Sub-Debye Phase-Distortion

A New Distortion-Source Model for Conductors

(Revision - 1)

PREFACE:

This first revision of the original paper has been authored for three primary reasons. In the original, we did not provide our information sources and they are now listed. Also, it was discovered that a source was in error and that has now been corrected as well. Finally, we feel it is important to state that this paper is not intended to represent a form that would typically be submitted for peer review to any professional and/or scientific organization. Rather, the term "model" as is used herein is applied somewhat loosely, with the definition thereof more that of the author's own interpretation than any strictly observed form commonly encountered in scientific circles. In that, it's purpose is not to hold to such rigorous forms or provide any absolute degree of proofs per se, but rather to be a first effort in suggesting a course of inquiry for further study.

To be succinct, our only goal is to find the truth, if there be any, regarding the root cause behind the preponderance of claims made in the audiophile community regarding the perceived differences in the sound resulting from different cable conductor metallurgies. Our effort here is based on one fundamental premise… that assuming such differences exist, they are, in fact, audible. We make no claims in support of such other than we find it to be statistically unlikely that the masses of claimants are either purely delusional and/or subject to some deceptive psycho-acoustic process of the human mind.

DOUBLY BLIND:

For positive audibility of conductor effects to become scientific fact, it must by some means be proven. Unfortunately, we highly suspect that traditional double-blind studies are inherently flawed as an effective test methodology for determining the facts one way or the other. While the following is little more than conjecture on our part at this time, we believe such high-resolution hearing ability requires secondary reference points in order for one to engage it. This is not unlike "perfect-pitch" hearing that certain musicians exhibit. It is often claimed this ability is associated with a form of sensory-synesthesia, wherein the subject associates auditory pitch with different colors such that they "see" the different musical notes and intervals as variations of hue in their minds. It is well known that visual memory is quite long whereas auditory memory in contrast is very short. This being the case, subjects exhibiting perfect-pitch likely "store" colors in their minds as reference points and then retrieve them at will and as needed to correctly identify the pitch of a given musical note.

Assuming the above is a reasonable assessment of the perfect-pitch phenomena, we then suspect a similar process is at work. Such a process is likely to be required for an individual to exhibit the necessarily high degree of acuity needed in differentiating between the said audible effects of differing audio cable formulations, as well as other electronic devices claimed to exhibit variations in the reproduction of low-level details. Due to the infinitely more complex nature of recorded music with respect to that of simple musical note pitch differences, such a high degree of hearing acuity cannot possibly rely on relatively simple references such as color associations. Rather, the secondary reference points in this case would likely be some form of prior knowledge regarding the complex details of the test conditions and/or materials.

As an example, prior knowledge of physical details regarding the cable formulation being auditioned may be necessary to give the listener a mental reference point of expectations, which would then act as a guide as to what must be listened for. Of course, it could just as easily be said the placebo effect is actually at work under such circumstances and that any such claims of audibility are merely the result of prior suggestion being processed by the subject's imagination. At this juncture, we see an impasse and offer no solutions to the dilemma. Nevertheless, we believe the above represents a valid argument in explaining why any form of double-blind study is unlikely to yield positive audibility results. In the absence of information regarding test conditions and/or the tested device's physical parameters, it is likely a negative result will be obtained. Then again, a negative result may simply mean the subject has no information upon which to synthesize an imaginary effect.

In the end, negative audibility results of double-blind studies may in fact be valid, but due to the complex nature of the human mind and the hearing process, there is sufficient cause for doubt in this author's mind for us to question the fact. In light of this and combined with the preponderance of anecdotal claims to the contrary, we choose to err on the side of positive audibility and hence, submit the following arguments.

OVERVIEW:

In the model below, we offer up a potential mechanism whereby the different metals used in cable formulations may at least partially give rise to the claimed observations. Again, this is little more than conjecture on our part due to the lack of scientific proof, but the correlations drawn are based on solid, scientific observations and documented facts. We invoke no new and/or exotic phenomena such as polorons, magnons, plasmons or the like, and all presented facts have been well established for many years. The proposed model lumps all complex microscopic processes within the conductor/stimulus system together and makes no attempt to identify any discrete process at the microscopic level as a primary source of said audible effects.

In closing, we would like to say that even though this paper does not conform to strict scientific protocols, nevertheless we believe that it represents value as a first step for further inquiry. Lacking proofs, there are those that would simply dismiss the ideas presented here out of hand. We would like to remind them though that many significant discoveries that have been made started with an idea based on valid assumptions. In fact, true scientific insight having led to the world's greatest discoveries and/or theories has usually been the result of "geometric thinking," as opposed to linearly progressive mental processes on the part of their discoverer. "Leaps" of understanding that seem to defy linear logic are seldom accompanied with scientific proofs in the beginning. While we make no claims of the same here with this white paper, we do believe the ideas presented therein are based on enough data to suggest that given the above, it represents a worthwhile effort and deserves at least a modicum of consideration.

