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NAVAL AIRCRAFT RADIO*

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INTRODUCTION

The importance of radio as applied to military aircraft is too self-evident to require extended comment. One of the most important functions of military aircraft is that of observing. In rapidly and accurately communicating at once the results of observation to a distant point lies the greatest value of obtaining such observations. Radio adds to this very great advantage that of being able to control the movements of aircraft from the ground or from other aircraft, and that of transmission of distress signals from disabled craft.

The naval aircraft radio problem is of a different character in many ways from that of the land military forces in that it introduces the use of this communication to a large extent in connection with anti-submarine and other coastal patrol duties where larger craft are used, and where larger and longer range radio sets are required. In these cases a specially trained operator is provided solely for radio, permitting the use of a set of greater complication of operation and greater transmission possibilities. This patrol duty involves the reporting of position as the aircraft covers its patrol territory, and the reporting of enemy craft or mines sighted, or vessels in distress. In connection with these duties there is involved that of convoy in which radio is useful in the aircraft communicating directly with the vessels under convoy.

The other phase of the naval aircraft problem in which radio plays a very important part is that of fire control from battleships. In this case the craft used are smaller, the radio usually being operated by the pilot, and the transmitting distance required is relatively short. Thus, from a radio viewpoint,

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naval aircraft radio is divided into two distinctly separate phases, calling for apparatus and equipment of a widely varying character.

At the beginning of the war there was doubtless no field of radio work newer than that of aircraft radio. Like many of the other new technical problems introduced by war demands, that of aircraft radio was attended by multiple difficulties. The problem faced was that of providing large quantities of equipment which would be simple and inexpensive to manufacture, small, light weight, and possessing extreme ruggedness and simplicity of control. In meeting this problem there arose the development difficulties of providing new methods of investigation as applied to aircraft, and training personnel to conduct these investigations from a basic knowledge which was extremely meager. It was necessary to provide a large number of aircraft of the various standardized types for testing purposes; this was difficult, due to the general lack of aircraft at the beginning of the war. It was also discovered that in the development work it was necessary to employ pilots who were rather sympathetic with the radio investigations in order to obtain the most satisfactory results in the shortest time.

After the preliminary investigations had been conducted it was necessary for the apparatus to pass rapidly from the development to the standardization stage. In standardization it was necessary to combine smallness, lightness of weight, and manufacturing simplicity with simplicity of control, waterproofness, and the highest degree of ruggedness in ability to withstand shock of a widely varying nature. Standardization was also attended by the difficulty of simultaneous standardization of radio equipment with that of aircraft itself.

Installation difficulties were largely solved by the careful choice of complete equipments including all detailed fittings and material necessary for a standard installation. The installation work required, however, the special training of personnel who would be familiar with aircraft so that the installations might not impair the general utility of the craft. The initial installations were made in a standard manner by equipping each aircraft before it was shipped from the aircraft factory.

The matter of operation also involved the special training of personnel. Radio operating on aircraft is of a very special and unusual nature. The operator must usually work in a space which is more or less restricted, under a large number of conditions such as motor noise and rough flying which seriously distract his attention from his radio duties. The use of more recent forms of apparatus such as vacuum tube transmitters, regenerative receivers, and the radio compass, has still further necessitated special training.

EARLY DEVELOPMENT

The first operation of radio equipment on a seaplane was conducted by the Navy Department on July 26, 1912, at the Naval Academy at Annapolis, Maryland. Ensign (now Lieutenant-Commander) Charles H. Maddox, U. S. N., acting as operator on the seaplane, transmitted a message from a height of 300 feet (91.5 meters) to the torpedo boat U. S. S. *Stringham*. The communication was maintained at that time up to a distance of three nautical miles (5.55 kilometers). The complete receiving apparatus was suspended in front of the operator by a strap passing over his shoulders as shown in Figure 1. A specially constructed helmet was used for holding the telephone receivers and keeping out external noises. A "balanced antenna" with similar portions in the upper and lower planes was employed.

FIGURE 1

Early in 1916 Lieutenant-Commander (now Commander) S. C. Hooper, U. S. N., of the Radio Division, Bureau of Steam Engineering, Navy Department, realizing the growing importance of the application of radio to aircraft, urged the establishment of a laboratory for this work. Such a laboratory was started at the United States Naval Air Station, Pensacola, Florida.

The first apparatus tested was a transmitter, a 250-watt tuned vibrator set manufactured by William Dubilier. Three sets of this type were installed on Curtiss pusher seaplanes of the type illustrated in Figure 2. The transmitter was strapped to the inclined struts near the pilot's seats, power being supplied from a direct current generator geared to the camshaft of the engine. Transmission was conducted on a wave length of 300 meters, a single trailing wire antenna 150 feet (45.7 meters) in length being employed. The entire equipment installed weighed 80 pounds (36.2 kilograms). On May 15, 1916, Chief Electrician (now Chief Warrant Officer) S. S. Halliburton, U. S. N., transmitted the first official radio message from a United States Naval seaplane in flight a distance of 20 nautical miles (37.1 kilometers) to the cruiser U. S. S. *North Carolina*.

FIGURE 2

The results of these tests so proved to the Navy Department the importance of providing aircraft with radio equipment that it was decided to purchase seventy-five seaplane transmitting sets at once. From the observations made in the preliminary investigations at Pensacola specifications were drawn up, the use of a propeller-driven generator and a single trailing wire antenna being called for, the metallic parts of the seaplane to be used as counterpoise. A total weight of 100 pounds (45.4 kilograms) was allowed for the equipment. Of the large number of samples submitted by manufacturers three types were purchased, a spark set, a buzzer excitation set, and a vacuum tube transmitter. The spark set was type CM 295, manufactured by the Marconi Wireless Telegraph Company. The vibrator arc set was type CS 350, invented by William Dubilier and manufactured by the Sperry Gyroscope Company and illustrated in Figure 3. The vacuum tube set, type CF 118, manufactured by the De Forest Radio Telephone and Telegraph Company and illustrated in Figure 4, was the first radio telephone equipment to be installed on aircraft.

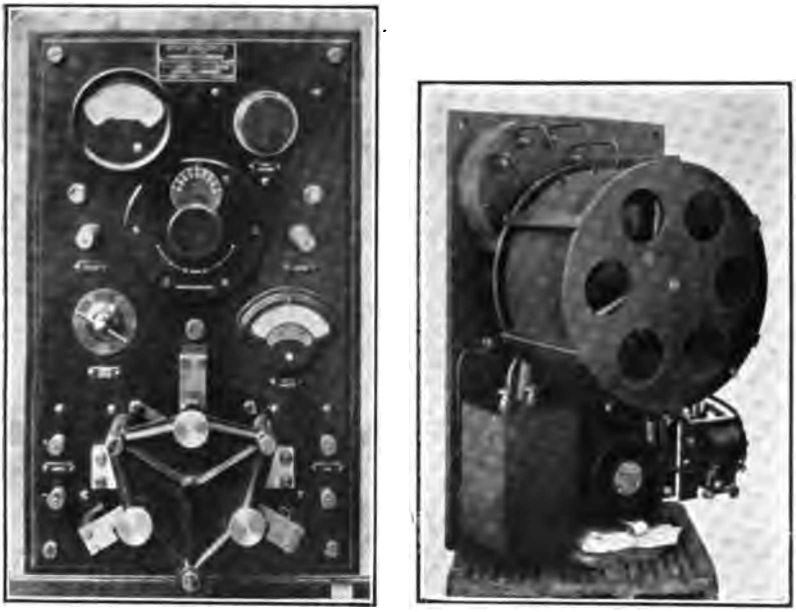


FIGURE 3

In the spring of 1917, the personnel at the station at Pensacola was considerably increased and more extended work in aircraft radio pursued. Measurements were made of antenna constants on seaplanes and the directive effect of trailing wire antennas was investigated. It became apparent that a satisfactory intercommunicating system between pilot and radio operator would be essential to the most effective use of the radio apparatus and a very satisfactory equipment of the voice tube type was developed together with a suitable helmet and other appurtenances.

At this time the Navy Department also realized the importance of the radio compass for aircraft, and investigations were started upon this subject. Experimental work was also conducted on the use of a high tension ignition magneto as a trans-

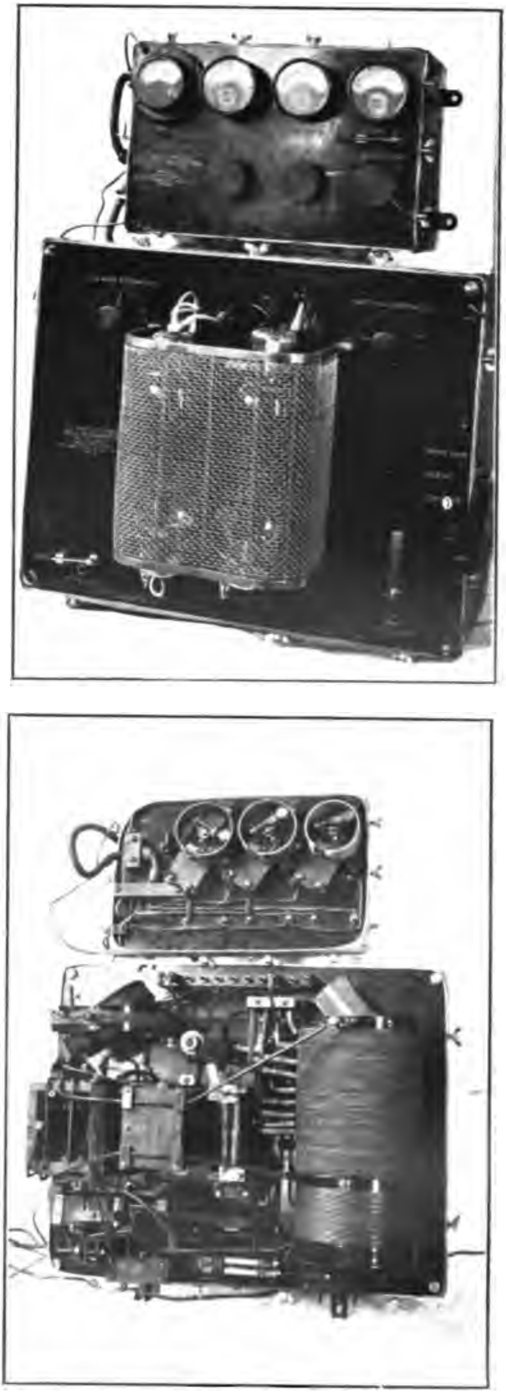


FIGURE 4

mitter of radio signals including the design of a key suitable for handling the high voltages involved. Development of installation fittings such as antenna reels and antenna weights was also undertaken.

At this time there was developed for the Navy Department the 0.5-kilowatt quenched spark aircraft transmitter, type CE 615, manufactured by E. J. Simon, New York, and illustrated in Figure 5. This transmitter was a very great step in advance

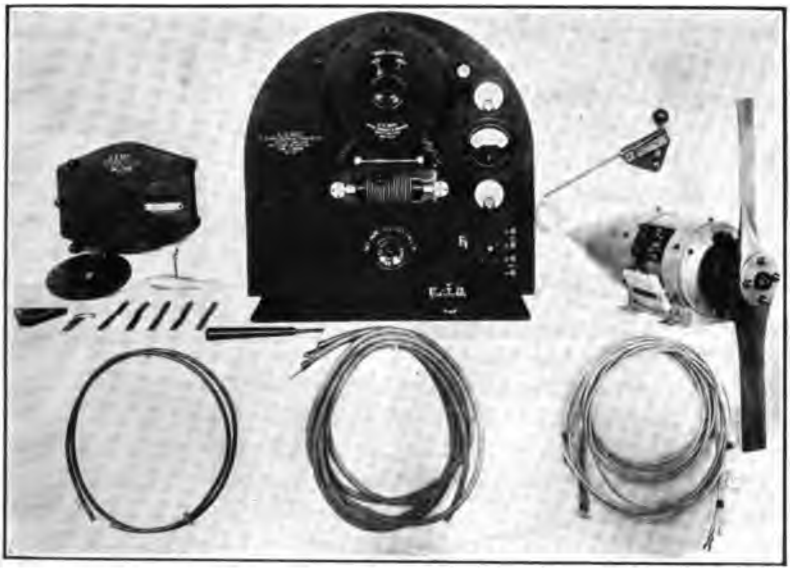


FIGURE 5

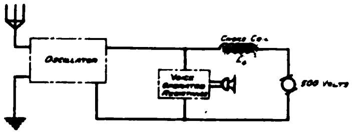
over any radio transmitters which had been previously designed for aircraft use. The transmitter consisted essentially of a panel on which were mounted the main elements of a quenched spark set, the top of the panel being rounded to fit the standard airplane fuselage in use at that time. A reel was supplied with this set which was made entirely of insulated material so that tuning of the antenna circuit could be accomplished by the variation of the length of trailing antenna while the transmitter was operated. Power was supplied from a propeller-driven generator mounted on the wing of the airplane, a brake being provided to prevent the propeller from revolving when the radio set was not in use. This set completely installed weighed approximately 100 pounds (45.4 kilograms). During the summer of 1917, signals were transmitted a distance of 150 nautical miles (278 kilometers) using this transmitter.

The only aircraft receiver of any practical value developed during this period was Type CE 937, manufactured by E. J. Simon, New York. This receiver contained in a case 13 inches (33 cm.) wide by 7 inches (17.8 cm.) high by 7.25 inches (18.4 cm.) deep and weighing 10.5 pounds (4.77 kilograms), was of the single circuit type having a wave length range of approximately 275 to 2,500 meters. A single variable air condenser was provided for tuning, being connected in series with the antenna inductance for low wave lengths and in parallel with it for the higher wave lengths. A single vacuum tube Type CW 933 was utilized as a detector, provision being made for regenerative action. The vacuum tube was carefully mounted on sponge rubber to guard it from shock. The receiver was extremely simple to control and was a distinct accomplishment in the design of aircraft radio apparatus at that time. The lack of additional amplification, however, soon rendered this receiver obsolete.

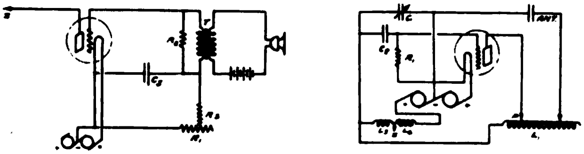
On January 1, 1918, the experimental laboratory for naval aircraft radio was moved from the station at Pensacola to the Naval Air Station at Hampton Roads, Norfolk, Virginia, and development work undertaken on a far more extensive scale with a view to accomplishing standardization of equipment and quantity production as soon as possible. At this time great stress was laid upon the development of vacuum tube transmitters for telephone use, and the radio direction finder apparatus. At this time there also became available flying boats of the latest standardized type, thereby permitting the standardization of radio installations.

The preliminary experimental work at Hampton Roads involved a very large number of fundamental investigations in connection with various details such as all forms of power generating apparatus including propellers, storage batteries, generators and dynamotors, all forms of antenna and ground systems, electrical intercommunicating systems, helmets, microphones, and the many other units forming a part of complete equipments.

The first tests of radio transmitters conducted at Hampton Roads were those made upon a vacuum tube transmitter developed by the Western Electric Company. This was in the form of a preliminary model utilizing ten 5-watt tubes, type CW 931, five being used as oscillators and five as modulators. The power was supplied from a 12-volt storage battery, the filaments being lighted directly from this battery, and the power for the plate circuits, 0.6 ampere at 300 volts, being supplied from a dynamotor run from the storage battery. The set was arranged for telephone or buzzer modulated telegraph transmission on 800 or 1,600 meters, antenna currents of 1.5 amperes and 1 ampere respectively, being obtained on these wave lengths. The weight of the transmitting and receiving set, including storage battery sufficient for 45 minutes' intermittent operation, was 185 pounds (91.3 kilograms). The modulator system used was the Heising system, the fundamental principle of which is indicated in Figure 6. The Colpitts' oscillator system, also illustrated in Figure 6,



Heising Modulation System



Voice Operated Resistance Or Modulating Tube.

Colpitts Oscillation Circuit.

FIGURE 6

was used. The receiving set was the vacuum tube type including a detector and three stages of audio frequency amplification. The best transmitting distances obtained from aircraft with this set were 45 nautical miles (83.4 kilometers) by telephone and 100 nautical miles (185 kilometers) by buzzer modulated telegraph on a wave length of 600 meters.

The second set developed by the Western Electric Company and tested at Hampton Roads was that shown in Figure 7. This set was arranged for transmission on 1,540 meters on a trailing wire antenna and on 600 meters on an umbrella type of antenna used when the seaplane was at rest on the water. Provision was made for continuous wave telegraph and telephone signals on both wave lengths. For telegraphing, eight type

CW 931 5-watt vacuum tubes were used operating in parallel, all as oscillators. The signals were made by operating a telegraph key which opened and closed the circuit supplying the plates of the oscillators. For telephoning, three of the tubes were used operating in parallel as oscillators, and the other five operating in parallel as modulators. Power for the set was supplied from a 24-volt storage battery from which the filaments were lighted directly, the plate circuits of the tubes being supplied from a 350-volt dynamotor which operated from the 24-volt storage battery. The schematic circuit diagram of this set is shown in Figure 8.

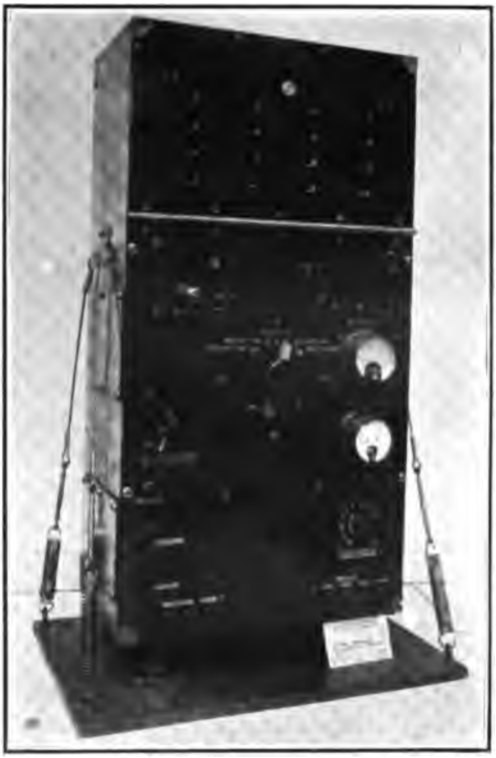


FIGURE 7

Operating this set on a trailing antenna, an antenna current of 1.6 amperes was obtained while telegraphing, transmission being conducted over a distance of about 100 nautical miles

(185 kilometers). The antenna current while telephoning was about 1 ampere, a range of ten nautical miles (18.5 kilometers) being the maximum over which satisfactory telephone communication was maintained. This short range was due to the improper functioning of the modulator, a defect which was not corrected as the development work on this set was discontinued due to its excessive size and weight.

