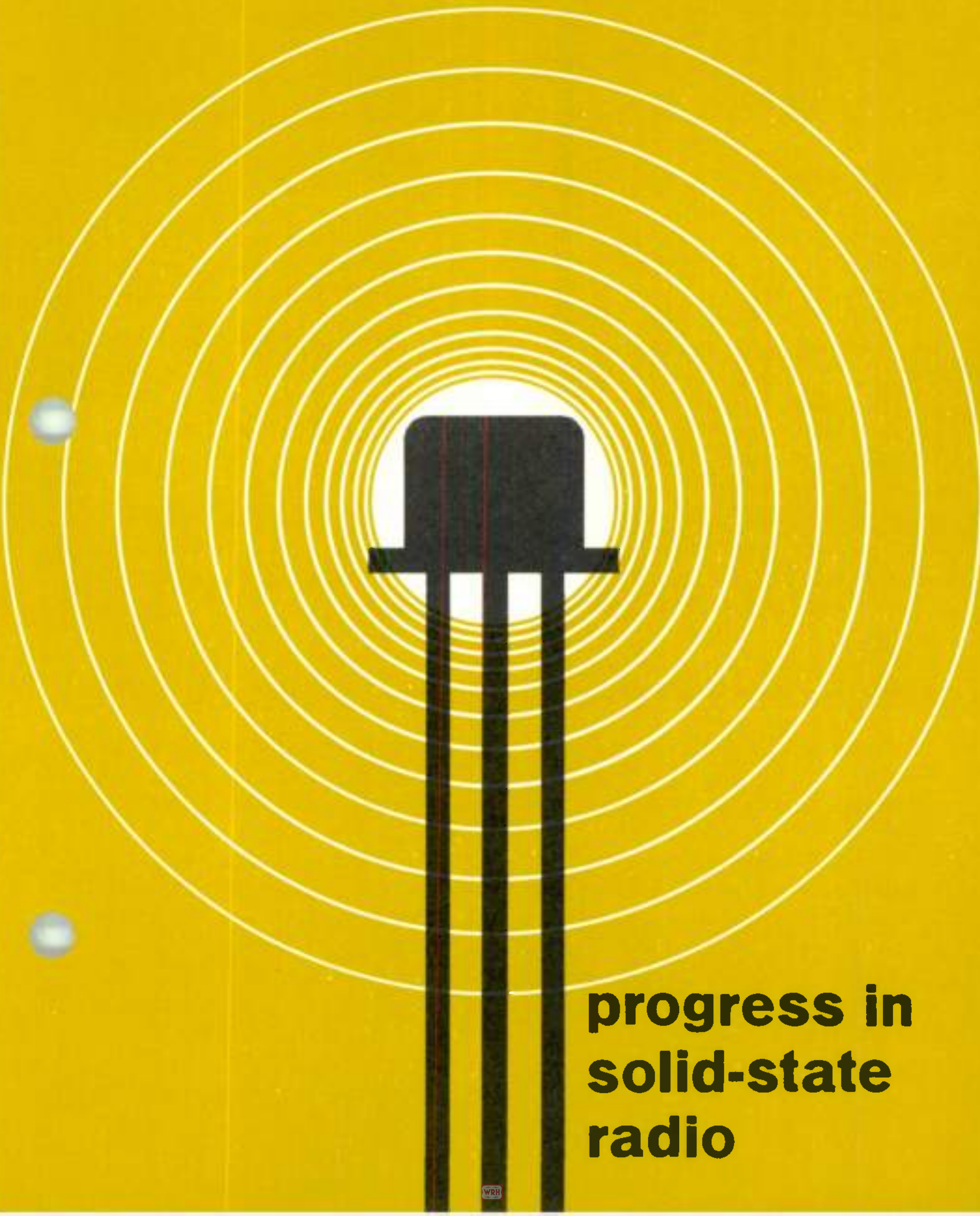
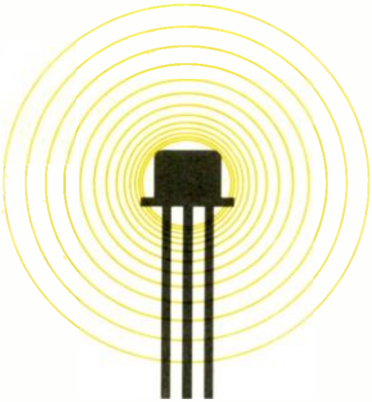
The Lenkurt DEMODULATOR

APRIL 1970



progress in solid-state radio



"Progress begins by getting a clear view of the obstacles."

Whenever there is a technological breakthrough, there is an automatic demand for "things" incorporating this new concept. Before design changes are made, however, it is mandatory to examine the present system closely to see what weaknesses exist and to determine what new problems might be created by incorporating this new development.

Unless careful thought and planning precede design changes, these changes can lead to a technological standstill —or even a regression— rather than a step forward.

More than a decade ago, semiconductors made their debut in the electronics world. Ever since that time, the demand for "solid-state everything" has become a way of life.

Microwave radio systems have not escaped the challenge to change to solid-state. Although, examining the obstacles involved, progress has not been as rapid as some expected.

Progress, as it concerns an all solid-state microwave radio system, must improve at least one of these areas —reliability, efficiency, noise performance, channel capacity, maintenance, or cost. If none of these areas are improved, the change is simply *that* —a change— and not progress.

To understand the progress of solid-state radio, it is necessary to get a clear view of the obstacles involved with microwave transmission —principally, generating a high power signal.

Microwave Repeaters

The baseband or remodulating type repeater shown in Figure 1 illustrates how the modulated carrier is received and demodulated and then remodulated into a transmittable electromagnetic wave. For comparison, a heterodyne repeater is shown in Figure 2. The heterodyne repeater amplifies the signal, without demodulating.

The received modulated carrier must be amplified, because it has a low power level. It is easier, however, to amplify a low frequency signal. So before amplification, it is desirable to lower the frequency of the received signal. This is done by mixing the received modulated carrier with a signal from a local oscillator (L.O.). The L.O. produces a fixed frequency signal equal to the carrier frequency plus or minus an intermediate frequency (IF).

