The Great Loudspeaker Mystery

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An exercise in Metaphysical Philosophy

A YEAR OR TWO AGO there appeared in a certain British technical journal an article by a loudspeaker manufacturer concerning the design of loudspeaker diaphragms. In it, there appeared the old platitude that the perfect diaphragm was a rigid piston of negligible mass. From this premise it was argued that since the perfect diaphragm could not exist, attempts should be made in practical work to approach this perfect concept as closely as possible. Therefore . . . and so on.

Now it so happens that I have never been particularly attracted by this notion of the perfect diaphragm, so I wrote a letter for the correspondence columns of the journal in question, the burthen of which was that the idea that the perfect diaphragm should be an infinitely rigid piston was nonsense, because, I went on to say, if the diaphragm were infinitely rigid it could produce only one frequency at a time—in other words it could reproduce only a sine wave. The editor's technical adviser wrote a private letter to me to ask if this letter of mine was a leg-pull, for if they were to take me at my word, the publication of my letter would make me the laughing stock of the audio industry of Britain. I said that it wasn't, and that I was quite ready to stand by the consequences of my letter being published, and would they please publish it? They did not, and I have never been able to determine whether it was done out of kindness to me or out of consideration for themselves. During a recent visit to New York I mentioned this incident to *your* editor, and he looked at me in a quizzical sort of way, not quite sure whether I was pulling his leg, or whether I had got something. I threatened him with a full thesis on the matter, and here it is. You have my assurance that it is a serious contribution to audio thinking, and I am prepared to abide by the consequences of putting my name to a major heresy.

Let us get the problem clearly stated. It is the conventional idea that the perfect speaker diaphragm should be an infinitely rigid disc, preferably of no mass. It is my idea that the perfect speaker diaphragm should be a flexible entity (shape not specified) which in its various parts vibrates in various ways so that the over-all effect is to reproduce all frequencies with constant output. The problem is therefore: Which is correct? I shall try to help you solve the mystery.

Logic vs. Mathematics

There has been some feeling that the articles in Æ should butter the popcorn. If this can be done without spoiling their authenticity I am all for it. Mathematical treatment of loudspeakers is not easy and can be so difficult as to be impossible in certain directions. I believe that my thesis can be comprehensive without being mathematical. Those readers who would like to have an extremely able exposition of the mathematical analysis of loudspeaker behavior are recommended to study the book "Loud Speakers" by N. W. McLachlan. I warn them that it calls for mathematical knowledge of a high order, and that is why I have considered my treatment should be rather one of non-mathematical logical thought. However, the technical statements I make are provable by rigorous mathematical processes.

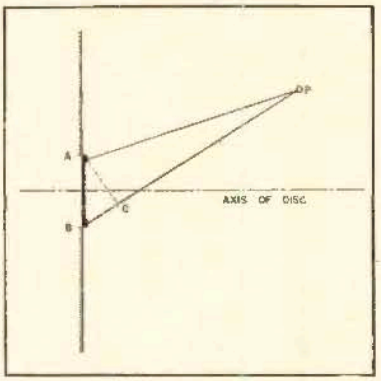

Fig. 1. Representation of a circular disc, AB, in a rigid baffle to show the cancellation due to phase distortion when the listener, P, is not on the axis of the disc.

My argument comes in the domain of metaphysics, and I hasten to add that metaphysics has nothing to do with mysticism. It is characteristically anti-metaphysical to suppose that this science of thought processes has anything to do with psychology, theology, or demonology. It is an exact science, concerned with the examination of thought, argument, and knowledge.

It is an axiom of metaphysical philosophy that argument based on opposing absolute presuppositions can never be resolved. If you and I start arguing in a general sort of way as to what is the most nearly perfect diaphragm for a speaker, and you say "The cone must be made as stiff as possible" and I retort that that is all wrong, we can argue about this until all is blue without getting any further because we hold conflicting presuppositions. Every statement made by a man is, consciously or otherwise, an answer to a question, and the question has arisen out of some earlier statement which in turn derived from another question. The metaphysician traces these statements and questions back to their source until he arrives at something which is not susceptible to logical treatment. That "bit of knowledge" when examined is found to be a matter of belief, not knowledge, and he calls it an "absolute presupposition" because it is the absolute source of your subsequent argument. He does not attempt to criticise the validity of your absolute presupposition, but he will unerringly point out any flaw in the logical development of your argument based on it.

