M/SGT. W.F. PODLIK

PHILCO

TECHREP DIVISION BULLETIN

HALL EFF. P 28

1. TRANSISTOR 1A p 11 Good Atomic Structure

2. INTERCARRIER T.V. p4

JANUARY
1952

New FCC Policy
Regarding Commercial Radio Licenses

Renewal Requirements Eased

One of the requirements for renewing a commercial radio operator's license without retaking the examination is proof that a specified amount of operating time has been obtained under the present license. This, of course, has been impossible for most field engineers.

In response to the numerous queries that we received from the field on this subject, we have contacted Mr. Roger E. Phelps, Engineer-In-Charge at the Philadelphia office of the FCC. The following is quoted from his letter:

> ***"Under date of April 5, 1951 the Commission issued Public Notice No. 62103 announcing amendment of its rules as follows:***
>
> ***'The Federal Communications Commission amended its rules governing issuance and renewal of commercial operator licenses.***
>
> ***'The first of these changes involves Section 13.28 of the rules relating to the renewal of commercial radio operator licenses. Under one order issued today by the Commission, the normal requirements that an operator must show two years satisfactory service under the license being renewed or take an examination are waived for the duration of the present emergency or until such earlier date as the Commission may order.***
>
> ***'The waiver of the requirements of Section 13.28 of the rules is designed to take into account the fact that many holders of operator licenses are rendered unable to comply with the present requirements of showing satisfactory service due to service in the armed forces of the United States or in various activities connected with the present emergency, plus the fact that there is a shortage of operators for service aboard ship. The establishment of a Temporary Limited Radiotelegraph Second-Class Operator License (TLT) is in recognition of the present shortage of qualified radio operators for service aboard ships of United States registry.' "***

Mr. Phelps concluded his letter as follows:

> ***"There is also in effect at the present time a rule which permits renewal of these licenses at any time during the year immediately following the expiration date of the license. Of course a license is not valid for use beyond the expiration date."***

If any personnel have any further questions on this subject, we suggest that they contact the Engineer-In-Charge, at their nearest FCC office.

PHILCO
TECHREP DIVISION
BULLETIN

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If any information contained herein conflicts with a technical order, manual, or other official publication of the U.S. Armed Forces, the information in the official publication should be used.

Letters to the Editor

Our BULLETIN circulation has now reached almost 6000, and is increasing at a very rapid rate. However, if the comments in the letters quoted below indicate a general field practice, then our readership is actually much greater than 6000, because of the sharing of each BULLETIN copy by many persons not yet on our mailing list. We wish to thank each reader who has been sharing his copies, for this extension of our circulation.

In the November, 1951 BULLETIN, in this column, we very carelessly listed Daniel Campbell as "Supervisor, Ground Forces, Tokyo Office," and L. A. Andrews as "Supervisor, Air Forces, Tokyo Office." Needless to say, these were rather overwhelming titles we gave these two men, who should have been listed as "Philco Supervisor, Ground Forces, Tokyo Office," and "Philco Supervisor, Pacific Operations," respectively. We trust that the Services involved will accept the apologies of an embarrassed and contrite editorial staff.

The following are typical of the letters we are currently receiving.

"I want to offer a bouquet for the fine material appearing in the TechRep Division BULLETIN. Several articles have proved very timely, and were gratefully received by myself and many of the airmen I am working with. Each copy of my BULLETIN passes through many hands before I finally place it in my files."

Richard Rembert
Philco Field Engineer
APO 863, c/o PM
New York, N. Y.

•

"For the past few months, my copy of the Philco TechRep Division BULLETIN has been moving from hand to hand so fast that I either lose track of it, or it is worn out. As a cure for this, I am giving you a list of names to be put on the mailing list. All the men here who read the BULLETIN like it very much."

Jerry Townsend
Philco Field Engineer
Camp Cooke, Calif.

"Congratulations to the BULLETIN staff for their 1951 effort. The supervisory personnel of this office consider it an excellent technical publication, which will continue to grow in popularity among the military personnel as well as our own Philco family. Our best wishes for the continued success of the BULLETIN during 1952."

Edwin O. Tarleton
Philco Supervisor
Atlantic Operations

•

"While in the Pacific area, I had the good fortune of obtaining and reading your monthly publication, the Philco TechRep Division BULLETIN. I found this booklet well planned and full of useful information. If at all possible, I would appreciate being placed on your mailing list."

Walter A. Ciaseive
General Electric Company Representative
ComServRon 3

•

"I have read with great interest several issues of the Philco TechRep Division BULLETIN. In each copy I have found information that has been helpful in my work in the Electronics Division of the Bureau of Ships."

Mr. Fred Chapman
Bureau of Ships
Washington, D. C.

•

"I feel that the Philco TechRep Division BULLETIN would prove very helpful to me in the research, development, and manufacture of Aircraft Accessories, which this company is performing for the U. S. Air Forces. . . ."

Mr. D. M. Ryan
Ryan Industries, Inc.
Detroit, Michigan

•

"Inclosed you will find my solution to the 'What's Your Answer?' appearing in the November, 1951 edition of the BULLETIN.

"All here with the Signal Corps are interested in the BULLETIN and enter into some very interesting discussions on the problems you publish. We would like more articles dealing with Signal Corps equipment.

"I have enjoyed working each problem that has appeared in the BULLETIN, and hope to see many more."

Will DuVall
Philco Field Engineer
Camp Carson, Col.

Editorial

NEW SERIES OF ARTICLES ON TRANSISTORS

By John E. Remich, Manager, Technical Department

One of the most significant advances made in electronics in recent times has been the series of discoveries which led to the development of the transistor. Since the initial announcement, in 1948, that practical crystal amplifiers had been produced, tremendous advances have been made in the field of solid-state (or transistor) electronics.

In view of these facts, and because of the interest shown in the subject, we have planned a series of articles which will bring BULLETIN readers up to date in terms of modern solid-state theory. The first article in the series appears on page 11 of this issue.

In conformity with our BULLETIN policy of publishing information of value to the maximum number of our readers, we have asked the writer to provide an explanation of transistor theory in terms which can be easily understood by all levels of electronics engineers and technicians. We believe he has been highly successful.

Certain of our readers may, at first glance, view the information in this introductory article of the series as delving too deeply into basic atomic theory. However, we have examined a considerable quantity of published information on transistor theory, hole conduction, surface-state theory, and other related phenomena, and have found that most of the available data presupposes an extensive knowledge of solid-state physics. Therefore, we feel that the fundamental approach to this subject is not only desirable, but absolutely necessary, if a thorough understanding of the later articles in this series is to be attained by a large percentage of our readers.

INTERCARRIER TELEVISION SYSTEMS

By Gail W. Woodward
Hq. Technical Staff

A practical discussion of the theory and adjustment of intercarrier-type television receivers.

(Editor's Note: A great many requests for television articles have been received from the field. We have, therefore, arranged for a series of articles covering recent developments in television. While a number of developments which have found field use are considered to be controversial, we will attempt to give a factual, unbiased account of the functioning of the circuits involved, and we would like to emphasize that a discussion does not constitute an endorsement. These articles will not include basic TV theory, since there are many excellent text books available which cover this phase of the subject, and since most of our readers already are relatively familiar with basic TV principles. This first article in the series will be followed by others at frequent intervals.)

THE INTERCARRIER-BEAT method of television sound detection has now been in use for several years, and most manufacturer's have receivers in the field using the system; in fact, at the end of 1950 almost three-quarters of all the TV receivers produced were of the intercarrier type. It was unfortunate that the earliest approach to this system was based upon the fact that fewer stages are required when intercarrier is used, as compared to those required for split-sound i-f systems. Since a reduction in the number of stages is very desirable, in terms of cost, this feature was thoroughly exploited in low-cost sets; so much so, that many people began to associate intercarrier with low cost, and lost sight of the other benefits of the system. Simply stated, these benefits are: The circuit is relatively free from microphonics introduced by the local oscillator; local-oscillator tuning is less critical because sound i.f. is determined at the transmitter; local-oscillator stability is also less critical; and the sound level is nearly constant for all stations.

While it is true that use of intercarrier makes possible a reduction in the number of stages in a receiver, the other advantages of the system can be realized only when the same care in design is used that has been given to split-sound systems. The advantages thus obtained are of great benefit, particularly to the consumer. In view of this, it seems probable that more and more intercarrier sets will find their way into the field.

INTERCARRIER ACTION

Figure 1 shows a block diagram of a typical intercarrier receiver. The tuner, i-f amplifier, detector, and video amplifier are relatively conventional, and are similar to the components of a standard video channel. For the purpose of explanation, assume a video i.f. of 26.6 mc.; conversion of the sound carrier will then produce a sound i.f. of 22.1 mc. If the indicated i-f amplifier is sufficiently broadbanded, both signals appear at the detector. The 26.6-mc. signal is detected, the video modulation is recovered, and, in the detection process, the 22.1-mc. signal beats against the 26.6-mc. signal, producing a frequency-modulated 4.5-mc. beat note. This beat note contains all the modulation components present in the sound carrier, and a conventional FM detector and audio system will recover the audio intelligence.

TRAP ACTION

The 4.5-mc. trap shown in the block diagram has two important functions: first, it prevents sound signals from appearing at the picture tube; second, the trap acts as a tuned input to the amplifier which feeds the sound detector. Figures 2 and 3 show two types of trap circuits which have found wide use.

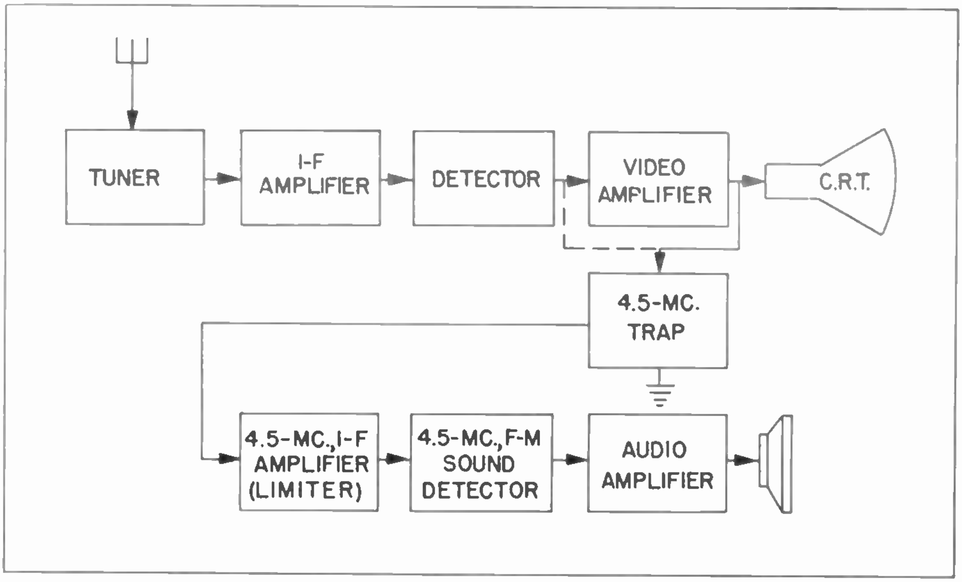

Figure 1. Block Diagram of a Typical Intercarrier Television Receiver

Figure 2 shows what is called a shunt-rejection sound trap. L_1, L_2, C_1, and C_2 form a slug-tuned transformer which is designed to resonate at 4.5 mc. Since the primary circuit (L_1 and C_1) is in series with the video-amplifier plate load, a parallel-rejection trap action is obtained. Thus, the action of L_1 and C_1 is to prevent sound signals, present at the video-amplifier plate, from reaching the picture tube.

In addition, by transformer action, the sound signal is coupled to the transformer secondary circuit (L_2 and C_2), where the sound signal appears as a 4.5-mc. voltage across C_2. The signal is then coupled to the grid of the sound amplifier by means of C_3. R_1 provides grid-leak bias, in conjunction with C_3, and thereby enables the sound amplifier to function as a grid-leak type of limiter. Limiter action is very important in removing any video signals from the sound channel, because video signals contain two, major, recurrent components, horizontal and vertical sync pulses, the latter of which would cause a very annoying 60-cycle buzz if present in the sound channel. Of course, a 15,750-cycle signal would also be present, but few persons can hear frequencies this high, even if the speaker could reproduce them. The limiter action is effective because the video signal is amplitude-modulated, and therefore limited, but the sound signal is frequency-modulated, and therefore the modulation is not affected by limiting.

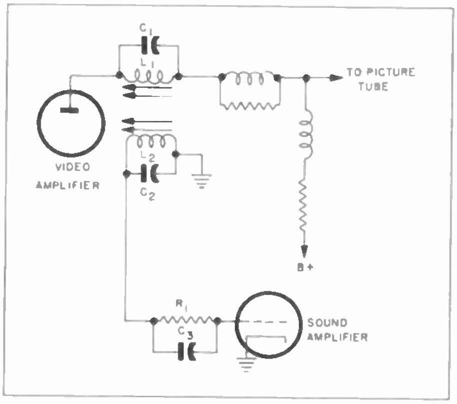

Figure 2. Shunt-Rejection Type of Sound Trap

A series-acceptor type of trap is shown in figure 3. C_1 and L_1 form a series-resonant circuit which is tuned to 4.5 mc. Since the series circuit has low impedance at resonance, signals at this frequency are by-passed to ground. How-

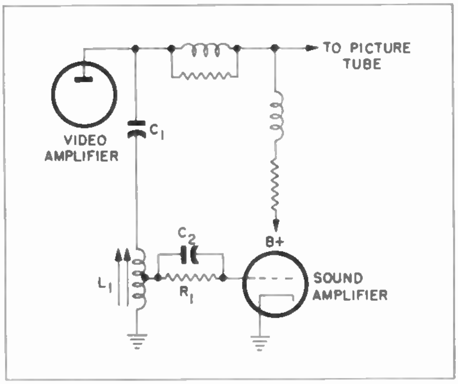

Figure 3. Series-Acceptor Type of Sound Trap

ever. L_1 will develop a fairly large resonant voltage, part of which is coupled to the sound amplifier. (If the sound amplifier were connected at the top of L_1, the tube's input capacitance would cause L_1 to appear as part of a parallel-resonance circuit at some relatively low frequency.)

Figure 4 shows a frequency-response curve which is used to explain the action of intercarrier-type receivers. This curve is different from that encountered during the sweep-generator-oscilloscope method of alignment, because it represents the combined response of the r-f, i-f, and video sections of the receiver, and cannot be displayed by standard methods. This curve is shown to illustrate the effect of the video circuits. The dotted line shows how the over-all response would look if it were not for the video-amplifier trap circuit. Inclusion of the trap causes the curve to dip at the sound-carrier point: the resultant curve is shown by the solid line. Two things occur: the sound-carrier portion of the curve is reduced in terms of response, and the curve is flattened about the sound carrier. Since the sound carrier is frequency-modulated, sound signals cause the carrier to slide back and forth along the flat portion of the response curve. It is apparent that no changes in voltage result from sound-carrier modulation, and, since the picture tube responds only to voltage changes, no sound-modulation energy appears in the picture. To cause perfect flattening of the response curve, the trap should be slightly detuned from 4.5 mc., but it is standard practice to use a precise 4.5-mc. adjustment to simplify tuning procedures. It is found that this practice does not introduce too great a slope in the sound portion of the curve.