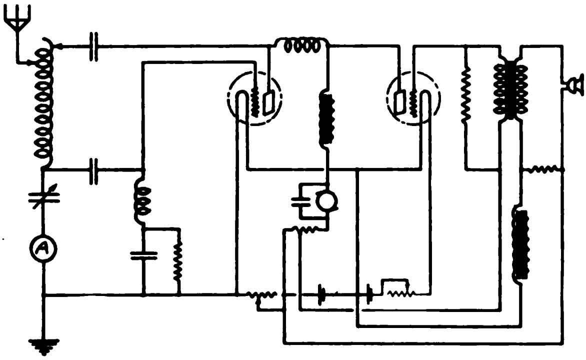


Figure 8—Western Electric Co. 100-mile set, Telephone Connection

Another set tested at Hampton Roads was one designed by the De Forest Radio Telephone and Telegraph Company, shown in Figure 9, and employing two De Forest tubes. It was arranged for transmission over two ranges of wave length, from 350 to 600 meters and from 1,000 to 2,000 meters, telephone and "chopped" continuous wave telegraph signals being used. Power for the plate circuits was supplied at 1,200 to 1,500 volts direct current from a propeller-driven generator. The filaments of the tubes were lighted from a 12-volt storage battery from which was also driven a small motor which operated the continuous wave interruptor or "chopper." The schematic circuit is shown in figure 10. Telegraph signals were transmitted for a distacne of 125 nautical miles (232 kilometers) from seaplane to shore but, no satisfactory telephone operation of this set was obtained.

There was also tested at Hampton Roads an 0.5-kilowatt quenched spark transmitter of improved type designed by E. J. Simon and illustrated in Figure 11. This transmitter was very compact and light, the total weight of the complete equipment being 42 pounds (18.1 kilograms). The transmitter in which the antenna reel was mounted was 12 by 11 by 11 inches (30.48

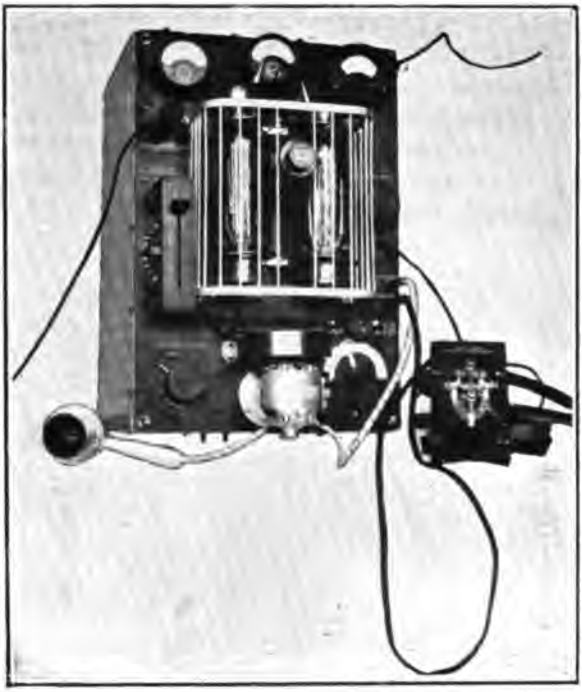


FIGURE 9

by 27.9 by 27.9 centimeters). Transmission on a single wave length of 375 meters was arranged for, power being obtained from a propeller-driven generator. The inductances used were

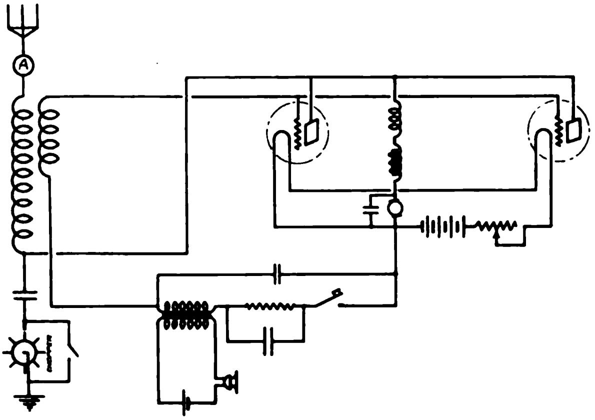
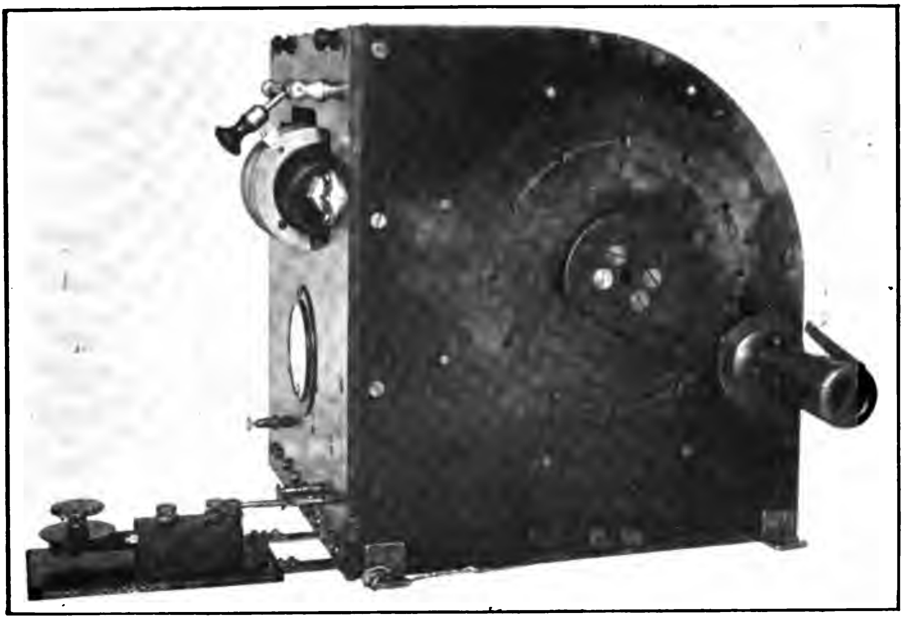


FIGURE 10



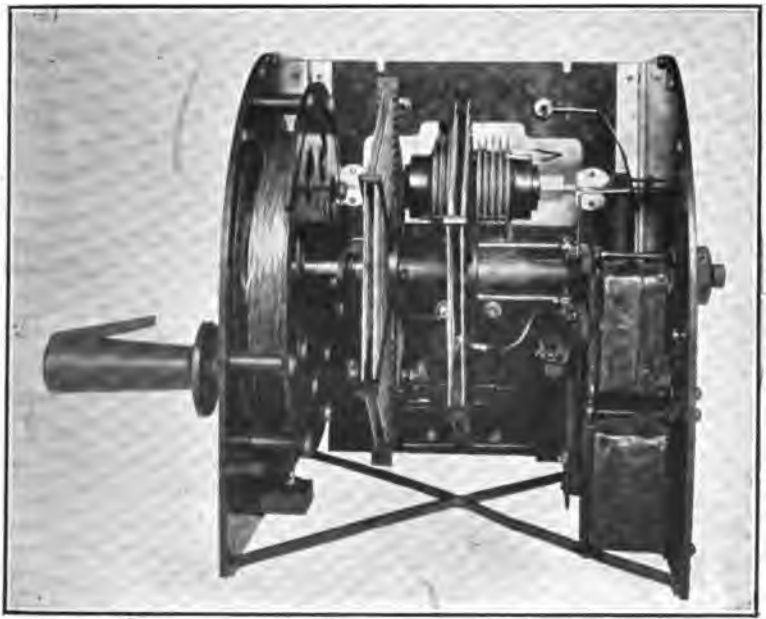


Figure 11

wound with litzendraht. A novel form of send-receive switch was operated by hinged movement of the transmitting key base.

In addition to the above experimental sets there were tested at Hampton Roads all of the standardized sets described later in this paper.

STANDARD NAVAL AIRCRAFT AND ANTENNA CONSTANTS

In reviewing the problem of providing standard radio equipment for naval aircraft, it is of interest to consider the standard types of craft used, especially as regards their size and the properties of the radiating systems applied to them. The aircraft used in the naval service may be generally classified as seaplanes, ship airplanes, flying boats, and dirigibles. The seaplane consists essentially of an airplane fuselage and wings supported by means of struts on pontoons. Seaplanes are used generally for training purposes only and consist of two main types known as N-9 and R-6.

Ship airplanes are small single-seat airplanes used essentially for fire control duty and designed for flight from and to the deck of a battleship.

Flying boats consist of a light boat body which accommodates passengers and fuel tanks and to which are mounted wings and tail stabilizers. The engines are usually mounted in struts between the wings. Flying boats are used for patrol and other heavy service duties where landings must occasionally be made in fairly rough water. The four standard types of naval flying boat are known as HS-2-L, H-16-A, F-5-L, and NC.

The dirigibles used in the naval service are all of the non-rigid type and consist of several classes of varying size. The fundamental physical characteristics of the standard naval aircraft are outlined in the tabulation of Figure 12, and the craft are shown in the photographs following.

In the design of radio equipment it is, of course, of prime importance to determine the constants of the antennas used in order to properly standardize on antennas for the various sets. The measurement of antenna constants on aircraft is beset with the most unusual difficulties. Adjustments of various kinds must be made under conditions of severe mechanical vibration and external noise which render ordinary methods of measurements very difficult to use.

The antenna constants discussed herein were measured by employing a calibrated oscillator utilizing a 50-watt vacuum tube, type CG 1144, using a plate potential of 350 volts. With very

Type of Craft	Span		Chord		Gap		Overall Length		Overall Height		Weight Loaded		Useful Load		Crew	Maximum Speed*		Cruising Radius in Hours	
	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Lbs.	Kilo-grams	Lbs.	Kilo-grams		Naut. miles per hour	Kilo-meters per hour	At full speed	At cruis-ing speed
Seaplane N-9	53	16	5	2	5	2	30	9	11	3	2,600	1,180	490	222	2	80	148	1.5	
Seaplane R-6	57	17	6	2	7	2	33	10	14	4	3,945	1,790	895	406	2	82	152	4.2	
Ship Airplane	28	9	6	2	Monoplane		22	7	8	2	650	295	284	129	1	65	120	2	
Flying Boat HS-2-L	74	23	6	2	8	2	38	12	15	5	6,432	2,910	2,135	966	3	91	168	4.4	6.4
Flying Boat H-16-A	95	26	7	2	8	2	46	14	18	6	10,900	4,950	3,500	1,590	5	95	176	3.9	5.5
Flying Boat F-5-L	104	32	8	2	9	3	49	15	19	6	13,000	5,900	4,750	2,160	5	83	154	5.5	7.9
Flying Boat NC	126	38	12	3.7	14	4	68	21	24	7	22,100	10,040	8,000	3,630	6	83	154	9.0	13.0

*Cruising speed is 66 per cent. of Maximum Speed.

Class of Dirigibles	Envelope						Length of Car		Useful Load		Crew	Speed				Cruising Radius			
	Length		Maximum Diameter		Capacity							Maximum		Cruising		At Cruising Speed with Normal Fuel		At Maximum Speed with Maximum Fuel	
	Feet	Meters	Feet	Meters	Cubic Feet	Cubic Meters	Feet	Meters	Lbs.	Kilo-grams		Naut. miles per hour	Kilo-meters per hour	Naut. miles per hour	Kilo-meters per hour	Naut. miles	Kilo-meters	Naut. miles	Kilo-meters
"B"	160	49	32	10	84,000	2,300	28	9	2,000	908	3	45	83	35	65	500	925	1,100	2,040
"C"	192	58	42	13	171,000	4,680	40	12	3,930	1,735	5-8	60	111	35	65	530	980	1,800	3,330
"D"	198	60	50	15	186,000	5,090	29	9	4,109	1,870	5-8	59	109	35	65	530	980	1,800	3,330
"E"	162	49	34	10	95,000	2,600			2,135	970	3	55	102	35	65	375	694	700	1,290
"G"	285	87	57	17	415,000	11,350	52	16	11,000	4,990	10	60	111	40	74	1,440	2,660	3,780	7,000

FIGURE 12—Approximate Data on size of Standard Naval Aircraft

loose coupling an antenna current of 125 milliamperes was thus easily obtained, and practically all the measurements were taken with a current of at least 100 milliamperes, a long scale instrument being used to assist in obtaining accurate results. With no added resistance in the antenna circuit and a meter reading of 100 milliamperes adjusted to by variation of coupling, resistances of 10 ohms and 20 ohms were successively inserted in circuit and current readings noted. The antenna resistance obtained in each case was compared, and, if results did not check, the set was again resonated and readings repeated.

The fundamental wave length was measured by coupling two small turns of the antenna circuit with the oscillator and resonating the circuit. To obtain the necessary range of wave lengths, coils of various inductance values were successively inserted. In computing the resistance of the antenna, the resistance of these coils at the frequencies used was deducted as well as the resistance of the meter, the set and the connecting wires forming the complete installation.

Great care was taken in arranging the circuit loading coils so that minimum capacity effects were experienced, and capacity currents which would distort the resistance results were avoided. The milliammeter was mounted on rubber cushions to absorb vibration. In spite of this it was often necessary to wait some time before the pitching and tossing of the aircraft decreased to a point where readings could be taken. In making these measurements the greatest of care was observed in so waiting until stable readings could be obtained.

In the results of these measurements, *effective capacity* is defined as that capacity which, used in conjunction with the antenna inductance, will resonate at the natural wave length of the antenna; and *equivalent capacity* at any loaded wave length as that capacity which, if used with an inductance equal to the loading inductance, will resonate at the same wave length as if the loading inductance were applied to the antenna.

Figure 13 illustrates the measuring apparatus set up in an H-16-A flying boat. The arrangement for obtaining variable coupling is shown on the left side against the ribs of the hull. The calibrated oscillator itself is shown in the foreground with the 125-milliampere meter mounted on a rubber suspension slightly above and to the right. The various loading coils used are on the shelf in the background.

The smallest type aircraft used in the naval service is the ship airplane illustrated in Figure 14, or several other types of similar

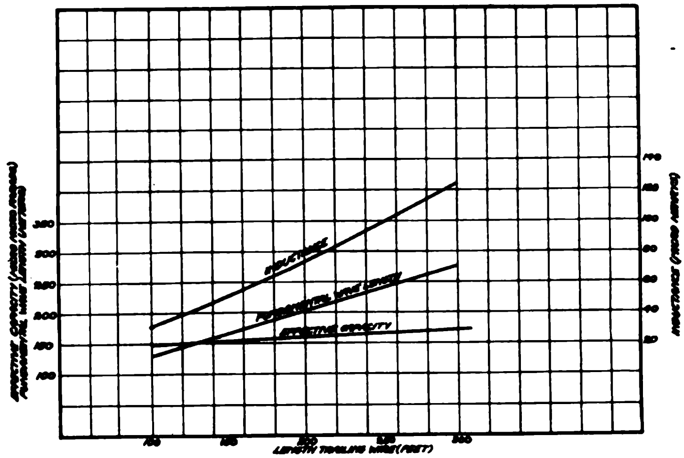
FIGURE 13

small craft designed for carrying a pilot only and for operation from the deck of a ship rather than from the water. With this type of craft there is used either a short single wire trailing antenna or the radiating system consists of wire networks in the two wings.

Figure 15 shows the type N-9 seaplane on a handling truck. The only type of antenna used on this craft is a single trailing wire, the constants of which are shown in Figures 16, 17, and 18.

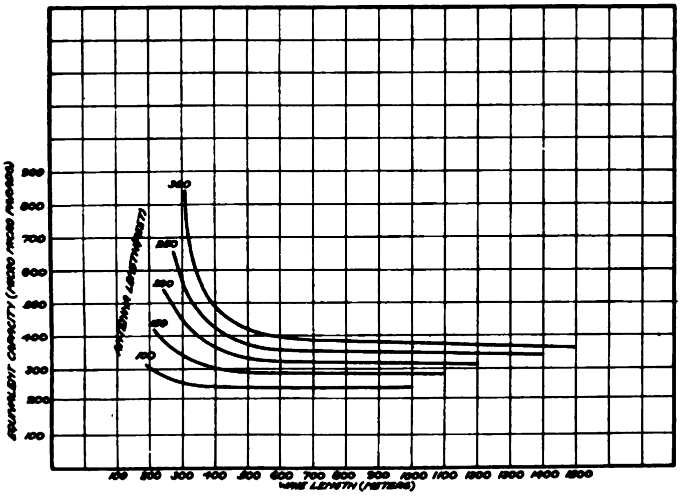
FIGURE 14

Figure 15



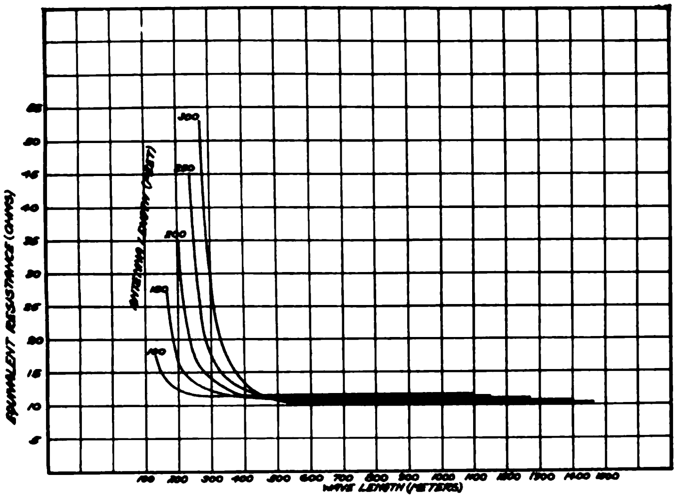
EFFECTIVE CAPACITY, INDUCTANCE
AND FUNDAMENTAL WAVE LENGTH
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
SEAPLANE TYPE N-9

Figure 16



EQUIVALENT CAPACITY
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
SEAPLANE TYPE H-9.

