Holophonics, a spread- out of the basic ideas on Holography into Audio-Acoustics

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ABSTRACT

Holophony is in acoustics what holography is in optics. Just as might claim to be the ideal optical illusion, so might claim to be the perfect auditory illusion. As illustration of general principles theoretical basis was obtained by the Bourbaki group, and otherwise by Gabor theory. It is shown that using limited number of secondary Huygens sources one can provide a very presentable auditory illusion imaging the primary sound source.

1. FOREWORD

In this lecture in memorial to Dennis Gabor, let us remember first of all his two remarkable papers in our field; in which he formulated a theory of communication[1] and applied it to hearing problems[2]. In many of his postulates regarding the functions of the ear and brain, he anticipated finding which have been experimentally confirmed only during the last decade. Gabor recognised the importance of investigating the simultaneous relationship between time ard frequency aspects. The basic relationship involved is the "Uncertainty Relation": $\Delta t. \Delta f \geqslant 1$. where Δ t is the effective duration and f the effective frequency resolution.

The widely used Fourier analysis can be basically applied to analysing an infinitely long signal. Gabor dealt with the problems as to how a signal of limited duration can then be evaluated. He recommended a Gaussian probability function, since with this particular shape of elementary signal, consisting of a continous harmonic oscillation modulated by a suitable window function, the uncertainty relationship becomes an equality. A Gaussian window function has the property that its Fourier transform has the same envelope as the time function. Other windows such as the Hanning window have subsequently been found to give satisfactory results.

Introducing an information diagram with time and frequency coordinates, which incorporates the limitations imposed by the uncertainty principle, an elementary signal can be represented by one information cell on a diagram with area $\Delta t. \Delta f$. Gabor postulated that one such information cell with an unit area is the smallest allowable quantum of information, which he called a "logon".

The application of this principle led to important knowledge about the preception of sounds. As the approaches a more or less steady state, higher frequency resolution is required to be able to estimate the pitch and pitch changes for a longer time. During a transient, rapid changes cocur in all the acoustic parameters. The maximum time resolution is then required with a corresponding lower frequency resolution. The shortest response time for the critical bands is 10 ms. The best reported frequency resolution in the case of musical sounds up to now is about 3 Hz, which would require a duration of at least 330 ms /Zwicker[3]/.

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2. ACOUSTICAL WAVEFRONT RECONSTRUCTION

The techniques developed for holography are particularly applicable, with regard to both the phase requirements and the dynamic signal utilization needed in order to produce a special pattern or an interference trace ensuring that a source is unique regardless of the wave propagation path. This helps in building the time interference patterns required. For this purpuse, we extend the optical holographic correlation filtering technique to acoustics. Our noise source is now analogous to the desired filtered Gaussian image. The acoustical hologram is now the complex spatial filter. This filter can be obtained by recording the diffraction pattern of the desired picture detail together with a coherent background in the Fourier transform arrangement. Ordinary acoustical holograms do not diffract acoustic waves as laser light holograms do light waves, because the thickness of the acoustic recording element is not of the same order as the acoustic wavelength. Therefore we have to transform the acoustical hologram obtained /the complex filter/, into a form which satisfies the diffraction laws for acoustic waves. The used background in optical holography of our latter detailed investigation is included in the Appendix /7/.

In optical radiation, the radian frequency is so great that no detector exists which can detect the amplitude and phase separately. A square-law detector is therefore used to measure intensity. Using phase-only acoustical holograms, one can use a linear detector to measure the phase and amplitude of acoustic waves separately. The advantages of phase-only acoustical holograms are: they require only half as many data as compared to ordinary holograms and thus save digital computing time. Furthermore, the dynamic range problem is avoided, which often plagues ordinary Fourier holograms.[4]

In optical holographic correlation filtering, the filtered image /g/x,y/ can be written in the form

$g/x,y/ = f/x,y/ \oplus h/x,y/,$

where f/x,y/ is the text being filtered and h/x,y/ the Fourier transform of the holographic filter function H/u'v'/ and $\oplus$ indicates a convolution /see Fig.1/.

Record the phase-only acoustical hologram, the holographic spatial filter function,

$$H' = e^{1\Theta} + A_O e^{i\phi} \qquad /1/$$

using the object wave = $/H/e^{i\Theta} = e^{i\Theta}$ and a reference wave = $A_O e^{i\phi}$ /see Fig.2./

With reference to Fig.1 the complex amplitude of the sound field transmitted through the filter is

$$F/u',v'/I/u'v'/ = F/u'v'//1 + A_O^2/ + F/u',v'/A_O e^{-i\phi} + F/u',v'/A_O e^{i\phi} \qquad /2/$$

/I/u'v'/ intensity recorded on filter/

The sound field transmitted through the filter is now subjected to a Fourier transformation of /2/ which gives the following field components:

$$F/u'v'//1 + A_O^2/ \rightarrow f/u'v'/ \oplus T/1 + A_O^2/ \qquad /3/$$

/a dc term centered at x = O, y = O/

$$F/u'v'/A_O e^{-i\phi} \rightarrow A_O/f \oplus h/_{x+b,\ y+c}/\text{centered at } x = -b,\ y = -c/ \qquad /4/$$

$$F/u'v'/A_O e^{+i\phi} \rightarrow A_O/f \ast h/_{x-b,\ y-c}/\text{centered at } y = +b,\ y = +c/ \qquad /5/$$

/⁎ indicates a correlation/

The desired noise source is in this case, f ⊕ h. For the hologram, we shall use the sonosensitive plate develoed by Greguss, and all the lenses used here are acoustical lenses.

