RADIODYNAMICS AND THE DESIGN OF A MODEL RADIO CONTROLLED AUTOMOBILE

Thesis for the Degree of B. S.

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RADIODYNAMICS

AND

THE DESIGN OF A MODEL RADIO CONTROLLED AUTOMOBILE

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THESIS

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PART I

RADIODYNAMICS

Historical

Radiodynamics is the science of remotely controlling mechanical devices without artificial interconnections. Consequently, the history of radiodynamics begins with the invention of the first means of communication using electrical phenomena as a basis. In 1727 the first signal using electricity was sent over a circuit of 700 feet by an electric discharge. Shortly after this the discovery of the Leyden jar increased the distance of sending signals by electricity to 2800 feet. The first telegraph system for sending intelligent signals was established in 1774. Soon after this the magnetic effect of an electric current was discovered which led to the invention of the galvanometer.

Following the invention of the electromagnet in 1825 and the discovery of the laws of the magnetic circuit in 1831, Morse devised the present electromagnetic telegraph system. A few years later Wheatstone invented the automatic recording telegraph which has a great significance from the viewpoint of radiodynamics. The development of long distance telegraphy brought about the invention of the relay which is one of the most essential devices used in remote controlled apparatus. A relay makes it possible for an almost inconceivably small

amount of energy to control the most powerful machinery in a large mill or power house.

Thus the development of teledynamics, which is the art of distant control with a physical connecting line, came about. The invention of the wireless telegraph, which is the basis of radiodynamics, has always been accredited to Marconi although a great deal of research work had been done with Hertzian waves before he established the first successful system.

It is not the purpose of this paper to give a history of methods of communication, but the invention of one other piece of apparatus should be mentioned. In 1905 Lee DeForest perfected the principle of the "audion" vacuum tube which has made radiophone communication possible. In recent years the development of radio vacuum tubes has been very rapid and the application of the electron tube relay has been of primary importance in the growth of radiodynamics.

Statement of Problem

The problem of radio control as it stands today consists of three distinct features; namely, the necessity of suitable radio sending and receiving apparatus, the design of super-sensitive, reliable relays, and the development of a suitable selector system. A glance at Fig. 1 of Part II will show the necessity of these features in the control system. In the following paragraphs each of these three items will be taken up in detail.

The Radio Equipment

Due to the wide popularity and increasing necessity of radio communication, this art has developed as rapidly as possible. In selecting suitable radio equipment for remote operation by wireless the feature of reliability must be one of the first considerations. It is well worth while to have a large factor of safety or reliability, that is, to send out signals from the transmitter which are actually stronger than those required to operate the receiver. On the other hand, there is the possibility of disturbing the regular paths or bands of radio communication. The author has found that the superheterodyne type of receiver, operating on a loop aerial, is quite adaptable to mobile radio controlled mechanisms. Any oscillating circuit transmitter of sufficient power is suitable for sending the control signals either by telegraph key, motor driven key, or other means.

The Relays

In order to change weak electrical currents into physical motion or to control greater currents, reliable, sensitive relays must be had. Relays which are rugged enough to be used on radio controlled cars and sensitive enough to operate on as small a current as one milli-

ampere are available. It is quite likely that in the near future relays more suitable for operation in radio receivers will be designed and manufactured.

Within the last two years an electron vacuum tube relay has been developed. This tube has a bimetal plate which makes physical contact with a fourth element in the tube. The increase of electron flow or bombardment increases the temperature of the plate which bends due to difference in expansion of the two metals and closes the contacts. The contacts can be closed in 1-1/2 seconds and opened in about 6 seconds. This is hardly fast enough for most radio control signals and so another tube having a fine wire anode for the plate was developed. This anode changes its resistance tenfold (from 40 to 400 ohms) for the increase of temperature in its operating range. This effect can be used to operate a relay at 25 cycles per second.

Mechanical Selectors

One of the most important features of radio control is the adoption of a suitable selector or device for picking out at the will of the operator any particular circuit. The most common of these is the mechanical step-by-step method. A rotating arm is made to move from contact to contact by a relay and ratchet arrangement. Each impulse sent out moves the arm one step or to the next contact. A time relay can be used in connec-

tion with this device which will allow any of the contacts to be passed over quickly without actuating the circuits which they control, thus making it possible to pick out any particular circuit without disturbing the others. The disadvantage of this system is that the operator must know the exact position of the contact makihg arm before each signal is sent.

Another method of mechanically operated selectors uses ~~the~~ synchronous contactors at the transmitter and receiver. Two contact making arms, one located on the transmitter and one on the receiver, are kept in exact synchronism. If an impulse is sent with the arm on the transmitter in a certain position then a corresponding circuit is actuated on the receiver mechanism. The arms may be operated at high enough speed so as to have quite rapid control. The disadvantage is of course in synchronizing the arms.

The most reliable mechanical selector is the so-called telephone selector switch which is now in common use in many types of dial telephone systems. The principle of operation of this device will be given in detail in Part II of this thesis.

Electrical Selectors

The next type of selectors is the electrical type. It is quite possible to have a different radio receiver for each circuit controlled, by using several wave lengths.

This necessitates considerable radio apparatus if many circuits are to be controlled but is ideal for two circuits, since an "alternating" switch may be used which alternately operates each of two circuits when the same impulse is repeated. An ordinary "off" and "on" snap switch is an example of this type; the same impulse or motion does either operation. In operating a radio controlled car the same signal that started the car would also stop it. The alternating switch can be used to advantage in most any control system since it eliminates the control of one circuit. A second method of selecting various circuits electrically is by the use of a single wavelength or carrier current with a different lower frequency superimposed for each circuit controlled. These superimposed frequencies could be of the nature of high audio-frequencies and would actuate relays in various tuned circuits, each circuit being tuned to a different frequency. This selector system promises to be the best so far developed.

A method which could be adapted to ordinary radiophone apparatus with practically no changes is that of tuned reeds. It is a known fact that an organ reed will be made to vibrate at its own frequency by a sound of this frequency. Using this effect, any one of a number of reeds could be set into vibration by a tone sent via radio. The vibration of each reed could be used to close a different circuit.

Where the time for selection of a circuit is not limited a device depending on the length of the impulse sent may be used to select various circuits. However, this is not suitable for a radio controlled automobile, as the stopping and steering operations necessarily have to be accessable in rapid succession under certain running conditions.

Summary of Requirements

The requirements of a good radio control system are then:

1. It must be simple enough and rugged enough to stand up under the condition for which it is to operate.

2. It must be exceedingly reliable. For instance, in the case of a radio controlled car, it is often necessary to stop the car when failure of controls would mean disaster.

3. The selector must be able to instantaneously pick out any one of a number of circuits. This makes the system very flexible and adaptable to operating automobiles in heavy traffic.

Applications of Radio Control

Radio controlled automobiles probably never will have a very widespread practical use, because of the following limitation. It is quite impossible to operate an automobile on our modern highways unless the operator had a good view of the road and nearby surroundings.

Possibly this difficulty will be overcome with the perfection of television.

Ships and aeroplanes are quite adaptable to this method of control. The battleship, "Iowa", was maneuvered about in the ocean with complete control at all times. Aeroplanes equipped with automatic stabilizing apparatus and landing gear have been flown with the pilot on ground controlling the plane with a radio transmitter.

Even up to our present day, radio controlled cars are quite a novelty. The Scientific American for October 8, 1921, describes one built several years ago by the Engineering Division of the Air Service at McCook Field, Dayton, Ohio.

"The car is of cigar-shaped construction, about 8 feet long and runs on three pneumatic-tired wheels. It travels at speeds ranging from 4 miles per hour to 10 miles per hour and the controls are so finely adjusted that it may easily be steered along a narrow roadway.

