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AIR NAVIGATIONAL FACILITIES

by

H. S. CHRISTENSEN

THE RADIO CLUB OF AMERICA, INC.
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AIR NAVIGATIONAL FACILITIES

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Aircraft Radio Corporation
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BEFORE ELECTRONICS, many elaborate schemes were evolved whereby the aircraft could be flown by dead reckoning to points more or less in proximity to the destination. The magnetic compass was the only instrument available and the pilot was kept busy verifying his position whenever an opportunity presented itself in the form of a town, river or other outstanding geographical landmark. Rotating light beacons were installed along some of the principal air routes to assist in visual navigation at night.

EARLY RADIO SYSTEMS

Some time later the 4-course radio range was proposed and work was started on its development. The first operational low-frequency range opened a new era of air navigation. Although nowhere near perfect it was the first enroute navigational information available to the pilot of other than a visual nature. Upon establishment of proof as to its operational feasibility, an aggressive program was undertaken to establish airways along which pilots could fly using this directional guidance. This low-frequency range provided four courses and the pilot could fly along any one of them using a simple receiver. Each of the sectors were identified as an "A" quadrant or as an "N" quadrant and since there were two of each, it was necessary to establish which one the pilot was in. Rather extensive and time consuming procedures were worked out so that orientation was possible.

Quadrants were identified by Morse characters "A" and "N" which the pilot had to learn to identify, and so resulted his first introduction to radio. It later became necessary to identify each station as the number increased and he had to learn still more. Sometime earlier, Kenny of the Department of Commerce and Doolittle (of Air Force fame) had been working with the newly developed bank-and-turn indicator. Using this instrument and the engine tachometer (with no such thing as a controllable or constant speed propeller at that time), they had worked out a system whereby they could actually fly into a large cloud and come out the other side right side up. The bank-and-turn indicator told them whether they were turning and if the airplane was in a skid or a slip, while the tachometer provided information as to whether the nose was too low or too high. If the nose got down the engine would speed up and vice versa. Here was the basic information required for instrument flight. In combination with the information available from the new ranges, it now appeared possible to fly along the beam without reference to the ground. Kenny made the first all-instrument cross-country flight from Washington to Mitchell Field and thereby created sensational news of that day. Descent from a high altitude at this stage was not infrequently accomplished by spinning the airplane down through the overcast. This appears foolhardy in the extreme, but it must be remembered that the spin was the only controlled descent maneuver known to most pilots at that time.

Soon better procedures were developed to permit let-downs over the range and to airports which lay along one of the legs. Instrument flight had begun in earnest. However, increased usage began to uncover the usual number of bugs inherent in any new device or system. Such things as fading, skip, bent and shifted beams, multiple courses, swinging beams, false cones, and that greatest bugaboo of all -- static -- began to plague the pilots. Several of these vagaries soon were recognized and methods devised to circumvent their effects. The lone holdout -- static -- continues to be the greatest scourge to successful use of the low-frequency radio facilities.

As soon as more than one airplane got into the air in a given locality at one time, the requirement for adequate communication made itself felt. Air-to-ground radio telephone transmitters were developed and a means for simultaneous voice transmission on the range frequency was devised. Traffic control was still no problem since the pilots could keep out of each other's way so long as each knew where the other was and there were not more than two or three airplanes involved. Unique let-down

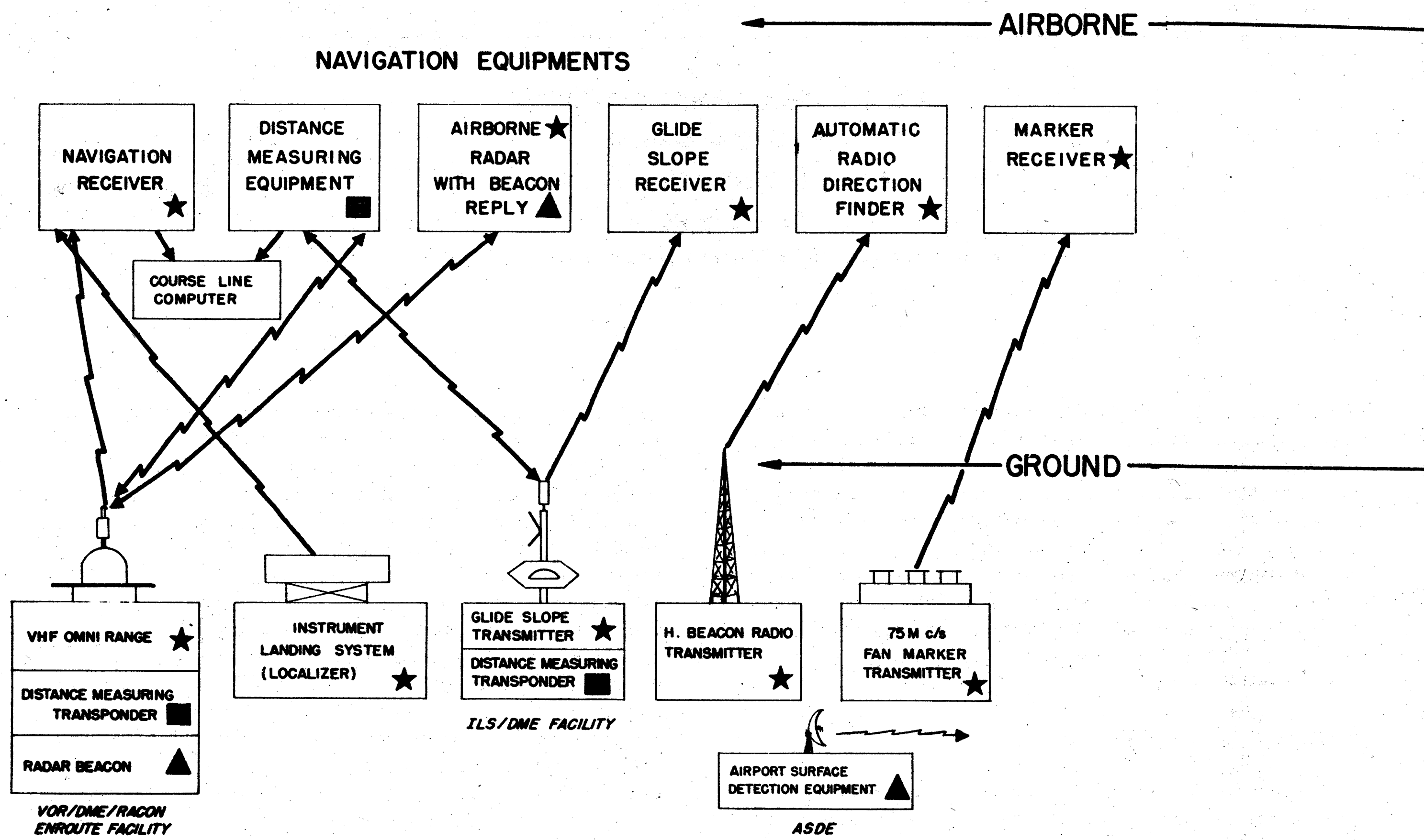


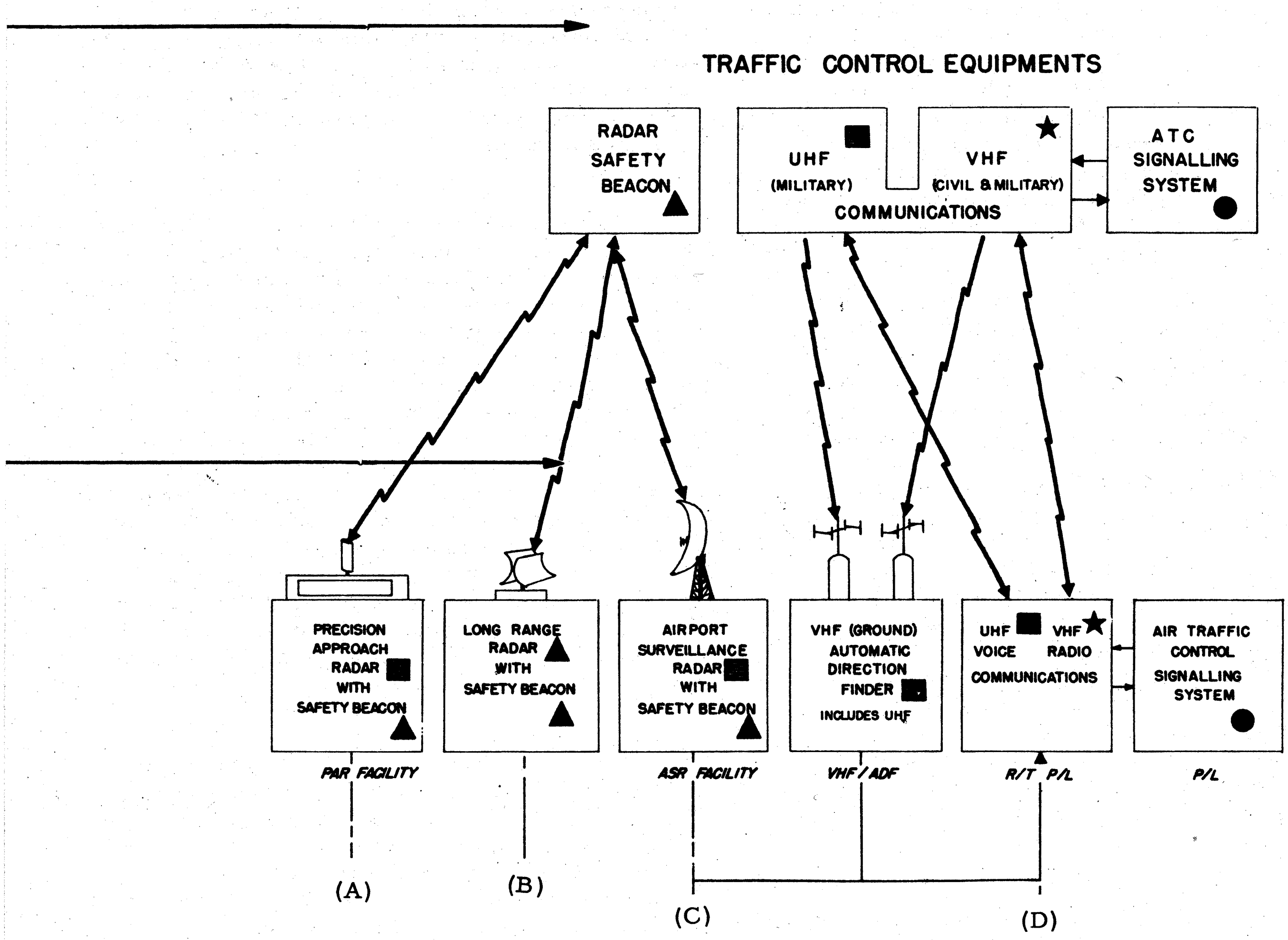
Fig. 1--Types of air navigation facilities and their present state of development. Explanation of symbols is given in Fig. 2.

