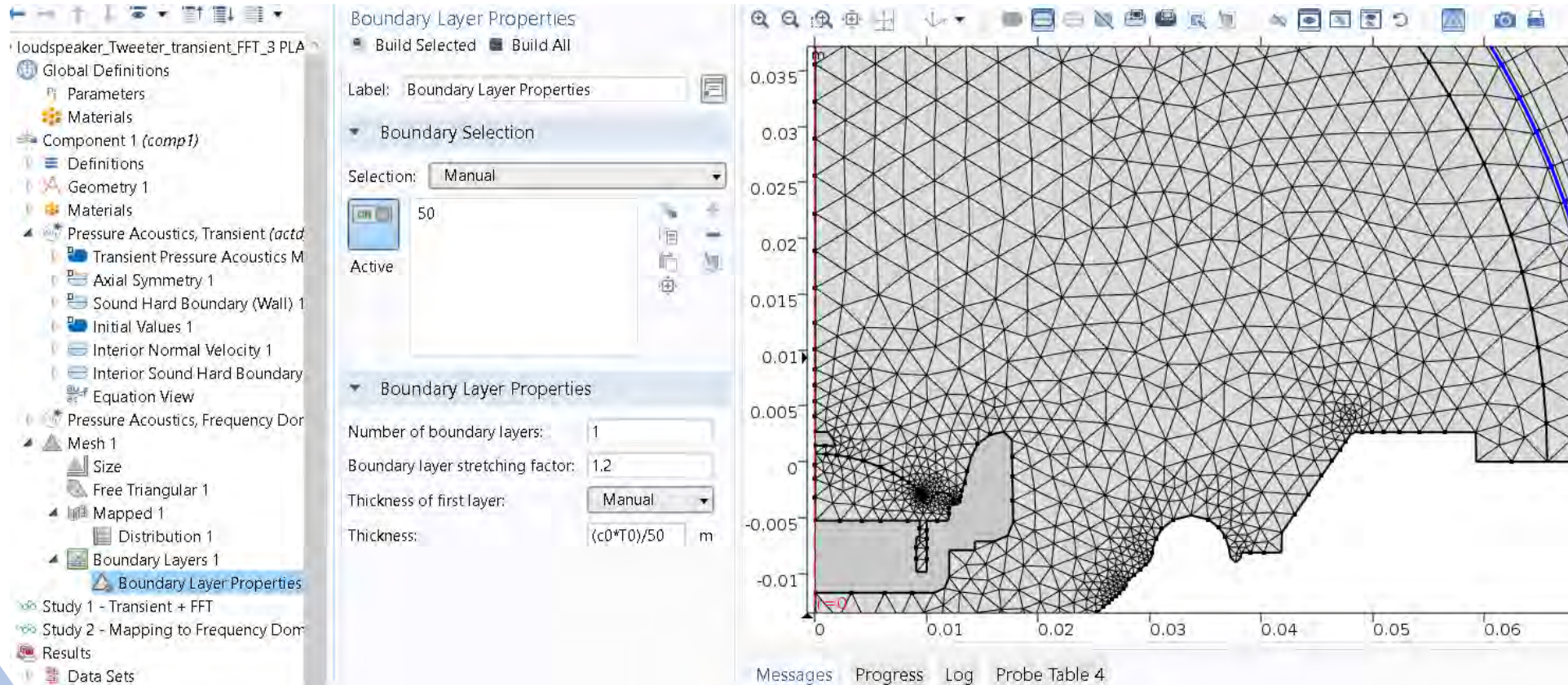
Resolution of narrow regions:  
1

Messages Progress Log Probe Table 4

COMSOL Multiphysics 5.3.0.316  
Opened file: C:\Users\balistrerir\Desktop\2017 Conference\loudspeaker\_Tweeter\_transient\_FFT\_4 adding freq simulation.mph  
Opened file: C:\Users\balistrerir\Desktop\2017 Conference\loudspeaker\_Tweeter\_transient\_FFT\_3 PLAYING WITH PML .mph

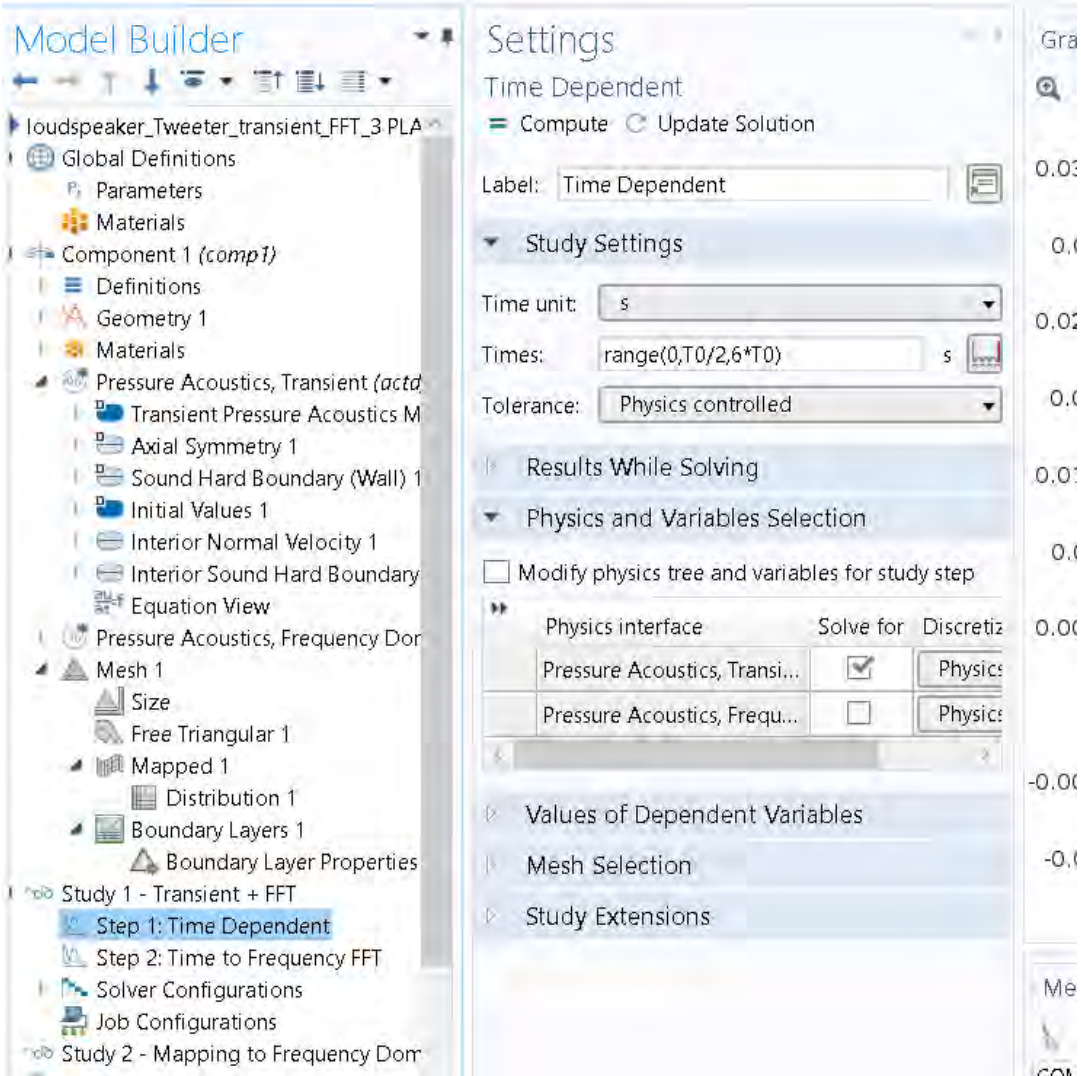


# Boundary to PLM





# Study



# Study

The screenshot displays the COMSOL Multiphysics interface with three main panels:

- Model Builder:** Shows a hierarchical tree of the model. The selected study is "Study 1 - Transient + FFT", which includes "Step 1: Time Dependent" and "Step 2: Time to Frequency FFT".
- Settings:** Configures the "Time to Frequency FFT" study. Key parameters include:
  - Label: Time to Frequency FFT
  - Input study: Study 1
  - Solution: Current
  - Use: Solution
  - Time unit: s
  - Start time: 0 s
  - End time: 500\*T0 s
  - Frequency unit: Hz
  - Maximum output frequency: f0 Hz
  - Scaling: Discrete Fourier
  - Window function: Hanning
  - Window start: 0 s
  - Window end: 1 s
  - Do not store negative frequencies for real input: checked
- Graphics:** Displays a mesh plot of the speaker geometry. The vertical axis ranges from -0.01 to 0.035, and the horizontal axis ranges from 0 to 0.01. The plot shows a dense triangular mesh.

# Frequency map

The screenshot displays the COMSOL Multiphysics interface for a simulation. On the left, the 'Definitions' tree shows a hierarchy of components: Analytic, Integration, Explicit (Speaker and Internal wall), Boundary System, Perfectly Matched Layer, View, Geometry, Materials, Pressure Acoustics (Transient and Frequency Domain), Axial Symmetry, Sound Hard Boundary, Initial Values, Far-Field Calculation, and Monopole Domain Source. The 'Monopole Domain Source' is selected at the bottom.

The central panel shows the configuration for 'Monopole Domain Source 1'. The 'Domain Selection' is set to 'All domains'. A table lists domain selections 1 through 6, with 2, 4, and 6 marked as 'not applicable'. The 'Equation' section shows the Monopole source equation: 
$$Q_m = -acprk^2/rho0*p$$

On the right, a 'Frequency map' plot shows a complex, irregular shape in a blue color. The vertical axis ranges from -0.03 to 0.05. Three yellow arrows point from the plot to the corresponding domain selection entries in the configuration panel: one points to domain 1, another to domain 3, and a third to domain 6.



# Mapping to Freq. Domain

The screenshot displays the COMSOL Multiphysics interface for a Pressure Acoustics, Frequency Domain study. The left-hand tree shows the model structure, including 'Pressure Acoustics, Frequency Domain' and 'Mapped 1'. The central 'Equation' pane shows the 'Equation form' set to 'Study controlled' and the 'Show equation assuming' set to 'Study 1 - Transient + FFT, Time Dependent'. The governing equation is shown as:

$$\nabla \cdot \left( -\frac{1}{\rho_c} (\nabla p_t - q_d) \right) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$$

$$p_t = p_2 + p_b$$

$$k_{eq}^2 = \left( \frac{\omega}{c_c} \right)^2 - k_m^2, \quad k_m = \frac{m}{r}$$

The 'Domain Selection' pane shows a manual selection of domains 1, 3, 5, and 6 (perfectly matched layer). The 'Pressure Acoustics Equation Settings' pane shows the circumferential mode number  $m$  set to 0. The 'Sound Pressure Level Settings' pane shows the reference pressure for the sound pressure level. On the right, a 2D plot shows the geometry of the speaker driver in a cross-section, with a vertical axis labeled 'm' ranging from -0.02 to 0.04 and a horizontal axis ranging from 0 to 0.02. The plot shows a blue region representing the fluid domain and a green region representing the speaker driver. A red label 'r=0' is visible at the bottom right of the plot. Below the plot, the 'Messages' pane shows the following text:

COMSOL Multiphysics 5.3.0.316  
Opened file: C:\Users\balistrerir\Desktop\20  
Opened file: C:\Users\balistrerir\Desktop\20

# Mapping to Freq. Domain

The screenshot displays the COMSOL Multiphysics interface. On the left, the 'Model Builder' tree shows a 'Transient Pressure Acoustics Model' with various physics and mesh settings. The 'Monopole Domain Source 1' is selected. The central 'Settings' window for this source shows the 'Domain Selection' set to 'All domains' and the 'Monopole source' equation as  $Q_m = -acpr.k^2/rho0*p$  with units of  $1/s^2$ . On the right, the 'Graphics' window shows a 'Probe Plot 1' of the acoustic field, with a color scale ranging from -0.02 to 0.04. The plot shows a complex acoustic field around a speaker-like structure. The bottom status bar indicates 'COMSOL Multiphysics 5.3.0.316'.





# Study

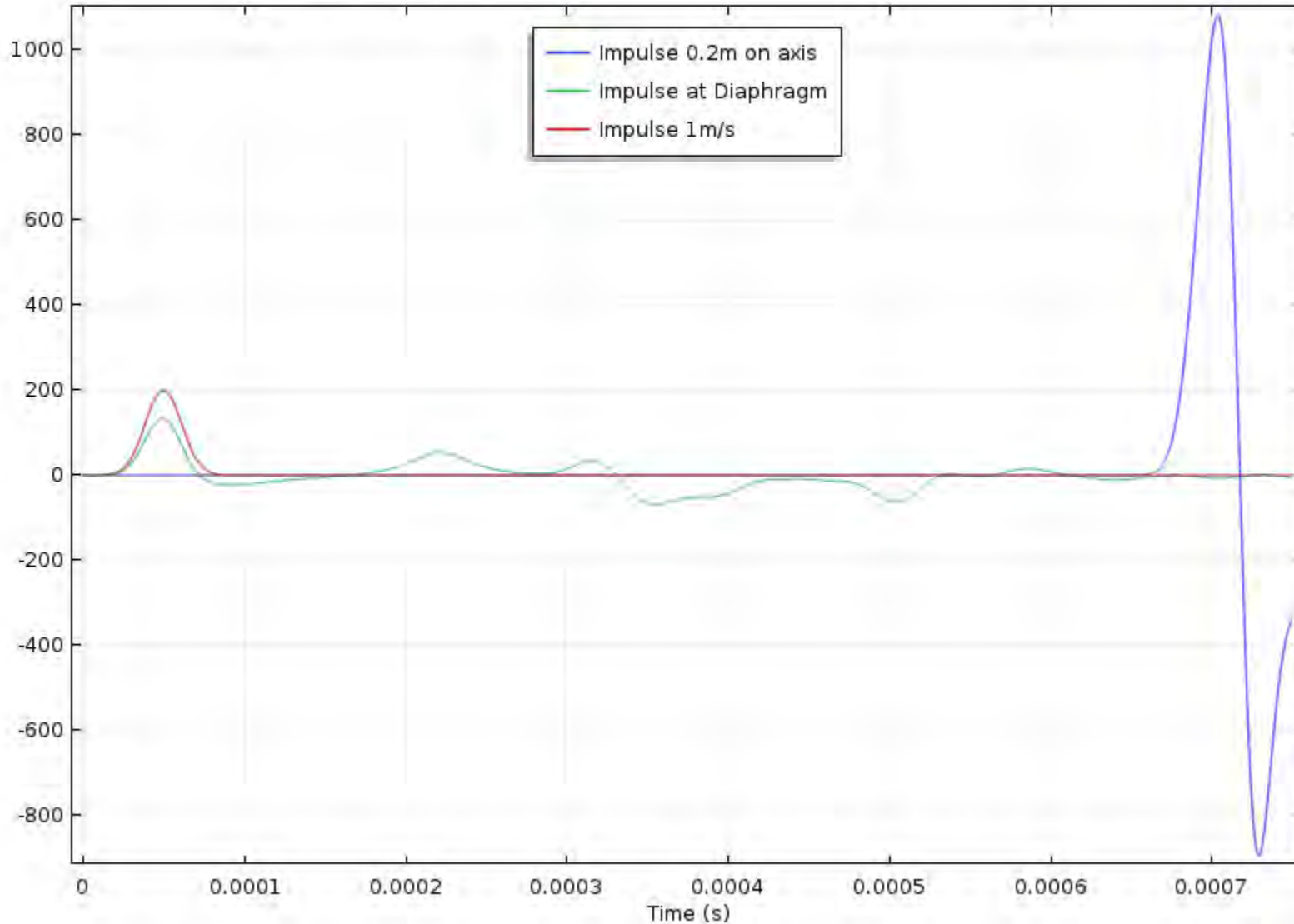
The screenshot displays the COMSOL Multiphysics software interface for a study configuration. The left-hand tree view shows the model structure, including 'loudspeaker\_Tweeter\_transient\_FFT', 'Global Definitions', 'Component 1 (comp1)', 'Pressure Acoustics, Transient', and 'Pressure Acoustics, Frequency Domain'. The central panel is titled 'Study Settings' and shows the following configuration:

- Label: Frequency Domain
- Frequency unit: Hz
- Frequencies:  $10^{(\text{range}(\log_{10}(400), 1/47, \log_{10}(\dots)))}$  Hz
- Load parameter values: Browse... Read File
- Reuse solution from previous step: Auto
- Results While Solving: (checked)
- Physics and Variables Selection:
  - Modify physics tree and variables for study step: (unchecked)
  - Physics interface: Pressure Acoustics, Transient (ac... Solve for: Discretization
  - Physics interface: Pressure Acoustics, Frequency D... Solve for: Physics settings
- Values of Dependent Variables:
  - Initial values of variables solved for: Settings: Physics controlled
  - Values of variables not solved for: Settings: User controlled
  - Method: Solution
  - Study: Study 1 - Transient + FFT, Time to Frequency FFT
  - Solution: Solution 1 (sol1)
  - Use: Solution Store 1 (sol2)
  - Time (s): All

On the right, a mesh visualization shows a cross-section of a tweeter with a triangular mesh. The vertical axis is labeled 'm' and ranges from -0.02 to 0.04. The horizontal axis ranges from 0 to 0.01. Below the mesh, there are tabs for 'Messages', 'Progress', and 'Log'. The status bar at the bottom indicates 'COMSOL Multiphysics 5.3.0.316' and shows the file path 'C:\Users\balistreri\...'.

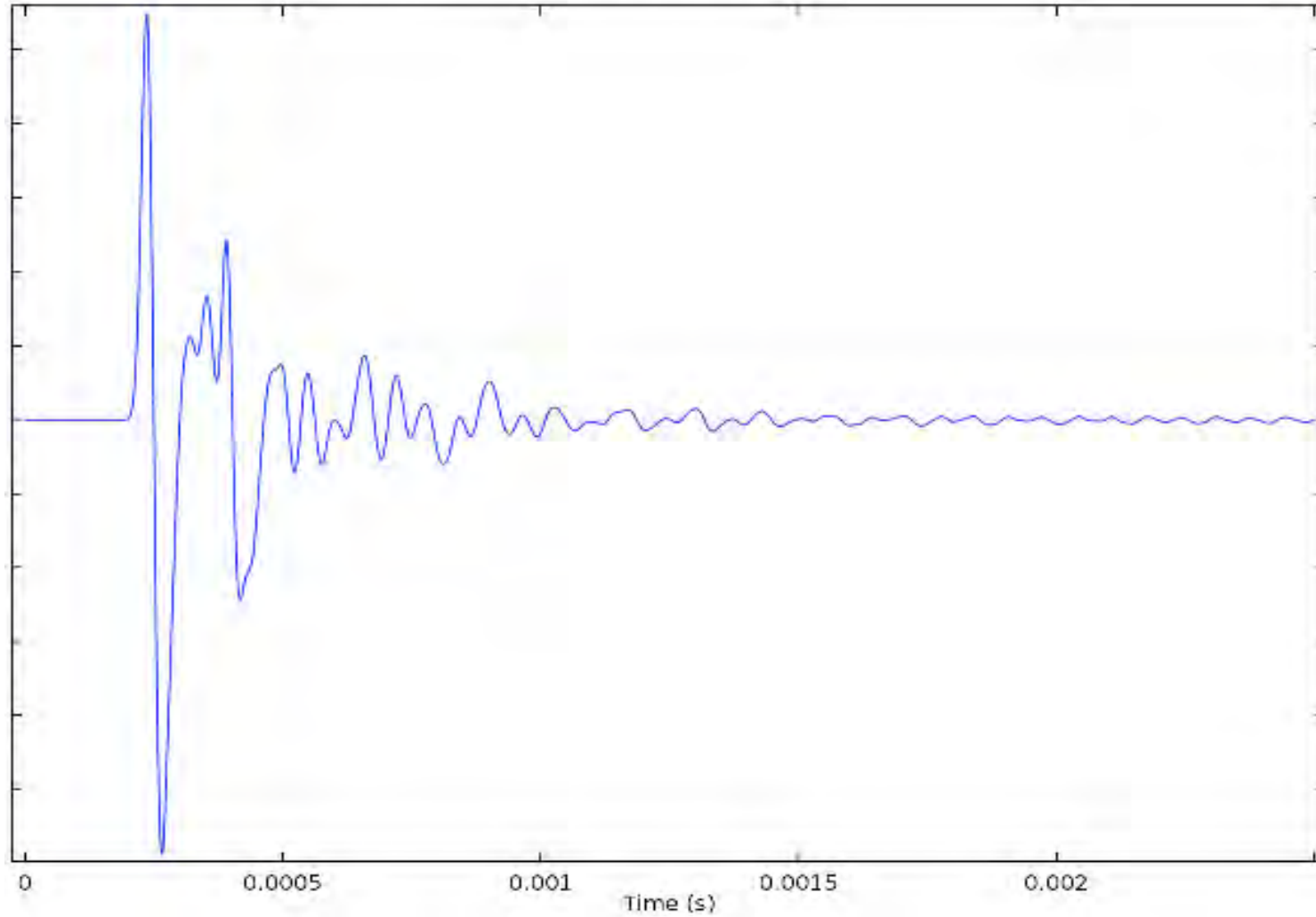
# Pressure pulse

Point Graph: Total acoustic pressure field (Pa) Global: (m/s)