"An examination of the interior of the car shows an amusing and confusing collection of batteries, switches, wires, vacuum tubes, potentiometers, relays, magnetos, etc., all of which are, of course, necessary to the complete control of the apparatus. The most interesting part of the apparatus is the 'selector' which is in reality the heart of the entire control system. Various combinations of dots and dashes are sent out by means of

a specially constructed transmitter, each combination calling for the accomplishment of a certain operation of the control apparatus. It is the function of this selector to 'Decode' these various combinations of dots and dashes which are sent out, and to close the circuits to the desired controls. The selector makes it possible to put into operation any one of twelve distant controls in less than one second."

PART II

DESIGN OF A MODEL
RADIO CONTROLLED AUTOMOBILE

SCHEMATIC DIAGRAM OF RADIO CONTROL SYSTEM

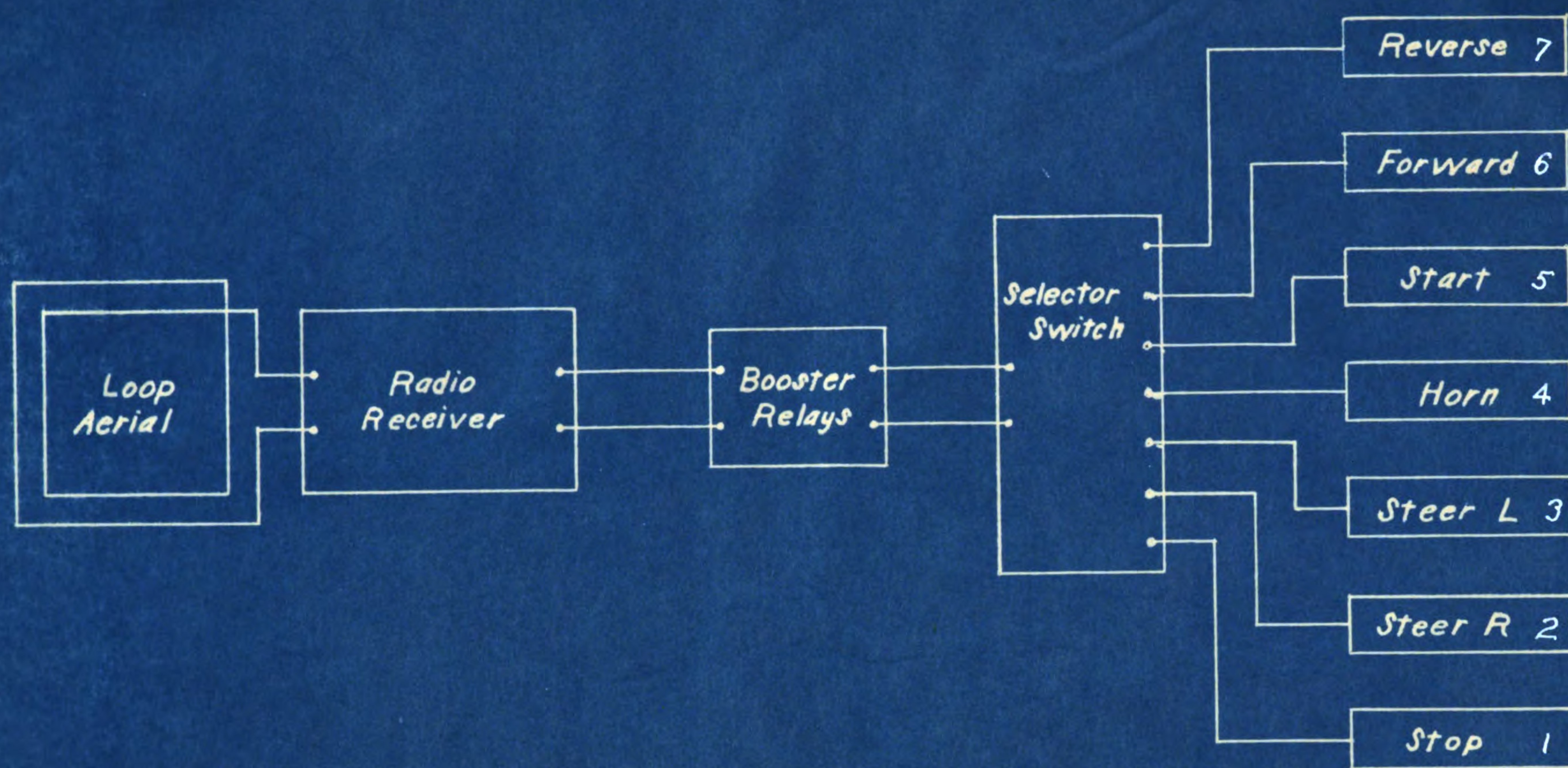


Fig. 1

PART II

DESIGN OF A MODEL

RADIO CONTROLLED AUTOMOBILE

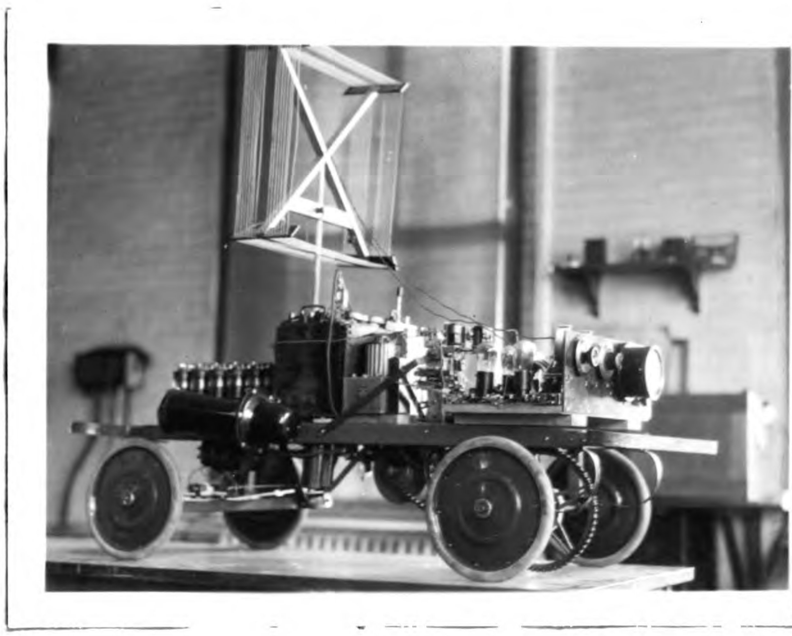
General Description

The general plan carried out in building this radio controlled car is shown on Fig. 1. A superheterodyne receiver operating with a loop aerial was found to be the most reliable means of detecting the control signals. An 800 ohm relay operating a 75 ohm Pony relay was connected in the plate circuit of the second detector tube of the receiver. The Pony relay sends the signals into the telephone selector switch which operates the various circuits as desired. Seven circuits can be controlled independently. By a slight modification of the selector it is possible to control 100 independent circuits with a single telegraph key.