procedures were devised at some airports where no range let-down was available.

For instance, one of the mail pilots found himself caught above an overcast at Chicago. He could see the lights of the city glowing through the clouds but had no way of knowing exactly where he was. Suddenly smelling the old Chicago stockyards, he immediately reduced power, turned left, and let down to a successful landing. Believe it or not, this was standard procedure for some time at Chicago. Its reliability depended to a great extent on the thickness of the overcast resulting in attenuation of the stockyard odor, and could not be used at all if the pilot had a cold. Similarly, at Kansas City the Bell Telephone Company very considerately put up a new telephone building which seemed always to penetrate through the low-lying Missouri River fog and city smoke. It just happened that the North face of the building was in perfect alignment with one of the runways at the airport and all the pilot had to do was to align himself with the North face of the building and let down to the runway.

These attempts to fly aircraft under instrument conditions spurred the development of better instruments, better communication, and better airways aids. The artificial horizon was developed and revolutionized the field of control of the airplane's attitude with respect to the earth (and gravity). Reliable air-speed indicators came into being. Simultaneous voice on the radio ranges provided the pilot with the latest weather information. At first ground operators just looked out the window for weather information. Then they started calling the local weather bureau for additional information. Finally the Bureau of Lighthouses, Department of Commerce (the CAA of that day), set up communications stations which could communicate and exchange weather data between themselves and thence to the pilots. Everybody in the air was strictly on his own in all respects, but as the number increased it became apparent that some sort of control would have to be exercised and so enroute traffic control was born.

Enroute traffic control exists for the sole purpose of preventing mid-air collision. To exercise such control requires certain information for the use of the controller and so the flight plan came into existence.



The pilot is required to furnish all pertinent information regarding his flight such as time of proposed take-off, air speed, route to be followed, altitude of flight and other details. With this information the controller can then assign a moving block of air 10 miles wide, 30 miles long, and 1000 feet thick in which the airplane can fly without having to worry about additional occupancy. As aircraft speeds and the number of airplanes in use increased, it was astonishing how soon the available elbow room was used up. One of the greatest problems was that all of these moving blocks must eventually converge at that relatively tiny spot in space known as the airport.

APPROACH CONTROL

To expedite the handling of aircraft within this limited air space "Approach Control" was created. Until recently the only information as to the position and progress of an airplane was that reported by the pilot as he made his way along his route. This information formerly was only as reliable as the reporting individual's ability to properly interpret his position. The requirement for positive fixes became a must. Accordingly, 75-megacycle marker beacons were installed at known points so that when the airplane arrived over one of them, a signal was received in the cockpit and the pilot could know and report his exact position. These markers also are used to locate high points along airways as well as other types of obstructions.

It can readily been seen that positions could only be estimated when the airplane arrived at a known geographical point. Then, the controller began to have something to work with. If no other airplane was in the area, the pilot could be cleared for a standard range approach to the airport. At this stage of development the usual letdown required from nine to fifteen minutes depending on the direction of approach, initial altitude and the competence of the pilot. All of the foregoing was still subject to the pilot's ability to read communications and to hear the low frequency range through the probably high level of atmospheric static.

Imagine the limitation imposed by such a system at LaGuardia Airport where peak traffic on July 2, 1954, reached 927 and on July 16th between 5 PM and 6 PM there were 40 take-offs, 28 landings and 7 helicopter movements accomplished. That is 75 operations in one hour. Such a rate is impossible to handle today under instrument conditions. It does typify the problem confronting us in the matter of expediting the handling of traffic since the use of aircraft in all kinds of weather produces a traffic potential of the magnitude cited here.

Communications had to be improved and operations had to be speeded up. Demands for more reliable scheduled operations had to be satisfied. The vagaries of the weather had to be overcome to the greatest possible extent. Operation in all but the worst weather conditions had to be achieved. The flying public demanded better air service. Limited airways routes had to be expanded to include all of the usable airspace. Schedules had to be tightened and straight lines had to be flown. More airplanes meant more and better control and that depended chiefly on better and faster communication. Tighter schedules and direct routes demanded better navigational facilities. Increased utilization of airports made airport traffic control imperative since no longer could each pilot proceed in accordance with his own desires any more than could auto traffic proceed at busy intersections without some sort of control. Such was the situation at the end of World War II.

POST WAR DEVELOPMENT

World War II served as a tremendous stimulant to development of technical devices. VHF radio communication had been developed to a point of reliability and performance unequalled by any other medium for short range work. Small, light equipment capable of operating in aircraft was soon to be produced. Dr. Luck had conceived the Omnidirectional range back in 1925 which would at last remove the inflexibility of the four-course range and permit full utilization of the airspace. The CAA had developed this device and had put it on very-high frequency. It was almost ready to go when the war came along and it had to be put on the shelf. Other developments during the war brought forth practical instrument landing systems, radar, vhf, df and navigational aids of all kinds. Soon many of these were to be put to work to solve the overwhelming tasks involved in increased utilization of the air space.

In 1946 the CAA began the installation of VHF Omni-ranges (VOR) in a program destined eventually to replace the old low-frequency four-course ranges. Instrument landing systems were taken over from the military, improved, further developed and are now standard throughout the country. Distance Measuring Equipment (DME) was conceived using radar principles developed during the war which would inform the pilot as to his exact position at all times. VHF DF equipment is in use by the military on a large scale and at a few CAA operated locations.

Earlier a modification of the four-course range had been devised wherein the visual aural range was placed on very high frequency and was designed to provide two visual courses and two aural courses. These are gradually being replaced by the Omniranges although some eleven of them are still in use. All of the foregoing leads us to our present day system of enroute aids, landing aids, communication systems, airways traffic control systems, airways and terminal radar systems, and local terminal approach and control systems. Most of the low-frequency range stations, Omni stations, and homing facilities along airways are manned 24 hours a day. These stations also provide communications and are known as INSACS. Each of these warrants a brief explanation of its operation in order that its place in the overall system may be best comprehended.

First of these facilities is the Low-Frequency Four-Course Range. These ranges operate in the frequency band from 200 to 400 kilocycles. They provide four legs or beams which can be followed by listening to an aural signal. If the airplane is on course the pilot hears a steady tone interrupted at intervals by the identification signal. If off course, the pilot will hear either an "A" or an "N" signal depending on which side of the course he is on. The legs, or beams, are usually aligned along airways although there is provision for swinging a leg to a new position for specific purposes. In using these ranges it is imperative that the pilot know definitely where he is when he starts his navigational problem. If he doesn't, he must resolve his position before proceeding. These ranges are subject to the disadvantage of inflexibility and atmospheric static. They are not infrequently unusable in regions of thunderstorm activity and are peculiarly susceptible to the phenomena known as precipitation static. There are currently some 350 of these ranges in operation although this number is destined to eventually be reduced to about eighty. The remaining ranges will serve to augment coverage in mountainous terrain where the VHF Omniranges do not provide fully satisfactory coverage.

OMNI-RANGES

The VHF Omni-directional range or VOR, is the modern counterpart of the old low-frequency range. The frequency has been changed to VHF where crash static is of no consequence and where precipitation static effects are very greatly reduced. Three of the four legs of the four-course range have been removed leaving one leg. Now for the first time, the pilot can be guided to where he wants to go rather than to some place where the beam has heretofore happened to be aligned. Along with this freedom of choice also goes an indicator in the cockpit which tells him whether the bearing chosen, or the one he is on, is the magnetic bearing to the station or whether it is his bearing from the station. Thus the ambiguity of position with respect to the station is resolved.

