## ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Naval Oceanic and Atmospheric Research Laboratory through the U. S. Navy-ASEE Summer Faculty Research Program and through Grant No. N00014-89-J-6002. They also acknowledge helpful discussions with James Matthews of NOARL, Maurice A. Meylan of the University of Southern Mississippi, and Kent Broadhead of the University of New Orleans. The authors are especially grateful to Dr. E. L. Hamilton for his careful reading of the manuscript and helpful suggestions. This document has been reviewed and is approved for public release. NOARL Contribution No. 244:064:89.

Bachman, R. T. (**1985**). "Acoustic and physical property relationships in marine sediment," J. Acoust. Soc. Am. **78**, 616–621.

Bachman, R. T. (**1989**). "Estimating velocity ratio in marine sediment," J. Acoust. Soc. Am. **86**, 2029–2032.

Hamilton, E. L. (**1970**). "Sound velocity and related properties of marine sediments, North Pacific," J. Geophys. Res. **75**, 4423–4446.

Hamilton, E. L. (**1978**). "Sound velocity-density relations in sea-floor sediments and rocks," J. Acoust. Soc. Am. **63**, 366–377.

Hamilton, E. L. (**1980**). "Geoacoustic modeling of the sea floor," J. Acoust. Soc. Am. **68**, 1313–1340.

Hamilton, E. L., and Bachman, R. T. (**1982**). "Sound velocity and related properties of marine sediments," J. Acoust. Soc. Am. **72**, 1891–1904.

Nobes, D. C. (**1989**). "A test of a simple model of the acoustic velocity in marine sediments," J. Acoust. Soc. Am. **86**, 290–294.

Press, W. H., Flannery, B. P., Teukolsky, S. A., and Vetterling, W. T. (**1986**). *Numerical Recipes* (Cambridge U. P., Cambridge, U. K.).

Rayborn, G. H., Ioup, G. E., Ioup, J. W., and Carr, J. C. (**1986**). "Normal-mode filtering with orthogonal functions to avoid mode leakage," J. Acoust. Soc. Am. Suppl. 1 **80**, S113.

Tindle, C. T., Guthrie, K. M., Bold, G. E. J., Johns, M. D., Jones, D., Dixon, K. O., and Birdsall, T. G. (**1978**). "Measurements of the frequency dependence of normal modes," J. Acoust. Soc. Am. **64**, 1178–1185.

Tindle, C. T., Hobaek, H., and Muir, T. G. (**1987**). "Normal mode filtering for downslope propagation in a shallow water wedge," J. Acoust. Soc. Am. **81**, 287–294.

Wood, A. B. (**1941**). *A Textbook of Sound* (Macmillan, New York).

Wyllie, M. R. J., Gregory, A. R., and Gardner, L. W. (**1956**). "Elastic wave velocities in heterogeneous and porous media," Geophysics **21**, 41–70.

# On the invention of active noise control by Paul Lueg

D. Guicking

*Drittes Physikalisches Institut, University of Göttingen, Bürgerstrasse 42-44, D-3400 Göttingen, Federal Republic of Germany*

(Received 9 January 1990; accepted for publication 11 January 1990)

A historical report is given on the invention of active noise control which is related to the person of Paul Lueg, a doctor of philosophy and medicine, who worked as a physicist for many years. He submitted, early in 1933, a patent application describing for the first time the principle of active noise cancellation. Long before any technical realization, he had recognized the essential aspects of this method. It was his personal tragedy that he ran, by this patent, into severe controversies with Nazi army authorities. Instead of recognition (and profit), the invention brought him nothing but detriments which overshadowed his further life.

PACS numbers: 43.50.Ki, 43.10.Eg

## INTRODUCTION

Active noise control, i.e., the cancellation of a sound field by superimposing an electroacoustically generated secondary field of opposite phase, has become feasible for several years. More and more practical applications are being reported, and papers on active noise control are now presented at almost all conferences on acoustics. The earliest printed document clearly expressing the idea of compensating a sound signal by another one in antiphase is a U.S. patent[1] granted to the German inventor Paul Lueg who appears to be unknown in the acoustic community except for this patent and its German counterpart.[2]

Stimulated by repeated inquiries from colleagues abroad, I tried to trace Paul Lueg's course of life; the attempts have finally been successful by meeting Paul Lueg's widow, Dr. Hedwig Lueg in Cologne who reported details revealing a fateful relation of this patent to Lueg's further life which appear worthy of being communicated to a broader public.

