HOLOGRAPHY AND ITS APPLICATIONS TO THE GRAPHIC-ARTS INDUSTRY

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Light is a form of physics energy to which the human sight is sensitive when an interaction occurs between it and the substance.

Then this interaction is transmitted to the brain and, here, codified and integrated in the sight which supplies different information (from brightness and its following variations to color included in the human sight range and to the three-dimensionality of the examined substance).

This interaction involves either absorption or reflection of the energy light. In the absorption, the color property changes according to the light wave length. At molecular level, it can be registered an excitation of the molecula which absorbs all wave lengths except that, or those, which supply the real color sensation of the material.

Therefore, a red coloured material absorbs all wave lengths except the red one which supply, once reflected, that particular sensation--stimulus definable in that color which our brain translates into "red color" according to past experiences.

The absorption explanation can be carried out at atomic level too, by considering it as an energy introduction into the system which causes an increase of energy level.

Naturally, this increase can be carried out by an energy strong enough to excite the electron and to bring it to an upper energy level by causing an orbital change tending towards the atom nucleus.

Then, coming back at its original energy level the atom releases energy in the shape of that wave length which is not absorbed and

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corresponds to the color sensation-stimulus perceived from the hu man'sight.

According to the Bohr atomic model, the light absorption process involves that an electron is transported to an upper energy level, while the emission process occurs when an electron "falls" to a lo wer level. This energy jump "E", between the original level and the ending one is strictly bound to the emitted light frequency "V" through the relation:

$$E = h \cdot V \text{ (where "h" is the Planck constant equal to: } 6.626 \cdot 10^{-34} \text{ Js).}$$

In the case of wave lenghts which are contemporary emitted with the same intensity, it results the white light effect (sun, filament lamps etc.).

Moreover, it can be registered a difference among the incandescent and un-incandescent light sources.

The first one change color and brightness according to the variation of the energy supplied to the same source. For the un-incandescent sour ces color depends on chemical nature of the used material and is indepen dent from the supplied energy. That involves both sources need an adequa te energy supplying before emitting light energy.

As photography, holography is a registration method of different light intensities coming from an object. The registration occurs on a photo-sensitive material which reacts chemically to the energy light stimulation. It is necessary to consider that the information registration doesn't present particular problems, while the phase registration involves the carrying out of a relief image enough suitable to cause a variation on the optical path of a light beam.

The phase information is convertible into a width information by a reference beam and by carrying out the following registration of the interference between it and the wave front which contains information.

The light source used for holography must be "relatively coherent", for example like laser.

After the exposure of the object to the light, on the holographic photo-sensitive material, like on the photographic one, non visible effect appears. It is possible to observe the image only after the development, shortstopping and fixing processes.

At this point, the picture can be observed without any particular instrument except the presence of a light source. However, the registered information is bidimensional, while, in reality, the photographed object is three-dimensional: the depth features are created by our brain which integrates such lack according to the past experiences and instructions.

Besides supplying this three-dimensional effect, holography offers the possibility of registering the so called "parallax"; that phenomenon which occurs when an object is observed from different positions.

By using coherent light (laser)as light source of the object, every point of the holographic plate receives information from the whole subject; moreover, always by using laser, it is possible to register a drawing of the light wave reflected from the object, which is called "interference drawing" and contains all information of the subject light. These"drawings" are several and allow to preserve the parallax and the depth: therefore the three-dimensionality.

In order to carry out a hologram, it is necessary to divide the laser beam into two different beams: one lights up the object and is called "object beam" ("O.B."); the other is directed to the hologra_ phic plate and is called "reference beam" ("R.B."). Its function is to supply a comparison with the object beam.

After having covered the same distance, these two beams strike the holographic plate or film and cause the registration of an in terference drawing called hologram.

At this point, in order to make it visible, it is necessary to carry out the development, shortstopping and fixing operations;after them it is possible to observe it by using laser light (but not al ways laser is only necessary). This light has the same angle of the original reference beam.

The hologram divides the coming light into a perfect reproduction of the object beam one and appears with the same three-dimensional features of the reproduced object.

In the registration of the interference drawing (hologram) it is possible to obtain information about the intensity of the two co herent light beams (object beam and reference beam) and also about their phase connection which is preserved as integrating part of the interference drawing.

It is above said that the light for holographic reproductions must be "relatively coherent", therefore monochromatic and must be able to create interference.

In order to produce interference, it is necessary to have cohe rence, which is a feature of the laser monochromatic radiation.

Therefore, coherence means that the two wave lengths are in phase through space and time, have a simultaneous movement and a same direction.