INTRODUCTION:

In the field of audio electronics, there is no area of greater controversy than that regarding the purported effects of conductors and/or cables on the quality of the transmitted signal. Specifically, it is frequently claimed by the audiophile community that various cables and interconnects impart a certain characteristic “sound” to the signal and that there is often a significant difference in performance from one brand or formulation to the next. Conversely, in lieu of any supporting double-blind study data, the scientific community meets this view with much skepticism and often well-known scientific facts are used as a basis for refuting such claims. While these scientific arguments hold the majority of weight regarding what we would term as “macro-level” signal conditions, this author believes and intends to show how it is most likely possible that conductors of different metallurgy possess the intrinsic capability of altering “micro-level” signals, and thereby validate audiophile claims. In that, a new "model," as it were, outlining the primary parameters governing these effects is offered herein.

KNOWN PROCESSES:

A cursory review of the various processes possessing the ability to effect low-level signals is in order so that we may then eliminate them from our discussion.

Impedance Concerns:

Much ado has been made regarding the characteristic impedance of signal carrying cables in audio applications. The common practice in most modern equipment design is to manufacture a given device such that its signal output (source) impedance is significantly lower than that of the following device’s input (load) impedance. That being the case, there is no opportunity for a given cable to provide any form of significant impedance matching capability in the audio band, and in all practical applications no such impedance matching is called for. As long as the driving source impedance is a factor of 10 or more below that of the driven device’s input load impedance, there generally will be little voltage drop incurred along the cable and signal fidelity will be maintained. While it can be claimed with some validity that a low degree of impedance reflection can result from such an impedance mismatch, any resulting reflections generally occur well above the operating range of the system and are therefore of minimal effect. Nevertheless, good audio cable design will consider this parameter as one small step in the process of improving system fidelity.

In contrast, video signal and other VHF/UHF frequency transmission systems require close attention with regards to the characteristic impedance of a given cable, as this parameter can have a profound effect upon system performance. Seeing that our discussion here is primarily concerned with low-level audio signal fidelity and a heretofore-undocumented distortion source, further discussion of this subject is not warranted.

Dielectric Effects:

The process of energy storage and release resulting from the dielectric materials used in the construction of capacitors is well documented. This process manifests as a form of hysteresis or electrical “memory” exhibited by these materials and holds further potential for affecting system performance. Also, micro-phonic mechanical vibrations can result due to dielectric properties combined with construction geometry. Distortion of low-level signals is a concern here as well, but it is generally considered to be of minimal effect due to the rather large spacing between conductors created by such materials and the relatively low voltages encountered in cables designed for audio system applications. Again, superior cable design still warrants attention to this potential source of distortion, but seeing that it is a well-documented subject, further discussion is not called for here.

Micro-phonic Effects:

It is well known in engineering circles that when two conductors are placed in close proximity to one another and an electrical current is caused to flow through them, electrostatic and electromagnetic forces are developed between and around them. These forces then impart a mechanical force such as to cause the conductors to either attract or repel each other. Depending on the mechanical methods employed in the construction of a given cable, these mechanical forces can then cause a small physical displacement of the constituent conductors. Such displacement can take the form of a modulated vibration or even full mechanical resonance, which then can give rise to secondary distortion currents being formed within the conductors. Again, seeing that this phenomenon is relatively well understood, we will not concern ourselves with the issue in this paper.

Metallurgical Effects:

This area of conductor/cable performance is one that consistently demonstrates the greatest level of controversy in the field of audio system performance. While many anecdotal claims are made to the differing audible effects manifest by different metals and/or alloys used in the construction of audio cables, there have been few if any scientific forms of validation to back such claims. Generally, the scientific community points out the obvious fact that the differing levels of resistance exhibited by virtually all common metals used in the construction of cables is so vanishingly small with respect to the typical current/load demands encountered in audio applications, that these differences cannot possibly have any audible effect. If the issue were truly one of simple conductance/resistance, we would be compelled to agree. When one considers that the typical load impedance of a device is 2 or more orders of magnitude greater than that of the entire conductor regardless of the metallurgy involved, little argument can be made against this view. Nevertheless, claims of differing performance continue and therefore warrant a deeper analysis of the issue. As a byproduct then of our analysis, we offer the following overview and new distortion model.

