PART III

AIRCRAFT RADIO COMMUNICATION EQUIPMENT

By

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4 DECEMBER 1945

SUMMARY

A reliable and adequate radio-communication system is essential to integrated aerial tactics. Basically a long-range liaison and short-range command system is necessary. Other special systems may be employed to supplement these.

At the outset of World War II, the Army and Navy liaison systems were BC348, BC191, RU, RAX, GO and the command units SCR274N, ATA, ATR. Because of obvious deficiencies a new series including liaison systems ART13, XANRB3, ARR15, ARB, BC348 and command systems SCR522, ARC1 were put into production and widely used.

Currently new transmitters and receivers are being developed which include such features as receiver-controlled transmitter frequency, Autotune and automatic tuning mechanisms. For the immediate future at least, the development of liaison systems will continue to make use of present frequency bands because of propagation considerations. New developments will take place in antenna design, in band-switching methods and in numerous individual components. Teletype, recording and voice-coding systems may also be worked out for this service.

Command systems will probably move to higher frequency bands (200 to 500 mc) to obtain more channels, smaller components, a wider choice of modulation methods, etc. Much work remains to be done on suitable switching mechanisms for multichannel communication, on oscillator stability, component development and practical antenna design.

Progress is being made and should be encouraged in the future toward adapting the very high frequency portions of the radio spectrum for communication systems. This should make possible highly directional channels, limited range systems and also systems which are difficult to intercept or jam.

Radio relays will be of considerable importance, both for the transmission of radar and television pictures and for multichannel speech systems. Much work remains to be done in this field and it should have a prominent place in an aviation radio research program.

INTRODUCTION

Aircraft radio communication is an essential and critical part of integrated aerial warfare. The transition from individual combat methods to integrated group tactics, although predicted at the close of World War I, did not occur in fact until fairly recently. It has placed demands upon existing radio-communication equipment which the latter is scarcely able to meet. Frequently, it has been necessary to use rather crude improvisation which has been far from satisfactory. As the development of integrated and coordinated aerial warfare progresses, even greater demands will be placed upon the radio-communication system. Therefore, particular attention must be paid to laying out a program for the development of adequate aircraft radio equipment as part of the major program of developing an air force sufficient to meet the requirements of security.

In laying out such a program full cognizance should be taken of the "systems engineering" as part of the problem as well as the equipment design, and production. The essential requirement is not for the communication between two planes, or a plane and a ground station but for the intercommunication within a group of planes which may number hundreds or even thousands. The integration of the system as a whole is fully as important as the design of the individual units.

It is extremely important that care be taken not to impose excessive technical demands upon the designer, in the type of equipment demanded. The gap is very great between the performance that can be expected from equipment in the laboratory in the hands of engineers or skilled technicians and equipment which is simplified to the point where it can be reliably operated by unskilled personnel, and rugged enough so it will stand the type of handling it must meet in actual service. Because of this gap, it may be necessary to divide the communication equipment into two classes, the first representing an essential minimum of absolutely reliable devices, the second, those which are desirable and useful but whose failure does not jeopardize the performance of the combat group as a whole.

For the next decade or perhaps longer, the first group of equipment will probably be represented by apparatus which is fairly similar to the type now in use both in military and commercial aviation. Aircraft experience to date indicates that it is almost essential to use a dual radio communication system comprising a liaison system and a command system. The liaison system operates at relatively long wavelengths and is capable of ranges from a few hundred to several thousand miles. The command system operates at a much higher frequency in order to permit a great many communication channels, and is limited to ranges up to one or two hundred miles, in other words, line-of-sight communications. These two systems constitute an irreducible minimum for coordinated air activity. With them, it is possible for one or more flights of airplanes to take off from several bases, fly to an assembly point and thence to the target and return, while at all times maintaining sufficient communication so that the required instructions and information can be reliably communicated.

The second classification will consist of equipment employing some of the newer radio techniques. For example, microwave transmission to give high directionality, special modulation systems to reduce probability of jamming and static interference, and special coding systems to reduce bandwidth and to prevent interception. In addition, it would be highly desirable to have an extremely short-range microwave communication system which could be used between planes in a formation instead of the high-frequency command system. By using a high enough frequency for this short-range communication system, it would be possible to restrict its communication distance to a predetermined range, and thus allow communication between planes while in effect maintaining radio silence as far as enemy ground defenses are concerned. Furthermore, indicator or recording systems are also extremely useful in controlling operations. Such systems may take the form of teletype recorders, reproducing written messages, facsimile recorders for the transmission of maps and diagrams as well as written material, or, to go to the other extreme, simply indicating equipment for the transmission of a half-dozen or more simple symbols designating prearranged maneuvers and instructions.

To make possible all-weather flying, the major air bases should maintain the equivalent of a "Teleran" system. This system locates all planes in the neighborhood of the base by radar and transmits the information back to the approaching planes in visual presentation; thus each plane receives a television image of a map giving not only its own location, meteorologic and other pertinent information, but also the location of all other planes flying at the same level. Furthermore, the system provides for the blind landing and take off of planes.

CURRENT COMMUNICATION PRACTICE

Before discussing future trends of aircraft-radio development, it would be well to review the development of radio-communication technique during the last four or five years, that is, since the onset of World War II. At the start of the war, the military aircraft radio equipment was far behind that used by the commercial aircraft companies. In fact, most of the equipment followed design practice that was at least ten years old.

The command set used by the Army at the beginning of the war was the SCR-274N system and the corresponding Navy equipment was the Navy ATA transmitter and ARA receiver. These sets operated in the neighborhood of two megacycles and were designed for communication between squadrons, and to control towers. They were pilot-operated and were carried in fighters, small bombers, etc. The first receivers of this series were tuned radio-frequency receivers. Later on, superheterodyne receivers were used. The transmitter followed more-or-less conventional design but employed master oscillator which was not crystal-controlled. The weight of the combination was approximately 100 lb. A basic production of 100,000 units of this type equipment was set up.

The liaison equipment of this period consisted, in the case of the Army, of a general purpose receiver (BC-348) physically resembling the Hallicrafter, which was carried in airplanes of the two-engine bomber class and larger. This receiver was a superheterodyne with two continuously tunable bands, one extending from 200 to 500 kc and the other from 1500 to 18,000 kc. The weight of this receiver was about 30 lb. The transmitter in this series for heavy bombers of the four-engine class and up consisted of 125-w CW and MCW units tunable over two ranges, namely, 300 to 600 kc and 3000 to 26,500 kc. An intermediate transmitter, BC-191 and BC-275, was used for twin-engine medium bombers. This was a CW and phone transmitter with plug-in units to change frequency in bands between 1500 and 12,500 kc. At the same time the Navy was using the RU (tuned radio frequency) and RAX (superheterodyne) receivers. These sets were narrow and deep in shape and each set had a rather limited band range so in order to obtain large coverage several units were used. In other words, instead of band switching which is now common practice, different receivers were employed. The Navy transmitter GO was similar to the Army long-range transmitter described above.

As the war progressed, it became increasingly evident that this radio equipment was entirely inadequate. In the first place, it was both Army and Navy practice to transmit and receive on the same wavelength. However, the stability of the sets described above was such that it was extremely difficult to maintain communication on this basis. Furthermore, if two planes from different bases were required to meet and to continue together in a combined operation, it was virtually impossible to arrange to adjust their receivers and transmitters beforehand so that they could establish immediate communication when they arrived at the assembly point. Therefore, much time was wasted in adjusting instruments after the rendezvous. Finally, because of the poor stability of the transmitter, the bandwidth that was necessary to carry on communication was so large that the number of channels available was entirely inadequate.

Because of the obvious inadequacy of these systems, new types of both command and liaison systems were put into production and are now in use. The command systems of the new Army series operate in the VHF region of the radio spectrum (i.e., 100 to 156 megacycles), and both transmitter and receiver are crystal controlled. These units have four operating bands which are selected by push-button controls. The receiver bandwidth is 50 to 60 kc in order to take care of the instability of the transmitter and receiver crystal oscillators. This system was designated as the SCR-522 system.

The Navy lagged behind the Army by two years in moving into the VHF region for its command equipment and then adopted the ARC1 system. This is similar to the Army unit in that both the transmitter and the receiver were crystal controlled, but has eight bands instead of four. The weight of the Navy unit is 50 lb and it was a nominal 10-w output.

