

# *The* RADIO ENGINEERS' DIGEST



SEPTEMBER 1944

VOL. 1, No. 2

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## *A Word of Thanks*

As the time arrives for the second issue of our magazine to make its appearance, we want to take this opportunity to thank our readers for the many friendly comments and helpful suggestions which they have sent us.

Such friendly interest, as exemplified by these letters, helps us to render a better service, by enabling us to gauge more accurately the types of articles our readers prefer, the topics they find most interesting. So, again we say — your comments and suggestions are most welcome!



## THE RADIO ENGINEERS' DIGEST

JOHN F. C. MOORE, *Editor*

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## THE COST OF TOMORROW'S PEACE

Reprinted by courtesy of the McGraw-Hill Publishing Co., Inc.

**T**ODAY peace-loving Americans are united with thirty-three other nations in a common objective of destruction.

Millions of our fine, young men and women find themselves invading foreign lands in order that their own shores may be spared, and their free way of life preserved.

Their sacrifices will be great. Their job will be well done.

But what of the job they will expect of us when they have finished theirs . . . the job of turning their hard-won victory into a lasting pattern of peace?

Can we come up to their great expectation? We must realize that this is the last opportunity of our generation. We must do a better job of it than we did in the Twenties and Thirties.

We have our backs to the wall, and the scars of World War I and a thirteen-year depression still are upon us. The final test of our way of life is at hand!

As we look over our shoulder into the immediate past, we see little to encourage us. But we also see much to make us pause. We see a tremendous fighting machine, created in a matter of months by the miraculous organization of our resources.

We, the largest of the peace-loving nations, have overnight become masters at the business of waging war. Today, as a result of the co-ordination of industry, labor, and government, we are producing *for war alone* as much as our total normal production for peace.

\* \* \*

We have amply demonstrated our ability to harness the vast productive capacity we possess. Why cannot these resources, which we have organized so efficiently for the destruction of life and property, be directed toward the destruction of the causes of war?

May not the patriotic and emotional strength and the unity of action which have been stimulated for the purpose of winning the war be directed, at least equally well, toward the attainment of world peace and international harmony?

If they are not so directed, what lies ahead but another war? And how can America, in a world that is so rapidly shrinking in size, avoid involvement in *any* of tomorrow's conflicts?

International peace is an ambitious dream and its price is high, but the price of war is even higher. Our world cannot long survive the periodic waste of its human and material resources.

Our country can be the most potent single force in bringing about the international understanding that leads to peace, in developing the unity that will make the most of the ample resources nature has provided everywhere.

\* \* \*

There is no unity in selfishness. There can be no unity if any one of the great powers fails to do its part in determining and eliminating from the world the basic causes of aggression.

These basic causes stem from greed and the suppression of opportunity for individual progress; for self-preservation is the first law of nature.

Mussolini's dramatic march on Rome in 1922 was made possible by disillusioned veterans of World War I who could find no jobs and whose future held no promise. Some of Hitler's most determined followers came from the same ranks.

Men denied the opportunity to make a living, for themselves and for their children, are easy prey to false doctrines and dangerous "isms."

In any realistic appraisal of our domestic problems—economic, labor, racial—it is clear that we can solve them, not by waiting until we reach some utopian accord, but by making a series of compromises. We do this because we know how discord can impair the very roots of private enterprise, self-government, and self-discipline—the essentials of a dynamic democracy.

Similarly, peaceful reconstruction of our world economy depends on the ability of nations to reconcile their differences in a series of working agreements.

If we in the United States want lasting peace and if we want to preserve our democratic way of life, we must take over our full share of the task of initiating these compromise measures. Acknowledging our inescapable responsibility as the greatest economic and military power in the world, we must attempt to insure the free flow of world trade, and develop—with profit for both parties—backward areas abroad as well as at home. And we must do this by making all nations share the responsibility, not by allowing ourselves to be maneuvered into being an international Santa Claus.

With our allies, we will have to see to it that the devastated portions of the world rehabilitate themselves as quickly as possible; that practicable and realistic trade and economic relations between nations are developed; and that the energies and productive capacities of these nations are set free to function in a climate that is favorable to the growth of free enterprise and individual initiative. As the most powerful economic force on earth, we have the most to gain and the most to lose at the peace table; and we must never forget that with our power comes responsibility.

We cannot hope to solve all of the problems of all nations—nor even all of our own—but our way can become the way for more of the world's humanity. Our strength can become the guiding spirit of the smaller nations.

\* \* \*

In the development of a sound American foreign policy, let us take care not to attempt to control the destinies of other nations. Let us remember that we must set the example of self-determination of independent, free peoples.

Freedom is essential to international peace; and free competition—whether it be between individuals, between businesses, or between nations—is the mainspring, the synchronizer, and the preserver of freedom. For competition always is synonymous with private enterprise.

We are not a covetous nation. We have no territorial ambitions. Our international commercial aspirations are dominated by the conviction that we have a great stake in world unity and world prosperity. We know that we can no longer live apart from other nations and that we cannot ignore the fundamental elements which affect the well-being of other countries.

Our foreign policy must encompass a world of trade, and help develop it.

We dare not blunder in the execution of that foreign policy if the American way of life is to survive. A democracy resolved upon isolation is doomed in the world of tomorrow.

Let us resolve that out of this devastating catastrophe we shall emerge with fuller understanding and greater determination to build the kind of world which can materialize only if this country has the vision and the will to see it through.

We still are free to decide our own fate—still free to shape our own future. We still are free to preserve the liberty and happiness that has made our country the hope of the world.



President, McGraw-Hill Publishing Company, Inc.

# HETERODYNE FREQUENCY METER

*Design data, constructional features, and applications of a highly precise frequency meter*

Reprinted from Radio

By Albert H. Carr

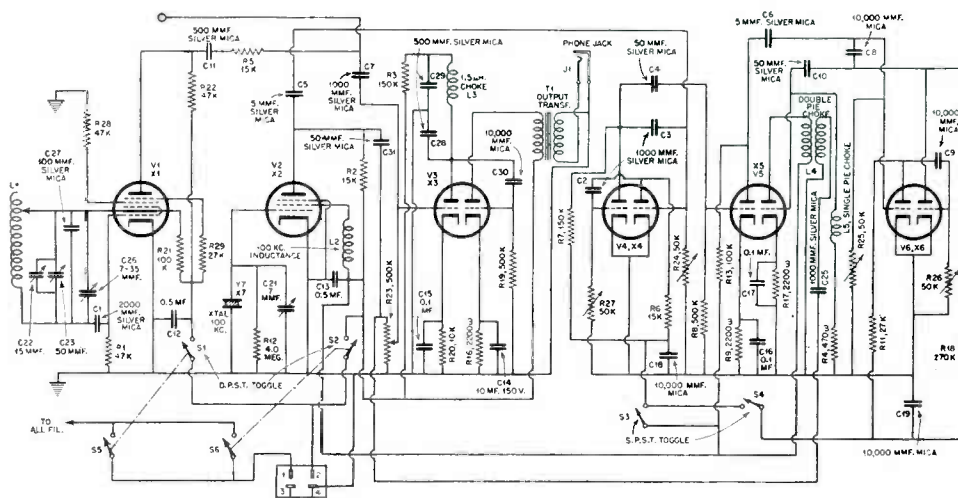
Chief Engineer, Fada Radio and Electric Co., Inc.

FOR some time, a very definite need for accurate, reliable, and completely portable frequency measuring equipment has existed. Mobile relay transmitters, emergency portable mobile equipment, as well as high-frequency relay (link) stations, are all required to maintain an accurate check on their operating frequency. With these needs in mind, the heterodyne frequency meter to be described has been developed. This equipment features unusual frequency stability under adverse conditions of vibration, temperature and humidity and may be easily, quickly and accurately recalibrated while in the field.

The Type SR-90 Heterodyne Frequency Meter is a completely self-contained instrument designed to facilitate the measurement of unknown radio frequencies falling within the range of 1 to 60 megacycles, these measurements being accomplished with an accuracy of .002% or better. The power supply consists of two 45-volt B batteries and four 1½-volt A batteries which are contained in the case. *Fig. 1. Schematic diagram of heterodyne frequency meter. Tube types are given in text*

## OSCILLATOR DESIGN

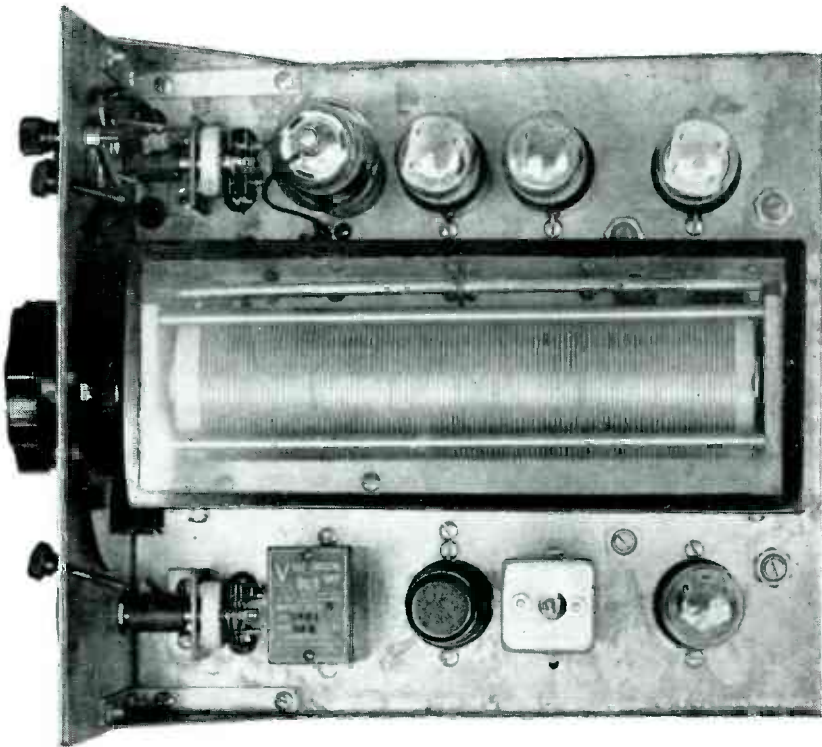
The variable frequency oscillator employed in this equipment is a high stability device, tuning over a fundamental frequency range of from one to two mc. A type 6K8GT tube is used in an electron-coupled ultra-audion circuit, the output of which is rich in useful harmonics. Harmonics up to the thirtieth are employed in extending the frequency range of the instrument to 60 mc.



*Fig. 1. Schematic diagram of heterodyne frequency meter. Tube types are given in text*

The frequency-determining element of this oscillator consists of an inductor (see *Fig. 1*) wound with silver-plated Nilvar wire on a threaded and glazed ceramic form of very rugged construction. Both the wire and the form employed have practically zero temperature coefficient, which results in a very high order of frequency stability vs. temperature.

This inductor is rotated directly by the main tuning dial, which is divided into two hundred divisions over an arc of 360 degrees. In conjunction with an 0-10 division decimal indicator, this arrangement permits direct reading to an accuracy of one part in two thousand. To cover the range of from 1 to 2 mc, this dial must be turned through seventy complete revolutions. Each revolution is indicated on a consecutively numbered dial which is located behind the front panel. Only the figures indicating the actual number of variable inductor turns in use are visible to the operator through a window in the panel above the main dial.



*Top view of frequency meter chassis*

The capacitive element of this oscillator circuit is provided in three forms. The main element consists of a 100  $\mu\text{f}$  silver-plated-on-mica capacitor, *C-27*, of substantially zero temperature coefficient. This capacitor is located at the lower left hand side of the variable inductor in order that it may be subjected to substantially the same temperature variations as the inductor itself. Physically, immediately forward of this capacitor is located an adjustable ceramic capacitor, *C-26*, whose characteristics are such that its temperature coefficient is negative. Located toward the front of the chassis and below it, is a variable air trimmer capacitor, *C-23*, of 50  $\mu\text{f}$  capacity. This unit has a positive temperature coefficient, and by use of the proper proportion of this and of the adjustable ceramic capacitor, any required coefficient

of temperature compensation may be obtained with the proper total value of capacity in the circuit. Finally there is provided on the front panel a variable air capacitor, *C-22*, of approximately 5  $\mu\text{f}$  capacity which is employed to "zero-set" the variable frequency oscillator. This small capacitor provides the means by which the variable frequency oscillator may always be set to a definite frequency for a given dial indication.