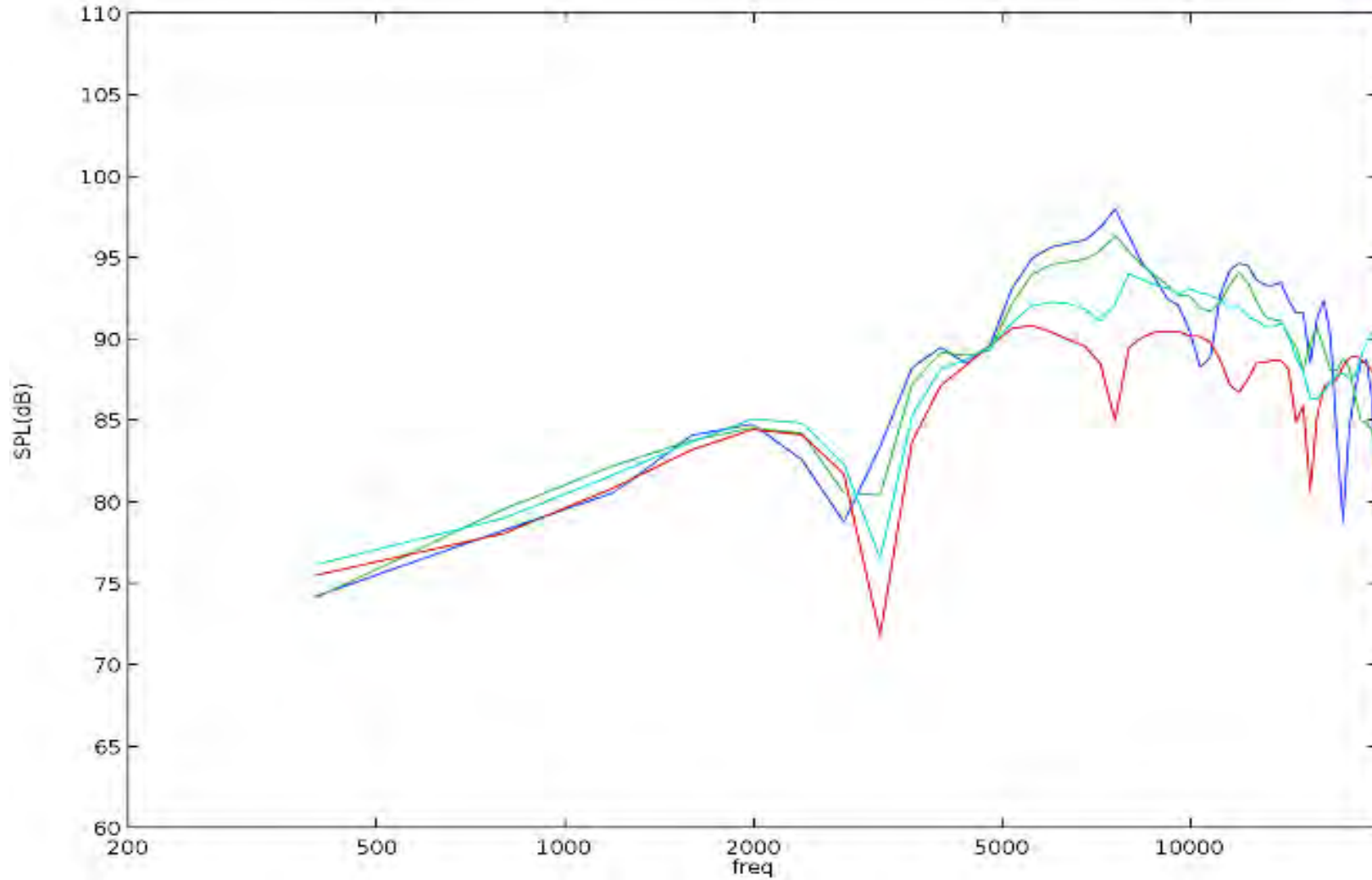


# Impulse in front of tweeter

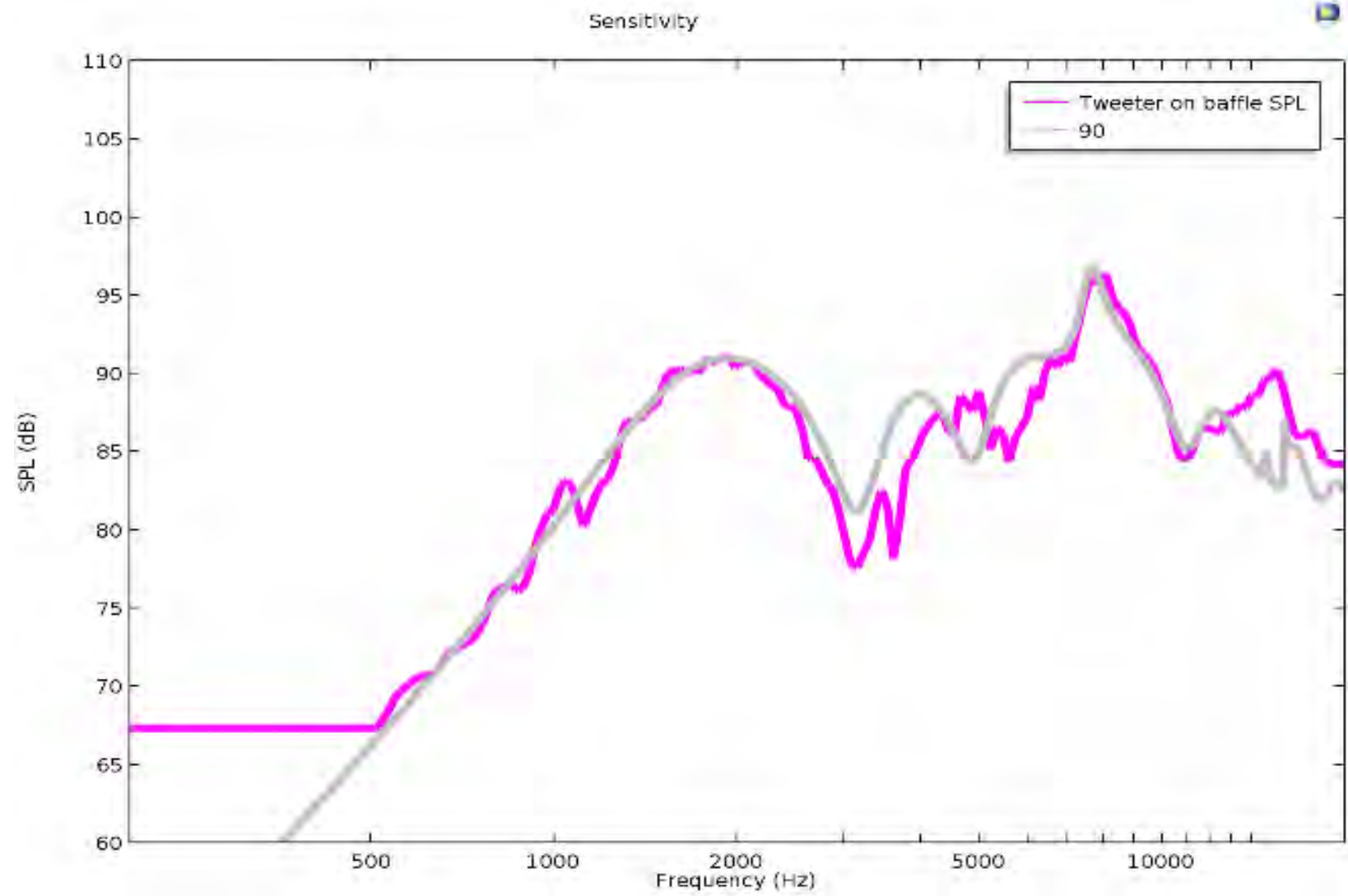
Point Graph: Total acoustic pressure field (Pa)



# FFT of Impulse

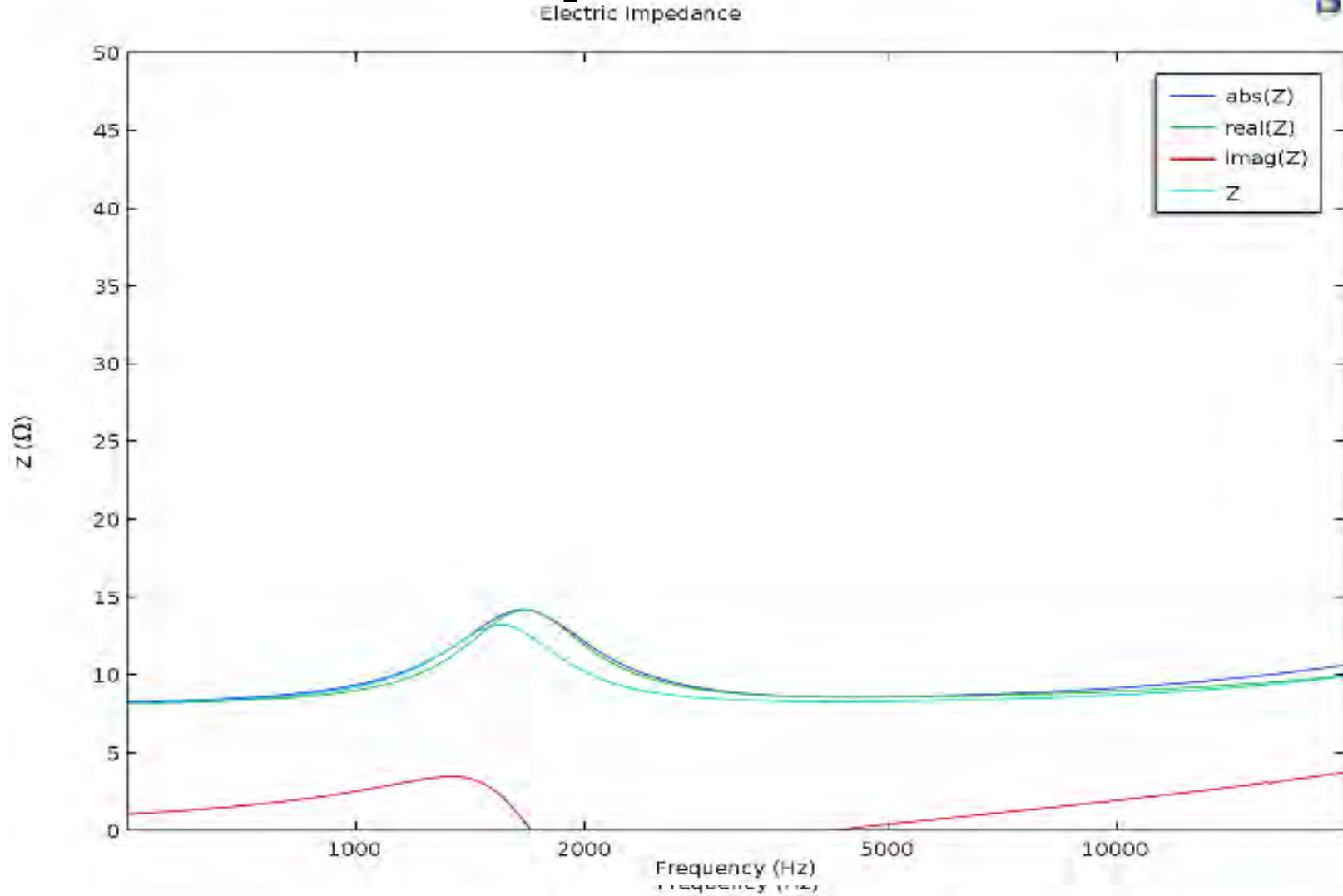


# Freq. domain vs. measurement



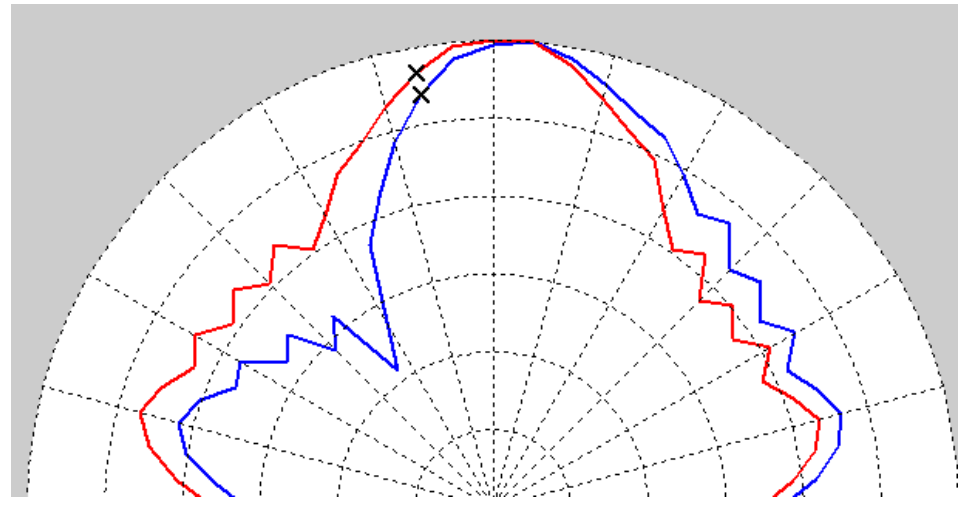
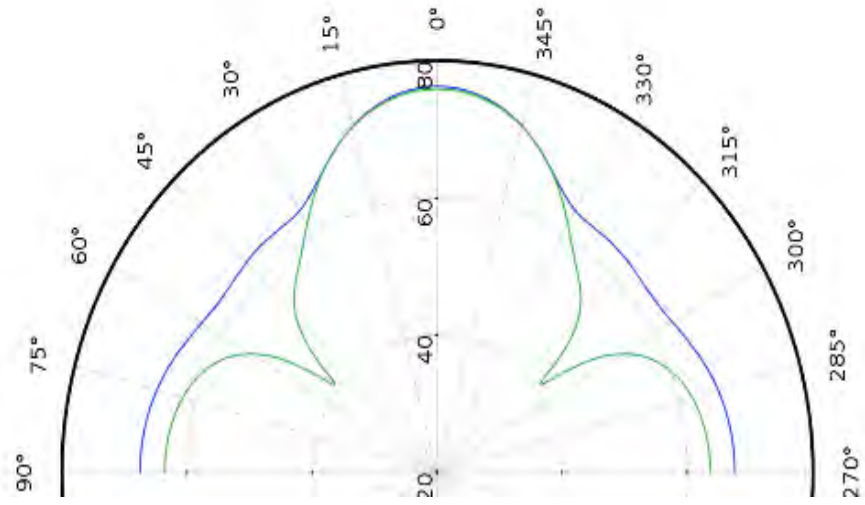


# Freq. domain impedance

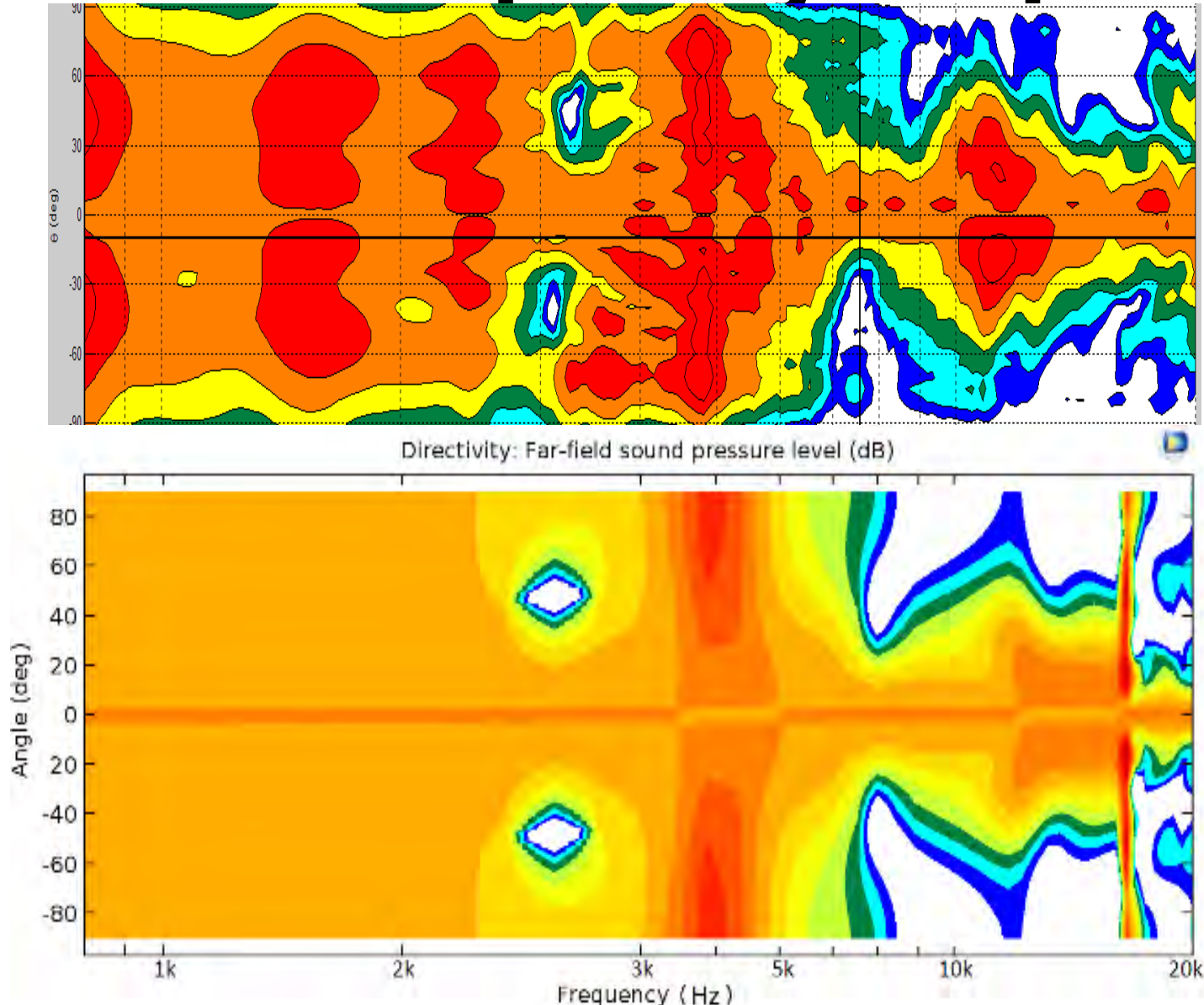




# Frequency map



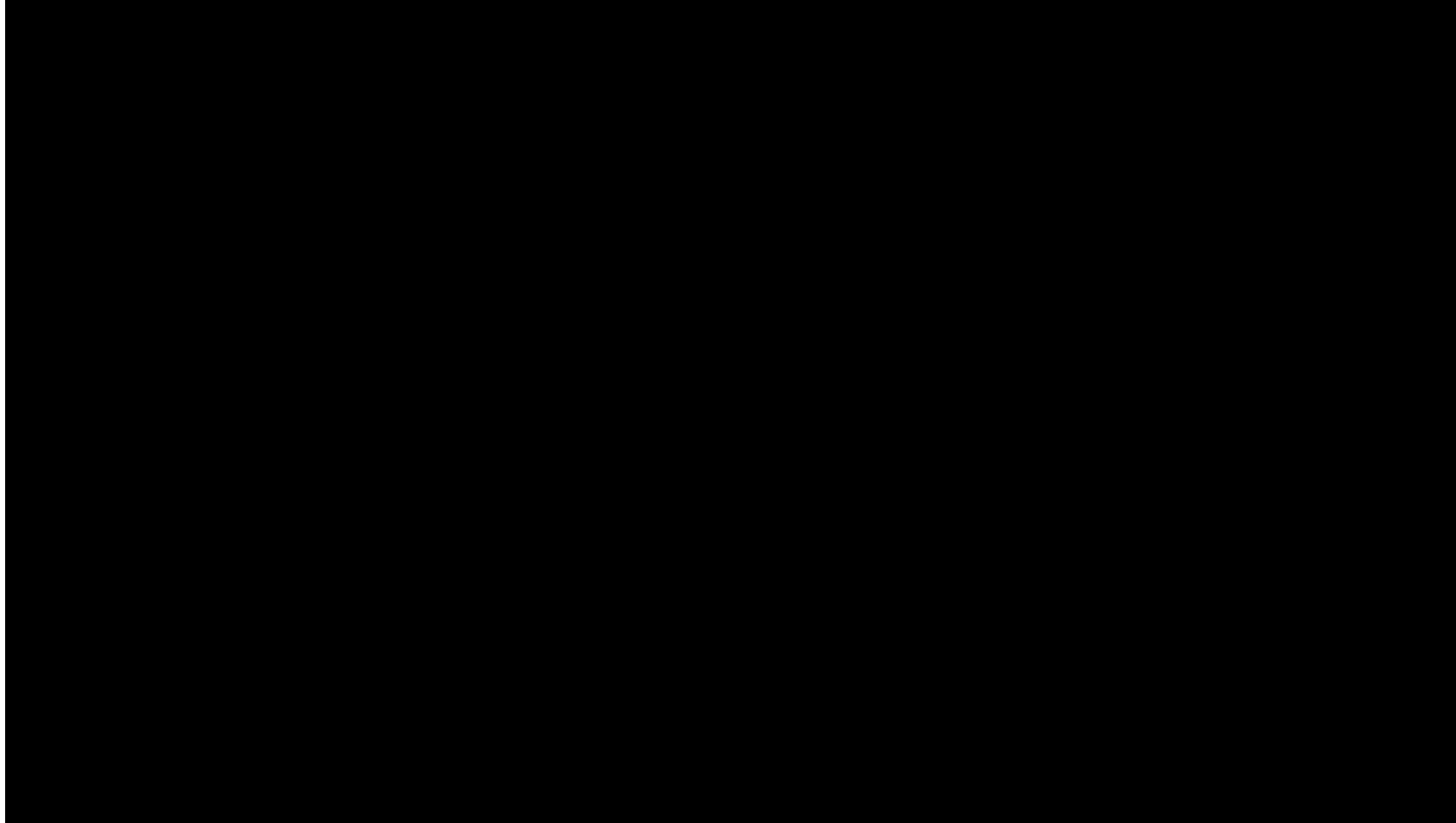
# Frequency map



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# Impulse Propagation

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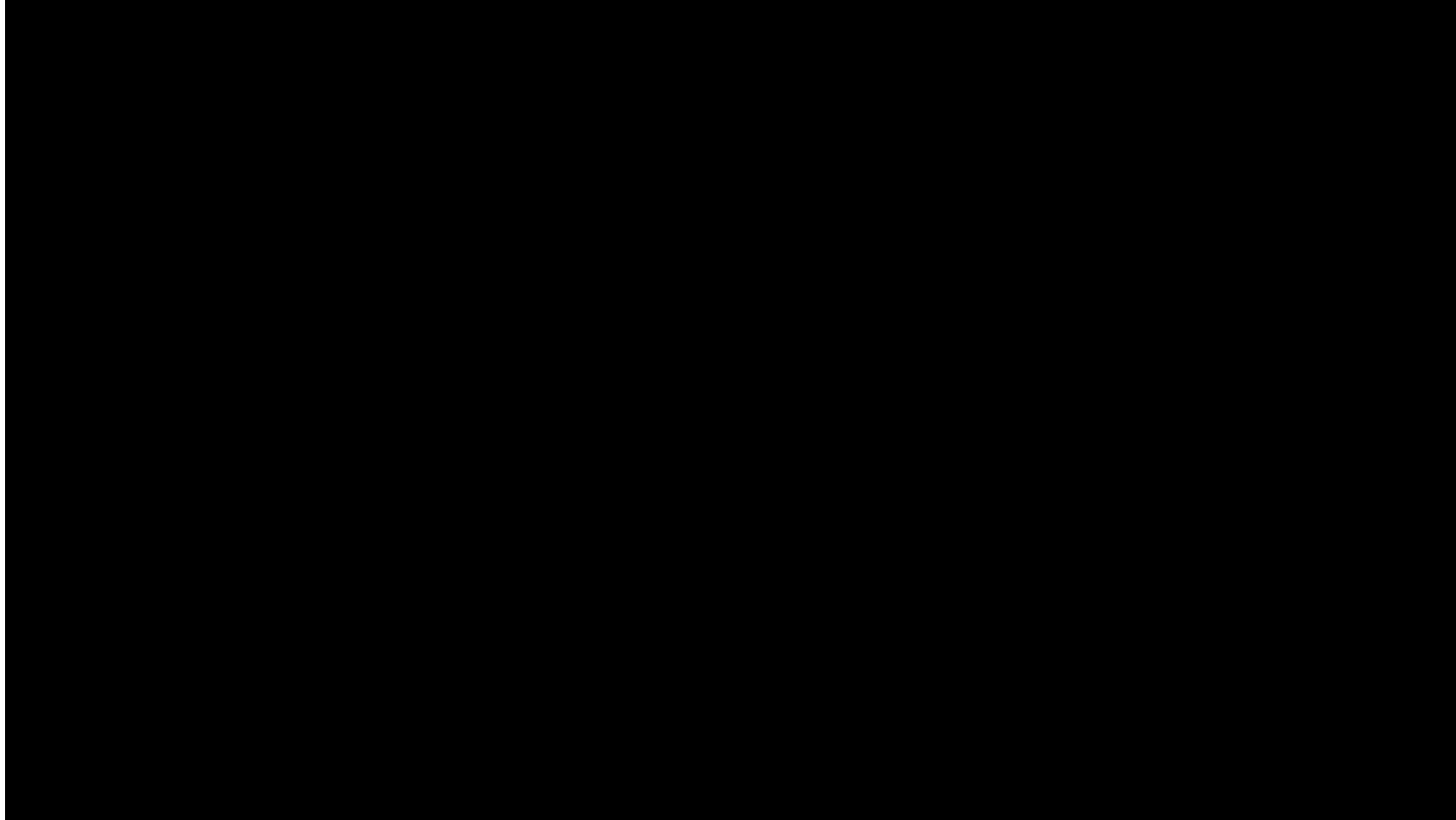




