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Division of Engineering and Applied Physics

Harvard University Cambridge, Massachusetts

A METHOD FOR PHOTOGRAPHING MICROWAVE WITH A POLAROID FILM

By

Keigo Iizuka

Division of Engineering and Applied Physics

Harvard University Cambridge, Massachusetts

ABSTRACT

A regular Polaroid film has proved to be applicable to a quick and easy direct mapping of an electromagnetic field. The method utilizes the selective development of the film in accordance with the thermal image produced by the electromagnetic field. The power required for the creation of a clear image is about 0.06 watts per square inch. The time of exposure to the microwave is about 15 to 60 seconds.

The method would be most useful for preparing microwave holograms. It can also be applied to the mapping of the temperature distribution in space.

Introduction

When it is desired to measure an electromagnetic field over a large area, no simple technique is at present available other than mechanical scanning with a small probe. This has such disadvantages as discrete recording, disturbance of the original field by lead wires and supports, and a lack of economy of time. Microwave holography has suffered from this basic difficulty since no convenient analog to the photographic plate has existed at microwave frequencies.

It has been found that a regular Polaroid film can be used to map an electromagnetic field. The principle involved in the new method is the temperature dependence of the developing speed of a uniformly exposed film. The method has proved to be inexpensive and accurate. Actually, the intensity of a given field can be measured simply by holding the film by hand for less than one minute. No other equipment is required.

Principle and method

Figure 1 shows a cross-section of Polacolor Type 58 film which is normally used for taking instant 4" × 5" color pictures. The film packet consists of negative and positive layers and a developing agent. The film is first "sensitized" by briefly exposing it in a uniform manner to the light. The negative and positive with a pod containing the reagent are together pulled through the pair of rollers of a Polaroid 4 × 5 Land film holder Model 500. This action breaks the pod and releases the viscous processing reagent in a thin layer between the negative and positive. As soon as the reagent is in intimate contact with the film the development of the film starts. Immediately after the reagent has been spread, the film is placed directly into

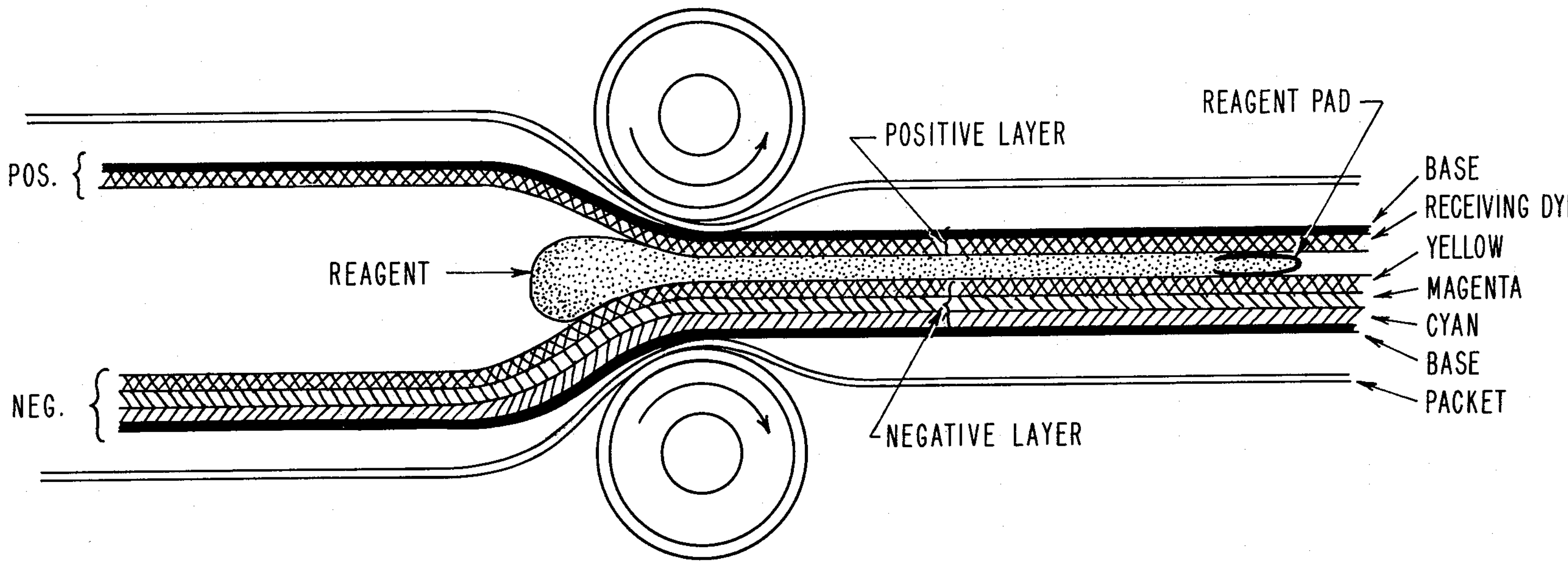

FIG. 1 CROSS-SECTION OF PACKET TYPE POLAROID COLOR FILM.