According to the quantum theory, light is created by photons (or wave bunches) with energy values which are equal and in simulta neous movement through space and time.

In holography, the time coherence is generally measured according to the real length of the laser tube: i.e. it is equivalent to the laser coherence length.

There is a ratio which delimits the dimensions of the reproducing object according to the lengths of an un-interrupted and continuos series of coherent light waves emitted by a laser.

For example, if the coherence length of laser is less than the depth of the subject, the light, which lights it up, will be not completely coherent. That causes a "not-registration" of the image.

The space coherence refers to light waves which are in phase both to the movement direction and to any other direction perpendicular to the movement direction.

It must be added that when the two in phase light waves maintain a costant distance, it is fulfilled the lateral coherence which is based on the lateral equidistance.At the end, when light is defined spacially coherent, the "phase" features, time and space coherences, are fulfilled.

Laser is a light source which is both a monochromatic light source and spacially coherent. So it doesn't need "space holes" to fulfil such feature, since the generated light is punctiform.

Therefore, it can be said that laser light is the ideal light source for the holographic reproductions.

While in order to observe holograms this light is not always necessary, sometimes it is sufficient to use the common filament lamps.

It is above said that, among several features, to carry out holographic reproductions light must create interference.

But what does interference mean?

It can be simply said that interference means interaction (or also contact) between two or more monochromatic light waves which are produced by a constant emission source like laser.

In the very moment when two or more waves of the same laser interfere, in the space it is created an interference drawing which can be observed if it is intersected by a (bidimensional) plane like, for example, a screen. When this interference drawing is visible, it appears either with concentric alternatively clear and dark circles, or like bands which are always alternatively clear and dark and called "interference fringes".

The interference drawing is (incorrectly) called "static" because the interference fringes seem to be standstill or stationary at a precise point; this phenomenon can be explained because the human sight cannot register the single moving light vibrations.

In fact, the human sight is able to register intensity variations which occur during about one twentieth of a second (1/20 sec.).

Therefore, it cannot register interference fringes which vary 10^{10} times in a second.

This interference drawing is a visible sign of an infinitely small event: the interference of coherent light waves. According to the light undulatory theory, this interference is due to a change of the light general intensity which occurs when two (or more) light waves are superimposed one upon another.

For example, when two light waves, in phase one with the other, meet in the space, they originate another light wave equal to the sum of the width values of the two original light waves.

In the case of the addition of the widths (minimum with minimum and maximum with maximum), it is produced a light which has a greater width, i.e. with a greater light intensity than that produced by one wave.

This kind of interference is called "constructive interference" (superimposition of light waves like widths sum) and causes the clear fringes in the interference drawing.

In the other case, when two light waves are in phase opposition of 180° and interfere, it is produced a light wave with a smaller width which results always from the sum of the width values but with oppo sed polarity corresponding to a smaller light intensity.

This phenomenon is called "destructive interference" and produces the dark fringes in the interference drawing.

This two kind of interference (constructive and destructive) are independent from the construction or destruction of light. In fact, in the case of two light waves whichhave equal widths and are in pha se opposition of 180°, light is not destroyed but simply staggered towards another direction causing the phenomenon of darkness.

If light goes through a narrow and rectangular opening, it produ ces an interference drawing with alternatively clear and dark bands; if it goes through a circular opening (or stenopeic hole) it produ ces an interference drawing with alternatively clear and dark circles.

It is possible to explain the case relative to an interference drawing produced by light passing through a rectangular opening, if it is considered the diffracted light which comes from the opening and is composed by secondary wave fronts. These irradiate themselves in all directions and are emitted by secondary punctiform sources, lo calized in each point of the original diffracted wave front.

Since constructive and destructive interference occur, also among these secondary wave fronts an interference drawing with clear and dark fringes is produced.

The interference drawing by single opening is composed both by a relatively luminous fringe which is localized at the center and passes through the opening without causing diffraction and by relatively narrow clear and dark fringes which stay at the two sides of the central fringe.

These narrowest fringes correspond to the reciprocal interference of all secondary wave fronts.