The accompanying photographs show the general construction and assembly of the car. The chassis is that of a toy automobile. It has a wheel base of 36 inches and a width of 20 inches. Photo C, an underside view of the car, shows the principle operating parts and their location on the frame; I is the steering motor, II is the steering gear, III is the driving motor which drives the rear axle by means of a bicycle sprocket and chain, and IV is a bottom view of the selector switch showing the contact bank. Photos 'a' and 'b' show the

a

Right Side View of Car



b

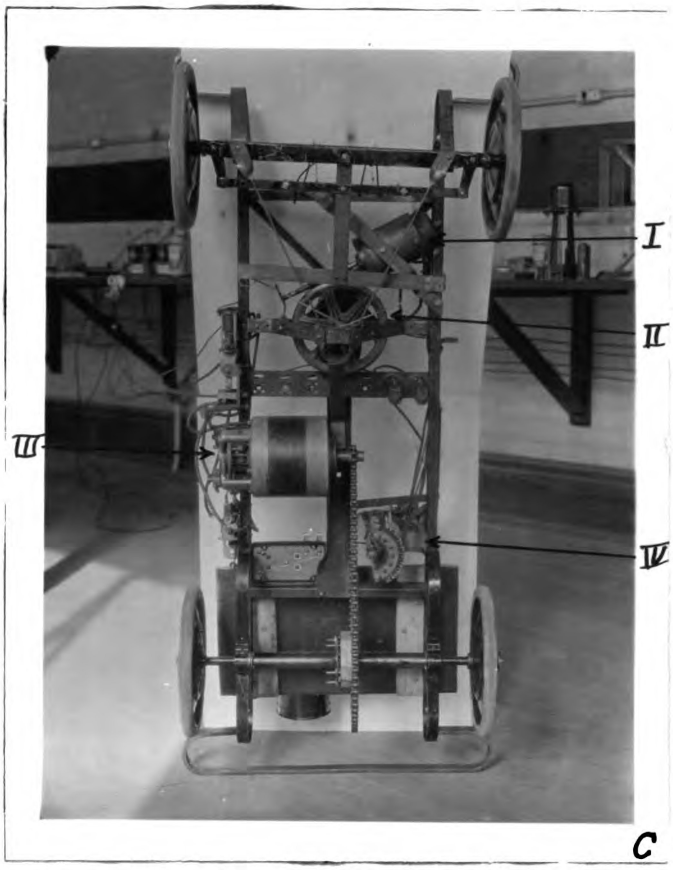
Left Side View of Car

general arrangement of aerial, receiver, and batteries. The large battery in the center is the 12 volt storage battery which supplies current for the two motors and for the filaments of the six vacuum tubes. On the front end of the car is the 48 volt storage battery which supplies the current to operate the controlling relays and the selector switch. The receiver is mounted on the rear of the car and is shown in greater detail in photo 'd'.

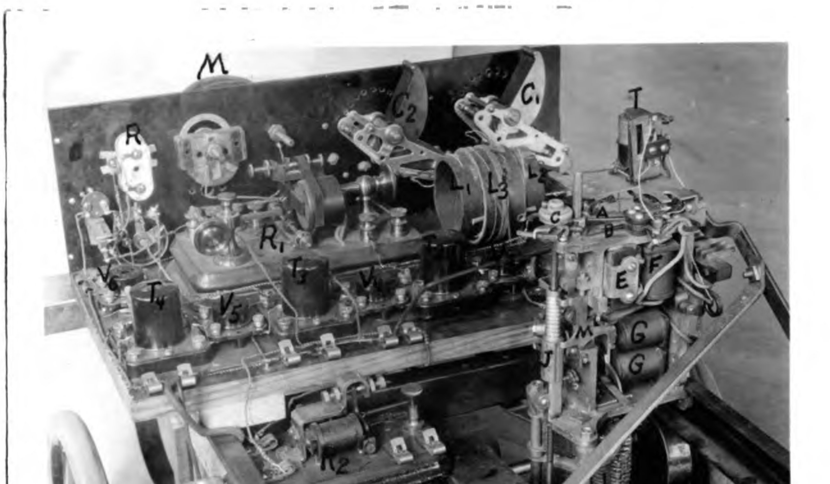
The Superheterodyne Receiver And Booster Relays

The connection diagram of the superheterodyne receiver used is shown in Fig. 2 and photo 'd' shows the arrangement of the parts. Condensers C_1 and C_2 are 23 plate, straight line type. C_3 is 1 mf. fixed condenser connected in series with L_1 and L_2. L_1 and L_2 are each 10 turns of No. 24 cotton covered wire on a 2-3/4" tube. L_3 is 5 turns of No. 22 cotton covered wire on a cardboard tube just large enough to slip over the other coils.

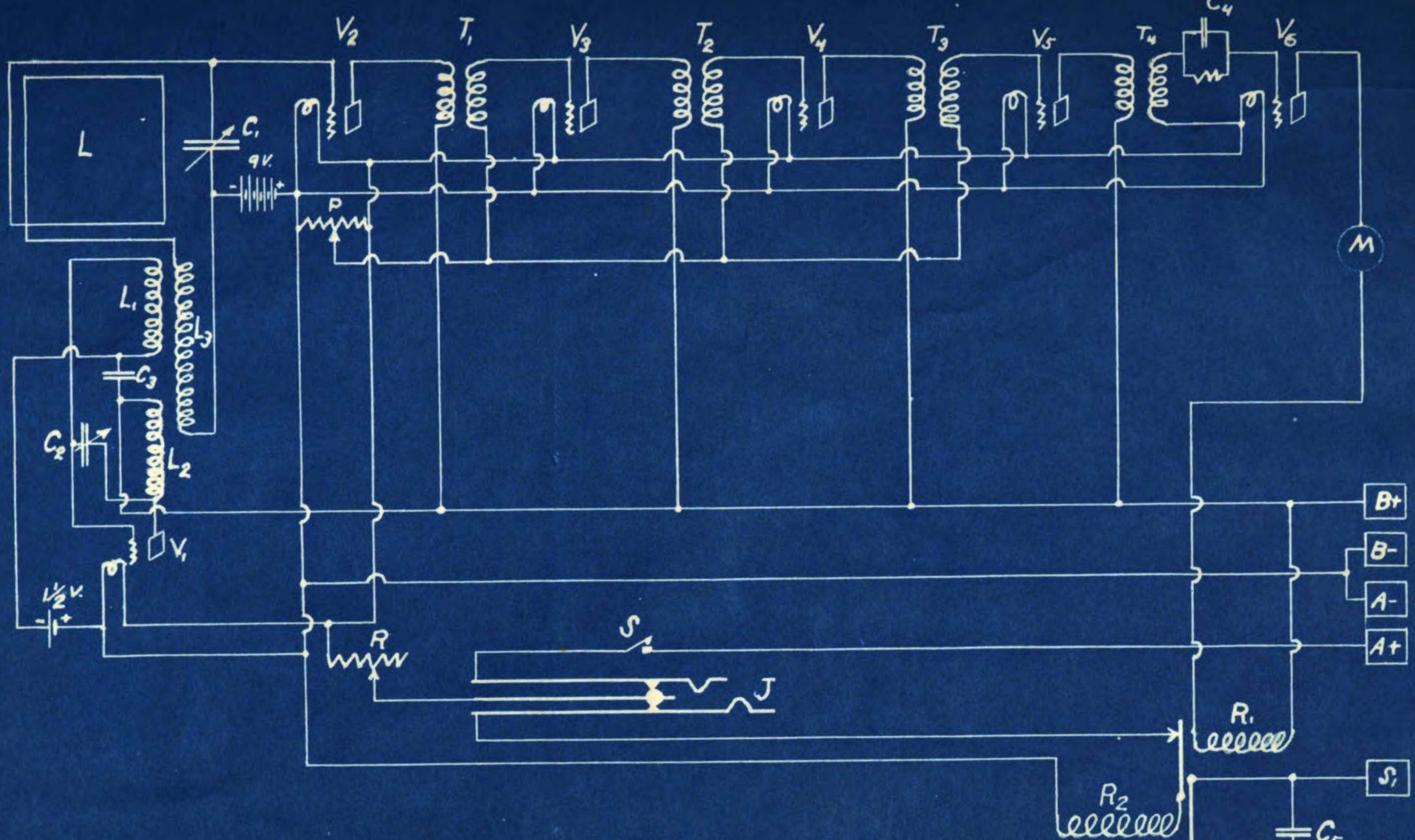
V_1 is the oscillator tube using a grid bias of -1-1/2 volts. It is coupled to the grid circuit of the first detector tube, V_2, through the inductances previously mentioned. There are three stages of 60 kilocycle amplification followed by the detector, V_6. A 0-25 milliampere meter, M, is located in the plate circuit of this tube in order to facilitate tuning. Relay



Underside View of Chassis



Receiver and Selector Switch



SUPERHETERODYNE RECEIVER AND CONTROLLING RELAYS.