Introduction

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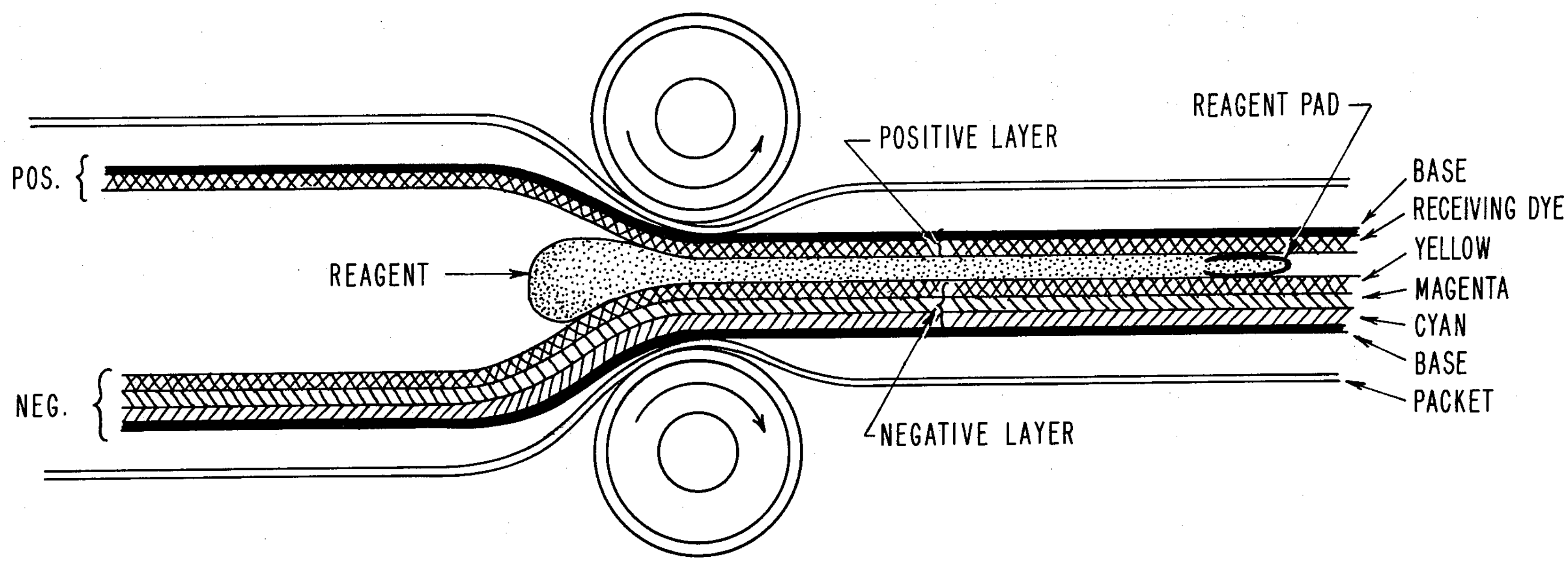


FIG. 1 CROSS-SECTION OF PACKET TYPE POLAROID COLOR FILM.

the electromagnetic field of a microwave. The formation of an "image" on the film by the field depends on the temperature sensitivity of the developing process of the film which has been uniformly exposed to the light.

The component of the electric field in the plane of the film generates heat in the exposed silver halide grains by means of an induced current. This raises the temperature of the grains in accordance with the square of the intensity of the field acting upon them. Thus, a thermal field which is a replica of the intensity distribution of the electromagnetic field is produced in the film. The localized heating in the grains leads to a localized increase in the diffusion rate of the developing reagent to the grain sites and additionally hastens the chemical development in the heated portions of the film.

The developer is removed from the film at a premature stage of the normal developing time. On the film a visible pattern corresponding to the field intensity distribution appears.

There are three ways to enhance the sensitivity of the film to the microwave.

(1) There is an optimum temperature at which the change in the growth of the silver grain with respect to the change in temperature is greatest. The experimental results indicate that this optimum temperature is in the vicinity of 25-35°F. The film is advantageously cooled to the temperature of dry ice before it is exposed to the microwave field because the film is warmed by the ambient temperature during the experiment. However, the reagent pod should not be cooled because it solidifies at around 32°F.

(2) The choice of the color of the light to which the film is pre-exposed for "sensitizing" the film also influences the sensitivity of the method. As shown in Fig. 1 the film has an emulsion-coated negative which contains dyes of different colors in nine separate layers at increasing distances from the surface of the negative. The time required for the developer for each of these dyes to reach the surface of the negative is dependent on the respective distance of each from this surface. If the negative is pre-exposed to light of a wavelength which allows only that dye which lies nearest the surface to reach this surface, a relatively short development time will result; if, on the other hand, the negative is pre-exposed to light of a wavelength which allows only that dye which lies farthest from the surface to reach this surface, then a relatively longer development time results. Thus, in the color film, pre-exposure to cyan colored light provides a longer developing time than is obtained by pre-exposure through a yellow filter. In effect, the effective thickness of the diffusing layer can be controlled by this technique. The choice of the color of the light is important. The pre-exposure to cyan colored light is useful for a relatively long exposure to a weak microwave field; the pre-exposure to yellow light is good for a short exposure to an intense microwave field.

In order to pre-expose the film, a box camera was utilized. The camera was aimed at a white sheet of paper which was illuminated by two carbon arc lights (5600°K) at 45° degree cycles. The incident illumination was measured by a Kodak Neutral Test Card. The reflected light from the card was 50 foot-candles. In order to obtain the desired cyan color, the film was first exposed through a blue filter (47) for 1/10 second with a lens aperture of F/9.5 and then through a green filter (61) for 1/5 second with the same lens aperture.

(3) The addition of a metal reflector placed parallel to the film was found to increase the sensitivity of the film at the cost of some disturbance of the original field. The maximum dissipation of microwave power in the film can be obtained by suitably adjusting the distance between the film and the metal reflector.

Besides Polacolor Type 58, other types of Polaroid film were tried. The black and white films like Types 52, 57, 55 P/N, and 107 were found applicable to the present purpose but with a reduced sensitivity to the imaging of the microwave field.