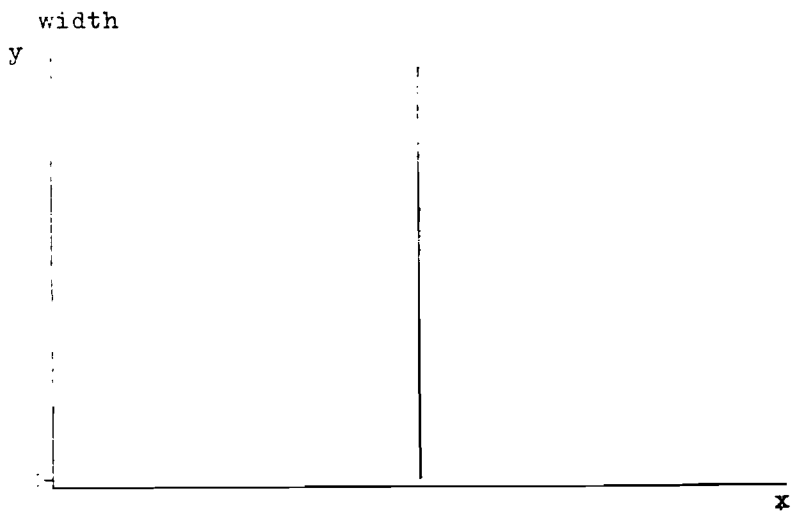
According to the Huygens principle, each point inside the slit can be considered as a secondary waves sources.

If the opening is divided into imaginary and small areas with equal width, it is possible to obtain the total light emitted from the slit towards a certain direction if it is summed the waves emit ted by the various areas towards that direction (principle of the wave superimposition).

Obviously, the sum of the secondary waves is complex by a mathe matical point of view, but it is possible to simplify if it is ima gined two among the several areas which divide the slit: one just under the middle point "M" and the other at the end and called "A".

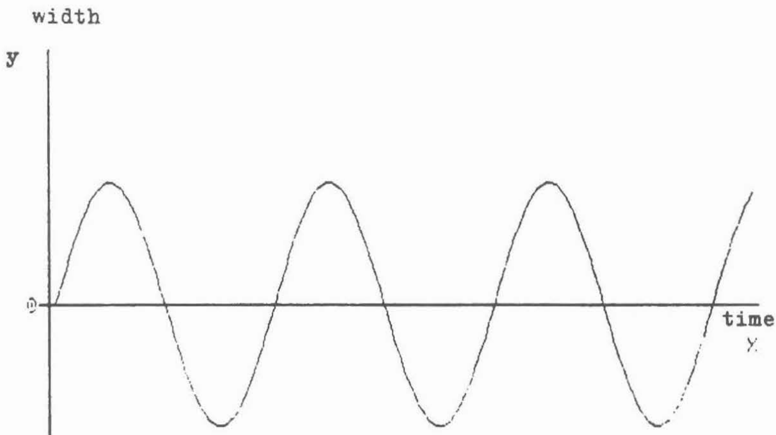
It is registered destructive interference when the optical path difference between the secondary waves coming from "A" and "M" is equal to $\lambda/2$; $3\lambda/2$; $5\lambda/2$; etc..

TIME COHERENCE



Frequency and λ are costant regarding to width

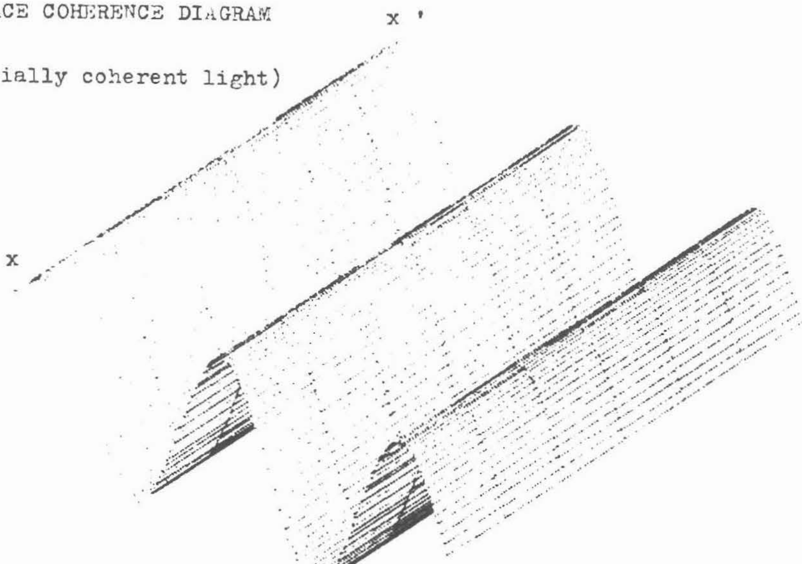
SPACE COHERENCE



Width changes as synusoidal wave relating to time (light which vibrates and oscillates contimuously as synusoidal wave)