The mixer takes the sum or difference of the received modulated carrier and the L.O. signal. Since a lower frequency signal is desired, the mixer output is the difference of the two signals —resulting in a modulated IF signal. A mixer used in this configuration is a down converter.

This IF signal is then amplified. At this point in the heterodyne repeater, the signal is converted back to a higher frequency, in an up converter. The signal is amplified once again and is ready for transmission.

Once amplified in the baseband repeater, the signal is fed to a discriminator which changes the frequency variations into a varying voltage. The discriminator is the demodulator; therefore, this varying voltage represents the baseband signal (the original signal before it modulated the carrier frequency to form the transmitted radio signal).

This baseband signal is used as the input to the transmitter where the varying voltage is modulated again to form a frequency varying carrier. This modulated carrier has the proper frequency and power for subsequent radiation.

A desired output power of at least one watt has been established as a nominal level for baseband repeater systems. This output power has been a major obstacle in designing an all solid-state microwave radio system.

First Attempts

Microwave radios began to change from vacuum tubes to solid-state designs, in the early 1960's. Total solid-state construction involves more than simply adapting semiconductor components and microwave design principles to meet existing industry standards for stability, noise performance,

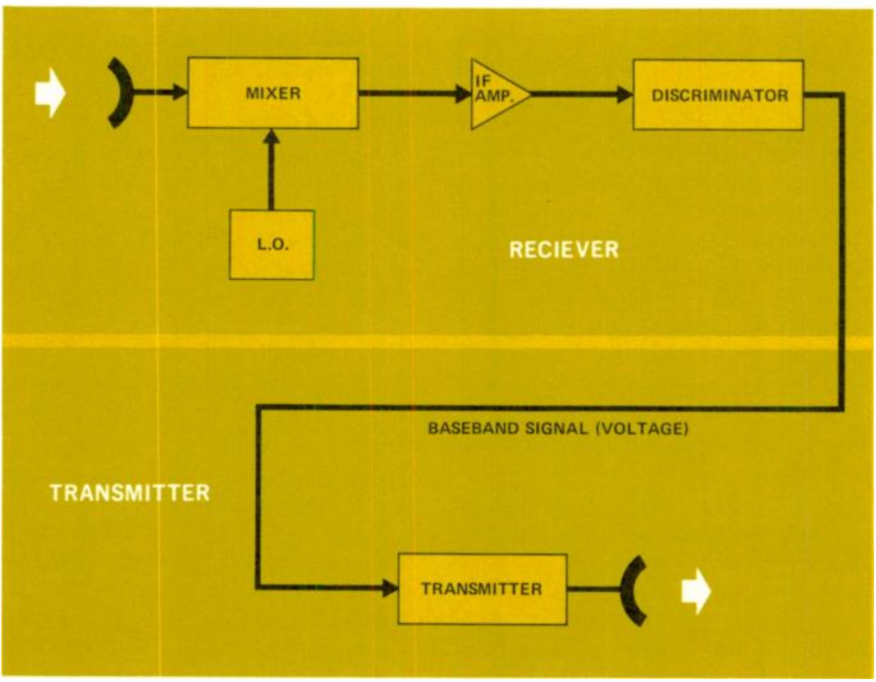


Figure 1. A microwave radio baseband or remodulating repeater is a receiver and transmitter in series.

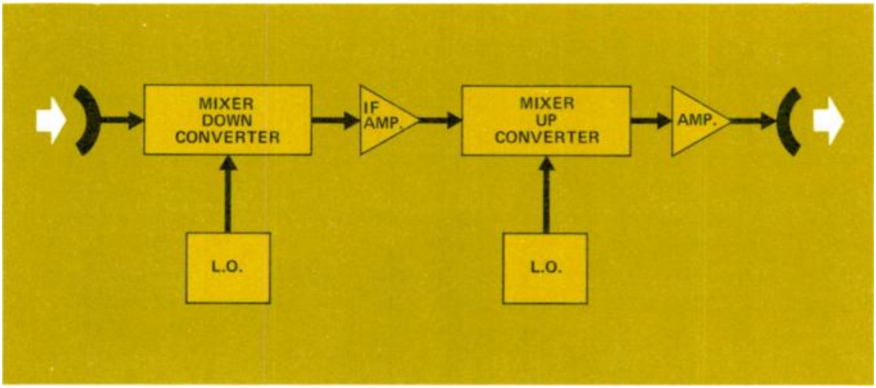


Figure 2. In a heterodyne repeater, the signal is amplified without being demodulated and remodulated.

bandwidth, and power. Cost, space, and reliability considerations are just as important.

The baseband receiver and transmitter both had a vacuum tube holdout—the klystron tube. In the receiver, the klystron tube was used as the local oscillator, and the transmitter was a klystron tube preceded by a modulation amplifier. A klystron tube simply takes a voltage input and produces a frequency output.

A solid-state replacement for the klystron would eliminate the need for a stable, high voltage power supply required for klystron operation. Solid-state devices do not need high voltages. It was expected that solid-state oscillators would also increase reliability making frequent field replacement of tubes unnecessary.

The local oscillator has one design requirement—low noise at low power. The transmitter design, on the other hand, has three such requirements—high power, low noise, and stable frequency output. The tighter specifications for the transmitter design makes it necessary to permit a higher noise level in the transmitter oscillator.

A solid-state oscillator was more readily designed to replace the L.O. klystron because of its lower power requirement. Consequently, a solid-state replacement for the transmitter klystron tube was an obstacle in the progress of all solid-state radio.

All Solid-State

Since solid-state devices generate high power signals more readily at lower frequencies, an all solid-state microwave radio in the 2 GHz frequency band, rather than 6 GHz or even higher, was easier to achieve.

Lenkurt's 2 GHz all solid-state radio system, which provides up to 300 voice frequency channels, is shown in Figure 3. In this system a nominal power output of 2 watts is obtained by using high power varactor diodes in the multiplication stage.