The sound-carrier amplitude level on the response curve is made 5% or less for a very definite reason. It is well known that in heterodyning, the beat-note amplitude is a direct function of the weaker of the two signals which produced the beat. If the sound signal is made very weak with respect to the video signal, the amplitude of the intercarrier beat will be controlled by the sound carrier, and the large amplitude changes present in the video signal will have only a very slight effect upon the amplitude of the beat-frequency signal; thus, the requirements of the limiter are not exacting. In summary, it could be said that it is imperative that the sound carrier be weaker than the picture carrier at the sound take-off point, and that the weaker the sound carrier is made, the less will be the effect of video in the sound channel (buzz). However, the more the sound carrier is reduced, the greater the gain required to obtain the desired sound

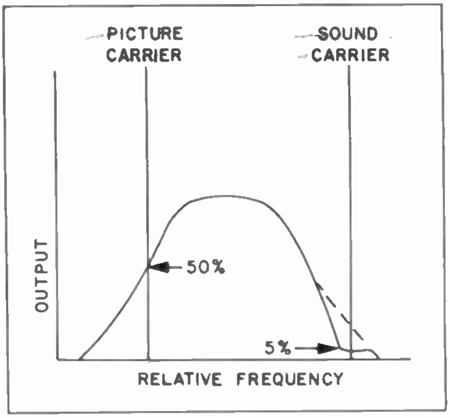

Figure 4. Over-all Response Curve for a Typical Intercarrier Receiver, Showing the Action of the Sound Trap

level. (Around 1% to 5% appears to be optimum, in terms of freedom from buzz and gain requirements.)

I-F AMPLIFIER CHARACTERISTICS

It has been found that the use of intercarrier principles simplifies the i-f system. This does not mean that careless design can be tolerated, but that the intercarrier i-f amplifier is a relatively simple system. In split-sound i-f systems it is standard practice to completely trap out sound-frequency signals. Some designs have incorporated as many as three traps for sound i-f signals alone, not to mention the adjacent-channel traps. Figure 5 shows a typical i-f system used in a relatively complex intercarrier receiver. Notice that the two traps are required, to obtain the symmetrical band-pass curve which is shown in figure 6. Actually only one trap would be required, at the sound-carrier end of the response curve, if symmetry in the response curve were of no concern. However, symmetry is desirable from the standpoint of the local-oscillator design. In a conventional receiver, the local-oscillator frequency must be above the r-f signal frequency for all channels, or below the r-f signal frequency for all channels, by the amount of the intermediate frequency (the former is standard practice). With a symmetrical intercarrier i-f response, the local-oscillator frequency for any channel can be either above or below the r-f signal frequency. This is because the sound signal is separated from the video signal *after* detection. With the present TV channels, the local oscillator (in the

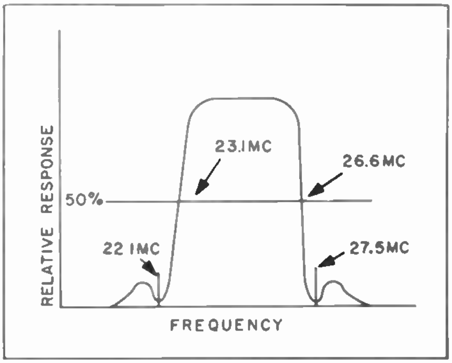

Figure 6. Response Curve for Circuit Shown in Figure 5

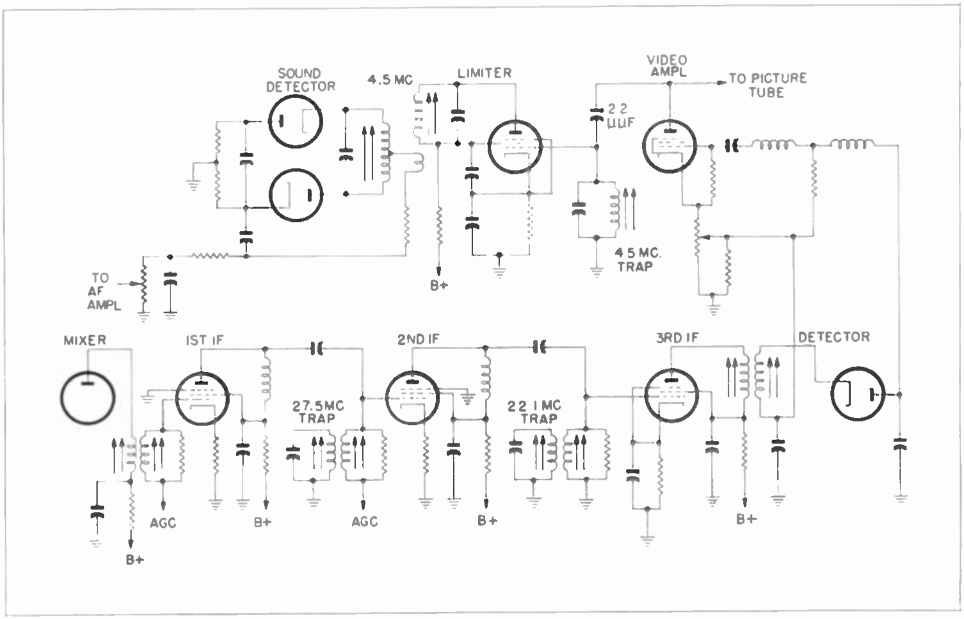

Figure 5. Typical I-F Amplifier Suitable for Intercarrier Operation

intercarrier receiver) is operated on the high side for the low channels (2 through 6), and on the low side for the high channels (7 through 13). This feature has been used in many sets, in order to simplify local-oscillator design, but modern developments have overcome most of the earlier local-oscillator problems. Therefore, later sets have incorporated an overall response curve which provides optimum picture detail, and the local oscillator is operated on the "high side" of the r-f signal, on all channels.

In addition to band-pass requirements, it is very important that overloading be avoided in the video or i-f system. If an i-f amplifier tube is driven beyond cutoff, the video carrier is interrupted during the period of cutoff. Since the sound signal is produced by beating the sound i.f. against the video i.f., the loss of either carrier results in a loss of sound signal. Since this would most likely occur during sync, the 60-cycle buzz would result. This difficulty can be minimized by careful design of the i-f and a-g-c systems, and by using the detector stage as the sound take-off point (see dotted line in figure 1). The latter measure also simplifies video-amplifier design. However, if sound is removed at the detector, the gain of the sound amplifier must be increased by a factor equal to the video-amplifier gain.

Detector sound take-off is represented in the system shown in figure 7 (this is the system used in most Philco intercarrier-type receivers). Here, the i-f and r-f circuits are adjusted to provide the required sound-to-video amplitude ratio. Since the sound signals represent a 4.5-mc. carrier after detection, the detector peaking circuit contains sound energy (the peaking circuits are mainly responsible for the gain of the video system at 4.5-mc.). An extra stage of amplification builds the sound signal up to an amplitude sufficient for effective limiting. The output of this stage drives a conventional limiter and ratio detector. The video amplifier contains a separate trap which serves only to remove sound signals from the picture.

ALIGNMENT OF A TYPICAL INTERCARRIER RECEIVER

Intercarrier alignment is quite simple in comparison to split-sound-system alignment, and precise frequency control is not nearly so important. The i-f system is aligned in the conventional

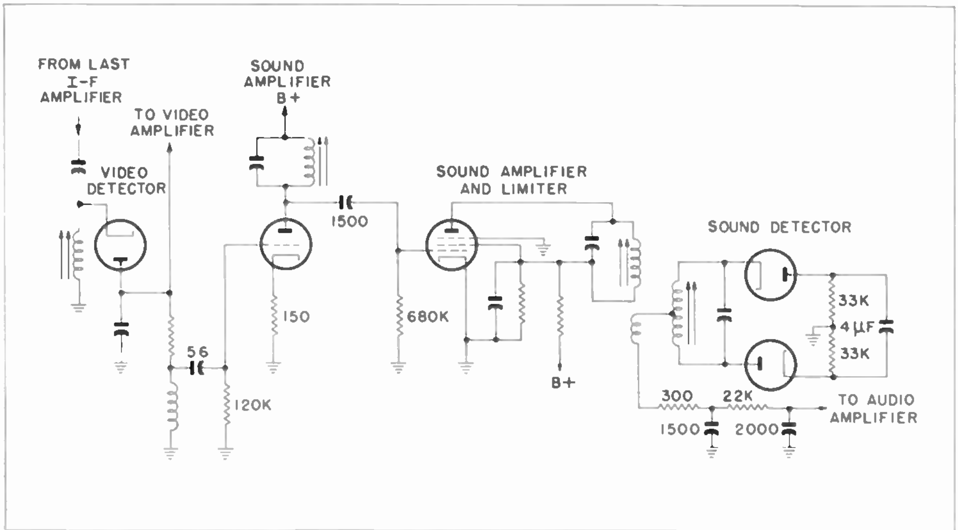

Figure 7. Sound-Detection System, Using the Video Detector as a Take-Off Point

manner, using a sweep generator, a scope, and a marker generator. The response curve specified by the manufacturer should be obtained, with particular emphasis being given to the response at the sound end of the curve (this is the point discussed as being less than 5% max.). The audio section can be aligned either before or after the i-f section, but the latter is more desirable because the audio alignment will not cause any change in i-f alignment.

For audio alignment, it is necessary to have a sensitive voltmeter and a 4.5-mc. signal (modulation is not necessary, but can be used). This signal can be obtained from an accurately calibrated signal generator, but it is generally easier to use the signal from a TV station. (These stations are required by the FCC to maintain an accuracy of .005%, for carrier separation.) The carrier frequency used is not important during alignment, since the sound system responds to the intercarrier beat. A weak signal should be chosen, so that the limiter is not driven too far into saturation; however, if a weak signal is not available it is fairly easy to attenuate the r-f input to a satisfactory level (this is most conveniently done by detuning the fine-tuner adjustment). Using figure 5 to indicate the connection points for alignment, proceed as follows:

1. Connect voltmeter from point A to ground.

2. Tune trap (primary and secondary) and discriminator primary for maximum-negative voltmeter reading.

3. Connect voltmeter from point B to ground.

4. Tune discriminator secondary for zero voltmeter reading. (This adjustment should be capable of causing the voltmeter to swing either positive or negative; hence, a zero-center scale is desirable.)

As an alternative, the 4.5-mc. trap can be tuned by adjusting the trap circuit (primary) for minimum 4.5-mc. signal

GAIL W. WOODWARD needs no introduction to readers of previous issues of the BULLETIN, since we have already published several of his articles, including *"S"-Band Propagation*, *High-Frequency Power Measurement*, and *Microwave Wave Guides and Components*.

Mr. Woodward was born in Salina, Kansas, on September 4, 1922. He became interested in electronics as a hobby, in high school, and has been active in this field continuously since that time.

While serving with the Navy during the recent War, he attended a number of electronics schools, including NATTC, in Corpus Christi, Texas. Following graduation from NATTC, he remained there as an instructor in Radar Fundamentals, Testing Techniques, and Rudiments of Maintenance. He was one of a selected group of instructors chosen for special training in S-H-F Test Techniques, at Massachusetts Institute of Technology.

Following his Navy service, he spent two years in radio and television servicing, and three years as a television instructor with Radio Television Institute (Philadelphia, Pa.), before joining the Philco TechRep Division as a technical writer in the Technical Publications Department.

After completing a major portion of the writing on the recently released Philco Training Manual on "Radar System Measurements," and a portion of the manual on "Philco Microwave Radio Relay Equipment (CLR-6)," he joined the BULLETIN staff as a technical editor and writer in the Technical Information Section of the Technical Department.

at the video-amplifier output. Also, it should be pointed out that the sound system can be tuned by the "sweep generator, scope, and marker" method, but the above method is quite satisfactory and far easier.

A very helpful field expedient for correcting excessive intercarrier buzz is simply to adjust the trap and discriminator secondary for minimum buzz. However, this is recommended only if a voltmeter is not available.

Some receivers use a discriminator circuit similar to the one shown in figure 8, in which case the alignment method given above is not applicable because of the unbalance to ground. When this circuit is being adjusted, connect two equal-valued resistors of about 100,000 ohms across the load circuit, as indicated by the dotted lines. The exact resistor value is not critical, but the resistance of the two must be equal. The above procedure can now be used if the voltmeter is connected to point C instead of to ground, in step 3.

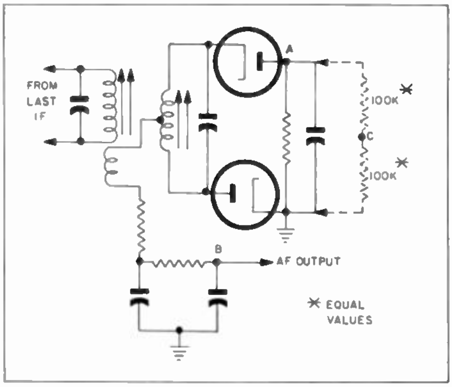

Figure 8. Typical Unbalanced Ratio Detector, Showing Balancing Resistors for Alignment

CONCLUSION

Since the advantages of intercarrier have been previously stated, it is only fair to point out the shortcomings which have so far been discussed only by implication. The most annoying objection is the intercarrier buzz which results from over-modulation of the picture carrier. This effect sounds very much like poor i-f design or misalignment, but quite often it originates at the station. Fortunately, this trouble appears most often during commercials (for reasons probably known only to sponsors). Obviously, receiver design cannot correct this fault, but as transmissions improve (as they have done and will continue to do), overmodulation becomes a less-frequent occurrence. Another disadvantage lies in the fact that if the picture carrier is disrupted, sound is also lost, and the station announcement that there is a temporary failure remains unheard. At worst, this can cause a working set to be pronounced dead by the owner. Lastly, when a customer has once owned a well-designed intercarrier set, it will be quite difficult to sell him a split-sound receiver.

Intercarrier television sound has, in field service, proved to be a very stable system. If properly engineered, it can greatly improve the characteristics of a receiver, and, from a maintenance standpoint, is easier to adjust and service than older systems.

Introduction To TRANSISTOR ELECTRONICS

Part IA

The Quantum and Electron in Solids (The Atomic View)

By John Buchanan

Technical Publications Dept.

The first article of a new series discussing the entire subject of transistor electronics. This article deals with basic atomic theory and modern theoretical advances which must be understood in order to master transistor theory.

(Editor's Note: For further information regarding this series of articles, see the editorial on page 3 of this issue.)