For calibration purposes, a quartz crystal oscillator of very high stability is employed. This oscillator employs one type 6SS7 tube in a conventional circuit. The crystal employed is an RCA Type VC-5, whose drift is less than ten cycles total over the temperature range of  $-24$  to  $+70$  degrees C. This oscillator has a fundamental frequency of 100 kc. Proper utilization of its harmonics permits calibration of the variable frequency at intervals of 100 kc over its fundamental frequency range of 1 to 2 megacycles.

Provision is made for bringing the crystal oscillator frequency to exactly 100 kc by means of a "zero-set" control, *C-21*, located on the front panel. A suitable harmonic of the 100-kc oscillator may be selected to beat against a primary standard of frequency, such as WWV, and the former brought to exactly zero beat with WWV by adjustment of *C-21*, which is a small variable capacitor connected directly across the 100-kc crystal to provide a tuning range of approximately plus or minus 200 cycles, which is more than sufficient in view of the very low drift of this type of crystal.

### THE MULTIVIBRATORS

Directly coupled to the 100-kc oscillator is a 6SL7GT dual triode employed as a 10 kc multivibrator, V-4, whose frequency is controlled by the crystal oscillator. The 10 kc multivibrator is followed by an isolation amplifier, V-5 left, which in turn is followed by a 1-kc multivibrator, V-6. The output of the 1 kc multivibrator is fed into a harmonic amplifier, V-5 right, which is peaked for maximum response over the range of 1 to 2 megacycles. The use of the amplifier, V-5, increases the harmonic voltage output of the multivibrators to a point sufficient to allow calibration of the variable frequency oscillator at intervals of 10 or of 1 kc in the range of 1 to 2 mc. The multivibrators may be used only in conjunction with the crystal oscillator inasmuch as their frequency is directly controlled by it. By a suitable switching arrangement the calibration intervals for the variable-frequency oscillator become progressively 100, 10 or 1 kc, and by means of curves provided the frequency of any signal, the harmonics, fundamental or sub-harmonics that fall between these points can be very accurately determined.

The 10-kc multivibrator is directly connected to the 100-kc oscillator and, when in proper adjustment, its frequency of oscillation is completely controlled by the 100-kc oscillator. A small amount of the output of the 100-kc oscillator is fed into the grid circuit of the first multivibrator section by coupling condenser *C-5*. It is possible to control the frequency of oscillation of the multivibrator by several methods, such as variation of the excitation voltage, variation of the capacitive elements of the circuit and variation of the resistive elements.

Inasmuch as the frequency of oscillation is determined by the time constant of the resistive and capacitive elements of the multivibrator circuit, variation of any of these would accomplish the same purpose. Variation of the resistive elements of the grid circuits was selected for this equipment because of its relative simplicity and stability. Two controls are provided, both located at the rear right-hand side of the chassis immediately adjacent to the dust cover. Their resistance is decreased as they are rotated in a counter-clockwise direction. These controls should be kept at similar settings; i. e., each should have approximately the same value of resistance in the circuit as determined by degree of rotation.

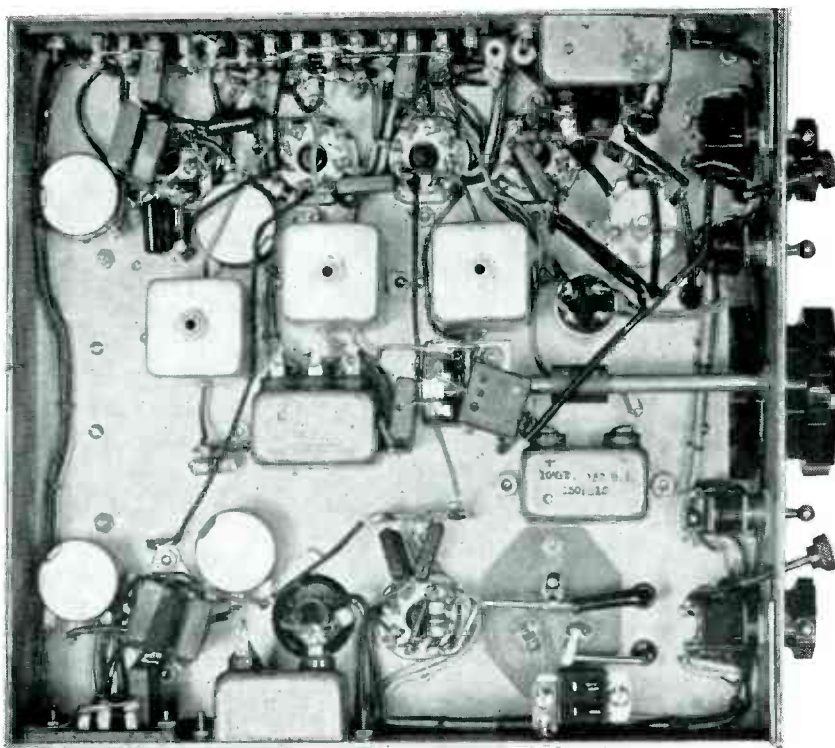
A fourth 6SL7GT dual triode tube, V-3, is employed as a combination mixer and a-f amplifier. A portion of the output of both the variable frequency oscillator and the crystal oscillator-multivibrator "string" is fed into this mixer-amplifier at the proper level to obtain a suitable mix. With care it is possible to beat these signals to a frequency difference of less than one cycle per second.

The output voltage is varied by means of the gain control located directly below the main tuning dial on the front panel. Suitable curves are supplied with the instrument to allow rapid and accurate check of calibration accuracy.

### CALIBRATION

The following procedure is indicated to correctly calibrate this equipment:

The calibrating oscillator and the variable frequency oscillator should be turned on and allowed to warm up for a period of 30 minutes. Assuming the variable frequency oscillator to be set to 1000 kc, as the tuning dial is advanced another beat note will be heard as the 11th harmonic of the crystal is approached. This note should be carefully set to zero beat and its dial setting checked for accuracy. The 10-kc multivibrator should be turned on and a 10,000 cycle audio note should be weakly heard in the phones. The main tuning dial should be carefully returned over the range between the setting where the 11th harmonic of the crystal was



*Bottom view of frequency meter chassis*

determined and the point where the 10th (1000-kc) harmonic was located. At every 10-kc interval there should now be heard a harmonic of the 10-kc multivibrator. This multivibrator is in proper adjustment (i. e., adjusted to exactly 10 kc) when it is possible to count nine beat notes between each and every harmonic of the 100-kc oscillator. In the event that either more or less than nine beat notes occupy this space, adjustment of the multivibrator compensating controls is indicated.



In case there are more than nine 10-kc harmonics present it is an indication that the frequency of multivibrator oscillation is too high, i. e., the resistive-capacity combination is charging and discharging too rapidly. Therefore an increase in the amount of resistance in the frequency-determining circuit is indicated. By turning one of the multivibrator adjustments slightly to the right (clockwise) an abrupt change in the tone of the beat note should be heard, indicating that the frequency of oscillation has changed.

The aforementioned procedure of counting the beats between adjacent 100-kc harmonics should again be tried. If further adjustment in the same direction is indicated, the other resistor should be varied until another change is heard in the tone of the note. By varying first one and then the other of the resistors, it should be possible to keep their value approximately the same, which is the desired condition. If the frequency of oscillation is too low, i. e., there are less than nine beats between 100-kc harmonics, the resistance should be varied in counter-clockwise direction.

If, by mishandling, the resistances become turned too far in the counter-clockwise direction, the multivibrator will become inoperative. The controls should be returned to a position approximating 50% of their rotation, and adjustments attempted again.

The procedure for determining the calibration of the 1-kc multivibrator is somewhat different from that outlined above inasmuch as the 1000-cycle tone generated by this unit is of much greater apparent intensity than that generated by the 10-kc multivibrator, requiring much greater care to accurately determine the actual point of zero beat. As zero beat is approached with the 1-kc multivibrator turned on, a flutter will be noticed in its tone and as the frequency difference becomes less, the beat difference may be counted. Perfect resonance is indicated by the "flutter" entirely disappearing. At this point the 1000-cycle tone becomes clear and steady, but flutters again if the dial is rotated further. In order to check the calibration of the 1-kc multivibrator, it is necessary to count nine of these resonance points between each of the 10-kc resonance points previously determined by the 10-kc multivibrator.

The procedure in adjusting the 1-kc multivibrator is similar to that stated heretofore except in certain details. Instead of counting the beat notes existing between adjacent 100-kc harmonics, it is necessary to count those existing between adjacent 10-kc harmonics. Two variable resistances are also provided for adjusting this multivibrator.

It should be remembered that when the 1-kc stage is turned on that there will be present in the phones a 1000-cycle note of strong intensity. This note is present at all times that the 1-kc stage is in operation and it is necessary to use care to detect the variation in it that is indicative of approaching zero-beat condition. Likewise more care is necessary in adjusting this stage because of the close proximity of one beat to another.

The variable frequency oscillator calibration may now be checked at any point on the dial (which is a multiple of 1 kc) against the calibration curve.

### OPERATION

Assuming that the required thirty minutes of warm-up time have elapsed, the following procedure is recommended:

A radio receiver capable of tuning to 5 megacycles should be tuned to WWV and this station carefully tuned in. Loosely couple the output post of the equipment to the antenna terminal of the receiver by means of an insulated unit having one end fastened to the output post and its free end wrapped around the receiver antenna lead-in for a few inches. Feed the output of the crystal calibration oscillator into the receiver. There should be little if any frequency difference between the 50th

harmonic of this oscillator and WWV. By tuning this frequency difference may be brought to absolute zero. It is desirable to observe the beat for several minutes in order to be sure that absolute zero frequency beat has been obtained, following which the radio receiver should be disconnected. The 100-kc oscillator is then turned to exactly 100 kc. This oscillator, if not subjected to rough handling, will maintain its calibration over long periods of time.

The variable frequency oscillator may now be turned on, and inasmuch as its filament has been lighted during the initial warm-up period, as well as during the period when the 100-kc oscillator was being adjusted, it should be stable. The variable frequency oscillator should be tuned to approximately 1000 kc, as determined by the calibration chart supplied. As this dial setting is approached, a beat note should be heard in the phones. This will be the beat between the variable frequency oscillator and the 10th harmonic of the crystal calibration oscillator. When the dial is tuned to the proper position as indicated by the calibration curve, the beat note may be brought to exactly zero by means of the control located on the front panel. Zero setting adjustment having established the variable frequency oscillator at exactly 1000 kc., rotate the dial to the reading corresponding to 2000 kc. Zero beat should be observed.

### MEASURING FREQUENCY

In order to determine the frequency of an unknown signal being received, the following procedure is indicated:

The unknown signal is accurately tuned in on a radio receiver. Preferably this receiver should be of the type that employs a resonance indicating device such as an "S" meter or a "Magic Eye." The "S" meter type is to be preferred for this use inasmuch as a much more accurate determination of exact resonance is possible with it.

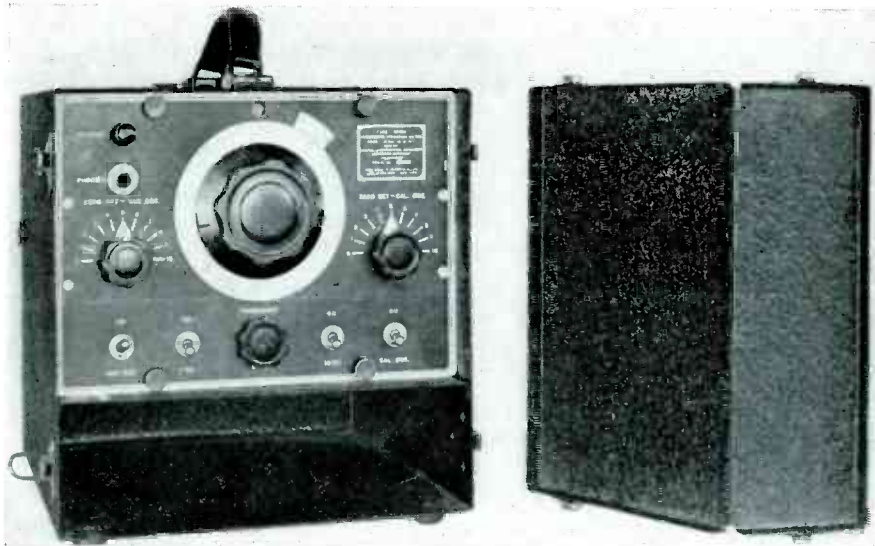
The output of the frequency meter is now fed into the antenna, the variable frequency oscillator tuned to close to zero beat with the signal to be measured, as indicated by the receiver, and the gain knob of the SR-90 adjusted its signal is approximately the same strength as the received signal. The most satisfactory "mix" will be obtained when these signals are of equal strength. As zero beat between the incoming signal and the variable frequency oscillator is now approached, it will be possible to count the beat difference between the two signals directly on the receiver's S-meter or "Magic Eye."

