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Presented before Radio Club of America on October 13, 1953

It is the purpose of this paper to describe some recent developments in multiplex signaling in the F.M. broadcasting field, with special reference to the experimental work that has been carried out in broadcast transmission and reception from Station KE2XCC[1] at Alpine, New Jersey. The transmissions from Alpine to which this paper is specifically directed began in April, 1948. The development of the equipment which is employed began with the termination of hostilities in World War II and was carried out at the Marcellus Hartley Research Laboratory at Columbia University.

HISTORICAL:

The subject of "multiplexing" in radio signaling is an old one, dating back, in fact, to the days of Marconi's "syntonic" radio signaling experiments in the year 1900 with spark transmitters. The term was originally applied to the simultaneous transmissions of two or more spark transmitters (the only workable transmitter of the day) through a single antenna system and their simultaneous reception via a single receiving antenna. Selection between the transmissions was limited to the capabilities of the radio frequency circuits of the time. Subsequently, the idea of time division between several transmitters and receivers was advanced.[2] It was proposed to progressively connect each transmitter and its corresponding receiver to their respective antennas for short intervals by mechanical switching arrangements operated synchronously with each other, a crude concept of some present pulse communication techniques. Still later,[3] it was proposed to transmit signals of different audible frequencies on a single wave length, and to separate them on the basis of tone selection circuits. Nothing practical resulted from this proposal.

The first concept of "frequency division" multiplexing, in the form of superaudible subcarrier modulation appears to have been due to R.A. Heising.[4] The system proposed was that of amplitude modulation of a carrier with appropriately spaced superaudible frequencies, which were, in themselves, amplitude modulated by the signals to be transmitted. While of effect for wire line signaling, the ravages of noise and fading appear to have prevented its use in the radio field.

The practical art of multiplexing in radio signaling, we believe, begins with the advent of the wide band system of frequency modulation in 1934. In November of that year, four different sets of signals were successfully transmitted from Station W2XDG located in the Empire State Building, New York City, to Haddonfield, New Jersey, a distance of 85 miles,[5] (41 megacycles). The signals transmitted on that occasion were a musical program on the main channel, a facsimile program on a superaudible subcarrier on a second channel, a synchronizing signal for the facsimile on a third, and a telegraph "order" channel on a fourth subcarrier frequency. Amplitude modulated subcarriers were employed in this instance. Subsequently, two musical programs (the Red and Blue programs of the NBC Network)[6] were simultaneously transmitted, using the same system of subcarrier modulation and still subsequently, (April, 1935) the amplitude modulated subcarrier was replaced by a frequency

* Marcellus Hartley Research Laboratory, Columbia University.

1 Formerly designated W2XMN.

2 Wireless Telegraphy and Telephony - Mazzotta (1906) p. 329 Cohen-Cole System.

3 Wireless Telegraphy and Telephony - Maver (1910) p. 118 Telefunken.

4 Radio Telephony - Craft and Colpitts, Transactions A.I.E.E. February, 1919.

5 "A Method of Reducing the Effects of Disturbances in Radio Signaling by a System of Frequency Modulation" by E.H. Armstrong, Proceedings I.R.E., May 1936.

6 Cited supra.

modulated subcarrier and the same two network programs transmitted with substantially improved results.[7]

These transmissions, while successful according to the standards of the times, would hardly measure up, either to the signal-to-noise ratio, or the quality of reproduction that are now the accepted standard of F.M. broadcasting. Nor would the receiving equipment designed to operate in that ideally untrammeled wilderness of the wide open spectrum spaces of 1934, when there was in existence one wide band transmitter and one receiver only, perform too satisfactorily in the presently well-settled FM territories where in many locations, signals on a score or more different channels may be picked up in a sweep across the dial of an appropriately sensitive and selective receiver.

THE SYSTEM PROBLEM

The problem that immediately confronts us in introducing a workable multiplex system is that of superimposing extra channels on a going broadcasting business which is fitted into an existing and not easily changed governmental allocation pattern - and doing this without affecting the quality of the transmitted wave and without creating disturbances in the receivers that are presently in use. General considerations indicate that a subcarrier frequency of the order of 30 kilocycles which is itself frequency modulated is a suitable compromise for the factors involved. Practical operation with this standard at KE2XCC where the subcarrier is now 27.5 KC has confirmed this. No instance has yet been reported of disturbances to existing receivers, nor have repeated tests with the standard make receivers shown any detectable effect on the main channel. The part of the problem which consists in the superposition of an auxiliary carrier without affecting the transmission on the main channel is not a difficult one, particularly when the modulation on the subcarrier is sinusoidal in character.

The corollary problem, that of keeping the effects of the main channel out of the auxiliary channels is not however, equally simple. This is the real problem in F.M. multiplex broadcast operations. It arises from cross-modulation in both the transmitter and the receiver.

[7] Cited supra.

THE TRANSMITTER PROBLEM:

The effect of cross modulation in transmitters is much more severe in high quality broadcasting than it is in communication circuits, where the criterion is primarily that of the transmission of intelligence. In broadcasting where the transmission is basically for entertainment, more difficult requirements must be met, particularly during the transmission of a separate program on a second channel when a diminuendo or a period of silence of that channel corresponds with a crescendo on the main channel. Experience indicates that cross talk above the level of the background noise of the second channel is objectionable, so that the energy content of the cross modulation with respect to signal level must be held to -50 decibels or less, or an energy content of the order of one one hundred thousandth part of the program level of the second channel. A ratio of 60 db or one part in a million is an attainable goal.[8]

Since the auxiliary channel lies in the 20 to 40 kilocycle band and since the second and third harmonics of the upper half of the main channel modulation fall within that band, it will be clear that the transmitter problem will not yield readily to a solution by any direct method of modulation, for the "free oscillator" type of circuit does not lend itself to the required low distortion level.

Present day practice in FM broadcast transmission indicates that the phase shift method of producing frequency modulation is destined, in the absence of some new discovery, to be the surviving method of modulation. The reasons for this are now well known to everyone. This result became inevitable with the invention by J.R. Day of the Serrasoid[9] type of modulator (which made use of an idea originally advanced by R.D. Kell)[10] that solved completely, for simplex signaling, the one remaining problem of the phase shift method of producing frequency modulation i.e. residual modulator noise.

It is in order here to refer briefly to the nature of the transmitter background noise diffi-

[8] The measure of the cross talk of the first into the second channel is obtained by modulating the first channel at the frequency which produces maximum cross talk in the second when that channel is unmodulated. A deviation of plus and minus 75 KC in the first channel is employed and the cross talk ratio is expressed in terms of the measured value of disturbance in the second channel below the output for full modulation of the second channel.

[9] The Serrasoid F.M. Modulator, Proceedings Radio Club of America, Vol. 26, No. 1 (1949).

[10] U.S. Patent 2,280,707-R.D. Kell.

culty. All phase shift modulators have had to contend with it, and it comes about basically because the limited initial frequency change that can be obtained in a phase shift modulator entails a high degree of frequency multiplication to produce the ultimately required deviation of the transmitted wave. This high order of multiplication has the effect of enhancing those noise frequency modulations that result from the interaction of thermal and tube noise currents with the basic carrier in the oscillator and modulator circuits; hence, an appreciable background hiss level was characteristic of the early phase shift modulators. The noise level of the early modulators (-65 db) was reduced to values that were relatively unimportant for simplex signaling by the invention of the double channel modulator, i.e., to better than -70 db, and with the invention of the Serrasoid to -80 db, a value which may be taken as giving a complete solution for simplex operation.

In multiplex signaling in the broadcast service, however, when an attempt is made to increase the frequency range of modulation, then, even with the Serrasoid modulator, the difficulty again manifests itself. This result comes about because the fluctuation current components lying 20 to 40 kilocycles distant from the oscillator frequency produce correspondingly enhanced frequency deviations within the range of subcarrier channels, and these deviations, after being enhanced by the same amount of frequency multiplication that is required for a 30 cycle modulating frequency, produce a level of background noise in auxiliary channels that is not acceptable. A second difficulty incident to introducing subcarrier modulation on phase shift modulators lies in the cross modulation introduced in the multiplier chain because of the selectivity characteristics required of the multiplier coupling impedances. It is essential that the lower frequency stages be sufficiently selective to eliminate the frequency modulation superimposed on the transmitted frequency at the basic oscillator frequency, a phenomenon that has its origin in the initial multiplier stages. Hence, the selectivity that is needed in the inter-multiplier coupling stages to remove this frequency modulation results in a lack of linearity in the phase characteristic for frequencies required to carry the subcarrier and so gives rise to cross modulation in those stages.