When only a small area of measurement is of interest, the 8-exposure pack (color 3 1/4 × 4 1/4 - inch) was found quite handy except that it is difficult to cool only the portion of the film exclusive of the reagent pods because the latter are encased in the pack.

For the mapping of a large area of a microwave field, the Polaroid Radiographic Packets Type TLX for X-ray (9 3/8 × 10 1/2 - inch) were found most useful.

Fig. 2 shows the arrangement used for measuring a field intensity distribution at the open end of an L-band waveguide, ($f = 2,770$ MHz or $\lambda = 10.83$ cm), by means of a pre-cooled film packet.

Fig. 3 (a) was taken with Polacolor Type 58. The film was not exposed to the light before its exposure to the microwave field and the multicolor dyes present are responsible for the formation of the image. The exposure to the microwave field was for 15 seconds.

Fig. 3 (b) was taken with the same type of film and the same exposure time as Fig. 3 (a) except that only cyan colored dye was left in the film. Fig. 3 (c) was taken with a black and white film Type 52. The film was exposed to the microwave field for 2.5 seconds.

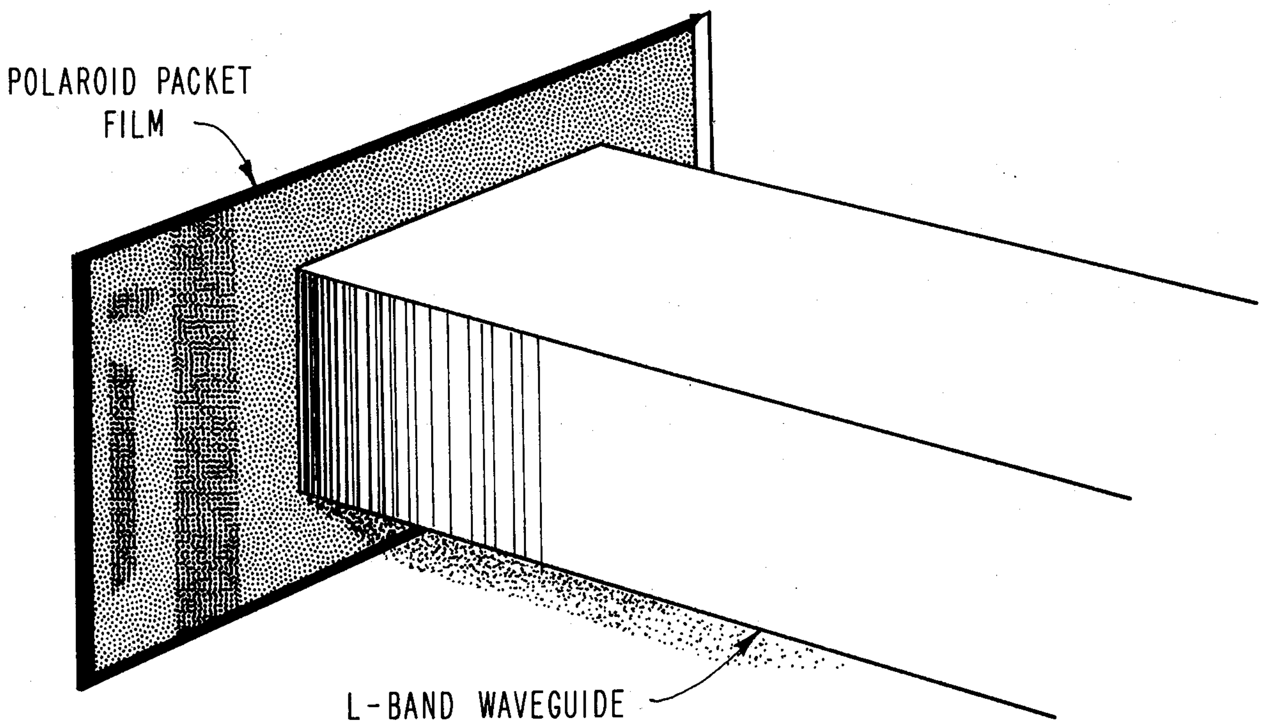
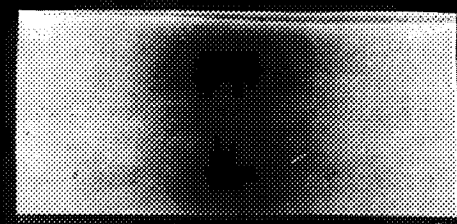
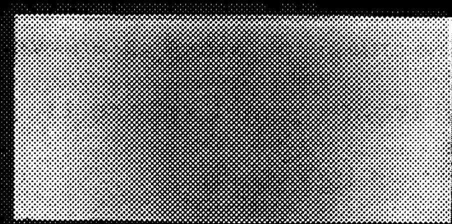


FIG. 2 MAPPING THE FIELD INTENSITY AT THE MOUTH OF AN OPEN WAVEGUIDE WITH A POLAROID FILM.



(a) WITH ALL COLOR DYES
(POLACOLOR 58)



(b) WITH CYAN DYE ONLY
(POLACOLOR 58)

(c) WITH BLACK AND WHITE
FILM (TYPE 52)

FIG. 3 FIELD INTENSITY OF AN OPEN-ENDED WAVEGUIDE MEASURED WITH A USE OF POLAROID FILM.

Fig. 4 shows an arrangement for measuring Young's fringe pattern of a microwave signal (f = 8, 900 MHz or λ = 3. 37 cm) launched from two horns making an angle of 90 degrees between them. The packet film was placed at equal distances from the horns and at 45° degrees with respect to the incident waves. The image recorded is shown in Fig. 5. Polacolor Type 58 was used. The exposure time to the microwave field was 60 seconds.