FIGURE 17



EQUIVALENT RESISTANCE
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
SEAPLANE TYPE H-9

FIGURE 18

Figure 19 shows a type HS-2-L flying boat. This boat is driven by a single 12-cylinder Liberty motor, the propeller being arranged as a pusher. The antenna systems on this craft are illustrated in Figure 20. The antenna used when in flight consists of a single trailing wire leading from the radio apparatus in the forward part of the boat thru a lead-out fixture and thru an insulator mounted on the under side of the lower port wing. The wire of standard length for the particular equipment used is wound on a metal reel by which the wire may be wound out

FIGURE 19

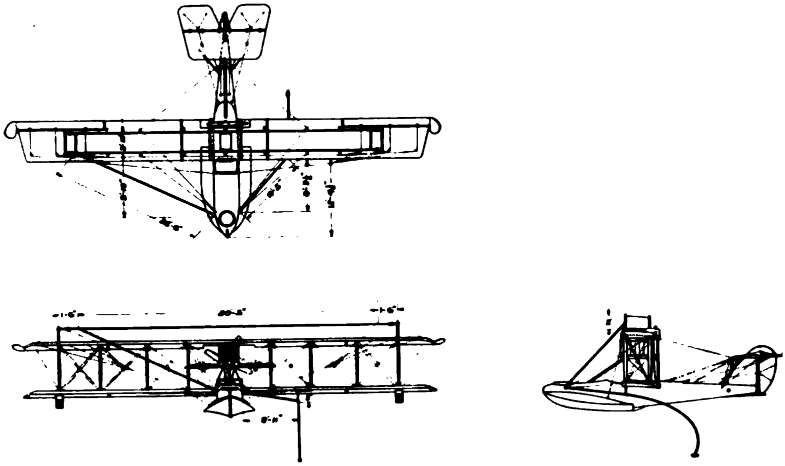


FIGURE 20

and in. The standard reel and fittings are illustrated in Figure 21. When in flight, the entire standard length of wire is unwound from the reel. The inner end of the wire is connected to the reel by a piece of insulating twine so that no high potentials are developed on the reel when the radio set is in operation An electrical connection is made to the trailing antenna wire thru the metal portion of the lead-out insulator. The standard

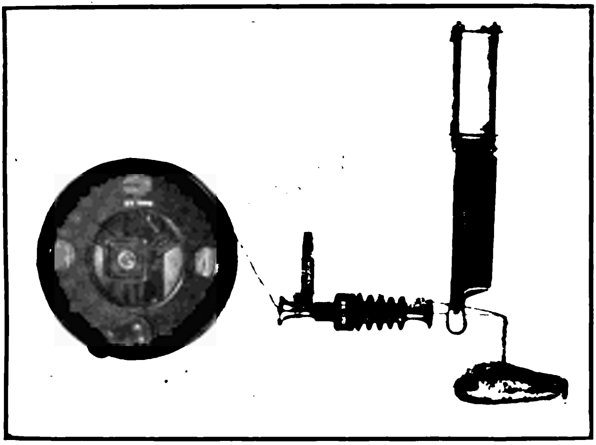
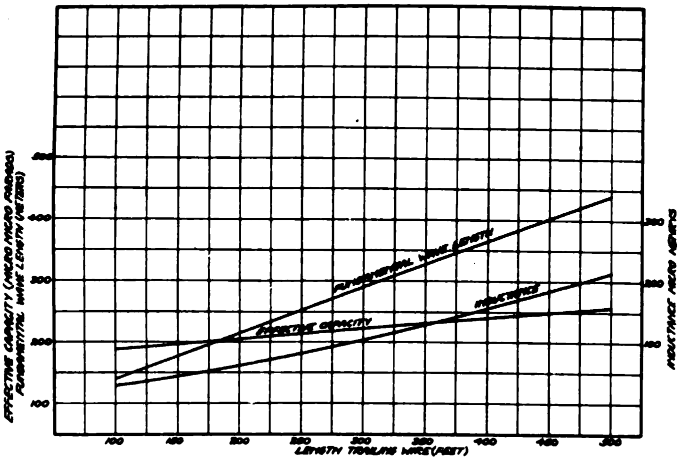


FIGURE 21

antenna wire used consists of six strands of seven silicon bronze wires of 0.008 inch (0.203 millimeter) cabled with strong 5-ply cotton thread. A two pound (0.91 kilogram) stream-line lead weight is attached by a swivel to the outer end of the trailing antenna. The International Radio Telegraph Company rendered invaluable assistance and co-operation in the development of the above reel.

The constants of this single wire trailing antenna are shown in Figures 22, 23, and 24. The counterpoise used consists of all metal pieces of the craft such as brace wires, flying wires, control wires, engines, and fuel tanks, electrically connected. These wires and fittings extend thru the entire wing area and body of the boat.

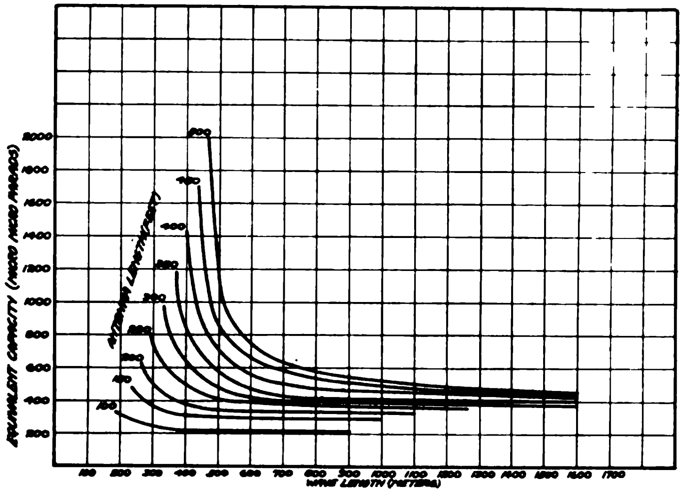
Another type of antenna used on this flying boat is known as the skid fin antenna and is mounted as a rectangle on the skid fins on the upper plane, the lead-in wire being carried from the forward starboard corner of the rectangle to a lead-in insulator on



EFFECTIVE CAPACITY, INDUCTANCE
AND FUNDAMENTAL WAVE LENGTH
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE HS-2-L

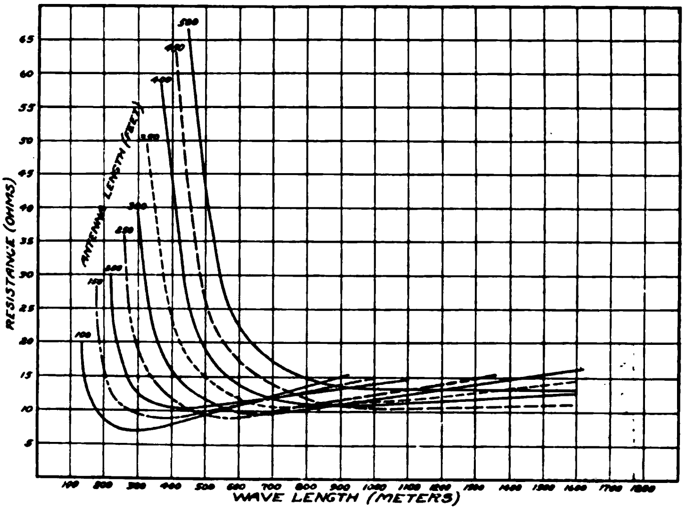
FIGURE 22

the starboard side of the boat forward, at a point corresponding to that at which the trailing antenna leads out on the port side.



EQUIVALENT CAPACITY
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE HS-2-L

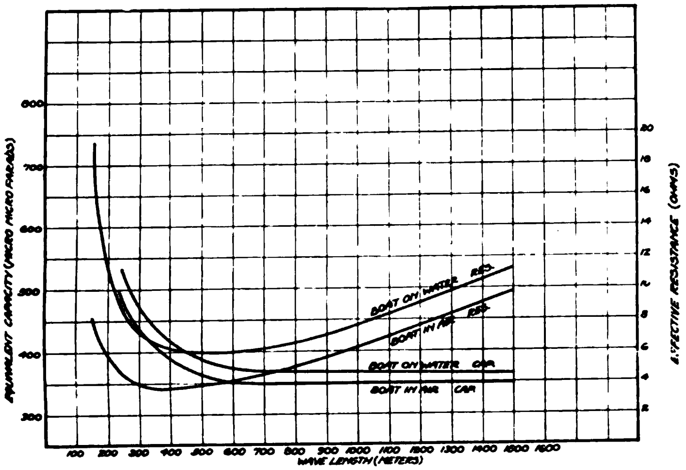
FIGURE 23



ANTENNA RESISTANCE
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE HS-2-L

FIGURE 24

This antenna must be used when the boat is resting on the water, but may also be used successfully when in flight, altho transmission distances obtained will not equal those obtained with the trailing antenna. The constants of this antenna, both when the boat is in flight and on the water, are shown in Figure 25.



EQUIVALENT CAPACITY & EFFECTIVE RESISTANCE
OF
SKID FIN ANTENNA
ON
FLYING BOAT TYPE HS-2-L

FIGURE 25

Figure 26 illustrates a type H-16-A flying boat. This boat is propelled by two 12-cylinder Liberty motors mounted outboard, the propellers usually being arranged to act as tractors. The

Figure 26

antenna systems employed are illustrated in Figure 27. Trailing wire antennas are also used on this type of boat with similar fittings to those used on the HS-2-L type, the main difference

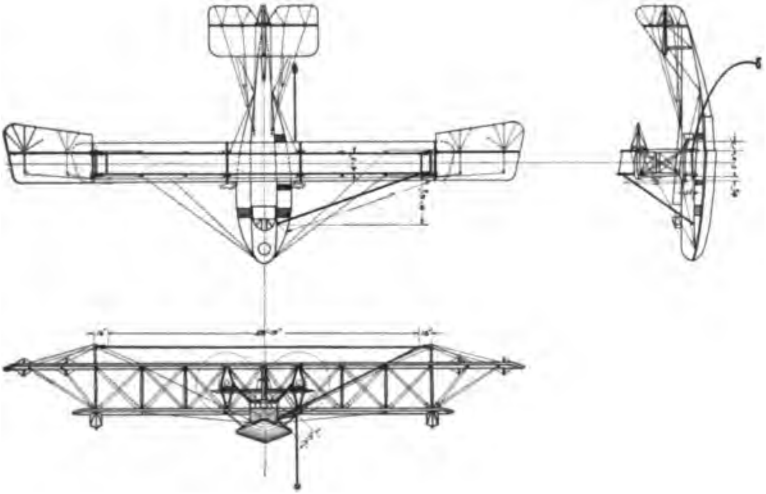
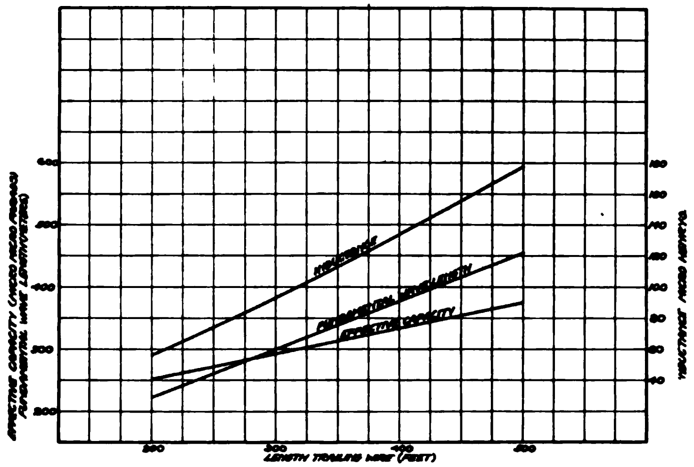


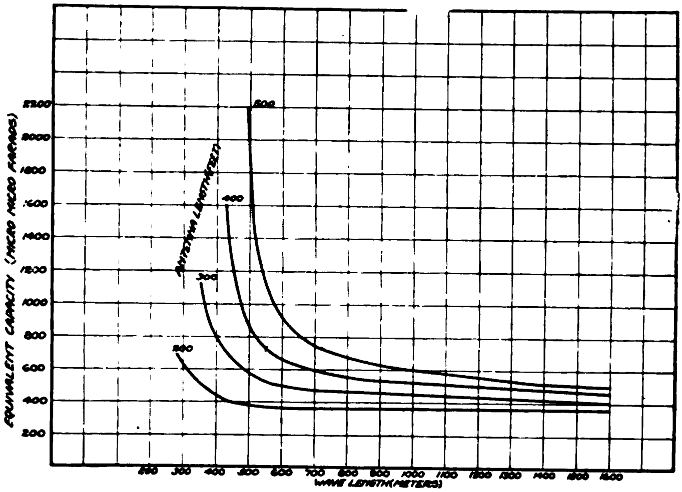
Figure 27

being that the radio apparatus is located just forward of the wings, and the antenna wires are led out from the hull at that point. In the case of this larger boat there has been used a double trailing antenna, the two wires being led off symmetrically on the two sides of the boat. The antenna characteristics of both single and two-wire trailing antennas are illustrated in Figures 28, 29, 30, 31, 32, and 33.



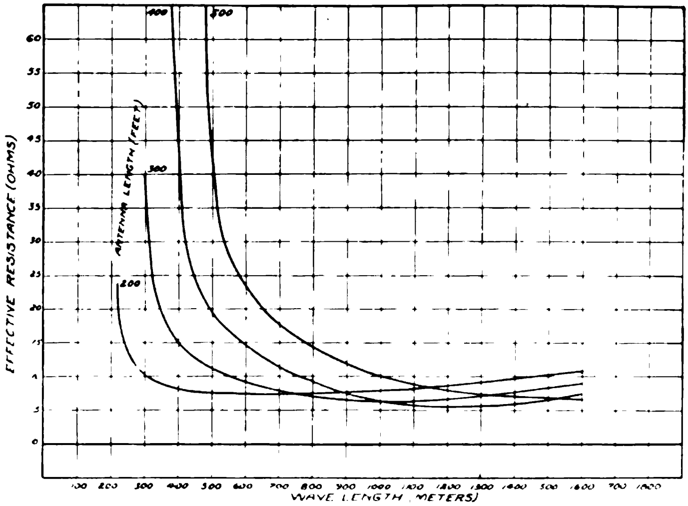
EFFECTIVE CAPACITY, INDUCTANCE
AND FUNDAMENTAL WAVE LENGTH
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE H-16-A

FIGURE 28



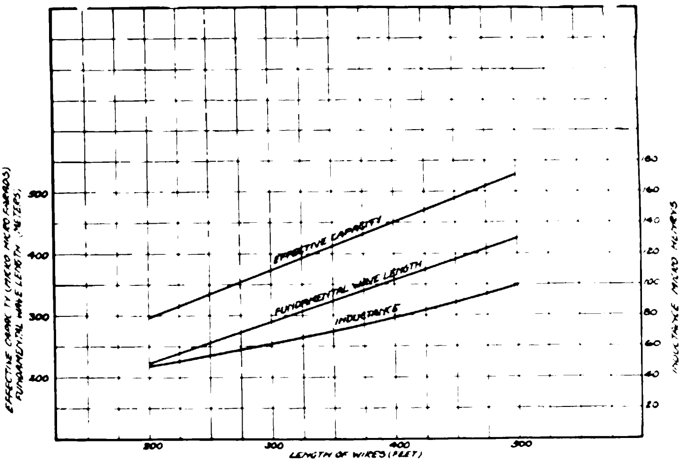
EQUIVALENT CAPACITY
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE H-16-A

FIGURE 29



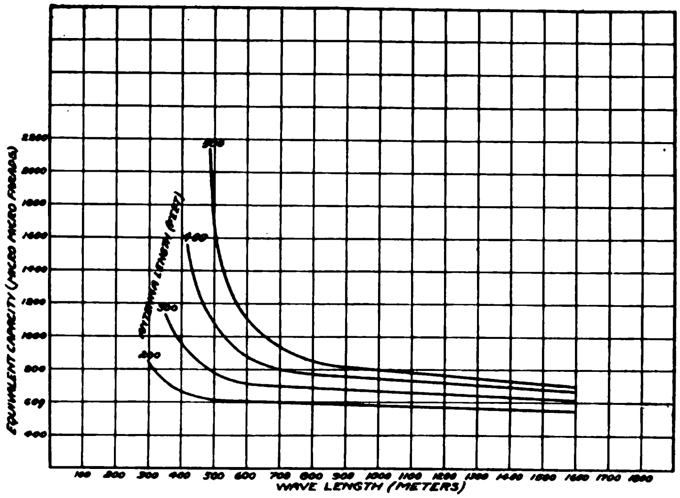
EFFECTIVE RESISTANCE
OF
STANDARD SINGLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE H-16-A

FIGURE 30



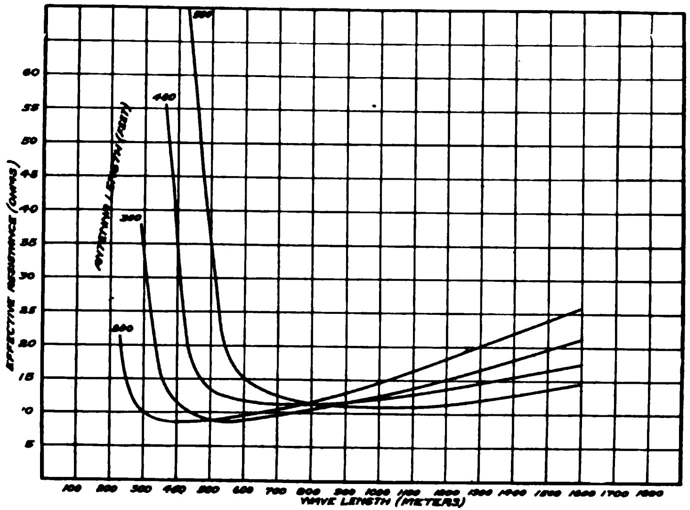
EFFECTIVE CAPACITY INDUCTANCE
AND FUNDAMENTAL WAVE LENGTH
OF
DOUBLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE H-16-A

FIGURE 31



EQUIVALENT CAPACITY
OF
DOUBLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE H-16-A

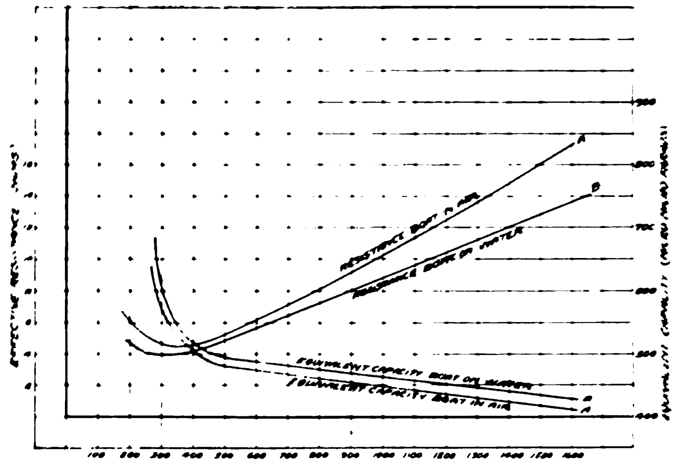
FIGURE 32



EFFECTIVE RESISTANCE
OF
DOUBLE WIRE TRAILING ANTENNA
ON
FLYING BOAT TYPE H-16-A

FIGURE 33

The skid fin type of antenna is also used on the H-16-A flying boat, consisting of a rectangle, and with a lead-in wire similar to that used on the HS-2-L boat. The antenna constants of this skid fin antenna are illustrated in Figure 34.



