FLAME AMPLIFICATION AND A BETTER HI-FI LOUDSPEAKER?

MUSIC FROM THE FIREPLACE MAY BE AROUND THE CORNER
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WE LIVE IN an era jaded by science's seemingly routine discovery of basic phenomena-coherent light and the laser; superconductivity and the super-cold realm of zero resistance; weightlessness and its impact upon space electronics. And now, flame amplification.

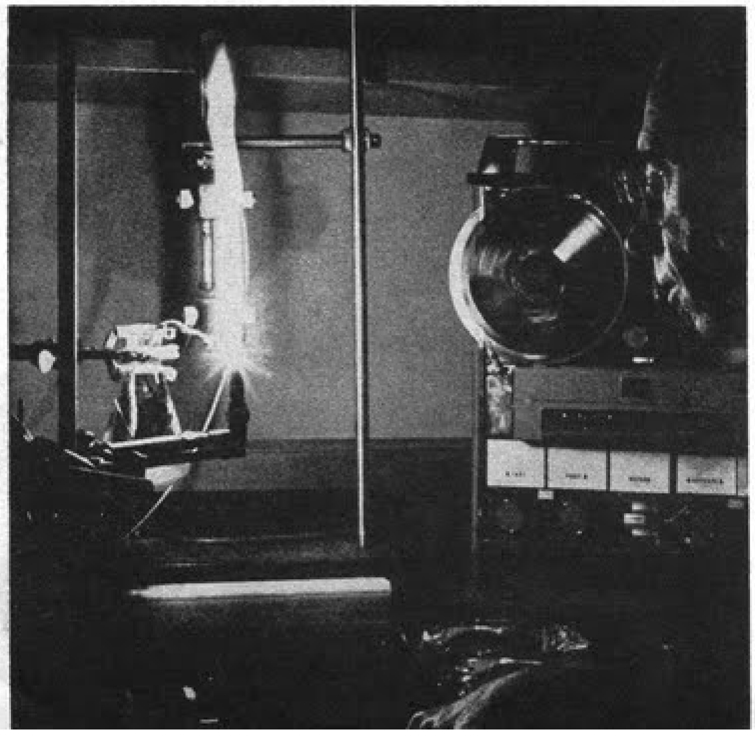
"Flame which behaves physically and electrically like a high-fidelity loudspeaker ... and has inherent amplification besides," explains Dr. A. G. Cattaneo, manager of United Technology Center's Sunnyvale, Calif., Physical Sciences Laboratory, and one of flame amplification's three co-discoverers.

So saying, Dr. Cattaneo strikes a match to an acetylene-oxygen fueled welding torch poised on a test stand in one of UTC's highly classified and restricted laboratories. Carefully, he adjusts the torch's flame until, blue-hot (about 4200°F), it burns with livid intensity.

"Notice the electrodes," Dr. Cattaneo continues, pointing to two small tungsten electrodes which, immersed in the flame, are set one above the other and separated by a few inches of fire.

Next, he indicates the high-fidelity sound system's handful of basic components: (1) a tape recorder which feeds a (2) power amplifier which, in turn, energizes the (3) primary windings of a transformer; and (4) a d.c. power supply whose negative and positive terminals are connected, through the transformer's secondary, to the two flame-immersed electrodes.

"Please observe that we have here all the necessary components of a high-fidelity sound system-everything, that is, except a loudspeaker," says Dr. Cattaneo as, deftly, he switches on the d.c. supply, then the power amplifier, and, finally, the recorder whose tape is transcribed with Beethoven's Fifth Symphony.



From the eerie glow of the flame from an ordinary welding torch comes Beethoven's "Fifth Symphony" in full fidelity—and the electrical flame loudspeaker is born.

Suddenly, music inundates the lab.

"The flame," gestures Dr. Cattaneo, "is the sound system's loudspeaker. More correctly-although we're not yet certain precisely how or why it works-it is probable that ions in the two fuels, oxygen and acetylene, actually perform the power conversion. That is, ions in the burning gas stream convert the amplitude-modulated input signal to audio.

