The Effects of Audio Cable as Related to Articulation of Speech and Music

by Bruce A. Brisson

MIT constantly gets questions from the field regarding system compatibility issues. Usually the questions are, "What cable sounds the best between this amplifier and that speaker?" or, "What cable sounds the best between this pre-amp and that amplifier?" This paper will deal only with the interfacing of the line level components, such as pre-amplifier to amplifier, and the associated articulation response. Another paper, due at a later date, will deal with the articulation response of the amplifier / speaker interface.

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The input impedances of low level components found in the consumer side of audio vary widely. These input impedances may run anywhere from 10K ohm to 100K ohm, with some balanced systems running as high as 100K ohm per leg, or 200K ohm total input impedance. This wide range of input impedances results in a termination problem for our dealers and customers, because the resistive load into which the cable is terminated has a major effect on the articulation of the system.

Our opinion at MIT is that customers should not have to spend money guessing what works best in their system. The installation / termination problem described above required MIT to engineer a solution. This engineered solution involves a technology we call Impedance Specific Networks, or ISN. Interfaces utilizing ISN come in three different variants, each having a network specified for particular termination impedance, fitted inside the cables' network boxes. In short, the ISN technology provides for an easy solution towards realizing maximum articulation in any sound system installation.

The typical –3dB corner frequency is well above 20 kHz. Generally it is found somewhere between 150 kHz and 1.5 MHz, well above the frequency range we hear.

Conventional wisdom views the only meaningful specification regarding interfaceing is the frequency response between components, for example, between the pre-amplifier and the amplifier. All audio cables function as a low pass filter, so there is always a high frequency roll-off, hopefully at a frequency much higher than 20 kHz. The typical –3dB corner frequency is well above 20 kHz. Generally it is found somewhere between 150 kHz and 1.5 MHz, well above the frequency range we hear.

However, there is a second response that exists well below the –3dB down corner frequency. This is the articulation response of the cable being used to interface the hardware, or the individual components, together as a system. Since this articulation response is what we actually hear, it is the response this paper will focus on. Measuring the articulation response reveals a problem which we hear primarily as a masking of detail or lack of intelligibility. Once this response has been measured and analyzed, it is easy to understand what cable should, or should not, be used to interface any number of components together into a high quality audio system. Or, if the articulation response is poor, we can see what should be changed to correct the problem. A system with wide frequency response but a skewed articulation response will never produce the high-quality sound that we desire.

The Articulation Response is a secondary response that exists well below the –3dB down corner frequency of the cable being used to interface the system. The Articulation Response is what we actually hear.

Articulation

When a system articulates properly, one immediately notices speech as being distinct and intelligible. Vowels are clearly articulated, not slurred, and consonants are sharp and distinct.

Some words that are used to describe articulation are: intelligibility; masking or clarity; discrimination; sensitivity; duration; timing; detail; attack and decay; rise and fall time; and loudness. Individually or collectively, these words are used to indicate a system's ability to articulate. When a system articulates properly, one immediately notices speech as being distinct and intelligible. Vowels are clearly articulated, not slurred, and consonants are sharp and distinct.

Articulation, as related to speech in particular, refers to the quality of a person's ability to enunciate. An extremely simple test of articulation, or of a device's ability to transmit articulated speech clearly, can be conducted by reading selected sentences to a group of listeners. A score is kept by each listener as to the intelligibility of each sentence, word, and syllable. Articulation tests of this type were reportedly started by Bell Telephone Laboratories in the 1940's. Today, there are much more sophisticated types of tests or measurements available, such as STI, %Alcons, and RASTI to name a few.

However, it is very doubtful that any two people hear in exactly the same way. So, in order to accurately determine the articulation or intelligibility of an audio cable, we must not only listen to it subjectively, we must be able to measure it objectively.

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Art Noxon of ASC, "The Tube Trap Company," has developed a test for measuring the articulation of listening rooms. This simple and affordable measurement utilizes a hand held dB meter and a CD from Stereophile magazine that provides the stimulus. The data can be put immediately to hard copy via a strip recorder, or it can be put onto a cassette tape and sent to ASC for analysis. Art calls this test the MATT (Musical Articulation Test Tones) test. The MATT test correlates reductions in modulation height and depth to loss of acoustical articulation. Art has also done a paper on the rise time and fall time of a room used for sound reproduction, which I believe anyone reading this paper would find very interesting reading. For more information go to ASC's website at http://www.tubetrap.com.

