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Editor
John E. Remich

Managing Editor
Gail W. Woodward

Technical Editors
Francis R. Sherman
John W. Adams

EDITORIAL OFFICE:
Technical Information Section
Philco TechRep Division
22nd St. and Lehigh Avenue
Philadelphia 32, Penna.

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Editorial

TECHNICAL WRITING

By John E. Remich, Manager, Technical Department

In view of the many advantages to be gained from technical writing, it is difficult to understand the reluctance of most engineers today to put their experiences in writing. Perhaps this reluctance is due to the evolution of the technical writing profession which has taken place in the last few years. Where previously most engineers were forced to develop some writing ability, now they too often place complete reliance on professional "ghost writers." The engineer who thus limits himself may fail to develop the ability to express clearly his thoughts and ideas, and thus may unfortunately place a low ceiling on his own abilities and professional opportunities.

Most engineers have a well-stocked supply of reasons for not engaging in any technical writing. The most frequently used reason is lack of background. There is an enormous feeling that scholastic achievement is the best index of writing ability. Actually, latent ability can be discovered only by actual trial, and in most cases writing skill can be developed and greatly improved by practice over a period of time. Many successful engineers who once felt that they had little aptitude for such work have been pleasantly suprised at their accomplishments in this field.

It is a good idea for the engineer to do a certain amount of writing, even though he does not intend to become a professional writer. Such activity tends to improve his thought processes and his ability to communicate effectively. In addition, very gratifying professional recognition can be gained by the publication of a few well-written articles.

Such publications as the BULLETIN and popular trade journals provide an ideal testing ground for the engineer who desires to evaluate and improve his writing ability. For those of you who decide to give it a try, here are a couple of tips. Editorial rejection of an article does not necessarily mean that it is unsuitable for other publications. The editor accepts material on the basis of suitability for *his* publication, and in light of *his* plans and recent history. For example, if your article covers a subject that was recently treated in a publication, it should not be submitted to that particular publication. Similarly, a maintenance-level article should not be submitted to an engineering journal.

Technical writing can do you a great deal of good. Try it.

THE PIEZOELECTRIC EFFECT

Part II (Conclusion)

by Gail W. Woodward
Headquarters Technical Staff

The second half of the article which began in the September, 1953, issue of the BULLETIN. This part covers some of the circuitry associated with piezoelectric crystals, the nonresonant aspects of crystals, and applications to modern science.

THE FIRST PART of this article (September, 1953, BULLETIN) covered the history and theory of piezoelectricity, piezoelectric materials, the basic principles of vibrating solids, and the resonant characteristics of crystals and crystal mountings. This concluding installment will deal with some of the common crystal oscillator and crystal filter circuits, the nonresonant characteristics of piezoelectric crystals, and some of the applications of commercial devices.

CIRCUITS

Many circuits utilizing the resonant properties of crystals have been developed. The purpose of this article is to discuss only the basic forms of circuitry to show the underlying principles.

Crystal Oscillator

Figure 1 shows the basic crystal oscillator and its equivalent circuit (part B of figure 1). In effect, the circuit functions as a conventional tuned-plate-tuned-grid oscillator with the crystal operating as an antiresonant grid tank. Feedback is accomplished through the grid-to-plate capacitance of the tube (if a pentode tube is used in place of the triode, a capacitor is often connected between grid and plate to provide sufficient feedback). Actually, in order to sustain oscillation, the crystal must op-

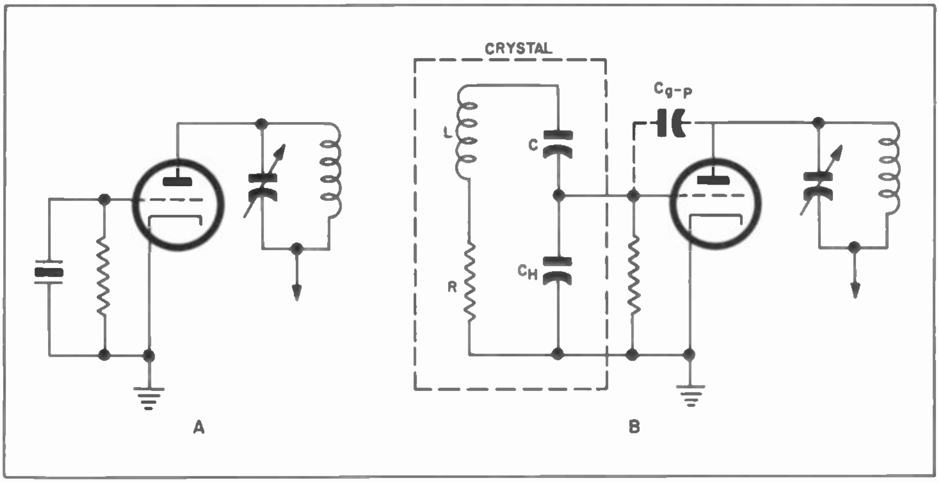

Figure 1. Crystal Oscillator
A. Conventional Circuit
B. Equivalent Circuit

erate slightly inductive (signal frequency slightly below antiresonance). The plate circuit is deliberately tuned to a frequency slightly higher than the frequency of oscillation. The resulting inductive plate load will reflect, by virtue of the Miller effect, a negative resistance into the grid circuit. This negative resistance effectively cancels the losses in the crystal and permits sustained oscillation. Since the crystal does not work at exact resonance (or antiresonance), it is apparent that changes in the circuit will produce definite changes in output frequency—while this characteristic is often undesirable, it does provide a practical means of precision adjustment.

Automatic bias is provided by means of the grid-leak resistor operating in conjunction with the crystal-holder and tube-input capacitances.

This circuit is widely used in the form shown and in many modified forms. However, in any of the forms, the basic principles of operation are the same as explained above.

Series-Resonance Oscillator

Figure 2 shows a circuit that uses the series resonant frequency of a crystal to control oscillation. Since this frequency is a function of the crystal alone, the external circuit has virtually nothing to do with it. The circuit is made up of a cathode follower (V_2) and a grounded-grid amplifier (V_1). Signals at the plate of V_1 are coupled to V_2 and are fed back through the crystal to the cathode of V_1. It can be seen that if no phase shift occurs through the crystal, the feedback signal is regenerative. This condition of zero phase shift exists at the series resonant frequency of the crystal, and oscillation will occur at only this frequency. (The crystal and holder appear resistive at antiresonance and therefore introduce no phase shift at that frequency, but the impedance is much too high to permit sufficient feedback to cause the circuit to oscillate.) Frequency stability is best when the circuit includes a broadband amplifier, because a broadband circuit minimizes the effect of reactive circuit components. The crystal will oscillate in its most active mode within this band. If it is necessary to favor one of the less active modes, resistor R_1 can be replaced with a tuned circuit that resonates at the desired frequency. The Q of this tuned circuit should be as low as possible and yet provide adequate rejection of undesired modes. Overtone modes can easily be excited in this circuit by resonating the plate circuit of V_1 to the desired overtone.

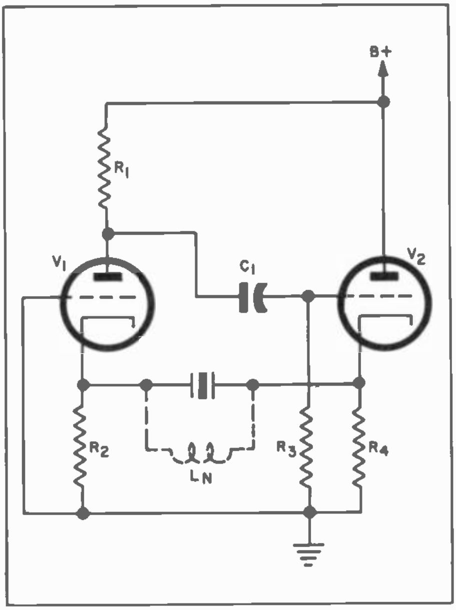

Figure 2. A Crystal Oscillator Designed to Use The Series Resonance Characteristic of a Crystal

When it is necessary to operate the circuit at higher frequencies, the crystal-holder capacitance may tend to shunt the series resonant circuit. The effect can be eliminated by connecting an inductor (L_N) across the crystal, as shown by the dotted lines, so that the holder capacitance is tuned to resonance at the

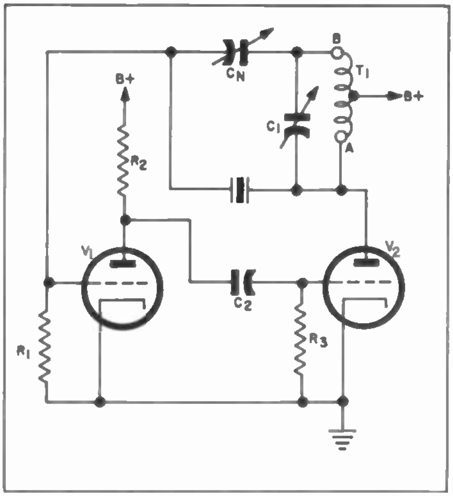

Figure 3. Crystal Oscillator, Showing Bridge Neutralization of Holder Capacitance

operating frequency. (The holder capacitance and the inductor form an antiresonant circuit that has a very high impedance to signal-frequency currents, thus leaving the series resonant impedance as the effective component.)

Figure 3 shows a highly stable circuit that utilizes a form of neutralization to eliminate the capacitance of the holder. The same circuit that provides neutralization also provides the required frequency selectivity. V_1 and V_2 form a conventional, two-stage, resistance-coupled amplifier. The plate of the second stage is connected to a push-pull autotransformer (T_1). Capacitor C_1 tunes T_1 to resonance. If C_N is adjusted to have a value exactly equal to the crystal-holder capacitance, any signal that is fed from Point A to the grid of V_1 through the holder is cancelled by an equal and opposite signal from Point B through C_N. Thus the effect of the crystal-holder capacitance is eliminated. As a result, oscillation occurs at only the series resonant frequency of the crystal, and the external circuit has practically no effect on frequency. This circuit represents one of the most stable crystal oscillators in existence.

Crystal Filter

A vibrating crystal can be used as a bandpass filter that has an extremely narrow bandwidth, because of the high values of Q associated with crystals. Bandwidth is related to Q by the formula:

$$\Delta F = \frac{F_o}{Q}$$

Where ΔF = bandwidth between half-power points

F_o = frequency of resonance

If a crystal with a Q of 500,000 were used as a 100-kc. bandpass filter, the bandwidth would be only 1/5 cycle.

Part A of figure 4 shows a typical

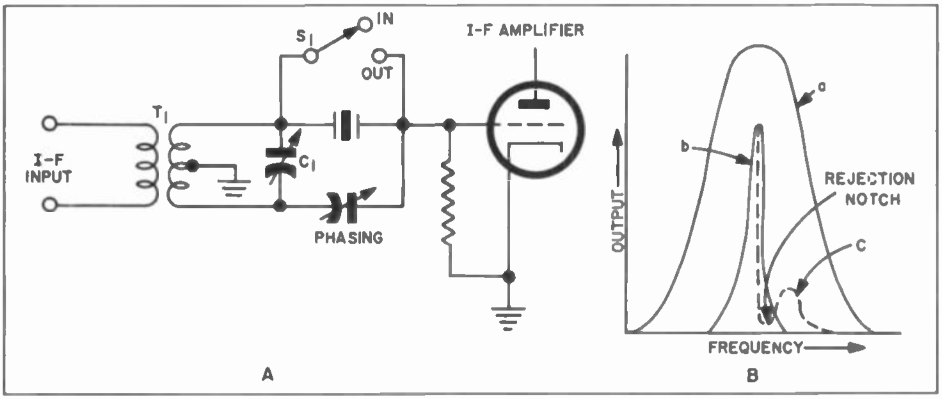

Figure 4. I-F Crystal Filter Circuit
A. Schematic Diagram
B. Response Curves for Filter Circuit

circuit used for an i-f crystal filter. When S_1 is closed, the circuit functions as a conventional i-f amplifier with a response as shown in curve a in part B of figure 4. When S_1 is opened, to place the crystal in the circuit, the circuit will function very much like the one shown in figure 3. Capacitor C_2, called the phasing control, acts as a neutralizing capacitor for the crystal-holder capacitance, and the crystal acts as a sharply tuned series resonant circuit that results in selectivity curve b. The value of the phasing capacitor can be reduced if desired so that complete neutralization does not occur. This will modify curve b so that it appears as modified by the dotted line, c. This produces an attenuation, or "rejection notch," that can be used to discriminate against frequencies very close to the desired frequency. The phasing control has the effect of moving the notch over a small range of frequencies.

NONRESONANT USE

Piezoelectric crystals have many nonresonant uses. Such applications as phonograph pickups, microphones, and speakers are well known. Even though resonance may be present, these applications are considered nonresonant because resonance effects are assiduously avoided or compensated for.