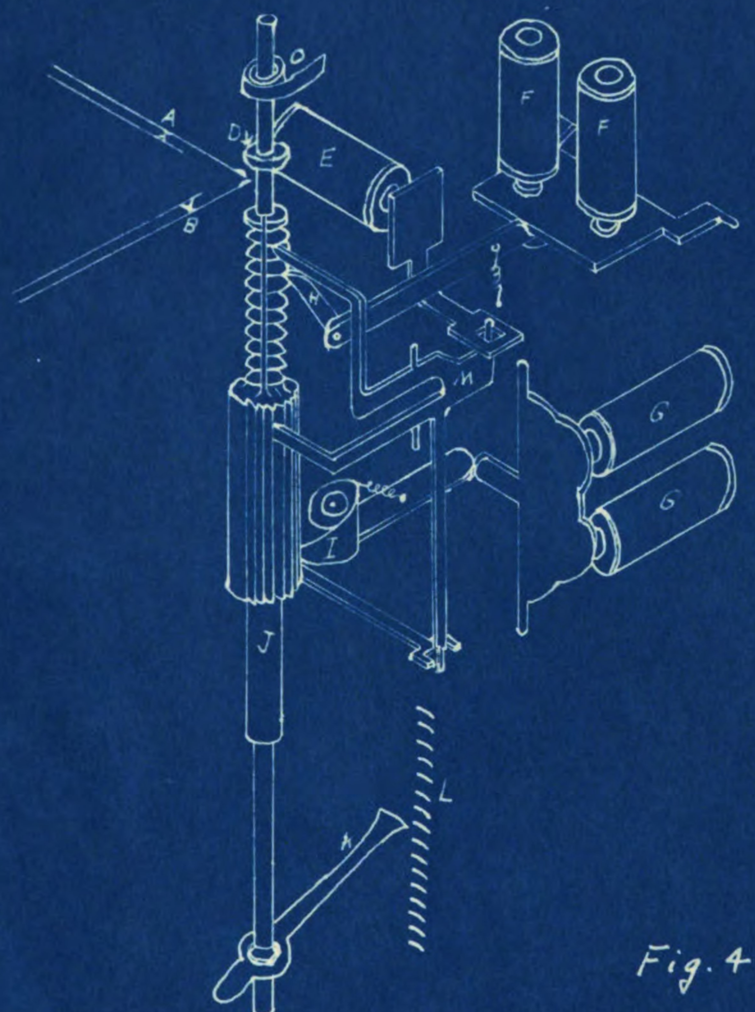
Fig. 2

R_1 is connected in series with the meter and its contacts are adjusted to close on a decrease of current. This relay has a resistance of 800 ohms and adjusting screws to vary the distance between the contacts and to increase or decrease the air gap of the magnetic circuit. A change of 5 milliamperes will operate the contacts, but 10 milliamperes change is much more reliable and can be obtained without difficulty.

Since the contacts of R_1 are rather small and sensitive to arcing they will not satisfactorily carry enough current to operate the selector. For this reason the relay, R_2, is used as a booster. Condenser C_5 of about 2 mf. is used across the points of R_2 to reduce arcing to a minimum. The jack J is used so that a telegraph key can be plugged into the circuit of R_2. This automatically turns off the filaments when it is desired to operate the car directly. At the right hand side of Fig. 2 the connections to the batteries and selector are indicated.

The Selector Switch

Fig. 4 is a perspective of the working parts of the telephone selector switch which is the heart of the radio controlled car. On the right hand side of photo 'd' the selector switch is shown mounted on the frame of the car. Fig. 3 shows the connections for this switch and for the horn and batteries.



SELECTOR SWITCH MECHANISM

SELECTOR SWITCH AND BATTERY CONNECTIONS

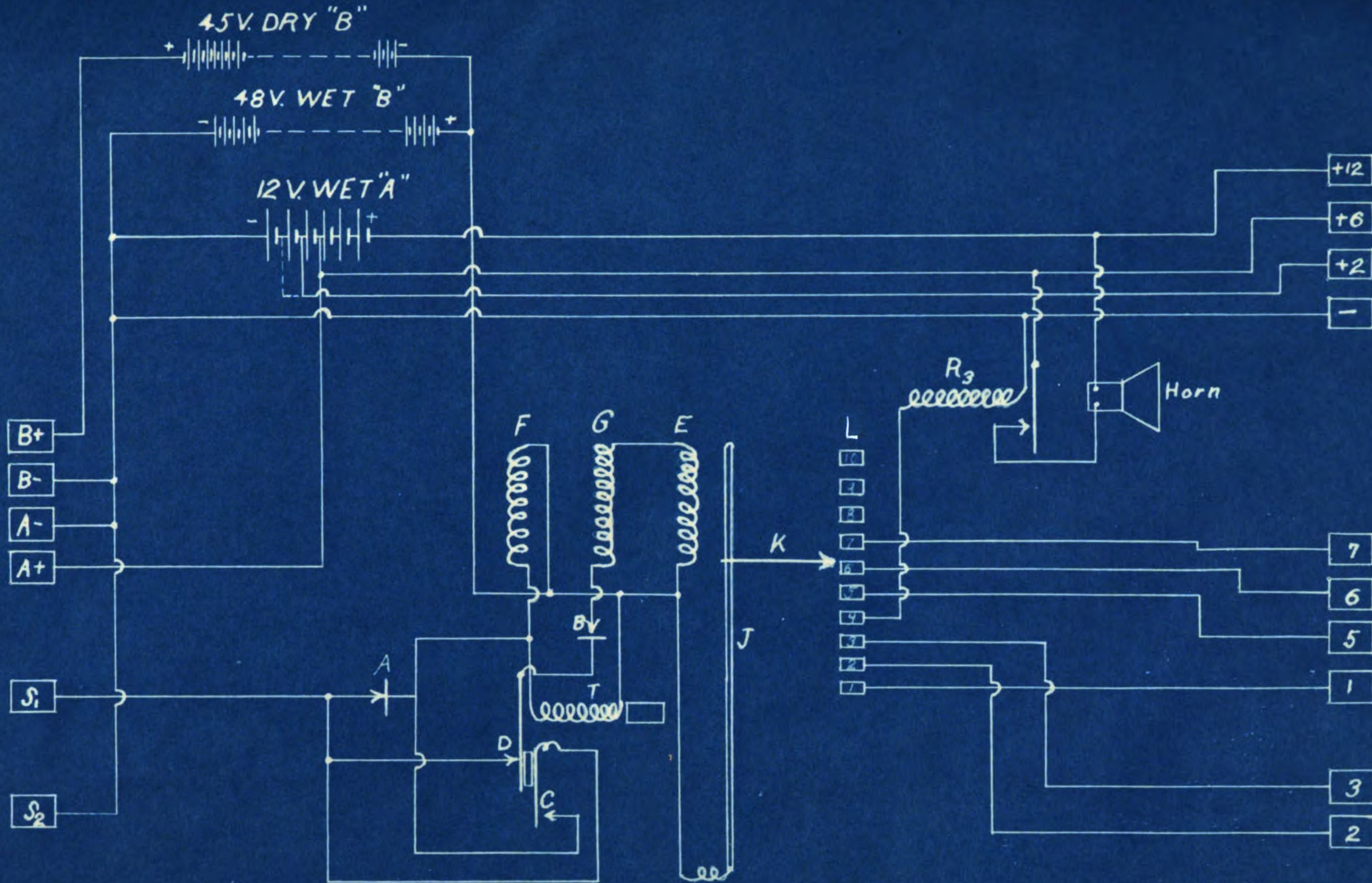


Fig. 3

The same notation for the various parts of the selector is used on both diagrams and the photo. The operation is as follows:

The object of the device is to connect arm K with any one of the contacts L at the command of the operator. When relay R_2 is closed (Fig. 2) current is sent through magnet F and time relay T, these two coils being connected in parallel. Magnet F actuates arm H and lifts the spindle J one notch. This action causes collar D to open contacts A and close contacts B. When relay T attracts its armature, contacts C are closed and contacts D are opened. The latter set of contacts must and do operate a fraction of a second before the former ones, because if A and C were both open, coils F and T would be de-energized and coils G and E would be energized since D and B would both be closed for a short interval of time. The lag of the spindle due to its inertia rather than the action of the time relay, which closes quickly but lags on opening, causes these contacts to operate in the proper succession.