Rooms acoustically affect the articulation and intelligibility of speech and music. Cables electrically affect the articulation and intelligibility of speech and music. The test and measurement architectures used in measuring rooms and measuring cables are, of course, very different, and the hard copy results look very different; nevertheless, the measurements reveal many of the same things.

Musical Sounds

Musical sounds are produced when the air or other medium is set into motion. Sound may be produced by a vibrating body as, for example, the sounding board of a piano, the body of a violin, or the diaphragm of a loudspeaker. Sound may be produced by the intermittent throttling of an air stream as, for example, the trumpet, or the clarinet, or any other reed instrument, including for that matter the human voice.

Musical instruments and the human voice produce fundamental frequencies and overtones of fundamental frequencies. The overtone structure is one of the characteristics which distinguishes various instruments and voices. (If musical instruments produced the fundamental without overtones, each instrument would produce a pure sine wave.) The fundamental frequency is the lowest frequency component in a complex waveform.

Speech and music both consist predominantly of two types of sounds: voiced and unvoiced.

Over and above this, musical sounds as well as speech are complex in nature. They may consist of several pure tones of different frequencies, along with an additional transient sound component that punctuates the more sustained elements. Speech and music both consist predominantly of two types of sounds: voiced and unvoiced. In speech, as an example, voiced sounds occur when air passes from the speaker's lungs through the voice box. Unvoiced sounds in speech occur when there is no vocal track excitation. These sounds are caused by the speaker using his or her tongue, lips and teeth to cause clicks, hisses and popping sounds. Furthermore, in both speech and music, there are spectral gaps, or spaces of time where no information exists, when silence is the only thing which is, or should be, heard. These pauses between acoustic sounds, also called juncture pauses, carry meaning and cannot be eliminated without impairing the intelligibility of speech or music. Sometimes audiophiles, or musicians, express voiced sound as different colors, while juncture pauses are just called black.

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Transportable Power, Energy Storage Elements, and The Power Factor

The most important or relevant measurements of an unterminated audio cable relate to its ability to store energy and to transport that energy as in-phase power on to the load. MIT's technical paper on this subject, entitled "Transportable Power in Audio Cables, Tech Paper #101," is available on our MIT website www.mitcables.com for anyone desiring to access it. The efficiency plots in that paper are for unloaded cables; that is, no load or resistor was attached to the cable while making the measurement. However, as noted above, the load value, given in ohms, into which the cable is terminated ultimately plays a large role on the cable's -- and therefore the system's -- ability to articulate. High quality recording or play back systems require that the cable and the load function together predictably, as a system, in order to produce high articulation. That is the focus of this paper and of the measurements shown here.

MIT test results show, even a high quality cable, when terminated into a load which is not ideal for that particular cable, will cause the articulation response to skew.

Interpreting the Articulation Measurement

Ideally, the articulation response of the cable used in any given system should cover the bandwidth uniformly over the entire frequency range of the sound being transmitted. In the case of music this is generally considered to be 20 Hz – 20 kHz. In the case of high quality speech it is usually 200 Hz – 7 kHz, and for low quality speech the frequency span is usually considered to be 350 Hz – 3.5 kHz. As our test results show, even a high quality cable, when terminated into a load which is not ideal for that particular cable, will cause the articulation response to skew. For many years, it was virtually impossible to determine what cable should be used to interface a given

> The rate at which a cable rises to its full value is also important. Cables that rise very slowly over a wide band of frequencies are not desirable, while cables that rises to at least 10% produces a minimum level articulation. But a cable that rises very quickly to 25% or higher is desirable.