Nonresonant crystals require much greater electrical excitation to produce a given mechanical displacement (and vice versa) than do resonant crystals. However, the use of more active materials somewhat offsets this disadvantage. Rochelle salt is widely used in preference to quartz in such applications because of the low activity of quartz. Of course, other salts and certain ceramics appear well on the way to displacing Rochelle salt in most uses.

Methods of excitation and crystal motion for nonresonant crystals are similar to those for resonant crystals, but mechanical resonance effects are ordinarily avoided.

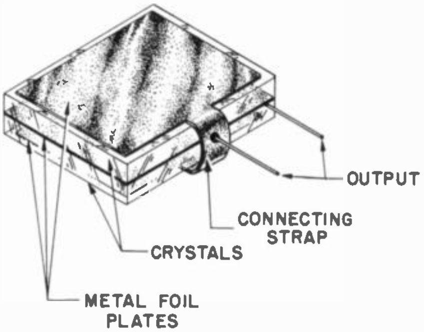

Figure 5. Constructional Details of a Bimorph Crystal

Bimorph* Crystals

Development of the Bimorph crystal element has done much to improve the mechanical-to-electrical transfer of energy. Figure 5 shows the Bimorph construction. Two crystals are mounted one on each side of a metal-foil plate, and two more foil plates enclose the assembly. If the two crystals are cut for thickness excitation and are mounted so that their axes are aligned, it can be seen that any voltage applied to the terminals will cause one plate to get thicker while the other plate gets thinner. For the purpose of discussion, suppose that the top crystal gets thicker as the bottom crystal gets thinner. The surface area of the top plate will decrease while that of the bottom plate will increase—a condition which will cause the four corners to curl upward. Reversing the applied polarity will cause the corners to curl downward. Such elements are widely used in speakers, microphones, and earphones. In such applications either the crystal surface itself is used as an acoustical diaphragm, or a conventional diaphraghm is attached to the crystal. Two methods of mounting the crystal are possible: the

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* Brush Electronics Company, trade mark.

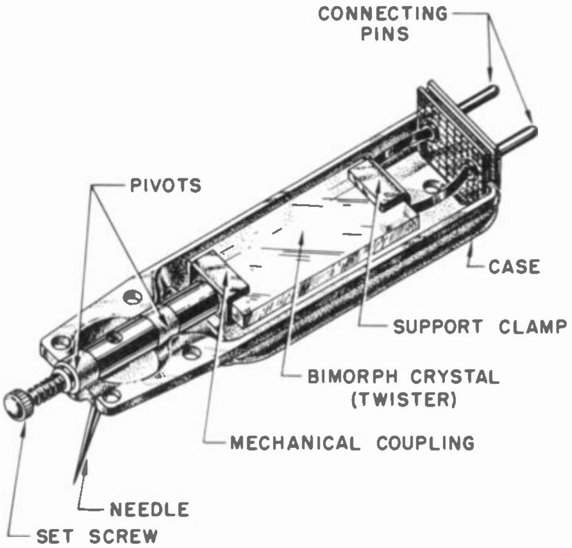


Figure 6. Phonograph Pickup Using a Bimorph Twister Crystal

four corners can be clamped and the center allowed to vibrate, or three corners can be clamped and the fourth allowed to vibrate.

The action of the Bimorph has the advantage of a ten-fold, or greater, increase in sensitivity over a conventional crystal.

By combining face-shear crystals in a Bimorph element, a twisting action can be obtained. Such an element can be directly coupled (mechanically) to a phonograph needle in such a manner that the lateral needle vibrations exert a twisting force on the element. A crystal pickup of this type (shown in figure 6) is very sensitive and can be used either to convert mechanical energy from a record into electrical energy or to convert electrical energy from an amplifier into mechanical energy for cutting a record.

Equivalent Circuit

Part A of figure 7 shows a simplified equivalent circuit for a nonresonant crystal. G represents the voltage produced by the piezoelectric effect, C represents the capacitance of the mounted crystal, and R is the leakage inherent in any capacitor. Ordinarily R can be ignored because it is quite large (on the order of hundreds of megohms) as compared with the resistance of any circuit that would be connected to the output terminals.

Since the crystal capacitance appears in series with the generated voltage it is obvious that the larger the value of C, the better the coupling. The high dielectric constant of Rochelle salt makes it an ideal substance in terms of capacitance. Typical Bimorph elements have capacitances on the order of thousands of micromicrofarads. Quartz is quite unsuitable in this respect because of its rather low dielectric constant.

The effect of capacitance in circuit applications is quite important. For example, if the circuit to which the crystal is connected has a large input capacitance, a capacitive voltage divider action is present that will reduce the effective voltage output. This fact explains why coaxial cables should not be used for running long crystal leads. For example, a 100-foot section of coaxial cable could easily have a capacitance of 4000 $\mu\mu$f. A 1000-$\mu\mu$f. crystal connected to this length of cable would have its output attenuated by 5 to 1, or about 14 db. Of course, the best solution is to use large crystal capacitances and small input-circuit capacitances.

If the crystal is connected to a resistive load, it can be seen that a high-pass filter is formed with the crystal capacitance. This means loss of low-frequency response. For example, if a 1000-$\mu\mu$f. crystal were connected to a 0.5-megohm grid circuit, the low-frequency cutoff would be over 300 cycles — a value unsuitable for most audio-reproduction purposes. Part B of figure 7 shows how compensation may be provided for this effect. The 5-megohm resistor extends the low-frequency response down to about 30 cycles. Of course, a loss of output is present but improved frequency response is achieved. An added refinement is often found in the form of a small high-frequency compensator capacitor (C_c), connected across the large series resistor.

Another method of improving low-frequency response involves the use of a cathode-follower input circuit connected for high input resistance, as shown in part C of figure 7. If the cathode-follower circuit shown has a gain of 0.9, its effective input resistance will be about 100 megohms, which is high enough to greatly extend the low-frequency response. This method is more expensive than the other methods discussed, but the loss in gain is only 10% (or less than one db).

Underwater Sound

Quartz crystals were first used as underwater sound transducers but they were very expensive and relatively insensitive. ADP crystals have largely replaced quartz in this application, and the ceramics will very likely soon replace ADP.

If one face of a vibrating (not necessarily resonant) solid object is placed in contact with a body of water, the vibrations are propagated in the water in about the same way radio waves are

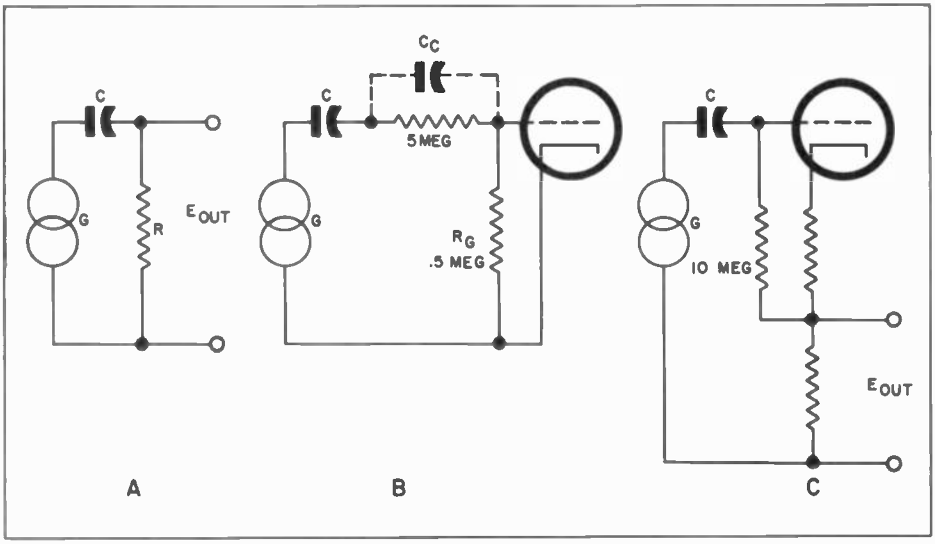


Figure 7. Equivalent Circuit of a Nonresonant Crystal
A. Showing Leakage Resistance
B. Showing Low-Frequency Compensation Resistor
C. Showing Cathode-Follower Circuit for Raising Input Resistance

propagated in space. If the size of the face in contact with the water approaches a half wavelength (of the water wave), the vibratory energy propagates through the water in the form of a beam—in fact, the behavior of such transducers is very much like that of r-f structures of the same relative size (in terms of wavelength). Thus an underwater sound transducer of proper size and with a properly shaped face can radiate a sound beam into water with very good efficiency, and the same assembly can also serve as a directional sound-pickup device. Sonar systems are designed to take advantage of this behavior, and piezoelectric transducers have been used extensively in fathometers, listening devices, and underwater detection devices.

A very interesting development of underwater sound is found in the radar trainer. This device simulates a radar beam in the form of an underwater sound beam. Since underwater sound travels much slower than radar waves in air, the trainer can be scaled down in size in accordance with the ratio of the velocities (almost 200,000 to 1, or roughly 37 miles to 1 foot). Relief maps made from some hard substance are placed in the bottom of the tank to represent land masses and other targets. The underwater sound signals, when displayed on a conventional radar indicator, look surprisingly like an actual radar search image of the simulated area. Such trainers can be used to simulate radar navigation and bombing problems with a high degree of accuracy and realism.

Delay Lines

The supersonic delay line utilizes the fact that sound waves require a definite time to travel through a fluid. If a mechanical vibration (on the order of 5 to 30 mc.) is introduced into one end of a mercury column, the vibration will arrive at the other end at some later time (up to several thousand microseconds). A piezoelectric transducer can be used both to excite and to detect such vibrations, so that it becomes an integral part of such a delay line. Quartz crystals (cut for thickness vibration) are ordinarily used as the transducer element, and the mercury column, which is usually employed as the propagating medium, is in direct contact with one crystal face. Thus the propagating medium also serves as one electrode. Usually, the crystal is operated at resonance, in the fundamental thickness mode. The Q of the crystal is extremely low, because the mercury mechanically loads the crystal to a high degree.

Although many substances can be used as the propagating medium, mercury is usually selected because of its relatively small (and, strangely enough, negative) temperature coefficient of velocity at room temperature. Also, it has a relatively low velocity of propagation (about 1450 meters per second at room temperature).

Delay lines are used primarily for data storage (memory) in certain forms of computers. Data are entered at one end of the line as a series of pulses—each pulse representing one datum. When the pulses arrive at the other end of the line, they can be "read" out and dropped, or they can be amplified and fed back into the delay line for future use. Such a circulating memory circuit can store considerable information for very long periods of time.

A typical example of a delay-line memory is the one employed in MTI radars. A delay line in this equipment is used to store all of the data from a receiver in each pulse period. These stored data are compared with the data in the next pulse period, to determine whether any changes have taken place.

Thus, in effect, the radar continuously remembers exactly what happened during the preceding pulse period.

Sonic Testing

Sonic testing utilizes sound propagation through a solid to determine the characteristics of the solid. This method of testing is nondestructive, as contrasted with the method of tearing into an object to look for flaws. For example, an air bubble in a large casting could be located by drilling a number of sample holes through the casting, but the test would destroy the object being tested.

Nondestructive testing has been tremendously advanced by using piezoelectric transducers to excite sound waves into the structure to be tested—an analysis of the sound wave behavior reveals a great deal of data on the structure without the slightest damage.

In one type of sonic tester an abrasive wheel can rapidly be examined for flaws by finding its resonant frequency. The wheel is excited by a piezoelectric transducer, driven from a variable frequency source, and a piezoelectric microphone picks up the sound waves produced by the vibration of the wheel. When the natural resonant frequency of the wheel is reached, the strong vibration of the wheel produces a large amplitude sound wave. For a given size wheel, resonance will occur at some specific frequency, and any flaws present will either introduce new resonant frequencies or modify the original frequency. Such testing is very rapid and accurate.

Another type of tester is more useful for general testing of large metallic solids. This device operates very much like a radar system; that is, short bursts of ultrasonic sound are produced and coupled into the solid, and then the device waits for echoes—ranging being accomplished by conventional timing techniques. Figure 8 shows a block diagram of such a tester.