If R_2 (Fig. 2) is now opened and closed several times in rapid succession spindle J will be lifted up as many more notches as R_2 is opened and closed. Due to the action of the copper collar on T, it will hold its magnetism during the intervals of open circuit. However, when R_2 is opened for a longer interval (approximately half a second) T loses its magnetism and contacts

D are closed and C are opened. Now both contacts A and C are open and F and T cannot be energized by closing R_2. Also contacts D and B are both closed so when R_2 is again closed magnets G and E are energized. Magnet G rotates spindle J, and arm K makes a contact in bank L which remains closed as long as R_2 is closed. When R_2 is finally opened the de-energizing of magnet E releases spindle J by tripping arm M. The spindle automatically returns to its initial position by action of coil spring O and gravity. Contacts A and B are consequently left closed and opened, respectively. It must be noted that magnet E trips the spindle when the circuit is opened rather than when it is closed, since E and G are simultaneously energized.

From the foregoing explanation it is evident that for the selection of a given circuit two sets of signals or impulses are required. The first is a series of quick impulses corresponding in number to the circuit which is to be selected. (See Fig. 1 or the lower right hand corner of Fig. 3). The second is a single final impulse which completes the operation. In the case of operating the horn or the steering motor the length of this impulse determines how long the horn sounds or how far the steering motor turns the front wheels (within certain limits explained later).

In the upper left hand corner of Fig. 3 the battery

connections are shown. B+ is connected to the positive side of the 45 volt dry "B" battery, which is in series with the 48 volt storage battery. B- is connected to the minus terminals of both storage batteries. A+ is connected to the center of the 12 volt battery and this arrangement supplies a potential of 6 volts to the filaments of the radio tubes. It is seen by studying the diagrams that the selector switch connects the 48 volt battery across any one of the relays R_3 to R_9 according to the signal received. Relay R_3, operated from position four of the spindle, completes the horn circuit as shown. On the right hand side of Fig. 3 are the connections of the selector and batteries that go to the driving motor and steering motor as shown in Figs. 5 and 6, respectively.

The Driving Motor

The driving motor is an automobile starter motor whose armature had been rewound with smaller wire. With the armature locked the motor takes 10 amperes at a terminal voltage of 5 volts. On the radio controlled car the current was supplied from 4 or 5 of the six cells (8 or 10 volts) depending on the condition of the battery. This gave a speed of about 3 miles per hour with the sprocket ratio of 7-1/2 to 1.

Fig. 5 shows how the motor is controlled. All four of the relays shown are of the type which lock in position; that is, when R_5 closes its contacts they stay closed

DRIVING MOTOR CONTROLS

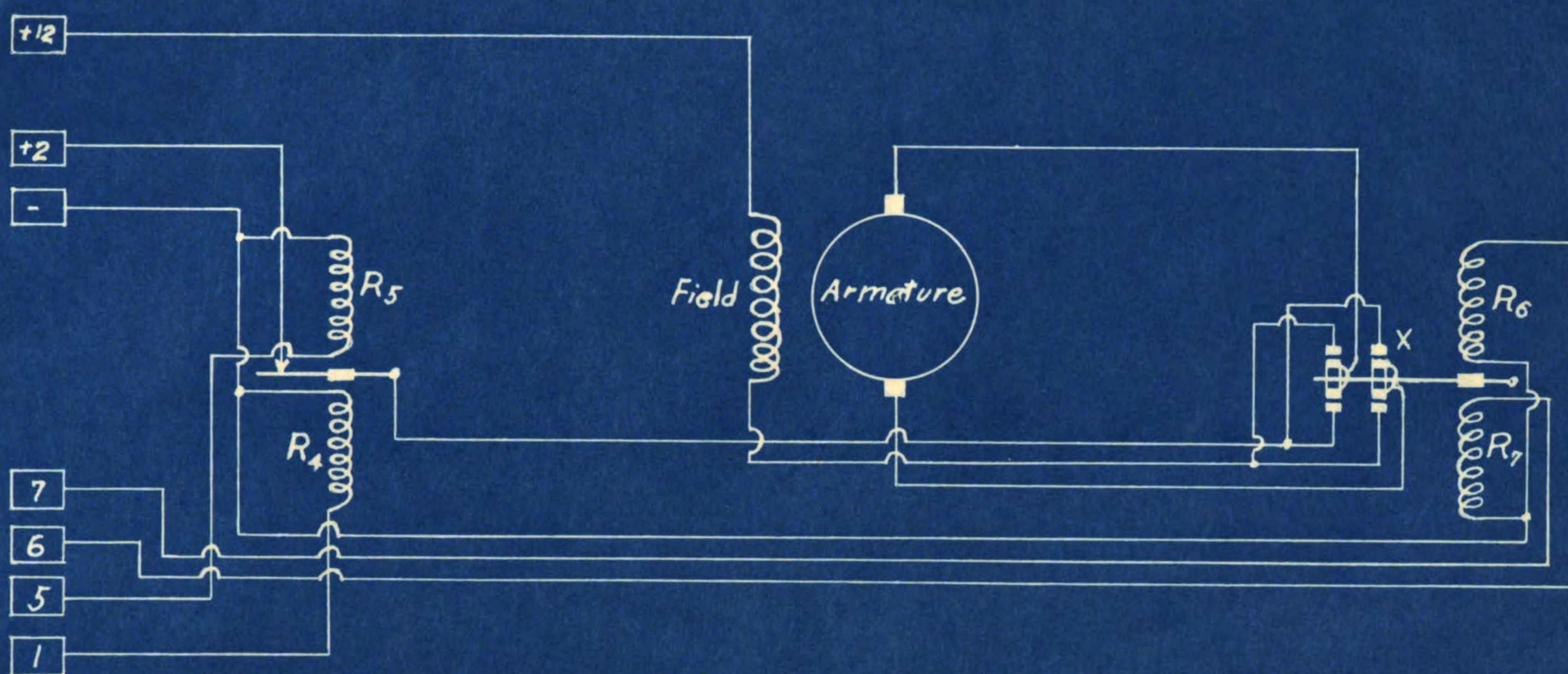


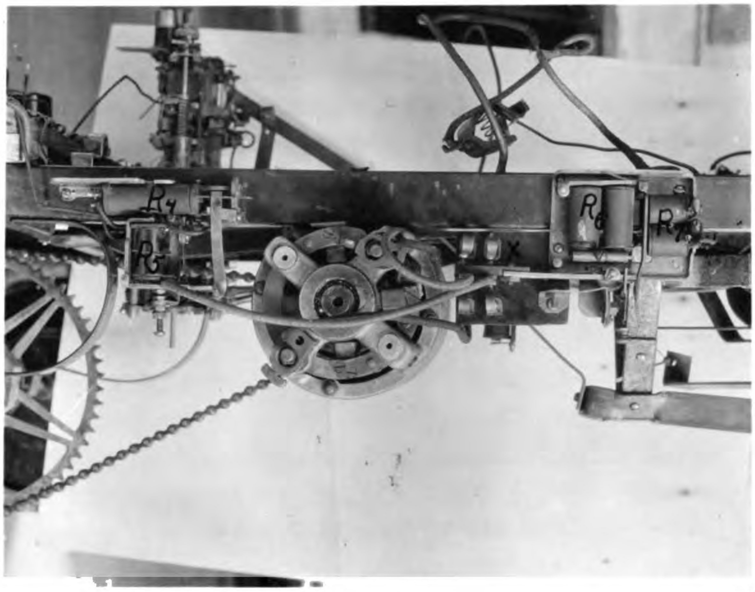
Fig. 5

until R_4 opens them. These two relays start and stop the car and correspond to positions 5 and 1, respectively, on the selector switch. Relays 6 and 7 operate a double pole, double throw set of contacts, X, which regulate the direction of current in the armature and consequently the direction of motion of the car. Forward and reverse positions of the selector switch are 6 and 7, respectively. Photo 'e' shows the mounting of the motor and its control relays.

