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Recent developments in radio-frequency control practice of precision frequency controls†

By D. E. REPLOGLE*

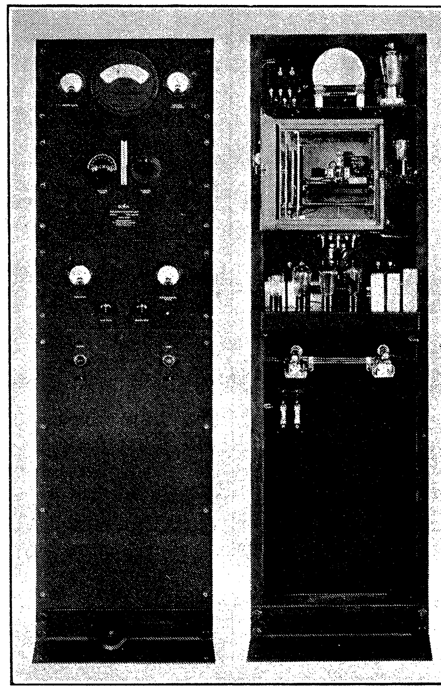


Fig. 1. Fig. 2.
Fig. 1. Front of DeForest frequency monitor Type A.
Fig. 2. Back view of DeForest frequency monitor Type A.

THE high quality of broadcasting, increasing the interest of the public has made the importance of satisfactory reception of radio broadcasts increase greatly month to month and year to year.

The work of the Federal Radio Commission has already resulted in clearing up much of the interference on adjacent radio channels and there is still much they are now working on. In order to clear up such interference and in order to put as many stations on the air as possible, there is urgent need for every existing station to operate accurately upon its assigned frequency with the least possible deviation. Any deviation will use space in the ether which is wanted and can be used advantageously by others.

Accurate frequency control is essential in many other fields beside that of broadcasting. The transmitters for service other than broadcasting have increased in number and in importance much faster than new channels have been opened for them. Aviation, fixed point to point telephone, moving vehicles, communication, press transmission, fixed point to point telegraph communication, and the growing need of large corporations with wide flung interests for inter-communication, educational broadcasting, governmental, marine and civil services, all have increasing need for more wavelengths and for great use of the ether.

The space each service requires in the air is determined by the audio frequency bands to be transmitted and the degree of selectivity that can be obtained in the reception of these wavelengths. The obvious means of inserting more stations in a given ether spectrum is to prevent the use of a wider area in that spectrum by a given transmitter than is necessary. This again calls for precision in the control of the carrier frequency.

Frequency Control Up to Manufacturer

With a given piece of equipment no station could, beyond a certain limit, do much to hold its frequency closer than the original design of the transmitter permitted. Hence, all Federal agencies connected with radio transmission have been following with mounting interest the development of frequency control units. In fact, it is understood that so desirous has the Radio Commission been for greater precision in carrier frequency control in the broadcasting field that as soon as an accurate frequency control at a reasonable cost could be assured, General Order No. 119 was put into effect. It is reasonable to expect that even better control units will be developed with stricter requirements. This is definitely up to the manufacturers of the transmitting equipment, with the problem of meeting the requirements of the art, in both original installations and also in installations now in operation.

When the De Forest Company first started to build transmitters, we used a crystal control unit made by a well known manufacturer and which, from our experience, was the best obtainable. Trouble immediately developed with this unit so that the frequency control problem became the most difficult one in our design.

In sending transmitters to various parts of the United States, with different temperatures and different conditions of operations, we ran into an unusual amount of frequency control difficulty which proved very costly. We then decided to investigate the control field ourselves and with the aid of the Radio Research Laboratory in Washington, have developed what we believe to be one of the most reasonable and highly perfected control units yet

† *Presented before the Club, February 10, 1932.*
* *Vice-President, in charge of engineering, De Forest Radio Co.*

known commercially. This unit has already gone through some very exhaustive and conclusive tests which have been passed satisfactorily.