Along the airways there are 269 fan markers which operate on 75 mc and provide definite geographical fixes. These markers transmit radio frequency energy in a definite vertical pattern so the pilot hears them only while directly over them. Most marker receivers also provide for the operation of a light signal for attention-getting purposes. The airways fan markers are coded for identification and the codes are assigned in accordance with their position along the airway. In addition to providing definite fixes, they are frequently used for establishing holding patterns when the airplane must remain outside a control area for a period of time. Another of the 75-mc markers is known as the Z-marker which is operated at the site of the low-frequency ranges. This marker supplements the so-called cone of silence for determining actual time over a low-frequency range. They are also used at the outer and middle markers on instrument landing systems.

Another airways aid is the non-directional radio beacon or "H" facility. Used in conjunction with an ADF receiver or a low-frequency receiver and a manual loop, they too provide a definite geographical fix. They are used along airways as reporting points, as let-down facilities, and for defining the inter-sections of two or more airways. Ground to air communication is frequently carried on over the "H" facility. They operate in the same band of frequencies as the low-frequency range and are therefore subject to the same problems of static. A recent addition is the DME or distance measuring equipment. This facility is located at the same spot as the Omni-ranges as well as at the touchdown points on runways when used with conjunction with instrument landing systems. The purpose of the distance measuring equipment is just what it says, to tell the pilot how far he is from a given point.

AIR TRAFFIC CONTROL

These are the aids provided along airways so that the pilot may follow the instructions, routings and procedures laid down for airways navigation.

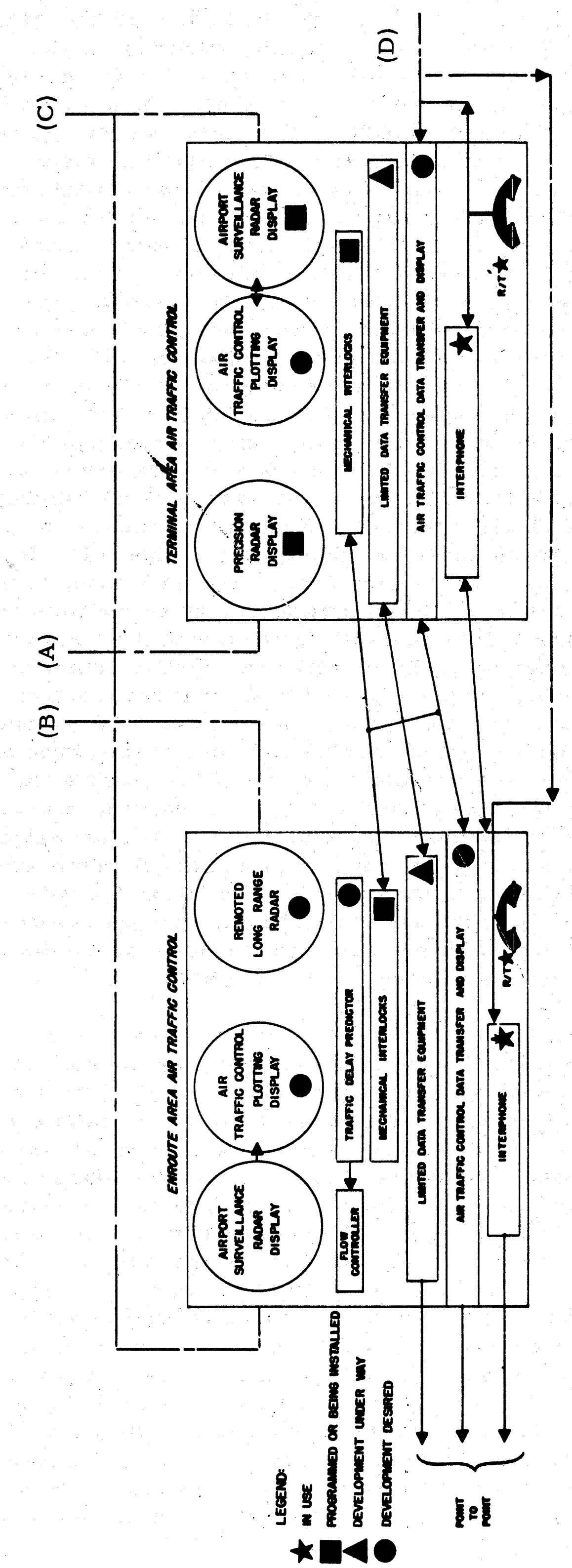


Fig. 2--Enroute and terminal traffic control centers. Letters indicate equipment of Fig. 1 used by these facilities.

The United States is divided into about 30 airways control areas. All aircraft operating under instrument conditions within each of these areas is under the direct control of the Air Route Traffic Control Center or ATC. The center is very appropriately named for here it is that the responsibility rests for channeling air traffic into, within and out of the area being controlled. Here each aircraft must be fitted into the flow of traffic in and through the area. Flight altitudes must be assigned each aircraft, speeds co-ordinated for same altitude utilization, overtaking and passing procedures established, co-ordination with the next control area to be penetrated, so the aircraft will not be delayed, determination of arrival time at destination, airways crossings arranged, together with a myriad of other details aimed at insuring the aircraft sole occupancy of the moving block of air assigned. When all of this is done, clearances must be transmitted to the pilot, to the center for the next area to be penetrated, to the destination and to all stations which at one time or another will be in radio contact with the aircraft along the way. Each center has certain communications channels assigned to it for direct communication with the aircraft in its area. All ground communication is carried on by either telephone or teletype circuits which link all of the centers and their satellite ground stations. Provisions must be made for handling any emergencies which may arise, for changes occurring as a result of unexpected headwinds or tailwinds which will change the rate of progress of the aircraft, altitude changes required when heavy icing occurs and for initiating holding instructions in case of a traffic jam.

Here it is that electronics reaches the peak of usefulness since it is here also that all of the aircraft travelling along airways must eventually converge. At the modern airport facility 20 or more communications channels are in use simultaneously. Range stations, fan markers, intersections of range legs or Omni radial, homing facilities, terminal Omnis, compass locators, air route radar, approach radar, departure radar, precision approach radar, the instrument landing system and high intensity approach lights all play their part in maintaining proper separation of aircraft and sequencing of the landing operation as well as assisting in the descent of the aircraft right down to the runway surface. This complex control system must also be ready instantly to cope with any emergency which may arise among the many aircraft in the pattern.

Here too is found a machine known as the traffic delay predictor. Its job is to take all available information and come up with a quick answer as to how long it will be before each aircraft can expect

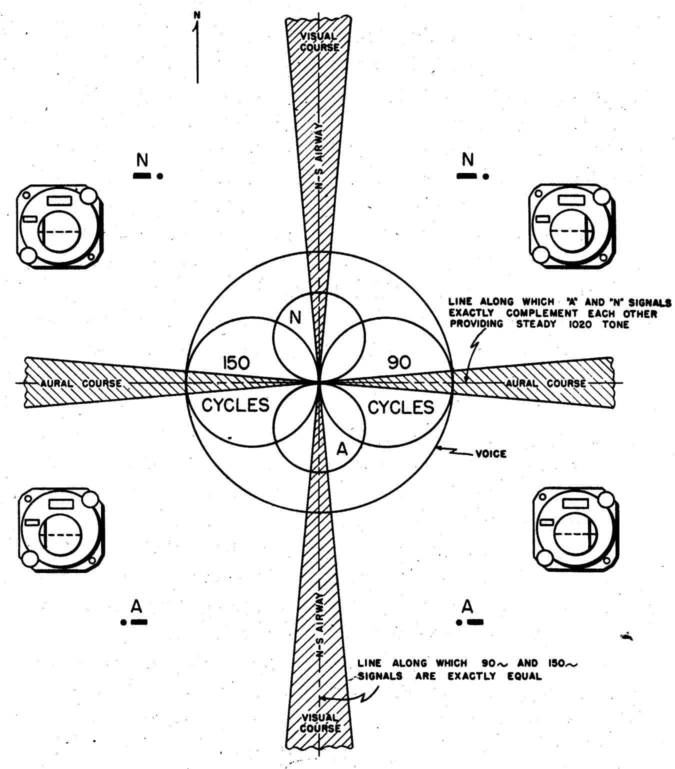
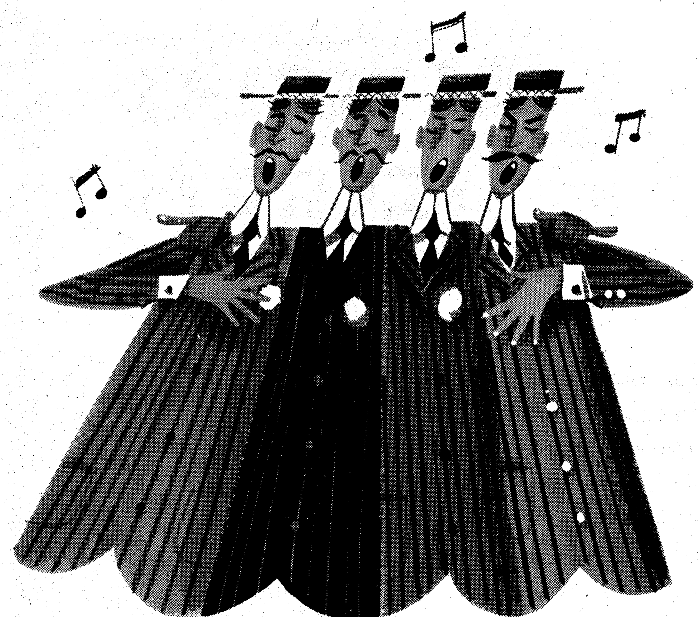