THE DEBYE EFFECT – AN OVERVIEW:

As one begins to research the basic physical parameters governing metals they will eventually discover the property of “specific heat” and the many variables that give rise to it. In simplest terms, the specific heat of a material is defined as being the amount of additional heat energy required in order to raise the sample’s temperature 1 degree Centigrade. Specifically, there are several methods for calculating this parameter based on the standard quantity of the material selected for the measurement. Examples are atomic mass (weight) or the number of atoms or molecules (moles) of the substance. Generally speaking moles are used in the analysis of metals. Regardless of the method chosen, all that matters is that like measurements are compared with like between the different materials being examined.

What is interesting to note is that the specific heat of virtually all metals is not generally a constant parameter, but rather changes with regard to the static temperature of the material at the time a given test is made. In order to simplify the discussion we shall refer to the “heat capacity” of a material as a slightly different interpretation of the process. In this, the heat capacity can be understood as the amount of additional heat needed to raise the temperature of a given quantity of material. An example might be that the heat capacity of a glass of water is much less than that of a bathtub full of the same. Therefore, we say a sample of material that exhibits a lower heat capacity requires less additional heat energy be added to raise its temperature than another sample exhibiting a higher heat capacity. What has been known for well over 100 years is that as a sample of metal is cooled below a given temperature, the heat capacity decreases at a slope defined by the Debye Model [1]. So that we are clear, the heat exhibited by a sample of material at a given temperature is the byproduct of all atomic and/or molecular vibrations taking place within it.

Upon closer analysis, we find that in the case of most common metals, their constituent atoms are tightly bound together by strong atomic bonds to form a basic microscopic crystalline structure. These basic crystals are considered the smallest structures to which the metal can be mechanically broken or separated into. In any case, these "lattice" structures have been assigned the term “phonons” because of the acoustic-like vibrational behavior they exhibit at certain temperatures. In scientific analysis, phonons are treated as "virtual" particles in that they exhibit independent properties similar to individual atoms or molecules.

Higher in scale, phonons bind together in regular patterns to form larger crystals that can even be visible to the naked eye. These larger crystals then form what is termed the "grain structure" of the metal. For typical metals this grain structure exhibits a quasi-random pattern, but certain alloys can be formulated that produce patterns of more consistency and/or periodicity. Also, specific processes have been developed to reduce the number of grains and/or lengthen them such that their major axis is in alignment with the major axis of the conductor.

Regardless of the total matrix geometry and as rigidly bound as they may seem, these phonons and their constituent atoms vibrate over a limited range of motion and at some relatively narrow range of frequencies that is highly dependent on the temperature of the material. Above the **Debye** temperature the heat capacity of the material exhibits a relatively constant value of specific heat; meaning that the heat capacity does not change significantly as the sample temperature is raised beyond the Debye point. The Debye temperature also represents a point wherein phonon vibration transitions from acoustical to optical (Infrared) frequencies.

In light of these facts, one can view the Debye temperature as a point above which phonon motional degrees of freedom are being reduced and/or constrained by those of neighboring phonons, such that a decreasing number of remaining available "modes" vibrate at increasing harmonic frequencies. This then implies that as temperature increases, the vibrational Debye frequency increases progressing toward ever-greater "monotonic" behavior.

Conversely, below the Debye temperature there remains unfilled motional "energy gaps," manifest as potentially available but unexcited modes, with the number thereof increasing as temperature decreases. Therefore, these gaps permit additional degrees of phonon motional freedom in the event that additional energy is added. This is evidenced by the fact that as the temperature is continually decreased, the heat capacity decreases as well. In other words, the metal's ability or "capacity" to receive and store additional heat energy in the form of phonon vibration increases as the ambient temperature decreases. This behavior then directly implies that there are un-excited phonon vibrational modes that are freely available to receive and vibrate upon the application of additional energy – whatever the source said energy might be. As a result, in the sub-Debye temperature range we then find an area of material behavior that is both interesting and potentially quite complex. In particular, such behavior suggests the potential for greater complexity of interaction when the material is utilized as a conductor of electron current flow, and therefore will be examined further below.

The Electrical Effect:

At this point we must examine the effect that phonon vibrations have on electrical parameters. The fact is that phonon vibration and interaction with charge carriers (electrons) is what gives rise to electrical resistance. As electrons (current) move in the direction of the applied voltage through a conductor, they are impeded in their movement as a byproduct of colliding with the vibrating phonons. As the temperature of the conductor is increased, the “mean-free-path” of the electrons is reduced and hence more collisions take place. This fact gives rise to the property of electrical resistance and it is common for most metals to exhibit an increase in resistance as the operating temperature of the conductor is increased. Virtually all typical conductors used in audio are manufactured from copper, silver, gold or brass, and all of these materials exhibit an increasing electrical resistance with increasing temperature.