On this basis let us consider the problem I have put to you. The statement that the perfect speaker diaphragm should be an infinitely rigid disc of no weight is an absolute presupposition, because it is an article of faith. How can it be otherwise? It is clearly impossible for any person to produce an infinitely rigid disc of no weight, so why call for an abstraction as the goal, except as an act of faith? But if we seek to find a *reason* for the common acceptance of a hypothetical device as the aim of all speaker designers, then the search is a short one, for the mathematicians will tell you that whereas analysis of the behavior of a disc *in vacuo* is comparatively easy, it has not yet been found possible to analyze the behavior of a cone. If, therefore, mathematical treatment is not available for this case it passes out of the realm of exact science, and there must be substituted something which can be analyzed mathematically, and that is the disc.

Now it can also be proved mathematically that under the impulse of a voice coil actuated by alternating currents the disc will distort in a way which can be exactly foretold without experiment. If, therefore, we are conscious that the disc in practice does distort, we easily pass on, or back, to the supposition that the disc, to be perfect, should not distort, and to achieve that it must be rigid. By the same process, but by different mathematical treatment, it can be proved that transient reproduction is differentially distorted the greater the mass of the disc, and the perfect diaphragm should also have no weight. And so you are back to your absolute presupposition, which, as I have pointed out, is not a matter of scientific knowledge but of faith. And I am entitled to disagree with your faith, even if I accept your facts.

But, I can imagine you saying, what am I getting at? On the one hand I admit that mathematics proves that a practical disc distorts, but a theoretical rigid disc would not distort, and mathematics also proves that a practical disc having mass also distorts, and by inference a theoretical massless disc would not distort. On the other hand I am obviously not satisfied with the idea that the perfect disc, infinitely rigid and infinitely light, which can be mathematically proved not to distort, is the ideal to which, in an imperfect world, we can only approximate to. Am I just being difficult? The statement made above would probably be acceptable without careful thought, but it contains two serious flaws in logical argument.

First is the assumption that if it can be mathematically proved that a non-rigid disc must distort, it follows that a rigid disc will not distort; and that a disc with mass hav-

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ing been proved to distort transients, it follows that a massless disc will not. The second is the assumption that there is no other form of distortion accompanying the use of a rigid massless disc. Both these assumptions are wrong, as can be proved mathematically. Let us take only two examples of the latter's wrongness.

In *Fig.* 1, AB represents a rigid circular disc mounted in an infinite rigid baffle. P is a point off the axis of the disc, a position such as might be taken by any listener to a speaker. Now P is nearer to A than to B and the radiation from B will be out of phase with that from A by an amount $2\pi(BC)/\lambda$, where BC is the difference in the two distances and λ is the wavelength of the radiation. At low frequencies BC is small compared with λ, and the phase difference is negligible; but at high frequencies λ may be larger than BC with consequent considerable phase distortion. Specifically, if $BC = \frac{1}{2}\lambda$ the radiation from A and B will be in opposite phase, and cancellation of the radiation will occur.

This can be translated into the form of a polar radiation curve. If the phase difference effect is not noticeable at low frequencies it can be assumed that the polar curve for a low frequency would be semicircular, and that the radiation would be hemispherical; mathematically treated it can be shown that at, say, a frequency of 4000 cps the polar curve will be an ellipse and the radiation ellipsoidal. Worse, the larger the disc the narrower the ellipse; and a little reflection will show that this must be the case, since the difference between PA and PB will be greater, the larger the disc. Since it is the purpose of a loudspeaker (and its diaphragm) to radiate sound as well as possible, one can naturally suppose that the radiation should be hemispherical at all frequencies, but we have just seen that the rigid disc is inherently incapable of achieving this.

The Flexible Disc

If the mathematical analysis be carried some stages further to examine the behavior of a flexible disc, one which develops nodes under the impulse of an electric current applied to the voice coil, we find that the polar curves at high frequencies are much better than those of a rigid disc, and again some reflection will indicate why this should be so, for in my figure B may be on a node and A at an antinode, thus reducing the difference between PA and PB.