The acoustical hologram assumes linear superimposition of acoustic signals which occurs only with weak acoustic signals. In the case of strong signals, there will be harmonic distortion, wave-wave interaction and induced secondary flows which cause phase distortion and hence affect the accuracy of the phase component of our noise interference pattern. This phase distortion can be calculated using Lighthill's theory.

Hence the acoustical hologram does not satisfy the diffraction laws for the acoustic waves which involve phase distortion. In order to obtain the acoustical correlation filtering arrangement shown in Fig. 1, our complex filter /acoustical hologram/ must therefore have the ability to diffract the acoustic waves. We therefore have to transform the obtained phase-only acoustical hologram to in a form which satisfies the diffraction laws for the acoustic waves. This transformation can be done by modifying the properties of the recording material of the sonosensitive plates.

It is a widely known fact that just as in optics, the acoustic sound field can be completely reconstructed in the whole space, provided that the sound pressure in a surface is completely known in terms of both amount and phase. This principle can be made use of for near-field measurements /NAH/ of the sound-velocity distribution on the surface of an acoustic radiator and the simultaneous determination of the local characteristics of sound field parameters.[5,6,7] Acoustic imaging through holography has a rich history spanning over the last 30 years and has been applied in many different fields such as short wave ultrasonics, as well as the long wavelength audio range. At first, the resolution was limited by the wavelength of the sound field probing. First in 1980 it was shown that one can image without any wavelength resolution limitation. From the measurements of the acoustic pressure obtained by two hydrophones placed near the surface of the radiator, the complete theree-dimensional sound field can be reconstructed using a computer technique. This generalized nearfield acoustical holography /GENAH/ is unlike conventional holography because it provides a high resolution image of the sound pressure field from the surface of the radiating source to the farfield. From two-dimensional measurements, GENAH reconstructs the vector velocity and the vector intensity fields /energy flow/ in the nearfield of the source, and identifies modes of surface vibration on the sound source.[8]

The audition involves not only recording a message conveyed by sound waves but also identifying, albeit imperfectly, the sound source emitting the message. The isolated message has one dimension, that of time. The spatial localization can be in one, two or three dimensions, depending on whether it determines the direction of the sound source by means of a single angle on a horizontal plane, two angles /one horizontal and the other vertical/ or, in exceptional circumstances, two angles and a distance. All in all, one can speak of 1-D, 2-D, 3-D and 4-D perception, by adding to the time dimension one, two or three spatial dimensions. Experiments have already demonstrated the existence of 3-D perception. However, the techniques currently used are aimed only at 2-D perception.

3. HOLOPHONY

Holophony must be to acoustics what holography is to optics. Just as the latter might claim to be the ideal optical illusions, so might the former claim to be the perfect auditory illusion. But both are merely illustrations of a general principle, the theoretical basis of which was obtained by analogy with the process used successfully in mathematics by the "Nicolas Bourbaki's" group of mathematicians: holochory which comes from the Greek ὅλος holos, "whole", and χορίον, χόρια, or χορός chorion, of any given physical field. In other words, the method proposed for reconstructing a field does not depend on the physical nature of the field in question, but is valid and can be stated independently from the relations existing between various field components. /Table 1./

Nicolas Bourbaki considered one kind of mathematics from a much more general view point than that adopted previously[9]. Basic axioms were applied not to objects clearly specified in advance, but to mathematical structures, that is to say, entities not specified from the outset, except that certain relations exist between them. By increasing the number of axioms on which the elements of a structure may depend, or by specifying the content, problems which had been treated directly and separately in the past emerged as so many illustrations of one general principle.

The greatest advantage of this approach is that any theorem which has been demonstrated for a general structure can provide, simply by applying it to particular cases, a whole family of theorems each of which is valid individually in a branch where the theory complies with the same axioms as the initial general structure.

The phenomenon of waves or fields extending to a certain area from points referred to as sources yields an abstract structure if the nature and medium involved, are not specified beforehand. It will simply be assumed that between the field F and its sources S there is a very general type of relation, such as OP F = S for example; this formula means that a certain sequence of operations symbolized by operator OP can be carried out on the components of field F, making it possible to go back to the sources S of the phenomenon under consideration.

