Touch-down of "Multi-Bug" on a touch-and-go landing. Note wheels and skid are all 2" above ground and elevator is almost full up. Shows what dual proportional can do.

Dual Proportional Radio Control —

Two-Tone Pulse Width System

By DR. WALTER A. GOOD

Editor's note: One of the most eagerly awaited developments in radio control during the past several years has been Dr. Walter A. Good's two-tone pulse width system. Like anything he has tackled in the model design and radio control field, Dr. Good conducts numerous tests and invites fellow experimenters to try out his ideas, too.

Only when all the "bugs" have been worked out will the noted researcher permit his work to be publicized. Now after a wait of more than two years "American Modeler" is proud to present the latest from the Good workshop. The reader will be interested in this background information on the unusual and now thoroughly proven system.

After extensive bench testing, the two tone pulse width system was installed in the WAG plane—the same plane that Dr. Good had used for his 3rd place tie at the '53 Nats—with expectations of entering the 1954 Nats R/C event. Bugs were worked out and some fine flying done, when it happened—straight-down crash into a barbed wire fence! Damage was repairable, best bet was to put the receiver into the old faithful Rudderbug since crash came just a week or so prior to Nats start. This receiver was rather bulky, used 7-pin miniature tubes and Kurman relays.

Dr. Good's text mentions sad results of this attempt, when besides diode heat problems, a recurring condenser defect prevented any good flights. After these troubles were straightened out, lots of fine flying was done, including some unsuccessful attempts at F.A.I. R/C Endurance record. Sub-min receiver was developed late in 1955, test flown in the old "Bug," of course.

It soon became apparent that a new and "hotter" plane than the Bug was required, if full possibilities of this extremely flexible control system were to be realized. The "Multi-Bug" emerged in the Spring of '56; first contest try for it and the sub-min receiver was at 1956 Nats, were a third place was recorded. Using members of his own club (the DC/RC) as willing guinea pigs, quite a few copies of the system were flying during 1956, both on 27¼ and 50 mc., and the equipment described here is result of this work, plus tips received from many other builders in various parts of the country, who have made copies.

It should be emphasized that this equipment is decidedly NOT for the R/C beginner, or even for the expert R/C flier who has little knowledge of radio. Admittedly complex, the results are what many expert R/Cers have termed the "ultimate" as far as control goes; an "approved kit" will be available to aid the builder. Dr. Good is already considering means to simplify the equipment, especially the transmitter, but it will doubtless be some time before this work can be finished and thoroughly tested. Meanwhile, for the experienced flyer and radio man, here's your chance to build a control system that is definitely HOT.

■ Push the stick just a little forward and hold that nose down into the wind. No use letting that favorite RC ship gallop up to high altitude when you've got proportional elevator. Now a little left rudder for a turn. The nose is dropping, ease back on the stick and hold it up. There's a smooth level turn that doesn't look like a spiral dive. Inverted flight is easy too when you can steer with the rudder while holding just enough down elevator to keep her flat and level.

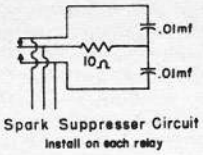
Dual proportional means a proportional rudder and a proportional elevator which are simultaneous so that any degree of rudder can be commanded along with any amount of elevator. Let go of the stick, it snaps back to center as do the rudder and elevator. The system described here also permits engine control and a fail safe connection which centers the rudder and elevator in case of transmitter failure or a jamming signal. Probably the easiest way to obtain the type of results mentioned above would be to use three separate receivers on three different frequencies. Receiver No. 1 could be pulsed for proportional rudder, receiver No. 2 could be pulsed for proportional elevator and receiver No. 3 could take care of the engine and failsafe operation. Although this would be a feasible method it would be heavy and cumbersome with three receivers in the plane and three transmitters on the ground. The Two Tone Pulse Width System described here is a way to obtain all of these features with one receiver and one transmitter.

