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BIBLIOGRAPHY ON RADIO EQUIPMENT IN AVIATION

By F. X. Rettenmeyer*

Contributed to the Proceedings of the Club

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*RCA Manufacturing Company, Camden, New Jersey.

Introduction

Commercial aviation was given its initial impetus in the year 1924 through the efforts of the United States Army and the Post Office Department which resulted in the establishment of airmail service between New York and San Francisco. This service was consigned to commercial companies during 1926, and some two years later air-transport passenger service was launched on a commercial basis. These early services consisted entirely of contact flying during fair weather and only during daylight hours.

In 1925 beacon lights were first established between Chicago and Cheyenne. Similar beacons were established during 1928 between Chicago and New York, and additional installations took place rapidly from that time on so that night flying became a practical reality.

During the past few years, air traffic at some of the busiest terminals, such as New York, Chicago and Burbank, has grown so rapidly that air-traffic control has become a problem of considerable magnitude. For example, during busy periods departures and arrivals at the New York Municipal Airport may be at the rate of one every one and one-half minutes.

To support present-day traffic, the Civil Aeronautics Board maintains some 350 radio-range stations and some 30,000 miles of tele-typewriter service. These provide for the dissemination of weather and other information.

In addition, each of the air lines must maintain a considerable array of ground-station and aircraft radio equipment for both navigation and communication. It, therefore, appears that a bibliography listing some of the pertinent references to aircraft radio equipment might be of general interest to the industry.

This bibliography makes no pretense to completeness. Particularly, with regard to time, it includes few references prior to 1937 or 1938. It does, however, present a number of recent references which may be useful to the reader. The arrangement is more or less chronological under each subject.

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CLUB NEWS

Annual Banquet

The Annual Banquet of the Club took place on November 1st at the Engineers Club in New York. The usual spirit of gaiety and reminiscence prevailed, and there were numerous amusing anecdotes and personal references.

Following the dinner, President Henney presented the Armstrong Medal to Greenleaf Whittier Pickard of Seabrook Beach, New Hampshire. Mr. Henney, and also other speakers later, referred to Pickard's long professional career starting with work on the Perikon detector, signal generators, field-strength measurements, and other subjects; also mentioned was his distinguished family connection as great nephew of the poet, John Greenleaf Whittier. In his acceptance remarks Pickard included a tribute to the Armstrong name, adding humorously that the Armstrong coin has heads on both sides, so that you can't lose.

President Henney then introduced Major Armstrong, who acted as toastmaster. The Major said a few words including the mention of a publication on the use of the wave meter, which was written in the early days — he had found this very interesting at the time. He then introduced the author, our speaker of the evening, now Major General J.O. Mauborgne, Chief Signal Officer of the Army.

In his address, General Mauborgne described conditions in the Signal Corps at our entry into the last war, and compared them with the much better situation prevailing at the present time. At that period, we had practically no apparatus, practically no designs, and practically no knowledge of desired types of equipment; about all we could do was to rush into production of Chinese copies of French and British apparatus. In all these respects of equipment, manufacture, design, and plans, our situation at the present time is far better.

General Mauborgne pointed out particularly that the Signal Corps is ready to consider operable apparatus which is in shape for further development to adapt it to the needs of the service. In distinction to this classification, persons with ideas requiring research, should contact a research group, the National Defense Research Committee, which has been formed under the leadership of Vannever Bush. An additional group under the head of C.F. Kettering, the National Inventors Council, has been formed to consider inventions submitted from any source. These research and invention groups are ready to consider all ideas submitted, and in addition will endeavor to have research projects undertaken, and inventions made, in compliance with specific requests from the military services.

In connection with developments made in the Signal Corps, General Mauborgne mentioned the necessity of terminating the work at possibly 80 or 85 percent of the desired extent, in order to get manufacture of apparatus started. Even under these circumstances, development work generally takes a year, and the inauguration of manufacture an additional nine months, so that it is almost two years before equipment is received in volume. The situation is more difficult on account of the fact that during quiescent times, little money is available for development work, and during critical periods, there is insufficient time. Sufficient money is available now for considerable development and purchase of signal apparatus, the total appropriation amounting to almost $200,000,000.