Fig. 3--Pattern of visual-aural vhf range. Combination of aural and indicator presentation is different for each quadrant.
--Courtesy Bendix Radio

approach clearance and get on the ground. Controllers must assign approach sequences, holding points when delays occur, shuffle and reshuffle aircraft from point to point so the next aircraft in the sequence is immediately ready to start its approach as soon as the path has been cleared by the preceding aircraft. These approach controllers have full responsibility for the aircraft from the time you enter the terminal area until it has completed its approach. Once the inbound aircraft has been cleared into position for an approach, it is turned over to local tower control. The final approach, landing and subsequent taxying of the aircraft to its final destination on the field is the responsibility of the tower and the ground control. They may be aided by airport surveillance radar, precision approach radar and surface detection radar permitting them to know exactly where each plane is and what it is doing while under their control. They must also see to it that the plane has an unimpeded path out of the area if it is an outbound flight. Aircraft must be guided outbound through all of the inbound traffic and fitted into the enroute traffic pattern safely, quickly and surely.

It can readily be seen that a high degree of coordination must exist between all of the controlling agencies if flights are not to be subjected to unacceptable delays and compromises with flight safety.



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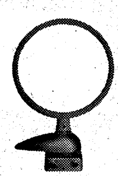
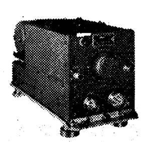
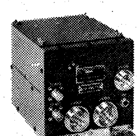
ARC COMMUNICATION EQUIPMENT







In addition to the widely used ARC Omni instruments, ARC has a complete "family" of communication and navigation equipment, designed to work smoothly together in various *combinations.*

Included are low frequency range and broadcast receivers with optional loop operation, marker beacon receivers, VHF receivers and transmitters, conversion units for UHF transmission and reception, the Isolation Amplifier to give two pilots independent simultaneous use of radio, and 8-watt amplifiers to relieve pilots of headset discomfort.

All this equipment is made to meet varying needs, from a minimum number of instruments in planes such as two-place helicopters to the more comprehensive requirements of considerably larger aircraft, and in more exacting flight plan service.

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This instrument is remarkably versatile. It can be modulated with either square waves or pulses. Its frequency can be adjusted accurately in slight increments at any point over its wide range. It is a general-purpose, thoroughly shielded source of power for use in laboratory or field. It is useful not only for driving slotted lines and the Admittance Meter but also for exciting antennas for field-strength measurements, and for high-frequency research and development work on pulse-type equipment of all kinds.

The Oscillator is designed to work with the many other G-R Unit Instruments — Oscillators, Amplifiers, Null Detectors, Pulse Generators, High-Frequency Detectors, Crystal-Controlled Oscillators, Power Supplies — to form a wide variety of flexible, economical measuring systems. These "building blocks" provide, without frills, the most in performance at lowest cost.

CIRCUIT: Grid-separation triode oscillator uses Type 5675 UHF Pencil Tube. Line sections with sliding contacts used to tune plate and cathode.

FREQUENCY RANGE: 900-2000 Mc.

HIGH UHF OUTPUT POWER: Continuously adjustable from low values to minimum of 200 milliwatts into 50-ohm load.

FREQUENCY CALIBRATION: Direct reading to 1% with slow-motion drive.

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MODULATION: Many kinds of external modulation can be applied: Sinusoidal amplitude modulation, pulse modulation and square-wave modulation from about 100 to 5000 cps.

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LOW NOISE: f-m noise due to vibration and microphonics is unusually low. Rectifier and filter for the heater voltage are built in to reduce modulation by the power-line frequency.

POWER SUPPLY REQUIRED: Type 1203-A Unit Power Supply ($40) for operation from 115-volt, 50-60 cycle power. The Type 1202-A Unit Vibrator Power Supply ($125) for operation in the field from 6 or 12-volt storage battery.

ACCESSORIES: Type 1217-A Unit Pulser for direct pulse modulation.

Type 1000-P7 Balanced Modulator for amplitude modulation up to 100% with negligible fm and pulsing with fast rise time and short duration.

Type 874 Coaxial Elements such as adaptors, attenuators, filters, voltmeters, mixers.

Type 1750-A and 1263-A Sweep Drive and Amplitude-Regulated Power Supply for automatic sweeping over the oscillator frequency range.

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Types 1217-A $225, 1000-P7 $225, 480-P7UI $14, and 874 Coaxial Elements are available from stock for immediate shipment. Types 1750-A and 1263-A will be available shortly.

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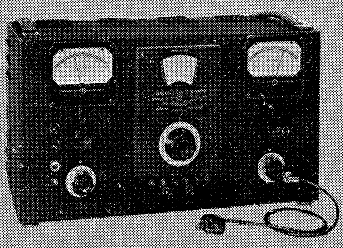

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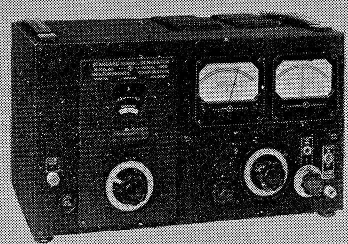

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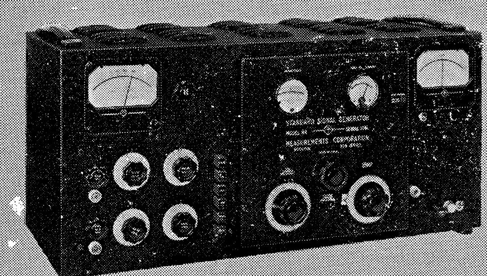

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1939 MODEL 54 STANDARD SIGNAL GENERATOR—Frequency range of 100 Kc. to 20 Mc. The first commercial signal generator with built-in tuning motor.

MODEL 65-B STANDARD SIGNAL GENERATOR—This instrument replaced the Model 54 and incorporated many new features including an extended frequency range of 75 Kc. to 30 Mc.

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1953 MODEL 59-UHF MEGACYCLE METER—With a frequency range of 430 to 940 megacycles, the first grid-dip meter to cover this range in a single band and to provide laboratory instrument performance.

1954 FM STANDARD SIGNAL GENERATOR. Designed, originally, for Military service, the commercial model embodies performance far surpassing that of equipment presently available.
Wide modulation frequency response, extremely low distortion, and high stability make this instrument useful for critical FM, multiplex, and telemetering applications.

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A DISCUSSION OF L. P. LESSING'S UNUSUAL BIOGRAPHY "MAN OF HIGH FIDELITY: EDWIN HOWARD ARMSTRONG"

by

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A COMPATIBLE SINGLE-SIDEBAND MODULATION SYSTEM

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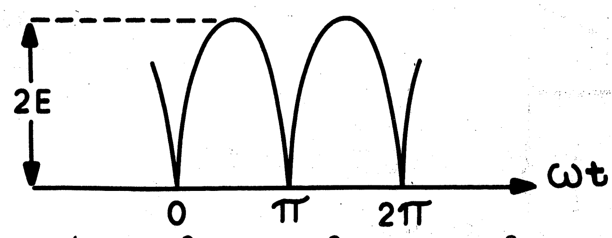
This paper describes a new modulation system that provides for spectrum economy and compares favorably in signal-to-noise and reduction of fading effects obtained with conventional suppressed or reduced carrier single-sideband systems. It is called Compatible Single-Sideband, or CSSB. Existing transmitting and receiving apparatus may be employed, and receiver tuning techniques are simple and do not require precise frequency control. CSSB is, thus, completely compatible with conventional double-sideband amplitude modulation systems.

The principle of CSSB operation may be best described by referring to the simplified block diagram in Figure 1. It may be seen that a full carrier single-sideband wave is produced by a conventional single-sideband generator. This wave is passed through a limiter in which the phase modulation component is first isolated and then amplified by Class "C" amplifiers (or amplifiers of any other class, for that matter) The signal is then fed to the modulated stage.

The full carrier SSB wave from the SSB generator is also fed to a product demodulator. Here the SSB modulated envelope is electronically multiplied by the carrier. The resulting audio wave is amplified and used to modulate the phase modulation component in the high level stage.

Since the modulation process has been made linear, the envelope wave at the output of the modulated amplifier is theoretically free of all harmonic distortion. (In practice, distortion figures of less than 1 per cent have been achieved.) Thus, demodulation in a conventional AM diode detector is achieved with theoretical zero distortion at 100 per cent modulation.

Although the CSSB wave looks exactly like AM on an oscilloscope, due to the signal's frequency modulation components, it is actually single-sidebanded, as may be seen on a Panoramic Panalyzor. (See Figure 3.)