The key part of the system was found in a QST article (Feb. 1952) by H. W. Lawson, Jr. who described a single proportional control, for a boat rudder, using the pulse width modulation of an audio tone. Instead of sending a nice even audio tone wave, it is possible to distort the tone and send an uneven wave. Fig. 1A shows a 100 cps wave with the narrow parts up. Figure 1B shows the same 100 cps with the broad parts up. These are the uneven waves. We call Fig. 1A a 20/80 tone and Figure 1B is an 80/20 tone. It is not difficult to make a diode bridge circuit which can tell the difference between the narrow pulses and the broad pulses. This circuit is called a Pulse Width Detector and is shown in the upper right hand side of Figure 2. It has the property of giving out a positive voltage at point "A" when broad pulses are used and a negative voltage when narrow pulses are used. This voltage is led to the grid of the relay tube. Thus, for broad pulses, the tube conducts and the relay pulls in (3 ma); for narrow pulses the tube is cut off and the relay drops out (0 ma). Now imagine the transmitter tone being switched back and forth from broad to narrow at four cycles per second. As a result, the receiver relay will also switch back and forth at four cycles per second and we have our elevator control using the pulse width detector. The four cps switching can be varied in dwell time to give regular proportional action.

The waves shown in Figure 1C and 1D are the same as 1A and 1B except they are 500 cps instead of 100 cps. Fortunately, the pulse width detector doesn't care about the difference in frequency as long as the narrow and broad pulses have the right shape; that is, 20/80 for A and C and 80/20 for B and D, so the elevator keeps right on switching for both 100 cps and 500 cps. Now if we could find another circuit that is sensitive to tone frequency but not to the tone width we would have a second independent control. This is exactly what the Pulse Rate Detector does in the lower right-hand side of Figure 2. It has the property of giving out a negative voltage at point "C" when a high tone is received and little or no voltage for a low tone. Thus, if we switch back and forth between 100 cps and 500 cps at 6 cps the relay will also switch at 6 cps and we have a rudder control.

We have arbitrarily selected 100 cps for Right and 500 cps for Left; narrow pulses for Down and broad pulses for Up.

While the elevator and rudder are being operated, there is always a tone present as in Figures 1A, B, C, D. Now we can connect a third relay tube to a negative diode and keep the relay open as long as a tone is received, very similar to the WAG three-tube tone receiver. This is easily done by tapping into the negative end of the PW bridge (saving a diode!) and adding the failsafe tube and relay as shown in the right side of