## I. THE YEARS BEFORE THE PATENT APPLICATION

Georg Heinrich Paul Lueg, born on 12 May 1898 in Cologne as a son of the merchant Karl Lueg and his wife Luise, attended high schools until 1920, with an interruption (1917–18) by military service during World War I. As a student, he joined the Polytechnic Institutes ("Technische Hochschulen") of Aachen and Berlin, and the Universities of Berlin, Rostock, and Bonn. His interests were widespread. He enrolled for courses in electrical and mechanical engineering, physics, chemistry, mathematics, German, philosophy, law, social sciences, and economics. He learned English, French, Spanish, and Latin and earned a doctoral degree of the Philosophical Faculty of the University of Bonn in 1924 with a dissertation on Beneke's theory of cau-



Downloaded 05 Jun 2013 to 128.197.27.9. Redistribution subject to ASA license or copyright; see http://asadl.org/terms

sality,[3] a philosophical treatise. After further studying until Spring 1926, he became an Assistant Professor in the Physics Department in Bonn. Here he did research work in the field of optical spectroscopy and on enhancing the sensitivity of photographic films. A number of publications,[4–10] some of them jointly with students whose Ph.D. theses he cosupervised, witnessed these activities which ended in the fall of 1933.

## II. THE PATENT APPLICATION AND ITS IMPLICATIONS

About the end of 1932 Lueg must have had the idea of employing modern electroacoustic transmission technology to the cancellation of unwanted sound. He formulated the basic idea and listed some possible applications on less than two printed pages for his German patent application[2]—presumably not foreseeing that this short paper would alter his life dramatically.

Lueg outlines the principle: The unwanted sound is picked up by one or more microphones, their electrical signals feed, after amplification, to one or more loudspeakers so that the sound wave produced is in "phase opposition" to the primary unwanted sound and cancels it. He discusses, for one-dimensional sound propagation, the mechanical means of obtaining the phase opposition by properly adjusting the distance between the microphone and loudspeaker in the case of a pure tone, realizes that an additional electrical adjustment would be necessary for nonsinusoidal sound, and that the microphone should be screened against the loudspeaker (obviously in order to avoid acoustic feedback). For three-dimensional sound fields, he proposes "zones of silence" to be created in the vicinity of the canceling loudspeaker, the application of active "acoustic barriers" in the openings of doors and windows, and to construct walls as vibrated membranes to silence rooms. He also claims that specific acoustic requirements might be met by accordingly modified equipment: Cancellation of echoes and other disturbing noise in theaters and concert halls, selective reduction of certain frequencies to adjust the acoustic quality of rooms to specific demands, or particularly the reduction of typewriter noise. The latter is said to be possible "in a very simple manner."

While the principle of active noise cancellation is described correctly, the claimed possibilities of practical application prove Lueg's lack of experience in the field of technical acoustics. Many of the problems which, according to Lueg's patent, should be solved easily have turned out to be beyond the technical possibilities even of today's sophisticated electronic potential.

He submitted the patent application on 27 January 1933 and we have to realize that this was the time of the "Machtergreifung," the seizure of power by the National Socialist Party in Germany.

With the exception of very few letters, the correspondence related to the patent has been lost in a bomb raid on Berlin during World War II, so the following passages are based mostly on personal communications given by Mrs. Lueg to the best of her recollection of many talks with her late husband; however, he got so excited when remembering these old events that she used to stop him, fearing for his health.

According to Mrs. Lueg, the Nazi administration initially considered the invention to be of military relevance. So it was classified as a secret matter and transferred into the responsibility of the patent office of the army ordnance department. There must have been a lot of controversy between Lueg and this office still in 1933. He wrote in a later curriculum vitae that he lost his position at the University of Bonn by 31 October 1933 because of a patent litigation of political nature, and that he performed scientific studies on private ventures in the following years.

It can be assumed that a major part of these private studies were devoted to prove the practical value of his invention after the army showed no further interest. This fact is documented by two letters of the patent department dated 20 January 1934 and 23 February 1934. The first very short letter states that the proposal is considered to present nothing new, and to be of no value for the army so that a classification would not be necessary. Obviously Lueg raised objections against this statement and fought for his idea. The second letter refers to another judgment on occasion of a practical demonstration by himself on 7 February 1934. The invention is now recognized as an original extension of the known principle of interference. However, a military application to annihilate aircraft noise, exhaust noise, and the muzzle boom of guns is considered not to be feasible because of the complexity of the equipment, its lacking ruggedness, its mass and volume, and the difficulty of obtaining the necessary sound intensity with loudspeakers.