Figure 9 shows the echo patterns of a cylindrical sample of metal. Part A

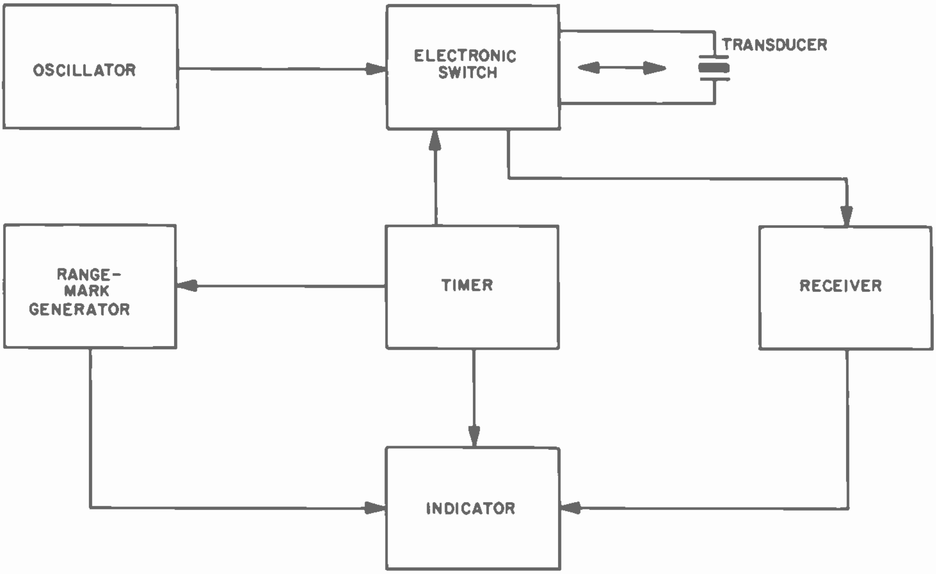


Figure 8. Block Diagram of Sonic Tester

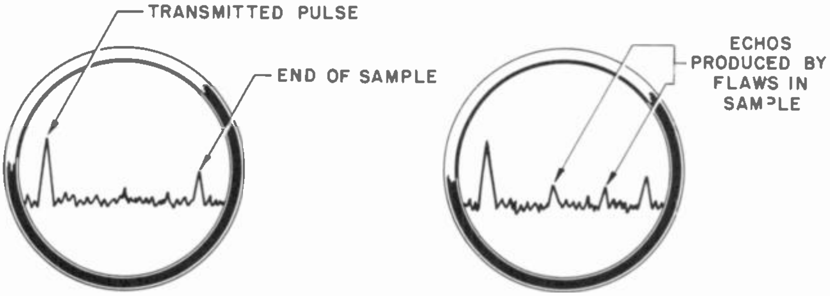


Figure 9. Echo Pattern of Metal Cylinder
A. Flawless Cylinder
B. Cylinder With Two Flaws

shows a flawless sample, and part B shows a sample with two flaws, one at the center and one close to the end. Figure 10 shows how the echo pattern of an irregular object would appear on the oscilloscope. Any other flaws would show up as additional echoes. Such a device is extremely useful in locating internal cracks in such items as railroad car wheels and axles, large castings, large motor and generator armatures, armor-plate sections, long sections of rods or tubing, etc.

The sound waves are usually coupled to the solid to be tested by means of a thickness-vibrating (X-cut) quartz transducer. Since these transducers are not necessarily of the same acoustical impedance as the object being tested, a film of oil or water is used to obtain a good acoustical contact. The size of the crystal is chosen to produce a sonic beam of the correct width in the metal. In general, the lower frequencies propagate with less loss and are favored in testing very large items, but the higher frequencies are capable of revealing smaller flaws and are used where greater resolution is desired.

The Accelerometer

An accelerometer is a device that indicates rate of change of velocity. If the typical one shown in figure 11 were accelerated upward along the axis shown, the pressure of the metal block against the crystal would increase, because of the inertia of the block, and a voltage would be generated. The pressure, and hence the voltage, is deter-

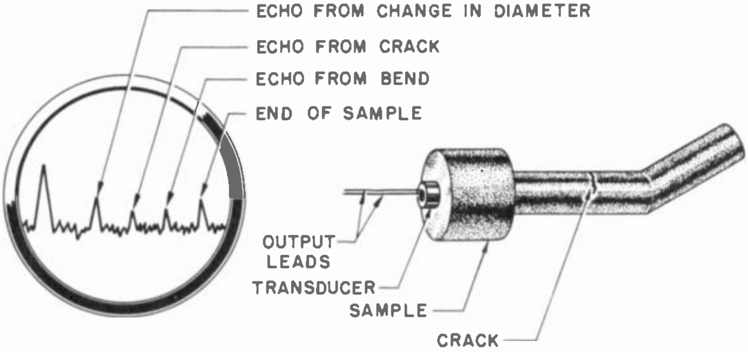


Figure 10. Tester Response to an Irregular Object
A. Oscilloscope Display
B. Object

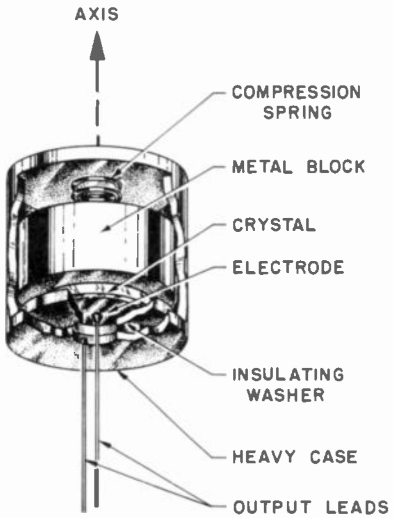


Figure 11. Construction of Accelerometer

mined by the rate of acceleration, and the voltage is therefore a direct indication of the magnitude of the rate. If acceleration occurred in the opposite direction, the pressure of the metal block against the crystal would be lessened, and a voltage of opposite polarity would be developed. Acceleration perpendicular to the axis would not be indicated, because it would not change the pressure of the block against the crystal. Uniform motion produces the same effect as no motion—no voltage being obtained for either.

The accelerometer can be used to measure impact. For example, suppose that the accelerometer were attached to the head of a 10-pound hammer. When the hammer is driven against a nail, the accelerometer will develop a voltage that can be converted to G's of deceleration. If 10 G's were recorded, the impact force of the hammer would be 100 pounds.

Another use of the accelerometer is in measuring explosion pressure. If the accelerometer is suspended with its axis pointed toward the center of an explosion, the pressure of the burst will drive the accelerometer outward. If the mass and surface area of the accelerometer are known, the value of acceleration can be used to indicate the explosion pressure, in units of force per unit area.

Still another use of the accelerometer is in vibration analysis. The accelerometer body is held against the machine to be tested (such as a motor or generator), and any vibrations will be converted to a voltage, which is amplified and examined on an oscilloscope or oscillograph. Such testing can disclose the nature of the vibrations for the purpose of counter-balancing, and, if used continuously, can assist in predicting an impending failure.

One possible use of the accelerometer is in a recently proposed system of navigation. Suppose that an aircraft were fitted with three accelerometers—one pointing along each of the three aircraft axes. Acceleration in any direction will result in output from one or more of the accelerometers. If all acceleration data were known, the position of the aircraft with respect to its starting point could be computed. For example, evaluation of the longitudinal acceleration data would give the aircraft speed while evaluation of the vertical acceleration would indicate the altitude. Of course, a computer would be necessary for the multiplicity of calculations that would be involved, but researchers in that field are more than able to develop the required device. The only other requirement for navigation would be an accurate chronometer for timing (which function could be provided by a quartz crystal resonator) so that distances could be determined. Such a navigation system has many interesting possibilities in that it would be self-contained. All other systems require the use of external observations (such as radio signals, earth's fields, or stellar positions), but the accelerometer system would provide a truly independent means of navigation that would work in interstellar space as well as in the vicinity of the earth.

CONCLUSION

Knowledge of the piezoelectric effect has been advanced to a point where piezoelectricity has become one of the most important facets of solid-state electronics. Development in recent years has tended to increase (during 1952 over 500 papers were presented on the subject of piezoelectricity as compared to around 300 for 1951) and greater correlation of theory has resulted in unifying various theoretical aspects of solids. A recent BULLETIN filler pointed out the use of ultrasonic beams for surgery. A new method of soldering aluminum with ultrasonics has been developed. To date the piezoelectric ceramics offer the greatest possibility in the widespread use of electromechanical transducers for a fantastically wide variety of applications. Past and present trends indicate that we can expect a continuous expansion of the applications of piezoelectric materials.

"What's Your Answer?"

This month's problem involves another of those tricky black boxes. This box, made of metal, has rectangular openings on two opposing sides, and these openings are joined together by a rectangular pipe, through which daylight can be seen. No obstructions are visible inside the pipe. The pipe dimensions are ½" x 1", indicating an X-band wave-guide structure. Therefore, an X-band signal generator is connected so as to inject energy into one opening. It is found that energy flows into the wave guide with negligible reflection, but a detector connected at the far opening shows that the signal reaching that point is essentially zero. Since the same conditions exist over about a 10% bandwidth, it is evident that the box contains no resonant structures.

What is in the box?

(Solution next month)

Solution to Last Month's "What's Your Answer?"

To identify the defective resistor and to determine whether its value is high or low with only three bridge measurements, proceed as follows:

For reference, label the resistors R_1 through R_{12}. Then, divide the resistors into three groups of four each. Connect the resistors of group 1 in series and attach to bridge terminals A, connect the resistors of group 2 in series and attach to bridge terminals B (see figure 1), and note bridge indication.

Three possible conditions could occur, as follows:

1. The bridge could balance, thus indicating that the defective resistor is in group 3 (R_9, R_{10}, R_{11}, and R_{12}), and that R_1 through R_8 are good.

2. The bridge could show that group 1 has greater resistance than group 2.

3. The bridge could show that group 1 has less resistance than group 2.

CONDITION 1

If condition 1 occurs, connect R_9, R_{10}, and R_{11} in series across terminals A, and connect three of the good resistors in series across terminals B. Note the bridge indication. Three indications are possible, as follows:

1. A balanced bridge would indicate that R_{12} is the defective resistor. A bridge comparison of R_{12} with one of the good resistors would then disclose whether its value is high or low.

2. If the bridge shows that the combination of R_9, R_{10}, and R_{11} has greater resistance, one of these resistors is defective and its value is too high. To determine which one is bad, compare R_9 with R_{10} on the bridge. Balance would indicate that R_{11} is bad, and imbalance would locate the defective unit on the side of the bridge that shows the higher resistance.

3. If the bridge shows that the combination of R_9, R_{10}, and R_{11} has less resistance, the defective resistor is in that group, and it would be located exactly as in 2.

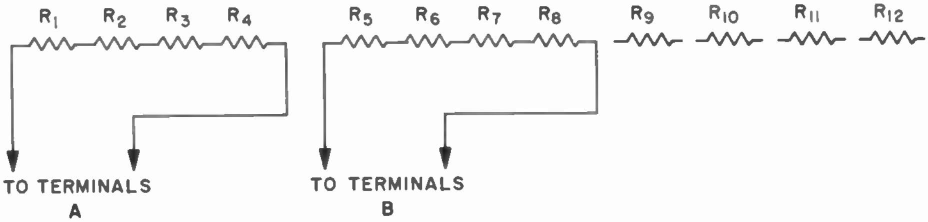


Figure 1. Step One, Showing Grouping of the Twelve Resistors

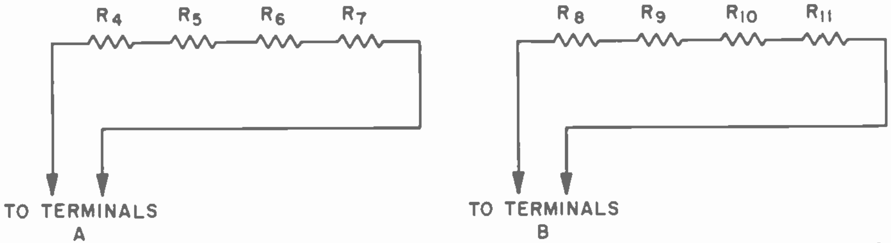


Figure 2. Rearrangement of Resistors in Case Condition 2 Occurred

CONDITION 2

If condition 2 occurs, it is evident that R_9, R_{10}, R_{11}, and R_{12} are good. Proceed as follows:

Remove R_1, R_2, and R_3 from one side of the bridge, and replace them with R_5, R_6, and R_7 (from the other side). Place R_9, R_{10}, and R_{11} on the side with R_8. The setup now looks like that in figure 2.

For this setup, one of the following three conditions must exist:

1. Imbalance remains in the same direction as in condition 2. This would mean that either R_4 or R_8 is defective because R_9, R_{10}, and R_{11} are known to be good, and if R_5, R_6, or R_7 were defective, switching the latter group to the other side of the bridge would have shifted the direction of imbalance. Next compare R_4 with a good resistor. Balance would mean that R_8 is defective and that it is too low in resistance (because group 2 was lower in resistance than group 1). If R_4 were bad, it would show a lower resistance than the good resistor on the third measurement.

2. The direction of imbalance is the opposite of that for condition 2. This means that the defective resistor must be in the group that was switched from one side of the bridge to the other (R_5, R_6 and R_7), and that it is too low in value (R_4, R_5, R_6, and R_7 are now on the low-resistance side). Compare R_5 with R_6. Balance would indicate that R_7 is defective, and imbalance would disclose the defective resistor on the low-resistance side.