Fig. 6 shows an arrangement for measuring the field scattered from a metal cylinder 17 mm in diameter. The E field was polarized in the direction of the axis of the cylinder. The film was oriented at 45 degrees with respect to the incident wave. The image obtained is shown in Fig. 7. A similar image of the field scattered from a metal sphere 11. 1 mm in diameter in place of the cylinder is shown in Fig. 8.

Fig. 9 shows an arrangement for mapping the radiation pattern of an X-band horn. The reference field is superimposed so that the distribution of the phase front is also known. The film was held on one of the vertical edges of the horn parallel to the center line. The direction of the polarization of the E field was in the plane of the film.

Fig. 10 shows the image of a transmitting horn obtained by this method (f = 8, 900 MHz). The location of the horn is to the right of the film and the reference signal impinges normally onto the plane of the film. The picture shows a wave front that grows toward the left; the wave fronts are parallel to one another.

Not only the field distribution but also the distribution of the charges along conductors can be mapped by the new method. Fig. 11 shows an arrangement for mapping the charge distribution along a monopole antenna over a ground plane.

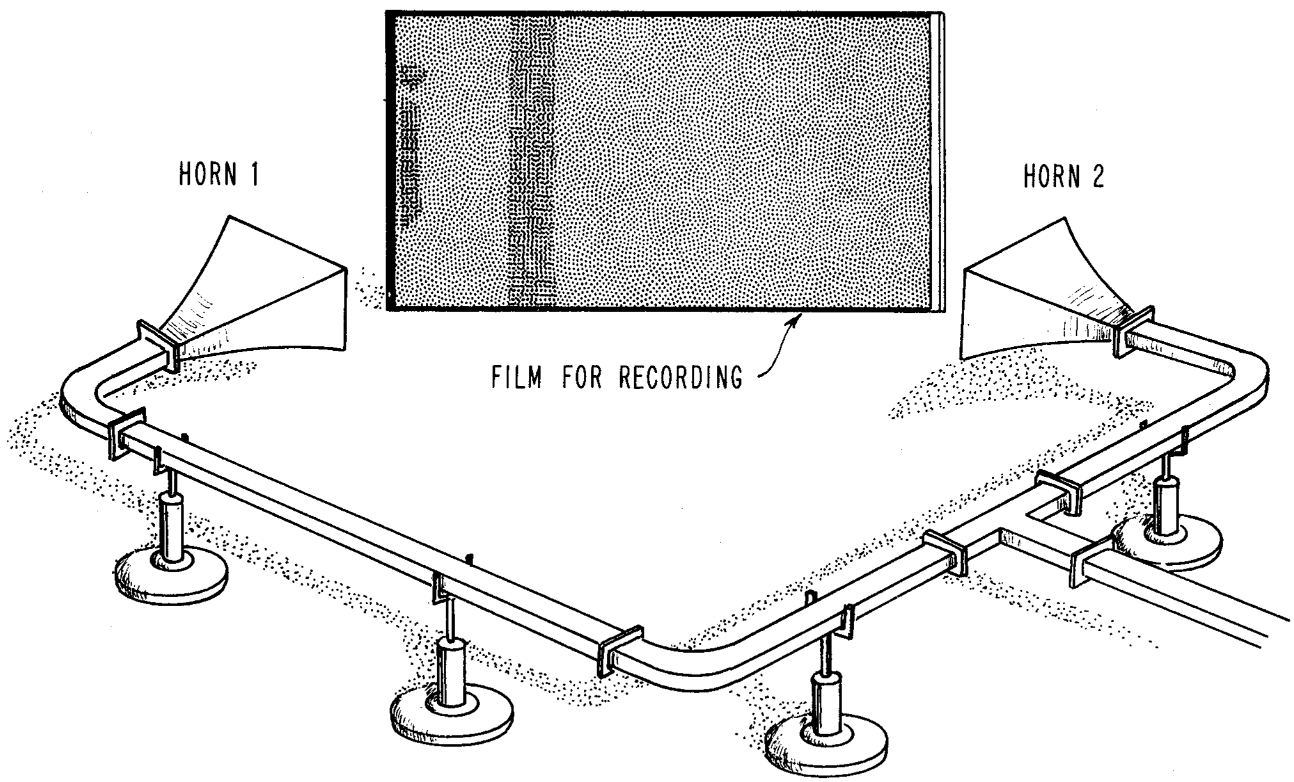


FIG. 4 ARRANGEMENT FOR MAPPING A YOUNG'S FRINGE PATTERN OF A MICROWAVE SIGNAL ($f = 8.900$ MHz).

FIG. 5 IMAGE OF A YOUNG'S FRINGE PATTERN FROM TWO X-BAND HORNS.