IN 1948, the invention of the transistor, a crystal triode amplifier of the type shown in figure 1, was announced jointly by J. Bardeen and W. H. Brattain, of the Bell Telephone Laboratories. Today, though it is still in the developmental stage, the transistor seems destined for an increasingly prominent role in shaping the future of electronics. Its operating characteristics are such that it will someday displace both vacuum and gas-discharge tubes in many low-power circuits; its use promises improved operating efficiencies, and economy in space as well as in initial cost (see figure 2). Unfortunately, from the electronic technician's point of view, basic transistor theory is not the usual extension of the ordinary circuit concepts based upon conduction by freely moving electrons. In fact, a completely opposite picture must be formed — that of conduction by "bound holes," where electrons, or rather electron energy states, are missing. The existence of the electron hole was not discovered directly by experiment, as was the case with the electron itself, but is an abstract concept first derived from the wave equations of quantum mechanics. However, it is not necessary to clutter one's mind with complex equations, to gain a working understanding of hole conduction, the electron hole itself invites a looking into. Sufficient background knowledge will be presented in the following paragraphs, to aid in clarifying the concepts which are essential to an understanding of the subject, and to prevent the new terminology from sounding like so much abracadabra for drawing the transistor out of a hat.

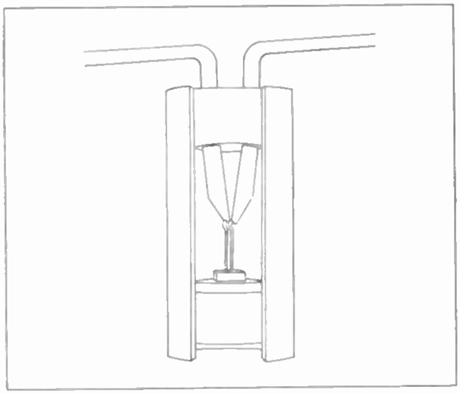

Figure 1. Cutaway View of a Transistor

TWO WAYS OF LOOKING AT SOLIDS

Transistor electronics is essentially an applied branch of the modern, or electronic, theory of solids. From an electronic point of view, solids are divided into three general classes: metals, or conductors, semiconductors, and insulators. At the present time there is no one theory that explains all the phenomena that have been observed in these three classes of solids. In fact, there are some observed effects that cannot be explained satisfactorily by any of the theories: an example is the superconductivity of certain elements and alloys whereby all

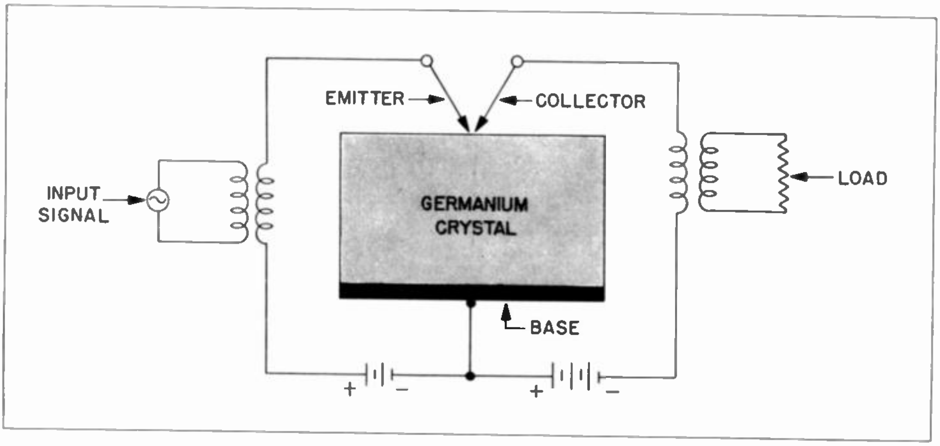

Figure 2. Schematic Diagram of a Transistor-Amplifier Circuit

resistance abruptly vanishes as the temperature nears absolute zero. There are, however, two general theories which are fairly well established, and from which it is possible to derive satisfactory explanations of the electronic behavior of different solids. One is the *atomic,* or *nuclear,* theory, and the other is the *free-electron* theory.

The atomic theory assumes that all the electrons are more or less bound in a series of concentric shells around atomic nuclei, with conducting electrons momentarily liberated by thermal vibrations. The free-electron theory, on the other hand, considers that none of the electrons in the outer shells are bound to definite atoms, but that they are free to move about the entire solid body. The word "free" here, however, does not necessarily mean "free to conduct"; it simply means "not bound to a particular atom or group of atoms." The atomic theory serves very well to explain insulators, but cannot be used to account for the high conductivity of metals; whereas, the free-electron theory accounts for metallic conduction, but fails to predict the low conductivity of certain insulators in which many electrons are known to be in an excited state.

The electronic technician is accustomed to the atomic view: to visualizing electrons as momentarily free to move short distances along a conductor before being recaptured. Such a picture is also important in the understanding of semiconductors; however, it is the all-or-none, free-electron concept that best explains the fine print of semiconductor behavior, and it was a concern for such things as the nature of the free electron, the effects of surface states, potential barriers, and the like that led to the development of the transistor.

While the atomic theory deals with electrons as discrete particles, the free-electron theory is more concerned with electrons as waves. The solid is treated as something of a cavity resonator, with a fixed lattice of positively charged holes into which an extremely dense electron gas has been injected. Both theories, however, take into account these three factors: the quantum, the electron spin, and the Pauli exclusion principle. We shall first discuss these concepts as they are set forth in the atomic theory, and then, more or less by analogy, apply them to the free-electron theory.

THE DISCOVERY OF THE QUANTUM

The word "quantum" is synonymous with the word "particle." Usually, however, the word "particle" implies bits of matter, whereas the word "quantum" is used for bits of any physical property — energy, momentum, magnetism, etc., as well as mass. The quantum was "discovered" by Planck about 1900. One of the problems of the physicists in those days was to find an equation which would explain thermal radiation from an ideal black body. The emission per square centimeter from such a body was assumed to be equivalent to the emission per square centimeter from a small hole in the wall of a cavity resonator. It was further assumed that within the cavity the electromagnetic energy was distributed at random among the standing waves of all possible harmonics of the resonant frequency. At the lower frequencies the mathematics of such a system agreed very well with the observed radiation: however, it could be seen intuitively that the number of standing waves would increase without limit unless some bounds were put on the number of harmonics that could be present. Consequently, this concept attributed to the shorter waves a greater share of the total radiation than they were known to have. This led the physicists of that time to coin the phrase "the violet catastrophe," since the radiation equation indicated that all bodies in the universe would dissipate their thermal energy in a burst of violet and ultraviolet radiation.

It was Planck who introduced a limiting factor in the radiation formula. This involved the assumption that a body must radiate and absorb electromagnetic energy in discrete bundles, or quanta, that are related to the frequency by the formula

$$E = hf$$

where E is the quantum of energy absorbed or radiated, f is the frequency, and h is Planck's constant of proportionality. To make the formulas agree with experimental results, h has been given the value of 6.52×10^{-27} erg-sec,

THE QUANTUM BEGETS THE PHOTON

The real meaning of Planck's constant is still not clearly understood, and in the beginning it was considered little more than a mathematical formality to force the right answer out of an equation. Planck himself spent much time trying to iron out the pleats in energy. Then, in 1905, the constant h assumed a new significance when Einstein introduced his photon theory to explain the photoelectric effect. Where Planck had understood the formula E = hf to represent the energy of radiation absorbed or emitted, Einstein declared it to be the energy of a compact particle of light. This particle, which was soon afterward named the *photon*, is variously pictured as a minute package of waves or as a kind of pulsing particle, its exact physical nature being as yet uncertain. According to Planck's original idea an emitting body was analogous to a singer who exhaled the same amount of air for each note, the energy and pitch of each emission being proportional to the lung capacity and the rate at which the air was expelled. The photon analogy goes a step farther by requiring that the vibrating air be propelled forth in bubbles.

Experiments with photoelectric substances show that when light impinges on such materials the maximum amount of energy that can possibly be absorbed by an electron remains constant as long as the wavelength of the light remains constant. Increasing the intensity of the light increases the number of electrons energized, but it does not increase the energy per electron. The photon was invented to explain how light intensity could increase without an increase in the amplitude of the light waves. A greater intensity simply means a greater number of photons per unit of time, each with a quantum of energy, the magnitude of which depends only upon frequency. (The same concepts may be applied to radio waves; however, there is little practical value in such an approach.) The existence of photons has been substantiated, in later experiments, by photographing the tracks resulting from collisions with other particles. Figure 3 illustrates the Compton effect, which is observable when a high-energy photon collides with an electron. The photon loses part of its energy to the electron, bounces off like a billiard ball, and assumes a lower frequency corresponding to its remaining energy.

The discovery of the photon led naturally to an investigation of how it was produced. Without waiting to tidy up the field that was left in disorder after its battle with the strongly entrenched wave theory, the quantum was now to advance on the atom and subdue the electron. It was this campaign against the electron that gave rise to the new quantum mechanics. Whereas the proponents of the older, or "classical," physics believed that matter consisted of discrete particles or atoms, and believed that the particles could assume a continuous range of values in their states of motion, the quantum has now overthrown this concept. The new mechanics atomizes everything — not only matter itself, but all the actions in which matter takes part.

THE QUANTUM LASSOES THE ELECTRON

Suppose we take another look at the quantum equation for radiation. Perhaps we may find at least a vague suggestion of the meaning of Planck's constant.

By rearranging: $h = E/f$
Since, f = cycles per unit time
Then, $1/f$ = time per cycle
Thus, $h = E/f$ = energy × time per cycle
But, energy (E) = force × distance
And, force = mass × acceleration
Thus, h = (mass × acceleration × distance × time) per cycle
Also, acceleration × time = velocity
And, mass × velocity = momentum
Then, h = (momentum × distance) per cycle

Could Planck's constant, by any chance, mean that the momentum of a particle in cyclic motion multiplied by the distance it travels in one cycle is a quantity, representing some sort of action, that is an integral multiple of h? Bohr, in 1913, thought it worth a try in his model of the hydrogen atom. He designed an atom with a small positive

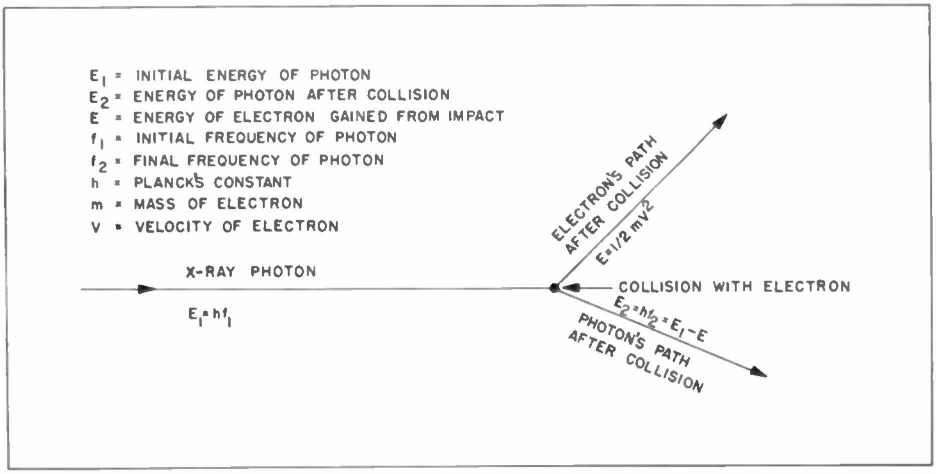

Figure 3. The Compton Effect (The observed path of an X-ray photon before and after collision with an electron.)

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John Buchanan

nucleus and a single planetary electron. He decided that the momentum of the electron must be such that the centripetal force exerted by the positive nucleus exactly balances the centrifugal force of revolution. That was the first requirement. A second requirement was that the numerical value of the electron momentum multiplied by the circumference of the electron orbit (distance per cycle) must be some integral multiple of h. The condition was such that:

$$(2\pi r)(mv) = nh.$$

where r is the radius of the orbit, m is the mass of the electron, v is its velocity, and n, the *quantum number*, is any integer (1, 2, 3, etc.). This, combined with the condition that the centrifugal force and nuclear attraction balance, permitted only certain circular orbits — one for each quantum number. Consequently, the electron could assume only certain energy levels; that is, the total electron energy (kinetic and potential) for each orbit had to be a distinct, fixed value. The lowest energy level occurred in the orbit nearest the nucleus, and the higher, or excited, energy states occurred in orbits of greater radii. However, the differences in energy levels between orbits became smaller and smaller as the distance from the nucleus increased, and approached zero, for all practical purposes, at large radii.

Now Bohr supposed that when an electron jumped from an outer orbit to an inner orbit, a photon would be emitted; and that a photon would be absorbed when the process was reversed. If this were true, then the frequency of the photon should obey the equation $f = E/h$, where E is the difference in the energy levels. It had long been known that each element had its own trademark in the frequency spectrum, radiating only certain frequencies when thermally excited, and under other conditions, absorbing the same frequencies. When the frequencies predicted for Bohr's atom (figure 4) were compared with those already observed for hydrogen, an amazingly close agreement was found. However, to account for all the observed frequencies, elliptical as well as circular orbits have since been permitted, and these, in turn, are allowed to be oriented only at certain azimuthal angles relative to the circular orbits, each orientation being considered a separate orbit. The energy levels of these additional orbits, however, are essentially the same as those of the orig-