3. Balance occurs. This condition indicates that the defective resistor was removed and that it must therefore be R_1, R_2, or R_3. Furthermore, the defective resistor must be high in value. Compare R_1 with R_2. Balance means that R_3 is defective, and imbalance will reveal the defective resistor on the high-resistance side.

CONDITION 3

If condition 3 occurs, proceed exactly as for condition 2 except change all of the "low" values to "high" and vice versa.

Note

While series connections were specified in the above solution, parallel connections may also be used. The only requirement is that the connections on both sides of the bridge must be of the same type. Minor variations in the solution given are also possible.

A SIX-CHANNEL INTRA-FACILITY INTERCOM

by H. S. Newman and C. G. Raymond
Philco Field Engineers

A versatile intercom set that employs voice-frequency ringing and standard telephone facilities. Up to six channels are available on a two-wire-line basis.

(Editor's Note: This intercom was designed for use with the Philco CLR-6—CMT-4 combination, but it can be used in a wide variety of applications. The July, 1953, BULLETIN carried an article on another intercom version designed by the authors for engineering channel use.

We would like to point out that Philco is currently supplying a Signalling and Termination Unit, CST-2, that provides either two or four-wire termination with either normal dial or ringdown operation. Signalling with either normal dial or ringdown operation is accomplished by the use of a 3500-cycle tone in this equipment.)

SEVERAL MONTHS AGO it became evident that a new type of intercommunication equipment was required — one which would serve as an efficient intra-facility order wire between the communications center, remote transmitter and receiver stations, and carrier and CW operating rooms. The present systems of intercommunication are lacking in versatility and compatibility, one of their greatest drawbacks being that they cannot be switched immediately from a normal metallic circuit to an alternate VHF/FM-carrier or SHF-multiplex channel. In some cases, voice-frequency ringers, line amplifiers, and speakers are installed; however, in view of their size and cost such installations do not represent efficient nor economical solutions to intra-facility communications. In this article an entirely new type of intercommunications equipment which is designed specifically to meet the needs of intra-facility communications is presented. This unit is pictured in figure 1.

REQUIRED CHARACTERISTICS

The following tabulation lists the major requirements of an intra-facility intercom set.

1. Transmission characteristics:
    a. 0-dbm. level, 2-wire, balanced lines.
    b. Analogous to a local-battery type telephone.
2. Signaling to be accomplished in the audio-frequency range, for compatibility with both carrier and metallic links. (1600-cycle military standard to be used.)

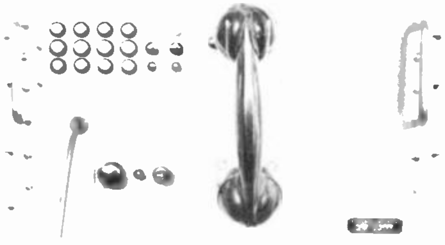


Figure 1. Front View of Six-Channel-Intercom

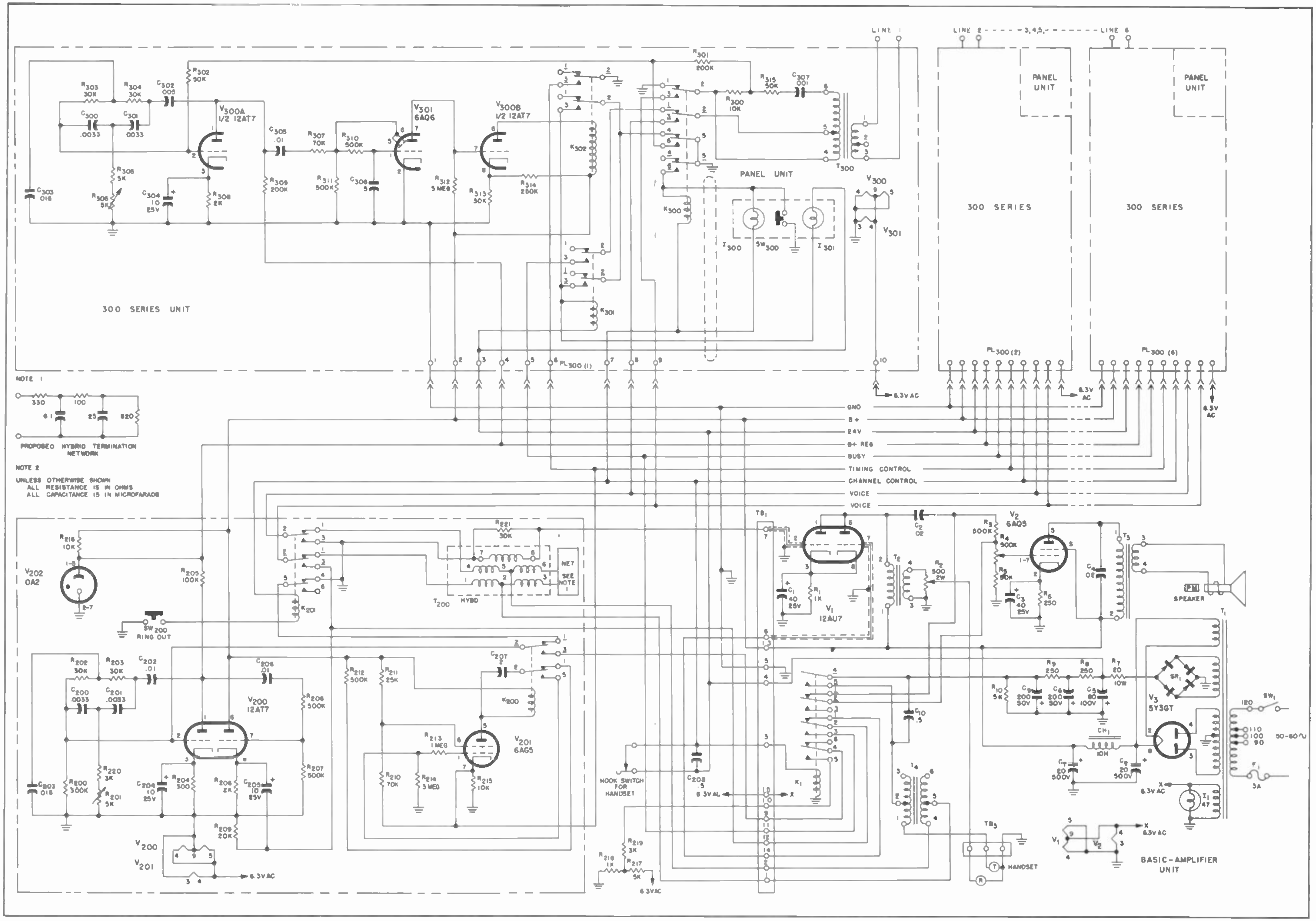


Figure 3. Complete Schematic Diagram of Intercom Unit

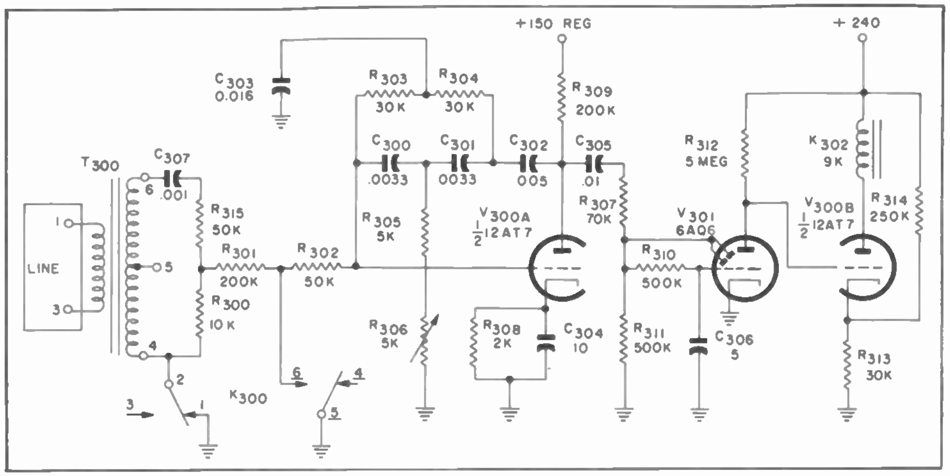


Figure 4. Simplified Schematic Diagram of Intercom Unit

   b. Unit to be self-contained except for speaker. (One speaker of a separate dual-speaker panel will be used.)

GENERAL

The device described in this article represents one solution to the problem of designing reliable, self-contained, intra-facility communication equipment possessing all of the aforementioned characteristics. To date, only one model of this unit exists, and all tests have been made under laboratory conditions.

Figure 2 is a block diagram of this 6-channel, special-purpose intercom. The functions performed by the tone-detector circuit (300 unit), timing circuit, and tone-generator circuit (200 unit), and the basic amplifier are shown in the complete schematic, figure 3. Figure 4 is a simplified schematic of the tone-detector circuit.

THEORY OF OPERATION

The heart of the instrument is the 300-series unit. The functions performed by this subassembly are as follows:

1. Tone detection and rectification.
2. Call holding and aural signal initiating.
3. Channel selection.
4. Call release and tone-detector disabling.

The tone-detecting and rectifying circuits presented the greatest problem. Considerable experimenting was done with L-C filters of the resonant and M-derived types; however, the limited space available for each 300-series unit and the unavailability of miniature, toroidal filter components eliminated the L-C type filter. Next, the R-C type filter networks were investigated. Of the various types, the parallel T with a vacuum tube to provide feedback at all frequencies except one (F_0) seemed most suitable, since it makes possible a small, inexpensive, and easily constructed assembly. (This is especially true in Japan where stable precision resistors and capacitors cost less than a dime.) Because little information was available on this type of circuit, the design was largely the result of the cut-and-try method. The schematic diagram of the filter and detector circuits appears in figure 3.

3. The operating position to provide both handset and speaker reproduction. (Hybrid-coil action will be required to prevent handset-speaker feedback.)
4. Provisions to be made for a maximum of six channels. (Individual channel units to utilize plug-in construction, so as to reduce unnecessary cost and maintenance on unused portions of the set in cases where less than six channels are required.)
5. The common amplifier to provide:
   a. Reasonably high gain during stand-by periods.
   b. Fixed minimum gain.
   c. Elimination of channel noise in stand-by condition.
   d. Automatic speaker-gain reduction during handset use.
   e. The receiver portion of the handset to receive one stage of amplification, and its level to be controlled by a screwdriver adjustment.
   f. Over-all amplifier gain of 47 db.
6. Additional features:
   a. Multiple conferencing and ring-out.
   b. Non lock-up feature. (Channels to be cleared automatically when handset is replaced on its hanger.)
   c. Incoming call to be indicated visually and aurally. (Aural signal to be present for 5 seconds.)
   d. Busy circuit to indicate to second calling party that the called station is busy.
      (1) Busy tone to be returned for 5 seconds.
      (2) Recycling of busy circuit desirable.
      (3) Second calling party to light call lamp which cannot be extinguished without the called station eventually answering the call.
      (4) Busy frequency of 60 c.p.s. at a 0-dbm level.
   e. Total net transmission loss between stations to be 15 db.
7. Physical data:
   a. Chassis and panel construction for standard cabinet rack.

