FREQUENCY RESPONSE MEASUREMENTS

by **GIULIANO NICOLETTI**

The measurement of frequency response is undoubtedly the most important tool for the analysis and evaluation of a loudspeaker system. The graph that represents the transfer function is able to provide clearer and more readable information on the sensations that are perceived by the listener, and it represents the most distinctive and easily accessible graphic for establishing direct relations between subjective perceptions and instrumental analysis.
To correctly display the frequency response of a loudspeaker - and produce graphs that are directly related to the subjectively perceived quality – it is not however enough to produce one simple response curve (as often happens). It is necessary to use a rather complex procedure, involving an environment suitable for acoustic measurements and a good dose of experience. Before going into an analysis of the setup developed for TAA, it's necessary to introduce some concepts that will be needed to correctly interpret the published measurements, some interpretive keys that should render our measurements useful and indicative.

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Curves

The graph of the frequency response of a loudspeaker displays the acoustic intensity with which the signal is reproduced when sent to the speaker system; the horizontal axis shows the values of frequency expressed in Hz, while the other shows the values of acoustic pressure expressed in decibels. The bandwidth that represents the audio signal conventionally extends from 20 to 20,000 Hz, this is indeed the range of frequencies that is perceived directly by our auditory system (this is a simplification that ignores the psycho-acoustic perception, but can be considered valid here). In most cases, the mechanical limitations of conventional electro-dynamic loudspeakers make it impossible to rely on a single component to play the entire audible spectrum, and it is therefore necessary to subdivide the audio band into smaller portions and assign reproduction to specialized transducers operating in a given frequency range.

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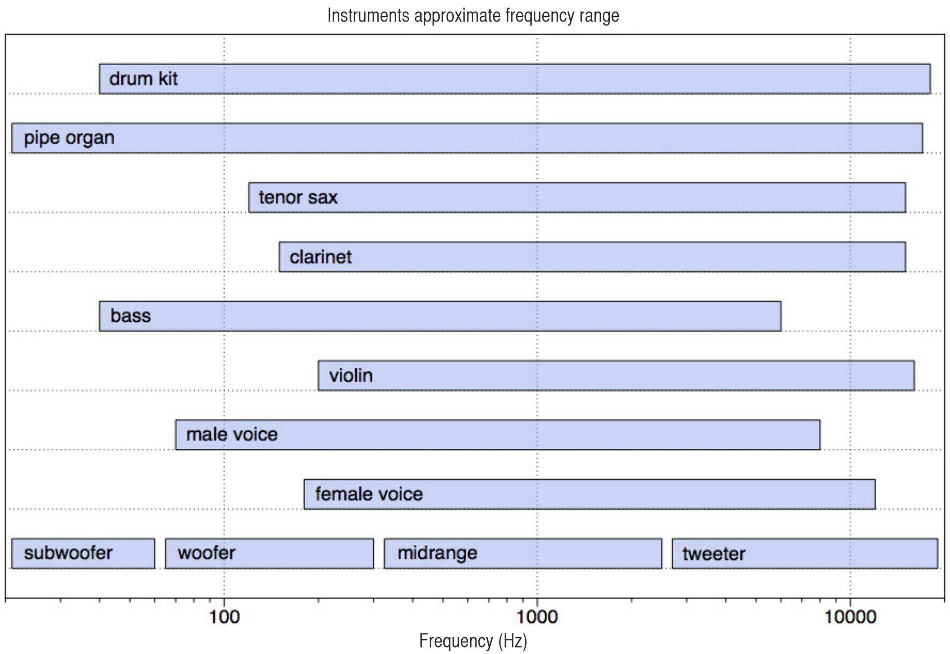

Frequency range

In the graph at the side, we show a breakdown of the various frequency ranges typically assigned to the different loudspeakers of a system, with indications of the bandwidth of some of the most popular musical instruments. Lovers of full-range systems will be pleased to note that most of the instruments used by men to create music are characterized by a bandwidth much wider than that which is covered by the individual components of a classic loudspeaker.
The first interesting indication that comes from a speaker's graph of frequency response is therefore the definition of bandwidth, the extent of the response in the audible spectrum.
This is not a purely qualitative