In the event that it is necessary to use a radio receiver for this purpose that is not equipped with an indicating device of this nature, it will be necessary to count this beat difference by ear. Zero frequency difference will be indicated by the absence of "flutter." With zero beat established between the received signal and frequency meter, the signal frequency may be read from the frequency meter calibration curve, if the signal is in the range of 1 to 2 mc. If it is not, then its frequency is the nearest known multiple of the frequency meter if higher in frequency, or the nearest known sub-multiple if it is lower in frequency. Signal frequency may be roughly determined by receiver calibration.

If it is desired to measure the frequency of transmitter at the point of transmitter location, the following procedure will be satisfactory:

The frequency meter may be located in reasonable proximity to the transmitter whose frequency it is desired to measure, but in no case should the equipment be located so close that the field of the transmitter is in excess of one (1) volt. It is preferable that the field be approximately one-half volt intensity. In the event of a strong field, i. e., 1 volt or more, it is very probable that no external coupling to the unit will be necessary. If the field is of low intensity, a coupling (antenna) wire should be attached to the output post of the equipment and the input signal from

the transmitter adjusted to the proper mixing level by means of the gain control on the front panel. The variable frequency oscillator may then be turned to zero beat with the transmitter signal and its dial position noted. The frequency of the transmitted signal may be read directly from the calibration curve, assuming the frequency meter calibration to have been accurately established immediately prior to measurement.



*Complete heterodyne frequency meter, ready for operation*

It must be borne in mind that the frequency as determined from zero beating of the heterodyne frequency meter against an external signal will be:

- a). A sub-harmonic of the 100 to 2000 kcs. range of the SR-90-A equipment where the external source is known to be below 1000 kc.
- b). As indicated by SR-90-A when the external source is known to be in the range of 1000 to 2000 kc.
- c). A harmonic of the SR-90-A where the external source is known to be above 2000 kc.

The ambiguity of measurement in (a) and (b) may be resolved from the use of a receiver of calibration sufficiently accurate to determine with which sub-harmonic or harmonic the measurement is concerned.



*The greatest invention of the nineteenth century was the invention of the method of invention.*

A. N. WHITEHEAD.

## ELECTRONIC CIRCUIT DESIGN

Reprinted from *Electronics*

By *S. B. Ingram*

Electronics Research Engineer, Bell Telephone Laboratories, New York, N. Y.

*Circuit development involves three steps: conception, the working model and the final engineering design, all affected by normal tolerances of parts.*

**T**HIS is an electronic war. Many workers in pure science, drafted by government agencies, find themselves suddenly charged with the engineering design of a practical electronic circuit. This article traces the nature of the three general steps required in the development of an electronic circuit: conception, the construction of a working model, and final engineering design.

In general, the circuit designer has a function which he wishes his circuit to perform. He has available an array of components: capacitors, inductors, resistors, transformers, switches, relays and perhaps non-linear elements such as saturable reactors—and finally, electron tubes.

The conception of the circuit is the intellectual exercise of originating, on paper, a device which the originator believes will perform the function required. If the designer is wise, he will give the circuit a thorough mathematical analysis at this stage as an aid to understanding its future operation.

The next step is to build a working model. For the engineer interested in tangible results, the production of the model is merely the application of the scientific method to his particular problem.

In general, unless the circuit is exceedingly simple and conventional, the first model will not work satisfactorily in all respects. Then it must be subjected to a more thorough analysis to determine how it works in its various sections, how its parts interact and how its behavior differs from the theoretical behavior expected on the basis of the original considerations. For this analysis, all the tools of the trade are required—meters, oscilloscopes and other measuring instruments. The analysis will generally explain the discrepancy in performance and will probably also suggest an alternative method of arriving at the desired result.

Both theoretical and experimental methods of analysis must be used and must go hand in hand. In this manner an actual circuit can be evolved which does what it is supposed to do and for reasons which are understood.

### ENGINEERING DESIGN

It is too often assumed that when a successful working model has been built the job is done and to put the circuit into production requires only the building of a number of other models just like the first. The fallacy lies in assuming that whole circuits can be exactly duplicated, when the components which they employ involve manufacturing variations and tolerances.

The engineering design of a device consists of making sure that all subsequently produced units will satisfy the performance specification when made out of components which vary over the entire range of their own manufacturing tolerances. Component part manufacturing tolerances are fixed by the limits contained in the acceptance specification of the component in question.

Having conceived the circuit and constructed a working model, the designer should try to make the circuit fail to perform by selecting adverse combinations of components and operating conditions. If he does not do this, his manufacturing

department or the users of the equipment will do it for him later to his embarrassment. If adverse combinations of components make it impossible to satisfy the requirements of the performance specification, consistency between the specifications of the components and the equipment must be established either by relaxing the requirements of the performance specification or reducing the specified tolerances on the components. Only when such consistency has been established can the engineering design of the circuit be considered complete.

### TUBE SPECIFICATIONS

Each of the circuit components must have its own specification which describes its nominal characteristics and the permissible manufacturing tolerances. In drafting tube specifications, for example, it is necessary first to determine which of the characteristics are important in circuit operation, then select tolerances consistent with circuit requirements.

If a circuit is being designed around tubes which already exist and whose characteristics are specified, the burden is on the circuit designer to see that his circuit can tolerate variations over the whole range permitted by the tube specifications.

It is interesting to note that the Joint Army-Navy Specification on tubes contains a statement that "equipment using the radio electron tubes covered by this specification shall be designed so that all tubes meeting this specification will perform satisfactorily in the normal service for which the equipment is designed."

This is not by any means a new conception. It is simply the electrical analogue of the concept of various "classes of fit" in mechanical engineering. The American standard on screw threads, for example, specifies tolerances on the dimensions of the threads of nuts and bolts so that for a Class 1, 2 or 3 fit any bolt falling within the tolerances of its specification may be fitted to any nut falling within the tolerances of the corresponding nut specification without the application of undue force or profanity by the mechanic whose job it is to put them together.

It is true that in mechanical engineering a procedure known as selective assembly, in which matched parts must be selected and assembled by a process of cut and try,

#### QUESTIONS TO ASK YOURSELF

Will the circuit work when you put in a spare tube?

Will *all* the models work when you put in *any* of the spare tubes?

You know the tolerance limits of the resistors and capacitors, but do you know the  $g_m$  limits of the tubes in the circuit?

is well recognized. But the Services have said before and continue to say in broadsides to manufacturers of electronic equipment, in which one can detect a slight note of desperation, that they do not want any electronic equipment which some doughboy is going to be called upon to put together under gunfire by a process of selective assembly. It is the joint responsibility of the designers of electronic circuits and tubes to see that it isn't necessary.

Tubes hold a unique position among the components of a circuit because they are generally the only components which are replaceable items. Resistors, transformers and other parts are usually soldered in for the life of the equipment. Their

replacement is a repair job to be performed by an expert. On the other hand, replacement of a tube is a more frequent procedure and the equipment must work with any spare tube which is inserted, and any spare tube means any tube which meets the requirements of the specification under which it was accepted.

In many tube specifications there is a tendency to fall back on operation tests, that is, satisfactory performance in a sample unit, as an over-all control of quality. Operation tests have the weakness that they prove only that a given tube will operate in a given unit. They give no assurance that the same tube will operate in another unit with a different combination of components.

### EXPERIMENTAL PROCEDURE

The process of establishing consistency between the specification of components and the overall circuit specification can be carried out by a variety of means. In many cases, circuit operation can be sufficiently well subjected to mathematical analysis that the effect of variations in tube characteristics on over-all performance, for instance, can be predicted. In other cases, effects similar to those resulting from variations in characteristics may be produced by substituting tubes known to have characteristics near the extreme specified limits. Variations in characteristics can frequently be simulated by artificial means. For example, a small capacitance may be introduced to represent a variation in the inter-electrode capacitance of a tube, or a small direct voltage from a potentiometer may be inserted in series with a grid to investigate the effect of a variation in grid characteristic.

Obviously, considerations as general as those given here will be found subject to many practical limitations when applied in a variety of actual cases. Under pressure of war schedules, it may frequently be impossible to do a one hundred percent job in applying ideal design principles. Nevertheless, any effort spent by the designer in assuring himself that the circuit is capable of accommodating the characteristic variations known to exist in the components is time well spent, since just that many causes of operation or manufacturing trouble will be forestalled



*By developing and improving . . . vitally important products, a comparatively small number of scientists may be a far more powerful fighting force than an enemy army of millions of men.*

DAVID SARNOFF.

## MODERN PHASE INVERTER CIRCUITS

Reprinted from Radio Service Dealer

*Audio phase inverters increase the reproduction fidelity. This section deals with their circuit and design.*

IN most audio amplifier circuits developed during the past eight years, the phase inverter has almost completely superseded the audio transformer formerly employed for interstage coupling. Because the sole elements of phase-inverter circuits are resistors and condensers which, in general, are not particularly critical in value, the phase inverter is economical both in cost and space requirements. The latter consideration is of special importance in the design of midget receivers. Further, with this type circuit, it is possible to obtain more uniform frequency response and higher voltage step-up—in some circuits—than can be secured with low-priced audio transformers. While good audio transformers provide greater inherent stability, and are therefore more generally used in commercial communications work and in higher-priced receivers, for the average low-priced household receiver the phase inverter has worked out very satisfactorily. Because of the necessarily high values of resistance employed in the grid circuits following the phase inverter, transformer coupling is preferred in designs employing power tubes operated in Class A-prime, where grid current flows over a portion of the applied signal cycle.

The purpose of the phase inverter is to couple a single-ended amplifier stage to a push-pull stage. In order to do this, the circuit is so arranged that output signals equal in magnitude but opposite in phase are produced. One of the simplest and most effective methods of accomplishing this is illustrated in the phase-inverter circuit of *Figure 1*. A simple triode, such as the 6J5, is used and the plate and cathode resistors are made equal in value. When a signal is applied to the grid of the 6J5, over the positive half-cycle the current in both resistors R1 and R2 increases. This increase in current causes an increase in the voltage drop across both R1 and

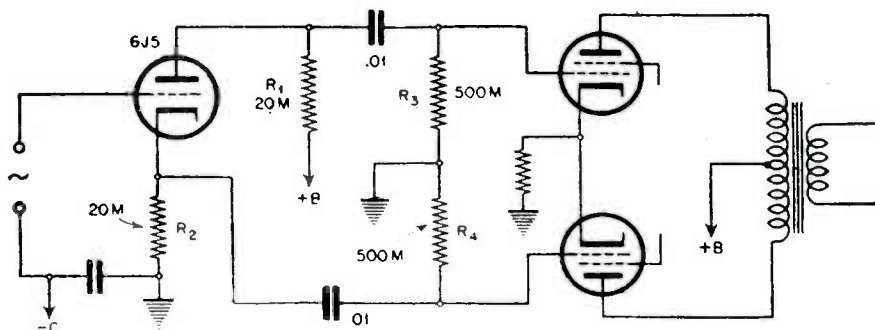


Figure 1

R2. As a result, the potential at the plate of the 6J5 becomes more negative with respect to ground. But, in the cathode circuit, the increase in voltage drop across R2 causes the cathode to become more positive with respect to ground. When resistor R1 and R2 are equal in value, the peak negative voltage at the plate is equal to the peak positive voltage resulting at the cathode. Because these two peaks are opposite

in polarity at the same instant, they are said to be 180° out of phase. Therefore, the signal voltages applied in the manner shown in Figure 1 to the grids of the output tubes which follow are in proper phase for correct push-pull.

A standard push-pull interstage transformer circuit is shown for comparison in Figure 2. Here the secondary is center-tapped and connected to ground. The signal voltage developed across the secondary is thus equally divided between the

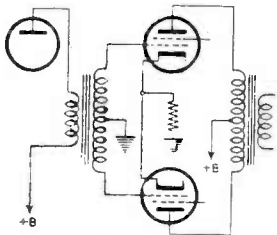


Figure 2

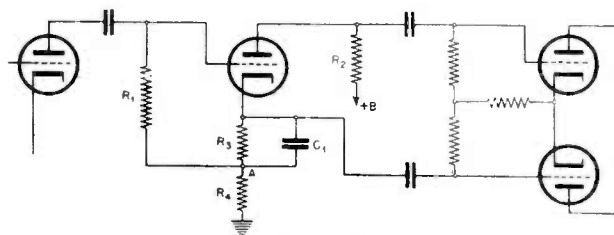


Figure 3

two halves of the transformer secondary. At the instant the upper end of the transformer secondary develops a maximum positive signal-voltage peak, the lower end is at a maximum negative peak. Thus the conditions for push-pull operation of the tubes which follow are realized.