A solution for this difficulty has been found by the segregation of the modulation functions in the manner indicated in Fig. 1, where the modulation and the initial multiplications of the main

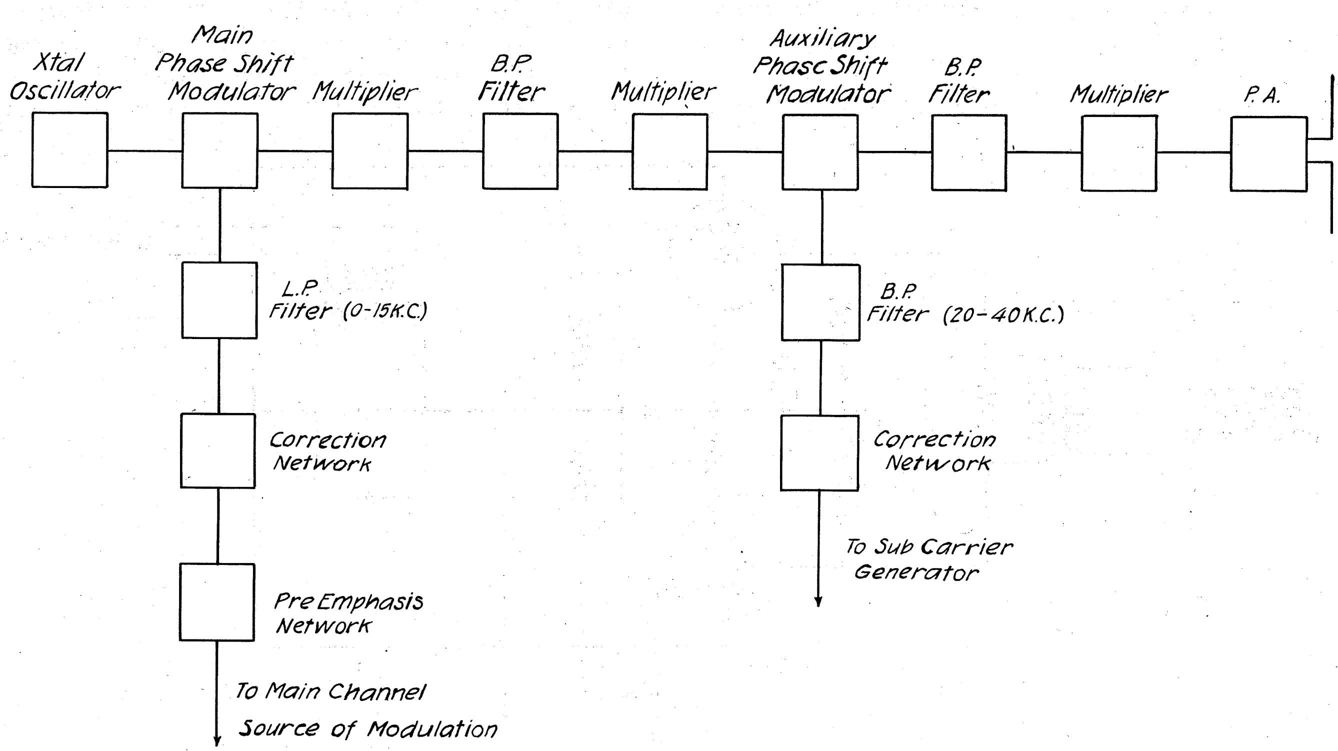


Fig. 1

channel are carried out (with certain modifications) as in simplex operation, and the modulation of the auxiliary channel is super-imposed at a point in the multiplication chain where relatively few additional stages are required to obtain the necessary subcarrier swing at the radiated frequency. An appropriate point for introducing the auxiliary modulation is around the 2 to 3 megacycle frequency range where the amount of phase shift necessary at the subcarrier frequency to produce the required ultimate change in frequency of the radiated wave is of the order of 1° in contrast to that necessary at the modulator for the main channel where approximately 150° phase shift (plus and minus) is employed to obtain the full deviation range for the low end of the modulation current band (30 cycles). As a consequence of this, no linearity problem results from the operation of two phase shift modulators in cascade. A phase shift modulator such as illustrated in Fig. 2 may be employed. The cross-modulation problem in the multiplier coupling stages is avoided because it is possible to make the coupling circuits of the last few multiplication stages quite broad. This can be done as the frequency modulations imposed on the transmitted carrier by the basic oscillator frequency and by the fluctuation disturbances lying in the subcarrier frequency range are no longer a problem at this point. The noise difficulties attendant to operating a wide range modulation frequency system have been avoided by the narrowing down of the band width of the early multiplication stages of the main channel, so that the frequency changes introduced by thermal and tube noise component currents lying more than plus and minus 15 kilocycles from the oscillator frequency are not passed on into the auxiliary channel. The cross modulation problem has been avoided by keeping the two channels separated until the normal circuit bandwidth requirements permit the use of circuits sufficiently wide to insure the necessary phase linearity to prevent the effect.

The principle of the system may likewise be carried out in the manner indicated in Fig. 3 or in some similar combination, although in general, the arrangement of Fig. 1 is preferable. It has been found that with plus and minus 75 kilocycles deviation on the main channel and plus and minus 20 kilocycles deviation on the auxiliary channel, the cross modulation into the second channel for full modulation on the main channel by the most troublesome frequencies can be held in the transmitter to better than -60 decibels. We believe this figure can be lowered.

Although there are a number of ways in which the auxiliary carrier modulating current can be produced, we have adopted at the Alpine transmitter the method illustrated in Fig. 4, making use of a Serrasoid modulator of standard design, which multiplies the frequency up to 10 to 12 megacycles and heterodynes this frequency down to the subcarrier frequency of 27½ K.C., by means of an