Concerning the chances of a technical realization of the proposal, this judgment (to which the Heinrich Hertz Institut in Berlin obviously had contributed) was doubtlessly correct; the problems of generating the compensation signal with the necessary accuracy not even being mentioned. But this letter reveals two more points of historical interest. The first one is related to the understanding of the physics involved. Besides "interference," the possibility of "annihilation" of acoustic energy is not generally excluded—an important aspect which has been accepted by many acousticians only in the 70s after laying the theoretical foundations of active noise control. The aspect of energy has not been mentioned explicitly in Lueg's patent application, but it can be assumed that he at least suspected his invention to be more than just an application of interference (and hence doubling the total acoustic power); otherwise he would probably not have struggled as persistently for its recognition as he did.

The letter also documents that Lueg had performed a demonstration experiment, long before H. F. Olson[11] did his well-known laboratory experiments. Mrs. Lueg remembers that her husband talked of employing fragile glass tubes which often broke, but no details of his setup are known.

After the authorities had released it from classification, Lueg filed his patent application in the USA on 8 March 1934,[1] and also in France, Italy, and Austria. The U.S. application was supplemented with some illustrations (Fig. 1). The upper drawing ("Fig. 1") is related to one-dimensional sound propagation in a duct. A noise source $A$ emits a sound



Downloaded 05 Jun 2013 to 128.197.27.9. Redistribution subject to ASA license or copyright; see http://asadl.org/terms

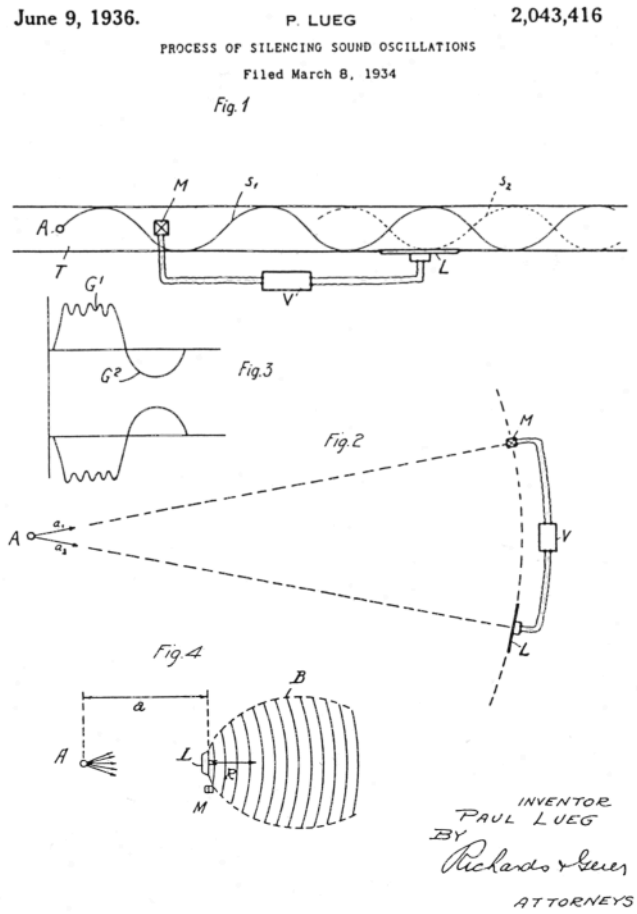


FIG. 1. Illustration page from P. Lueg's U.S. patent.[1]

wave $S_1$ which is monitored by a microphone $M$; its output signal, after passing an amplifier $V$, feeds the loudspeaker $L$ such that a canceling wave $S_2$ is emitted. "Fig. 2" refers to a spherical wave where microphone and loudspeaker are located at the same distance from the source in order to achieve phase opposition by simple pole reversal. "Fig. 3" illustrates the meaning of phase opposition for a nonsinusoidal time function, and "Fig. 4" shows the noise-reduced zone beyond the loudspeaker $L$ which is here fed from a microphone $M$ in the immediate vicinity.