As well as improved reliability with a 2 watt output, the all solid-state design offers many advantages. Replacing vacuum tubes with solid-state devices has the added benefits of longer life, reduced power consumption, and smaller systems in modular designs for simplified maintenance.

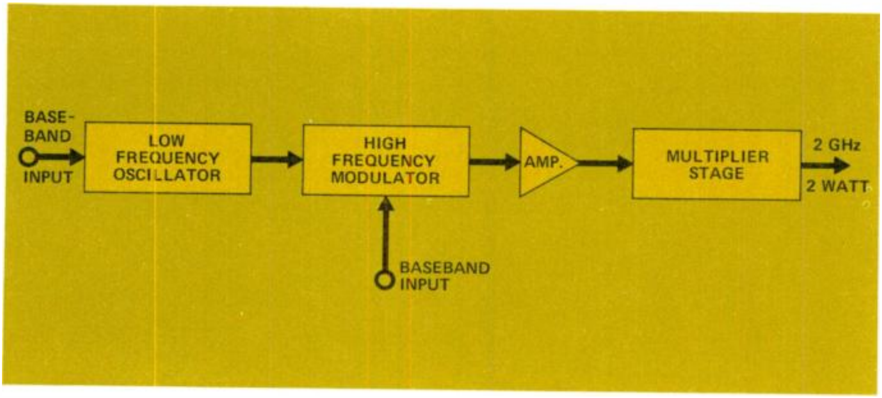


Figure 3. Lenkurt's 2 GHz radio transmitter was among the first on the market in that frequency band.

An operative all solid-state transmitter was a great challenge. Designers, working with state of the art components, persisted in their efforts to meet this challenge.

A marketable, all solid-state, 6 GHz microwave radio system was first produced, in 1962, by R.C.A. This system uses a crystal oscillator and has a capacity of 300 voice channels with an output power of about 1/2 watt.

The system shown in Figure 4 uses a crystal oscillator for generating a carrier frequency which is then amplified. Subsequent multiplication is accomplished by a varactor-diode multiplier chain, producing the desired carrier frequency at a reduced power level.

The transmission signal (the baseband signal) is used as the input to an FM oscillator (FMO). The FMO, in turn, converts the signal voltage to a varying frequency. The multiplied carrier frequency and the output of the FMO are up converted through a mixer, the output of which is the sum of the two frequencies. This output is also the desired modulated carrier frequency. One disadvantage of this system is that power is lost in the up conversion.

The first obvious improvement desired in the crystal oscillator transmitter was an increase in the system's output power since it is directly related to the channel capacity. Another needed improvement was the lowering of the necessary multiplication factor, since noise is closely related to the frequency multiplication.

As transistors are improved for microwave application, it becomes possible to replace the crystal oscillators with transistor oscillators which could offer higher frequency outputs; therefore, a lower multiplication factor, to reach 6 GHz. It might also be possible to improve solid-state transmitters to provide a power output of one watt.

Transistors pose severe challenges to circuit designers; their problems are not worse than electron tubes but they are quite different. The problems associated with klystron circuits are all very familiar, and can be approached, therefore, with known alternatives. This is not the case when working with transistors in the microwave range.

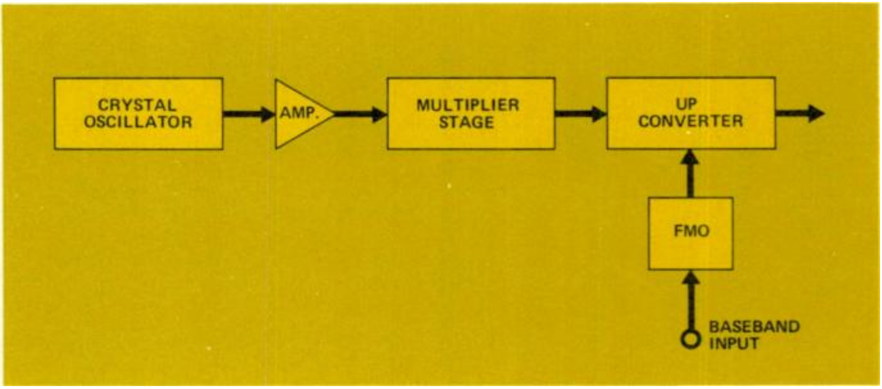


Figure 4. Crystal oscillators were the first solid-state replacements for the transmitter klystron.

These transistors are so new that the problems associated with them are not necessarily all understood. The preferred solutions to even the known problems have not yet all been found. Because of the newness of these transistors, it is necessary to follow design principles conservatively in order to guarantee a sufficient degree of system reliability. It is possible that present transistor designs will prove capable of meeting higher specifications than are now guaranteed.

Transistor Oscillator

Transistor oscillators used in the present 6 GHz, all solid-state transmitters have a higher frequency output than the crystal oscillators first used. This higher frequency requires a lower multiplication factor to obtain the desired carrier frequency.

Transmitters using transistor oscillators have an automatic frequency control (AFC) device to insure that the output frequency is 6 GHz. In these solid-state transmitters, the baseband signal is used as the input to the transistor oscillator rather than being mixed with the carrier frequency

Lenkurt's new 6 GHz microwave radio offers improved, low noise performance. This all solid-state radio has a one watt output and a channel capacity of 1200 channels –large enough for transmission of two video signals, as well as voice and data. The low per channel deviation of this system makes it possible to provide 600 channels in the industrial band.

The "heart" of the transmitter is the FMO as shown in Figure 5. This unit provides a modulated microwave signal output at one-fourth the desired operating frequency. A crystal referenced AFC device provides precise frequency stability.

After modulation, the signal is fed through an amplifier. With a new power level of 6 to 8 watts, the modulated carrier goes through two frequency doublers. The output is a frequency modulated signal at one watt and a carrier frequency of 6 GHz –ready for transmision.