Quite fundamental structural theorems can be demonstrated on the basis of simple premises of this kind. One of the most direct theorems is that of 'reshaping'. The reshaping of field F' means replacing it by a field MF', in which M is a modification operator. This operation can be carried out by resorting to secondary sources S", the reshaping theorem of which can be stated as follows: S" = /OP M - M OP/F'.

4. PARTICULAR CASES OF ACOUSTICS: HOLOCHORY BECOMES HOLOPHONY

In space V /reproduction space/, a field F is assumed to have been created earlier in space V_p /projection or propagation space/. The reshaping theorem shows how to carry out this reconstitution: secondary sources S" must be constituted in accordance with the general formula stated above and provided with appropriate inputs. To avoid repeating ourselves we shall now consider the case of acoustics and turn our attention to holophony. Space V_P will for example be a concert hall /Fig.3/ equipped with a stage and an orchestra pit where there are sound sources S producing the acoustic field F. The field F which existed in a selected area in V_p during the performance is to be reconstructed in an auditorium V. /which could be any music lover's living-room/. According to our theory this would require a number of appropriate sound sources /groups of loudspeakers/ to be deployed in V_A which, for listeners L sitting in V_R /the central part of V_A/ would replace the sources S that they would hear if they were sitting in seats L' in theatre V_P.

In principle, the secondary sources S" should fill the whole of volumene Z, the space surrounding V_R and each of them should be piloted by the values of field F picked up by microphones placed in V_p in areas similar to areas S", if one imagines the reproduction space in the appropriate positin whithin the projection space. These are ideal conditions, but they do offer an approach and a research programme which could be adapted to bringing about improvements in 3-D and 4-D sound relief. In any event, they identify several shortcomings in current sound-relief technology, be it in the area of real-time sound systems or play-back.

In theory, holophony requires a host of individual sources filling the entire volume between the walls of the room to be fitted and that part of the room corresponding to one acoustical hologram where the sound reproduction is required to be identical with the original. However, many arguments can be adduced to suggest that a fairly limited number of secondary sources might suffice to provide a very presentable 'auditory illusion'.

5. BASIC HOLOPHONY

Sound information originates from sound sources, and is carried by sound waves. They can be a classified as "wanted" or desired, and "unwanted" /i.e. noise/. One approach to wave and field physics can be said to deal with the gap between simple propagation and diffraction. The first is governed by Green-Kirchoff theorem, and the second by particular integral equations. Jessel[10] and later Resconi and Jessel[11] gave great importance to the abstract entities /the secundary Huygens sources/ which replace the primary sources in the wave propagation and account for the basic diffraction phenomena. In Gabor's[12] theory it is further pointed out that the Huygens secondary waves carry the common original information about the primary source.

In practice secondary additional information is usually superimposed on the carried sound waves /reflections, wave scattering, absorption, dispersion, noise waves arising from noisy surroundings etc./ To take into account all the source information carried by the acoustic waves, let us introduce the following definitions.

- Coding information on sound waves; corresponds to "generating" the sound with defined source characteristics in time and space and putting them "on" carrier sound waves /emission of sound waves/.

- Decoding information from sound waves corresponds to the "read out" process of original sources information "from" carrier sound waves /detecting by microphone/.

- Recoding information on sound waves, corresponds to the process "putting" the modified sound source information "onto" the carrier sound waves /sound control/. The result of this information-recording can be a reshaping of the sound field.

The key to reshaping is the notion of an operator M /"modifier" or "reshaper"/, the definition of which involves reversing the common way of reasoning[11,13,14]. This reverse approach may be called reproduction": it is combined with deduction in order to appropriately analyse a feedback loop mechanism.

Another essential feature of FRT is the formulation of the secondary reshaping sources S" as the "Lie product" of two operators OP and M. This product just acts on the field F' which is to be reshaped. We have [15]

/a/ $S'' = /OP\ M - M\ OP/F'$ /Theorem I/ and: /6/

/b/ $q'' = /\text{grad}\ m/.\underline{v}'\ ;\ \underline{f}'' = p'\ /\text{grad}\ m/\ :\ \underline{g}'' = /\text{grad}\ m/ \times \underline{v}'$

According to Gabor, every Huygens source carries all the information conveyed by the whole wave, however complex its primary sources may be. For instance, any piece of a broken hologram still contains the same 3-D image as the unbroken one: only the sharpness of its details will have deteriorated. A similar assertion may be deduced from our FRT formulas /a/ or /b/: the primary field F' /resp. p' $\underline{v}'$ completely depicts the behaviour of its sources S' as well as the secondary sources S" /resp. q", f", g"/ given by /a/ or /b/. However, with Active Absorption, field intensity also has to be accounted for: its overall value has to be maintained in anti-source discretization!