"Generally," he continues, "the hotter the flame, the greater the ionization of the fuels . . . and the louder and more faithful the sound reproduction."

To demonstrate, Dr. Cattaneo turns down the flame (reducing the oxygen acetylene supply). Beethoven's Fifth is still audible, although muted in volume and far less faithfully reproduced than when the flame burned with blue-hot and ionizing intensity. He turns up the flame -and Beethoven comes on in volume and fidelity again.

Pluses of the Flame Speaker. Dr. Cattaneo might have added some other pertinent facts about flame amplification and the remarkable "ion speaker." For example, it is likely the world's first truly omni directional loudspeaker. The sound emitted from the flame is broadcast with equal force in all directions . . . spherically through a full 360 degrees.

Frequency range and fidelity are other sizable pluses of the flame speaker. Its frequency response range is three to four times that of any known mechanical speaker-and future tests, far beyond the audio spectrum, may well show even higher response. Where, for, example, even the best and costliest of diaphragm type speakers can reproduce, at their highest range, only about 30,000 Hz (at best, about 12,000 Hz above what even the most acute human ear can hear), the flame speaker has shown it can reproduce at least 100,000 Hz.

Moreover, where response of mechanical speakers begins to fall off toward the high audio side (beginning at about 10,000 Hz), the flame speaker shows no evidence of this defect at all. It reproduces with equal fidelity the lowest lows (down to 16-20 Hz) and highest highs thus far measured.

"Seeding" The Flame. Dr. Cattaneo had, thus far, demonstrated for POPULAR ELECTRONICS only part of the phenomenon of flame-its use as a high-fidelity sound reproducer. Now, to conclude an already profound visual and audio experience, he thrust a short length of sodium silicate glass tubing into the hot flame.

The reaction was immediate. The flame changed color, turning from blue to blaze orange. At the same instant the flamespeaker's volume seemed almost to double, until the lab fairly reverberated with sound.

"Amplification-in the order of 32 times," Dr. Cattaneo said. "By 'seeding' the flame with some easily ionized alkali metal-the sodium in this sodium glass tube, for instance, or even a pinch of sodium chloride, common table salt many more ions are introduced into the flame-stream. Super-ionization not only permits the flame to carry more current, but quite significantly reduces the resistance between the electrodes-from a high of about 1 meg ohm when the gas stream is unignited to a low of 2500 ohms when the flame is super-ionized by 'seeding.'

"So more current flows through the modulating circuit and between the electrodes. And you have what you hear-real and basic amplification. The gain, insofar as we've been able to measure, is 15 decibels ... amplification, as I say, in the order of 32 times."

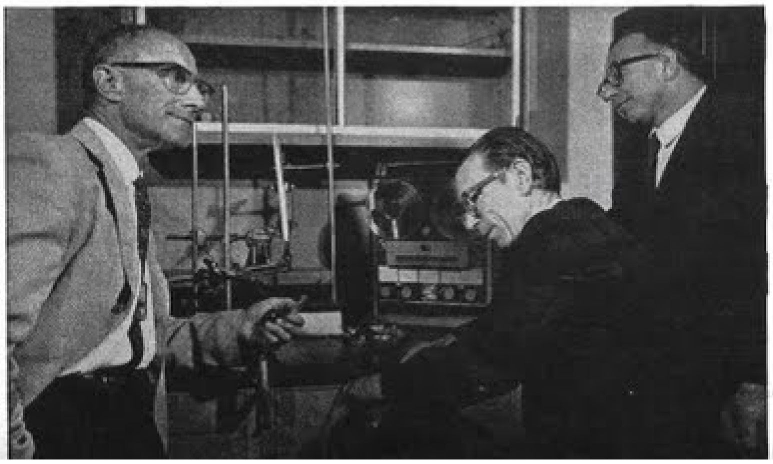
Exciting, Yet Simple. Certainly one of the most exciting and significant physical science breakthroughs of the decade, flame amplification is also one with far-reaching application in electronics, physics and rocket research. For example, UTC plans to use a rocket's own fiery exhaust as a sound detector of internal rocket engine ailments. Such trouble -a potential rocket-destroying resonance, to name but one-likely modulates the rocket engine's flame-stream and can be readout and diagnosed by a "sound doctor" familiar with rocket ills.