Advantages of the circuit of Figure 1 are its simplicity and independence of changes in tube characteristics. If the tube depreciates, the signal voltage across each resistor, R1 and R2, is reduced proportionately, but proper phase inversion action is still obtained and the signal voltages across each resistor remain the same. Further, since this is a cathode-follower circuit with considerable degeneration, distortion is reduced. Disadvantages are that a voltage divider is required to apply the proper C-bias voltage to the grid of the 6J5. Furthermore, the maximum output voltage delivered across the push-pull grids is only about 1.8 times the applied input signal voltage at the 6J5 grid. This is generally insufficient to drive any of the larger power tubes, such as the 6L6 or power triodes, to full output, though it is just adequate for the 25L6 and others requiring less than approximately 7.2 volts at the grid for full power output.

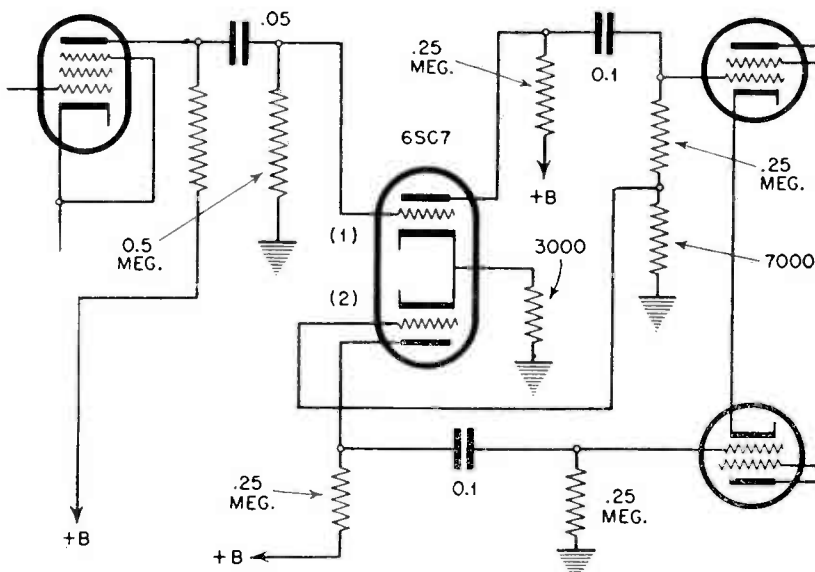


Figure 4



A modification of the circuit of *Figure 1*, which eliminates the need for a separate C bias and which provides much greater gain, is shown in *Figure 3*. Resistors R2 and R4 are made equal in value, as in *Figure 1*, but a cathode bias resistor R3, heavily by-passed by condenser C1, is employed to provide the proper bias voltage for the grid of the inverter tube. The grid return is then made to the junction of resistors R4 and R3. Because resistor R3 is by-passed, substantially no signal voltage is developed across it and, consequently, there is no degeneration. Thus a gain of the order of 14, as against 1.8 for the circuit of *Figure 1*, may be obtained. From an academic standpoint, the circuit of *Figure 3* is not quite as good insofar as proper phase inversion action is concerned because stray capacitances shunting resistor R4—which include that of the wiring of the output of the preceding tube—tend to cause a decrease in the signal voltage and consequent unbalance, at higher frequencies. From a practical standpoint, this effect is negligible in household receivers.

The type of circuit shown in *Figure 4* has achieved wide popularity in modern receivers because of the relatively high gain which may be obtained from it, as well as its simplicity. Using the values of resistors shown, a gain of 36 (approximately)

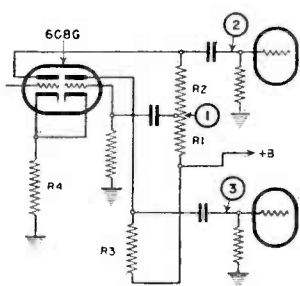


Figure 5

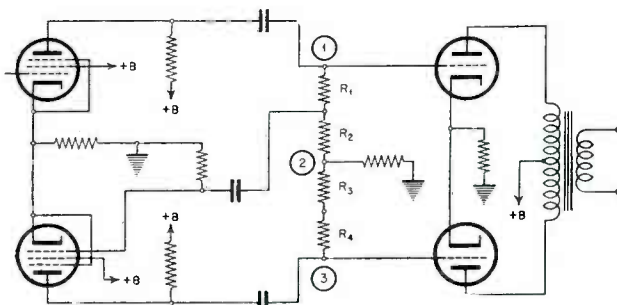


Figure 6

is obtained from each section of the 6SC7, or a total signal voltage output across the push-pull grids of about 72 times the input voltage. Because the maximum input signal voltage must be kept below 2 volts, as compared with about 8 volts for the circuits of *Figures 1* and 3, the comparative possible output voltages are not quite as greatly in favor of this circuit as might at first appear. But the low signal input voltage required gives the circuit of *Figure 4* an edge insofar as sensitivity is concerned.

In operation, a signal voltage applied to the grid of the first section of the 6SC7 at point (1) is amplified and the resulting output voltage is applied to the grid of the following (upper) tube and across the grid resistors of .25 megohms and 7000 ohms, in series. The signal voltage developed at the junction of these grid resistors is equal to 7000/257,000th of the total voltage across these resistors. This is equal to approximately 1/36th of the output voltage, and is in turn equal to the input voltage applied at point (1) of the upper section of the 6SC7, provided the gain of the tube and circuit is 36. This output signal voltage is opposite in phase to the input voltage. Consequently, when applied to the grid of the lower section of the 6SC7, point (2), it is equal in magnitude and opposite in phase to that at point (1). Because the plate load resistors of each power section of the 6SC7 are equal, and because the grid resistors of the following power tubes are likewise substantially equal in value, the output voltages obtained are equal in magnitude and opposite in phase.

Another phase inverter circuit, incorporating the 6C8G tube, is shown in *Figure 5*. The action is substantially the same as that described for the circuit of *Figure 4*, but the gain is somewhat less—about 21. When functioning properly, the output signal voltages from points (2) and (3) to ground should be equal in magnitude

and opposite in phase, and the voltage at point (1) should be the same as that applied to the first section grid. It is good to know that the circuits of *Figure 4* and *5* may be used interchangeably when procurement difficulties arise insofar as tube replacements are concerned. The fundamental difference between these two circuits lies in the fact that, in the circuit of *Figure 5*, the divider circuit is employed in the plate load of the tube, while in the circuit of *Figure 4*, the divider is in the grid circuit. There is some advantage in taking off the inverted signal voltage from the plate circuit in that any phase shift which may occur at low frequencies due to the grid coupling condenser is eliminated; this is not too serious.

In any of the circuits, such as those shown in *Figures 4* and *5*, where proper equalization of output voltages is dependent upon the gain of each tube (or of each tube section in twin-type tubes), being identical, it is occasionally necessary to select tubes to make certain balanced output voltages are obtained. Alternatively, a circuit which automatically compensates, in part, for variations in tube characteristics may be employed. Such a circuit (which is a modification of the circuit of *Figure 4* and which is widely used), is shown in *Figure 6*. Here the modification consists of incorporating in the grid-return circuits of each of the output tubes, a resistor,  $R_3$ . Thus, the total signal voltage developed across each output tube grid is composed of that which is developed across points (1) and (2), for the upper section, and points (2) and (3) for the lower section, but opposed by a bucking voltage which is developed across resistor  $R_3$ . This occurs because the signal voltages from each grid return circuit have to pass through resistor  $R_3$ . When considering the positive half-cycle of the signal voltage, it is necessary to realize that a portion of the negative half-cycle voltage is likewise being formed across resistor  $R_3$ . The result is that any difference in output signal voltage from one section of the phase inverter is counterbalanced by an increase or decrease, as the case may be, of the opposing

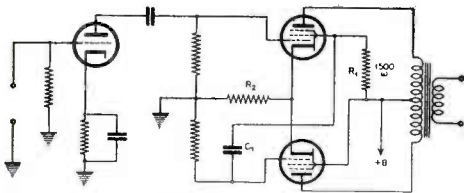


Figure 7

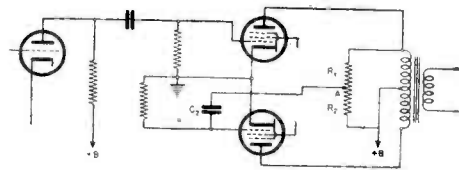


Figure 8

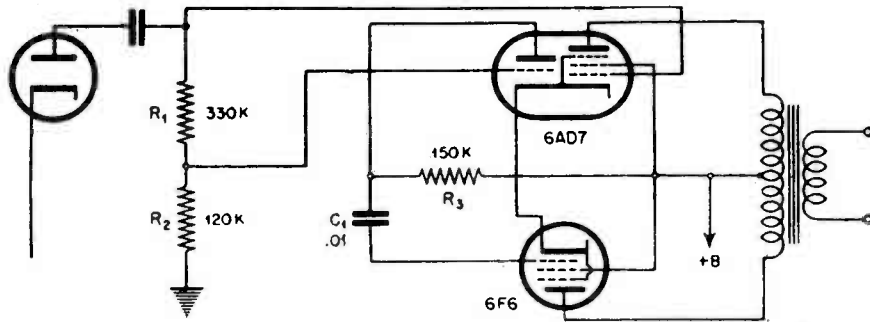
voltage across resistor  $R_3$ . Thus a degree of automatic balancing of the output voltages is obtained. Because this action is slightly degenerative, the gain is not quite as great as is realized with the simpler circuits of *Figures 4* and *5*, but improved performance results.

Methods have been devised for obtaining phase inversion in the output power tubes themselves, thus eliminating the need for intervening tubes and circuits. An example is shown in *Figure 7*. Here a resistor,  $R_1$ , is inserted in series with the screen of one of the power output tubes and the signal voltage developed across it is fed back to the input control grid of the other power tube through condenser  $C_1$ . The action is the same as for the circuits previously described.

Still another method, one of the earliest, is shown in *Figure 8*. In this circuit, a voltage divider composed of the resistors  $R_1$  and  $R_2$  is shunted across one-half the output transformer primary. The voltage developed across resistor  $R_2$  is fed through condenser  $C_2$  to the grid of the second push-pull output tube. For proper balance, the voltage across resistor  $R_2$  must be equal to the input signal voltage applied to the upper tube grid. In order to obtain this, the ratio of the resistance of resistor  $R_2$  to resistor  $R_1$  plus resistor  $R_2$  must be the same as the ratio of the input signal voltage to the output signal voltage developed across one-half the output transformer primary. Thus, if the gain is 15—which is about right for a power

pentode—resistor R1 could be 14,000 ohms and resistor R2, 1000 ohms, or each of these values could be multiplied by any desired number provided the proportions are maintained. In general, the total resistance should be of the order of 50,000 ohms. If it is made lower, appreciable loading of the transformer primary will take place. If higher, the balance at higher frequencies will be affected, due to stray capacitances. This circuit is a neat way of getting around shortages in replacements for standard phase-inverter tubes—and it saves space in remodeling sets.

Another circuit using the signal voltage developed in an output tube for phase-inversion purposes is shown in *Figure 9*. The 6AD7 triode-pentode is employed. Because the pentode section of the 6AD7 is identical in characteristics to the 6F6, equality of output voltage and power may be obtained provided the input signal voltages are identical. This is obtained by employing the triode section of the 6AD7 as a phase inverter, the input signal voltage being applied through the grid-return voltage divider, resistors R1 and R2. These resistors are so proportioned that, when used with the plate load resistor R3, the signal voltage applied to the 6F6 is the same as that applied to the pentode section of the 6AD7, but reversed in phase.



*Figure 9*

In all the preceding circuits phase inversion has been obtained by using an amplifier tube in some fashion. It is also possible to do the job with a diode detector. Just how this is done is shown in *Figure 10*. In this circuit, resistors R1 and R2 are made equal in value (about 100,000 ohms each) and the junction is grounded. The output demodulated voltage wave across the two resistors then resembles that secured when a center-tapped transformer secondary in a push-pull coupled circuit is used. The output voltage is fed through condensers C3 and C4 to the respective grids of the push-pull amplifier tubes.

