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MODERN RADIO EQUIPMENT FOR AIR MAIL AND TRANSPORT USE*

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Summary—*The general requirements for aircraft radio equipment for air mail and transport use are discussed. This is followed by a discussion of the factors which were considered in the design of an aircraft radio telephone and telegraph equipment. A description is then given of the mechanical and electrical features of a specific equipment.*

IN THE course of the last four years, during which aviation radio has developed along with our aviation systems, the requirements for aircraft radio transmitting apparatus have been pretty well established.

Some operating companies have built their communication systems around radiotelephone operation from plane-to-ground and ground-to-plane while others have selected cw telegraph communication for their systems. The conditions governing the choice of the most suitable system are many and varied. Of these, the most important are the length of the flight or the distance between route radio stations, the terrain, weather, and transmission and reception conditions.

For radiotelephone operation, two general classes of equipment are being used. One of these classes provides a 50-watt carrier, and the other provides a 10- to 15-watt carrier. Both have provisions for complete telephone modulation.

Where cw telegraphy is chosen for the communications system, the circumstances mainly governing its choice are that communication distances required are so great that to provide sufficient radiotelephone power would result in an impractical weight, size, and power drain for the equipment, and also that the average atmospherics and transmission conditions are such as to make telephone communication well-nigh impossible.

The general power output requirements for cw telegraph systems have been found to be from 10 to 20 watts. This amount of power in telegraph operation has provided regular plane-to-ground communication of several hundred miles even under the most adverse conditions.

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The chief advantages of the cw telegraph system are the small size, light weight, and low power drain of the equipment, while the chief disadvantage of the system is the relative inconvenience of communication by telegraphic code. In some systems, the radio communication by cw telegraph is carried on as one of the duties of the copilot, while in others, a radio operator is carried. In the latter instance, it has been argued that the total equipment weight including an operator and a small cw equipment provides such excellence and reliability of service that it is fully justified.

Having stated the very general requirements for the three classes of aircraft radio equipments, it is now planned to discuss the design of one type equipment, namely, a radiotelephone transmitter equipment for air mail and transport use. The important factors which must be considered in the design of such an equipment will be discussed, and finally there will be given a description of a specific equipment, the General Electric type RT-76-A, which has been brought out for the airmail and transport service.

In the design of aircraft radio equipment, the fundamental requirements to be considered are:

(a) Low weight with sufficient ruggedness to stand hard service.
(b) Small dimensions.
(c) Low power drain.
(d) Ability to operate into various types of antennas.
(e) Capability of emergency operation.
(f) Simplicity of adjustment and operation.
(g) Accessibility of construction to allow rapid servicing.
(h) Conservative operation of the circuit elements to insure low maintenance costs.
(i) Low initial investment cost for the equipment and installation.

Of first importance in the design of the transmitter is the selection of vacuum tubes. Since the power output desired was at least 50 watts, the UV-211 tube was chosen. This tube is nominally rated at 100 watts output so that by its use, a considerable amount of overload capacity was available. Also the UV-211 tube has proved its reliability and ruggedness in many other branches of radio service, and accordingly its use in aircraft seemed entirely justified.

The selection of the UV-211 type tube predicates the use of 1000 volts direct current for plate supply. This plate supply can be obtained from a number of sources namely:

(a) Wind-driven direct-current generator with constant speed propeller.
(b) Engine-driven direct-current generator.

(c) Dynamotor operating from the airplane's 12-volt storage battery.

(d) Alternating-current generator, driven by a self-regulating propellor or by the airplane engine. The alternating current is generated at low voltage and is stepped up and rectified by the conventional circuits.

Of the possibilities for obtaining the vacuum tube plate supply, the dynamotor has found most general use. Its advantages are mainly that it is independent of the airplane engines, it is not required to be mounted in the air stream where it would increase the parasitic drag, and since it is not dependent on the motion of the airplane or its engines, it provides emergency operation together with the possibility of easily checking the radio equipment's operation before the take-off. The dynamotor's chief disadvantage is of course, the fact that it causes a heavy drain on the aircraft storage battery, necessitating that the battery be continuously charging from a low voltage generator attached to the airplane engine.

Of the other two direct-current machine possibilities, the engine-driven generator is perhaps more generally used. With either the engine-driven or wind-driven generators there is of course, no possibility of emergency operation when the airplane is down, and checking of the radio equipment operation before the take-off is relatively difficult.