Although the German army had released Lueg's patent application from classification, it was, as Mrs. Lueg reports, considered a treason to his country when he applied for the foreign patents. Possibly as a defense against this reproach, he presented newspaper articles reporting an English invention which he conjectured to be based on his own ideas and concluded that information on his patent application must have been communicated abroad earlier by the German army or the Heinrich Hertz Institut. This assertion was aggressively refused by the army patent office in a letter of 23 October 1934 which has been preserved. It is understandable that Lueg's relations with the Nazi authorities were not the best after all, and he felt threatened by the Gestapo, the Nazi secret police. The fear of detention during night time led to a trauma persisting for the rest of his life.

Lueg wanted to work again as a physicist with a university, but all his applications were refused, obviously by order of the Nazi authorities to which he appeared "unreliable." Also his good relations to his former academic teacher, Professor Konen in Bonn, may have appeared suspicious. Konen was discharged from his position as a professor immediately after the Nazis' "Machtergreifung" and thereafter massively persecuted because of his courageous fighting for truth and freedom as can be read in an obituary. Lueg was offered, as a probation after his "transgression," a dubious mission in Russia which he considered to be a trap and refused.

For some time he received a scholarship from the German Science Foundation to write a comprehensive textbook on physics. The uncompleted manuscript still exists—it would have been an excellent book if it had been published. But the prolongation of the scholarship beyond June 1939 was refused, as well as an application for a single subsidy to cover due patent fees. Even the recommendation of Professor Esau, then president of the Science Foundation, could not help.

## III. THE PHYSICIAN PAUL LUEG

Realizing that under the existing political regime further work as a physicist appeared impossible, Lueg decided—at the age of 40—to start studying medicine and did this, according to his nature, with full engagement. He studied in Berlin from summer 1939 through January 1945 when he passed the final examinations and earned another doctorate in medicine.[12] He was assigned to work in a military hospital for the last few months of World War II; after some intermediate occupations he opened a practice in Cologne in 1951. He married in 1955 (Mrs. Lueg is also a doctor of medicine) and spent the rest of his life as an esteemed and popular physician in Cologne, near the place of his birth. The photograph, Fig. 2, shows him at the age of 77. He died on 19 July 1979.

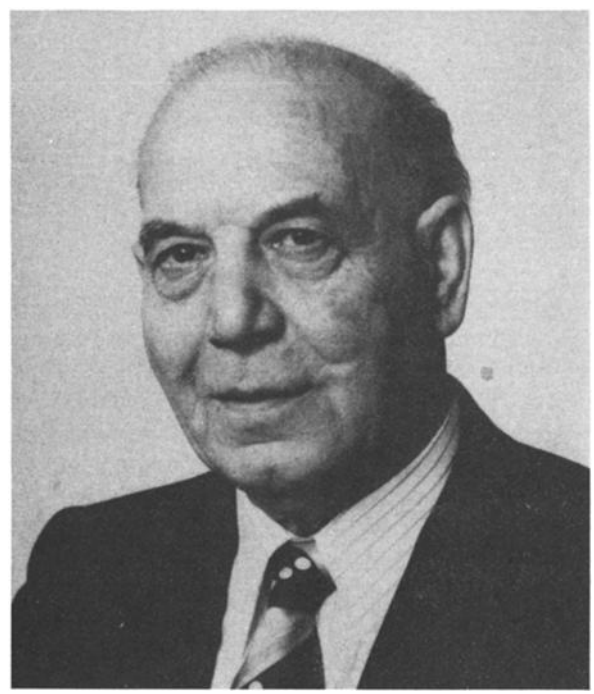

FIG. 2. Paul Lueg in the year 1975.



Downloaded 05 Jun 2013 to 128.197.27.9. Redistribution subject to ASA license or copyright; see http://asadl.org/terms

## IV. FINAL REMARKS

Paul Lueg deserves the posthumous recognition of being the first person who clearly understood and described the principle of active noise control. He was convinced of its technical potential although he never experienced any appreciation of his idea during his lifetime. His patent application anticipated the next successful laboratory demonstrations[11] by 20 years, and the first technical applications by 50 years. It was his tragedy that he believed in the possibility of rapid technical realizations, and that he became a victim of the totalitarian Nazi regime.


## ACKNOWLEDGMENTS

I wish to thank Dr. Hedwig Lueg, Cologne, for providing copies of the documents still existing, for the photograph of her late husband, and for several conversations giving the necessary information to round off this exceptional life story. Thanks are also due to Prof. Dr. M. R. Schroeder for critically reading this manuscript.



[1]P. Lueg, "Process of silencing sound oscillations," U.S. Patent No. 2,043,416. Application: 8 March 1934. Patented: 9 June 1936. Priority (Germany): 27 January 1933.