Because a strong signal is necessary to obtain sufficient demodulated voltage to drive even the more sensitive power output tubes, this circuit application is generally limited to feeding push-pull inter-stage amplifier tubes. It is important, too, that resistors R3 and R4 be alike in ohmage. This is likewise the case in preceding circuits discussed where the grid resistors form a portion of the load circuit.

Trouble-shooting in phase inverter stages is simple when the push-pull tubes employ a common cathode resistor in the bias circuit. One method, suggested by *Reich*, is to connect a pair of phones across the cathode-bias resistor and adjust the resistors until the signal at the fundamental frequency is a minimum. There will be harmonics, of course, but they are readily identifiable by their higher pitch. A *Chanalyst* or other signal-tracing instrument can be similarly employed, using the audio channel, and adjusting for minimum indicated signal level. The cathode-ray

oscillograph is an ideal instrument for the purpose because it indicates phase relations as well as the magnitude of the voltages. By connecting to grid and ground of each output tube in turn, the height of the resulting observed image will indicate relative magnitudes of the applied voltages. They should be identical. The phase relations are identified by noting the position of the positive and negative peaks. When a maximum peak in one direction is obtained with the oscillograph connected from one grid to ground, a maximum peak in the opposite direction should appear on the cathode-ray tube screen when the input is connected to the other grid and ground.

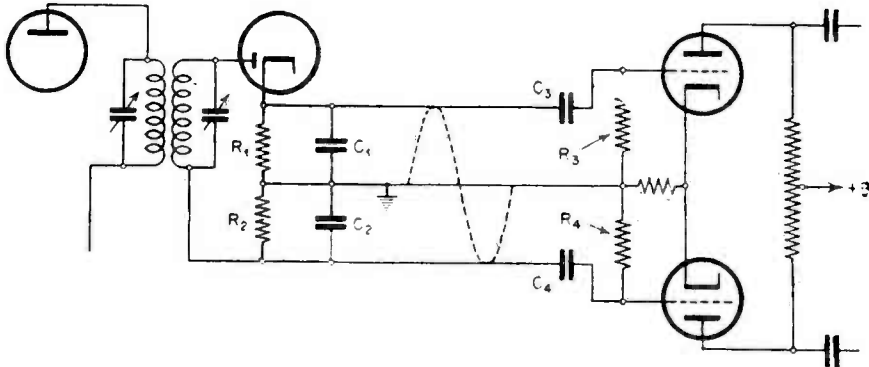


Figure 10

Minor differences in unbalance are not serious in any push-pull circuit; they tend to be equalized, at a slight sacrifice in power output, in the output transformer and its circuits.



*Research is the reconnaissance party of industry, roving the unknown territories ahead independently, yet not without purpose, seeing for the first time what all the following world will see a few years hence.*

S. M. KINTER.

## RADIO SPEAKER TESTS

Reprinted from Radio-Craft

*By Jack King*

IN the old days it was common to find a magnetic loud-speaker in a receiver or amplifier system. The limited power handling capability of such speakers and the relatively poor response on bass notes was a drawback. Other odd forms of loud-speakers, such as the gooseneck horn type, crystal and condenser varieties have now become obsolete. The crystal variety of late has found a new application in "radio pillows" which allow sick patients to hear sounds without the head being raised above the pillow. Such units are generally high impedance types and may be found in hospital sound systems.

In small radio receivers the magnetic loud-speaker is sometimes found, but usually the speaker is an electrodynamic type. In many cases a permanent magnet dynamic type—commonly referred to as a "PM" speaker—may be used. These units find wide application in portable P.A. systems as well as permanent ones because they do not require special power supplies to energize the fields.

In all cases the job of the speaker is to convert an electrical impulse into sound. The efficiency with which it does this job is dependent upon the design of the speaker and the circuit in which it is used, as well as upon the design of the baffle or cabinet and the acoustic properties of the space where the sound is to be distributed.

### TESTING MAGNETIC SPEAKERS

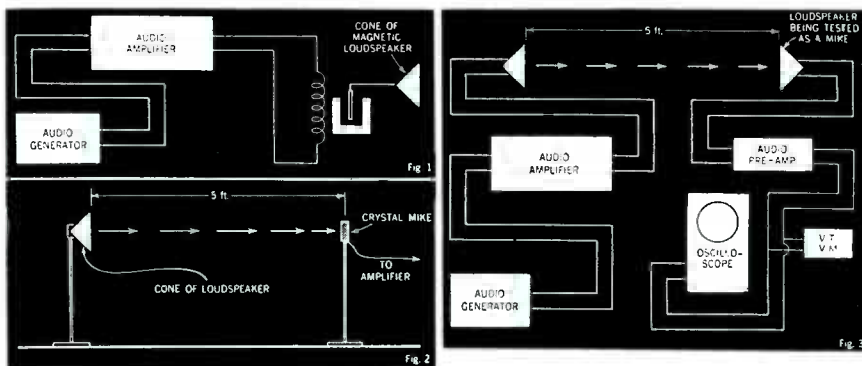
In checking the speaker we want to know the following things: maximum power handling ability, frequency response at various points in the audio band and relative amount of harmonic distortion; power input required for a given amount of sound output.

To check the power handling ability we may use the test set-up of Fig. 1. The same test circuit may be used for magnetic or electrodynamic speakers. When dynamic speakers are checked, provision must of course be made for a suitable field supply. Otherwise the technique is identical. The audio amplifier should be of a high-fidelity type and be capable of delivering 20 watts without distortion. Needless to say, a high quality audion generator must also be used. Impedances should simulate actual operating conditions.

The speaker will have more of a tendency to rattle on low notes than on high, though some speakers have a resonant point which may be in the middle frequency range or at a high frequency, depending upon the defect. Tests may be made at several points in the audio band between 30 and 15,000 cycles. At each test frequency, the power supplied the speaker is raised by adjustment of the amplifier gain control until audible distortion is observed. At high volume levels the ear of an observer may be an unreliable judge of distortion. A crystal microphone may be connected directly to the vertical input of an oscilloscope which has a high gain vertical amplifier, or a pre-amplifier stage having a linear response with frequency may be used to build up the microphone signal to the point where it is usable by the scope. Amplification is desirable in order to secure sensitive indications and to permit using the mike at a distance of about 5 feet away from the speaker and on

a line which is exactly at a right angle with reference to the vertical plane of the speaker cone, as shown in Fig. 2. If desired, the output of the mike may be fed into a 100,000 ohm resistor at the end of the mike cable and the voltage across the resistor can be checked for various values of sound power fed to the loud-speaker. In dynamic speakers, the voltmeter may usually be placed directly across the voice coil. The crystal mike—if it is of reasonably good manufacture—will usually have a substantially flat response over the audio band.

The efficiency of loud-speakers may then be compared. If one speaker gives a greater output for a given value of input than a second speaker, as indicated by the vacuum tube voltmeter connected across the crystal load or to the output of the pre-amplifier, the first speaker is the more efficient from the standpoint of conversion of electrical power into sound. In making measurements, it is desirable to have a room which has sound dead walls of soft material so that reflection effects will not be bothersome.



### SPEAKER RESPONSE

The response of a typical magnetic may be fair from 200 to 4,000 cycles, with a sharp slope off from 200 to 30 and 4,000 to 15,000, but a great deal depends upon the individual speaker and the baffle used with it. In plotting the response, the electrical voltage output of the mike working into the pre-amplifier is checked. It is convenient to connect the vacuum tube voltmeter to the output of the pre-amplifier rather than across the load of the crystal for the reason that indications are more easily read.

The point where chattering and distortion begins can be determined by ear. When this point is reached the V.T.V.M. can be used for checking the voltage across a small resistor which is in series with the speaker to determine the current. The power may then be found by squaring the current and multiplying by the resistance of the speaker. This will be the real power, not the volt-amperes product. The magnetic speaker load is somewhat inductive. It varies with frequency because of the inductive effect, since  $X_L = 2\pi fL$ .

In specifying the working conditions it is convenient to give the voltage across the speaker terminals required for maximum undistorted output at 400 cycles or some other arbitrarily selected but convenient test frequency, such as 1,000 cycles.

It is also convenient to give the minimum input voltage required to give an easily understood sound output in a quiet room or space, using a specified form of cabinet or baffle. Then, with such knowledge at hand, intelligent planning of a hotel or similar installation is possible.

### PERMANENT MAGNET SPEAKERS

These are used in inter-office communicators to a great extent. The test set-up previously given can be used for checking the speaker as an output device or a converter of electrical to sound energy, but a somewhat different arrangement is necessary to check the speaker efficiency as a microphone; for now its job will be to translate sound into electrical impulses. We need to create a sound pressure at the diaphragm and to measure the electrical output voltage. This voltage may be checked across a resistor or across the output of a standard pre-amplifier circuit to make the V.T.V.M. read easily. For various reasons, talking into the speaker is not good practice. The speaker in Fig. 1 may be replaced with a good quality electrodynamic type having a wide frequency range and being linear over that range. The speaker to be tested may then be set on the same level. The procedure is to set the audio generator at various test frequencies and to vary the output of the test amplifier until various degrees of sound intensity are produced. The sounds impinging upon the test speaker are then converted into electrical impulses which drive the pre-amplifier. The output of this unit is then fed into a vacuum tube voltmeter. The test set-up is shown in Fig. 3. The output of the audio amplifier is adjusted by means of the amplifier's gain control until the scope pattern starts to exhibit kinks and bends.

The speaker which is used for the development of the sound intensity should have adequate reserve power handling ability so that it, itself, does not introduce distortion due to quivering of the cone, rattling, overload or any other defects. The level of the signal supplied the pre-amplifier must not exceed its safe input value and should be checked with the vacuum tube voltmeter. Similar tests may be run on electrodynamic and magnetic speakers.

The sensitivity of magnetic speakers is often high, of the PM and electrodynamic, fair.

Classification by types is not a good criterion as much depends upon the design of the individual speaker and the care that went into its manufacture. If at hand, a wave analyzer or harmonic distortion meter may be used to check the distortion content at various levels of output voltage and sound intensity.

It may be desired to check the output power for various amounts of field power and to specify the characteristics of the speaker for various field powers. If the field is weak the flux density in the vicinity of the voice coil will be less and a smaller induced voltage for any degree of voice coil movement will be the result, giving lowered output. In the PM speaker the field power remains substantially constant.

It may also be desirable to specify the harmonic distortion in the output,

assuming a sine wave input, for various *types* of field power, so much percentage ripple voltage at 60 cycles or harmonics of 60. The hum level of the speaker will directly be related to the hum current flowing in the field and voice coils. A suitable power supply designed to furnish the required power to the field should be on hand.

## POSTWAR AIRWAYS

### *Communications Planning*

*Availability of much medium frequency apparatus indicates continued regular use after war's end—UHF equipment not expected to be sufficient for change to that type of communication immediately.*

*By Allen Scott*

Reprinted from Air Transport

**R**ADIO frequency channels are to radio communication just as airways are to aircraft, rails to railroads and highways are to the bus or truck—essential, and frequently difficult to provide.

There is just so much space in that invisible medium we refer to as *ether*, although fortunately it can be occupied simultaneously by both aircraft and their communication. Just as with the airway, that part of the radio frequency spectrum now allocated to aviation communication is well crowded and, as with the airway, our crystal ball indicates that tomorrow will require a transition to other pastures if we are to enjoy satisfactory aircraft-ground communication.

To appreciate the situation of today and as it may be expected to be tomorrow one must go back to a few fundamentals and to history.

### *CLEAR CHANNELS NECESSARY*

To provide satisfactory communication one must have usage of clear channels—a space within the radio frequency spectrum clear of interference from other radio stations. Freedom from interference involves many diplomatic as well as technical angles. Certain radio frequencies, particularly those within the commonly referred to medium high frequency band—2,000 to 30,000 kc.—have habits which are both good and bad, depending upon whether one is discussing the technical or diplomatic angles of the case in hand. With no intention of getting into the technicalities too deeply, these particular frequencies have what is commonly called “skip distance” characteristics. This means that these frequencies under certain generally known conditions display both ground and sky waves. The ground wave is the wave transmitted along or through the earth's surface while the sky wave is a wave radiated upwards to one of several gaseous layers existing from 40 to 200 mi. above the earth's surface and reflected back to earth by those layers reappearing on the earth at long distances from point of transmission. Power of the transmitter determines distance of ground wave transmission to a major degree but, power of the transmitter has but a minor part to play in sky wave transmission. For that reason a relatively low-powered transmitter, operated on properly selected frequencies between 2,000 to 30,000 kc., can provide relatively reliable communication over great distances. Therein lies the bothersome diplomatic problem—we of the United States cannot assign and use these frequencies without due regard to and with the cooperation of other worldly users of radio communication. While we may be concerned with only the communication problems of aircraft operated between New York and Washington, our indiscriminate use of such frequencies could severely strain international relationships—sky waves can bounce around the world and play havoc



with attempted communication of friends and enemies alike though scattered throughout the globe.

