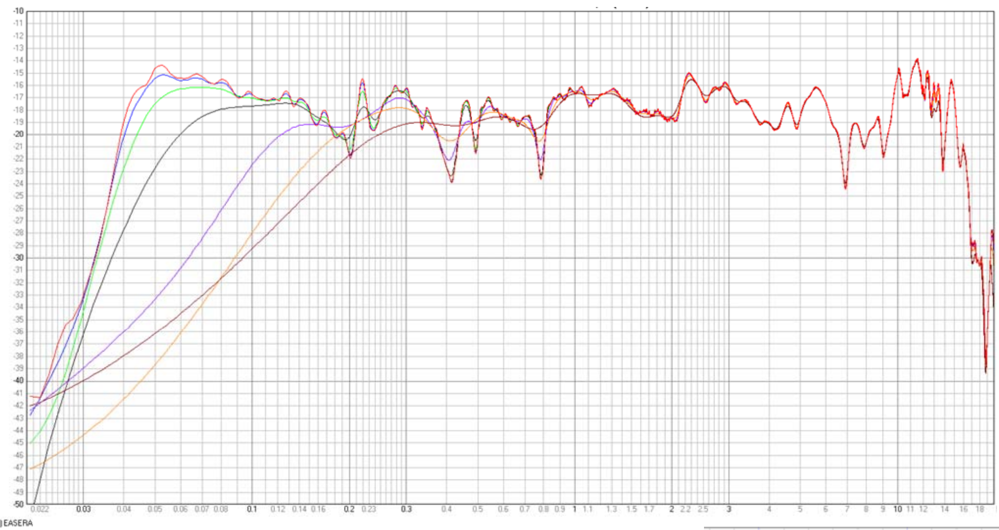
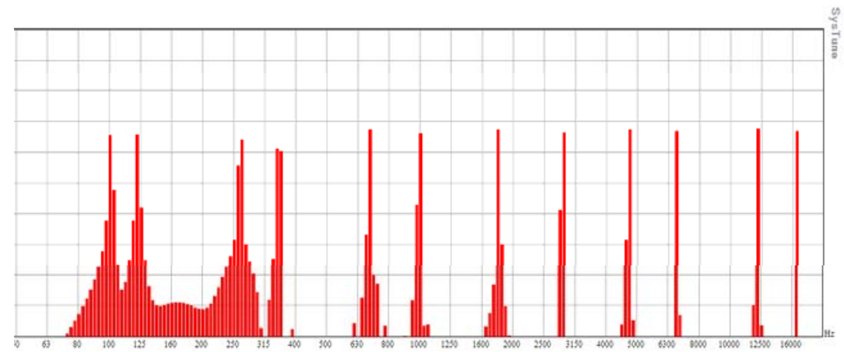
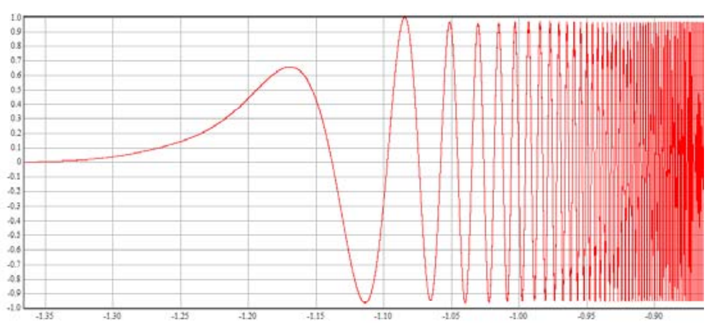
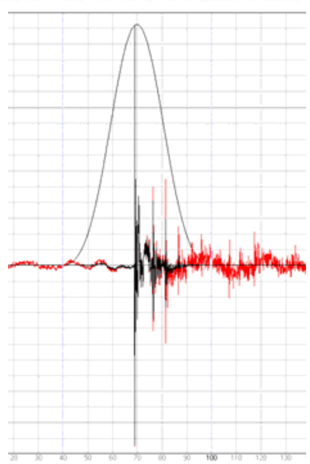
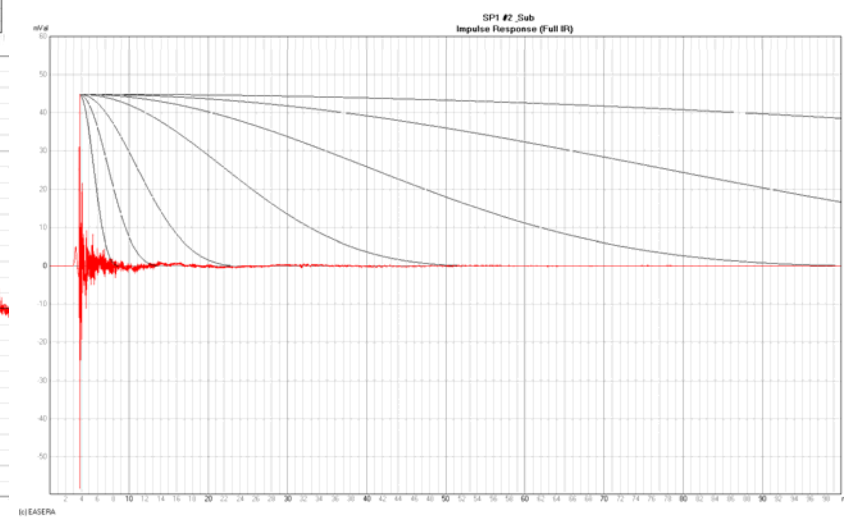
Introduction to Measurements of Loudspeakers and Rooms

Outline

- Things to Always Keep in Mind
- Types of Measurement Analyzers
  (FFT Based Analyzers)
- Types of Test Signals
- Measurement Microphones
- Measuring Loudspeakers vs. Measuring Rooms
- Time Windows
- Interpreting the Data
- Corrective Action

Things to Always Keep In Mind

Why are we measuring something?

What are we measuring?

Is it audible?

Does it matter?

Things to Always Keep In Mind

The Measurement Paradox:

To accurately measure a system one must first have knowledge of how the system performs. If the performance of a system is known, it need not be measured.

Why Are We Measuring?

- What do we hope to accomplish?
- How will the data be used?
- Are we troubleshooting to find the cause of a problem?
- Are we documenting performance?

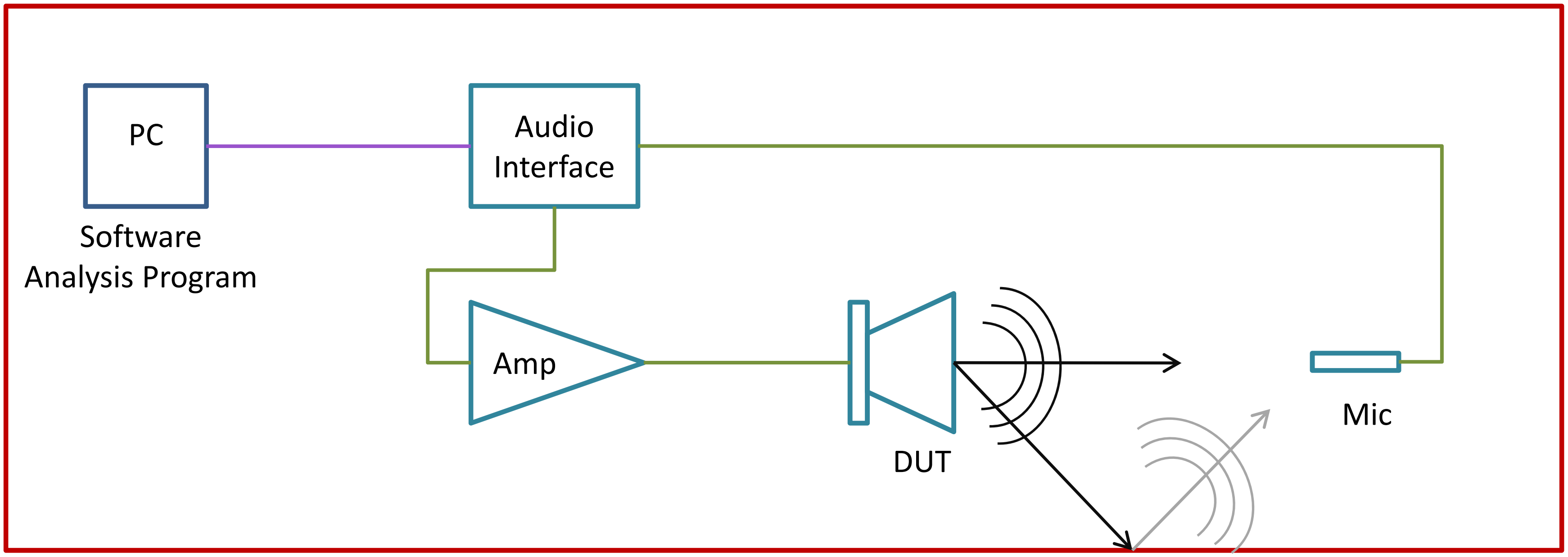
The answers will help to determine:

- Type of analyzer
- Test signal
- Resolution requirements (1/n octave)
- Calibrated or not

What Are We Measuring?

This may be different from what you think you are measuring.

- Mentally separate the Analyzer from the Device Under Test (DUT)
- Examine the signal flow
- Everything not the Analyzer is included in the measurement even though it may not be part of the intended DUT



What Are We Measuring?

Do we need to modify the measurement set-up to address things that are not actually part of our intended DUT?

Compensate for, or exclude, unwanted effects

- Non-flat microphone response
  - Microphone correction data (typically on-axis response only)
- Reflections
  - Can reflections be windowed out or can the DUT be moved?
- Noise
  - Can we increase the SPL of measurement signal or can we modify the measurement parameters for increased S/N?

Is it audible? **Does it matter?**

Types of Measurement Analyzers

- Ears & Brain
- RTA (Real Time Analyzer)
- Oscilloscope
- Dual-Channel FFT (Fast Fourier Transform)
  - Smaart, SIM, EASERA, SysTune, ARTA, etc.
- TDS (Time Delay Spectrometry)
  - TEF
- MLS (Maximum Length Sequence)
  - MLSSA

Which one to use depends on what we're trying to do.

Why are we measuring? **What are we measuring?**

Types of Measurement Analyzers

- Dual-Channel FFT (Fast Fourier Transform)
  - Smaart, SIM, EASERA, SysTune, ARTA, etc.
- TDS (Time Delay Spectrometry)
  - TEF
- MLS (Maximum Length Sequence)
  - MLSSA

These are Time Selective measurement systems.

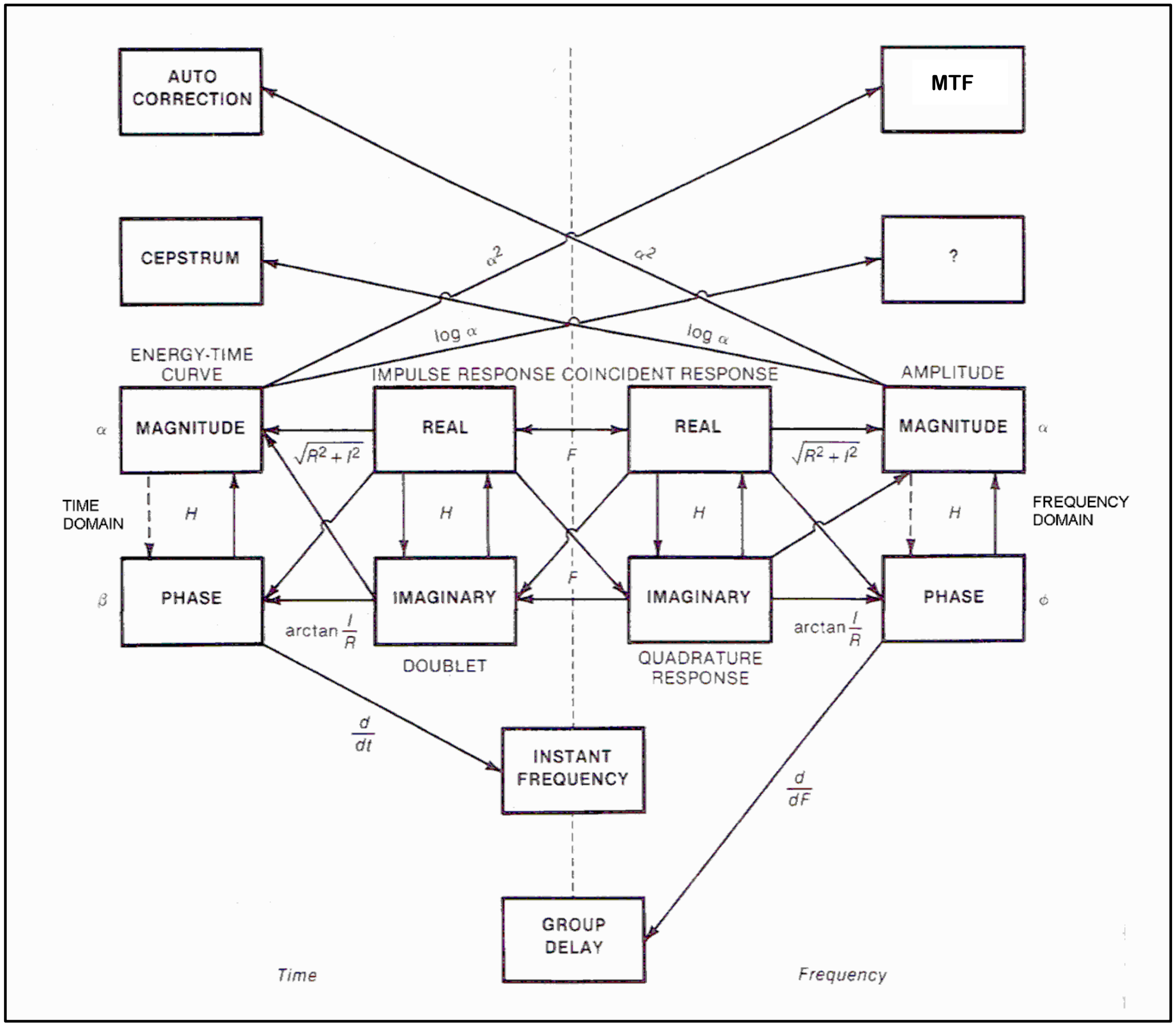
They give us the Impulse Response (IR) and the Transfer Function (TF) of a system.

The IR and TF are the exact same data but viewed from perspectives.

The IR is the view in the Time Domain.

The TF is the view in the Frequency Domain.

Fourier Transform Chart



FFT-Based Analyzers

An FFT block size must be selected.

This is the number of samples used to calculate the FFT. It is typically a power of 2 to take advantage of the binary mathematics used in modern computers.

An FFT block of 4,096 samples is 2^{13} samples.

The time length of an FFT block is the block size divided by the sample rate being used.

At 48 kHz, an FFT block of 4,096 samples is 85.33 ms long.

FFT-Based Analyzers

The frequency resolution available from an FFT block in the frequency domain is the sample rate divided by the block size (or the inverse of the FFT block time length).

At 48 kHz, an FFT block of 4,096 samples yields a resolution of 11.72 Hz.

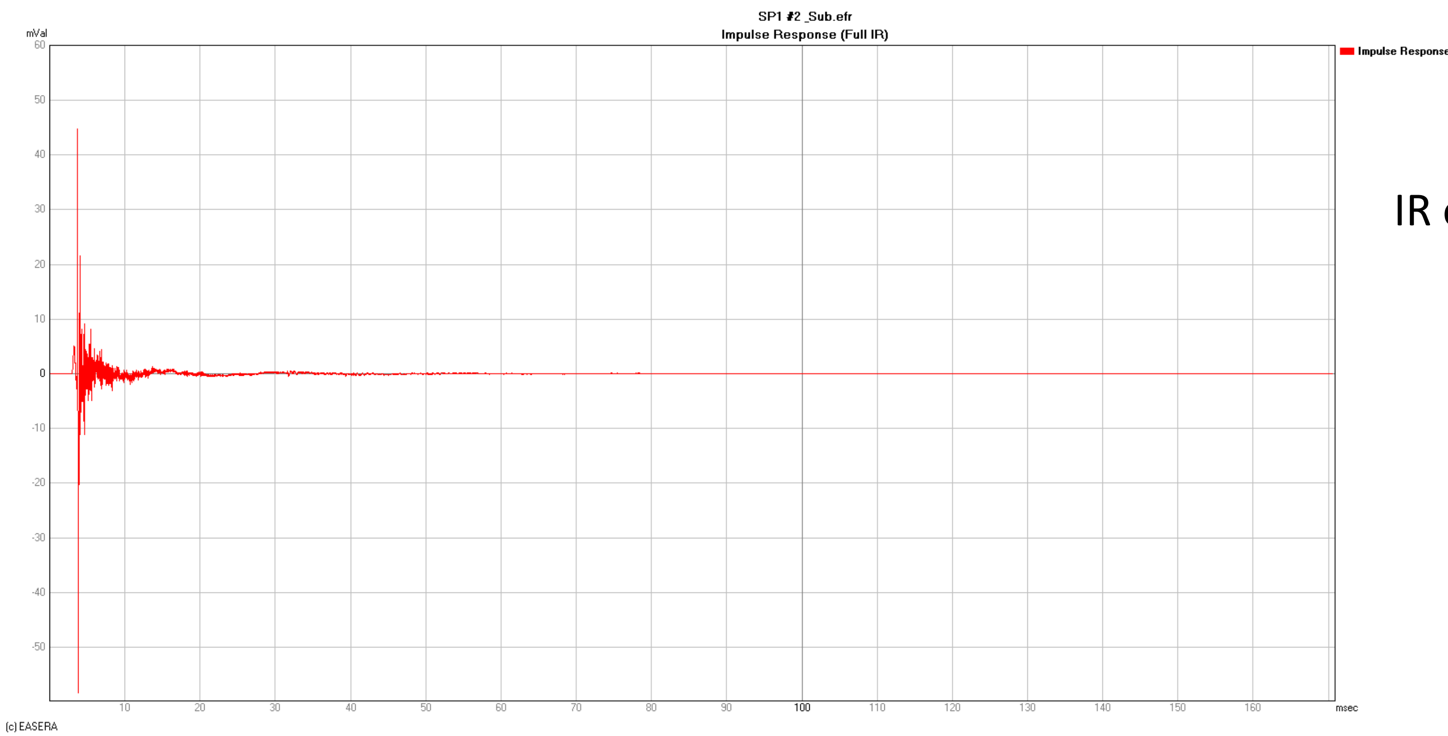
The more samples used in the FFT block, the better the frequency resolution.

More samples used in the FFT block results in a longer measurement time.

At 48 kHz, an FFT block of 65,536 samples yields a resolution of 0.73 Hz.
This FFT block is 1,365.33 ms (1.365 seconds) long.

FFT-Based Analyzers

The entire IR of the DUT must fit within the FTT block.

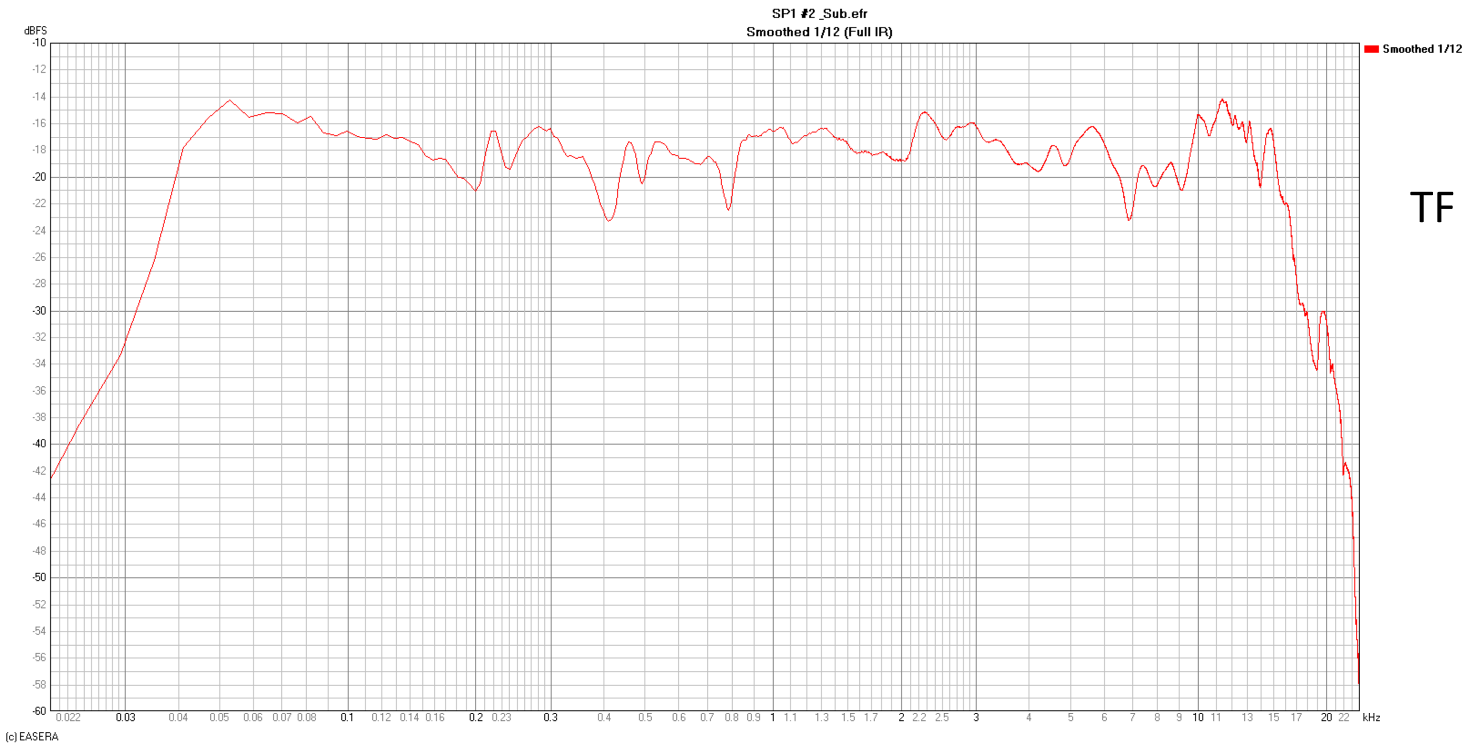


IR of a loudspeaker

The entire IR fits within the 171 ms FFT block (8,192 samples).

FFT-Based Analyzers

An FFT of the IR yields this frequency response.

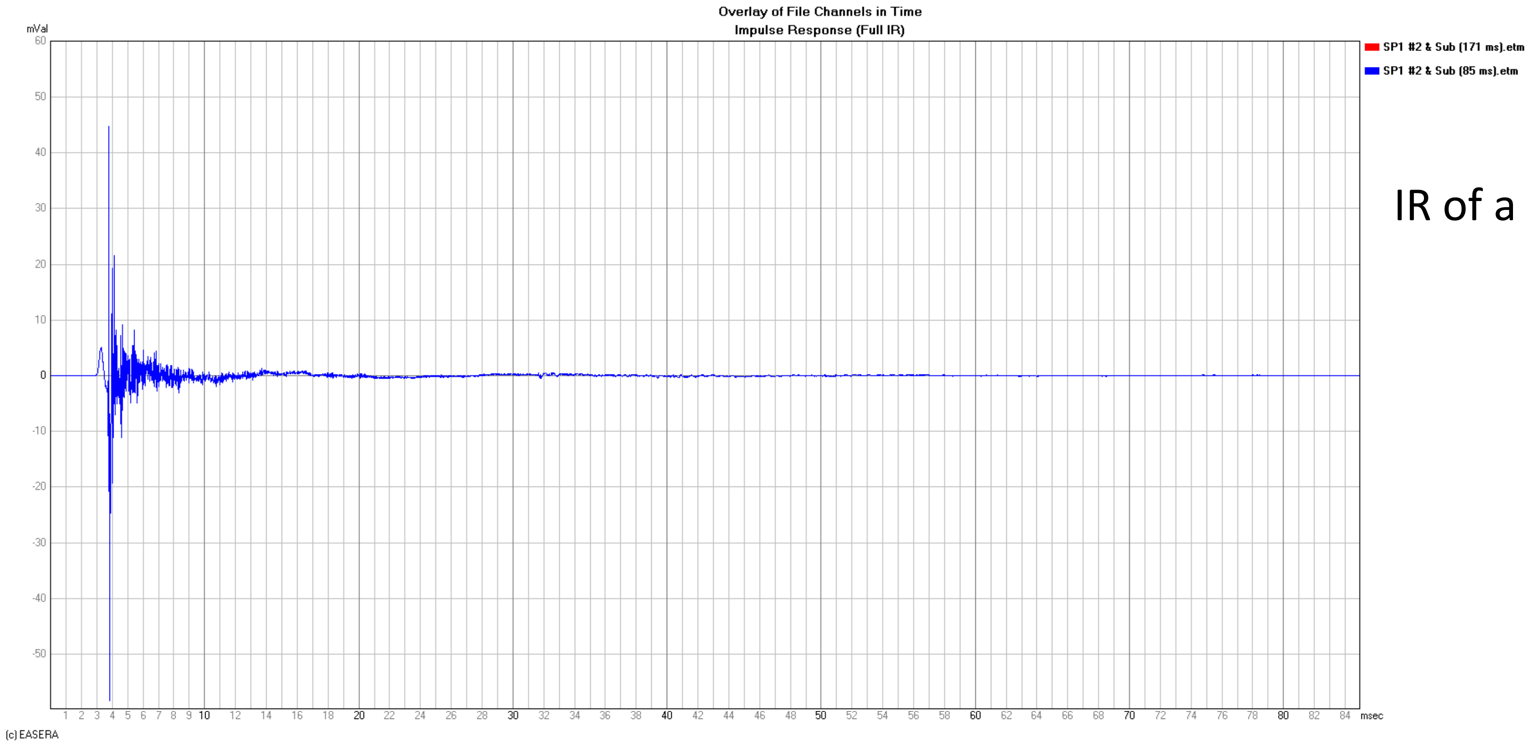


TF of a loudspeaker

The 171 ms FFT block yields a frequency resolution of 5.86 Hz.