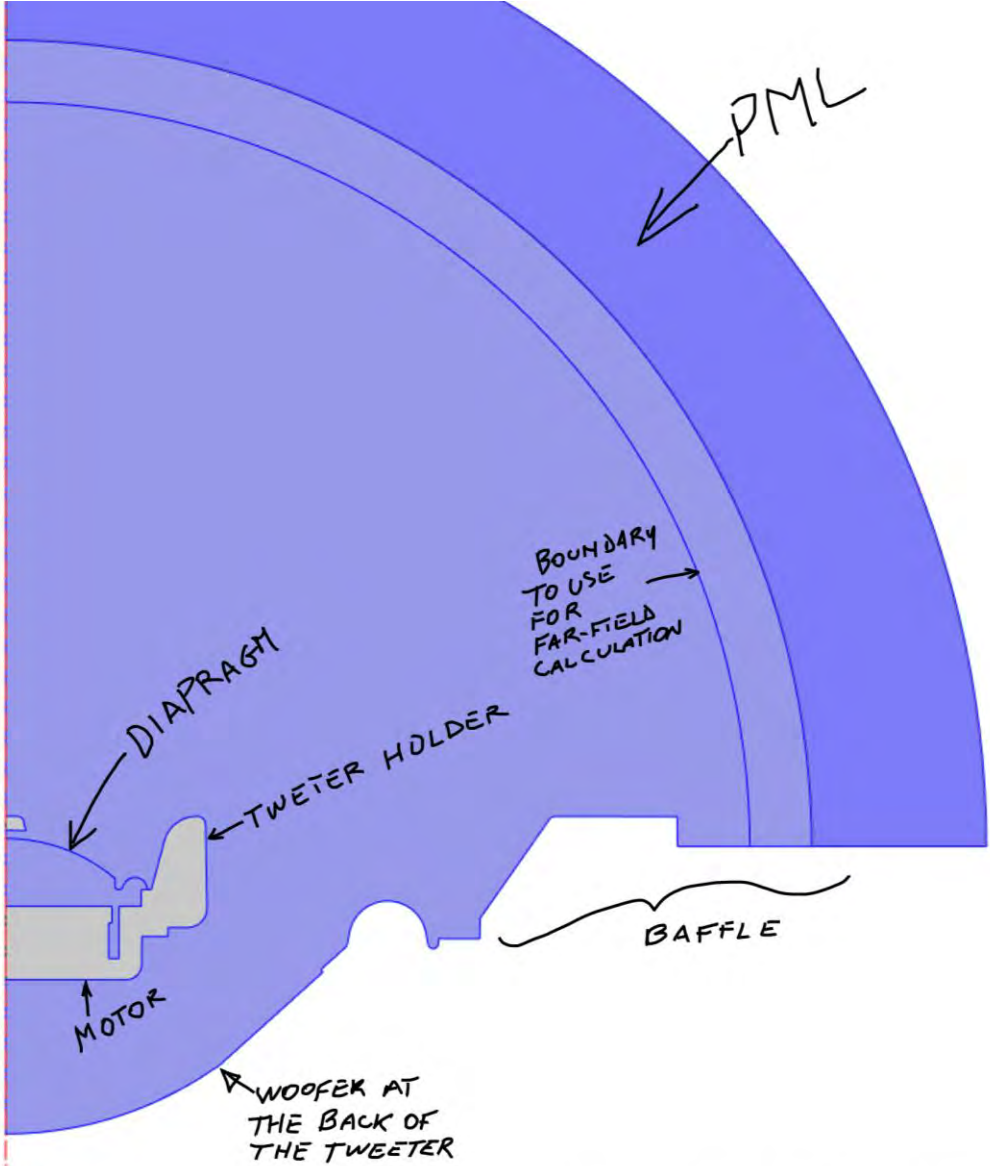
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# Impulse Propagation

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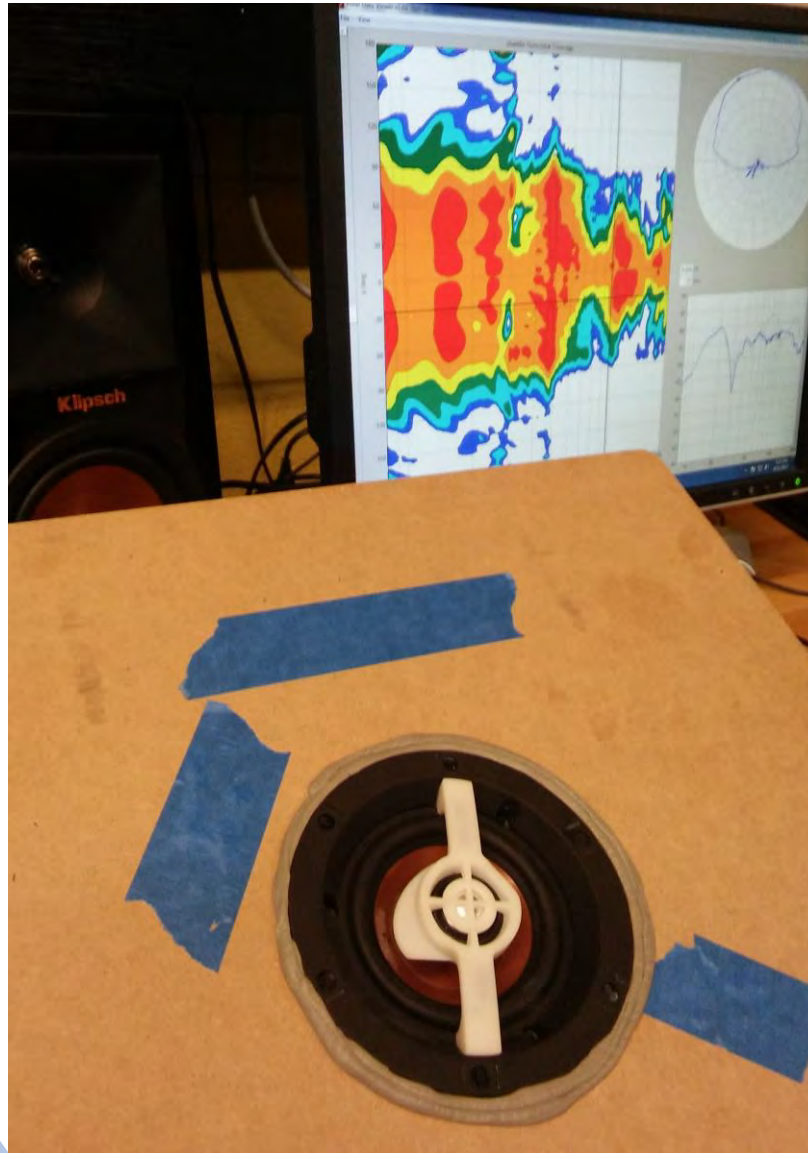
# Bad Symmetry!