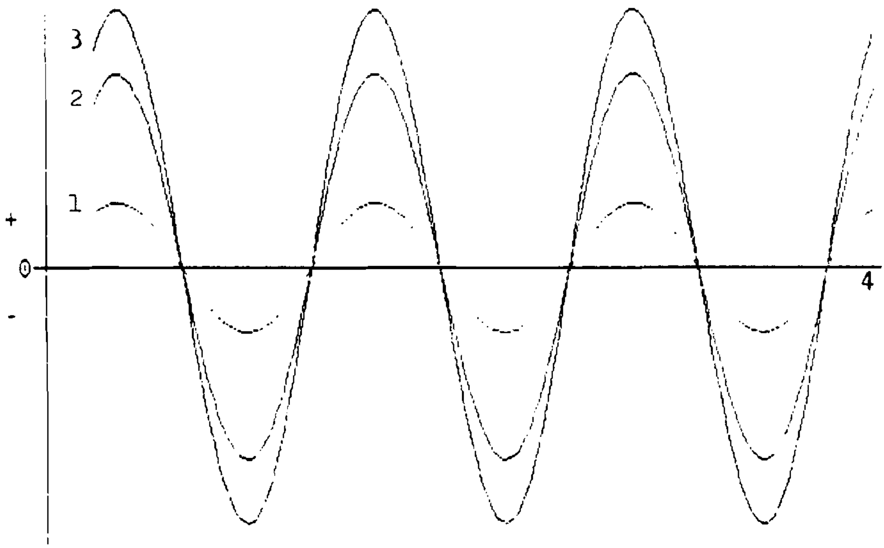
SPACE COHERENCE DIAGRAM

(spatially coherent light)



x - x' = Lateral coherence (based on lateral equidistance)

CONSTRUCTIVE INTERFERENCE DIAGRAM



1) = wave n°1

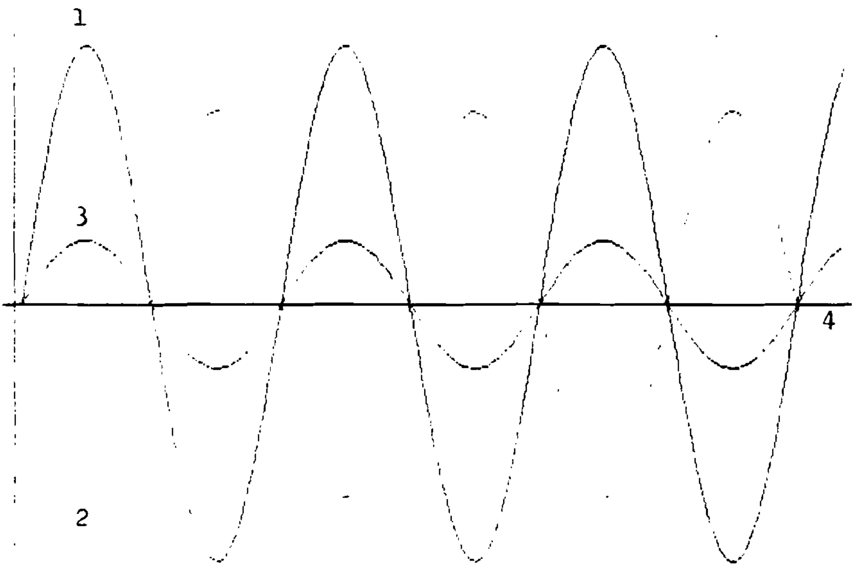
2) = wave n°2

3) = wave resulting from the widths sum of 1) and 2)

4) = direction of light movement

The wave resulting from the widths sum of 1) and 2) has an "increased" width.

DESCRUCTIVE INTERFERENCE DIAGRAM



1) = wave n°1

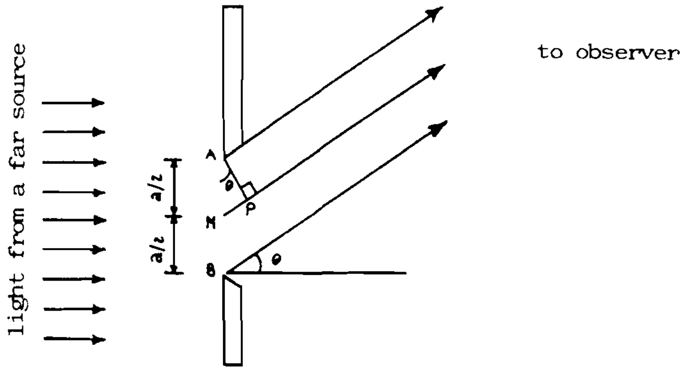
2) = wave n°2

3) = wave resulting from the widths sum of 1) and 2)

4) = direction of light movement

The wave resulting from the widths sum of 1) and 2) has a "decrease" width.

The optical path difference is equal to: 1/2 a sin θ, where "a" is the slit width.