The difficulty with these systems is that they have required enormous pools of accurately calibrated crystals distributed all over the world. There are now over a million special crystals in these pools and this is still not an adequate supply.

For liaison communication, the Army and Navy adopted the ART-13 transmitter. This is a 100-w crystal-controlled unit, weighing about 110 lb. It has 11 spot frequencies, one band being in the region of 200 to 600 kc, the other ten in the 2 to 18 megacycle band. Experience has shown that the 200 to 600 kc band which was designed for communication with naval vessels, etc., is rarely used and will probably be abandoned. In addition to its increased stability as a result of being crystal controlled, this transmitter marks a great advance over those previously used in that it employs the Autotune or automatic tuning mechanism for changing bands. This consists of a series of preset notched cams mounted on a shaft which is motor driven. The cams make it possible to stop the shaft rotation at the position of exact tuning from a remote point.

A number of attempts were made to design special receivers for this transmitter but so far they have not been wholly successful. The XANRB3 was designed for this purpose but was rejected for lack of frequency stability. Recently the ARR-15 has been developed to take its place but as yet the acceptance tests are not complete.

In the meantime, the Army has been using the BC-348 receiver which was described above. The Navy is using the ARB general purpose receiver which is very similar to the BC-348. These receivers, when their application makes remote tuning necessary, must employ the expedient of a flexible shaft from the operating point to the appropriate dial on the receiver. Block diagrams showing the tube components in the transmitter ART-13 and BC-348 are given in Fig. 1.

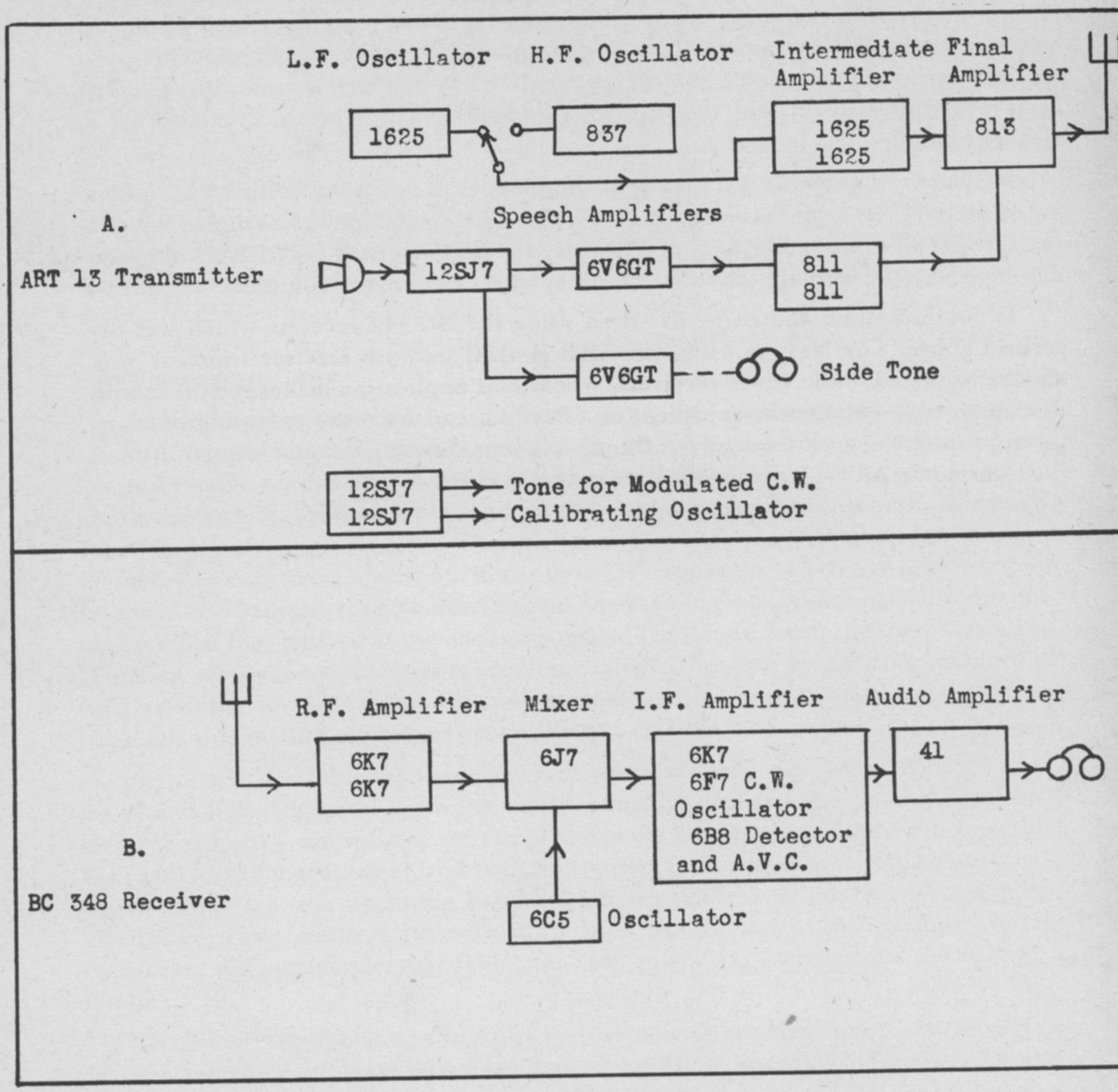


Figure 1 — Block Diagrams of Equipment

RECENT DEVELOPMENTS

A dual liaison receiver has been designed and has been accepted for production by the Navy which eliminates a good many of the difficulties enumerated, in particular, that of making contact between two parties from different bases. A block diagram of this transmitter-receiver system is shown in Fig. 2. The receiver is a superheterodyne with a main oscillator which is variably tuned over a narrow range of frequency, for example, one octave. However, the oscillator is arranged so that its output has a large harmonic content. Therefore, the second harmonic can be used to cover the octave beyond the fundamental frequency band and the fourth harmonic, the octave beyond that. This method is employed to give continuous tuning over a range from 1500 to 12,000 kc. An oscillator which has as narrow a tuning band as this can be made to have a reasonably high degree of stability even though not crystal controlled. Since the set is push button actuated with spot bands of predetermined frequencies, it is necessary to have a fine tuning adjustment. This is done by adjusting the intermediate frequency against a calibrating standard. A second oscillator (D) is arranged to tune with the IF adjustment so that the frequency that it generates is always identical with the output of the IF frequency. This is hetrodyned with the output of the local oscillator (B) and after going through the detector (E) generates a frequency identical with the frequency to which the receiver is tuned. This frequency is used to control the transmitter, consequently the receiver and transmitter always operate on exactly the same frequency. If the operator tunes his receiver until he hears a transmitter, he will know that his transmitter is tuned exactly to transmit his receiver frequency. Furthermore, assuming that the operator communicating with him is using the same type of system, he can be sure that the latter's receiver is also on this frequency. This greatly simplifies the problem of making contact.

Another type of receiver-transmitter which is in the design stage and may be in production in the immediate future is shown in Fig. 3. This system is similar to the one described above in that the transmitter frequency is controlled by the system's receiver so that the transmitter always operates on exactly the same frequency that is being used for reception. It differs from the previous unit in that the main oscillator is crystal controlled and, therefore, has higher stability. Furthermore, the IF amplifier and second oscillator is tunable rather than merely being adjustable. This means that the frequency is continuously controllable over a certain bandwidth. In order to facilitate remote control, this outfit uses Autotune or automatic tuning mechanisms throughout.