The use of alternating current with rectification and filtering has been discussed in a previous paper presented before the Institute.[1] This type of operation, although possessing certain advantages, is not finding very wide use in the commercial field.

The General Electric RT-76-A transmitter has been designed primarily for dynamotor operation although it can by slight modification be adapted to operation from an engine-driven direct-current generator.

In selecting a radio-frequency power amplifier circuit for the transmitter, there were three possible methods of obtaining the required output and modulation capabilities. They were:

(a) Class B power amplifier requiring modulated radio-frequency input.

(b) Grid bias modulated amplifier.

(c) Class C power amplifier requiring plate modulation.

The class B power amplifier circuit has been described elsewhere.[2] The main advantage of this type circuit is that by its use, modulation can be accomplished at a power level lower than the output. This re-

[1] Miner, Proc. I.R.E., vol. 19, pp. 59–77; January, (1931).
[2] Fay, Proc. I.R.E., vol. 20, pp. 548–569; March, (1932).

sults in the use of smaller tubes and lower filament and plate drain for the modulators, a very important consideration in the design. The disadvantages in the use of class B power amplification, however, outnumber the advantages. In Fig. 1 is shown the typical operation of a UV-211 as a class B amplifier. Although a peak power of 200 watts is possible, thus allowing the use of a 50-watt carrier output with 100 per cent modulation, it may be seen that some distortion would be introduced by reason of the curvature of the characteristic at high modulation. As a matter of fact, the UV-211 is rated at only 40 watts carrier

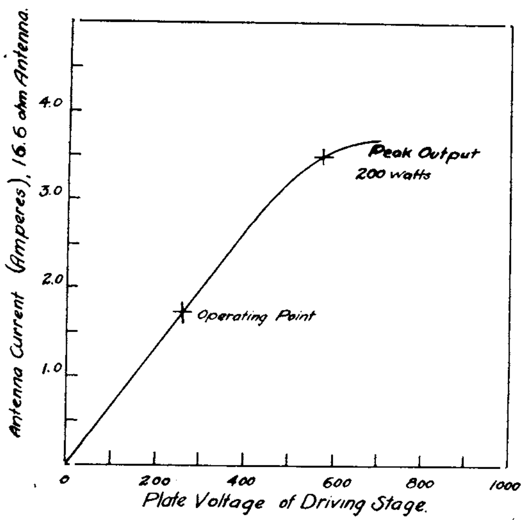

Fig. 1—Typical operation of a UV-211 as a class B amplifier. Drawing stage, UX-210.

output for class B service. Thus, to provide at least a 50-watt carrier plus provision for losses in the antenna tuning system, and provision for overload capacity, two UV-211 tubes would have to be used in the amplifier stage. A further disadvantage of class B operation is that the driving stage must be completely modulated. This means that an intermediate amplifier must be inserted in the tube line-up for the purpose, since it would not be possible to generate the radio-frequency oscillations and produce complete modulation in a single stage. The introduction of an intermediate amplifier stage would require an additional tuning control and space for its tuned circuit. Also, with the plate supply of 1000 volts available, the smaller tubes which could be used in the generation, intermediate, and modulator stages would all have to be operated at lower voltage than the power amplifier. This would necessitate the use of power wasting, voltage dropping resistors.

The bias modulated power amplifier falls in practically the same category as the class B amplifier in so far as its utility in the present equipment is concerned. The bias modulated system does not require the input radio-frequency excitation to be modulated, since modulation is obtained by varying at an audio-frequency rate, the axis of a constant input radio-frequency voltage instead of, as in the class B system, maintaining a constant axis and supplying an amplitude modulated radio-frequency excitation. The elimination of the modulated radio-frequency input requirement for bias modulation would allow

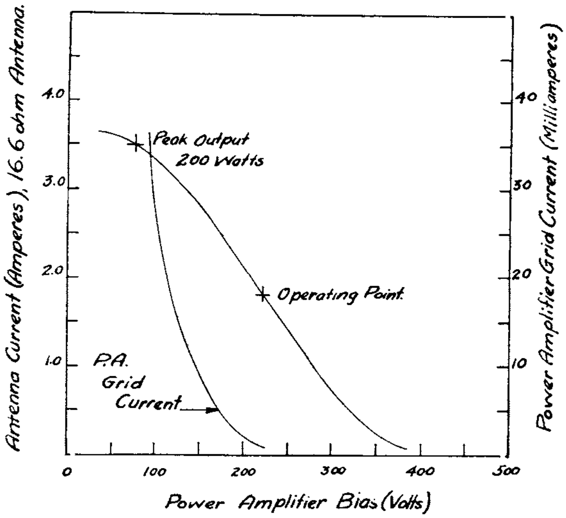

Fig. 2—Typical operation of a UV-211 as a bias-modulated amplifier.