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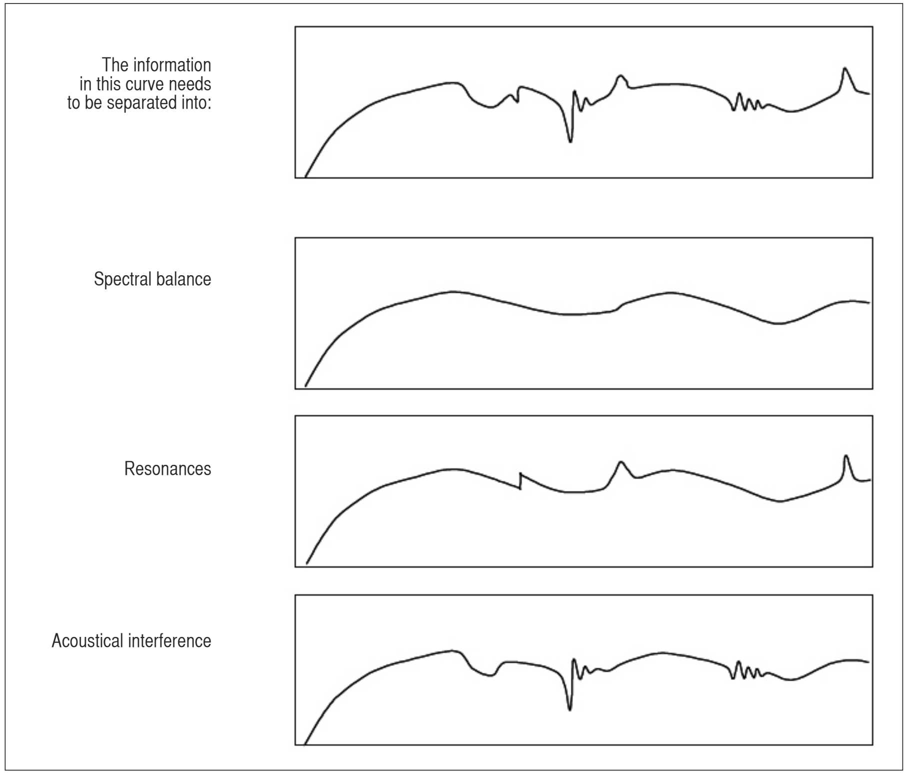
parameter, as there are excellent speakers with limited extension to the extremes of the bandwidth, but it is an important quantitative characterization, which must be related to one's own preferences and listening environment.

The second interesting indication relates to the regularity of the response, namely the way in which a line moves through the graph. The curves themselves contain some clear macro-information, within which we must distinguished micro-information. This kind of information layering requires some important interpretative clues: a path free from alterations, peaks or troughs is clearly preferable, but we must always interpret what is observed, placing the graphic indications in relation to the phenomena that have generated them, and the influence which they will then have during listening phase. Some characterizations may simply be sought in the engineering and design phase or depend on the interaction of the crossover filter with the speakers, others are generated by the acoustic interaction between the various loudspeakers in the system, or the acoustic load of the cabinet, while others must be related to presence of resonances.

As a general indicator, the phenomenon of acoustic resonance does not need to be demonized (in the end, all musical instruments exploit this mechanical principle), but it is essential to be able to measure and interpret it correctly. Look at the next graph, taken from the invaluable work of Floyd Toole, Acoustics of loudspeakers and rooms: the characterizations of the curve tell different, overlapping stories, and the observer has the task of knowing how to discern and interpret them, so that the graph itself is an aid to understanding, and not a condition to be met with distrust. In the coming months, as new loudspeakers come up before the microphones in our laboratory, we will monitor developments, evaluate their characteristics and interpret the data received in the subjective listening phases.



Ambient sound

Acoustic speakers also emit sound in closed environments, and thus generate reflections that have a significant influence in the generation of the subjective perception. What the listener perceives has to be separated into three basic components:

direct sound - what comes to our ears directly from the speakers.

early reflections - the acoustic waves that are reflected only once from the walls of the environment, and then arrive at the listener with a short delay (usually between 2 and 10 milli-seconds).