So far, radio equipment has been discussed in terms of the requirements for fighters and bombers. The communication equipment needed for transports is very similar to that required for large bombers and, in general, the same types of liaison and command radio equipment are employed. Artillery liaison flying, which is generally done in small planes operating close to the ground, places somewhat different

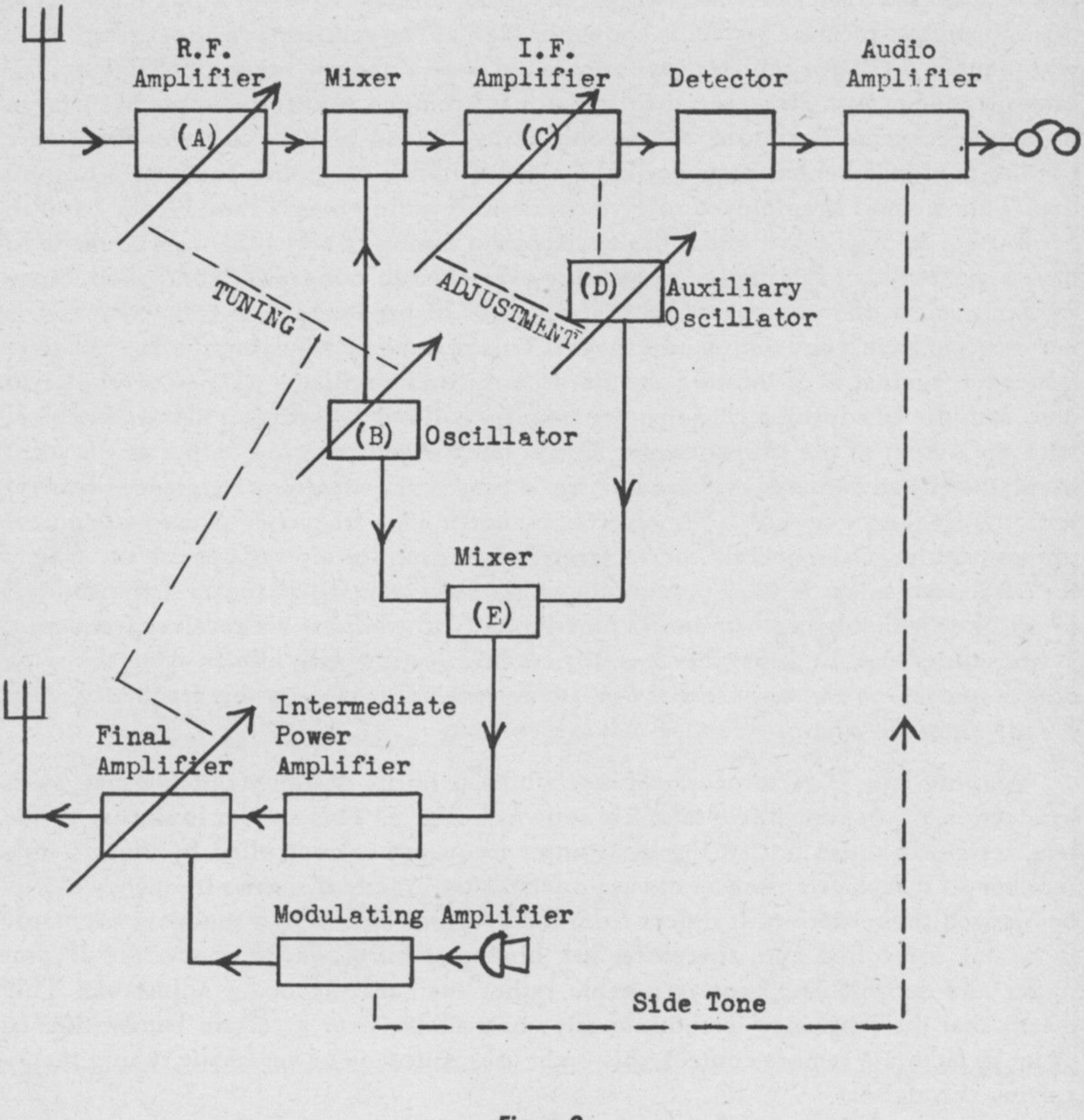
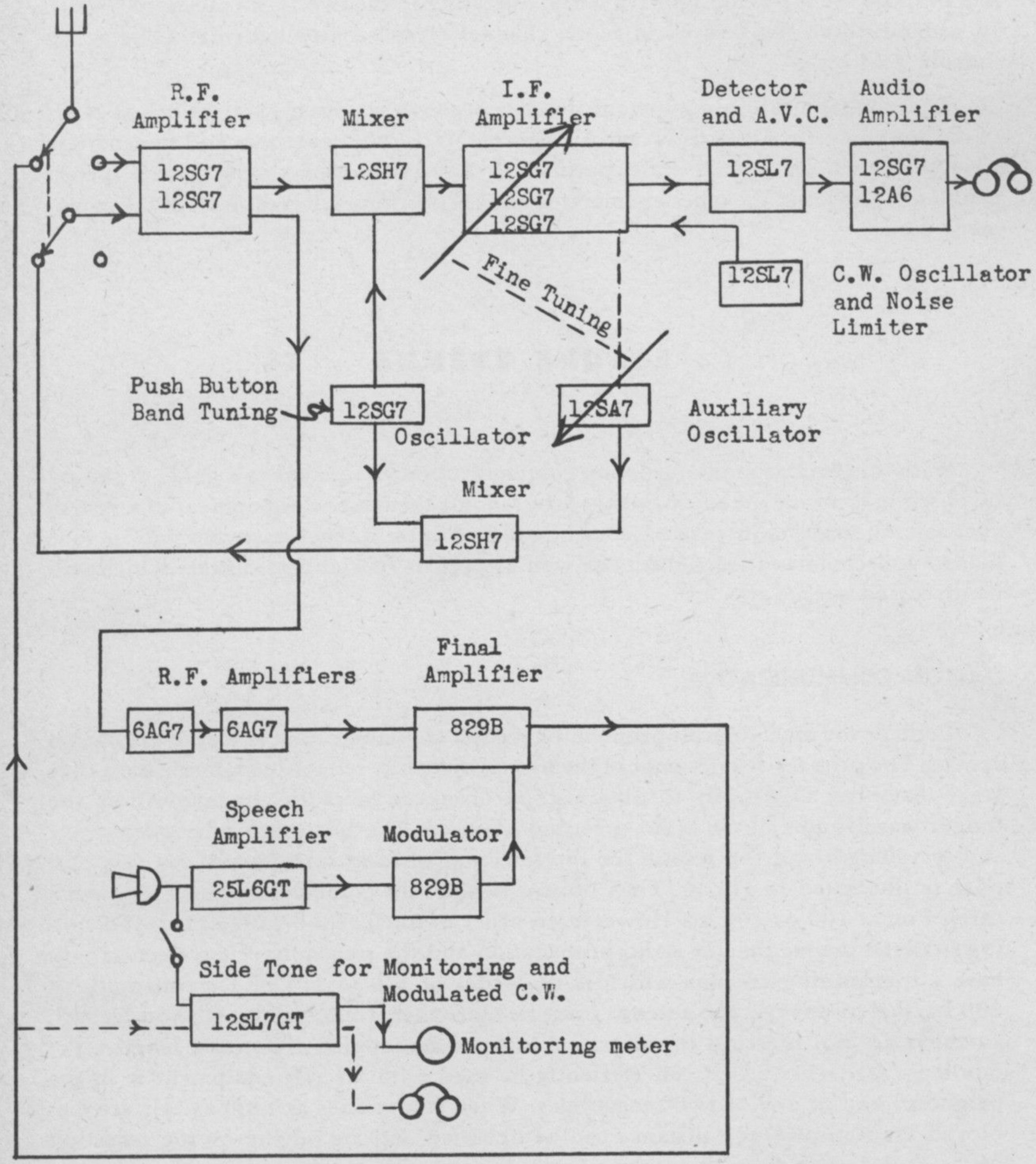

R.F. Amplifier
(A)
Mixer
I.F. Amplifier
(C)
Detector
Audio Amplifier
TUNING
ADJUSTMENT
(D)
Auxiliary Oscillator
(B)
Oscillator
Mixer
(E)
Final Amplifier
Intermediate Power Amplifier
Modulating Amplifier
Side Tone

Figure 2



R.F. Amplifier
12SG7
12SG7
Mixer
12SH7
I.F. Amplifier
12SG7
12SG7
12SG7
Detector and A.V.C.
12SL7
Audio Amplifier
12SG7
12A6
12SL7
C.W. Oscillator and Noise Limiter
Fine Tuning
Push Button Band Tuning
12SG7
Oscillator
12SA7
Auxiliary Oscillator
Mixer
12SH7
R.F. Amplifiers
6AG7
6AG7
Final Amplifier
829B
Speech Amplifier
25L6GT
Modulator
829B
Side Tone for Monitoring and Modulated C.W.
12SL7GT
Monitoring meter

Figure 3

requirements on its radio equipment. In spite of the relatively small distances over which communication must be maintained, it cannot employ the very high frequency which characterizes command communication sets. This is because the airplane must stay close to the ground so that line of sight is quite limited. Almost all sets used for this purpose are medium high frequency, operating in the two to six megacycle band. In general, these sets consist of a one channel crystal-controlled transmitter and a tunable receiver.