In addition, Joule ^{2} heating of a conductor takes place as the current passing through the conductor increases. This is a simply result of the fact that there are more electrons passing through the conductor and therefore more electron/phonon collisions occurring. As the electrons collide with the phonons, some of their energy is transferred to the phonons which then increases their vibrational energy and hence, the temperature of the conductor in general. At some high temperature point, the metal will begin to radiate optical photons in the visible band, and this effect is put to good use in the common light bulb. As an extreme example, given sufficient electrical current flow the phonon vibration becomes so severe that the mutual bonds between them fail and the conductor then “burns” apart and abruptly stops conducting! This is the very action behind the behavior of a typical electrical “fuse” that is commonly used to protect electronic equipment from internal damage occurring due to excess current flow.

Regardless of temperature though, all metallic conductors exhibit electron scattering due to phonon interaction, which reduces their mean-free-path and thereby gives rise to electrical resistance. At sub-Debye temperatures, such scattering is the result of many excited phonon vibrational modes taking place simultaneously. Above the Debye temperature of a given sample, electron scattering is more "diffuse" than that below the Debye point. This is because the electron mean-free-path is greatly reduced due to the higher magnitude and frequency of phonon vibration. As the temperature of the sample is lowered to the vicinity of the Debye temperature, electron scattering gradually begins to be dominated by small-angle deflections resulting from lower “acoustical” phonon vibrational modes/frequencies. Lower yet in temperature, the primary source of electron scattering is due to electron-electron collisions. Seeing that this behavior only manifests as a dominant effect within about 20 degrees of Absolute Zero we can surmise that, while still present, the other dominant mechanisms mask its effects at room temperatures.

Whatever dominant source of electron scattering may be at work, the primary effect is to produce electrical resistance. For certain metals, thermal scattering above the Debye temperature dominates their room temperature behavior, while for others small-angle/low frequency acoustic phonon scattering below the Debye point is the primary scattering mechanism. In fact, there is a considerably wide range of differing Debye temperatures for the various metals used as conductors. Gold and silver’s Debye points are approximately -163°F and -55°F respectively, while at the other extreme, copper’s is a comparatively high +158° F and aluminum is significantly higher yet at +311°F.

One may ask how such great discrepancies affect electrical parameters? Specifically, is there an impact upon what is commonly referred to as the “temperature coefficient” of a given metal? One should understand that the temperature coefficient of resistance is the property of a material wherein it’s electrical resistance changes with temperature. Typically, most common metals used as conductors in audio exhibit an increase in resistance as the temperature of the metal increases.

Fortunately, the rate of change or “slope” of resistance with respect to temperature is relatively linear at room temperatures for all of these commonly used metals. That being the case, we then find that regardless of the mechanism governing electron scattering and/or the given Debye temperature, commonly used metals are all relatively good choices for use as conductors – depending on application. Obviously if this were not the case, they wouldn’t be used. Conversely, if the slope of a metal’s temperature coefficient were to change significantly within the range of their common operating parameters, it would then be a poor candidate for use as a signal-carrying conductor due to a non-linear transfer function of voltage and current that would result.

Nevertheless, considering the whole one may begin to suspect that the Debye temperature of a metal may have some effect upon conductor performance. If so, it would likely be manifest at extremely low signal levels near the edge of audibility, as otherwise there would be little debate.

Conversely, it seems intuitive that at higher levels any such effect would likely be “swamped” by the higher levels of charge carrier (electron current) flow. Under these conditions electron-electron collisions would be much more frequent, and this would tend to increase the level of electron diffusion similar to conduction above the Debye point. In fact, Joule heating under short duration/higher current flow events would also temporarily increase phonon vibrational frequencies as well, and would result in a type of phonon frequency "modulation." The effect would be virtually undetectable though as assuming normal operational conditions in a properly designed audio system, Joule heating would be integrated over time such as to produce only a very modest increase in average conductor temperature.

The key here is that optical phonon vibrational rates are exceedingly high and reside just below the visible band in the infrared (heat) range. As such, they represent a high degree of electron "diffusion" and therefore a totally random scattering of electron mean-free-pathways. Therefore, any suspected form of current modulation/secondary distortion effects resulting from said scattering would also reside well beyond the audible range. Simply stated, this means that under all signal conditions no audibly detectable distortion is likely to be generated within the conductor if electron scattering is solely the byproduct of optical phonon vibrations.

Also, electron-electron scattering would be expected to produce a similar form of diffusion. This is due to the fact that electrons residing in the conduction band of a metal have no rigid structure to which they are bound, as they are shielded from the nuclear core charge of the atoms by the core orbital electrons. Therefore, they freely propagate as Bloch Waves [3] along the path of the conductor. Coulomb repulsion [4] will still cause them to scatter, but the process is statistically random and their energy is conserved. No mechanism exists within the process whereby any form of ordering, co-modulation, or other similar effect in the audible band can result.