The phenomenon is so basically simple and easy to duplicate that any electronics experimenter can concoct a flame speaker at home-using nothing more than a Bunsen burner, or perhaps one of those disposable fuel-cartridge welding tools. Even your kitchen stove's pilot flame will reproduce some sound, though the flame temperature is too low (being methane-natural gas-fueled, rather than fueled with hotter burning oxygen acetylene) to give really good or faithful sound.

The members of United Technology Center's flame amplification team headed by Dr. Cattaneo, with much of the theory put to lab practice by Wayne Babcock, a brilliant innovator, and K. L. Baker-were not the first or only experimenters through the years to recognize flame's audio response. Indeed, UTC's flame amplification team claims (and has patented) only one sizable advance in the state of the art: they were first to achieve electrical modulation of flame. Previous experimenters had merely physically modulated flame using various pressure-wave generating devices-a speaker diaphragm, for example. Such basic systems left much to be desired in acoustic output.

When It All Started. Back as far as 1858, British scientist John Leconte noticed, while at a concert, that the theater's gas lights responded to certain beats of the music. What Leconte observed was the gas light's response to the bottom end of the audio spectrum, on the order of a few hertz. For the unaided human eye cannot detect frequency response much above 16 or 17 Hz. It is noteworthy that very low frequency response can likewise be observed in the flame-speaker's flame. At any rate, Leconte reported his observations to the Royal Academy, declaring, "we must look upon all jets as musically inclined."

From left to right are Dr. A.G. Cattaneo, Wayne Babcock, and K.L. Baker—United Technology Center's "flame amplification" team—listening to their flame amplifying loudspeaker as it reproduces taped music.



"Oscillatory Combustion" was the subject of a special session of the fourth symposium of the Combustion Institute, in 1952-where combustion experts discussed flame's response to external modulating pressures. Involved was some pretty basic physics, for it has long been axiomatic that combustion temperature increases as pressure increases. (Sound pressure in the flame loudspeaker, the UTC researchers report, gets the same and expected-result : as sound pressure rises, so does flame temperature. And as temperature rises, ionization increases. This may be one factor in the flamespeaker's fidelity and amplification over so impressive a frequency spectrum.)
More recently, Stanford Research Institute came up with what its scientists dubbed a "dragon horn": a diaphragm type speaker horn (the kind used in public address systems) screened at the end and through which, when additional volume was required, methane and air were introduced and ignited. The screened horn-end, converted to a burner, belched flame (thus, "dragon horn"), and, SRI found, effectively boosted audio output by some 15 dB. Significantly, this is precisely the gain of UTC's flame amplifier speaker.

The UTC's researchers probed deepest, however, and stumbled, quite by accident, upon the full significance of the phenomenon while trying to duplicate in the lab the jet-flame exhaust of rocket motors.

Experimental "Put-Together." Says Wayne Babcock, who did much of the experimental put-together, "One day, about two years ago, some of our people came in and asked if we could simulate a rocket's exhaust flame. The idea was to feed sound into the propulsive exhaust system at one place and take it out at another-for a better understanding of the relationship between rocket combustion and noise. For one thing, we hoped to discover what various noises told about a rocket's internal behavior. And especially if certain undesirable internal resonances could be detected by analyzing noise from a rocket's fiery exhaust."

