The Campbell Letters

From the very day of publication, John Campbell's article concerning "sineward distortion" has been the subject of much comment by readers. Here are some of the comments plus a rejoinder by Mr. Campbell.

Sir:

I have gotten a number of earnest arguments from several readers, complete with mathematical arguments as to why sine-wave analysis is perfectly correct and adequate. All such analyses, of course, starting with the built-in assumption that sine-wave analysis *is* correct . . . which makes that assumption come out as the proven conclusion, naturally enough.

In the time since I wrote the article, I've gotten quite a bit more data. Dr. Wayne Batteau, of United Research, who's been playing what he calls "the ears game" has got some three-dimensional sound recordings that'll raise hair on a bald pate! I do NOT mean ordinary stereo; that's two dimensional at the very best; he's got *three* dimensions. You should hear a plane take off and fly over your head, curve, and climb. . . . Or a father and small son discussing it, just off to your right rear, and hear the father's voice coming from about 5'2" up, and the son's voice coming from about 3' up. . . .

Dr. Batteau claims to have clear evidence that the human auditory system can distinguish pips separated by 2 microseconds or less—and some clues that the "less" may be as small as 0.2 microseconds! That the curious crumpling and folding of the external ear is *no* accident—but a magnificently engineered acoustic delay-line, and that it is that acoustic delay-line that allows us to do vertical sound-source location. An acoustic delay line even that short is highly significant . . . to a system that readily distinguishes 2 microsecond shifts!

John W. Campbell, Jr.,
1457 Orchard Road,
Mountainside, New Jersey

Sir:

When I saw the article on "'Sineward' Distortion in High-Fidelity Amplifiers" I scanned it with interest, hoping to learn of a new principle, because I had never heard the expression "sineward distortion" before. I read on patiently, through misleading presentations of evolution, music, hearing, neurology, and the basis of Fourier analysis, patiently, ignoring the incomplete factual bases and the wrong deductions, because I wanted to find out what Mr. Campbell had discovered.

And at last Mr. Campbell stepped down from his soap-box and told us: He has discovered phase-shift!

Dear Mr. Campbell: Phase-shift is not new. Respectable physiologists have never deprecated it except to make this claim: The "quality" (Tonfarbe) of a steady "note" (periodic acoustic oscillation) as perceived by the ear is largely a function of the frequencies of the Fourier components of the waveform and their relative amplitudes, and is only negligibly affected by their phase relationships (and is certainly not affected by the process through which the waveform is generated, whether it be synthesis or the filtering of square or saw-tooth waves!). The reason that the phase-shifting amplifier sounds bad roots somewhere else: It sounds bad because phase-shift relative to frequency disturbs transient response—and the importance of transient response is well known, wherefore we have square-wave tests and such.

Furthermore, Mr. Campbell: Fourier analysis is a method of mathematical analysis, and is quite unconcerned with the mechanism of the ear. It is merely a way of describing wave shapes. Let those who do not understand it accept this much: It is a perfectly valid tool when it is used correctly. Similarly, sine-wave response, distortion figures, and so forth, are valid tools when they are applied and evaluated correctly. We must, of course, know how to interpret the results. We can find, for example, relationships between certain performance measures, such as that between harmonic distortion and intermodulation distortion.

One should have both the sine-wave response plot and the phase-shift curve to predict the transient response of a system if it is inconvenient to measure it more directly. But one can actually make a shrewd guess from only one of these, since all ordinary amplifier circuits are approximate to so-called "minimum-phase" systems, in which a definite relationship exists between response and phase-shift. In short, it amounts to this: Phase-shift relative to frequency occurs in the vicinity of a rise or drop in response—hence the worry about "holes" in the response curve, and hence the insistence on flat response well beyond the limits of audibility. That is also the reason why our tone-controls are phase-shifting controls as well!

The details are in the textbooks. The reproduction of sound *can* be analyzed and reproduction defects *can* be quantized. We need information about the ear only in order to know how much reproduction defect it will tolerate, or even detect. (Hence we can pass over Mr. Campbell's dubious description of the workings of the ear without further comment.)