Gabor pointed our the importance of Huygens' Principle in his analysis of wave propagation which led him to holography. However, as he had to deal with square-law detection, he relied exspecially on energy and field-intensity computations. His basic formula was that of the energy flux W entering the photographic emulsion or the detecting antenna:

/c/ $W = F.F^* + R.R^* + F.R^* + R.F^*$ $/^* =$ complex conjug./

The significant terms are FR^* and RF^* which express interference between the main field F and the reference field R. When printed into a photographic emulsion, these interference patterns compose a hologram.

In Gabor's theory, this reference wave R plays the same role as the reshaping operator M in FRT: it seems possible to regard R as a special form of a modifier M. A complete identification would deserve further detailed study. Here it is only mentioned in connection with holochory.

Hologhony lies within the confines of acoustics. There exists a holophonic theory of binaural hearing: using Gabor's formulation /c/ we may ragard F as the perceptual effect of a sound wave having entered one ear, while R would be the effect of the same sound having entered the other ear. This theory can be related to a holographic approach to brain function, memory and perception.

6. DECODING SOURCE INFORMATION BY HOLOPHONY

Sound source information is as follows:

- existence of the source /it has energy/,
- time history of the source,
- intensity of the source as well as that of any parts of the source,
- spectral content of the source,
- radiating properties of the source,
- geometry and the spread out of the source,
- location of the source,
- source distance from the observer,
- kind of radiated sound source information /signal shape, speech or music signals, sound signals of noise sources e.g. working machine/
- existence of other sources in the neighbourhood of the investigated source,
- disturbing noise emission from the source, or beyond the investigated source.

These, and some other source information is coded into the sound field by carried primary sound source. The aim of the source recognition process is to distinquish which belong to the wanted information. In the most practical cases it is necessary to recognize only some parts of the source information /location of the source, the radiated signal content or other special properties of the source/.

During the wave propagation, further new secondary information is coded into sound field. This "unwanted information" disturbs the primary source information. In practice one can distinguish between the following typical steps of sound field manipulation:

a/ Decoding the wanted source information from carrier sound waves - Directed Source Recognition /DSR/

b/ Reconding the Modified Source Information into a determined part of the sound field, in order to reshape and eliminate the unwanted sound waves in the assigned area /RMSI/.

In the DSR holophonical methods can be applied. A further extension can be explained by the analogues mechanisms of the binaural hearing system including some kind of acoustical wave recognition. In the natural organisms the sound source are identified by the two ears, and the diffraction effects aroung the head. This is the basic feature of wavefront reconstruction: diffraction at the diffraction pattern". In acoustics we can assume the natural superimposition of sound field parts as a hologram in the form of wave interference. Blauert[16] pointed out that some typical hearing processes have an analogy with signal processing techniques. Most of them are equivalent to the recognition of typical source information. A parallel view is given as follows.

hearing proces	source information
frequency analysis	spectral content
binaural summation	imaging
autocorrelation in single ear channels	activity
short time correlation	varying in time
binaural cross-correlation	location
interaural coherence	spatial extension, dimension
rotation effects on the head	extented location, stability

The application of the general theory of wave-front reconstruction /Fig.4/ for several source-identifying tasks is based according to the binaural hearing process on summation of the input ear operators /S_1 and S_2/[17]. The acoustic field is assumed to be linear and time invariant. The input operators are linear operators, they characterize the transmission of sound waves between the source and the measuring detectors or the ears and carry the original source information /Fig.5/.

The head diffracted sound field can also be considered as an acoustical hologram. The wanted source information is that resulting from the wavefront, and reconstruction of this,is based on a process similar to that involved is natural binaural senstion.[18]

The multiplication of input ear operators results in the reconstruction of the characteristic source features. Fig. 6 gives contains four terms. The first two terms correspond to the intensities at the ears, and the source image /the surface intensity and the localisation of the source/ can be derived from the mixed terms. In practical cases the source is extended, or has more separable source parts /n sources/, moreover the sound is propagated and received in a diffuse sound field. In this case the deduction of the mixed terms fields the results in sets of information /Fig.7/. Here we have the separated information term about the propagation /field and room components/, and about the source components. /e.g. the source intensities: Q_1^2/. Analysing the source components using the well-known signal processing methods /coherence, crosscorrelation technique, adaptive filters method, etc./ makes the wanted source information avaible. The holophonical treatment results in simple mathematical expression formulated source separation and the possibility of source identifying.

The method described here produces similar effects to the well known "cocktail party" effect on the auditory system.

Subjective investigations on sound image quality support our statements. We refer to psychological studies performed by Kurozumi and Ohgushi.[19] There analysis of the experimental data showed that:

a/ sound image quality depends mostly on the width and the distance of the sound image,

b/ the width of the sound image depends on the crosscorrelation coefficient,

c/ the distance of the sound image depends on the crosscorrelation itself,

d/ with respect to the physical and psychological factors governing sound image quality, there is no fundamental difference between the results of investigations carried out in anechoic chambers, and these with echoic surroundings.