Our metaphysician may now be allowed to say a few more words. He did not quarrel with your absolute presupposition that a rigid massless disc was the theoretically perfect diaphragm, because he showed that that was a matter of belief, and you are entitled to believe what you like; but you are now under an obligation, if you insist on adopting the scientific way of thinking, to find out if there are any grounds for your belief, and I have just shown that there are not. I am not prepared to accept the excuse that you *believe* your perfect disc is the best *compromise*, for science has no room for compromises—a thing or a thought either is or it isn't. But it has been truly pointed out by no less a savant than the late Professor R. G. Collingwood that people are very touchy about their absolute presuppositions, so I shall not labor the point. I shall content myself by observing that the belief that a massless disc is the perfect diaphragm has no justification either in theory or practice.

And now, if I may, I should like to put my second cat among the pigeons—my argument that if the perfect diaphragm, the infinitely rigid disc of no weight, could be made, it could only reproduce a sine wave. I am afraid that when we enter this field of speculation we cannot have confirmation from mathematics, for the problems are so complex as to defy analysis. Our speculation can only be philosophical, and we can only accept what appears to be the more reasonable theory. Let us examine this notion of mine.

A rigid disc is inflexible. If vibrations can be transmitted through it then it is flexible. Since it is rigid it can only act as a pure piston incapable of being deformed. Apply a sine-wave to it through the medium of the voice-coil and former of any frequency you like, say 100 cps. The disc, being a suspended diaphragm, vibrates to-and-fro at that frequency. Now, while continuing to cause it to vibrate at 100 cps, you also apply another frequency of, say, 200 cps. What will happen? Since it is your supposed perfect diaphragm it will reproduce both frequencies at amplitudes strictly proportional to the amplitudes of the applied currents, but how can it do this? Since it is infinitely rigid it cannot vibrate in one part at 100 cps and in another part at 200 cps so the only possible theory is that it moves forwards and backwards non-sinusoidally, the form of its movement being the counterpart of the harmonic sum of the two separate frequencies. This also involves the acceptance of the consequence that the movement of the diaphragm includes accelerations and decelerations with each half-cycle. I agree that if the diaphragm has no mass it could perform in this way, but only *in vacuo*, for in air the air friction would be enough to cause distortion of the necessary accelerations and decelerations. This implies that the definition of the perfect diaphragm being an infinitely rigid disc of no mass must also be restricted to the condition *in vacuo*, but this makes nonsense of the whole idea, for without air we cannot hear sound, and without sound output the perfect diaphragm is useless.

But the perfect piston protagonist has another headache coming. We have seen that his belief necessitates the diaphragm moving forwards and backwards in a non-sinusoidal manner exactly reproducing the non-sinusoidal current applied to the voice-coil. Forgetting the *in vacuo* restriction, a fatal snag, we have to envisage the piston moving forwards and backwards reproducing the fantastically complex waveform of a full orchestra by vibrating to-and-fro with hundreds, possibly thousands, of accelerations and decelerations in a tiny fraction of a split second. Is this conceivably possible? And if it is, how can it, having escaped the air friction, transmit this extraordinarily complicated waveform to an elastic medium like air, which will initially absorb all the fine detail long before it has a chance of being propagated? As we must expect the perfect diaphragm to reproduce all the frequencies applied to it, it is clearly impossible for it to do so by complex oscillation to-and-fro, so whether my statement that the infinitely rigid disc could only produce a sine-wave is true or not, the chances are overwhelmingly in its favor that it is true and it certainly cannot be proved wrong. We have also seen that the rigid disc cannot be perfect by its very nature, so it seems time that the whole of this absolute presupposition can be jettisoned. It follows that all the theoretical ideas based on this presupposition must also be thrown out. In short I am constrained to follow the late Henry Ford's example when he spoke of history and say that all conventional loudspeaker design of a theoretical nature is bunk.

"Design" of Speakers

How, then, you may well ask, how *does* one design loud speakers?