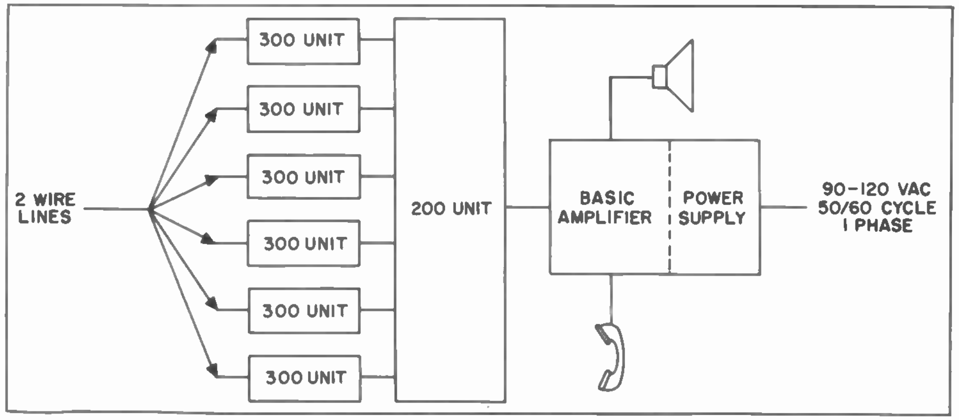


Figure 2. Block Diagram of Intercom Unit

The calculation of the series arms (R_{303}, R_{304}, C_{300}, C_{301}) of the T were determined by the standard formula,

$$F_o = \frac{1}{2\pi RC}$$

where the value of R was chosen to be 30K. C was then computed to be .0033 μf. at 1600 c.p.s. The values of C_{302}, C_{303} and of R_{305} and R_{306} were determined by experiment. Tests indicated that the values of the shunt arms were probably a function of stage gain. A constant (K) may be derived from the stage gain, and when this constant is divided into the original values of C and multiplied by the original value of R, the result is the theoretical values of the shunt arms; however, the capacitance of the feed-back capacitor, C_{302}, and the total shunt capacitance (including Miller effect) make necessary an adjustment of these values. Once the circuit values had been determined, tests indicated that the stability of the circuit was excellent as long as the plate supply remained constant; therefore, a VR tube (0A2) was added to the 200-series unit. It was also found that reducing the size of the plate load resistor and increasing the value of the feed-back capacitor would cause the circuit

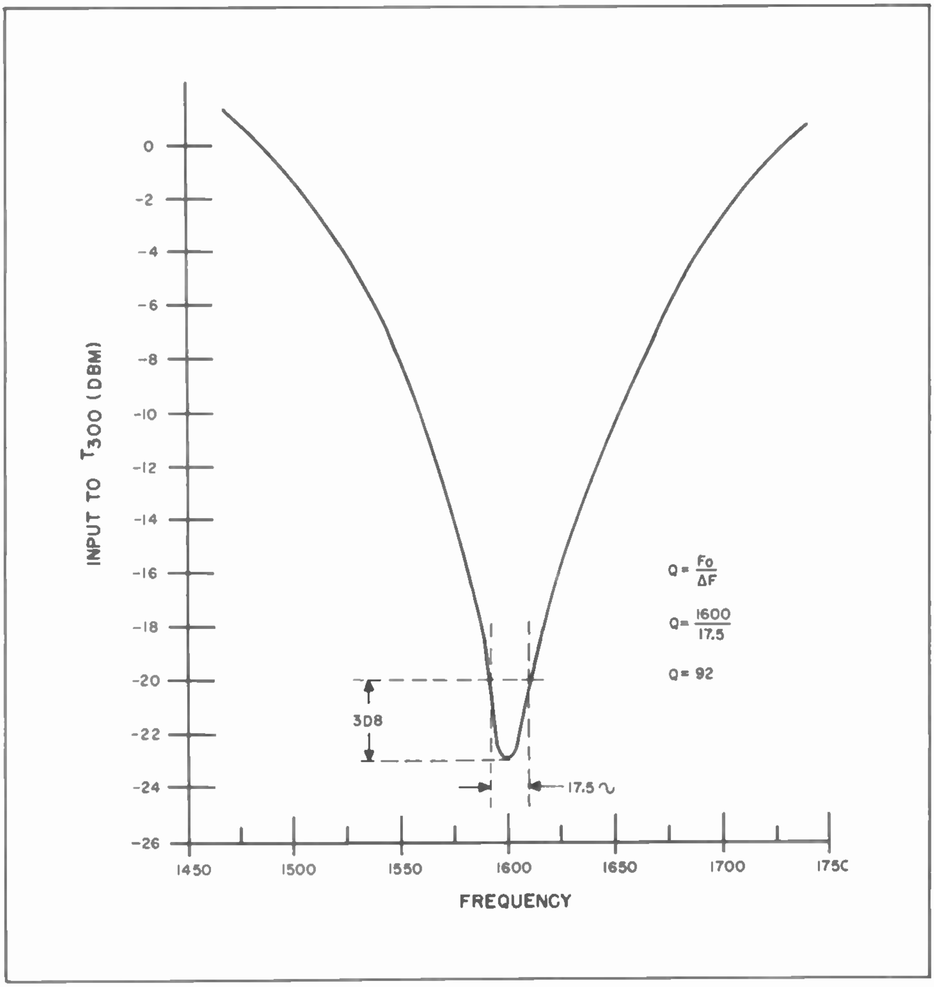


Figure 5. Input Required to Operate K_{302} Versus Frequency

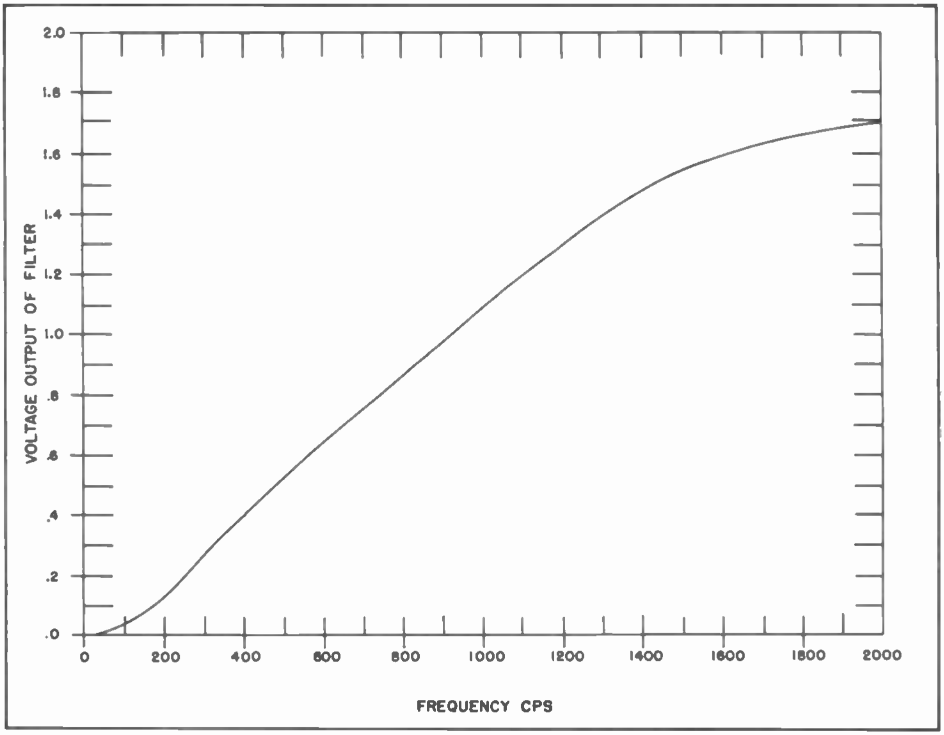


Figure 6. High-Pass Filter Characteristics, 300-Series Unit

to oscillate at nearly the same frequency that it would ordinarily select. Reduction of the shunt resistance arm adjusted the frequency to exactly 1600 c.p.s. This circuit was used for the tone generator (V_{200}) of the 200-series unit. The resultant selectivity curve of the tone detector is shown in figure 5. This graph indicates the input to T_{300} required to produce 3.3 volts a.c. at the plate of V_{300A} (3.3 volts being the minimum voltage required to operate K_{302}).

The output of T_{300} passes through a high-pass filter before being applied to selective filter assembly. This additional filter was employed to prevent 60-cycle busy tone within the equipment or 20-cycle ringing tone on adjacent telephone-cable pairs from swamping the filter and actuating the circuit. The response of this filter is shown in figure 6.

The tone rectifier, V_{301}, and relay control tube, V_{300B} (see figure 3), convert the 1600-cycle plate variations of V_{300A} into d.c., which, if of sufficient magnitude, will operate relay K_{302}. During the no-signal condition, V_{301} conducts, and, because of the extremely high value of plate load resistor, the plate is approximately 18 volts above ground. This 18 volts, by virtue of direct coupling to V_{300B}, holds V_{300B} in a cutoff condition. When a 1600-cycle signal of at least 3.3 volts amplitude appears at the plate of V_{300A}, the signal is rectified and the resultant negative voltage is applied to the control grid of V_{301}. This negative voltage causes a rise in plate voltage, which, through direct coupling, causes a current flow of 4 ma. in V_{300B}, and relay K_{302} is operated. In order that transients and high-level off-resonance signals will not easily trip the circuit, the time constant of the input circuit of V_{301} is such that a

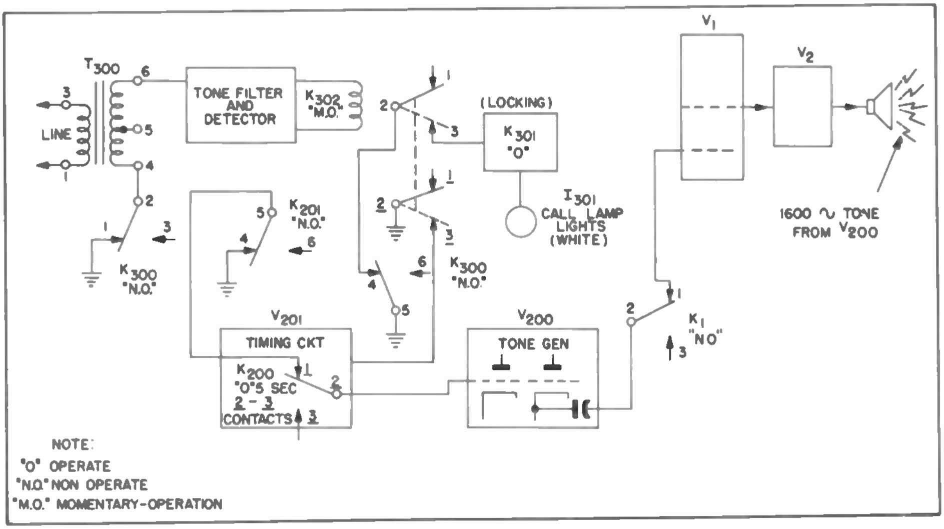
1600-cycle signal at −23 dbm requires a half-second application before the signal is of correct magnitude to bias V_{301} to cutoff. The additional functions of the 300-series unit can more easily be understood after a detailed study of figures 7, 8, and 9, which will be made shortly.

The 200-series unit provides five functions as follows:

1. Timing circuit.
2. Tone generator (signal and busy).
3. Voltage regulation (+150 volts).
4. Distribution to six 300-series units.
5. Hybrid (speaker-to-handset feedback reduction compromised for 1 line in operation).

The timing generator, V_{201}, operates relay K_{200} when this circuit is keyed by any K_{302} in any installed 300-series unit. The 1, 2, and 3 contacts unground the grid of the tone generator, V_{200}, allowing it to function either as a 1600-cycle, parallel-T tone oscillator or as a 60-cycle amplifier. The operation is dependent upon the condition of hookswitch relay, K_1, as follows: when K_1 is unoperated, the tone generator is in the 1600-cycle condition, and, when K_1 is operated (indicating the busy condition), the tone generator acts as a 60-cycle amplifier. (A better understanding of this operation will be gained when the functional diagrams, figures 7 and 8, are discussed.) The second half of V_{200}, which functions as a cathode follower, provides isolation for the tone generator and also acts as a high-to-low impedance-matching device for feeding either of the tones to one or more lines.

Channels are selected by operating one or more SW_{300} push buttons, which in turn lock their associated K_{300} relays, lighting the green light, I_{300}. After selection of the channel or channels, ringing may be accomplished by operating SW_{200}, which controls relay K_{20}.. This relay switches the two-wire talk line from the hybrid coil, T_{200}, to the output of the cathode follower. Note that the 5 and 6 contacts of K_{201} unground the grid of the tone generator, and thus provide 1600-cycle operation while SW_{200} is being operated.



NOTE:
"O" OPERATE
"N.O." NON OPERATE
"M.O." MOMENTARY-OPERATION

Figure 7. Functional Block Diagram, Showing Initial Incoming Call

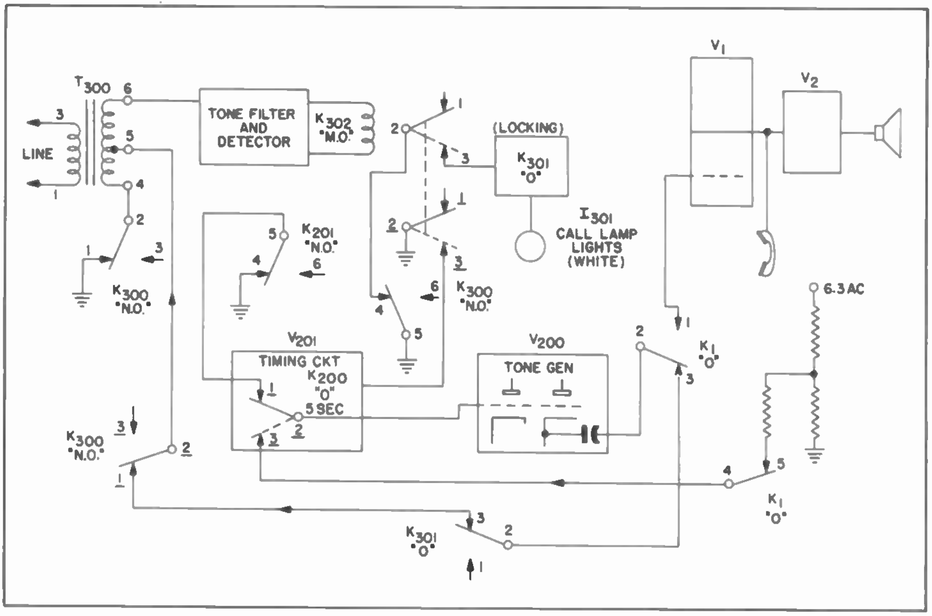


Figure 8. Functional Block Diagram, Showing Second Incoming Call

The hybrid transformer has been incorporated in the 200-series unit to provide an anti-sidetone feature which permits the speaker to operate at high levels without causing feedback through the transmitter of the handset. The termination network indicated on the schematic, figure 3, will provide approximately 25 db sidetone reduction with a single line connected. This feature permits operating personnel to make adjustments on their station equipment while being supervised or monitored by another station in this system.