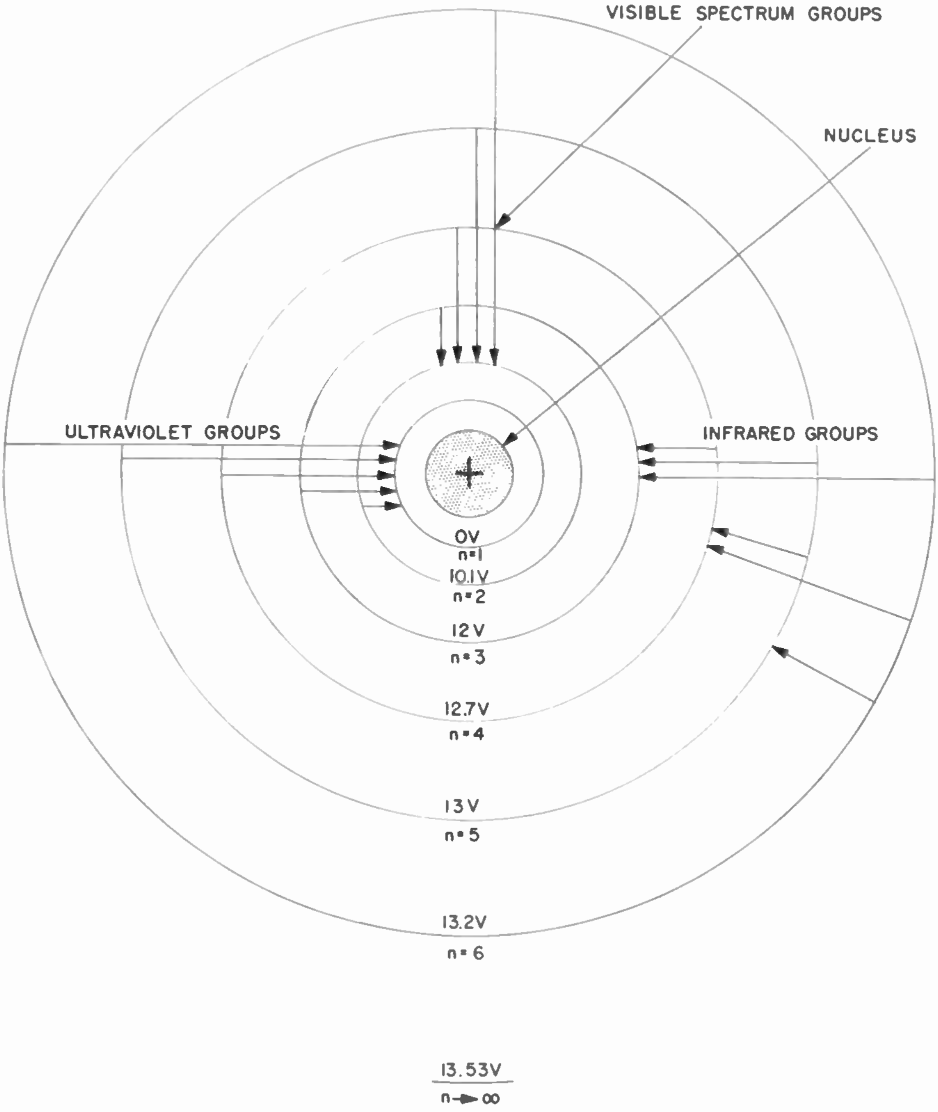

Figure 4. The First Six Bohr Orbits for a Hydrogen Atom, Showing Quantum Jumps Which Give Rise to Different Radiation Groups (Note that each of the first five orbits determines a separate spectral series. The energy per unit charge of the levels is represented in volts, with the first orbit as the zero reference. The level indicated for the condition where n approaches infinity also equals the ionization potential required to cause an electron to move from the lowest orbit completely out of the atom.)

inal circular orbits having the same principal[*] quantum numbers.

ANOTHER QUANTUM OFFSPRING—THE ELECTRON SPIN

In spite of Bohr's remarkable success with the hydrogen atom, his method became much too complex for accurate calculation when more than one electron was involved. Nevertheless, this general scheme was to be applied in designing atomic models for all the other elements; but there was still the problem of determining the number of electrons in each orbit. The three degrees of freedom already quantized — those determining the size, the shape, and the angular position of an orbit— were still not sufficient to explain all the photon radiations that could be observed when hydrogen atoms were excited while in a strong magnetic field. ~~It was~~ necessary to give the electron a fourth degree of freedom — that of rotation about its axis. Just as the earth rotates about its axis while at the same time revolving around the sun, so it was assumed that the electron spins like a top while following a planetary orbit. When the electron spin was introduced, it also was quantized, being permitted an angular momentum exactly one-half of that already attributed to the smallest planetary orbit. This value was an irritating necessity, for the original atomic model suggested that the smallest angular momentum possible was that found in the smallest orbit, and now it was necessary to face a value one-half as great. However, in return for what was lost by having to split an "atom" of angular momentum, even more was gained, because the electron spin preserved and strengthened the concept of an "atom" of magnetism.

AND STILL ANOTHER—THE MAGNETON

An electron orbit may be viewed as a conducting loop carrying a current with a value $I = Q/T$, where Q is the electron charge, and T is the time of one cycle. As such, the electron orbit is equivalent to a small magnet with a certain magnetic moment. (When a small magnet is placed so that its poles are at right angles to an external magnetic field, the ratio of the torque exerted on the magnet to the external field intensity defines the magnetic moment of the magnet.) The magnetic moment is the magnetic analogue of the electric charge, for the charge of a particle may be defined as the force per unit electric field intensity. Thus, just as $Q = F/E$ so $M = J/B$, where Q and M are electric charge and magnetic moment, F and J are force and torque, and E and B are the external electric and magnetic fields, respectively. And just as the electron was discovered to be a fundamental unit of electric charge, computations and experimental observations also point to the existence of a fundamental unit of magnetic moment — the *magneton*. Bohr's smallest electron orbit is equivalent to one magneton, the next orbit to two magnetons, the third to three, and so on. When the electron spin was discovered, this magnetic quantum held its ground, for the spin was found to equal exactly one magneton. Now, with the magneton, a new element enters the atomic picture, for balance no longer involves electrical charges only — an equilibrium also must be found between magnetic moments. The concept of a neutral atom with one planetary electron for each nuclear proton readily explains the balance between charged particles. On the other hand, the balancing of the magnetons is a bit more complex if explained quantitatively, since vector quantities are involved. Intuitively, however, the picture is essentially one of spinning and orbital magnetons automatically orienting themselves so as to

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[*] Two additional quantum numbers have been introduced to identify the shape and angular position of an orbit. The original quantum number, n, which equals the multiples of h per orbit, is now called the principal quantum number.

cancel each other's effects, thus producing a net magnetic moment of zero.

Briefly, in an atom with many electrons, the permissible orbits for a given energy level are those which enable the effects of the magnetic moments to cancel, and which, at the same time, comply with the other quantum conditions. These orbits are characterized by the azimuthal orientations already mentioned. This does not mean that all atoms are magnetically neutral in the normal state. When a beam of atoms is shot from an oven through a magnetic field, as are electrons in the cathode-ray tube, deflections may occur. These deflections indicate that the atoms of a large number of elements have net magnetic moments. Copper, silver, and gold, for instance, each show moments equal to one magneton. The magnetons resulting from electron spin tend to solve their problem among themselves by teaming together in pairs, and thus cancelling each other's effects. This is accomplished by two electrons being paired in the same orbit and spinning on their axes in opposite directions. In the iron atom, however, there are four unpaired spins; and this fact, rather than an unbalance among the orbits themselves (as was once believed) is the cause of ferromagnetic behavior. The pairing of electrons is a primary factor in the binding together of atoms. An unpaired electron in one atom tends to seek out a mate in an adjacent atom, and the mutual attraction provides a chemical bond for holding the atoms together.

THE PAULI EXCLUSION PRINCIPLE

The question now arises: how many electrons can crowd into a single orbit?

When an atom is at absolute-zero temperature, there are no thermal vibrations to prevent the electrons from settling to the lowest possible energy levels. This completely unexcited state of an atom is called its *ground state.* One might suppose that in the ground state all electrons would be in the orbit of lowest energy. That this is not so is accounted for by the *Pauli exclusion principle* — a concept of foremost importance in the theory of conduction in solids.

The Pauli exclusion principle is not a logical deduction from more basic principles. Exactly why it should be true is not known. Rather, it was an intuitive concept which Pauli presented because it could explain the experimental facts. In its simplest terms, it declares that no two electrons within an atom can have the same four quantum conditions. Roughly, the first quantum condition determines the energy; the second, the shape of the orbit; the third, the azimuthal position; and the fourth, the direction of spin relative to the plane of the orbit. This last condition can have only two values, for electron-spin polarity must be either parallel or anti-parallel to the magnetic field of the electron orbit. It cannot be at equilibrium in some intermediate position. Now the first three quantum conditions define a single orbit, so the exclusion principle permits two electrons in each orbit provided that their spins are opposite.

THE STRUCTURE OF THE ATOM

It turns out that for each principal quantum number, n, there are n^2 possible orbits. Thus, $2n^2$ electrons are permitted at each energy level. The result is that the planetary electrons are divided into a series of concentric shells about the nucleus. The shells are, in turn, divided into a number of subshells, each of which represents orbits of a given shape. Table I indicates the arrangement of electrons in the first four shells.

TABLE I

Principle Quantum Number n	Total Number of States for Each Shell = $2n^2$	Total Number of States for Each Subshell
1	2	2
2	8	2 6
3	18	2 6 10
4	32	2 6 10 14

If we arranged all the known elements in the order of increasing atomic weight, we would find that the lightest element, hydrogen, would have one electron; the next element, helium, would have two electrons; and so on up the scale, each step being accompanied by the addition of one electron. Of course, each additional planetary electron also means an extra proton in the nucleus, plus an added neutron or two to hold the proton in position. Now, in the ground state the electrons tend to seek the lowest energy levels possible, filling the inner shells and leaving no vacancies until their numbers are too few to fill an outer shell. There are important exceptions to this rule, however, among the heavier atoms; for instance, no electrons will enter the third subshell of the number 3 quantum level unless there are also one or more electrons at the number 4 level. Isolated atoms are normally in their ground states. This is because their thermal energies at ordinary temperatures are much smaller than the differences between the levels, and hence are not sufficient to raise an electron from an inner shell to one farther out. We shall see that when atoms are very close to each other, the outer shells may be distorted and easily overcome. But even so, the inner shells may always be considered as filled and drawn tightly around the nucleus, or even looked upon as part of the nucleus. An important factor to note concerning the Pauli exclusion principle is that these lower-level electrons are completely immobilized, and cannot enter into conduction processes, nor can they absorb any energy less than that of a photon in the X-ray spectrum. On the other hand, the outermost electrons are permanently barred from the lower states, even at absolute-zero temperature. In fact, they must maintain energy states far in excess of the thermal energy of the atom itself.

THE VALENCE ELECTRONS

The electrical, chemical, and physical characteristics of an element in its normal state depend only upon the nature of the outer shell of its atom. The electrons in this shell are called the *valence electrons*. The term "valence" refers to the number of chemical bonds one atom can make with other atoms. These bonds are brought about by valence electrons (it would probably be more accurate to say "valence magnetons") of one atom seeking to pair off with those of other atoms. From the point of view of an atom, the primary purpose of existence is to surround one's self with an impenetrable outer shell. Ever since the creation, this has been the common goal wherever atoms congregated. Every chemical reaction or crystallization is a mass movement to fill the outer shells or subshells, so that each atom involved may face its world from behind a solid barrier. Atoms with all their shells filled in the natural state have no need of chemical bonds. These are the inert gases that lead a lone existence. Neon, for example, has ten electrons — just sufficient to fill the second shell. Solids, however, are composed of atoms with unfilled shells in the natural state. The method by which the chemical bonds are formed and the facility with which the valence shells are filled determines a solid's conducting properties.

VALENCE BONDS

There are three types of valence bonds: the metallic, the ionic, and the covalent. The metallic bond occurs when the outer shell is almost empty. The valence electrons are then relatively free to pass from atom to atom. Such bonds exist in the metallic elements, in which the valence electrons are shared by all the atoms in the solid. This arrangement leaves the electrons free to conduct.

An ionic bond is formed when a metallic atom combines with an atom whose outer shell is almost full. In this latter type of atom the valence electrons are more confined, and there is a tendency to fill the shell by capturing the less-restricted metallic electrons. This results in a negative ion, while the metal atom becomes a positive ion. The two ions are then held together by the electrostatic attraction between opposite charges. Since all the valence electrons are bound, this type of compound in its pure state is an insulator. Examples are the metallic oxides and the salts — the sodium-chloride (table salt) molecule is shown in figure 5. There are cases, however, of ionic solids that conduct; this conductivity is due to the fact that some of the ions themselves are free to move. Conduction of this type occurs, for example, in silver-bromide crystals; but these cases are the exceptions rather than the rule.

The third type of chemical bond, the covalent bond, is of particular importance in transistor theory. Here, electron pairs are formed that are shared by both atoms. Such a bond occurs when two atoms of the same element combine, for neither atom can attract the electron pair more than the other. It is also the favorite bond of those atoms with approximately half of their valence shells filled. An example is carbon, which has six planetary electrons in all. Reference to Table I will

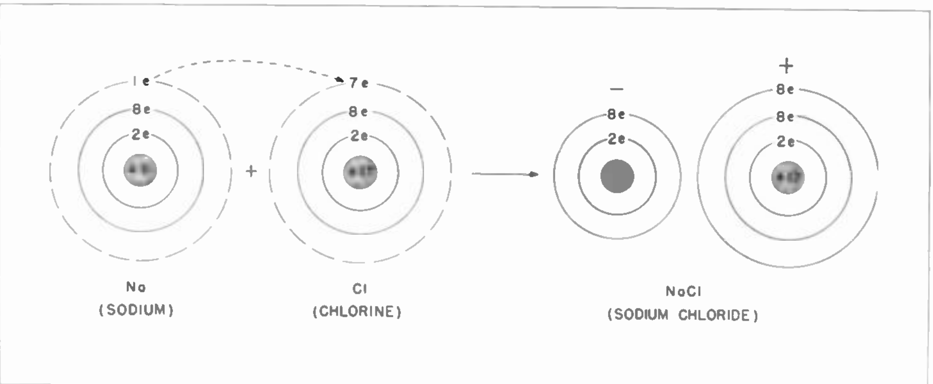

Figure 5. Formation of Sodium-Chloride Molecule (The ionic bond is formed by a chlorine atom capturing a sodium valence electron.)

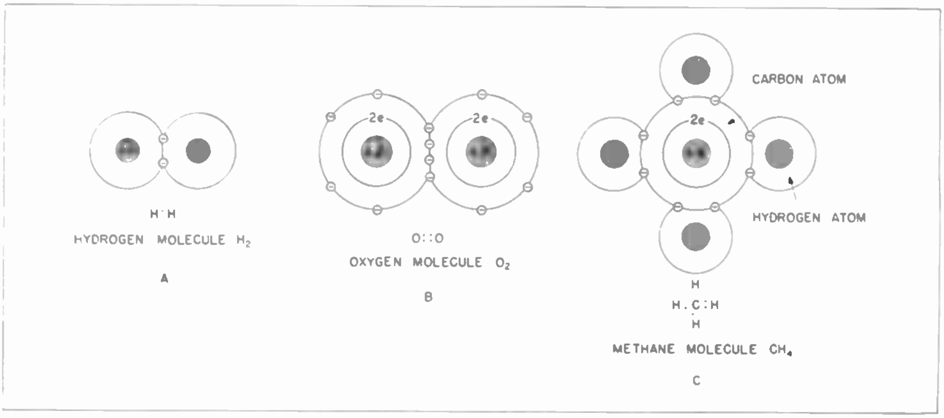

Figure 6. Covalent Bonds Formed by Sharing of Electron Pairs

show that carbon, with four valence electrons, needs four more to fill its outer shell. Figure 6 illustrates three examples of covalent bonds: example A shows the bond formed between two atoms of hydrogen (H_2 is hydrogen's normal gaseous state); in example B, two electrons are shared by each of two oxygen atoms (O_2 is normal atmospheric oxygen); while in example C, one carbon atom unites with four hydrogen atoms by four separate covalent bonds, to make one molecule of methane. Note that in all the above examples the electron valence pairs effectively complete the shell of each atom. While hydrogen needs only two electrons in its outer and only shell, carbon and oxygen both need eight electrons.