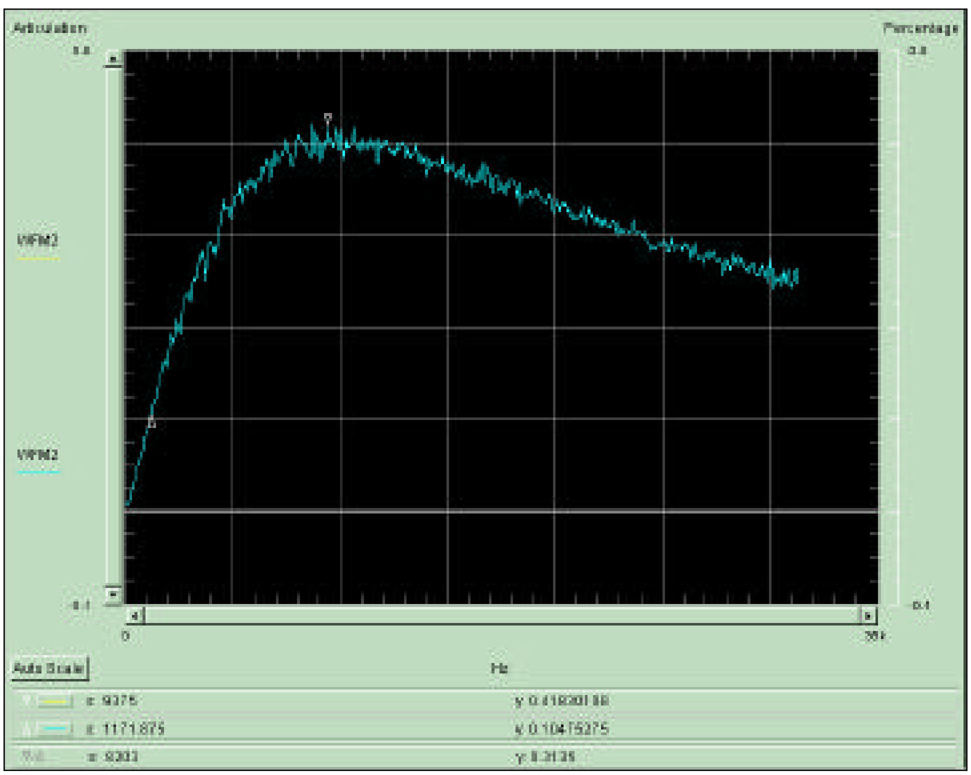
> A cable that rises and peaks at a frequency equal to 50% of the desired bandwidth (20 kHz / 2 = 10 kHz) will be accepted by both the recording and the audiophile communities.

component / load. This lack of knowledge inadvertently resulted in many systems' having wildly skewed articulation responses, thereby degrading their performance. Today, with the aid of the articulation measurement, and with the ISN technology from MIT, it is easy to choose the correct cable for any installation.

In the following graphs, the vertical (y) axis is scaled as a percentage, and the horizontal (x) axis is frequency. The dark line running from left to right across the graph horizontally represents zero (0%) percent articulation. A cable starts to become articulate at 10%, while 25% is desirable, and 50% articulation represents a perfect cable. The rate at which a cable rises to its full value is also important. Cables that rise very slowly over a wide band of frequencies are not desirable, while cables that rises to at least 10% produces a minimum level articulation. But a cable that rises very quickly to 25% or higher is desirable. Generally speaking, a cable that rises and peaks at a frequency equal to 50% of the desired bandwidth (20 kHz / 2 = 10 kHz) will be accepted by both the recording and the audiophile communities. Below 10% articulation, it can be expected that the cable will greatly degrade the performance of the components and the system it is interfacing.

In each graph, the first cursor values show the point of peak articulation for the given cable into the given load: the (x) value is the frequency at which peak articulation occurs; the (y) value is the percentage of articulation at that frequency. Remember that 50% represents perfect articulation. The second cursor values show the frequency at which the cable achieves at least the minimum (10%) articulation.

Articulation Measurement #1: Properly Terminated Test Cable



Articulation measurements #1, #2 and #3 were all made using the same high quality cable for the test. The cable was chosen because it is very efficient and possesses a very good power factor. For the purpose of this paper, this single cable was terminated into various resistive loads to document the articulation responses imposed by those loads on this single cable. What a given listener prefers will forever be that listener's choice. It is hoped, however, that the measurement results shown here will help the readers of this paper understand how sonic differences manifest themselves when they are installing or changing cables in their systems.

