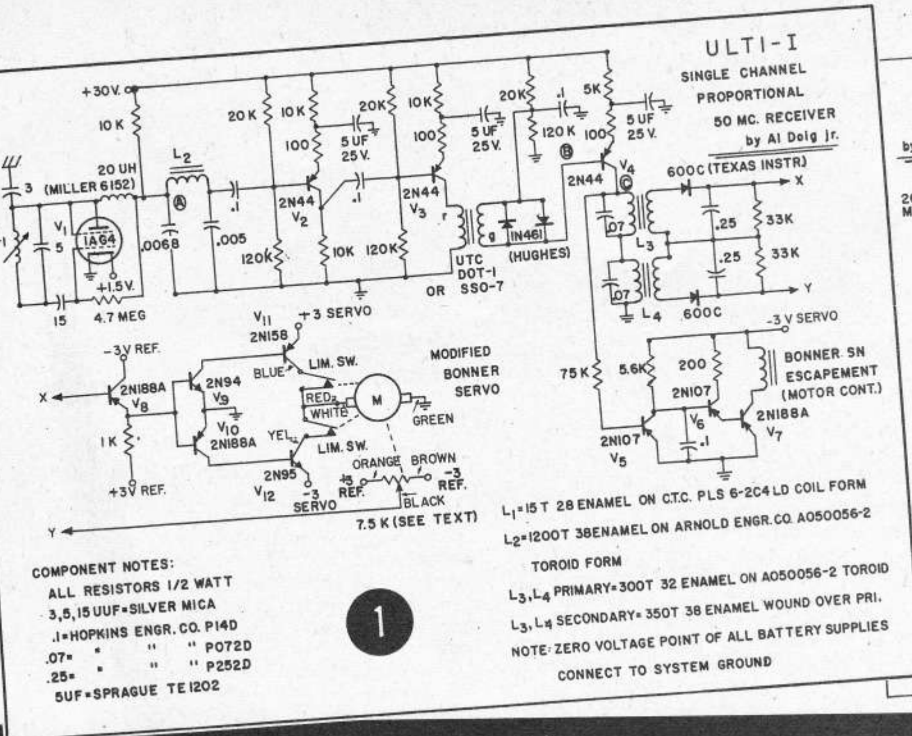
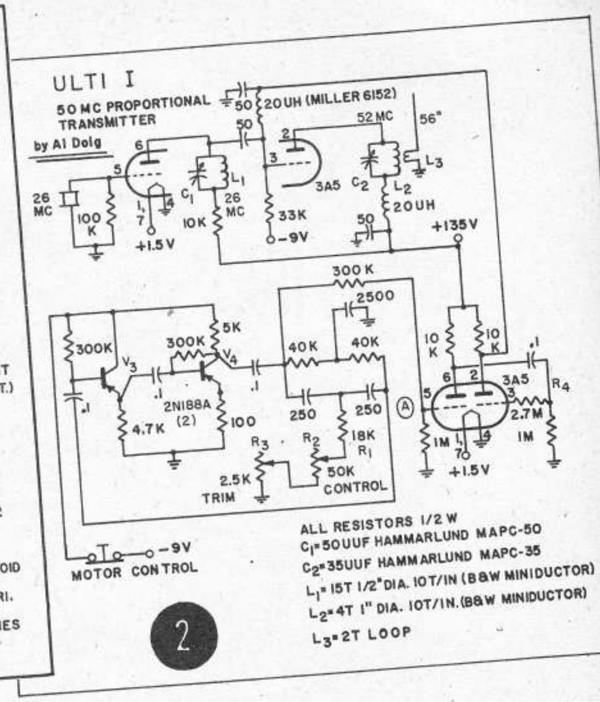
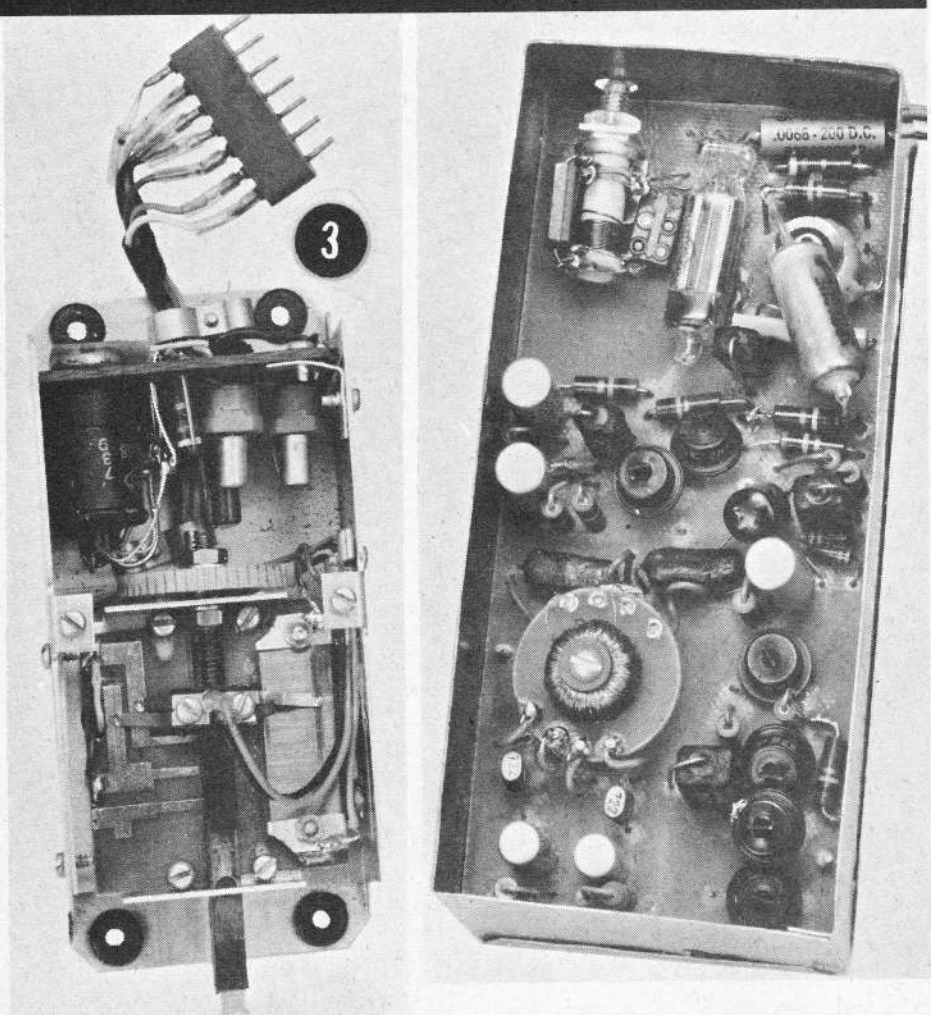




