Radio Photography and Television

How the Use of Several Wavelengths Simplifies the Problem

By Dr. E. F. W. ALEXANDERSON

SINCE the transmission of music and speech by radio has come into its own, many scientific experimenters have been looking for new fields to conquer, in this same realm of radio. Photographs have been transmitted across the Atlantic Ocean by radio in twenty minutes, and now that this is an accomplished fact, improvements on the method are being sought.

Dr. E. F. W. Alexanderson, one of the foremost radio engineers in the world, has been working for the past few months on the improvements mentioned above. He has succeeded in transmitting, by radio, photographs in one tenth of the time that it previously took; and the copies, taken from the air at the receiving end, are excellent reproductions of the originals. Dr. Alexanderson, however, is looking beyond the transmission of photographs; his goal at the present time is "television," his theory of accomplishing which he outlines in the accompanying article.

—EDITOR.

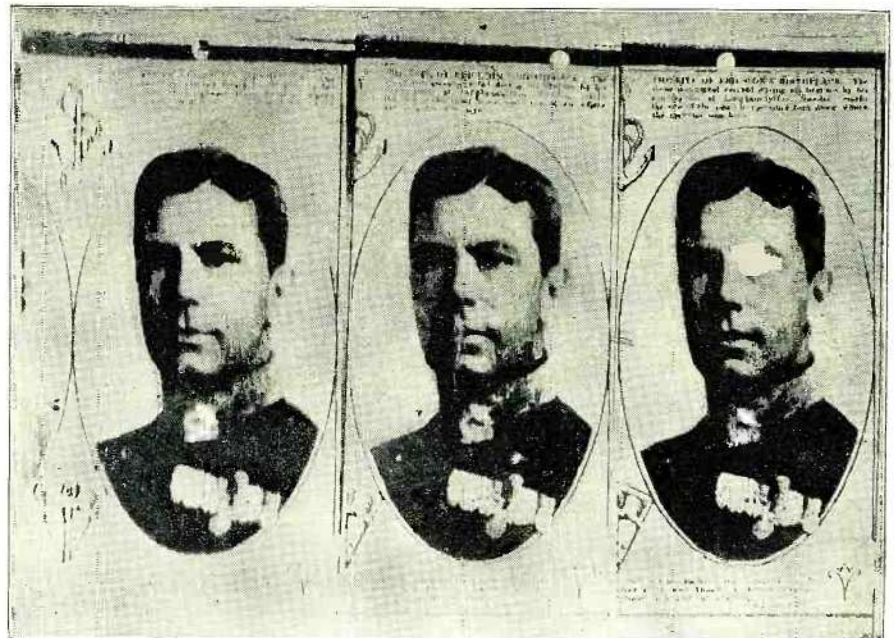
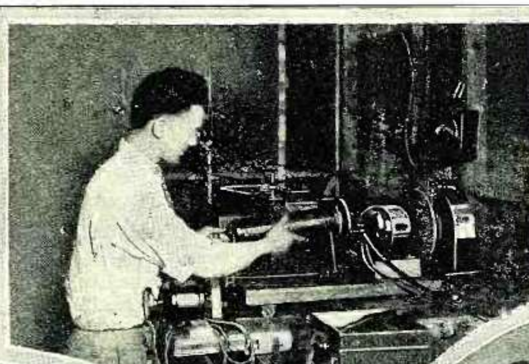


Fig. 1. These three copies of the same photo were transmitted at different speeds. They were sent in two, four, and eight minutes, reading from left to right, as explained in the article.