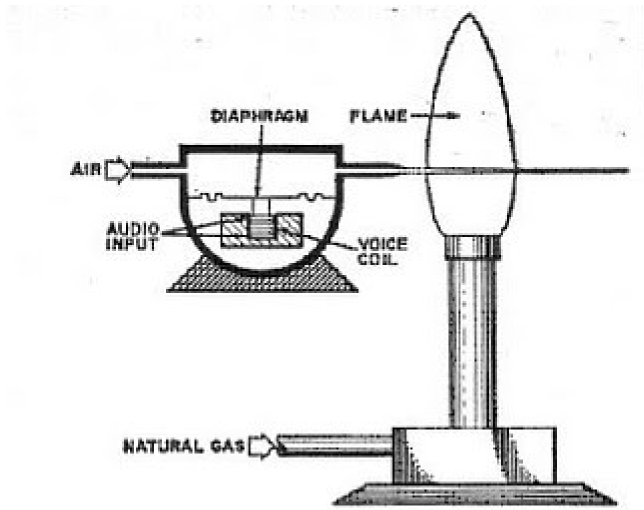


Fig. 1. Original mechanical "modulator" consisted of a speaker mechanism and a Bunsen-burner flame.

Babcock's first "put-together" was purely mechanical (Fig. 1). Adjacent to and level with the visible part of the natural gas flame of a Bunsen burner, he set a "modulation unit"-nothing more than a loudspeaker voice coil attached to an air chamber, one of whose flexible sides could be vibrated by the voice coil. When hooked to an audio frequency source, the diaphragm responded, and "modulated" a stream of low-pressure air jetted at the flame through the chamber and out a copper tube nozzle.

"If you put your ear to the flame, you could hear sound . . . quite good and faithful sound, considering so simple and loss-prone a flame-modulating device," remembers Babcock.

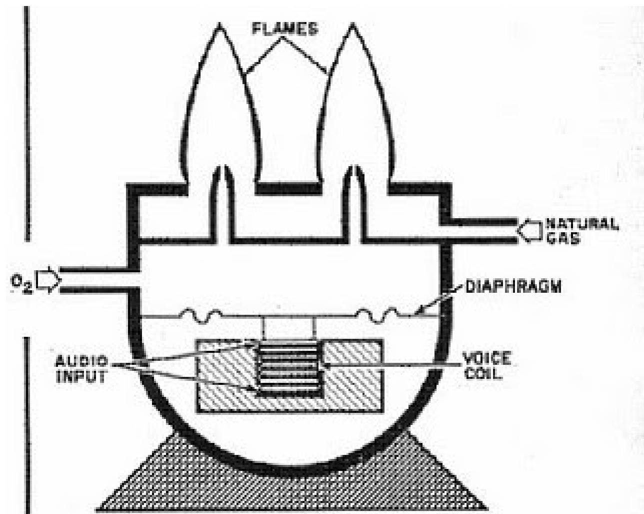


Fig. 2. Variation of mechanical flame modulator provided a louder sound and better audio quality.

Babcock and Baker experimented with other mechanical modulators. In one, Fig. 2, they rigged a diaphragm to modulate the natural gas and oxygen supply to a welding torch. This hotter fuel mix (about 3200°F) produced louder sound and good fidelity over the diaphragm's limited frequency range. The hotter the flame, found the researchers, the more efficient the flame amplifier, and the louder the flame's audio output.

How, And Possibly Why. Combustion, by its very nature, produces ions. Ions are the stuff of electricity. The hotter the combustion, the relatively greater the number of ions that will be naturally produced. Moreover, this ionization of the combustion zone can be artificially increased by "seeding," as previously mentioned.

Given a highly ionized flame, the conditions would seem right for current to flow, ion-supported, between two electrodes immersed in the ionized combustion zone, thus completing an electrical circuit. Were this current externally modulated with a frequency within the audible range, it might naturally follow that the flame would reproduce the sound.

Why modulated ionized current might "couple" with adjacent air molecules in a power conversion of electrical energy to audible sound energy had already been suggested by some researchers who had explored the behavior of highly ionized gases. One researcher, as far back as 1951, came up with the following provocative theory.

Although the molecules in a gas do not normally "hang together" as in a liquid, highly ionized gas molecules do. And thus, in such special cases of high ionization, the ions in gas exhibit cohesion much as in a liquid. Being cohesive, the ions have substance enough to exhibit "surface tension"- again, just as do ions and molecules in a liquid. As such, gaseous ions form a kind of invisible diaphragm which might logically be expected to couple with and to exert force upon adjacent air molecules. If such were, in fact, the case, a modulated highly ionized electrical current in a combustion zone might "beat" against adjacent air molecules, converting its electrical energy to audio energy, much like the physical behavior of a loudspeaker's solid diaphragm on the air around it.