The communication equipment described above represents the principle types of units used by the Army and Navy Air Forces. Many other receivers and transmitters have been used on a small scale, particularly for test purposes and to meet special problems. However, the types enumerated above constitute the great bulk of the equipment used.

FUTURE TRENDS

With this background of existing communication equipment as a guide, it should be possible to formulate a reasonable program for the future development of a system adequate to meet the increasing demands placed upon it. Such a system will include liaison and command instruments as well as certain special transmitters which will be discussed later.

LIAISON COMMUNICATION

Perhaps the most difficult problem of aircraft communication is that of the liaison system. The primary requirement of the liaison system is reliable communication over large distances. Ordinarily to obtain great distances in radio communication, the longer wavelengths of the radio spectrum are used. The relationship between range and wavelength and the reason for the selection of long wavelengths for this purpose is illustrated in Fig. 4. Thus transoceanic radio communication is frequently carried on at 100 or 200 kc. However, in order to obtain moderately efficient coupling between the medium of radio propagation and the transmitter, it is necessary to have a transmitting antenna which is the order of 3/8 to 1/4 of a wavelength. At 200 kc, this means that the antenna must be more than 1000 ft long. Obviously, such antennas are not practical for aircraft. From the standpoint of antenna lengths, the minimum frequencies that can efficiently be used with aircraft equipment is in the neighborhood of one or two megacycles. When frequencies as high as this are employed, transmission at a distance can be obtained only by relying on the reflection of the radio waves from the various ionized layers of the upper atmosphere as illustrated in Fig. 5. Since for any one frequency these reflections are quite variable, it is not possible to depend on a single frequency where absolutely reliability of communications is essential. It has been found that if the receiver and transmitter are capable of selecting one out of eight or ten different frequencies in the band between two and

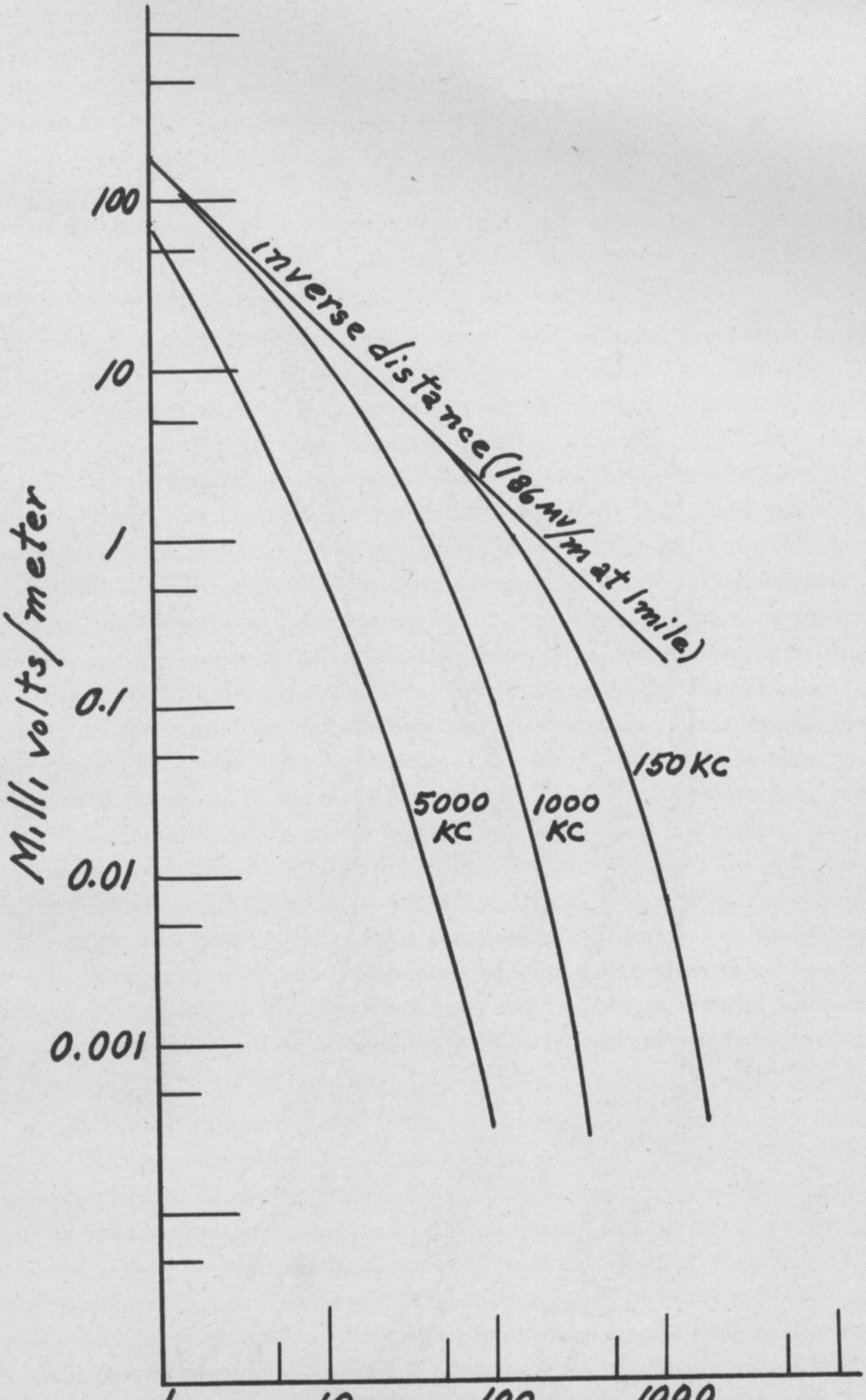


Figure 4 — Dependence of Ground Wave on Distance & Frequency (good ground)

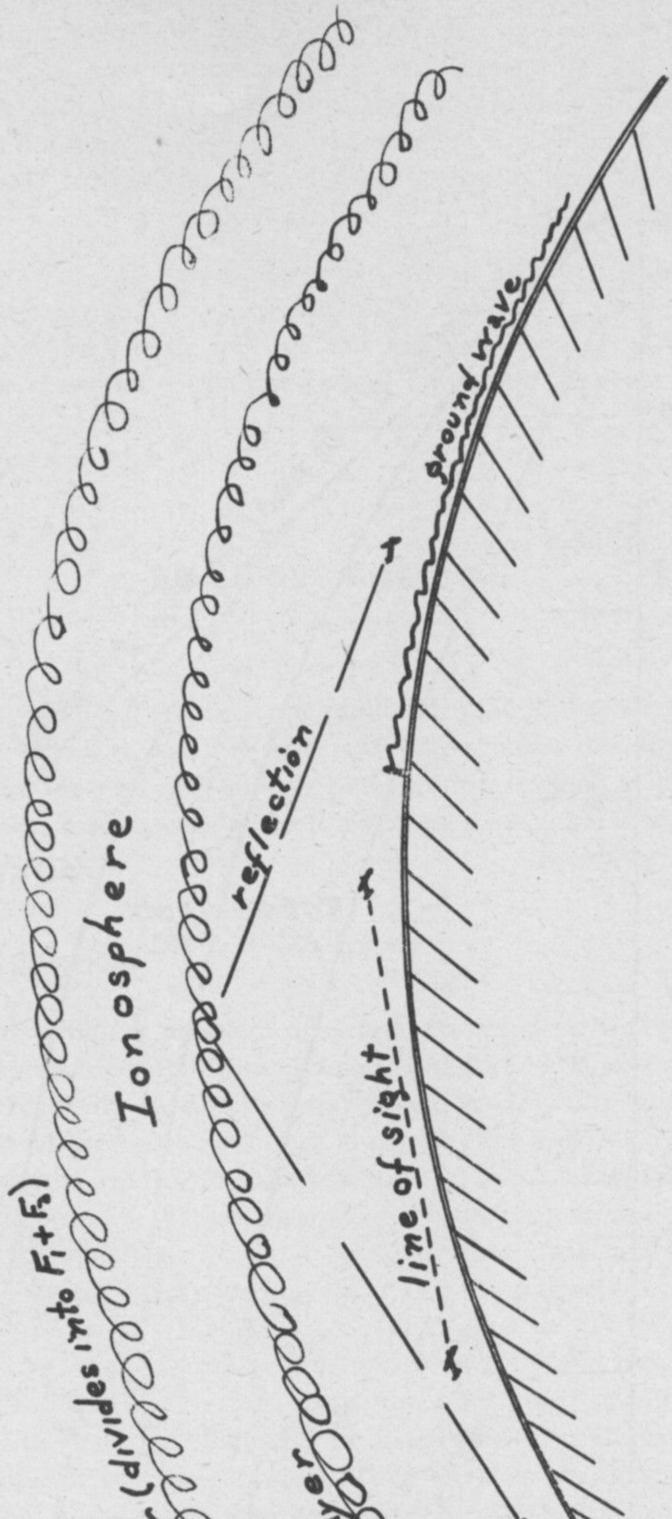


Figure 5 — Radio Transmission

thirty megacycles, reliable communication in general is obtained. Even when this is done, communication may occasionally be interrupted during periods of violent magnetic storms and sunspot activity. At present, no means is apparent for overcoming this difficulty in long-range transmission and the liaison equipment of the future will probably operate in the same region of the radio spectrum as at present. However, improvements will be made in the method of shifting from one band to the next in order to find a channel over which satisfactory communication can be established. It is possible that automatic tuning systems can be devised for making this selection so that the operator does not have to pick out the channel himself.