EQUIVALENT CAPACITY & EFFECTIVE RESISTANCE
OF
SKID FIN ANTENNA
ON FLYING BOAT TYPE H-16-A

	IN AIR	ON WATER	
INDUCTANCE (MICROHENRY)	31	30	AT FUNDAMENTAL WAVE LENGTH
EFFECTIVE CAPACITY (MICRO MICRO FARADS)	297	326	

FIGURE 34

Another large type of flying boat is the F-5-L type, illustrated in Figure 35. This boat is approximately the same size as the H-16-A, and differs only in minor structural details. The radio problems connected with the two boats and antenna characteristics may be considered identical. The type F-5-L is a later development and a more standardized form of boat.

The largest flying boat in the naval service is that known as

FIGURE 35

the NC type, illustrated in Figure 36. It is this model which was used on the trans-Atlantic flight. Only two types of antenna have been used on this craft, the single trailing wire and the skid fin antenna. On the NC boat the radio station is located in the extreme after-part, and the single trailing antenna passes from the tail almost amidships. The skid fin antenna is arranged similarly to those on the other flying boats, but is somewhat larger and the lead-in is carried aft instead of forward. The antenna characteristics of this boat are not available at the present time.

FIGURE 36

Several types of non-rigid dirigibles are used in the naval service as indicated in the table in Figure 12. The dirigible most in use is class "C." illustrated in Figure 37. At first a

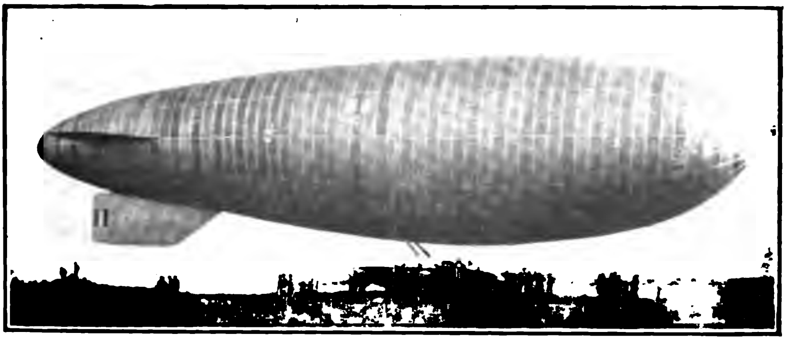
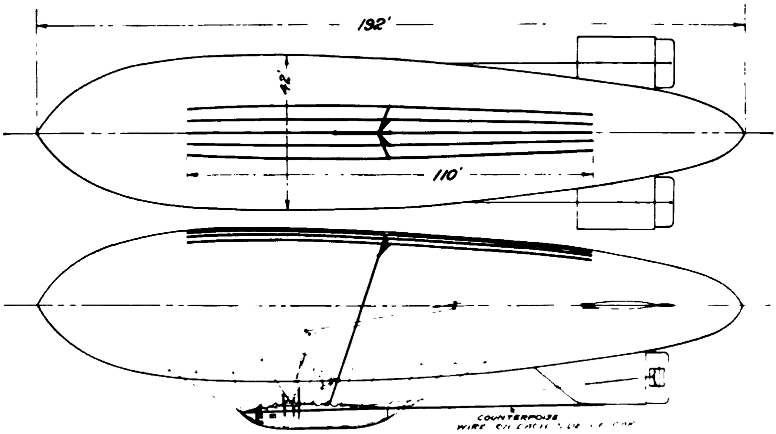


FIGURE 37

single wire trailing antenna was used on all dirigibles but recent investigations have proven the advisability of using a 5-wire "T" antenna suspended within the envelope. The standard form of this antenna, as used in the class "C" dirigible, is illustrated in Figure 38. It is approximately 110 feet (33.5 meters) long, the wires being placed about 3 feet 6 inches (1.07 meters) apart and placed, not in one plane, but at a fixed distance, 11 inches (27.9 centimeters) from the top of the envelope. The wire used consists of sixteen strands of number 30 B. and S. gauge copper wire* wrapped with one layer of cotton and one layer of para rubber. The counterpoise used consists of two of these rubber-covered wires run along the sides of the dirigible car and aft to the stabilizer surfaces as illustrated in Figure 38. The characteristics of this radiating system are illustrated in Figure 39.



ANTENNA INSTALLATION
ON
INTERIOR OF ENVELOPE OF NON RIGID DIRIGIBLE CLASS "C"

NOTE:— WIRES SPACED 3 FEET 6 INCHES APART
AND 11 INCHES FROM TOP OF ENVELOPE.

FIGURE 38

STANDARD TRANSMITTING EQUIPMENT—SPARK TYPE

There are at the present time in use in the naval aircraft service four types of standard spark radio transmitters. The low-power short-wave spark transmitting equipment for small flying boats, such as type HS-2-L, is known as type SE 1300, the

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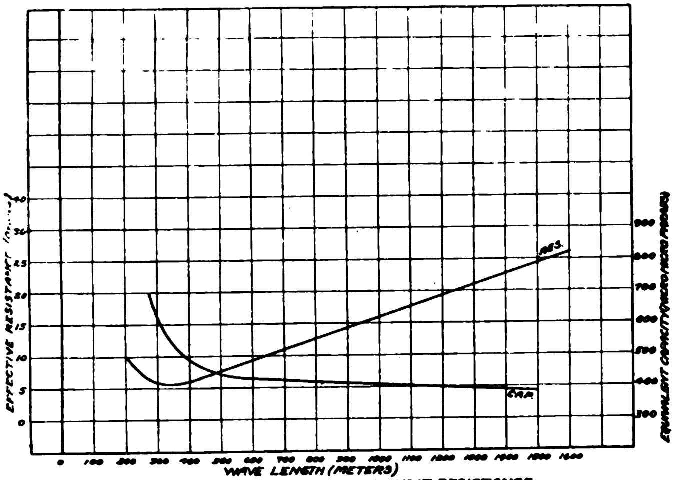
[*] Diameter of number 30 wire = 0.010 inch = 0.25 mm.



EQUIVALENT CAPACITY & EFFECTIVE RESISTANCE
OF FIVE-WIRE ANTENNA INSIDE OF ENVELOPE
OF NON-RIGID DIRIGIBLE CLASS C-5
L = 44 MICRO HENRYS
EFF. C. AT 210 METERS = 282 MICRO MICRO FARADS.

FIGURE 39

main elements and connections of which are illustrated in Figure 40. This set is manufactured by the International Radio Telegraph Company. The equipment completely installed weighs 65 pounds (29.4 kilograms), and will render normal operation from aircraft to shore over all distances within 100 nautical miles (185.9 kilometers). Its important features are its simplicity of control, freedom from operating difficulties, small space

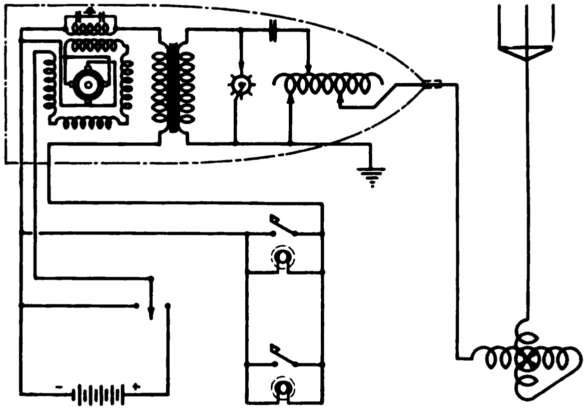


FIGURE 40

[illegible], and lightness of weight. The set is of the synchronous rotary spark type consisting of a radio transmitter containing the main elements of a spark transmitter, a wavemeter mounted within the flying boat body for tuning the antenna circuit, semi-automatic switch, a generator field priming battery and necessary connections and fittings.

The radio transmitter, illustrated in Figure 41, is mounted

FIGURE 41

in a streamline case on the wing of the flying boat, the generator and spark gap, which are mounted in the forward end, being driven by a small propeller. Behind the generator and spark gap are mounted the power transformer and condenser, and oscillation transformer.

The generator is a special inductor type alternator rated at 5,000 r.p.m., 127 to 140 volts on open circuit. The frequency of the generator at normal speed is 1,000 cycles per second. The power transformer is of the closed core type. The mica condenser has a capacity of 0.004 microfarads.

The spark gap consists of a rotary brass disc forming one electrode of the gap and a tungsten electrode forming the other or fixed member.

The oscillation transformer consists of solid bare copper wire wound in grooves around a hollow redmonol cylinder fastened to a redmonol disk which is supported on a short shaft held in the insulating frame of the set. Sixteen and one-half turns of this coil serve as the primary and the remaining eight turns as the secondary, the two coils being inductively coupled with their common point grounded. Nine primary taps are brought out to contact buttons on the disk at the front end of the coil and each button is marked with the corresponding wave length of the closed oscillatory circuit. The available wave lengths are 200, 226, 257, 291, 331, 377, 426, 485, and 550 meters. The streamline hood which houses the radio assembly is made of canvas bakelite.

The output current from the oscillation transformer is delivered to the antenna circuit thru a special coil spring and socket connector in the tip of the hood which bears on the contactor of the oscillation transformer secondary switch. The antenna current is lead thence from the radio assembly to the body of the boat and thru the variometer and lead-off fittings to the trailing antenna.

The variometer, shown in Figure 42, consists of a cylindrical coil of 87 turns of number 18 B. and S. gauge bare solid copper wire* wound on a thin hollow cylinder of insulating material.

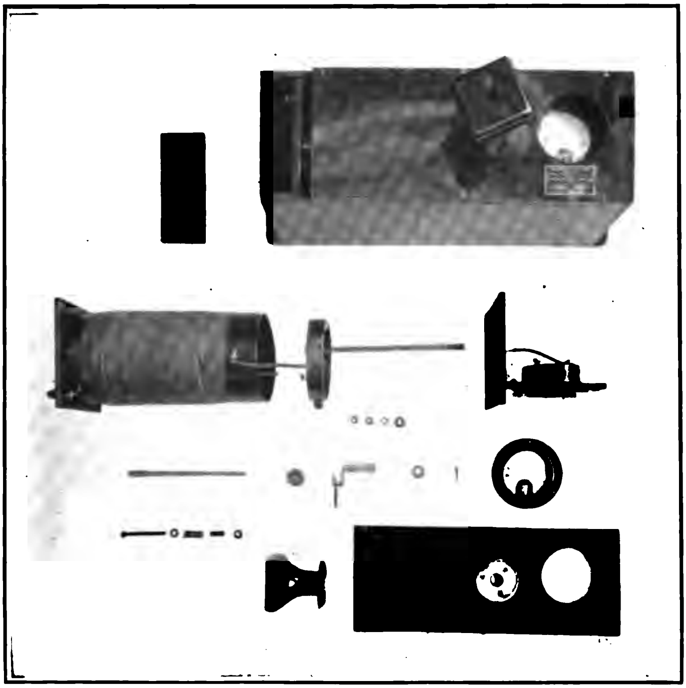


FIGURE 42

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* Diameter of number 18 wire = 0.040 inch = 1.014 mm.

The inductance is varied by means of a trolley mounted within the coil which moves parallel to the axis of the coil, and makes contact with the bare turns of the wire as it passes. It can thus be made to cut out or cut in one turn of the wire at a time as it is moved along. This trolley is moved by means of a handle on the cover of the box which rotates a pinion engaging with a ratchet on which the sliding trolley is fastened. The dead end of the coil is connected to the trolley contact and is thereby short-circuited. A short copper cylinder disc, moving with the trolley inside the coil, serves to prevent sparking at the trolley contact by shielding the magnetic lines of force from the turn short-circuited by the trolley. It serves also to make the changes in the inductance more gradual. The eddy current losses in this disc are negligible. The inductance may be varied between the limits of 35 and 400 microhenrys, and is insulated for 25,000 volts.

The aircraft flameproof keys are used in connection with this set, being connected in parallel, one key in the observer's cockpit forward and the other near the pilot's position. In order to allow either operator to recognize when the other is transmitting, the keys are provided with small incandescent lamps of standard 6-volt type placed in the low tension winding of a small transformer, the high tension winding of which is connected directly across the key contacts. Hence both lamps glow when neither key is depressed and the generator is functioning properly. The transformer lamp and key are all mounted on a single base in a light compact unit.

The send-receive switch is arranged so that as the lever is being thrown to the transmitting position, the generator field is momentarily excited from the priming battery, insuring the building up of the field which is closed without external excitation when the switch is in full transmitting position.

The standard high power short wave transmitting equipment, similar in type to that just described, is known as type SE 1310, also manufactured by the International Radio Telegraph Company. This is also designed for flying boats such as type HS-2-L, and consists of the same essential elements, connected in the same manner, as in Figure 40. This equipment, completely installed, weights 77 pounds (34.9 kilograms), and will render normal operation from aircraft to a shore station over all distances within 300 nautical miles (598 kilometers). This range is specified for normal operating conditions only. Far greater range may easily be obtained with this equipment as demonstrated by the trans-Atlantic flight results, described later.

The radio assembly, illustrated in Figure 43, is of the same general design as that of the 200-watt set, but is somewhat larger and contains several slight differences in constructional detail.

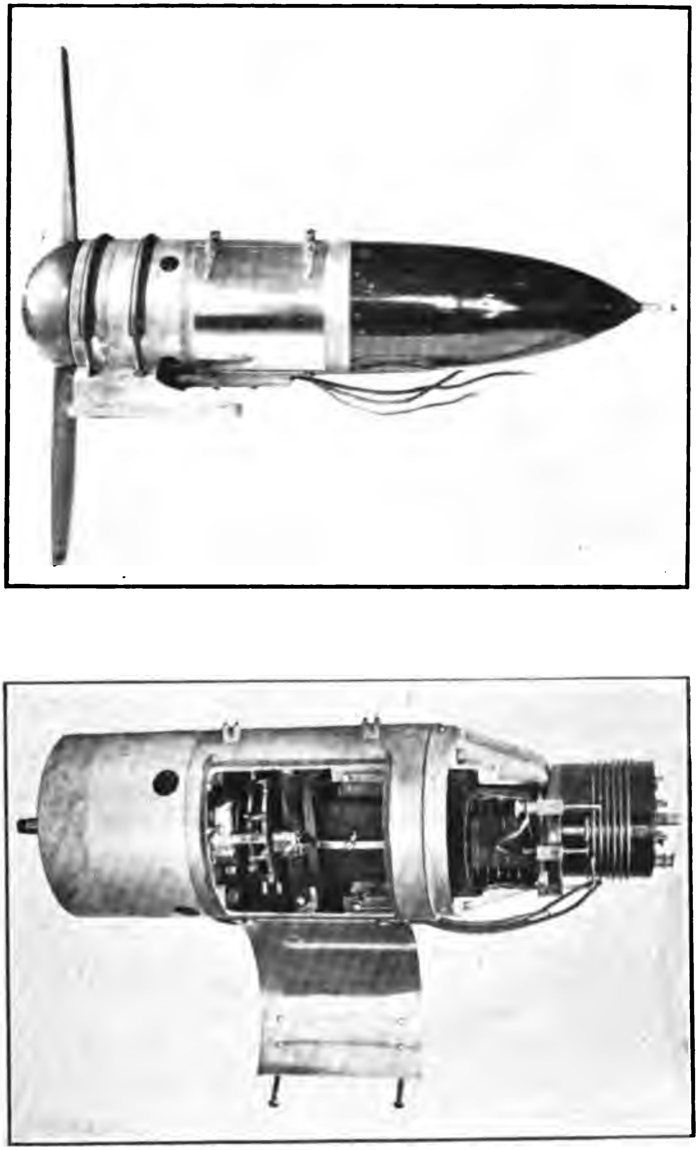

FIGURE 43

The generator is a special inductor type alternator rated at 5,000 r.p.m., no-load voltage 135-150, full-load voltage 90, 500 watts. The frequency of the generator at normal speed is 1,000 cycles per second. The power transformer is of the closed core type. The mica condenser has a capacity of 0.010 microfarads.

The spark gap consists of a combination eight-tooth and twelve-tooth rotor mounted on an insulating hub, with a tungsten electrode arranged for operation with either rotor. This spark gap arrangement enables the operator to adjust the spark frequency for 1,000 sparks per second or 666 sparks per second, without changing the gap rotor.

The oscillation transformer consists of solid bare copper wire wound in grooves around an insulating cylinder fastened to the condenser frame. The oscillation transformer is of the usual conductive coupled type having the coupling turns common to the primary and antenna circuits, and having the common point grounded. There are seven turns total, with taps brought out to give 335, 375, and 425 meters respectively. Coupling is provided by bringing out taps from the three turns adjacent to the ground end of the coil. These taps terminate in a suitable switch provided at the end of the oscillation transformer to permit proper coupling adjustments.

The output current from the oscillation transformer is delivered to the antenna circuit in the same manner as in the case of the 200-watt set.

The variometer is of the same general construction as is indicated in Figure 42, consisting of a cylindrical coil of 50 turns of number 14 B. and S. gauge bare copper wire*. The inductance may be varied from 120 microhenrys to approximately zero.

Two aircraft flameproof keys with indicator lamps and a standard send-receive switch are used, as in the case of the 200-watt set.

Another type of standard high power short wave transmitting equipment supplied for installation on flying boats is known as type SE 1320, and is designed and manufactured by Cutting and Washington, Incorporated. This equipment, completely installed, weighs 77 pounds (34.9 kilograms), and will render normal operation from aircraft to shore over all distances within 200 nautical miles (370 kilometers). The main elements and method of connection are illustrated in Figure 44. The trans-

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* Diameter of number 14 wire = 0.064 inch = 1.625 mm.

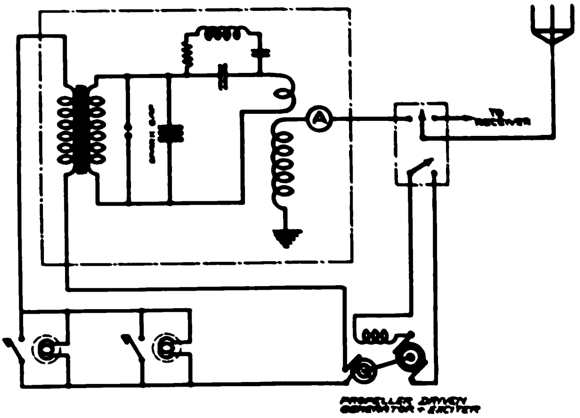

FIGURE 44

mitter is of the impact excitation type[1] and is designed for transmission on a wave length of 375 meters only.

