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THE IMPORTANCE AND TECHNIQUE OF PERFORMANCE MEASUREMENTS ON RADIO-TELEPHONE TRANSMITTERS

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The transmission of intelligence by radio, whether that intelligence be in the form of an entertainment program or a definite message, depends upon some form of modulation of a so-called carrier wave. By modulation is meant the process by which the instantaneous character of the carrier is made to change in accord with the variations of the intelligence to be transmitted. The character of the modulated wave may be completely defined for a particular instant if the phase, frequency and amplitude at that instant are known. For radio-telephone transmission, at least, experience has seemed to indicate that the most suitable form of modulation is achieved by varying the instantaneous carrier amplitude in response to the variations of the signal energy to be transmitted. Experience has likewise indicated that it is desirable to maintain the carrier frequency and phase as nearly constant as possible during the modulation cycle.

Amplitude modulation of a constant carrier-wave by a complex signal wave results in the production of side-bands of variable width and amplitude. These side-bands are displaced from the carrier on both sides by a frequency interval equal to the modulation frequency at a particular instant. The amplitude of the side-bands is determined solely by the degree of modulation.

Since the intelligence-bearing portion of the modulated wave is not the carrier but the side-bands, it follows that the greater the side-band amplitude the greater is the ratio of useful power to the total output power. For a completely modulated wave, that is one modulated 100 per cent, two-thirds of the total power is concentrated at the carrier frequency with the remaining one-third in the side-bands. The signal energy varies between this one-third maximum and zero directly as the square of the modulation degree.

If the side-band power is calculated as a function of modulation degree it is found that the following relations hold:

MOD. DEGREE	% TOTAL POWER CARRIER	% TOTAL POWER SIDE-BANDS
0	100	0
25	97	3
50	89	11
75	78	22
100	66.6	33.3

In a wave modulated 25% only 3% of the total power is useful signal producing power. A 100% modulated wave delivers 11 times as much signal energy as one modulated 25%. Certain general rules may be set down as follows:

1. Doubling the modulation degree for a given carrier power doubles the signal level without increasing the nuisance field.

2. Doubling the carrier power while holding the modulation degree constant results in a signal level increase of only 41.4 per cent and in an equal increase of the nuisance field.

3. To obtain a signal level increase equivalent to that obtained by doubling the modulation degree, holding carrier power constant, requires a carrier increase to a value four times the original, maintaining the same modulation degree. In other words, doubling the modulation degree pays the same dividend in signal level as a four to one carrier power increase.

Thus it appears that both the relative and absolute efficiencies of radio telephone transmitters are directly dependent on the modulation degree and will be the maximum obtainable for the condition of complete modulation.

Were efficiency the only condition with which the station engineers are concerned it would be a simple matter to adjust input signal level to a value sufficient for complete modulation and let matters take their natural course. Unfortunately

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the processes whereby modulated radio frequency energy is generated and amplified involve the use of elements which inherently are non-linear. Such non-linearity results in the production of distortion of the original signal wave which appears in the form of measurable harmonics of the signal frequencies. For high quality transmission these harmonics must be reduced to limits at which the distortion is not perceptible to the ear. In the processes under consideration this distortion is primarily an amplitude function, that is, the harmonic amplitudes depend on the length of the portion of the non-linear characteristic traversed during the modulation cycle. This, in turn, is directly a function of the modulation degree and we are thus brought to the term "modulation capability". As defined, the "modulation capability" of a transmission system is that modulation degree which can be attained without exceeding the distortion limit which has been determined to be acceptable for a particular class of service. "Modulation capability" is not a term which can be indiscriminately applied without specific stipulation of the acceptable distortion limit for the class of service in question.

Useful modulation and the only modulation in which operators of high quality radio-telephone stations can be interested, is that modulation which does not exceed the capability of the transmission system. What that capability must be can only be determined after the permissible amount of distortion has been ascertained. This capability as determined will not represent efficient use of channels or transmission plants unless complete modulation can be attained. At present, the minimum capability acceptable to the Federal Communications Commission is that in which a modulation degree of 75% can be attained without the production of combined harmonics in excess of 10%. It is certain that with increasing activity in the field of high fidelity this requirement will be made more stringent with respect to the allowable harmonic content, and perhaps, in the interest of efficiency to the absolute modulation degree attainable as well.