Even in the two to thirty megacycle bands, the antenna presents a formidable aerodynamic problem. In order to obtain efficiency it should be about 100 ft long. According to present practice, it consists of a wire stretched between the nose of the plane and the tail fin. However, as airplane speeds increase, such a wire and its supports cannot be tolerated, and other types of antenna construction must be found. Some interesting experiments have been carried on, using the wings of an airplane as the antenna. Figure 6 illustrates the way these tests were conducted. The wing of the airplane from the engine nacelle to the tip was made of plastic. The radiator was an internal conductor stretched from the engine to the wing tip. The wing tip itself was metalized to form a capacity cap. The conductor was fed from a matching tuner located close to the engine. This tuner was in turn supplied by coaxial cable from the transmitter. As different frequency bands are selected it is necessary, of course, to reset the tuner. This was done by means of Autotune mechanisms from a remote control point in the cabin. In the test described, only one wing was used as the antenna because of phasing difficulties when both wings were tried. However, this phasing difficulty can be overcome by further developmental work, thus making it possible to employ the full length of both wings for the radiator. This should constitute a very efficient radiator and present no serious aerodynamic obstacles. In this connection, it is interesting to note that some very promising experimental work on bonded glass as a structural material for airplanes has been carried out at Wright Field. Bonded-glass wing structures would be admirably suitable to carry the liaison antenna wire.

Because the nature of the propagation characteristics makes it necessary to use one of a number of rather narrow bands at different frequencies, the problem of maintaining several communication channels is difficult. Since intelligible speech requires a bandwidth of about 2000 c, if double side-band transmission is employed only four or five channels at the most can be maintained. By going to single side-band transmission, it may be possible to double this number. If more than this number of channels become necessary, recourse will have to be made to teletype communications or a speech-coding system, along the lines investigated by the Bell Telephone Company in their work with the Vocoder. At present, little would be gained by going to these systems because practical oscillator stabilities are not better than about 0.02% which means that stability alone will require some six kilocycles band width at the high-frequency end of this communication band. However, oscillator stabilities are almost certain to improve as the radio art continues to develop.