In discussing facsimile, General Mauborgne reported that encouraging results are being obtained. With regard to television, he stated that the requirements are severe, it being desired to see an object the size of an automobile on a dull day by means of a television camera in an airplane at a height of 12,000 feet or more.

Dues Waived for Members Entering Service

The Board of Directors at a meeting on September 16th, adopted a provision that the dues of all members who join any branch of the defense services will be waived throughout their term of duty if they notify the Treasurer of their service connection.

Results of Postal-Card Survey

The survey of members' opinions and suggestions, which was conducted by postal card during the summer, resulted in the return of 53 cards and three letters, containing numerous valuable items relating to the future activities of the Club. Almost all those living in the neighborhood of New York City indicated their willingness to serve on Committees and the Board. Numerous prospective members, and suggestions of suitable subjects and speakers, were received. Efforts will be made to use all of these results for the advancement of the Club.

It may be recalled that a space was provided to indicate whether the Club should give more emphasis to amateur topics, and similarly whether more emphasis should be given to servicing topics. The results of the postals indicated a substantial majority in favor of more material of interest to amateurs, while the response for more servicing material amounted to about one-third of those replying. Other suggestions relating to the technical activities of the Club were to distribute the diagrams and equations at each meeting, and to hold a one-day convention.

Several suggestions relating to the meeting notices and the Proceedings were received. These included a suggestion to get the meeting notices out earlier, to have sooner and more regular publication of presented papers in the Proceedings, to publish contributed papers, and to print the titles of papers on the front cover of the Proceedings. Efforts will be made to put all of these suggestions relating to meeting notices and Proceedings into effect.

The social activities of the Club should be expanded, according to the desires of a majority. In particular, a majority favored an additional get-together during the year to supplement the annual banquet, and the Board of Directors are giving thought to a suitable inexpensive event along this line. In general, a desire for more social activity was manifest, and the Directors will endeavor to meet this need.

Contribution of Material to Proceedings

The Publications Committee of the Club will be pleased to consider any papers, technical reports, or other items, submitted by members for publication in the Proceedings. These may be short items, or extended treatments requiring a complete issue.

FREQUENCY MODULATION MEETING AT W2XOR

On September 26th the Club met at transmitting station W2XOR located at 444 Madison Avenue, New York City. At this point a 1-kilowatt frequency-modulated transmitter is located on an upper floor of a high building, and an antenna mounted on top of the building. The program at the meeting consisted of several short papers on frequency modulation, high fidelity, and the apparatus used by W2XOR; descriptions were given of the equipment located at both the transmitter and at a special high-fidelity studio situated with other studios of the Mutual Broadcasting System at 1440 Broadway. One event of the program was a transmission of various special sounds to demonstrate the realism of the reproduction. The transmitter was then inspected by the members and guests of the Club.

The present issue of the Proceedings gives the general material presented by the various speakers of the evening.

FM and Its Economic Advantages
By J.R. Poppele*

Practically all progress in the world of radio has come about by having faith in a notion and then sticking with the notion until it either succeeded or failed. The people who backed the right notions because they were farsighted and understanding have usually been the ones who came to the top of the radio industry.

Frequency modulation, in my opinion, is the most promising development in a whole decade of radio broadcasting. It is promising not only because it has many technical and economic advantages, but also because we now see it in an advanced state, ready to take its place commercially on Jan. 1, 1941 beside regular standard broadcasting as a new and distinct service to the American public.

One year ago practically no one except a few well informed engineers knew what FM was. As a laboratory curiosity, it received the plaudits of several technical societies - yet only a handful of men were farsighted enough to realize that FM had the ability and properties necessary to change the entire landscape of radio.