SPARK SUPPRESSOR CIRCUIT (LEFT) INSTALLED ON RELAYS. SERVO CONNECTIONS (BELOW), FIG. 3

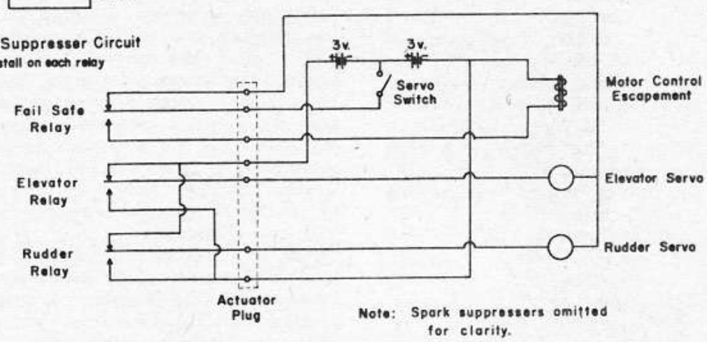


FIG. 1: DUAL-PROPORTIONAL SIGNAL WAVE FORMS

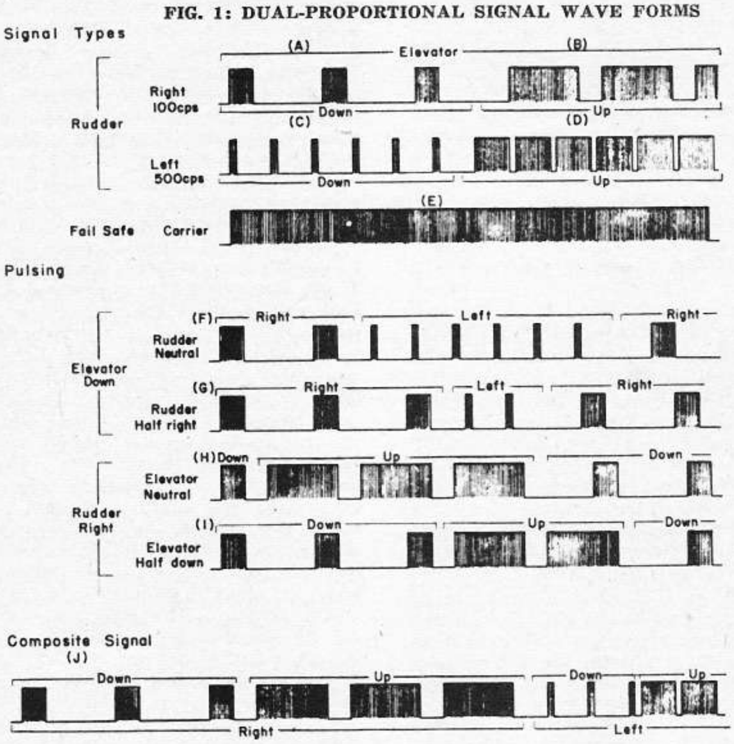


FIG. 2: DUAL-PROPORTIONAL AUDIO RECEIVER

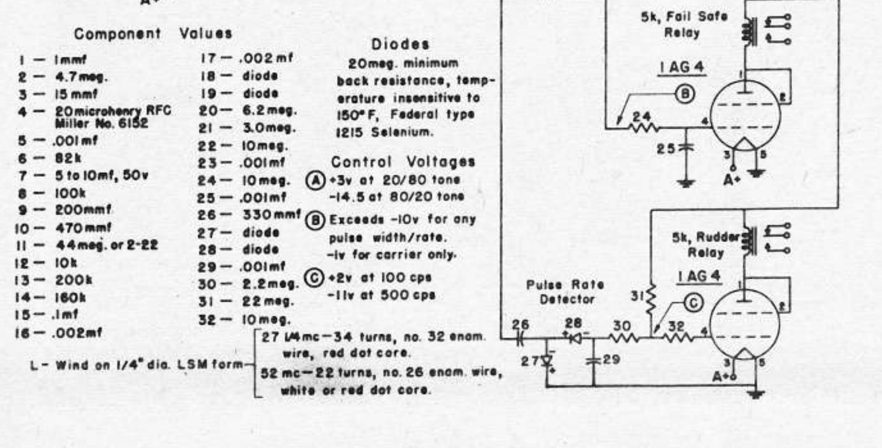


Figure 2. When no tone is sent, such as carrier or no signal, all three relays pull in. This would normally result in a full Right and full Down except that the back contact of the failsafe relay is connected to the actuator battery and removes the voltage from the rudder and elevator actuators allowing them to return to neutral due to the rubber band centering. The other contact on the failsafe relay is hooked to an engine control actuator, escapement or motor, as shown in Figure 3. Thus, a 0.1 second blip of carrier momentarily centers the controls and steps the engine to its next speed. A long siege of carrier or transmitter failure causes immediate centering of rudder and elevator and could also cut the engine if desired.

Let's see what some of the signals look like for various combinations of the controls. Refer to Figure 1F and notice the change in tone frequency in even segments at 4 cps. This is neutral rudder. Since only narrow pulses are shown, this is also full down elevator. The elevator is not being switched in Figure 1F. In Figure 1G the right segments are longer than the left segments indicating approx. one-half right rudder. Figures 1H and 1I show the cases for neutral elevator and one-half down elevator. In both cases, the rudder is in full right.

When both signals are combined for neutral rudder and neutral elevator, Figure 1J shows the result. This is a typical signal emitted from the transmitter during actual flight. Note how the elevator can switch in the middle of a Rudder segment without affecting the Rudder. This explains why the controls are simultaneous. If these signals are played into a speaker you will hear a sound like dee-da, dee-da, dee-da or as some observers say, kapockita, kapockita, kapockita!