The acceptability of the service of any station depends, aside from purely artistic considerations, upon the ratio of the wanted signal output to the total extraneous noise output at the receiving loudspeaker. Measurements seem to indicate that this ratio must be at least 1000 to 1 for high quality service. Extraneous noise originates at several points in the transmission system. Switching transients, shot-effect in vacuum tubes and thermal agitation in associated tube circuits, insufficient filtering of power supplies and modulation by mechanical shock all combine to cause noise modulation products to appear in the output wave. At the receiving end of the system local interferences from various discharge devices, loose and vibrating contacts between metallic surfaces and poor filtering of receiver power supplies combine with interchannel interference and heterodyning effects to increase the apparent carrier noise on the wanted signal. The transmission engineer can control the absolute level of the noise originating in the transmission circuits by proper design and treatment at the source. Furthermore, the relative noise level may be reduced by maintaining the modulation as nearly complete as possible. While control at the source of the noise originating in the transmission medium and the receiving end of the system is denied, in-so-far as absolute noise level is concerned, the relative level may be reduced by consistent maintenance of high modulation degree at the transmitter.

It would appear, then, that the case is clear for the requirement that the modulation capability of transmission systems be raised to the absolute physical maximum as regards modulation degree and that under this condition of complete modulation the total harmonic content be within the limits found to be acceptable for the particular class of service. High quality broadcasting would seem to require that total distortion be less than 5%. In no case should the practice of reducing distortion at the expense of absolute modulation degree be followed.

That the need exists for improvement all along the line is amply indicated by the results of measurements made on 69 stations East of the Mississippi by our engineers last year. In most cases the figures represent actual capability of the transmission system defined as that modulation degree which could be obtained without noticeable shift of the mean carrier amplitude during the modulation cycle. The stations are rated in five classes as follows:

CAPABILITY RATING	% IN EACH CLASS
Less than 25%	4.3
25 to 50%	34.8
50 to 75%	47.7
75 to 100%	10.2
100%	2.9

Included in this group are fifteen 100 watt, eight 250 watt, twelve 500 watt, sixteen 1 kilowatt, seven 5 kilowatt, one 10 kilowatt, three 25 kilowatt and seven 50 kilowatt stations.

The average capability for the whole group is 60% with the average within each power class about the same throughout.

It is not and cannot be the purpose of a paper of this nature to treat rigorously with the exact technique involved in the making of performance measurements on transmission systems. Rather it is desired to review the current methods in a general way and to indicate the possible inaccuracies of each together with the requirements which must be met if reliable results are to be obtained.

1. Modulation Measurement:

The measurement of the degree of amplitude modulation involves not the measurement of a physical quantity but rather a ratio. This ratio exists between two quantities in the same dimension and hence may be determined at any absolute level.

Methods of modulation measurement fall into two classes depending upon whether measurement is made before or after demodulation of the envelope of the output wave.

Into the first class, that is where measurement is made prior to demodulation, fall the methods involving the cathode-ray oscillograph, direct-reading peak voltmeter and the thermo-galvanometer.

The cathode-ray method permits the observation of a trapezoid the shape and dimensions of which furnish some information. This method has two inherent drawbacks. Accurate scaling of image dimensions is difficult if not impossible. In a pattern 1 square inch in area the normal double trace width can be responsible for an error of approximately 12%. Furthermore, as the operator proceeds in measurement from the condition of no modulation to the desired test condition with modulation it is impossible to detect a shift of the boundaries of the unmodulated pattern. Since the width of this pattern is the reference level of the unmodulated carrier, it is essential that that width remain constant during the modulation cycle. The process of measuring the long side, subtracting the length of the short side and dividing by 4 is fallacious in that it yields absolutely no information as to the symmetry of the modulation. Performing this process on a pattern obtained under the condition of 25% positive and 75% negative modulation yields the mathematical value of 50% which in the absence of evidence to the contrary is taken to mean that a symmetrical modulation of 50% is actually being obtained.

The only way in which such a method can be trusted to yield reliable indications is to use an auxiliary carrier-shift indicator. Pursuing the use of the method beyond the point where carrier-shift becomes evident is useless.

The direct-reading peak voltmeter used either before or after demodulation possesses the same inherent fault. It has an advantage over the oscillographic methods in that it is not subject to scaling and trace-width errors.