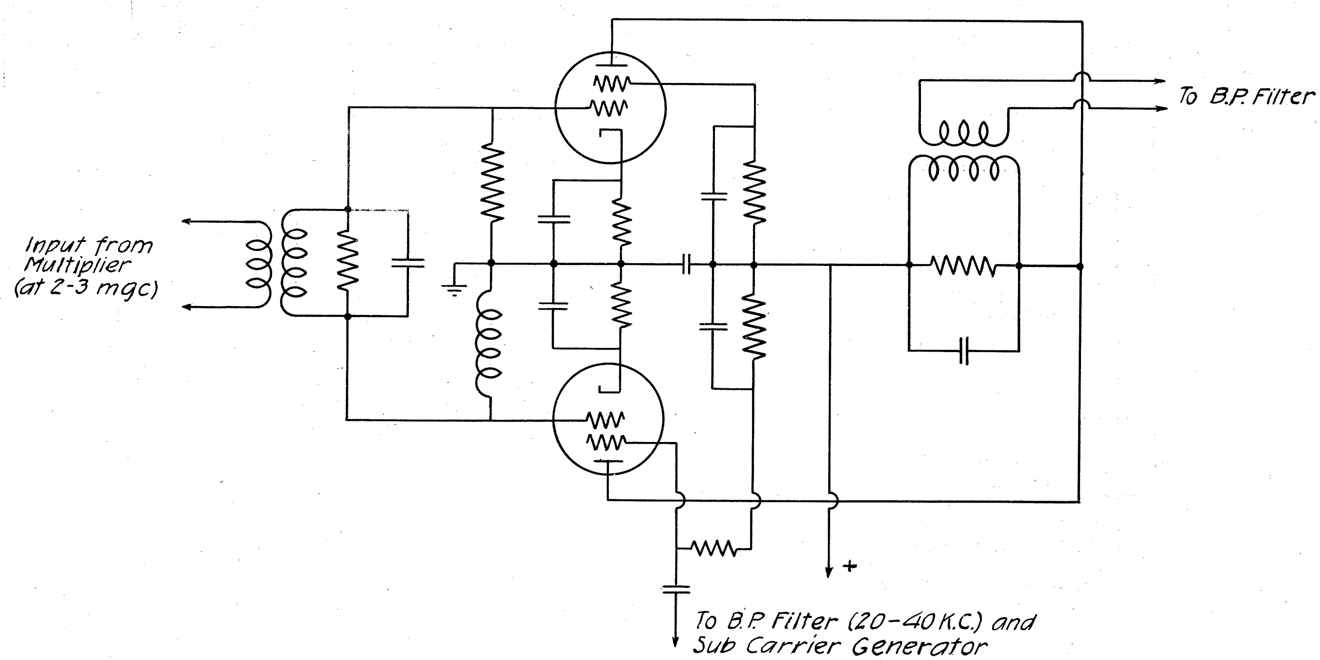


Fig. 2

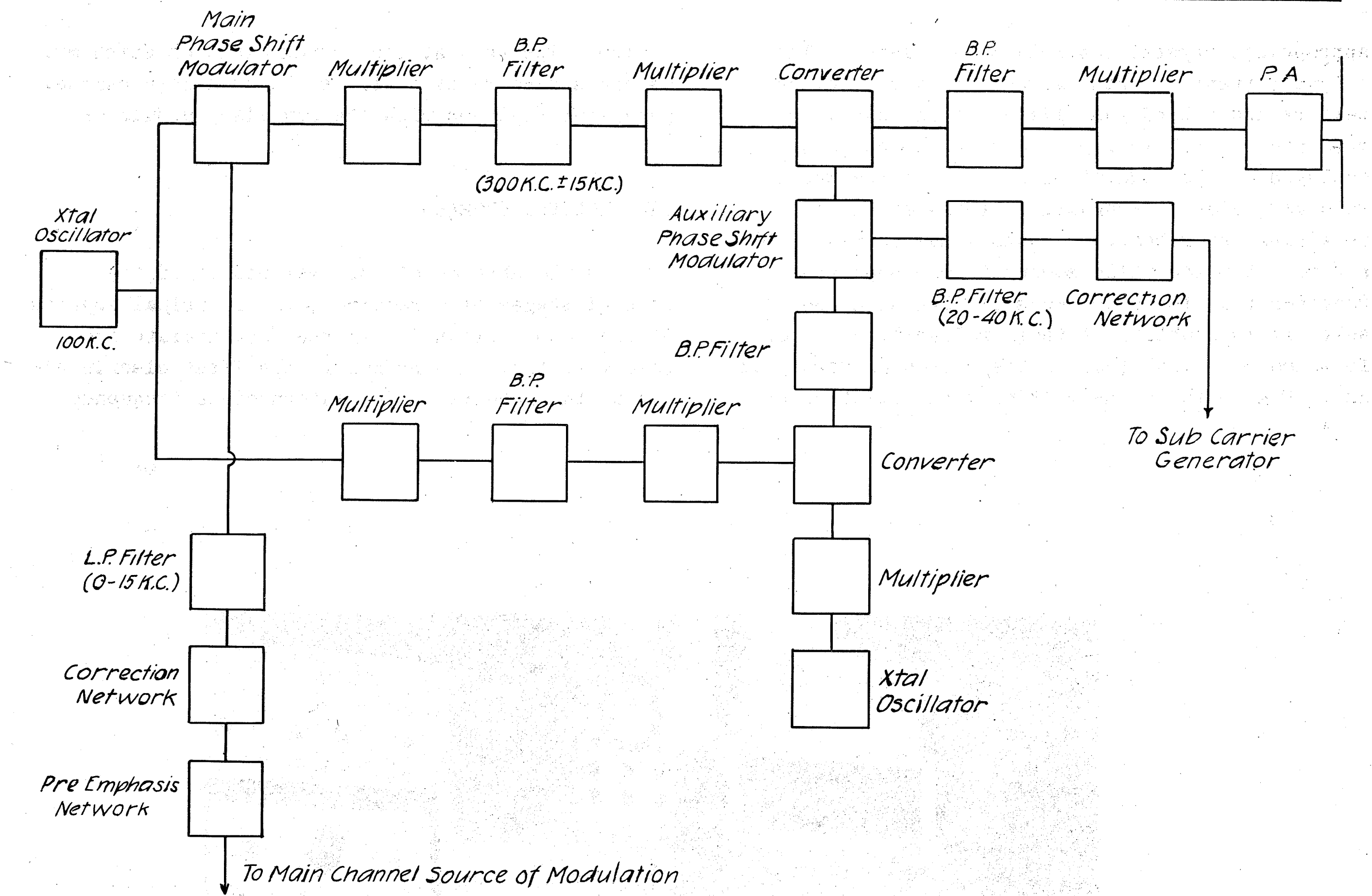

Main Phase Shift Modulator
Multiplier
B.P. Filter
Multiplier
Converter
B.P. Filter
Multiplier
P.A.
(300 K.C. ± 15 K.C.)
Xtal Oscillator
100 K.C.
Auxiliary Phase Shift Modulator
B.P. Filter (20-40 K.C.)
Correction Network
B.P. Filter
To Sub Carrier Generator
Multiplier
B.P. Filter
Multiplier
Converter
L.P. Filter (0-15 K.C.)
Multiplier
Correction Network
Xtal Oscillator
Pre Emphasis Network
To Main Channel Source of Modulation

Fig. 3

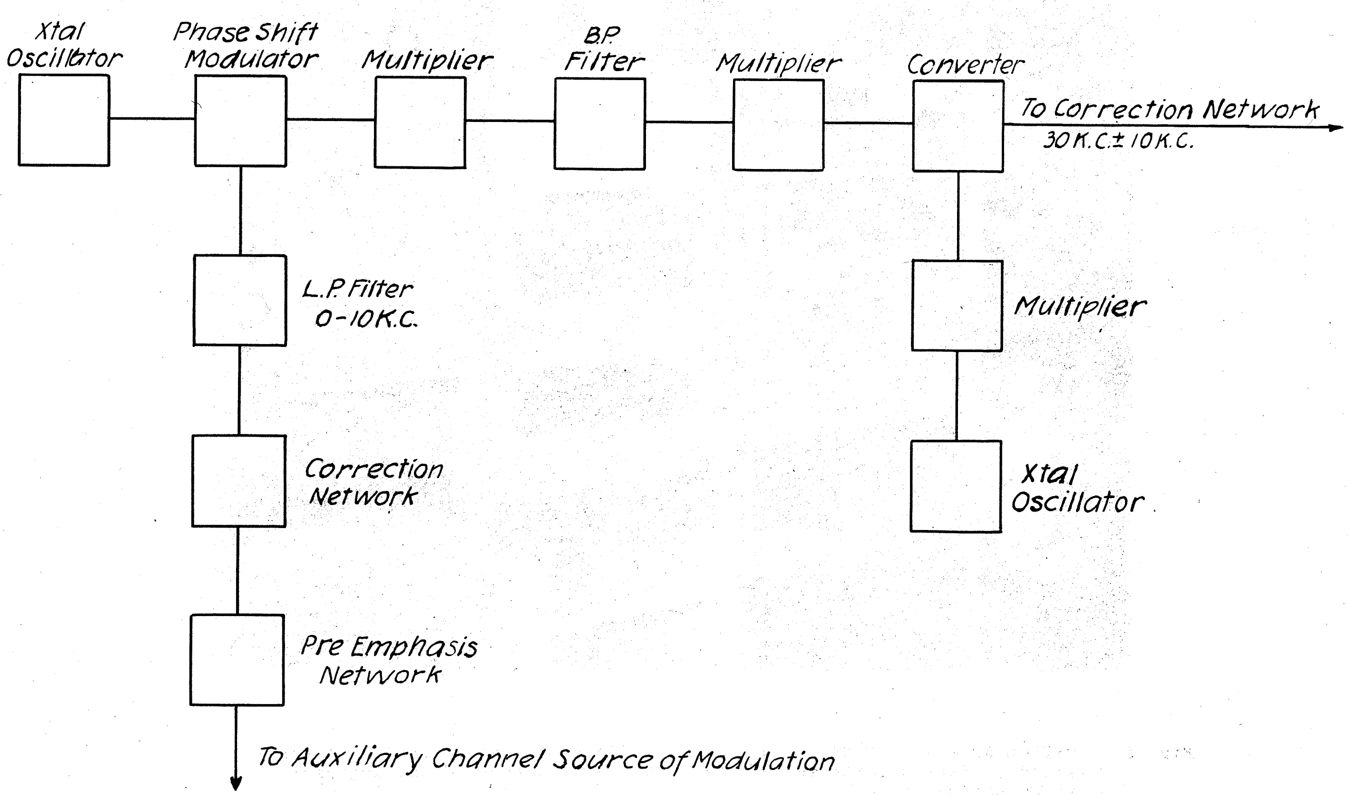

Xtal Oscillator
Phase Shift Modulator
Multiplier
B.P. Filter
Multiplier
Converter
To Correction Network
30 K.C. ± 10 K.C.
L.P. Filter 0-10 K.C.
Multiplier
Correction Network
Xtal Oscillator
Pre Emphasis Network
To Auxiliary Channel Source of Modulation

Fig. 4

appropriate crystal controlled oscillator. The output current is then passed thru a correction network and a band pass filter to the auxiliary modulator. The usual pre-emphasis circuits are employed in the modulation applied to the Serrasoid modulator. In practice, this method of obtaining the subcarrier channel has proven stable and reliable and while somewhat more apparatus is required than for other ways of obtaining the result, it is doubtful if their reliability or performance can equal that of the method presently in use. Fig. 5 shows the multiplex installation at Alpine. The rack at the extreme left on which Mr. Osborn's hand rests contains the auxiliary channel generator together with the auxiliary modulator.