# Bad Symmetry!



# Results

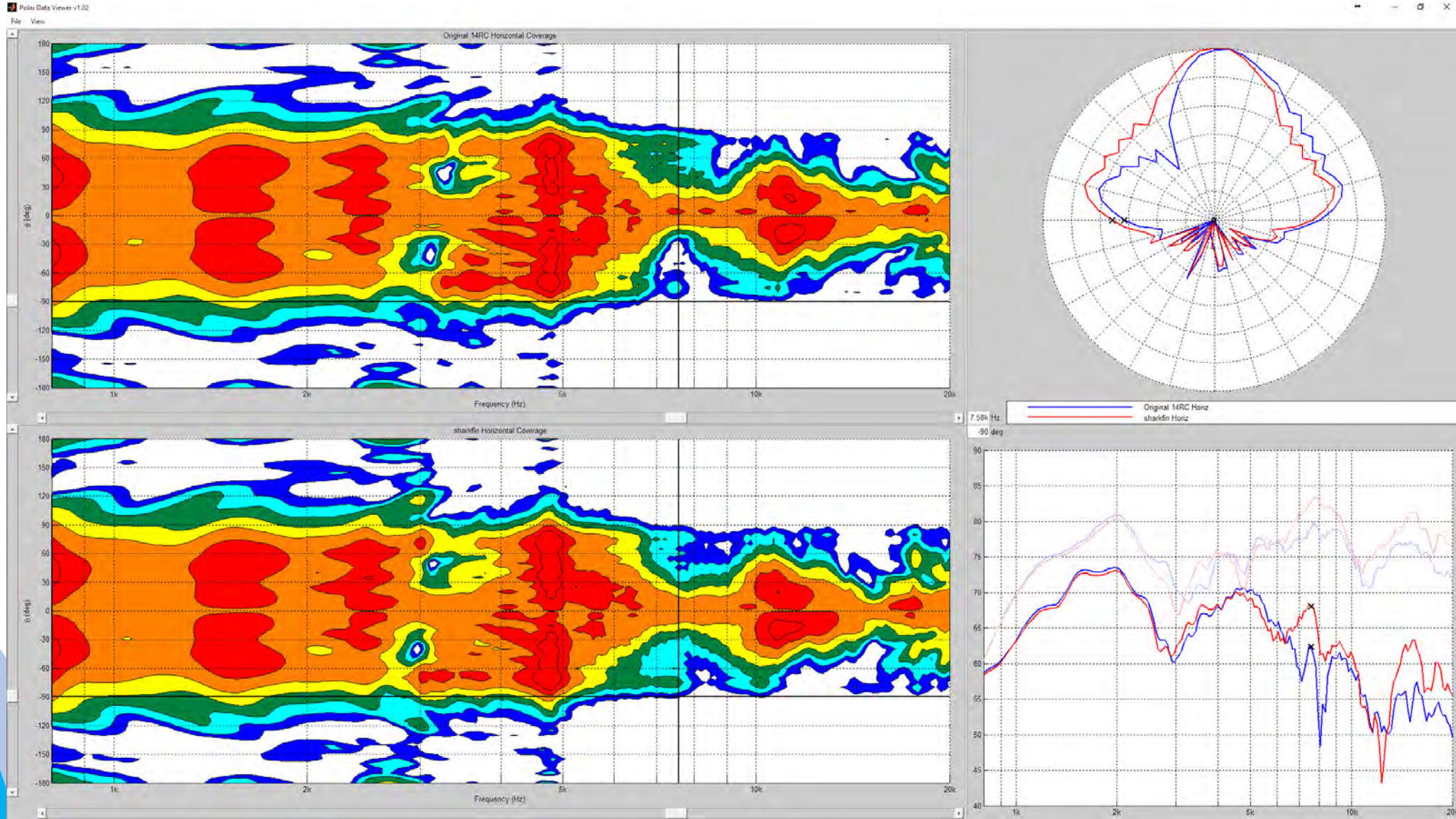


Polar  
measurement  
system

DUT device  
under test

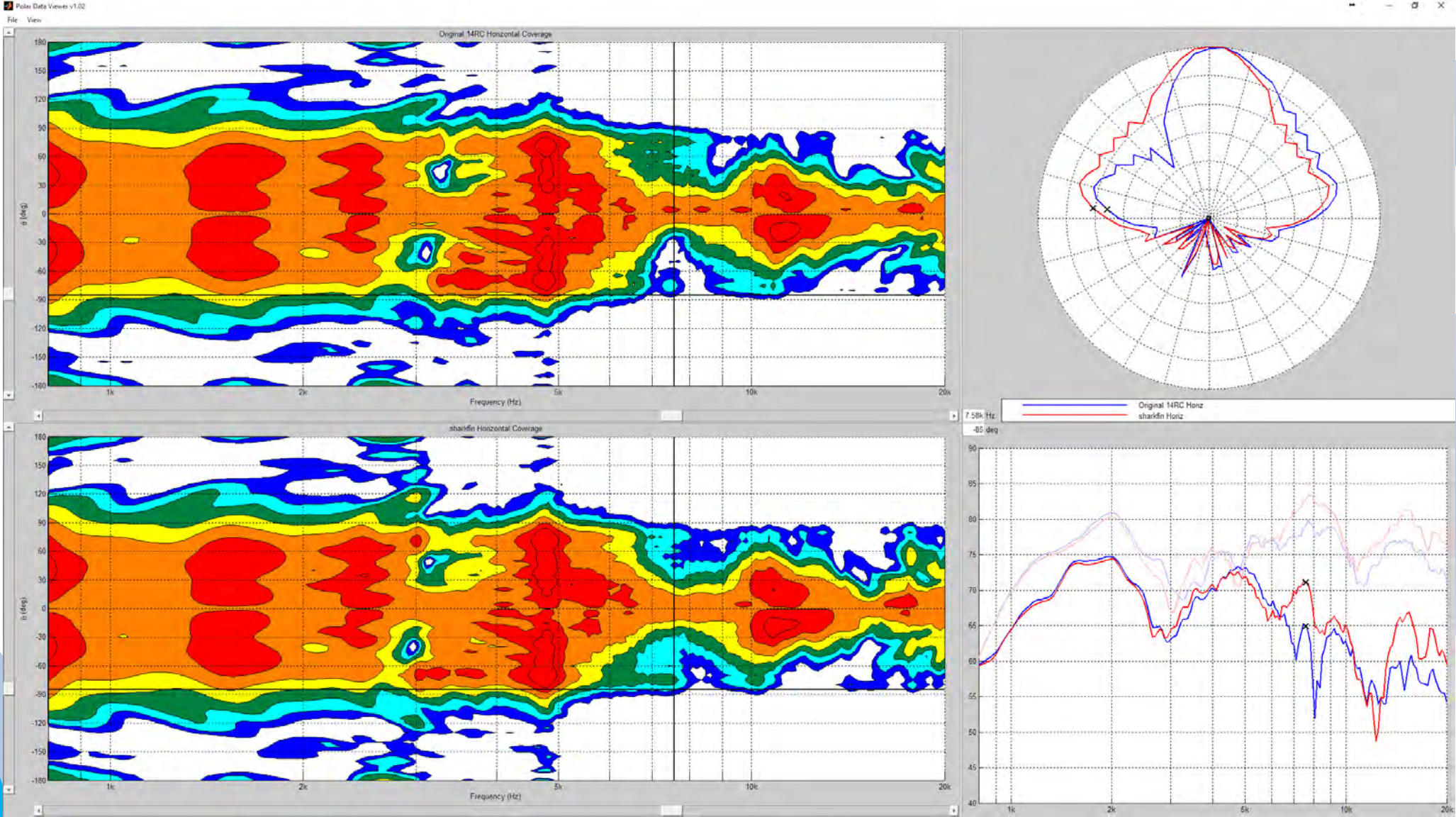


# Results



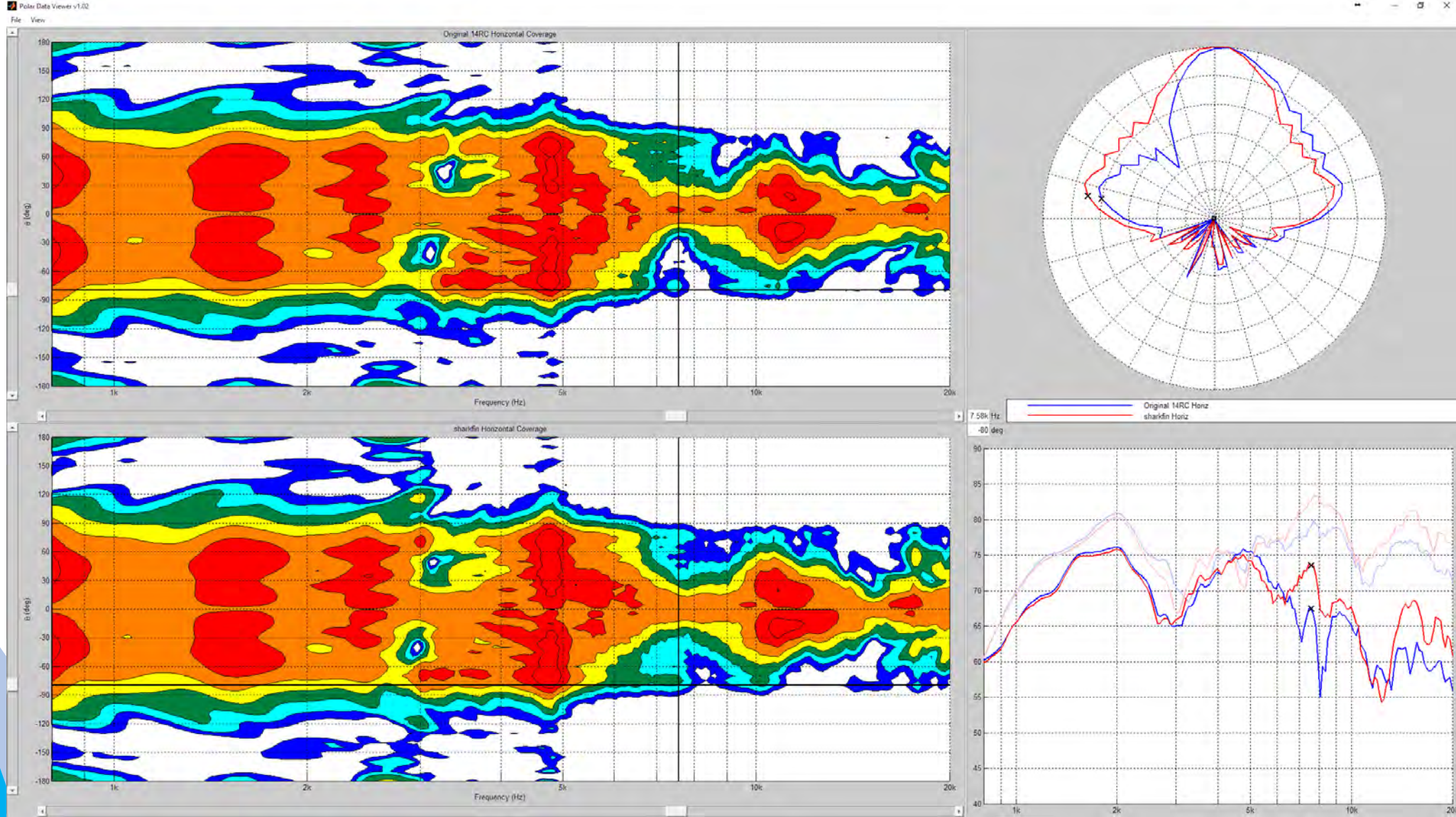


# Results



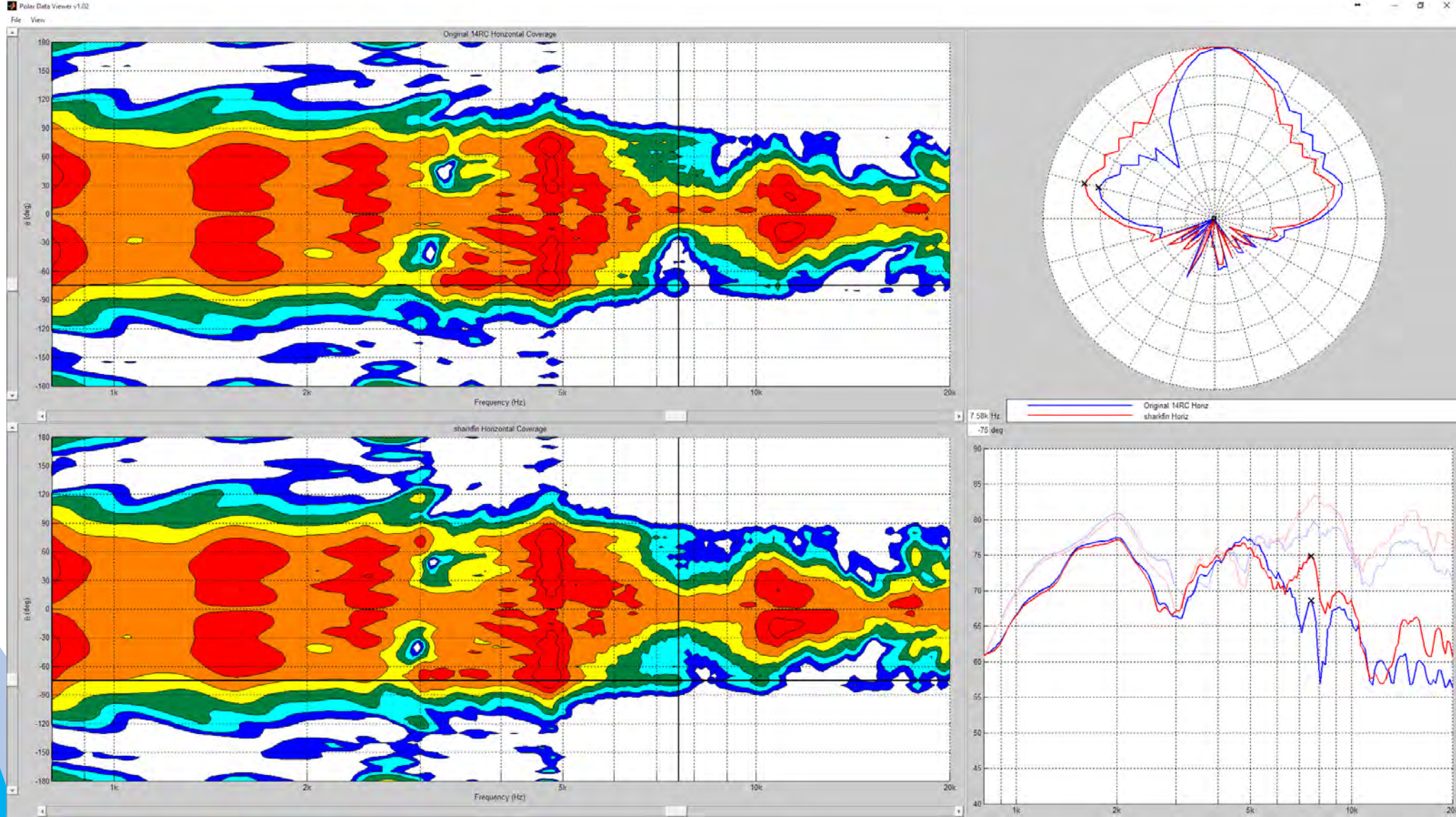


# Results



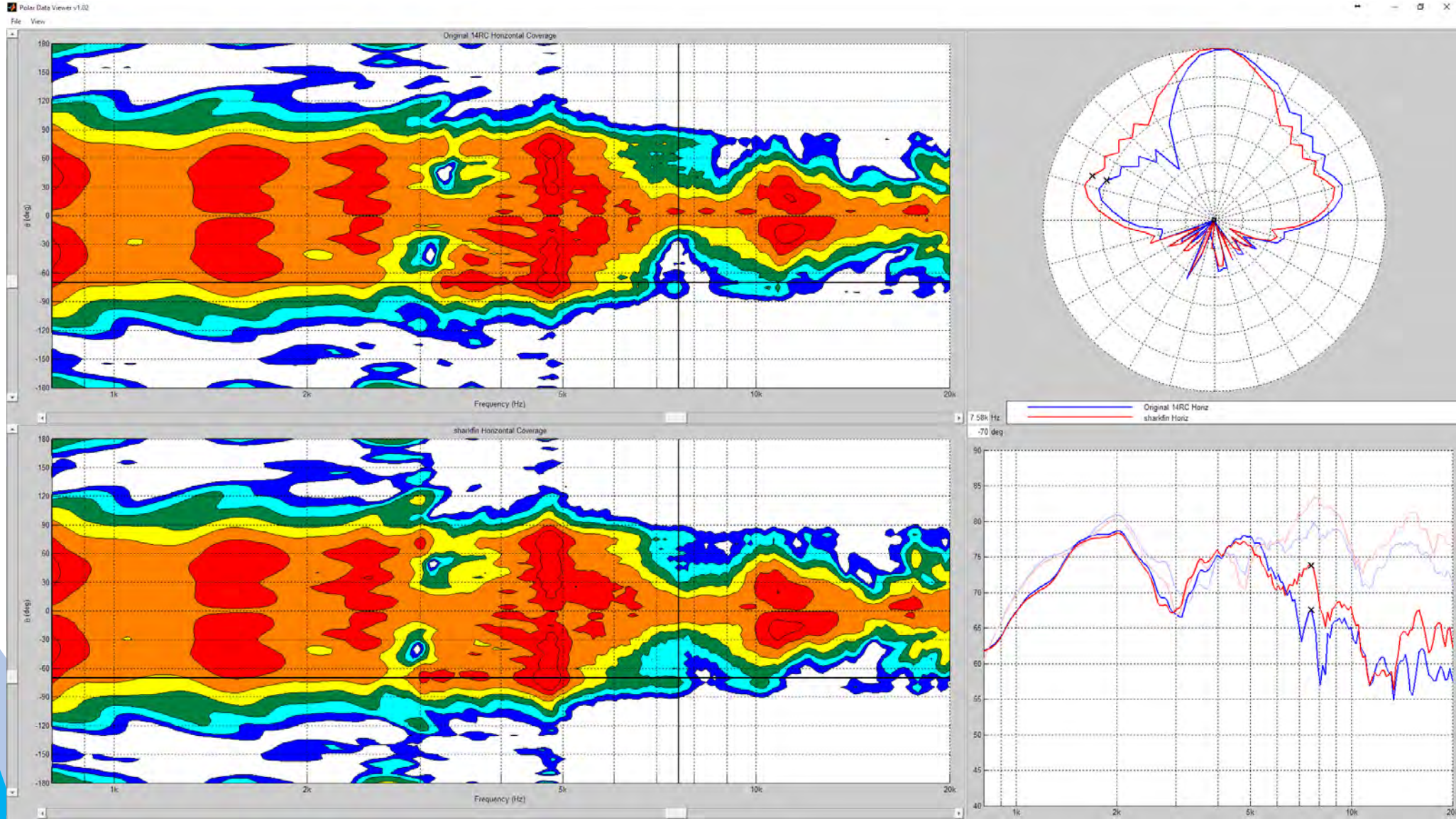


# Results



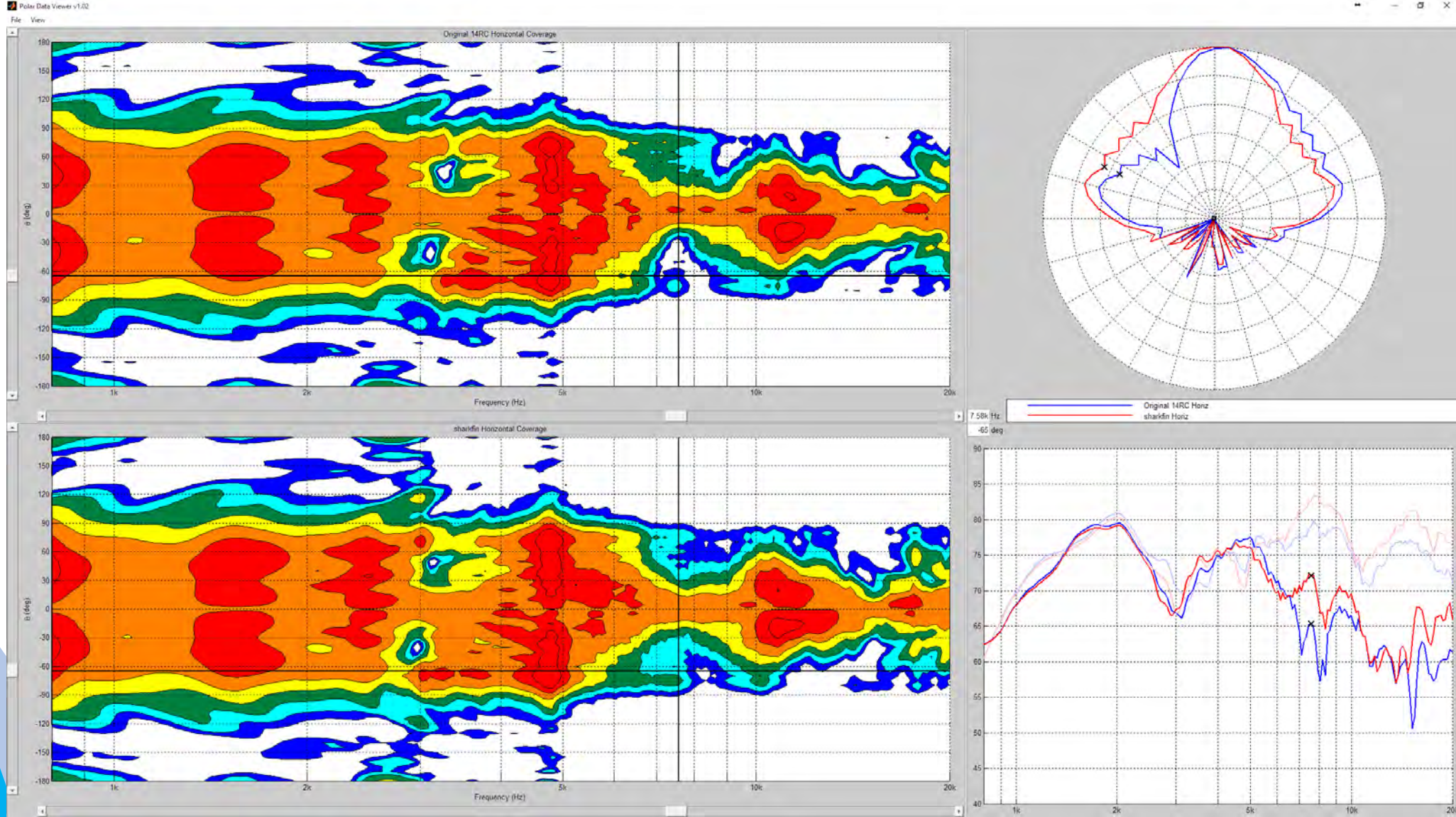


# Results



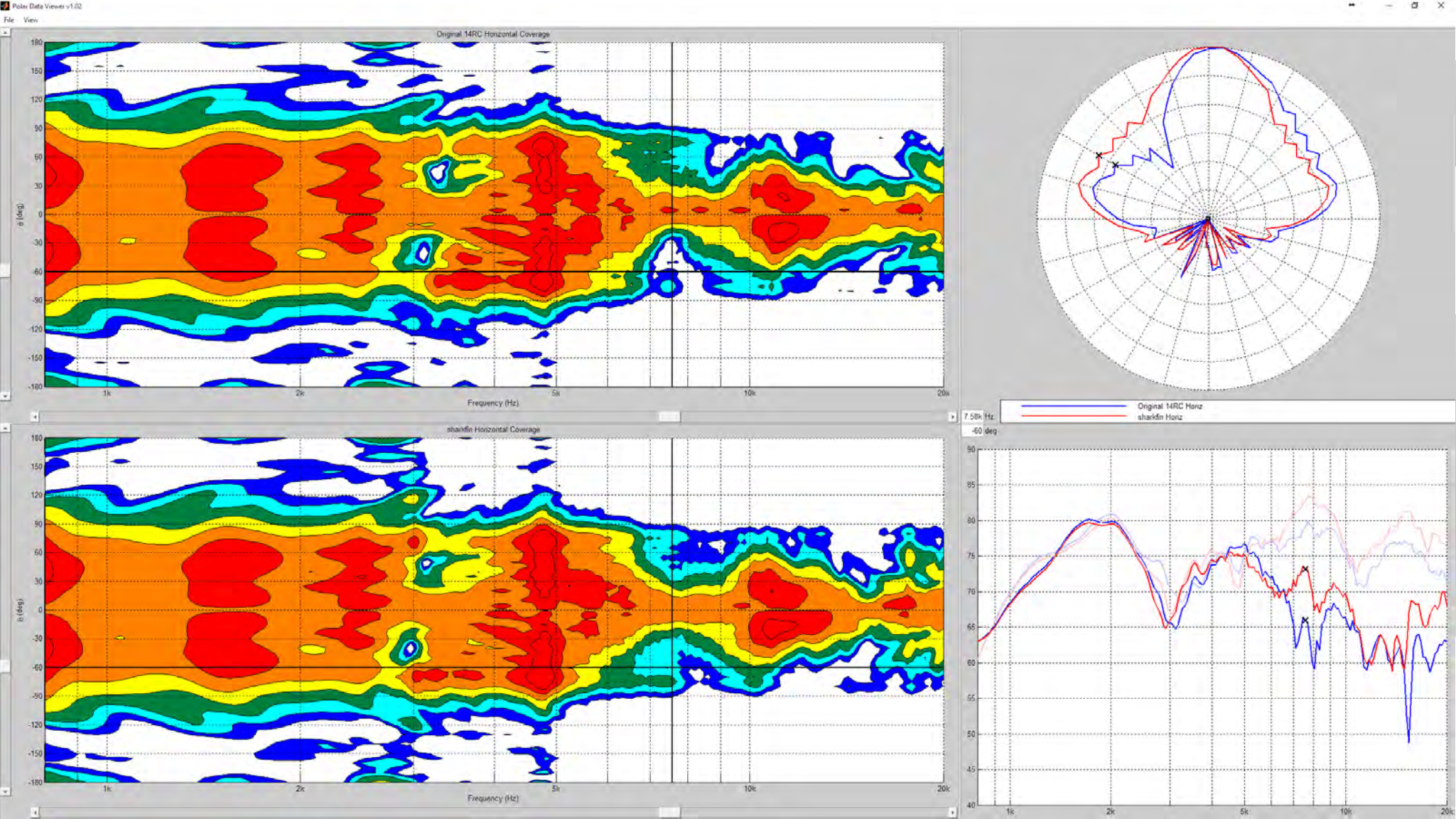