The strength of the lathes statement lies in the proof that the influence of reflexted waves, i.e. the interference in the sound field, does not disturb the source-identifying! This fact seems to be a typical "holophonical" phenomenon.

7. APPENDIX

7.1. Backround - optical holography

The starting point of Gabors Wavefront Reconstruction was to think out a method for overcoming the theoretical and practical limits in such optical imagine systems as the electron microscope was in 1947. Overcoming the barrier a "trick was needed" it was the use of coherence[20,21]. Adding a known simple wave to the unknown complex wave they produce interference fringes. This fringe system contains all the information and from which the object could be reconstructed by a simple, general and direct solution. Illuminating the fringe-pattern with a plane monochromatic light wave the diffraction at the diffraction pattern must be reconstructed. As a component the original wave, can reconstruct the original undistorted waveform, and one true image of the object. This was the principle of Wavefront Reconstruction.

Practically there are a reference beam with complex amplitude A/x,y,z/exp/-jwt/ and an object beam coherent with it, with amplitude B/x,y,z/exp/-jwt/ added vectorially on any energy detector /e.g. photographic plate/. Such a detector completely ignores the phase factor and records only the resultant energy which is proportional to the joint intensity

$$I = /A + B/ \ . \ /A^{*} + B^{*}/ = AA^{*} + BB^{*} + /AB^{*} + A^{*}B/ \qquad /7.1./$$

The first two terms are the intensities of the beams, the last is the interference term.

Assuming the perfect coherence, the Van Cittert-Zernicke coherence factor is expressed in form:

$$\gamma = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad /7.2./$$

I_{max}, I_{min} are the maximum and the minimum of the intensity in interference pattern, when A and B are equal. γ is zero for incoherent light and unity for full coherence. A correction is needed only when the optical paths for A and B differ by not less than the coherence length.

Illuminate the hologram with the reference beam A. We obtain the transmitted amplitude:

$$/AA^{*} + BB^{*}/A + /AA^{*}/B + A^{2}B^{*} \qquad /7.3./$$

where the first term is essentially the illuminating beam unmodified; the second term is the reconstructed wave; and the third term is the twin image.

In the case of plane reference wave parallel to the plane of the energy detector, the second term differs from the "Twin object" only by all its phases changed into the opposite. /In this case $A^2 = AA^{*}$/. Let incidence the reference beam at an angle θ to the energy detector plate normal. This means that the factor B^{*} now modulates a wave which is turned by twice the angle θ. The twin object has suffered an "affine transformation" by the angle 2θ.

It is clear that the equations here hold true for every thin layer of a tick emulsion in the recording. There can be difference in the reconstruction, because the holograms in the various layers will interferre with one another. These effects are the colour selectivity and directional selectivity.

Thin holograms which ones has been taken with one wavelenght can be illuminated with any other wavelength, and they will give reconstruction. Illuminates one with a wavelenght X times longer than the original the diffraction angles will be increased in the ratio X.

A deep or volume hologram will give good reflectances only for narrow range of wave lengths /holography in natural colours/. If the illuminating light with wave-number k' is different from the original one k, assuming that the emulsion thickness d has not changed in the process, for small incidence angles the first zeros of the reflectance are at

$$\frac{\lambda' - \lambda}{\lambda} = \pm \frac{\lambda}{2d} \qquad /7.4./$$

where λ and λ' are the wavelengths in the emulsion.

Later the wide researches of holographers have shown that in holograms the phase is much more important than the intensity. This has been demonstrated also by Metherell 23 in acoustical holography.

In 1964 Leith Upatnieks published the first "diffused" holograms, which were taken with diffuse wide angle illumination of the object. It's the superposition of a very great number of "regular" holograms, thrown over each other, and distributed over the whole area, at random. It has two very important consequences:

- the illumination is diffused over the whole hologram, looking-through the hologram with two unaided eyes, one could see the object in three dimensions.

- Any small area of hologram contains the inforration on the whole object.

The formulation of the spread out the information in wave fields was the Huygens' Principle. It states that if one known all the data on a closed surface which contains all the sources one can calculate the light effects everywhere. But it's physically impossible to measure the light vector as a function of space and time at any surface. A resonable formulation expressed in modern form, states that the information in light beam is an invariant[22]. The same information can be extracted from it at any cross section. Such a physical description of natural incoherent light is very complicated. The spectrum of white light is not the Fourier transform of the amplitude as function in time, but a periodogram; it contains only the power, that is the squared amplitudes, integrated over time. It is known that the power spectrum is the Fourier transform of the autocorrelogram ϕ of the amplitude A/t/

$$\phi/x/ = \lim_{\tau = \infty} \frac{1}{2T} \int_{-T}^{+T} A/t/A/t+\tau/dt \qquad /7.5./$$

In order to put physical sense into Huygens' Principle it is necesarry to take a full spatial-temporal representation of natural light in terms of measurable data. Moreover we must specify more clearly what we mean by a "point". Introducing the degrees of freedom of a light beam /F/ can we say that the number of independent data in a coherent beam is invariant

$$F = \frac{\text{Beam Area x Solid Angle of Beam}}{\text{Wavelength swuared}}$$

This formulation is not quite precise it applies well only to compact areas.