$e = \frac{4}{\pi} E \left(1 + \frac{2}{3} \cos wt - \frac{2}{15} \cos 2wt + \frac{2}{35} \cos 3wt \ldots\right)$ 67% equivalent modulation approximately 23% distortion. For 10% distortion equivalent modulation 37.8%

FIGURE 2

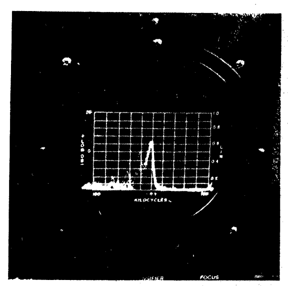


FIGURE 3

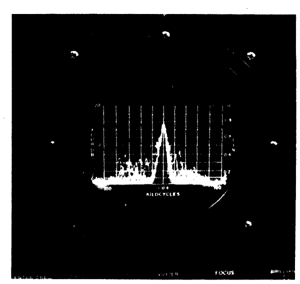
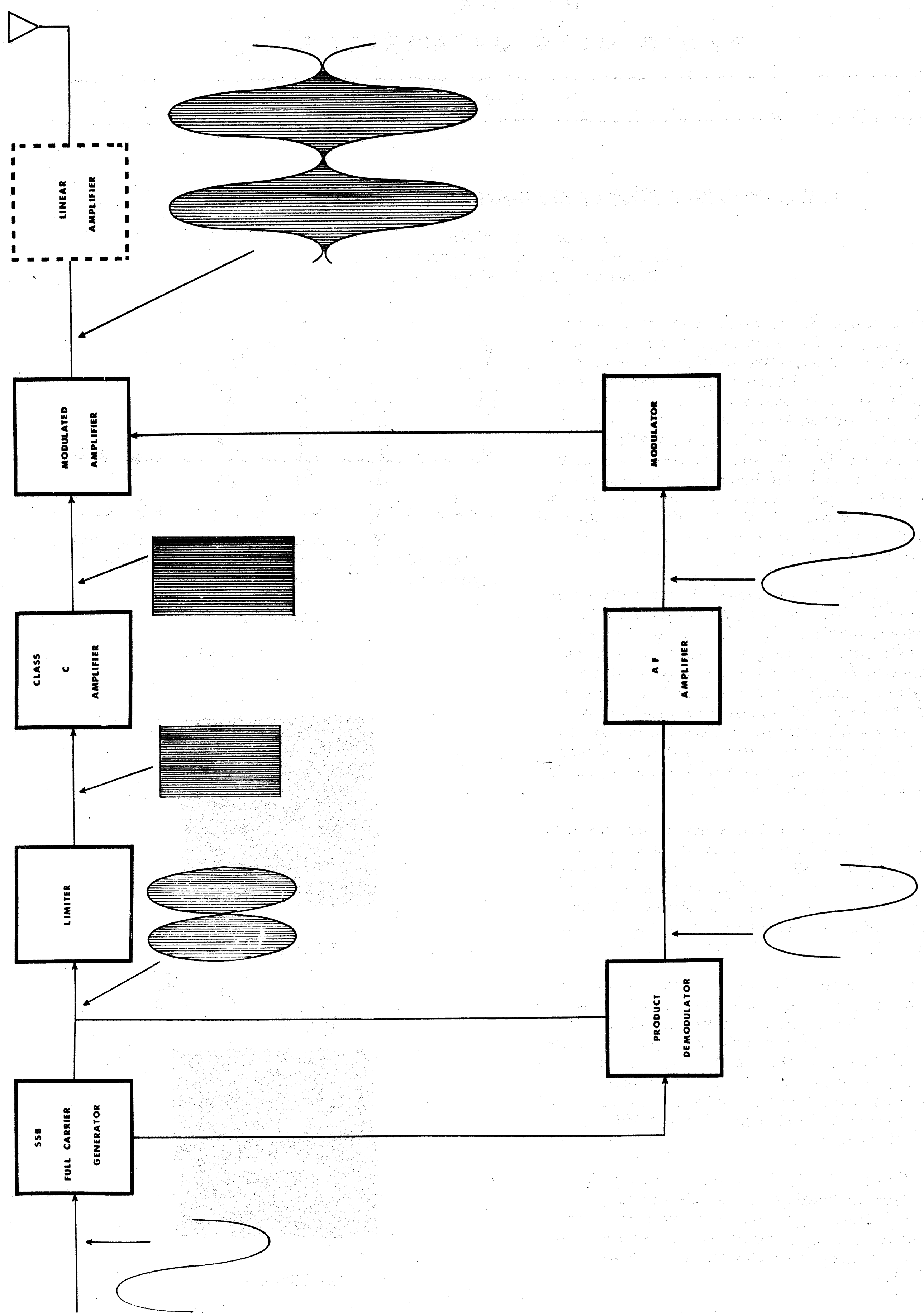


FIGURE 4



BLOCK DIAGRAM OF BASIC COMPATIBLE SSB SYSTEM

FIGURE 1

The hardware requirements for CSSB involve an adapter for the transmitter which may be easily added to an existing plant without engineering modifications. The adapter is simple to install and maintain and does not require delicate or repeated adjustments.

A CSSB adapter used in tests at a New York 50 kw broadcast station was run continuously without adjustment for two months, and the undesired sideband at the end of this period measured 30 db down from the desired sideband. When the adapter was adjusted at the beginning of the period, spurious was down 32 db. Figure 3 shows an actual photograph of the CSSB wave viewed on a Panoramic Panalyzor after two month's operation without adjustment. Figure 4 shows the waveform after switching back to conventional double-sideband AM transmission.

Obviously, the function of the CSSB adapter may be readily integrated with conventional transmitter circuits in the case of a new design.

CSSB FOR BROADCAST SERVICE

CSSB is particularly well suited for use in broadcast applications and offers the following significant advantages over normal AM methods:

1. Double to triple effective transmitted power detected by conventional home receivers.

2. Reduction of adjacent and co-channel interference through two-to-one spectrum economy.

3. Minimized selective fading distortion.

4. Improved audio fidelity

The principle advantages of CSSB are due to the following reasons:

For example, the effective doubling or tripling of transmitted power and improvement in audio fidelity result from the narrow bandwidths of most receiver RF and IF amplifiers. In other words, the full bandwidth transmitted by double-sideband AM cannot be fully utilized by these receivers. The CSSB wave, however, occupies only one half of the normal AM spectrum, thereby permitting much more efficient use of such narrow band amplifiers. Thus, CSSB offers a means for appreciably improving the effective signal-to-noise and audio fidelity of conventional home receivers. If the receiver's IF amplifier is extremely narrow, as is the case with/ most inexpensive sets, improvements in signal-to-noise greater than 3 db can be expected. If the receiver is one of the relatively few AM high fidelity sets containing wideband amplifiers, no significant improvement in fidelity or signal strength will be noted, and the only improvements will be a significant reduction in selective fading distortion and less interference.

Since the CSSB system concentrates energy in one sideband, a large reduction in adjacent and co-channel interference will be noted. In the case of adjacent channel interference, the use of CSSB can increase the spacing of adjacent sidebands by two times the highest audio frequency transmitted. Therefore, increasing the effective sideband spacing greatly reduces adjacent channel interference. Interference of this type may be divided into three main categories: (1) Sideband monkey chatter, (2) Crosstalk, and (3) Carrier heterodyne.

In the United States the 10 kc separation between carriers tends to reduce the carrier heterodyne form of interference because of the receiver's restricted IF and audio fidelity, as well as the listener's aural limitations. Crosstalk effects are greatly reduced by an AM capture effect and are relatively unimportant. The main source of adjacent channel interference is sideband monkey chatter, wherein the desired carrier beats with the undesired sideband components. With CSSB the lowest frequency of this chatter will be above 10 kc and, therefore, is outside the passband of conventional home receivers.

Co-channel interference on stations equipped for CSSB operation may be greatly reduced by tuning to the desired sideband of the carrier. The optimum tuning point appears to be 1 1/2 to 2 kc on the desired sideband side of the carrier, and with conventional home receivers this tuning point allows a signal-to-interference gain of from 5 to 8 db. Special high selectivity receivers can be used that will provide listeners in poor reception areas with as much as 30 db signal to co-channel interference gain.

CSSB also offers considerable improvement in selective fading distortion. In normal AM transmission it may be shown that the main cause of fading distortion is incorrect relative phasing of the carrier and the sidebands. This condition may be demonstrated in the laboratory by eliminating the carrier from an amplitude modulated wave and then reinserting it at different phase relationships. When the carrier differs by 90° from its correct phase, the signal demodulated in an AM detector is completely distorted. Such distortion is independent of the percentage of modulation.

Since one of the sidebands of CSSB is greatly reduced, the relative phase between the carrier and the remaining sideband is much less critical. Therefore, the system is almost completely free from this type of signal degredation. It should be pointed out that this insensitivity to phase deviation is another reason for a reduction in co-channel interference. When the undesired signal has a carrier frequency approximately equal to that of the desired frequency, the combined carriers will be phase modulated at a low frequency rate. A form of beat note distortion will be produced as the wave goes in and out the proper phase. CSSB avoids this difficulty because it is far less sensitive to phase discrepancies.