Monitors Desirable for Station Operation

The first step in attempting to obtain greater precision of frequency control is to set up and consistently operate a monitor which will as accurately as possible tell the deviation of the carrier frequency from the assigned value. There are a number of places in the United States where checks on frequency can be made. A call to a local United States radio supervisor will usually bring a frequency check on the carrier. A telegram to the Department of Commerce, central monitor station at Grand Island, Neb., will always bring a response on frequency precision, but it is highly desirable that a monitor be in continuous operation so that the operator can check from time to time on the frequency deviations. Hence, the requirement of the Federal Radio Commission that such a monitor be in operation in every broadcasting station. The most successful form of a monitor is the use of a local precision oscillator which beats against a carrier frequency, the beat note being indicated by some accurate method.

Monitor Requirements

The following characteristics should be met in such a monitor if the best practice is used:

1. The local oscillator should be of the highest precision, if possible to be maintained within 4 cycles.
2. It should have precision heat control.
3. It should have a continuous means of indicating the beat note.
4. It should be entirely independent of temperature variations.
5. It should be independent of supply voltage variations as far as possible.
6. All the meters or indicating devices employed should be corrected for temperature variations.
7. It should be capable of operating through wide extremes of temperature.
8. It should be capable of being set up in the station to be monitored without complicating adjustments.
9. The indicating means, if possible, should be continuously and easily visible through months of operation without attention and without adjustment.
10. It is undesirable that the precision and accuracy of the monitor be dependent upon adjustments which must be made by an operator from time to time.

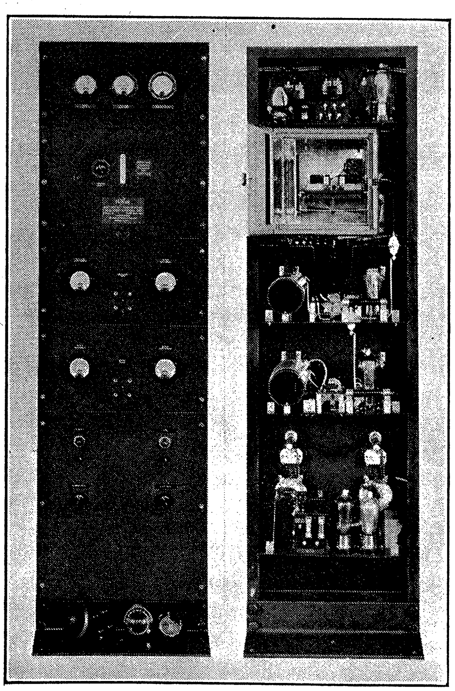


Fig. 3. Fig. 4.
Fig. 3. Front of DeForest Type B crystal control unit. Note removable adjustment dials.
Fig. 4. Back view of DeForest Type B crystal control unit.

In the De Forest monitor the precision frequency control is the first and outstanding development which merits attention.

Precision Frequency Control for Transmitters

The definition of "precision frequency control" has changed rapidly during the past few years. Not so long ago any vacuum tube oscillator was notable because of its excellent frequency stability. Later, a master oscillator circuit was regarded as the acme of perfection in frequency control, and even today any transmitter equipped for crystal control, whether or not the crystal is in actual command of the situation, is regarded with respect by a respectable percentage of the radio engineering talent.

The precision of any method of frequency control lies largely in the degree of engineering effort spent in the design of the circuits and in the care expended by the operating personnel in maintenance and supervision. It is a recognized fact that many self-oscillators are more stable in their frequency characteristics than some master oscillators, while a fair percentage of crystal controlled circuits are inferior to some well designed master oscillators.

While crystal control has in general led to better frequency stability with greater ease of operation there have been, and still are, many installations in which the frequency control is still poor and this despite the fact that the crystals are operated within cabinets supposedly maintained at a constant temperature. This paper deals with frequency control employing quartz crystals held at a constant temperature, as the frequency stabilizing means.