But it's good enough for almost all practical applications.

In optics and also in communication theory two descriptions have equal importance: spatial distribution and Fourier description. The first is the representation of a complex but coherent beam by dividing it up into Gaussian beamlets. The second will be the representation by "eigenfunctions". The Fourier description is equivalent to the expansion of the distribution in terms of plans waves with spatial frequencies k_x, k_y. At the small incidence angles used in holography one can state that a beam which is Gaussian in one plane remains Gaussian all other planes. Furthermore is to say the Gaussian beam spreads, at great distances, like a spherical wave centering on Z = 0.

The well known theorem of Fourier Theory states that a beamlet cannot be limited both in x and in the corresponding spatial frequency k_x so as to infringe the uncertainty relation.

$$\left\langle x^2 \right\rangle \cdot \left\langle k_x^2 \right\rangle \geqslant 1 \qquad /7.6./$$

Both x and k_x are measured from centroids of their distribution in terms of energy.

Gabor has shown[22], that the information in a light beam, in the Shannon sence and taking only photon noise into consideration is finite and invariant in every cross section of one light beam so long as no energy is lost. It is same in the object plane and in the Fourier /Fraunhoffer/ plane of a lens. It even remains the same putting a diffuser into the light beam /unless it diffuses some energy backwards/ and we can extract the information from it anywhere by holography.

8. REFERENCES

1. D. Gabor, "Theory of communication", J. Inst. Elec. Eng. 93 III. 429, 1946.
2. D. Gabor, "Acoustical quante and the theory of hearing". Nature 159, 591. 1947.
3. E. Zwicker, J. Acoust. Soc. Amer. 62, 675, 1977.
4. W.S. Gan, Proc INTER-NOISE'74, Washington Sept. 30. - October 2. o. 113-116.1974.
5. E.G. Williams, J.D. Maynard, and E. Skudrzyk, J. Acoust. Soc. Amer. 68, pp. 340-344. 1980.
6. J.D. Maynard, E.G. Williams, and Y. Lee, J. Acoust. Soc. Amer. 78, pp. 1395-1413, 1985.
7. M. Möser, "Holographie". Acustica, 61, pp. 288-300, 1986.
8. E.G. Williams, H.D. Dardy, J. Acoust. Soc. Amer. 81 /2/, pp. 389-407, 1987.
9. N. Bourbaki, Éléments de mathematiques, Masson, Paris, 1934.
10. M. Jessel, Acoustique Théorique Masson, Paris, 1973.
11. G. Resconi, M. Jessel, Int. J. General Systems, 12. pp. 159-182, 1986.
12. D. Gabor, in "Progress in Optics", Ed. E. Wolf, Vol. 1, pp. 111-153, 1961.
13. F.D. Waldhauer, Feedback, Wiley-Interscience, New-York, 1982.

14. W.A. Wickelgren, How to solve problems, Freeman Co, San Franc. 1974.

15. M. Jessel, Proc. INTERNOISE'88, Avignon Vol. 2. pp. 953-958, 1988.
A. Illényi, and M.Jessel, Proc. INTERNOISE'88, Avignon Vol.2. pp.963-966, 1988.

16. J. Blauert, Spatial Hearing - The Psychophysics of Human Sound Localization, MIT, Cambridge, 1983.

17. A. Illényi, Proc. 9th ICA, Madrid, report O3, Vol II. p 763, 1977.

18. A. Illényi, Proc. 8th Coll. on Acoust., Budapest, pp. 123-128, 1982.

19. K. Korozumi, and K. Ohgushi, J. Acoust. Soc. Amer., 74, pp. 1726-1733, 1983.

20. D. Gabor, "Wavefront Reconstruction" in Optical and Acoustical Holography Ed. E. Camatini pp. 15-22, 1948.

21. D. Gabor, "The Principle of Wavefront Reconstruction" in Optical and Acoustical Holography, Ed. E. Camatini pp. 9-14, 1948.

22. D. Gabor, "Information Theory in Holography" in Optical and Acoustical Holography Ed. E Camatini pp. 23-40, 1948.

23. A.F. Metherell, H.M.A. El-Sum, L. Larmore, Acoustical Holography Vol. 1. Plenum Press 1969.

Table 1.