The basic amplifier and power supply unit performs the following functions: (Refer to figure 3 for the schematic diagram of the unit.)

1. Dual input amplifier.
2. Handset connection.
3. Speaker connection.
4. Power supply.
5. Automatic speaker gain reduction.
6. Busy tone—signal tone switching.
7. Minimum gain provision.

The similarity between the basic amplifier power supply subunit of the Engineering Channel Intercom Set used with Philco CLR-6 and CMT-4 group (July, 1953, BULLETIN) and this set was intentional—in fact, design of the two sets was carried on simultaneously. In the attempt to standardize parts, several compromises were required. The basic amplifier power supply subunits of the first prototypes differed only in the size of the disk rectifier, the chassis assembly, and one strapping change in the input circuit of V_2. In the Engineering Channel Intercom, the strapping option of K_1 eliminates the speaker when the handset is in use, while in the 6-channel unit the strapping option provides for an automatic speaker gain reduction when the handset is in use.

The amplifier itself is standard except for the choice of the impedance coupling between V_1 and V_2. This choice made it possible to match the receiver portion of the handset and still get sufficient voltage swing to drive the power amplifier, V_2. The over-all gain of the amplifier is 47 db.

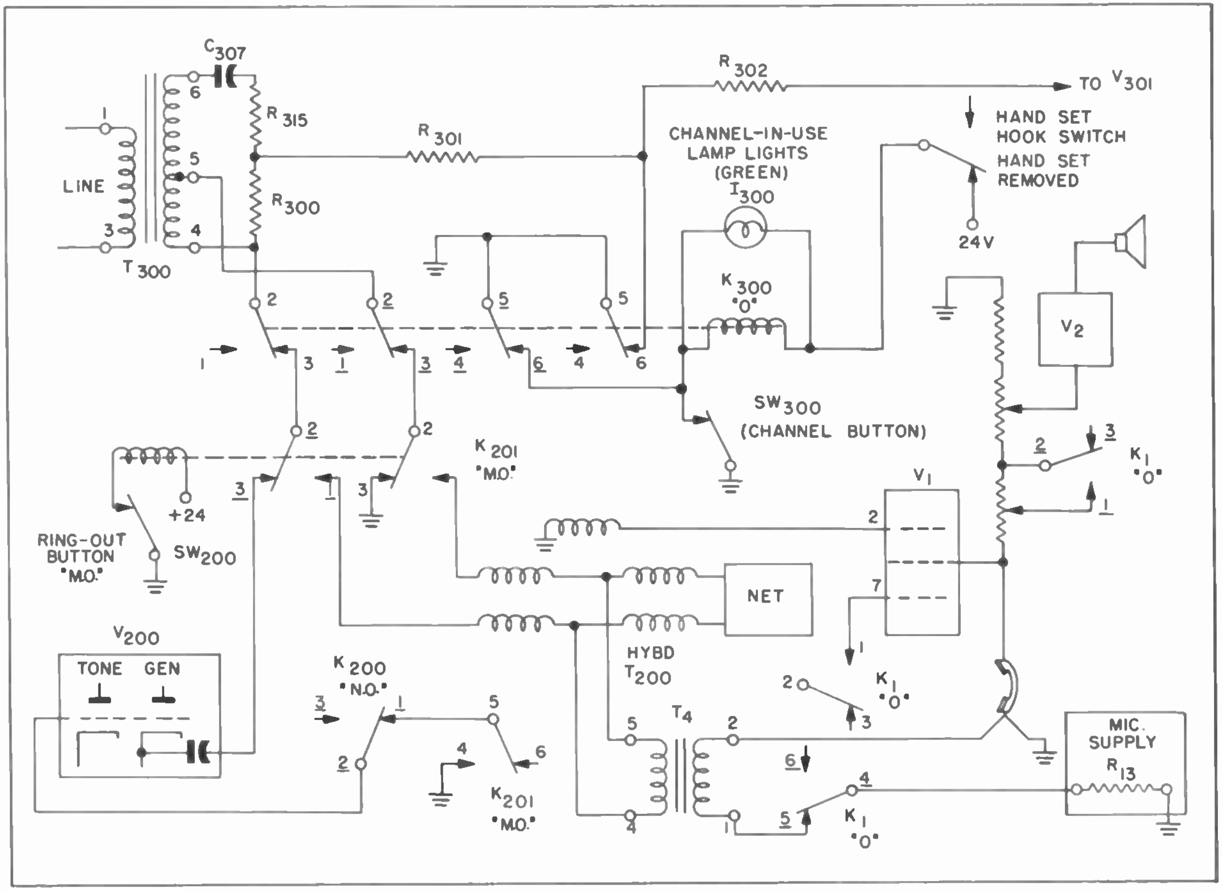


Figure 9. Functional Block Diagram, Showing Ring-out and Talk

Figures 7, 8, and 9 indicate the sequence of operation under the following respective conditions: initial incoming call (figure 7), second incoming call while initial call is still in progress (figure 8), and ring-out and talk, i.e., answer to second call (figure 9). Reference to figure 3 must be made in conjunction with the following explanation:

In figure 7 the circuit is at rest and the handset is on the hook. The incoming call impresses a 1600-cycle signaling tone of the proper magnitude across T_{300} for the time required to operate the tone detector and K_{302}. Contacts 2 and 3 of K_{302} complete the circuit of K_{301}, which locks through its own contacts and lights the white call lamp, I_{301}, in the panel unit. This lamp remains lighted until the call is answered, at which time the white lamp is extinguished and the green lamp of the channel to be used is lighted (see figure 9). Contacts $\underline{2}$ and $\underline{3}$ of K_{302} cause the timing generator, V_{201}, to operate K_{200} for approximately five seconds. Contacts $\underline{1}$, $\underline{2}$, and $\underline{3}$ of K_{200} unground the grid of the tone generator, V_{200}, causing this tube to function as a 1600-cycle tone oscillator. The 1600-cycle tone is fed, through the second section (cathode follower) and V_{200}, the non-operated contacts $\underline{1}$ and $\underline{2}$ of K_1, and V_1 and V_2 of the basic amplifier, to the speaker, for five seconds.

In figure 8 the second incoming call finds the circuit in use, the handset off the hook, and K_1 operated. In the same manner as previously explained in figure 7, the 1600-cycle signaling tone will cause K_{302} to operate, lock K_{301}, light the white call lamp, I_{301}, cause V_{201} to conduct and operate K_{200}, which ungrounds the grid. However, K_1 is now operated, and contacts 4 and 5 of this relay connect 60 cycles, from the filament circuit to the grid of the tone generator, through K_{200} (contacts $\underline{2}$ and $\underline{3}$). The amplified 60 cycles is fed, through the operated relays K_1 (contacts 2 and 3), K_{301} (contacts 2 and 3), and the non-operated K_{300} (contacts $\underline{1}$ and $\underline{2}$), to T_{300} and into the line of the calling party as a busy signal for a period of five seconds, as controlled by the timing circuit (V_{201}) of the called party.

Figure 9 shows the ring-out and talk procedure with the handset off the hook and K_1 operated. The white lamps (I_{301}) of the channels which have called while the initial call was in progress will remain lit until their call is answered as follows: SW_{300} is depressed, operating K_{300}, which locks through its contacts $\underline{5}$ and $\underline{6}$. K_{300} causes the green light, I_{300}, to light (indicating channel in use), breaks the holding circuit of K_{301}, extinguishing the white light, I_{301} (refer to figure 3), and grounds the input to V_{301} to prevent feedback. The selected station is now called by depressing SW_{200}, and thus operating K_{201} for the period of time SW_{200} is depressed. K_{201} switches the two-wire talk line from the hybrid coil, T_{200}, to the output of the tone generator, V_{200}, through contacts 2, 3 and $\underline{2}$, $\underline{3}$. Contacts 5 and 6 unground the grid of the tone generator, to provide 1600-cycle signaling tone while SW_{200} is depressed.

Reference to the block diagram (figure 2) shows that up to six 300-series units may be plugged into a 200-series unit which is connected to a basic amplifier and power supply. All connections are made by Jones-type plugs, and all similar units are interchangeable.

Figure 10 is a rear view of the panel pictured in figure 1, showing the physical location of the various subassemblies and their principal components. Four Jones-type plugs, of the six channels available, are shown, and two 300-series units are shown in position, and marked "LINE 5 and 6". The cables from the two units in use are laced together and run between the panel unit and are connected to the 300-series unit by means of Jones-type plugs.

The following Table lists the parts not covered in the schematic diagram:

TABLE I

SYMBOL	DESCRIPTION
T_1	Power Transformer, cased and shielded; primary, 90-100-110-120 v a.c., 50/60 cycles; secondaries, 5 v at 3 amp., 6.3 v at 5 amp., 40 v (tapped at 35 v) at 4 amp., 225-0-225 v at .12 amp.
T_2	Interstage Transformer, cased and shielded; primary, 15,000 ohms, 20 ma.; secondary, 200 ohms; response, plus or minus 1.5 db, 300—3000 c.p.s.
T_3	Output Transformer, cased and shielded; primary, 5000 ohms, 50 ma.; secondary, 5 ohms; response, plus or minus 1.5 db, 300—3000 c.p.s.
T_4	Microphone Transformer, cased and shielded; primary, 100 ohms, .1 amp.; secondary, 600 ohms; response, plus or minus 1.5 db, 300—3000 c.p.s.
CH_1	Choke: cased, 10 hy., 125 ma., 150 ohms.
K_1	Relay, miniature telephone; contact arrangement, 4-C; coil 24 v d.c., 300 ohms.
Handset	F1A 3-wire telephone handset.
SR_1	Selenium Rectifier, f-w bridge 24 v d.c. at 4 amp. output.
K_{200}	Relay, miniature telephone; contact arrangement, 2-C; coil, 5000 ohms; operating current, 6 ma.
K_{201}	Relay, miniature telephone; contact arrangement, 3-C; coil, 24 v d.c., 300 ohms.
T_{200}	Transformer, Hybrid, cased and shielded; 600-ohm input, 600-ohm output; 30 K-ohm terminating net to provide 25-db loss between 2-5 and 7-8 terminals at 1000 c.p.s.
K_{300}	Relay, miniature telephone; contact arrangement, 4-C; coil, 24 v d.c., 300 ohms.
K_{301}	Relay, miniature telephone; contact arrangement, 2-C; coil, 24 v d.c., 300 ohms.
K_{302}	Relay, sensitive; contact arrangement, 2-C; coil, 9000 ohms; pick-up, 2.5 ma., drop-out 2.5 ma.
T_{300}	Transformer, cased and shielded; primary, 600 ohms at 1000 c.p.s.; secondary, 60,000 ohms tapped at 600 ohms at 1000 c.p.s.; response, plus or minus 1.5 db, 300—3000 c.p.s.
I_{300}	Channel-in-use lamp, telephone type, green cap.
I_{301}	Call lamp, telephone type, white cap.
SW_{300}	Push button, telephone type.