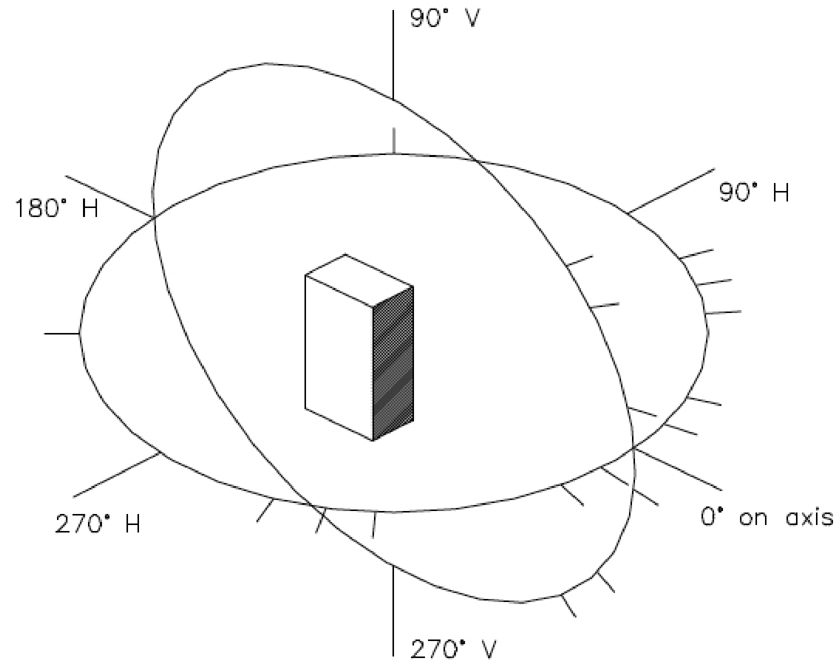
reverberant field - the sound that is reflected by all that is present in the listening environment and which reaches the listener after multiple reflections, until there is a total absorption of the energy emitted into the room by the *it's important to consider that which takes place in a normal listening room in a home environment is very different from that represented by simple formulas*

speakers.

Finally, it's important to consider that which takes place in a normal listening room in a home environment is very different from that represented by simple formulas. The resonances that are generated in our rooms at low frequencies, from about 3-400 Hz down to lower frequencies are almost always dominant in determining the quality of the timbre perceived subjectively, and this is why lower frequencies are also those most closely related to the listening position.

It is of course possible (and recommended) to carry out acoustic tunings that are able to significantly reduce the interaction between the speakers and the listening environment, but we must keep in mind that at low frequencies the relationship between the measurements made in an anechoic environment and those carried out in real environments are hardly comparable. The entire mid-high range can be derived, however, in a more direct manner from the measurements, but once again, you must be able to predict how the speakers emit energy at different angles: towards the floor, ceiling, side walls, front and rear. Drawing a single response curve on the main axis of a loudspeaker makes little sense, is of little use, and may instead generate misunderstandings and - especially - the loss of public confidence in the possibility of establishing direct comparisons between instrumental testing and subjective listening tests. What should we measure, then? To quote Floyd Toole: "In short, one must measure everything".

TAA Lab - Laudspeaker transfer function spatial mapping



The measuring setup

Some manufacturers of speaker systems have developed complex measurement systems based entirely on this short quote. The Harman Group's immense firepower has allowed them, for example, to develop an automated data collection system that takes about 70 measurements spaced at 360 degrees around the speaker. The measurements are then averaged according to a spatial distribution factor that takes into account an analysis of the average characteristics of home listening environments (room sizes, speaker-listener distances, characteristics of absorption and reflection). Finally, they produce a chart that shows four independent curves. Obviously this is a very time-consuming procedure, but certainly very significant and distinctive.

For TAA's Laboratory, we decided to take inspiration from this setup and simplify it to make it reasonably applicable, but still valid for the characterization of the loudspeaker being tested. This means measuring around each speaker under test along all the main axis of radiation, for a total of 22 measures of frequency response.