Essentially then, high current events would be inherently "self-correcting," if you will. Increased electron-electron collisions would increase dispersion and Joule heating would temporarily increase the Debye frequency of phonon vibration during the interval of the high current event. Except under conditions of high conductor RMS power dissipation, such high current events typically manifest as transient signals and therefore impart little in the way of any lasting effect on the average temperature/phonon Debye frequency. Therefore, one would certainly not expect to perceive any obvious changes to the reproduced signal during high-level current events, as they are of short duration and therefore experience a lower statistical potential for any modulation effects in general due to greater electron dispersion.

On the other hand, any postulated low-level current effects are by their very nature difficult to perceive at all – assuming they even exist in the first place. Still, if phonon modulation effects are to be observed or possibly even documented, they will likely occur during low current signal conditions. It is our contention that they may very well exist, and we submit the following "model" as a possible avenue for further research in the discovery of the truth. It seems reasonable that very low conductor current densities are at a greater statistical "risk" of suffering from phonon modulation, grain boundary and/or impurity effects in the audible band, especially if they are flowing through conductors being operated at ambient temperatures below the metal's Debye temperature. Hence… we offer the "model" below.

THE SUB-DEBYE PHASE-DISTORTION MODEL:

Subjective Observations:

Before delving into the finer details of the model, we feel it is of value to lay a foundation for our discussion on some basic observations that have been made in the audiophile community regarding several areas where metallurgical processes may be at work.

First it is commonly observed that either silver or gold (or some combination thereof) conductors seem to offer greater levels of detail and resolution in the resulting musical presentation. One can rationally argue that a system exhibiting greater resolution is one that also exhibits less distortion in the realm of low-level signals.

Second we find that copper conductors are claimed to often exhibit a “warmer” sound and consequently, slightly less detail. Occasionally some manufacturers apply silver plating to copper conductors in order to, as they claim, “strike a balance between the two” effects (but more likely to reduce manufacturing costs otherwise incurred in the use of pure silver).

Third it is rumored that copper wires of single strand, solid core construction produce very high levels of resolution, but only if small gauge wire is used. The primary drawback in this approach is that if used as amplifier/speaker conductors, then near-field/low power listening conditions must be maintained, as the wire gauge is too small to support typical higher power use.

Finally, the use of amorphous metal or “metallic glass” conductors are claimed to produce the most neutral and highest resolution performance possible. To be sure, such metals and alloys are on the cutting edge of present technology and will not likely be a viable option at reasonable price-points for some time to come. As a somewhat seemingly “compromise” solution, cables are being offered that are constructed of single-crystal metals (typically copper) having been drawn into long lengths for use as conductors. Again, rare and somewhat expensive, but adherents swear to their effectiveness in providing very neutral and highly resolving performance.

Our purpose in providing these examples is to show later on how each of them support our model theory in that the observed effects correlate well with model predictions.

The Model:

As a foundational framework for our model it is important to establish that the sum-total of all mechanisms giving rise to electron scattering is the byproduct of many exceedingly complex processes. In fact, these mechanisms are so manifold in nature that they presently represent a significant area of cutting-edge research in Solid State Physics. We have provided a “short list” of these mechanisms for example. Please understand that it is not implied here that all of the mechanisms listed below are at work in our model. Rather, we simply provide them to give the reader an idea as to the complexity of the situation. Nevertheless it should be remembered that even though there may be one dominant scattering mechanism at work under a given set of conditions, it is virtually certain that several are in operation at any given time.

Phonon- Carrier (electron) scattering
Carrier-carrier scattering
Phonon – Phonon scattering
Grain Boundary scattering
Ionized impurity scattering
Scattering by neutral impurity atoms and defects
Piezoelectric scattering

1/f Noise – the Mystery:

A cursory review of electronic design will yield several sources of noise that plague most devices and/or processes to one degree or another. One that is directly related to our phonon discussion is that of "Nyquist" or thermal noise. It represents a significant challenge in the design of higher impedance circuits as it results from the thermal phonon vibrations that take place above the Debye temperature. Thermal noise is specific to DC systems and exists in any element exhibiting resistance. In particular, it is manifest by resistors commonly used in electronic circuits and must accounted for in good low-noise design.

Apart from this there is another noise source that is manifest throughout all natural systems, electronic or otherwise. It is commonly referred to as "flicker" or "1/f" noise because it exhibits a frequency component that decreases in amplitude with increasing frequency. The lower frequency limit apparently has no bounds as studies have shown it to exist at frequencies in the sub-1Hz range and for as low as can be measured. As such, the exact source of 1/f noise remains somewhat of a mystery and is likely to be the result of all complex interactions with nature, from the sub-atomic scale on up. It is obvious that whatever the dominant mechanism is, electron-phonon interaction, at and below the Debye temperature, is surely a major contributor.