The one watt output insures a high enough signal-to-noise ratio for Lenkurt's large channel capacity. The thermal noise amplification introduced by the frequency multiplication is dir-

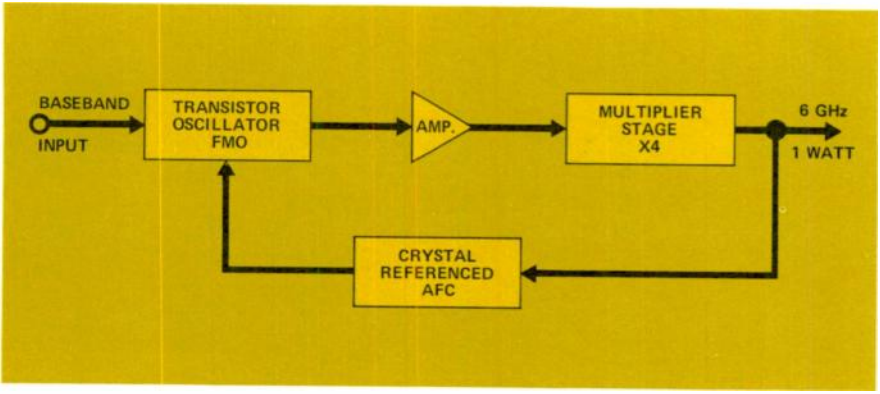


Figure 5. Lenkurt's 6 GHz solid-state microwave radio system uses two frequency doublers in the transmitter.

ectly related to the multiplication factor. Since the oscillator is by far the major source of transmitter thermal noise, this low multiplication factor minimizes output noise.

Ideal Transmitter

The ideal solid-state transmitter would have a baseband input to a single "black box" whose output is a one watt, or greater, 6 GHz signal —without any need for power amplifiers or frequency multipliers.

At this point, high power output transistors have uncertain life expectancies. But, it is possible that such a transistor or even a new type semiconductor device may become available in the future. When these devices are developed, it could be several years before a new system could be in production.

There are two devices presently available that may, eventually contribute to the design of an ideal solid-state transmitter. The avalanche diode might be used in place of the transistor oscillator to produce a 6 GHz signal at almost one watt.

The unsolved problems with the avalanche oscillator are that it is noisy and difficult to simultaneously stablize and frequency modulate.

The Gunn diode has also been considered as an oscillator. It is much quieter than the avalanche diode at 6 GHz, but its present maximum power output at this frequency is only about 100 milliwatts. The same stabilization problems exist as for the avalanche diode.

Still another possibility is to use the Gunn diode as the oscillator, since it is quiet, and the avalanche diode in a power amplifier configuration. However, at present, neither the power nor frequency of the avalanche amplifier are sufficient for a solid-state transmitter. Despite these obstacles, the avalanche/Gunn combination appears to be the most promising next step in solid-state transmitter design.

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FEBRUARY 1970

DEMODULATOR

HOLOGRAPHY

Holography, from the Greek root *holos* meaning whole, is a picture making process that captures the three-dimensional aspects of an object, rather than the flat, fixed-viewpoint of conventional photography.

In holography, three-dimensional images are formed from two-dimensional photographic negatives. In the recording process, a coherent wave source is split into two parts (Figure 1). Half the source (reference wave) strikes the holographic plate directly. The other half (object wave) illuminates the object to be recorded. Each point on the object reflects light onto the holographic plate. Having traveled different paths, the two waves are no longer in phase, and therefore reinforce or cancel each other as they converge on the holographic plate – producing an interference pattern (Figure 2). There is a unique interference pattern recorded over the entire holographic plate, for each point on the object.

Laser light is the most commonly used coherent source, but illumination may also be accomplished with electron waves, X-rays, microwaves, and acoustic waves.

Once the holographic plate has been exposed and processed, it is capable of reconstructing the original three-dimensional object. Reconstruction is accomplished by illuminating the hologram with the same frequency reference wave used for recording. Since the hologram records all the information that the object wave contains, the reconstructed image will display this information – the size and shape of the object; the brightness of every point on the object; and the position of the object in space, from all angles that are intercepted by the holographic plate during the recording process.

Basically, a hologram is a recording of two coherent waves. When the hologram is illuminated with one wave, the other wave is simultaneously reconstructed.

There are two fundamental types of hologram – transmission and reflection. In a darkened room, transmission holograms are illuminated from behind with monochromatic light (one color). Reflection holograms, however, with their built-in filters are illuminated with white light (all colors) from the side where the viewer is standing, so