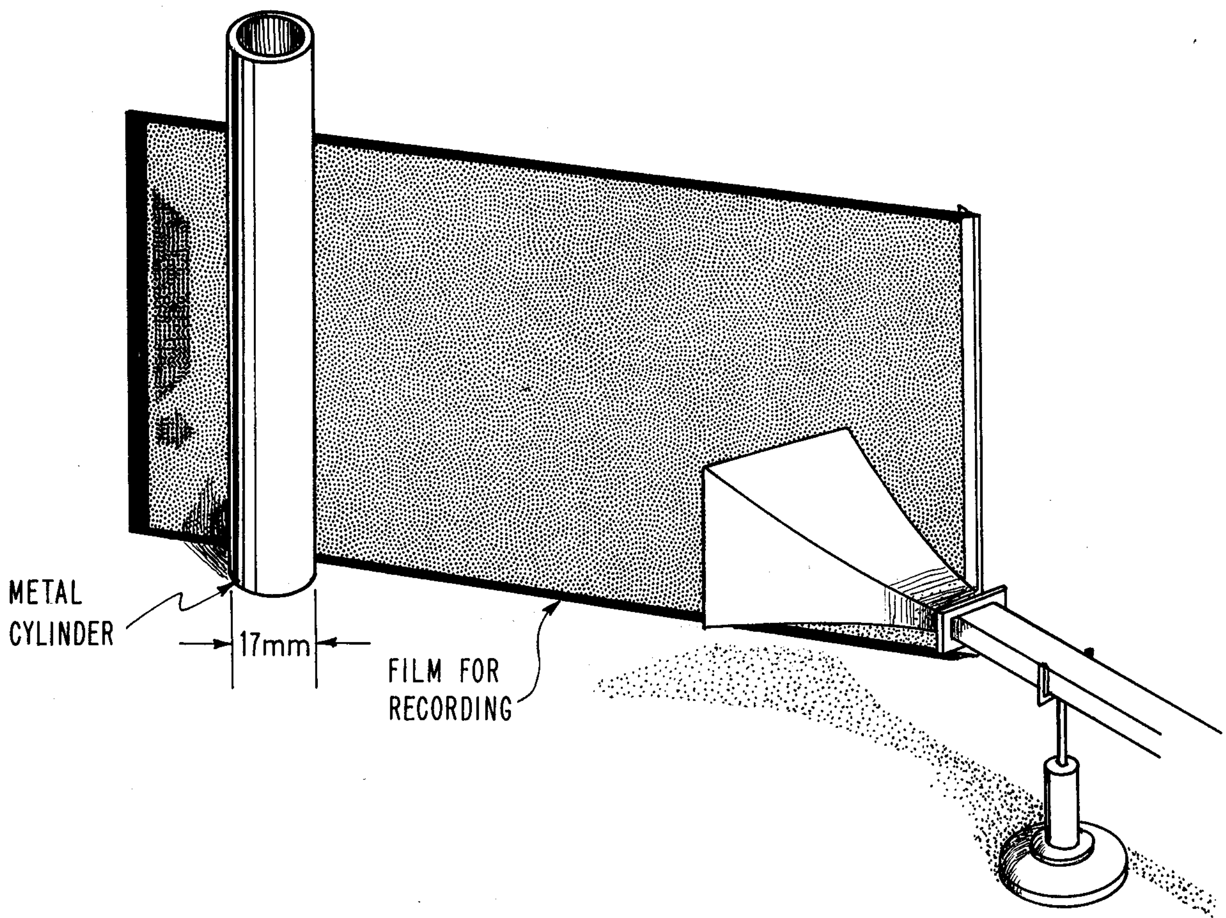


FIG. 6 ARRANGEMENT FOR MEASURING SCATTERED FIELD FROM A METAL CYLINDER.

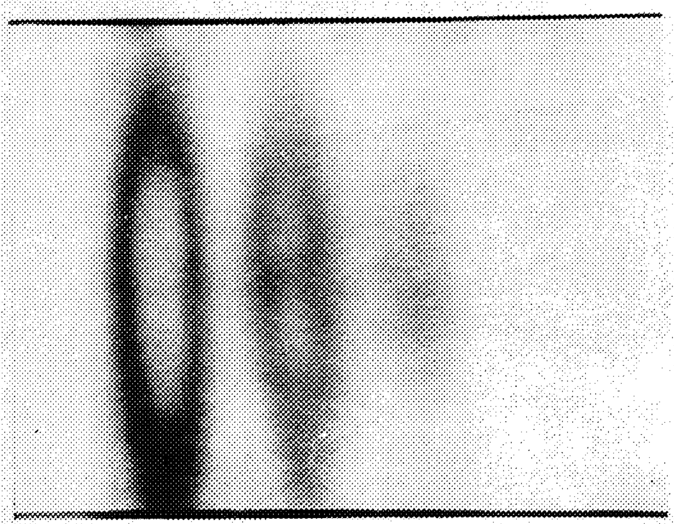


FIG. 7 IMAGE OF THE SCATTERED FIELD FROM A METAL CYLINDER 17 mm IN DIAMETER.

FIG. 8 IMAGE OF THE SCATTERED FIELD FROM A METAL SPHERE 11.1 mm IN DIAMETER.