Scientific Support:

Van der Ziel [5] noted that when AC current flows through carbon or thin-film metal resistors, 1/f noise manifests in the form of two "sideband" signals (distortion products) being generated. These sideband frequencies are the result of spurious noise being added to and subtracted from (sum and difference) a given AC current test signal. He also pointed out that the source of this spurious noise was indeed due to small fluctuations in electrical resistance and that its magnitude increases as a function of the standard power term "I^2." Seeing that resistance is the direct result of electron-phonon interaction, one can readily surmise that phonon vibrational modes are randomly changing during the test period. Therefore, it would be reasonable to assume that such phonon mode fluctuations are at least one major source of 1/f noise in all conductors used in AC systems.

In the following text, the experiments of Voss and Clarke [6] are referenced. These researches developed a special test protocol that used filtering as part of a method of noise detection. Results of these tests showed that one component of 1/f noise was a result of temperature fluctuations in the conducting material and a subsequent formula was developed describing the mechanism. As it turns out, this formula was based on a function of heat capacity of the material under test. As we have previously noted, the heat capacity of a material is directly tied to its Debye temperature. We find this quite interesting.

Further on in the referenced text, Voss and Clarke provided a table [7] listing the measured noise levels of several different tested metals. In this table, we find that the noise levels seem to directly follow the trend one would expect to see if the Debye temperature were to be a governing parameter. Specifically, Copper was found to exhibit 2 orders of magnitude greater noise than Silver, Silver was found to exhibit one order of magnitude greater noise than Gold and Tin was found to exhibit only slightly more noise than Silver.

Our model would suggest that Tin should exhibit less noise than Silver because its Debye temperature is lower. Interestingly, while the other metals tend to exhibit a trend that closely tracks what our model would suggest, Tin seems to be an anomaly. Nevertheless, there seems to be a quite simple answer for this. While Silver, Copper and Gold exhibit very similar levels of electrical resistance; Tin is considerably inferior in that regard. In fact, it exhibits a level of resistivity that is approximately a whole order of magnitude greater than the others. It seems clear then that the Tin test sample represented a higher level of resistance in general to that of the others, and therefore generated more noise as a result – albeit by a very small amount. Had the researches prepared the test sample's bulk resistances to all be equal (in this case, the Tin sample would require a thicker film layer), then Tin would have likely followed the trend suggested by our model and actually been superior to Silver.

Shytov, Levitov and Beenakkei [8] undertook an effort to show that electrons moving in a conductor can transfer momentum to the lattice phonons via collisions with impurities and boundaries, giving rise to a fluctuating mechanical stress tensor. They were able to show that electron current flow caused a direct displacement of the conductor lattice structure orthogonal to the current flow through it. The researchers above also noted that there was a direct correlation between current flow density and the amount of conductor displacement, with higher currents causing greater displacement.

We find this discovery most interesting and supportive of our argument. Unless we are expected to dismiss Newton's Third Law, [9] we are forced to assume that if electrons can exert a detectable mechanical force upon phonons, then the reverse must also be true. Considering the fact that not only is the effect merely "detectable," but is also sufficient to actually cause the entire conductor to move, it then becomes obvious that the combination of a conductor and the current flow through it must be viewed as a "system" wherein one affects the other in potentially significant ways. Even if we dismiss all other scientific research pertinent to our argument, this one discovery alone is sufficient evidence to support our case.

Phase Noise – Old and New:

Another common noise problem that once plagued electronic devices is commonly referred to as “Phase Noise.” Unlike the previous two forms of noise, it is specific to AC systems and specifically resonant oscillator circuits as are commonly used in radio equipment. Such oscillators are designed to resonate at one frequency to the exclusion of all others and any deviation from such is a source of error. Modern “Phase Locked Loop” circuitry and quartz oscillators have all but vanquished this problem in modern radio apparatus, but prior to the advent of these, phase noise was a troublesome problem plaguing radio equipment design.

The effects of phase noise are relatively easy to explain and comprehend. Oscillators subject to it are caused to have their resonant frequency shifted slightly above and below the desired point, and at a random rate. In fact, the shift is so small it really becomes one of signal phase more than that of frequency. For our discussion though, the distinction between the two is somewhat irrelevant, as all we need to understand is that it is a function of slightly altering an AC signal from its intended form.

Far more significant than the above distinction and also quite interesting is that phase noise in an AC circuit is DIRECTLY the result of both thermal… and more predominantly… 1/f noise. So as we can see, 1/f noise can and DOES impart an effect on AC systems, and it all comes down to a matter of detection. In retrospect it seems that an oscillator circuit turns out to be an ideal detector for 1/f noise in AC systems – although this fact is likely to have been much to the chagrin of early radio equipment designers! Little did they realize that their failed efforts to develop a stable oscillator circuit were in fact, the ideal solution for detecting 1/f noise in AC systems.