The actuators are Mighty Midget Motors with rubber band centering on the motor shaft and a torque rod connected to the counter shaft. In both the WAG and the original Rudder Bug the Mighty Midgets were used "out of the box" with 1½V batteries in each leg. Over 150 dual proportional flights were put on these two ships before they joined the Down Elevator Club. The control was adequate, but weak, especially on the elevator. On the new Multi Bug an extra gear (another Mighty Midget pinion and gear) was added and 3V were used in each leg as shown in Figure 3. This delivers about 8 inch ounces of torque which really holds down elevator for "tuck under" dives and outside loops. Incidentally the Multi Bug has 120 flights with the 3V arrangement.

The battery complement is 45V for the plate supply, 1½ for filament and two sets of 3V for the actuators. We use the K-45 size of B battery with one stack removed. This cuts it from 67½V down to 45V and 5 oz. The B drain is about 4 ma average and runs to 10 ma for the failsafe condition. Silver cells are the lightest choice for filament and actuators. Five (about 6 oz.) of the one ampere-hour type (Yardney LR-1) will give over three hours of flying on one charge. Dry batteries may be used but will weigh somewhat more. The filament drain is 200 ma while the average drain from each leg of the actuator battery is 350 ma.

The photographs and Figures 4 and 5 show the ruggedized construction of the receiver. One fiberglass board (1/16" thick) holds the components, the second-board holds the three Gem relays. The five subminiature tubes are sandwiched between the two boards which are separated by a frame of 3/16" x ⅜" basswood. The whole receiver slips into an aluminum can 2" x 2⅜" x 4" with only the tuning screw exposed. We used the National RO shield can which is unfortunately out of production but a replacement is available from National. The only difference is a few small holes in the can. The can protects the relays and components from dirt, flying objects and greasy fingers. Once adjusted we have flown as many as 50 flights without removing the receiver from the plane. Even the straight down demise of the old Rudder Bug did not damage the receiver. It's the one in the photo! The receiver weighs 7 oz. complete and even though the can and mounting boards account for 3 oz. of this, we think its worth it. The total weight of the installation is 24 oz. considering receiver 7 oz., B battery 5 oz., filament and actuator batteries 6 oz., two Mighty Midgets 3 oz., escapement 1 oz. and switches and wiring 2 oz.

The receiver circuit in Figure 2 is for both 27¼ mc and 52 mc. The only difference is the coil. The first 1AG4 stage is the superregenerative detector which is fairly conventional. Capacitor 7 and resistor 12 form a decoupling filter which prevents "motorboating" with worn B batteries. Resistor 8 and capacitor 9 are the quench filter and attentuate most of the 80 KC quench frenquency before it gets to the grid of the audio stage. The 1AH4 amplifies the audio and distributes it to the three relay circuits, as described earlier. The filters 22, 23 and 24, 25 remove any tone before reaching the relay tube grids.

Construction of the receiver is straight forward but we would be kidding ourselves if we said it was as simple as a gas-tuber or a three-tuber. It isn't. Do a careful "no rush" job and you'll end up with a reliable unit. In fact any elevator ship demands the utmost in perfection. Get sloppy and it will let you down—straight down!

Drill the fiberglass boards according to the patterns in Figure 5. The component board is the one with the most holes and both the top and bottom views are shown in Figure 4. Note how the component wires drop through the holes and are bent flush on the reverse side and soldered to the appropriate junctions. No eyelets are used. Try to keep the wiring on the tube side as flat as possible.

The only critical area contains the coil, parts 1, 2, 3 and 4 and the superregenerative tube. Be sure to ground the coil base to the metal front panel and hence to the A minus. Also wind the coil near the open end of the form with about 1/16" separation between the coil and end clips. If you rearrange these parts, you're on your own! The rest of the circuit is unaffected by layout arrangement and will allow variations in resistor and capacitor brands but not in component values except item 9 may be either 200 MMF or 220 MMF.