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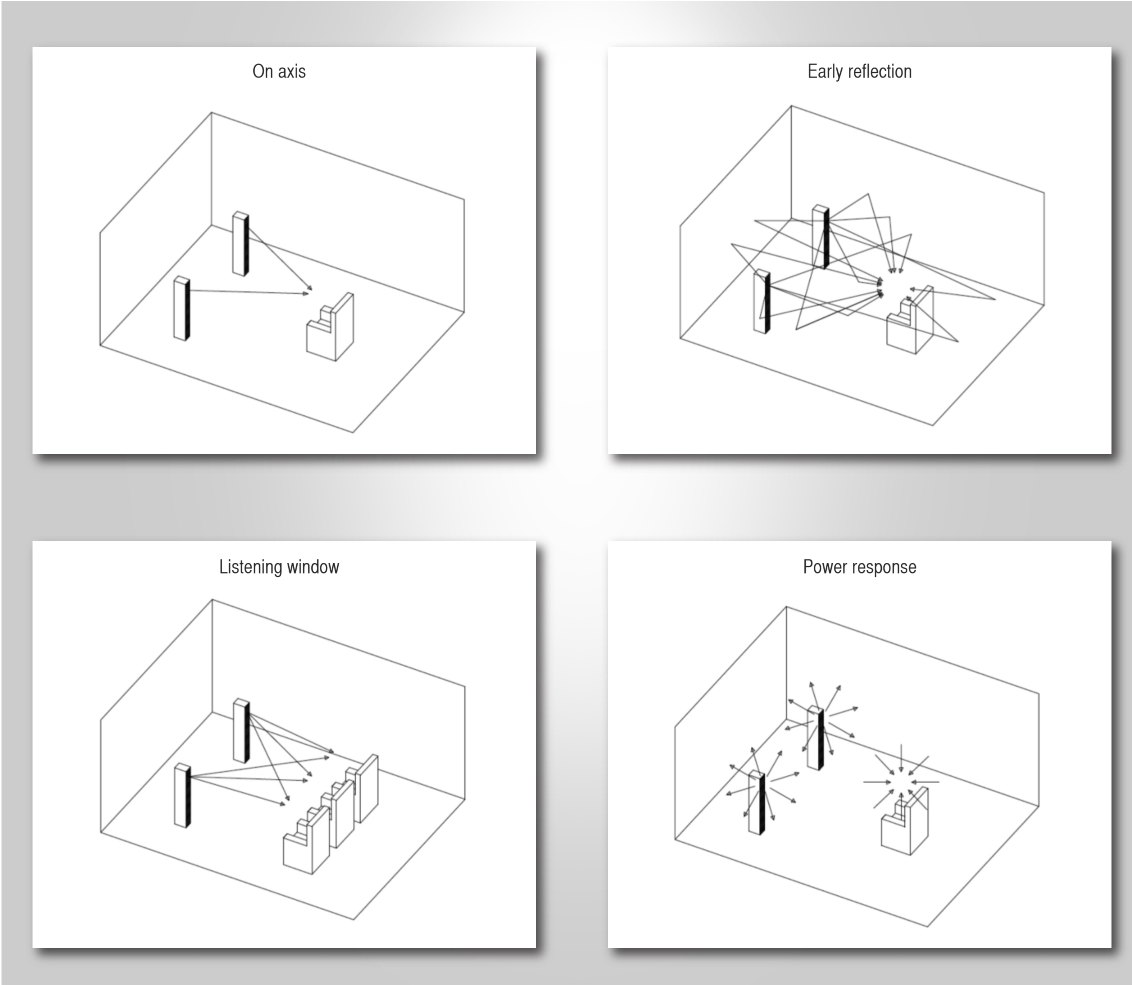
On the frequency response graph there are five resultant curves:

Axis: is the single measurement taken on the main axis of emission, usually in line with the tweeter or at around an effective height of 90 cm above the floor. This is the least interesting curve, but still remains a standard; it's quickly displayed and its fans are loyal, so we decided to maintain it as a reference to what is often released by manufacturers.

Listening window: This is the curve obtained from the average of 7 measurements taken in a window of +/- 20 degrees on the horizontal axis and +/- 10 degrees on the vertical axis. It shows the sound perceived directly by the listener in the area usually devoted to listening, and represents a significant average of the acoustic interactions of the various speakers and the acoustic load of the front panel; it smoothes the extremes and at the same time illustrates the trend. It shows the basic timbre setting of the speaker

Early reflection: To obtain this curve, we first take the averages of the sound emitted at the front (7 measurements), the rear (5 measure-



ments), sides (3 measurements), ceiling (3 measurements), floor (3 measurements). These five curves are in turn averaged again and produce a final one that represents the trend of the response emitted towards the points that generate the early environmental reflections, directly responsible for the perception of spatiality and the sound image. It should be read as the first response of the environment, and placed in relation with the listening window curve, with which it needs to be compared for consistency and performance.