The Audio Effect:

In order to address the cumulative effects of phonon vibration and/or the resulting 1/f noise in AC systems and audio conductors specifically, we would submit the following view. Similar to the approach of Voss and Clark, if one envisions the 20 kHz audible spectrum as if it were a radio signal, we believe our analysis will be more easily visualized.

The first step in this approach is to imagine the 20 kHz spectrum as two equal bands of 10 kHz, with the center of this band residing at 10 kHz. In addition, we must also view it as a “suppressed carrier” system wherein what otherwise would be the 10 kHz carrier signal, has been subtracted. This technique has been commonly employed in radio applications for many years in Frequency Modulated (FM) systems. Early in radio development the carrier was transmitted along with the sidebands that result from audio modulation of the carrier signal, but later developments allowed the carrier to be subtracted or “suppressed,” wherein only the modulated sidebands are transmitted.

Once we have envisioned this scenario, it then becomes a simple matter of examining the “sidebands” (the actual audio signal) to see if there are any frequency or phase modulation effects. Specifically, is the signal being randomly phase-shifted from the original? To be sure, any such effects will be very low in amplitude and extremely difficult to detect unless very special equipment were developed to do so.

In lieu of such a high-resolution measurement system, we suspect that nature has already provided us with one… the human hearing mechanism. It is this author’s opinion that the audible effect of such distortion is one of a very mild “blurring” of low-level details in the music. Phase-shifted signals would impart a sort of “echo” or “shadowing” effect manifesting randomly on either side of the original signal that would tend to make spatial cues and subtle harmonic overtones slightly less distinct. One analogy would be a high-resolution camera lens that is ever so slightly out of focus. As an interesting side note, photographers and videographers occasionally apply such blurring intentionally in order to impart a “softer” or “warmer” feel to an image.

Another analogy might be a very mild form of “ghosting” effect seen in video images, wherein the outline of an object seems to be duplicated at a very small spacing around its periphery. As one examines the claims of the audiophile community regarding the effects of different conductors, it appears there is a direct correlation of the above description with that of the predicted effects.

Model Predictions:

In order to qualify our model such that its predictions can be correlated with anecdotal observations, we believe matters will be simplified if we divide the conductor metallurgy issue into three main groups. One (group A) would then be characterized as those metals that exhibit a Debye temperature that resides somewhere within or above room temperature conditions, and the other (group B) would be those that exhibit a Debye point near the very low end or below room temperature. Group “C” finally would be that class of new amorphous or “metallic glass” metals of the highest technological formulation… and cost.

---Group “A” Metals ---

Rhodium	(+404°F)
Nickel	(+350°F)
Aluminum	(+311°F)
Copper	(+158°F)
Brass	(++100°F ≃ varies with alloy formulations)

---Group “B” Metals ---

Palladium	(+34°F)
Platinum	(-28°F)
Silver	(-55°F)
Tin	(-100°F)
Gold	(-163°F)

--Group “C” Metals ---

No Data (Debye Temperature should be vanishingly low)

Based on our model theory and predictions, those metals of Group “A” would more likely generate higher levels of phase distortion due to the fact that their phonon vibrational frequencies would be lower at room temperature. Sub-Debye temperature operation then implies that acoustic phonon modulation of electron motion (at or near audio band frequencies) will increase statistically.

Conversely, Group “B” metals should exhibit less phase distortion due to the fact that they are being operated at temperatures above their Debye point. This then suggests that due to the optical frequencies dominating phonon vibrational modes, any modulation of electrons will reside well above the audible band and be undetectable. To be succinct, the phase of the affected audio signal due to phonon modulation will manifest such extremely small variations in angle as to be essentially undetectable.

Application of the Model to Group A Observations:

Our model suggests then that Group “A” metals would sound slightly less detailed and resolving. The possibility exists that they could even impart a certain “warmth” and/or “softness” to the sound. This is in direct agreement with stated observations concerning copper and brass conductors. Aluminum has been used as well and similar claims have been made of it.

One offshoot of the theory would suggest that using the least amount of these metals in the signal pathway is best so as to cause charge carrier “bunching” or “crowding,” wherein carrier-carrier collisions would statistically increase due to their *forced* closer proximities to each other. This would then increase the ratio of these collisions as compared to acoustic phonon scattering events and tend to “swamp” them out. In practice this would translate to using the smallest gauge wire possible and terminals using the least amount of metal in their contacts.