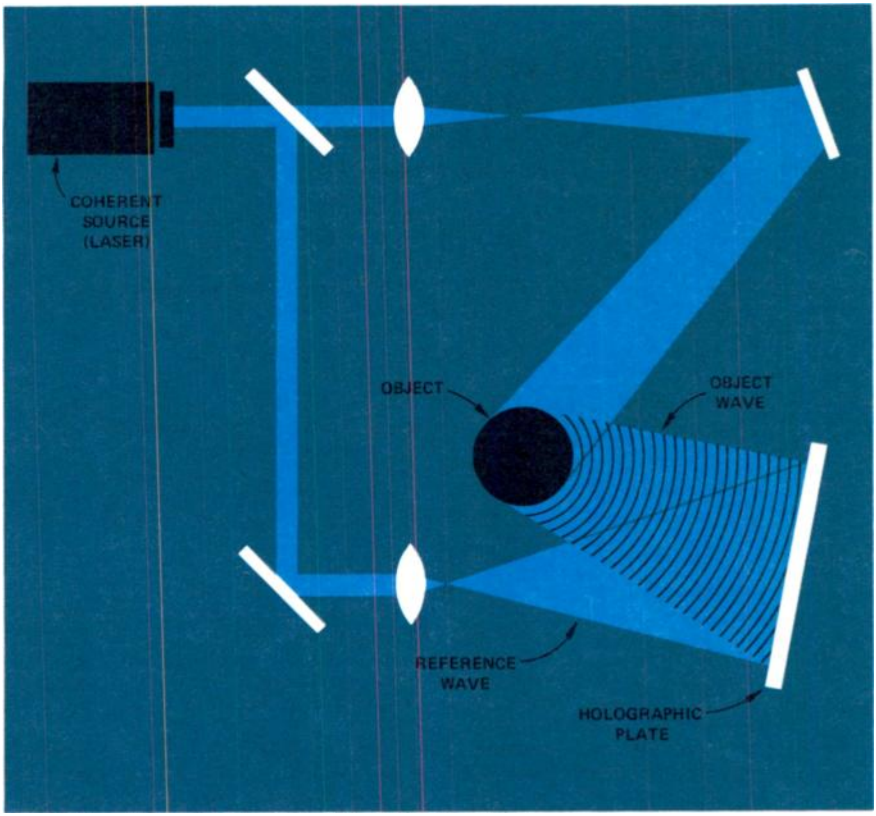

Figure 1. Holographic recording process using laser illumination. The laser beam is split, with the object waves illuminating the object and the reference wave providing a coherent background. The two waves interfere at the holographic plate forming the hologram.

the light is reflected from the hologram to the viewer. A reflection hologram is easier to handle because it may be illuminated in subdued lighting; although, it is not as dramatic as the transmission hologram.

Background

Holography is not a new concept. Dennis Gabor, in 1948, introduced the theory of holography. It was his hope that holography could be used to improve the resolution of electron microscopes. Unfortunately, limited by the intensity of the illumination, the photographic processing, and a disturbing background image, Gabor and the others experimenting with holography did not get the results they desired. The most important of these

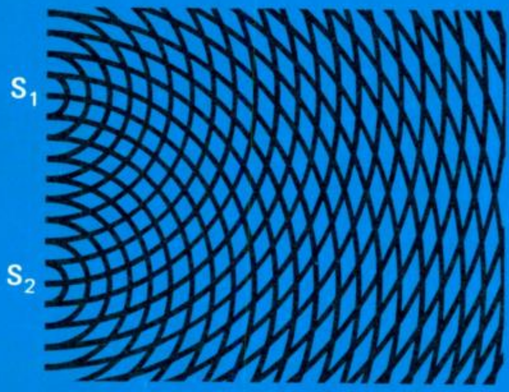

Figure 2. Interference pattern formed from two arbitrary point sources (S_1 and S_2). Place your eye near the left edge and look along the figure. The areas that look white show the cancellation of the waves; between these areas there is reinforcement.

limitations was the illumination intensity.

By 1962, with the development of the laser, intense coherent light became available – over-coming the illumination limitations and eliminating the background image. Laser light also made it possible to record objects which were not easily recorded in Gabor's original system. Objects with dark backgrounds and continuous tones could now be holographically recorded.

Volume Holograms

Gabor's original hologram theory did not use coherent light; therefore, the thickness of the recording emulsion was considered inconsequential and the hologram was viewed as two-dimensional. With the use of coherent laser light, however, the emulsion thickness became an important factor. Specifically, if the emulsion is thicker than the width of the interference fringes (see Figure 3), the object wave and the reference wave will interfere throughout the depth of the emulsion. This produces a volume hologram which is a stack of surface holograms, one atop the other.

If a reflection, volume hologram is made by using three colors of light (blue, green, and red), three holograms will be recorded within the same emulsion. When this hologram is illuminated by white light, each hologram will select the color from the white light to which it responds, and the result will be a three-dimensional color image.

Whole from Part

The entire image from transmission holograms can be reconstructed from a fragment of the original hologram. This is not surprising, since each point on the object is recorded as an interference pattern, or diffraction grating, over the entire hologram surface. This grating can be thought of as a Fresnel lens (see Figure 4). Such a lens focuses all the light falling on it at a particular point. A Fresnel lens also has the property that regardless of how many "rings" there are in the lens segment, or whether there is a complete ring, the light will still be focused at the same point. The resolution (clarity) of the point is determined by the number of rings used. Therefore, as a smaller and smaller section of each Fresnel lens or diffraction grating is used, the clarity is diminished, but the point will still be imaged.

For the same reason that a part of the hologram will reconstruct the whole image, the hologram is relatively insensitive to blemishes and dust parti-

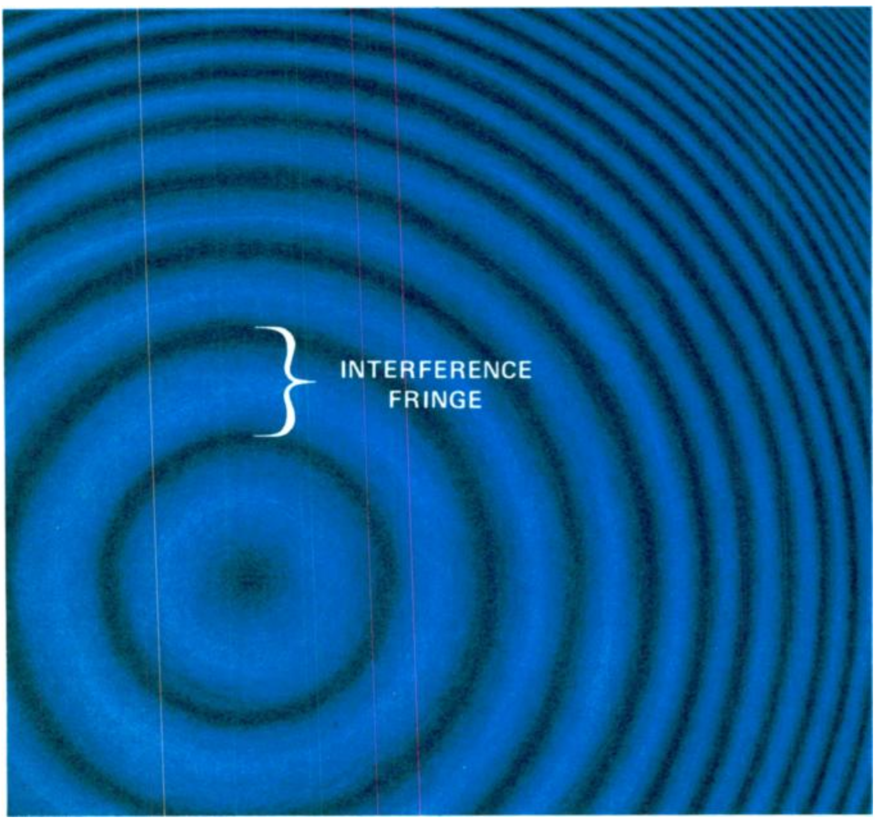

Figure 3. A concentric ring, diffraction grating, for one point on the object, covers the entire holographic plate. The center of the grating need not be on the holographic plate. Such a grating, with variable spacing, focuses the light falling on it at a particular point.