THE RECEIVER PROBLEM:

In the absence of the overloading of the initial stages of a receiver, the principal sources of cross modulation lie in the intermediate frequency selective means and in the first discriminator of the receiver. The intermediate frequency

Fig. 5. CONTROL ROOM AT ALPINE -- Main and auxiliary modulation equipment contained in rack on extreme left with Mr. Perry Osborn, Chief Engineer, KE2XCC beside it.

selectivity will not be a problem in metropolitan areas where the signal to be received is substantially stronger than adjacent channel interference, but can become so on the fringe of reception where the adjacent channel signal level is commensurate with, or may be in fact, stronger than that of the channel to be received. With the licensed service area of F.M. transmitters located on the Eastern seaboard limited to a level of 1 millivolt field (at 30 ft) however, it is not anticipated that serious difficulties will be found. The problem of cross modulation in the discriminator, however, will be present at all locations, and must be guarded against, as it is the most pernicious source of all cross modulation effects. Low conversion ratios are mandatory to secure the necessary freedom from them. A second point of vulnerability lies in the limiting and detection system of the second channel which must be well protected by a high pass filter from the effects of the main channel modulation. The general arrangement of the receiving equipment used in the field tests hereinafter referred to is illustrated in Fig. 6. This comprises a R.F. stage of amplification, converter, crystal controlled oscillator, 5 stages of 10.7 mgc. amplification, a double limiting system and a phase shift discriminator detector system. 13 tubes in the main channel receiver are employed: no attempt has been made to design for other than maximum effectiveness for experimental use.

The auxiliary channel section of the receiver comprises a 15 kc. high pass filter, resistance coupled amplifier, a band pass filter, and a frequency sensitive network, driving, thru limiters, a detector tube which may conveniently be of the 6BN6 variety. The total number of tubes involved are 6 without the audio amplifier. A 10 kc. low pass filter is presently provided for preventing overload of the audio amplifying system of the second channel by the subcarrier frequency but this is determined by the choice of 8 kc for the modulating band of the second channel. The general arrangement of this channel is illustrated in Fig. 7. Here likewise the design has been along the lines of maximum flexibility for experimental use. Subcarrier receivers requiring four tubes have been designed and built, which, while not affording the ultimate performance of the six tube type described will, nevertheless, give suitable performance for home use. Fig. 8 shows an auxiliary channel panel of the type used in the field tests above mentioned.

The characteristics of the two channels that are in use at Alpine at the present time are as follows: The main channel is modulated by a frequency band of 30 to 15,000 cycles with a maximum deviation which it is endeavored to maintain at about 50 kc. The deviation of the second channel is of the order of plus and minus 20 kc with a frequency deviation of the modulation on the subcarrier of plus and minus 5 kc. The maximum modulation frequency for the second channel is 7.5 kc. The usual pre-emphasis standards are used on all channels. Counter or phase shift type detection may be used on the subcarrier frequencies.

FIELD TESTS

The method of modulation herein described was installed at Alpine in 1948, and has been used for conducting a series of tests comprising facsimile, binaural and two audio program transmission. The

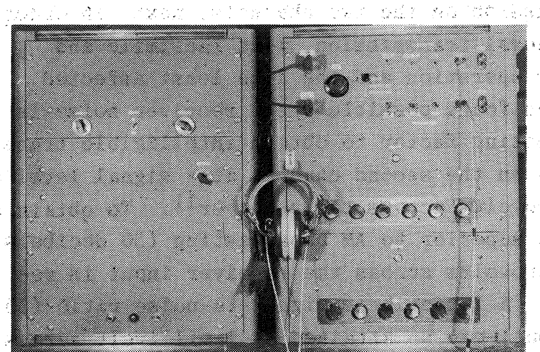


Fig. 6 (a)

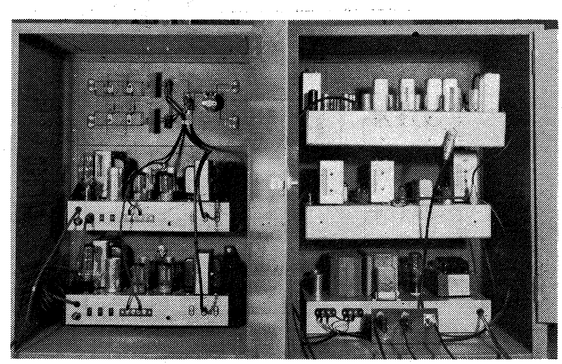


Fig. 6 (b)

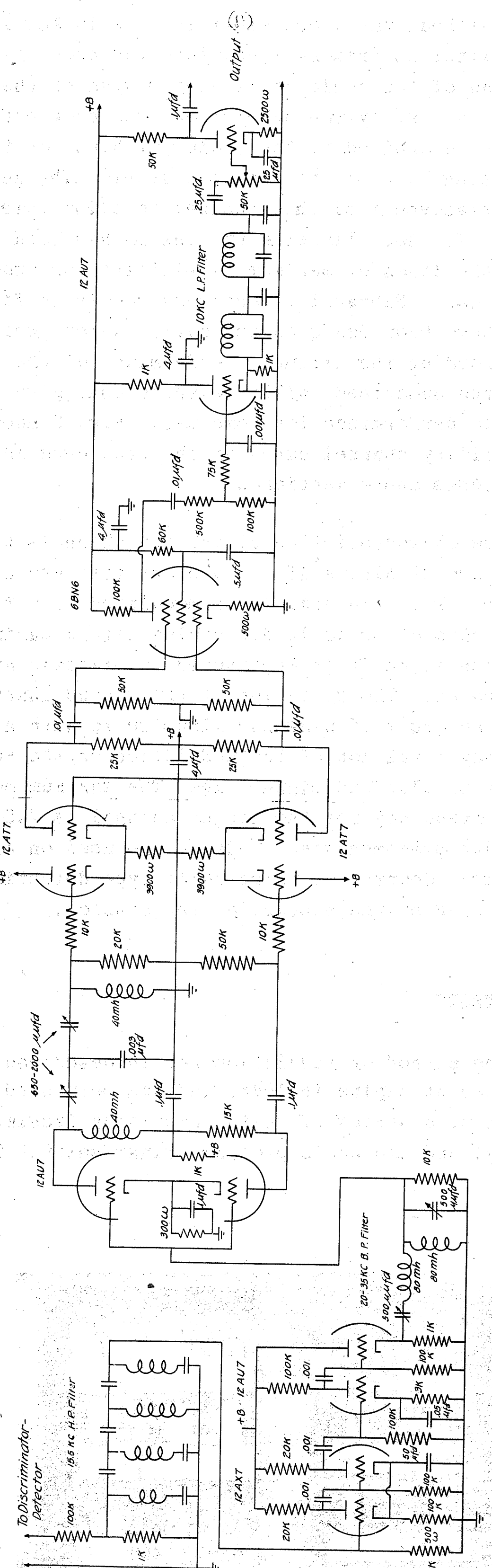


Fig. 7

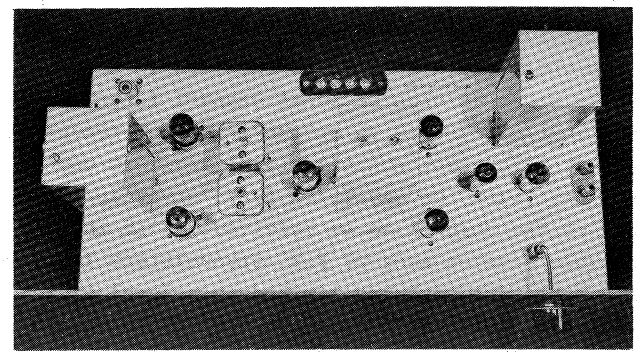


Fig. 8

performance of the multiplex channel has been perfectly stable; adjustments are permanent, and the operation is carried on with no more attention than that attendant to the operation of the main channel. The relative signal-to-noise ratios for the particular conditions chosen for the two channels differ by 10 to 20 decibels depending on the signal input level. The difference decreases at the higher signal level as the determination of the signal-to-noise ratio shifts from receiver noise as the governing factor at low levels to transmitter noise which governs at the higher levels. At the 1 millivolt line, the signal-to-noise level of the second channel for fluctuation noise is above 60 db with a single dipole antenna at the designated 30 foot elevation. Higher signal-to-noise ratios can be obtained at this line by the use of directional receiving arrays, and 70 db. is an attainable goal with arrays of practical dimensions.