Let's forget the term "sineward." It's imprecise and misleading, and useful only in science fiction.

Peter Moretti
Dept. of Mech. Eng.
Stanford, Calif.

Sir:

Mr. Campbell's article is quite a piece of science fiction, however it is not all a loss if it causes some thought about testing. Certainly the specifications that Mr. Campbell gives are not sufficient to guarantee a high-fidelity amplifier. He does not indicate what kind of a load he was operating the amplifier into when he made all these measurements. If he is, in fact, using a feedback amplifier, a drop of 1 db at 55,000 cps indicates a problem. Feedback will not make a poor amplifier good; it must be good before the feedback is applied.

Mr. Campbell does not mention the response of the amplifier at frequencies below 10 cps. It is possible to have a peak in the response at or below 1 cps which may cause distortion in the amplifier or the associated speaker. Many designers do not realize the importance of protecting the power amplifier and speaker from low frequencies which they cannot handle.

The phase shift situation shown in *Fig. 3* would most certainly cause a peak in the response curve which would be indicated by an increase in the amplification at the frequency of positive feedback or by ringing on the top of lower frequency square waves. I refer Mr. Campbell to authorities such as Terman to find illustrations of *peaking in* feedback amplifiers.

The problem is not in the use of sine waves to test amplifiers; it is in the failure to use them properly. The response of an amplifier should be fully checked before the inverse feedback loop is connected and again after it is connected. If the amplifier does not cover the full frequency range desired before the inverse feedback is added—back to the drawing board! Any deficiency in the pre-feedback response will result in a smaller feedback margin at the deficient frequency ranges with the accompanying loss in distortion and output impedance reduction at these frequencies.

I can't imagine why anyone would feed in a square wave of sufficient level to overload an amplifier. The square wave is most useful to check for peaks in the frequency response of the amplifier without going to the trouble of making a frequency run after each adjustment.

A little study of basic network theory would demonstrate that there is a most definite relationship between the sine wave frequency response of a network and its transient response. In amplifiers we can have the additional complication of driving one of the tubes beyond its linear operating point. However, this would show up immediately in intermodulation or harmonic distortion measurements.

W. B. Bernard, Capt., USN Retired,
144 Harrison Drive,
Sarasota, Florida

Sir:

Mr. Campbell's article on waveform distortion interested me very much indeed, because I have heard strange, intangible defects in some very highly regarded amplifiers.

Remarkable though the article is, it suffers from a number of inaccuracies, which if corrected would add considerable force to the argument.

First, there is no such thing as the instantaneous phase of a random music waveform. In fact, phase is defined first and foremost for sinusoidal waveforms, and even then, if measurements are being made, one must follow the oscillation through at least one cycle in order to determine the pattern and set up phase angles with respect to the zero line.

Also, since sound waves exist in space as well as time, phase is defined only for a fixed point with respect to the source.

Probably what Mr. Campbell means when he asserts that the ear is phase-sensitive is that the brain is somehow informed of the instantaneous *position* of each eardrum, and also, that the brain is, after one cycle of the fundamental, able to note the phase angle between that fundamental and its harmonics. (The phase angle between the crossing of the axis of the fundamental and the nearest crossing of the axis of the harmonic can be measured.)

His most serious error, however, was in condemning Fourier analysis of complex waveforms. Fourier analysis (the breakdown of a complex wave into its component sine

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waves) *preserves waveshape,* and is a true and accurate method of investigation. If audio engineres have preferred to ignore the phase relationships inherent in a Fourier series, that is their error, not the mathematicians'. To do violence to his example, a square wave generated by sine waves added in the proper frequencies, amplitudes, and phase relationships is absolutely indistinguishable from a square wave generated by clipping. There is *no* difference between them—*none.*

All these considerations, of course, do not detract from the possibility that phase shift between fundamentals and harmonics is a source of listening fatigue, and I for one am grateful that Mr. Campbell brought the matter to light.

Robert McNeill
Briarcliff Manor, New York

Sir:

The article on "Sineward Distortion" by John Campbell, is not new. Referring to October, 1956 issue of *CQ*, there is an article entitled "The Sawing Machine," by the same John Campbell. The title referring to a sawtooth generator capable of forcing this mysterious distortion out in the open.