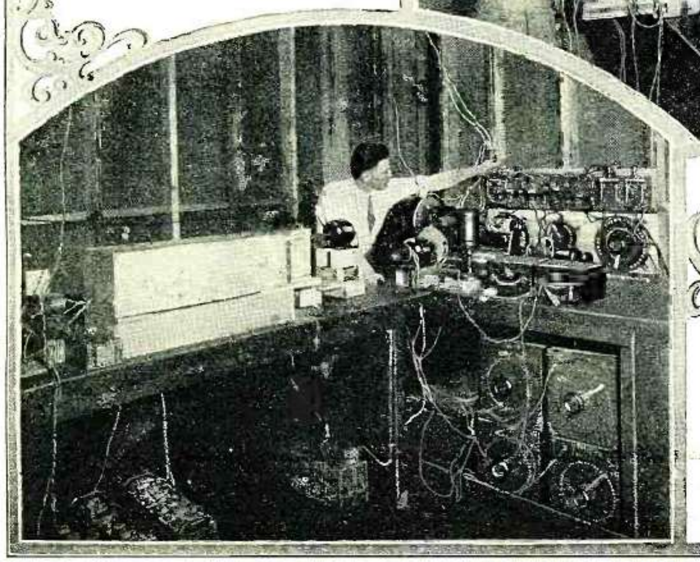
IN the well known play by George Bernard Shaw, "Back to Methuselah," is described a scene which is supposed to take place in the year 2170. The head of the British Government holds conferences with his various cabinet ministers several hundred miles away. He has at his desk a switchboard and in the background of the room is a silver screen. When he selects the right key at the switchboard, a life-sized image of the person with whom he is speaking is flashed on the screen at the same time that he hears the voice. The fact that one of his ministers is a lady lends some dramatic color to the incident, but this is beside the point.

A passage of this sort from the pen of a great writer, is significant. The new things that civilization brings into our lives *are not created or invented by anybody in particular:* it seems to be predestined by a combination of circumstances that certain things are going to happen at certain times. Great writers and great statesmen seem to have the first presentiment of what is coming next. Then the inventors and engineers take hold

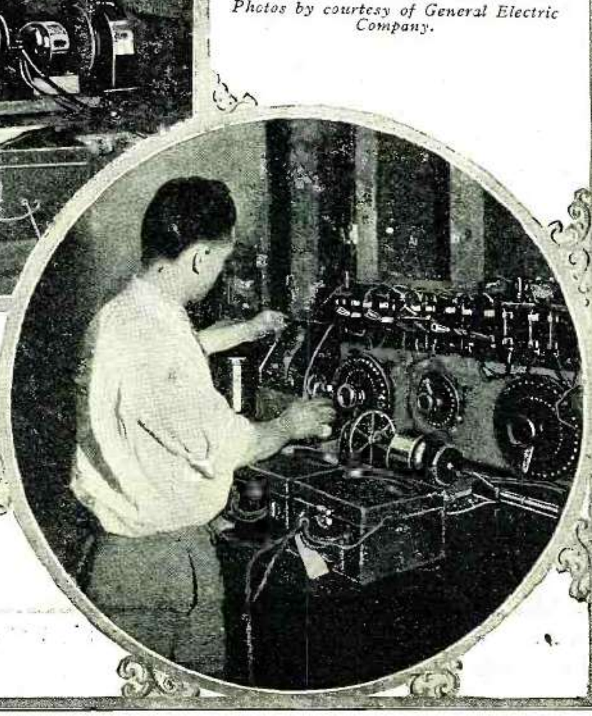
At the right is shown the receiving mechanism of Dr. Alexanderson's apparatus. The cylinder, in which is enclosed the negative, is being removed from the motor attachment that rotates it.