The signal level required to produce an acceptable signal-to-noise ratio depends on the type of modulation on the second channel and of course, on the judgment of the listener. The order of vulnerability to noise and cross-modulation is highest for separate musical program transmission on the two channels, next in order is binaural transmission, with facsimile and printer operation and the like least affected. It has been found possible where receiver noise is the limiting factor to obtain intelligible transmission on the second channel at a signal level of 10 microvolts across the receiver[11]. To obtain a service superior to AM broadcasting (50 decibels) 100 microvolts across the receiver input is required. A 70 decibels signal-to-noise ratio (50 ohm input) can be attained at 1 millivolt across the terminals provided the transmitter residual noise is kept below this level.

11 50 ohm input.

As a practical matter, the ability to transmit voice intelligence at a signal level of 10 microvolts across the receiver means that with Yagi antennas of a type readily available, the system is operable for the transmission of intelligence at a field strength of less than 10 microvolts per meter. These figures are given as the result of measurements on 2 receivers of the type illustrated here and indicate the field strength range over which the system may be effectively applied. Further tests are in progress at the present time which will be reported subsequently.

During the summer and fall of the year 1952, a series of tape recordings of the Alpine transmissions were made at Bayport, Long Island, over a distance of approximately 50 miles. The results indicate that the reception of the second channel was uniformly superior to that of the 50 kw standard band New York AM stations. Some comparisons between the same program material transmitted on the second channel and a standard AM channel were obtained by receiving at the Alpine transmitter the FM signal of a New York AM station, transmitting it on the second channel and comparing it directly to the reception of an AM receiver of the same station's AM outlet. During heavy static, the comparison was of the same order of that demonstrated with simplex transmission in 1935 on the Empire State signal between New York and Haddonfield, New Jersey, a demonstration which many of those present here tonight will remember.

Like superiority was obtained during nighttime transmission when standard broadcast signals were garbled by selective fading and interference from stations located without the United States. The margin of superiority is sufficient to warrant the belief that a third channel can be multiplexed with performance better than that of the standard AM system.

DIFFICULTIES AND PRECAUTIONS:

With the solution of the transmitter and receiver problems, the sole remaining difficulty is that of the vagaries of the transmission path. The second channel in some localities will be affected by multipath transmission. Within cities, the effect will follow the same general laws of television multipath and can be treated in the same manner. The full extent of it will have to be determined by large scale experience.

CONCLUSIONS:

We believe we have demonstrated a system which provides a new dimension in the broadcast art. It is capable of being used in so many different ways for providing new services that we will not not attempt to enumerate or comment on them, other than to say that the practical broadcaster will in due course discover additional uses that we have never thought of. We would like, however, to point out that a system which can be made to operate on a field strength of less than 10 microvolts but which is restricted in its practical application by a Federal Communications Commission limitation of service area of F.M. stations to the 1 millivolt line is far ahead technically of the allocation plan imposed when a Commission, as formerly constituted, acted on the basis of incorrect technical information. Future demonstrations of the system will shed additional light on this aspect of the situation. Reports on these demonstrations will be made as they are conducted.

ACKNOWLEDGEMENTS:

We wish to make due acknowledgement of the work of Messrs. Richard G. Gillen, Armando Perretto, and the late Glenn Musselman, for the development and construction of the equipment, and to Perry Osborn and the staff of KE2XCC for its successful introduction into the practical art of F.M. broadcasting.

APPENDIX

The following demonstrations were made during the course of the presentation of the paper at Pupin Hall, Columbia University (distance to Station KE2XCC, Alpine, New Jersey, approximately 11 miles):

1. Transmission of the regular program from KE2XCC on both channels simultaneously with the speaker system switched alternately between them.
2. Transmission of the regular program on the main channel with the speaker system on the second channel and with the modulation on this channel removed at Alpine to demonstrate the freedom from cross-modulation by the first into the second channel.
3. Transmission of the regular program on the main channel together with a program from Station WASH-FM (in Washington, D.C.) on the second channel transmitted to Alpine via a high-quality wire line (approximately 250 miles.)
4. Transmission from KE2XCC of a binaural tape recording for simultaneous reproduction on the two channels at Columbia University.
5. Transmission of a tape recording on the main channel at KE2XCC simultaneously with a program received at Alpine from Station WALK-FM, Patchogue, Long Island, (50 miles) re-transmitted on the second channel.

In addition to the above mentioned multiplex transmissions from KE2XCC, the following series of tape recordings of the Alpine signals previously received at Bayport, Long Island (47 miles) were demonstrated.

1. A program from WALK-FM, Patchogue, was received at Alpine on an R.E.L. type 646 receiver, re-transmitted via the second channel of KE2XCC, and received and recorded at Bayport, Long Island. The recorded second channel signal at Bayport was compared with a recording of WALK-FM received directly (3 miles) on an R.E.L. type 646 receiver, similarly located. No difference in quality or noise level could be observed.
2. A second recording compared reception at Bayport on the second channel modulated by reception at Alpine of the F.M. program of a New York network station with the 50 kw AM transmission of the same station. The recording was made during early evening hours and for the reasons stated in the paper, the AM channel was unusable and the FM signal quiet.
3. A third recording was made under identical conditions with the preceding recording at the same receiving location, but was made during the afternoon hours under typical summer thunderstorm conditions (August 6, 1952). For the reasons stated in the paper, the AM channel was unusable, and the second FM channel quiet.

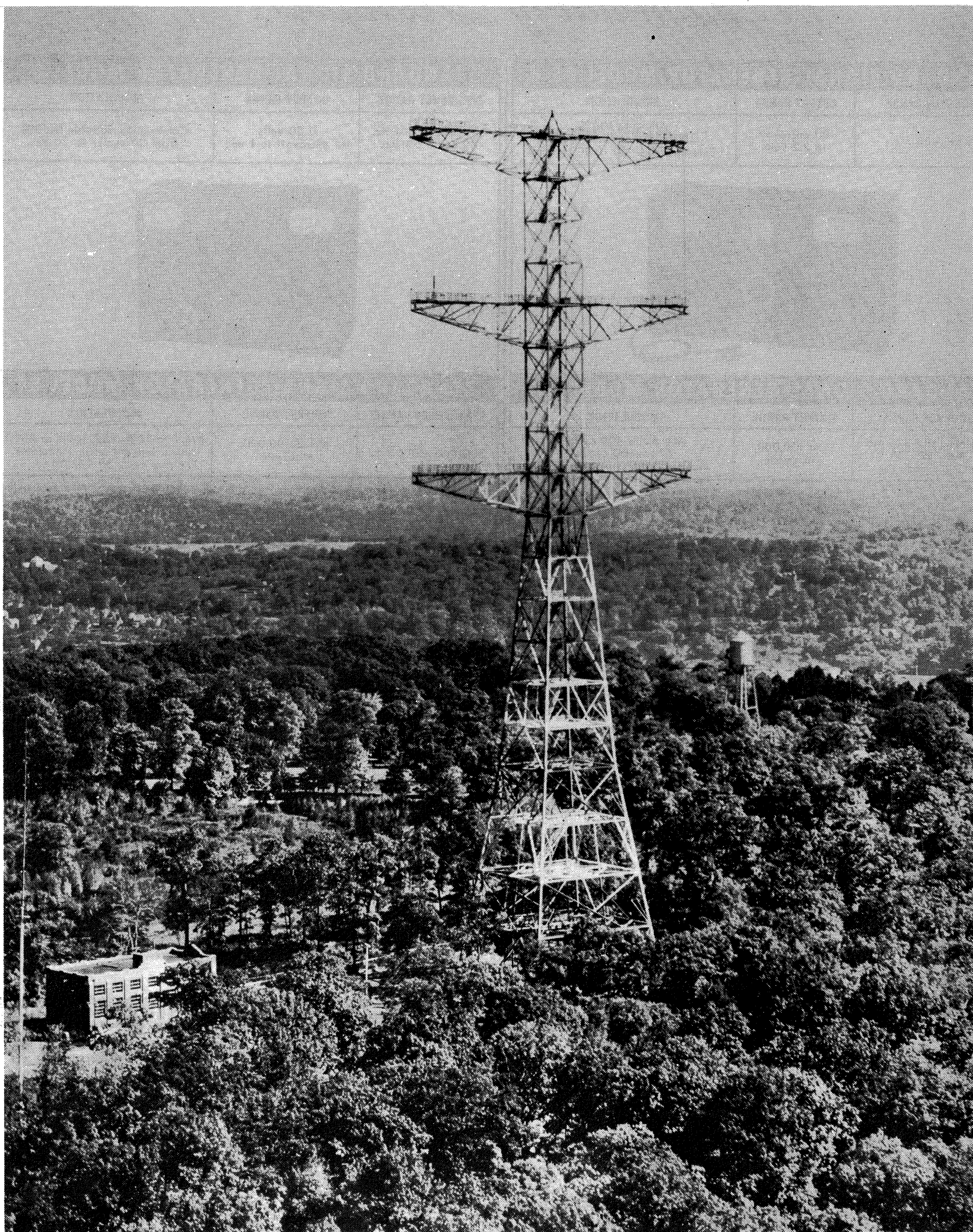


Fig. 9. Station KE2XCC located at Alpine, N.J. on the 500 ft. cliffs of the Palisades, approximately 17 miles north of New York City.