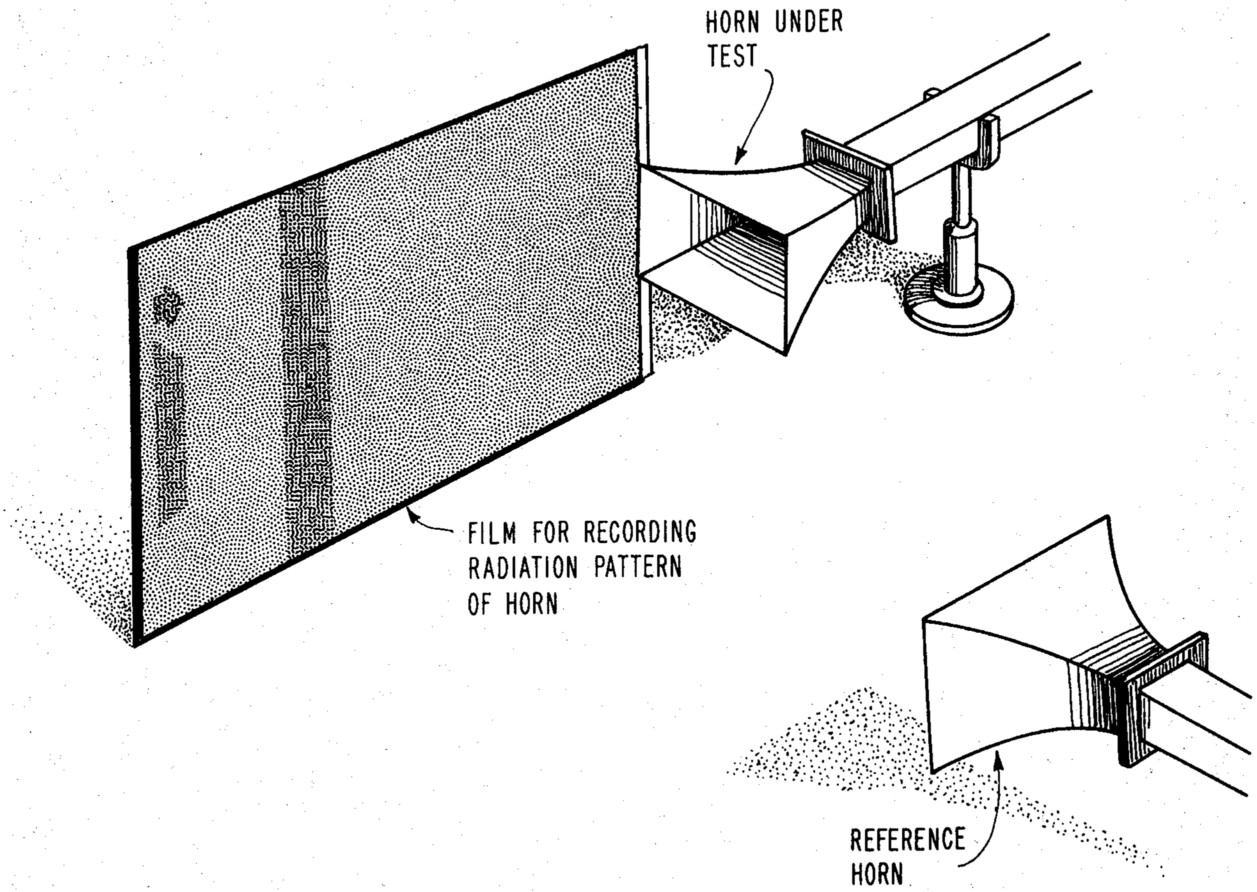


FIG. 9 ARRANGEMENT FOR MAPPING THE RADIATION PATTERN OF AN X-BAND HORN.

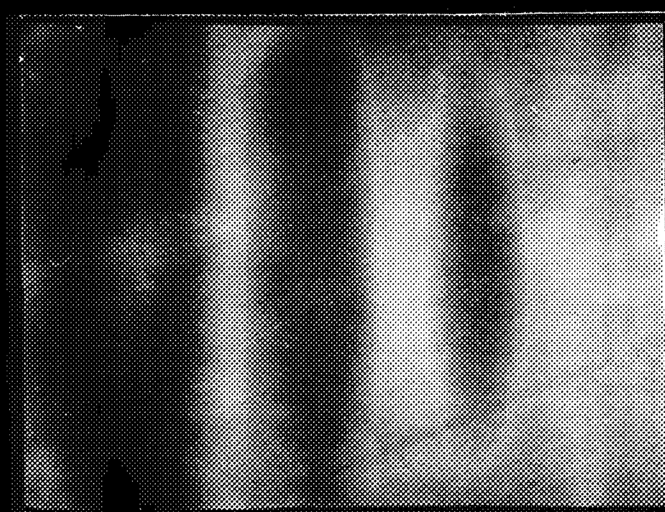


FIG. 10 IMAGE OF AN X-BAND TRANSMITTING HORN. THE LOCATION OF THE HORN IS TO THE RIGHT OF THE FILM AND THE REFERENCE SIGNAL IMPINGES NORMAL TO THE FILM SURFACE.