Crystal Cuts

There are two common cuts of quartz crystals known as the zero angle cut and the 30° cut. In the zero angle cut the crystal is manufactured from a quartz plate which has been cut through the plane, perpendicular to the X-axis of the natural quartz crystal. The 30° crystal is, as its name implies, made from a quartz plate cut from a natural crystal along a plane 30° from the X-axis.

Each cut has its advantages. The zero angle crystal is less likely to have spurious frequencies, while the 30° crystal is more active. From the manufacturing standpoint, the 30° crystal is the best product where immediate profit is concerned, since these crystals will generally oscillate readily and without a great deal of effort on the part of the grinder. These crystals, however, will frequently and without apparent reason shift their frequency of oscillation several kilocycles. This is particularly true if the load on the crystal changes or if the temperature of the crystal is subject to change.

Zero angle crystals are considerably more difficult to manufacture but when properly made will have little tendency to spurious frequencies and can be obtained with a guarantee that spurious frequencies will not show up during a 30 per cent. change in plate voltage, a 10 per cent. change in filament voltage or a 10° change in temperature. The specifications under which crystals are purchased should by all means include these items as a safeguard against crystals having "doubles."

The size of the crystal has some influence on its desirability and in general, for power purposes, the crystal should be substantially square and of not less than 1 inch in surface area.

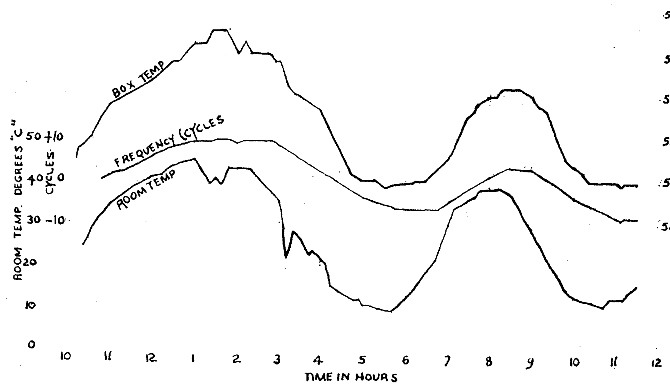
It should be stated here that the matter of zero angle crystals and 30° crystals is one in which there is still controversy between many radio engineering organizations. While the proponents for 30° crystals admit that the possibility of spurious frequencies exists, they claim that the spurious frequencies can be removed by proper treatment. It is for the purchaser to decide whether he cares to risk a type of cut which is only slightly cheaper and may have spurious frequencies as against a cut which probably will not have spurious frequencies at only a slight increase in cost.

Causes of Frequency Drift in Crystal Controlled Oscillators

The change in temperature of the crystal is probably the best advertised of the several factors which lead to frequency drift in a crystal controlled oscillator. This change, due to temperature, is caused by the fact that as the crystal becomes warmer it expands and therefore its natural frequency of vibration is retarded and vice versa. This shift in frequency may be from ten to twenty-five parts in a million; that is, ten to twenty-five cycles at 1000 kcs. for each Centigrade degree change in crystal temperature. The entire change is, however, not due to the crystal expansion alone but also to the type of mounting and kind of cut of crystal. A second factor which may cause frequency drift is a change in capacity or inductance of the tuned circuit to which the crystal is connected. By adjusting the tuned circuit it is often possible to shift the frequency as much as 50 cycles and if the components of the tuned circuit are such as changing temperature, aging, etc. or undergoing a process of expansion or contraction, the frequency must inevitably shift. Other factors leading to frequency drift are changes in the loading on the crystal due to shifting plate or filament voltages, reactions from amplifier circuits, or other similar causes.

Most of the causes which underlie frequency drift in oscillating crystal circuits have been known for some time but the means by which they may be eliminated have either been neglected or not sufficiently worked out to be incorporated in commercial designs.