cles. If a blemish destroys part of a diffraction grating, but not all of it, the light will still be properly imaged. The image will not be destroyed unless the total surface of the hologram has been obliterated.

One Hologram Worth Many Words

The large depth of field of holograms is a great advantage in microscopic investigations. It is particularly valuable for examining moving, microscopic objects in a thick sample. A pulsed laser is used to "freeze" the movement in a sample so it can be recorded on the hologram. When the object is reconstructed and viewed through a microscope, different layers of the sample can be brought into focus – something that cannot be done with a photograph where the movement has been stopped with a strobe light. This principle has been used to analyze the size and distribution of particles in aerosols, liquids, and smog. The old adage, "a picture is worth a thousand words," can be extended – "one hologram is worth a great many pictures."

It was Gabor's hope that holography, being lensless photography, would improve the resolution of electron microscopes. Unfortunately, many of the problems that faced Gabor are still present today; since a magnification hologram has all the distortions observed with conventional lenses.

For holography at non-visible wavelengths, the situation is vastly different. For example, magnification is possible using X-rays for recording and visible light for reconstruction – producing a sharply focused, magnified image. However, the technical problems of X-ray holography are severe, and have prevented its practical realization. Obtaining an X-ray source with sufficient intensity and coherence is a major obstacle.

3-D Imaging

The three-dimensional aspect of holography has received widespread attention. Holography has several advantages related to 3-D imaging. Holographic reconstruction gives an image with high resolution and great depth of field. Parallax, as observed in reconstructed holographic images, allows the viewer to see around objects. Holograms also have some economic advantages such as full color images formed from less expensive black and white emulsions and no need for additional imaging optics.

Holographic three-dimensional imaging also has some disadvantages. The object must remain perfectly still for recording. The object motion can, however, be stopped by using a pulsed-laser for illumination. At the present, it is virtually impossible to take holographic pictures in daylight or under normal illumination because the object to be recorded must be illuminated with only one wavelength of light. Multi-color images are not promising, since these images require long exposures. The size of the object to be recorded is limited by the laser power. The largest hologram that has been made is 18 x 24 inches.

A 3-D holographic television system could be designed today, if available

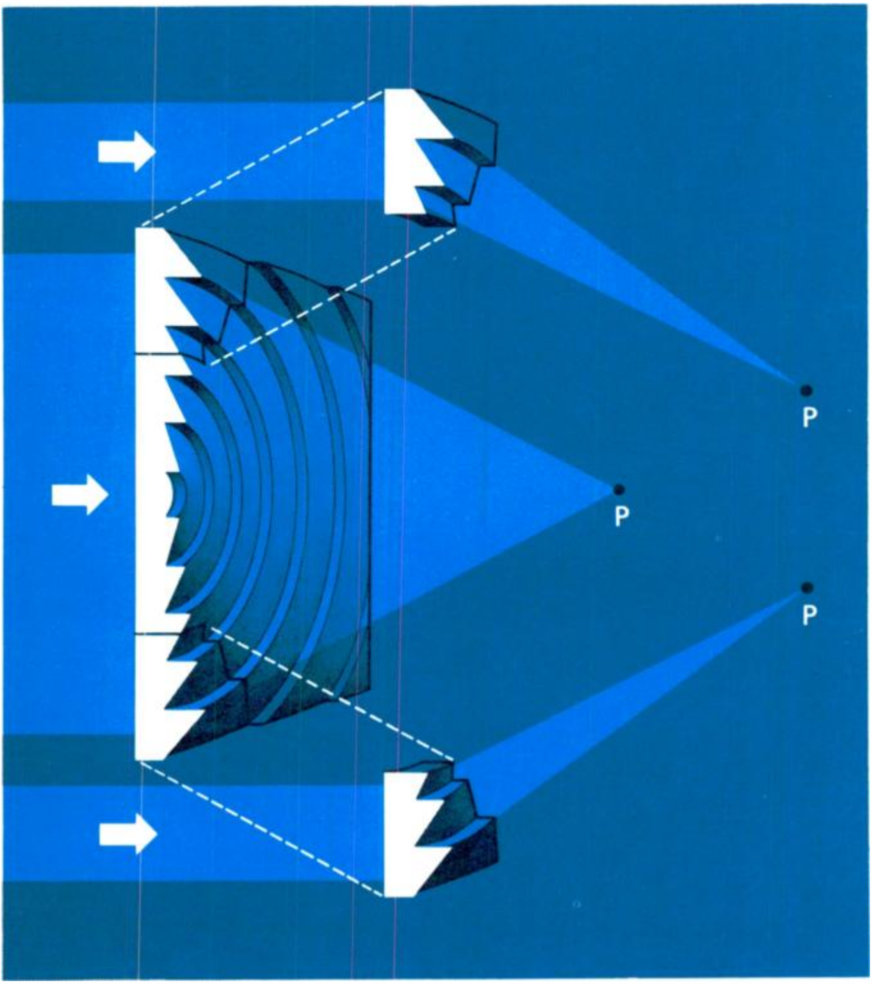

Figure 4. The light falling on a Fresnel lens will focus at a particular point (P) regardless of how large a segment of the lens is used.

components held tighter specifications. For example, a hologram 10 inches square and having 1,000 lines per millimeter has 6 x 10^{10} picture elements, compared with 2.5 x 10^5 for a conventional television picture. If the scan rates of present TV systems were maintained, a 10^5 increase in bandwidth would be necessary – a jump from 6 to 600,000 MHz. The entire radio-frequency spectrum, including the microwave region, would be inadequate to meet this requirement. If a suitable transmission method can be found, it may one day be possible to watch holographic 3-D television in the middle of your own living room.