Perhaps the worst method from the standpoint of possible error is that in which a thermo-galvanometer is used as a direct indicator of modulation degree. True, on purely sinusoidal test tone and in the complete absence of carrier-shift the indications thus obtained will furnish valuable information simply and quickly.

The type of modulation here discussed is an amplitude function. Maximum amplitudes must be determined if proper evaluation of modulation degree is to result. It is obvious that this method fails in the presence of complex wave modulation since only effective and not maximum values are indicated by a thermal instrument. The blind use of such a method with complex wave modulation and in the absence of carrier-shift indication can lead only to results erroneous in the extreme.

Methods of measurement which involve the process of demodulation possess all of the foregoing possibilities for error plus that resulting from non-linearity in the demodulator.

Perhaps the most satisfactory and accurate modulation measuring equipment is based on the principle of measurement after demodulation and incorporates a carrier-shift indicating device together with some form of peak voltmeter--preferably direct reading.

2. Distortion Measurement:

The determination of the modulation capability of the transmission system necessitates the simultaneous measurement of both modulation degree and harmonic content. The methods of modulation measurement have been outlined.

Total harmonic content may be evaluated as a lumped quantity directly or by the mathematical combination of the various harmonic amplitudes measured separately.

For general use in which quantitative results are sufficient the method of determination of distortion as a lumped factor is most satisfactory. Briefly, the method consists of segregating the harmonics from the fundamental by means of differential filter systems and evaluating the total harmonic root-mean-square amplitude in terms of the fundamental amplitude. The result multiplied by 100 yields the harmonic content as a percentage directly. Granted that the filter systems are correctly designed as to cut-off, image impedance and working level it is still necessary to be certain that the demodulator preceding the differential system is strictly linear and that the amplifier interposed between the filters and the output indicator is linear with respect to both amplitude and frequency. The output indicator must be a strictly square-law device if the true root-mean-square value of the harmonics is to be indicated. Furthermore, the source of test frequency must produce an absolutely pure wave.

This method has the disadvantage that it is limited to measurements at a single frequency. Unless the elements in the transmission system remain constant with frequency, measurements of capability at one modulation frequency do not necessarily indicate the true capability at any other. If, however, the system will modulate consistently in the absence of carrier-shift over the entire signal-frequency range, it is reasonably safe to rely on single frequency distortion measurements as a true indication of capability.

For rigorous measurements of distortion some form of wave analyzer is necessary. Separate harmonic amplitudes can be measured and combined mathematically as the square root of the sum of the squares of each to yield the true value of the combined distortion. Of course, the same requirements are placed on auxiliary equipment as in the case of the first method.

A carrier-shift indicator, while not capable of measuring distortion, is nevertheless the most reliable and fool-proof tool available for capability determinations. Carrier-shift is absolute evidence that non-linearity and hence distortion is present in the system. The converse is not necessarily true because a perfectly linear system will still pass freely all distortion present in the source.

Unfortunately the correlation of carrier-shift with quantitative distortion is not as simple as it would appear. A given carrier-shift at one modulation degree represents an entirely different distortion condition than does the same amount of carrier-shift at some other modulation level. If a carrier-shift indicator is to yield quantitative results it will be necessary to provide a complete family of characteristics of distortion versus carrier-shift for many convenient values of modulation degree. Measurements made so far indicate that this is entirely practicable. In general, the lower the absolute modulation level the greater the distortion for given amounts of carrier-shift.

Fourier analyses of oscillographic traces are limited for quantitative purposes by the same inherent inaccuracies indicated in the discussion of oscillographic devices as modulation indicators. If anything, errors are even more serious from these sources in distortion measurement than in the case of modulation measurement.

3. Carrier Noise Measurements:

Carrier noise can be measured directly as a modulation degree of small magnitude or in terms of a ratio to a given reference modulation level.

The measurement of noise directly and quantitatively involves tremendous difficulties if gross inaccuracies are to be avoided. When it is realized that a noise level 60 Decibels down from a 100% modulation level corresponds to an absolute noise modulation of only 1/10 of 1% the problems involved in such methods of measurement will be better recognized. Furthermore, noise in the measuring equipment itself can, without careful design, easily be greater than the noise which it is desired to measure. It is not felt that direct measurement of carrier-noise is practical.