SYSTEMS APPLICATION

This intercom is a "special purpose" unit, as distinguished from the run-of-the-mill "squawk-box" variety commonly found in offices. This unit is recom- (1 mw. into 600 ohms) transmission mended only in cases where zero-level is required between communications installations which are connected by wire and/or carrier-loaded radio-link

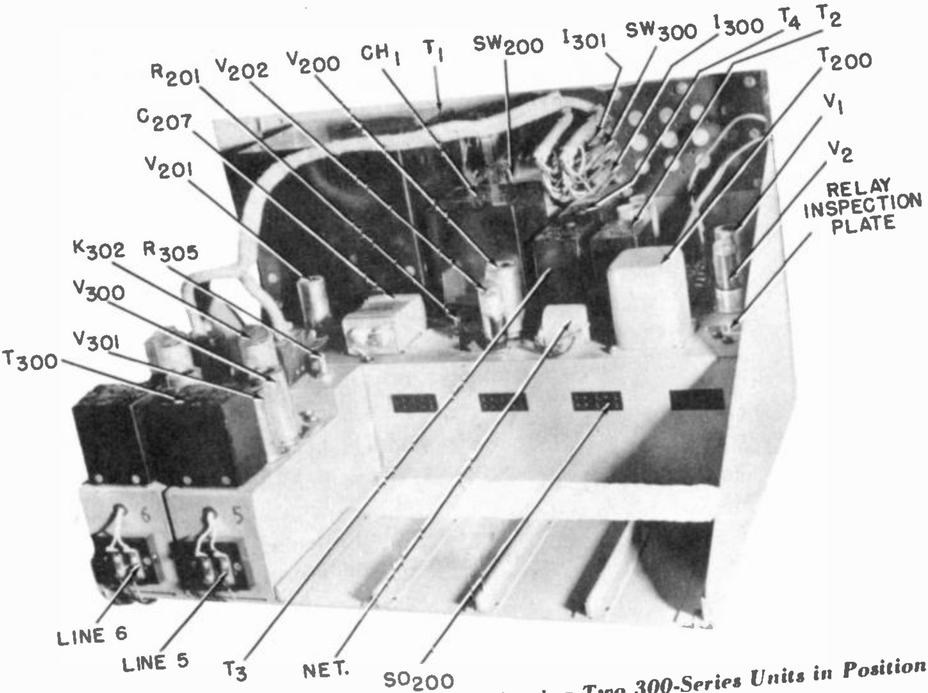


Figure 10. Rear View of Intercom, Showing Two 300-Series Units in Position

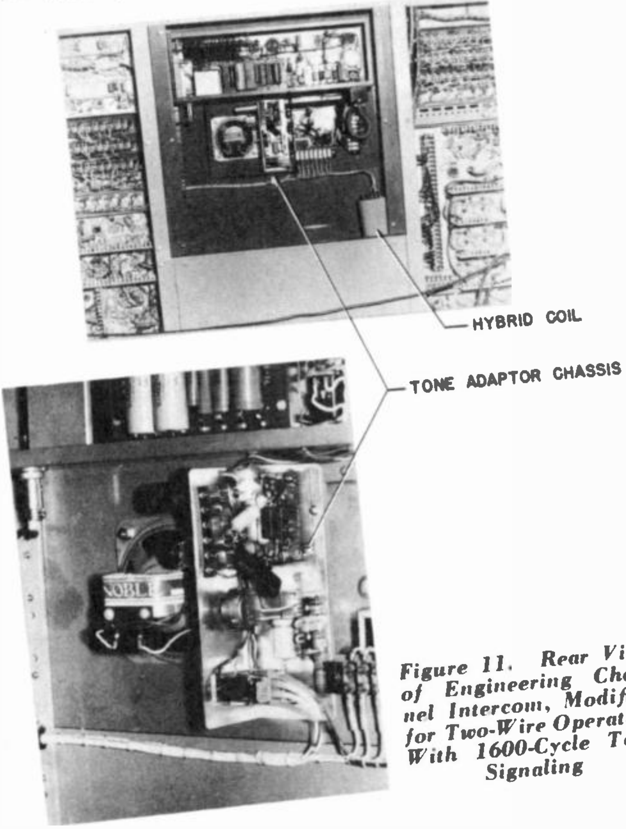


Figure 11. Rear View of Engineering Channel Intercom, Modified for Two-Wire Operation With 1600-Cycle Tone Signaling

equipment. Furthermore, this unit is not recommended for use where the net loss between stations is greater than 15 db, or, in terms of length of aerial 19-gauge quadded toll cable with H 88-50 loading, 40 miles. In terms of a carrier-loaded radio link with a normal 8 db net loss irrespective of length, an additional loss of 7 db could be tolerated in the connecting wiring.

In order to permit the two types of intercommunication equipment to work together, as is desirable in some applications, a modification kit has been designed to permit one direction of the Engineering Channel Intercom to signal and operate into any channel of the six-channel unit. This kit is composed of a hybrid coil, for converting the present 4-wire output of the Engineering Channel unit into a 2-wire circuit, and a small subchassis containing the same tone-generator circuit found in the 200-series chassis in the six-chanel unit. In addition, the subchassis contains a three-pole relay which is operated by the present directional selector button in the 100-series unit of the Engineering Channel Intercom Set. This relay provides plate voltage for the tone generator, and switches the two-wire voice line from the hybrid to the output of the cathode follower, thus applying 1600 cycles to the line while the button is operated. The Engineering Channel Intercom Set with the aforementioned modification kit installed is shown in figure 11.

The need for equipment compatibility arose from a possible operating requirement in which the technical control facility of a high-frequency command-administrative communications system, utilizing certain trunk facilities provided by a microwave long-lines system either on a normal or alternate basis, would require an order wire to the nearest multiplex terminal. In the case of a terminal multiplex station, only one of the two channels of the Engineering Channel Intercom Set is used, thus allowing the other channel to be modified for working into a six-channel unit. At the present time, a prototype link connecting the two units under typical conditions is in operation, and the results have been entirely satisfactory.

The authors wish to extend their thanks to Mr. Kenneth L. Seaton, Philco Field Engineer, for his valuable assistance.

ELECTRONICS AND PAIN

(Editor's Note: This item is a good example of the well known "switch". In most applications electric shock is the cause of pain.)

Human brains are being wired to produce tiny electric shocks capable of relieving the horrible pain associated with cancer. The process, which was described at the Tulane University Medical School, New Orleans, involves planting two to eight wires through small holes in the front, top part of the skull as deep as three inches into the brain. The other ends of the wires are connected to a machine which sends small currents through certain parts of the brain. These electric currents, according to the doctor who developed the process, seem to spur the action of hormones which cut down the pain of cancer and similar ailments.

A RECORDING ANALYTICAL BALANCE

An Electromechanical Instrument for the Automatic Recording of Rapid Changes in Weight.

An analytical balance, shown in figure 1, recently developed at the National Bureau of Standards automatically makes a continuous record of changes in weight, following even rapid changes with good accuracy. Developed by Floyd A. Mauer of the NBS mineral products laboratory, the new instrument is being used at the Bureau to record changes in weight of samples of complex minerals during thermal decomposition. Because it combines versatility and convenience with low cost, the device is suitable for many other laboratory applications requiring a record of weight as a function of time.

The NBS instrument uses a conventional laboratory balance modified as shown in figure 2 so that changes of weight are balanced by adjustment of a magnetizing current. The balancing force results from the interaction of the magnetic field of a solenoid (coil of wire) with the field of a permanent bar magnet suspended, inside the solenoid, from one side of the balance. Automatic balancing is achieved by means of a photoelectric sensing arrangement (see figure 3) in which a beam of light is reflected to a dual phototube from a mirror mounted on the balance beam. The two sections of the phototube are connected in a bridge circuit, the output of which is amplified and applied to the solenoid. Any change in weight tending to produce unbalance is promptly counteracted by whatever change of solenoid current is needed to maintain

Figure 1. Adjusting the Recording Analytical Balance Recently Developed at the National Bureau of Standards

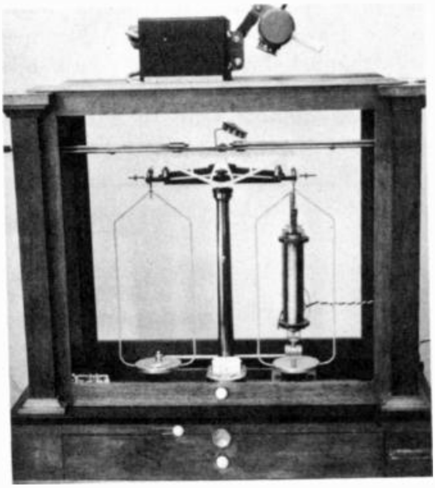


Figure 2. Close-up of the Modified Laboratory Balance That Is the Heart of the Recording Instrument (In the work for which the new instrument is being used at the Bureau, specimens are suspended from the left-hand balance tray into a small electric furnace under the table that supports the balance. While the specimen is being heated, its weight is recorded continuously)

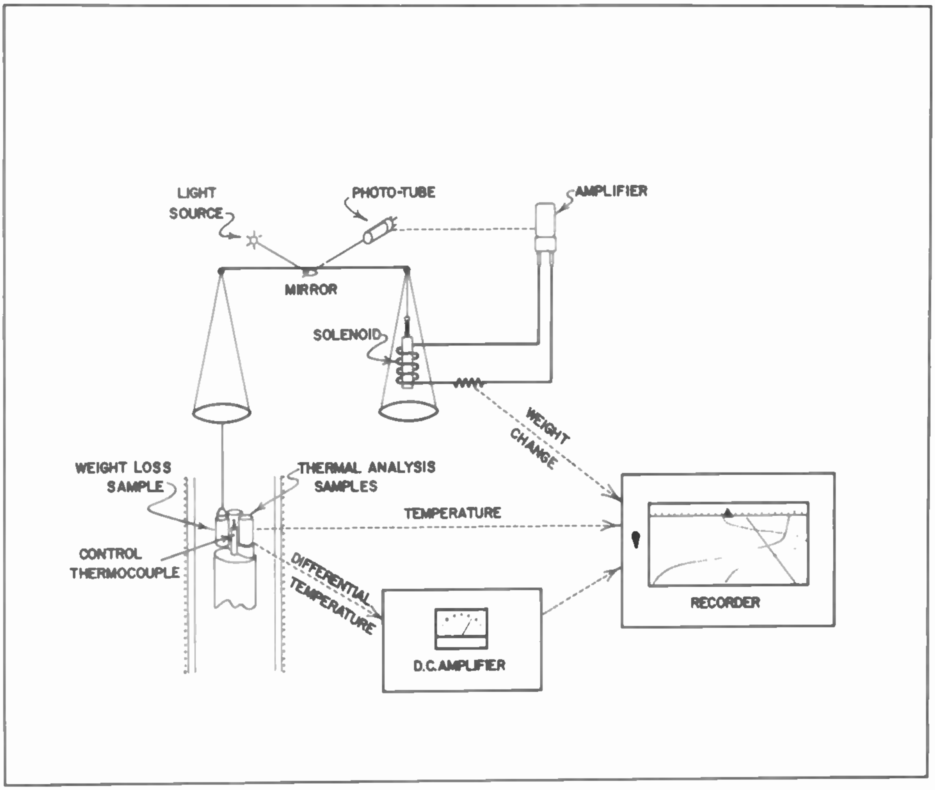


Figure 3. Diagram Showing How the NBS Balance Is Used To Record Changes in the Weight of a Mineral Sample on the Same Chart With Its Differential Temperature Curve

balance (within a small fraction of a division of the balance scale). An electronic damping circuit eliminates oscillations and enables the electrical output of the instrument to faithfully follow very rapid changes of weight.

The record of weight changes is obtained by connecting a resistor in series with the solenoid and applying the voltage developed across this resistor to a commercial recording potentiometer of the strip-chart type. An example of a typical chart is shown in figure 4. Since the balancing force exerted on the magnet is directly proportional to the current through the solenoid, the weight scale is linear and the recorder is easily made to read directly in milligrams. By substituting a different dropping resistor, a different magnet, or both, full-scale ranges of as little as 10 milligrams or as much as 1 gram are obtained. For ranges of 100 milligrams or more, accuracy is better than ½ of 1 percent of full scale.

The electronic circuitry of the balance is quite simple. In addition to the phototube, the entire tube complement consists of two twin-triode amplifiers, a power-supply rectifier, and three voltage regulators. When the two sections of the phototube are equally illuminated, the output of the bridge circuit in which they are connected is zero. Any movement of the balance beam results in a bridge output voltage that is proportional to the departure of the beam from its equilibrium position.

If this voltage is amplified and ap-

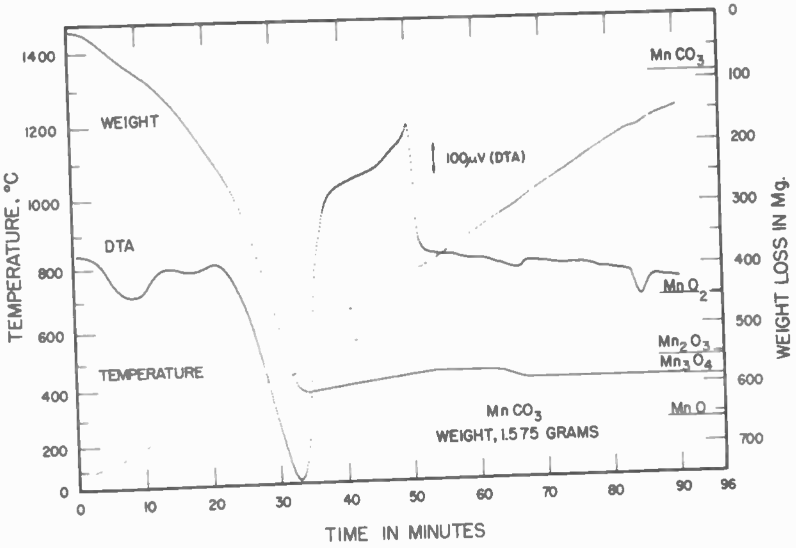


Figure 4. ***Example of Chart with Simultaneously Recorded Weight-Loss and Differential-Temperature Curves of a Mineral Specimen***

plied to the solenoid without any provision for damping, the balance tends to oscillate around the equilibrium position. To eliminate this oscillation, both magnetic and viscous damping were tried successfully, but a simple modification of the electronic circuit to provide velocity damping proved far more convenient. This velocity-damping circuit, a type commonly used in servo systems, senses the rate at which the unbalance signal is changing (this rate is proportional to the velocity of the balance beam) and applies to the solenoid a component of current that is proportional to this rate. This current is phased so as to oppose the motion of the beam. The result is a braking force, proportional to the velocity of the beam, that can be adjusted to eliminate the tendency of the beam to oscillate. When the damping control is properly adjusted, an abrupt change in weight as great as 1 gram can be recorded in 3 seconds without excessive hunting.