As noted earlier, the vertical axis is scaled as a percentage, and the horizontal axis shows frequency. The dark line running from left to right across the graph represents zero (0%) percent articulation. Note the first (x) cursor value at 9,375 Hz. This represents the frequency at which peak articulation occurs for this cable, terminated into this load. Note the first (y) cursor value at 0.4183, or 41%. This represents the percentage of articulation at that frequency. (Recall that 50% articulation would be a perfect cable.) Note the second (x) cursor value at 1171.875 Hz, at the point where the (y) cursor value is 0.104, or 10%. This represents the frequency at which this cable, terminated into this load, will become articulate.

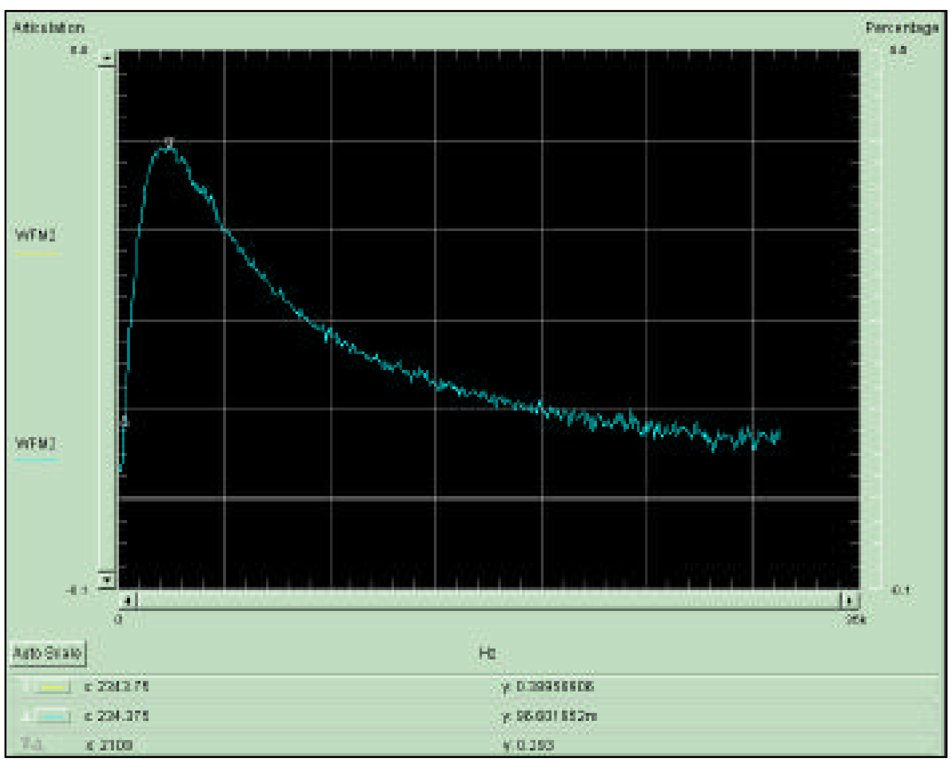
Articulation measurements 1, 2 and 3 were all made using a single high quality cable for the test. The cable was chosen because it is very efficient and possesses a very good power factor.

When conventional cables are used to interface a system, the articulation response shown here is one that many audiophiles and recording engineers tend to prefer. This cable, terminated into this load, will perform moderately well, growing and not declining through the presence (1.0 – 3.0 kHz) area. Also, un-voiced sounds, such as clicks, hisses, and popping sounds, will be well defined with the proper spaces of silence, or juncture pauses, through this important area. Audiophiles usually agree that this cable terminated into this load value has "very good detail." But still, low frequency articulation will be masked, some very high frequency transient articulation (above 35 kHz) will be lost, but the high frequencies within the audio band will still remain connected to the midrange. Although this articulation response is one that is accepted by many audiophiles and recording engineers, it still represents a compromise. Basically we have compromised the articulation at the extremes of the audio range. A good compromise, but still a compromise.

For the purpose of this paper, a single cable was terminated into various resistive loads to document the articulation responses imposed by those loads on the single cable.

Again, the vertical axis is scaled as a percentage, the horizontal axis is frequency, and the dark line running horizontally across the graph represents zero (0%) percent articulation. In this case, the first (x) cursor value is at 2,343.75 Hz. This is the frequency at which peak articulation occurs for this cable terminated into this load. The percentage of articulation at this frequency, shown in the first (y) cursor value, is 0.3895, or 39%. (An articulation value of 50% would be a perfect cable.) Note the second (x) cursor value at 234.375 Hz. This represents the frequency at which this cable, terminated into this load, will become articulate, as shown by the associated (y) cursor value of 0.0966, or 10%.