Fig. 5. Variations of frequency in oscillation with room temperature and with box temperature.



Crystal Temperature

The temperature of an oscillating quartz crystal is dependent on two things: first the ambient temperature of the atmosphere immediately surrounding the crystal, and, secondly, upon the heat generated by the crystal itself.

The common way of maintaining the ambient temperature at a fixed value is to mount the crystal within a constant temperature cabinet. There are many types of constant temperature cabinets employed for maintaining constant crystal temperatures. Unfortunately, however, most of the cabinets have certain defects in design which make them of little or no value from the standpoint of crystal temperature regulation. The heart of a constant temperature cabinet is the thermostat by which the temperature is regulated. In the usual design of cabinet the thermostat is located at a point relatively remote from the crystal. The temperature at the thermostat may be constant but the temperature even an inch away from the thermostat may vary within considerable limits, as much as several degrees. Where a high capacity heater is employed together with insufficient insulation and where the room temperature of various points within a "constant temperature cabinet" will jump up and down a surprisingly large amount. This variation is noticeable when the thermometer is mounted with its bulb close to the crystal or where the bulb is in some part of the cabinet other than close to the thermostat, but such variations in indicated temperature do not improve sales so the practice has been to mount the thermometer close to the thermostat but to let the crystals remain at some point several inches away from the thermostat. With one exception the correct design of a constant temperature cabinet requires that the crystal, the thermometer and the thermostat be jammed as close together as is mechanically possible in order that the point of regulation shall be at the crystal and not at some point removed therefrom.

The exception referred to is where the crystal is mounted in an inside box having several attenuating layers between the crystal and the thermostat and between the thermostat and the heaters. This scheme will give extremely even temperature control, especially if two heaters and two thermostats are used in a series arrangement whereby the wide changes of room temperature are largely taken care of by the outside heater-thermostat-attenuating layer, while the finer temperature control is exercised by the inside heater-thermostat-attenuating layer. We have then two methods for obtaining the desired constant temperature; first, to confine the thermostat and crystal within a small area in a well insulated box and, second, to have the crystal mounted within a series of attenuating layers in a box whose temperature is regulated by a thermostat in one of the outer layers.

The second arrangement, while ideal from the standpoint of maintaining constant the temperature of a non-oscillating or very weakly oscillating crystal, does not satisfy the requirements where the crystal is being operated under considerable load. During the development of constant frequency apparatus it was noticed that despite the most careful regulation of temperature with the crystal non-oscillating a rise of several degrees in crystal temperature as evidenced by frequency drift would take place during the first hour the crystal was in operation. By substituting a resistance element of small size in place of the crystal it was ascertained that the particular crystal involved would rise 3° in temperature when operated under a comparatively light load. The task of eliminating this rise in temperature due to molecular friction within the vibrating crystal proved to be rather difficult. It is obvious that the second type of cabinet mentioned (attenuating layers) would not be suitable since the transfer of heat from the crystal to the thermostat would take several hours and the entire system would not be stabilized unless the constant temperature cabinet were kept operating and the crystal oscillating continuously. Such an arrangement is neither satisfactory nor economical. By employing rapid circulation, properly designed crystal holders and mounting plates, and correct thermostat location, the temperature of the crystal may be held constant within a very small fraction of a degree whether oscillating or non-oscillating, and a state of equilibrium can be established from the cold, non-operative position to the 50° oscillating frequency within a few minutes.

With this description of the local oscillator, the next point of interest in the De Forest monitor is the method used to indicate the beat note. An amplifier is used to amplify the beat frequency, and this is fed directly into a temperature compensator, a highly accurate Weston frequency meter which has a large scale which can be seen for some distance. It will be noted that this meter is driven by frequency only, and if ample safety factor on output voltage is provided the indication meter will be independent of the strength of the beat signal. Hence, changes in voltage in the amplifier will relatively be unimportant with little or no effect on the indicating device. Thus, a visual indicator at all times is accurately available to the operator without a single adjustment.