Within the space of one year a host of converts have flocked to the ranks of FM boosters. Nearly 50 applications for large, commercial FM stations have been filed at Washington. The Federal Communications Commission, convinced that FM is ready to operate as a bona fide service, has assigned a new FM band of 40 channels, sanctioned

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*Chief Engineer, Station WOR, New York City commercial operation, and in general administered a cordial pat on the back to frequency modulation.

The future is still ahead, but stemming from such a rosy present, it seems inevitable that FM will have an illustrious career of steady growth. FM is the radio of tomorrow. By a process of evolution, it may well supersede most of our existing system of radio before ten years or less. The new FM stations, contrary to popular opinion, have wide coverage areas in which they can deliver strong signals, unbothered by natural or man-made noises, carrying programs which are clearer and more realistic than anything the average listener has ever heard before. It is interesting to note that the applications for FM stations now awaiting action in Washington, if granted, will supply FM reception to more than 75,000,000 potential listeners.

Within the space of a year or two we will unquestionably see the formation of large national networks, disseminating high-quality programs from Atlantic to Pacific. Two such networks are under consideration at the present time. The many new stations will open up employment for thousands more engineers, announcers, singers, musicians and station staff members. Increased competition may do much to raise the calibre of programs.

In the sphere of the manufacturer, we will undoubtedly see extra employment for many thousands who will be needed to design and build new FM combination receivers that can receiver either FM or ordinary broadcasts. Building of new stations also means greater investment of capital and increased employment.

Major General J.O. Mauborgne, Chief Signal Officer of the U.S. Army, Major E.H. Armstrong, and Brigadier General Dawson Olmstead, head of the Fort Monmouth Signal Corps Laboratories at the Annual Banquet of the Club.

President Keith Henney (left) presenting the Armstrong Medal to Greenleaf Whittier Pickard at the Annual Banquet. Dr. Pickard's record in radio research, from the earliest days to the present, justifies the title, "Radio's Most Active Pioneer".

The ability of FM to reproduce sound with startling realism opens the way for new efforts in the dramatic field, placing a greater premium on artistry and strengthening the value of good music as program material.

In other words, FM gives radio an unparalleled opportunity to put its house in order, to rectify many ills, and to create on the sound foundation of an already precocious industry an even greater, brighter and more useful one.

New Transmitter Circuit for Frequency Modulation

By J.F. Morrison*

Important new developments in communication, as in sciences, are often retarded in their commercial application by the lack of apparatus and techniques that are

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*Bell Telephone Laboratories, Whippany, New Jersey suitable for actual use in the field, where exacting standards of performance have to be met over long periods of time with complete reliability. Wide-band frequency modulation presents its share of these practical problems, but through the coordination of a number of new and distinct laboratory developments, the approaching expansion in FM broadcasting finds equipment ready for use that meets the most rigorous requirements. These new developments are embodied in Synchronized Frequency Modulation, which makes its appearance for the first time in the 1000-watt Western Electric 503A-1 Radio Transmitting Equipment.

Probably foremost among the practical problems is that of frequency stability—a term which in FM must of course have a new meaning, since it can refer only to the average frequency. In amplitude-modulation systems the crystal oscillator has provided all that could be desired in the way of frequency stability; but in a mode of transmission employing deliberate variation of frequency over a wide range, the direct use of the crystal as the source of oscillations would necessarily give rise to a conflict between the factors which stabilize the frequency and those which are to produce the desired variation. Yet the mean frequency in FM transmission is subject to the same strict regulation prevailing for the carrier frequency in amplitude modulation, requiring that in some manner the virtues of the crystal oscillator be utilized.

Now the mean frequency in a frequency-modulated signal may be defined as the total number of cycles occuring in a second, whatever their distribution in time over this interval may be; so that a logical and direct procedure in maintaining the mean frequency at the assigned carrier value, would be to count continuously the number of cycles per second, comparing this with the number generated by a precise fixed-frequency standard, and adjusting the source of the oscillations to keep the two always exactly the same. This is in effect what is accomplished in Synchronized Frequency Modulation. The procedure has a close parallel in electric-power-system practice, where cycle counting by means of synchronous-motor clocks permits accurate control of the average frequency.