Articulation Measurement #2: Cable Terminated into Higher than Optimum Impedance

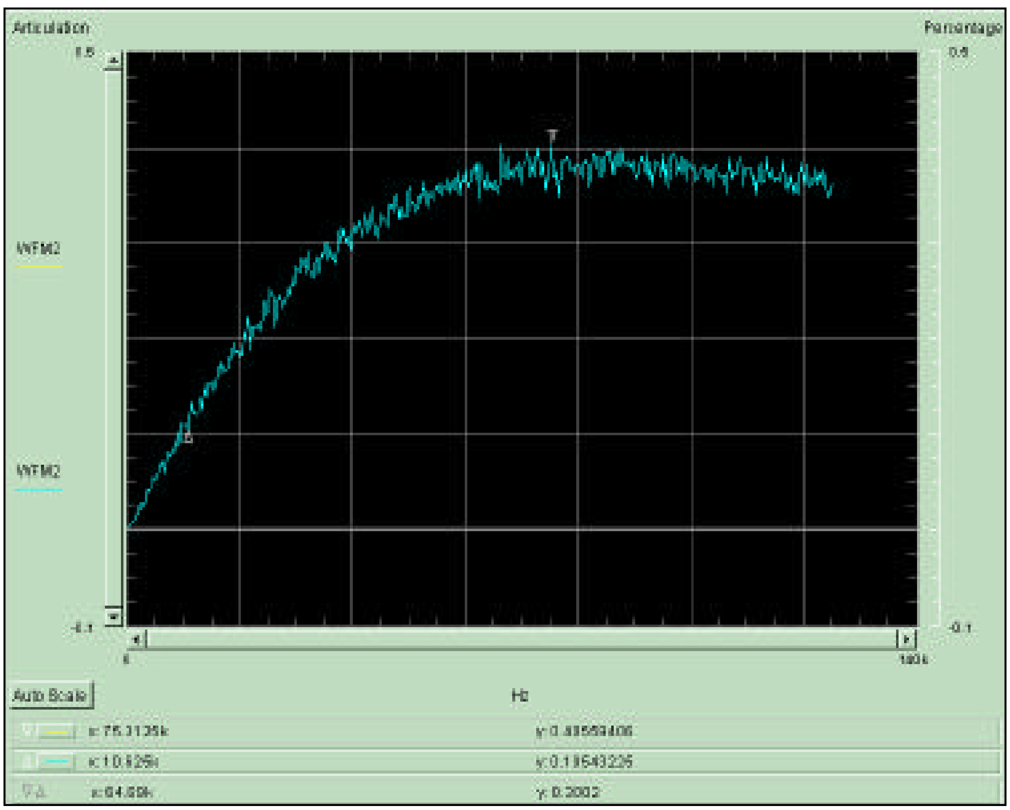


Two wrongs don't make a right: Trying to correct one problem by combining and offsetting it with another problem means we are engineering or assembling a non-linear system and non-linear systems will not perform in a predictable manner.

The only thing changed from the situation shown in Measurement # 1 is the load resistor; the cable itself remains the same. However, the measurement results show a completely different articulation response. The articulation of this cable / termination combination will be very good in the low to mid range frequencies. Attack and immediacy are projected correctly, and there will be musical realism through the 250 – 2.5 kHz region. The system should exhibit good to excellent presence, continuing even well into the 5 kHz region. However, after 2.5 kHz, the articulation response is driving downward, which will ultimately take its toll on the high frequencies and degrade system articulation in the last one and a half octaves or so of the audio range. This cable, terminated into this load, could work well in systems requiring high quality voice. Driving just the low frequency amplifier, the articulation response of this cable / termination combination has worked well in some bi-amped installations. Although this approach can be made to work, it can also be disastrous unless serious system architectural considerations are fully examined first.

Some sound systems that include bright speakers or amplifiers, or are placed in highly reflective rooms, might seem to benefit from this cable / termination. But our goal is, or should be, to engineer and assemble a linear, and thus predictable, system. Two wrongs don't make a right: Trying to correct one problem by combining and offsetting it with another problem means we are engineering or assembling a non-linear system. Non-linear systems are not predictable. If we change something in a non-linear system, we cannot anticipate how the system will react to that change. And if we have a further problem with the system, we will not know what to do to correct it.