The original article showed examples and one practical solution. It seems Mr. Campbell should have sent the first story to AUDIO, as it seemed to arouse little interest at the time.

In 1956 Mr. Campbell was editor for *Astounding Science Fiction*. Space travel was once science fiction, and apparently some think the same of "Sineward Distortion." Perhaps a few examples and solutions will bring it down to earth.

John C. Cook
1736 Eveleth Avenue
San Leandro, Calif.

Sir:

A complex waveform, even a genuine musical tone, is or can be composed of a number of harmonically related sine waves. For example, a plucked string in a music instrument can be demonstrated to be vibrating in several modes simultaneously with each mode producing its sinewave component of the net musical waveform.

A complex waveform can be converted into a sine wave only by removing from it all but one sinewave component, usually the lowest or fundamental frequency. No amount of phase distortion will do the job. However, phase distortion will alter the waveform. Mr. Campbell made a point of this alteration by phase distortion, even though it directly conflicts with his contention that the complex wave is not made up of components. By definition, phase expresses a relationship between two or more things or conditions, and if the waveform did not have two or more components in it, it could not possibly suffer phase distortion.

The not quite oscillating phase shift oscillator in *Fig.* 2 will not function as a perfectly good RC coupled amplifier stage. It is not valid to state that it can be tested with a conventional sinewave generator without misbehavior or that its frequency response is flat across the audio spectrum. On the contrary, it is very difficult to test because of its misbehaviors and the frequency response is *far* from being flat. This conclusion is based upon theory and my own laboratory tests.

The three tube version in *Fig.* 3 is not the equivalent of *Fig.* 2. In fact, it is not even an amplifier. With the feedback shown the output is tied directly to the input, thus making it impossible for gain (or loss) to exist. It is nothing but a frequency-sensitive shunt across essentially a common input and output terminal.

There are so many things wrong with

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Mr. Campbell's concept of how the ears work that I hardly know which errors to point out in a short letter. First, multiplying the number of nerve fibers by the number of bits per second capability of each does *not* give you the bandwidth or bandpass of the ear. If a telephone cable carried ten telephone circuits, each capable of handling, say, 4000 cps, you surely wouldn't say the bandpass of the cable was 40,000 cps. And if such logic were correct, as stated by the author, there would be no capability left for loudness detection since the full capability would have been used for frequency detection. Furthermore, each nerve fiber is capable of handling not a piddling 12 bits per second, but can handle up to about 1000 bits per second.

Contrary to Mr. Campbell's concepts, the ears *do* analyze sound waves for frequency components. By actual measurements of action potentials on individual nerve fibers it has been found that each nerve is "tuned" to a narrow band of frequencies. The bandwidth of each increases with loudness. The number of bits per second transmitted by a single fiber is a function of both frequency and loudness.

The ears are relatively insensitive to phase in a complex waveform. This I have read many times and have verified it on both myself and my wife. Mr. Campbell's lengthy proof of phase sensitivity is OK, but it was for sensitivity to phase in the sounds reaching the two ears. That is a completely different subject that has no bearing on amplifier design.

I'll bet it must have been a shock to the Hammond Organ people to learn that *no* successful music instrument has ever been built that used sine waves. Depressing a key on a Hammond does nothing more than connect the outputs of a number of sine wave generators to the audio system. Of course the number of sine waves and their relative amplitudes are controlled, but they *are* sine waves.

Sineward distortion as defined by Mr. Campbell still does not exist. The article was just science fiction.

Kenneth E. Stone,
91 Pine Street,
Iselin, N. J.

Sir:

Cleverly interweaving accepted science with imaginative conjecture has earned John W. Campbell, Jr. a reputation as a science fiction author. There are parts of the article that persuade me to believe Campbell is sincere in his ridicule of "hidebound" scientists who consider the ear insensitive to phase shift. This view is held in spite of his pure fabrication concerning "sineward distortion." An RC phase-shift network is given an illusory flat frequency response (maybe it was short circuited) and an erroneous attenuation—"in practice it takes a high-gain pentode to oscillate." Numerous triodes and transistors provide more than the required voltage gain of 29 for a phase-shift oscillator with three identical RC sections.