Al Doig's "ULTI"... the ultimate in radio control systems?



■ This paper describes a proportional control system that overcomes many difficulties inherent in the pioneer proportional schemes. It must be pointed out at the outset that the described system has not yet been fully proven. It has been flown in both triple and single proportional versions but the extent of the field trials is not sufficient to make any strong claims. Because of these facts and a design that is reasonably complex, construction should not be attempted by those without a fair electronic background. It is hoped that by an early release of information, the system may proceed more quickly to a reliable and cheap control system. With the above warnings I proceed to a description of the essential characteristics of the system.

1. The system is truly proportional. A "closed loop" servo gives positional accuracy to plus or minus 2%.
2. Full power of a Bonner servo is available (over 2 lb. starting load). Additional power and speed may be obtained with increased servo voltage.
3. Pencells used for servo batteries have reasonable life.
4. The only maintenance required is keeping batteries fresh.
5. The only adjustment necessary is tuning to the transmitted R.F. frequency. A properly installed system will survive the hardest crash.
6. Although no attempt was made to keep prototype cost low, there is nothing inherently expensive in the system.
7. The system is easily expandable. One can start with single channel and expand to multi as time, experience and finances permit.
8. Weights of the prototypes were approximately as follows: Single channel receiver 4 oz, 4 channel 7 oz, servo 4 oz each, total batteries 8 oz.
9. The receiver is inherently fail-safe. The servo returns to neutral or any trim desired upon loss of signal or receiver failure. Neutral trim is adjustable in the air.
10. The controlled surface is not in continuous agitation but stays quietly in the desired position until moved.
11. The number of actions that can be controlled is limited only by the bandwidth of the filters and the number of tones that can be successfully