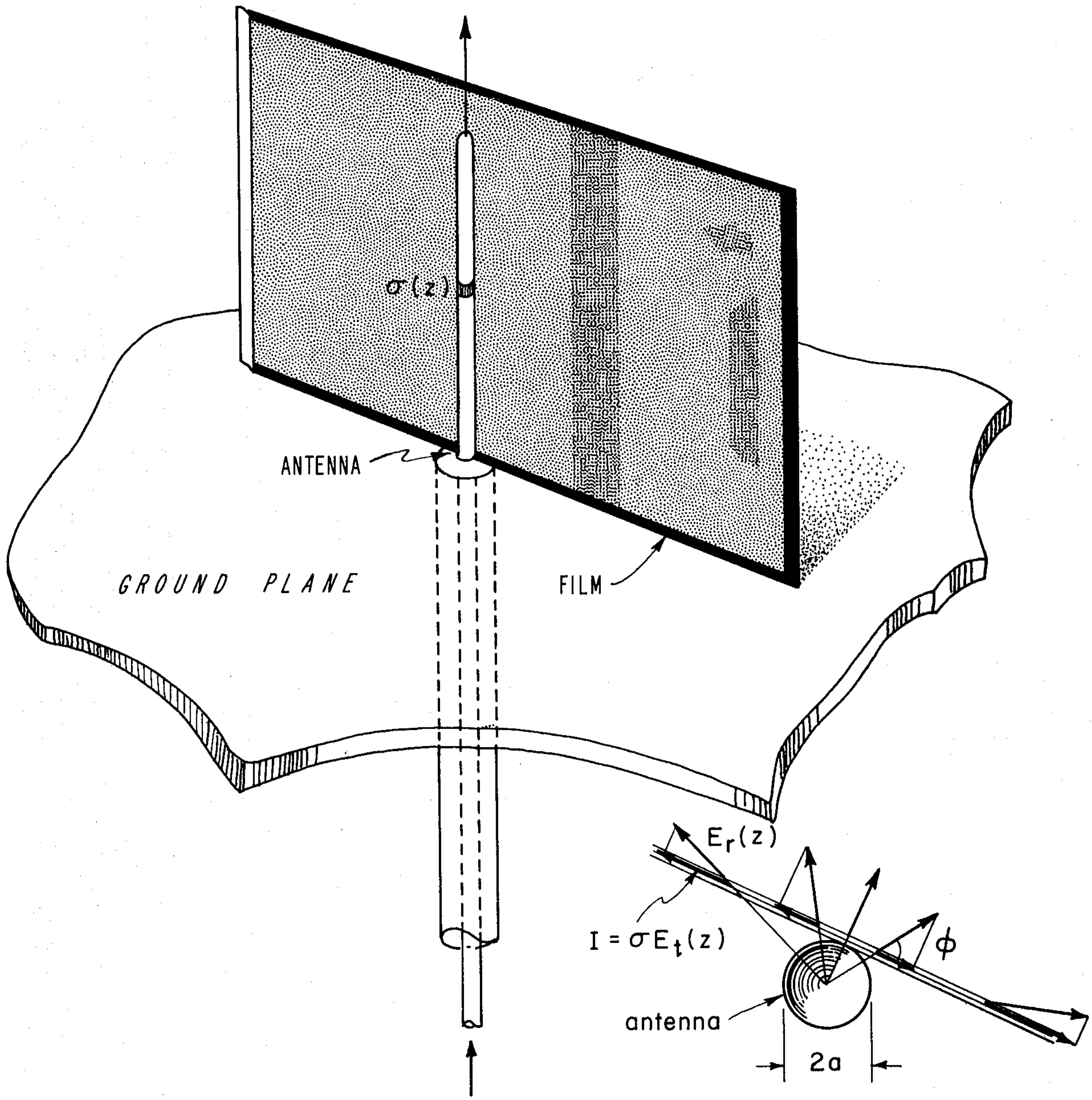


FIG. 11 ARRANGEMENT FOR MAPPING THE CHARGE DISTRIBUTION ALONG A MONOPOLE OVER A GROUND PLANE.

The film was placed in contact with the antenna and the ground plane. The radial component of the E field except near the tip of the antenna is

$$E_r(z) = \frac{a\sigma(z)}{r}$$

where $E_r(z)$ is the radial field intensity at z, $\sigma(z)$ is the surface charge density at z on the antenna, a is the radius of the antenna wire, r is the radial distance from the axis of the monopole.

The electric field responsible for inducing the current on the film is

$$E_t(z) = E_r(z) \cos \phi$$

where ϕ is the angle between the radial component of the electric field and the plane of the film. Thus, by knowing the mapping of $|E_t(z)|^2$ the distribution of $|\sigma(z)|$ can be obtained.

Fig. 12 shows the mapping of $|E_t(z)|^2$ along monopoles with $\beta h = \frac{2\pi}{\lambda} h = 4.64$ and $\beta h = 2.96$ at f = 2,770 MHz. The field near the driving-point could not be mapped because of the margin of the film. It is interesting to note that at the tip of the antenna a minimum surrounded by maxima in the immediate vicinity can be clearly seen. This may indicate a good power of resolution of the mapping. The minimum is that of the tangential component $E_t(h)$ of the field. The large component $E_r(h)$ is perpendicular to the surface of the film, $\phi = 90^o$. (See Fig. 11).

The minimum field intensity at frequencies between $1 \sim 10$ GHz which would suffice to produce a relatively clear image is approximately 0.06 watts per square inch. It would not be difficult to prepare a microwave

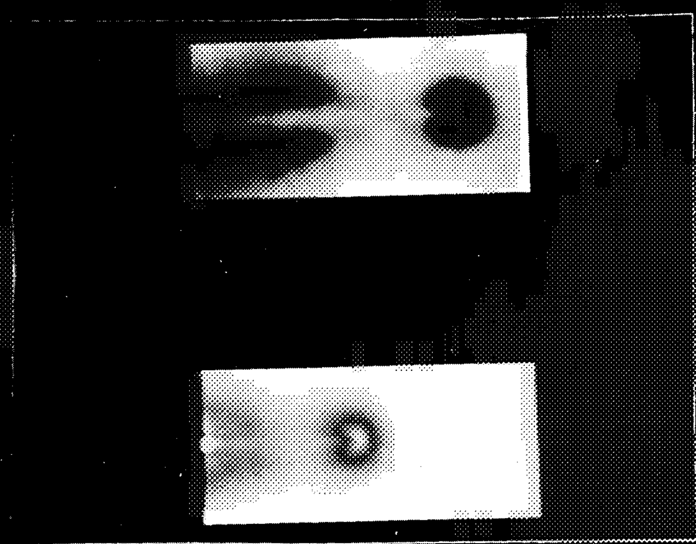


FIG. 12 MAPPING OF THE CHARGE DISTRIBUTION ALONG THE MONOPOLE OVER A GROUND PLANE $\beta h = 4.64$ ABOVE AND $\beta h = 2.96$

hologram with an area of 1,000 square wavelengths by this method utilizing only a common medium-sized X-or K-band magnetron.