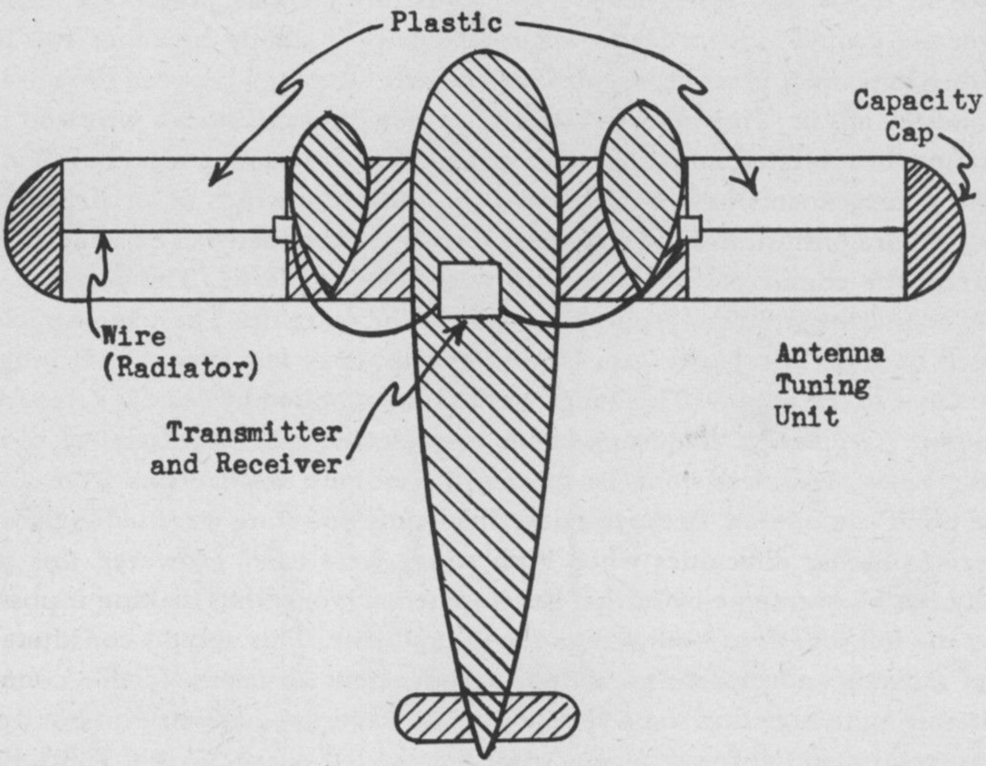


Figure 6 — Antenna System with Plastic Wing Sections

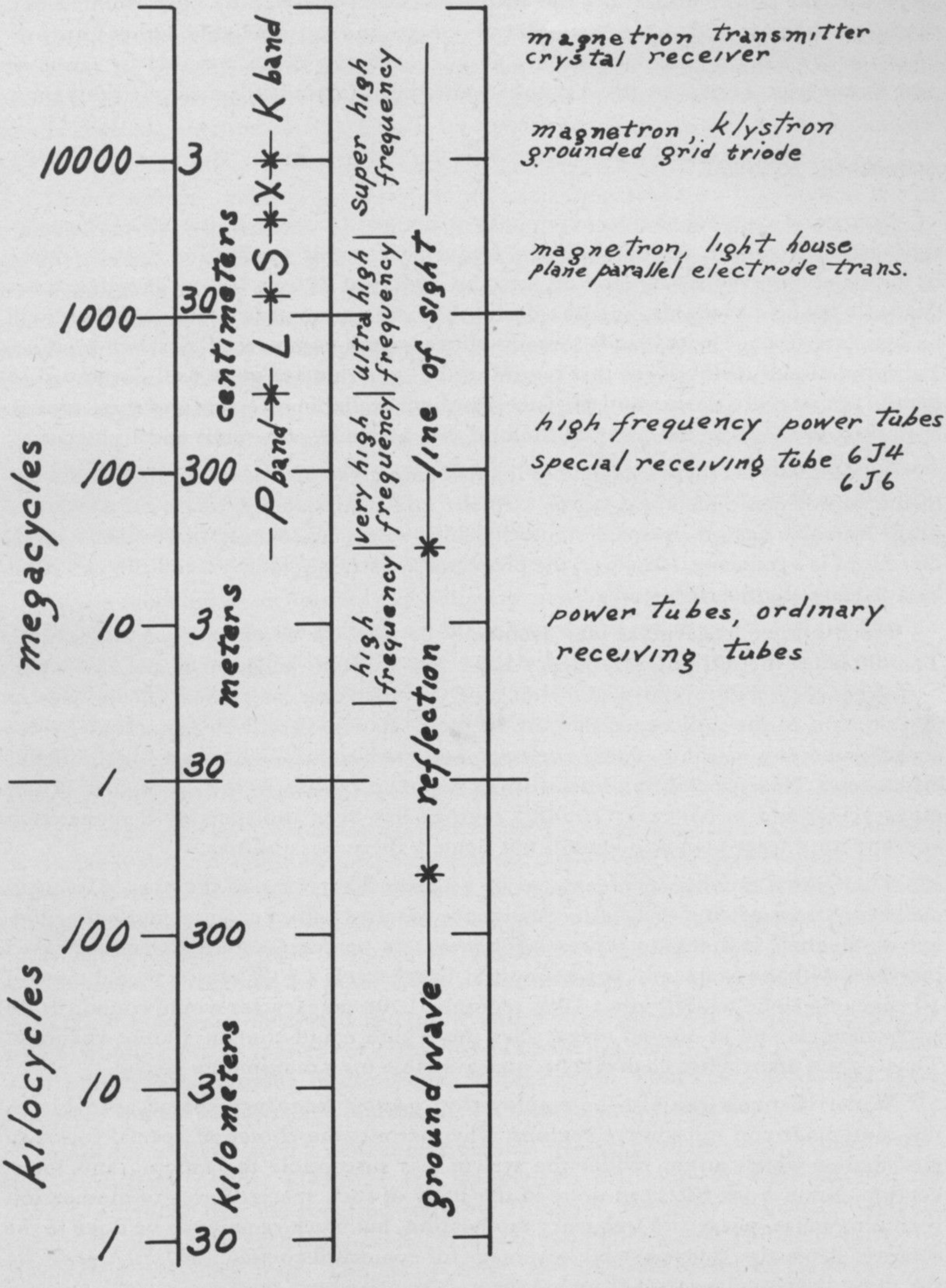


Figure 7 — Radio Spectrum

The radio transmitter and receiver itself will not differ basically from those used at present. Improvements will be made in tubes and circuits which will allow more efficient power utilization and in particular, as has already been pointed out, tuning mechanism will be made simpler to operate and more reliable. Other improvements in the liaison communication equipment may be made possible by virtue of new discoveries. However, these cannot be included in plans formulated at this time.

COMMAND SYSTEMS

Command communication equipment at present operates in the 100-156 megacycle band. However, undoubtedly the frequency for this application will be raised in the immediate future. By moving into the region of 200 to 500 megacycles, more channels become available, antenna design becomes somewhat easier, and there will be less interference with bands already allocated for commercial postwar aviation. Tube and circuit methods for this region of the spectrum are quite well developed so that it is possible to design and produce absolutely reliable receivers and transmitters. Furthermore the essential parts of the unit can be made very small and lightweight.

The antenna for these frequencies is small enough so that it can be contained within the aerodynamic members of the airplane and consequently, offers no additional drag. Antenna design presents some difficulty where uniformity of response in all directions is a requisite. However, the problems are straight forward and can be solved by adequate engineering studies.

Much higher frequencies may eventually be used for command communication. This includes the ultrahigh-frequency band 300 to 3000 megacycles and the superhigh-frequency region above 3000 megacycles. However, at present, techniques in this portion of the radio spectrum are in their infancy. It will be some time before accumulated engineering experience compares with that which exists for the lower frequencies. Nevertheless the feasibility of communications in the centimeter (1000 megacycles) and microwave (10,000) regions has been indisputably demonstrated and any long term planning should not neglect these possibilities.

There are a number of advantages to be gained by going to the higher frequencies. Since transmission of speech intelligence requires a fixed channel width the number of channels in a region representing a certain percentage of the frequency used increases with the frequency. For example at 1 megacycle a 10% region would contain 10 channels 10 kc wide, while a 10% region at 1000 megacycles would contain 1000 such channels and at 30,000 megacycles the region could contain 30,000 channels. Thus a great many more channels become available for a multiphone system.

Wider channels can also be employed in greater frequency spread available in the centimeter and microwave regions. This permits the choice of special forms of modulation which might render the system less susceptible to jamming and interception. Some work has been done in the study of such special forms of modulation including pulse, phase and frequency modulation, but much remains to be done in the future to determine their possible advantage for command communication. A program for radio development should include more extensive tests on these various types of modulation, particularly with regard to their susceptibility to jamming and interference and ease of enemy interception. Except for their less economical use of communication bandwidths and certain other minor objections, in general such modulation systems may prove to have important advantages.

Greater directivity can be obtained as the radio carrier frequency is increased. This may be important in connection with certain types of operations. In general, however, this is an undesirable feature since most frequently an omnidirectional system is desired. Antennas giving a uniform pattern in all directions are more difficult to attain at very high frequencies and the power utilization is less efficient.

Under wartime pressure, research in the ultrahigh-frequency regions has led to major advances in technique. The introduction of the lighthouse tube and other plane parallel-electrode ring-seal tubes represent an important step. Great improvement has been made in wave guide and coaxial systems. When certain problems of frequency stability have been overcome and the engineering design problems worked out ultrahigh-frequency radio systems will become very important. It is quite possible that equipment working in the 1000 to5000 megacycle region will come into extensive use supplementing the command systems discussed above working at the lower frequencies, or possibly it may replace them entirely. Microwave systems may have important application for military aviation communication. They are characterized by certain unique advantages as well as disadvantages. Most prominent among the advantages is the extreme directionality that can be achieved; also in this region of the spectrum there is practically no natural static.

While microwave techniques are still very new, nevertheless enough work has already been done to lay the ground work for future systems. A good deal of valuable experience has been gained with S-, X- and K-band radars which can be applied to communication systems. Tests also have been made on phone transmitters and receivers operating in this portion of the radio spectrum.

As illustrative of microwave communication possibilities a system proposed and described in reports from the Radiation Laboratory at M.I.T. will be discussed.*

The system is to provide transmitter-receiver combinations on a large number of airplanes in such a way that communication can be effected between any pair independent of all the others. Thus it would provide what amounts to a telephone exchange between planes; calling another plane would simply be a matter of dialing the appropriate number. By the response of his own receiver, the individual calling can tell immediately whether the party called is within range and is receiving his signal.

Like the systems illustrated in Figs. 2 and 3 there would be a single oscillator which would serve as master oscillator for both the transmitter and receiver. However, unlike these systems transmission and reception would not be on the same frequency but on frequencies differing by the intermediate frequency.

In order to make such a system feasible it is necessary to use very stable oscillators. Ordinarily neither klystrons nor magnetrons operating at these frequencies provide anything like the required stability. However, the units in question can be stabilized against an accurately made, temperature-compensated resonant cavity by means of a feed-back loop. The cavity serves as the master frequency-determining

*Radiation Laboratory Reports #815 and #830 by R. V. Pound.

element of the transmitter-receiver unit. Normally this cavity will be set at the frequency assigned to the particular station. In making a call the operator adjusts the frequency of the cavity until it has the required value for the station he is calling. The adjustment will probably be made by means of some dial system similar to those currently in use for ordinary telephones. Proper contact will be indicated by a light or meter on his receiver. At the same time the receiver at the station being called will flash an indication.

A schematic diagram of a transmitter-receiver combination for such a system is shown in Fig. 8. In the absence of incoming signal, energy from oscillator B is divided by "magic tee", C, into two equal portions, one of which is radiated from the antenna A and the other is fed to the stabilizing cavity D. The cavity D and two crystals E and E′ act as a discriminator and generate a voltage when the oscillator differs from the resonant frequency of the cavity. This voltage is amplified and supplied to the frequency-control element of the oscillator. When the frequency is too high this voltage is in the direction to decrease the frequency, and conversely, the voltage tends to increase the frequency if it is too low. The degree of stabilization that can be achieved depends upon the stability of the cavity and the properties of the feed-back loop. Preliminary experimental oscillators have been stabilized to 10 kc and better in this way.

The oscillator output can be frequency modulated simply by introducing the modulation voltage into the feed-back loop as shown in the figure.

When used as a receiver the incoming signal enters the same antenna used for transmission. The signal is divided at the "magic tee" and the useful portion goes through a wave guide to the balanced discriminator F, F′ where it beats with the signal from the local master oscillator B. Since the incoming signal has a carrier frequency which differs from that of the oscillator B by the IF the output from F, F′ leads to a frequency-modulated signal on a carrier of the correct intermediate frequency. In general the intermediate frequency cannot be low enough so that it represents the spacing between channels. Practical considerations suggest that the IF might be in the neighborhood of 30 megacycles. With an elaborate system of switching and image rejection one half the total number of channels available could be used for communication. A more practical and straight forward arrangement would permit one-third of the total number of channels to be used. This arrangement is shown in Fig. 9.

Group A in the figure is the distribution of transmitter (master oscillator) frequencies, the receiving frequencies and the image frequencies. A calling station adjusts its master oscillator to the receiving frequency of the station being called. This is seen in Group B. The calling station will receive the station called on his image frequency. Since his normal receiving frequency will be over a group of image-response channels no interference will result.