The old Rudder Bug was taken to the 1954 Chicago Nationals in hopes of showing off the dual proportional control. One flight was finished in the morning and things looked good. In the heat of early afternoon the second and third attempts ground looped badly in spite of full opposite stick. A quick run to a shady test spot 10 miles away revealed no trouble. Back to the hot runway, another ground loop. You've probably guessed the trouble. The now-discarded germanium diodes were affected by the high temperature on the hot runway and wouldn't perform properly. Since then we have found only one low-cost (less than $1) diode which is suitable. It is the Federal No. 1215 selenium unit. Another good one is the junction type silicon diode such as the 1N137 or 1N138 but they are more costly, about $6. We use the No. 1215. When soldering, clamp the wire between the diode and the point of soldering with a pair of pliers to prevent heat from reaching the diode. Otherwise the diode may be damaged.

When you have finished wiring the component board there will be a number of wires emitting from it. One is the antenna, three are the A plus, A minus-B minus, and B plus and the remaining four run to the relay coils on the relay board. It is wise, at this time, to have a critical friend inspect your wiring job for omissions, unsoldered connections and mistakes.

The relays are mounted and wired according to the diagram in Figure 3. This will bring out seven wires from the relay contacts. We use one plug for these seven wires and another plug for the 3 power wires.

The preliminary checkout of the receiver may be made with any 100 per cent modulated transmitter that puts out a tone between 100 and 500 cycles. The final checkout will require the complete transmitter which will be described in a forthcoming issue.

The first test is to check the superregenerative stage. Plug in only the 1AG4 in this stage. Leave the other sockets empty. Apply 1.5V on the filament, 45V on the B and turn on the tone transmitter. We use a grid dipper modulated with an audio oscillator. If you use a transmitter set it for low power. Place a VTVM (such as Heathkit V-7) on the 1.5V ac scale and clip to point "D" in Figures 2 and 4. Tune the receiver coil to give a peak meter reading. It should read 0.5 volt rms or higher. If it doesn't, try another tube. The other test is to lower the B supply to 36V in 1½V steps and see if the detector stays in operation. You'll find that a tube which gives high output at 45V may die before reaching 36V or a low output tube may go down below 30V before stopping. Usually at least one of the four 1AG4's will give the 0.5V at 45V and also work at 36V. If it doesn't it will be necessary to juggle the grid condenser No. 3. For more output, lower the value of No. 3 by several micromics. For operation on low B voltage raise the capacity. A range from 10 MMF to 27 MMF should cover most situations. For a real pesky receiver you may need to lower resistor No. 6 from 82K to 47K to obtain the low B voltage operation. Once you're in business, mark the tube so it won't get mixed with the others.

Next plug in the 1AH4 and be sure to insulate it with a pen bladder sack or tape because it has a grounded metal coating which could short to the receiver wiring. Set the VTVM on the 50V ac scale and clip to point "E" and ground. The meter should read 10V rms or higher with a tone signal.

Before checking the relay stages adjust all the relays with a battery and pot to a "pull-in" current of no more than 2.0 ma and a "drop-out" of no less than 1.5 ma. Plug in the failsafe tube and place a current meter (10 ma scale) in the B plus line. With tone-on the failsafe relay should be open and the meter should read only the current from the first two stages, about 0.5 ma. With carrier, the meter should increase about 3 ma and the relay pull in smartly. With no signal the current will be about 2.5 ma and the relay pulled in. If this latter case is not met, try another 1AG4. When satisfied mark the tube and remove it. Plug in the rudder relay tube and try a 500 cps tone. The relay should open and the current stand near zero. With 100 cps tone the current should increase over 3 ma and pull in the relay. This completes the preliminary testing of the receiver. In particular, we have omitted the elevator section which requires the use of the 80/20 and 20/80 tone. Later the complete receiver checkout procedure using the final transmitter will be described.

The author would like to acknowledge the valuable assistance he has received in the development of this system from the DC/RC members as well as from RC friends over the country. They have contributed many improvements and have spent many hours as "guinea pigs" helping debug the early models.

The remaining diagrams along with helpful photos of the equipment will be presented in the next issue.

Elements of Dual Proportional system. Receiver in aluminum can and foam rubber vibration pads. Batteries, K-45 B and Silvercels. Motors for R&E; engine escapement.