The sprocket on the motor shaft has eight teeth and is coupled with a bicycle chain to a sixty tooth sprocket fixed rigidly on the rear axle. To allow for differential action one rear wheel is free to turn on the axle and the other is fixed.

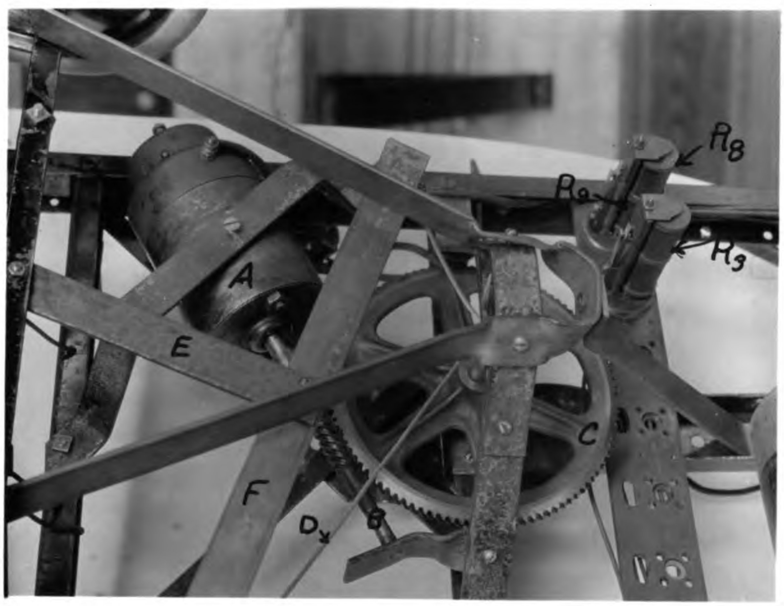
The Steering Motor and Steering Mechanism

The steering motor is a 6 volt motorcycle generator whose field connections have been brought to separate binding posts on the shell of the motor. This motor is the shunt type as contrasted to the driving motor which is series connected. Photo 'f' shows the construction and details of the steering mechanism. Worm spindle B is rigid on the shaft of the motor and drives gear C. The shaft of this gear acts as a small drum and winds and unwinds cable D. The cable is connected to the ends of cross piece F which is bolted to the steering arm E.



e

Driving Motor and Controlling Relays



f.

Steering Mechanism

Photo 'c' shows the remainder of the steering gear which is similar to that used on automobiles.

Fig. 6 is the connection diagram of the steering motor and the relays which control it. Relays R_8 and R_9 close the circuit for energizing the field and relays R_{10} and R_{11} control the armature current. R_{10} is connected in parallel with R_8, and R_{11} in parallel with R_9. By examining the diagram it is seen that the upper armature terminal is directly connected to the center or 6 volt tap of the storage battery. The other armature terminal is connected by relays R_{10} and R_{11} to either the positive or negative end of the battery. This connection gives an excellent means of reversing the armature current and consequently the direction of rotation. The interlocking link L shown on photo 'g' prevents relays R_{10} and R_{11} both being closed at the same time, as this would place a short circuit on the battery. The field polarity is kept the same for both directions of rotation. A 15 ohm resistance was connected in series with the field in order to increase the speed to a maximum.

The steering mechanism is made "fool proof" by the limiting contacts T and S. These contacts are mounted on the front axle of the car and are connected in series with the relays which control the armature current. When the front wheels are turned to their limit either

STEERING MOTOR CONTROLS

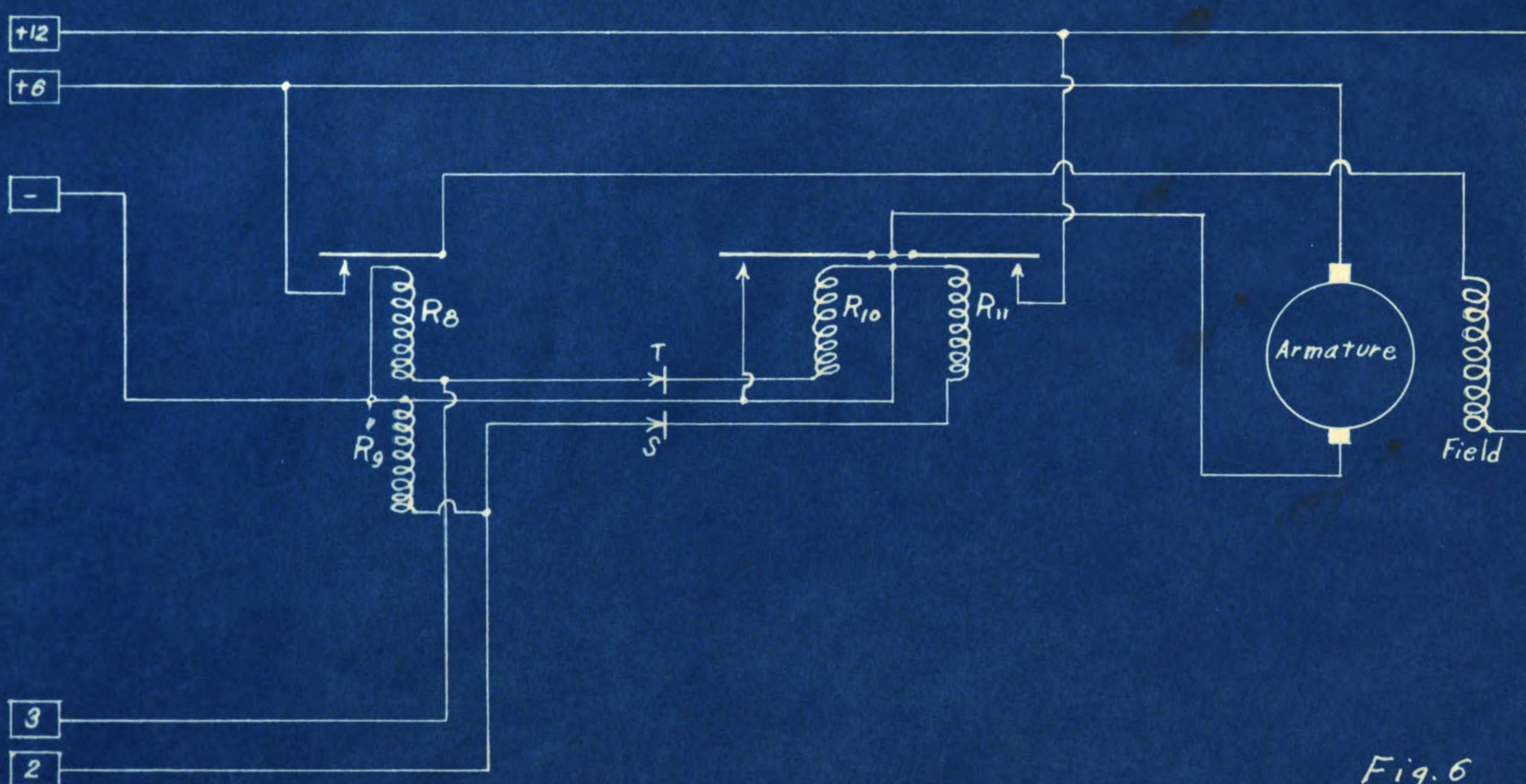
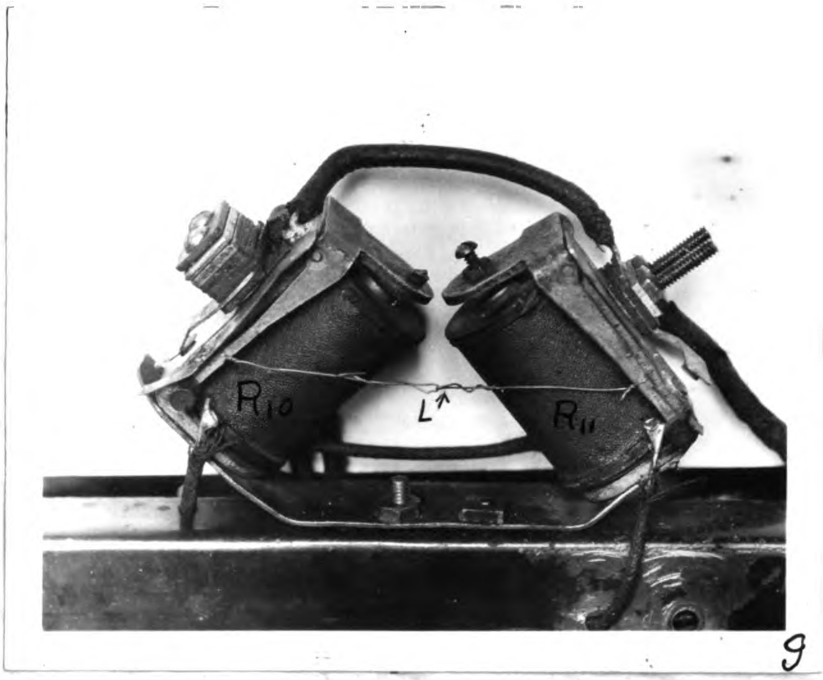