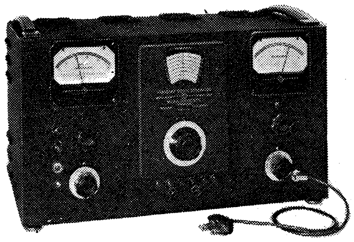
This picture was taken shortly after the station went into operation in 1938 on 40 megacycles under the designation W2XMN.

MEASUREMENTS CORPORATION

Laboratory Standards

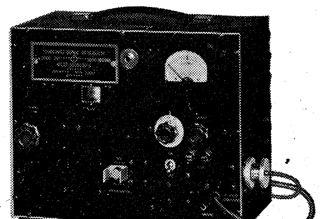
STANDARD SIGNAL GENERATOR MODEL 65-B

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
75 Kc.—30 Mc.	0.1 microvolt to 2.2 volts	AM. 0 to 100% 400 cycles or 1000 cycles External mod., 50-10,000 cycles



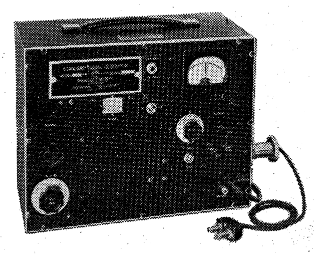
STANDARD SIGNAL GENERATOR MODEL 78

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
15-25 Mc.; 195-225 Mc. 15-25 Mc.; 90-125 Mc. Other ranges on order	1 to 100,000 microvolts	AM. 8200-400 cycles 625—400 cycles Fixed at approximately 30%



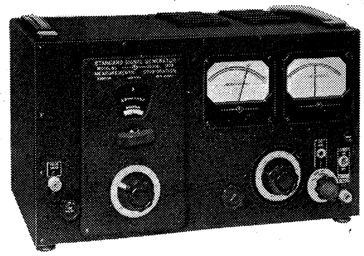
STANDARD SIGNAL GENERATOR MODEL 78-FM

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
86 Mc.—108 Mc.	1 to 100,000 microvolts	Deviation 0-300 Kc. 2 ranges FM. 400-8200 cycles External mod. to 15 Kc.



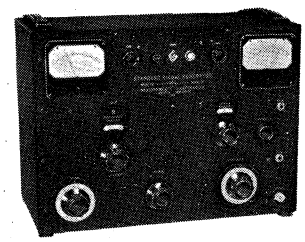
STANDARD SIGNAL GENERATOR MODEL 80

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
2 Mc.—400 Mc.	0.1 to 100,000 microvolts	AM. 0 to 30% 400 cycles or 1000 cycles External mod., 50-10,000 cycles



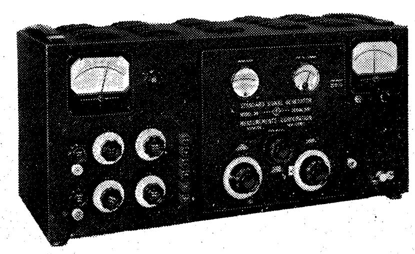
STANDARD SIGNAL GENERATOR MODEL 82

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
20 cycles to 200 Kc. 80 Kc. to 50 Mc.	0-50 volts 0.1 microvolt to 1 volt	Continuously variable 0-50% from 20 cycles to 20 Kc.



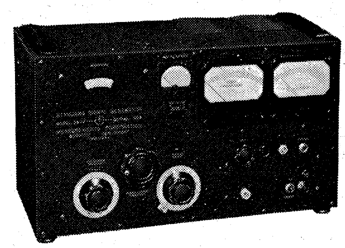
STANDARD SIGNAL GENERATOR MODEL 84

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
300 Mc.—1000 Mc.	0.1 to 100,000 microvolts	AM. 0 to 30%, 400, 1000, or 2500 cycles. Internal pulse modulator. External mod., 50-30,000 cycles.



STANDARD SIGNAL GENERATOR MODEL 84-TV

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
300 Mc to 1000 Mc	Continuously variable from 0.1 microvolt to 1 0 volt	Continuously variable 0 to 30% External modulation 20 to 20,000 cycles.

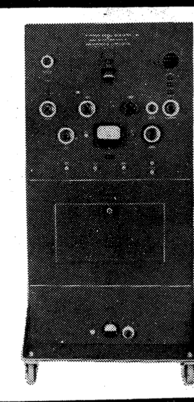


STANDARD SIGNAL GENERATOR MODEL 90

FREQUENCY RANGE	OUTPUT RANGE
20 Mc.—250 Mc.	0.3 microvolt to 0.1 volt

MODULATION

Continuously variable, 0 to 100% Sinusoidal modulation 30 cycles 5 mc. Composite TV modulation.



MEASUREMENTS CORPORATION BOONTON, N. J.

MEASUREMENTS CORPORATION

An unseen value in the choice of any product is the experience represented in its design, development and manufacture. Throughout the world, Measurements' reputation for accuracy and reliability is your guarantee of the utmost in satisfactory service.

PULSE GENERATOR MODEL 79-B

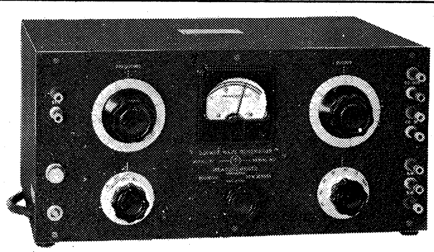
FREQUENCY RANGE	PULSE WIDTH	OUTPUT
60 to 100,000 cycles	Continuously variable from 0.5 to 40 microseconds	Approx. 150 v. positive with respect to ground. "Sync Output" 75 v. positive with respect to ground.

VACUUM TUBE VOLTMETER MODEL 67

VOLTAGE RANGE	FREQUENCY RANGE	INPUT IMPEDANCE
.0005 to 300 volts peak-to-peak	5 to 100,000 sine-wave cycles per second	1 megohm shunted by 30 mmfd.

SQUARE WAVE GENERATOR MODEL 71

FREQUENCY RANGE	WAVE SHAPE	OUTPUT
Continuously variable 6 to 100,000 cycles	Rise time less than 0.2 microseconds with negligible overshoot	Step attenuator: 75, 50, 25, 15, 10, 5 peak volts fixed and 0 to 2.5 volts continuously variable.

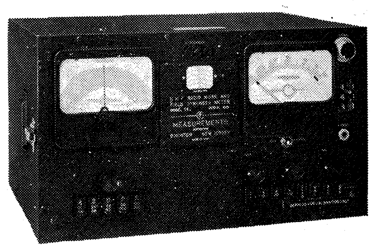


INTERMODULATION METER MODEL 31

INTERMODULATION RANGE	FREQUENCIES (CYCLES)	ANALYZER INPUT VOLTAGES
0.5% to 30%	LF: 60 cps HF: 3000 cps	Full scale ranges of 3, 10, 30 volts RMS

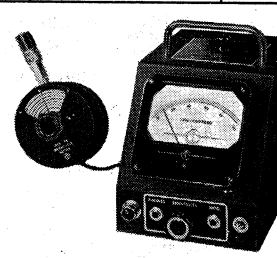
U.H.F. FIELD STRENGTH METER MODEL 58

FREQUENCY RANGE	INPUT VOLTAGE RANGE
15 Mc. to 150 Mc.	1 to 100,000 microvolts in antenna. 1 to 100 microvolts on semi-logarithmic output meter, balanced resistance attenuator with ratios of 10, 100 and 1000 ahead of all tubes.



MEGACYCLE METER MODEL 59

FREQUENCY RANGE	FREQUENCY ACCURACY	MODULATION
2.2 Mc. to 400 Mc.	Within ±2%	CW or 120 cycles fixed at approximately 30%. Provision for external modulation



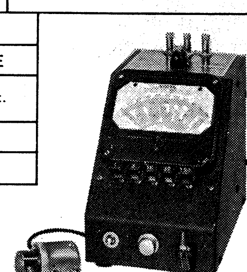
VACUUM TUBE VOLTMETER MODELS 62 & 62-U.H.F.