# Results



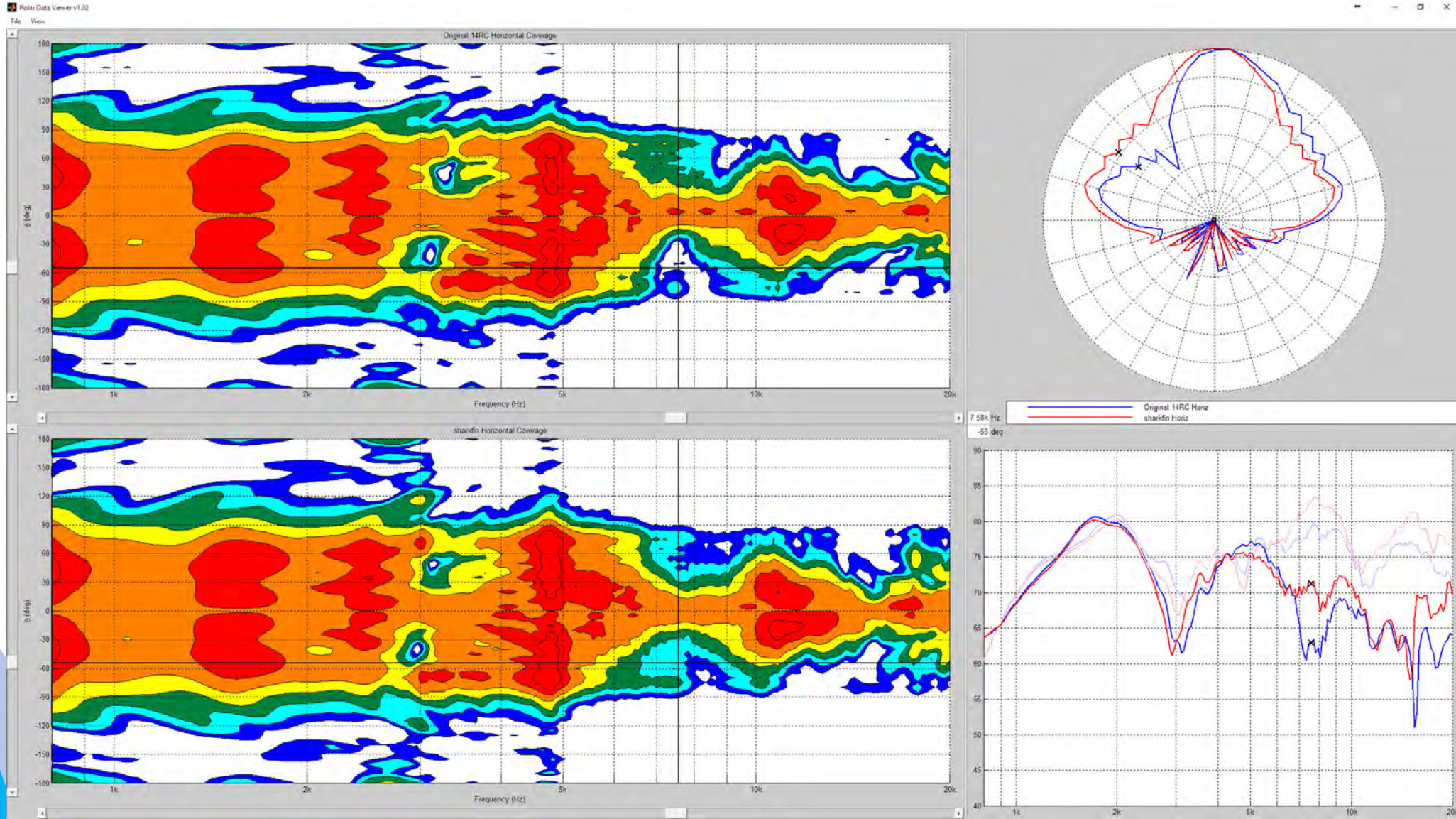


# Results



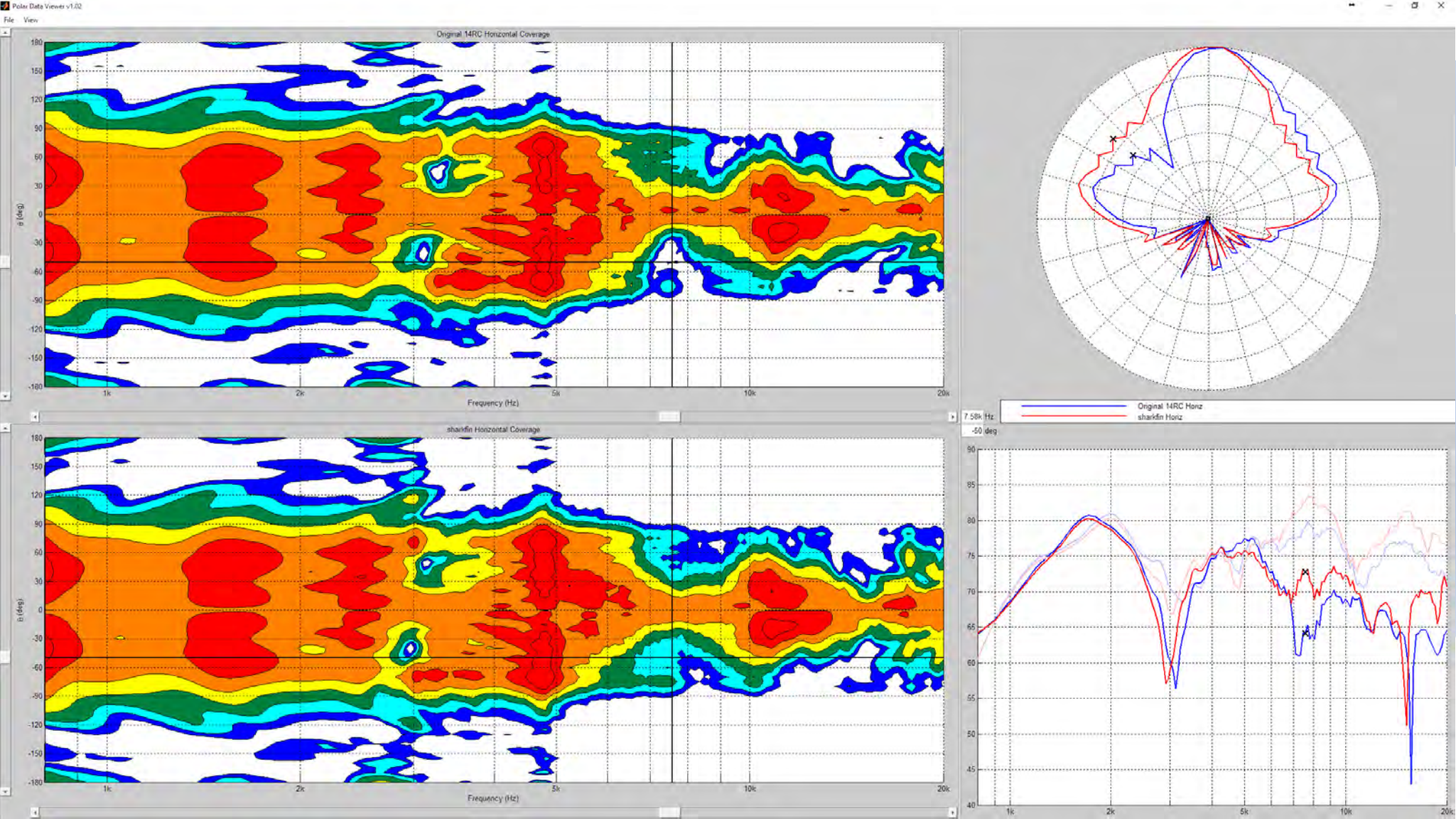


# Results



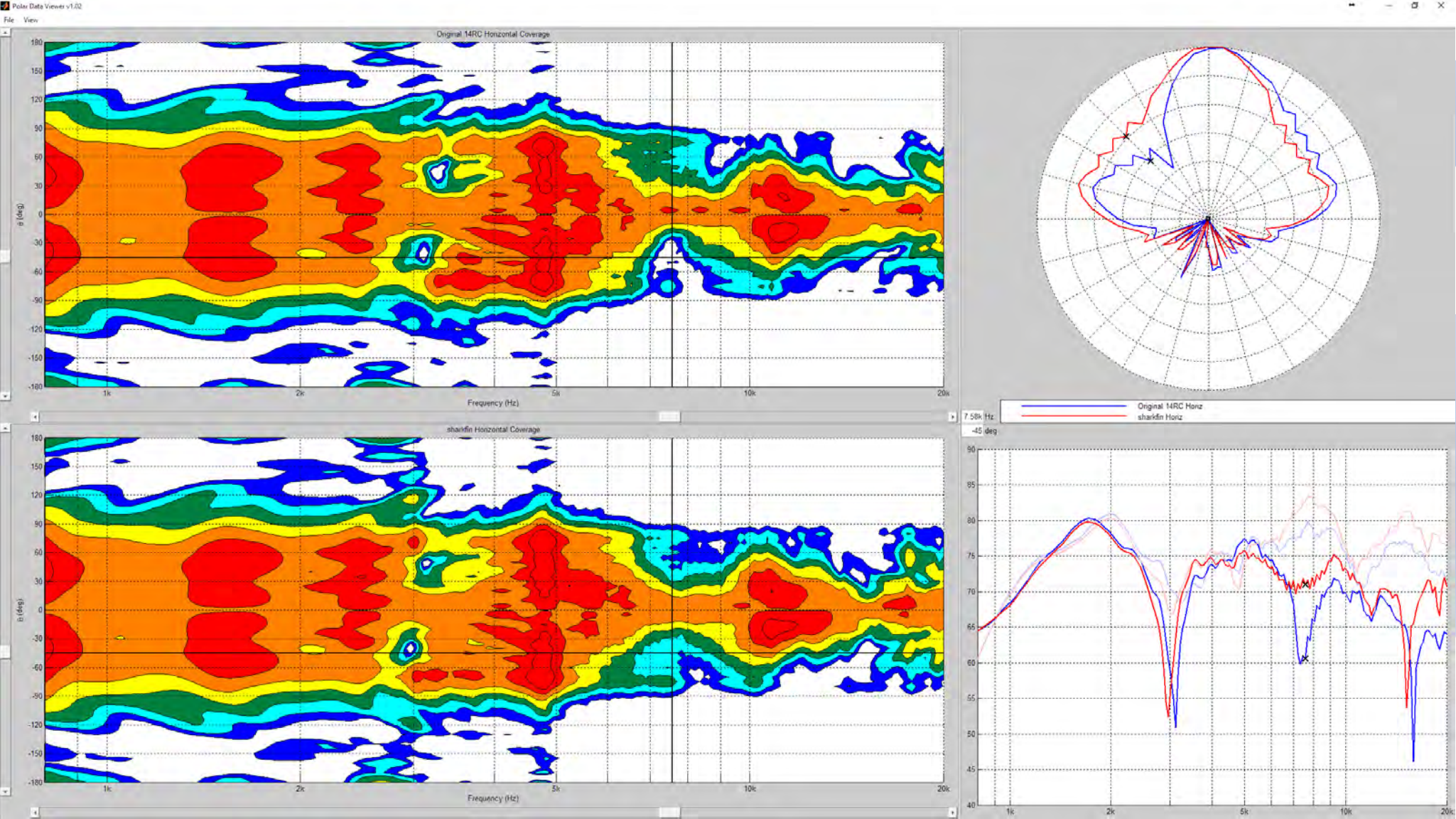


# Results



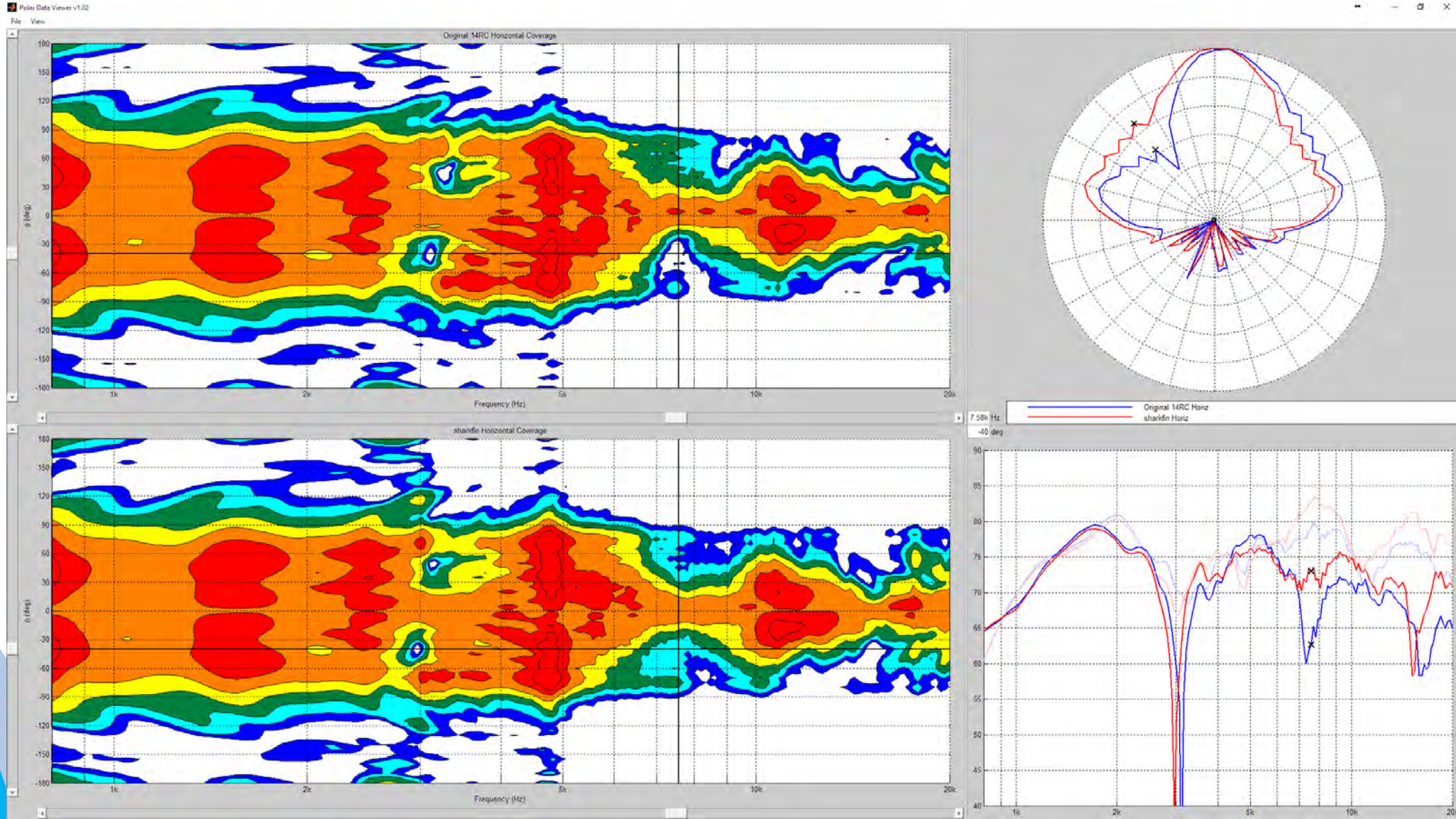


# Results



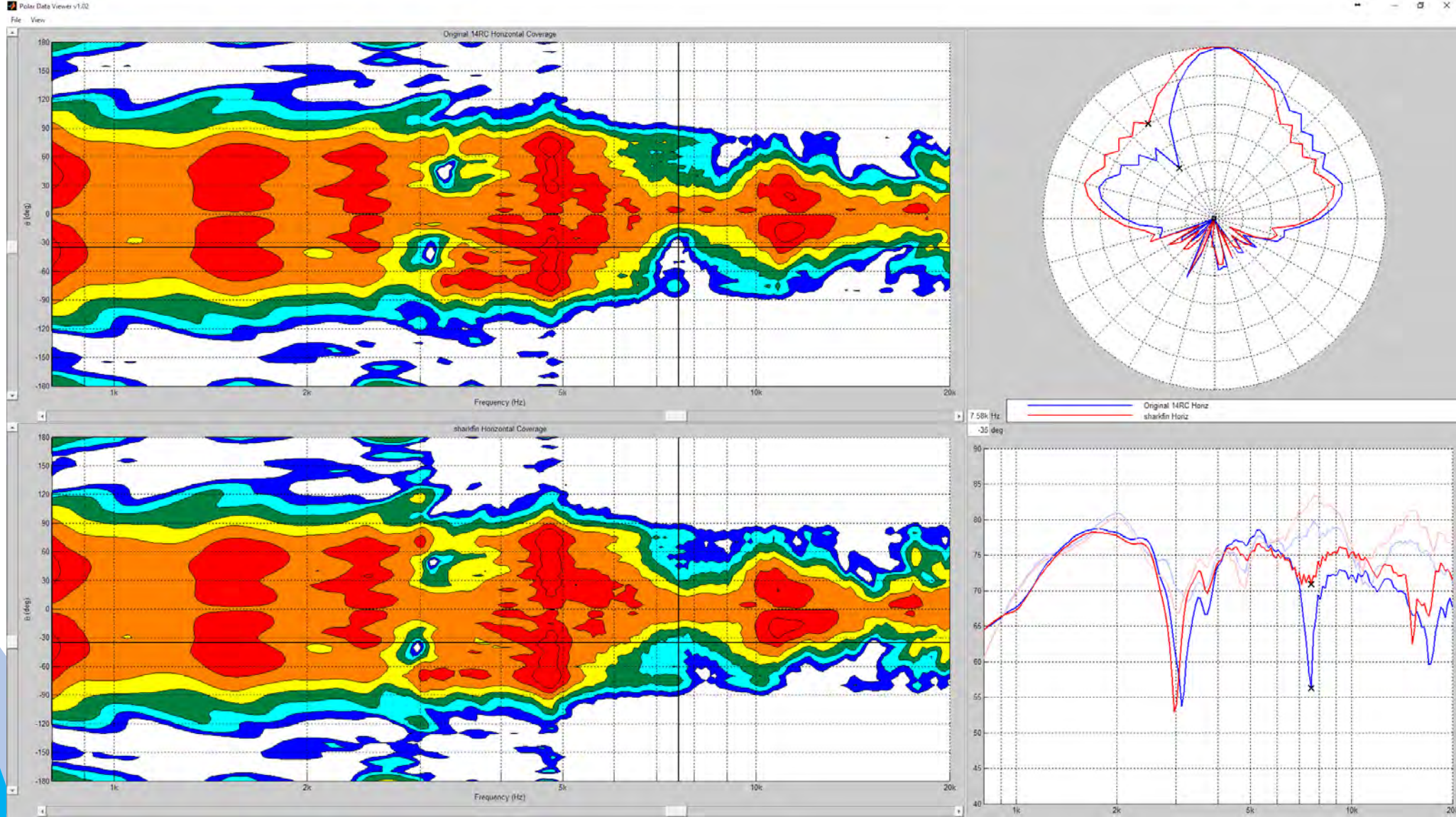


# Results



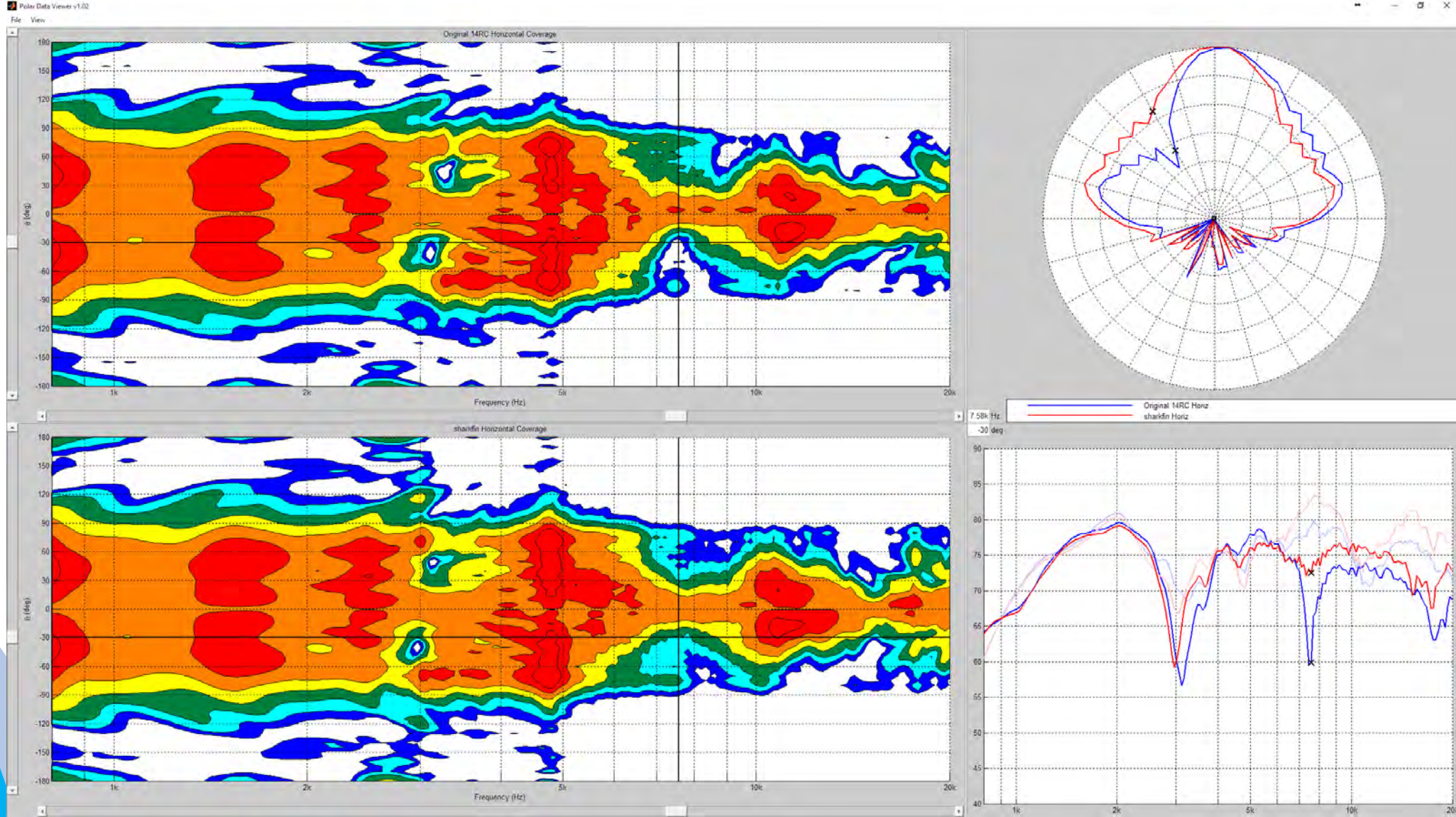


# Results



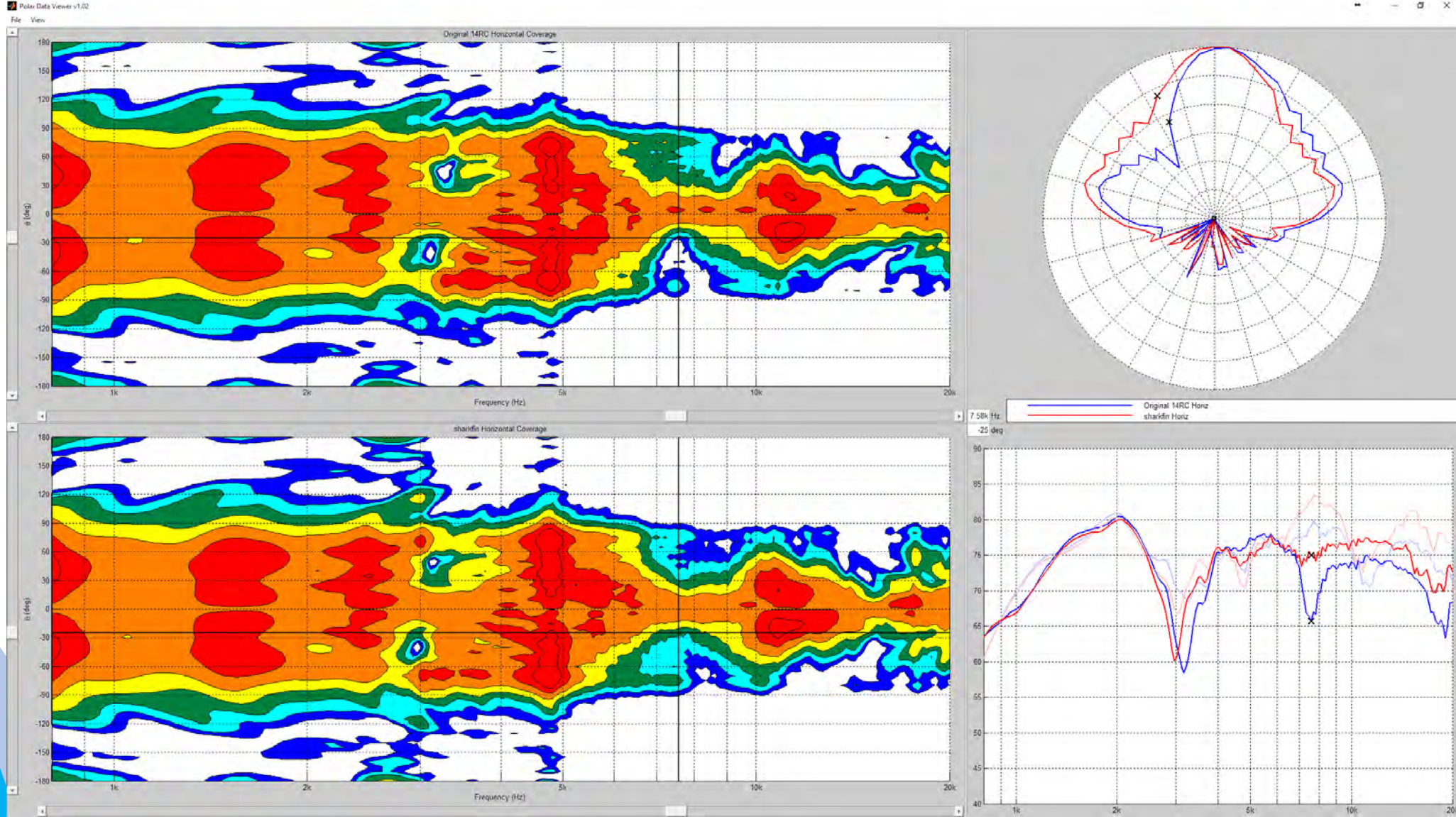