FFT-Based Analyzers

The entire IR still fits within the smaller FFT block.

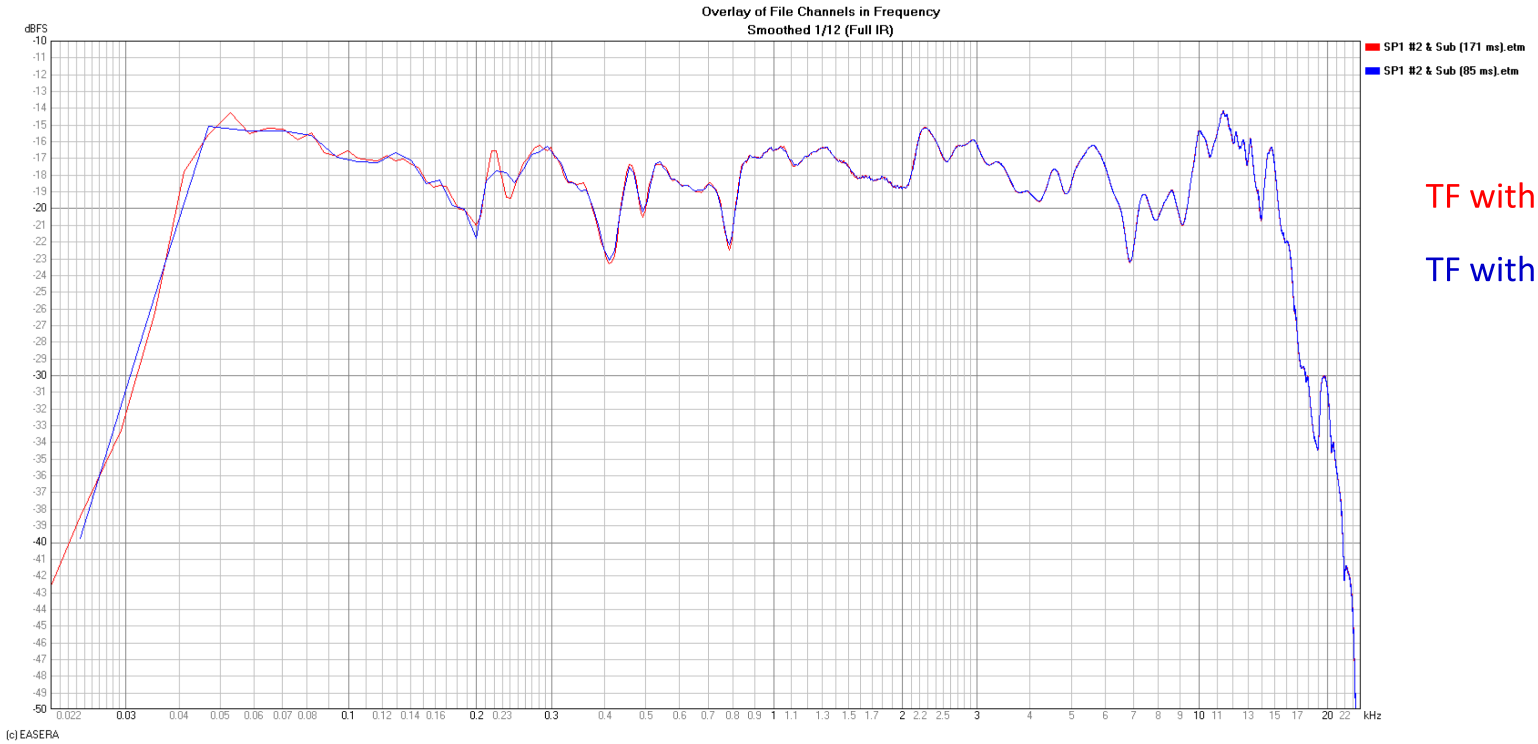


IR of a loudspeaker

An 85 ms FFT block (4,096 samples)

FFT-Based Analyzers

The entire IR still fits within the smaller FFT block.



TF with 171 ms FFT

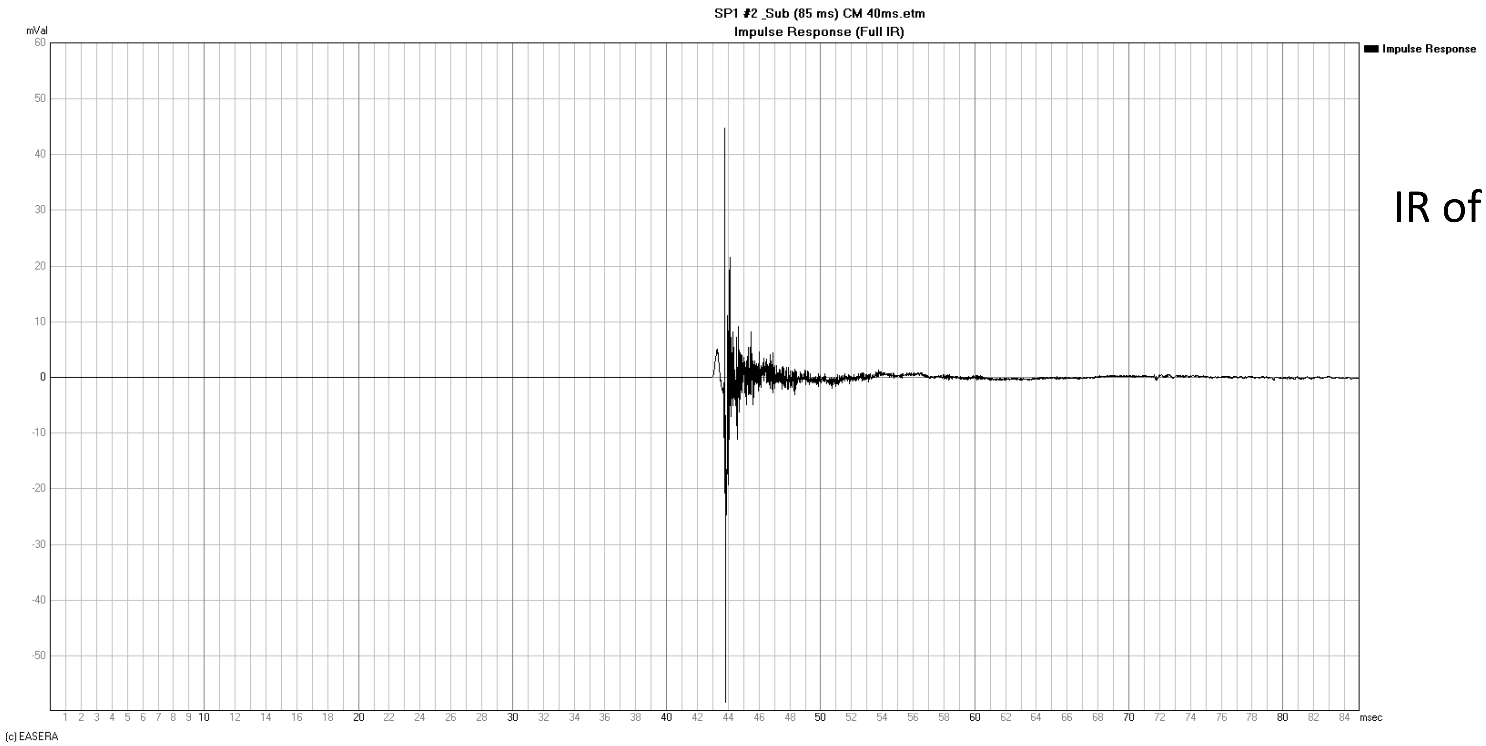
TF with 85 ms FFT

171 ms FFT block with 5.86 Hz resolution

85 ms FFT block with 11.7 Hz resolution

FFT-Based Analyzers

The loudspeaker is about 40 ft farther away. The entire IR does not fit within the FFT block.

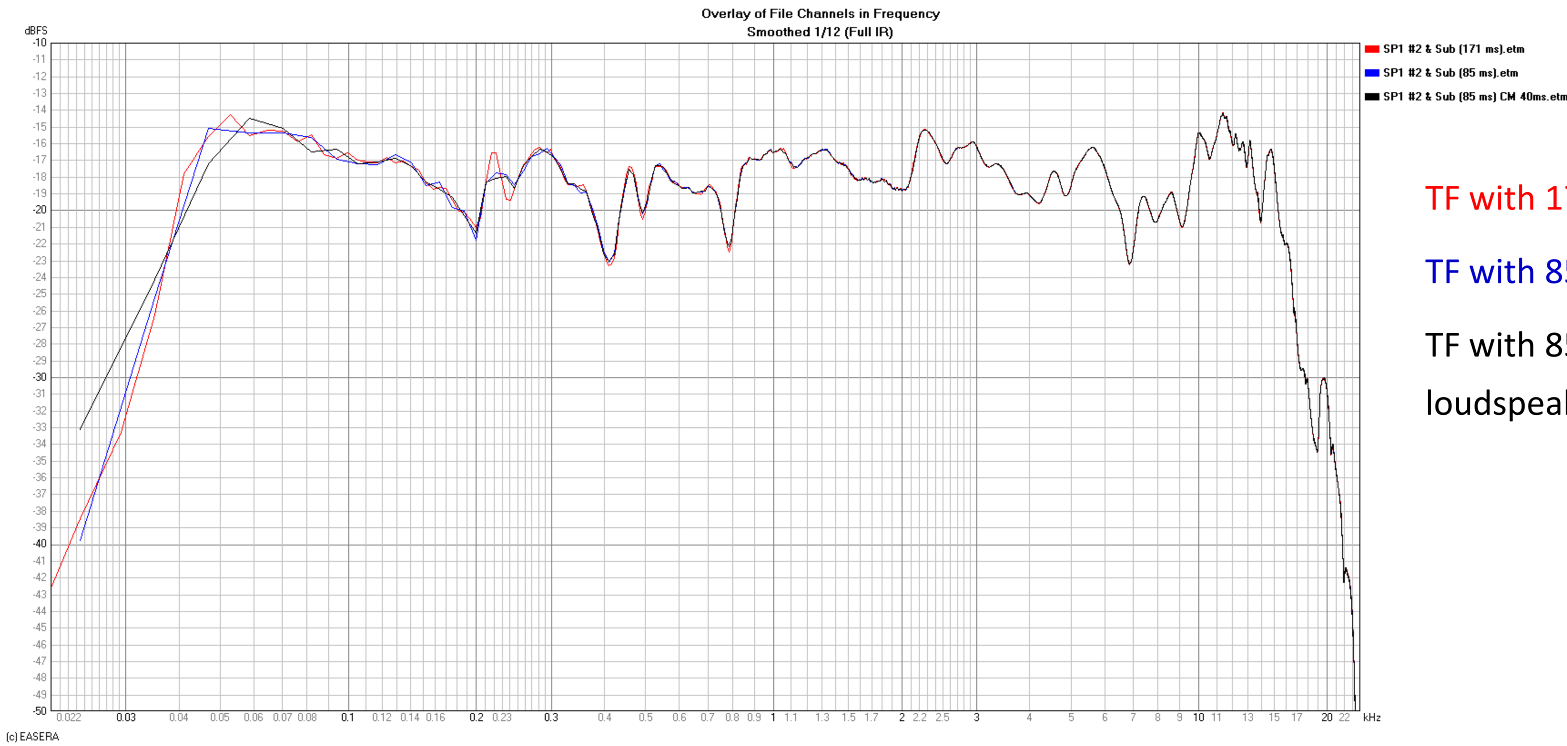


IR of a loudspeaker

An 85 ms FFT block (4,096 samples)

FFT-Based Analyzers

The entire IR does not fit within the FFT block. This results in errors in the Transfer Function.



TF with 171 ms FFT

TF with 85 ms FFT

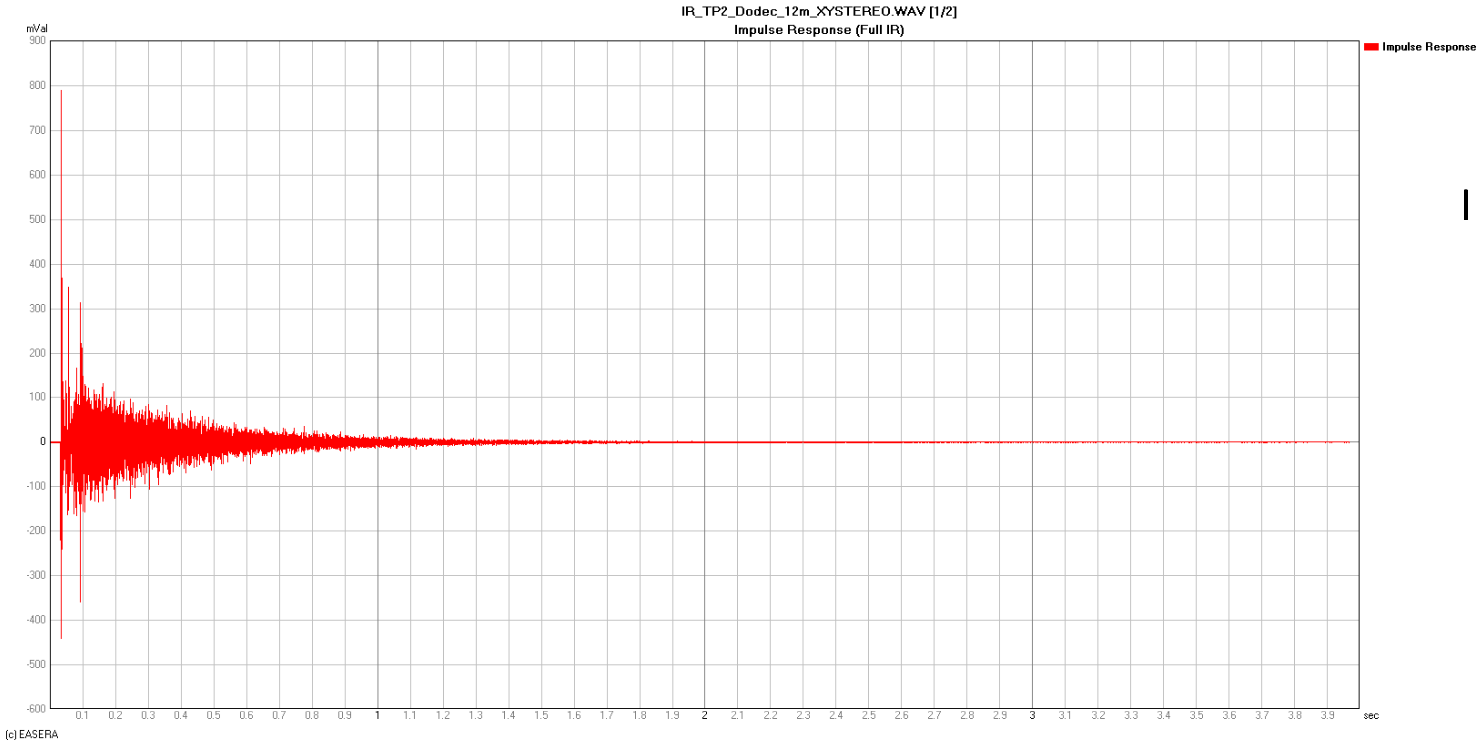
TF with 85 ms FFT, loudspeaker 40 ft away

171 ms FFT block with 5.86 Hz resolution

85 ms FFT block with 11.7 Hz resolution

FFT-Based Analyzers

It can be difficult to determine the required FFT size for room measurements from viewing the IR.



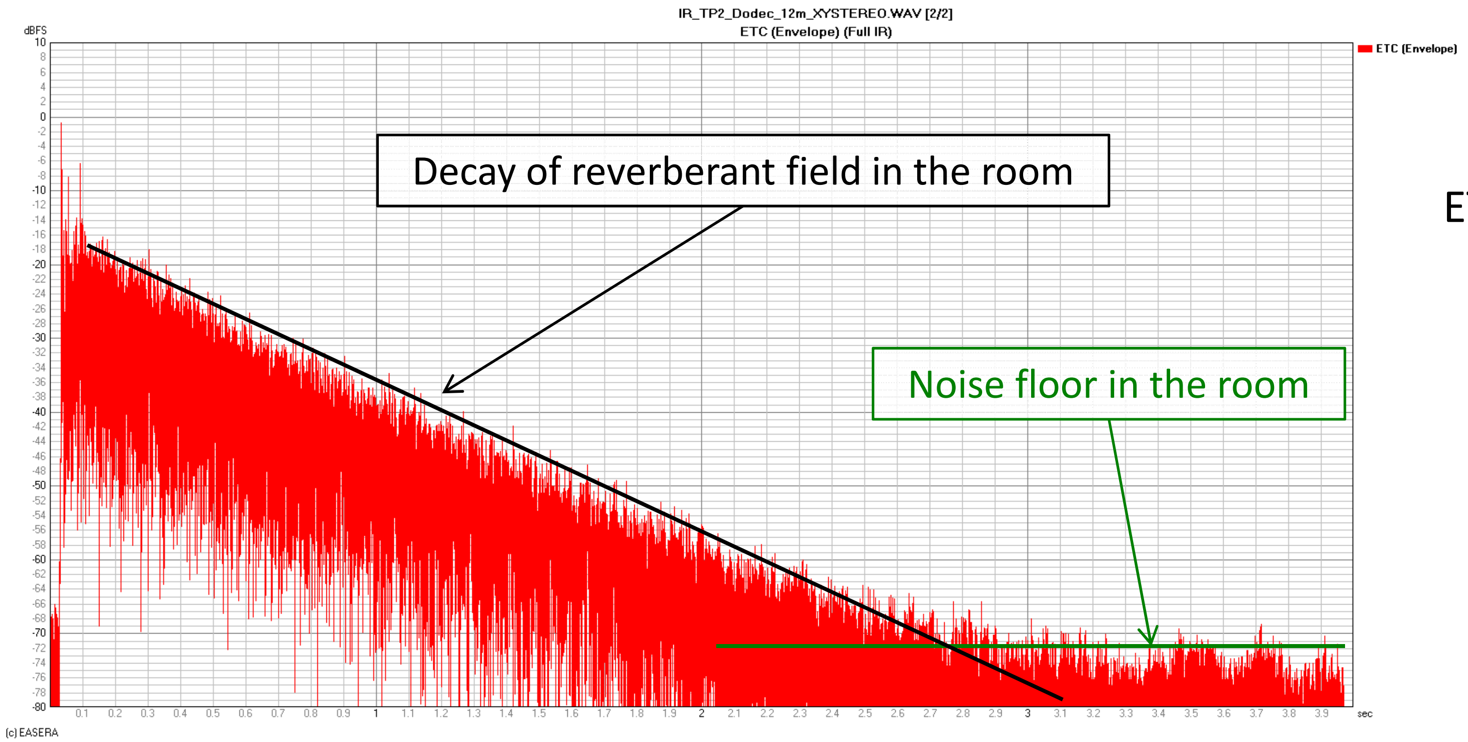
IR of a room

Measurement is just under 4 seconds.

An FFT block of 262,144 sample would be 5.46 seconds.

FFT-Based Analyzers

Looking at the ETC (Envelope Time Curve) can be more helpful.

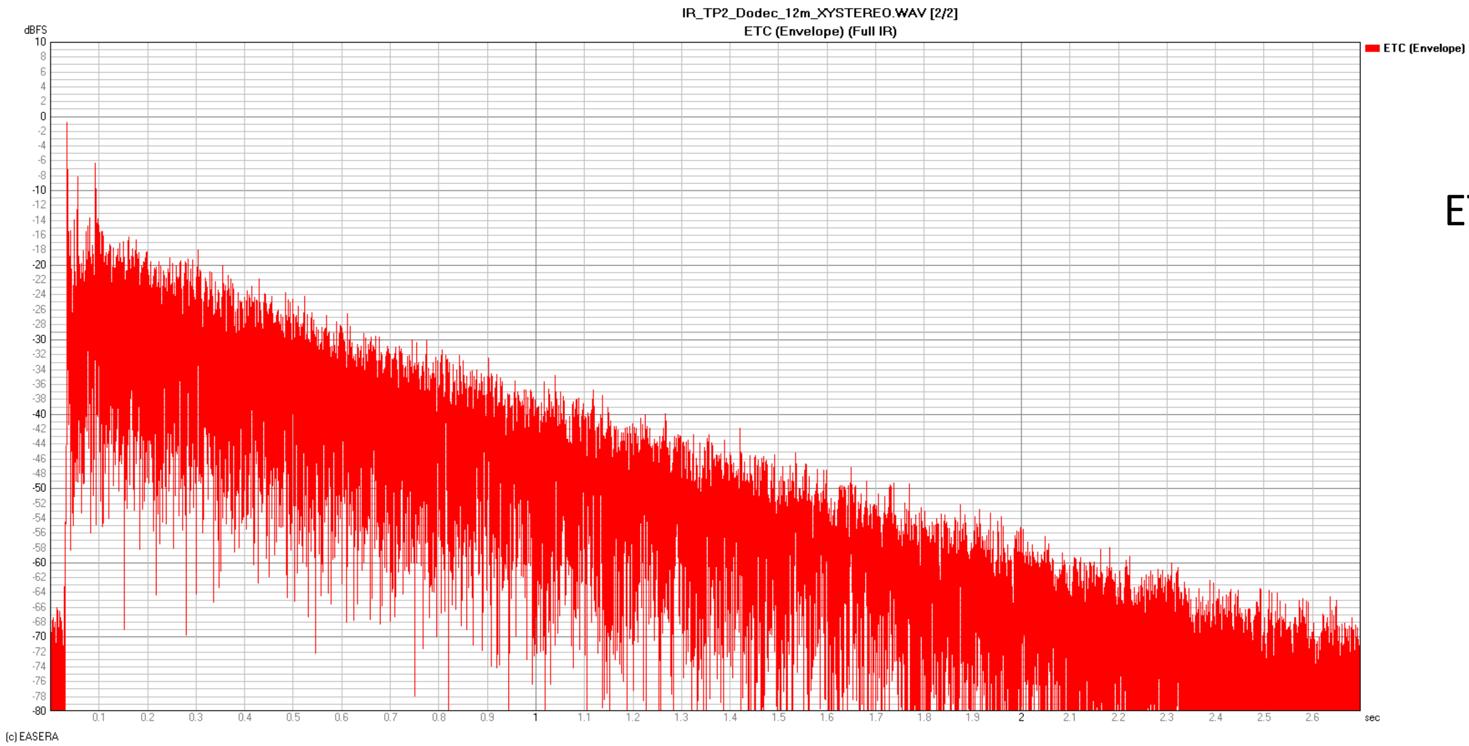


ETC of a room

The 4 second measurement length is long enough to see the full decay of the room into noise floor.

FFT-Based Analyzers

Looking at the ETC (Envelope Time Curve) can be more helpful.



ETC of a room

A measurement length of only 2.73 seconds (131,072 samples) may or may not be long enough.

FFT-Based Analyzers

When employing analyzers that use the Fourier Transform as the basis of their operation, the systems to be measured need to be Linear and Time-Invariant (LTI). Sometimes it may be possible to exclude the non-linearities from the data.

A system is linear if its output does not change as a function of its input.

Examples of non-linear systems:

Compressors, Expanders, a device driven into clipping

A system is time-invariant if neither it nor its response changes over time.