On the other hand, "Physicists and acoustics people have, for years, said that the human ear is not sensitive to phase-shift in sound. That's still standard theory. It's false," is a statement requiring expansion. The location of point sound sources is commonly credited to *two-ear* phase detection as opposed to phase distortion sensitivity. The "phase-shift" which humans are incapable of detecting is more properly called "phase-distortion," i.e. a *steady state* displacement of the phases of harmonics of a periodic waveform with respect to themselves. Mounds of data obtained under controlled experiments classify the human auditory system as being incapable of sensing phase distortion. If these experiments over several decades are accurate, the ear is insensitive to straight phase distortion and therefore, since waveshapes are determined by phase relations among the harmonics, the ear is insensitive to waveshape. I might add for those "do-it-yourselfers" that experiments of this type must be carefully devised to avoid erroneous conclusions. Phase shift of Fourier components can result in rather spike-like waveforms which the amplifier in use may clip, causing audible distortion coincident with phase shift adjustment. Multiple-point sound sources (such as stereo) are to be avoided for these tests, because relative phase shift between the amplifiers can mislead the listener by changing the apparent amplitude of the harmonics. Abrupt phase shifts are detectable as "clicks" and slow periodic ones as vibrato.

If the work of physics and acoustics people is to be discredited by conjectures linked to physiology and evolution (without supporting evidence) perhaps a conjecture of similar nature and opposite hypothesis is all that is needed to restore nature to equilibrium. The human auditory system is a twin receptor system linking transducers, relay stations, nerve networks, pattern recognizers, coders, decoders, and so forth, into one harmonious whole. Being a reliable, long life, successful system constructed from rather unreliable components, redundancies are not only implied but demanded. For example, in the ear there are five hairlike cells per nerve fibre associated with frequency determination. Why should we depend on phase data alone to locate sounds? We don't! If one ear can locate a sound source without aid from the other, each ear must contain a phase detector. False! Optical center *Gestalt* (a square is recognized independent of orientation) implies auditory phase detection capability. Persuasive but not conclusive. Auditory *Gestalt* could just as easily be the ability to recognize aurally a clarinet independent of the orientation of the instrument.

With the cochlea of the ear capable of resolving frequencies which differ only one part in a hundred, it seems quite proper to view this part of the auditory system as a Fourier analyzer. Thus, every impinging waveform is resolved into its sinewave components at proper relative amplitude. After propagating through several frequency non-linear linkages (see Fletcher-Munson curves) it would be naive to believe that phase relations among the harmonics have been preserved in the impinging sound. Even in the presence of phase distortion in the ear, if both right and left channels have similar phase distortion, a common data processor can still perform phase and time discrimination. Note this point well, for it shows any common right-left phase distortion will not affect the ability to locate a sound source and therefore phase relation between fundamental and harmonics is unimportant *even at the source of sound.* Hence, waveform is unimportant in the battle for survival of the fittest.

Relative right-left phase should not be our only source of direction information. In abrupt noises, the time displacement between the spectrum impinging on one ear and the other ear gives a very rapid location signal to the brain, making us jump the right way when lions roar. In addition the 180-deg. ambiguity of our two sensor system is minimized by our "pointed ears" which alter the rearward spectrum drastically. Likewise, spectrum changes resulting from trees, bushes, and head interference aid the survival of a one-eared man, but he's still more vulnerable than the two-eared type and eventually would be exterminated by the stereo model.

A baritone and a soprano singing harmony sound quite pleasant to the ear, in spite of the fact that drastically different waveforms are being emitted from the tone sources. If their tone relation is a musical third, the third harmonic of the baritone's note is the same frequency as the second harmonic of the soprano's note and the same respectively for the sixth and fourth, ninth and sixth, and so forth, harmonics. In view of this consonance having nothing to do with waveform and everything to do with harmonics, still further strength is given to the argument that the auditory system must resolve a sound into its sinewave components.

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