Even with this reduction to one-third of the total number of channels available there are still a large number which can be used. Assume the band to be used to be that at 10,000 megacycles and that the tuning range be 10% or 1000 megacycles. Then if 100 kc is allowed for each channel the total number is 10,000 and the useful number over 3000. This figure is conservative and it is certain that practical stabilities of better than the 100 kc can be achieved, thus increasing the number of useful channels.

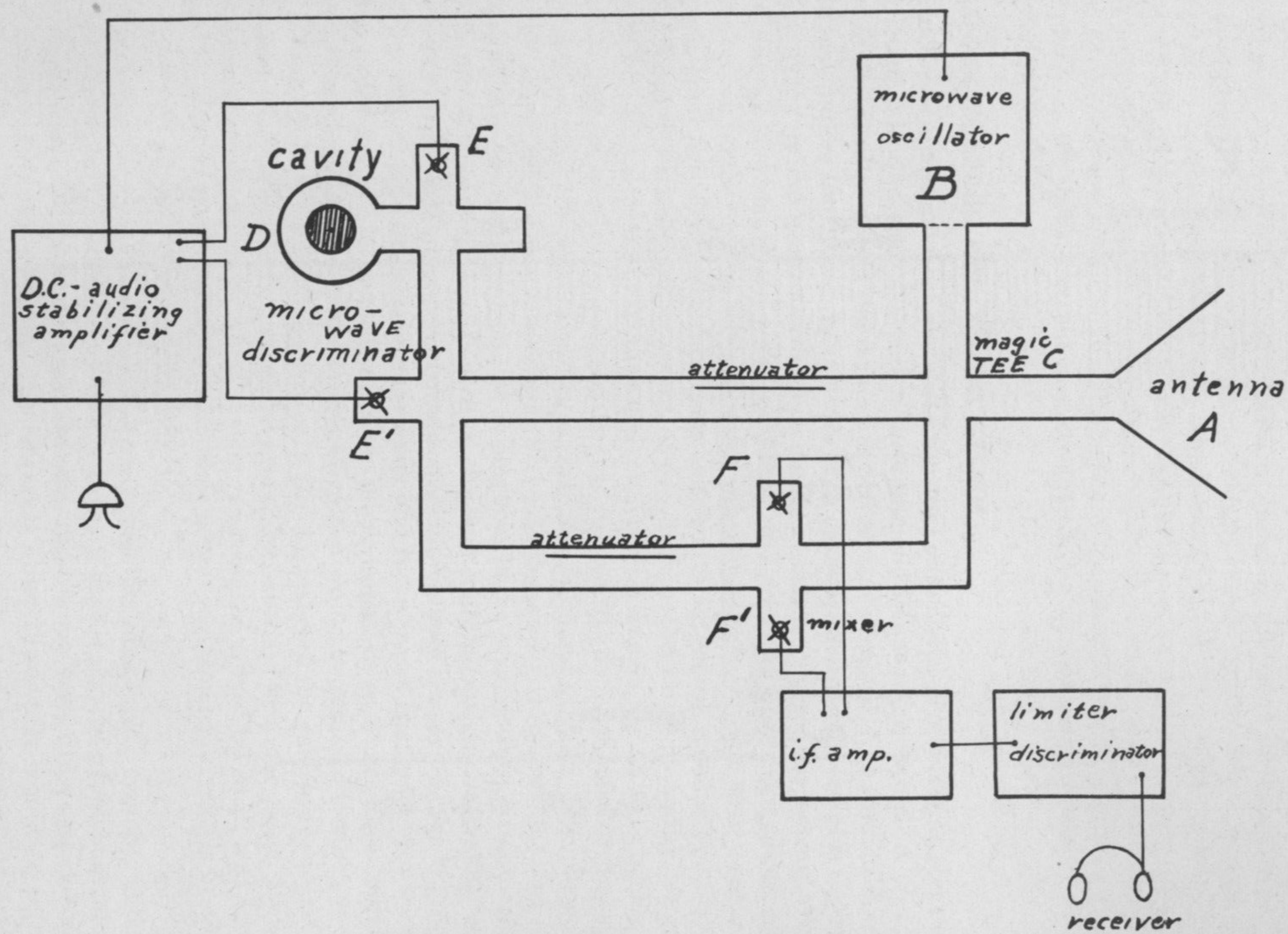


Figure 8 — Stabilized Microwave System

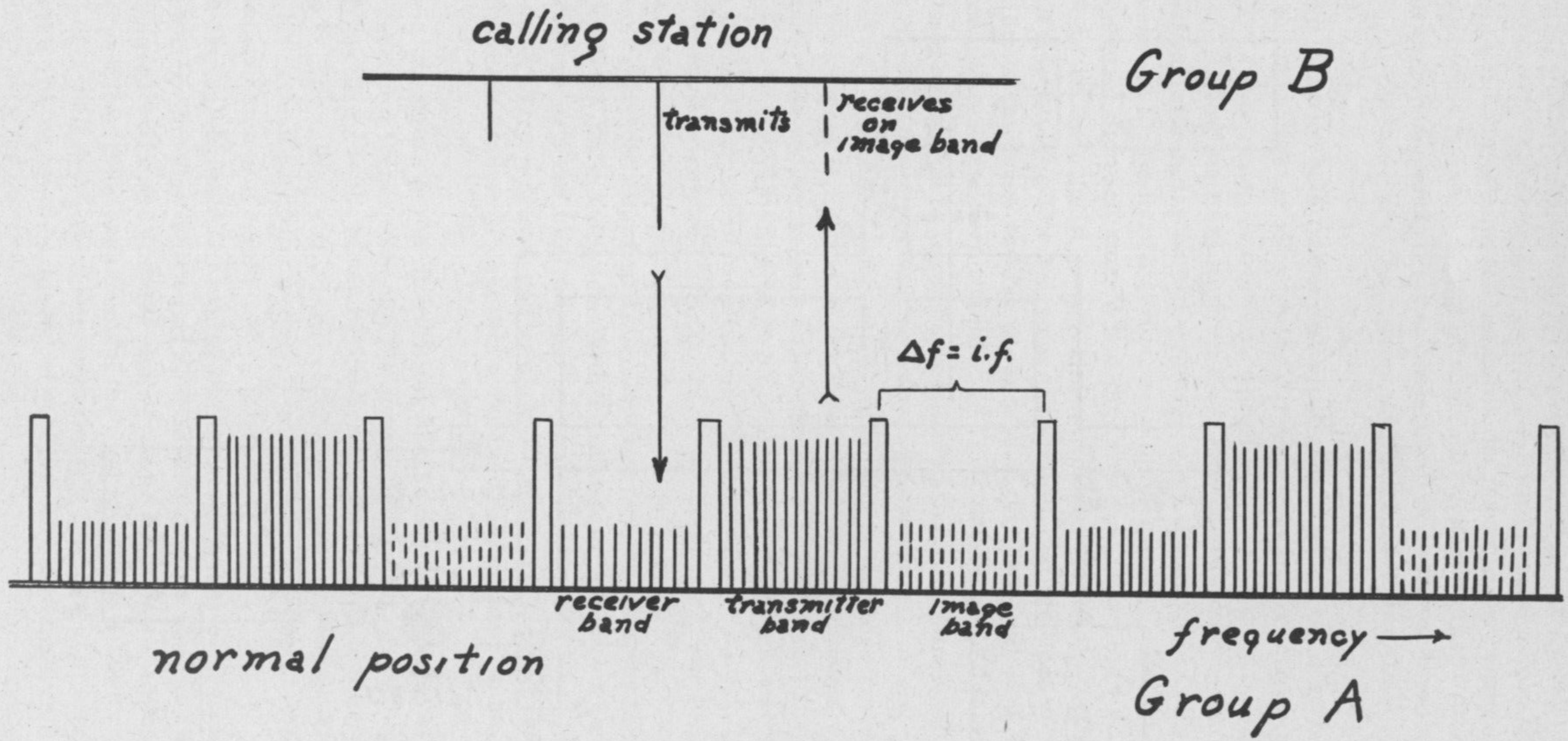

calling station
Group B
transmits
receives on image band
Δf = i.f.
receiver band
transmitter band
image band
frequency →
normal position
Group A

Figure 9

An experimental transmitter-receiver combination of this type has already been experimentally tested and shown to be entirely feasible. In view of the rapidity with which the microwave field is advancing, the technical availability of the system is assured.