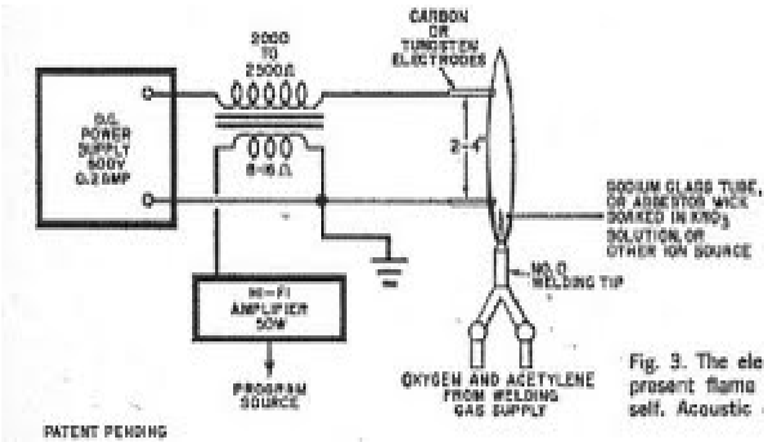


Fig. 3. The electrical arrangement of the present flame amplifier is simplicity itself. Acoustic output is omnidirectional.

The Present UTC Setup. Figure 3 shows the basic components and their hookup. The output of a Sony 365 tape recorder is fed to the input of a McIntosh 75-watt amplifier and the amplifier's output to the 8-ohm secondary winding of a reverse-connected power output transformer. A Hewlett-Packard Model 712-B (500 volts d.c. at 200 mA) power supply is connected through the transformer's primary winding to the two tungsten (or carbon) electrodes which, immersed in the flame, are spaced 2 to 4 inches apart. Neither the spacing of the electrodes nor their positioning within the flame zone is particularly critical.

The welding torch, fueled by acetylene and oxygen and fitted with a #0 tip whose small opening produces an almost hissless flame, is the kind any welder might use. How the easily ionized alkali metal is introduced to the combustion zone is relatively non-critical too, except that for best results super-ionization should take place below the lowest electrode. That is, the lower, hotter part of the flame should be ionized so that the ions "float" upward, past both electrodes. (Lacking a sodium glass rod, an asbestos wick drawing from a salt solution quite readily achieves super-ionization.)

Operationally, the procedure works like this:

The torch is lighted and adjusted slightly on the "rich" fuel-mix side (more oxygen than acetylene). This makes for a hotter flame. The flame itself is adjusted for minimum hiss. What you get is a quiet, brilliant blue flame.

Now the power supply is turned on. With one eye on a milliammeter connected in series with the electrodes, the flame-speaker's operator begins to "seed" (if he's "seeding" with a sodium glass rod, he gently intrudes its end into the base of the flame). As the flame turns brilliant orange, indicating super-ionization, he adjusts the power supply, flame controls, and the sodium rod for maximum current-which may go as high as 200 to 300 mA.

Finally, the tape recorder is turned on. And from the flame booms amplified sound.

Getting All the Frequencies Out. One critical factor is the physical height of the flame. Sound from UTC's 6-inch high torch flame, while good, obviously is missing some in the low frequencies.

"But," grins Babcock, "we know that the tape's every frequency is actually being reproduced in the flame. The flame's height is simply too short to make them all audible."

So saying, he turns to a 6-stage photomultiplier which, set on a tripod nearby, is focused like a telescope on the flame. With its photocell masked by a yellow Sodium-D line filter (5890 angstrom units), the multiplier "sees" only the light from the sodium ions. The multiplier is plugged into a Dynakit amplifier driving a hi-fi speaker. Now Babcock powers the hookup-and from the speaker comes a flame-rendition which contains all the lows missing in the flame reproduction itself!