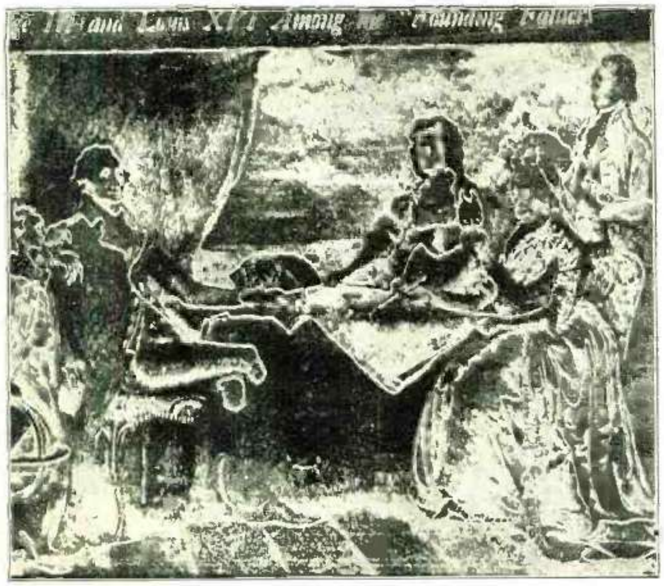


Below is shown the transmitter. The revolving shutter for interrupting the light source is seen under the man's elbow. The impulses are amplified before they are transmitted.



Below is a closer view of Dr. Alexanderson's apparatus for transmitting photographs by radio. The photo to be sent is being placed on the revolving cylinder, which is synchronized with the cylinder at the receiving end. *Photos by courtesy of General Electric Company.*





This distorted picture was made from a newspaper reproduction of a steel engraving of "Washington's Family" by E. Savage. The distortion is due to the improper adjustment of the receiver apparatus. This picture may serve to give a visual idea of the audible distortion sometimes experienced by broadcast listeners.

of the same ideas and dress them up in practical form. It is now several years since Mr. Owen D. Young, at a banquet, expressed his hope that radio would soon give us visual means of communication. The idea seemed at the time absurd to many of the technical men present; but work was promptly started and we have at least gone so far that a commercial radio picture service is in operation across the Atlantic Ocean.

It takes at present twenty minutes to send one of these pictures, whereas the imagination of Bernard Shaw forecasts a *direct* vision of distant moving objects.

From moving-picture practice we know that the realization of this idea would require the transmission of a series of pictures at the rate of sixteen per second. It is a long way from twenty minutes to one-sixteenth of a second. It means that we must work almost twenty thousand times faster than we do now. However, we have tackled this problem; and I shall attempt to show what prospects we have of realizing practical television. In doing so we shall think of the scene described by Bernard Shaw as the ultimate goal.

TELEPHOTOGRAPHY

The principle of picture transmission over wires or radio was worked out about fifty years ago, and all work done at the present time is based on this same principle. The work of fifty years ago, though described in many books and patents, fell into neglect; but the development of radio has renewed interest in the subject. We have also some new tools to work with, such as the vacuum-tube amplifier and the photo-electric cell. Radio photography has thus become an established fact. A practical realization of television, or the art of seeing moving objects by radio, involves some difficulties which have heretofore seemed almost insurmountable.

However, before dealing with the problems of the future, I shall give a brief picture of the contemporary art of telephotography. So much has already been published on this subject that I need give only a few references. Since the interest in telephotography revived, the work has been taken up simultaneously in America, France, England, and Germany, and the names of a number of engineers, Korn, Belin, Jenkins, Ranger, Ives, Karolus, Petersen and Baird among others, have become familiar. I hesitate in giving these names, because there are surely some equally important ones that I have left out.

The accompanying illustrations show some telephotographs made in Schenectady. The originals were made at a rate of sixteen square inches per minute, and thus were produced in two minutes. They were made as a preliminary study of commercial transmission of pictures and facsimile messages over long distances. The recording instrument used in making these originals is a standard General Electric oscillograph, with some adaptations, the availability of this highly developed instrument having made it possible for us to enjoy rapid progress in the development of a practical technique in telephotography. Our energies can now be devoted largely to the main problem, which is the adaptation of the radio art to this new use, and particularly to devise ways of dealing with our old enemies—static and fading—when we wish to transmit pictures over long distances.

STATIC AND FADING

The radio art has, up to the present, developed two distinct methods of signalling: by modulation and by interruption. The first is usually associated with broadcasting and the second with telegraphy. Both of these methods of signalling may be adapted to radio photography, and each will have its distinct field. The effective range of a broadcast station is very much shorter than that of a telegraph station of the same power; but within this range it gives a service of excellent quality. The accompanying samples of pictures were made with a modulation-frequency of 3000 cycles, which can easily be transmitted by the ordinary broadcast stations. It is therefore possible that a picture service may be given by these stations, which will be of the same standard of quality as their musical entertainments.