I invite you now to consider *my* absolute presupposition, which is that the perfect diaphragm is a flexible entity which vibrates in various sorts of ways so that the sum total of its performance is to reproduce all the frequencies imparted to it by the current applied to the voice-coil by imparting movement to various zones of air so that the ultimate sound-waves impressed on the listener's ears create a sensation exactly similar to that created by listening to the original performance. This rather complicated sentence carries within it an inferential absolute presupposition—that you cannot design speakers by any mathematical process, since analysis of the process is beyond human knowledge. I have already explained how even high-grade mathematics can only undertake what are really the simplest phenomena, and then only suppositional cases, for, in general, the formulas developed presuppose conditions which are not met with in actual practice.

There is a good deal of justification for accepting my absolute presupposition as an article of faith (for it is nothing more) and using it as a basis for a logical development of argument. Consider, for example, a musical instrument such as a violin.

It is an ordinary commonplace scientific fact that the fundamental frequency of the note produced by drawing the bow across the strong is a function of the length of the string between the bridge and the performer's applied finger. Whether the performer is a virtuoso or a tyro, provided the distance is x inches the frequency of the note will be y cps. But in practice the *quality* of the note (of given frequency) depends on at least two things, one the way in which the bow is drawn across the string, the other the nature of the body or belly of the instrument. It requires no great musical knowledge to be able to hear the difference between the sawing of the beginner and the polished perfection of the great violinist. It is not just a matter of producing the right notes at the right moment—sheer practice in manual dexterity will in time produce this result—but more important is the nature of the sound produced, and that depends on bowing. But the expert is not content with this; he will try to obtain a specimen of the work of an Amati or a Stradivari so that his fingering and his bowing will not be spoiled by poor instrumental tone. When all this has been

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positive. The positive-going voltage at the plate of the second triode is the screen voltage for the 954. Thus, while the probe signal caused the 954 screen to go negative because of increased current flow, the second triode compensates for this by bringing it positive again. The amplification added by the triode to the compensating signal actually produces a positiveness which is more than proportional to the original change in 954 screen voltage. In this way, instead of going negative with increasingly positive 954 grid and cathode voltage, the 954 screen actually goes more positive than before to keep in step with its own cathode voltage. This maintains a fairly constant screen-cathode potential, preventing distortion for probe signals as high as 100 volts.

The four potentiometers need be adjusted only once, then locked. The idea is to adjust them for linear operation at the highest possible input voltage.

The additional features of wideband operation and low input capacitance are, of course, inherent in cathode followers, but they are bettered by the screen compensation as well.

A copy of any U. S. patent may be had on request from The Commissioner of Patents, Washington, D. C., for 25¢.

LOUDSPEAKER

(*from page 34*)

brought together you have great music.

Now it is conceivably possible that all this complicated ritual might be scientifically analyzable, but I do not think it has ever been done. The result is determined by long empirical experiment both in making the instrument and in playing it, and the excellence of the result is determined by aural testing in the presence of musical experts. The Amati family, for example, found by repeated trials that a certain type of wood, cut and shaped in a certain way, assembled in a particular manner and varnished with a lacquer of a certain composition, produced violins that were esteemed by musicians, and they had not the foggiest notion of the mathematical principles underlying their work, nor—may we hazard a guess?—has anyone else. Their instruments had a certain "tone color" which was greatly admired by violinists and musically conscious listeners, and how they got that tone color was their family secret, found out by empirical experiment.

When one comes to consider the design of a loudspeaker a similar state of affairs exists, but the aim is different. A speaker is not a musical instrument, it is a reproducer of musical instruments, and therefore it must have no tone color at all, otherwise its reproduction of the original music will be false. There is no way of scientifically determining beforehand how to achieve this desirable property, and when the design has been completed there is no way of finding out if the design is successful except by listening to it. And that is where the trouble starts. That is why so many musicians do not like that type of reproduction commonly called "high-fidelity." They seem to prefer the sort of distortion that one gets with "middle-fidelity" rather than the distortion one gets with high-fidelity. It is useless to point out that "high-fidelity" means freedom from distortion, for freedom from

distortion in that sense only implies that scientific measurement does not reveal distortion. The non-musical scientist may "prove" that there is no distortion, but the musician will not be impressed with such a "proof." He will merely point out that it doesn't sound like the real thing, and that is enough for him.