Articulation Measurement #3: Cable Terminated into Lower than Optimum Impedance



Note: This plot has been re-scaled on its X (horizontal) axis.

As before, the vertical axis is scaled as a percentage, and the horizontal axis is frequency. For this set of results, however, the horizontal (x) axis has been rescaled, to show more of the high frequencies. The first (x) cursor value, at 75.312 kHz, shows us the frequency at which peak articulation occurs for this cable, terminated into this load. Note that the first (y) cursor value, representing the percentage of articulation at this frequency, is 0.405, or 41% (where 50% would be the value for a perfect cable). Note the second (x) cursor value at 10.625 kHz. with its associated (y) value of

0.1054, or 10%. This represents the frequency at which this cable, terminated into this load, will become articulate.

Once again, the only thing changed from the test situation shown in Measurements # 1 and #2 is the load resistor; the cable remains the same. And again, the measurement results show a completely different articulation response. The articulation of this cable, into this load, will be very good in the high frequencies. But this cable / termination combination will quickly lose articulation below 10kHz. This is a rather major problem, since the majority of the music we listen to is below 10 kHz. Because of the poor articulation, this very important frequency range will be heavily masked, lacking clarity and intelligibility.

Systems with dark amplifiers or dark speakers may appear to benefit from an interface with a skewed articulation response that favors high frequencies. In fact, there are individuals who prefer to use dark hardware and then brighten it up with a "fast cable".

The loss of articulation created by this cable / termination combination will also create an apparent disconnection of the high frequencies from the low frequencies. The high frequencies will respond properly, with correct attack and immediacy and a general realness associated with them. However, the lower frequencies, including those where all the fundamentals of speech and music are located, will sound slow and, without the proper attack and immediacy, will lack the liveliness and realism of the high frequencies. As a result, with this cable / termination combination, the harmonics of the music will sound detached from the fundamentals. Our experience with systems of this type is that the listener will continually be turning up the sound to try to get the lower frequencies to respond properly. However, as the volume is turned up, the higher frequencies tend to overpower the listener. This becomes very fatiguing, very quickly. Also, a system using this cable with this termination load can never produce a soundstage with proper size.

Because the harmonics will be disconnected from the fundamental with this cable / termination combination, the musicians in the recording studio will complain that the tone, or the overtones of their instruments, is not correct. And no amount of equalization, if used, can return the correct tone for them. In fact, the use of equalization with this type of cable / termination combination just tends to muddy up the fundamental tones of the music. People working on sound effects for films have a different description of this problem. They complain by saying everything has to be closely miked. This is because, if the effect they are trying to capture is not closely miked, no detail can be retrieved. But, they complain, this type of close miking puts the sound right in the listener's face all of the time, giving no distance or space to certain important sound cues where time and distance are important to the movie scene.

One should consider the consequences of assembling a non-linear vs. a linear system. In the long run, the linear system approach will always save time and money.