[2]P. Lueg, "Verfahren zur Dämpfung von Schallschwingungen," DRP (German Patent) No. 655 508. Filed: 27 January 1933. Patented: 30 December 1937.

[3]P. Lueg, "Die Kausalitätstheorie Benekes—historisch und kritisch betrachtet," Phil. Diss., Bonn 1924.

[4]P. Lueg, "Das ultrarote Absorptionsspektrum von Didym in Gläsern und Lösungen," Z. Phys. **39**, 391–401 (1926).

[5]Th. Dreisch and P. Lueg, "Der Einfluss der Borsäure auf die Dispersion einiger optischer Gläser im kurzwelligen Ultrarot," Z. Phys. **49**, 380–385 (1928).

[6]P. Lueg, "Über Sensibilisierung photographischer Platten und Aufnahmen verschiedener Spektren im nahen Ultraroten," Z. Phys. **60**, 13–19, (1930).

[7]P. Lueg and K. Hedfeld, "Die Rotationschwingungsbanden des Wasserdampfes zwischen 0,9 und 6,5 $\mu$," Z. Phys. **75**, 512–520 (1932).

[8]P. Lueg and K. Hedfeld, "Das Rotationsschwingungsspektrum des Ammoniaks," Z. Phys. **75**, 599–612 (1932).

[9]K. Hedfeld and P. Lueg, "Das Rotationsschwingungsspektrum des Acetylens," Z. Phys. **77**, 446–458 (1932).

[10]W. Scheib and P. Lueg, "Das Rotationsschwingungsspektrum des Äthylens im nahen Ultrarot," Z. Phys. **81**, 764–770 (1933).

[11]H. F. Olson and E. G. May, "Electronic sound absorber," J. Acoust. Soc. Am. **25**, 1130–1136 (1953).

[12]P. Lueg, "Über Herpes gestationis," Med. Diss., Berlin (1945).


# Comments on "Broadband repetition pitch: Spectral dominance or pitch averaging?" [J. Acoust. Soc. Am. 84, 2058–2062 (1988)]


Frans A. Bilsen

*Faculty of Applied Physics, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands*



(Received 25 July 1989; accepted for publication 26 January 1990)



The article "Broadband repetition pitch: Spectral dominance or pitch averaging?" by R. M. Warren and J. A. Bashford, Jr. [J. Acoust. Soc. Am. **84**, 2058–2062 (1988)] calls for some remarks and clarifications concerning current views on the perception of pitch and repetition pitch, in particular.



PACS numbers: 43.66.Hg, 43.66.Ki [NFV]


The article "Broadband repetition pitch: Spectral dominance or pitch averaging?" by R. M. Warren and J. A. Bashford, Jr. [J. Acoust. Soc. Am. **84**, 2058–2062 (1988)] deals with the repetition pitch of stimuli consisting of broadband or filtered white noise added to (or subtracted from) its delayed replica: RP + (or RP − ). The experimental data confirm earlier results by, among others, Bilsen and Ritsma (1967/1968) and Yost *et al.* (1978), viz., broadband or bandpass RP + corresponds to $1/t$ ($t$ is the time delay) and broadband RP − deviates by roughly 10% up- or downward from $1/t$. In addition, Warren and Bashford performed new experiments with low-pass (first–seventh peak), bandpass (third–seventh peak), high-pass (seventh peak–4000 Hz), and bandreject (third–seventh peak) stimuli. They found significant differences between the low-pass and broadband-antiphasic pitch values. Because these results seemed to contradict the spectral dominance concept (Bilsen and Ritsma, 1967/1968), i.e., a narrow-band positioned at three to five times the frequency value of the pitch to be the sole determinant of the pitch, they introduced the alternative hypothesis of "pitch averaging." This implies that "the perceived pitch is based upon a pooling of information across critical bands. At each cochlear locus, the effective repetition period responsible for pitch is equal to the sum of the repetition delay and any additional local frequency-dependent delay produced by polarity inversion. The weighted average of these local time delays corresponds to the repetition pitch heard broadband."

Thus, in Warren and Bashford's view, the average of the low- and high-pass pitches is expected to approximate the broadband pitch, which indeed seems to be confirmed by the new experimental data. However, in the light of modern in-




Downloaded 05 Jun 2013 to 128.197.27.9. Redistribution subject to ASA license or copyright; see http://asadl.org/terms