Example causes of time-variance in systems:

Change in temperature, change in temperature gradients, change in wind speed or direction

Types of Test Signals

- Impulse
- Broad Band Noise (Pink, White, other weighting)
- Swept Sine or Chirp (Linear sweep or Log sweep)
- Maximum Length Sequence (MLS)
- Stepped Sine
- Multi-tone

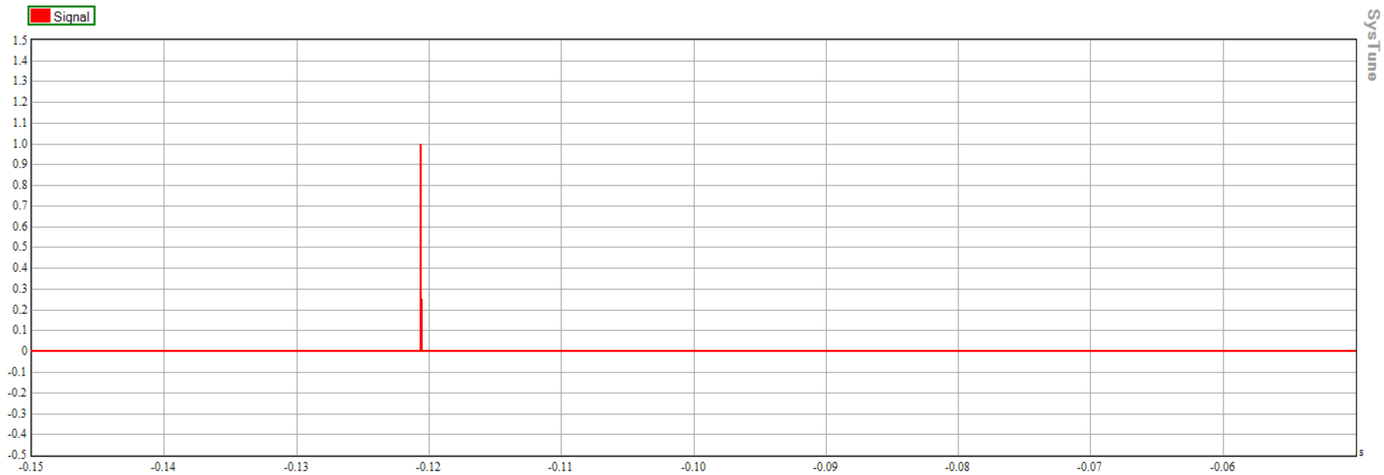
Each one has advantages and disadvantages.

Which one to use depends on what we're trying to do.

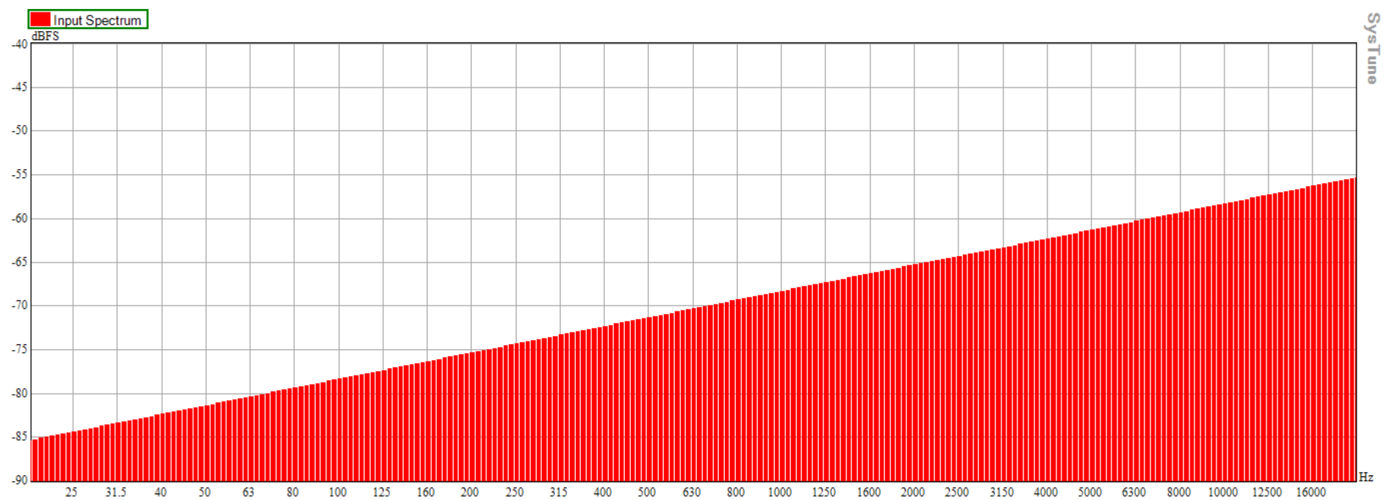
Why are we measuring? **What are we measuring?**

Types of Test Signals

Impulse



Time Domain

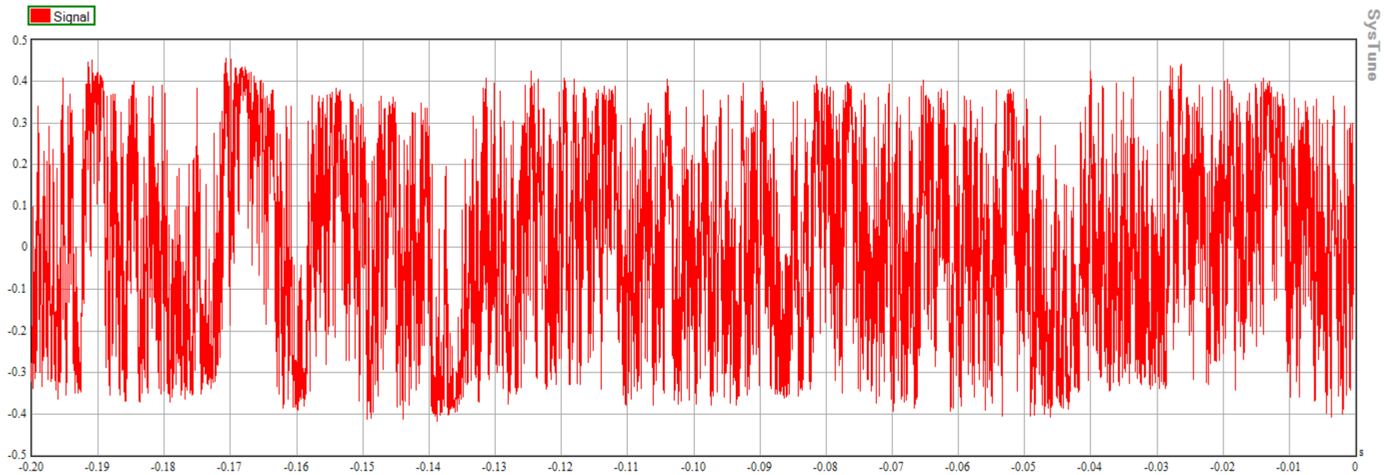


Frequency Domain

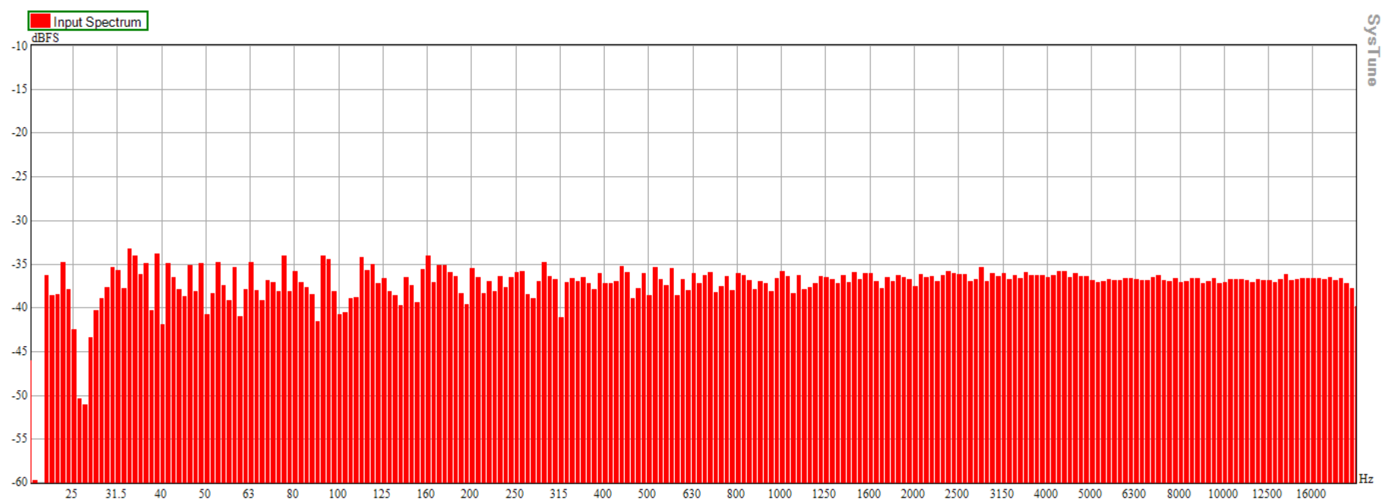
(1/24 octave)

Types of Test Signals

Pink Noise



Time Domain

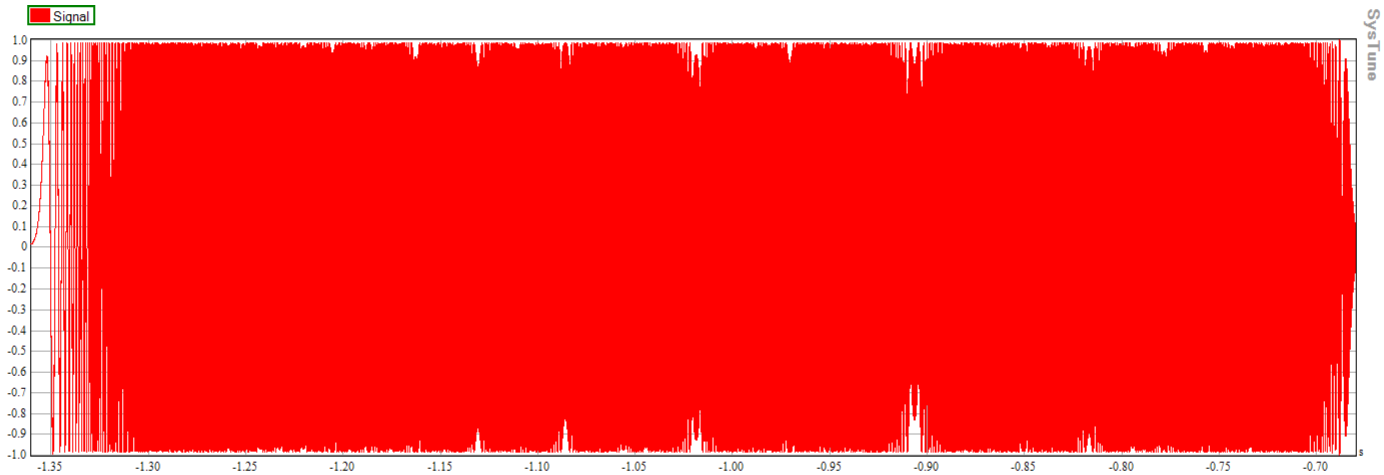


Frequency Domain

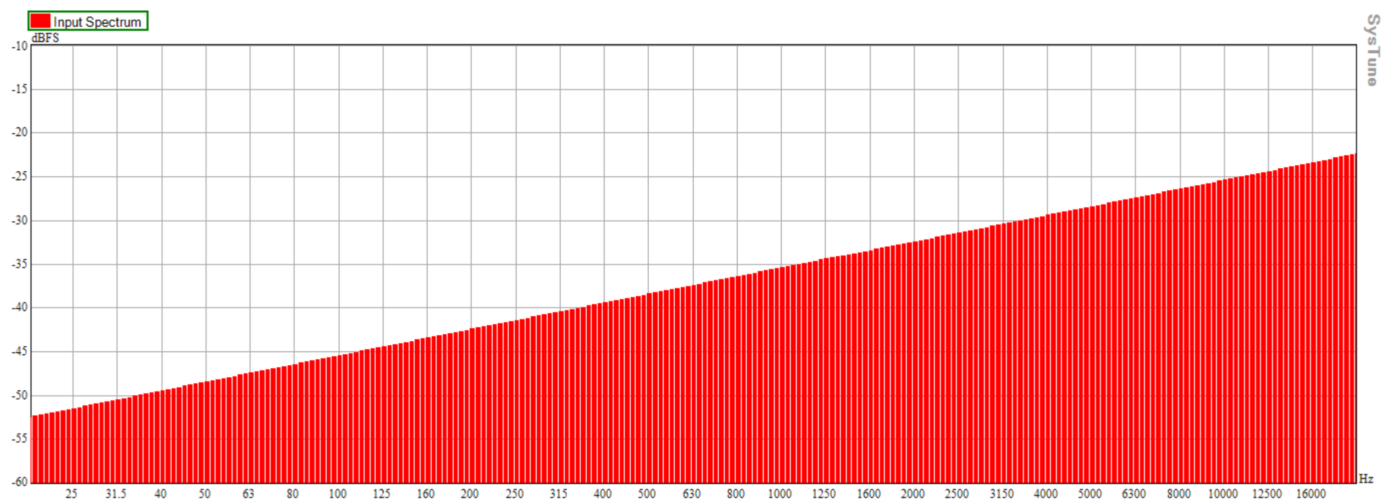
(1/24 octave)

Types of Test Signals

Linear-Swept Sine



Time Domain

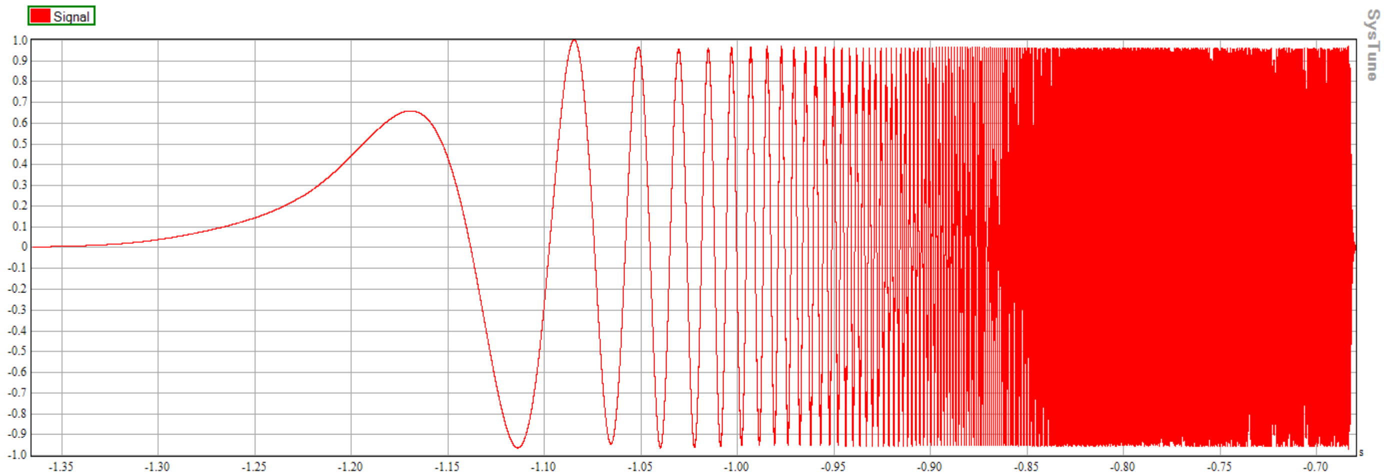


Frequency Domain

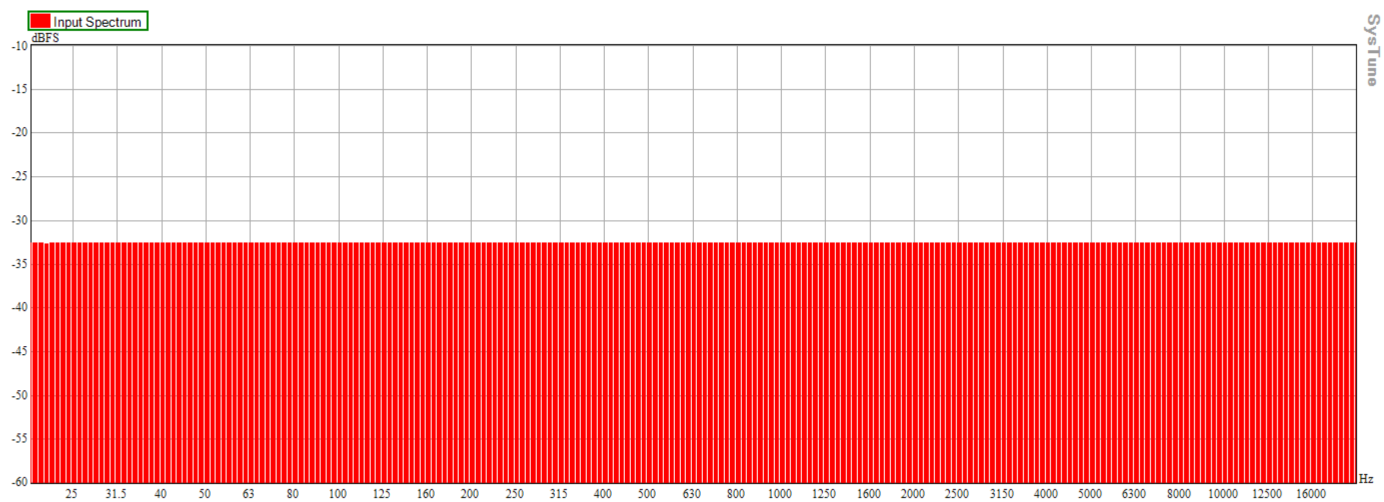
(1/24 octave)

Types of Test Signals

Log-Swept Sine



Time Domain

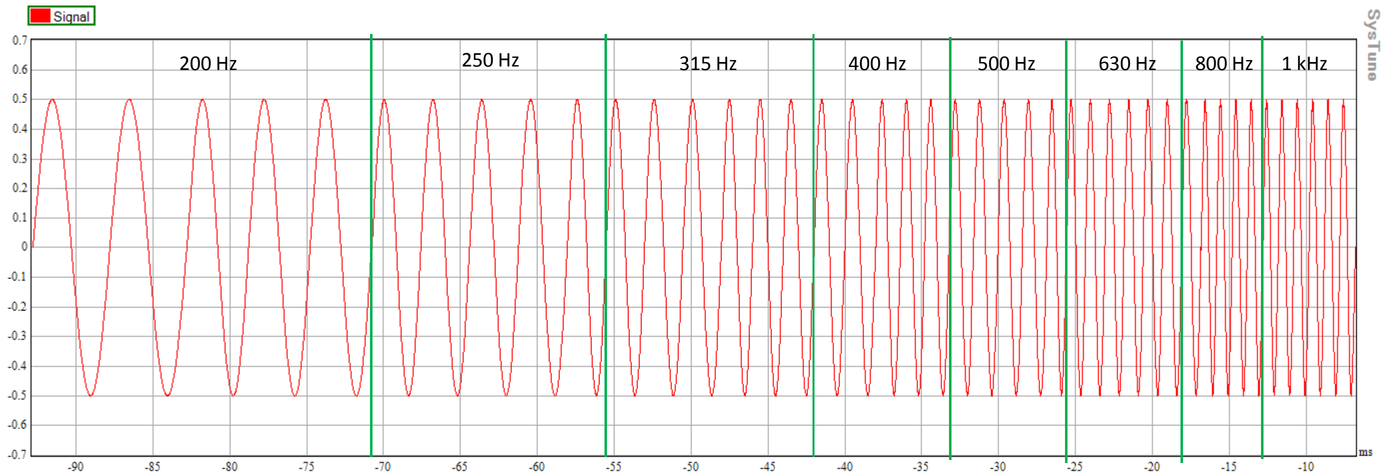


Frequency Domain

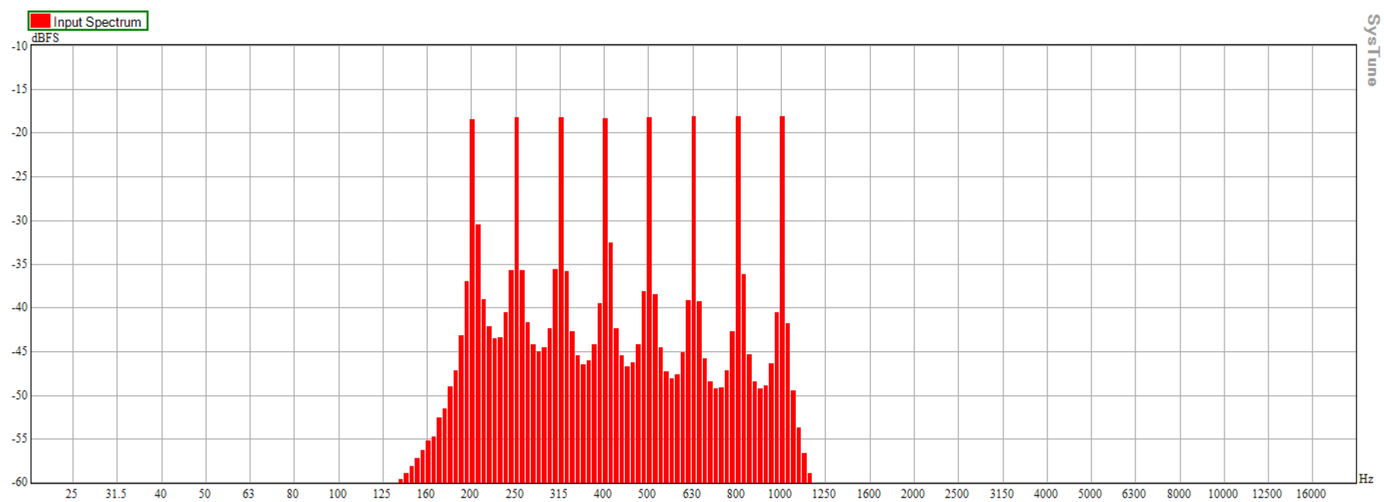
(1/24 octave)

Types of Test Signals

Stepped Sine



Time Domain

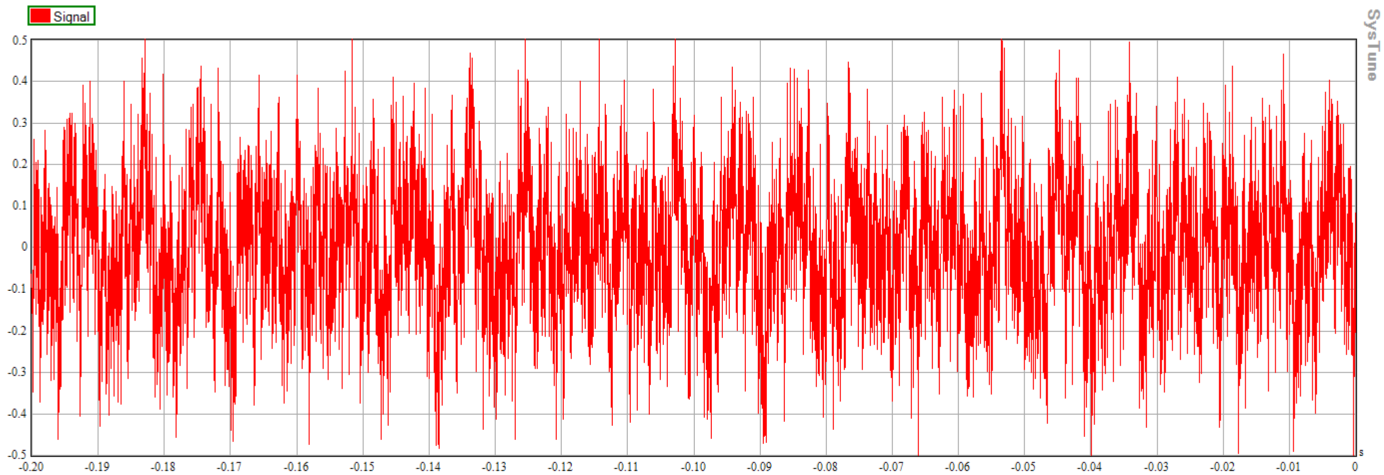


Frequency Domain

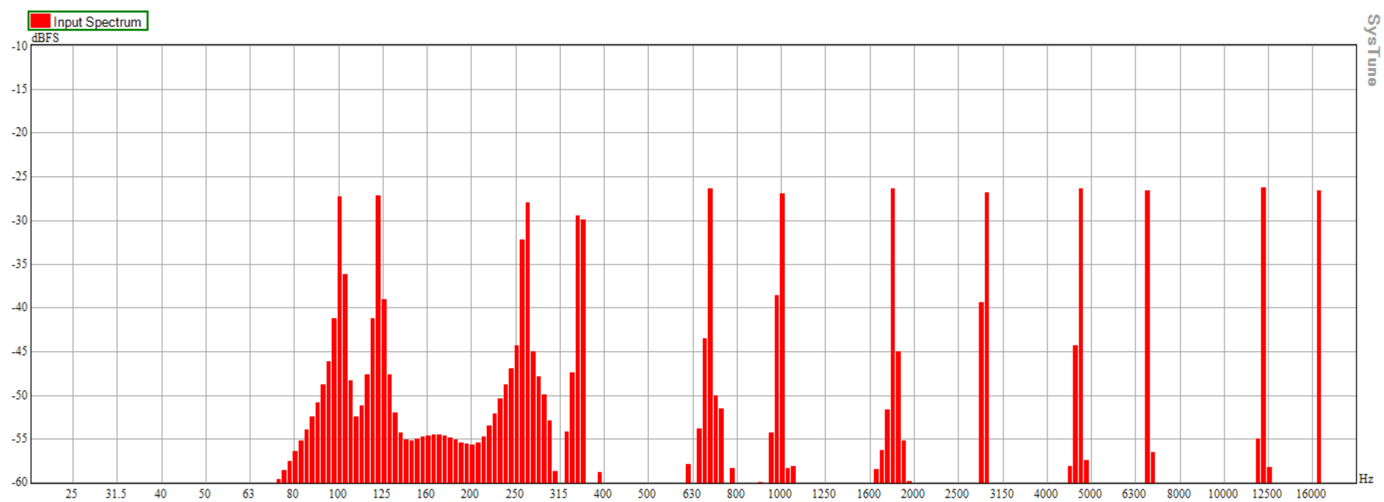
(1/24 octave)

Types of Test Signals

Multi-Tone



Time Domain



Frequency Domain

(1/24 octave)

Measurement Microphones

- Size
  - 1”, ½”, or ¼”
- Directivity
- Accuracy
  - Type 0, Type 1, Type 2, or no standards compliance
- Construction
  - Mylar diaphragm or Metal diaphragm

1” microphones can become increasingly directional at higher frequencies, even though it may be an omni-directional mic. They can have very low self-noise.