VOLTAGE RANGE	FREQUENCY RANGE	INPUT IMPEDANCE
0-1, 0-3, 0-30 and 0-100 volts AC or DC	30 cycles to over 150 Mc.	Approximately 7 mmfd.

MODEL 62 U. H. F.

VOLTAGE RANGE	FREQUENCY RANGE
0-1, 0-3, 0-30 and 0-100 volts AC or DC	100 Kc. to 500 Mc.

INPUT IMPEDANCE
Approximately 2 mmfd.



CRYSTAL CALIBRATORS MODELS 111 & 111-B

FREQUENCY RANGE	FREQUENCY ACCURACY	HARMONIC RANGE
250 Kc.—1000 Mc.	0.001%	.25 Mc. Oscillator: .25-450 Mc. 1 Mc. Oscillator: 1-600 Mc. 10 Mc. Oscillator: 10-1000 Mc.

MODEL 111-B

FREQUENCY RANGE	FREQUENCY ACCURACY
100 Kc.—1000 Mc.	0.001%

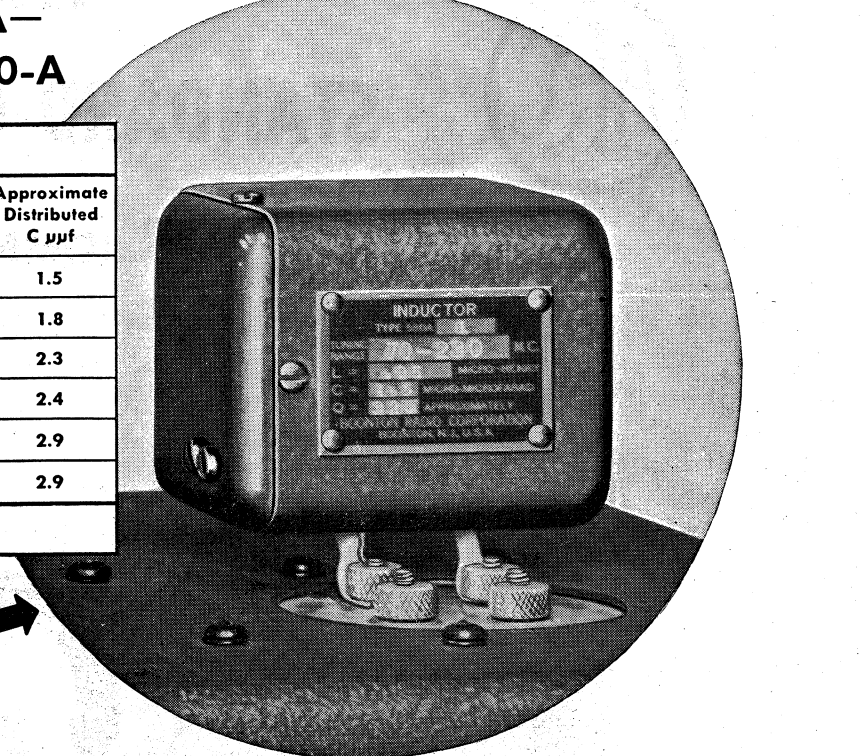
HARMONIC RANGE
1 Mc. Oscillator: 1 — 450 Mc. 1 Mc. Oscillator: 1 — 600 Mc. 10 Mc. Oscillator: 10—1000 Mc.

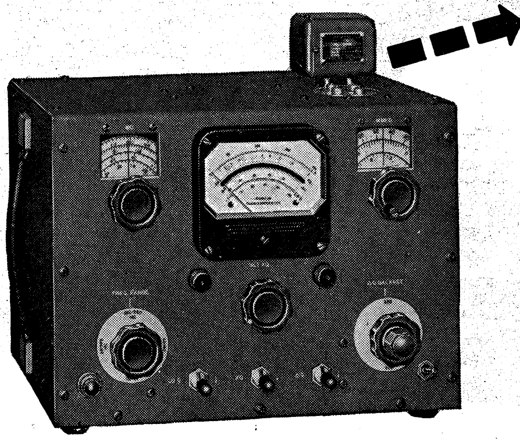
MEASUREMENTS CORPORATION BOONTON, N. J.

NEW Q Meter Inductors for measurements up to 260 mc!

INDUCTORS Type 590-A— accessories to Q Meter Type 190-A

TYPE 590-A INDUCTORS					
Type	Inductance µh	Capacitance µµf	Approximate Resonant Freq. mc	Approximate Q	Approximate Distributed C µµf
590-A1	0.05	8.0 — 95.0	70 — 230	320	1.5
590-A2	0.1	10 — 100	50 — 160	350	1.8
590-A3	0.25	8.0 — 80.0	30 — 100	310	2.3
590-A4	0.5	7.5 — 80.0	25 — 70	340	2.4
590-A5	1.0	7.5 — 65.0	20 — 50	300	2.9
590-A6	2.5	9.0 — 25.0	20 — 30	300	2.9
PRICE: $10.00 each F.O.B. BOONTON, N. J.					





Q METER Type 190-A

This new 190-A Q Meter measures an essential figure of merit of fundamental components to better overall accuracy than has been previously possible. The VTVM, which measures the Q voltage at resonance, has a higher impedance. Loading of the test component by the Q Meter and the minimum capacitance and inductance have been kept very low.

SPECIFICATIONS—TYPE 190-A

FREQUENCY RANGE: 20 mc. to 260 mc.

RANGE OF Q MEASUREMENT:

Q indicating voltmeter	50 to 400
Low Q scale	10 to 100
Multiply Q scale	0.5 to 3.0
Differential Q scale	0 to 100
Total Q indicating range	5 to 1200

PERFORMANCE CHARACTERISTICS OF INTERNAL RESONATING CAPACITANCE: Range—7.5 mmfd. to 100 mmfd. (direct reading).

POWER SUPPLY: 90-130 volts — 60 cps (internally regulated).

Type 190-A Price: $625.00 F.O.B. Factory

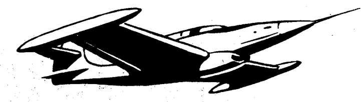
Inductors Type 590-A are designed specifically for use in the Q Circuit of the Q Meters Type 170-A and 190-A for measuring the radio-frequency characteristics of condensers, resistors, and insulating materials. They have general usefulness as reference coils and may also be used for periodic checks to indicate any considerable change in the performance of the Q Meters.

Each inductor Type 590-A consists of a high Q coil mounted in a shield and is provided with spade lugs for connection to the coil terminals of the Q Meters. The shield is connected to the lugs which connect to the Low Coil terminal in order to minimize any changes in characteristics caused by stray coupling to elements or to ground.