The main element of the set, a transmitter panel, 12 inches (30.5 centimeters) wide, 17 inches (43.2 centimeters) high, 10.5 inches (26.6 centimeters) deep over-all, and weighing 15 pounds (68 kilograms), is illustrated in Figure 45. This is made up of

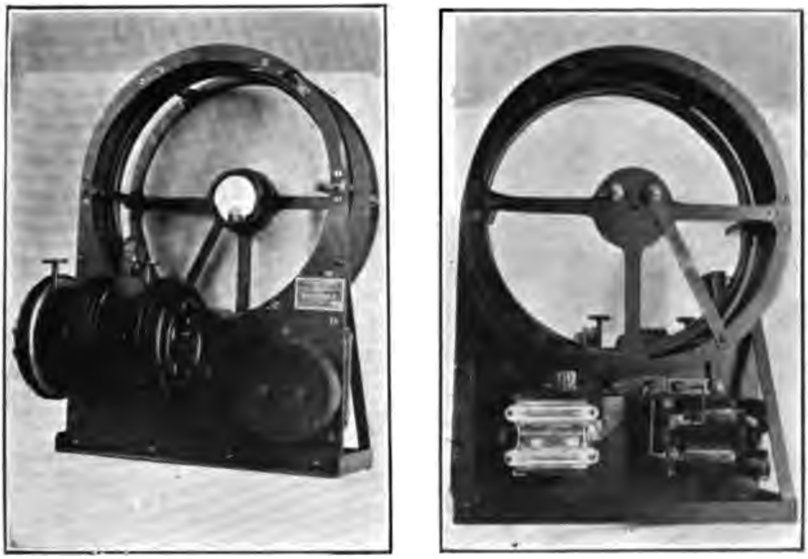

FIGURE 45

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[1] See Bowden Washington, "On the Electrical Operation and Mechanical Design of an Impulse Excitation Multi-spark Group Radio Transmitter," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1918, volume 6, page 295.

a small formica panel with a formica ring at the back supporting the primary and secondary coils, ammeter, transformer, spark gap, condenser, and concentration circuit, the whole being assembled on a mounting base arranged for fastening down to a shelf in the body of the boat. On the front of the panel below the oscillation transformer are the spark gap and concentration circuit inductance. At the rear below the oscillation transformer are the primary condenser, safety gap, concentration circuit, and transformer. On the rear helix posts supporting ring is the antenna ammeter reading from zero to 5 amperes.

Power is supplied from a propeller-driven alternating current generator contained in a stream-line case and mounted on one of the wings of the craft. The generator exciter and armature are mounted on the same shaft. The exciter is bi-polar and delivers 110-volt direct current to the generator field. The generator is of induction type with eight projections on the rotor and four stator coils in the eight slots delivering 220 volts, 500 cycles at no load. This generator was designed and manufactured by the Crocker-Wheeler Company.

The spark gap consists of two tungsten gaps in series, separately adjustable and with heat radiating fins for cooling. A locking device is provided so that after adjustment a gap can be locked in operating position. Flameproof keys with indicator lamps and a send-receive switch are used as in the case of the other spark transmitters.

STANDARD TRANSMITTING EQUIPMENT—VACUUM TUBE TYPE

In describing the vacuum tube radio transmitters used on naval aircraft, it is of interest to first consider the standard types of tubes utilized. Among the four standard transmitting tubes used it will be noted that one has a coated cathode filament and the others tungsten filaments.

The question of a "Wehnelt" or coated cathode filament versus tungsten filament and electrodes for vacuum tubes is similar to many engineering questions, which involve the development of two different devices or two different methods to fill substantially the same need. Each device or method has its advantages as well as its disadvantages, the best device or method to use depending upon the many conditions of service. As in almost all questions of this kind, so in this case, each type of filament and construction will find and fill its own field. At the present time these features may be classified as follows:

The coated filament type of tube has these advantages:

(1) For the same filament current and voltage, the filament is of greater length (3 to 6 times), this increased cathode area facilitating the design of a tube of low impedance. Other factors remaining constant, the lower the tube impedance, the greater the energy amplification possible. This is of particular value when the tube is used as an amplifier or modulator.

(2) For a given life and total electron emission the coated filament requires less energy for filament excitation. This energy ratio in the small transmitting tubes described (Type CG 1162) would be about 1 to 1.5.

(3) Low initial electron velocity. This aids in the design of receiving tubes to have a very high input impedance. This factor is of importance in a tube used for the amplification of small voltages, that is, for amplifying faint received signals.

The coated filament has the following disadvantages, most of which are due to the fact that the filament is not of a homogenous material:

(1) The coating of applied material may tend to become irregular, causing so-called "hot spots," making the life of such tubes short.

(2) The so-called secondary emission or "blocking," owing to the nature of the emitting material, is on occasions a most mysterious and baffling difficulty preventing the functioning of the tube.

(3) The lower filament temperatures, together with the non-homogeneity of the filament, increases the likelihood of contamination of the filament surface, making its manufacture and use more critical to degree of vacuum and lowering the uniformity of the product.

The tungsten type of tube has these advantages:

(1) Ease of both obtaining and maintaining a high vacuum.

(2) All parts may be operated at a comparatively high temperature continuously which, with the use of a very high voltage direct current, makes practical the production of high power tubes of reasonable design operating at very good efficiencies.

(3) Owing to the comparative ease of handling and exhaust treatment, the quantity production of a com-

mercial number of tubes is a better manufacturing proposition. This factor in favor of the tungsten tube increases with the power of the tube.

(4) Tungsten filaments are made of a very pure metal and tungsten is a very stable material, so that the uniformity of the manufactured tube is very high, mechanical dimensions and spacing being the only factors.

The tungsten tube has the following disadvantages:

(1) The cathode having smaller area necessitates close mechanical work to secure a tube of low impedance.

(2) The variation of electron emission with temperature is greater, therefore the output of a tungsten power tube varies more with change of filament current. In certain cases this feature of less inherent regulation is an advantage as it allows a tube to be forced for high output if a very short life can be tolerated. It is also a property that is taken advantage of in the construction of "kenotrons" for use as regulator tubes.

It is believed that a study of these features will show that for receiving tubes and very low power transmitting tubes the coated filament type may have a balance in its favor. For transmitting tubes, from five watts up, the balance is probably in favor of the tungsten tube and its advantages relatively become greater, the higher the power of the tube.

The essential data on the various transmitting tubes utilized is tabulated in Figure 46.

Tube type CW 931, illustrated in Figure 47, is a coated filament tube, manufactured by the Western Electric Company. Its characteristic is shown in Figure 48.

Tube Type CG 1162, illustrated in Figure 49, is a tungsten filament tube, manufactured by the General Electric Company. Its characteristic is illustrated in Figure 50.

Tube type CG 1144, illustrated in Figure 51, is a tungsten filament tube, manufactured by the General Electric Company. Its characteristic is illustrated in Figure 52.

Tube type 916, illustrated in Figure 53, is a tungsten filament tube, manufactured by the General Electric Company. Its characteristic is illustrated in Figure 54.

Navy Type Number	CW 931	CG 1162	CG 1144	CG 916
Signal Corps Type Number	VT-2	VT-14	VT-18	None
Manufacturer	Western Electric Company	General Electric Company		
Manufacturer's Type Number	E	T	U	P
Watts Output	5	5	50	250
Filament Volts	7.0	7.5	10.0	18.0
Filament Amperes	1.35	1.75	6.5	3.6
Plate Volts	350	350	750–1000	1500
Plate Amperes	0.040	0.040	0.150	0.250
Length over-all	4.25 inches 10.8 cm.	4.31 inches 10.92 cm.	7.5 inches 19.0 cm.	14.25 inches 39.15 cm.
Diameter, Maximum	2.28 inches 5.78 cm.	1.75 inches 4.44 cm.	2.0 inches 5.08 cm.	5.0 inches 12.7 cm.
Weight	1.87 ounces 53 grams	1.86 ounces 52.6 grams	5.88 ounces 166.5 grams	23.31 ounces 660 grams

FIGURE 46—Transmitting Tubes

FIGURE 47

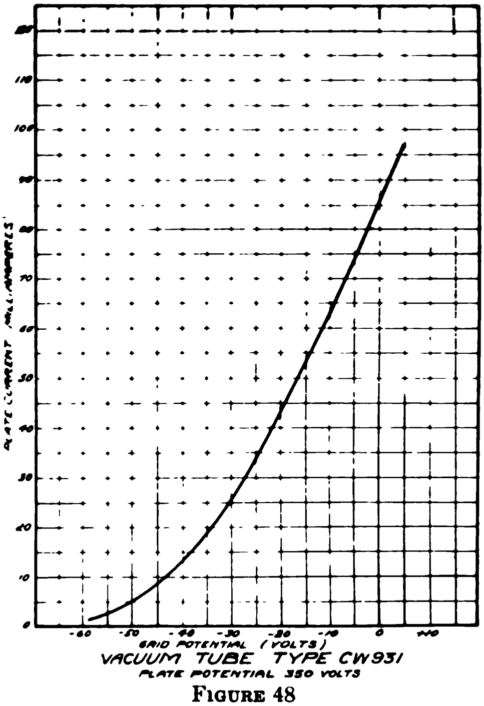

FIGURE 48

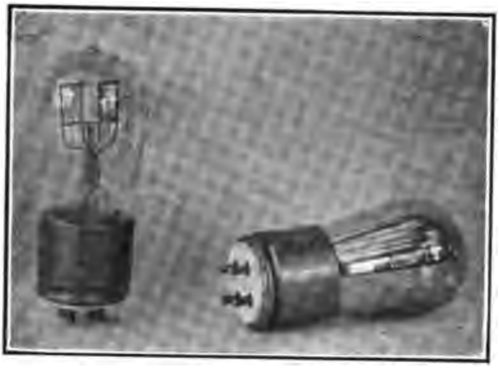

FIGURE 49

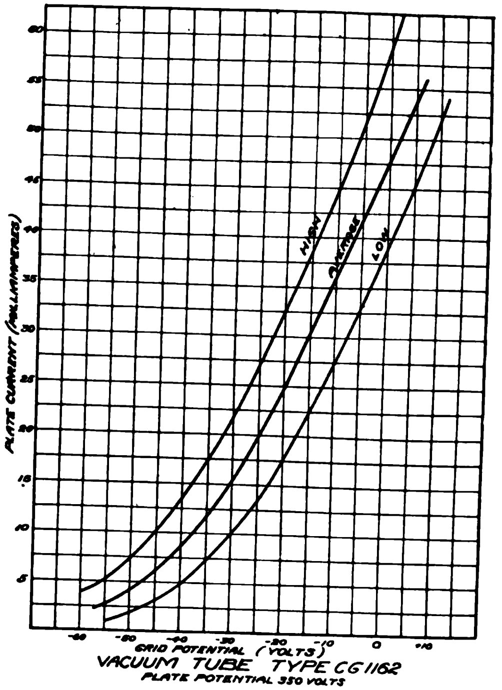

FIGURE 50

Figure 51.

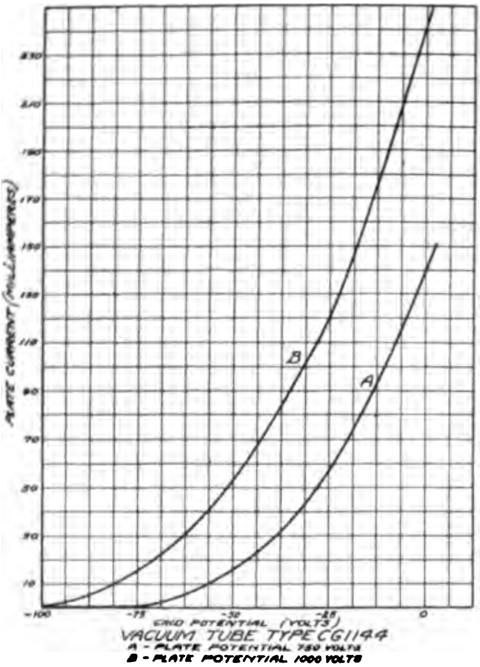

Figure 52

FIGURE 53

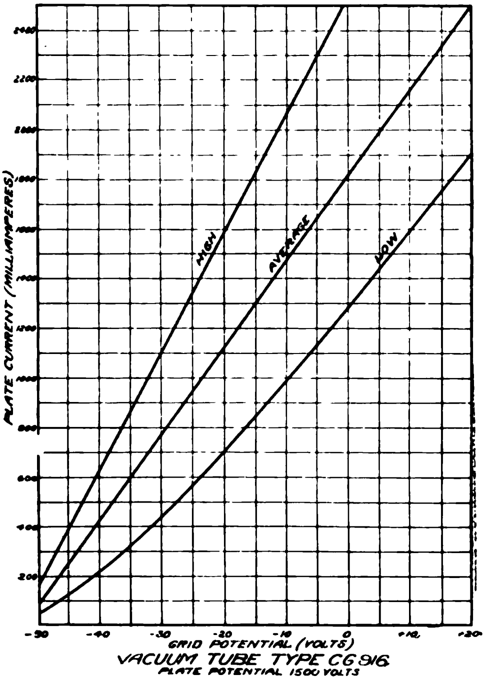

FIGURE 54

In the tabulated data on the above tubes it will be noted that no numerical figures of life are given. This is because, as in an incandescent lamp, life and efficiency are opposing factors, and life is a matter of engineering judgment rather than a property. For aircraft work where weight efficiency becomes very important, a short life suffices if a tube is operated at a very high efficiency.

In the production of radio telephone sets for naval aircraft it was found necessary to develop a microphone transmitter which would operate satisfactorily under the terrific noise conditions existing on naval seaplanes and flying boats. Any standard microphone transmitter was absolutely useless, and even those which had already been developed for aircraft work did not operate with a high enough degree of satisfaction, especially for long distance transmission.

After a period of experimenting on the part of several manufacturers, the Magnavox Company of San Francisco, California, solved the problem most satisfactorily by a transmitter of the design illustrated in Figure 55. In this construction the diafram is so mounted that it is exposed on both sides to extraneous noise vibrations, and thus is only actively affected by the directional impulses of the voice from one side of the diafram. In order to prevent the carbon granule from falling away from the front electrode when the transmitter is held in a horizontal position, as when the observer is looking over the side of the boat, the button is mounted at an angle of 30 degrees with the diafram, which insures operation in nearly any position in which the pilot or operator is apt to place himself.

The transmitter is supported in front of the mouth by two light silk-covered rubber straps fastened to the helmet. As the transmitter is very light, weighing only three ounces (85 grams), this means of support causes no inconvenience, and is of very decided advantage in that the transmitter is always in position for use. All connections, as well as the carbon granule button, are enclosed in a light aluminum spray-proof case.

In the naval aircraft service, radio transmission from the craft while resting on the water is of great importance, especially in cases where the aircraft has become disabled and assistance must be summoned. At such a time there would be no power available from a propeller-driven generator. In the design, therefore, of tube transmitters, a new arrangement for power supply was made. This consisted of a storage battery, floating across the leads of a direct current generator driven directly

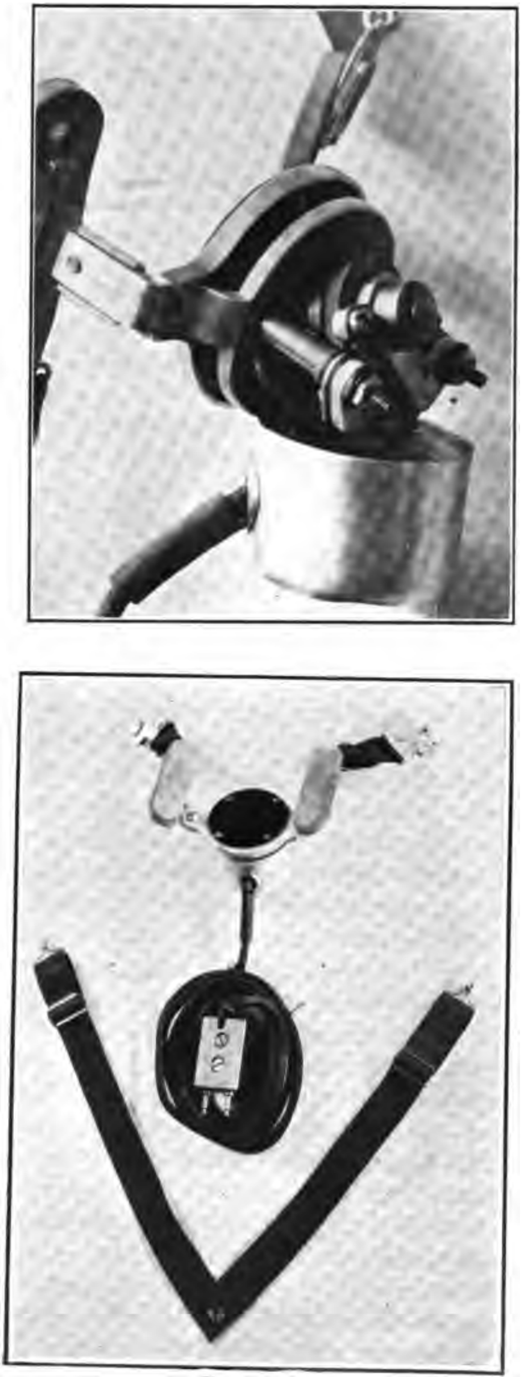

FIGURE 55

by the aircraft engine. In this way whenever the aircraft is in flight the radio power is derived as directly as possible from the primary source of power on the craft, and the engine-driven generator will assist in keeping the storage battery charged for use at any time when the engines are not running. With a standard engine generator connected to each engine, the higher power radio sets on the larger craft are properly supplied from additional generators available due to the additional engines used.

In view of the above arrangement the standard tube sets described herein are given a time rating of operation based on alternate five-minute periods of transmission, and ten-minute periods of reception, power being taken from a standard storage battery consisting of 63-pound (28.6-kilogram) 12-volt units. In the case of the 12-volt equipments a single unit is assumed, and in the case of 24-volt equipments two units connected in series are assumed unless otherwise specified. An arbitrary rating of one hour's operation therefore may be interpreted as four five-minute periods of transmission with four intervening ten-minute periods of reception with a standard receiver. All of the 12-volt storage battery units supplied for naval aircraft radio are of the lead plate type.

Several of the most successful vacuum tube transmitters used on naval aircraft, now to be described, have been developed and manufactured by the General Electric Company. While the transmitters developed by that company differ greatly in many respects, they have, in general, the same fundamental circuit arrangement. Figure 56 shows schematically this fundamental circuit of a radio telephone and telegraph transmitter capable of providing radio communication by either continuous wave telegraphy, buzzer-modulated telegraphy, or telephony.

The elements of the vacuum tube generating the high frequency energy are designated by "F," "G," and "P" representing filament, grid, and plate respectively. The grid and plate circuits are inductively coupled to the antenna circuit by means of the antenna coil "L," the grid coil "L_2" and the plate coil "L_3." With the filament lighted and plate circuit closed, feeble natural oscillations will be set up in the antenna circuit due to the slight transfer of energy between the plate and antenna systems. Because of the inductive relation of the grid and antenna coils these oscillations will be impressed on the grid of the vacuum tube. This results in amplified oscillations in the plate circuit which, thru its inductive relation to the antenna system, reinforces the oscillating energy in the antenna circuit. This action is repeated with the antenna current constantly increasing until it is limited by the antenna and tube characteristics. The values of the grid leak "*R*" and grid leak condenser "C_2" are determined principally by the tube, and are designed to permit the tube to operate on the proper portion of its characteristic curve. The design of the coil system depends upon the wave length, antenna, and tube characteristics. The condenser "C_1" acts as a radio by-pass and also as a protective condenser for the generator. The condenser "*C*" functions as a radio by-pass for the oscillating current in the plate circuit. The modulation indicator "*M*" and the reactance "L_3" will be considered later.