the intermediate stage to be dispensed with. The system is limited in output capability in the same manner as the class B amplifier, and in addition requires special precautions in the design of the modulator circuit, since the load on the modulator varies considerably over the audio-frequency cycle. Fig. 2 shows typical operation of the UV-211 tube in a bias modulated power amplifier circuit. Note particularly the rapid change of grid current with bias voltage.

The class C type of power amplifier circuit was chosen for use in the RT-76-A transmitter because of its obvious advantages over the other systems mentioned. The UV-211 is rated at 100 watts output for class C operation. Thus there is ample provision for a 50-watt carrier plus antenna tuning system losses, plus considerable overload capacity without operating the tube beyond its rating. Also the class C amplifier is simplest in operation since it is not critical to adjustments of bias voltage, radio-frequency excitation, or power output loading.

The consideration of a driver circuit brought forth the question of whether a crystal oscillator or master oscillator type of circuit should be used. With the crystal oscillator, there was the possibility of attaining a frequency stability of approximately 0.025 per cent. On the other hand, there was the disadvantage of having to use the crystal oscillator tube at a relatively low voltage, thus necessitating a power wasting potentiometer for its low voltage plate supply. There was also the necessity of introducing between the crystal oscillator tube and power amplifier, an intermediate amplifier circuit capable of doubling

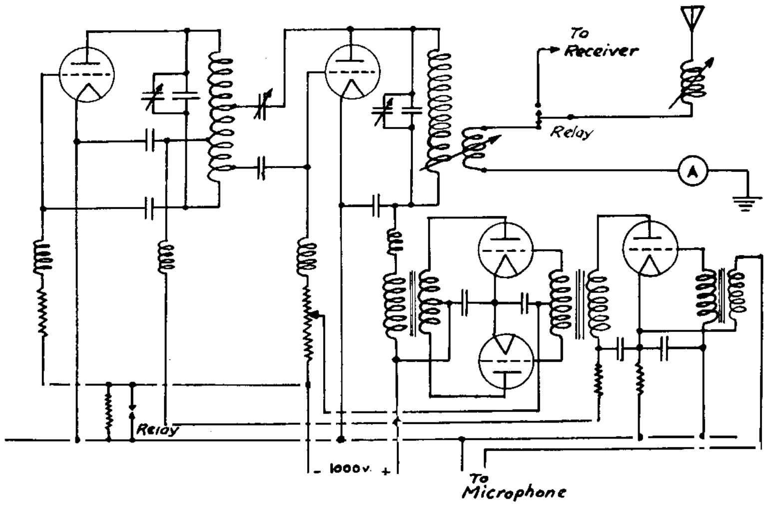

Fig. 3—Schematic diagram, RT-76-A transmitter.

the crystal frequency, since some of the output frequencies desired were too high for practical fundamental frequency operation of the crystals.

In order to provide a linear relationship between power amplifier plate voltage and output load current up to a plate voltage of 2000 (the condition for complete modulation), the UV-211 tube requires a driving power of from 5 to 10 watts. This amount of power would be difficult to obtain from the frequency doubling stage without exceeding the limits of conservative operation of the crystal and doubler stages.

The master oscillator type of circuit was selected for use, because of its inherent simplicity and reliability. A UV-211 tube was used for this purpose also, since it could be operated at the same plate voltage as the power amplifier. Furthermore, the use of a lightly loaded, high power master oscillator protects against frequency variation due to antenna detuning, and against frequency modulation caused by variation of the power amplifier input impedance with modulation.

In the design of the master oscillator circuit, a frequency stability of at least 0.05 per cent was sought. This value, well within present-day requirements, represents a stability which can be attained by careful design. Master oscillators with better stabilities than the value given above are of course possible, but the attendant complexities are such as to eliminate their consideration in aircraft radio.