It is not necessary, however, to count millions of cycles each second, for the frequency may be reduced to any desired degree through the new technique of frequency division, whereby a low frequency is obtained which is an exact submultiple derived directly from the original frequency and having its variations reduced in proportion. The frequency divider, a tool of considerable promise in the communication field, consists basically of a modulator (shown as M in Fig. 1) and a vacuum-tube amplifier. The frequency f_2 appearing in the output of the modulator is the difference between the frequency fed back from the output, which is f_2 itself, and the frequency f_1 applied to the device; that is, $f_2 = f_1 - f_2$. This requires that $f_2 = f_1/2$, so that we have an exact halving of the frequency; and the output wave, although produced by a regenerative action, is under complete control of the input by virtue of the modulation process through which it originates.

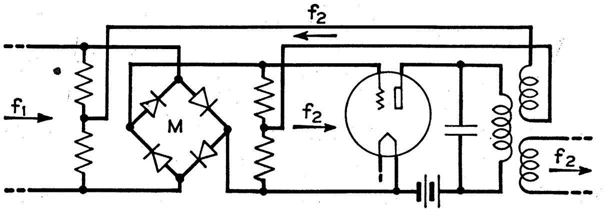

Fig. 1 - Schematic of a 2-to-1 frequency divider.

Using a modulator of the copper-oxide type, which recent refinements have rendered suitable for use at frequencies of several megacycles, the frequency divider becomes a very compact and simple device. By cascading a series of such dividers, we obtain for synchronizing purposes a frequency as low as desired, in exact submultiple relationship to the carrier frequency. In synchronized frequency modulation the dividing process ends up with a frequency of about 5000 cycles, or about 1/8000 of the carrier frequency.

Referring now to the block diagram of the system, Fig. 2, the role of the frequency divider becomes apparent. The divider is energized from the output of a frequency-modulated oscillator operating at about five megacycles, and its function as a part of the synchronizing system is to insure the constancy of the mean frequency of this oscillator, and hence of the final output frequency (42 to 50 megacycles) to be obtained by doublers following the oscillator.

There has been in use for some years a method of synchronizing two frequencies wherein the frequencies are combined in a modulator to produce a rotating magnetic field whose speed and direction of rotation correspond to the amount and sense of the frequency difference. As a small armature, geared to the tuning condenser of one oscillating source, brings the frequency back toward synchronism, the speed of rotation of the field decreases and the armature slows down, coming to rest when exact synchronism is attained.

At first thought, one would not expect such a device to be applicable in an ultra-high-frequency system because the departures in frequency are so great as to be beyond the capacity of a mechanical system to follow; but when the frequency is reduced by our dividing process to the

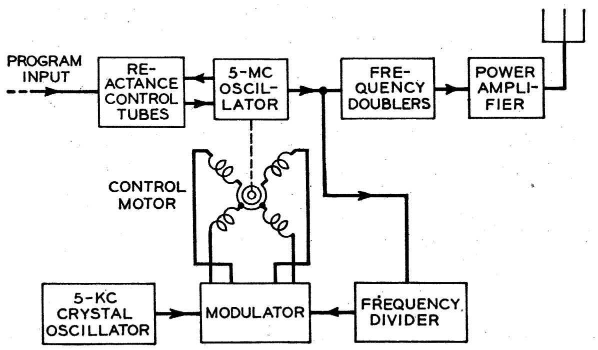

Fig. 2
Block diagram of the frequency-modulation transmitter.

order of 5000 cycles, or 1/8000th of the output frequency, we find that variations of hundreds of kilocycles in the output frequency are represented by variations of only tens of cycles, so that with a low-frequency crystal oscillator as the comparison standard we obtain a rotating magnetic field readily followed by the armature. So effective and immediate is the control that if the output frequency through some cause were to depart suddenly by as much as *four hundred kilocycles* from its assigned value, it would be returned to exact synchronism in two to three seconds; while gradual changes in frequency of as much as several megacycles will also be corrected because the change is followed continuously.