Often there are bonds partly ionic and partly covalent. This may be due to one atom attracting an electron pair much more strongly than does its covalent partner. Or it may result when one atom contributes both electrons of a covalent pair. This latter arrangement is called a *coordinate* bond. Figure 7 shows two examples where the bonds are partly covalent and partly ionic. In example A, the chlorine atom of a hy-

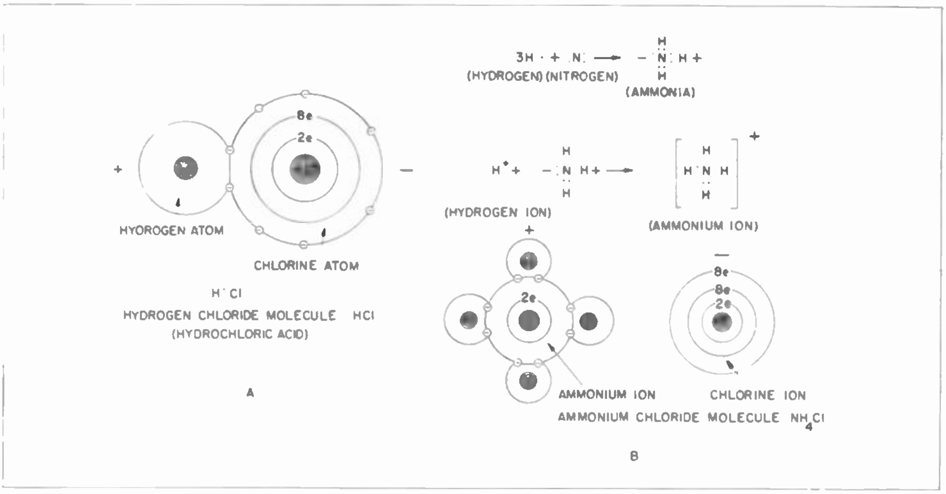

Figure 7. Examples of Covalent Bonding Combined with Electrostatic Bonding

drogen-chloride molecule tends to monopolize the electron offered by the hydrogen atom, creating a small electric dipole with the chlorine end slightly negative with respect to the hydrogen end. In example B, the formation of a coordinate bond is shown. A nitrogen atom has five valence electrons and needs three more to complete its outer shell. It accomplishes this by three covalent bonds with hydrogen, to form a molecule of ammonia. This leaves the nitrogen atom somewhat negatively charged, so it readily shares both its odd electron pairs with a hydrogen ion, to form an ammonium ion. The positive ammonium ion will then unite in an ionic bond with any negative ion, to form an ammonium compound.

It should be kept in mind, however, that when many atoms are joined together in a complex molecule or within a crystal structure, the individual valence bonds are by no means completely independent of each other. Rather, they should be viewed as loosely coupled into a chain or network. Any disturbance of ionic or covalent arrangements at one point will induce a shifting of electrons in adjacent areas. An example of teamwork among several covalent bonds occurs in the benzene ring, shown in figure 8. The benzene molecule is composed of a closed ring of six carbon atoms, with a hydrogen atom bound to each carbon atom. Each carbon atom is linked between two others, with a single bond on one side and a double bond on the opposite side. An instant later, all the double bonds will have exchanged positions with the single bonds. This alternation back and forth is a continuous process, occurring simultaneously throughout the ring, and the bonds are said to be in *resonance*. In all types of covalent bonds, however, the electrons are bound to local areas, and at normal temperatures such materials are insulators.

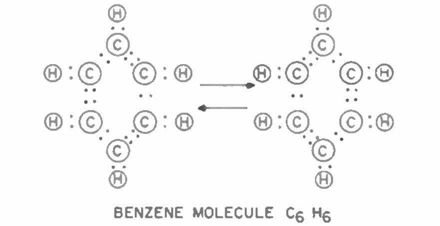

Figure 8. Resonance of Covalent Bonds in Benzene Ring

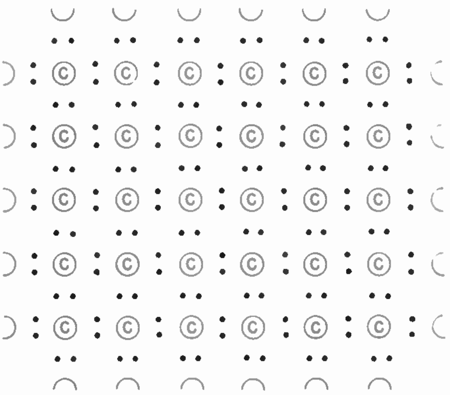

Figure 9. Diamond Lattice with Each Carbon Atom Bound by Four Covalent Bonds to Its Closest Neighbors

THE DIAMOND CRYSTAL LATTICE

The covalent arrangement of most interest to us is that occurring in the diamond type of crystal lattice. The diamond is a carbon crystal with each atom forming strong covalent bonds with four other atoms. This crystal is shown in figure 9, and for the sake of simplicity its tetravalent lattice is shown in two dimensions, rather than in three dimensions as it actually exists. Notice that the bonds effectively provide each atom with a completed outer shell of eight electrons. All electrons are equally shared and there are no local areas with an excess of charge. These factors render the crystal relatively inert to chemical change and electrical conduction.

In figure 10, the atoms of silicon (with 14 electrons) and germanium (with 32 electrons) are illustrated, for comparison with the carbon atom. All three elements play important roles in semiconductors. Notice that the outer shells of the silicon and germanium atoms are similar to that of carbon, in that each contains four valence electrons. Because of this, these elements are also similar in their electrical and chemical behavior. Of particular importance, is the ability of silicon and germanium to form the diamond type of crystal lattice. Thus, figure 9 illustrates equally well a silicon, germanium, or carbon crystal. The four covalent bonds provide each atom the equivalent of eight electrons in its valence shell. These electrons completely close the 2-electron and the 6-electron outer subshells. Only in the case of carbon is this sufficient to fill the entire outer shell. However, in all three elements the bonds are stable, though much stronger in carbon than in silicon or germanium. Where the silicon and germanium bonds may be broken with energies of approximately 1.1 and .7 electron volts, respectively, it requires approximately 7 electron volts to break the carbon bond, which accounts for the diamond's great durability and hardness. Because of the bond stabilities, each of the elements is an insulator, in its pure, crystalline state.

SEMICONDUCTORS FROM INSULATORS

The foregoing picture of valence electrons seems to have divided all the solids into metals and insulators, and to have omitted the possibility of semiconductors. Actually, the semiconductor is basically an insulator in which electrons free to conduct have, in one way or another, been produced. An unbound electron, once within the interior of an insulator, will conduct as readily as it will within a metal. The science of semiconductors, particularly the field related to transistors, is much concerned with the controlled production of electron carrier within insulators.

The line dividing semiconductors from conductors on the one side, and semiconductors from insulators on the other side, is somewhat arbitrary. The resistivities of metals are on the order of 10^{-5} ohm-cm.; those of semiconductors range from 10^{-2} to 10^{5} ohm-cm., while materials normally classed as insulators have resistivities of 10^{6} ohm-cm., and higher. Under normal conditions an increase in temperature increases the resistance of a metal, but decreases that of semiconductors and insulators. This is explained in terms of the atomic theory by assuming that in metals the number of free electrons remains essen-

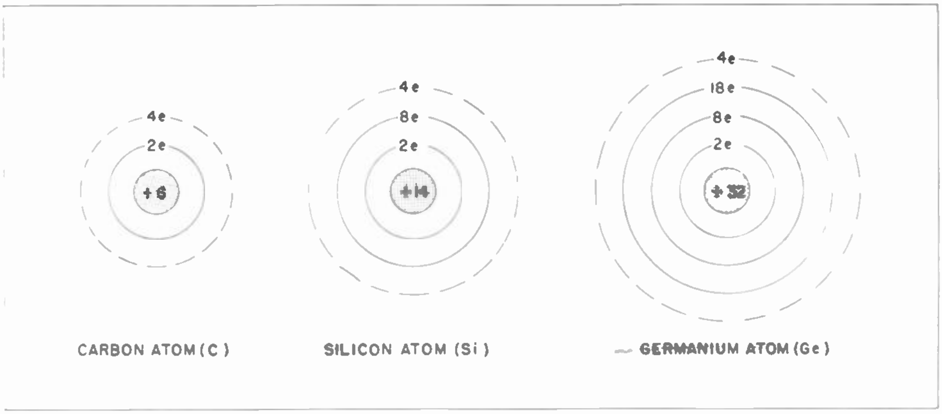

Figure 10. Carbon, Silicon, and Germanium (Each has four valence electrons.)

Note!

tially constant, but that the increased thermal vibrations of the atoms increases the frequency of collisions between electrons and atoms, thus reducing the average mobility of the electrons. As far as insulators and semiconductors are concerned, an increase in temperature also reduces the free-electron mobility; however, the added thermal energy at the same time increases the number of electrons liberated, so that the overall conductivity becomes greater. At low temperatures, many semiconductors might well be classed as insulators.

These thermal effects suggest that certain solids are semiconductors simply because the valence bonds are too weak to withstand room temperatures. It is true that this is an important factor, and a necessary factor in transistor crystals, but the production of current carriers may result from other causes, as well. Theoretically, these carrier sources may be grouped into two categories: those which inject the carriers from the outside, and those which produce the carriers internally. We shall treat the first type only briefly, but shall return, in later discussions, to the principal factors involved.

FAILURE OF EXTERNAL CARRIER INJECTION

The concept of carriers being injected into a crystal from the outside is intended to be taken only in its narrowest sense. For instance, at the junction of a metal and a semiconductor, electrons may flow from the metal into the semiconductor. We shall not assume, however, that such current carriers have an external source unless the total density of electrons within the semiconductor is increased. In other words, unless the semiconductor itself has an over-all space charge, we shall assume that all its current carriers have been produced from within. It is important to keep this distinction in mind; otherwise, the terminology used for describing transistors may lead to confusion in the understanding of carrier source. In the transistor, the carriers are produced internally; however, one of the transistor electrodes does effectively perform the function of carrier emission, and is thus called the *emitter*. But there is a marked difference between it and the thermionic emitter of a vacuum tube: the latter emitter actually supplies all the carriers between the electrodes; the transistor emitter, on the other hand, merely aids in the production and control of carriers which are contributed by the semiconductor itself. Therefore, no over-all space charge is developed within the bounds of the transistor crystal, and its carrier source should not be confused with our first category.

Conversion of insulators to semiconductors solely by the injection of carriers from the outside has had relatively little practical application up to the present time. This is due principally to the fact that the energy required to lift an electron from a metal is greater than that required to break the valence bonds within an insulator. The thermal energy of electrical potential necessary to force electrons from a metal into an insulator would first break down the insulator, and hence would hardly be practicable.

When an insulator is bombarded with electrons, the excess charge concentrates at the surface of the insulator and the electrons tend to become immobilized in surface states. This type of immobilized electron, however, is not explainable by our atomic theory. When electrons are not bound to atoms they should be free to conduct, or so it seems. It was an insight into the effects of these surface states that led to the development of the transistor. A general explanation must await discussion of the free-electron theory; for the present it is sufficient to note that it is not practicable to produce semiconduction by simply forcing electrons into insulators. The early cathode-ray-tube screen is an example of failure in this respect. The bombarding electrons converted the screen into a semiconductor, partly by their own presence and partly by the presence of the secondary electrons they liberated inside the fluorescent coating. However, there still resulted a gradual accumulation of negative charge which tended to retard the beam as the operation continued. It was another case of excess electrons becoming bound in surface states. The modern screens overcome this difficulty because they are designed so that the number of secondary electrons emitted from the surface exactly equals the number of primary electrons impinging on the screen.

It appears, then, that the first of the two categories of carrier sources is little more than a theoretical one. This is essentially true insofar as the current depends solely upon externally donated carriers. Injection of a conducting space charge has not found its practical application in solids as it has in vacuum tubes. Semiconduction is due almost entirely to locally produced carriers. The reasons for accenting the first category at all are largely negative. Its mention serves as a warning that the atomic picture will not provide a complete explanation of semiconduction, and it serves to highlight the concepts to be avoided in visualizing transistor phenomena. Furthermore, an understanding of the factors that prevent the introduction of external carriers into solids is of prime importance in explaining semiconductor rectifiers and amplifiers. In fact, it was the failure of an experimental crystal amplifier (to be discussed in a later article) in which carriers had been introduced from an external source, that first suggested the possibility of the transistor principle.

CARRIER PRODUCTION FROM WITHIN

Current carriers are produced inside of a semiconductor either by bombardment by high-energy particles or by the thermal vibration of the atoms. Bombardment by particles is the familiar method used in the modern cathode-ray tube: in the photoelectric cell, where the bombarding particles are photons; and in crystal counters, which conduct in pulses under the impact of radioactive rays. The requirement here is that the particles have energies sufficient to free one or more electrons from their valence orbits.

Nrk!

Thermal energies play the predominant role in all semiconductors where the quantum jumps necessary to overcome a valence orbit are of the same order of magnitude as the vibration energy of the atom. At room temperature the average thermal energy per atom is approximately .05 electron volt. (An electron volt is a unit of energy equivalent to that which a single electron will gain when it falls through a potential of one volt.) However, this represents only an average value of a random distribution of energies. At any one instant, some atoms will have vibration energies much greater than the average. Where the energy difference between the electron-conduction level and the valence level is between .3 and 1.0 ev., one would expect to find a semiconductor. In practice, however, the major part of the conductivity thermally produced is due to the presence of impurities, or, in the case of compounds, to a stoichiometric* imbalance between the elements forming the compound. It is by the intentional introduction and control of these impurities and imbalances that semiconductors are manufactured to meet specifications.

A stoichiometric imbalance would result when more atoms of one element were used than could enter into the re-

---

* The term "stoichiometric" refers to the measurement of the correct proportion between two or more elements which are to be combined in a chemical reaction.

action. Thus, in the metallic-oxide semiconductors there is normally a certain percentage of metallic atoms, scattered at random, that have not combined with oxygen atoms to form oxide molecules. This imbalance, then, may be viewed as simply a particular type of impurity. Different impurities affect a crystal in different ways; however, an increase in conductivity always arises from the fact that the presence of impurities produces scattered valence shells that are easily broken by thermal energies.

It may be that the impurity atoms can wedge themselves between the crystal atoms without greatly disturbing the lattice arrangement. In this case an increased conductivity may simply be due to the impurity having a weak valence shell of its own. On the other hand, an impurity may tend to join its valence forces with those of the crystal atoms around it. This may distort the crystal structure and weaken the valence bonds to a point where they are easily broken by thermal vibrations. If the valence shell of the impurity, however, is equivalent to that of the crystal atom, it will arrange itself in the normal crystal lattice, and the impurity will have little effect on the conductivity. Thus, many carbon or silicon atoms, for example, could fit into a germanium crystal without increasing the number of current carriers.