# Results



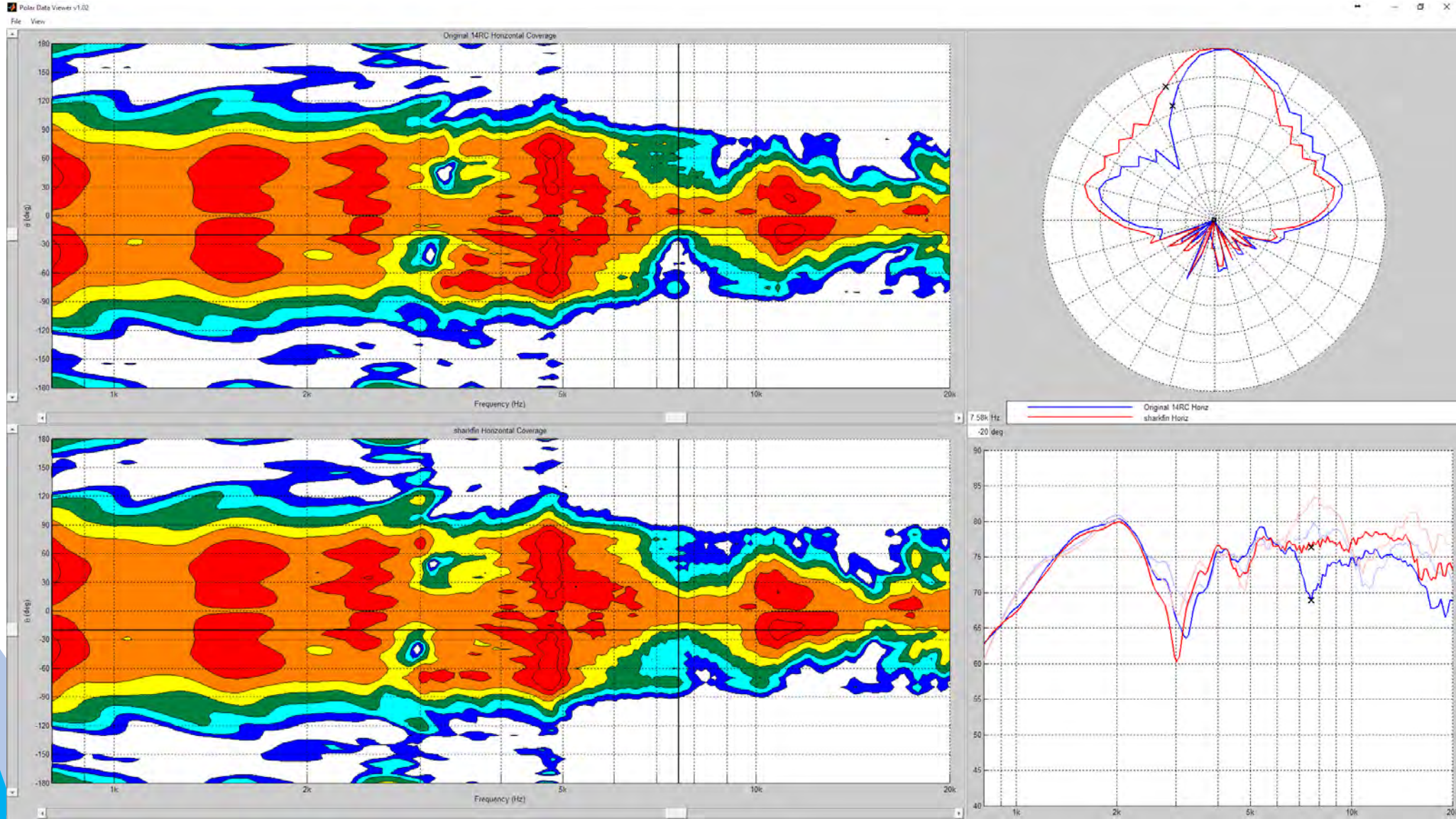


# Results



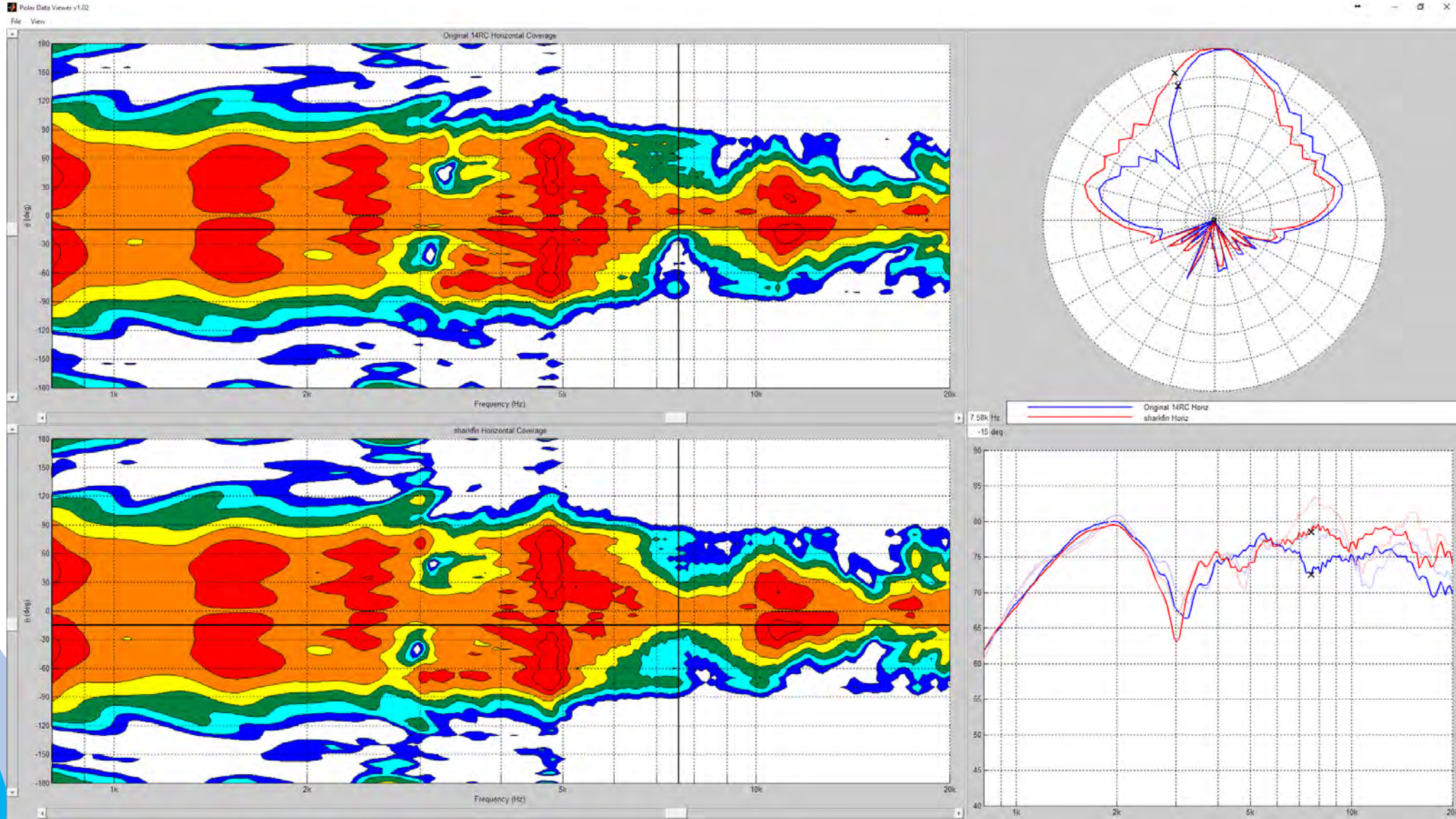


# Results



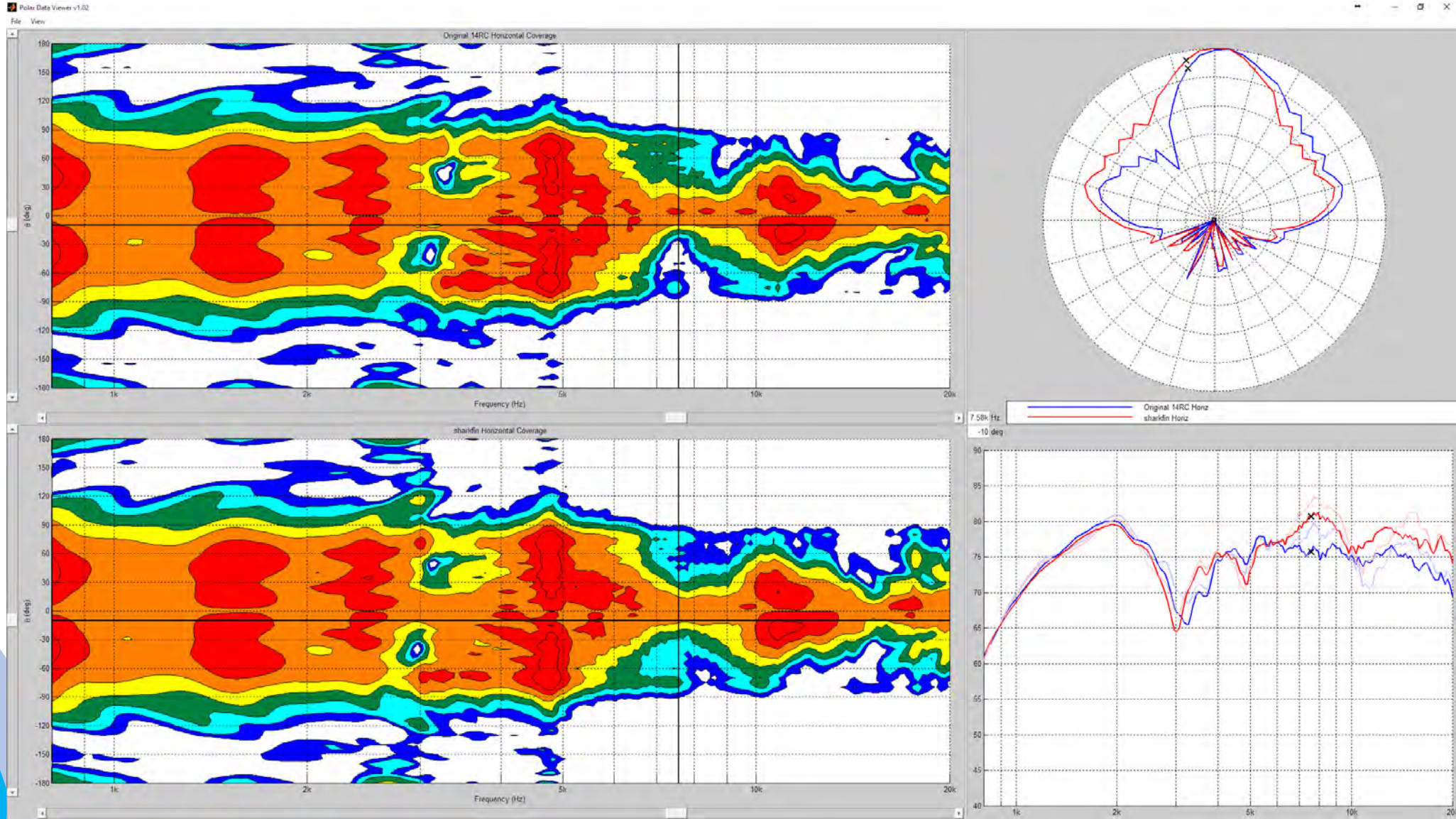


# Results



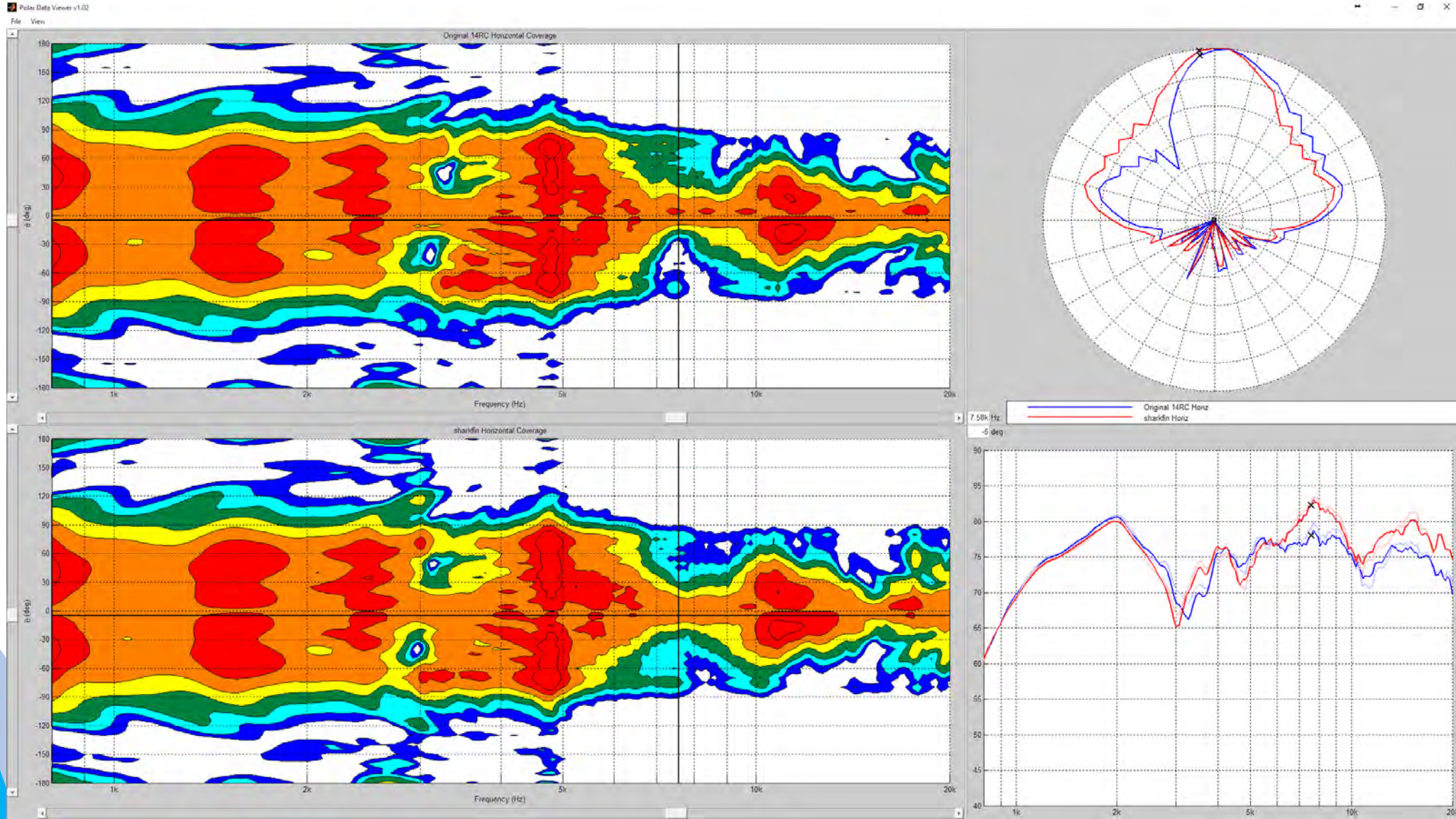


# Results



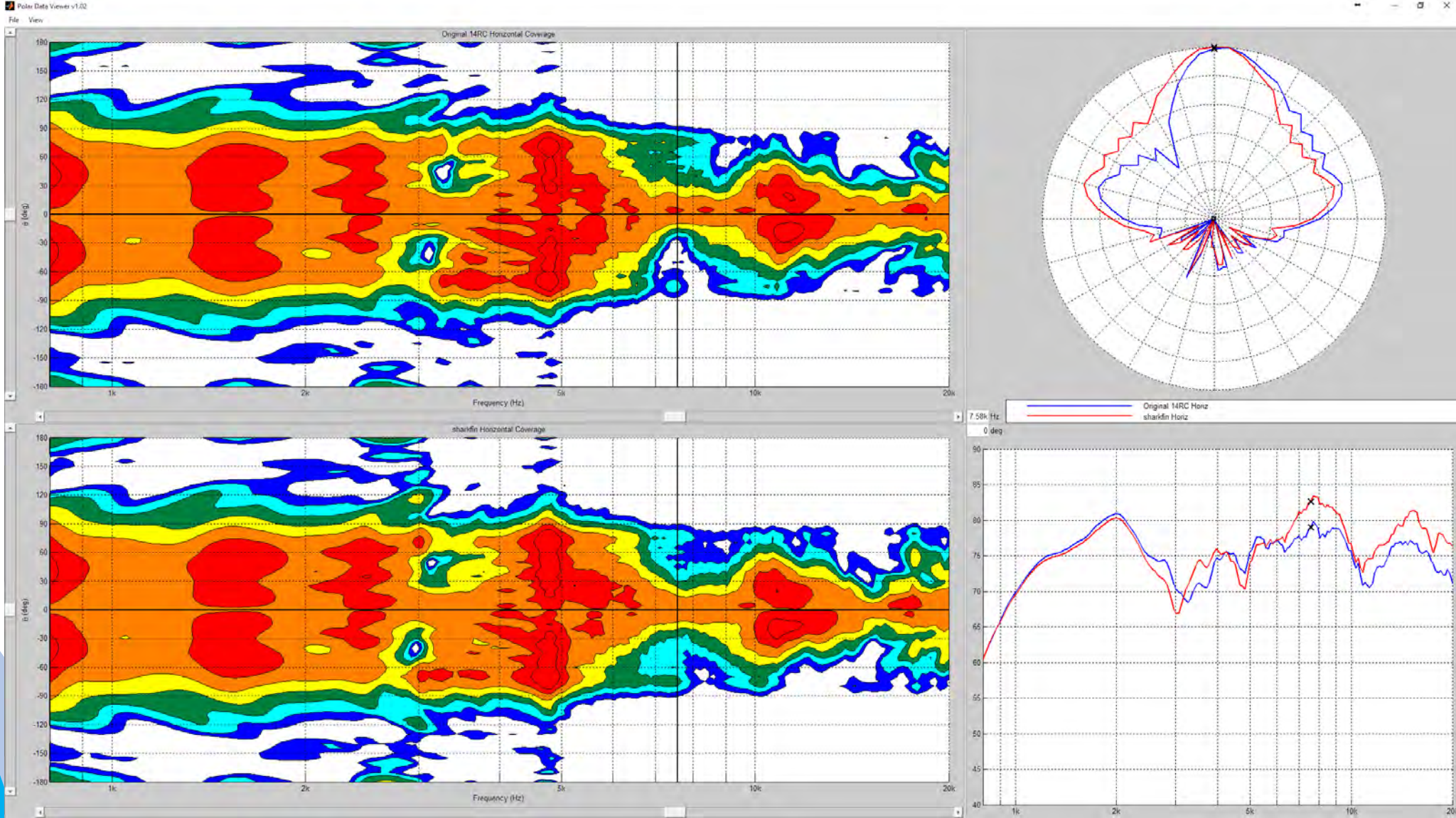


# Results



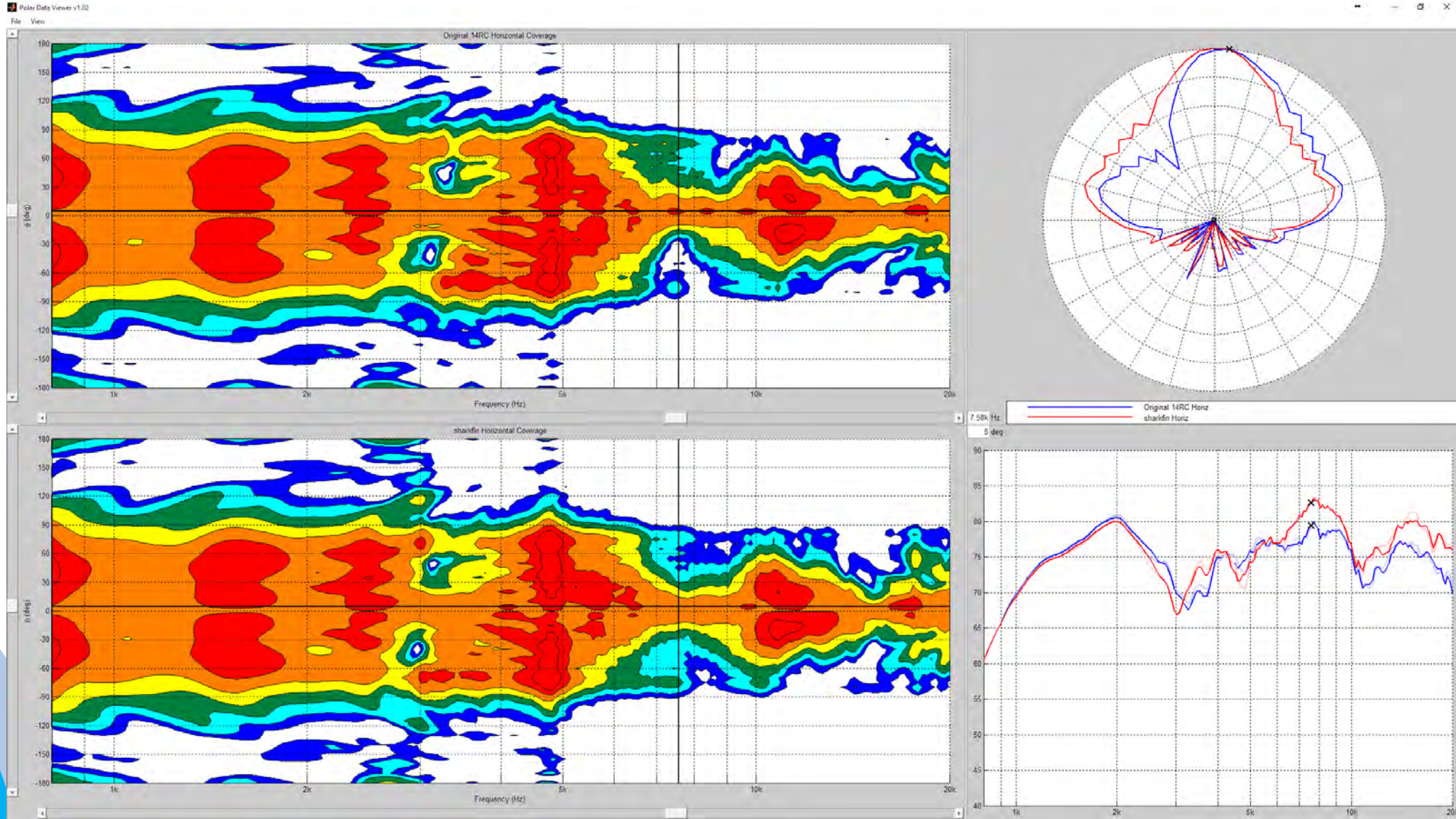


# Results



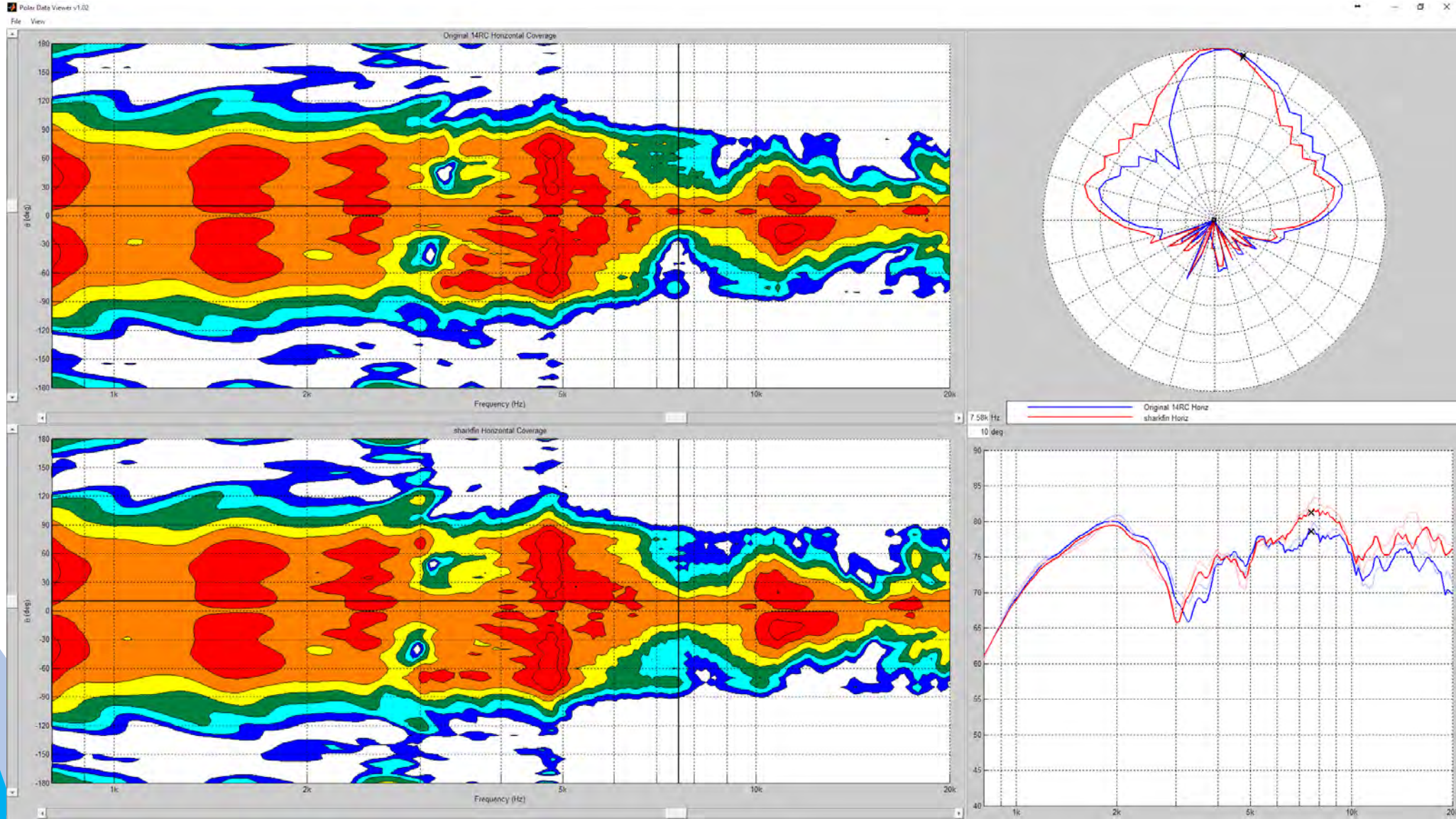


# Results



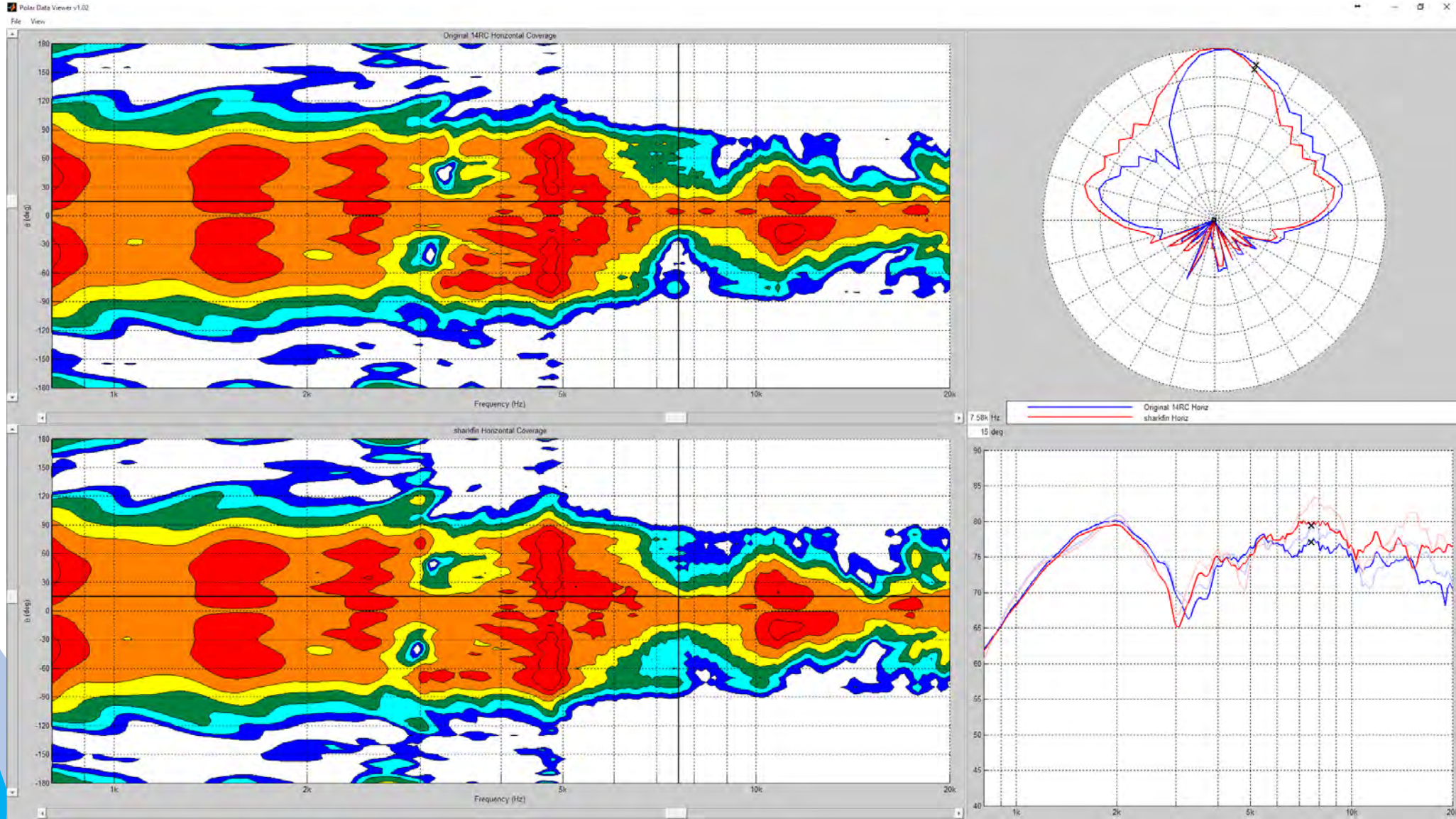