BOONTON RADIO Corporation

BOONTON · N · J · U · S · A ·

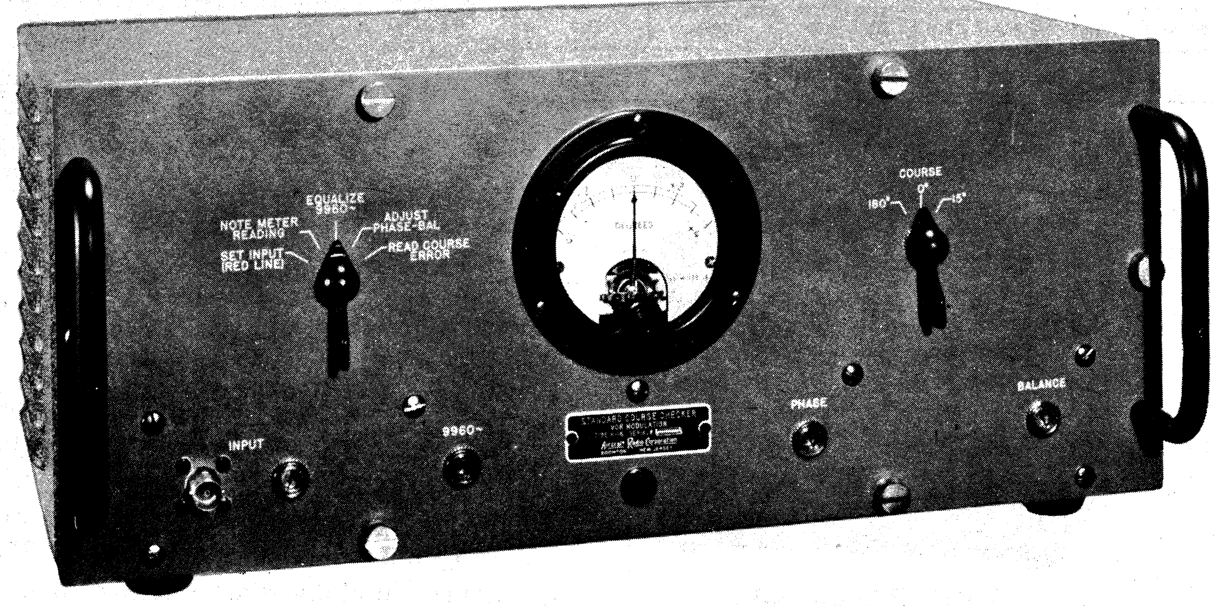
AIRCRAFT RADIO CORPORATION



TYPE H-16

STANDARD COURSE CHECKER

FOR VOR (OMNIRANGE) MODULATION



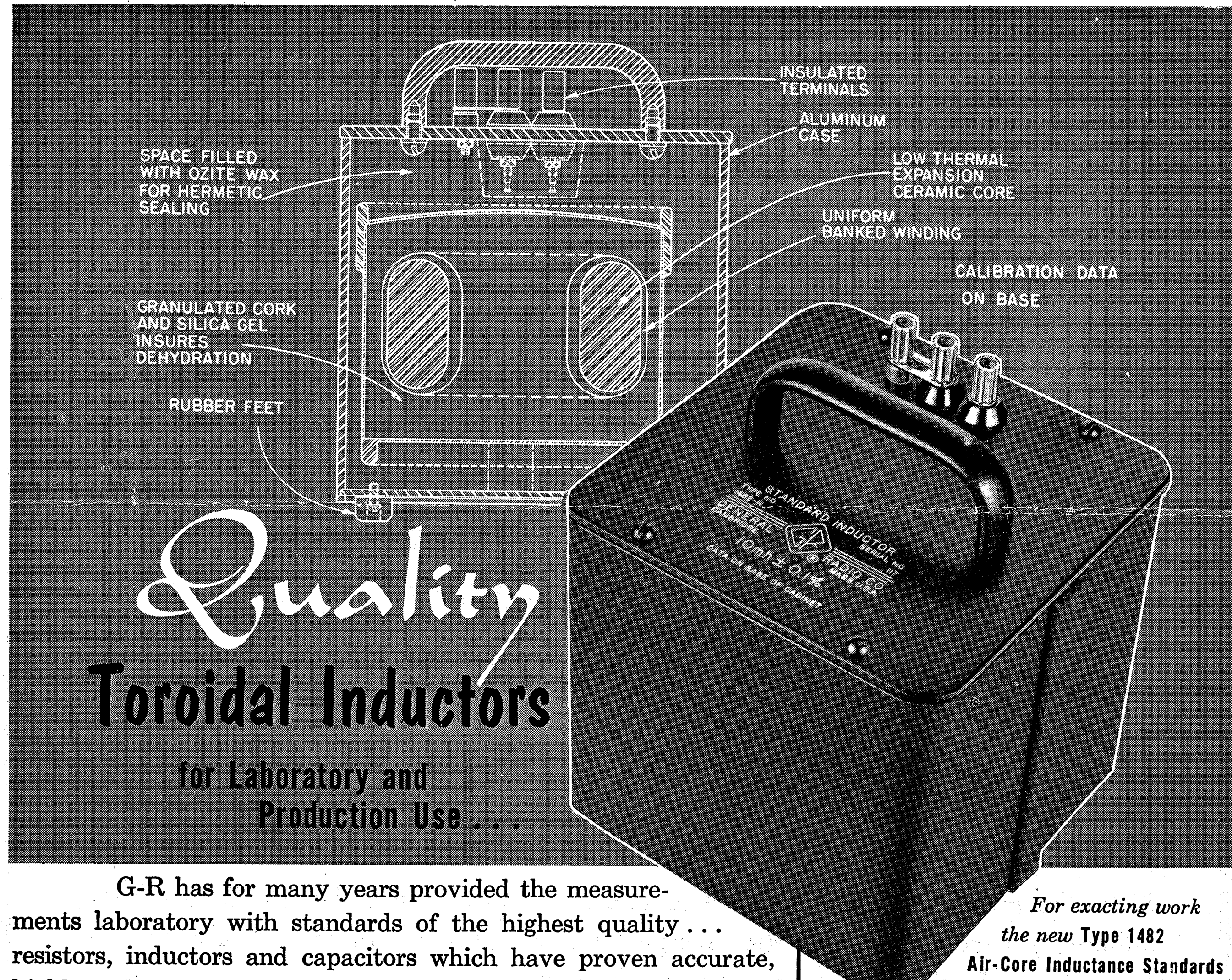
Purpose of the Instrument

To provide a means for precisely checking the phase-accuracy of the modulation on VOR (Omnirange) Signal Generators.

Features a Built-in Self-Checking Circuit

Background

A great deal of work on omnirange receivers and signal generators has been done since 1946, but it now becomes necessary to have a device for general use which will check the accuracy of the phase relationship in the VOR modulation; in particular, a means for measuring the phase differences between the 30 cps envelope of the 9960 $\pm$ 480 cps reference modulation and of the 30 cps variable modulation. Such a measurement has of course been necessary since the start of work on the omnirange, but the amount of equipment and the difficulty of measurements have been great. The H-16



Quality Toroidal Inductors

for Laboratory and Production Use . . .

G-R has for many years provided the measurements laboratory with standards of the highest quality . . . resistors, inductors and capacitors which have proven accurate, highly stable and reliable in operation. The new Type 1481 Standard Inductors with powdered-iron cores and Type 1482 Air-Core Inductors are in keeping with the superior characteristics of past General Radio R-L-C components. They are particularly designed for use at audio frequencies.

These new inductors are symmetrically-wound toroids with negligible coupling to adjacent units and external fields . . . Q's are as high as is practically attainable, the units are electrostatically shielded, they have low and predictable temperature coefficients, and are practically immune to the effects of humid atmosphere.

For exacting work the new **Type 1482 Air-Core Inductance Standards** *are highly recommended.*

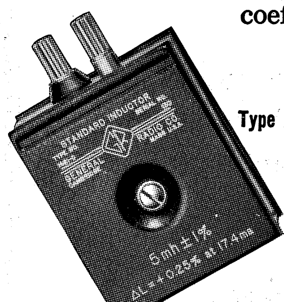
Sixteen models available with inductance values ranging from 100 µh to 10 h inclusive in 1, 2 and 5 unit values, $60 to $185.

100 µh and 200 µh units adjusted to nominal value of ±0.25%; all units 500 µh and higher adjusted to ±0.1%.

Hermetic sealing and strain-free mounting insures high degree of stability — temperature coefficient of inductance definitely established at 30 parts per million per degree C — accurate temperature corrections can be simply made from resistance measurements.

Calibration certificate on each unit gives inductance to within 0.005% at 100 cycles and indicated stabilized temperature — resonant frequency, d-c resistance, and incremental inductance changes with frequency tabulated on each unit.

Dimensions are 6½" x 6½" x 8" — weight is 11½ lbs.



Type 1481 Toroidal Dust-Core Inductor impregnated toroid is clamped between two felt washers in rectangular aluminum case affording electrostatic shielding. Net weight is 14 oz.; case dimensions are 3⅝" x 3⅛" x 1⅝".

Type 1481 Toroidal Dust-Core Inductors complement the air-core Type 1482's, each type having advantages for specific applications.

Twelve different molybdenum-permalloy dust-core inductors are available with nominal values between 1 mh and 5 h inclusive, in 1, 2 and 5 unit values . . . $24.50 to $30.00. They have *maximum Q's of between 200 and 300;* Q is more than unity down to 6 cycles or lower — these inductors are inherently astatic, coupling between adjacent external fields being negligible — temperature coefficient of inductance is low, −0.0025% per degree C between 16 and 32 degrees — units are calibrated to within ±0.25% for larger inductors, ±1% for smaller units.

GENERAL RADIO Company

275 Massachusetts Avenue, Cambridge 39, Massachusetts, U. S. A.
90 West St. NEW YORK 6 — 920 S. Michigan Ave. CHICAGO 5 — 1000 N. Seward St. LOS ANGELES 38

Admittance Meters ☆ Coaxial Elements ☆ Decade Capacitors ☆ Decade Inductors ☆ Decade Resistors ☆ Distortion Meters ☆ Frequency Meters ☆ Frequency Standards ☆ Impedance Bridges ☆ Modulation Meters ☆ Oscillators Variacs ☆ Light Meters ☆ Megohmmeters ☆ Motor Controls Noise Meters ☆ Null Detectors ☆ Precision Capacitors Pulse Generators ☆ Signal Generators ☆ Vibration Meters ☆ Stroboscopes ☆ Wave Filters U-H-F Measuring Equipment ☆ V-T Voltmeters ☆ Wave Analyzers ☆ Polariscopes