TRANSISTOR IMPURITIES

Of primary importance in transistor crystals are those impurities that align themselves in the regular crystal structure, but do so in spite of the fact that they have one valence electron too many, or one too few. The first type easily loses its extra electron and thus becomes a positive ion; but in so doing it increases the conductivity by contributing a free electron. For the diamond lattice, this type of impurity would have five valence electrons. Phosphorous, arsenic, and antimony fall in this class. The second type of impurity tends to make up its deficiency by acquiring an electron from its neighbor. This makes

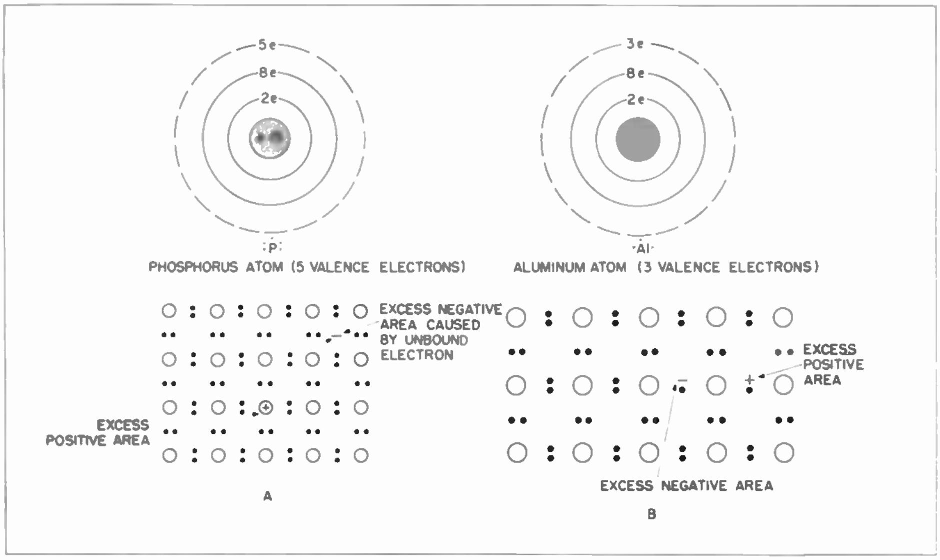

Figure 11. Part A—Atom with Five Valence Electrons in Diamond Lattice Donates Excess Electron and Becomes a Positive Ion

Part B—Atom with Three Valence Electrons in Diamond Lattice Captures an Electron and Becomes a Negative Ion, while Making Its Neighbor a Positive Ion the impurity atom a negative ion, and leaves its neighbor a positive ion. Impurities of this type in the diamond lattice will have three valence electrons. In this category are boron, aluminum, gallium, and indium. Figure 11 illustrates these two types of impurities.

Note

INTRODUCING THE ELECTRON HOLE

The positive ion produced by an electron-seeking impurity will soon capture another electron, thus neutralizing itself but effectively passing its positive charge along. Normally, this charge may be viewed as being in a loose orbit that circles about the negatively-charged impurity atom. However, if an electric field is applied, the positive charge will tend to drift toward the negative electrode. This is because the electrons which are adjacent to a positive ion, and strained toward it by the applied field, are aided in making the jump, while the electrons on the other side are strained away, and thus are hindered. As a result, the positive charge is effectively carried to the negative terminal. Figure 12 illustrates this process. For the sake of simplicity, only one valence electron is shown for each atom, and the electron vacancy is represented by a positive sign. The charge is relayed along by a series of electrons, each making but a single jump to the next atom. Even though nothing is involved but a movement of electrons, the effect is the same as if a positive particle, with a mass and a charge equal numerically to that of an electron, were actually present and carrying the current. These current carriers are the "electron holes" that were mentioned at the beginning.

Figure 13 illustrates hole conduction by a crude, billiard-ball analogy. Each ball represents a valence electron (disregard the dotted lines temporarily). The depth of the groove in which it is held represents the quantum of energy it must gain in order to move to an adjacent hole: the empty groove represents an electron hole; and the tilt of the ramp is analogous to a difference of potential which is positive at the bottom with respect to the top. Now, with the

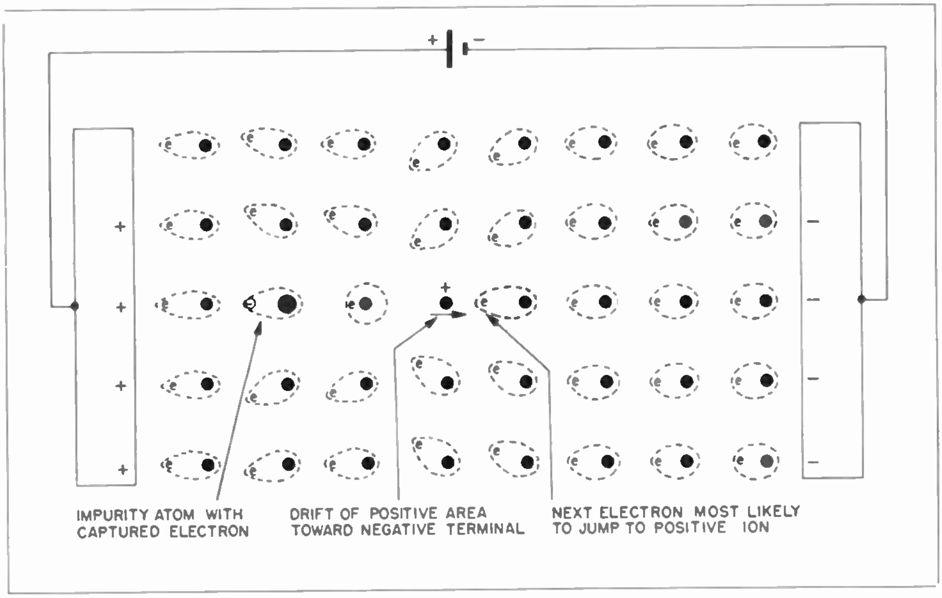

Figure 12. Conduction of Positive Charge Resulting from Electron Vacancy

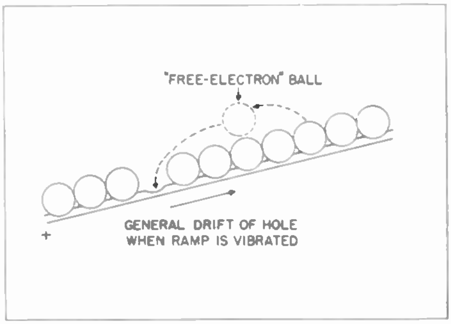

Figure 13. Billiard-Ball Analogy of Hole Conduction

ramp at rest, the system would be in stable equilibrium, and nonconducting at the angle shown. But if, a fair amount of random vibration is imagined along the ramp, then it is easily seen that an adjacent ball might jump into the hole. Also, on the average it can be expected that the hole will be filled more often from above than from below. Furthermore, as the balls step down, the hole steps up. Notice that none of the balls are free to move along the ramp except those next to the hole: that is, unless one received so much energy that it could clear the entire valence structure and become a "free-electron" ball. Such an event is indicated by the dotted-line ball rolling over the top of the others. The chances are that this ball will fall into the first hole it meets. However. the hole it left at its original position is still free to carry on the conduction.

Heretofore, we have considered the conducting particles as having been produced one at a time. This is true in the examples described—that of semi-conduction from impurities alone. However, if an electron is liberated in any way from the regular crystal structure, not one, but two current carriers are produced—a free electron, and an electron hole. In figure 13, as long as the dotted-line ball is free, it may be said that there are three current carriers: the free ball and two holes. But when the free ball again becomes bound, not one carrier, but two carriers are lost. We shall find that this multiplication of carriers, gained or lost, is an important key that opens the way to crystal amplification.

Insofar as its electromagnetic effects are concerned, the electron hole may be viewed as a discrete particle of positive charge. Indeed, when its presence was first discovered it had no other logical explanation; for that was before the quantum nature of the atom had been derived. However, the hole's mobility, though varying within different crystals, is roughly half that of a free electron in the same material at normal temperatures.

THE HALL EFFECT

The presence of positive carriers of electricity in solids was first indicated by the Hall effect. This was discovered in 1879, which was before the full flowering of the electron theory. Consider a rectangular conducting plate connected in a d-c circuit as illustrated in figure 14. The plane of the sides of the plate is shown cutting a magnetic field at right angles. This is simply a special example of a current-carrying conductor placed perpendicularly to a magnetic field. With the directions of magnetic field and current as shown, the motor force resulting tends to move the conductor upward. Now notice that

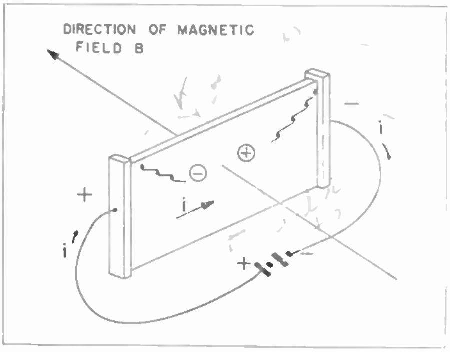

Figure 14. Behavior of Positive and Negative Carriers when Conducting in a Magnetic Field

this is true regardless of whether the current carriers are negative and traveling to the left, or are positive and traveling to the right. The original purpose of this experiment was to gain an insight into the nature of solid-state conduction. If the conduction were due to charged particles, then, whether negative or positive, they should be deflected in the same direction, in this case upward, and the top of the rectangle should become either negative or positive with respect to the bottom. Solids of all kinds were tested. In almost every case a negative carrier was indicated, and the Hall effect became an important step in the development of the electron theory. However, here and there a semiconductor would show up with a positive carrier. One can readily imagine that this was a tough nut for the electron theory to crack—particularly, in the case of a juncture where negative and positive carriers met and apparently disappeared. It is now known that these positive carriers are simply electron holes.

Note

In the experiment above, the difference of potential that is electromagnetically induced between the top and bottom edges of the plate is known as the *Hall effect*. The ~~chief~~ importance of this potential difference ~~lies~~ in its ratio to the current, and in its ratio to the applied electric field. It can be shown that the first ratio, for a given plate thickness and magnetic field, depends only upon the density of elementary carriers and their individual charges. The second ratio, of transverse to longitudinal voltage (or rather transverse to longitudinal electric intensity) for a given magnetic field, depends only upon the mobility of the carriers. Hence, the Hall effect has been of great importance in determining the type, number, and mobilities of current carriers in different solids. Metals show about one free electron per atom; though bismuth and antimony are exceptions, producing only about one free electron per 10^3 or 10^4 atoms.

Note
Hall
Effect

The Hall effects of transistor-type semiconductors indicate about one carrier for each impurity atom. This is true regardless of whether the carrier is an electron or an electron hole. The germanium crystal, which is the principal semiconductor used at the present time in commercial transistors, has approximately one impurity atom of five valence electrons for every one-hundred million germanium atoms. Hence, this semiconductor has negative carriers of approximately the same density. With the impurity atoms so widely separated, it is not difficult to imagine that once an odd electron is shaken free, it will remain so for a relatively long time before being recaptured. There are approximately 10^{22} atoms per cubic centimeter; therefore, even with only one free electron per 10^8 atoms, as many as 10^{16} negative carriers are present within each cubic centimeter.

Note

SEMICONDUCTOR TERMINOLOGY

Six terms commonly used in the technical literature of semiconductors are defined below. The first two terms classify semiconduction according to the source of the carriers. The next two terms classify semiconduction according to the charge of the carriers. The last two terms classify the impurity sources that produce the two types of carriers.

Intrinsic Conductance—The conductance of a pure substance as a result of thermal effects alone.

Extrinsic Conductance—The conductance resulting from impurities or external causes.

N-type Conductor — A negative-type conductor; one with free electrons as the principal carriers. This implies the presence of donors (defined below).

P-type Conductor — A positive-type conductor; one with electron holes as the principal carriers. This implies the presence of acceptors (defined below).

Donors—Impurities that donate free electrons, becoming positive ions themselves (phosphorous, arsenic, and antimony).

Acceptors — Electron-seeking impurities that become negative ions and thereby create electron holes (boron, aluminum, gallium, and indium).

It should be noted that the elements listed as donors and acceptors may not exhibit such properties in crystal structures other than the diamond type. Aluminum, for example, which is classified here as an acceptor, is well known as an excellent donor of free electrons when in its pure crystalline state.

ELECTRON PROBABILITY DENSITIES

The atomic picture of semiconduction, as just presented, perhaps has been oversimplified. For instance, the valence electrons are no longer viewed as arranged in neat little orbits, but rather as dancing all over the place. However, there is a much greater probability

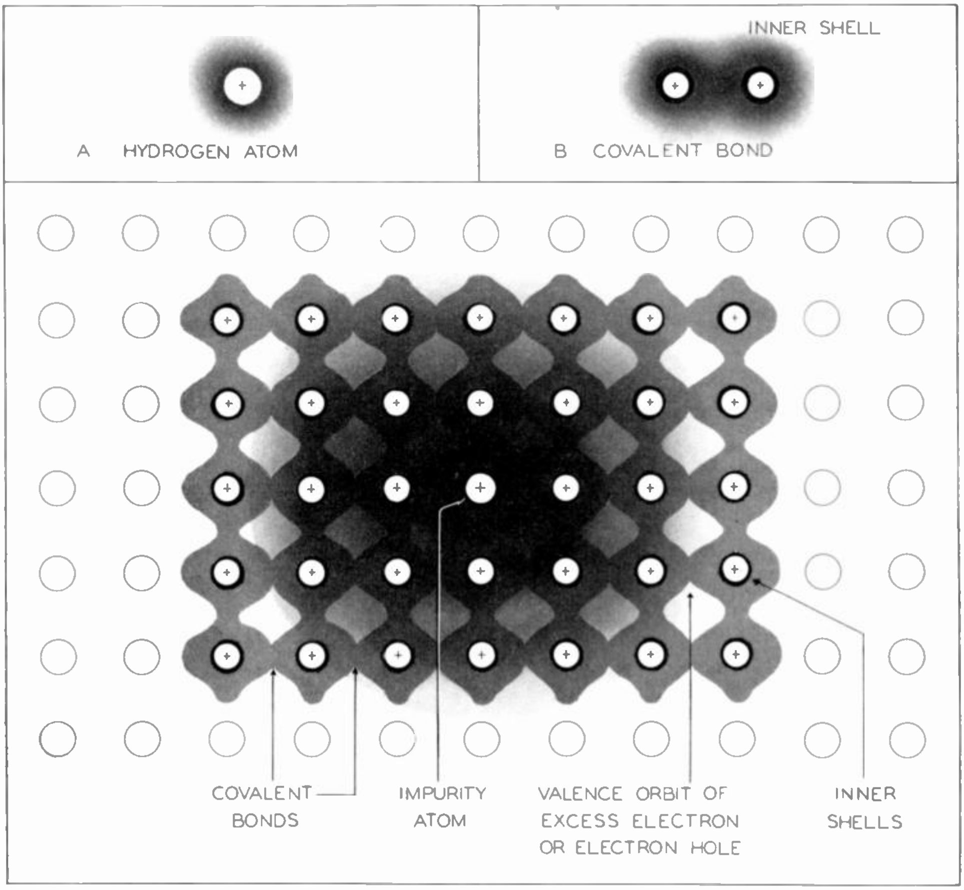

Figure 15. Parts A and B—Localized Space-Charge Densities Resulting from Probabilities of Electron Behavior (At any given instant, an electron is most likely to be found in the area of greatest density.