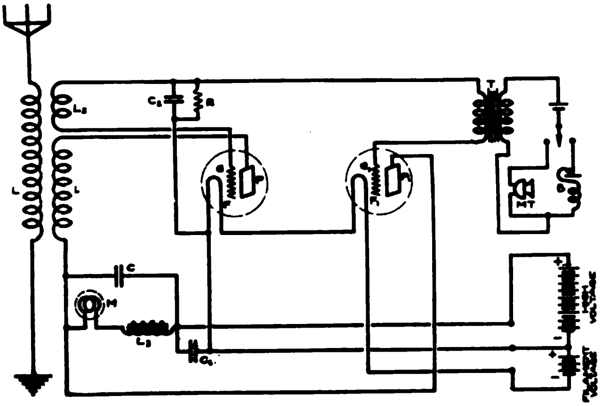

FIGURE 56

For use in continuous wave telegraphy the telegraph key is inserted in the circuit so as to open the grid leak or else to remove a short circuit from a second condenser in the grid circuit. The effect is the same in both cases, namely to stop the tube from oscillating. In aircraft radio, the first method is usually desirable in that an additional condenser is not necessary, hence decreasing the weight.

The elements of the vacuum tube employed as a modulator are represented by "F_1," "G_1," and "P_1." The microphone transformer is shown as "*T*." The buzzer "*B*" and the microphone transmitter "*MT*" are interchangeable by means of suitable switching. The modulation of the radio frequency energy generated by the oscillator tube is accomplished by means of amplifying the output of a microphone transformer, the primary of which is in series with a microphone and a source of direct current. The secondary of this transformer is connected to the grid of a vacuum tube termed the modulator, the grid being maintained at the proper operating point on its characteristic by a sufficient amount of negative potential. The output of the modulator is introduced into the plate circuit of the oscillator thru the incandescent lamp "M," or modulation indicator, and an iron core reactance "L_3." The brilliancy of the lamp "M" is varied by the fluctuations in plate current, hence indicating the functioning of the modulator tube. When used as a radio telephone transmitter suitable switching connects in the microphone and short circuits the telegraph key. When used for interrupted buzzer telegraphy a buzzer replaces the microphone and the telegraph key controls the oscillations of the tube oscillator as in continuous wave telegraphy.

The lowest power vacuum tube set, developed by the General Electric Company, is a combined transmitting and receiving equipment known as type SE 1345. This equipment is used on a small ship airplane for fire control work in connection with battleships, the airplane being of the one seat type so that the radio set must be operated by the pilot. The important features are smallness, lightness of weight, and simplicity of control, it being merely necessary to operate the send-receive switch after initial adjustments are made. The apparatus gives an antenna input of 5 watts and is designed for telephone communication with a battleship within an operating radius of thirty nautical miles (55.5 kilometers). The main element of this equipment, as shown in Figure 57, is a cabinet 14.38 inches (36.4 centimeters) wide by 5.38 inches (13.6 centimeters) high by 7.5 inches (19.0 centimeters) deep, weighing 12 pounds (5.44 kilograms).

The transmitter employs two vacuum tubes, type CG 1162 one tube being used as an oscillator and the other as a modulator. The receiver employs three receiving tubes, type CW 933, one being used as a detector, and the others in connection with two stages of audio frequency amplification. The tubes are mounted on a rubber cord suspension. It has been found that while rubber cord suspension is more satisfactory for receiving apparatus or combined sets of low power, spring supports are preferable for transmitting tubes. The plate circuit power and filament current for the transmitting tubes are supplied from a propeller-driven generator, illustrated in Figure 58. Constant rotary speed for this generator thruout varying airplane speeds is accomplished by means of a self-regulating propeller. The filament current for the receiving tubes is supplied from a 4-volt storage battery which will permit of reception for a period of four hours.

The schematic diagram of connections is illustrated in Figure 59. This equipment is arranged for operation on one wave length only, merely sufficient inductance variation being pro-

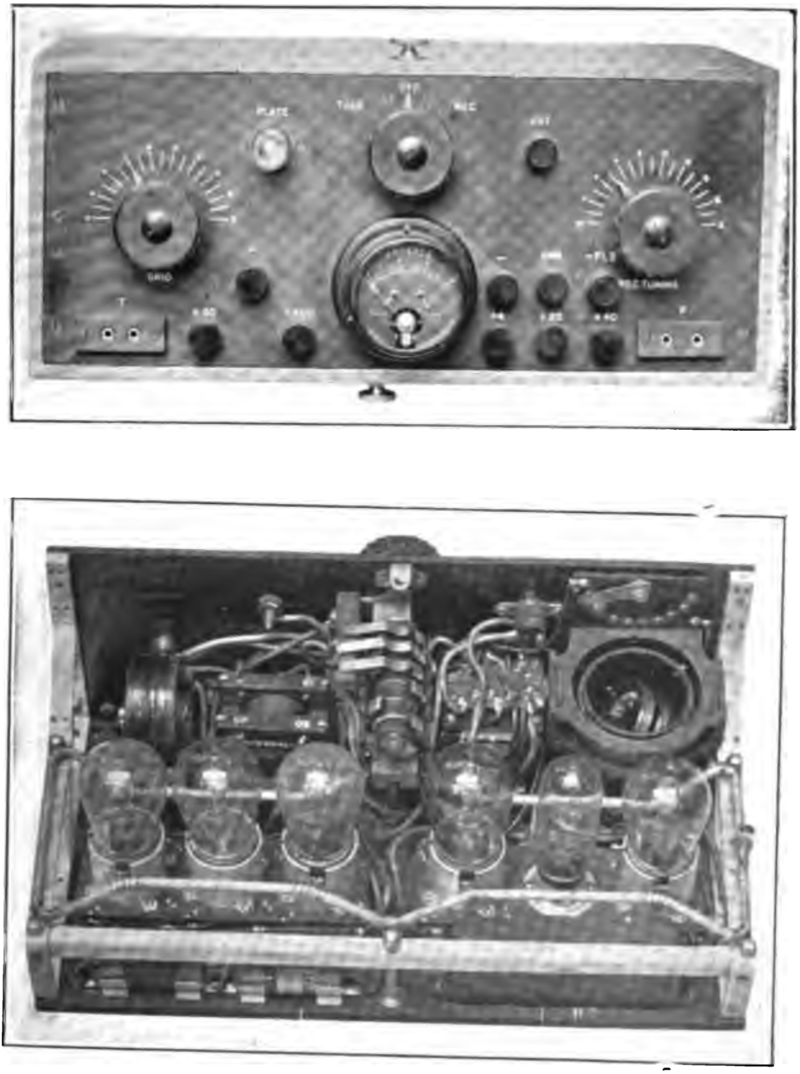

FIGURE 57

[illegible]

[illegible] antenna utilized. The [illegible] between [illegible] and [illegible] meters. The [illegible] on the front of the cabinet panel, consist [illegible] switch, a transmitter grid coupling [illegible] receiver variometer for tuning. On the front [illegible] mounted an antenna ammeter and a small [illegible] in the transmitter plate circuit as a modula- [illegible]

[illegible] phone transformer is provided with a side tone [illegible] that the pilot may hear his own speech and thus [illegible] the intensity of his voice. An iron filament [illegible] placed in series with the filaments of the two transmitting tubes, is used to maintain constant filament current of 1.75 amperes thruout all operating ranges of generator speed. An important feature of this equipment is that the panel and entire apparatus mounted behind it may be removed from the containing case without disconnecting the leads and rendering the set inoperative.

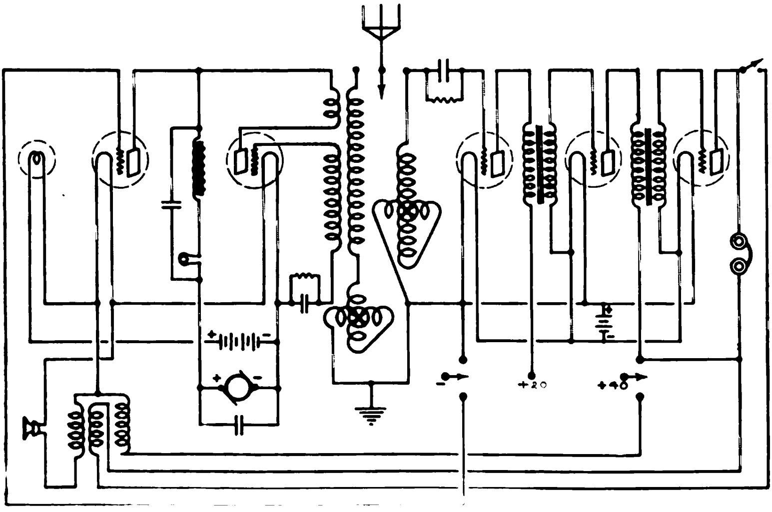

FIGURE 59

This equipment is arranged for use on an antenna composed of the two sides of the metal portions and brace wires of the plane, or in connection with a light trailing antenna used against the entire metal portion of the plane as a counterpoise. In the latter case, a special release is provided by which the trailing wire may be cast off with but a slight movement on the part of the pilot.

Another of the low power vacuum tube transmitters used is that embodied in combined transmitting and receiving equipment, type CW 1058, an adaptation of Signal Corps type SCR 68 equipment to naval uses. This apparatus is manufactured by the Western Electric Company. In this case the power for the transmitter plate circuits is supplied from a dynamotor driven from a 12-volt storage battery instead of from a propeller-driven generator as in the case of the Signal Corps equipment. The transmitter employs two low-power transmitting tubes, type CW 931, one used as an oscillator and the other as a modulator. The receiver consists of a detector and two stages of audio frequency amplification, three receiving tubes, type CW 933, being used. A schematic circuit diagram of this equipment is illustrated in Figure 60. The cabinet, illustrated in Figure 61, is approximately 17 inches (43.1 cm.) wide, 10 inches (25.4 cm.) high, 7 inches (17.8 cm.) deep, and weighs 21 pounds (9.5 kilograms).

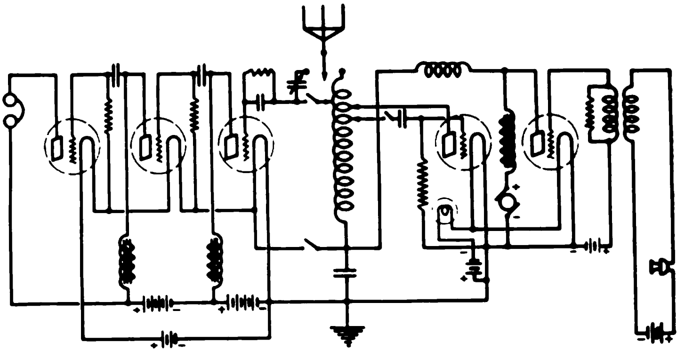

FIGURE 60

The dynamotor requires a current of 12 amperes from the 12-volt battery, the transmitting tubes a filament current of 2.7 amperes, and the receiving tubes a current of 3.3 amperes. A total current of 14.7 amperes is thus drawn from the battery while transmitting, and a current of 3.3. amperes while receiving. A standard 63-pound (28.6-kilogram) battery, fully charged, will permit continuous operation for a period of three hours on a basis of alternate five-minute periods of transmission and ten-minute periods of reception. The dynamotor is mounted on a case holding the receiving plate batteries, the entire dynamotor unit weighing 19 pounds (8.6 kilograms).

This equipment is arranged for transmission or reception on wave lengths of 215 to 450 meters using a trailing antenna. The antenna coil is oval shaped and is used for both transmitting and receiving. The transmitting tubes are mounted within this coil, an arrangement originally made to reduce the range of the set for Army uses and to economize space. Taps on this coil are connected to the dial switches marked "Wave length" "Coupling," and "Input" located in the penthouse on the front of the panel. By means of the dial switch marked "Input," the voltage across the [illegible] [illegible] [illegible] [illegible] the proper grid voltage to make the tube os[illegible] The [illegible] [illegible] of the coil can be varied by the [illegible] [illegible]. [illegible] coupling [illegible] as to secure the maximum power in the antenna [illegible] [illegible] time the inductance can be varied [illegible] the [illegible] [illegible] "Wave length" to give the required wave length [illegible] [illegible] [illegible] With this equipment [illegible]

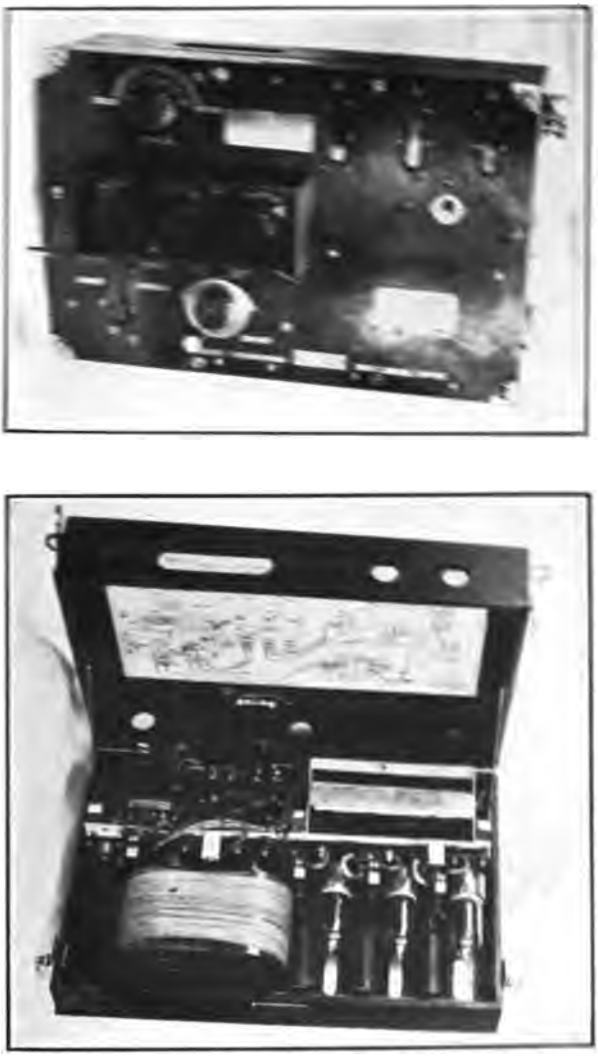

FIGURE 61

can be maintained between aircraft and ground station up to a distance of 10 nautical miles (18.5 kilometers), and between aircraft up to a distance of five nautical miles (9.3 kilometers).

(To be continued)

LONG DISTANCE RADIO COMMUNICATION IN CHILE[*]

By

E. W. Fielding

(Radio Telegraphic Instructor in the Chilean Navy, Valparaiso, Chile)

The high power stations of Llanquihue and Punta Arenas are practically identical, each station being provided with 100-kilowatt and 5-kilowatt Marconi apparatus. The following brief description will give a general idea of the equipment.

Both stations are fitted with a 220-horse power, three-cylinder, Diesel engine running at 200 revolutions per minute, and coupled to a 250-volt, 600-ampere dynamo. A 170-brake horse power, 220-volt motor runs in conjunction with a 100-kilowatt, 220-volt, 200-cycle alternator running at 1,500 revolutions per minute, and this in turn is coupled to a 16-stud rotary disc set, thus producing a spark frequency of 400 per second. The battery consists of 122 accumulators; capacity approximately 2,000 ampere-hours.

The 100-kilowatt set is arranged to give wave lengths between 2,400 and 5,000 meters, while the 5-kilowatt set ranges between 600 and 1,600 meters. All the antenna insulators are of porcelain, the leading-in ones containing oil. The earth wires are disposed in the form of two semi-circles; the radius for the circle being 200 feet (61 m.).

There are four antennas.

Antenna A consists of 20 wires, 2,000 feet (610 m.) long.
" B " " 12 " 1,475 " (450 m.) "

Receiving antenna has two wires 1,800 feet (549 m.) long, and the 5-kilowatt set has the usual four-wire antenna.

These antennas are arranged between seven sectional steel masts each 253 feet (77 m.) high; A, B, and receiving antennas being in the form of inverted L's, directive to Punta Arenas, and vice versa. Measuring the fundamental wave length of the two-wire receiving antenna by an atmospheric spark direct to earth, during a storm, gave a result of 2,650 meters.

For reception, the Marconi long wave receiver is used, tuning

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[*] Received by the Editor, February 3, 1919.

up to 7,000 meters, and employing carborundum and the Fleming valve as detectors.

Figure 1 shows the masts and buildings of one of the stations, Figure 2 the Diesel engine, Figure 3 the storage battery, and Figure 4 the remote-controlled antenna switch and the receiving set.

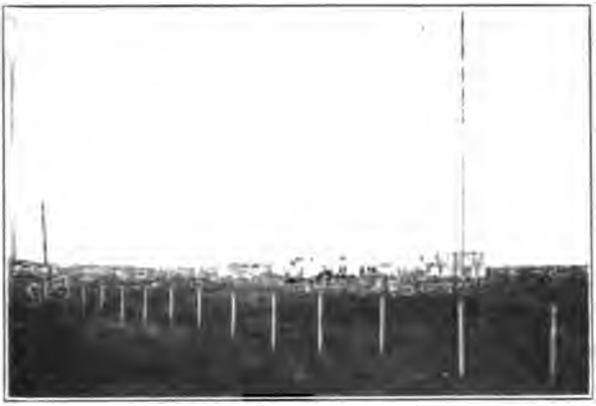

FIGURE 1

The climate at Llanquihue (41° south latitude) is very damp: rain falls very frequently thruout nine months of the year, and during the remaining three months, is generally about to do so. This dampness has caused considerable trouble with the apparatus at various times, generally in the winter, and during this season the buildings have to be continuously heated.

The oil-filled condensers have worked well, only two giving out during three years, the oil having been boiled previously to use.

Punta Arenas and Llanquihue are about 875 miles (1,349 km.) apart. Tests carried out proved that best all-round results, taking into consideration the energy used, were obtained with the wave length of 3,600 meters working with 50 kilowatts. Using 100 kilowatts at 5,000 meters, stronger signals were recorded, but not in proportion to the increase of energy. The 3,600-meter wave, requiring but little added antenna inductance, since it is nearer to the fundamental than the 5,000-meter wave, is now used for all traffic.

Work thruout the winter can be carried on with but small interruption from strays, but during the summer months signals between two and four of the afternoon are considerably weakened, at times dying out altogether. This same effect is also noticed occasionally during the morning, from ten to eleven, the changes in signal strength taking place very quickly. The same phenomena are also noticed in Punta Arenas when receiving from Llanquihue.

