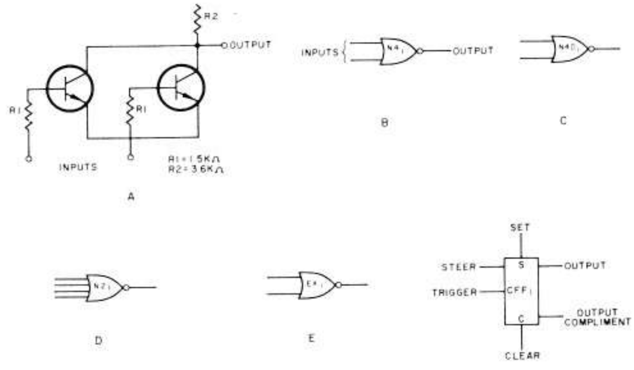
THOROUGHLY FLIGHT TESTED FOR ALMOST TWO YEARS, GARY P. FISHER'S MINI-QUAD PROPORTIONAL SYSTEM IS AN ARTICLE OF MILESTONE VALUE TO THE I.C. DESIGNER . . . ONE THAT WILL BE USED AS REFERENCE MATERIAL FOR SOME TIME TO COME.



LOGIC CIRCUITS
FIGURE 1

MINI-QUAD PROPORTIONAL

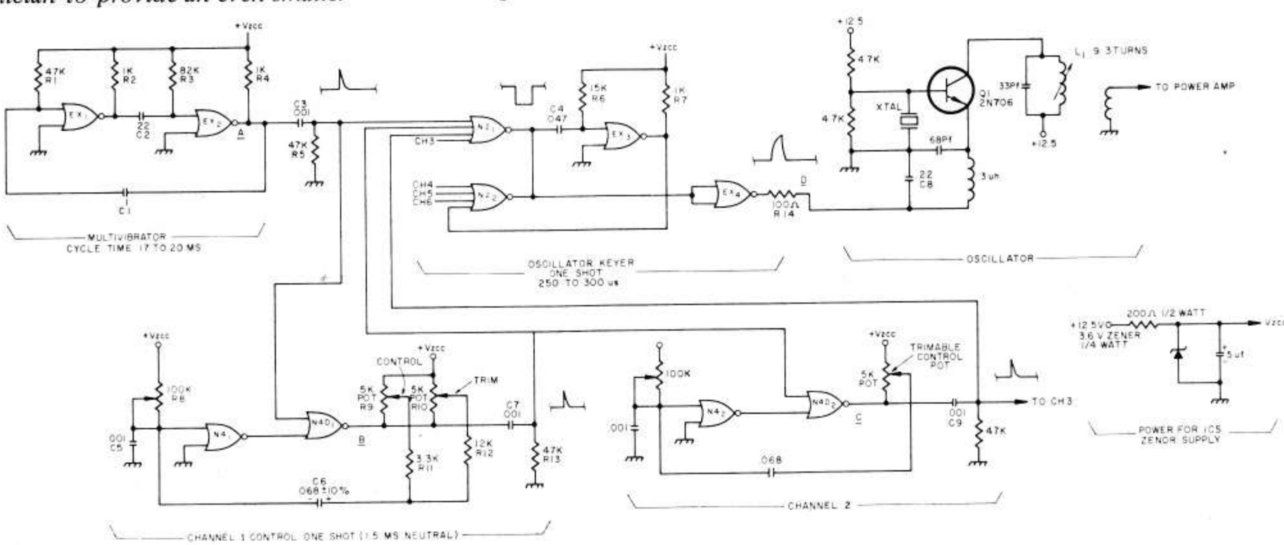
PREFACE

Tech Editor's Notes:

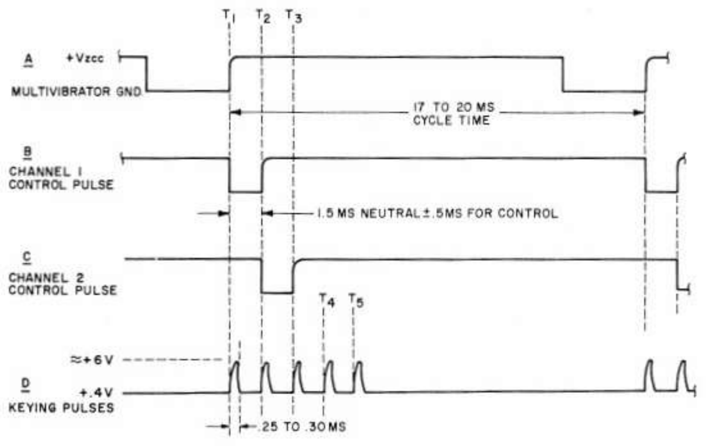
Here's an article describing an integrated circuit digital RC system that will undoubtedly be used as reference material by home-builders and RC manufacturers for some time. Mr. Fisher's article is unique in several respects. His design is based on low cost integrated circuits that are readily available. His design has been flight proven in almost two years of successful operation. Mr. Fisher's system has been thoroughly checked at RCM's technical facility and passed or exceeded all of the author's claims and is indeed an excellent system. The IC's used by Mr. Fisher can be substituted with 1/4" packages by the competent technician to provide an even smaller system. This, of course, will run the cost up slightly. Possibly the most important contribution this article will make to RC modeling is its reference value to the IC designer. The technical staff of RCM is proud to pass on to you what we consider an article of milestone value in the rapidly advancing technology of radio control systems.