HOLOCHORY	optional wave source to carry out information	first wave w_1	second wave w_2	synthetic field of w_1 and w_2 H	H + ref. wave R	sensor P
HOLOGRAPHY	light source	primer light wave	reference light wave	optical wave field	H + ref. wave	eye
ACOUSTICAL HOLOGRAPHY	/ultra/ sonic source	primer ac. wave	second.ac. wave	synthetic sound field	H + ref. light wave	eye
HOLOPHONY	sound-source/s/	acoustical primer wave	acoustical second wave	acoustical field wave	H + acoust. ref.wave	ear
MICROWAVE HOLOGRAPHY	microwave emitter	primer microwave	second microwave	EM field of microwaves	H + ref. microwave	decoder

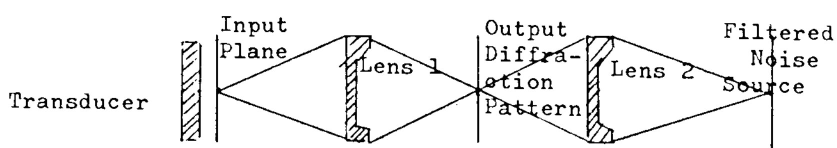


Fig. 1. Acoustical correlation filtering.

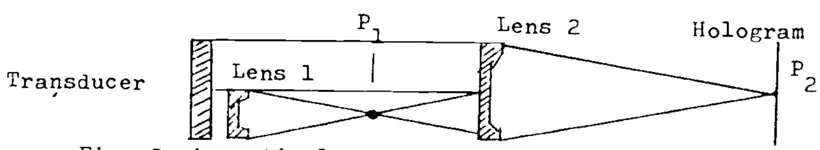


Fig. 2. Acoustical phase-only hologram recording of a complex filter.

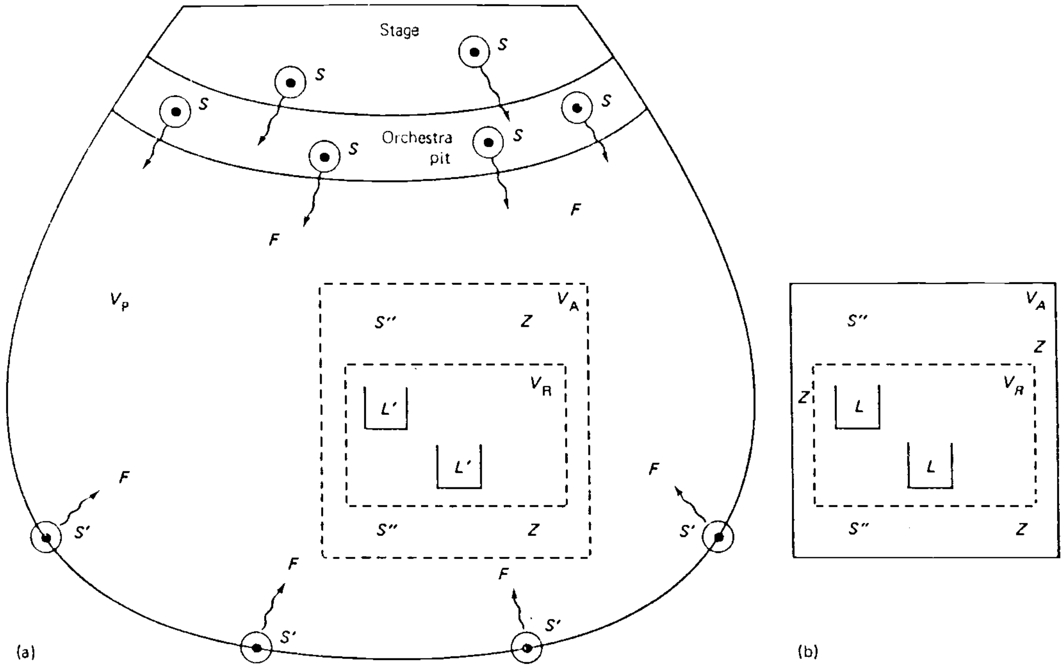
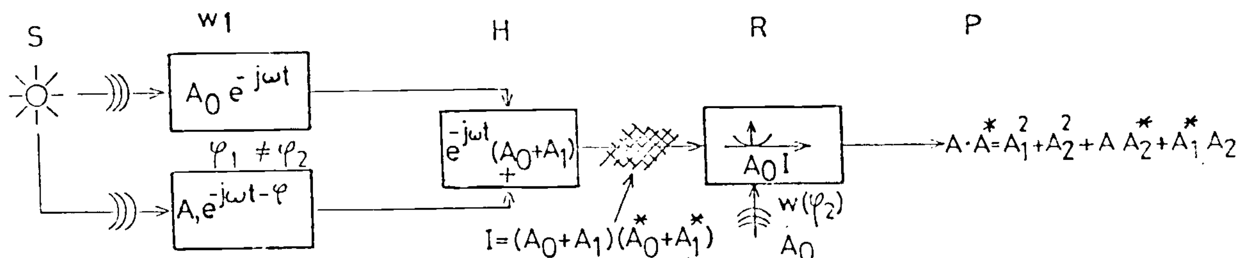
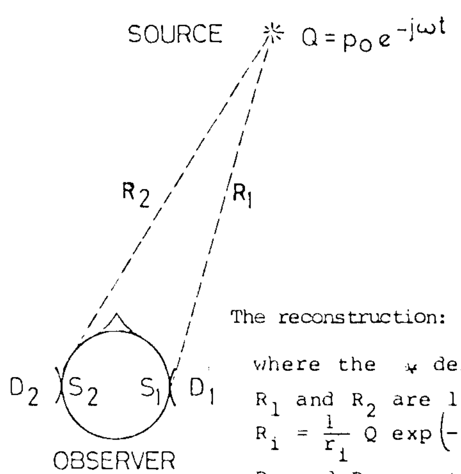