Though we have labeled his system "Ulti," originator Doig still feels it is capable of much further development, mainly to lower cost, also to put it on 27 mc. Al says he has spent all the time he can spare in development work—now he wants to learn to fly the system! He hopes (and so do we) that builders will let us know of results, improvements, additions, so may publicize them to the advantage of all. We believe this system has tremendous advantages, combining as it does relayless operation, low drain "non-wiggle" feedback servos, great flexibility (you can start with single channel, add more as you desire, with no circuit problems). Multi-proportional seems destined to expand rapidly, as proven by announcements of forthcoming equipment from several of largest R/C manufacturers: at least one of these follows basic equipment developed by Doig. Get in on the ground floor with the equipment covered here and in Part Two (which will appear in a forthcoming issue of American Modeler). One caution; as the author emphasizes, this is not R/C beginner material—even in the single channel form. It is presented for those well-versed in electronics, able to do their own trouble-shooting, parts substitutions, etc.

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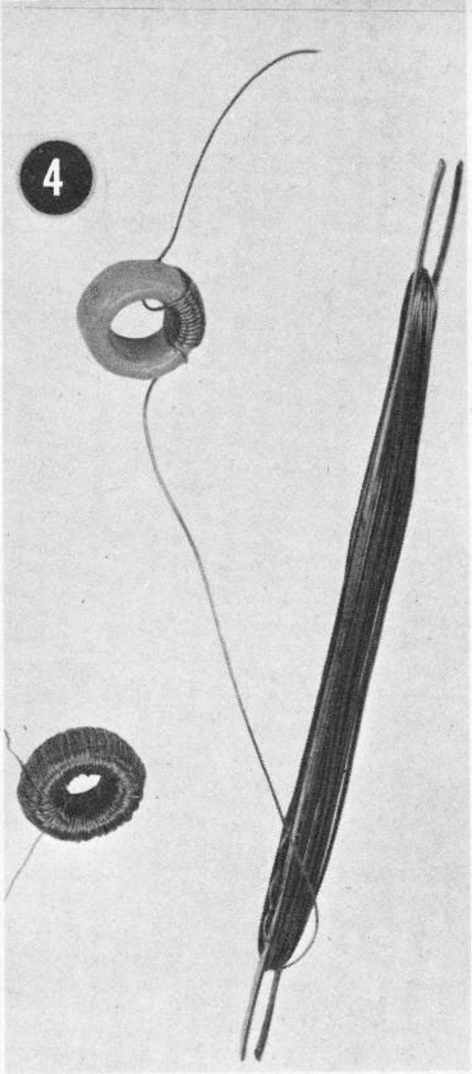

transmitted and detected simultaneously.

The development of the ULTI ("the ultimate in multi") control system was the result of approximately two years work with bandpass receivers. The original aim was to build a reliable receiver using no reeds or relays. The receivers built to these principles were extremely successful. One 2-channel receiver has been triggering rudder, motor and elevator escapements in a Champion for well over a year. During this time the receiver has never been out of the airplane and no adjustments have been made to either receiver or transmitter.

A natural outgrowth of the bandpass work was the discriminator principle and variable tone detection. The present system operates as follows: Referring to fig. 2, the 3A5 crystal-oscillator, doubler is standard. A stick-variable tone is generated in the transistor phase-shift oscillator (V3, V4). The emitter-follower, V3, provides isolation and permits a higher impedance phase-shift network. Resistors R1, R2, and R3 are used to control the frequency of oscillation. R2 (the control pot) is a standard high-quality linear taper potentiometer. The control stick attaches to the potentiometer arm and suitable stops are used to limit the travel to 60 degrees, making the effective resistance about zero to 10K ohms. Centering is provided to return the stick to a solid, well defined neutral. R3 is an adjustment pot on top of the transmitter to allow adjustment of the neutral trim. The audio frequency generated varies between approximately 8250 cps and 9120 cps. A two-stage applifier provides the voltage swing necessary to grid modulate the RF stage. The transmitter, then, provides an RF carrier modulated by an audio tone whose frequency depends on the position of the control stick. In one extreme stick position the audio tone is 8520 cps, at neutral it is 8820 cps and at the other extreme it is 9120 cps. At intermediate positions the tone frequency is proportional to the stick position between the two extreme limits.