# Results



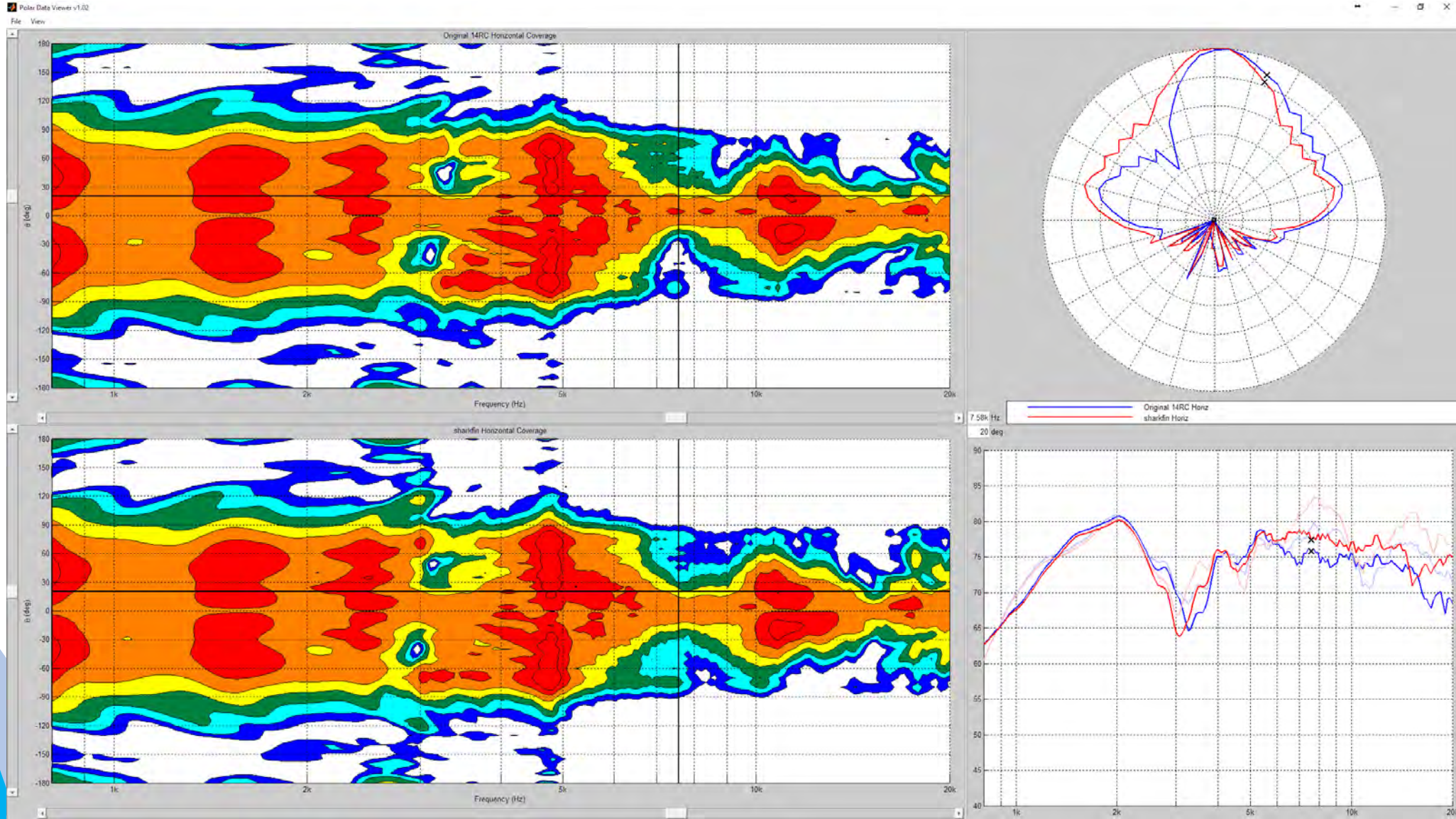


# Results



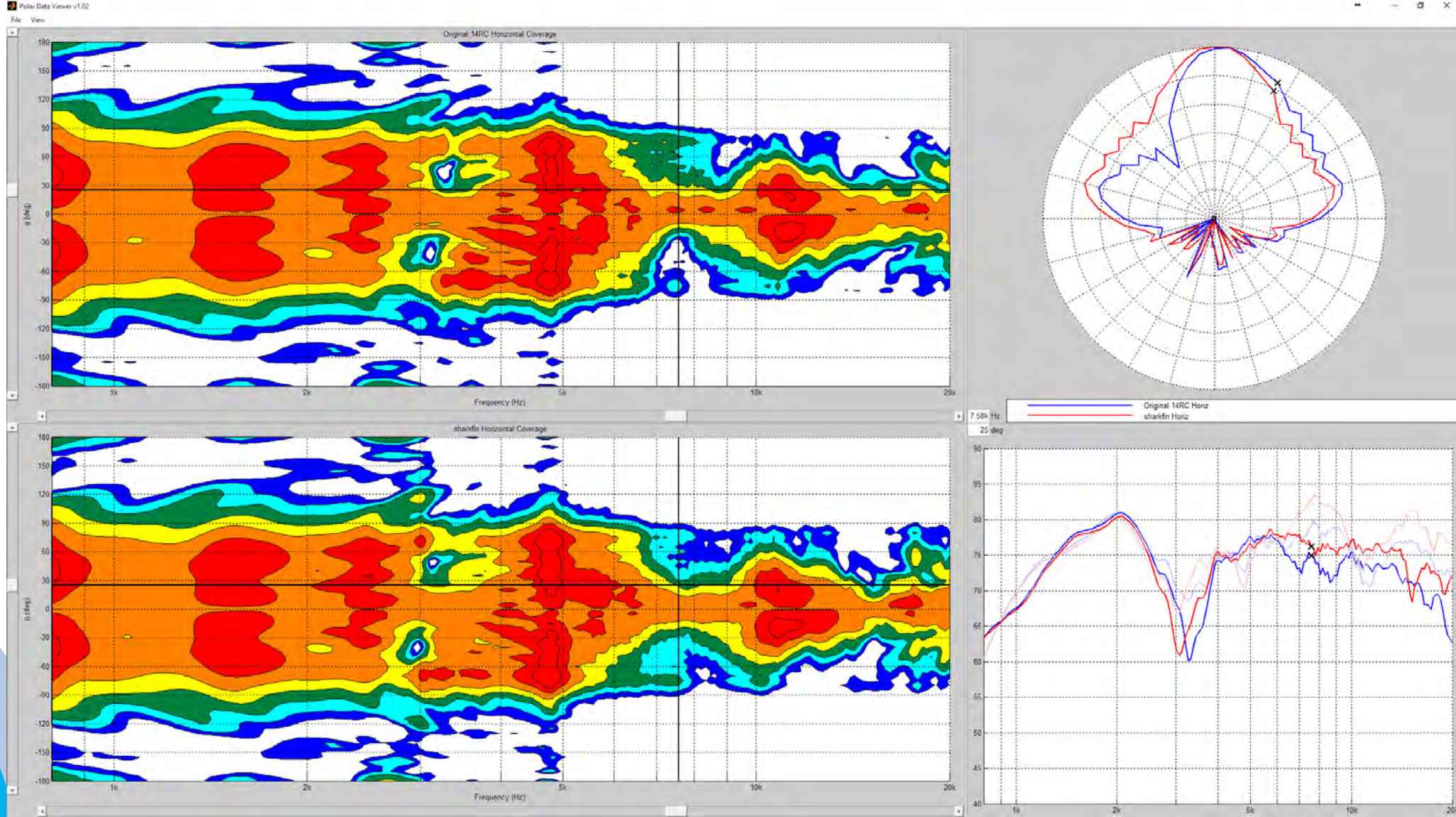


# Results



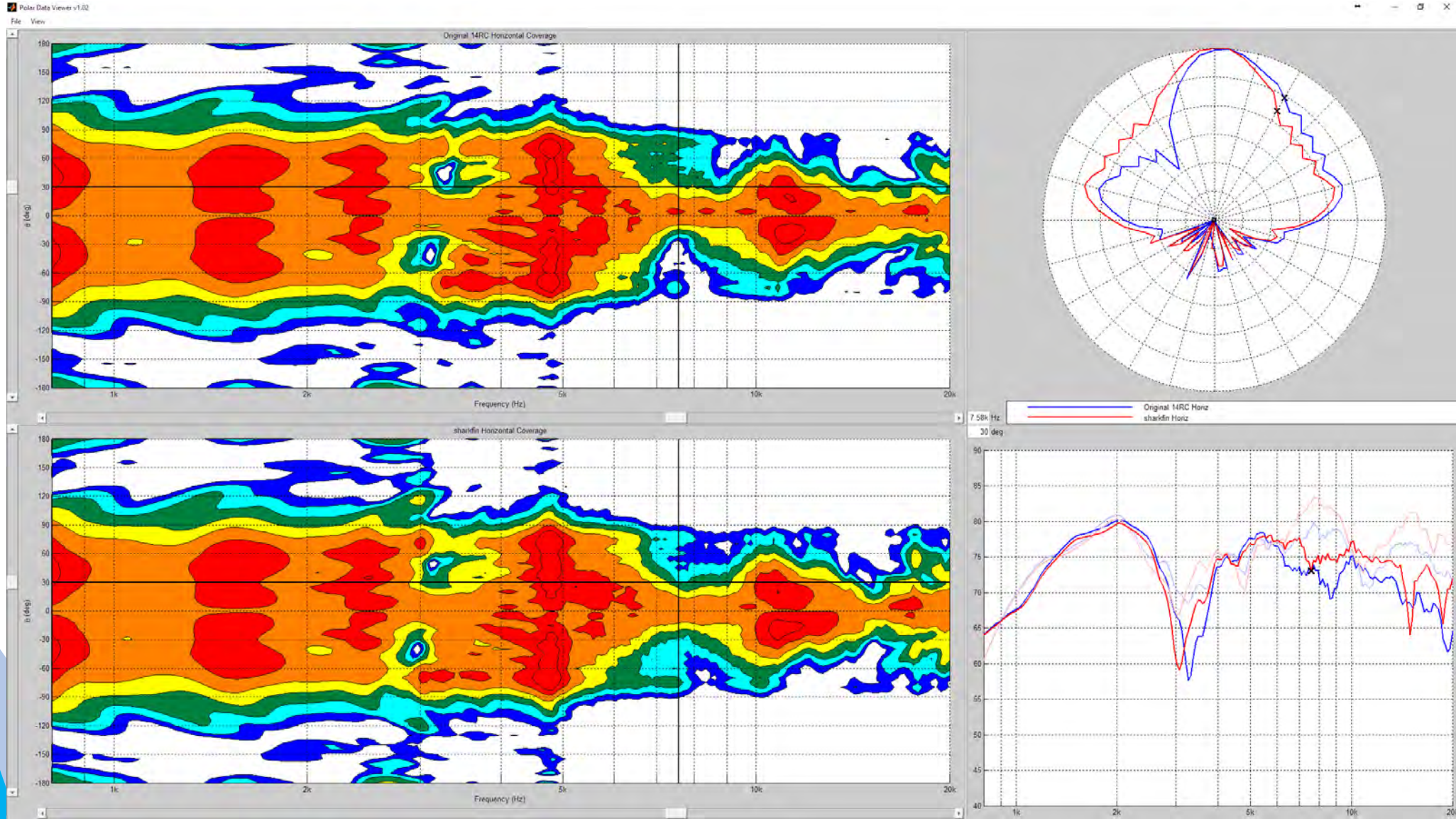


# Results



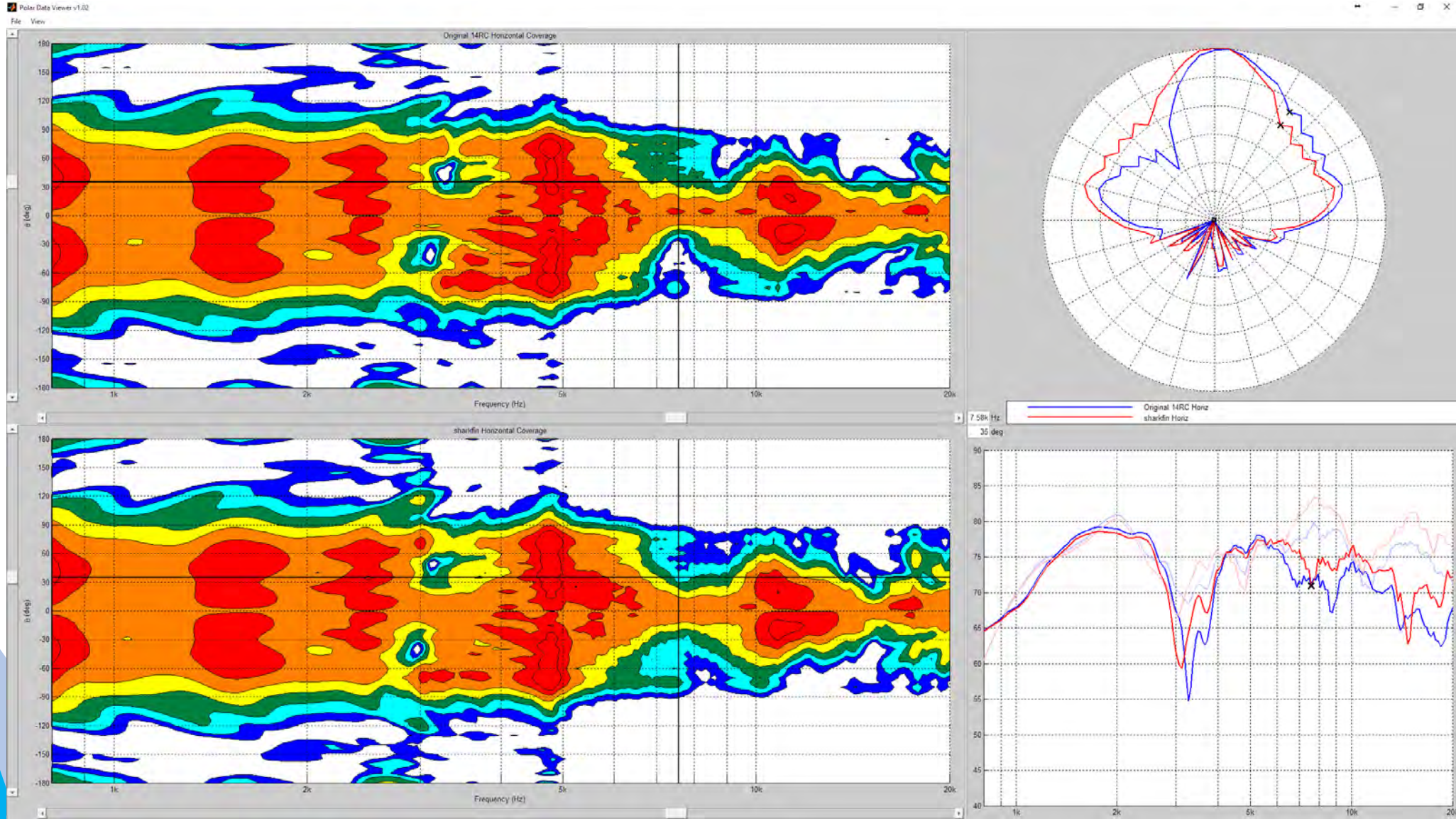


# Results



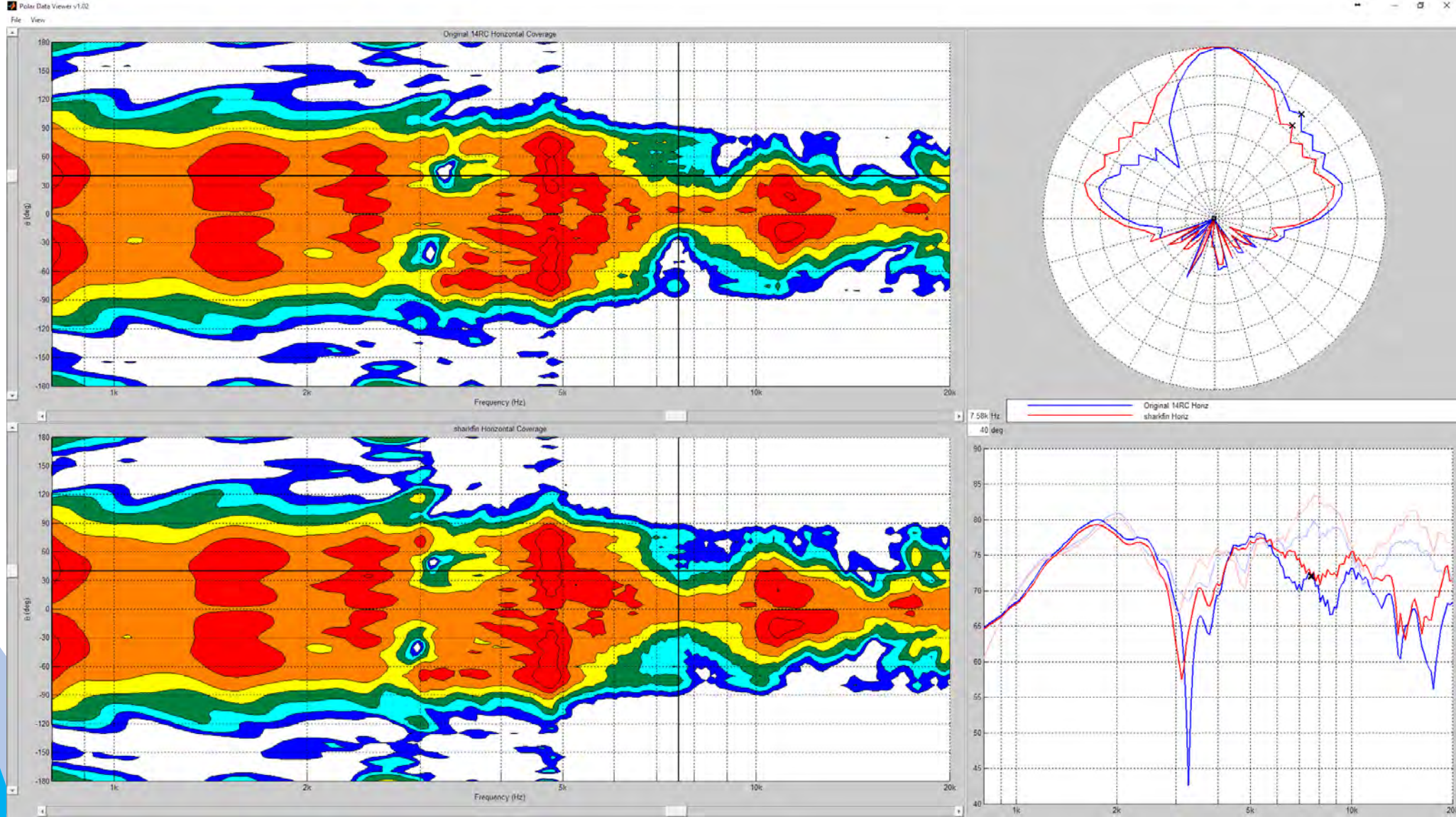


# Results



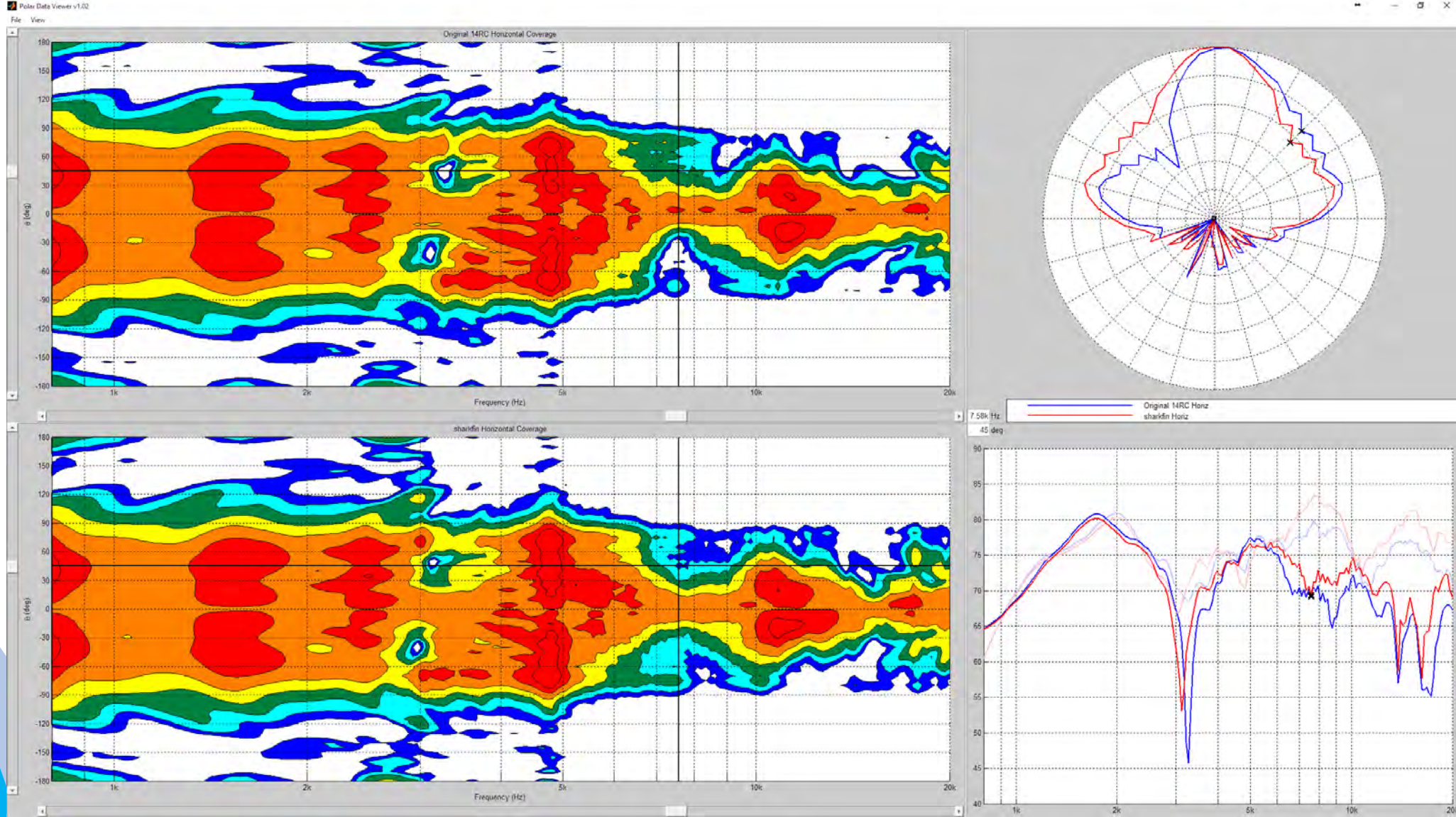


# Results



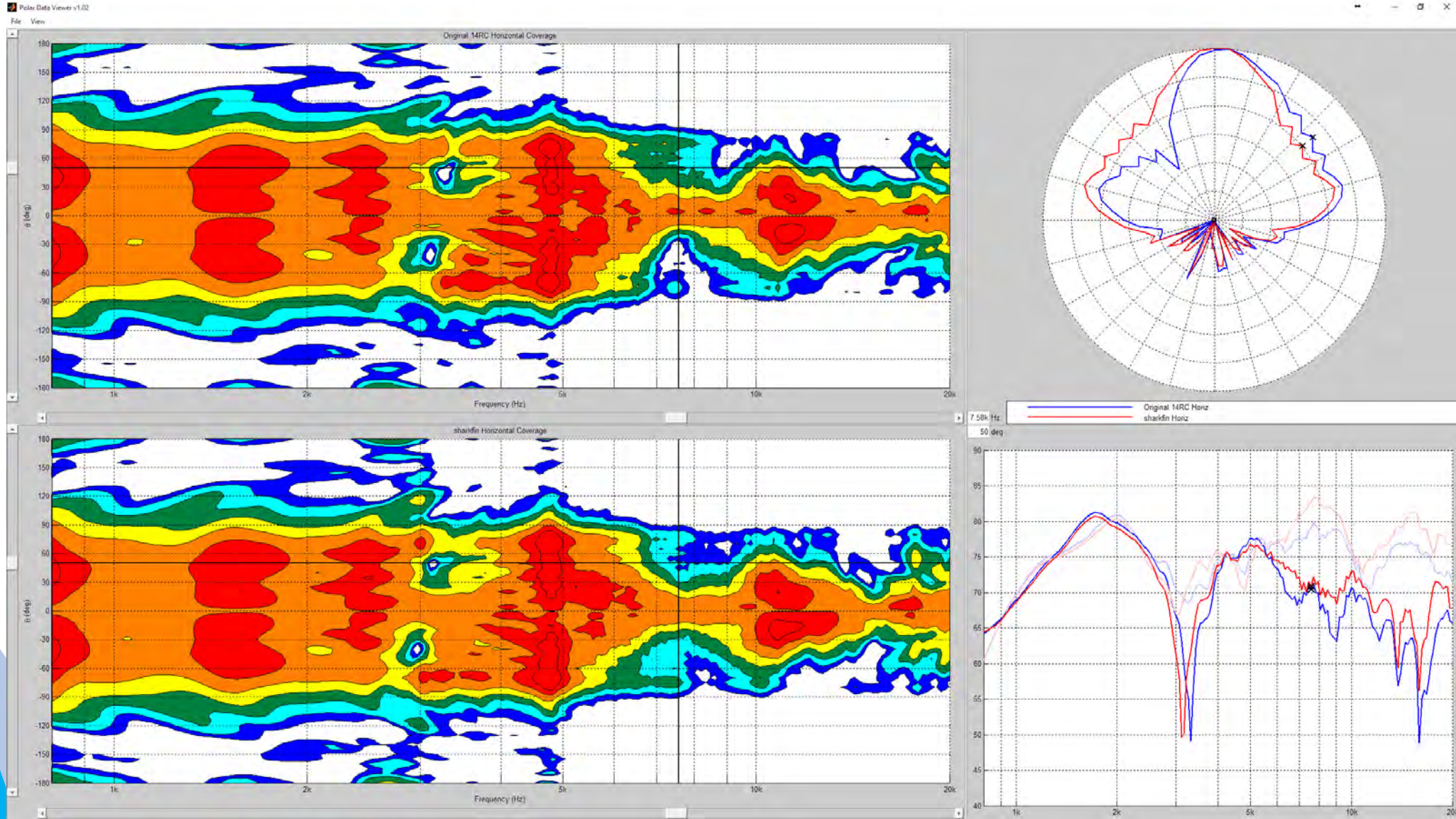


# Results



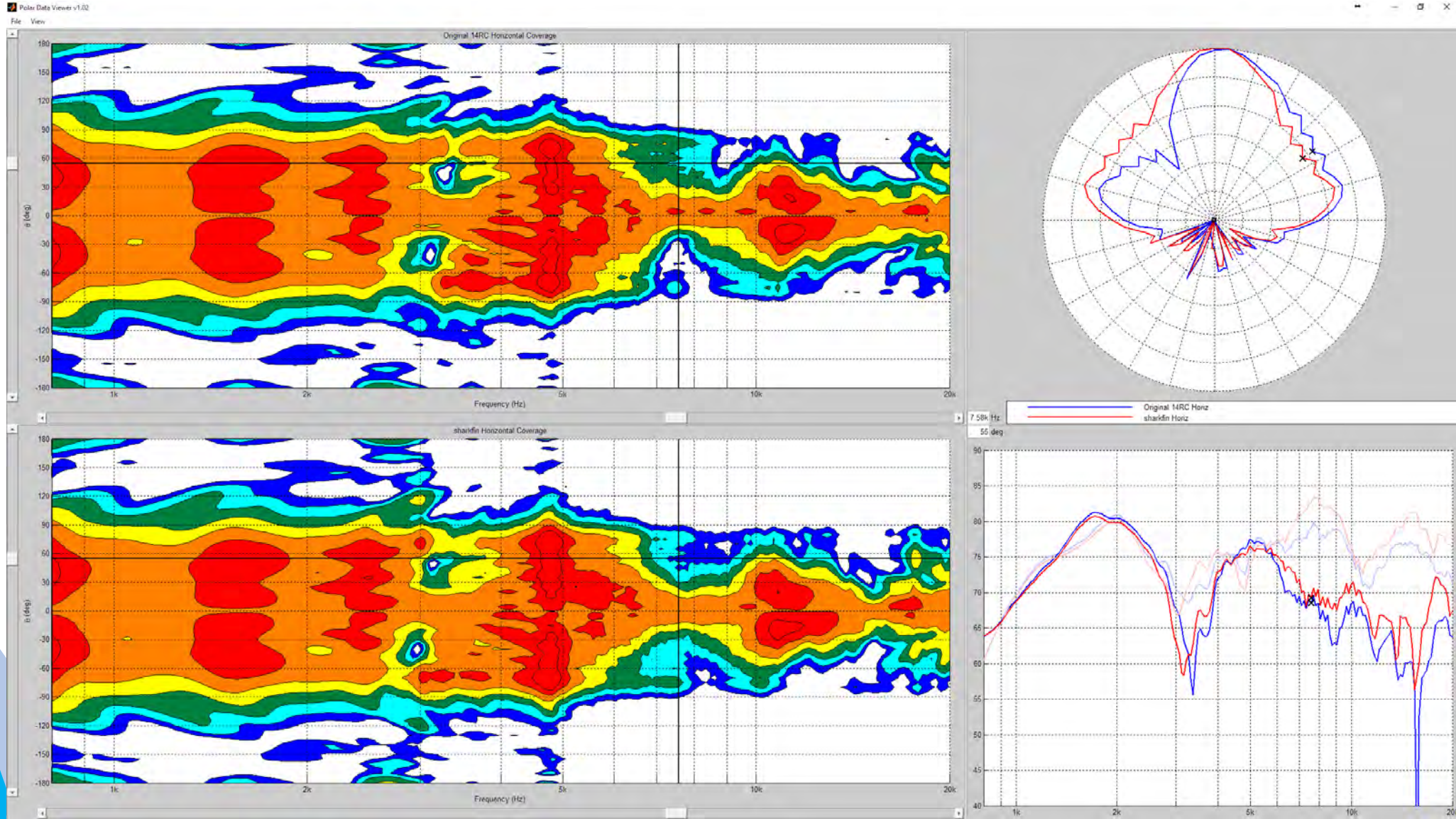