For most field work a 1/2” diaphragm, omni-directional microphone will work well. At very high frequencies these can have some off-axis attenuation.

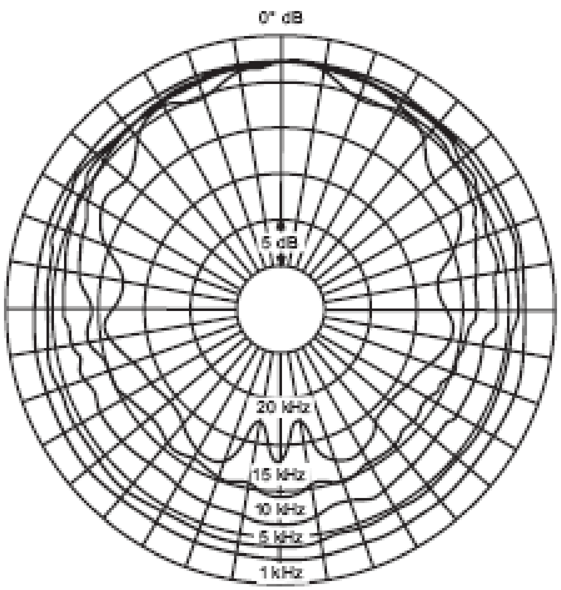
1/4” diaphragm microphones can be used as long as self-noise is not a concern.

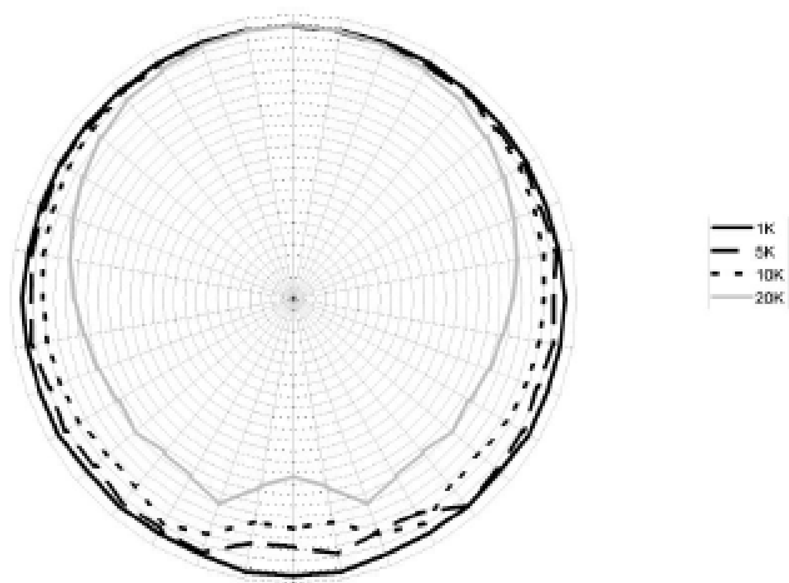
Measurement Microphones

Omni-directional Microphones

DPA 4007 (½” diaphragm)

Earthworks M30 (¼” diaphragm)





Measurement Microphones

- Size
  - 1", ½", or ¼"
- Directivity
- Accuracy
  - Type 0, Type 1, Type 2, or no standards compliance
- Construction
  - Mylar diaphragm or Metal diaphragm

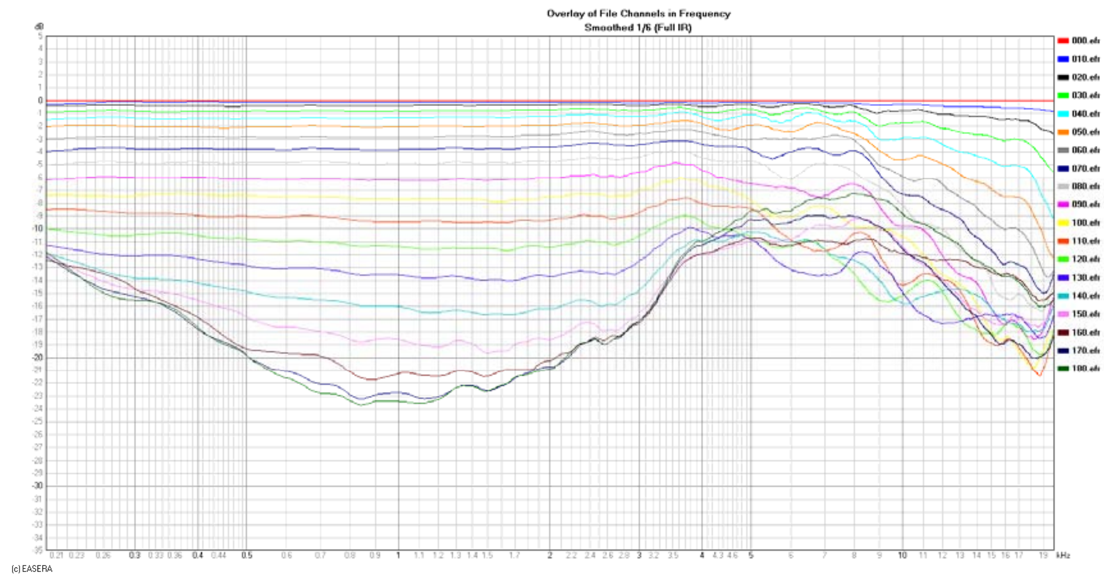
Typically omni-directional microphone are used for measurement work.

Cardioid microphones can be used. They can help to attenuate rear reflections and/or reverberation. This can be useful when trying to determine the loudspeaker response alone. Requires flat on & off axis response (expensive).

Boundary microphones can help to eliminate comb filtering (floor bounce).

Measurement Microphones

Cardioid Microphone

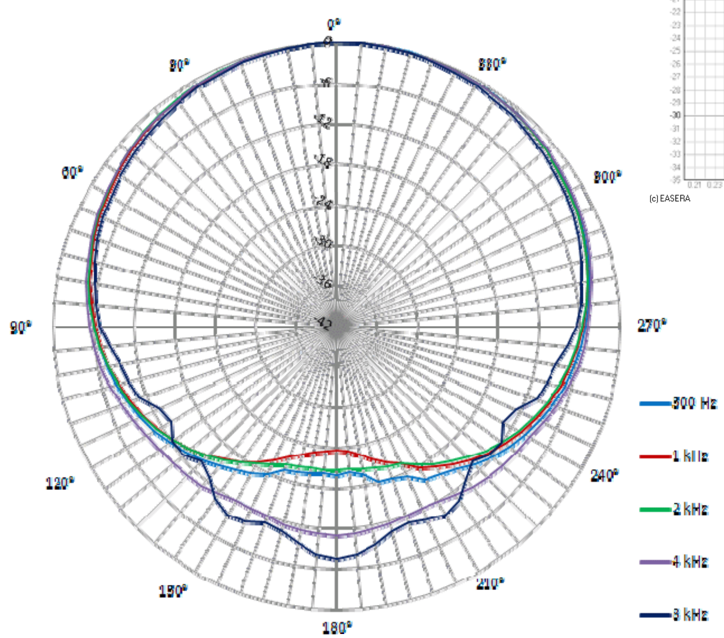


Off-Axis Frequency Response

10° increments

(normalized to on-axis response)

Polar Response



Measurement Microphones

- Size
  - 1”, ½”, or ¼”
- Directivity
- Accuracy
  - Type 0, Type 1, Type 2, or no standards compliance
- Construction
  - Mylar diaphragm or Metal diaphragm

Type 0 instrumentation must be within +/- 0.7 dB

Type 1 instrumentation must be within +/- 1.0 dB

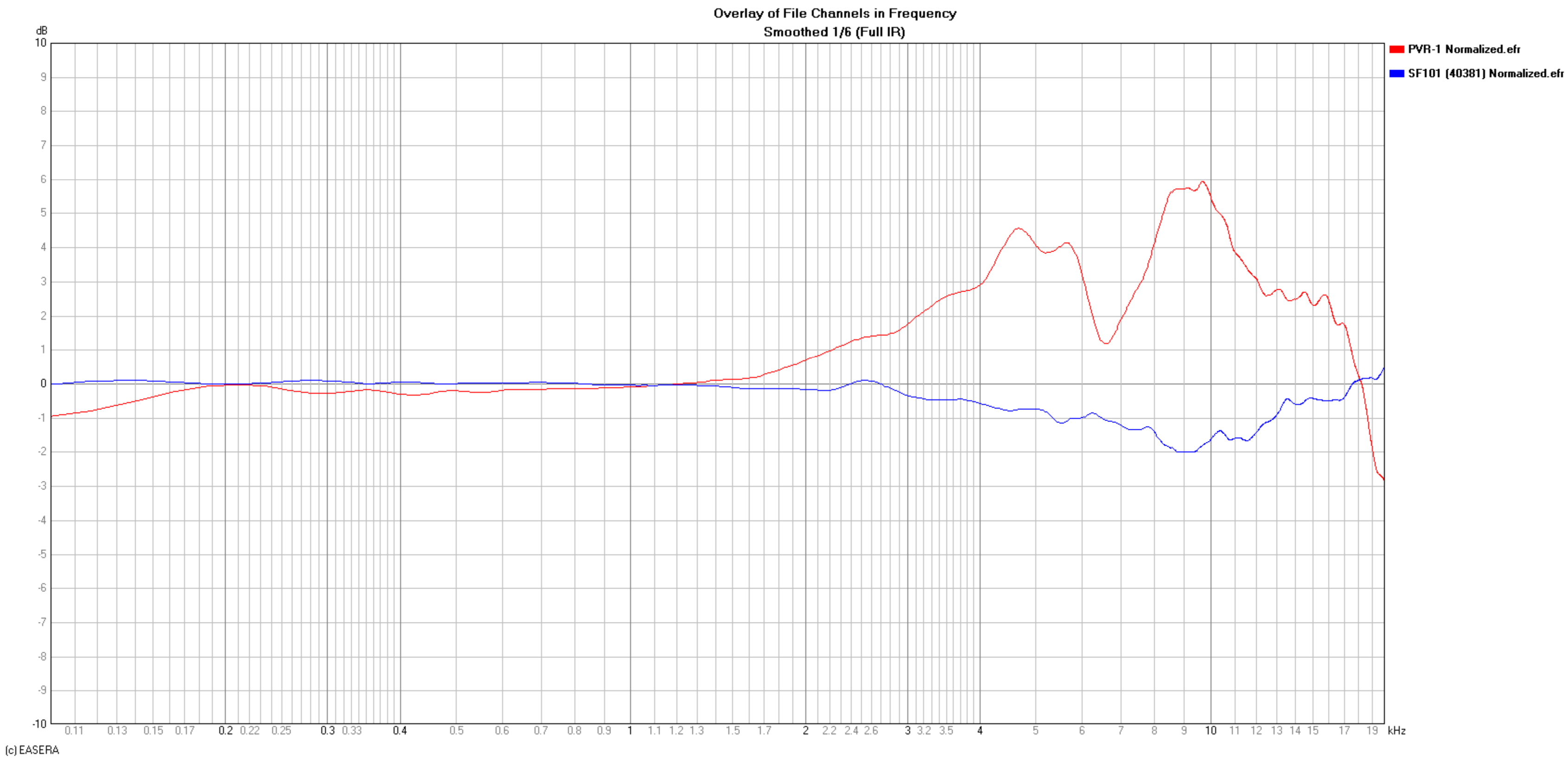
Type 2 instrumentation must be within +/- 1.5 dB

There are additional requirements but those listed above are more closely related to microphones.

(ANSI S1.4)

Measurement Microphones

Accuracy



Non-Standards Compliant Microphone

Type 2 Microphone (response is just good enough to be Type 1)

Measurement Microphones

- Size
  - 1”, ½”, or ¼”
- Directivity
- Accuracy
  - Type 0, Type 1, Type 2, or no standards compliance
- Construction
  - Mylar diaphragm or Metal diaphragm

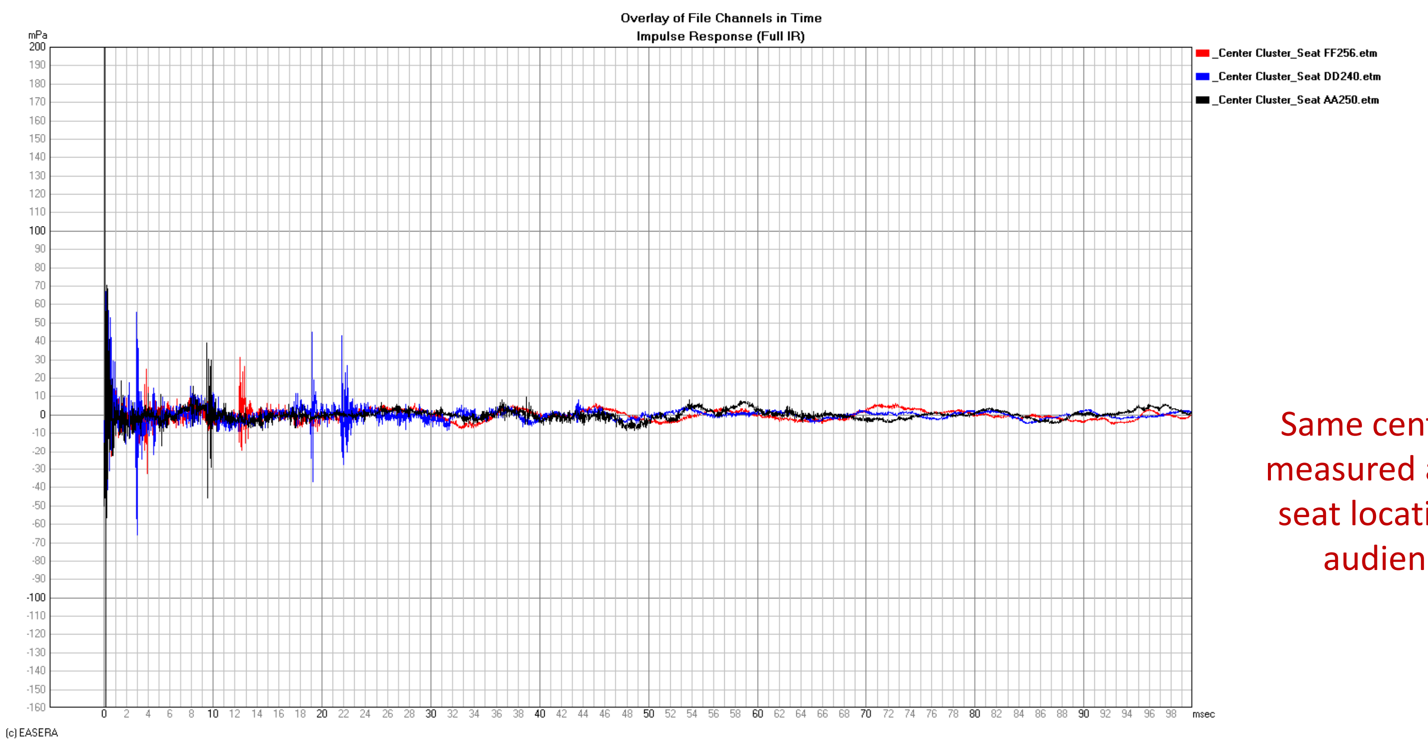
Mylar (or plastic) diaphragm material can deform with age and especially when subjected to heat.

Metal (nickel, titanium) diaphragms are much more stable. They are also more expensive.

Measuring Loudspeakers vs. Measuring Rooms

Loudspeakers and rooms are similar in that they don't each have a single IR or Transfer Function.

The IR is location dependent. It changes as a function of where the measurement microphone is located.



Same center cluster measured at different seat locations in the audience area

Measuring Loudspeakers vs. Measuring Rooms

When measuring a loudspeaker we typically want the direct field only.

No reflections, reverberant sound, or noise

When measuring a room we want the reflections and reverberant field.

We will typically be measuring loudspeakers in rooms.

We will also typically measure a room by using a loudspeaker it excite it.

There will be some amount of interaction between the loudspeaker and the room present in our measurements.

Measuring Loudspeakers vs. Measuring Rooms

A fundamental difference between the loudspeaker and the room is the length of their Impulse Response.

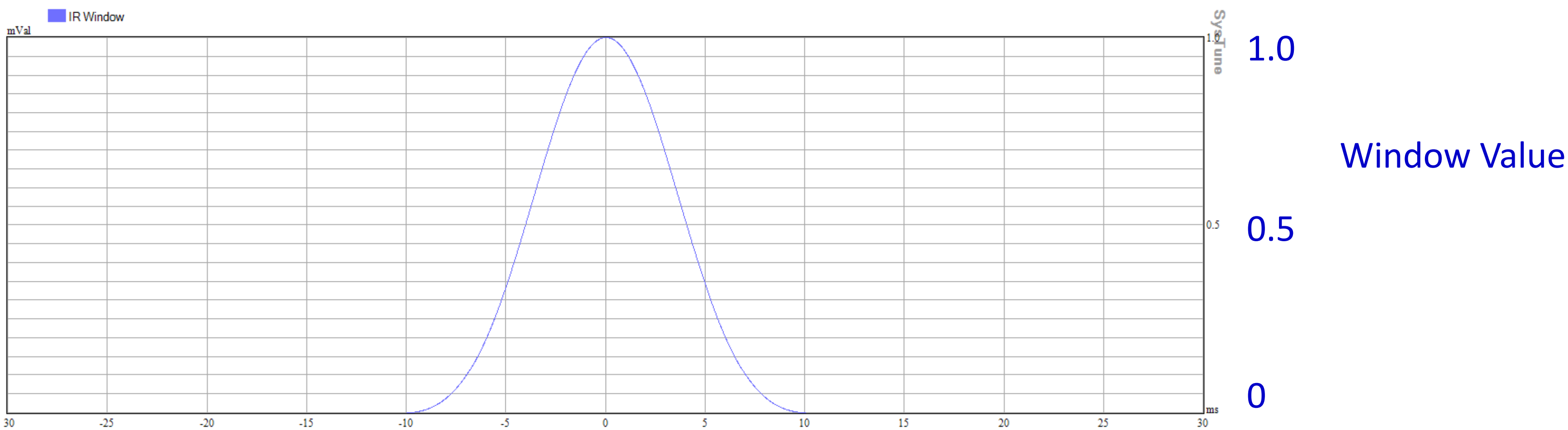
Loudspeakers typically have a shorter IR. Rooms have a much longer IR.

Our measurement must be at least as long or a bit longer than the IR we are attempting to measure.

We can apply a time window to minimize the effects of the room on the measurement data of a loudspeaker.

Time Windows

A window is a way to attenuate some of the original measurement data so that it does not show up in the final measurement.

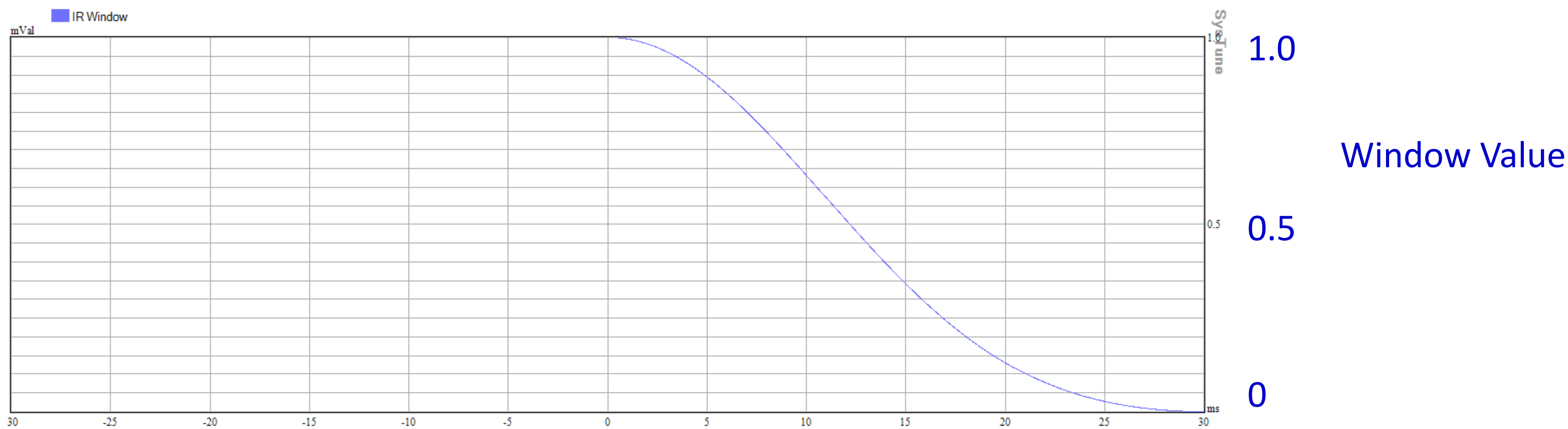


Symmetric Window

The window value is multiplied times the amplitude of the IR at each point in time to get the windowed IR.

Time Windows

The data important to us is usually after t=0, or the peak of the window, so the right half of the window needs to be longer for better frequency resolution.

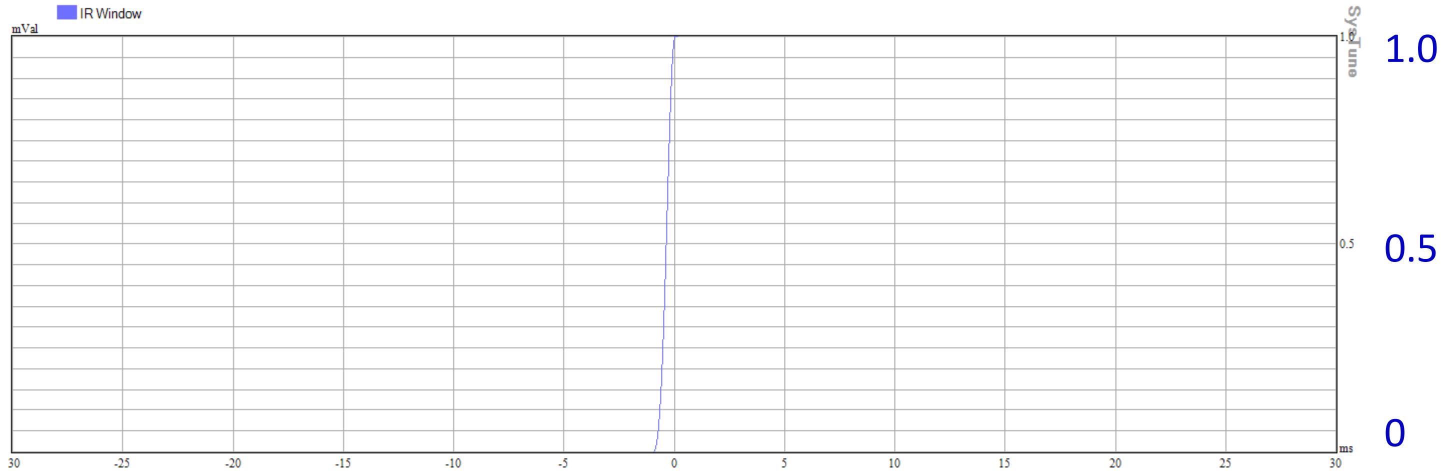


Right Half-Window

The left half of the window has a value of 1.0; it is completely open.