Part C—Diamond-Type Lattice with Impurity Atom in Center (The circular pattern represents the loose orbit of either an excess electron or an electron hole that has not broken its electrostatic bond to the impurity ion. When free, the carrier effectively spreads out even more than shown.)

that they will be found in certain areas at any given instant than that they will be found elsewhere. These favored areas coincide with the same shells and orbits that have just been described. These orbits accurately represent those paths around the nuclei containing the greatest average densities of negative charge. Some physicists do not attempt to picture the planetary electron as a discrete particle, but merely as a negative charge smeared all around an atomic nucleus, though more concentrated in certain layers than in others, according to its energy. From this point of view, the covalent bonds simply become negatively charged areas between the atomic nuclei, holding the nuclei together, as illustrated in figure 15. This concept, however, seems only a convenient average taken over a period of time. Keep in mind that at any given instant the electron has a concentrated center of charge that is very small compared to the area through which it roams. The diameter of the orbit of an excess electron or of an electron hole about an impurity atom is inversely proportional to the force of electrostatic attraction between it and the nucleus. Since this force is reduced by the dielectric medium, the diameter of the orbit becomes roughly proportional to the dielectric constant. In fact, the orbit may be considered as being spread over a diameter equal to the width of k hydrogen atoms, where k is the dielectric constant.

Qualitatively, the atomic theory offers the clearer picture of solid-state conduction. Quantitatively, however, the free-electron theory is the more accurate. Furthermore, a general understanding of the basic concepts and terminology of the free-electron theory is a necessary preliminary to an understanding of transistor behavior. Nevertheless, the atomic theory forms a very important part of the foundation on which subsequent articles will be built.

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AFC Tuning for AN/APQ-13

By Bud M. Compton

Philco Team Leader

A tuning method developed by the author in an endeavor to meet requirements imposed by Artic flying conditions.

As a result of difficulties experienced in tuning C-516 and C-504 of AN/APQ-13 by standard procedures, the following method of tuning has been adopted with great success. The only test equipment required is an oscilloscope and a voltmeter. While the procedure calls for a TS-34, any equivalent oscilloscope can be used.

PRELIMINARY ADJUSTMENTS

The voltages affecting a-f-c action are adjusted as follows:

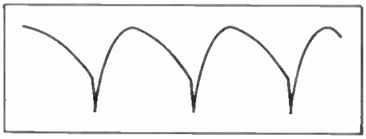
1. Set regulated negative output from RA-88 to 375 volts.
2. Turn MANUAL TUNING to full-counterclockwise position.
3. Turn AFC VOLTS ADJ. (R-474) to full-counterclockwise position.
4. Adjust BALANCE ADJUST (R-506) for a-f-c voltage of 100 volts.

PROCEDURE

1. Set up the TS-34 oscilloscope as follows:

   INPUT IMPEDANCE — HIGH, 0 db.
   ATTENUATION—2 db.
   IMAGE SIZE — Any convenient level.
   SWEEP SELECTOR — SAWTOOTH.
   SWEEP SPEED — MED; set FINE for 2 or 3 cycles.
   EXT SYNC — Set SYNC VOLTAGE for stable scope pattern.
   INPUT—Use input probe.

2. Connect the TS-34 to the radar as follows:
   - a. Connect input probe to pin 3 or pin 6 of V-503.
   - b. Connect sync input to IR jack or cable 41.
3. Make the following adjustments:
   - a. Tune in maximum radar targets in MANUAL, so that klystron is in the 150-volt mode.
   - b. Switch to AFC.
   - c. Adjust C-510, C-516, and C-504 (in that order) for maximum amplitude of signal on the TS-34. (See illustration for scope pattern.) NOTE: C-516 and C-504 tune broadly, while C-510 tunes sharply.



Correct Scope Waveform

ERRATA November, 1951 issue, page 13: Mr. Spencer Ross, author of "The Platte Story," was inaccurately referred to as "Ass't Engineer, Systems Engineering Group." His proper title is "Senior Engineer, Microwave Systems Engineering Group." (Our most sincere apologies to Mr. Ross.)

Same issue, page 24: The headline for the "carried-over" material at the bottom of the page should read "AN/MPN-1" instead of "AN/APN-1."

Also see "Letters to the Editor," page 2 of this issue, for an erratum note regarding that column.

Solution to . . .

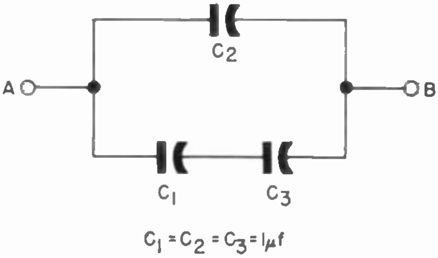
Last Month's "What's Your Answer?"

At the end of step 4, C_2 will be charged to 10 volts, with C_1 and C_3 each charged to 5 volts.

The solution is as follows:

With S_1 in position 2, each capacitor will charge to 10 volts. When S_2 is closed, C_1 and C_3 each assume a 15-volt charge, and when S_2 is opened, C_2 will remain discharged. When S_1 is moved to position 3, C_1 and C_3 will charge C_2 until the voltage across C_2 is equal to the combined voltages across C_1 and C_3.

The resultant circuit, after step 4 in the problem, is shown in the figure. The total capacitance between points A and B is now 1.5 μf., whereas C_1 and C_3 formed a combined capacitance of .5μf. It follows, therefore, that if C_1 and C_3 were charged to a total of 30 volts, the new 1.5-μf. equivalent, being three times as large, will be charged to one-third of the initial voltage. Therefore, the charge between points A and B will be 10 volts. This is the voltage across C_2. C_1 and C_3, being equal in capacitance and connected in series, must have equal voltages which add up to 10 volts. Thus, C_1 and C_3 each have a 5-volt charge.



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In Coming Issues

Next month, another of Gail W. Woodward's TV articles will appear — this one titled "TVI Elimination." The article grew out of a letter the author recently wrote to Captain Rodney Applegate, Post Signal Officer, at Fort Knox, Kentucky. (Captain Applegate had some TVI problems, and Gail's letter was so comprehensive that we asked him to expand it into an article.)

Of particular interest to those BULLETIN readers who enjoy building test equipment, is an article, scheduled for the February issue, titled "A Secondary Frequency Standard," by Philco Field Engineer John Servetnick. The article describes a relatively simple device, easily constructed on a 3″ x 5″ chassis from miniaturized parts; however, it is capable of most functions ordinarily available only from equipments much more complex and expensive.

Two Useful Tools For Radio-Compass Maintenance

By Ralph R. Saylor

Philco Field Engineer

Easily constructed test equipment to facilitate operational checking and adjustment of the AN/ARN-7 or similar radio-compass equipment.

HAVE YOU ever wished that there were a simple, positive method of line-checking radio-compass operation, or that someday some nice gadget would come along to permit super-accurate data-line correction, while at the same time making adjustment of the loop compensator a less nerve-wracking job? Here are two easily constructed "headache eliminators" which considerably simplify the testing and maintenance of radio-compass equipment.

TARGET SIGNAL GENERATOR

The first, a target signal generator for operational line testing of the radio compass, requires but a few parts, and, unless a showroom model is desired, can be assembled in one afternoon. Table I lists the parts needed to build the signal generator; the circuit used is shown in figure 1.

The main component of the signal generator, the coil section, is an r-f coil section from the AN/ARN-7 compass receiver. The coil section shown in the illustrations was obtained from a smashed receiver in salvage, although the part is carried in Air-Force stock. (Be sure to reverse the plate and B+ leads as shown, to fulfill the requirements for oscillation.) The tube used in the circuit, a 1C5, is a "hot" little power pentode. For a band-change switch, any long-shaft, four-position, wafer switch with a good detent can be used. Don't worry if the switch you find has broken wafers, because only the shaft and detent are utilized. For a chassis, an I-196 box

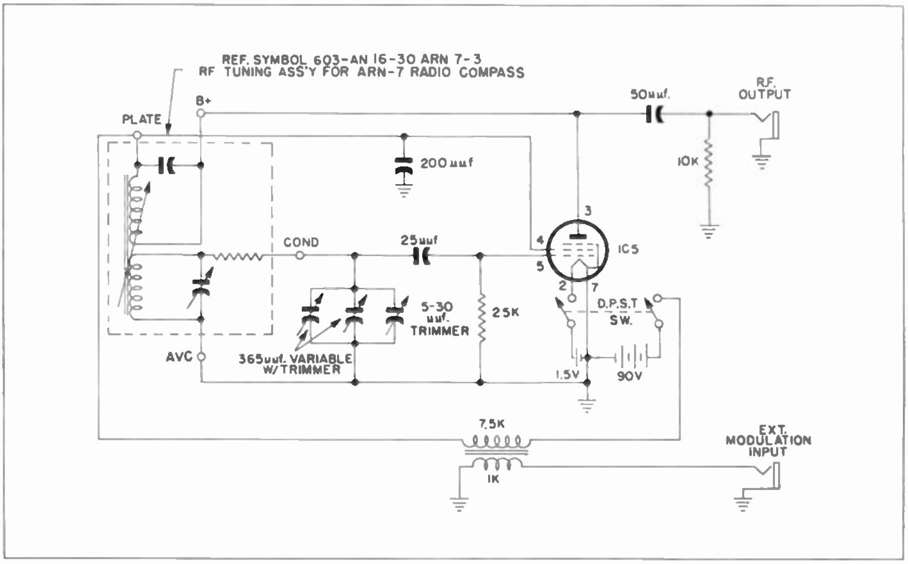


Figure 1. Schematic Diagram of Target Signal Generator

RALPH R. SAYLOR was born on March 20, 1923, at North Canton, Ohio, where he received his early education.

Prior to World War II, he spent three years in training as a tool-and-die maker, an experience which ably supplemented his later training as an electronics technician, and which fitted him well for the design of special maintenance devices such as those described in this, his first BULLETIN article.

In February, 1943, he enlisted in the U. S. Marine Corps, and, after a year of training in the maintenance of airborne electronic equipment, at NATTC, Corpus Christi, Texas, he was retained as an instructor at this same school for 18 months. He also was assigned to an Air Warning Group at Cherry Point, North Carolina, for three months prior to his discharge from the Service.

After the War, he was employed by the Ford Motor Company in Canton, Ohio, where he performed maintenance on industrial electronic equipment until he joined Philco, in October, 1950.

and carrying bag was used, which more or less dictated the parts layout, but any suitable chassis will do. The tuning capacitor used was a variable, 2-section, 365-µµf. capacitor; however, only one section was used. It was salvaged from an old broadcast, t-r-f receiver. The modulation transformer may or may not be included, as desired. At one time, this set was the only signal generator in the shop, and to obtain a modulated signal a portion of the 115-volt, 400-cycle power from the compass mock-up was tapped off through a voltage divider and a potentiometer. The antenna used was an old IFF antenna with the hexagonal portion sawed off; however, any steel rod which will fit into a PL-55 will do. The end which fits into the plug is filed off, soldered to the plug tip, and insulated

Table I. Parts Required to Construct Target Signal Generator

Quantity	Item
1 ea.	Tuning assembly, r-f (from ARN-7 radio-compass receiver R5 or R5A), A.F. Stock #1600-214349 486, or Sig. C. Stock #2C 3035-5/T7.
1 ea.	Tube, vacuum, 1C5
1 ea.	Socket, octal
1 ea.	Detent mechanism and shaft (from single-pole, 4-position wafer switch)
1 ea.	Switch, d.p.s.t.
2 ea.	Jack, phone
1 ea.	Plug, phone, PL-55
1 ea.	Transformer, audio (1000-ohm primary, 7500-ohm secondary)
1 ea.	Capacitor, variable, midget, 365 µµf.
1 ea.	Capacitor, trimmer, 5-30 µµf.
1 ea.	Capacitor, mica, 200 µµf.
1 ea.	Capacitor, mica, 25 µµf.
1 ea.	Capacitor, mica, 50 µµf.
1 ea.	Resistor, 25K, 1w.
1 ea.	Resistor, 10K, 1w.
2 ea.	Knob (with pointer)
2 ea.	Battery, BA-53, 45v
1 ea.	Battery, BA-35, 1.5v
1 ea.	Antenna, AN-95-A, A.F. Stock #1660-202 312 000 (or any steel rod that will fit into a PL-55)
8 ft.	Tubing, aluminum, 3/8-inch (for "on-the-line" antenna)
As Req.	Hardware, misc. (for panel, chassis, and case)

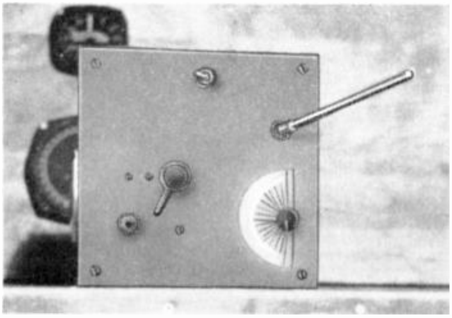


Figure 2. Front-Panel Arrangement of Target Signal Generator

from the sleeve with plastic tape. This antenna can be seen in figures 2 and 3, extending out from the front panel. These figures also show the placement of parts in the original unit.

Alignment and Operation

A paper scale was cemented to the panel adjacent to the tuning-capacitor knob, and a BC-221 frequency meter was used to align the oscillator at the low end of each band. The coil slugs and trimmer capacitors in the coil section are adjusted so that the lowest frequency occurs on each band when the tuning capacitor is fully meshed. The additional trimmer across the tuning capacitor must be juggled to accomplish this. The band-change switch should, of course, be set for the band being tuned. After these low-end adjustments are completed, the frequency meter is set to the high end of each band and a mark is made on the paper scale to indicate the position of the tuning capacitor when the generator output is zero-beating with the frequency meter. (The high ends of each band will not coincide, as the low ends did.) The i-f frequencies and trap frequencies as well as the broadcast r-f and i-f alignment frequencies should also be marked on the paper scale.