CSSB COMPARED WITH BRITISH POST OFFICE/UNITED KINGDOM STUDY

Application of single-sideband techniques to AM broadcasting has been, heretofore, considered impractical, since its adoption would involve modifications of home receivers. However, a number of years ago the British Post Office prepared a United Kingdom proposal to use a full carrier single-sideband system for high frequency broadcasting. Engineers argued that full carrier single-sideband signals could be received on conventional AM receivers. But after careful examination it was revealed that a full carrier single-sideband wave possessed some rather serious limitations. Furthermore, it would have been necessary to replace, or extensively modify, existing transmitters.

The limitations pointed out in the British study may be seen by referring to Figure 2, which represents an analysis of a full carrier single-sideband wave modulated by a single tone under peak modulation conditions. The envelope wave shape is obviously far from being sinusoidal, and a little more than 23 per cent harmonic distortion is present.

It should also be noted in the mathematical analysis that the fundamental term has a peak envelope of 67 per cent, relative to the DC term. Therefore, maximum effective modulation of a full carrier single-sideband wave is only 67 percent.

Although distortion can be minimized by reducing sideband level, effective modulation becomes greatly attenuated. For example, when distortion is reduced to 10 per cent, which is considered barely acceptable for most communications equipment, but not good enough for broadcast service, the effective modulation is only 38 per cent. This results in an effective power reduction of over 5.3 db. In terms of the 67 per cent modulation condition, a power loss of 3.5 db is experienced. This means that a transmitter that can be rated at 1 kw, on either AM or Compatible, can only be rated at 444 watts on the full carrier system. CSSB does not suffer from these defects, and therefore, opens the way to major improvements in AM broadcasting.

Two proposals 4, 5 have been made for reducing the distortion effect at the lower frequencies by transmitting double-sideband for low audio frequencies and single-sideband for higher frequencies. However, these systems require more spectrum and are more critical to selective fading than pure single-sideband systems. These systems also require the replacement of most existing transmitters.

CSSB FOR AERONAUTICAL SERVICE

One of the most serious problems facing the aeronautical service today is the shortage of available channels and the interference situation on existing channels.

Replacement of conventional AM transmission by various single-sideband systems has been proposed, and almost all of these systems offer definite advantages with respect to spectrum economy. However, many of these systems introduce problems which are not inherent in standard AM transmission. For instance, a double-sideband transmission is relatively insensitive to minor frequency shifts, and frequency drifts of a few hundred cycles cause very little damage to intelligibility. On the other hand, carrier suppressed systems require the use of special involved frequency generating devices heretofore only found in laboratories.

Clipping techniques have been used generally in AM transmission because of the appreciable signal-to-noise gain and also as a safeguard against over-modulation. As will be shown later, clipping techniques are not very effective when used with conventional single-sideband systems. AM signals are also much less sensitive to overload and, since appreciable variations in signal strength are experienced in aeronautical service, this factor is of prime importance.

Single-Sideband signals, other than Compatible Single-Sideband, are very sensitive to overload because of the intermodulation distortion produced. However, the main reason why AM appears to be still quite attractive is its simplicity. AM transmitters are relatively insensitive to misadjustment, and, of course, it is hard to conceive of a simpler receiving system than the conventional AM receiver.

The Compatible Single-Sideband system appear .o be operationally quite similar to standard AM transmission except that the spectrum energy is concentrated on one side of the carrier. Standard AM receivers may be used and adapters have been constructed for adapting both high level and low level AM transmitters to Compatible Single-Sideband operation. CSSB also may be used immediately without a transition period of mixed operation. In other words, present AM equipment is completely compatible with CSSB equipment. However, it is felt that the main advantage of Compatible Single-Sideband is its simplicity where it closely rivals standard AM transmission. There is no requirement for extremely stable oscillators in CSSB circuits. There is also no need for special precautions against overload, and the desirable effects of voice clipping can be fully utilized. Use of the CSSB adapter system would not require replacement of receivers on the ground or in the air and in most cases would not require replacement of transmitters.

Conventional suppressed carrier SSB suffers from several basic difficulties not characteristic of CSSB. The most significant examples are those of Doppler effect and frequency stability. If the carrier is transmitted at reduced levels, automatic frequency control type circuits can be used to reduce the Doppler or instability effects, but AFC systems are sensitive to capture by interference or jamming and are slow to operate. Since many messages are of very short duration (in the order of one or two seconds), the AFC systems appear to be seriously handicapped because by the time it operates, an appreciable percentage of the information may be lost. If the carrier is not transmitted and reliance is placed upon the stability of the oscillators, then complexity of the receiving and transmitting equipment is greatly increased. Also, there is a question of reliability of these involved type frequency generating units, as well as cost. One such unit, for example, uses 75 tubes just for frequency synthesis purposes.

There is also the problem of Doppler effect which will become more severe as aircraft speeds are raised, and it is a problem even today. There would appear to be a number of schemes that would correct for Doppler, such as the use of subtones or by careful analysis of the spectrum characteristics of voice. However, such systems would suffer all of the disadvantages of automatic frequency control. Any technique dependent upon analysis of the voice spectrum would appear to be impractical in that the equipment would be very involved and the system would be extremely sensitive to capture by interference and/or jamming. Also, such techniques would be appreciably more complicated than the already complex AFC system.

It has been suggested that during the transition from conventional AM to suppressed carrier SSB, a full carrier SSB system be used. Also, in order to transmit selective calling signals, this "bi-mode" type of operation has been proposed as a permanent situation, even though it suffers from severe distortion and a 3.5 db signal-to-noise ratio loss, as described under the British Post Office study noted above.

SIGNAL-TO-NOISE COMPARISON

Of course, a major consideration of any communications system is its signal-to-noise ratio. The single-sideband suppressed or reduced carrier system offers a 6 db improvement in signal-to-noise over the Compatible Single-Sideband system because the carrier is not transmitted or is greatly attenuated. However, there is a further point that must be considered in such signal-to-noise comparisons. There is wide use of clippers in HF communications service because of the reduction in peak power requirements and the resulting important improvement in signal-to-noise ratios.

It has been pointed out that volume compressors do not compare favorably with clippers. The reason for this is interesting and briefly it may be stated that extensive studies reveal that high amplitude, low frequency components in all modern languages are immediately followed by low amplitude, high frequency components. The latter are extremely important in maintaining intelligibility. Volume compressors always quickly reduce gain in order to catch peaks and then very slowly restore gain in order to minimize clicks or pops. Thus, the volume compressor, while reducing the peaks, desensitizes the system for high intelligibility by attenuating the high frequency sounds immediately following these peaks.

Since the use of clippers provides approximately 10 db signal-to-noise gain, we must carefully consider the effect of clipping in the various systems proposed. Clipping, in a suppressed carrier or appreciably reduced carrier system, is relatively ineffective, as may be seen by analysis of a clipped suppressed carrier single-sideband signal. Actually, the peaks are raised by a factor of 6 db after passing a clipped wave through a single-sideband suppressed carrier generator. This is true even when the phase characteristics of the single-sideband filters are perfectly linear. Analysis indicates that a clipped Compatible Single-Sideband system provides approximately 2 db signal-to-noise improvement over a clipped suppressed carrier single-sideband system. Thus, the Compatible Single-Sideband system, under practical operating conditions, offers improved signal-to-noise ratios. At very low signal-to-noise ratios, the single-sideband suppressed carreir system shows improvement, but since these ratios are below intelligibility, this is mainly of academic interest.

In the single-sideband full carrier system, which has been proposed by some as usable during the transition period, clipping again is relatively ineffective, and there is a 4.8 db loss in comparison with Compatible Single-Sideband. Thus, a 1 kw full carrier single-sideband wave is only equal to a 330 watt Compatible Single-Sideband wave.

Another reason why the full carrier single-sideband system does not appear to be practical, is that it is extremely sensitive to overload, and intelligibility suffers greatly with even slight overmodulation. Also, as mentioned above, there is severe inherent distortion in this full carrier system.

OVERLOAD PROBLEM IN SUPPRESSED CARRIER SINGLE-SIDEBAND OR DOUBLE-SIDEBAND SYSTEMS.

It has been long recognized that single-sideband suppressed or reduced carrier signals are very sensitive to overload in receivers. In fact, better single-sideband receivers have attenuators in the antenna input circuit of the receiver in order to minimize this difficulty. AVC, based upon carrier, has helped this situation but has not cured it. The reason for this abnormal sensitivity has not been described in the literature, and it might be interesting to consider this problem because of the wide range of signal strength experienced in aeronautical operation.

Briefly, the reason is that overload distortion in single-sideband receivers produces large amounts of intermodulation distortion. In AM or in Compatible Single-Sideband, however, only harmonic distortion plus a small amount of intermodulation distortion are produced. when AM receivers are overloaded. It has long been recognized that the ear is much less sensitive to harmonic distortion than it is to intermodulation distortion, and therefore, single-sideband suppressed or reduced carrier systems lose intelligibility much more rapidly under overload conditions.

AERONAUTICAL SERVICE CONCLUSION

Use of the Compatible Single-Sideband system does not require immediate equipment alteration, as this mode of operation is completely compatible with existing equipment.