International conventions of past years have labored long over world allocation and usage of these frequencies. The participants have done well to reduce worldly interference to the degree they have. However, the constantly increasing use of radio communication has gradually strained the situation to almost a breaking point. Gradually, nation after nation has increased the use of this frequency spectrum until today an available channel is much scarcer than the proverbial "hen's tooth"—there just isn't a one.

While the diplomats and engineers of these international conventions have labored over their duties, many others, particularly the research and design engineers, have improved equipment designs and operating practices to provide more and more service from the space available. Channels which, as example, may have been 30-kc. wide by necessity ten years ago are now much narrower. Engineers have designed and redesigned constantly to provide more selective receivers and transmitters requiring less band width. Channels but 6-kc. wide are no rarity today. However, the art has progressed to a point where engineers cannot hold out hope of much technical improvement over that existing today. So, it becomes a situation where one must look over far horizons to determine or establish a transition which will provide not only the requirements of tomorrow but those of ten, twenty and more years hence.

### *UHF TROUBLE FREE*

The UHF (those frequencies from 30,000 to 300,000 kc.) hold much promise in this regard. They are not, however, without many major technical problems. Fortunately their diplomatic problems do not appear as troublesome.

The aviation radio engineer has long looked to these higher frequencies for the essential transition. Much research and development has been accomplished and today considerable aviation communication apparatus is functioning well in this new spectrum. This research has brought out that, while not as intense as lower frequencies, those frequencies between 30,000 and roughly 100,000 kc. still display at times bothersome sky wave transmission phenomena. State and city police services which were early users of these higher frequencies have been often startled by reports of reception over great distances. It appears that frequencies above roughly 100,000 kc. still having sky wave transmission characteristics, have such skip distance factors that their sky waves miss the earth completely following reflection from the Heaviside gaseous layers. So aviation planning has concentrated attention largely to application of frequencies above 100,000 kc.

While some earlier plans, for example, as regards UHF airway markers on 75 megacycles and glide paths on 90 megacycles, have permitted limited services on slightly lower frequencies, it appears unlikely that much additional aviation service can be safely allocated anything less than 100 megacycles.

It would appear that as airway traffic increases the aircraft to ground communications service thereof must be planned for UHF. Prewar planning provided space for this and specific allocations. The Federal Communications Commission, Civil Aeronautics Administration, Radio Technical Commission for Aeronautics and Aeronautical Radio, Inc. representing airline interests ably planned and thus provided the channels required for tomorrow. The advent of war upset equipment manufacturers from supplying desired UHF to the airlines so that to date little value has been obtained from that planning. Its worth will, however, be very evident tomorrow. Unquestionably the war will result in a much higher grade of UHF

service being available immediately upon the return of peace. Which brings us up to essential history—another short story of who deals out aviation frequencies.

### *HAD FEW FREQUENCIES*

The FCC issues the authorization to employ frequencies requested by other than governmental departments. Years ago when airline aviation was in its baby clothes the FCC had so few frequencies available and so many requesting their exclusive use that it very wisely suggested to these airline applicants that they get together and form some one agency to provide a pool usage of the very few frequencies available, thus to obtain a maximum of utility from each. In due time the then existing airline applicants got together and formed Aeronautical Radio, Inc., a non-profit organization controlled and operated solely by these airlines. It has continued through the years wisely judging each requirement against the channels available, paring down channel widths to provide greatest use of the limited spectrum available and in general planning and protecting the airline interest in communication channels. As new airlines have come into existence they have joined with the older lines in their common communication interest in AR Inc.

As early planning likened airline communication to that of railroads AR Inc. through FCC has in general provided each airline with exclusive use of a pair or a multiplicity of pairs of frequencies within the medium high frequency band. Technical development of apparatus brought out economies by employment of two frequencies for a given route, one used for day, the other for night communication. A route employing two carefully selected frequencies could by a combination of ground and sky waves of both frequencies, during both daylight and night-time operations, obtain a reliability of communication with an aircraft transmitter of nominal power and consequently of minimum size and weight.

### *REQUIREMENTS INCREASED*

As airline traffic grew in density communicational requirements grew. Whereas at first one pair of frequencies was sufficient to provide essential communication over a coast-to-coast route, the increase of schedules shortly required two pairs, then three pairs of frequencies to provide only the essential route reporting. The utility of an aircraft communication channel is directly proportional to the number of aircraft transmitting a given route sector per hour. Certain position reports are required and it is possible to transmit only a few specific numbers of such reports per hour before the channel is saturated. Time and necessity have reduced the number of reporting points, the length of transmission and channel widths to the absolute minimum and so further use of available medium frequencies can be accurately calculated from data now available. AR Inc. doubtless knows today exactly how many more airline aircraft schedules can be flown before their communication will fully saturate the available channels—based upon the present scheme of airline communications. We wager the expansion practical would be extremely limited.

UHF offers a possibility but, as said before, it is not without many a technical and economic problem. The economics of a transition to UHF are major. Much medium frequency apparatus will surely be available for further use come the day of armistice and surely that apparatus cannot be junked overnight. Also, suitable UHF aircraft apparatus may not be immediately or readily available. All things considered it might be well to seek still further devices to permit use of the medium frequencies for some time to come.

Airline operations themselves have suggested such a device. Army and Navy employment of airline aircraft, each fitted with crystal controlled communication

apparatus tuned only to the owner line frequencies, brought out many a communication problem when such aircraft had to be operated over other than their own routes. One airline's radio would not talk into that of another airline—and crystal procurement conditions have been such that obtaining new crystals for an unexpected "off line" operation presented a major problem. From such experience came the suggestion of pooling again all available airline medium high frequency channels and reissuing them not for exclusive individual airline use but by "zones." It has been proposed that the total area of the United States be zoned and each zone provided pairs of frequencies. With channels capable of handling only so many standard airline position reports per hour it is obvious that such zones would vary in size in proportion to airway traffic load. The New York, Washington or Chicago areas might well be of very small zone or each such area might comprise more than one zone, depending entirely upon aircraft schedules.

### *IMPARTIAL SERVICE*

Such zoning would obviously require that AR Inc., rather than the individual airlines, operate all ground radio communication facilities to provide an impartial airline owned and operated service. In view of AR Inc.'s service over many years this should prove acceptable to all airlines.

Further, it is believed the establishment of such a zone operating scheme might be more than ordinarily interesting to the Army and Navy. They, constantly flying more and more in all weather along civil airways and lacking the complete coordinated ground flight control systems of the airlines, would be able to utilize these already existing safety factors which, heretofore, have not been fully available because of communication problems. Also it is conceivable that military use of such airline ground facilities would bring about a highly desirable standardization of airline and military aircraft radio equipment.

While some have suggested government ownership and operation of requisite ground communication facilities such is legally impossible for the air carrier. The carrier has a legal responsibility for safe direction of flight which cannot be passed to government control without serious public reaction. Railroad, steamboat, bus and other public carriers have progressed through many cycles of such effort without any change in basic control. It is unlikely that aviation's development will swing public opinion any further than has been tried before—with failure.

Zone operation should considerably simplify a transition of existing aircraft to UHF and certainly provide more simply for new aircraft utilization of UHF. With the wide variation of traffic density over the United States it is certain that such a scheme would provide for still greater use of the medium high frequencies by keying zone size to words of communication per hour rather than to the fortunes of an individual airline. Last, but not least, in favor of zone operation would be the possibility of airline communication and ground flight control facilities becoming readily available to the military. The factor of standardization of aircraft apparatus is also of much economic value for both present and future.

As the needs of aviation communication are rapidly growing and the existing facilities constantly are becoming more strained, there is need for more thought and action toward a solution of this difficult problem.

## F-M AND A-M TRANSMITTER ANALYSIS

*Based On A Recent Study Of "On-the-Air" Operating And  
Maintenance Characteristics*

*By Scott Helt*

Chief Engineer, WIS

Reprinted from *Communications*

**A** RECENT investigation of f-m transmitter design, operation and maintenance, during which on-the-air transmitters and antennas were studied and operated, disclosed that f-m offered many favorable features.

An important f-m characteristic noted for instance during the tests, was the absence of peak power during modulation.

In amplitude modulation the power in the carrier wave becomes four times as great when the percentage of modulation is doubled. When a carrier is modulated 100% in amplitude modulation, the total power of carrier plus sideband is 50% greater than that of unmodulated power. With lower percentages of modulation the sideband power is proportional to  $m$  squared, where  $m$  is the percentage of modulation expressed as a decimal. Since all this power must be supplied directly to the plate of the r-f amplifier tube during modulation, when modulating 100%, the plate of the r-f amplifier must dissipate 50% more power than when the carrier is unmodulated. The additional power dissipated at the plate must be supplied by the modulator. Thus, for 100% modulation, the modulator stage in the transmitter must supply undistorted audio frequency power equal to 50% of the unmodulated carrier plus 50% of the power dissipated at the plate of the r-f or modulated r-f amplifier, when modulated.

The instantaneous peak power output during modulation is  $(1 + m)^2$ . Thus, at 100% modulation the r-f amplifier must be capable of delivering instantaneous peak power of four times the normal carrier power. The greater the percentage of modulation, the more power has to be applied to the r-f amplifier. Therefore, with high powers of modulation in a-m, the plate of the r-f stage must dissipate more power, and the temperature of the plate is increased. In a-m, the r-f amplifier tube is selected for its ability to handle the modulation peaks, and the modulator tube is selected for its ability to dissipate, at the plate, the unmodulated power output.

In f-m, modulation takes place at low level, and the modulator is followed by high efficiency class *C* amplifiers. In a-m, if low-level modulation is used, the modulated stage must be followed by relatively low efficient class *B* linear amplifiers. It can be shown mathematically that 33% is the maximum efficiency that can be obtained from a class *B* linear amplifier, while class *C* amplifiers have been constructed to operate at efficiencies of 60% to 70%. While such high efficiencies have not yet been obtained in the class *C* amplifiers used at 40 to 50 mc in f-m, the efficiency obtained is much greater than that of the average class *B* linear amplifier. Of course less tube capacity is required, too, in the f-m amplifier of equivalent power rating, since in f-m it is not necessary to account for peak power.

F-M transmitter design, therefore, allows the use of smaller components for the same power output, as compared with a-m, and smaller installed tube capacity in

the modulator stage as well. This makes for more economical operation and greater equipment dependability, since there are no peaks of amplitude modulation to overload the components. As a matter of fact, in the Armstrong modulator practically all the tubes used in the modulator unit are of the receiver type.

In f-m transmitter design it is possible to apply 60-cycle a-c, single phase, directly to the filaments of the class C amplifiers following the modulator, and the noise level can be kept within limits without the use of inverse feedback.

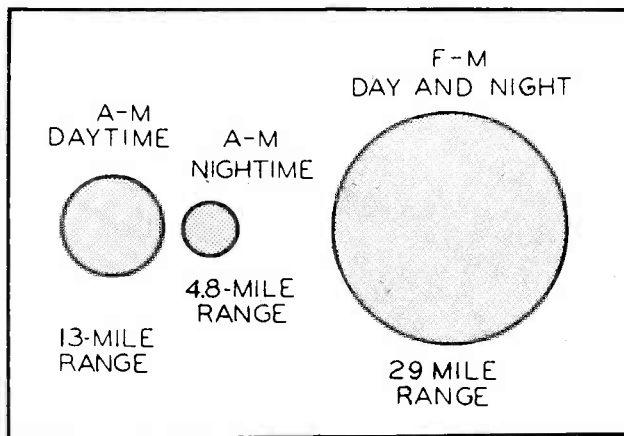
INVERSE FEEDBACK

In many high power a-m transmitters it is usually necessary to employ considerable inverse feedback over the power stages to maintain the noise level within the limits prescribed by the FCC. In the higher powered f-m transmitters now in operation, no inverse feedback is used anywhere. And the noise level, without feedback, is regularly measured as better than 60 to 70 db below the carrier level.

Generally, less power can be used in f-m than in a-m to effectively cover the primary service area of a station. In a-m broadcasting the primary service area is determined by the 500-microvolt per meter contour. In f-m broadcasting the primary service area is determined by the 50-microvolt per meter contour. This is due to the fact that less field voltage is required to develop a satisfactory signal at the receiver output in view of the absence of a-m noise which any a-m transmission system must override. Thus, less transmitter power can be generally used to efficiently service a given area, except of course, in mountainous areas.