Going to still higher frequencies, 60,000 megacycles or more, the portion of the spectrum is reached where molecular absorption of the gases in the atmosphere is of consequence. Employing these frequencies, it should be possible to design short-range radio communication systems which would allow the transfer of intelligence between planes in a formation and yet have the signal strength attenuated so rapidly that the enemy at a slightly greater distance could not intercept or even detect radiation. Furthermore, it would be virtually impossible to jam the communications between the planes in the formation, short of sending jamming transmitters actually into the formation itself.

CHANNEL CONTROL AND SPECIAL SYSTEM

Much developmental work remains to be done as to methods of selecting and switching communication channels within the command-frequency spectrum. A command system designed to obtain the maximum performance from a large formation of aircraft may require individual channels for each of the airplanes involved plus additional channels for various groups of these planes and a master channel for the entire formation. If such a system is used, the switching and selecting must be made as easy as ordinary telephone dialing. Already work is being done to develop such a system. An experimental British receiver has been built which incorporates some 300 channels. These channels are slected by means of two dials, each having positions designated by letters of the alphabet. To tune the receiver and transmitter to any channel, one merely dials the two letters designating that channel. There is no fundamental reason why this system cannot be extended to include a thousand or more channels and the dial be simplified to a single telephone dial with the ten digits marked on it, on which one dials three or four numbers just as one does in the case of using the conventional telephone. Where this system is used, each plane could be assigned a channel so that any other airplane wishing to communicate with it would simply dial the appropriate number which tunes the calling transmitter and receiver to a channel which the plane being called keeps continuously open for the reception of such messages. Submaster and master channels also kept continuously open would be reserved for the use of the formation leaders. Some channels would also be reserved for emergency work. Such a system would require two or three transmitter-receiver sets per plane. However, with the short distances involved the power required would be small and each set could be made very compact. The switching system required could readily be evolved from present day telephone technique.

Mention has already been made of the possibility of reducing jamming and interference by the use of various modulated systems. There is also the problem of minimizing enemy interception of messages. This may make it necessary to use speech-scrambling systems in order to render the messages unintelligible. It would be relatively simple to develop scrambling systems whose coding could be changed at predetermined intervals in such a way as to make enemy interception virtually impossible. Intelligence transmitted by teletype or facsimile may possibly play some role in command communication system. However, this appears to be less likely than in the case of the liaison communication. Both teletype and facisimile methods are so well developed that they need no further comment.

For some aircraft work, it is desirable to have a system which gives a permanent or semipermanent indication of the command being transmitted. This is particularly important in the case of a fighter pilot as there is a considerable probability of his being occupied at the moment the message is being sent, and if it is not recorded he may lose the information. Work has already been done along these lines in connection with a British system named "Beechnut" and a corresponding American system designated as "Voflag."

In the "Voflag" system the message, consisting of six units of intelligence, is preset into the transmitter together with the calling signal code. An electromechanical scanner surveys the preset message and directs subcarrier frequency modulation keying of an amplitude-modulated ultrahigh-frequency radio transmitter.

At the aircraft receiving the message, the "Voflag" signal is intercepted by a voice communication receiver and converted to an electrical audio output. The audio output is fed to discriminator circuits with very high selectivity which separate out the keying signals. These operate a small synchronous motor which distributes the code signals to a teleselector mechanism. The output of the teleselector controls the annunciator messages display box or can be used to control a printer.

The system is equipped with an automatic repeat-back which informs the transmitting station of the correct delivery of the message.

Because of the high selectivity of the receiving circuits and the protective feature of the balanced equal-length signalling code used, the system is very difficult to jam.

The systems discussed in the preceding paragraphs are still only in the research stage. It will be many years before they are brought to a point of development where they can be considered part of the absolutely essential minimum. However, long before this stage is reached, they may serve as important adjuncts to the fundamental communication system.

All radio communication above 50 or 100 megacycles is essentially limited to line-of-sight transmission. If radar patterns or television pictures requiring the transmission of bandwidths of several megacycles becomes an important part of the aircraft communication system, it will become necessary to develop airborne radio relay links in order to maintain communication over great distances. This will be particularly important if the transmitters are part of remote-controlled missiles. A good deal of work has already been done in developing automatic relay systems for television and multichannel telephone communication. The present equipment is, in general, too bulky for airborne use but it can be said with considerable assurance that the bulk and weight of this equipment can be reduced by a large factor without going beyond present technical knowledge. Operation at 3000 megacycles or more it will undoubtedly be possible to design a relay unit which will give several hundred miles line-sight communication range, with a nominal output power of 50 w or less. Equipment of this type could be carried in either pilot operated airplanes or remote-controlled ships and could serve to retransmit either pictures or multichannel voice communications. A number of such airborne repeater stations spaced at intervals between the aircraft formation and its operational control point may in the future serve to maintain liaison communications as a supplement to a long-wave transmitter. This would have the advantage of permitting a great number of communication channels, of being virtually free from static and atmospheric interference and of being less susceptible to jamming. Probably the long-wave transmitter would be retained only to be used in event that the relay chain was broken.

Control of the landing, take-off and flight formation of planes from a ground station or base becomes very difficult when large numbers of planes are involved, particularly under the black-out conditions imposed by war. The presence of fog, heavy rain or other unfavorable meterological circumstances greatly increases the hazard and makes accurate control essential. The employment of a "Teleran" system or its equivalent will expedite these operations and to a large extent reduce the danger associated with them.

The "Teleran" system includes the radar location of all planes in the neighborhood of the base and transmitting this information together with other data to the planes in the form of a television picture. It also provides for the blind-landing of planes as ordered.

For this system the space above the air base is divided into levels. The planes as they come in are assigned to the various levels. At the ground station all the planes are located by radar and the location of the planes in the different levels are plotted electronically. A map of the air-base terrain, including meteorological indications, with all of the positions of planes in a level is transmitted by television to all the planes in that level. Thus every pilot not only is informed of his own location but also knows the location of all other planes at his level and can thus avoid the possibility of collision.

A complete blind-landing system, with guide beams and indicators is provided in the lowest level.

Such a system gives the air base complete control of incoming and outgoing planes and should greatly increase the safety of what is now a very hazardous operation.

COMPONENTS

In addition to the development of systems and equipment outlined above, a good deal of effort should be spent on perfecting components which go into making up the communication equipment. Industrial engineering has developed excellent components, tubes, inductors, capacitors, resistors, and insulators for commercial radio equipment. However, the demands placed on components, and reliability required is very different for military aviation radio than for ordinary commercial practice, even commercial aviation.

The development of components should be carried out in collaboration with parts manufacturers to ensure an eventual adequate supply of these elements. Attention should be focused on such factors as stability, resistance to shock, insulation under extremes of pressure, temperature, humidity, etc.

It is certain the components with the required characteristics can be produced, and the only reason they are not at present is that they are uneconomical to use in commercial equipment.

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Other developments in the technique of radio communication undoubtedly will occur and obviously will make it necessary to alter the program. However, the program as outlined can be considered to represent the minimum realizable communication system and any deviations from it will necessarily be in the direction of improvement.

RECOMMENDATIONS

The discussion above outlines a course of radio-communication equipment development which would meet the basic needs of an effective air force. It also suggests special lines along which research should be directed. These are the following:

Liaison Systems (2 to 30 megacycles)

1. Antenna research in collaboration with aeronautical designers.
2. Improvement of oscillator stability.
3. New tuning methods, with an aim to obtaining automatic band selection if possible.
4. Investigation of voice coding systems for reducing the band widths required per channel.

Command Systems (200 to 500 megacycles)

1. Antenna design.
2. Stability of oscillators and other components.
3. Development of multichannel switching and selector mechanisms.
4. Study of antijamming and anti-interception methods.
5. Modulation methods.

Components

1. Development of suitable tubes.
2. Development and production of insulators, resistors, capacitors, etc.

Special Systems

1. The study of centimeter, microwave, and millimeter wavelength systems. This includes the investigation of all components including antennas.
2. Highly directional transmission and reception.
3. Pulse modulation.
4. Application of facsimile, teletype and indicator systems to aircraft needs.
5. Television and radar picture transmission.
6. Airborne radio relay links.
7. "Teleran" air base control systems.