The first attempt at holographic movies involved taking a series of pictures of still objects and then viewing them in rapid succession producing a sensation of motion – the animated cartoon concept. The term "true" is used to describe the newest 3-D movie because it is a motion picture of a moving object. (Figure 5). This reconstructed image is truly three-dimensional and may be viewed without additional lenses or filters.

Change Detection

Holography has many properties that make it natural for application to interferometry, a technique used to detect structural changes. For example, a hologram placed in its recording position will display the reconstructed image on top of the actual object. A subsequent slight movement of the object produces interference fringes between the object and image waves.

A hologram can be exposed more than once. The image waves, recorded at different times, can be simultaneously reconstructed and their interference pattern observed (Figure 2). Shock waves, for example, produced by projectiles passing through air or gas density changes can be easily recorded with pulsed-laser, double-exposure holograms.

A new method of holographic interometry (HI) has been introduced which uses a single-exposure, two-wavelength laser pulse in the recording process; rather than the double-exposure, single-wavelength formerly used. This new technique can double sensitivity by proper choice of wavelengths and physical arrangement of components.

The field of nondestructive testing makes extensive use of HI. Holographic nondestructive testing (HNDT) is a method of detecting or measuring the significant properties or performance capabilities of materials, parts, assemblies, equipment, or structures without impairing their serviceability. HNDT is simply HI combined with suitable test-object stressing. Common types of stressing include temperature, pressure, sound, and vibration. HNDT is now a practical design and quality control tool for analyzing sandwich structures, tires, rubber-to-metal bonds, and many other objects. Large areas may be inspected quickly, a variety of flaws can be detected simultaneously, and a choice of several low level stressing methods is available.

Cryptography

A hologram is a coded message that can be decoded by using a coherent illumination source. If, however, the hologram were made with a diffuser such as ground glass placed between the object and the holographic plate, it could only be decoded using the same diffuser. If the same diffuser is placed so that it coincides with its own image, a sharp, clear picture of the original object is reconstructed – as if the diffuser were a clear glass.

The same diffuser must be used in both recording and reconstruction. A section of ground glass, 1 centimeter

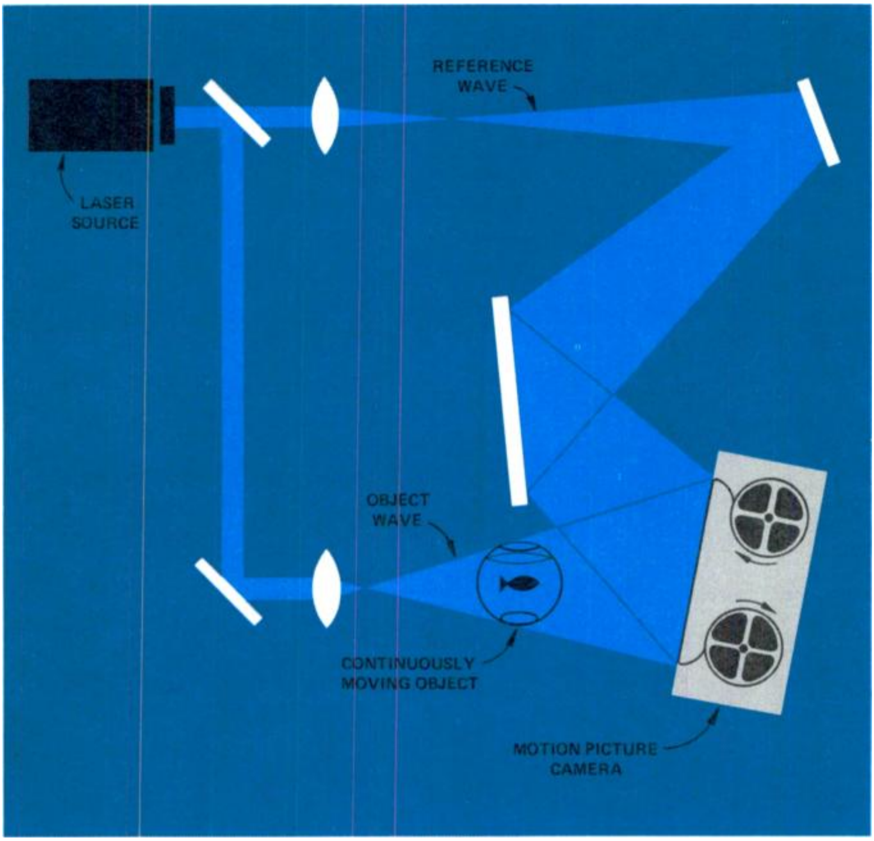

Figure 5. The basic system used to make the first "true" holographic movie.

square, can contain a billion distinct resolution elements, each of which retards the transmitted light. It is not probable that two ground glass samples would be similar enough to allow an image to form. With only one "key" to a cryptographic hologram, the message is considered secure.

Memories Can Forget

Holograms are useful for data storage because many holograms can be superimposed on the same photographic plate. Built-in redundancy is a must in today's computer systems — transmission holograms, with their insensitivity to blemishes and ability to reproduce an entire image from a small fragment, provide the necessary redundancy. Optical memories capable of storing 10^4 bits of data on each page are stored in 1 mm^2 on the hologram. A 10 cm^2 hologram stores 10^4 pages — totaling 10^8 bits per hologram.