This too is in direct agreement with stated observations. It is claimed that small gauge copper wire operated at reduced current/system volume levels along with near-field listening yields highly resolving performance. Also, at least one manufacturer uses a “least metal” construction method in the fabrication of their copper binding posts… and has received much acclaim along with a large market share for doing so.

Another prediction regarding Group “A” metals is that if there were a means of reducing conductor grain boundaries and/or impurities, phase distortion could be reduced as well. Again, acoustic phonon modulation would be reduced as a result. “Ohno” casting/single-crystal copper as well as OFC/high purity copper should yield superior performance, and the claims thereof abound. Again we find direct correlation and agreement with our predictions.

Application of the Model to Group B Observations:

Our model then also predicts that Group “B” metals should exhibit higher levels or resolution due to operation above their Debye point. In this range, charge carrier scattering events are dominated by optical phonon frequencies, and therefore as stated above, any resulting phase distortion will reside well outside of the audio band and be virtually undetectable.

Silver and gold… what shall we say? Anecdotal claims abound in that they provide the highest levels or resolution and detail in the transmitted signal. Also, tin foil capacitors are often claimed to produce the most resolving performance. Once again, we find direct agreement with model predictions.

Application of the Model to Group C Observations:

Group C stands alone in its uniqueness and rarity. Presently this author could find no data regarding any Debye temperature… or much else for that matter. Seeing that the material is supposedly completely amorphous, there is no crystal lattice structure per se. While it would most likely exhibit some form of phonon behavior, logic would dictate vibrational modes would be purely optical in frequency, and therefore the material would exhibit no detectable acoustic phonon modulation of charge carriers whatsoever. That being the case, our model predicts that such a material would be about as close to a perfect conductor (short of super-conducting) as possible – at least with regards to the generation of secondary distortion products. Therefore Group C metals would exhibit no detectable phase distortion and would represent the most accurate and neutral conductor material that could possibly be used.

CONCLUSIONS:

We have presented a new distortion model that accurately predicts the audible behavior of the various metals in common use for audio applications. This model is based on rational, scientific facts and clearly defines the basic underlying source of said distortion, as well as the process whereby it operates to alter audio band signals. While laboratory measurements and data do not validate the audibility aspect of our model, a preponderance of anecdotal evidence surely does.

Apart from any direct proof of audibility, the scientific facts most certainly do support our claim that phonon modulation of electrons (and vice-versa) actually takes place. In fact, the work of Shytov, Levitov and Beenakkei suggests that there is an increasing effect when electron flow density increases, such that there is a proportional increase in phonon motion. Newton's Third Law then dictates that the reverse must also be true. Assuming then that we consider the ambient temperature of a conductor under test is being held constant, then phonon vibrational energy levels within it will remain relatively constant as well. Consequently, as electron flow density decreases through a given conductor (as in weak audio signals), said conductors being held at constant temperature (as in room temperature operation) will via phonon vibration impart an increasing level of electron modulation. Simply stated, as long as the temperature of a conductor is held relatively constant, from a percentage standpoint distortion levels will increase as audio signals become weaker. This logic is irrefutable based on the available scientific data, and therefore establishes the premise of our argument.

In the absence of any evidence to the contrary, we then submit that audio signals are, in fact, subject to conductor metallurgy and that low-level signals represent an area of audio performance that carries the highest statistical risk of being affected thereby. We also submit that conductors comprised of metals exhibiting higher Debye temperatures represent those most likely to impart alteration of said low-levels signals. Finally, we suggest that if the highest possible levels of audio resolution and reproduction of musical details are desired, then conductors comprised of metals exhibiting the lowest possible Debye temperatures should be at least part of the cable formulations developed for such use.

In lieu of any other quasi-scientific model known to this author, we submit this offering for review and use by all parties, private or corporate, for guidance in selecting such materials and optimization of their use.

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SOURCES:

[1] Wikipedia online encyclopedia -- http://en.wikipedia.org/wiki/Debye_model

[2] Wikipedia online encyclopedia -- http://en.wikipedia.org/wiki/Joule_heating

[3] Wikipedia online encyclopedia -- http://en.wikipedia.org/wiki/Bloch_wave

[4] Wikipedia online encyclopedia -- http://en.wikipedia.org/wiki/Coulomb_barrier

[5] Advances in electronics and electron physics, Volume 49 By L. Marton - p. 244

[6] Advances in electronics and electron physics, Volume 49 By L. Marton - pp.245-249

[7] Advances in electronics and electron physics, Volume 49 By L. Marton - p.250

[8] PHYSICAL REVIEW LETTERS Volume 88, Number 22, June 3rd, 2002 – Shytov, Levitov and Beenakkei "Electromechanical Noise in a Diffusive Conductor"

[9] Wikipedia online encyclopedia -- http://en.wikipedia.org/wiki/Newton's_laws_of_motion