Checking the Results

With this in mind we can now consider my presupposition that the speaker diaphragm is something flexible which flaps about in the air to produce a complexity of sounds. I have shown that mathematical analysis of this is impossible, but scientific experiment has been able to lay down certain desiderata. It has been shown, for example, that a restricted frequency response will not permit of satisfactory reproduction of music—there is lack of bass and woolliness owing to suppression of the higher harmonics of the instruments being "reproduced"; speech, also, is "plummy." Accordingly, for what is called high-fidelity reproduction, a frequency range of about 50 to 15,000 cps is postulated. But in addition to this there must be good reproduction of transient noises otherwise the reproduction will lack what is usually termed "attack." Apart from wide frequency response this requirement postulates a very low degree of inertia in the reproducing system, otherwise it will not be able to deal with sudden impulses without delay, or return to the normal sufficiently quickly to deal with the next impulse. If we assume that the design of the amplifier has been completed satisfactorily (and the design of this can be done mathematically, and tested scientifically, because it is designed to handle electrical currents which can be measured for amplitude, frequency, phase, and transient distortion) we are left with the problem of designing a physical body which has to produce audible sounds which can only be partially measured.

If the speaker cannot be designed by scientific methods it can only be done by trial and error, and this requires a knowledge of what is required, how it can be done, and how it can be checked. Leaving out the magnet system and the voice-coil assembly, we are left with the problem of designing a diaphragm which will flap about in such a way that the sum total of its flapping is the reproduction of all musical sounds within the prescribed limits without audible distortion. How this can be done does not come within the scope of this article, but how it can be checked has already been mentioned—by listening to it. You may object that it is not fair to condemn a certain technique without offering a replacement technique, and provided the terms of reference of the argument had not been laid down the objection would be valid.

Terms of reference were, however, laid down. They were: an inquiry into the contention that the perfect diaphragm should be an infinitely rigid disc of no mass is absurd and also my assertion that if such a diaphragm could be produced it could only reproduce a sine-wave. From this inquiry emerged an argument which suggests that the mathematical design of a loudspeaker is impossible, and if this is so, then

the thing can only be done by trial and error guided by practical experience. Finally, it can only be assessed by subjective artistic standards. That is the result of adopting my absolute presupposition, but as the two opposing presuppositions are by their very nature articles of belief, since there is no *a priori* knowledge to which you can refer, your acceptance of one or the other is a matter for your taste and logical conscience. But your choice will determine the final result.

In selecting a loudspeaker to entertain and instruct you you can, on the one hand, go to a great deal of trouble in finding out all about it in a technical way, having previously armed yourself with the technical specification of what is required electrically to create undistorted reproduction. You will demand response curves, figures for electro-acoustic efficiency, intermodulation distortion, and anything else that occurs to you, and when you have made your choice you will erect the reproducer and say "That is the last word on high-fidelity reproduction." You will, in fact have joined the ranks of what some people call "audiophiles," and you will be hurt and annoyed when some ordinary individual comes along, listens, and says "I think it is lousy." You will dismiss him as a man who knows nothing about musical reproduction.

On the other hand you can say "I do not believe that the sound of an orchestra can be defined by a mathematical equation. When I go to a concert I hear things which please me or annoy me, but whatever I hear is the result of people consciously making music. What I want in my home is as close an approach as possible to the sensation created in me when I go to a concert." And the only way you can assess the qualities of any equipment offered to you is to listen to it, taking very great care that you are comparing its performance with original music and not with other equipment. If this is how you select your equipment, then the very last place to go to is one of those "audio test rooms" wherein a dealer will let you hear twenty different speakers working on twenty different amplifiers. In such a place you will certainly be able to compare one equipment with another, but your ears will become so "conditioned" to the sound of an electronic device that you will forget what happens in real life. If you do not believe me, go and listen to all the equipment you can hear in any big city, try and carry it in your mind. And then go to a concert. The shock is profound. You will, in fact, realize, as others have done before you, that "high-fidelity" is getting farther and farther away from realism. Without the audio engineer you cannot have the foundations of realism, but without the musician you will remain an audiophile.