Compatible Single-Sideband adapters have been built and used with Class "C" high-level modulated transmitters, as well as low-level modulated transmitters, without any alteration whatsoever of the transmitter. Class "C" amplifiers provide an appreciable power gain over Class "B" amplifiers which are required for suppressed or floating carrier single-sideband transmission. Modification of high-level modulated transmitters to linear amplifiers appears to be impractical in that the modified transmitter will have a peak envelope rating of only two-thirds of the carrier rating of the unmodified transmitter. If this same transmitter were to be adapted to Compatible Single-Sideband operation, the peak envelope rating would be four times the carrier rating. Of course, receivers need not be altered in order to receive such signals, but improved selectivity may be incorporated in any new equipment purchased.

RF amplifier efficiency obviously has a great deal to do with system performance. A linear amplifier with plate circuit efficiency of 60 per cent under full drive has an average efficiency of only 47.1 per cent for the two equal tone case. Assuming 80 per cent efficiency for a Class "C" amplifier, the efficiency of CSSB is then about 65.4 per cent. Therefore, the ratio of power output from the CSSB system is about 2.5 times that of the linear amplifier system (assuming, of course, identical total plate dissipations).

In summary, it should be said that Compatible Single-Sideband offers a simple and economical means for obtaining spectrum economy and compares quite favorably in signal-to-noise and reduction of fading effects with conventional suppressed or reduced carrier single-sideband systems. No critical or involved equipment is required for reducing the severe effects of Doppler, and there is no transition period problem. Last, but by no means least, Compatible Single-Sideband is a simple system.

CSSB OPERATIONAL TESTS

The first Compatible Single-Sideband installation was made on the Voice of America's megawatt transmitter located in Munich, Germany, wherein a 4 megawatt Peak Envelope Power CSSB wave was produced. This system has been in continuous daily use for the past year and a half. Domestic tests during commercial broadcast hours are currently being conducted by WABC, the New York key station of the American Broadcasting Company, and shortly tests will be started at WSM's 50,000 watt clear channel station in Nashville, Tennessee.

Numerous measurements and listening tests of CSSB signals have been made on various types of receivers. They include communications models such as Hammarlund SP-60, the Collins 51-J, a Signal Corps R390A/URR, and a Hallicrafter 538-D. Conventional home-type receivers such as a Grundig Majestic Model 880U/USA, an RCA transistor set, a Craftsman Tuner, and many other types were also used. No difficulty was experienced in tuning any of these receivers, and reception was completely free from system distortion. When communications receivers were used, it was possible to demonstrate that the receiver's bandwidth could be reduced to 2 kc and still maintain usable quality.

During WABC tests it was noted that WBBM could be clearly heard in the New York metropolitan area. This is significant because the assigned carrier frequency of WBBM is 780 kc, while WABC's is 770 kc -- only 10 kc away. When transmitting on the lower frequency sideband, WABC did not interfere with WBBM, in spite of the small frequency separation between the two stations plus WABC's greater signal strength in the local area. Upon resuming conventional double-sideband AM transmissions, WBBM, as expected, suffered from WABC interference. Thus, CSSB demonstrated appreciable reduction in adjacent channel interference, even under this extreme condition.

CONCLUSION

It has been shown in actual operation that the CSSB system offers the user significant reductions in interference and selective fading, as well as improvements in signal-to-noise and audio fidelity. The auxiliary circuits are easy to install and maintain and do not require delicate or repeated adjustments. Because of its unique design and compatibility with existing AM receivers, the many advantages of single-sideband transmission may now be fully realized by the radio broadcasing and HF communications industries.

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A DISCUSSION BY CAPT. PIERRE BOUCHERON OF L. P. LESSING'S UNUSUAL BIOGRAPHY "MAN OF HIGH FIDELITY: EDWIN HOWARD ARMSTRONG"

Pub. by J. P. Lippincott Co.

This is more than a book about a great American inventor, Howard Armstrong, and his basic contributions to the fast moving art of communications. It is also an accurate, though necessarily short, record of electrical signalling from Faraday's seminal discoveries in 1832 to Morse, Bell, Clerk-Maxwell, Lodge, Marconi and DeForest, and the great part played by the amateurs from 1900 on to the present day.

I first met Howard Armstrong at one of the early meetings of The Radio Club of America. Here was a band of dedicated boys, many still in knickerbockers, who called themselves "wireless experimenters," most of them equipped, as I was, with an one-inch spark coil, a varying length of untuned antenna, and a cat's whisker-crystal detector. My special benefactor at the time was George Eltz who later introduced me to Howard as well as to Ernest Amy, Tom Styles, Doctor Hudson, George Burghard, Randolph Runyon, Fred Klingenschmitt and Weddi Stokes who operated a more elaborate rig atop his father's New York hotel, the Ansonia.

In my scrapbook, I have a faded clipping dated November 30, 1910, that tells of a group of forty amateur wireless men, of which number I was proudly one, who met at Astoria, L.I., to denounce the Depew Bill. Shortly after that, W.E.D. Stokes, Jr., the 14-year old president of The Radio Club went to Washington along with one of his father's attorneys to oppose this "dastardly Bill," a bill that was meant to kill off the amateur experimentations of those early days headed by our hero and star performer, Howard Armstrong. I did not see much more of Howard until after we were all back in civilian life following World War I. Later, I saw much of him while I was editor of the original Radio Amateur News, and again many times in the outer office of another genius in the making, David Sarnoff, presided over by the lovely Esther Marion MacInnis, secretary to the then vice-president and general manager of the Radio Corporation of America, and to whom I reported as assistant for public relations. Howard, after his U.S. Army Signal Corps tour of duty as a major in France, had become quite an ardent Francophile and he liked to practice his A.E.F. French on me, a native of Paris.

Although Armstrong was a unique conceptor of original ideas, and therefore highly justified in defending to the utmost the children of his brain, there's an old saying among artists, authors and inventors that worthwhile ideas are often born in the minds of many men at exactly or nearly the same time. This truism is one that Armstrong refused to recognize. If he had been a little more tolerant, and I may add, more realistic and practical, he might have been a happier, less frustrated man during what should have been his "golden years."

One of the more telling chapters of this stark record of pure achievement, and one indicative of the kind of research that Lawrence Lessing displays throughout the book, appears under Chapter XIII, THE SUPERHETERODYNE FEAT. I quote the first sentence because it is a prelude to an easy-to-understand outline, of the schematic circuit diagrams in this chapter:

> "The superheterodyne circuit was a brilliant display of Howard Armstrong's genius for taking up the seemingly unrelated facts and combining them, by intuitive thinking, logic and hard work, into new instruments of amazing effectiveness. The superheterodyne was not quite as basic an invention as the regenerative circuit, but it was a fundamentally new manipulation of electromagnetic waves so deft as to appear almost a feat of slight-of-hand. Even now, to the ordinary man, uncalloused by too much technical knowledge, it still appears as a magical box of tricks. To understand how it was accomplished and what it meant, it is necessary to go back a bit into some of the fundamentals of radio."

And Mr. Lessing does just that, so that any 14-year old pre-science, high school student will be more than fascinated not only by the superheterodyne feat but also by the other two pieces of electronic magic, the regenerative circuit and frequency modulation.

Of course, while Howard did the basic thinking, he had much valuable help from others. In the long list of friends and associates whom the colorful Armstrong drew around him over the years, there stand out three top-flight men that come to mind at this time: the able research engineer, Harry W. Houck, the legally trained George Burghard, and the general factotum, Thomas J. Styles. These three men, and others who came later, encouraged, assisted, advised, as well as helped in the technical development and legal handling of the three basic inventions -- not to forget helping Howard out of his usual pre-occupation and social reticence. They insisted on occasional "let's get away from it all and have some fun" bits of relaxation. Later, there was romance, too, and 100 mph rides with Esther Marion in his Hispano-Suiza, the foreign sport car of the roaring 20's. He married the attractive secretary of the RCA executive suite on December 1, 1923. Esther, who had intelligence besides knowledge of stenography, proved to be a devoted and understanding helpmate for over thirty years.

The book, "Man of High Fidelity," is a fast-moving word portrait of a brilliant inventor, eccentric yet withall quixotic genius -- a modern David who, however, was unable to subdue, let alone slay, the modern Goliath. Frustrated at the very end, he chose the only way out, as he saw it, with an exit and finality seldom found so tragic.

Let us not say too quickly that he should not have performed this final act of defeat. Here was a man of great personal honesty and intellectual capacity. As Judge Julius Mayer once said, Armstrong was a remarkably clear thinker at all times. Surely, Howard knew exactly what he was doing and why. There's an old proverb that says: "Those whom the gods would destroy first make mad." But this was not the act of a madman, of a deranged or neurotic mind, nor was it the act of a cornered "big shot" industrialist exposed by the higher-ups. This was disenchantment of the highest degree. Armstrong saw no way out without sacrificing principle and his high sense of justice. A more timid and mercenary soul would have compromised with the powerful corporation and the astute man at its helm.