Freedom from disturbances is insured by having a large number of stations interlinked by a wire system, so that a good selection of entertainment is available in all parts of the country. This method of dealing with static and fading may be characterized as "brute force"; but after all it is this mode of operation that has developed radio into the great industry that it is now. This whole broadcasting machinery is now available, should the public become interested in radio photography for entertainment or otherwise.

For long-distance communication we have, fortunately, another method of using the radio wave, which is much more sensitive and economical. The most striking illustrations of this are the feats of amateur operators in communicating with their friends on the other side of the earth with small home-made sets adjusted to short wavelengths. So far this method of signalling has been limited to dots and dashes; but ahead of us are the possibilities of using this wonderful medium of communication to transmit pictures, facsimiles of letters or printed pages and moving-picture films. These fascinating possibilities have induced so many investigators to work on this problem.

In our research work on the development of radio photography and television, we have

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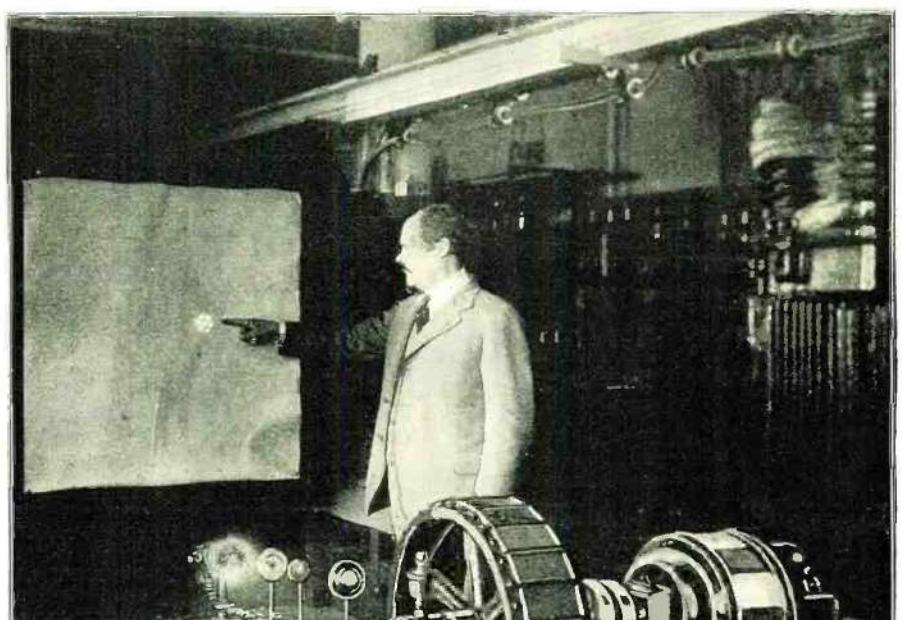

Fig. 2. Dr. Alexanderson in his laboratory indicating the seven light-spots, which are used in the method proposed by him for television. In the foreground is the drum on which are mounted the mirrors, with the motor for rotating it. A system of lenses may be seen, together with an arc light.

What's New In Radio

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Mechanically, this new panel is very strong, while it can be easily drilled with either wood- or metal-drills and cut with ordinary saws. The material lends itself readily to embellishment, and may be treated with lacquer, solid colors and imitation marble and antique designs. Decalcomanias or transfers may also be used on it, as well as various processes of engraving, lithographing, stencilling, etc.

The material is stated to have a dielectric constant of 4, the same as that of hard rubber. According to tests made on samples of it in a large mid-Western technical laboratory, it has a resistance of 746,000 megohms per cubic centimeter.