Fig. 1 is a schematic of the single channel receiver. V1 is a superregenerative detector stolen directly from Walt Good. It has proven very reliable. A transistor detector was not used because of the difficulties of stabilization with temperature and voltage. The pi-section filter L2 effectively removes the quench voltage. Although L2 was wound on a toroid form to reduce weight, any 80 to 100 mh choke would be electrically equivalent. V2 is a straight voltage amplifier driving a second voltage amplifier V3. The back-to-back diodes across the audio transformer secondary compress the audio voltage from about 5 to 1 volt peak-to-peak. This provides an automatic gain control that keeps a constant input voltage regardless of range.

Clipping was not used because during clipping, part of the available audio power is dissipated in higher-order harmonics. This is not particularly a problem in the single-channel receiver but for the more general application to multi-channel it can be bothersome. The filter stage V4 has in its collector two tuned toroid filters. These filter elements have an inductance of approximately 3 to 4 milihenrys and a 1000 cycle Q of about 18, providing a relatively narrow bandpass. One of the filters is tuned to 8520 cps and the other is tuned to 9120 cps. If the incoming signal is at 9120 cps, most of the voltage will appear across the 9120 filter. At neutral, equal voltage will be developed across both. At intermediate frequencies, the voltage will divide linearly according to the relative impedances to that particular frequency. Filter secondary windings isolate these voltages. Rectifiers and filters convert the alternating voltage to a DC voltage and we now have a very familiar discriminator circuit. If point Y were now grounded, point X would swing positive and negative depending upon what frequency were present. At mid-frequency the voltages would be equal and point X would be at ground potential.

We now have achieved the desired result, a DC voltage that is in some way proportional to the position of our control stick. All that remains is to convert this voltage into mechanical motion. V8 of fig. 1 is an emitter-follower used to provide a high impedance to the discriminator. V9 and V10 is a voltage comparator circuit. If the input voltage is positive (with respect to ground), V9 will conduct, driving current into the servo amplifier V11. This starts the servo motor running in one direction. If the input voltage is negative, V10 conducts, driving the current into servo amplifier V12, starting the servo motor in the other direction. All that remains is to close the loop. A pick-up pot on the servo provides a voltage that is proportional to servo position. Point Y,

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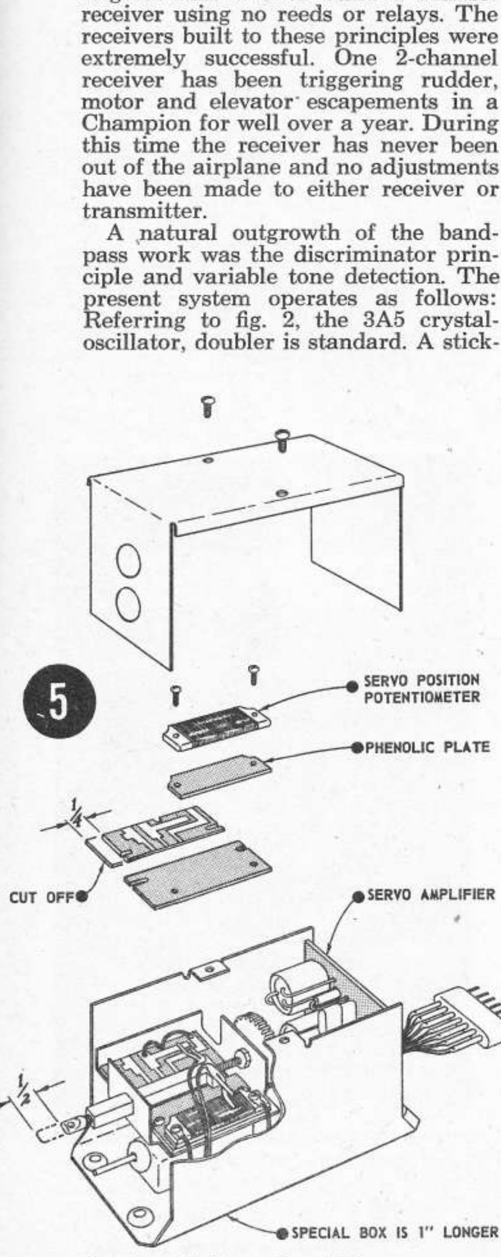