So far a method has been described for mapping electromagnetic fields. However, the method is not limited to this application. It may be employed advantageously to record any physical phenomenon capable of generating a thermal image of the field to be recorded. For example, the temperature distribution within the flame of a candle was successfully mapped by holding the film vertically in the flame for a few seconds as shown in Fig. 13. The temperature distribution within the flame generates a corresponding distribution within the emulsion and causes the film to form an "image" whose intensity is directly proportional to the temperature distribution of the candle. The mapping of the temperature thus obtained is shown in Fig. 14. The bottom portion of the flame could not be mapped because it was in the margin of the film. The film was pre-exposed to magenta light of uniform intensity. The existance of a low temperature area at the lower center of the flame is also distinguishable in the mapping.

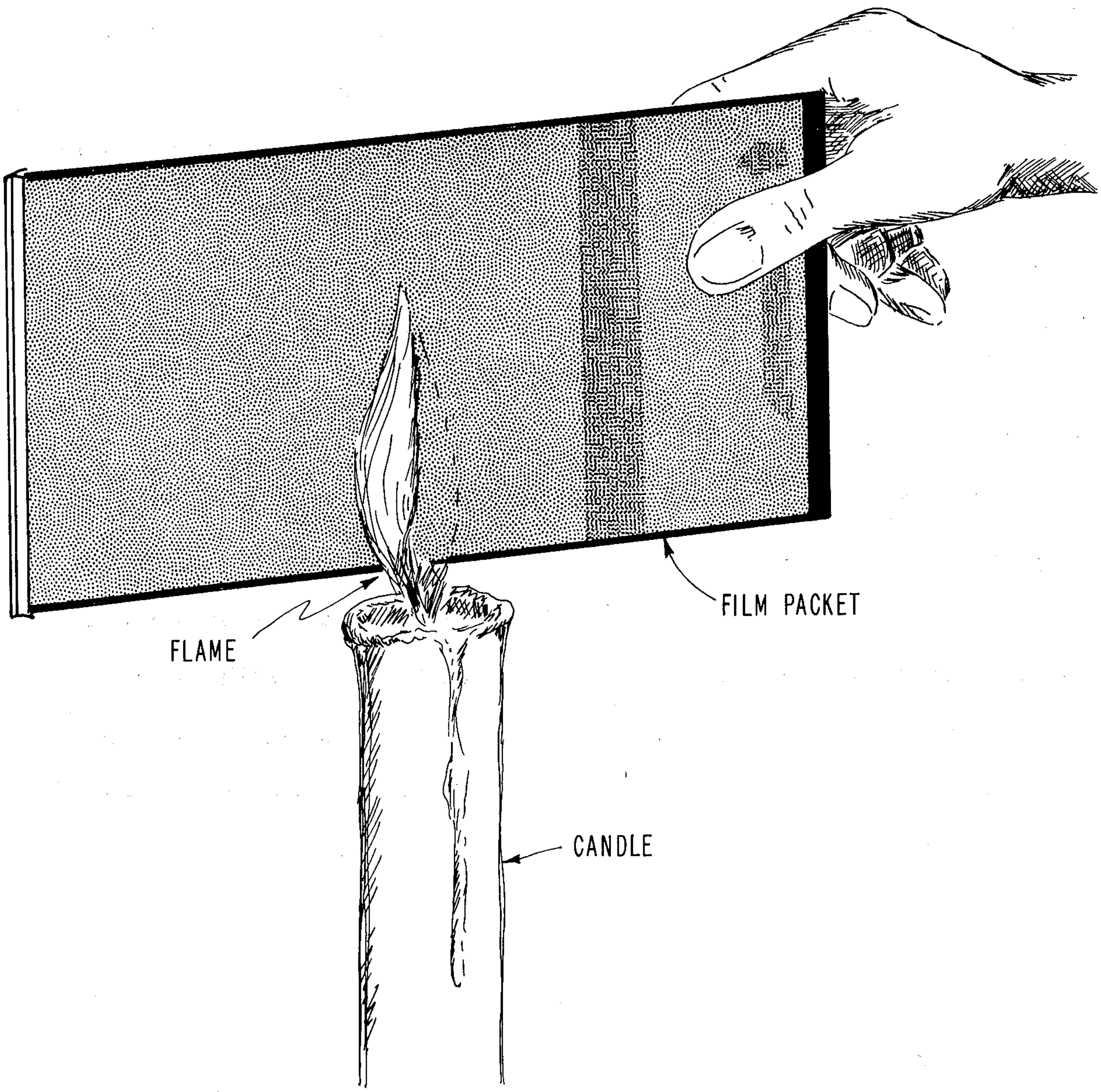


FIG. 13 QUICK WAY OF MAPPING THE CROSS-SECTIONAL TEMPERATURE DISTRIBUTION OF A CANDLE FLAME.

FIG. 14 CROSS-SECTIONAL TEMPERATURE DISTRIBUTION OF A CANDLE FLAME MAPPED BY A POLAROID COLOR FILM.

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13. ABSTRACT

A regular Polaroid film has proved to be applicable to a quick and easy direct mapping of an electromagnetic field. The method utilizes the selective development of the film in accordance with the thermal image produced by the electromagnetic field. The power required for the creation of a clear image is about 0.06 watts per square inch. The time of exposure to the microwave is about 15 to 60 seconds.

The method would be most useful for preparing microwave holograms. It can also be applied to the mapping of the temperature distribution in space.

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