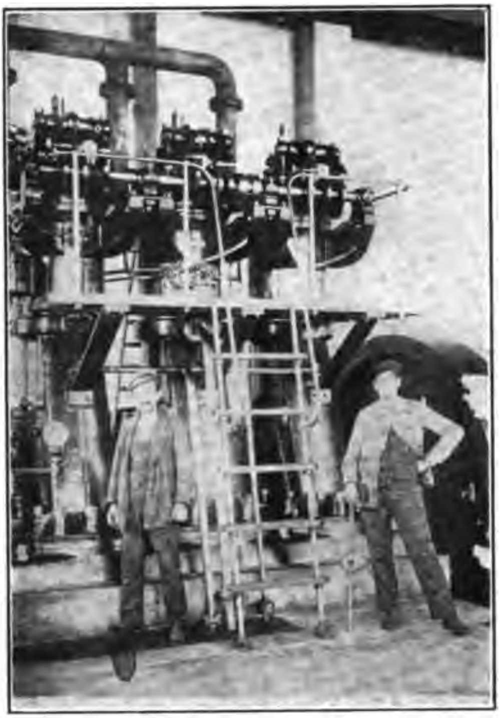

FIGURE 2

From twilight to dawn, signals from Punta Arenas are quite strong when using the carborundum detector, strays as well being at a maximum during this period. Except for hot summer weather or during squalls, these strays can be cut out sufficiently to permit reception. Balanced crystal working gives best results, and by selecting the crystals employed, strays can be heard as one continuous blur; the signals being of different tone can then be easily read. The Fleming valve used in a partially insensitive position also gives good results.

It will be noticed that these two stations lie very nearly on the same degree of longitude. Everything goes to prove that the weakening of signals, produced when working from East to West, is the same as when working from North to South where the stations enter the daylight zone at nearly the same time

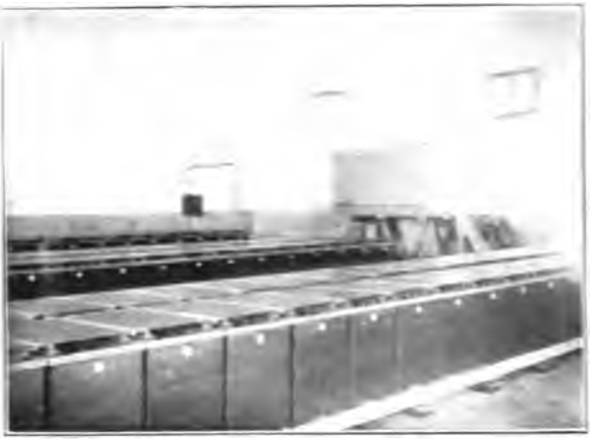

FIGURE [illegible]

During the eruption of "Mount Calbuco," situated about 60 km. 40 miles from the Llanquihue station, a considerable increase in atmospherics was noticed, and great difficulty in working resulted. At night time, San Francisco and Honolulu can easily be heard but read with difficulty owing to the atmospherics. Signals are improved by using silicon, and employing a very weak current, but extra strong atmospherics will cause it to lose its sensitiveness.

These stations constitute a considerable improvement in communication for this country; and Chile now possesses an uninterrupted chain of radio stations stretching from Arica to Punta Arenas, thus ensuring quick and ready communication.

Needless to say, they have already proved of great utility; and the rapid exchange of radio messages in connection with the Shackleton expedition resulted in the rescue of the seamen stranded on Elephant Island.

With the advent of the vacuum tubes, communication will be made all the more secure and communication with distant countries all the more certain.

FIGURE 4

SUMMARY: The Chilean radio stations at Llanquihue and Punta Arenas are described in detail. The best wave length and power for this 875-mile (1,349-km.) transmission are given. The effects of strays, their reduction, and signal fading are discussed.

THE DEPENDENCE OF THE AMPLIFICATION CONSTANT AND INTERNAL PLATE CIRCUIT RESISTANCE OF A THREE-ELECTRODE VACUUM TUBE UPON THE STRUCTURAL DIMENSIONS*

By

JOHN M. MILLER

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In an earlier paper[1] the writer pointed out the importance of the amplification constant and internal plate circuit resistance in determining the behavior of vacuum tubes as amplifiers and outlined a simple and direct method of measuring these quantities. In the present paper, formulas based upon theoretical considerations are derived which relate the values of these quantities to the dimensions and spacing of the three electrodes.

The two-electrode tube has been treated theoretically by Child[2] and Langmuir.[3] The latter author has derived expressions for the electron current flowing between the filament and plate of such a tube as limited by the space charge in two particular cases and has shown the general law of dependence of the current upon the voltage between the electrodes. In one of the particular cases the filament was assumed to be an infinite plane emitting electrons and the plate likewise an infinite plane parallel to the filament at a distance x and maintained at a positive potential with respect to the filament. In the other case the filament was assumed to be a cylindrical wire of infinite length surrounded by a concentric cylindrical surface of infinite length constituting the plate.

The limitation of the current by the space charge comes about in the following manner. Those electrons which are in motion from the filament to the plate constitute a space distribution of negative electricity which exerts an electrical force in the region of the filament opposite to that due to the plate. No

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* Received by the Editor, April 26, 1919.

[1] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 6, page 141, 1918.

[2] C. D. Child, "Physical Review," 32, page 498, 1911.

[3] I. Langmuir, "Physical Review," 2nd series, 2, page 450, 1913.

matter how many electrons are emitted by the filament per second, the current flow to the plate cannot exceed that which just neutralizes the force due to the plate at the filament surface, assuming the initial velocity of the emitted electrons to be negligible. This limitation of the plate current by space charge is the condition which also obtains in the normal operation of a three electrode vacuum tube and which permits the grid to control the flow of plate current. For if the voltage of the grid is positive so that its electrical force aids that of the plate, the current will increase until the combined forces of grid and plate are neutralized at the surface of the filament. If the grid voltage is negative, it will itself neutralize the force of the plate to some extent and the plate current will be reduced. On account of its position in the tube, a change in voltage of the grid will produce a change in the electrical force at the filament, and a resulting change in plate current much greater than an equal change in voltage of the plate. The amplification constant is a measure of the relative effect of grid and plate voltages on the plate current and may be defined as the ratio of changes of the plate and grid voltages necessary to produce equal changes in the plate current.

In the case of the two parallel planes the flow of electrons as limited by the space charge was found by Langmuir to be

$$i_p = 2.33 \times 10^{-6} \frac{V_p^{\frac{3}{2}}}{x^2} \tag{1}$$

in amperes per square centimeter of surface. In terms of the electric force due to the plate,

$$f = \frac{V_p}{x}$$

the current is

$$i_p = 2.33 \times 10^{-6} \frac{f^{\frac{3}{2}}}{x^{\frac{1}{2}}} \tag{2}$$

This equation may be interpreted to mean that the current i_p flowing from filament to plate exerts a force at the filament equal and opposite to the force f. If f is increased or diminished the current will vary in proportion to the three-halves power of the force. If the electrical force f arises from the joint action of both a plate and a grid, it will be assumed that the plate current will vary in accordance with this same law. In case the grid becomes positive enough so that an appreciable flow of electrons to the grid takes place, this can be taken account of by substituting the total current $i_p + i_g$ in place of i_p. These assumptions appear justifiable because the density of the space charge is a maximum in the neighborhood of the filament where the electrons are moving at the lowest velocity. This makes the space charge effects depend mainly upon the distribution in the region between the filament and the grid.

In order to obtain an equation for the current flow which takes into account the action of the grid, it is necessary to get an expression for the combined electrical forces due to the grid and plate when these elements are at certain definite potentials with respect to the filament. Maxwell[1] in considering the screening effect of a grating of parallel wires has given a solution of the electrostatic problem of two infinite plates with a grid of equally spaced cylindrical wires between them. This permits an extension of the first case of the two-electrode tube as given by Langmuir to that of a three-electrode tube.

From Maxwell's treatment it is found that the force at the surface of one of the plates, which we will consider to be the filament, is given by

$$F = -\frac{1}{x - \frac{b_1 b_2}{a}}\left(V_p - \frac{b_2}{a}V_g\right) \qquad (3)$$

where

b_1 = distance filament to grid.

b_2 = distance grid to plate.

$x = b_1 + b_2$

and

$$a = -\frac{l}{2\pi}\log_e\left(2\sin\frac{\pi c}{l}\right) \qquad (4)$$

where c = radius of grid wire

l = distance between grid wires.

In the derivation of this equation it is assumed that c is small with respect to l. Substituting equation (3) in (2) we obtain for the equation of the plate current in a three-electrode tube

$$i_p = \frac{2.33\times10^{-6}}{x^{\frac{1}{2}}\left(x - \frac{b_1 b_2}{a}\right)^{\frac{3}{2}}}\left(V_p - \frac{b_2}{a}V_g\right)^{\frac{3}{2}} \qquad (5)$$

Equation (5) is of the same form as the expression

$$i_p = A(V_p - kV_g)^{\frac{3}{2}} \qquad (6)$$

which Langmuir has given as representing the characteristic surface of the plate current. In this formula k is the amplifica-

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[1] Maxwell, Electricity and Magnetism, volume 1, page 31[illegible]

tion constant. The formula for the amplification constant is therefore

$$k=\frac{b_2}{a} \tag{7}$$

The quantity a is given by equation (4) and depends only upon the dimensions of the grid. Hence the amplification constant is independent of the distance from the filament to the grid but is proportional to the distance b_2 from grid to plate.

The internal resistance of the tube in the plate circuit R_p is the reciprocal of the slope of the plate current-plate voltage characteristic. Differentiating (5) with respect to V_p.

$$\frac{\partial i_p}{\partial V_p}=\frac{3}{2}\cdot\frac{2.33\times10^{-6}}{x^{\frac{1}{2}}\left(x+\frac{b_1 b_2}{a}\right)^{\frac{3}{2}}}\left(V_p+\frac{b_2}{a}V_g\right)^{\frac{1}{2}} \tag{8}$$

The reciprocal of this expression gives the internal resistance R_p. Hence

$$R_p=\frac{x^{\frac{1}{2}}\left(x+\frac{b_1 b_2}{a}\right)^{\frac{3}{2}}}{3.5\times10^{-6}\,.\,S}\;\frac{1}{\left(V_p+\frac{b_2}{a}V_g\right)^{\frac{1}{2}}} \tag{9}$$

Since the current i_p is the current per square centimeter of area, the total area S must be introduced in the denominator of the expression for the total resistance R_p.

It is of interest to see with what accuracy the formulas (7) and (9) can be applied to calculate the constants of actual tubes from the dimensions, since actual tubes deviate considerably from the simplifying assumptions necessary in the theoretical treatment. Using formula (7), the amplification constant was calculated for a considerable number of types of tubes from dimensions obtained either by measurement of burned out tubes of the same type, from data supplied by the manufacturer or from somewhat difficult measurements upon good tubes. These values of the amplification constant were then compared with those obtained from the electrical measurement of either the same tubes or a number of tubes of the same type. In the case of tubes having plane grids and plates, the agreement between the measured and computed values was very satisfactory over a wide range of tube constructions. The formula when applied to tubes having cylindrical or elliptical plates and grids gives much less satisfactory agreement. The results of the comparison for tubes having plane elements are given in Table 1. This table gives the maker, type of tube, the dimensions used in the calculation and, in the last two columns, the computed and measured values of the amplification constant. Three types of tubes having cylindrical plates and grids gave computed values respectively 20, 40, and 40 per cent. higher than the measured values. The agreement in the case of the 20 per cent value was aided without doubt by the relatively heavy wires used in supporting the grid helix which would increase the measured value, so that in general the computed values would be about 40 per cent high for tubes of this type.

The curves in Figure 1 permit the amplification constant to be readily determined when the diameter of the grid wire in mils (1 mil = 0.001 inch = 0.025 mm.), the distance between the grid wires in millimeters (or turns per inch) and the distance from grid to plate in millimeters, are given. Each curve corresponds to a particular size of grid wire which is customarily drawn to diameters given in mils. The abscissas are given in tenths of a millimeter distance between grid wires (the heavy vertical lines corresponding to turns per inch as numbered) while the ordinates give the values of amplification constant for each two millimeters of distance from grid to plate. Thus the type D tube of Table 1 has 8 mil grid wire spaced 10.7-tenths of a mm. apart. From the curve the amplification constant is 22 for each two mm. distance plate to grid. This distance is 4.8 mm., hence the amplification constant is 2.4 times 22 = 53.

In applying formula (9) to compute the internal plate circuit resistance of actual tubes in which the filament is a wire instead of a plane as assumed in the derivation of the formula, the difficulty arises as to what values should be used for the area. A suggestion as to a possible solution of this difficulty is gained from the second two-electrode problem for which a solution was given by Langmuir.[5] He finds in the case of a straight round wire for the filament and a concentric cylinder as the plate, that the current flow is independent of the wire radius if this is small compared to the radius of the plate but does vary in proportion to the length of the system. It therefore seems probable that in the case under consideration the resistance might vary inversely as the length of the filament so that an equivalent breadth could be found which would be constant for all of the tubes and which, when multiplied by the length of the filament, would give the correct value of the area to use in the formulas.

To test this assumption values of the resistance for unit area

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[5] Langmuir, previous citation.

TABLE 1

Maker	Type	b_2 cm.	a cm.	c cm.	Amplification Constant	
					Computed	Measured
W. E. Co.	D–Voltage Amplifier	0.48	0.107	0.010	52	40–49
W. E. Co.	V–Voltage Amplifier	0.417	0.121	0.009	30	28–29
G. E. Co.	P–High Power	0.435	0.083	0.0038	26	25
De Forest	3.75-inch–High Power	0.6	0.114	0.0032	19	17
De Forest	(VT–21)–Receiving	0.255	0.137	0.010	14	10–12
W. E. Co.	E (VT-2)–Low Power	0.465	0.29	0.010	6.9	6.7–7.7
W. E. Co.	J(VT-1)–Receiving	0.175	0.25	0.020	6.4	5.3–6.8.
W. E. Co.	L-Current Amplifier	0.49	0.35	0.009	4.8	4.5–5.2.

were computed for all of the types of tubes given in Table 1. These values were then divided by the experimentally determined values of the actual tube resistance giving the effective area for each type of tube. Again dividing these values for the area by the length of the filament the equivalent breadth was obtained. The range in the observed resistance values for different tubes of the same type is usually considerable, so that similar variations in the equivalent breadth are to be expected. The results obtained indicated that the equivalent breadth is a constant for the different types of tubes as accurately as tubes of the same type are reproduced. This is shown in Table 2 where the first five columns give the type of tube, the values of x, b_1, and V_p and the computed resistance for a unit area. In the sixth column is given the range in values of the experimentally observed resistances which were obtained at the plate voltage V_p and grid voltage zero. In the last four columns are given the effective area, the filament length and the range and average of the computed values of the equivalent breadth. Apparently an equivalent breadth of 0.5 cm. (0.2 inch) will give computed values of the plate circuit resistance for the different types of tubes which will fall close to or within the range of values observed for a number of tubes of the same type.

Using this value for the equivalent breadth, formula (9) can be rewritten so as to express the internal plate circuit resistance of a tube in terms of its filament length L and the other dimensions. Thus

$$R_p = \frac{x^{\frac{1}{2}}\left(x+\frac{b_1 b_2}{a}\right)^{\frac{3}{2}}}{1.8L} \, \frac{10^6}{\left(V_p+\frac{b_2}{a}V_g\right)^{\frac{1}{2}}} \text{ ohms} \qquad (10)$$

This formula is applicable only to tubes having a plane plate and plane grid on each side of the filament.

In conclusion it might be well to call attention to certain experimentally observed deviations in the behavior of actual tubes from that corresponding to the simple theory. At low plate voltages or low values of (V_p+kV_g) the measured values of the amplification constant are lower and the three-halves power law does not appear to hold. This is probably a result of neglecting the initial velocity of emission, the voltage gradient along the filament, and so on. For positive grid voltages when appreciable current flows to the grid, the measured and effective values of amplification constant and internal plate resistance are affected

TABLE 11

Type	x cm.	b_1 cm.	V_p volts	Resist. in 10^5 ohms		Effective Area cm^2.	Filament Length cm.	Equiv. Breadth	
				Computed Per $\frac{1}{\text{cm.}^2}$	Meas'd Total			Range cm.	Average cm.
D	0.65	0.17	100	6.71	1.13–3.25	5.9–2.1	5.7	1.04–0.36	0.70
V	0.62	0.20	100	1.21	0.49–0.51	2.5–2.4	5.7	0.44–0.42	0.43
P	0.64	0.22	300	2.11	0.22	9.6	16.	0.60	0.60
3.75″	0.80	0.20	300	1.45	0.27	5.3	10.	0.53	0.53
VT–21	0.36	0.10	20	0.89	0.68–1.21	1.3–0.74	2.4	0.55–0.31	0.43
E	0.63	0.16	200	0.36_5	0.035–0.065	10.6–5.6	13.	0.81–0.43	0.62
J	0.35	0.15	20	0.67	0.16–0.32	4.2–2.1	5.7	0.74–0.37	0.55
L	0.71	0.21	100	0.17_2	0.049–0.052	3.5–3.3	5.7	0.62–0.58	0.60

thereby. The quantities k and R_p as given above are no longer determined by the slopes of the plate current characteristics alone but by the slopes of the grid characteristics also. Thus if we write as mentioned above

$$i_p+i_g=A\,(V_p+k\,V_g)^{\frac{3}{2}}$$

then

$$\frac{\partial i_p}{\partial V_g}+\frac{\partial i_g}{\partial V_g}=\frac{3}{2}A\,k\,(V_p+k\,V_g)^{\frac{1}{2}}$$

and

$$\frac{\partial i_p}{\partial V_p}+\frac{\partial i_g}{\partial V_p}=\frac{3}{2}A\,(V_p+k\,V_g)^{\frac{1}{2}}$$

from which

$$k=\frac{\dfrac{\partial i_p}{\partial V_g}+\dfrac{\partial i_g}{\partial V_g}}{\dfrac{\partial i_p}{\partial V_p}+\dfrac{\partial i_g}{\partial V_p}}=\text{constant}$$

$$R_p=\frac{1}{\dfrac{\partial i_p}{\partial V_p}+\dfrac{\partial i_g}{\partial V_p}}$$

while the measured and effective values would be given by

$$(k)_{meas.}=\frac{\dfrac{\partial i_p}{\partial V_g}}{\dfrac{\partial i_p}{\partial V_p}}=\text{function of } V_g$$

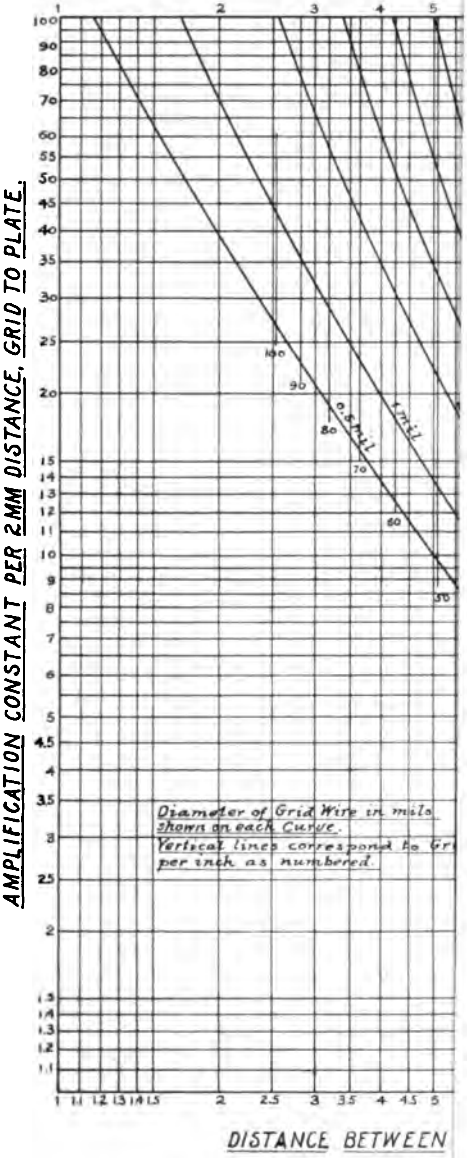
$$(R_p)_{meas.}=\frac{1}{\dfrac{\partial i_p}{\partial V_p}}$$

It is not to be expected therefore that the formulas (7) and (9) will give results in close accord with the measurements when (V_p+kV_g) is small or V_g is considerably positive.