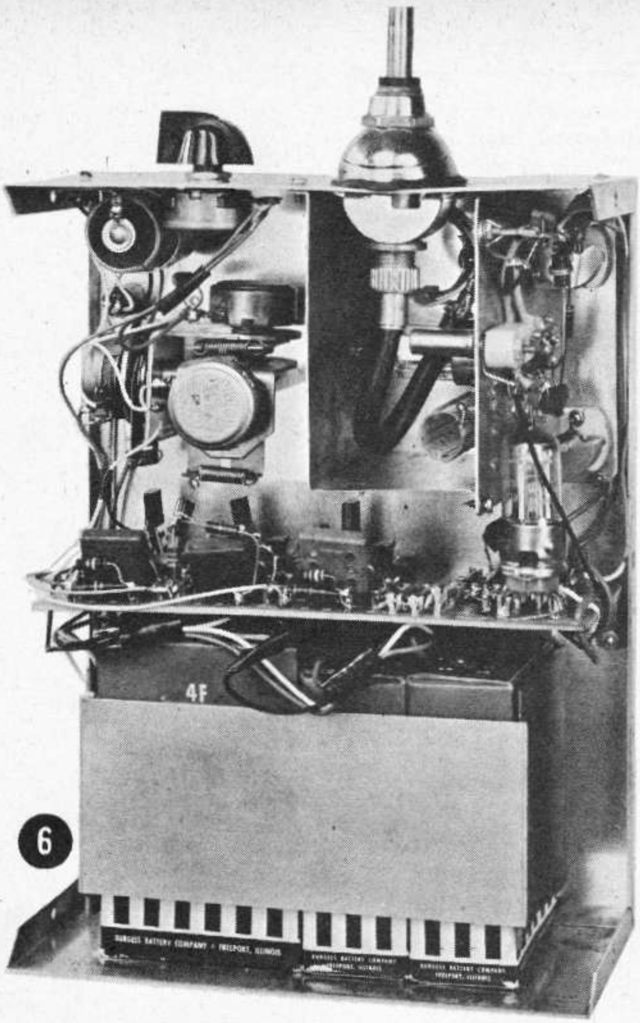

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then, provides a voltage to the discriminator that cancels the discriminator voltage, keeping (or tending to keep) point X always at ground potential.

If the signal is lost for any reason, the servo will run back to neutral and stay there. If a slight turn upon failure is desired, the plane linkage is adjusted to this turn with the transmitter off and the receiver on. Flying neutral is provided by adjusting R3 neutral control on the transmitter.

The motor control operates when the tone is interrupted with the carrier left on. If the motor control button on the transmitter is held down, the rudder will neutralize. In practice, the motor control button is "blipped" which changes motor speed without affecting rudder position. V5 fig. 1 is an integrating amplifier. As long as a tone is transmitted, V5 stays in saturation, cutting off V6. Upon loss of tone, V6 conducts, forcing V7 into conduction which triggers the motor control escapement.

SINGLE CHANNEL RECEIVER CONSTRUCTION. Fig. 3 shows the general method of construction for the prototype receiver. The layout can be duplicated easily by the experienced builder. The only note of caution—the system has considerable gain. If the layout permits magnetic coupling between the filter stage and the front-end low level stages, oscillation will result.

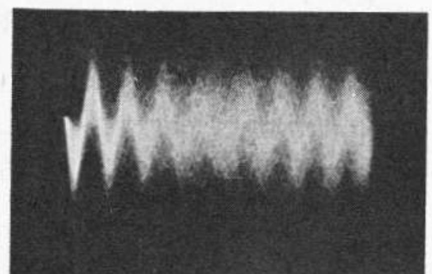
Although printed circuit boards were used, these are certainly not required and in fact sometimes lead to trouble. The filter construction is the only thing likely to give annoyance. Lacking a toroid winder, the writer hand-wound all coils. The Arnold Engineering A050056-2 toroid forms are available, in general only from Arnold Engineering Co., Box G, Marengo, Ill. The cost has been approximately one dollar each in quantities over ten. A ten dollar minimum order is required.

The bobbin used to wind the toroids is shown in the photograph of fig. 4. A pair of yarn needles were obtained from a knitting shop. These needles are about 2¼ inches long and have a very large eye. The needles were welded point to point and the ends trimmed from the eyes. The whole bobbin was then buffed to a smooth finish. The appropriate wire is then wrapped on the bobbin (one turn on the bobbin gives approximately ten toroid turns) and the sewing process started. The first layer should be made as neatly as possible and all the windings made tightly in order to get all the turns on before the hole is filled. About 45 minutes is required for each winding except the quench filter, L2 which takes about 90 minutes. Only the primary windings are initially put on filters L3 and L4.