Relative or comparison methods have the advantage that resistance attenuators, which can be made exceedingly accurate, can be used. They form the only variable element in a properly designed system. Errors from noise in the measuring set-up cancel out in the process of comparison measurements. Furthermore, the range of an attenuator can be carried to limits permitting measurement of magnitudes far beyond the capability of direct methods. It is a simple matter to convert a ratio in terms of Decibels to the actual noise modulation level if desired.

If such a measuring system is to be used certain precautions in design are necessary. The system as a whole must have a high, stable and controlled gain. The frequency response must be uniform and comparatively wide--preferably from about 25 to 10,000 cycles per second--due to the fact that tube noises and circuit noises have components lying in the upper speech frequency range. The variable element, the attenuator, must be capable of variation in small steps--say 1 Decibel. The output indicator must possess a strictly square-law characteristic if the true root-mean-square value of the noise modulation products is to be accurately indicated.

If high quality broadcasting is to progress as much in the future as it has in the past a rigorous routine of performance measurements must be a definite part of the duties of the operating staff. New wide range receivers, when and if they are made available to the public are bound to cause adverse criticism of many of the services now being accepted as satisfactory. Not only must technical equipment of suitable design be provided the operating engineer but some judgment be used in the initial selection of operators. This will require a more careful attention to the capabilities of persons supervising operation at transmitting plants. Too many now so employed are content to throw the burden of monitoring programs on the control room staff. It seems that a transmitter operator should be held responsible for overmodulation and poor quality originating beyond the control of the studio personnel.

DISCUSSION

At the conclusion of the reading of the paper the meeting was thrown open to discussion by President Houck.

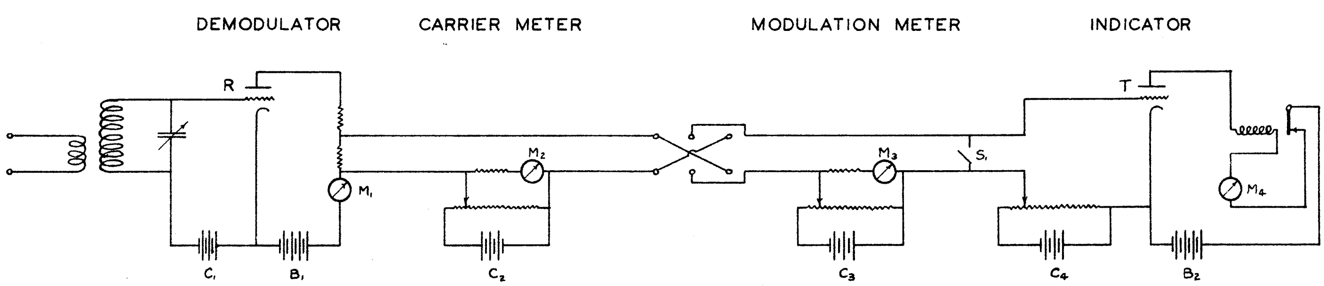
Inquiry was immediately directed toward the details of the apparatus suited to making the measurements the need for which was the point of Mr. Lent's paper. In reply to a specific request as to the nature of the apparatus used for measurement of carrier magnitude shift, Mr. Lent showed the following circuit arrangements and discussed their functions and usefulness.

The modulation meter consists essentially of a linear rectifier and appropriate circuits and apparatus for the measurement of the ratio of that portion of the rectifier output which is proportional to the carrier to that portion of the rectifier output which is proportional to the low-frequency variation of the high-frequency envelope resulting from the process of modulation. It differs largely from circuits and apparatus commonly employed for this purpose in the use of a triode rectifier, and in the use of a thyratron as the indicator of balance in the measuring system.

It was pointed out by Mr. Lent that while the high internal impedance of the conventional triode-- as against that of a diode of the same dimensions more commonly used for this purpose-- requires that an extremely high resistance be employed for the plate load of the triode, with the consequent problems incidental to the maintenance of the insulation resistance at appropriately high values, the advantages to be gained through the isolation of the plate, or measuring circuit from the grid, or signal circuit, well justified the employment of the necessary precautionary measures in the design and the operation of the device.

The operation of the thyratron indicator circuits was explained as follows: Since the problem of the measurement of the modulation degree is essentially that of the balancing of the several potentiometer voltages with those available at the rectifier output, the problem reduces itself to one of determining a voltage balance. In the past simple indicating instruments have been used for this purpose, and have brought with their use several unavoidable limitations on the precision of the determination of balance. Outstanding amongst these, is the fact that where an instrument of sufficiently low current sensibility to avoid the need for frequent replacement is used, the determination of balance is necessarily poor, and, in any event, conventional meters all suffer from so high a degree of inertia that they are useful only when a repetitious form of modulation is employed, such as simple tone modulation.