After the selection of the radio circuits, the modulator was next considered. The class B type[3] of modulator system is admirably suited

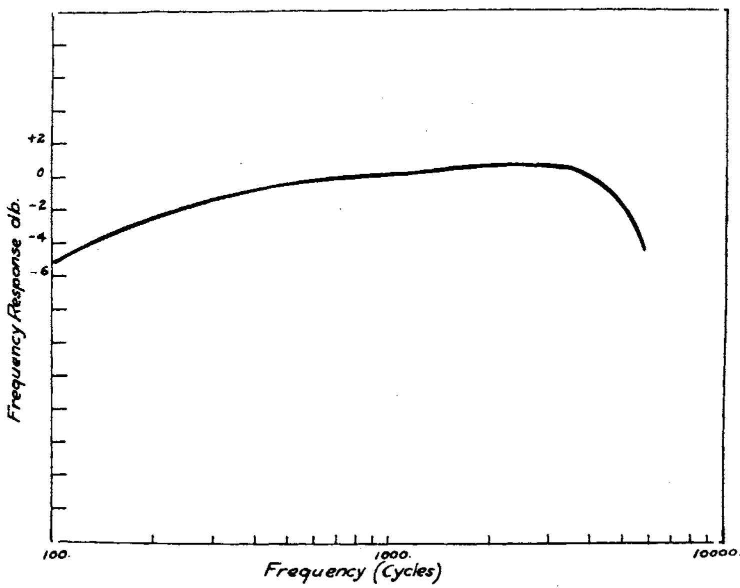

Fig. 4—Frequency response, RT-76-A transmitter.

to use in aircraft equipments because of the fact that it provides the maximum power output for a given tube line-up, and also it has the great advantage that no plate power is required unless modulation is supplied.

Two UV-211 tubes were selected as modulators, and for a speech amplifier to supply the necessary excitation, a single UX-841 was used. The single stage of speech amplification was found to supply ample grid voltage swing and driving power for the UV-211 modulators since they were called upon to supply only approximately 50 watts of audio power. The chief reasons for selection of the UX-841 were the ease of obtaining its bias, since it is a high amplification factor tube, and the fact that its operating plate current, obtained from the 1000-volt supply through a dropping resistor, is low.

[3] Barton, Proc. I.R.E., vol. 19, pp. 1131–1150; July, (1931).

The antenna tuning system was designed and built as a unit separate from the transmitter, mainly for reasons of flexibility of operation, and reduction of over-all transmitter dimensions. It was believed that in certain aircraft installations where space is at a premium, it would be considerably easier to locate and mount two smaller units than to find space for a single large unit containing both the transmitter and antenna tuning equipment.

Fig. 3 shows a schematic diagram of the circuits used in the RT-76-A transmitting equipment. The tuned circuits of the master oscillator and power amplifier, together with the necessary radio-frequency chokes, and antenna coupling inductance are mounted in a replaceable tuning unit shown in Fig. 6. Two tuning units are included with each equipment, one for the 3000-kilocycle band of aircraft frequencies, and one for the 5000-kilocycle band. In addition to this, the design has been carried out to the point that tuning units are available for any frequencies in the band, 1500 to 6000 kilocycles.

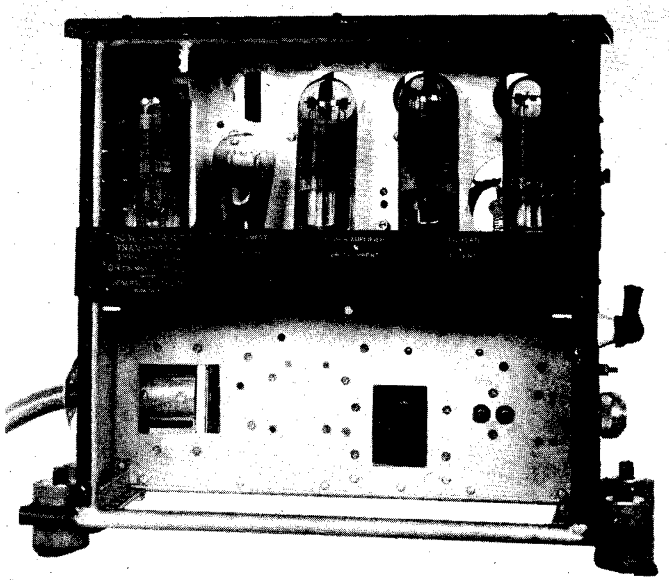

Fig. 5—Front view of RT-76-A transmitter with tube shield off and tuning unit out.

Sufficient mutual inductance is provided for feeding antennas of resistances as high as 16 ohms. The coupling to the power amplifier tuned circuit is variable, and is controllable from the front panel of the tuning unit.