"One way to explain our loss below about 2000 Hz," explains Babcock, "is this : physically, our 6-inch-long ionized flame-front-really, just 2 to 4 inches of modulated ions, depending on the distance between electrodes-simply isn't long enough and therefore hasn't either ions or energy enough to vibrate to audibility the far more numerous air molecules you'd need to excite in order to produce these longer wavelength, lower frequencies."

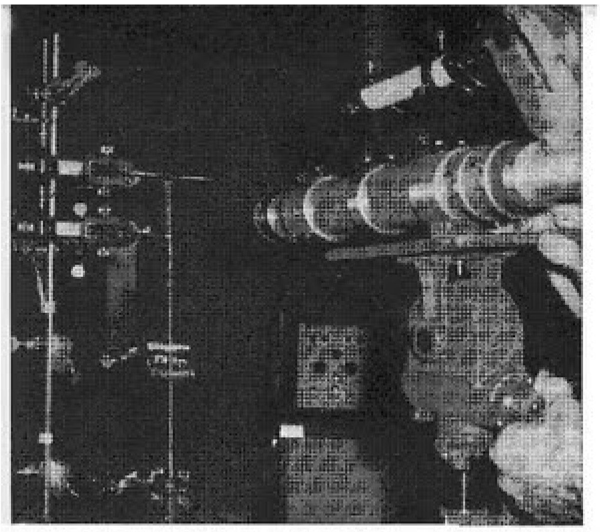
Continues Babcock, "There's just not flame length enough for a satisfactory flame-to-air molecule coupling when the wavelength you're trying to excite is measured in inches and feet, and is far longer than the flame itself.

"We think there's an analogy here," he concludes, "between the kind of reproductive performance you get from a large-diameter diaphragm loudspeaker and from a small one. If we used a really long flame-perhaps one of those oil field gas flames which are sometimes 20 to 30 feet long, we would probably get out every frequency we put in."

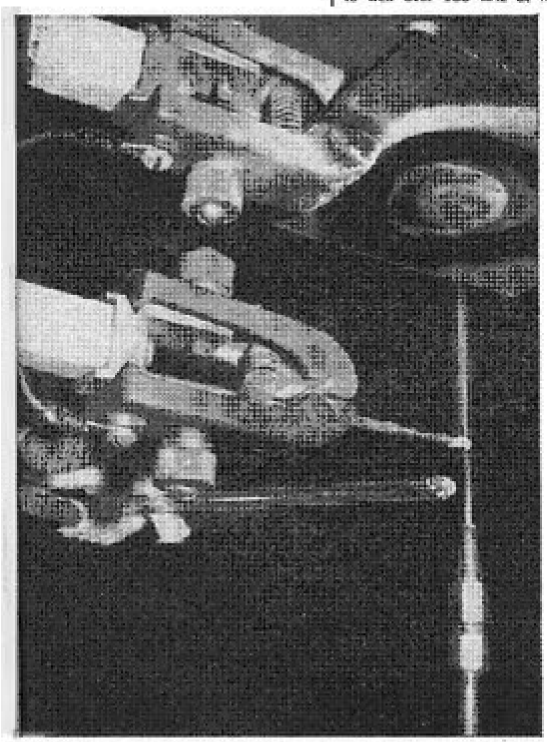
Actually, of course, Babcock's team does get all the frequencies out-by using the photomultiplier to pluck unheard low frequencies from the flame itself.

Talking Flames. Flame amplification's most immediate uses are highly classified, involving missile and rocket engine research. But momentarily you can expect "talking flames" to make their appearances as crowd-pleasing oddities at fairs and trade shows.

Far deeper, however, will be the impact of flame amplification on the future of electronics. For flame has become an electronic component.



Because the welding torch flame is too small to support the low audio frequencies, a photomultiplier system "picks them out" and supplies them to a separate amplifier system. Overall frequency response is from a few cycles to well over 100 kHz at high sound level.



Electrical signals are fed in via two insulated alligator clamps while glass rod "seeds" the flame.

http://www.swtpc.com/mholley/PopularElectronics/May1968/Flame_Amplification.htm

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