It's true! Today's advanced digital RC systems do use integrated circuits. However, IC use has not been extensive in RC and consequently present systems have not realized the full cost advantages of IC's. In a design effort to bridge this gap of limited use, I took the digital logic designer approach of utilizing standard IC logic elements for all digital functions. This meant all IC's from the receiver output to the servo drive transistors in the airborne package and for all functions in the transmitter except RF.

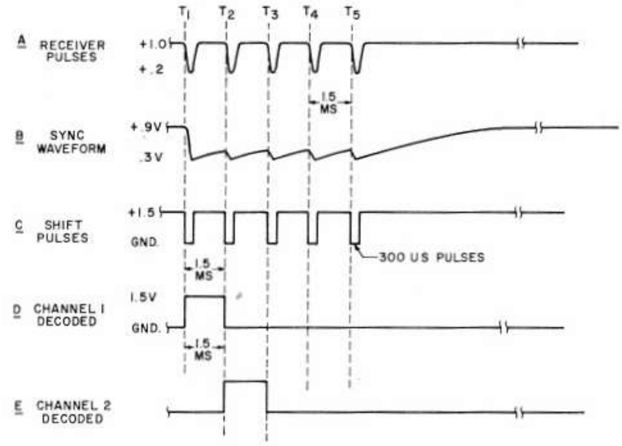
Of course the circuit development required and received the usual ingredients of much time, effort, frustration and money. And as usual I received the words of encouragement from the better-half like, "Why don't you give it up," and "you must be nuts to spend your time on that **thing**." But through it all I began to see light and realized that sure enough the **thing** was going to fit together and work like a digital system. The circuits do work and in the past 2 years I have built and tested two complete systems with excellent results. The first system was a six channel rig and the second a four.



TRANSMITTER LOGIC
FIGURE 2



TRANSMITTER TIMING
FIGURE 3



RECEIVER TIMING DIAGRAM
FIGURE 5

Some interesting post-project results on the second system were: 1. The total cost was $148.69; 2. the four channel receiver and servos weighed 11¼ oz.; 3. the system in terms of stability, servo resolution, response and power is one of the best I've ever seen; 4. the system performed flawlessly over a temperature range of 15° to 140° F (freezer to oven).

In this article, the logic circuits of MINI-QUAD will be presented. The transmitter RF amplifier and the receiver RF and IF circuits will not be covered as these portions of the system offer nothing new or unique to the reader.

The system operation is very standard employing a variable one shot in both the transmitter and receiver to generate the reference and comparison pulses respectively. If you're not familiar with a digital system's over-all concept, I suggest you read Ed Thompson's articles on the Digitrio or Classic in past issues of RCM.

Technical Description

Logic elements: The integrated circuits used (sometimes referred to as "little magic plastic spiders") and recommended are the Motorola MRTL, MC700P series integrated circuits. The circuit of figure 1A shows in detail one fourth of the MC717P quad 2 input gate. It is simply a resistor - transistor logic gate and is represented logically in figure 1B. 1B is a convenient way of representing the circuit of 1A without drawing the detailed circuit each time the gate is used. A positive level of .8 volts or higher applied to either (or any) of the inputs will produce an output of ground or logically speaking the gate will be "on". If both (or all) inputs are at ground, the output will be positive and the gate considered "off". Technically and logically that's all there is to it. Read the above three sentences again to make sure you've got it straight because from this point on the circuits will be presented as in fig. 1B, C, D, and E and referred to as being on or off. Fig. 1F is a type "D" flip-flop and will be covered later.

I'll make my point about the economy of IC's by letting you consider this. The circuit of figure 1A has a cost of 28 cents. In one MC717P at $1.08 there are four circuits just like it containing a total of 8 transistors and 12 resistors. Try buying the same quantities of components for that price.