It is well known in frequency-modulation theory that the phase deviations are directly proportional to the frequency swing and inversely proportional to the audio rate at which the swing is produced. The frequency swings employed in wide-band frequency modulation are so great as to entail phase deviations of thousands of degrees; that is, the frequency-modulated wave is alternately advanced and retarded by many complete cycles with respect to an unmodulated comparison wave. When a high order of frequency division is introduced, however, the frequency swing becomes small while the audio rate is unchanged, so that the phase departures due to modulation are then only a few degrees.

The magnetic field in the control device therefore oscillates only slightly at audio frequencies about its mean position, and the oscillation is not followed by the motor because of its inertia; the slightest change in *mean* frequency, however, produces a continuous rotation of the field and is corrected at once. The frequency divider, then, serves two important purposes: to reduce the whole phenomenon to a time scale suited to electromechanical operations, and to obscure the effects of modulation so that only changes in the mean frequency, or total number of cycles per second, can influence the frequency-control mechanism.

Not long ago 50 kilocycles was regarded as an extremely low frequency for quartz crystals. The appearance of a 5-kilocycle crystal oscillator in the block diagram of Fig. 2 is a reminder that advances in the frequency range of radio equipment are not being confined to the high-frequency end of the spectrum. This is a low-temperature-coefficient crystal oscillator giving the same percent stability as obtained in the best broadcast crystals. The stability is well under one part in a million per degree centigrade, making temperature control entirely unnecessary.

This system of frequency control is so unique in a number of important characteristics as to bring to light immediately certain limitations of other methods that might not otherwise be obvious. For one thing, the stability is identically that of a single crystal oscillator, unaffected by any beating process with other oscillators, or by changes in gain or frequency characteristics of associated circuits. There are no temperature-controlled networks for converting frequency changes into amplitude changes, opening the door to errors due to gain fluctuations; everything in the control system is kept in terms of frequency. In the second place, the actual control exercised on the oscillator to maintain its mean frequency is mechanical, involving a variable condenser; and being mechanical, when the oscillator is brought to the correct frequency it is *left* there, without the necessity of any sustaining voltage such as must be supplied when slope-circuit control is used, and therefore without the danger of a sudden wide departure in the frequency should the control voltage fail.

Mechanical control, moreover, completely relieves the frequency-modulating elements of any connection with the stabilization of the mean frequency, so that these elements may always be operated at the optimum point for linear modulation and the frequency swing obtainable is not limited by the necessity for correcting frequency drifts in the oscillator. Finally, the entire synchronizing system, including the crystal oscillator, is completely external to the program-carrying part of the transmitter, and no failure or misadjustment within it can have any influence on either the quality or the continuity of the transmission.

Frequency modulation holds such promise as a vehicle for high-quality noise-free broadcast service that no pains have been spared in producing a transmitting-circuit design of extremely low distortion and background noise level. By modulating at a carrier frequency of five or six megacycles, where the phase deviations are large, the difficulty encountered at low initial frequencies from phase modulation due to power-supply hum and microphonics is removed. In synchronized frequency modulation, moreover, the complete separation of the two functions of modulation and frequency stabilization permits the use of push-pull reactance control tubes for modulating the oscillator, so that ripples in bias or plate supplies do not modulate the frequency. The balanced circuit (Fig. 3) employed for these tubes and for the oscillator, together with other refinements in design, permit a frequency excursion of hundreds of kilocycles on either side with very low distortion.