For the light coming from "A" and "M", the first angle where destructive interference occurs, is represented by the ratio:
$1/2 \; a \sin \theta = \lambda/2$.

Also the light coming from the lower areas "A" and "M" has the same path difference.The same phenomenon is registered for all couples of areas which are equidistant between them by a half-opening. The above proposed equation represents also a general condition for the first destructive interference and, since the θ angle is often so small that it can be mistaked for sin O, it can be written as: $\theta = \lambda/a$.

The condition to fulfil the destructive interference (therefore the null width) is given to the ratio: $\theta N = (2N - 1)\lambda/a$.

This ratio provides the position of the width minima. Therefore, when a light beam passes through a slit or a circular opening, light is diffracted by the same opening, i.e. it undergoes a deviation from its straight line path in all directions.

It can be realized that this phenomenon has important consequences.

Looking out from a window, it can be registered a real image of the objects beyond it, since the light wave lenght is smaller than the dimensions of the window. So, according to the ratio $\theta = \lambda/a$, which refers to the first angle with destructive interference, almost the whole light intensity is transmitted with straight line.

When light enters into the human eye pupil, the diffraction of the light beam is negligible, because the pupil diameter , equal to 2.10^{-3}m., is greater than the light wave length which oscillates from 4.10^{-7}m. to 7.10^{-7}m..

This implies that in the normal vision, diffraction doesn't cause difficulties and the resolution limit of the human eye, i.e. the smaller distance between two objects to be distinctly perceived, is controlled by the distance among the light sensitive cells on the retina and not by the dimension of the pupil.

But in the case of operations by spy-satellites of different or adverse countries, it must be considered the smallest dimensions of the object which must be observed and it is necessary to remember that a part of the light, which strikes the object and is, therefore, reflected, is diffracted during its crossing through the circular lens of the objective telecamera causing diffraction fringes.

The light,coming from another object point, produces diffraction fringes too, which don't cause superimposition if they have a very little width according to their reciprocal separation distance.

For these reasons a neat image of the object is obtained. But if also a minimum superimposition occurs, the image is vague.

According to the Rayleigh principle, it can be said that two parts of an object are resolved if the first maximum of the diffraction fringes of the one is in correspondence to the first minimum of the fringes of the other (with a maximum angle separation equal to $\theta' = 1.22\lambda/a'$).

For example, it has been calculated that a lens with a 7.5 cm. diameter assembled on a satellite telecamera objective distant km. 320 from the earth, has the maximum resolvable distance at 3 m. with a light of λ = 550 nm..

This is very important if it is considered the high surveillance degree among opposed and/or adverse countries and in fact it has in fluenced very much dialogues originated by the SALT treaties.

This is the calculus in order to determine the minimum resolution quantity:

$\theta' = 1.22 \cdot 5.5 \cdot 10^{-7} / 7.5 \cdot 10^{-2}$ (radiants) =

$\theta' = 9 \cdot 10^{-6}$ radiants

$9 \cdot 10^{-6} \cdot 320 \cdot 10^{3}$ m. =

= ca. 3 m.

If the lens is redoubled, the minimum resolution quantity is re duced to a half (lens with $\varnothing$ = 15 cm. --→ 1.5).

If the opening, through wich the light goes, is formed by several and multiple paraller slits withan equal distance and length, it is called "diffraction reticle". The obtained diffraction drawing is formed by a great number of narrower interference fringes which beco me narrower and narrower to the proportional increase of the slits, appearing neater and narrower until they don't appear as fringes but as microscopic narrow lines.

The diffraction reticles are (normally) obtained by engraving the surface either of glass or of a specular metal or of an evaporated aluminium layer with proper machines.

These grooves, so obtained, are tens of thousands in a centimeter.

In the case of grooves engraved on glass, it obtains a transmission reticle, because light is transmitted through the ungrooved glass.

In the case of grooves engraved on aluminium, light, which arrives on the ungrooved surface, is reflected in the direction of the coming light and is called reflection reticle.

In the case of a concave or spherical aluminium surface, it is obtained a concave reticle and it can be used to compare different light wave length and also to diffract UV frequencies.

In the holographic process, the interference picture is formed not only on the emulsion surface but through the whole thickness.

Holograms diffract light too and, therefore, they can be considered as diffraction reticles. In fact, diffraction occurs through the emulsion thickness in which silver, fouled down at the developing moment, acts as a mirror reflecting and/or refracting light.

The lighting angle which is necessary to reconstruct the "O.B." provided with the intensity (or brightness) as great as possible, must be equal to the incidence angle of the "R.B.".