FIG. 3. Holophony principle: (a) sound projection area (V_P); (b) reproduction area (V_A).
S = True primary sources; S' = Auxiliary primary sources producing real or differed echoes; V_R = Precise volume of reproduction; Z = Area related to secondary reproduction sources S''; C = Acoustic field produced by sources S and S'.





$$S_1 = Q R_1 D_1 \quad (1)$$

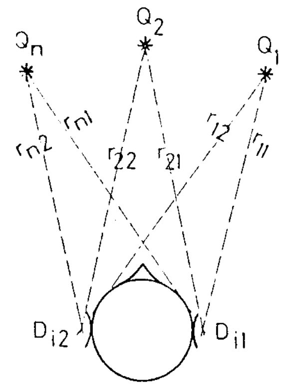
$$S_2 = Q R_2 D_2 \quad (2)$$

$$S = S_1 + S_2 \quad (3)$$

Fig. 4.

The reconstruction: $SS^* = S_1^2 + S_2^2 + S_1 S_2^* + S_1^* S_2$ (4)

where the $*$ denotes the complex conjugate,
R_1 and R_2 are linear operators of sound paths
$R_i = \frac{1}{r_i} Q \exp\left(-\frac{r_i}{c}\right)$; c denotes the sound velocity,
D_1 and D_2 are the operators of the diffraction around the ears, S_1 and S_2 are input ear operators.



in free field two sources

$$S_1 = Q_1 R_{11} D_{11} + Q_2 R_{21} D_{21} \quad (5)$$

$$S_2 = Q_1 R_{12} D_{12} + Q_2 R_{22} D_{22} \quad (6)$$

$$SS^* = S_1^2 + S_2^2 + S_1 S^* + S_1^* S_2$$

$$S_1 S_2^* + S_1^* S_2 = Q_1 Q_2^* (\ldots\ldots) +$$

$$+ Q_1^2 (R_{11}^* D_{11}^* R_{12} D_{12} + R_{11} D_{11} R_{12}^* D_{12}^*) + \quad (8)$$

$$+ Q_1^* Q_2 (\ldots\ldots) + Q_2^2 (R_{21}^* D_{21}^* R_{22} D_{22} + R_{22}^* D_{22}^* R_{21} D_{21})$$

Fig. 5.

n sources

$$S_1 = S_{11} + S_{21} + \ldots\ldots S_{n1} \text{ and } S_2 = S_{12} + S_{22} + \ldots S_{n2} \quad (9)$$

$$S \rightarrow S_1 S_2 + S_1 S_2 = \sum_{i=1}^{n} Q_i^2 (R_{i1} D_{i1} R_{i2}^* D_{i2}^* + R_{i1}^* D_{i1}^* R_{i2} D_{i2}) +$$

$$\sum_{i,k=1/i\neq k} Q_i Q_k^* (R_{i1} D_{i1} R_{k2}^* D_{k2}^* + R_{i2} D_{i2} R_{k1}^* D_{k1}^*) +$$

$$\sum_{i,k=1/i\neq k} Q_i^* Q_k (R_{i1}^* D_{i1}^* R_{k2} D_{k2} + R_{i2}^* D_{i2}^* R_{k1} D_{k1}) \quad (10)$$

n sources in diffuse room $S = S_1 + S_2$

$$\{Q_i^2\} \in (1,n)$$

$$\{Q_i \; Q_k^*\} \; \{Q_i^* \; Q_k\} \quad i, k, \in (1,n) \qquad i \neq k$$

$$S_1 S_2^* + S_1^* S_2 \longrightarrow Q_1^2 \{\ldots\ldots\} + \leftarrow \text{Source 1}$$

$$+ Q_2^2 \{\ldots\ldots\} + \leftarrow \text{Source 2}$$

$$+ Q_n^2 \{\ldots\ldots\} + \leftarrow \text{Source n}$$

$$+ Q_i Q_k^* \{\ldots\ldots\} \text{ propagation}$$

$n \rightarrow N$	$S \rightarrow Q^2$

$$+ Q_i^* Q_k \{\ldots\ldots\} \text{ room informations}$$