Where the degree of transient modulation, such as speech and music, is to be measured, conventional measuring instruments, per se, are completely unsuitable and an indicator of negligible inertia is essential. Such a low inertia indicator is provided in the thyratron. When once the potentiometer, C_4 is so set that plate-circuit current barely does not flow, only an extremely minute reduction of the thyratron grid bias, for the barest instant of time, is required to initiate plate current after which it continues to flow until manually or automatically interrupted, and the previous critical conditions reestablished.



Provision for the preliminary adjustment of the thyratron operating conditions is provided through the use of the isolating switch, S_1, which when closed provides for the adjustment of the battery, C_4, to the lowest value of negative bias on the thyratron grid at which no plate current flows. The relay in the plate circuit provides a closed circuit for the plate current that will later flow and make itself evident by the meter, M_4, and the operation of the relay.

Once this adjustment has been made, the balance of the local d-c voltage available from C_2 for the determination of the relative value of the carrier amplitude, and the balance of the d-c voltage available across C_3 for the determination of the relative value of the modulation amplitude, may be determined with unusually high precision.

The scales of meters M_2 and M_3 are so chosen as to give a direct reading of the per cent modulation on M_3 .

Mr. Lent pointed out that not only did the equipment provide for the measurement of the degree of modulation, but provided for the determination of frequency with which the modulation exceeded any value for which the apparatus might be set. The thought was contributed by the membership that by the addition of a simple electrical counter to the plate circuit of the thyratron, the system might then integrate the number of such excesses of modulation, and by the further addition of an electric clock movement carrying appropriate recording discs it might time such excesses.

Considerable discussion of the degree with which so essentially a power series device as the electron tube could approach strict linearity brought out from Mr. Lent the fact that, in so far as his measurements were able to reveal it, there was no departure from strict linearity in the triode rectifier included in the equipment.

The discussion soon turned to the matter of high fidelity transmission in connection with which it was brought out that broad frequency response is only a part of the high-fidelity program, and that of almost equal importance is the matter of dynamic range. It was recalled that during the Bell Laboratories demonstrations last spring it was shown that a full orchestra has a dynamic range of at least 70 db. As against this, the average broadcasting station can transmit a dynamic range of only about 20 db.

The studio operator, in a modern broadcasting plant, is the man who is charged with the responsibility for seeing that the actual dynamic range that goes out from the studio to the station does not exceed the capabilities of the station. To do this successfully requires rehearsal of the program, so that the points of greatest intensity or highest level may be noted on the cue sheet, and proper notes made as to how the level is to be controlled during the program. The level must be cut down gradually and well in advance of the loud passages, if the audience is to get as much of the dynamic range as the apparatus will permit without overloading and distortion either at the transmitter or receiver.

At the upper limit of the dynamic range there is the modulation capability of the transmitter. At the lower limit there is the noise level. If these were, let us say, 100 db apart, so as to leave a factor of safety over anything that even the full orchestra can do, the measurements outlined in Mr. Lent's paper would be far less important. The fact is, however, that the dynamic range of the transmitter is less than one-third of what it should be, even when all the equipment is in the best possible order. Additionally, the modulation capability tends to fall, and the noise level tends to rise, unless the station is expertly maintained, and this requires frequent and precise measurement of each of these quantities, with the most accurate and convenient apparatus that can be secured.

Nothing can be more detrimental to the full enjoyment of the best programs than to have overmodulation and distortion occur, even if only for an instant, at those very points in the score that represent the climatic heights of the music. To have the quieter and more contemplative passages obscured below the noise level is only a slightly lesser evil. Expert handling of the studio gain controls, based on a complete and current knowledge of the capabilities of the station, is therefore a primary requisite in the high-fidelity campaign.

Mr. J. H. Miller

The discussion has brought out the fact that the majority of rehearsed programs will have a cue sheet correctly marked with the position of the gain control for the various parts of the program. The gain control position is presumably set for that value which gives maximum modulation without exceeding 100% at any time due to orchestral crashes or other peaks.