Time Windows

The data before t=0, or the peak of the window, is usually not important to us so we can use a shorter window. This will not adversely affect the frequency resolution. It helps eliminate noise, if present.

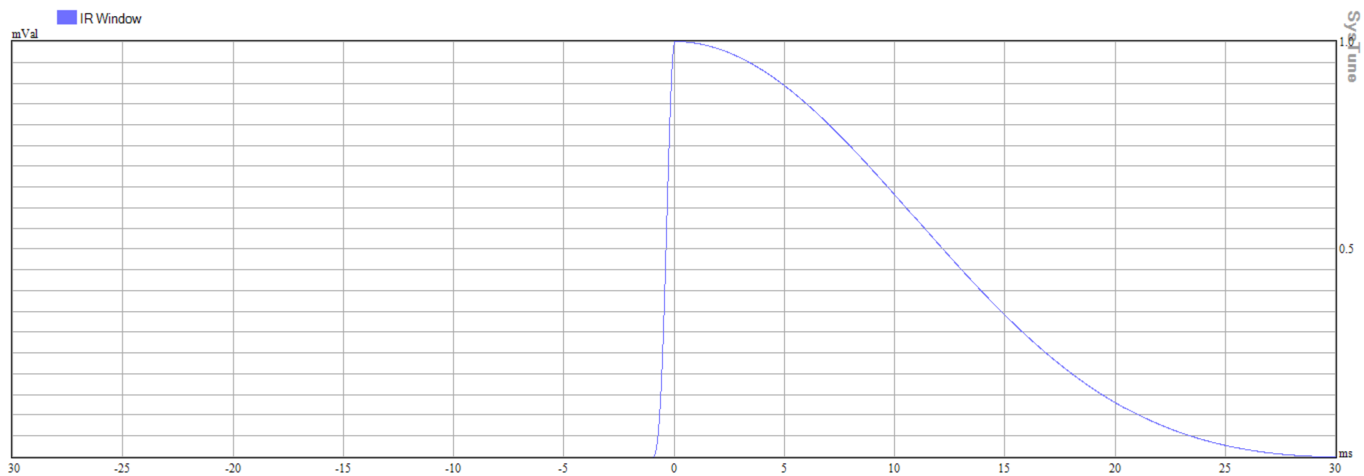


Left Half-Window

The right half of the window has a value of 1.0; it is completely open.

Time Windows

Combined different length left and right half-windows.



1.0

Window Value

0.5

0

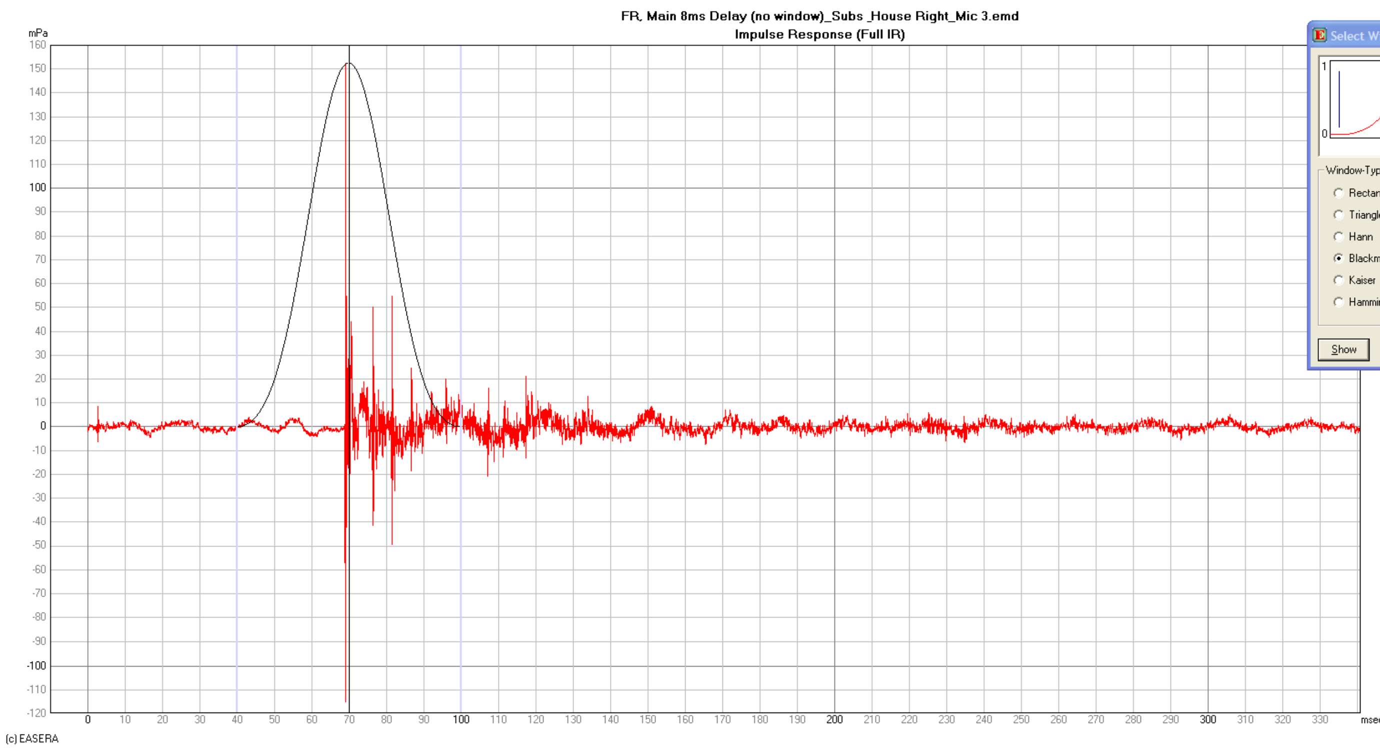
Left Half-Window

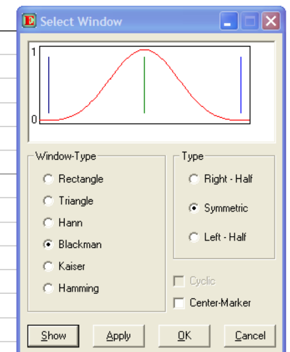
Right Half-Window

This allows for good frequency resolution while minimizing reflection after the arrival of the direct sound as well as unwanted noise that may be present before the arrival of sound from the DUT.

Time Windows

A symmetrical window shown before it is applied to an IR.





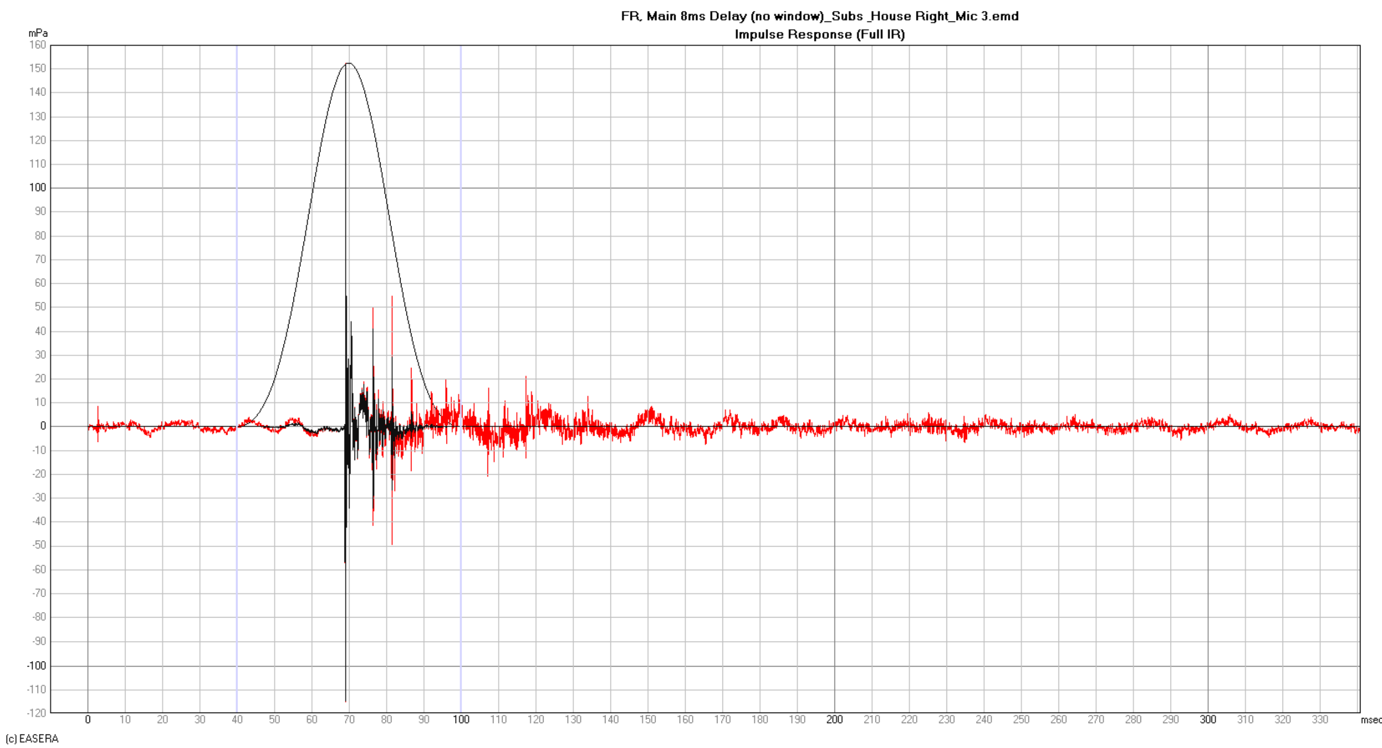
IR of a loudspeaker in a room

0 ms

340 ms

Time Windows

The IR with and without the window applied.

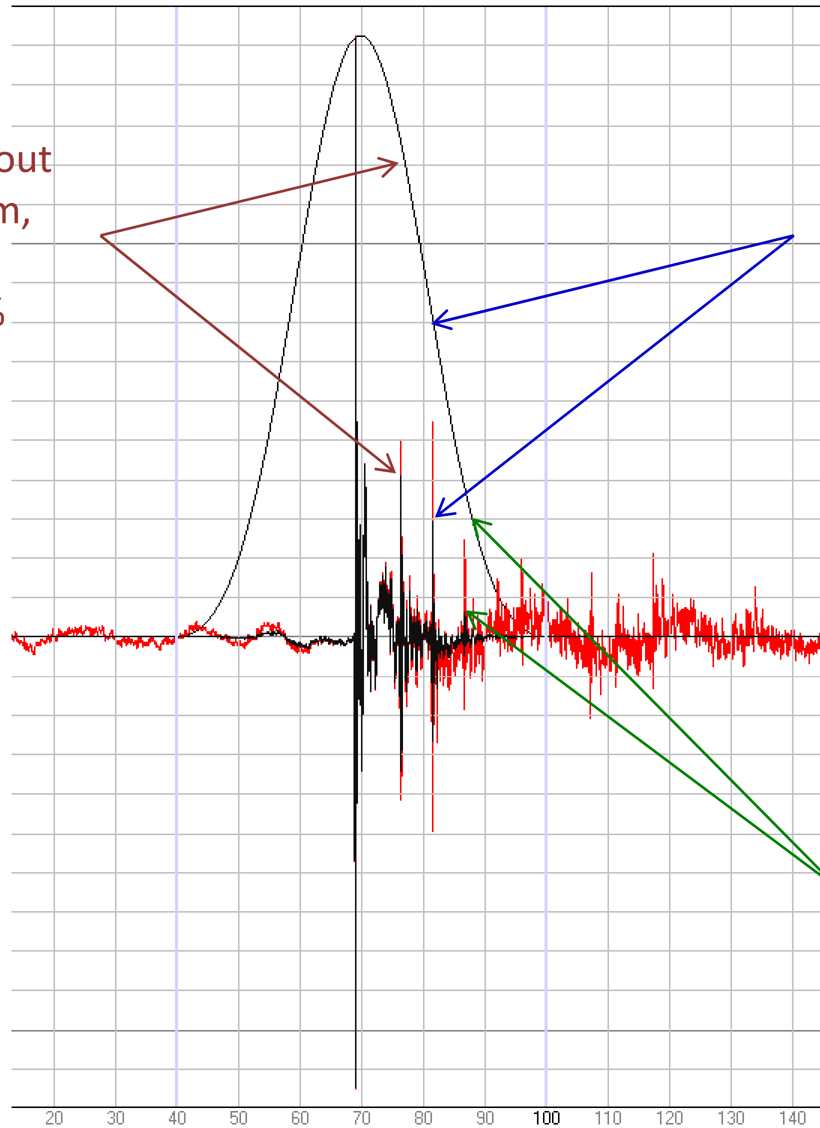


IR of a loudspeaker in a room

Time Windows

Window value of about 80% of its maximum, decreases the IR amplitude by 80%

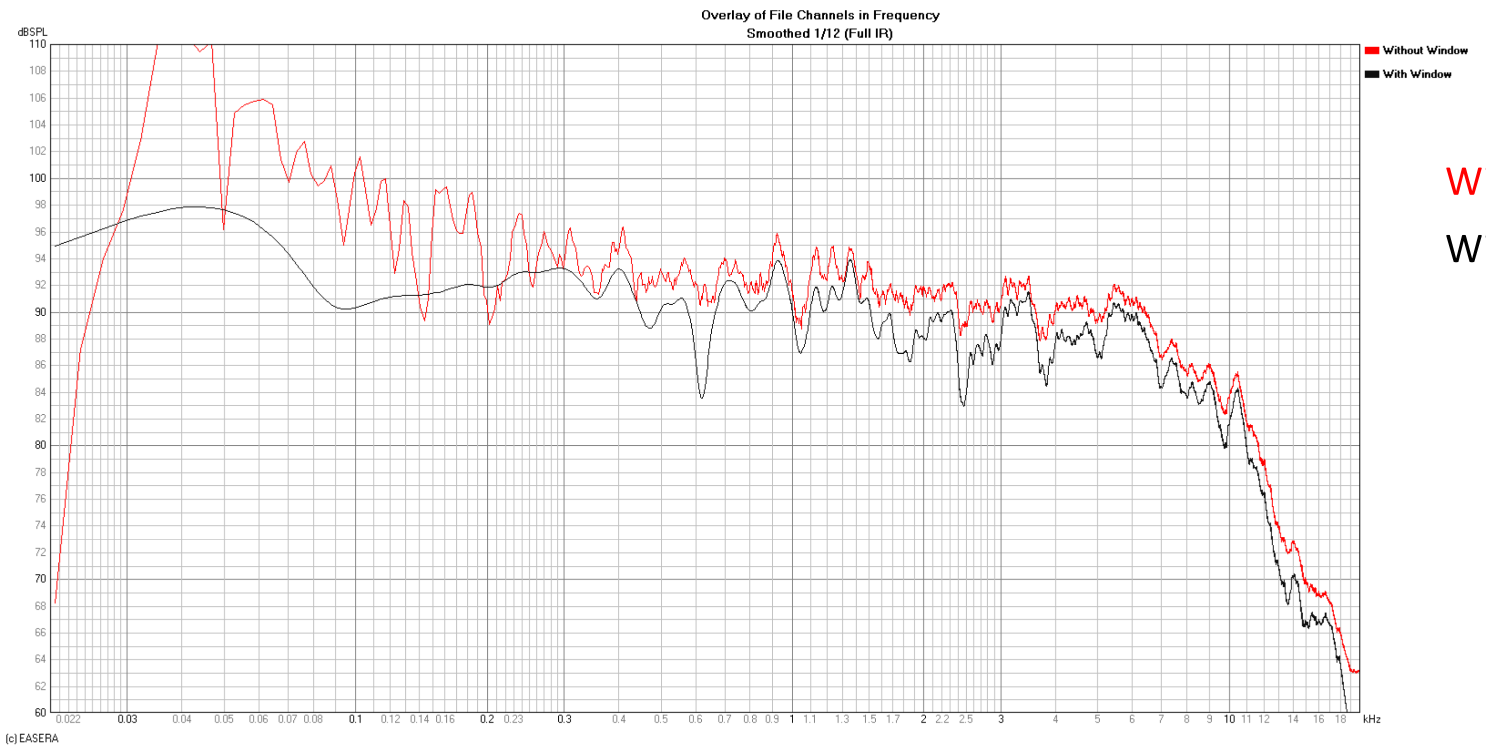
Window value of about 50% of its maximum, decreases the IR amplitude by 50%



Window value of about 20% of its maximum, decreases the IR amplitude by 20%

Time Windows

The Transfer Function with and without the window applied.



Without Window

With Window

The windowed response allows us to see less of the effects of the room.

This allows a better view of the response of the loudspeaker.

Time Windows

Time windows can also affect the frequency resolution of a measurement. This is a result of the reduction in data used for the Fourier Transform between the Time Domain and the Frequency Domain.

The resolution in the Time Domain and the resolution in the Frequency Domain are related by the Uncertainty Principle.

$$\Delta t = 1 / \Delta f$$

The larger of a time span (Δt) we have, we can resolve a smaller frequency span (Δf).

The smaller of a time span (Δt) we have, we can only resolve a larger frequency span (Δf).

Time Windows

When a rectangular window is used the frequency resolution can be calculated from the length of the time window.

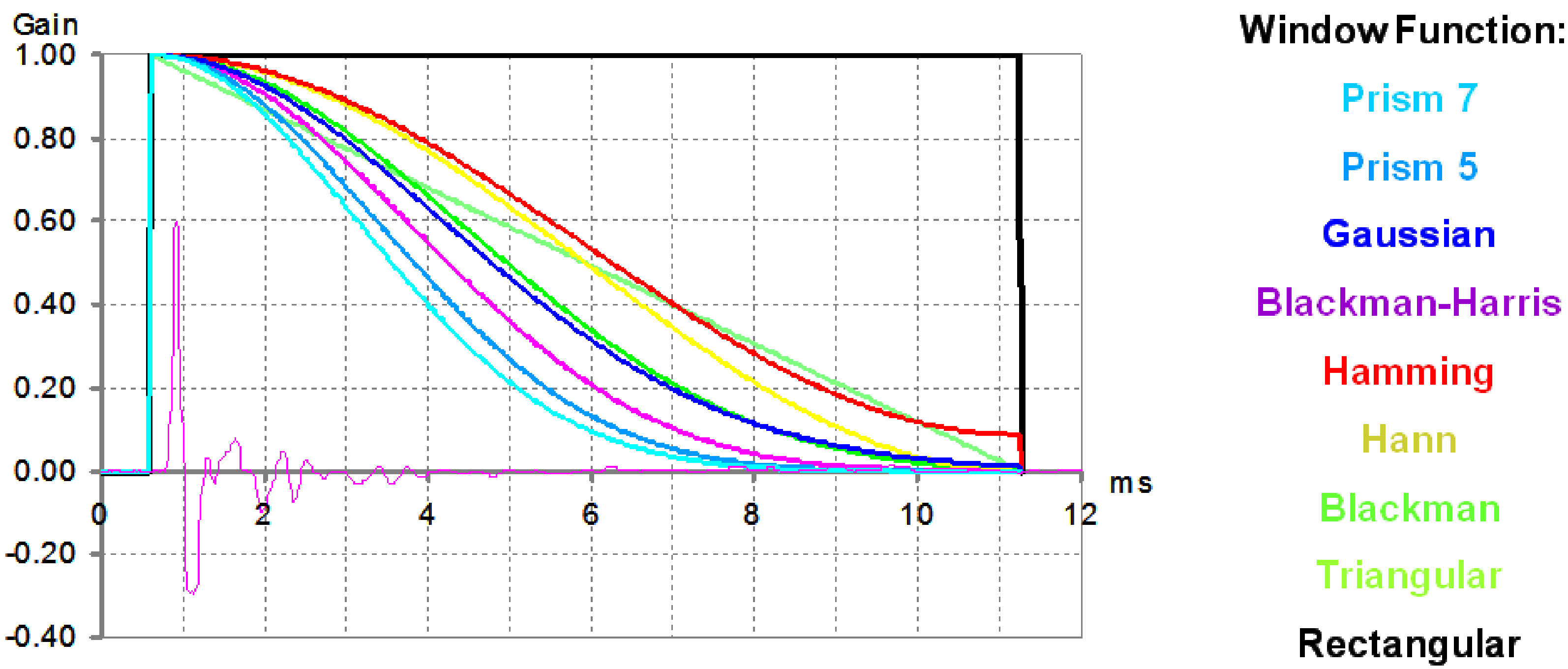
$$\Delta t = 1 / \Delta f$$

When a window other than a rectangular window is used the frequency resolution will be decreased (higher number).

This is due to the attenuation of energy from the IR. This results in a loss of information. This does not occur with a rectangular widow since it has a value of 1.0 all the way to its end.

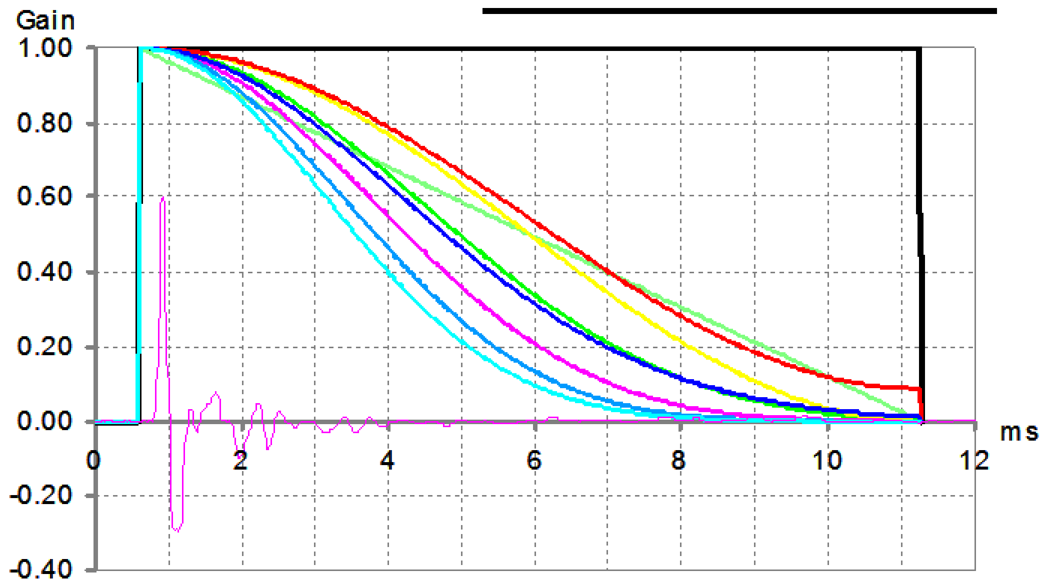
Time Windows

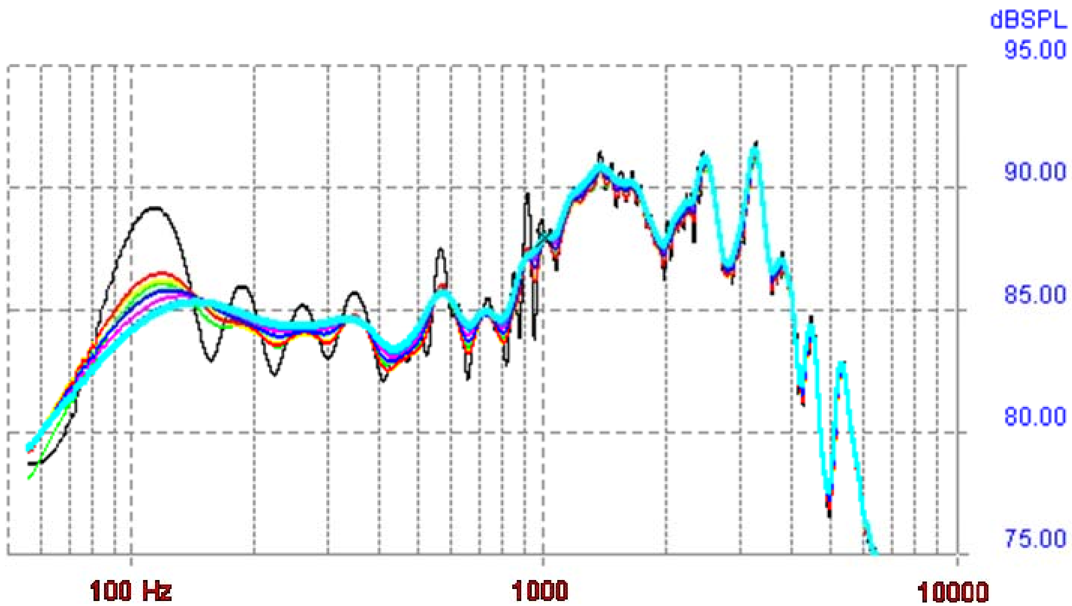
When window functions other than rectangular are used, the frequency resolution will be decreased even though the same window length is used.