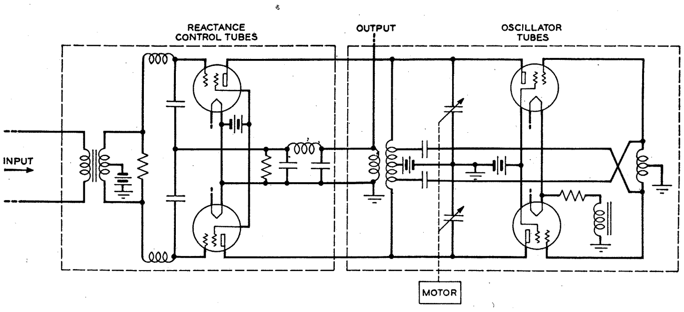

Fig. 3 - Schematic of the frequency-modulation circuit.

Following the modulated oscillator in the 503-A-1 equipment are four pentode stages, three of them being doublers, and all extremely simple in design. At the final output frequency two triode stages increase the power to 1000 watts for transmission to the antenna. These triode stages use the 356A and 357A, stemless and baseless ultra-high-frequency tubes in the molded-hard-glass type of envelope. The 357A is rated at 350 watts plate dissipation, with full voltage rating up to 100 megacycles. Two of these in the range from 40 to 50 megacycles deliver 1000 watts for FM with great ease.

The 1-kilowatt broadcast transmitter, in which the 357A tube made its debut a year ago, introduced a new mechanical construction and an exceptionally attractive modern cabinet design. These features have been received so favorably for broadcasting and high-quality police service that the same lines have been followed in this first commercial Western Electric frequency-modulation transmitter. All apparatus is mounted independently of the cabinet; every part is immediately accessible for inspection or maintenance; all controls are protected by narrow side doors flanking the main door. The apparatus has been designed to give long and trouble-free life.

The new techniques and apparatus refinements that are made use of in synchronized frequency modulation have been contributed by various departments of the Bell Laboratories, and acknowledgement is made of these indispensable foundations.

Audio Facilities for Frequency Modulation

By Edward J. Content*

In considering audio facilities for a frequency-modulation station, we must give attention to the standards of good engineering practice which have been set up for these stations by the Federal Communications Commission. These standards include the following provisions:

> "(2) The equipment is capable of satisfactory operation at the authorized operating power or the proposed operating power with frequency swing plus and minus 75 kilocycles. At any frequency between 50 and 15,000 cycles at a swing of 75 kilocycles, the combined audio frequency harmonics generated by the transmitting system shall not be in excess of 2 per cent (root-mean-square value).
>
> "(3) The transmitter and associated studio equipment shall be capable of transmitting a band of frequencies from 50 to 15,000 cycles within 2 decibels of the level at 1000 cycles. In addition provision shall be made for pre-emphasis of the higher frequencies in accordance with the impedance-frequency characteristics of a series inductance-resistance network having a time constant of 100 microseconds.
>
> "(4) The noise in the output of the transmitter in the band from 50 to 15,000 cycles shall be at least 60 decibels below the audio-frequency level represented by a frequency swing of 75 kilocycles (100% modulation)."

Very few people realize how rigid these requirements are in considering the audio-frequency response characteristics. The complete audio system, from microphone to transmitter, includes fifteen audio transformers and fifteen vacuum tubes operating in tandem. The characteristics of all of these individual units naturally will add to provide the overall frequency characteristic, providing the impedances of all the circuits are properly matched. Also included is the telephone line for linking the studio to the transmitter. In considering the signal-to-noise ratio, we must keep in mind that the output level of a microphone is approximately minus 60 VU. (The VU, or volume unit, is the number of decibels from one milliwatt when observed on a volume indicator of standard characteristics.) The thermal noise produced by the most quiet types of tubes in practice is approximately minus 130 to minus 125 VU. Therefore, the best signal-to-noise ratio possible with the present microphones and tubes is plus 65 to plus 70 db. This is really the bottle-neck of the system as far as signal-to-noise ratio is concerned, as in systems properly designed the signal level in the audio circuits is never again allowed to approach this low level.