This involves an obvious but fundamental principle, i.e. in the presence of an emulsion with an unnegligible thickness, a hologram must be lighted up during both registration and reconstruction operations. The emulsion thickness affects its behaviour, because it can produce either tipical effects of the superficial diffraction reticle in the case of a "thin" thickness or three-dimensionality effects in the case of a "high" thickness.

The terms "thin" and "high" must be codified and quantified and can be defined in such a way if they correspond to the following features:

a) "thin" = $S<2y$; i.e. with the thickness "S" smaller than the smallest "2y" periodicity of the reflecting silver planes

b) "high" = $S>y$; i.e. with the thickness "S" greater than the distance "y" among the silver planes.

The middle planes product three-dimansionality effects too, but they are not easily perceived, so they are not examined.

If the silver planes are set more or less perpendicular to the length of the holographic plate, a registration of the coming light is transmitted through the hologram.

This kind of hologram is called "transmission hologram", because it diffracts light by transmission. If the hologram diffracts light by reflection, it is called "reflection hologram". This occurs when the planes of the fouled silver grains are parallel to the plane of the holographic plate and correspond to the planes of the interferen ce fringes; therefore they reflect back (i.e. the reproduction is vi sible by reflection).

Light which "goes into" a hologram (or diffraction reticle) is diffracted according to the Bragg equation (or equation for the reti cle):

$$2\theta = \frac{\lambda}{d};$$

where: 2θ = the angle between the on coming light (or incident light)and the outcoming light (or diffracted light);

λ = wave length of the incident light;

d = length of each interference fringe (i.e. distance among the interference fringes).

If the wave length of light and the angle between the "R.B." and the "O.B." are known, it is possible to calculate both the distance (or space) among the interference fringes and the angle to which the hologram diffracts the light in the best way.

It is necessary to remember that these calcula of distances, spaces and angles are expressed in nanometers (the emulsion mea sures from 6 to 15 nm. and the silver bromide - AgBr - grains of these holographic emulsions with highst resolution are less than a 1/10 of nanometer).

In the holographic plates (or films) the light fringes are registered when the very thick AgBr grains are submitted to a laser light exposure which interferes constructively; the latent image is formed by the interaction of light with the electrons present in the AgBr. By exposure to the laser light and the following development, the AgBr cristalls of the latent image are transformed into silver grains which form the visible image.

Holography is based on electromagnetic radiations, the light waves, correspondent with the optical (or visible) frequencies, which are modulated and demodulated .

The modulation is intended as superimposition of different widths, frequencies and, therefore, as a phase information on a vector which is an invariable and stable kind of wave and can be represented by a sinusoidal wave of alternating current.

The demodulation consists of the decoding of the information superimposed to the vector.

Therefore, in holography the vector function is carried out by the hologram and is modulated by phase and width information which form the holographic image.

In order to have a good result, the holographic reproductions need the respect of some features.

Aboveall, it is necessary to select the place for the holographic laboratory. It must be isolated and far from vibrations caused by noises, by any kind of mechanical movement and by heat that could cause the un-registration of the interference fringes drawing.

In fact, even a small vibration produces a movement of the fringes and the following un-registration of the hologram: it is necessary to have a tollerance stability at least equal to 1/4 of wave length. All this involves that besides foundations and walls, also all holographic components need stability.

For this reason, it is essential to have an aseismatic table, built in such a way to minimize all vibrations.

Then, this apparatus must be proved by an interferometric test which controlls the interference between a punctiform source of the object light and a punctiform source of the reference light.

The beams form the superimposed reference drawing which create a single area (called of Fresnel) of concentric alternatively clear and dark circles.

A minimum vibration (greater than 1/4 of the tollerance wave length) causes the shifting of the clear fringes in the dark fringes area and, consequentely, of the dark fringes in the clear fringes area. This doesn't allow the registration of the hologram.

Another feature is represented by the measurement and proof of the space and time coherence which is considered as coherence length of laser.

In the end, it is necessary to measure the intensity of the "O.B." and of the "R.B.", because from this relation (or light relation) it is possible to draw the exposure time.

These two point must be considered unitedly; usually it is adopted such a technics which causes the separation of the laser beam in two different beams with precise and different optical path.

In fact, if it is used a laser with a un-single frequency, it must be considered that the difference between the two paths must be less than the coherence length of laser.

Normally, these optical paths are measured in such a way as the final difference is null or measures only some centimeters.

A single frequency laser with a tube 1 m. long has a coherence 1 km.long; while a helium-neon laser (always with a tube 1 m.long) has a coherence length of 1 m..

Therefore, it is argued that by using a single frequency laser it is not necessary to measure the two beams, because objects with great dimensions can be reproduced too.