F-M has worked up to the second and third horizons, due to slight refraction of the wave along the earth's surface. Lower power consumption from the power

*A comparison of a-m (1400 kc) and f-m (42-50 mc) signal ranges for a 250-watt station. The FCC allocation plan for local f-m stations is based upon the following signal strength data:*



Time	Signal	Range	Possible Interference at That Range
Day	500 $\mu$ v/m	13 miles	25 $\mu$ v/m signals
Night	4000 $\mu$ v/m	4.8 miles	200 $\mu$ v/m signals

*These data are taken from the FCC records and assumes an antenna height of 331'. The FCC mileage separation for allocation purposes is 173 miles for these stations. A 250-watt f-m station with a single bay antenna 331' high would have a corresponding day and night range of 29 miles to the 50  $\mu$  v/m contour. Only 50  $\mu$  v/m are required for satisfactory f-m reception, whereas 500  $\mu$  v/m are required for similar a-m reception, reports Mr. Helt.*

line was another economy factor noted during the study. Only 109 kw are required for the 50kw amplifier such as the G.E. type. This results in smaller and less expensive transformer substation equipment at the transmitter.

Another economical factor is the smaller water cooling system required for the r-f stages. This is due to lower plate dissipation when operating tubes at class C telegraph ratings.

The distortion, noise, and frequency response characteristics of a given f-m transmitter was found to hold constant over a longer period than these same constants in an a-m unit. This is because no peak power is present to overload, heat up, and change the electrical values of circuit components; also, because no inverse feedback is necessary to reduce distortion and noise level.

In one 40-kw f-m installation we found that no distortion, noise or frequency response measurements had been made for fifteen months. This was due to the pressure of important research work that was assigned to the staff. But, notwithstanding the fact that the transmitter kept a schedule every day during this period, the characteristics had not appreciably changed during all these months, and when measurements were made, it was still delivering a high fidelity signal into the turn-stile well within the FCC performance requirements. This does not imply that routine quality measurements should not be made on f-m transmitting equipment, but it does indicate the dependability of the equipment and its circuits.

There are 85 a-m stations operating in the United States on the frequency of 1400 kc; 81 of these stations are 250-watt outlets, and 4 operate with 100-watt outputs.

The FCC-allocation plan for such local stations is based upon the following signal-strength data:

<i>Time</i>	<i>Signal</i>	<i>Range</i>	<i>Possible Interference</i>
Day	(microvolts/m)	miles	<i>at That Range</i>
Night	500	13	(microvolt signals)
	4000	4.8	25
			200

This data was taken from FCC records and assumes an antenna height of 331 feet. The FCC mileage separation for allocation purposes is 173 miles.

In comparison, a 250-watt f-m station with a single bay antenna 331 feet high, would have a corresponding *day* and *night* range of 29 miles to the 50-microvolt-per-meter contour. An f-m signal of 50-microvolts per meter is considered equal or better than a 500-microvolt-per-meter a-m signal.

The range of a-m station interference is variable over wide limits with time of day, time of night, seasons of the year, and conditions of the ionosphere (sun spots, northern lights, etc.). This is not true for f-m transmission. The necessary signal-to-noise or interference ratio for clear reception is 100 to 1 in a-m, and only about 2 to 1 in f-m.

Another interesting fact disclosed was that an f-m link between transmitter and studio can be used to advantage by both a-m and f-m stations. With low power (about 25 watts in the average installation) and with a directional receiving and transmitting antenna of small physical size (but with a power gain of 10 to 1 in the forward direction), which makes the 25 watts equivalent to 250 watts of power in the useful direction, wire lines can be eliminated connecting these points, and with

higher fidelity transmission than can be had economically with line transmission. Such a system won't go out in storms, and is far more dependable than wire links.

Incidentally, due to the absence of peak power at high percentage modulation in f-m, coaxial lines, connecting the transmitter output with the antenna system, can be of smaller diameter. This is an advantage when considering installation costs, particularly if the antenna is some distance from the transmitter building.

High gain f-m antenna systems have been developed. These permit lower installed transmitter power. For instance, a four-bay G.E. f-m circular antenna, also known as the *doughnut* antenna, has a power gain of 4.26, which means that if 10,000 watts of installed transmitter power are provided, the station employing this four-bay antenna system would have a power output equivalent to 42,600 watts. The single-bay antenna of this type has a power gain of .841, the two-bay antenna a power gain of 2.0, and the eight-bay antenna of this type has a power gain of 8.71. With antennas of such power gain, economies can be effected in installation costs. For instance, a 10-kw G.E. f-m transmitter sold for \$23,000 before Pearl Harbor, and a four-bay G.E. circular antenna sold for \$6,000. However, if 10-kw of f-m power were required for a given installation, it might be well to buy a 3-kw transmitter at \$12,833 since, when employing the \$6,000 four-bay antenna with a power gain of 3.47, only \$18,833 would be invested, as compared with \$23,000 for the ten-kw transmitter and a simple antenna of the Franklin type.



*For a generation we have been living on the edge of a new world; we are only now beginning to realize it.*

DONALD M. NELSON.

## INTEGRATION OF ENGINEERING

Reprinted from *Electrical World*

In a number of cities the local chapters or sections of national engineering societies have banded together to form a local engineering society. Some of them have been in existence a long time and others are springing up from time to time, indicating an unmistakable trend.

There are several reasons for these local all-inclusive engineering groups, some economic and some more inspirational. They are all expressions of a need for unity at the grass roots level.

While the practical considerations, such as sharing the costs of a secretary and of meeting notices and some times of a meeting place, are all of great importance to local groups working with small fixed budgets, the greatest value comes from something less tangible. Regardless of whether a man is practicing electrical, mechanical, civil, illuminating or any one of the several branches of engineering, he is nevertheless an engineer and these local all-inclusive bodies are a cementing force that can give cohesion to the profession.

Engineers need cohesion partly to protect the profession from unwarranted regulation but more to create a public consciousness of engineering as a great profession. The onward march of industry has created a steadily growing demand for specialization yet despite the fact that there are dozens upon dozens of different kinds of specialized engineers, fundamentally they are all engineers and as such they have an entirely different approach to problems than have members of other professions.

The engineer is different because his education was different, so different, in fact, that many a father has insisted that his son take an engineering course regardless of what kind of occupation the boy might choose to follow. It is this training in the solution of new problems in an orderly way that has made the engineer the creative force of the country.

Regardless of what specialized branch of engineering a man elects to take up he has certain things in common with other engineers, part of which is his training, part of which is his inquisitiveness into the operations of natural forces and part his closeness to the service of the public. These qualities should help to integrate engineers in spite of the growing differentiation.

The need for engineering cohesion has been recognized nationally for some time. An expression of this was the American Engineering Council. However, because this was organized at the top, it never truly reflected the rank and file of engineers. Some time, a national body of engineers that has its roots down in the local communities may be possible, but that cannot happen until the local organizations become more widespread and clamorous for national direction and coordination.

In the meantime, every encouragement should be given to the formation of these local groups. They not only can bring greater cohesion to the profession but they can frequently bring to light the dangers of independent action by national engineering societies. One excellent example of this is the recent excursion by one group into collective bargaining for all engineers.

No profession has greater specialization than medicine, yet it is well integrated. The same is true of law. Through the local societies the profession of engineering may in time perhaps be equally well integrated.



# ETCHING TECHNIQUES IN THE MANUFACTURE OF QUARTZ OSCILLATOR PLATES

by Clifford Frondel

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The term etching is applied to the process whereby the surface layer of a solid material is dissolved by a solvent, just as sugar is dissolved by water, and copper by sulphuric acid. Etching quartz presents a special problem because it is insoluble in all ordinary solvents, and is appreciably attacked only by hydrofluoric acid and some related compounds.

Etching techniques are used in the quartz oscillator-plate industry for four different purposes. These are: first, to reveal a type of imperfection in quartz known as twinning; second, to orient rough crystals or sawn blocks of quartz preparatory to sawing; third, to reduce the thickness, i.e., increase the frequency, of a partly finished oscillator-plate to the desired value; and fourth, to stabilize oscillator-plates against deterioration with age. These topics will be discussed separately on the following pages.

Figure 1. A sawn wafer of quartz in which electrical twinning has been revealed by etching.



Figure 2. Quartz oscillator-plates racked in notched Pyrex glass trays preparatory to cleaning and mull etching.

## ETCHING TO REVEAL TWINNING

The term twinning is applied to a type of imperfection in quartz in which two or more crystals are intergrown at angles to one another. There are two common types of twinning in quartz. One of these, known as optical twinning, can be recognized by certain optical tests, but the other type, known as electrical twinning, because the polarity of the piezo-electric X directions are reversed in the separate parts of the twin, can be proven only by etching or electrical tests. Unfortunately, almost all raw quartz is twinned in rather large amount, and care must be taken during

manufacture to ensure that twinning is avoided in the finished plates. The presence of twinning in an oscillator-plate is quite objectionable and must be avoided, because the frequency-thickness constant and the temperature-frequency coefficient of the quartz are different in the separate parts of the twin. A twinned oscillator-plate would thus have undesirable characteristics when the crystals are tested or used. In plant practice, all of the sawn pieces of quartz are etched in an early stage of manufacture and the areas of both optical and electrical twinning are marked out so that they can be subsequently avoided. The twinning shows up on etching because the solvent eats tiny pits bounded by plane sides into the quartz. In a twinned crystal, the little triangular pits are turned at angles to one another in the several parts of the twin. Hence, when a twinned piece of quartz is etched and turned about in reflected light, the parts of the twin are separately visible and can be distinguished, as shown in *Figure 1*.

### ETCHING TO ESTABLISH ORIENTATION

The tiny etch pits, formed by the action of a solvent, are bounded by plane surfaces which are oriented to the internal atomic structure of the substance in the



*Figure 3. Trays of crystals being cleaned in hot sulfuric-chromic acid solution (left). The crystals are next rinsed in dilute sulfuric acid (right) preliminary to being washed in water and etched. Electric hot plates are used to heat the cleaning solution (lower left). A soapstone tank in which spent acid is neutralized before discarding is seen at the lower right. All of the operation is carried on in a ventilated internally illuminated hood.*



*Figure 4. Trays of crystals being etched in Frequency-Etch solution contained in shallow Pyrex dishes. The crystals are washed in running water (left) before being etched.*

same way as are the external crystal faces. These minute faceted holes can be used to effect the orientation of a rough piece of quartz which lacks the natural prism and rhombohedral faces. In practice, the rough mother crystal is first oriented with respect to the optical or Z axis by means of an optical test and a saw cut is made perpendicular to this direction. The sawn surface is now etched in a solvent until etch pits are developed and is then placed over a pinhole beam of light. A visible triangular or other pattern appears on the etched surface, due to the oriented scattering of the light by the oriented etch pits. The sides of the triangles run more or less parallel to the X axes of the quartz, guide lines can be ruled out with pencil on the surface and the sawing can proceed. Differently shaped pinhole patterns are produced in differently oriented sawn sections, but in all cases, the pattern is definitely oriented to the crystal axes of the quartz. Formerly, this method was in rather wide use in the crystal industry in orienting quartz, especially when natural faces were lacking, but it has since been supplanted by x-ray techniques.

### ETCHING AS A FINISHING TECHNIQUE

The etching method as a means of finishing quartz oscillator-plates has come into general use in the crystal industry only in the past year or so. Formerly most manufacturers finished the crystals to final frequency by hand lapping with fine abrasive on a glass lap. Before this operation is described, the general method of manufacture may be broadly outlined. The raw quartz crystals are first graded to eliminate cracks and other visible imperfections and are then sawed at the correct angle into thin wafers. The wafers are etched to reveal twinning and are sawn up into small rectangular blanks of approximately the same size as the desired crystal. The blanks are cemented together into a loaf of 50 or so, and are ground by a diamond wheel, or otherwise, until the proper edge dimensions are reached. The crystals are now uncemented and are lapped first in relatively coarse abrasive, in a drill-press type of machine lap; then with a finer abrasive, in a planetary machine lap. The thickness of the blanks is reduced in this way until the frequency is within 5 to 40 Kc of the final desired value. The crystals are now issued to the

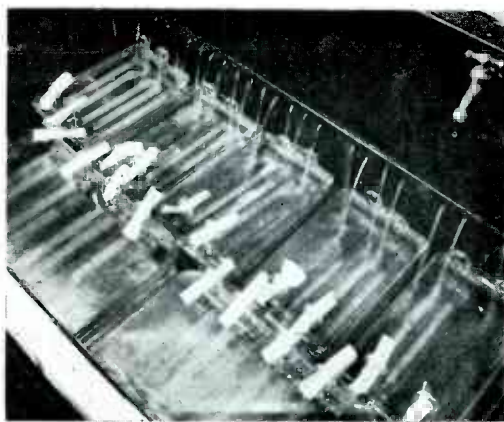


Figure 5. The racked crystals are washed in running water after being etched.