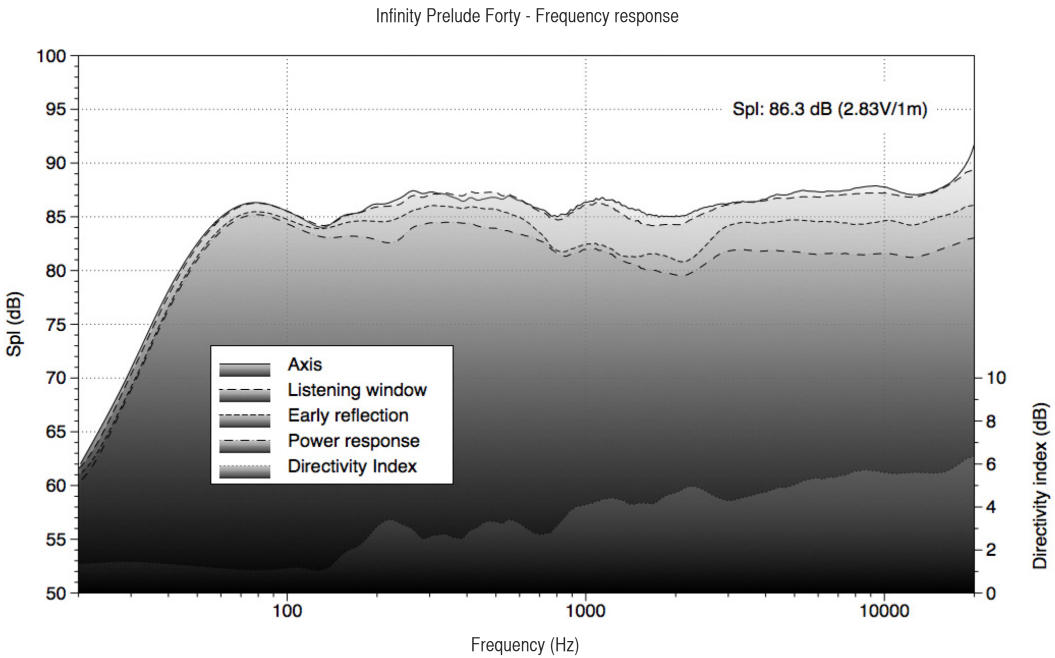
Power response: This is the weighted average of all the 22 curves produced, and shows the way in which the speaker emits acoustic energy at 360 degrees. It is therefore representative of the reverberated field of the environment, and also shows the principal resonances of the speakers.

Directivity index: This is the difference between the listening window curve and the power response. It thus shows the directivity pattern, and also highlights the presence of the main resonances, which are typically emitted in all directions. In some cases these resonances indicate problems, in other simple characterizations. It's therefore important to assess the regularity of the progression of this curve, and the extent of the more abrupt changes.

All the response curves are produced in a room with low reverberations, 5.6 x 6.6 x 8 meters in size, positioned about three meters above the floor; the individual measurements obtained are imported into a series of specially prepared spreadsheets and then imported and edited by a dedicated program to finally produce the graphs published in the magazine.

Conclusions?

It's difficult to say; the reviewer's task is to guide readers towards interpreting the curves and in turn provide meaningful and solid points of reference, which can contribute to slowly building the architecture of an independent opinion. The setup provides extensive and significant indications, in a much more modern and interesting way than can be obtained from individual curves (or, worse, from misleading and much-abused axis measurements). It remains impossible to provide direct indications, firstly because there are many different ways to interpret the design of a loudspeaker, and then different instrumental results. All the same, it will be possible to identify certain limits, more or less obvious defects, and trace a sonic path that will hopefully constitute a solid base and alternative assessment that can complement the subjective evaluation made in the listening phase. For this reason, we've placed little "traffic-lights" next to the main charts which indicate a broad qualitative assessment, in a simple and clear way. These are complemented by technical notes, to provide useful information at different levels of complexity. We remain convinced that these two phases of analysis (measurements and listening test) should remain independent, but at the same time share information and help in their own way to build an overall assessment as objective and reliable as possible of the speaker under test. ■



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WHO IS FLOYD TOOLE?

Floyd E. Toole studied electrical engineering at the University of New Brunswick, and at the Imperial College of Science and Technology, University of London, where he received a Ph.D. In 1965 he joined the National Research Council of Canada, where he reached the position of Senior Research Officer in the Acoustics and Signal Processing Group. In 1991, he joined Harman International Industries, Inc. as Corporate Vice President – Acoustical Engineering. In this position he worked with all Harman International companies, and directed the Harman Research and Development Group, a central resource for technology development and subjective measurements. Early in 2007 Dr. Toole retired.

Dr. Toole's research has focused on the acoustics and psychoacoustics of sound reproduction in small rooms. Most notably, he established methods for subjective and objective evaluations which have been used to clarify the relationships between technical measurements of audio equipment and listeners' perceptions. All of this work was directed to improving engineering measurements, objectives for loudspeaker design and production control, and techniques for reducing variability at the loudspeaker / room / listener interface. For papers on these subjects he has received two AES Publications Awards and the AES Silver Medal. A book, "Sound Reproduction", for Focal Press (2008) is his most recent project. He is a Fellow and Past President of the Audio Engineering Society and a Fellow of the Acoustical Society of America. He is currently active in teaching and course development in CEDIA and in 2008 he was awarded the CEDIA Lifetime Achievement Award. ■