This is due to the attenuation of energy from the IR, resulting in a loss of information in the frequency domain.

Time Windows



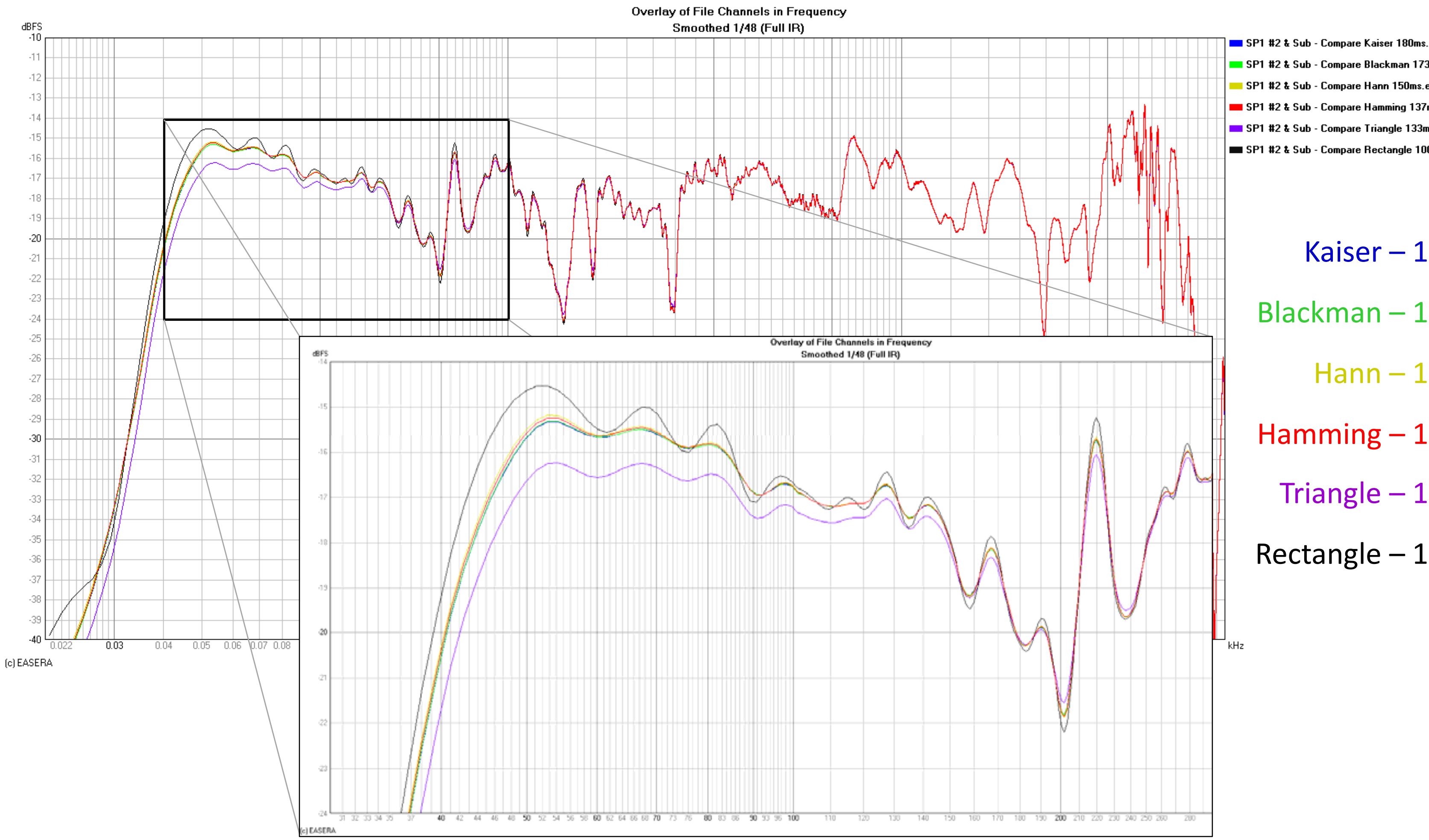


Window Function:	Equivalent Bandwidth
Prism 7	-
Prism 5	-
Gaussian	1.80*
Blackman-Harris	2.01
Hamming	1.37
Hann	1.50
Blackman	1.73*
Triangular	1.33
Rectangular	1.00

* Depends on additional window variable α

Time Windows

Different window functions, with different length to yield equivalent frequency resolution of 10 Hz.



Kaiser – 180 ms

Blackman – 173 ms

Hann – 150 ms

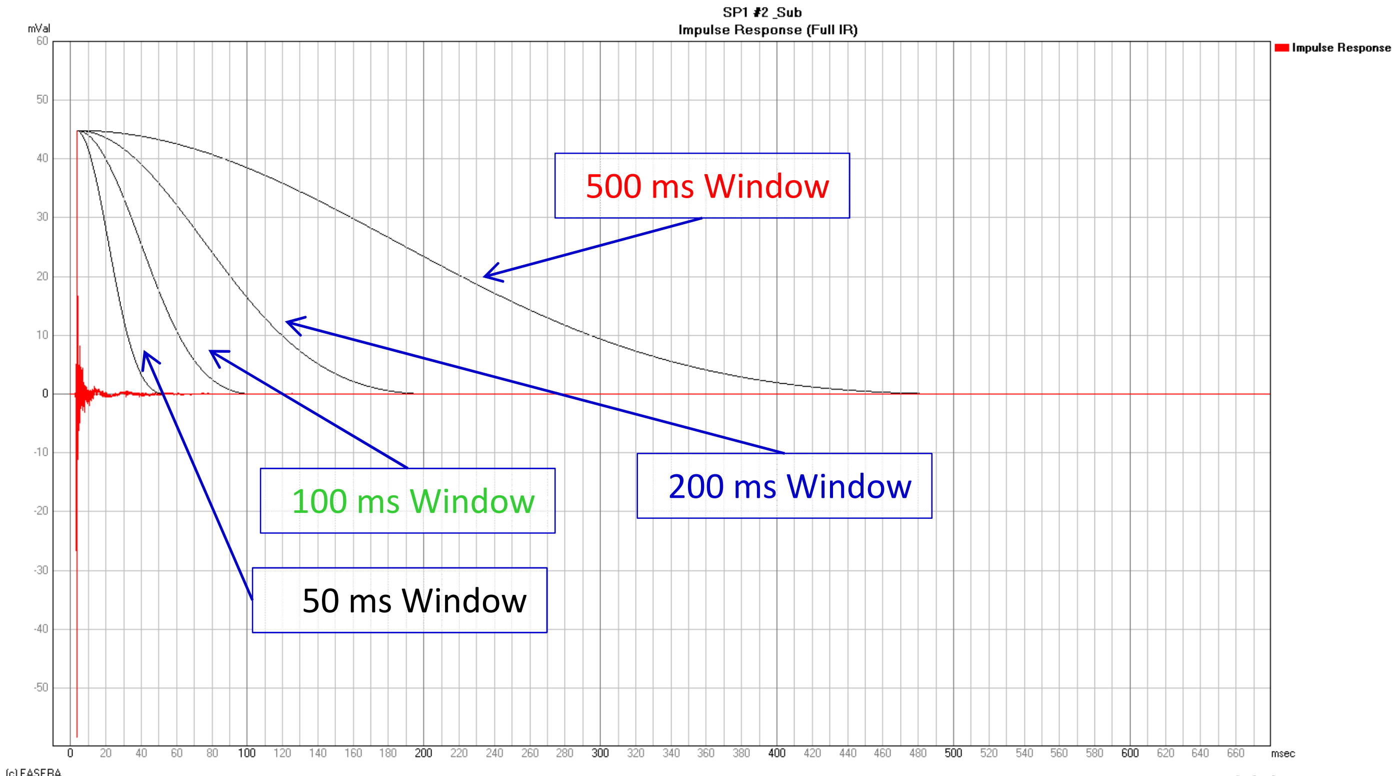
Hamming – 137 ms

Triangle – 133 ms

Rectangle – 100 ms

Time Windows

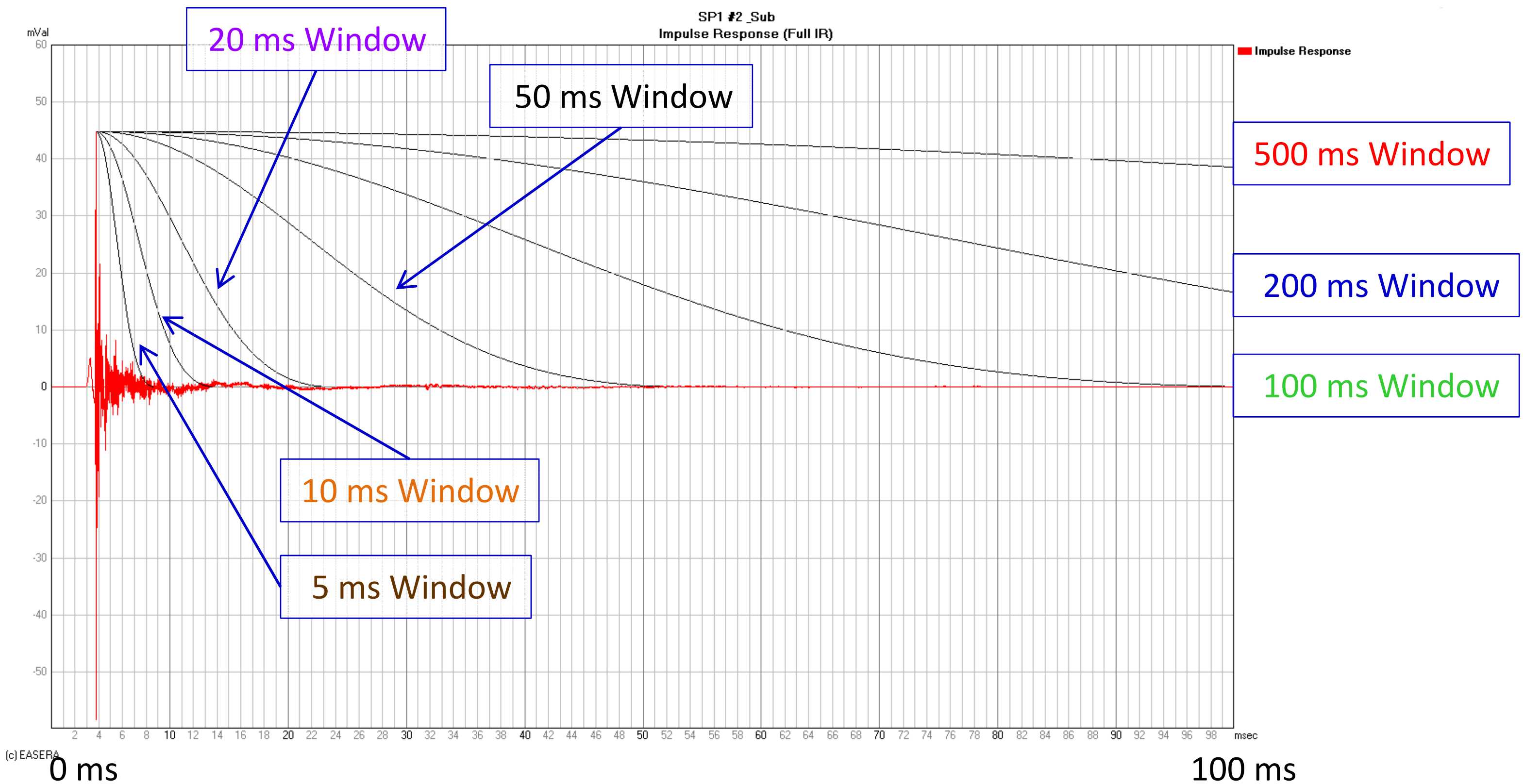
Different length time windows (Blackman window)



0 ms 680 ms

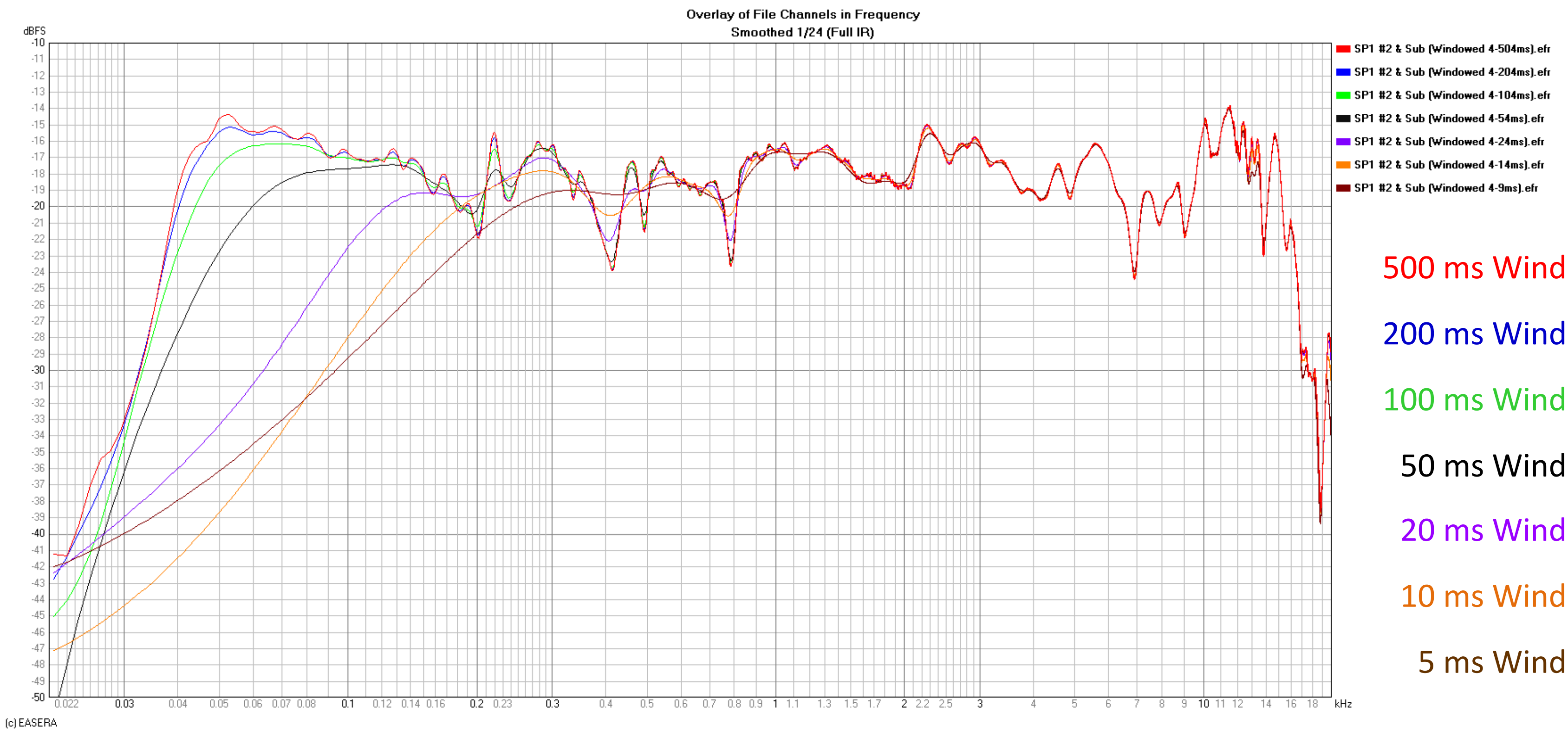
Time Windows

Different length time windows. Zoomed in to first 100 ms of the IR



Time Windows

Frequency resolution differences with shorter time windows



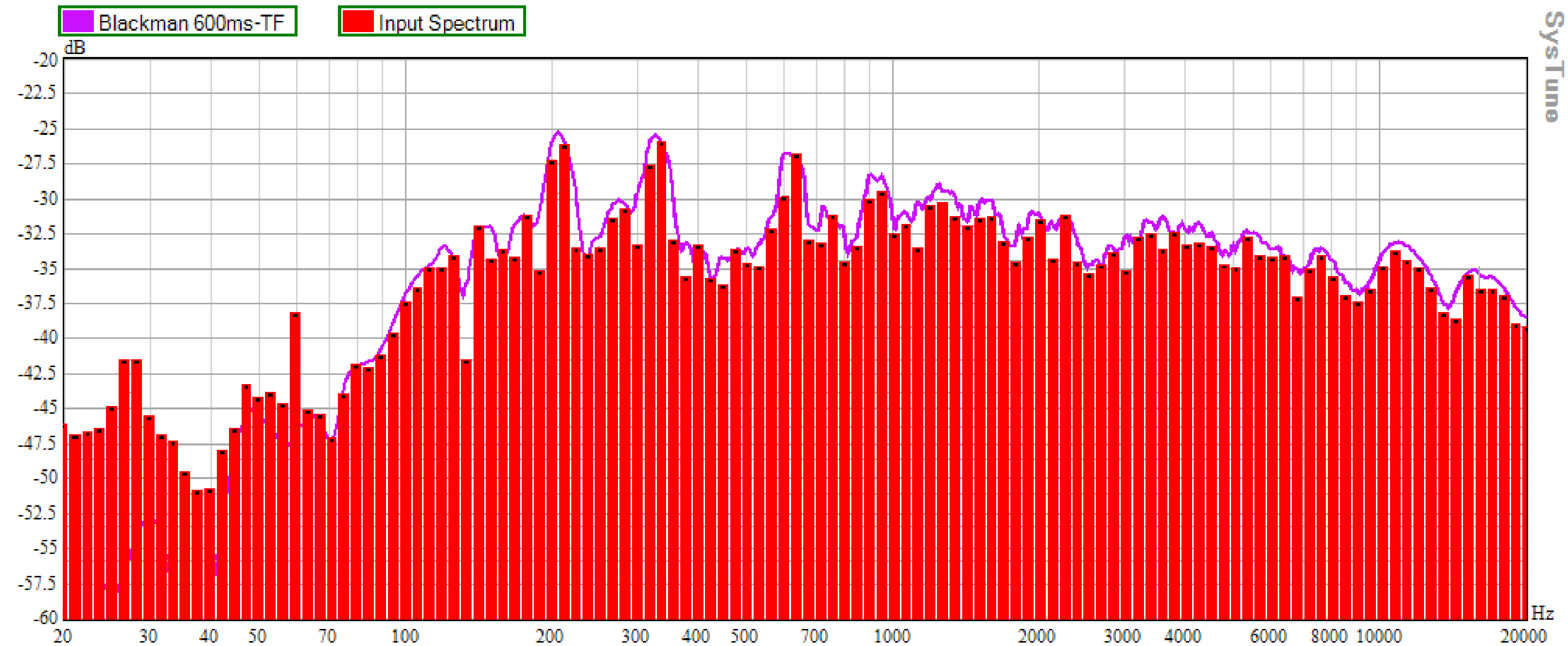
500 ms Window
200 ms Window
100 ms Window
50 ms Window
20 ms Window
10 ms Window
5 ms Window

Frequency Resolution (approximate – Blackman equivalent bandwidth 1.73)

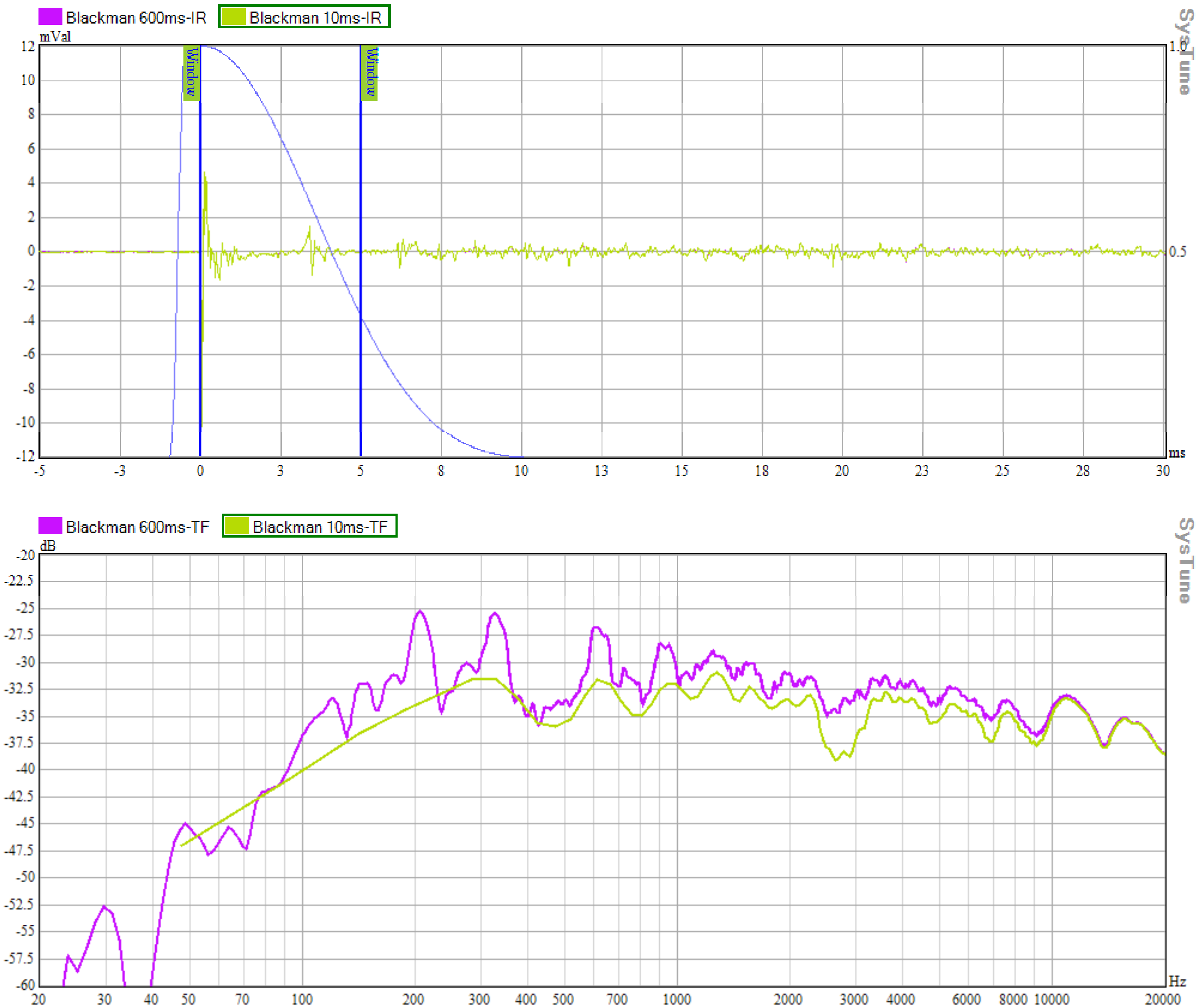
3.5 Hz	17 Hz	87 Hz	346 Hz
8.7 Hz	35 Hz	173 Hz	

Interpreting the Data

How do these peaks/dips need to be addressed? EQ?