Fig. 6



Interlocking Armature Current Relays

of Steering Motor

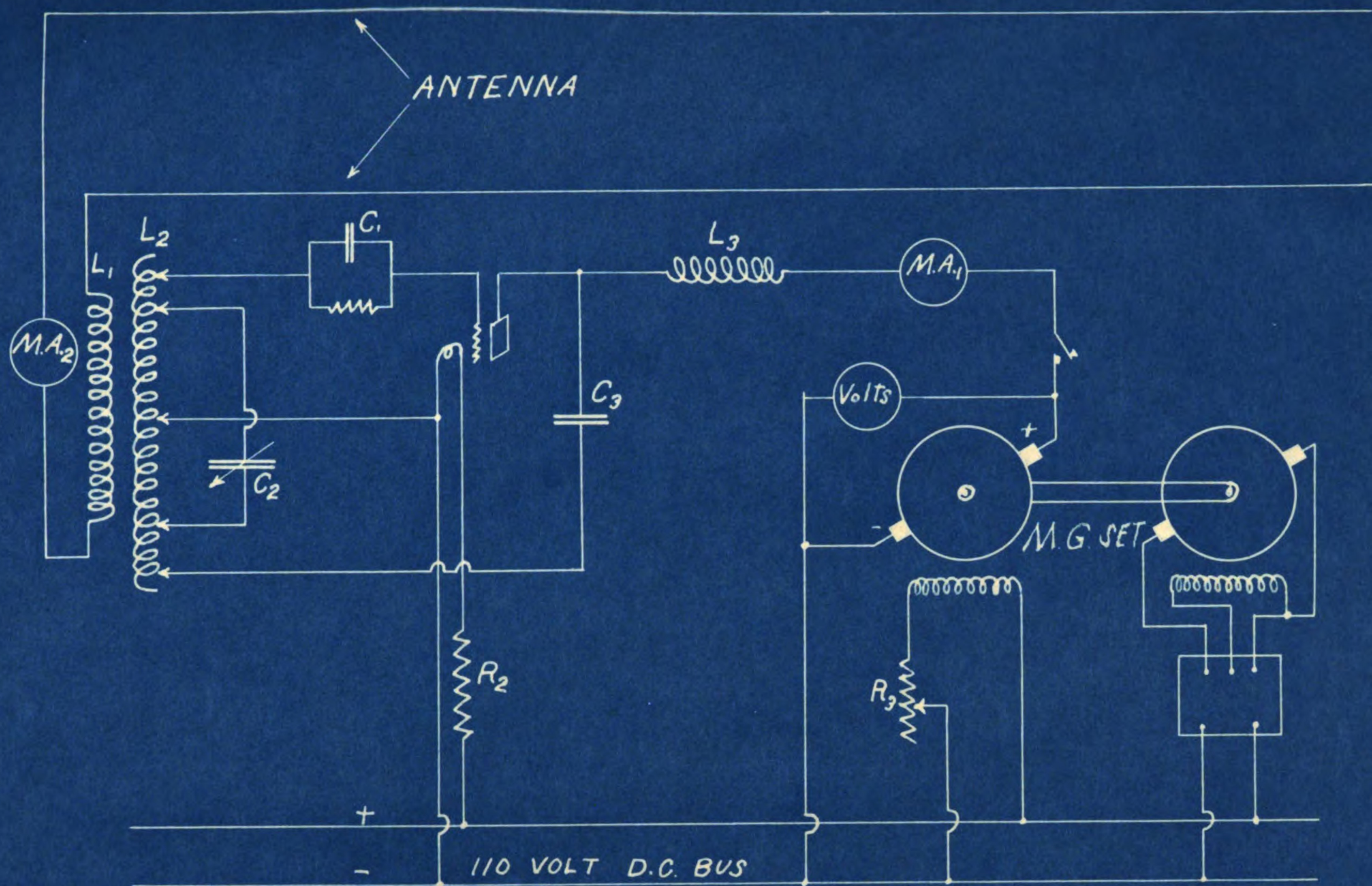
to right or left, one of these contacts is opened by an arm on the steering rod and the motor stops turning the wheels farther.

Transmitter

Fig. 7 is the connection diagram of the 50 watt oscillator used to transmit signals to the car. The antenna which was most successful was a hundred foot single No. 10 copper wire set up in a U-shape around the room. The seven turn pancake inductance L_1 was connected in series at the midpoint of the antenna. Inductance L_2 was a fourteen turn pancake coil loosely coupled with L_1.

The filament of the tube is lighted from a 110 volt D.C. source through a lamp bank rheostat. An 800 volt D.C. plate supply is furnished by the motor generator set shown in the diagram. Condenser C_3 (.001 mf.) keeps the plate voltage from shorting through L_2, and L_3 keeps the high frequency oscillations from leaking through the motor generator set.

The transmitter is tuned by C_2 (a variable 15 plate condenser) and the variable taps on the tuning inductances. Milliameters MA_1 and MA_2 indicate the operating condition which is best with maximum antenna current for a minimum plate current. The best condition found was 2 amperes for the former and 60 milliamperes for the latter. The signals are controlled by the telegraph key, K, in the high voltage side of the generator.



50 WATT CODE TRANSMITTER

Fig. 7

Operation

As previously noted the car has seven control operations as listed below with the signals:

No.	Operation	Signal
1	Stop	– –
2	Right turn	– – ———
3	Left turn	– – – ———
4	Horn	– – – – ———
5	Start	– – – – – –
6	Forward	– – – – – – –
7	Reverse	– – – – – – – –

The length of the dashes and spaces respresant the length of time for the key to be closed and opened, respectively. The long dashes indicate that the key is to be kept closed as long as the operator desires. In the case of steering this will depend on how far it is desired to turn the front wheels and in the case of the horn the sound will continue as long as the key is closed.