A Three-Foot Roll-Type Speaker

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but it has no strength unless formed into a cone or roll, after which it serves as an excellent diaphragm. In the cone the vibrations are applied at the apex and waves radiate outward; in the roll speaker the transition between vibratory and undulatory motion is more gradual, giving it a distinctive tone of its own, not found in other speakers.

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looked upon the adaptation of the telegraphic method of communication to picture transmission as one of the essential problems. A system has been worked out for transmitting half-tone pictures in a way which takes advantage of the more efficient methods used in radiotelegraphy. The underlying principle which makes this possible is the use of a system of signalling in which the results are independent of the signal strength. Thus, if the signal is strong enough to be recorded at all, it gives the same kind of records at the maximum as at the minimum signal intensity. This makes the recording independent of fading. If, furthermore, the signals are stronger than the prevailing static, it is possible to eliminate the effects of static by introducing a *threshold value* of signal strength in the receiver, so that nothing is received unless the signal exceeds this value.

THE MULTI-SHADE PROCESS

"Half-tone" effects are produced by dividing up the picture into five or more separate shades such as white, light gray, medium gray, dark gray and black. The transmitting and receiving machines analyze and reassemble these shades automatically. Various methods may be worked out for translating light intensities into radio signals. One method would be to use five wavelengths, one for each shade. The pictures that are shown here have, however, been made by a process utilizing a single wavelength.

The transmitting machine is made in such a way that it automatically, at every moment, selects the shade that comes nearest to one of the five shades, and sends out a telegraphic signal which selects the corresponding shade in the receiving machine. This sounds more complicated than it really is, because the telegraphic code by which different shades are selected depends upon the synchronization of the two machines, which is necessary under all circumstances. Thus black in the picture is produced by exposure of the sensitive paper to the recording light spot during four successive revolutions; whereas light gray is produced by a single exposure during one of the four revolutions and no exposure for the three succeeding revolutions. The overlapping exposure is progressive and the thing is a continuous process.

TELEVISION

When we embark on such an ambitious program as television, it behooves us to reason out, so far as it is possible, whether the results we expect to get are going to be worth while, even if our most sanguine hopes are fulfilled. We have before us a struggle with imperfections of our technique, with problems which are difficult, but which may be solved. In every branch of engineering there are, however, limitations which are not within our control. There is the question whether the medium with which we are dealing is capable of functioning in accordance with our expectations and desires.

We are dealing with the photoelectric cell, the amplifier, the antenna and the radio wave. The photoelectric cell and the amplifier employ the medium of the electron, which is extremely fast; but the use of the radio wave itself imposes certain speed limitations on account of the limited scale of available wavelengths. The question therefore remains: what quality of reproduction may we ultimately expect in a television system if we succeed in taking full advantage of the ultimate working speed of the radio wave? An experimental study of the problem and the conclusions may be illustrated by the comparison of some pictures made at different speeds.

The three pictures shown in Fig. 1 were made with the selective-shade process, under conditions which reproduce the characteristics of one of our long-wave transatlantic transmitting stations with a wavelength of 12,000 meters, or a wave-frequency of 25,000 cycles. The picture at the left is the result we get if the time of transmission is two minutes. For the middle picture the transmission time is four minutes and for the picture to the right eight minutes. Everything else in the three cases is identical. Relatively, these pictures represent the effect of the sluggishness of the tuned antenna upon the sharpness in the reproductions. The two-minute picture is not as sharp as the eight-minute picture. With this particular subject we may be satisfied with a two-minute picture; but with other subjects containing more details it would pay to use eight-minute transmission time.

However, if we wish to draw conclusions regarding the practicability of television, we may say that if we are speaking with a friend across the ocean and if we can see his features as clearly as we do in this two-minute picture, we will be satisfied, and probably quite pleased. This picture has been produced, as accurately as we can determine by laboratory equivalents, with a wave of 25,000-cycle frequency.