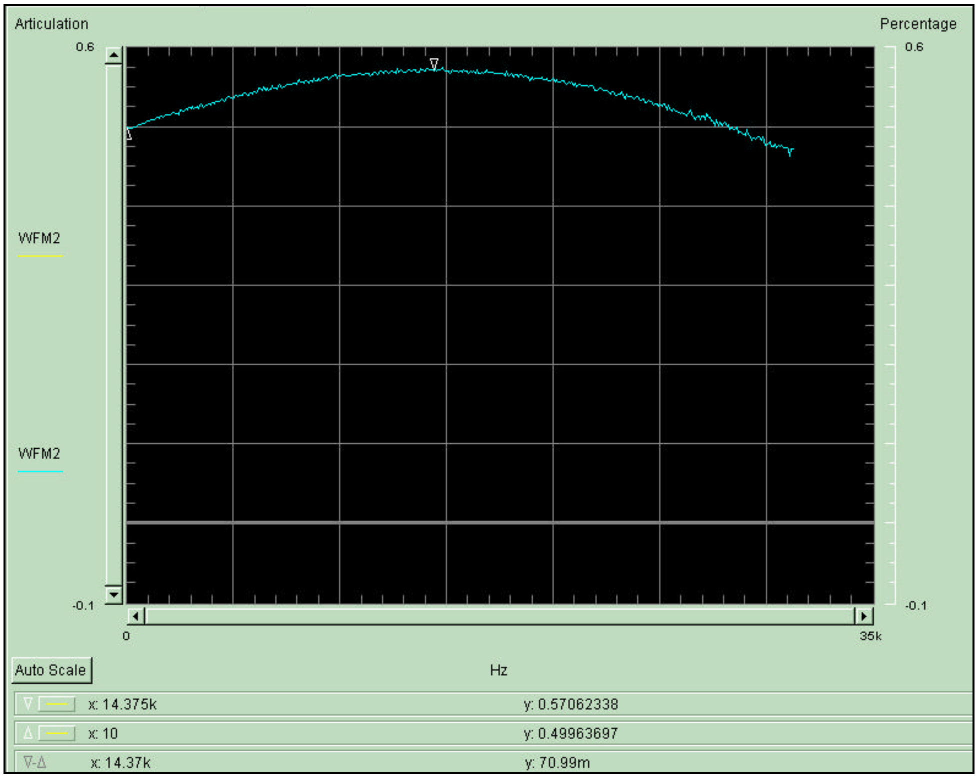
This type of interface is preferred only in certain darker systems used in some sectors of high end play back. That is, systems with dark amplifiers or dark speakers may appear to benefit from an interface with this articulation response. In fact, there are individuals who prefer to use dark hardware and then brighten it up with a "fast cable". Once again, one should consider the consequences of assembling a non-linear vs. a linear system. In the long run, the linear system approach will always save time and money.

▶ Summary of Performance Tests for Measurements #1 - #3:

Studying the three measurement results above, one immediately notices that the articulation response across the entire audio frequency range has a substantial peak to trough. In fact, all of the measurements show important frequency regions falling below the minimum required 10% value. It becomes apparent that all we are doing by changing the termination load is shifting, emphasizing or de-emphasizing a certain band of frequencies. The results of Measurement #1 are the best, but still a compromise for high quality music recording / reproduction. The results of Measurement #2 show a cable / termination combination suitable for high quality voice, but not for high quality music reproduction. Measurement #3 shows a combination that should not even be seriously considered.

The criterion for judging the articulation response of an audio cable interfacing a system is a simple one. The articulation response should cover the entire frequency range the system is expected to reproduce. In the case of a system recording or reproducing high quality music, that range of frequencies is usually defined as 20 Hz – 20 kHz.

Articulation Measurement #4: Properly Terminated Test Cable



This measurement shows the MIT - ISN technology has no loss of articulation, even well below and well above the audio range; that is, No Compromises.

The criterion for judging the articulation response of an audio cable interfacing a given system is a simple one. The articulation response should cover the entire frequency range the system is expected to reproduce. In the case of a system recording or reproducing high quality music, that range of frequencies is usually defined as 20 Hz – 20 kHz.

Now let's consider a very different set of results. The graph format is the same: the vertical axis is scaled as a percentage, and the horizontal axis is frequency. *The vertical (y) axis has been extended up by 10, to 60%, to show these results properly.* Note the first (x) cursor value at 14.375 kHz. This represents the frequency at which peak articulation occurs for this cable, terminated into this load. The (y) cursor value at this frequency is 0.570, or 57%. This represents the percentage of articulation at that frequency. The second (x) cursor value, at 10 Hz, shows the lowest frequency at which this cable, terminated into this load, will become articulate. Note that the associated (y) value is 0.499, or 50%, in stark contrast to the 10% minimum values in the earlier measurements.

No Music Lost! No Compromises! The ISN Technology by MIT exhibits articulation ranging from 50% - 57%, across the frequency range of 10 Hz – 35 kHz, far beyond the ability of conventional audio cable. For years systems engineered and sold for high quality music recording / reproduction have been compromised by the interfacing cables. This measurement shows the MIT - ISN technology has no loss of articulation, even well below and well above the audio range; that is, No Compromises.

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Conclusion:

It is well understood that a cable influences the frequency response of the individual components it is interfacing into a system. From the measurements in this paper, it is apparent that the cable must also be matched to the termination load of the component it is interfacing. If this is not done, the articulation response and system performance will needlessly suffer to some degree.