On the contrary, by using an un-single frequency laser, it can be joined to a reflecting cavity, called "etalon" which is formed by half-reflecting surfaces by glass or quartz.

These are parallel among themselves and "filter" the laser beam (which swings longitudinally with various "modes"); so the laser beam which comes out from the etalon can be considered as a single frequency laser.

When the two beams, obtained from the separation of the laser beam, interferes on the holographic plate, the intensity of each beam must be measured to determine the exposure time.

It is previously said that this relation is called "light relation" and it changes also according to the kind of hologram which must be obtained.

In the case of a reflection hologram, the relation between the "O.B." and the "R.B." must be from 1:1 to 3:1; for a transmission hologram from 2:1 to 10:1.

The "R.B." is brighter than the "O.B.", because the first has the function to "bring" light, while the second has the information relative the object and must modulate the first one.

APPLICATIONS AND MATERIALS

In the holographic technics it has an information registration for each point distributec on the whole hologram.

This has an important advantage, i.e. in case of loss of a part, the reconstruction of the whole image is not compromised but it is registered only a reduction of the relation signal - noise.

This occurs because the data contained in the hologram have the feature to be, among the other things, redundant and self-protected.

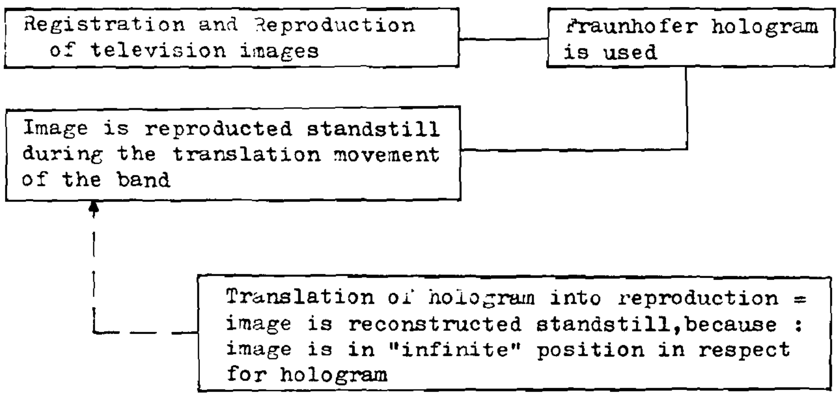
This is a very important feature in relation to the possible applications at the communication field and information storage system.

Also for the graphic arts field it is very interesting the possible information storage carried out by optical memories which offer a quick access and a wide capacity for data processing.

Such a system will have a great advantage, because the registered and stored data are not lost, even if negative exterior factors as scratches or dust occur.

" SELECTA VISION - R.C.A. "

SYSTEM



On the contrary, these factors caused the deterioration of data when the where stored by photographic technics with binary data on microfilms according to a matrix plot.

Moreover, holograms offer the possibility of a high storage density.

This can be very useful; in fact, to store television signals, a huge quantity of material is needed if the common magnetic method is used.

By applying the holographic Fourier transform, it is possible to cary out operations for recognition systems, for example, of type and finger-prints.

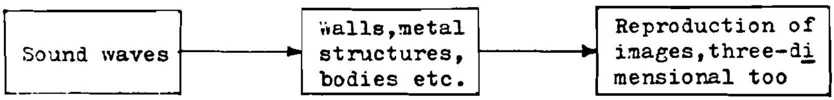
Or it is possible to register images also at presence of aberrations regarding to either the surrounding medium, or the optical system.

That can be carried out if both beams ("O.B." and "R.B.") are allowed to pass through the aberration source (or medium).

In fact the Fourier hologram is neither damaged nor influenced by these aberration media.

Precise studies are realized to obtain holograms from sound (or acustic) waves.

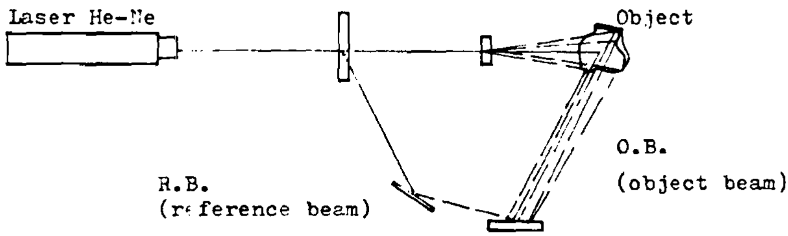
The reading is carried out by luminous sources and gives an optically visible image as result.