In conclusion, I beg to acknowledge the valuable assistance of Dora E. Wells of the Bureau of Standards, who performed most of the experimental work cited above.

SUMMARY: The amplification constant of three electrode vacuum tubes is mathematically derived in terms of readily measurable physical dimensions of the tube. Curves are plotted enabling the rapid pre-determination of tube amplification constant on this basis. The curves are shown to give results agreeing with experiment for a number of types of tubes.

The internal resistance of the tube is similarly deduced, and an agreement between theory and experiment shown. Certain deviations in specific instances are explained.



Diameter of Grid Wire in mils shown on each Curve.
Vertical lines correspond to Gr
per inch as numbered.

AN EXPERIMENT ON IMPULSE EXCITATION*

BY

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The question of how much current will flow in a given circuit, when it is excited by impulse excitation, is capable of mathematical analysis by the application of Fourier's Integral, or other methods, providing the shape of the exciting pulse is given. However, an experimental analysis is always worth while as a verification of the theoretical conclusions.

Atmospherics (strays or static) are undoubtedly a kind of pulse; certain experiments seem to show that these atmospheric pulses are sometimes oscillatory, with rather high damping, but the probability is that most of the disturbance from static is due to unidirectional pulses impressed on the antenna by sudden motions of electricity, either in the atmosphere or in the earth. With the idea of showing how a unidirectional pulse affects an oscillatory circuit, an experiment was carried out with the circuit arranged as shown in Figure 1.

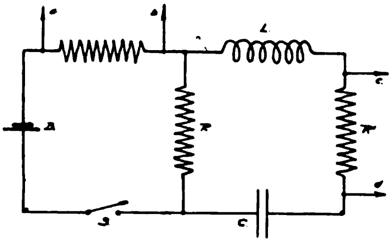

FIGURE 1

The oscillating circuit was made up of a coil of 0.206 henry and condenser of 20 microfarads, having a natural frequency of 78.6 cycles per second. A battery *B* was arranged to cause

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* Received by the Editor, April 12, 1919.

current to flow thru the resistance *R* when the switch *S* was closed. This switch was so built that its time of contact could be varied from about 0.002 second to any longer time desired. The resistance of *R* was 0.01 ohm.

Another resistance was put in the circuit at *R′*, the value of this being about 5 ohms. The resistance *R* was made low so that the current thru it from the battery would be very much larger than the current in the oscillatory circuit, to keep the current from the battery constant whatever the form of the current in the oscillatory circuit. The current from the battery was 10 amperes while the current in the oscillatory circuit was only a fraction of an ampere.

The voltage impressed in the oscillating circuit by the battery is the *IR* drop thru the resistance *R* and the form and duration of this current was obtained by one vibrator of the oscillograph being connected across the points *a-b*. Another vibrator connected across the terminals of the resistance *R′* gave the form of the current in the oscillatory circuit.

Films were taken for various times of contact of the switch *S*, from the shortest time possible to somewhat greater than the natural period of the circuit. Several of the films are given in Figures 2-5; they show the form of pulse used for excitation and also the magnitude of the resulting current. It is also possible to obtain at once from the film the ratio of the pulse duration to the natural period of the circuit. For the longer pulses

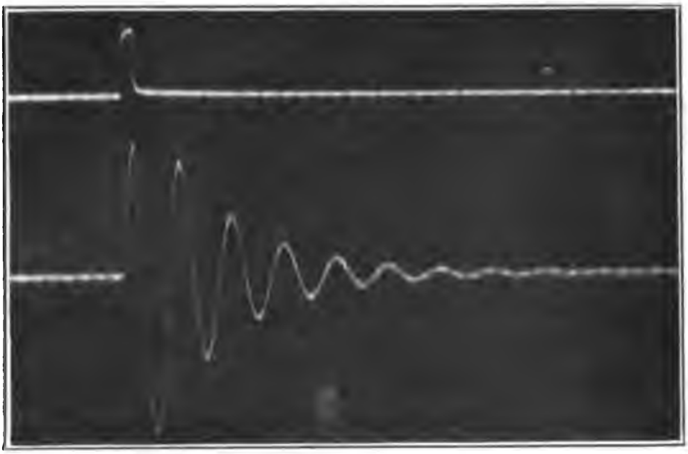

FIGURE 2

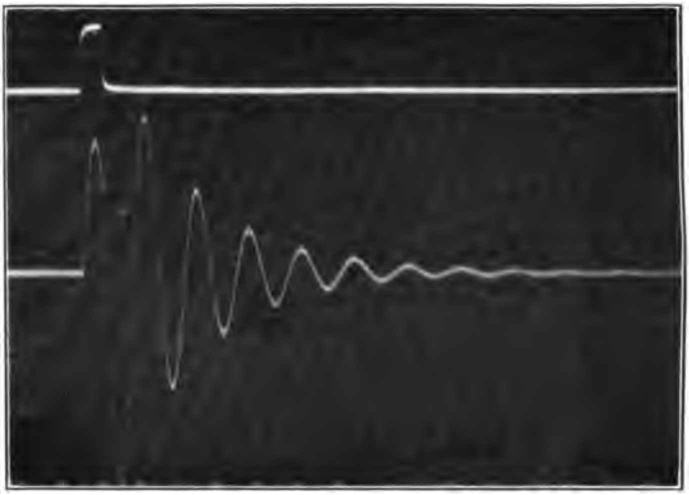

Figure 3

the form approximates a rectangle, but the shortest ones (the corners of the pulse being absent) have a form more like sine wave.

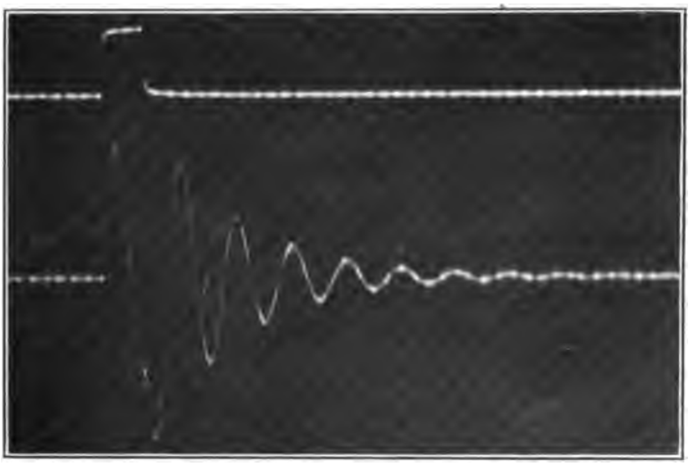

Figure 4

The amplitudes of the first and second alternations of the oscillating current were measured and these values plotted in the form of a curve, using as abscissas the ratio of the pulse length to the natural period of the circuit. These values are given in Figure 6. It is seen that for the shortest time used the amplitude of the first and second alternations are practically the same and that the amplitude of the first alternation does not increase after the pulse has a length equal to one quarter of a cycle. As the pulse was lengthened the amplitude of the second alternation increased until the pulse length was equal to practically one-half the natural period of the oscillating circuit. If the

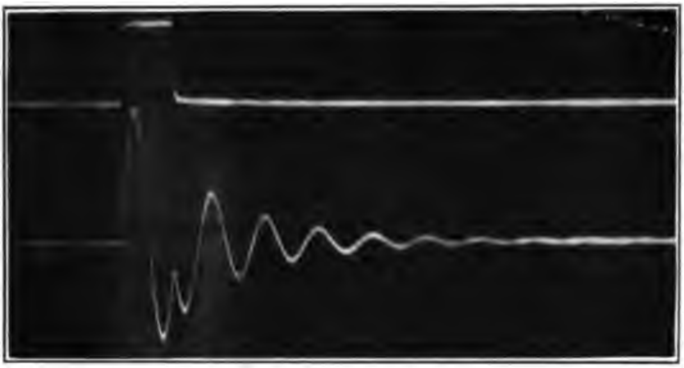

FIGURE 5

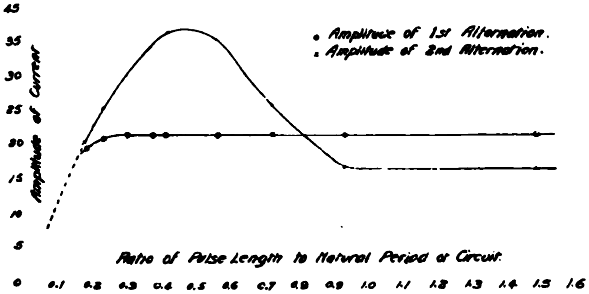

FIGURE 6

decrement of the circuit had been lower the greatest amplitude would have been produced by a pulse somewhat longer than that which did actually give the greatest amplitude in the test.

For pulses lasting longer than one-half period the amplitude of the second alternation decreases until it has that value which is fixed by the amplitude of the first alternation and the decrement of the circuit; for any longer pulse the amplitude of the first and second alternations are not affected.

It is seen therefore that the greatest disturbance is produced in an oscillatory circuit by a rectangular pulse when this pulse has a duration equal to one-half the natural period of the circuit.

The complex form of current occurring in an oscillatory circuit as a result of irregularly timed pulses, of various durations, is shown in Figures 7 and 8; if this form of excitation occurs at very short intervals of time, the frequency of the oscillating circuit being above audibility, the resulting noise heard in the phones of a coupled circuit (such as the ordinary closed circuit of a receiving circuit) would be the scratchy noise known as static.

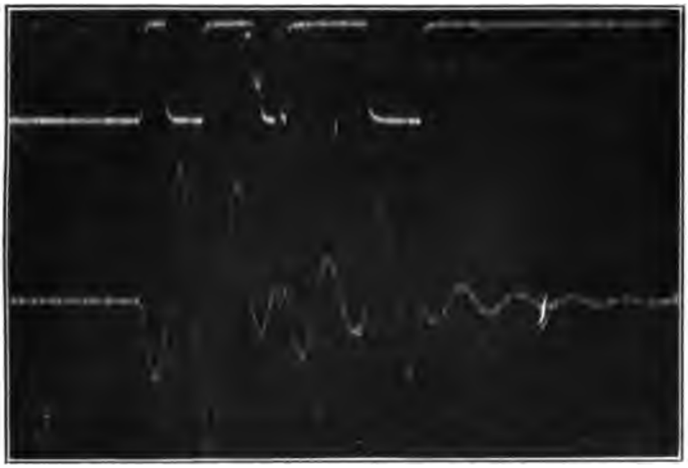

FIGURE 7

It is to be noted that the pulse of emf. shown in Figures 3-8 was introduced directly into the oscillating circuit. I mention this point because incorrect conclusions might be drawn if it were supposed that the results were applicable to shock excitation in which a pulse of current in one circuit is utilized to excite oscillations in another magnetically coupled to it.

FIGURE 8

If a square pulse of current (of form similar to the emf. pulse of Figures 3-8) is allowed to flow in a primary circuit it will not generate oscillations in the coupled circuit in agreement with the conclusions reached above. This is due to the fact that a square current pulse in one circuit will not generate a square emf. pulse in a coupled circuit, but a very different form of pulse. Figure 9 shows about what would occur; a trapezoidal form of current in the primary circuit would induce in the secondary circuit two very short pulses of emf., these two pulses being in opposite directions. Hence the action of such a current pulse in the primary, in so far as producing current in the secondary is concerned, is the same as tho two very short pulses of emf. were introduced directly into the secondary circuit, the two pulses being in opposite directions and separated by a time about equal to the length of current pulse in the primary circuit.

Since the above notes on impulse excitation were written the author attended a meeting of THE INSTITUTE OF RADIO ENGINEERS at which another phase of impulse excitation was brought up and on which there is apparently some difference of opinion.

If a so-called infinite impedance circuit is used in an antenna for weeding out a certain frequency, how well will this circuit weed out pulses, or, what amounts to the same thing, how well will it prevent interference from a damped wave station? Suppose an inductance, *L*, and a condenser, *C*, are connected in parallel as indicated in Figure 10; then if the antenna is excited by a signal of the same frequency as that for which the parallel

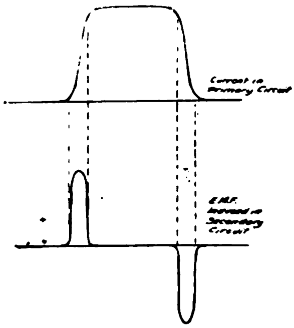

FIGURE 9

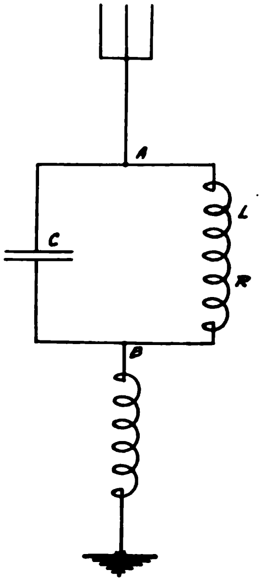

FIGURE 10

circuit is tuned, it is shown in many text books that the impedance offered by this parallel path is resistance only and its value is equal to the actual resistance of the coil multiplied by the square of the ratio of the coil reactance to the coil resistance, this on the assumption that the condenser resistance is negligible. This impedance may be thousands of times as much as the resistance of the coil; thus if the coil has an actual resistance of 5 ohms and a reactance-to-resistance ratio of 200, (a quite possible figure), the impedance between the points A-B is 200,000 ohms, *for the steady state of an alternating current of the proper frequency.*

Now the question arises, will this circuit act towards a pulse with such a high impedance, and of course the answer is *No.* Suppose the critical frequency of the parallel circuit is 100,000 cycles and to make the analysis as simple as possible let an emf. pulse be impressed on the antenna, the pulse being sinusoidal in form and lasting 0.000,005 second. This assumption makes the pulse the same shape as one alternation of that emf. for which the parallel path offers such a high impedance; it seems evident that such a pulse will produce less current thru the circuit than any other form. If the pulse is not sinusoidal in form it may be resolved (according to a quite generally accepted idea) by a Fourier's analysis, and the different members of the series obtained may be treated separately. Thus the sinusoidal pulse assumed may be considered as the result of such an analysis of a more complex pulse.

The current flowing in the antenna as the result of excitation by such a shaped pulse is shown in Figure 11. The first curve (a) is the emf. impressed, the second curve (b) is the current thru the condenser, and the third curve (c) is the current in the inductance branch, this being drawn on the assumption that the resistance of the coil is negligible with respect to its reactance. The current flowing in the antenna (or line in which the infinite impedance circuit is introduced) is obtained by adding the two branch currents and is shown by the rectangular current (d) of Figure 11. The amplitude of this rectangular current is the same as the maximum value of the current flowing in the condenser; quite evidently the parallel path permits the flow of a large current and so can scarcely be considered as having infinite impedance, even for a pulse of the form most favorable for the filtering action of the circuit.

The reason that the predicted impedance does not exist for the impulsive emf. is this—the equations from which the value of this infinite impedance are obtained neglect the transient terms and for impulsive forces these transient terms are the whole solution.

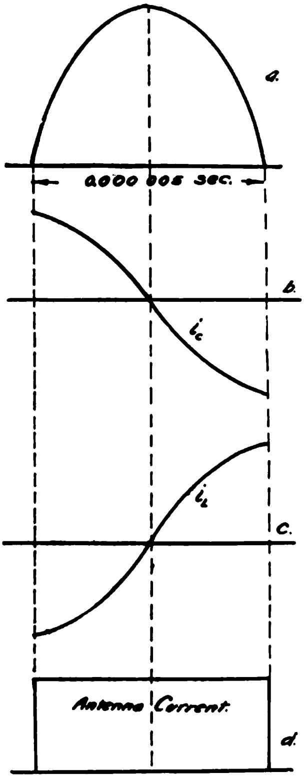

FIGURE 11

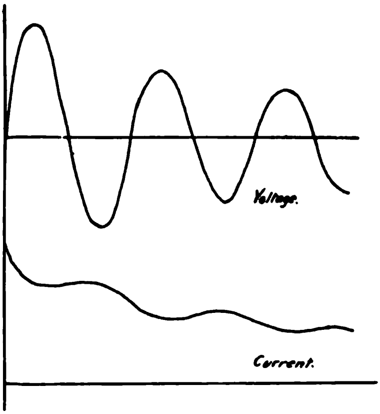

FIGURE 12

In case the circuit of Figure 10 is relied upon to weed out interference from a spark station it must be remembered that at the beginning of every wave train there are transient terms which do not obey the laws holding for the steady state. In Figure 12 is shown what may be expected when the infinite impedance circuit is excited by a damped wave of emf. The current which flows in the antenna (in so far as it is limited by the infinite impedance circuit) is shown to be a quite appreciable current, rising at once to the maximum current in the condenser branch and then gradually dying away with slight ripples of the interfering signal frequency. Such a current flowing in the antenna coil of the receiving circuit would certainly be very difficult to tune out.

SUMMARY: There is described an oscillographic investigation of the current produced in an oscillatory circuit by a brief rectangular pulse of emf. directly introduced into the circuit. The pulse length is regulable. It is found that a pulse having a duration of one-half the natural period of the circuit produces the maximum disturbance. The bearing of the results on the effects of strays in reception is discussed.

The behavior of "infinite impedance" loop circuits when subjected to pulse excitation is studied, and it is found that for pulses their filtering action is much reduced.