A "Send-Receive" relay is included in the transmitter unit. For telephone operation, the relay is controlled by a push-switch located on the microphone, while for cw operation, the "Send-Receive" switch may be mounted on or conveniently near the transmitting key. In addition to turning the transmitter carrier on or off, the "Send-Receive" relay transfers the antenna from transmitter to receiver and vice versa. A set of contacts is also provided, which may be used for making the receiver less sensitive when the transmitter carrier is on.

The transmitter is designed to be operated with the usual antinoise carbon microphone. The output of the microphone required for complete modulation of the transmitter is 0.25 volt. Fig. 4 shows the over-all frequency response of the RT-76-A transmitter.

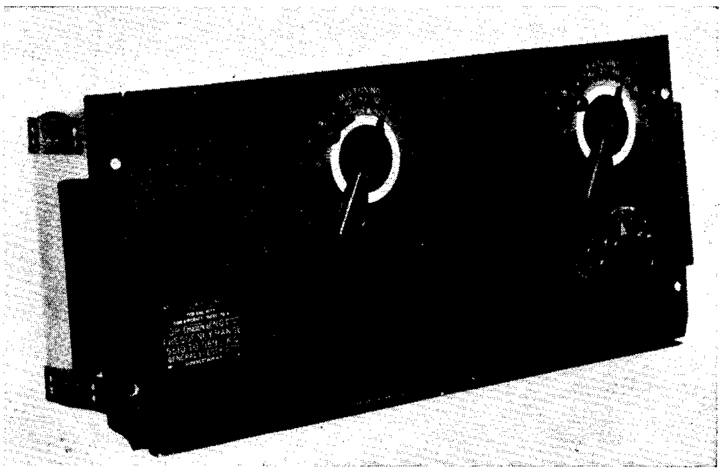

Fig. 6—Tuning unit for RT-76-A transmitter.

In practice, the transmitter may be located in any convenient position in the airplane. When set on frequency, it does not have to be touched, except for inspection or resetting to a different frequency. Control of the transmitter is provided by the control box shown in the complete equipment photograph, Fig. 7. This control box contains the dynamotor "Start-Stop" switch with a telltale indicating lamp, and a "cw-phone" switch. This latter switch, when in the "cw" position, cuts out the modulators, and allows the transmitter to be operated for cw telegraphy. For cw telegraphy, the carrier output power may be raised to 75 watts without exceeding the rated input to the transmitter.

The power drain of the equipment when operating on telephone with a 50-watt carrier output is:

275 to 300 milliamperes at 1000 volts direct current
15 amperes at 12 volts direct current

Since the class B system of modulation is used, the total plate-current drain varies with modulation. The above values are given for average conditions. Assuming a dynamotor efficiency of 60 per cent, the total drain for the complete equipment is approximately 54 amperes from the airplane's 12-volt storage battery.

Fig. 8 shows the general appearance of the transmitter unit ready for use, and Fig. 5, the same transmitter with the top shield of the front panel removed to provide access to the tubes, and with the tuning unit withdrawn from its compartment in the bottom section. It can be

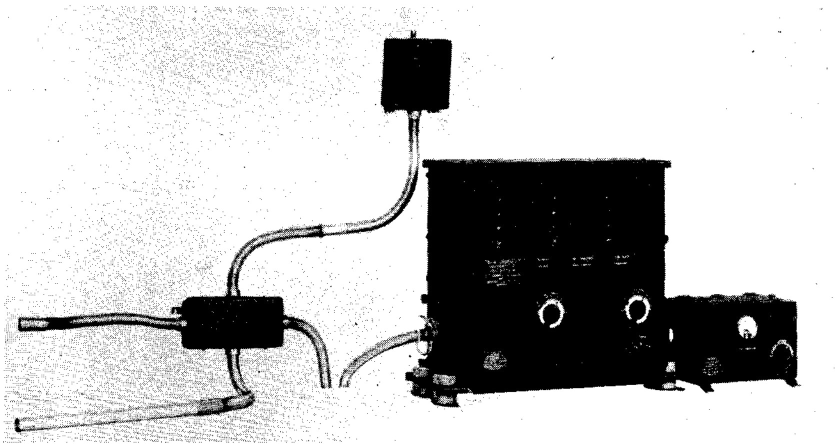

Fig. 7—Complete aircraft transmitter equipment type RT-76-A.

seen from this picture that in general construction, this transmitter consists of a rectangular skeleton frame made of chrome-molybdenum steel tubing of the kind generally used for construction of the fuselage structure in the majority of commercial airplanes. The front and rear bottom tubes are extended beyond the confines of the transmitter to afford convenient means for mounting the transmitter on conventional shock absorbers of sponge rubber. The completed frame is cadmium plated to protect it from corrosion. The center duralumin strip fastened to the front of the frame affords support to some of the fixed circuit elements, and to the tube shelf. The remainder of the circuit elements are mounted on the vertical duralumin shield extending from top to bottom of the transmitter unit, and separating it into front and rear compartments.