We find that in these frequency control units the oscillator tube must be thoroughly seasoned in order to obtain a high degree of precision.

The frequency control units herein described are run for a week's period or until such time as there is no further deviation in the frequency due to possible changes in tube characteristics.

Chances for error in the frequency change of the local oscillator may be due to the following:

Temperature shift of 35° Centigrade may cause a maximum change in the oscillator of 12 parts in a million.

Change in oscillator tubes may cause a change of 4 parts in a million.

Ten per cent. plus or minus in the supply voltages will affect the local oscillator frequency less than 1 cycle.

Change due to heavy pounding or vibration will affect the frequency less than 2 parts in a million.

A change of ambient temperature 1° Centigrade in the outside of the heater box will cause 100° change in the temperature inside of the heater box, which is roughly one-half cycle change for each degree centigrade in the ambient temperature.

Hence, for temperature changes a calibration chart is furnished which will give an absolute frequency value with the local oscillator in any degree of ambient temperature. The normal operating temperature in a heater is 55° Centigrade.

Crystal Control Units for Transmitters

The same type of crystal control units manufactured by the De Forest Radio Company in their transmitters are for use separately for other transmitters. This control is capable of precision up to one part in a million. It is possible to use these crystal controls for synchronization of broadcast stations. A very successful experiment is now in progress between stations WATC, Rochester; WAK, Albany; WHP, Harrisburg; WCAH, Columbia, Ohio, all operating sychronously on 1430 kc. These stations have been checked within two cycles for a period of a month, and for several months no station has been away ten cycles from the others. It might be of interest to note that the precision obtained here is even greater than at times obtained with wire synchronization from master frequency. One of the leading stations has recently been measured more than ten cycles off from its fellow synchronizing station.

In connection with the degree of precision which has just been mentioned it may be interesting to note that the best of astronomical clocks is built with no better precision than one part in 10,000. Average observed accuracy shown on this crystal controlled unit of one part in a million can be regularly expected. The units as built, even with rough treatment, can be expected to hold within three parts in a million.

Every unit is made with a thermometer so that the oven temperature is observable at all times, and if desired, a meter can be put in that will indicate any change in over temperature by audible means. At present we use a fusable link in the heater box to protect the heater from over-heating in case of thermostat failure.

In the crystal controls a ceramic holder is used with a very low temperature coefficient. The holder of the crystal itself is uniquely done, which facilitates slight changes of frequency, but maintains a given setting indefinitely. In the frequency control units ample power is allowed so that we tune considerably away from resonance for greater stability. Crystals are guaranteed to arrive very near their absolute frequency. A selective service with proper control units allows measurements of all important circuits. Monitors and frequency controls are checked a long period of time before shipment. There are no buttons to push, no incorrect effects from temperature, nor voltage variations in any of the units.

Conclusion

Precision frequency controls of this type are making much easier the development of satisfactory transmitters for operation on the ultra high frequencies. Particularly is this desirable in the wide acceptance of the super-services for television where doubling and tripling is desirable and frequency errors are multiplied accordingly. Even aviation demands a crystal control unit with the result that greater accuracy in crystal units must be developed.

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SUGGESTIONS TO CONTRIBUTORS

CONTRIBUTORS to the Proceedings, by bearing in mind the points below, will avoid delay and needless expense to the Club.

1. Manuscripts should be submitted typewritten, double-spaced, to the Chairman of the Papers Committee.* In case of acceptance, the final draft of the article should be in the hands of the Chairman on or before the date of delivery of the paper before the Club.

2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are inacceptable.

3. Corrected galley proofs should be returned within 12 hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The Club reserves the right of decision on the publication of any paper which may be read before the Club.

* For 1932 the Chairman of the Papers Committee is Mr. F. X. Rettenmeyer, 463 West Street, New York City.