Now (if we let our imaginations loose) we will use a wavelength of twelve meters instead of 12,000 meters, and a frequency of 25 million cycles instead of 25,000 cycles. If the photoelectric cell and the amplifier and the light control can keep up with this pace, the radio wave will do its part and transmit a picture, such as seen here, in 1/1000th part of two minutes; *i.e.*, in one-eighth of a second. We are thus able to predict that it will be possible to transmit a good picture in a space of time which is of the order of magnitude of the time required for moving picture operation, the exact figure being one-sixteenth of a second.

TELEVISION PROJECTOR

But Bernard Shaw's specification has one more requirement. He wants the television picture shown, life-size, on a large screen. In this lies one of the fundamental difficulties.

Fig. 2 shows a model of a television projector, consisting of a source of light, a lens and a drum carrying a number of mirrors. When the drum is stationary, a spot of light is focused on the screen. This spot of light is the brush that paints the picture. When the drum revolves, the spot of light passes across the screen. Then, as a new mirror, which is set at a slightly different angle, comes into line, the light-spot passes over the screen again, on a track adjacent to the first; and so on until the whole screen is covered. If we expect to paint a light-picture of fair quality, the least that we can be satisfied with is ten thousand separate strokes of the brush. This may mean that the spot of light should pass over the screen in one hundred parallel paths, and that it should be capable of making one hundred separate impressions of light and darkness in each path. If we now repeat this process of painting the picture, over and over again, sixteen times in a second, it means that we require 160.000 independent strokes of the brush of light in one second. To work at such a speed seems at first inconceivable; moreover, a good picture requires really an elemental basis of more than 100 lines. This brings the speed requirements up to something like 300,000 picture-units (dots) per second.

Besides having the theoretical possibility of employing waves capable of high-speed signalling, we must have a light of such brilliancy that it will illuminate the screen effectively, although it stays in one spot only 1/300,000 of a second. This was one of the serious difficulties; because, even if we take the most brilliant arc-light we know of, and no matter how we design the optical system, we cannot figure out sufficient brilliancy to illuminate a large screen with a single spot of light. The model television projector was built in order to allow us to study the problem and to demonstrate the practicability of a new system, which promises to give a solution of this difficulty.

Briefly, the result of this study is that, if we employ seven spots of light instead of one, we will get 49 times as much useful illumination. Offhand, it is not so easy to see why we gain in light by the square of the number of light-spots used, but this can be explained with reference to the model. The drum has twenty-four mirrors and, in one revolution of the drum, one light-spot passes over the screen twenty-four times; and when we use seven sources of light and seven light-spots we have a total of 170 light-spot passages over the screen during one revolution of the drum.

ADVANTAGE OF MULTIPLE LIGHT-RAYS

The gain is using seven beams of light in multiple is twofold. In the first place, we get the direct increase of illumination of 7 to 1; but we have the further advantage that the speed, at which each light beam must travel on the screen, has been reduced at a rate of approximately 7 to 1, because each light-spot has only 24 tracks to cover instead of 170. While the light itself may travel at any conceivable speed, there are limitations of the speed at which we can operate a mirror-drum or any other optical device; and the drum with 24 mirrors has already been designed for the maximum permissible speed. A higher speed of the light spot can therefore be attained only by making the mirrors correspondingly smaller, and mirrors one-seventh as large will reflect only one-seventh as much light. The brilliancy of the light-spot would therefore be only one-seventh of what we realize by the multiple beam system, which gives seven light-spots seven times as bright, or 49 times as much total light.

There is another advantage in the use of the multiple light-beam; each light-beam needs to move only one-seventh as fast and therefore needs to give only 43,000 instead of 300,000 independent impressions per second. A modulation speed of 43,000 per second is high with our present radio practice; but yet it is within reason, being only ten times as high as the speed we use in broadcasting.

The significance of the use of multiple light beams may be explained from another point of view.

It is easy enough to design a television system with something like 40,000 picture units per second, but the images so obtained would be so crude that they would have very little practical value. Our work on radio photography has shown us that an operating speed of 300,000 picture units per second will be needed to give pleasing results in television. This speeding up of the process is, unfortunately, one of those cases in which the difficulties increase by the square of the speed. At the root of this difficulty is the fact that we have to depend upon moving mechanical parts.