Operations 6 and 7 do not stop or start the car, but simply determine whether the car goes forward or reverse when the start signal is given. No. 1 was selected as the stop signal since it takes the least time for the selector to reach this contact. Operations 2, 3, and 4 can be carried out while the car is in motion; that is, it may be steered or the horn may be sounded without first having to stop.

The car was first demonstrated in Room 208, Olds Hall of Engineering, Michigan State College during the Annual Electrical Show of February 1, 2, and 3, 1928. At this time a 10 watt oscillator was used for transmitting signals and the operation, though quite successful was not as good as that obtained later with the 50 watt transmitter already described.

The car was most successfully demonstrated in Convention Hall, Detroit, at the Radio Fan Fair held April 2-5, 1928. During the time between these two exhibitions the radio controlled auto was completely overhauled. The selector switch was simplified and speeded up, the speed of the steering motor was approximately doubled, and the entire car rewired; also, some mechanical difficulties were overcome. With these new conditions the radio control was as perfect as could be hoped for. The transmitter and receiver were operated on 95 meters wavelength.

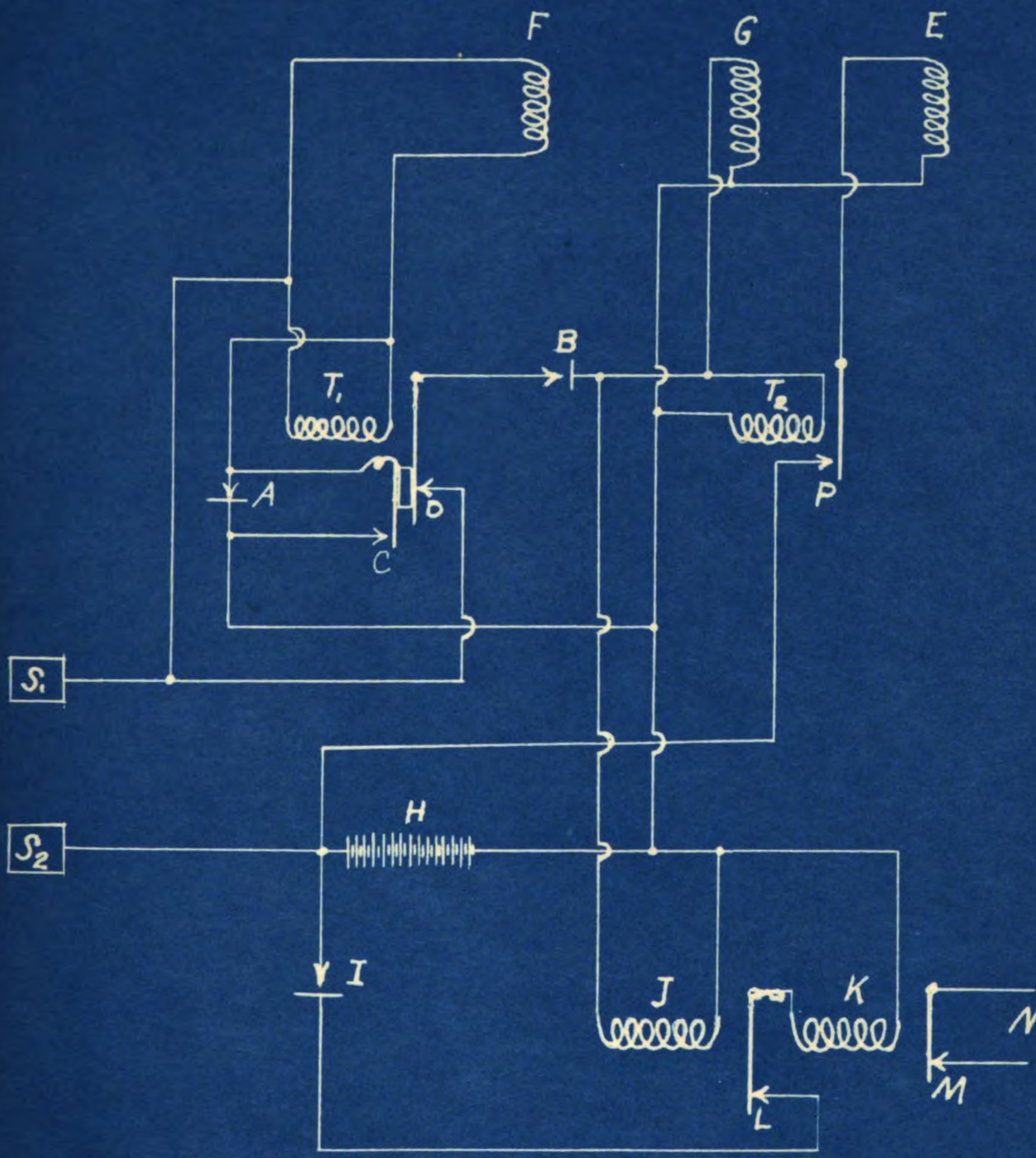
Difficulties Encountered and Overcome In Building the Car

Since it is not practical and hardly possible to operate a radio controlled car with a ground connection, the receiver had to be of a type that would work on a small aerial or a loop. A two tube receiver hookup using a short aerial was tried, but the distance of control was limited to a few feet. An 8 tube superheterodyne receiver

belonging to the Engineering Department was experimented with and found satisfactory except that it used CX-299 type tubes which did not supply a large enough plate current to operate a relay satisfactorily. As a result of this the 6 tube receiver shown in Fig. 2 was built and found suitable.

Fig. 8 shows how the selector switch was originally connected for operating the car. By this arrangement, it was possible to select any one of a hundred independent circuits. The operation of the switch was nearly the same as it is at present except that ten steps of rotary motion could be obtained instead of only one. Relays J and K (Fig. 8) closed the contacts after the circuit had been selected and time relay T_2 released the magnet which let the spindle return to its initial position. The reason for simplifying the selector switch was to speed up the time to control any particular circuit and to decrease the possibility of trouble with extra relays.

Two other incidents or minor difficulties encountered are worth mentioning. When the car was first wired the driving motor and filaments of the vacuum tubes were connected to the same cells of the 12 volt battery. When the motor was started the heavy current drawn decreased the battery terminal voltage. This caused a corresponding decrease in filament voltage which caused the main sensitive relay to operate on account of the decrease in



CONNECTIONS OF SELECTOR SWITCH

Fig. 8

plate current. This difficulty was overcome by increasing the normal filament voltage and by connecting the motor on the opposite end of the battery from the filament leads. (It still had 2 cells in common with the tubes when the motor was connected across 10 volts.) The second difficulty was the arcing of the contacts of relay R_2 (see Fig. 2). This was due to the inductive kick of the coils in the selector switch and was easily overcome by using a 2 mf. condenser across the points.

CONCLUSION

The object of this experiment or work was to build a radio controlled car which would operate satisfactorily and demonstrate the practicability and future possibilities of radio control. The car which was designed and constructed proved that radio control can be made reliable, but as yet is not practical for ordinary use on automobiles because the operator must be able to see the car he is guiding. "Wired wireless" which is a slight modification of actual radio control is successfully used for remote operation of power substations.

Probably the best type of radio control which will be developed in the future is that one mentioned in Part I. This is the type using a single carrier frequency with superimposed lower control frequencies. In connection with this the car will be so designed that it will automatically stop when it fails to receive the carrier frequency. This will eliminate the danger of the car getting out of the region of control. Selection of any number of circuits at a time will be practically instantaneous. There will also be many other minor improvements over the model described in this thesis.

ROOM USE ONLY