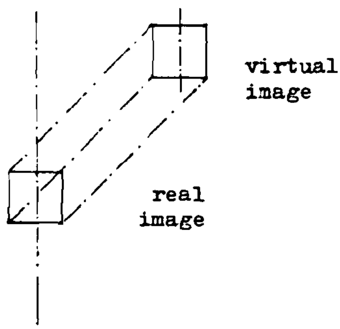
Use : - Not-destructive analysis of materials;
- Underwater explorations;
- Underground explorations;
- Identification of vibrations and strains of various structures and mechanical members

" Displaced Reflection Hologram "

(Secret kind of radar studied by Leith and Upatnieks)



"R.B." is inclined respect to "O.B."



For years, several organisations both industrial and not directly linked to a precise industrial activity have been studying the reconstruction of images, which come from sound waves.

In fact, it is sufficient to consider the studies realized on sonar equipment which were able to furnish only a bidimensional image of specific objects submitted to "control" or research.

Also radars are interested by holographic applications, because usually they furnish a bidimensional image.

On the contrary, by the acoustic (or also microwave) holography, which preserves intensity and phase information, three-dimensional images are obtained.

By using a data processor is possible to calculate and then create holograms of unreal objects.

So it is possible to observe the three-dimensional images of these objects which are unreal or exist only partially.

This application of holography to computer is very interesting for the graphic arts.

With a good program, this system can help planners and/or designers, because it allows to carry out three-dimensional drawings or "reproductions" of models, equipments etc., without constructing them.

Always in the research field of possible applications to the graphic arts, it has been carrying out experiments and tests to reproduce a hologram without using photo-sensitive materials with high resolution.

In order to be more precise, we are talking about a reproduction of a hologram, which is already an accurate three-dimensional reproduction of an object.

This reproduction is intended for graphic field and, particularly, for print which, nevertheles, must not be considered with the common terms given by the graphic technology.

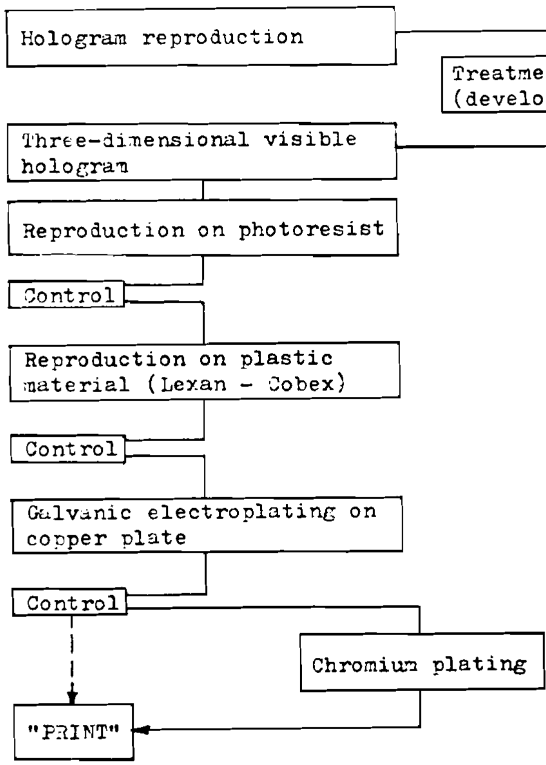
Unfortunately, it is not possible to speak in detail about these processes which could interest the print of particular security systems for paper-money.

It can be only said that we have suceeded in obtaining an accurate reproduction of a hologram on a plastic stand not photographically sensitive which maintains all features of three-dimensionality, parallax and polychromy.

Successive applications with particular artifices have produced good results; in fact we have succeeded in reproducing a hologram reproduction on a special stand, always maintaining the proper features of three-dimensional, polychrome reproduction.

These steps are graphically visible in the following diagram.

It is clear that from the reproduction on plastic material it is possible to obtain so many successive reproductions as needed.



We are studying the application to print and it must start from obtaining so precise reproductions on plastic material as to satisfy the features of security systems for paper-money and currency.

The problem of material for holographic (aboveall three-dimensional) applications is very important, because emulsions with a high resolution power are needed.

In order to obtain such features, it has registered some disavantages like, for example, the low sensibility of the same emulsion. For this reason, it is necessary long exposure times, calculated on the basis of the relation (called light-relation) between the intensity of the "R.B." and the "O.B." one.

Obviously, long exposure times need a very good stability of a holographic circuit to avoid any vibrations.

Both to-day holographic plates and films are able to furnish very precise three-dimensional results with the emulsion thickness.

It has been studying new kind of materials which can be used, then "erased" and utilized again.

For this reasons, it has been studying substances composed by ferro-electrical crystalls, liquid crystalls, etc., but without obtaining good results.