Figure 6. The trays are now transferred to an electric oven and the crystals are baked for several hours. After baking, the crystals are checked for frequency and are then issued to the finishing department where they are individually etched by hand exactly to final frequency.

hand finishing department. Here they are individually lapped by hand with a very fine abrasive until exactly the right thickness - or frequency - is reached. The finishing operator alternately laps the crystal with abrasive and measures the frequency against a standard crystal frequency on a comparison oscillator. This process is repeated until the crystal reaches the final desired frequency. Edge grinding is resorted to when the crystal activity drops below an acceptable value. This operation is both tedious and extremely delicate, and, for reasons pointed out in more detail below, is objectionable, because the crystals thus made tend to deteriorate on standing for a short period of time after they have been completed and tested.

It was early realized that this final finishing process of making the last minute adjustments in frequency could be done by etching the crystal down to thickness instead of lapping with abrasive. Nevertheless, the etching method did not come into general use in past years for several reasons. First of all, the solvent used, hydrofluoric acid, was extremely dangerous, and the strength of the solution was not

easily controlled. Moreover, due to the relatively marked pitting produced by this particular acid, the activity of the crystals was on the average lower than that which could be obtained by the abrasive lapping method. Very recently, however, the situation has radically changed. This has come about largely because of the discovery that etched crystals remain stable and do not show the ageing characteristics of abrasive lapped crystals. For this reason, the Signal Corps now requires that all high frequency crystals be etched. Further, the development of safe etching compounds which produce a fine grained etched surface, and hence give a high crystal activity, has facilitated the use of etching methods. These etching compounds, known as Frequency-Etch and Safe-T-Etch, were developed by the Hudson American Corporation and are now coming into general use in the industry.

#### AGEING OF OSCILLATOR-PLATES

The Armed Services have had a great deal of trouble with high frequency oscillator-plates that have deteriorated in storage after acceptance from the manufacturer. It is commonly found that crystals with a frequency in the range over



*Figure 7. A final finishing position where the crystals are individually etched to the desired final frequency. The crystals are held in plastic tongs and are etched in a dish of Frequency-Etch solution. During the etching the frequency is checked intermittently against the standard frequency in a comparison oscillator until the desired value is reached. The crystal activity is brought up, if necessary, by edge grinding in a Hudson American diamond-Bonded edging wheel (right).*

5 to 6 megacycles spontaneously increase in frequency with time, often to such a degree that they will go over the upper frequency tolerance. There is at the same time, an accompanying decrease in crystal activity, and it is not uncommon for a high frequency crystal to go entirely dead, only a few days after it has been made. As a matter of fact, one of the reasons that the whole field of ultra-high frequency crystals, in the range over 15 megacycles, is undeveloped has been the difficulty of making the quartz plate permanently stable.

The principle cause of ageing has been found to be a deterioration of the surface of the quartz crystal itself. When the quartz is lapped with an abrasive, the surface of the plate is strained and becomes cracked and granular on a submicroscopic scale due to the cutting and grinding action. This thin surface skin of misaligned quartz strongly absorbs water and with time tends to spall off and recrystallize. The traces of white powder seen on the surface of an aged, dead, plate is of this origin. The increase in frequency of the plate is, of course, due to the decrease in its effective thickness. This effect is, as a matter of fact, well known in metal and other materials that have been polished or lapped mechanically. It was first discovered by an English metallurgist, Sir G. T. Beilby, who claimed, many years ago, that the polished surface of a metal or crystal became amorphous due to

the abrasive action. More recently this belief has been confirmed by electron diffraction studies and x-ray evidence. Proof that the ageing effects in quartz were due to this so-called Beilby layer was afforded by work carried out in various laboratories in Great Britain, the Camp Coles Signal Corps Laboratory, the Bell Telephone Laboratories and the Reeves Laboratory. It was then shown that the Beilby layer could be eliminated, and ageing effects obviated if the quartz plate were etched in a solvent, thus removing the misaligned and strained surface layer of quartz and exposing solid "bedrock". The etching method was developed and applied in production as an anti-ageing measure in the Reeves oscillator plant early in 1943 and the success of this pioneer work pointed the way to the general adoption of etching techniques in the industry.

### *METHODS OF ETCHING CRYSTALS TO FREQUENCY*

A number of different manufacturing methods are employed in etching crystals to frequency. Generally speaking, the crystals are first machine-lapped close to the final thickness. The crystals are then cleaned and are etched; in mass, an amount necessary to satisfy the minimum Signal Corps requirements. The minimum etch required, corresponds to the removal of a thickness of one micron of quartz from the surface of the crystal. This first mass etch is continuous and is done in a relatively concentrated or hot solution of Frequency-Etch in order to gain speed. The etching is so designed as to carry the crystal within a few kilocycles of the final desired frequency. The crystals are now etched individually exactly to the final frequency by use of a dilute and hence slow acting and easily controlled solution of Frequency-Etch. Various types of apparatus have been devised to permit the simultaneous handling of large numbers of crystals in the first mass etch. A method used successfully in the Hudson American - Signal Corps crystal salvage plant is shown in Figures 2 to 7. Here the crystals are racked up in Pyrex glass trays which are transferred successively through cleaning, etching, and washing baths. Other mass etching methods have been devised in which the crystals are carried through tanks of etching solution on an endless chain.

In the final finishing procedure the crystals are first measured electronically to determine the amount of quartz that still must be etched off to reach the final desired frequency. The crystals are then held individually in small plastic tongs and are immersed in a small dish of etching solution. Change of frequency on etching is measured intermittently against a standard on a comparison oscillator, much in the same way that the finishing operators formerly would alternately hand lap and measure the crystals. When the final frequency is reached, the crystal is thoroughly washed in water and is placed in a holder for its final production tests.

The calibration and control of an etching solution is not an easy task, and the following hints on the etching of crystals may be of value.

### *SOME FACTORS IN ETCHING CRYSTALS TO FREQUENCY*

**ETCHING RATE:** The rate at which a crystal changes its frequency when etched in a Frequency-Etch solution increases both with the concentration and the temperature of the solution, as shown in Figures 8 and 9. The rate of etching also depends on the initial frequency of the crystal itself, and is greater, the higher the frequency. Different oscillator cuts such as AT, BT, and X-cut crystals, etch at different rates in crystals of the same frequency. This is due to the variation in the rate of solution of quartz with crystallographic orientation. The kind of abrasive finish on the surface of a crystal markedly influences the rate of etching: the coarser the abrasive finish, the faster the rate. If a number of crystals of the same frequency are being etched simultaneously and it is desired to obtain a uniformity of behavior, the abrasive finish on all crystals must be identical. When a crystal is etched, it is found that the relation between etching time and change of frequency becomes essentially linear only after the first minute or so of etching. The rate in the first period ordinarily is relatively large. This is apparently due to the action of the solvent in stripping off the more easily soluble Beilby layer together with the sharp edges and corners of the abrasive pit. The initial nose on the graphs, as seen, for example, in Figure 8,

becomes more pronounced the coarser the abrasive finish on the plate and the more dilute the etching solution.

**CLEANING CRYSTALS:** It is essential that the crystals to be etched are absolutely clean in order to obtain a uniform attack. Traces of grease protect the crystals and slow down or stop the etching action. A variety of cleaning methods are in use in the industry. In one method, the crystals are first de-greased with an organic solvent and then are scrubbed with a toothbrush and either soap solution or trisodium phosphate, followed by a thorough rinsing in pure water. Crystals also can be cleaned in bulk by tumbling in the cleaning solution. A tumbling solution composed of oxalic acid and soapless soap has proven satisfactory, as has trisodium phosphate solution. Another cleaning mixture contains 2 oz. of trisodium phosphate and 1 oz. of sodium oleate to a pint of water. The most effective cleaning agent is sulfuric acidchromic acid solution. This is prepared by adding 2 oz. of solid sodium dichromate to 1 liter of concentrated sulfuric acid. The method of using this solution is shown in Figure 3. The acid should be replaced when it turns green.

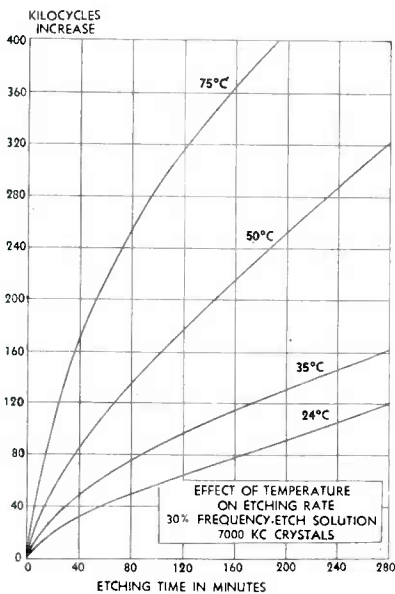


Figure 8

Figures 8 and 9. Curves showing the relation between time of etching and increase in crystal frequency in Frequency-Etch solutions of various concentrations and temperatures.

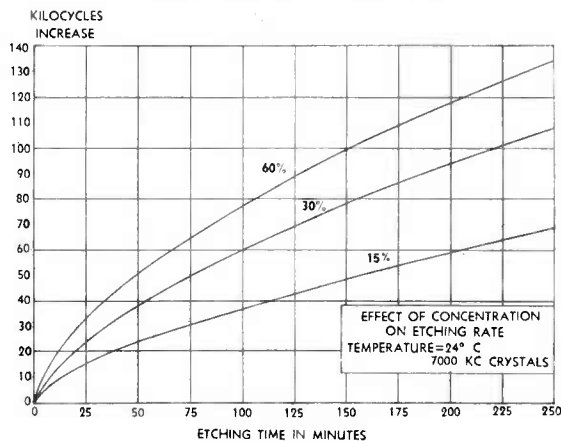


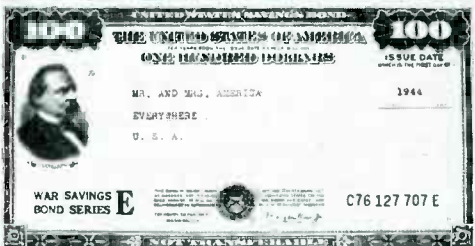
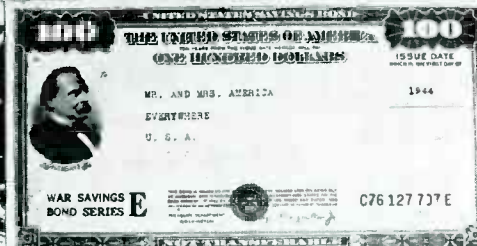
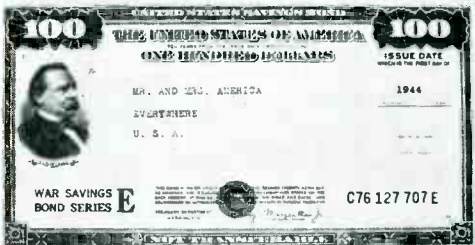
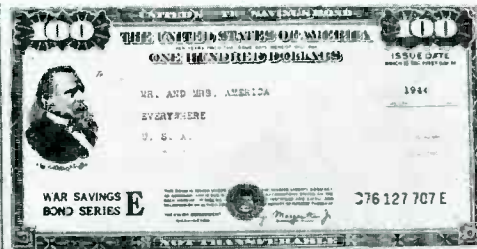
Figure 9

Sulfuric-chromic acid is very dangerous and contact with the skin must be avoided.

**WASHING ETCHING CRYSTALS:** Etched crystals should be thoroughly washed in pure running water to remove all traces of the etching compound. Neutralization with an alkali such as sodium bicarbonate, however, is unnecessary. If it is desired to quickly stop the etching action, the use of a dilute solution of ammonia is recommended.

**NEUTRALIZING SPENT ETCHING AND CLEANING SOLUTION:** Spent etching solutions and sulfuric-chromic acid cleaning solutions should be neutralized with solid sodium carbonate before they are discarded in order to avoid corroding the drain pipes. The solid carbonate is added until effervescence stops and the solutions should then be tested with litmus paper to make certain that they are neutral or slightly alkaline. Serious corrosion of piping has resulted from the lack of these precautions.





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