Before the filter secondaries are wound, the filters are tuned. Because of the tolerance of capacitors, it is not possible to give exact numbers of turns and capacity to tune to a particular frequency. The process is to choose a given capacitor, unwind sufficient turns to give the correct frequency, and keep this capacitor and filter together as a matched set.

To tune the filter some high-quality electronic instruments are required. As a minimum, a calibrated audio generator and an oscilloscope or high input-resistance AC vacuum tube voltmeter is needed. To keep consistency between prototype and future units, the writer used an EPUT counter to set the audio generator. To tune the filters, the parallel LC to be calibrated is wired in series with a 10K resistor across the output of the audio generator. The oscilloscope vertical input is connected across the parallel LC circuit (if oscilloscope is not available use AC scale of VTVM). A large increase in peak voltage will be found at the point of resonance as the audio oscillator is rotated through the appropriate range of frequencies. Turns are removed from the toroid until the peak occurs at the desired frequency.

The frequencies given are by no



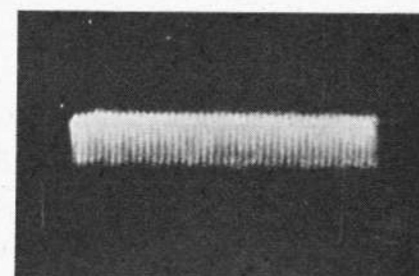


Fig. 7 (left): waveforms taken at point "C" on Fig. 1. Top pattern with transmitter "off"; center pattern with transmitter "on", stick neutral; lower pattern with transmitter "on", motor control button depressed. Scope settings: 1V/cm vert; 100 us/cm horiz. Fig. 8 (right): waveforms at point "B" of Fig. 1 under same conditions as Fig. 7. Scope settings: 0.5V/cm vert; 100 us/cm horiz.

means sacred. Any pair may be used for single channel operation observing only the percentage separation. After both toroids are thus tuned, the secondaries may be wound. It is desirable to pigtail the leads and wrap the coils with mylar tape. This is even a more tedious operation than winding and may be eliminated if extreme care is taken with the leads to adequately support them against vibration.

If the parts shown on the schematic are used, the total cost of all parts comes to about $59 excluding the Bonner servo and escapement. If certain economies are observed, such as using the UTC SSO-7 transformer instead of the more expensive DO-T1, this price can be reduced.

SERVO MODIFICATIONS. The servo "can" also houses the servo amplifiers. This certainly is not necessary but makes a nice universal package. A new metal can was made exactly like the original except one inch longer. A board was made on which to mount the five transistors in the servo amplifier.

Actual servo modifications are relatively simple. A 4 watt, 25K wire wound potentiometer was purchased at a local surplus store. The holding rivets were drilled out and the resistance element removed. The element was placed in an oven and heated to a temperature of 450 degrees F. At this temperature the base material softens so the unit can be flattened. A pair of brass end-terminals were cut and drilled, the resistance element cut to ¾ inch, and mounted to a thin piece of phenolic sheet. Countersunk screws were used so the phenolic could be mounted flat. One of the printed circuit boards (see fig. 3 & 5) was removed and reversed. The resistance element was glued in the position shown using radio speaker cement which purports to be immune to vibration. The board is then replaced and the wiper arm bent to wipe along the resistance element. The orange and brown wires that were removed to take this board out are now soldered to the ends of the resistance element. The remaining board is removed, trimmed as shown in fig. 5 and replaced.

The Bonner servo color code is shown on fig. 1. Existing wires are used throughout but their function changed. Before rewiring the servo, make sure the use of each wire is understood. This will prevent miswiring with subsequent loss of expensive transistors. Check all wiring thoroughly before applying power. Mounting the servo amplifiers and wiring completes the servo construction.

TRANSMITTER CONSTRUCTION. The RF portion of the transmitter (fig. 6) is quite standard and indeed any existing transmitter may be used with only the audio portion modified. The transmitter shown in fig. 6 is one used with both single and multi-channel receivers but points up general construction practices. The multi stick assembly shown will be described in "American Modeler." For single-channel operation, the control pot could be mounted on a bracket with the control stick protruding through a slot in the front panel. Centering springs would be adequate for neutral return. A more positive neutral return will be described in A.M., too.