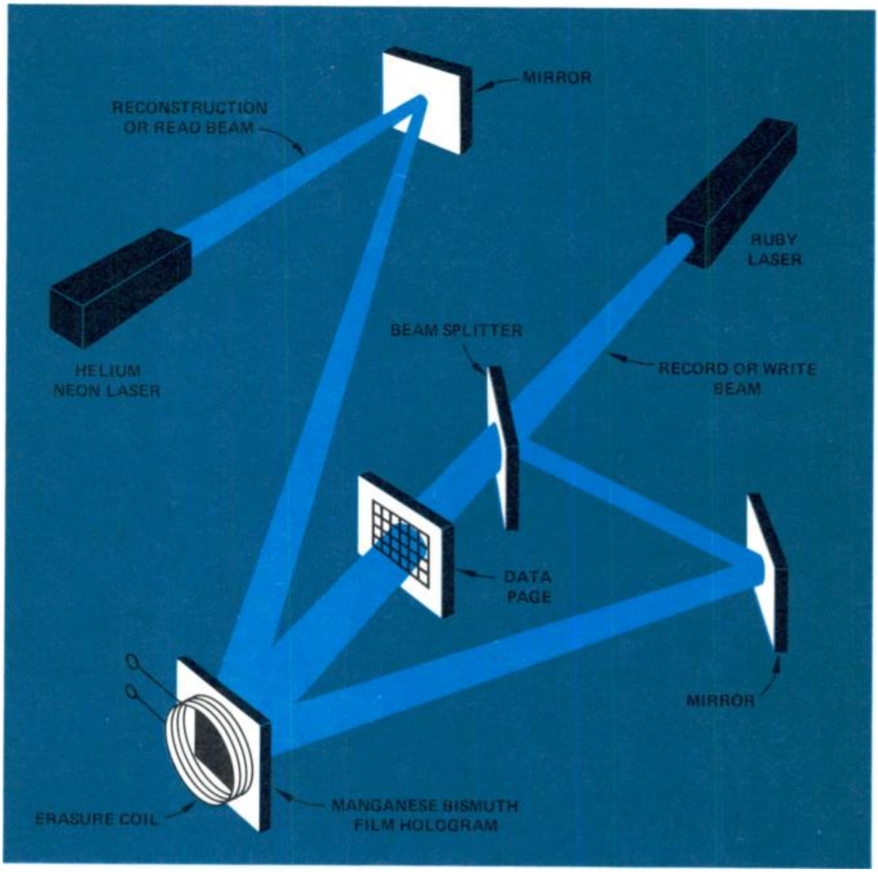

Figure 6. The simplified system for writing, reading, and erasing the magnetic hologram memory.

Until now, optical memories have been confined to the static, read-only type. This means, once made and inserted into the memory, the hologram can be read whenever necessary. This information cannot, however, be changed. Whenever a change is required, the old hologram has to be removed and a new hologram made and inserted into the memory.

A dynamic, read-write memory is now in the laboratory stage. These optical memories are capable of being written in the memory, stored, read at will, and then erased when new information must be entered. Ideally, these can be reused indefinitely.

These new holographic memories are made by depositing a single crystal layer of manganese bismuth (MnBi) on a base of mica. A strong magnetic field, applied to this film, causes the magnetic moments of the atoms to line up making it ready for use as a hologram. During the hologram recording process, the magnetic moments of the atoms move out of alignment in accordance with the laser light interference pattern. The recording time for such a hologram is about 10 nanoseconds. The hologram is erased by simply applying a voltage to a nearby coil, creating a strong magnetic field perpendicular to the hologram surface. This magnetic field realigns the magnetic moments of the MnBi crystal (Figure 6). The hologram memory has now forgotten the old information and is ready to record the new data.

Advertising

Reflection holograms have opened the door to hologram use in advertising. Not many people have lasers handy for reconstructing a transmission hologram image, but most people have a white light source, such as a flashlight or high intensity lamp, to illuminate a reflection hologram. Presently, the cost of producing hologram copies is rather high. Holograms, nevertheless, are beginning to appear in the print media.

Advertising holograms seem best suited for inclusion in magazines, although books and newspapers can also carry them. As for direct mail – mailing a hologram is no more difficult than mailing a photograph.

Although many uses have already been made of holograms, there are probably others that have not been explored. Advertising with holograms will provide public exposure to holograms – the more exposure, the more possible applications.

Commercial Applications

Holography is no longer just a laboratory curiosity, but now has applications in the fields of nondestructive testing, microscopic investigation, entertainment, information storage, and advertising. In fact, in the last two years, more than 500 companies in the United States alone, have made economic gains by taking advantage of this extraordinary form of photograhy, which permits the viewer to see around obstacles. Dr. Dennis Gabor, the inventor of holography, has forecast that by 1976 his brainchild will become a billion-dollar industry.

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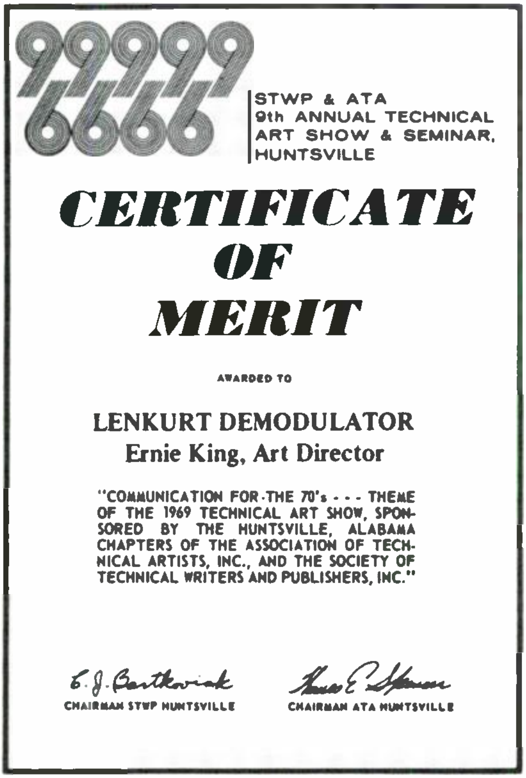

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