Here then, is a beautifully done and sympathetic document about a strange and remarkable man. It is also an authentic report about a fast-disappearing species -- the contemporary sole inventor. Every attic and garage tinkerer, every young engineer starting out bravely on a career in electronics and mass communication -- indeed, every adult technician, communicator and commercial man of radio, television and the associated arts should read this fascinating biography of a great American. He or she will find not only inspiration of a sort, as well as usable information, but will understand better that nowadays the complexity of so-called free-enterprise, the "organizing genius of modern corporations," and at times abuse of power, make it extremely difficult for any one brain to win singular acclaim -- and acceptance -- as an original inventor of a basically new electronic circuit, instrument, machine or device. With this better understanding, perhaps the embryonic inventor will pursue ways and means to protect himself by expert legal and patent law advice. Mr. Lessing makes this clearer when he says:

> "Until society devises some more rational means to affirm the title and rights of its scientific creators, inventors have no other avenue but patent law by which to defend their creations. U.S. patent law gives the inventor, in return for his full disclosure of a new device or process to society, a handsome embossed paper granting his exclusive possession, exploitation and assignment of his discovery for seventeen years. It gives him no more than this. It gives him no means to develop his invention or to carry it into use. It grants him no defence of his rights except that which he can muster for himself in a court of law by his own energies and resources. By the time an invention gets into court it invariably involves large industrial forces battling for position, and the drama becomes turgid. Yet it still pivots on the inventor. In the case of great inventions, the human drama rises to an unholy pitch, for it turns upon the determination of the actual moment of creation."

This unusual biography should live a long time in patent circles and elsewhere because it not only exposes the machinations, and some times utterly dishonest practices of corporations, as well as the stuffy, hidebound mental processes of Supreme Court justices, but this book also proves, step by step, logically and irrevocably that Howard Armstrong was the one and only inventor of the three basic circuit-systems. These three, the regenerative, the superheterodyne, and frequency modulation which last one gave us not only the "Hi-Fi" sound for television reproduction (a fact studiously never advertised by the powers-that-be), but the one invention that solved the baffling problem of static elimination. Indeed, "a new communication system of great beauty and utility was inaugurated -- that, and for good measure, a new kind of radar for the National Defense. Without these major accomplishments, radio and television as we know it today would have been well-nigh impossible.

In evaluating the originative work done by Howard Armstrong, we must not overlook or underestimate the invention of Lee DeForest of the triode tube or Audion.

Certainly, the three element tube was a necessary contribution to the electronic art. For that matter, so was its antecedent, the Fleming two-element tube. It is a little far-fetched, however, to call any one contemporary inventor "The Father of Radio." If any one deserves that controversial title, it is Marconi.

Finally, and to return to Armstrong and DeForest, it is a pity that these two pioneers and antagonists could not have joined forces, patent-wise. What a team they would have made, and, properly advised and assisted by the Messrs. McCormack, Houck and Burghard, and others in the DeForest camp, might have in great measure brought the powerful opposing corporations to less exhaustive, more equitable and rewarding terms.

G-K means SPECIALISTS

Ballantine Laboratories, Inc.

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Sierra

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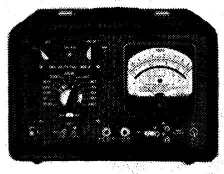
BALLANTINE ELECTRONIC VOLTMETERS

Famous for
ACCURACY - STABILITY SENSITIVITY

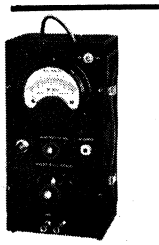
Each Ballantine Voltmeter has only one voltage scale, with decade range switching, which provides the **same accuracy of reading at all points on the logarithmic voltage scale.** A linear decibel scale is also provided for use by acoustical engineers. Each Voltmeter also may be used as a high gain wide band amplifier.

TRUE RMS INDICATION — MODEL 320



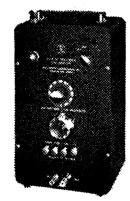
Voltage Range .... 100 µv — 320 v
Frequency Range .... 5 cps — 500 kc
Accuracy .... 3% 15 cps — 150 kc
5% elsewhere
Stability of Internal Calibrator 0.5%
Input Impedance . . .
10 megs shunted by 18 µµf below 10 mv
10 megs shunted by 8 µµf above 10 mv

AUDIO to 150 kc — MODEL 300



Voltage Range .... 1 mv — 100 v
Frequency Range .... 10 cps — 150 kc
Accuracy .... 2% ENTIRE RANGE
Input Impedance .... ½ meg shunted by 30 µµf

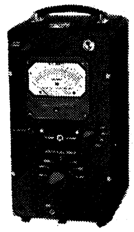
DC & AC PRECISION CALIBRATOR — MODEL 420



Voltage Range .... 0-10 v RMS; Pk-to-Pk; or DC
Frequency (Std. Model) .... 1 kc
(other values on special order)
Accuracy (long term) Better than 0.5% above 1 mv
Distortion and Hum .... Less than 0.25%
Setting Resolution Approaches 0.01% above 10 mv
Output Impedance (AC) .... 2-20 ohms depending on range setting

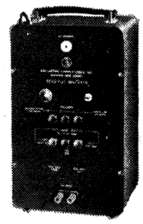
SUB-AUDIO to 150 kc MODEL 302C

Battery Operated



Voltage Range .... 100 µv — 1000 v
Frequency Range .... 2 cps — 150 kc
Accuracy .... 3% 5 cps — 100 Kc
5% elsewhere
Input Impedance .... 2 meg shunted by 10 µµf*
*Shunt capacitance, 25 µµf on two most sensitive ranges

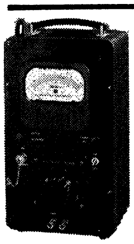
SENSITIVE INVERTER — MODEL 700



For Measuring DC Voltages when combined with any AC Voltmeter

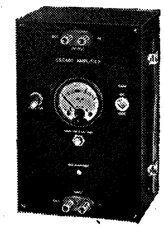
Voltage Range .... 1 µv — 100 v DC
Ratios DC Input to RMS Output .... 1:100 & 10:1
Accuracy .... 1% 100 µv — 100 v
Input Resistance .... >10 meg for 1:100
50 meg for 10:1

PEAK-to-PEAK — MODEL 305



Voltage Range .... 1 mv — 1000 v pk-to-pk
Frequency Range ...... 10 cps — 100 kc (sine wave)
Pulse Width .... 3 µsec — 250 µsec
Min Rep Rate .... 20 pulses per sec
Accuracy .... 5% for pulses
Input Impedance .... 2 meg shunted by 8 µµf*
*Shunt capacitance, 15 µµf on two most sensitive ranges

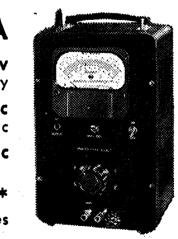
DECADE AMPLIFIER — MODEL 220B



For Increasing the Sensitivity of any AC Voltmeter by 10 or 100 times

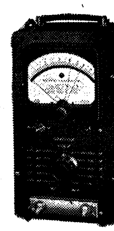
Voltage Range .... 20 µv — 50 mv
Frequency Range .... 10 cps — 150 kc
Accuracy .... 2% ENTIRE RANGE
Input Impedance .... 5 meg shunted by 15 µµf

AUDIO to 2 mc — MODEL 310A



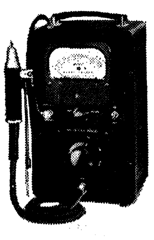
Voltage Range .... 100 µv — 100 v
Down to 40 µv at reduced accuracy
Frequency Range .... 10 cps — 2 mc
As null detector 5 cps. — 4 mc
Accuracy .... 3% 15 cps — 1 mc
5% elsewhere
Input Impedance .... 2 meg shunted by 9 µµf*
*Shunt capacitance, 19 µµf on two most sensitive ranges

DIRECT READING CAPACITANCE METER — MODEL 520



Capacitance Range .... 0.01 µµf to 12 µf
in 9 decade ranges covering over a billion to 1
Accuracy .... 2% above 0.1 µµf
5% below 0.1 µµf
Capacitor Power Factor 0.15
Test Frequency .... 1 kc

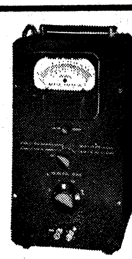
AUDIO to 6 mc — MODEL 314



Voltage Range .... 1 mv — 1000 v
(100 µv — 1 mv without probe)
Frequency Range .... 15 cps — 6 mc
Accuracy .... 3% 15 cps — 3 mc
5% elsewhere
Input Impedance .... 11 meg shunted by 8 µµf
(1 meg shunted by 25 µµf without probe)

ACCESSORIES are available for all voltmeters to extend voltage measurements down to 20 µv and up to 10 kv, and to measure currents from 0.1 µamp to 10 amp, and to provide DC from the Model 300 Voltmeter to drive external recorders or remotely located meters.

INFRASONIC to 30 kc — MODEL 316



Voltage Range .... 20 mv — 200 v pk-to-pk
Frequency Range .... 0.05 cps — 30 kc
(Down to 0.1 cps with correction)
Accuracy .... 3% ENTIRE RANGE
Input Impedance .... 10 meg shunted by 17 µµf
or 40 µµf depending on setting

BALLANTINE LABORATORIES, Inc.