The RF tube and coils were mounted in a shielded section as a precau-

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"ULTI"

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tionary measure but no evidence that this is required has been found. The entire audio section is mounted on a phenolic board above the battery section. The transmitter can used was made with dimensions identical to those of the Orbit 8 channel transmitter. The antenna is a standard 56″ auto antenna. This has not proved very satisfactory because it cannot be removed for transit.

TESTING TRANSMITTER. The RF section is tested in the usual manner. The frequency of the audio tone is easily adjusted if an EPUT counter is available. If not, the Lissajou method described in the Amateur Radio Handbook will be quite satisfactory using the two calibrated frequencies from the audio generator which were used to set up the receiver filters. The frequency is brought into range by changing R1. Lacking the equipment or inclination, the frequency can be adjusted by observing the effect upon the receiver.

When the audio section is operating properly, the modulation percentage should be checked as described in the Amateur Radio Handbook. Adjustment to give 100% modulation is made with R4 (2.7M). Batteries used are Burgess 4F for plus 1.5 v, two Burgess XX45 for plus 135, and one Eveready 226 for minus 9 volts.

TESTING RECEIVER. The battery complement used on the prototype receivers is as follows: Two pencells (parallel connected) for plus 1.5 v heater, one Burgess U20 for plus 30 v, four Burgess No. 7 miniature pencells for plus and minus 3 v ref., and eight standard pencells (series parallel) for plus and minus 3 v servo. If airplane weight is a problem, four pencells can be used for servo batteries and will last during many days of hard flying.

Initial tests are made on the receiver with the servo points X and Y disconnected. With the heater and 30 volt supplies connected to the receiver, the waveforms shown in fig. 7 should be observed with an oscilloscope connected between point C of fig. 1 and ground. Now connect a high resistance voltmeter between points X and Y with point Y temporarily grounded. With the transmitter on, stick movement should result in a DC voltage swing of approximately plus and minus four volts. At neutral, the voltage will rest slightly above zero. Waveforms shown in fig. 8 are observed at the base of V4 (point B).

When the receiver is operating properly, connect the servo voltages as shown. If the servo runs to one limit and stops, reverse the leads to the servo position potentiometer. The slider on the servo position potentiometer should come to rest at approximately mid point. If it comes to rest off center it is the result of transistor contact potentials and can be corrected by adding a fifth cell to the reference voltage making it plus 4½ and minus 3 v. Connecting points X and Y to the receiver should result in proper system operation. Further transmitter audio range adjustment may be necessary to bring the neutral adjustment on the transmitter into proper range. This is done by changing the value of R1.

FLYING. If you have never flown proportional equipment, it is best to initially fly the plane as though it were a bang-bang servo, at least on takeoff. It is easy to over control. The prototype equipment is installed in a Livewire Champion with an all-up weight of 4¼ pounds. The rudder area was increased about four times with a throw of about plus and minus 30 degrees. With this much control, beautiful rudder rolls and true spins result. The only operational difficulty to date was throwing the Fox 25 engine out of the model in the middle of a violent true spin (the engineless ship was landed easily).

The equipment has been flown in ambient temperatures exceeding 100 degrees F. with no shift in receiver operating point. It is noticed that the transmitter neutral does shift with increased temperature but is easily compensated by the neutral adjustment. Some elevated-temperature bench tests resulted in some changes in the transmitter audio oscillator that have greatly helped but not eliminated the problem. It is apparent that the phase shift is changing in the audio amplifier with temperature. With the phase-lift oscillator used, the result is a change in frequency.

It is hoped that an early release of information on the system will result in system improvements not only in this area but others.

SINGLE CHANNEL RECEIVER PARTS LIST: These notes supplement those on Fig. 1. Many components were selected for small size and are rather expensive; the circuit is relatively insensitive to components and liberal substitutions may be made to reduce costs. Silver mica condensers are El Menco; all resistors are 10%; .0068 mf and .005 mf condensers were CRL DD-682 and DM-502, CRl DA-104 can substitute for Hopkins .1 mf; 5 mf 25 volt are Sprague TE1202; AF transformer (UTC DOT-1) has 20K pri. and 800 ohm sec.; toroid core info given in text.