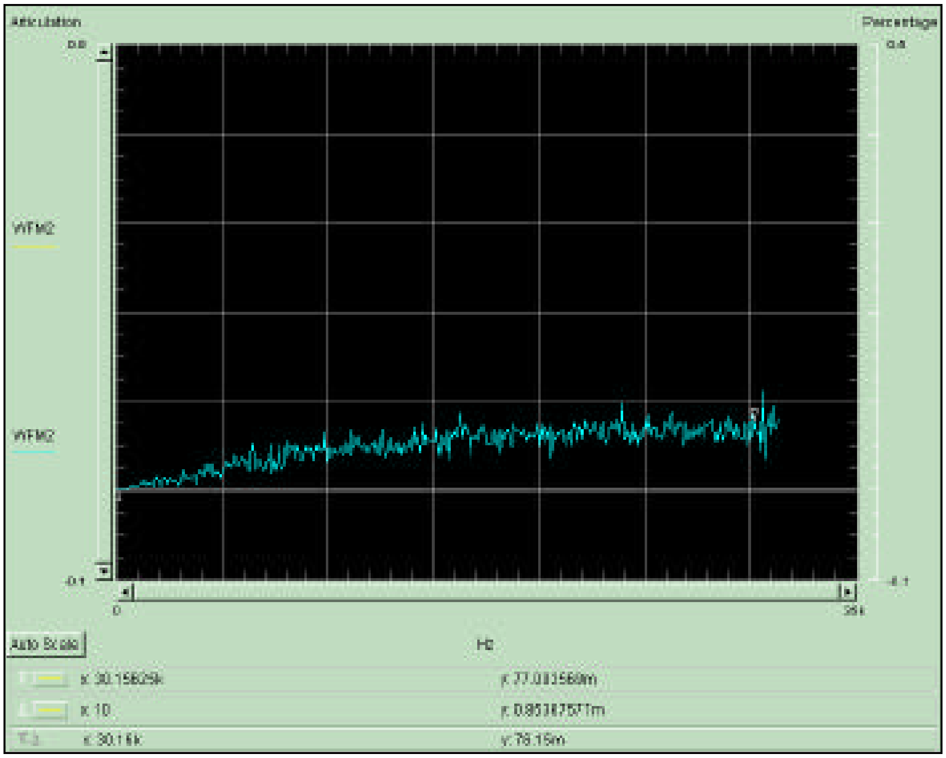
Conventional methods of specifying the interconnections, based on the highest bandwidth possible, should be changed to include the widest articulation response possible within the audio bandwidth required by any given system. If no attention is paid to the articulation response of the cable, as specified into its termination load, system performance can be expected to suffer significantly, and customer satisfaction will be needlessly sacrificed.

Just for fun:

I have been calculating or measuring the articulation response of cables for several years. My wife calls me the world's biggest pack rat. Stored in different places around my ranch, I have the original prototype cables I engineered for the Monster Cable company, MIT, Spectral Audio, Goldmund, Wilson Audio Specialties, Avalon Acoustics, and many other companies I have had the pleasure to work with and for over the last 20 years or so. From time to time I will re-measure all of these cables, as well as cables manufactured by our competitors. During these test and measurement sessions, which can last for as long as a week at a time, I am able to clearly see the performance improvements made over the years. I can't speak for my competitors, but for me, although a few of those improvements did come fairly easily, the vast majority were hard won.

Not too long ago I measured my oldest friend. In concluding this white paper I thought I would share the measurement of the worst interconnect I have ever measured with everyone, along with the story behind it. This is a cable I purchased approximately twenty-five years ago. This cable changed the sound of my system so much, and sounded so bad to me, I just had to find out why. Yes, this is the cable that got me started designing audio cables. Today, with all of the technological advances in test and measurement hardware / software, one can plainly see that this cable's articulation within the audio band was non-existent.

Articulation Measurement #5: World's Worst Interconnect Cable



No need for cursor values here. Yes, the cable has an articulation response that is low, flat, and never rises to 10% anywhere in the audio band. And finally, yes, the cable was terminated into its ideal load. But what the hell, I only paid about $10 for the pair in 1975. And they still sound exactly the same -- 25 years later -- dreadful.

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