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*Assistant Chief Engineer, Station WOR, New York City

The studio audio facilities for W2XOR, which have been installed in the WOR No. 1 Studio at 1440 Broadway, consist of the following equipment:

- 7 Premixing Western Electric Type 120-A amplifiers
- 8 Mixing controls
- 1 Regular and 1 emergency Western Electric Type 120-A booster amplifier
- 1 Regular and 1 emergency Western Electric Type 121-A line amplifier
- 1 Western Electric Type 124-A monitor amplifier and the necessary keys, jacks, relays, etc., to provide the complicated switching operations in the most simple manner possible.

These audio facilities provide for the simultaneous operation of six microphones, one transcription reproducer, and one incoming program line.

The telephone-line circuits, between the studio and the transmitter, have been furnished by the New York Telephone Company, and are flat to within 1 decibel from 30 to 20,000 cycles.

The audio facilities at the transmitter include a three-channel mixer; this links the output of the regular and the emergency lines from the studio as well as the output of the local announcing microphone at the transmitter. This mixer feeds a Western Electric Type 121-A amplifier, from which the signal goes to a high-frequency pre-emphasis circuit, thence thru a Western Electric Type 126-A limiting amplifier to the frequency-modulation transmitter.

Measurements made of the complete system have shown that all of the Commission's requirements have been met, and in most respects surpassed.

Studio Acoustics for High Fidelity

By J. P. Maxfield*

For good acoustics a studio must be satisfactory in all of the following respects:

1. The amount of reverberation (which is commonly expressed as the time required for the original sound to die away, after sudden interruption, to a value 60 db lower);
2. The frequency characteristic of the reverberation of the room, that is, the curve showing the reverberation time at various frequencies; and
3. The "bumpiness of the die-away curve" - the larger bumps in this curve are caused by the large-order standing waves in a room.

The reverberation time of a room can be controlled by the use of sound-absorbing material distributed on the walls, ceiling and floor, and by shaping the walls in such a manner that the sound hits the absorbing material more often. In the early days of broadcasting the tendency was to use only acoustic material and to distribute this over large areas, paying very little attention to the resulting frequency characteristic of the reverberation. Under these conditions a great deal too much acoustic treatment was necessary to eliminate serious standing-wave patterns in the studio. In later years, however, it has been found that studios can be designed with the optimum reverberation period, provided sound-absorbing treatment of proper frequency characteristic is distributed properly over the wall areas, and also provided that the walls are broken up by slightly angled sections to avoid large reflecting areas in such positions as to cause bad standing-wave patterns. In other words, Items 2 and 3 above are now taken into consideration to the benefit of acoustic design.

Studios with too short a period of reverberation are very unnatural, and the musicians and artists cannot perform at their best because they do not hear the musical and vocal tones in the normal manner. The tendency of performers in such a studio is to force the volume at the expense of tonal quality. It has been observed that when studio acoustics are ideal for the performer, the conditions are also best for the broadcast program.

To provide good acoustics, it is also necessary that the large-order modes of sound reflection be practically eliminated by breaking them up into a large number of smaller reflections. These large-order modes of vibration, or resonances, are caused by large, flat, untreated portions of walls, ceiling, or floor which, when opposing each other, cause a sound to be reflected and re-reflected many times. Such reverberation causes a peak in the reverberation-frequency curve for the room. Therefore, it is necessary either to distribute the acoustic material in a large number of small areas rather than a small number of large areas, or to provide angled reflecting surfaces on the various walls for a more uniform distribution of the sound reflection throughout the room. It is in this manner that the third requirement is met. In actual practice both of these methods are combined. There is still considerable uncertainty as to the exact shape of the ideal curve of reverberation as a function of frequency. Practical experience, however, has shown that in small studios the curve which is nearly flat with frequency gives the best general results; however, as the studios get larger and approach theatre proportions it is desirable to have the reverberation time at the lower frequencies greater than that in the treble region. By the time the studio has reached the size 500,000 cubic feet or greater, the reverberation time at 128 cycles should be about one and one-half times that at 512 cycles.

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*Director of Commercial Engineering, Electrical Research Products, Inc., New York City.