The balance has been used at the Bureau to provide thermochemical data for a study of the kinetics of the dehydration reaction of kaolins. This weighing technique has proved ideally suited to the automatic recording of both weight-change and differential temperature curves on a single chart, and has made it possible to obtain large amounts of needed data with a minimum of attention from laboratory personnel.

An example of a potential application of the NBS recording balance is in the drying of cotton fibers, or other moisture-absorbent material, to constant weight. A commercial manufacturer of instruments has already indicated an interest in constructing a model of the NBS instrument tailored to this particular use. Another contemplated use is in the study of the high-temperature oxidation resistance of certain of the cermets that are now being tried as turbine blade materials.

THE TV RECEIVER AS A SOURCE OF LOW-FREQUENCY COMMUNICATIONS INTERFERENCE

by David T. Geiser, Senior Engineer
Sprague Electric Company

How interference signals are radiated from a TV receiver and how such interference can be reduced.

The ever-present television receiver often poses a real interference problem to the low-frequency communications system. Such interference is usually most severe in the frequency range below 20 megacycles, because of the lower power levels of the communications signals and the higher interference power levels of the television receiver. Though radiation problems of the TV receiver i-f strip and local oscillator are often severe, this discussion will be limited to the problems encountered at and below 20 megacycles.

GENERATION OF INTERFERENCE

"Interference" is as difficult to define as "pleasure," but for this discussion it will be defined as any electrical field emitted by the television receiver. While this definition may seem too strict, it is justifiable in that all the viewer wants is the program sound and picture.

In surprising contrast to much other electronic equipment, there is only one sine-wave (single-frequency) source of interference in the television receiver. This is the local oscillator, but, as its frequency lies well outside the arbitrary limits set for this article, the problems associated with it will not be discussed.

The most common interference from a TV receiver is of the repetitive pulse type, consisting of a relatively narrow pulse repeated at regular intervals. Fourier analysis of pulses such as the common synch pulses shows that they are composed of a fundamental frequency equal to the pulse repetition rate and a seemingly infinite number of harmonics of decreasing amplitude. While certainly many of the higher-order harmonics do not constitute practical interference, it is not justifiable to establish an arbitrary "no-interference" limit. However, an *idea* of the maximum frequency of interest may be obtained from the following relation:

$$\text{frequency} = \frac{20}{\text{pulse width in seconds}}$$

This equation applies to the narrowest portion of a rectangular pulse.

Any signal within the receiver may be radiated. Various workers besides the writer have noted the radiation of i-f signals as well as video signals (after detection). In the intercarrier receiver the FM sound signal is particularly troublesome in that the process of demodulation results in the generation of harmonics of the 4.5-megacycle FM signal. These i-f, video, and FM signals are unusual because their interference strength depends on the strength of the received television signal.

The production of harmonics in the FM detection process points out another possible source of interference generation: The presence of any nonlinear element within the receiver, or outside the receiver but within its interference field, may cause the generation or reinforcement of interference harmonics from either a sine-wave or pulse interference source.

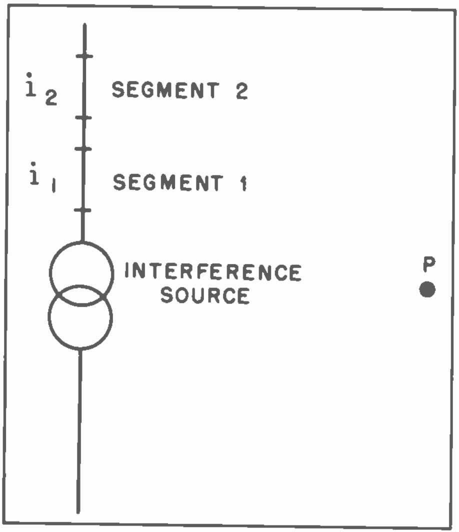


Figure 1. Interference Antenna, Showing Two Segments

INTERFERENCE RADIATION

A convenient simplification in the discussion of interference radiation is obtained by assuming that all of a given interference signal is radiating from a single antenna, called an interference antenna. Though the problem is rarely so simple, this assumption points out the means of reducing interference radiation.

The interference antenna in figure 1 is fed with the interference source, which causes current i_1 to flow in segment 1, and current i_2 to flow in segment 2. If the antenna is divided into segments so small that there is very little current change across each segment, the effects of the individual fields at point P can be added to find the total interference field at P. Since each individual field depends on the length of each segment and the current flowing through that segment, it becomes apparent that if there were fewer segments (an effectively shorter antenna) or less current flowing in each segment (less antenna power) there would be a smaller total interference field at point P.

If the communications system antenna is located at point P, it is easily understood that the less effective the coupling of the communications antenna is to the interference field, the less actual interference will result. This coupling can be decreased by increasing the spacing between antennas, by cross-polarizing antennas (in the classical case, low frequency radiation from the TV receiver is vertically polarized), or by a null-response of the communications antenna in the direction of the interference antenna.

RADIATION REDUCTION

For the sake of this discussion, it will be assumed that the television receiver is the traditional black box, and that any means used to reduce interference radiation must be external to the existing circuit.

Reduction of the effective length of the interference antenna is best accomplished by shielding the receiver and bringing *all* external leads to the shield potential at the interference frequency. The problem is simplified in that only frequencies below 20 megacycles are considered. When properly installed, conventional power-line and high-pass antenna filters are very effective, between 100 and 20,000 kilocycles, in bringing the power and antenna leads to the shield potential. This procedure (assuming ideal filters) subtracts power and antenna lines from the interference-antenna length. The shield in the ideal case totally encloses the remaining length of the interference antenna and prevents the occurrence of an external interference field. Fortunately, it is rarely necessary that more than superficial shielding be used.

Interference-antenna current reduction also justifies the use of shielding and filtering. If the antenna is excited by conducted currents, an ideal filter would totally block the exciting path. If the coupling is capacitive or magnetic,

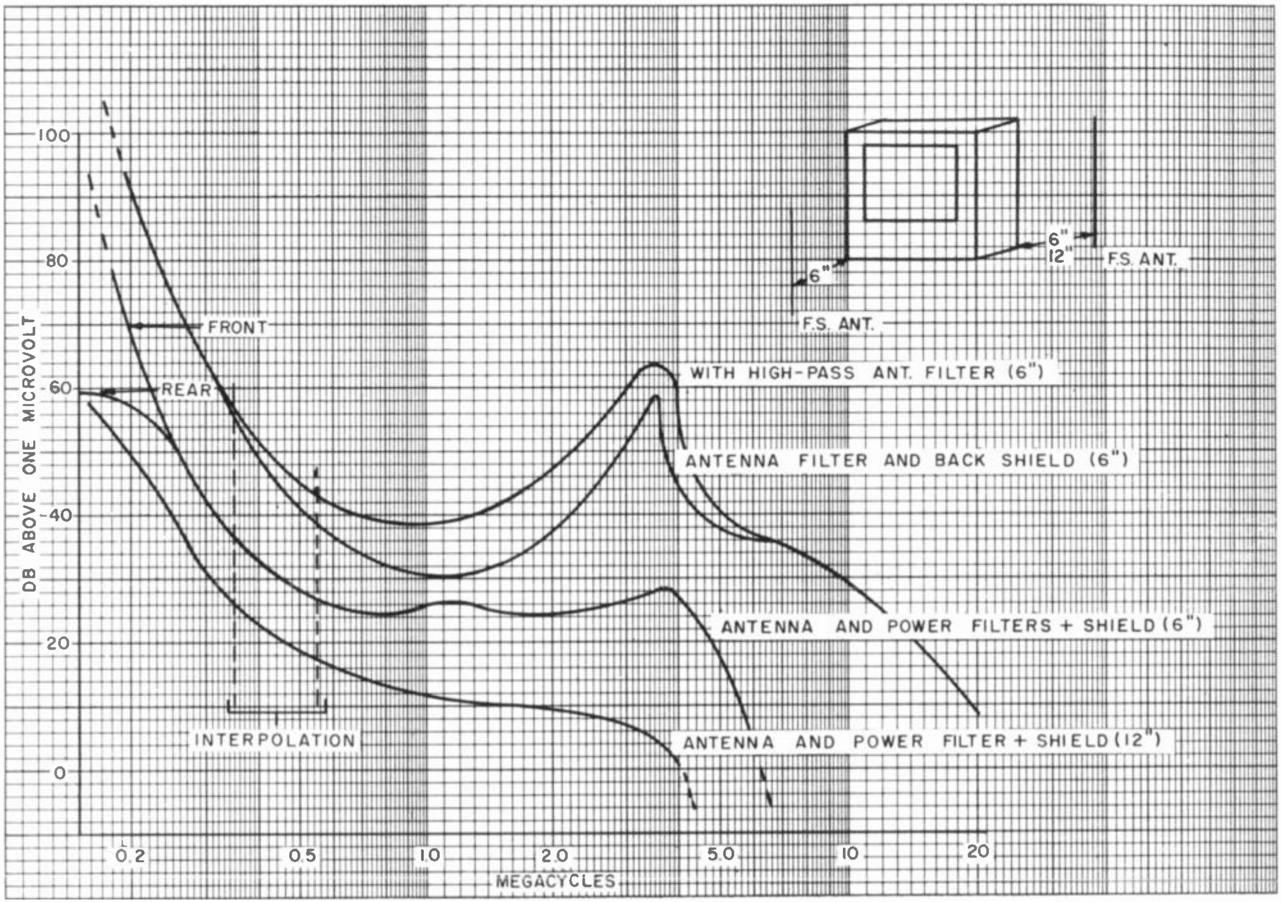


Figure 2. Graph Showing Interference Signals Versus Frequency for Various Conditions

an ideal shield would reduce the coupling to zero.

In actual practice, conduction, and capacitive and magnetic coupling each play a part, and the filters and shielding are not ideal. Perhaps the most valid approach from the economic standpoint is the initial installation of good filters, followed by whatever shielding is necessary. Though the full effect of good antenna and power-line filters cannot be realized without ideal shielding, the handwork necessary in accomplishing shielding dictates that as little shielding as possible be used.

A CASE HISTORY

A television receiver was located within 30 feet of communications receivers and receiving antennas covering the frequency range of 100 kc. to 250 mc. Severe interfrence was experienced from the horizontal deflection circuits and from the 4.5-megacycle FM signal and its harmonics. The video signal was objectionably strong between 3 and 4 megacycles.

The interference path was located by disconnecting the antennas from the communications receivers. Disappearance of the interference showed that the path into the communications receivers was along the antenna and not along the power lines. Removal of the television antenna feed line from the TV receiver greatly reduced the interference, indicating that the major radiation path included the TV antenna.

Heating ducts, conduits, and plumbing in the area were checked and grounded to eliminate possible external nonlinear harmonic production and interference conduction by the metal. No change was noted.

Adequate selectivity was present in the antenna coupling circuits of the communications receivers to prevent input circuit overloading and generation of the interference within the communications receiver.

A high-pass filter was installed in the TV antenna lead at the receiver. Since the receiver was not designed for the addition of such a commercially available filter, the filter ground was connected to the metal cabinet of the receiver. Lack of improvement indicated that the cabinet was floating with respect to the chassis at radio frequency.

A back shield and power-line filter were installed, with the cabinet as the common ground. The apparent progressive improvement is shown on the graph in figure 2. Rough subsequent checks have shown that the power and antenna filters are equally effective, though individually each appears to have little effect. Lack of a back shield cuts down the filter effect about ten decibels, while better shielding should improve filter action by at least 30 decibels.

The lowest curve on the graph shows the effect of doubling the six-inch separation between the TV receiver and the Ferris Model 32A Field Strength Meter that was used to make all measurements.

NOTICE

Five of the Philco Trouble-Shooting manuals described on page 16 of the July, 1953, issue of the BULLETIN were listed as RESTRICTED. These publications have all been declassified by the Security Review Board, Department of Defense. This means that any interested persons can now obtain these manuals.

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