The plug-in tuning unit is completely encased by a shielding box.

This permits storage of the unused tuning systems without danger of damage to them, and also serves as a protection against dirt and dust which might cause electrical breakdowns. The shielding box is readily removable, exposing the circuit elements for inspection. As can be seen from Fig. 6, the front of the tuning unit serves as a part of the transmitter panel when in place.

Since all of the connections to the tuning unit are carried through plugs which engage with the jack elements mounted in the transmitter, the change in the frequency band is accomplished without changing a

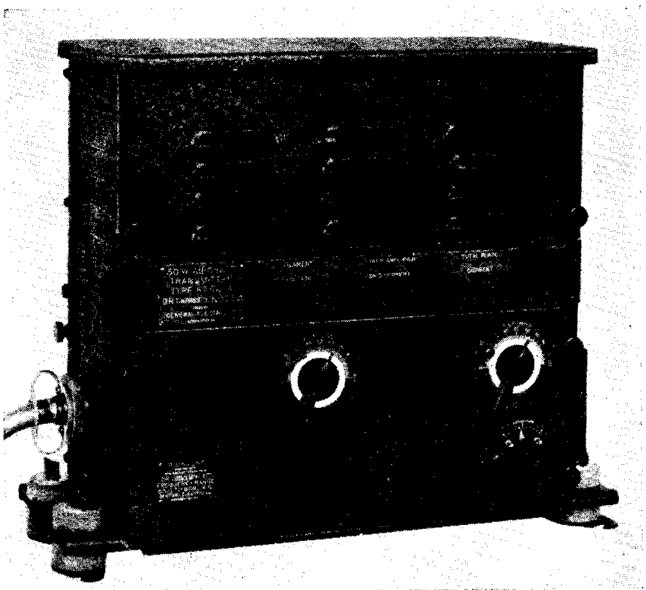

Fig. 8—Transmitter, type RT-76-A.

single wire connection. Guides provided in the bottom of the compartment in which the tuning unit is inserted secure proper alignment between the plug and jack elements, and add to the facility with which a quick interchange of tuning units can be accomplished.

The circuit fuses used in the transmitter are easily replaceable through the door in the left side of the transmitter, and the relay contacts may be inspected through the door on the right side of the unit.

To mount the transmitter in an airplane, four especially designed studs are provided. They are fastened permanently to the supporting framework in the airplane, and need not be removed when the transmitter is taken out for inspection or servicing. To do so, it is only necessary to disconnect the antenna and ground leads, remove the two connection plugs, and free the rubber mounts by depressing the rubber and throwing the retaining crossbars hinged in the ends of the studs into vertical position. After this, the unit can be freely lifted out of its place in the airplane.

The skeleton frame of the transmitter is enclosed on all sides by quickly detachable aluminum shields, and as a result of this type of construction, a complete accessibility of all parts is secured, making for unusually convenient servicing of the unit. As can be seen from the illustrations, the side shields have louvres and the top has overhanging edges, concealing the space between the frame and the top. This arrangement provides an adequate ventilation for internal parts of the transmitter, and yet affords protection against splash or rain so that the transmitter can be used in airplanes of the open cockpit type.

The cable outlets from all of the component units which this equipment comprises are furnished with a length of flexible braided tubing, electrically connected to the cases and grounded. This flexible braided tubing makes it possible to arrange the interconnecting wires in straight-line runs between the units and to enclose them in varying lengths of aluminum tubing. The ends of the flexible tubes are slipped over the aluminum tubing to provide an uninterrupted electrical shielding harness over all of the wires.

The total weight of the equipment described including the interconnecting shielded wires, plugs, dynamotor, control and junction boxes, and the transmitter with antenna tuning unit is under 90 pounds. The weight of the transmitter unit itself is 37 pounds and its over-all dimensions are $20\frac{1}{4}$ inches $\times 17\frac{3}{4}$ inches by $8\frac{3}{4}$ inches.