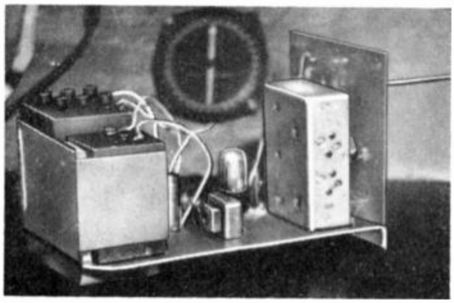


Figure 3. Side View of Target Signal Generator, Showing Placement of Parts

Figure 4. Target Signal Generator Being Used for Line Testing of Aircraft

For checking in the shop, the rod antenna serves to radiate sufficient signal for alignment checks. For line testing, an 8-foot aluminum tube is slipped over the rod, and the generator is placed about 75 to 100 feet from the aircraft, as shown in figure 4. Since the 850—1750-kc. band radiates best, the generator is set to a frequency on this band and carried in a circular path around the aircraft, while someone in the cockpit watches the indicator needle of the radio compass. Although the surrounding terrain and configuration of the aircraft in the "at-rest" position precludes the possibility of extremely accurate ground checks, the target signal generator will quickly spot the belly-mount loop which, by some means unknown to anyone, was top mounted, or will spot that loop plug which was incorrectly assembled after repair. Of course, the c-w switch on the control box should be in the "on" position for test, and the tuning indicator serves as an output indicator.

This little signal generator is extremely stable, and exhibits a barely perceptible frequency shift when the antenna is grasped in the hand. There are sufficient harmonics available from the low bands to check the higher compass-receiver

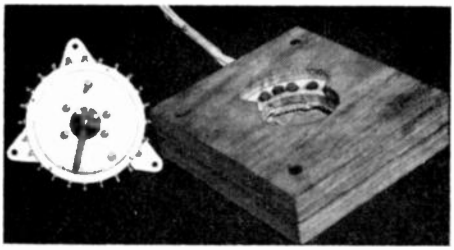


Figure 5. Pilot Model of Loop-Compensator Jig

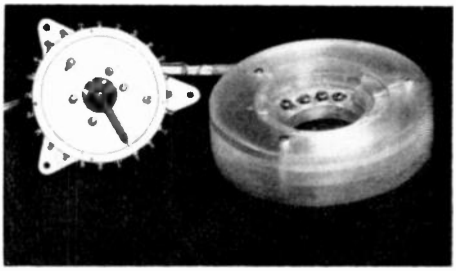


Figure 6. Later Model of Loop-Compensator Jig

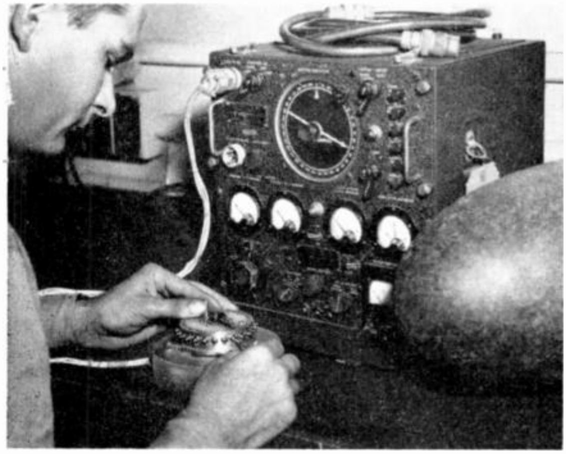
bands, but, to be absolutely certain of the correct frequency and to obtain the maximum power output, the band-change feature is a must.

LOOP-COMPENSATOR JIG

For the shop which is lucky enough to have an I-100 radio-compass test set, the loop-compensator jig is a must. Figure 5 shows the pilot model, which was hurriedly constructed from ¾-inch plywood. This little beauty is the brain child of T/Sgt. W. W. Padgett, Shop Foreman of Communications and Radar Repair, 314th Maintenance Squadron. Figure 6 shows a deluxe version of the little gem, constructed of ¼-inch plexiglass sheets. In each case, the contacts (brush-holder springs on the pilot model, and screws on the deluxe model) are soldered to springs which, in turn, are soldered to wires terminating in a PL-112 from which the threads have been filed off to simplify plugging into the test set.

The terminals of the compensator contact the spring-loaded contacts in the jig, and the compensator and test set function exactly as they would if the compensator were assembled in the loop. For super-accurate, speedy, correction, compensation is adjusted in the usual manner except that the master test-set indicator is used instead of the scale on the periphery of the compensator. Those .5° corrections are very easy to see on the large indicator scale. Figure 7 shows a loop compensator being adjusted by means of the jig and the test set.

Figure 7. Adjusting a Loop Compensator, Using Jig and Test Set



If you build this jig, your local instrument shop will probably be using it half of the time, because establishing electrical and mechanical "zero" after lubrication of the compensator simply involves holding the pointer at zero (with the autosyn excited from the test set), turning the shaft with a small Phillips screwdriver until the master indicator reads zero, and then tightening the pointer on the shaft. This is the only absolutely accurate method for re-establishing electrical and mechanical zero, and is certainly easier than trying to match a scribed line on the pointer with a similar line on the autosyn shaft.

The investment of a few hours of time in the construction of these worthwhile tools will pay large dividends in time saved and in peace of mind.

Tester for Octal-Base Relays

By Howard Bushman

Philco Field Engineer

A description of the construction and use of a simple relay tester.

A NATURAL result of the trend toward making radar equipment more automatic has been the increased use of relays. When the number of relays in one radar set reaches approximately one hundred, the need for a relay tester becomes quite apparent.

The tester described here was designed to test two types of octal-base relays—the 120-volt, a-c type and the 28-volt, d-c type. It is also possible, by a method described below, to check 50-volt, d-c relays. All of these relays are of the double-pole, double-throw type, with one pair of contacts normally closed in each set (see figure 3). Operation of the contacts, as well as continuity of the coil, is checked by the tester.

CONSTRUCTION

The metal chassis for the tester measures approximately 7 x 5 x 4 inches. This can easily be made locally in a sheet-metal shop. Figure 1 shows the top view of the tester, and the layout of the various parts. The parts required for the tester are listed in Table I, and are all available in any electronics shop. A double-pole, double-throw switch can be used for S_2, but tests will be simplified if this switch has a center "off" position.

There is nothing tricky in the wiring; however, if it is desirable to use the set to check 50-volt, d-c relays, a third switch (to short R_2 out of the circuit) should be added. The circuit of the tester is shown in figure 2.

TABLE I

Parts List for Relay Tester

R_1 - 150 K
R_2 - 400 ohms
C_1 - 15 µf
F_1 - 3-ampere fuse to fit holder
I_1 - Neon bulb
SR_1 - Selenium rectifier
X_1, X_2 - Octal sockets
P_1, P_2, P_3, P_4 - Suitable test prods for inserting in octal socket
S_1 - D-P-S-T toggle switch
S_2 - D-P-D-T center "off" switch
Fuseholder
Power cord
Socket for neon bulb
Chassis (4" x 5" x 7")

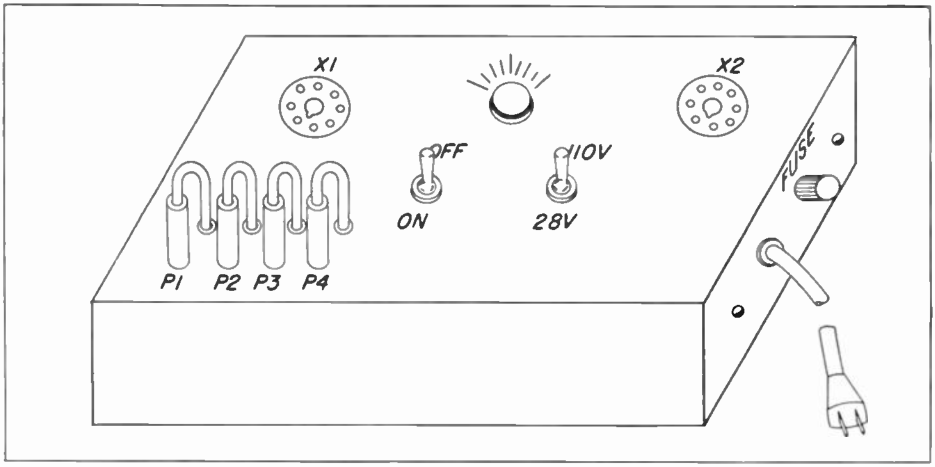


Figure 1. Top View of Relay Tester

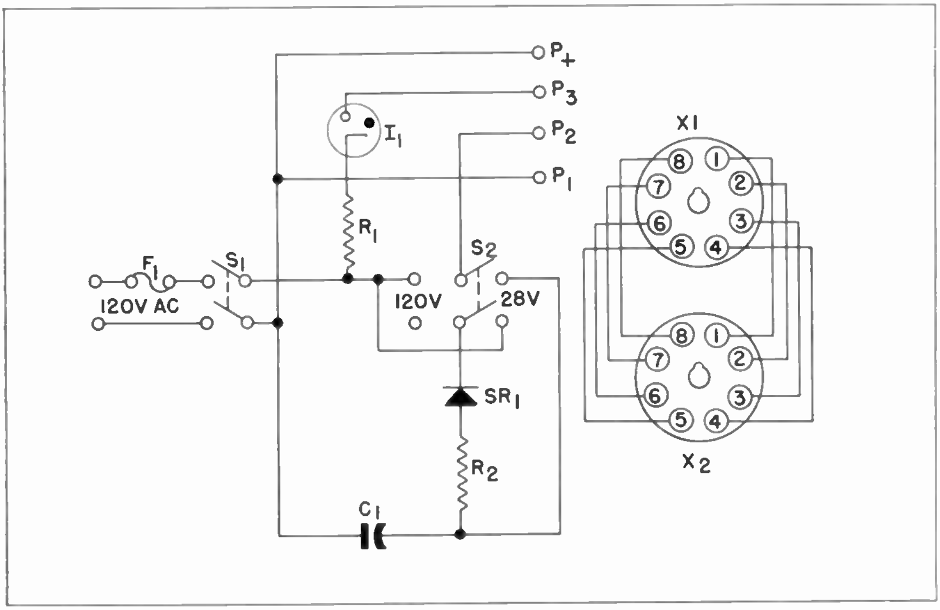


Figure 2. Schematic Diagram of Relay Tester

Test leads P_1, P_2, P_3, and P_4 are short lengths of hookup wire with test prods fastened on the end. They are to plug into the holes of socket X_1, and any prod which will make good contact in the socket may be used. Four holes are drilled in the chassis, adjacent to the test leads, to serve as holders for the prods when the set is not being used.

(Editor's Note: Blank pin jacks could be used here as holders, to eliminate the possibility of short circuits during continuity tests.)

OPERATION

The operation of the tester is very simple. For example, assume that a double-pole, double-throw, 120-volt, 60-cycle relay (figure 3) is to be tested. The relay contacts which are connected to socket pins 1 and 4, and 8 and 5 are normally closed, while the contacts connected to pins 4 and 2, and 5 and 7 are normally open. Pins 3 and 6 are the connections for the relay coil.

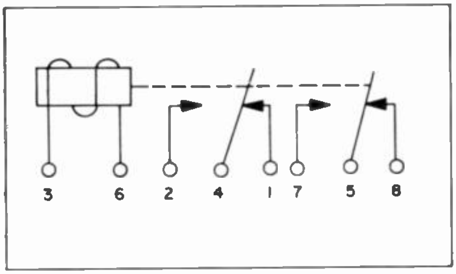


Figure 3. Schematic Diagram of Typical Octal-Base Relay

Before starting to test the relay, place "on-off" switch S_1 in the "off" position, and voltage-selection switch S_2 in the "120-volt" position. Test prods P_1 and P_2 are placed into pins 3 and 6 of socket X_1, and prods P_3 and P_4 are inserted into pins 2 and 4. The relay is placed in socket X_2, and the power plug is connected to a 120-volt, a-c supply.

Turning switch S_1 to the "on" position should cause the neon light to glow. This indicates that the normally open contacts have been closed, and the relay is operating. If the light does not glow, the relay is defective.

Next, either remove P_1 from socket X_1, or, if S_2 has a center-off position, put S_2 in the "off" position. This should cause the light to go out, indicating that the contacts have opened. If these contacts are sticking, the light will not go out. The other pair of normally open contacts may be tested similarly.

To test the normally closed contacts, which are connected to pins 1 and 4, and pins 5 and 8 of the test sockets, the preceding steps are again followed. However, test prods P_3 and P_4 are inserted into socket pins 1 and 4, instead of pins 2 and 4. When the power is applied to the relay, the light should not glow, and when the coil is de-energized, the light should glow. Any deviation from this will indicate a defective relay.

CONTINUITY CHECK

When the above tests show malfunctioning of the relay, the coil should be checked for continuity. This check will serve to determine whether defective operation is due to the coil or to bad contacts.

Power switch S_1 is placed in the "off" position, and prods P_1 and P_2 are removed from socket X_1. Care should be used to see that the prods are not shorted together. Prods P_3 and P_4 are placed in pins 3 and 6 of socket X_1.

Turning switch S_1 to the "on" position should now cause the neon bulb to glow. If the neon bulb does not glow, the relay coil is open. However, if the bulb glows, then the previous indications of defective relay operation were due to bad contacts, or to binding of the armature.

If both sets of contacts exhibit the same indication, the cause is probably that the armature is not free to move. However, if only one of these sets of contacts tests defective, the faulty contacts are either dirty or welded together.

With a slight amount of practice, a relay may be tested in 30 seconds or less. When continuous testing is to be done, it is suggested that four sets of continuity test leads and four neon bulbs be used, together with an energizing switch. This will permit even faster testing of relays.

The relay tester described here was originally designed and built by Sgt. Victor Johnson and Sgt. Merlin Welch, both of the 752nd AC&W Squadron, with the help of the author. Approximately 8 man-hours were required to construct the tester.

WHAT'S YOUR ANSWER?

The problem this month looks very easy, but it is best to check the answer before trying the circuit. We find that there is a tendency to wire short circuits into the solution.

The technician has the following items available: a 110-volt power source, a d-p-d-t toggle switch, and two 40-watt, 110-volt lamps. The object of this problem is to wire the switch and the bulbs to the power source so that the switch will connect the lamps in parallel (across the 110-volt power source) in one position, and in series in the other position. Of course the series-lamp circuit will produce a dim light, while the parallel connection will produce full brilliancy. The two switch positions can be labeled BRIGHT and DIM.

(Solution next month)

"ELI the ICE Man"

Many times when instructing new personnel in basic theory, the field engineer may find that his students have a difficult time remembering the phase relationships between voltage and current in an inductive or capacitive circuit.

One remedy for this situation is to ask the student to remember the phrase, "ELI the ICE Man," where E is voltage, I is current, L is inductance, and C is capacitance. The phase relationships are now obvious. In the word ELI, E precedes I; therefore, the voltage leads the current in an inductive circuit.

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