If we knew of any way of sweeping a ray of light back and forth without the use of mechanical motion, the answer might be different. Perhaps some such way will be discovered, but we are not willing to wait for a discovery that may never come. A cathode ray can be deflected by purely electromagnetic means, and the use of the cathode-ray oscillograph for televisions has been suggested. If, however, we confine our attention to the problem as first stated, of projecting a picture on a fair-sized screen, we know of no way except by the use of mechanical motion. If we also insist upon a good image, we find that we must speed up the process seven times and, in doing so, we must reduce the dimensions so that we will have only one-forty-ninth as much light.

SEVENFOLD TELEVISION APPARATUS

Our solution to this difficulty is, not to attempt to speed up the mechanical process, but to paint seven crude pictures simultaneously on the screen and interlace them optically so that the combination effect is that of a good picture.

Tests have been made with this model television projector, to demonstrate the method of covering the screen with seven beams of light working simultaneously in parallel. The seven spots of light may be seen on the screen as a cluster. When the drum is revolved these light-spots trace seven lines on the screen simultaneously, and then pass over another adjacent track of seven lines until the whole screen is covered. A complete television system requires an independent control of the seven light-spots. For this purpose, seven photoelectric cells are located in a cluster at the transmitting machine and control a multiplex radio system with seven channels. A Hammond multiplex system may be used with seven intermediate carrier waves, which are "scrambled" and sent out by a single transmitter, and then unscrambled at the receiving station so that each controls one of the seven light beams.

Seven television carrier waves may be spaced 100 kilocycles apart, and a complete television wave band should be 700 kilocycles wide. Such a radio channel might occupy the waves between 20 and 21 meters. If such use of this wave band will enable us to see across the ocean, I think all will agree that this space in the ether is assigned for a good and worthy purpose.

How long it will take to attain this end I do not venture to say. Our work has, however, already proven that the expectation of television is not unreasonable and that it may be accomplished with means that are in our possession at the present day.

The "Ham"

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nor those above 600. But then, who knew but that the increase in the number of broadcasting stations might force the government to open the higher and lower wavebands for broadcasting, and thus create an instant demand for a universal receiver? He firmly believed that he could create and market such a receiver, but one day seemed an inadequate time allowance.

In such times of stress and strain, the mind and muscles follow routines established by habit. Bixby continued to twist the dials, without being more than half conscious of what he was bringing in. At the moment when Mrs. Bixby arrived to deliver, personally, her ultimatum, he had been working on the short-wave end of his receiver.

Short waves intrigued him. Radio itself is the miracle of the ages, but short waves are a miracle of miracles. Gigantic transmitting stations, costing millions of dollars and using the highest power developed by modern generators, send their long waves, from aerials miles in length, to maintain communication with the nearest stations on the other side of the ocean. But mere boys, fifteen and sixteen years of age, build short-wave transmitters, costing less than a hundred dollars and using less power than an ordinary electric lamp, and reach India, Australia, and other points on the other side of the earth, almost at will.

Bixby's short-wave receiver had often brought in the ham stations of the antipodes. He idled now with the tuning controls to see who might be "on the air" on the far side of the globe. Before long the faint whistle of Australian "a6KX" cut through the barrage of American stations, as the boiled owls went to roost. The "Aussie" was working some station in Africa whose call letters Bixby did not catch, as he had not picked up the Australian at the start of the message. Bixby reached for a "QSL" card; for he knew that a6KX would be glad to know that his signals were "QSA" in America.

As Bixby's pen rested on the card, ready to write his greeting to his distant brother ham, the latter's message finished with a "K"; which is the operator's invitation to the man at the receiving end to do his share of the talking. Bixby tuned carefully and caught the African's wave. There was a steadiness and business-like quality about it that convinced him the station was built and operated by an engineer, not by a ham who used the "by-guess and by-gosh" method