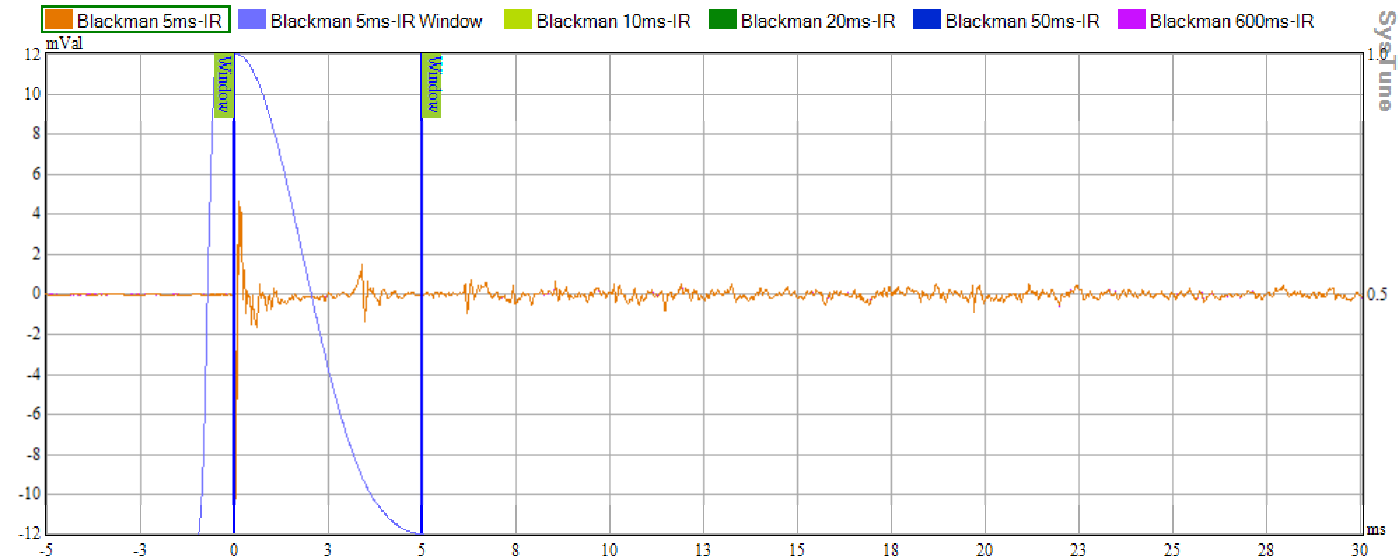
Interpreting the Data

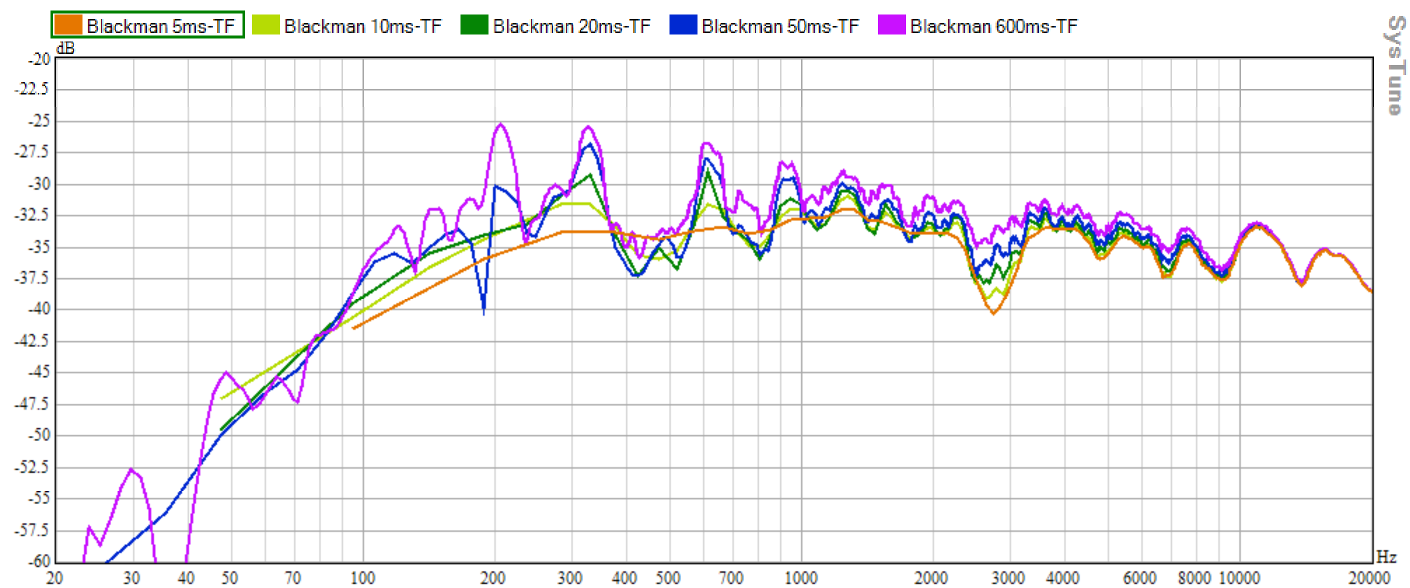


600 ms Window (no window)

10 ms Window

Interpreting the Data





600 ms Window (no window)

50 ms Window

20 ms Window

10 ms Window

5 ms Window

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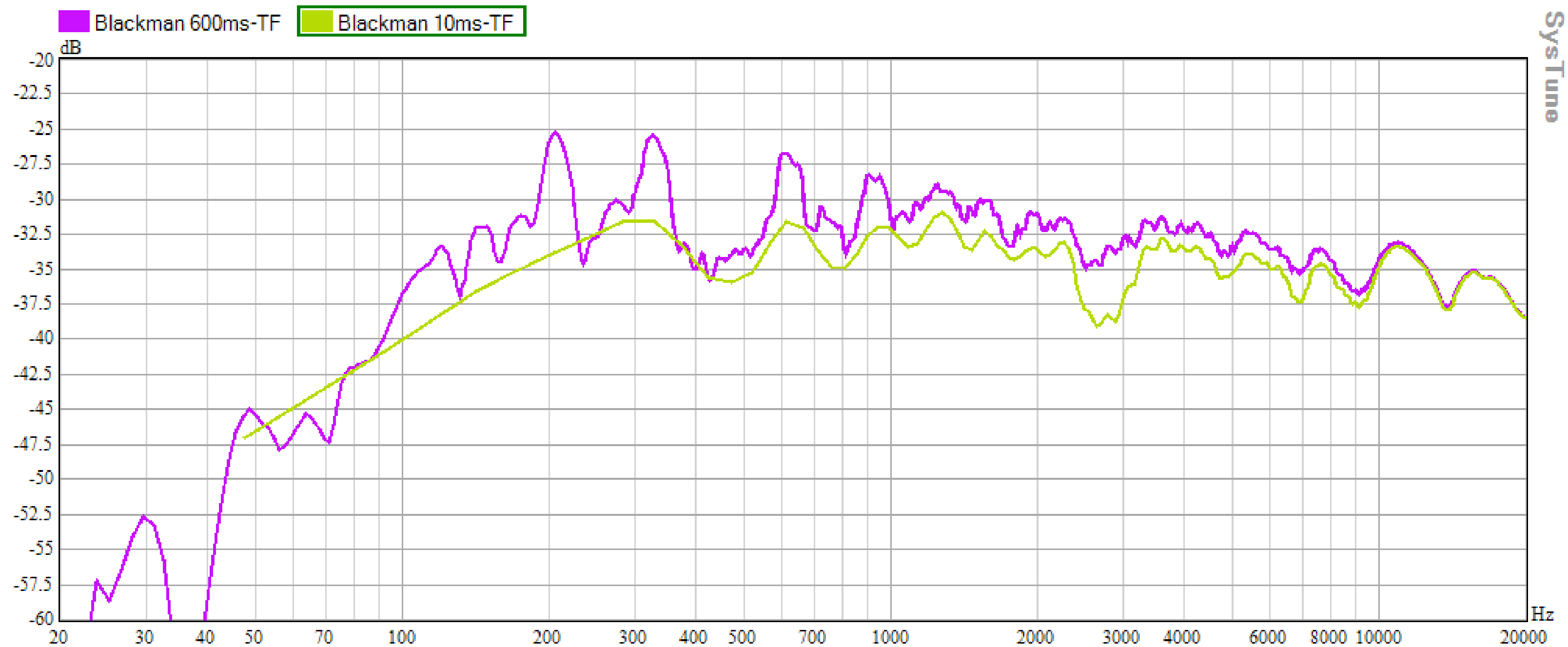


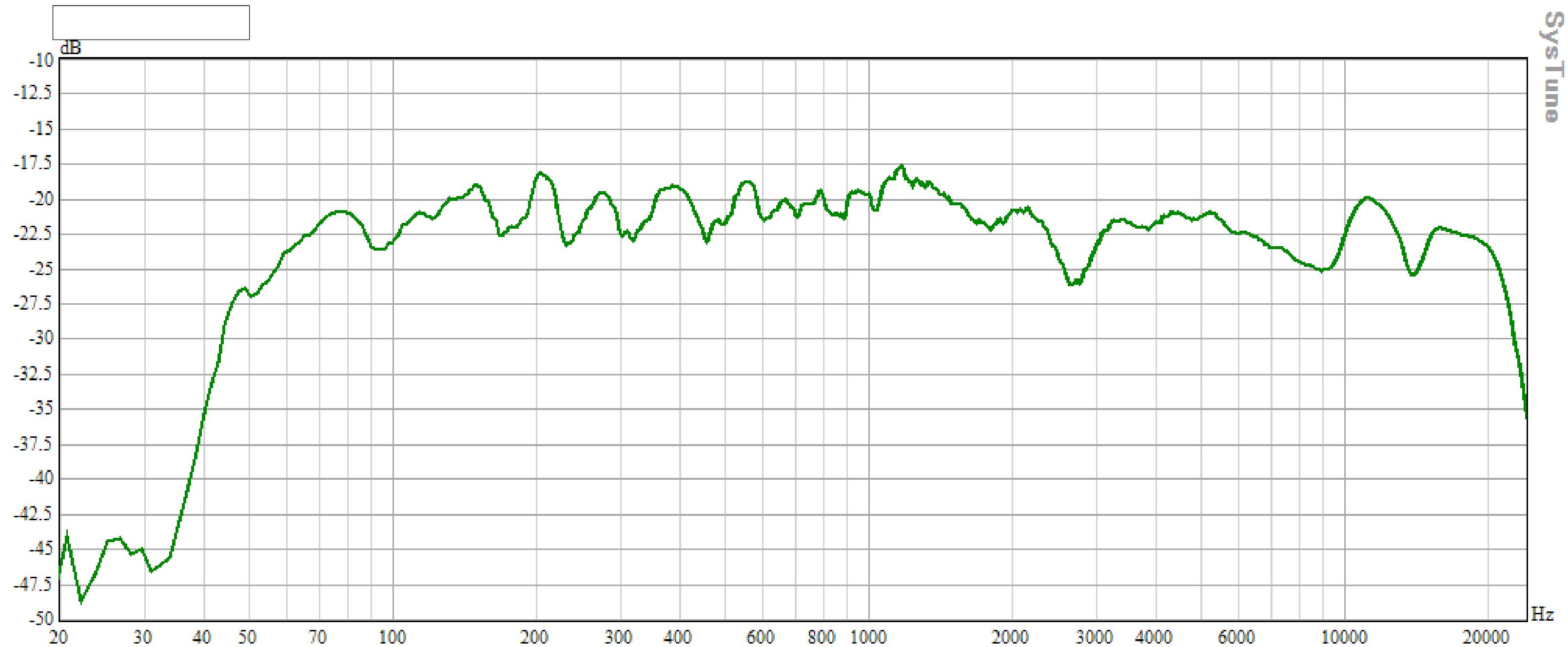
We now know the frequency region of possible concern.

Is it audible? **Does it matter?**

Interpreting the Data

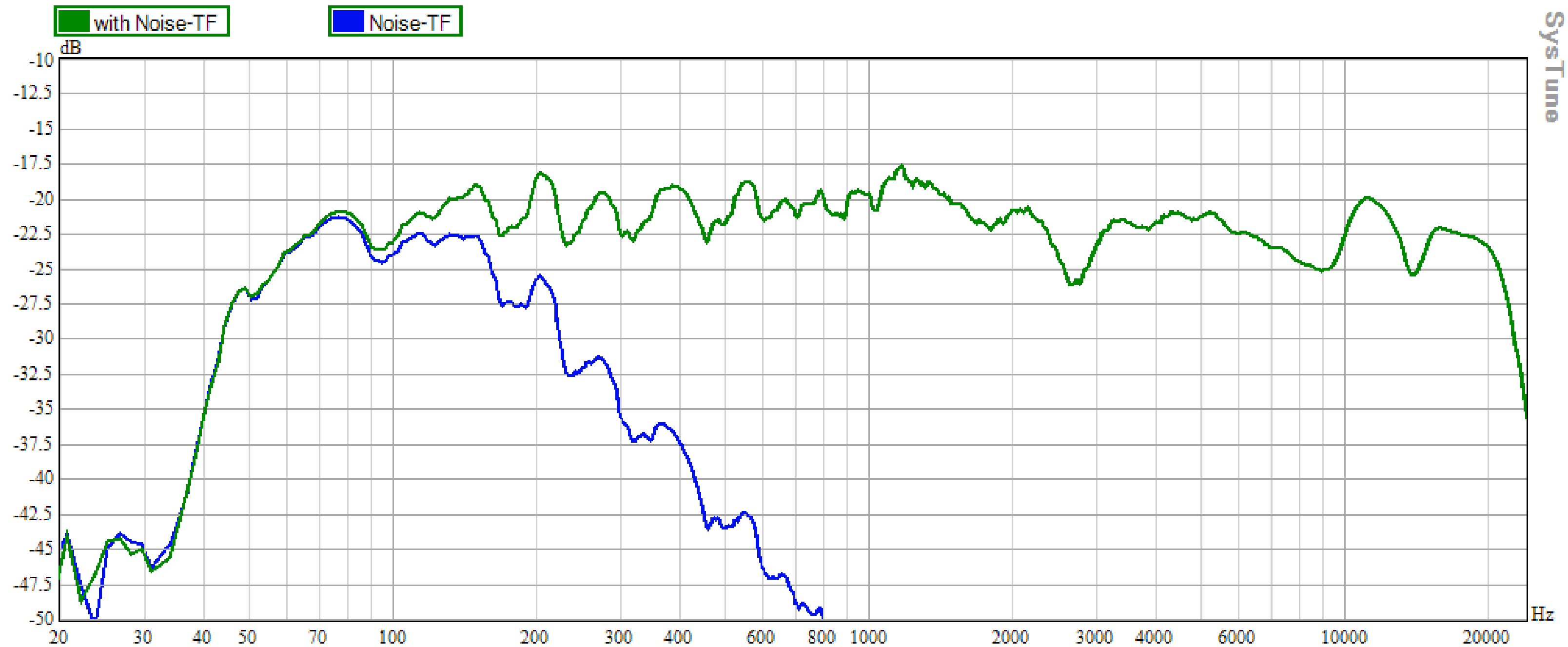
Is this a good response for a loudspeaker system?

Two-way loudspeaker with an 8 inch woofer & an HF horn



Interpreting the Data

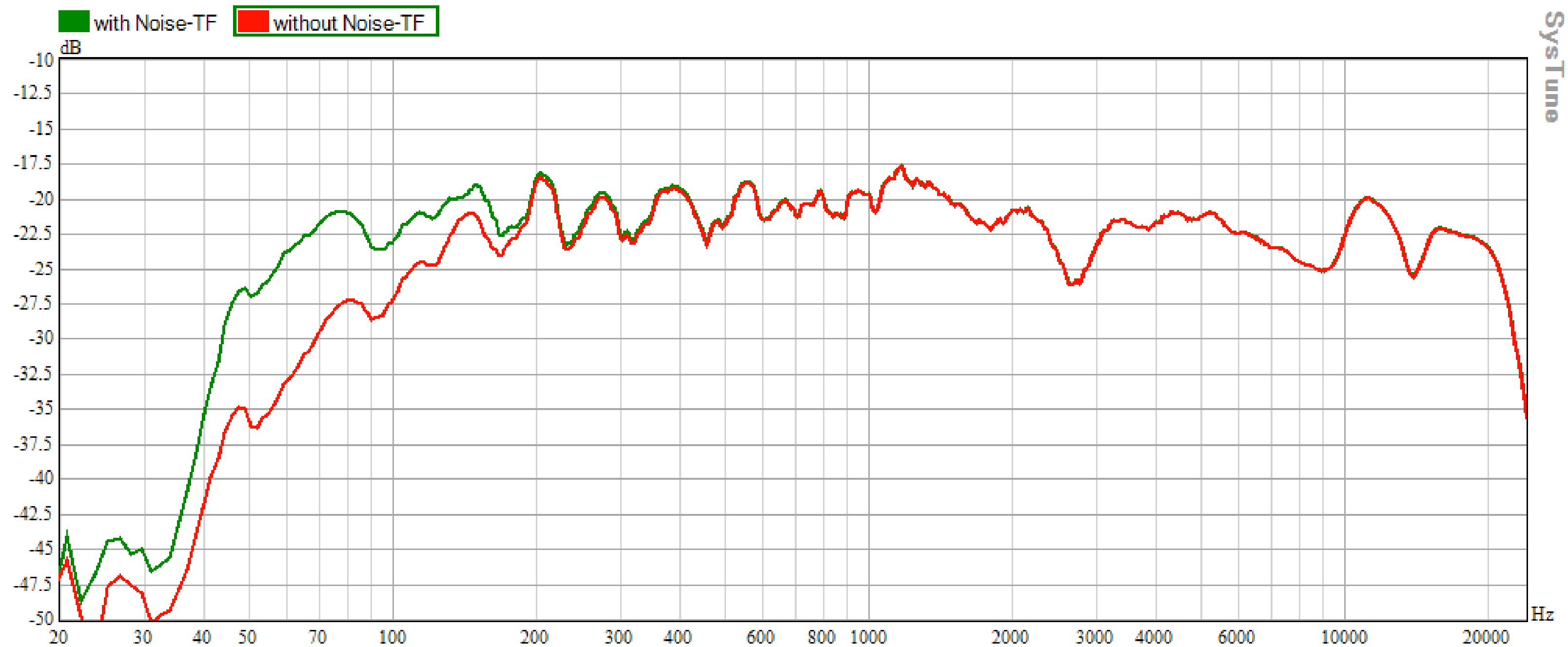
Is this a good response for a loudspeaker system?



Do we know the noise floor and spectrum in our room?

Interpreting the Data

Is this a good response for a loudspeaker system?



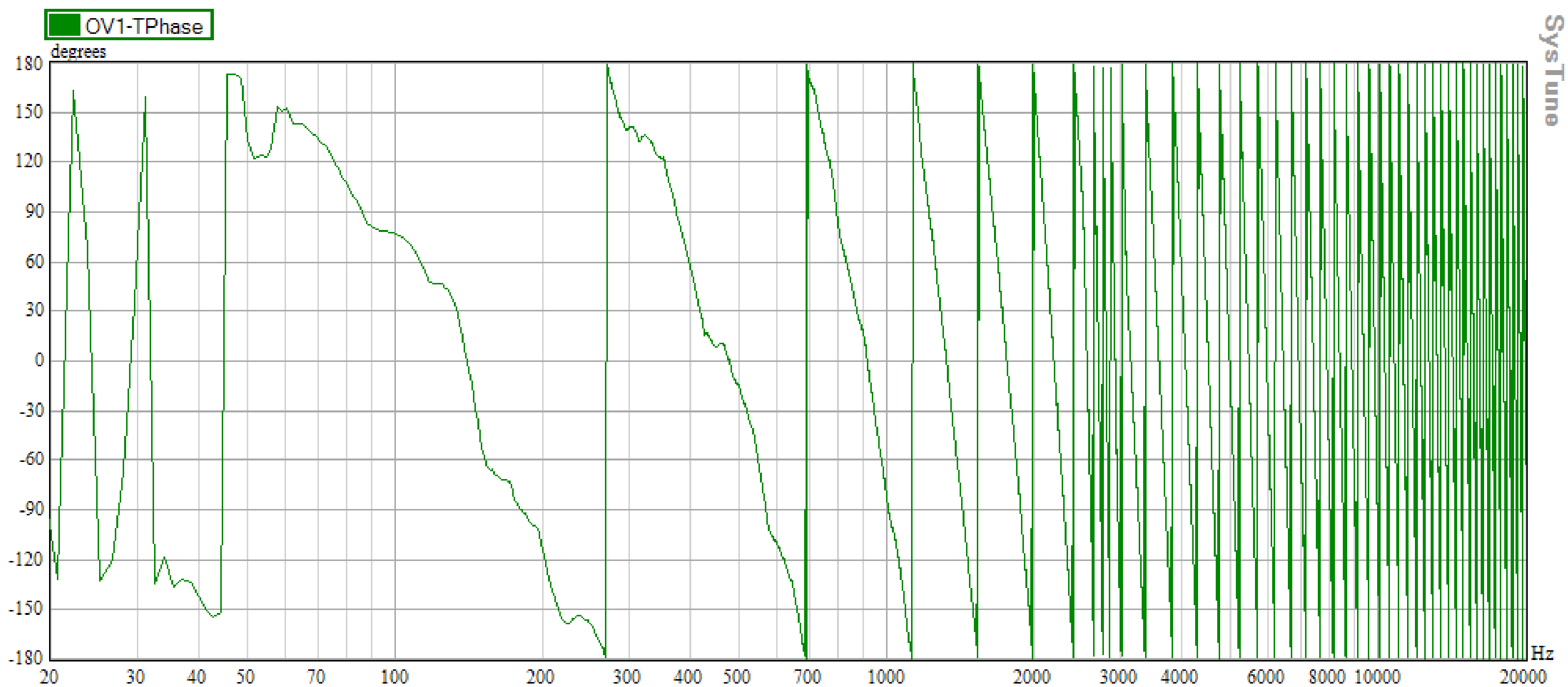
Noise removed from the measurement via more averaging.

We may need a subwoofer.

Interpreting the Data

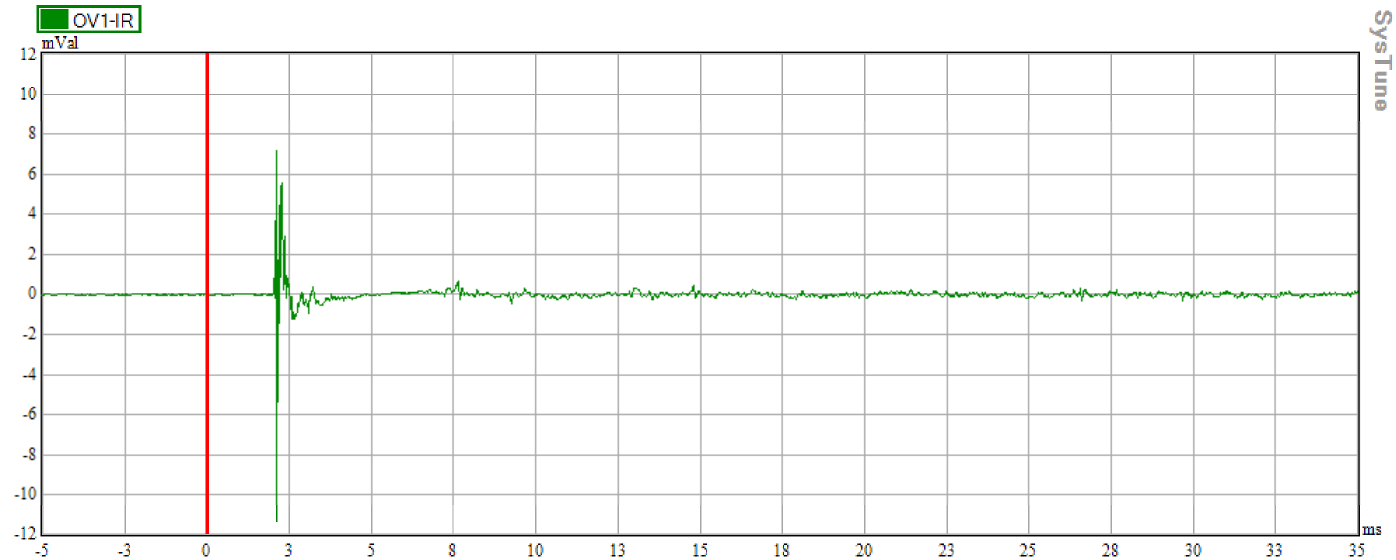
Have you ever seen a phase response that looks like this?