At the same time it must be realized that many programs can not be rehearsed. This obviously applies to running accounts of sports events and to certain studio features. It is here that the volume level indicator, integrating over certain time periods, becomes of value.

The device described by the speaker which indicates that modulation has exceeded 100%, indicates only after the event occurs; the commercial volume indicators indicate continuously.

A considerable gain in the available control is now had through the use of level indicators with varying speeds. Through the use of a pair of these instruments, one slow speed unit with a period of about 1.5 seconds and the other a high speed unit with a period of about 0.3 second, a reasonably good control may be had over a program. The instrument with the longer period is usually kept as high as possible so that the maximum use of the facilities may be had. The high speed instrument which will indicate peaks must be kept below the overload point, usually arranged well up on the scale, and by thus watching both instruments a reasonably good monitoring job may be done. It would seem that with these two instruments, a cue sheet, and a device giving a record of overload peaks, we would have the best possible arrangement of equipment to give a high quality program and at the same time make use of the available facilities to the utmost.

It is believed that the speaker's statement that absolutely no overloads should even be tolerated would result in operating a station at too low a modulation level. If we will allow an occasional modulation peak of over 100% we will immediately arrive at a reasonable compromise between the maximum use of facilities and a program of general high quality and such a reasonable compromise would seem to be the optimum condition.

Mr. W. C. Lent

I have read Mr. Miller's discussion and it occurs to me that he missed somewhat the purpose for which the modulation measuring system discussed was intended.

That apparatus is not intended for everyday monitoring purposes but rather to enable the supervisory staff to check the operation of a station in the hands of the operators. For station use an entirely different type of modulation meter is more suitable. This instrument actually indicates modulation degree directly and continuously during the program. Obviously this meets the objection of Mr. Miller. The system under discussion was not presented as one suitable for monitoring purposes which fact apparently Mr. Miller did not understand.

Mr. E. A. Tubbs

It seemed to be the consensus of opinion that a transmitter should be allowed to pass beyond its modulation capability on occasional signal peaks, the point at issue being to what extent it should be allowed to so overmodulate.

From personal observation I have found that a station, which may seem to have no noticeable distortion when properly tuned in, may at the same time be causing serious interference with a weak signal on an adjacent channel. It seems to me that this should be given serious consideration when deciding how far and how often a transmitter be allowed to overmodulate. If this adjacent channel interference is kept to a low value then I do not believe a station need worry about the amount of distortion its signal is undergoing.

This seems to me to be doubly important in as much as the lack of fidelity with which a station reproduces its program is mainly harmful to itself; but when it creates adjacent channel interference it is in effect destroying the fidelity of stations on neighboring channels, for listeners located near the offending transmitter.

While it may be true that there are very few receivers capable of receiving a weak signal on a channel adjacent to that of a powerful local station, yet such receivers can be built and I believe there would be more creative effort expended in this direction if the prevalence of adjacent channel interference were given such more serious consideration as would minimize or eliminate it.

JOINT MEETING

ROCHESTER, NEW YORK
November 12, 13, 14, 1934

RADIO CLUB OF AMERICA

INSTITUTE OF RADIO ENGINEERS

ENGINEERING SECTION R. M. A.

Program of the joint meeting will be forwarded to the membership shortly. In the meantime hotel and other reservations for the meeting should be made by addressing

MR. O. L. ANGEVINE

Rochester Engineering Society

HOTEL SAGAMORE ROCHESTER, N. Y.

Year Book

In view of the fact that 1934 marks the twenty-fifth year of the Club's activities, the Board has determined to commemorate the occasion by a "Twenty-Five Year Book".

That publication will supplement the material of the usual form of year book by a detailed and intimate history of the development of the radio art and industry as participated in by the club members. A questionnaire devised to serve as a basis for such an historical volume has already been distributed to the membership and all are urged to supply the desired data at once. In addition to this data any photographs which will more graphically indicate the part played by the membership in the development of radio are urgently solicited.

June Meeting

The meeting of June 13th was devoted to a paper by Mr. W.G.H. Finch on the adaptation of the conventional Teletype printers to the radio system of the International News Service and on the compact radio printer which he has developed for mobile work.

The membership will be glad to know that one of its number, in the person of Mr. Finch, was appointed to a place on the engineering staff of the Federal Communications Commission and that while the taking over of his new duties has made impossible the completion of his paper for publication as originally scheduled, it is expected that it will appear in the Proceedings shortly.