Book Review

"AIRCRAFT RADIO," by Myron F. Eddy, published by the Ronald Press Co., New York City, 1931. *Price,* $4.50. (284 *P. P.* 68 *figures. Cloth.*)

Have you ever stopped to think of the great importance that radio plays in the aeronautical field? Most of us who are not directly concerned with this branch of radio do not realize the extent that radio communication has been applied to this growing form of transportation. Until the recent appearance of *"Aircraft Radio"* there was no suitable manual containing complete information about this application of wireless.

"Aircraft Radio" is written by a former naval instructor in aircraft radio and is in the form of an elementary-semi-technical book prepared for the average student desirous of further investigating this particular field of radio. The work considers all methods of communication based on the applications of radio principles to aircraft. It is assumed that the reader of this book has had previous knowledge of the elementary principles of electricity as taught in public schools. For this reason the introductory chapters contain a brief review of the history of radio in aircraft and a discussion of elementary electricity as applied to radio practice. Although this introduction is somewhat superficial, its inclusion proves of value and serves as a suitable preparation for the more complete study included in the following chapters that directly concern radio equipment of more complex construction.

Following an explanation of the operation of the thermionic valve and its various applications in radio circuits, the reader is next introduced to radio telegraph and broadcast communicating equipment and a discussion of radio aids to aerial navigation. Here we learn more about the radio compass systems as applied to aeronavigation, rotating, radio range, and marker beacon systems; considering both the aural and visual forms, and the deviometer which is described and explained for the benefit of the interested reader. The text further explains how to solve problems regarding the installation of radio equipment in an airplane and contains an instructive discussion of bonding and shielding together with information on the installation of antennae. Sources of power supply for the operation of aircraft radio apparatus are likewise considered.

In addition there is included in the latter portion of the book the regulations of the U. S. Federal Radio Commission pertaining to aircraft operation and also a glossary of radio nomenclature together with a list of standard circuit symbols for the drawings relating to radio schematics as discussed in the foregoing chapters.

In general this work is more descriptive than theoretical and it appears that the text could have been more thoroughly illustrated to further enhance its value to the reader. Nevertheless, *"Aircraft Radio"* proves to be very instructive and is a timely work that should be included as a part of the radio library.

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"FOUNDATIONS OF RADIO." *By Rudolph L. Duncan. Published by John Wiley & Sons, Inc., New York City,* 1931. *Price* $2.50. (246 *pp. Illustrated-Cloth*).

Here is a timely work of recent publication written by one of our fraternal members who is an acknowledged authority on the subject. Students, and instructors as well, have long voiced their desires for a complete and easily comprehendable treatment of the elements underlying radio principles for use in mastering the radio science. The majority of popular radio books now in use are generally devoid of a complete treatment of elementary electricity such as forms the foundations of radio. For this reason there are numerous persons who learned radio through the self-study method and who are now engaged in various fields of the industry in practical work that have only a superficial knowledge of these basic facts. Such persons consequently have a vague conception of what actually occurs in various electrical circuits comprising radio apparatus. Mr. Duncan's new work now fills a gap in radio literature that will be appreciated by beginners and the like.

Nine chapters compose *Foundations of Radio* each of which is written in the author's well known style giving in plain language an understandable consideration of the principles involved. This treatment throughout the book is simplified by the use of suitable analogies and other pictorial diagrams to assist the reader in his study of electrical laws and theories that may otherwise leave the students somewhat clouded by technical explanations as commonly employed in such work. The use of intricate mathematical formulae has been entirely eliminated and only simple arithmetical calculations are employed in examples necessary to give the reader a working knowledge of the subject under discussion. The last chapter is devoted to preparatory mathematics wherein a review of elementary arithmetics and square root is included to familiarize the reader with problems involving such treatment and which are commonly employed in actual radio practice.

Foundations of Radio is an excellent "first book" for radio instruction prepared particularly for the student to whom it will prove most valuable.——*Review by Louis F. B. Carini.*