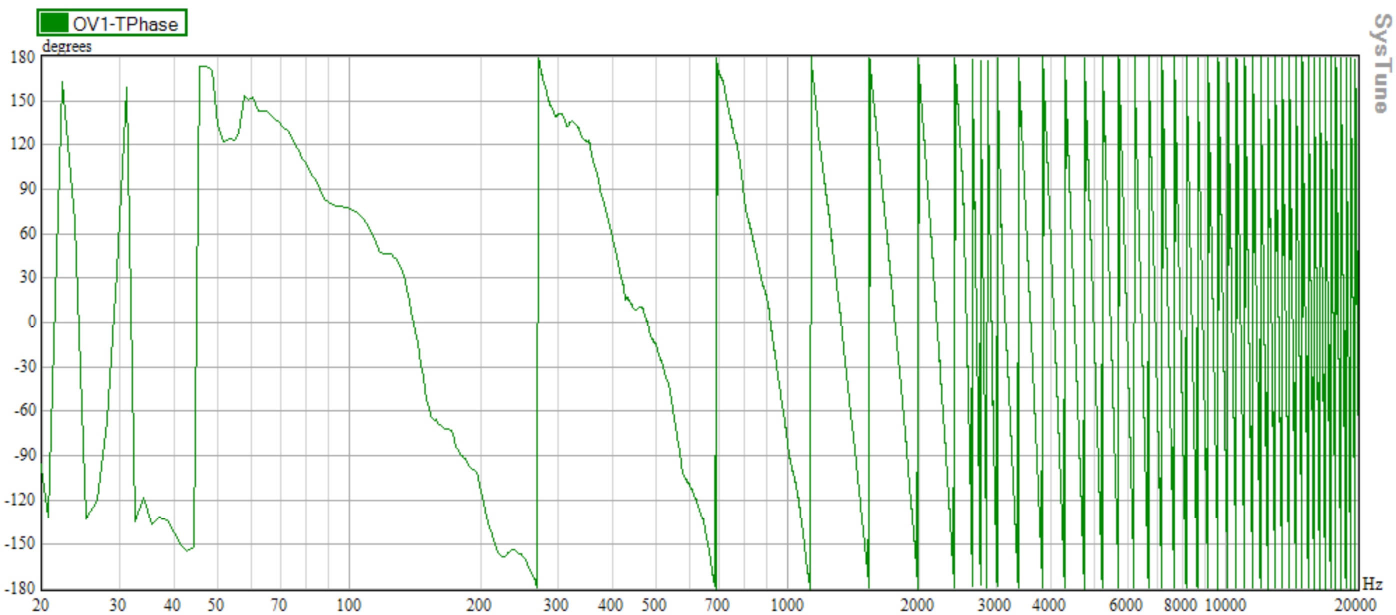
Phase response always ***decreases*** as frequency increases.



The faster it decreases (wraps) indicates the longer the energy arrival occurs after the analyzer time t=0.

Interpreting the Data





Interpreting the Data

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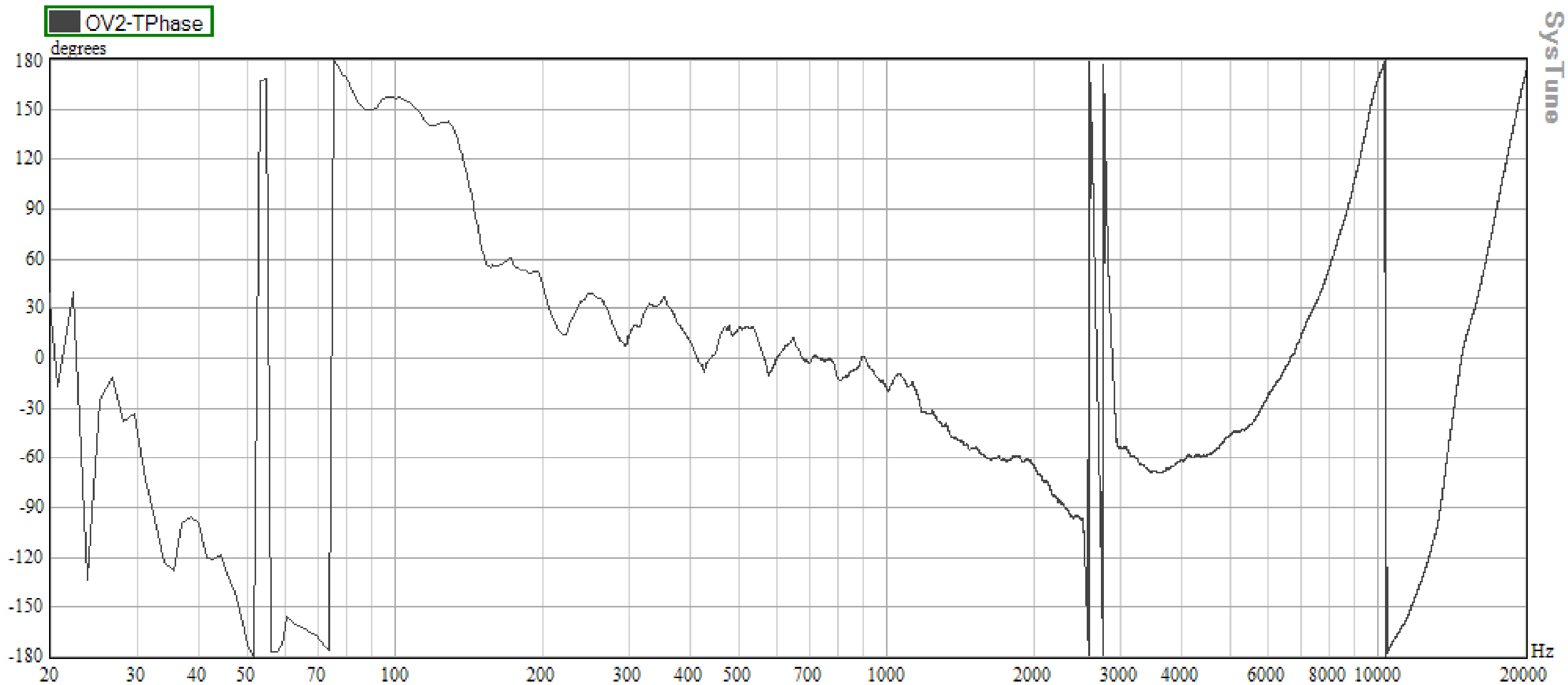
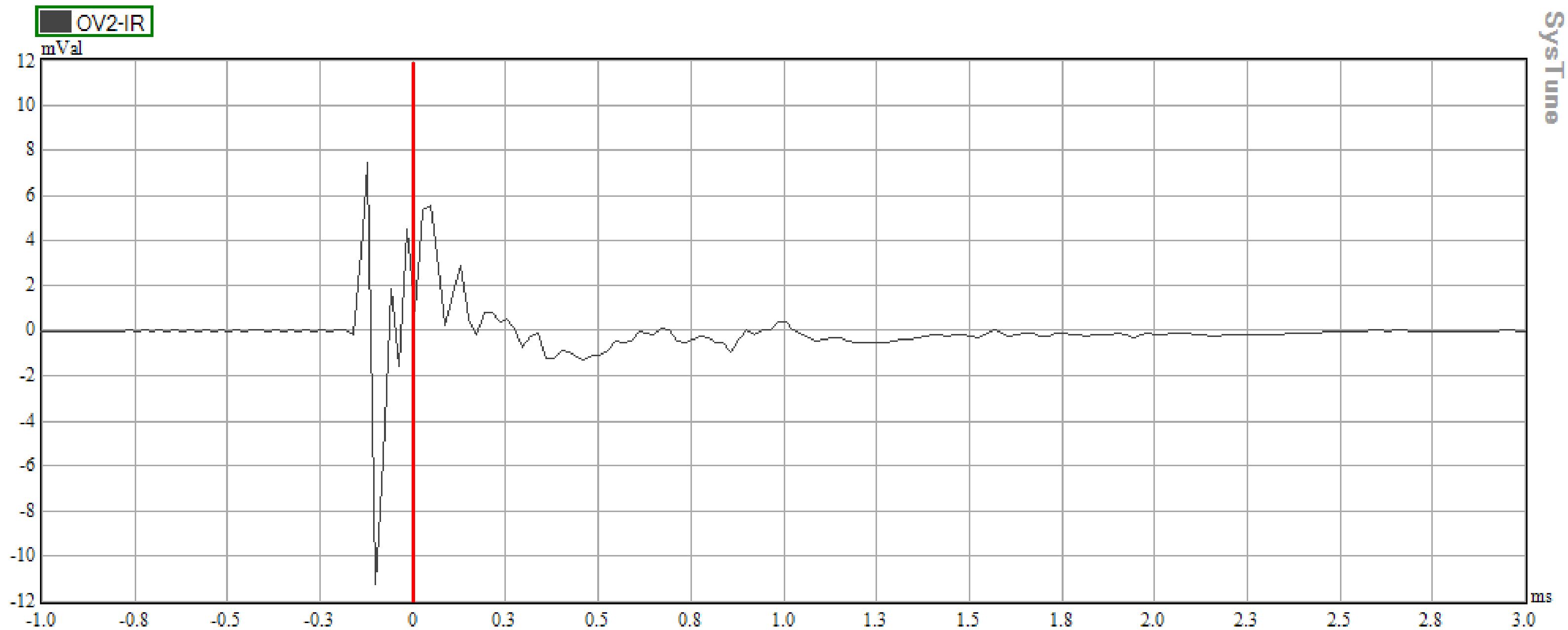


Phase response that ***increases*** with increasing frequency can not occur in nature in real time.

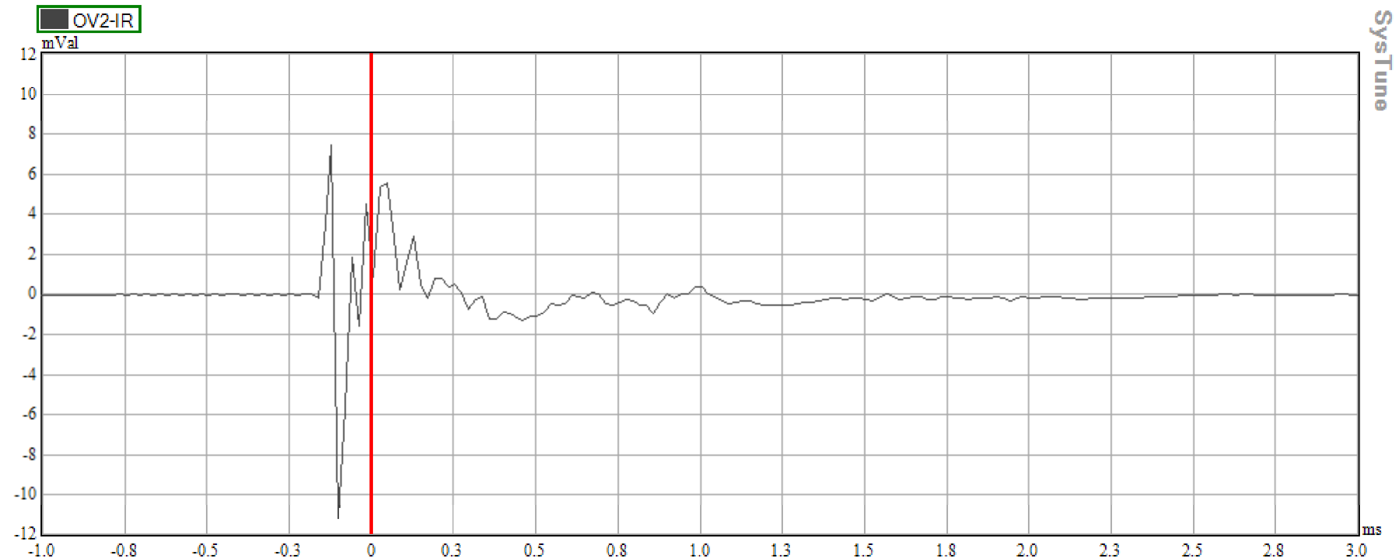
Interpreting the Data

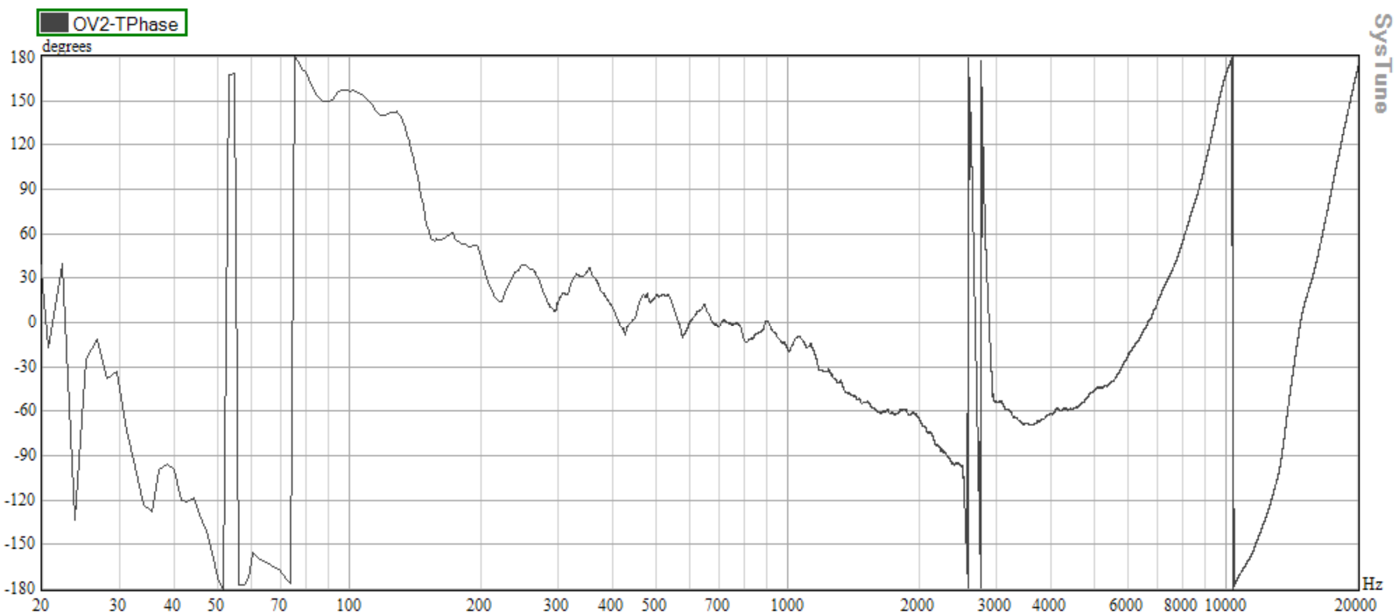
The up-turn in the phase response is a result of the arrival of energy prior to the time t=0 of the analyzer.



The signal is returning to the analyzer before it leaves the analyzer!

Interpreting the Data





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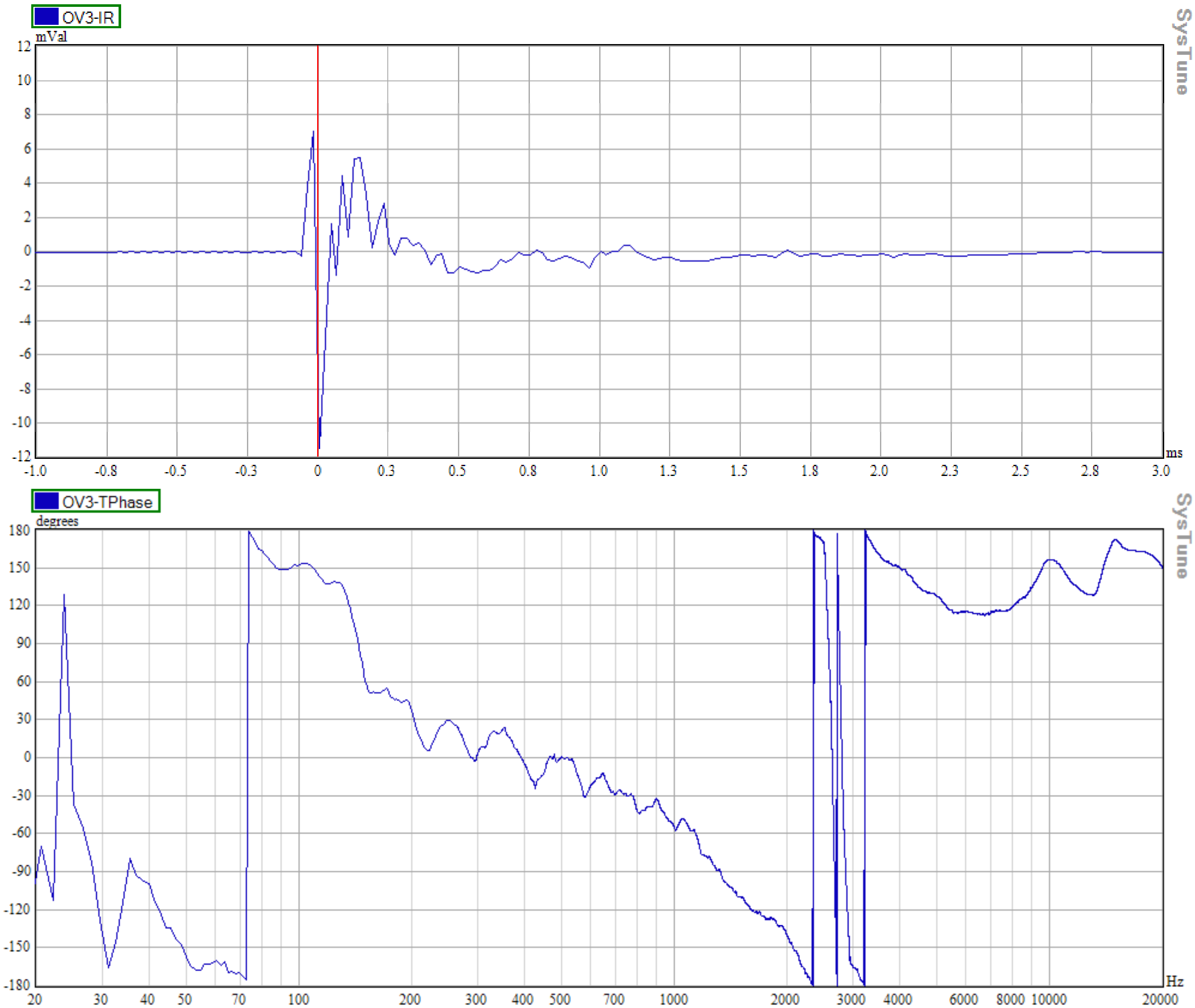

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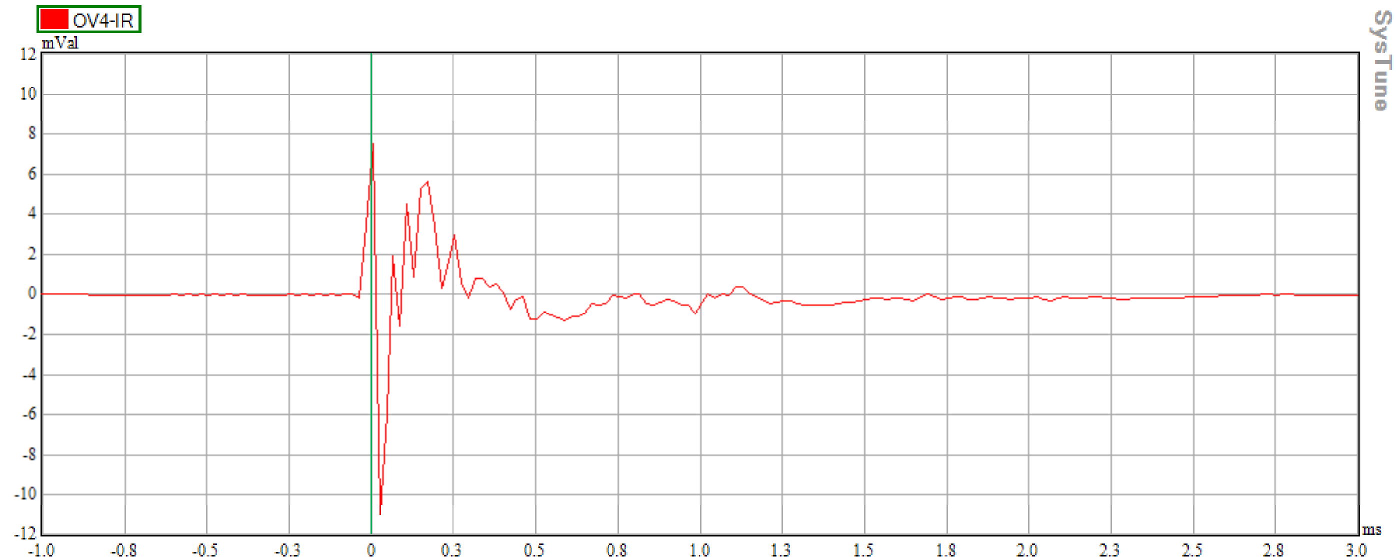

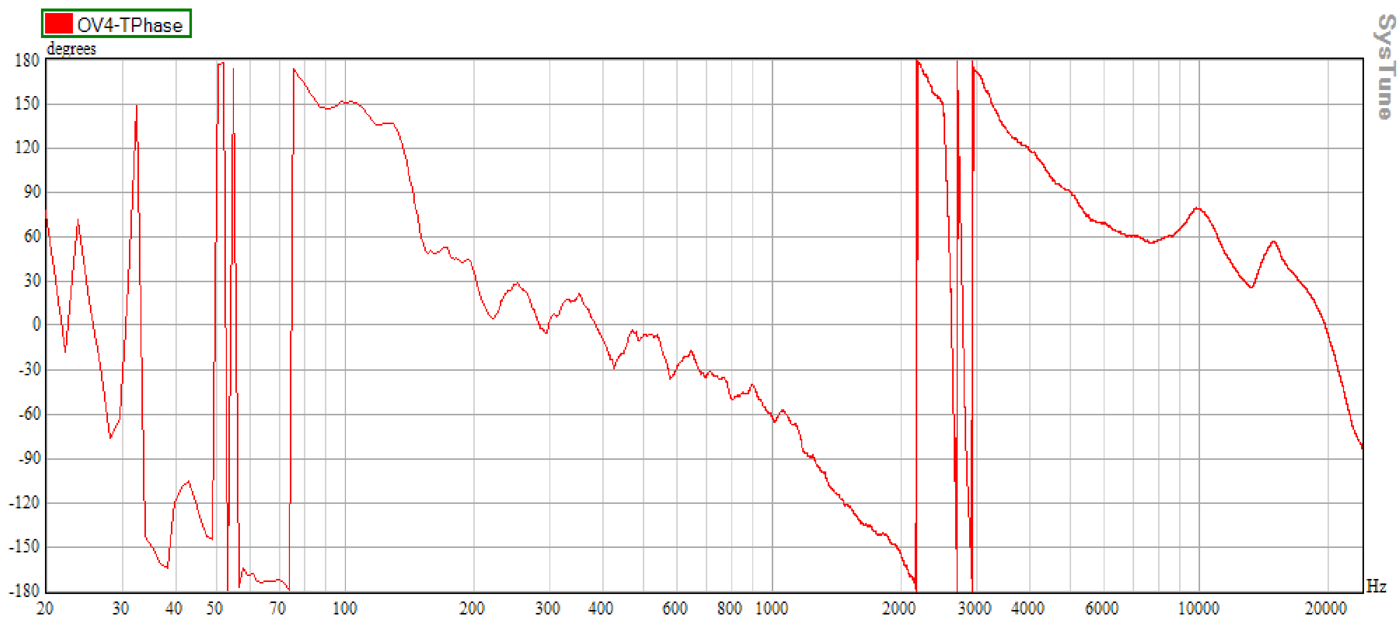

Corrective Action

What type of corrections or modifications are to be considered?

- EQ and/or Delay (electronic only)
- Relocating or Re-aiming Loudspeakers
- Acoustical Treatment

Limit your measurement observations to what you intend to correct or modify.

- Direct field & boundary loading of the loudspeaker only
- Boundary loading and near-by reflections
- All reflections or specific room reflections

Is it audible? **Does it matter?**

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Is it audible? **Does it matter?**

Corrective Action

Make sure you can observe the effects of your modifications!

- Changing crossover filters or post-crossover EQ or delay
- Moving loudspeakers in an array
- Acoustical Treatment

Possible consequences

- Changes the directivity response in the crossover region
- Affects the maximum SPL capability
- Reliability

Is it audible? **Does it matter?**

Corrective Action

Make sure you can observe the effects of your modifications!

- Changing crossover filters or post-crossover EQ or delay
- Moving loudspeakers in an array
- Acoustical Treatment

Possible consequences

- Changes the directivity response
- Affects the maximum SPL capability in some areas

Is it audible? **Does it matter?**

Corrective Action

Make sure you can observe the effects of your modifications!

- Changing crossover filters or post-crossover EQ or delay
- Moving loudspeakers in an array
- Acoustical Treatment

Possible consequences

- Reduction of reverberation may make discrete reflections more annoying

Is it audible? **Does it matter?**

Recap

- Things to Always Keep in Mind
- Types of Measurement Analyzers
  (FFT Based Analyzers)
- Types of Test Signals
- Measurement Microphones
- Measuring Loudspeakers vs. Measuring Rooms
- Time Windows
- Interpreting the Data
- Corrective Action

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