# Results



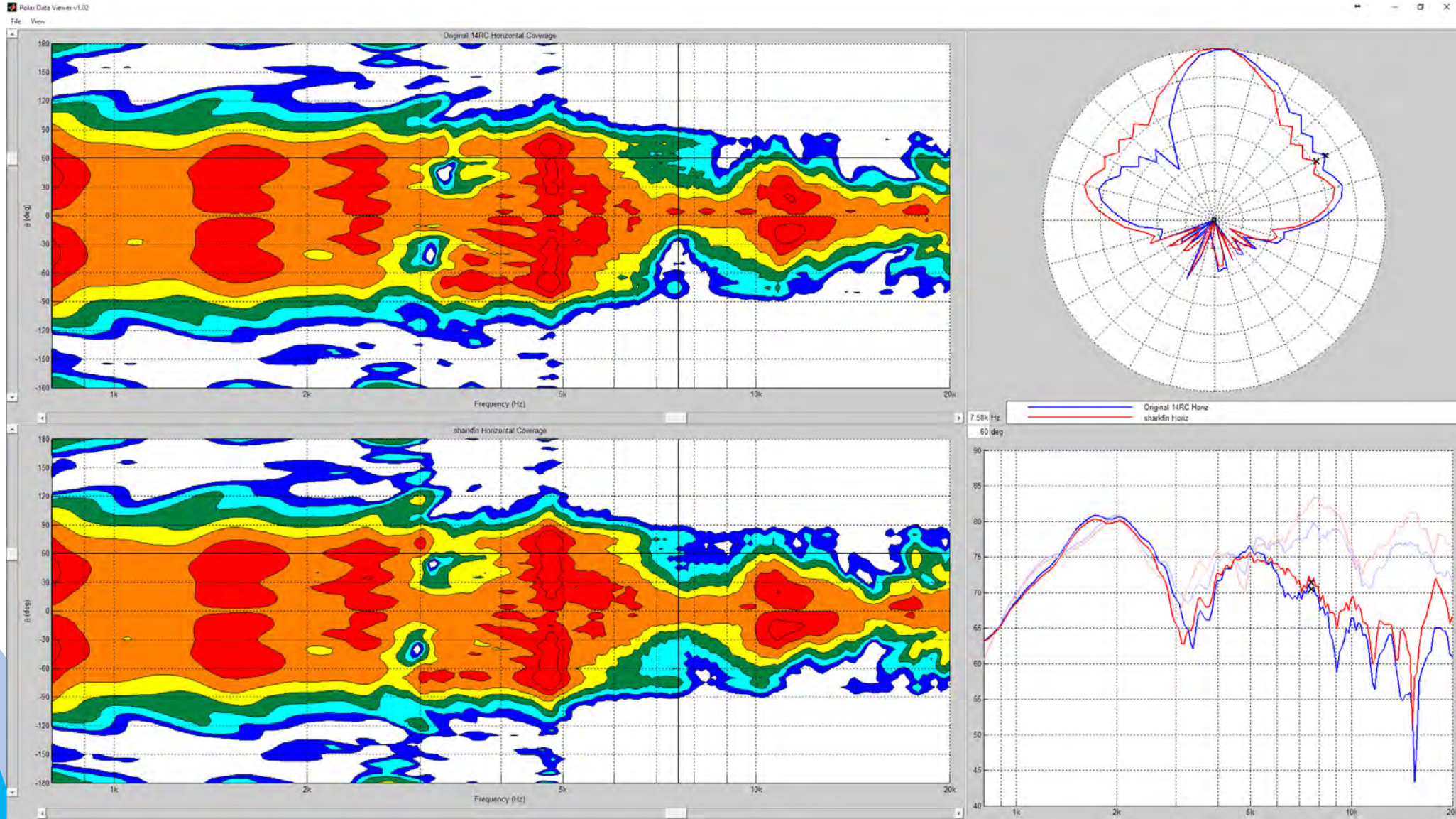


# Results



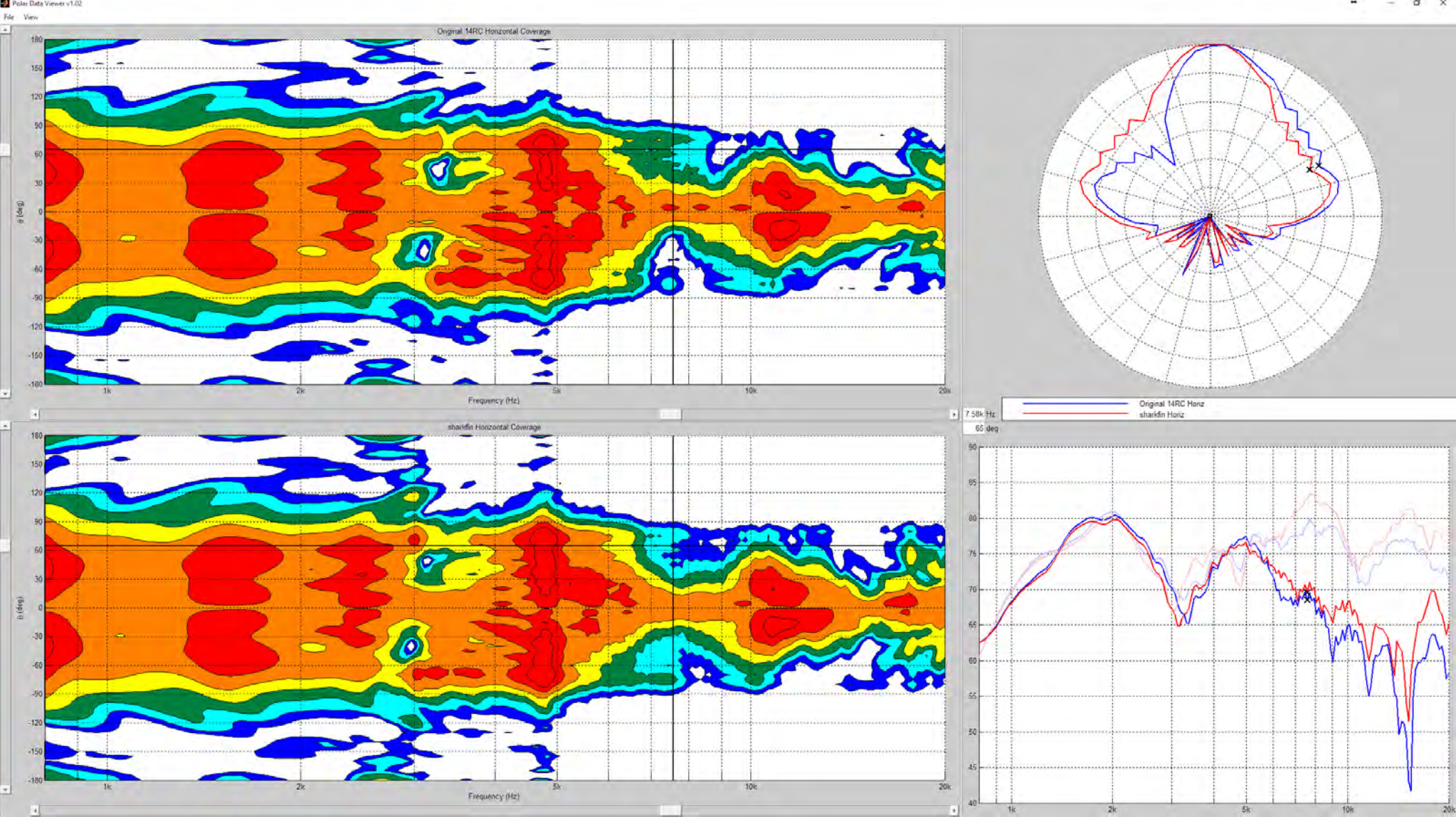


# Results



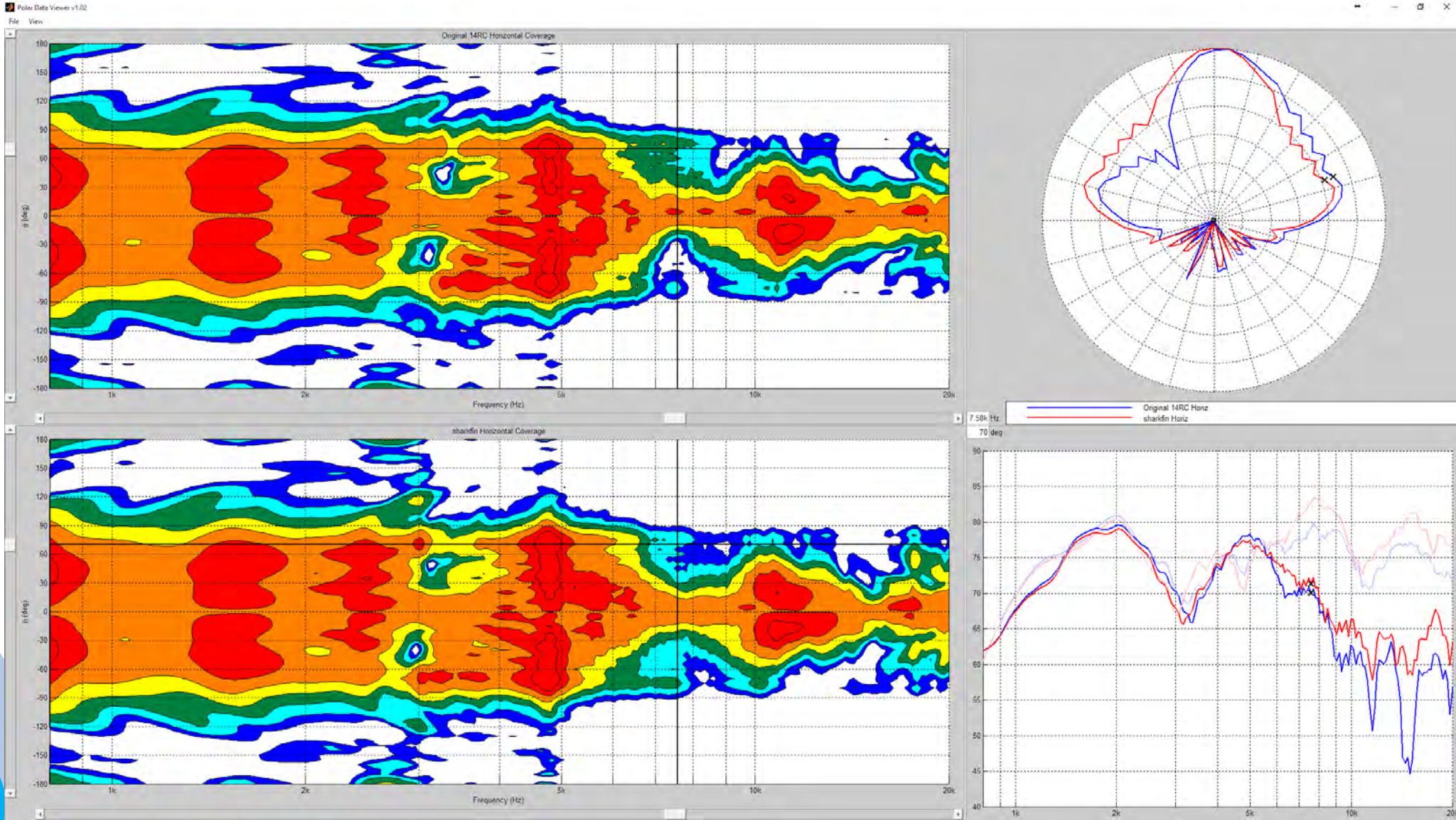


# Results



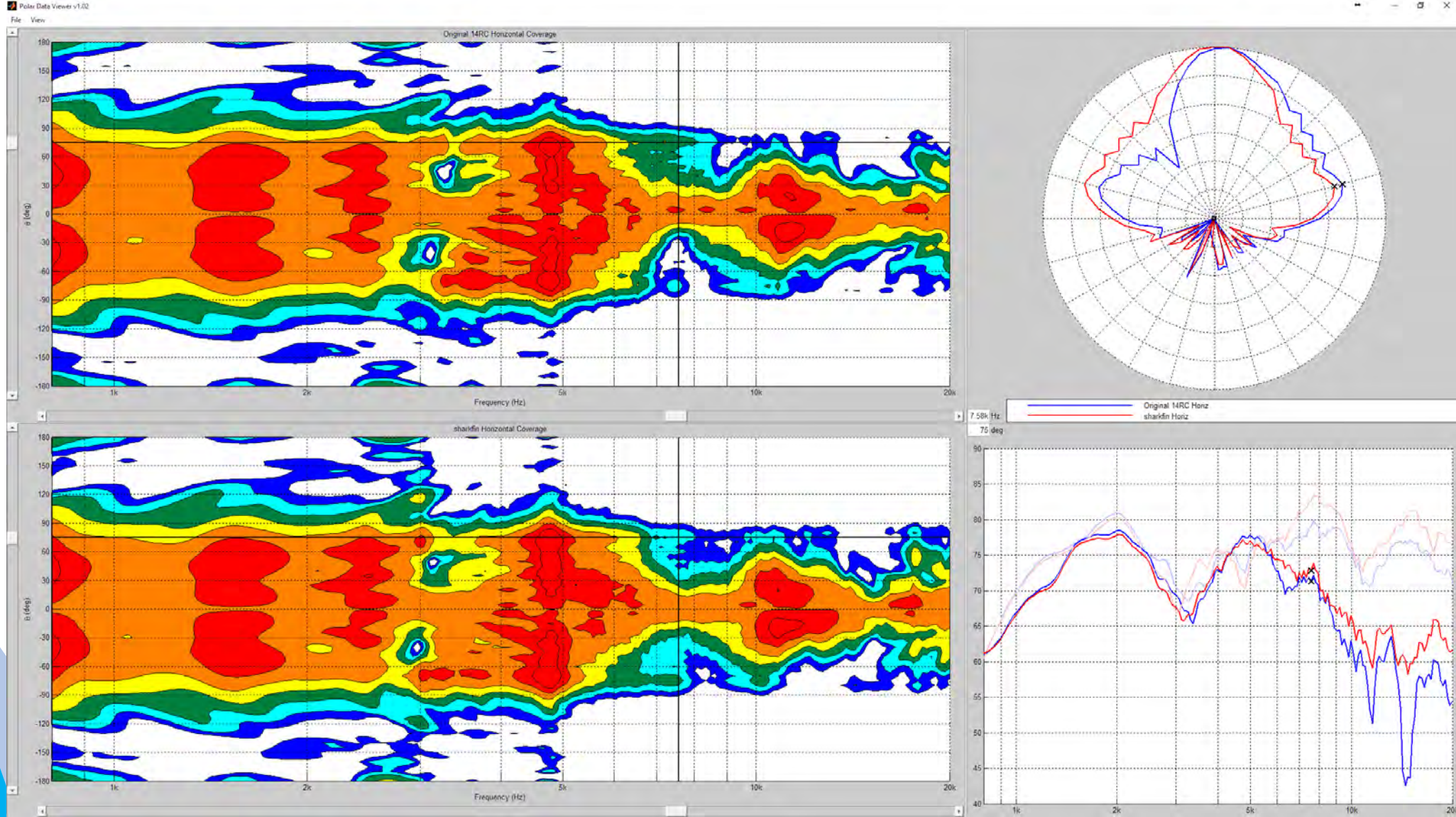


# Results



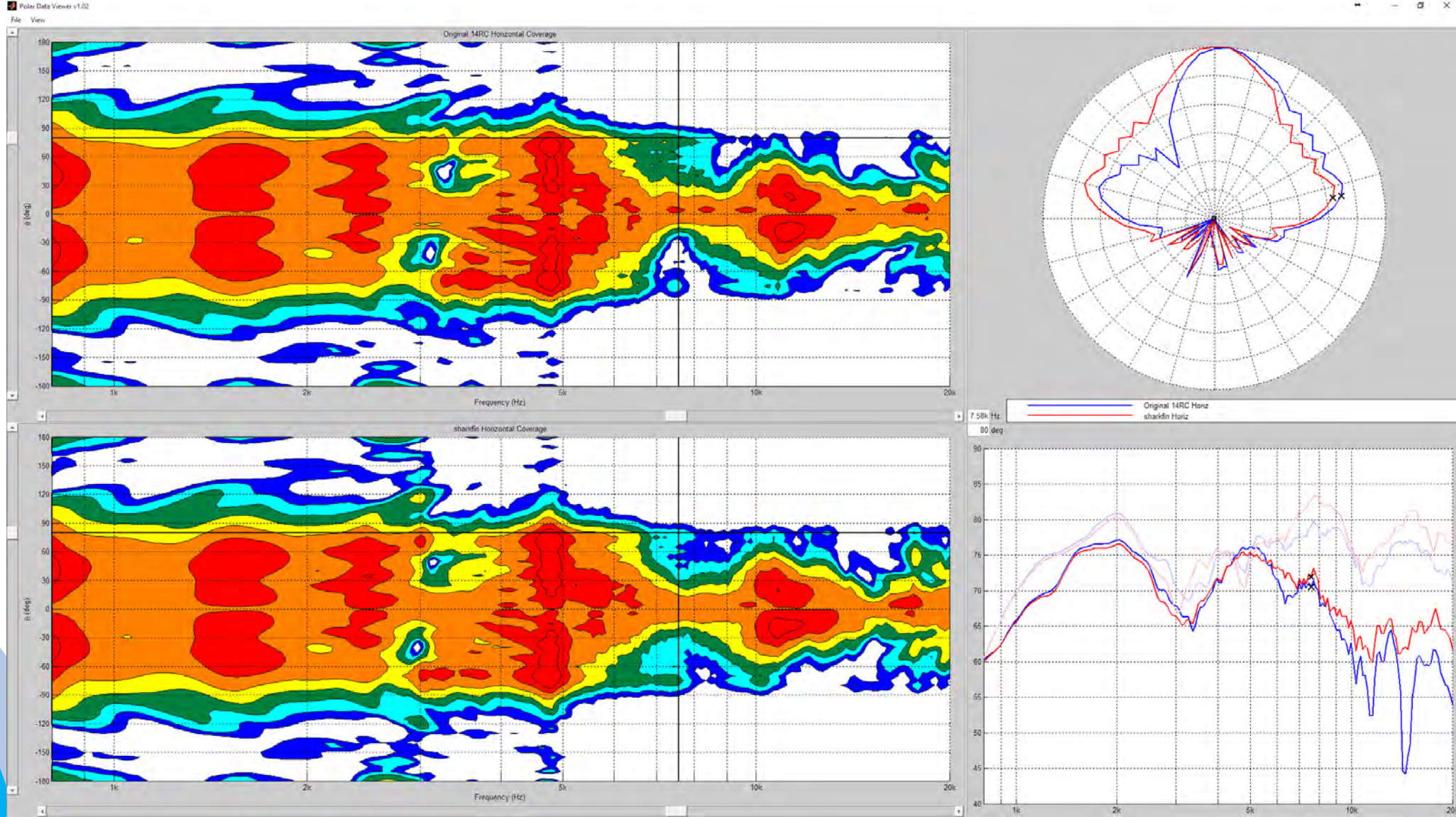


# Results



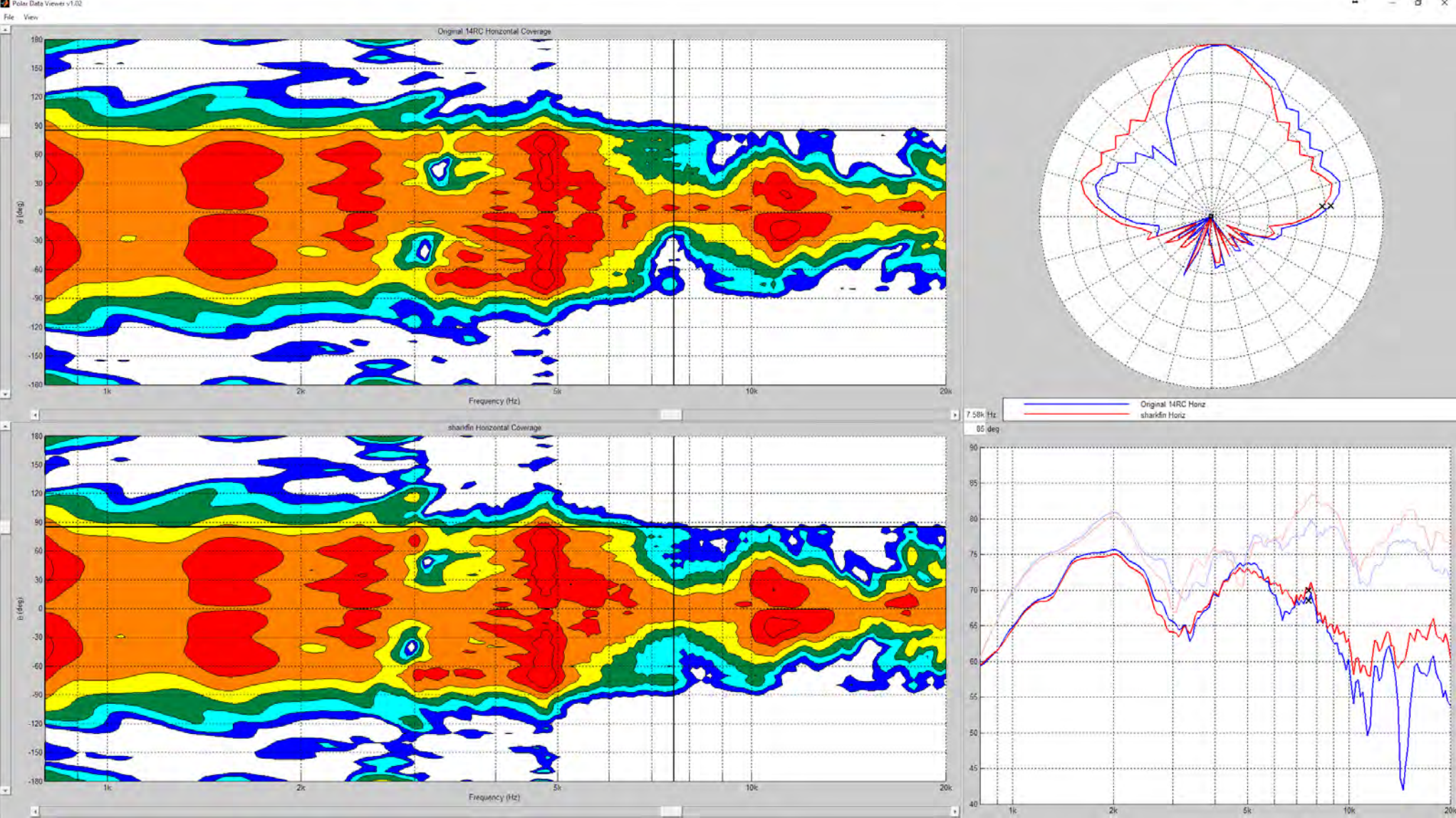


# Results



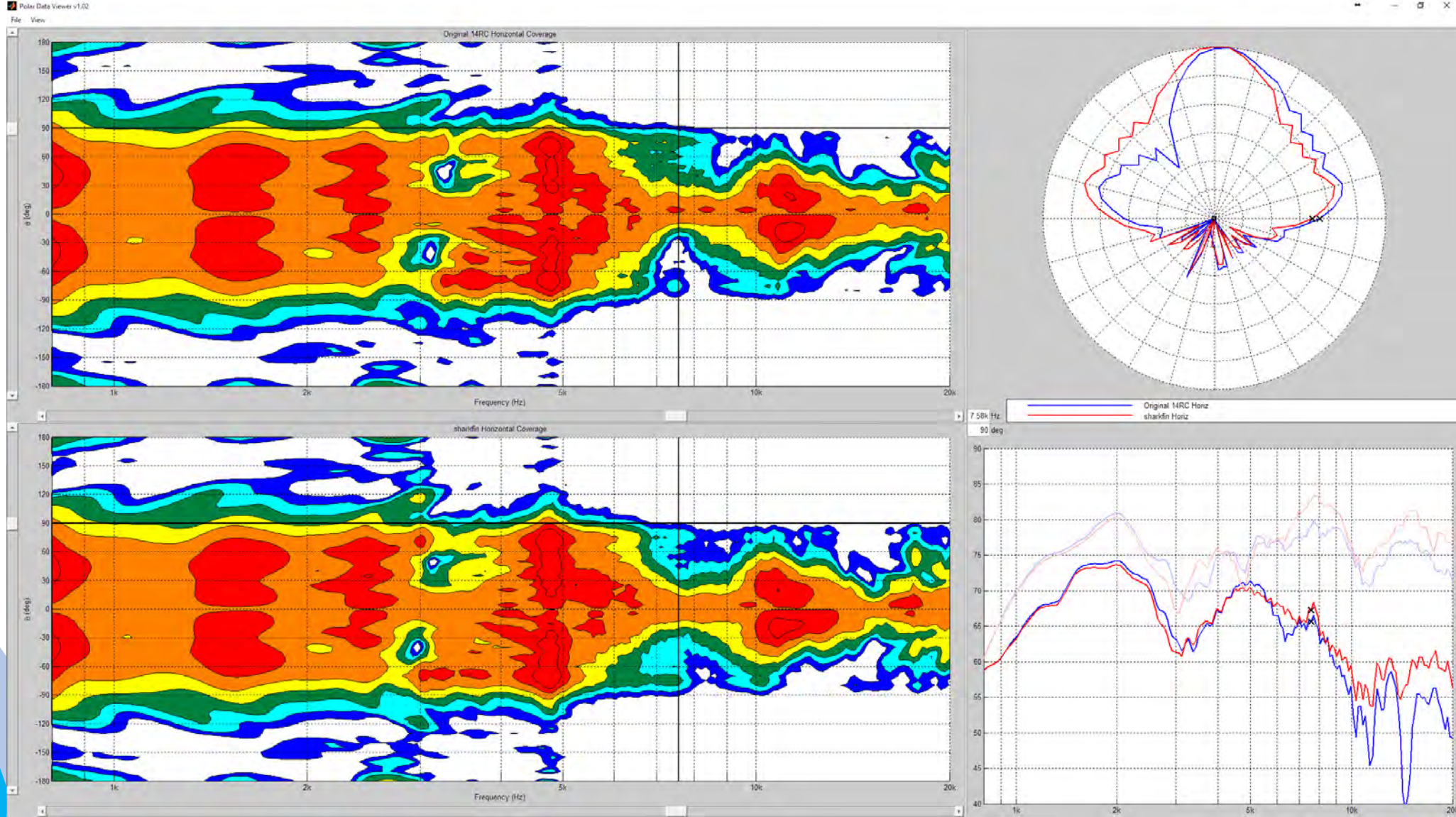


# Results





# Results





**Thank you**