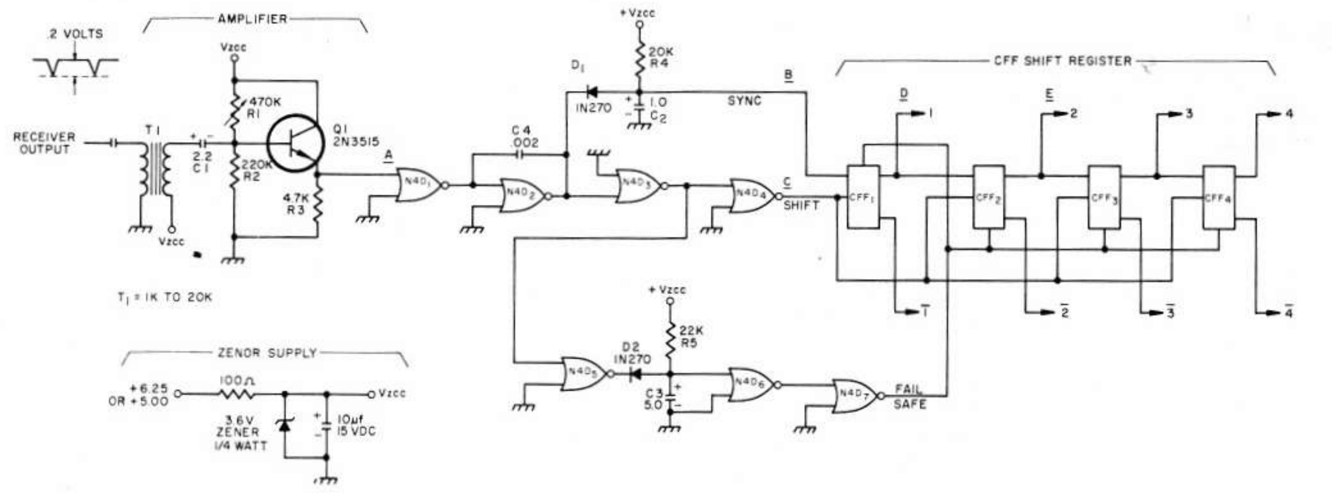
Other IC's used in the system are:

1C. Quad 2 input gate MC724P. This gate is identical to 1B except that the collector and input resistors have lower values. R1 = 450 and R2 = 640.

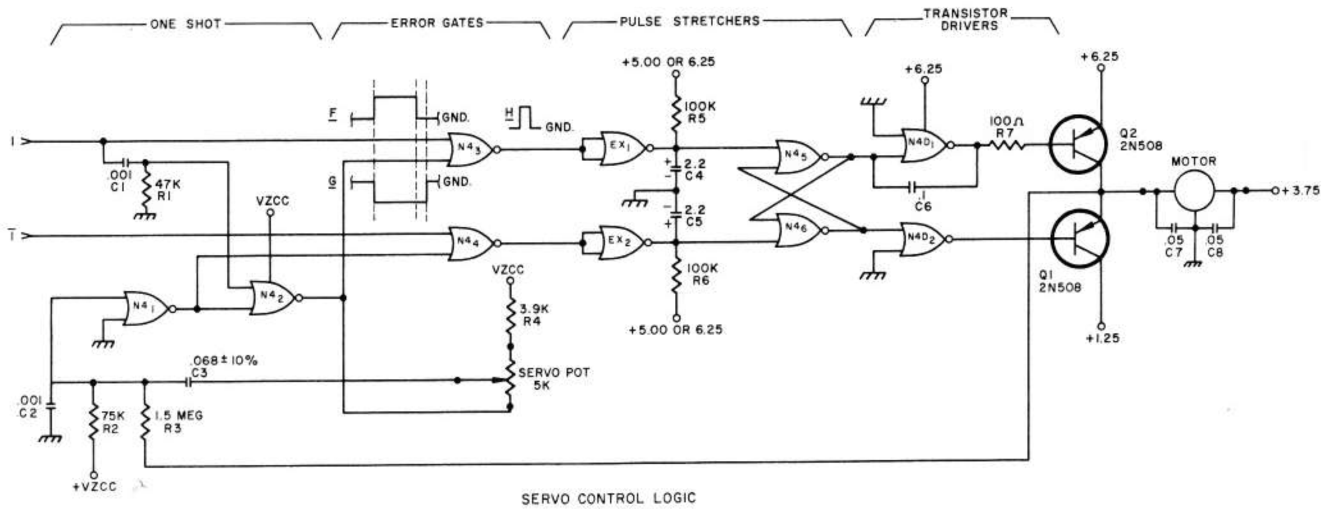
1D. Dual 4 input gate MC725P. Each gate has four inputs and each MC725P package contains two gates. R1 = 450 and R2 = 640.

1E. Quad 2 input expander MC785P. Each gate has two inputs and each MC785P package has four gates. R1 = 450. These gates have no collector resistors and are used in special circuits where a unique or no collector resistor is desired.

1F. Dual Type "D" flip-flop MC778P. Each package contains two clocked flip-flops. The details of the flip-flops operation will be covered in actual application when required for the



DECODER LOGIC
FIGURE 4



SERVO CONTROL LOGIC
FIGURE 6

decoder explanation.

Those of you who intend to build a system using these circuits must first obtain technical data sheets for the MC700P series IC's from Motorola, Semiconductor Products Inc., P.O. Box 955, Phoenix, Arizona. These sheets will provide such pertinent information as pin connections and loading factors.

Transmitter

The digital logic for a four channel transmitter (figure 2) consists of four IC's. One each N4, N4D, N2 and EX are used to construct the multivibrator, four control one shots and oscillator keyer one shot.

Multivibrator: The multivibrator provides the main timing base for the system and consists of two EX gates operating in a closed loop producing the waveform of figure 3A. To understand its operation we must consider its initial states when power is applied. At turn on V_{zcc} rises at a rate determined by the RC time constant of the Zenor supply. As V_{zcc} rises, EX_1 turns ON first because of the lower input resistance of R versus R2 to V_{zcc}. EX_1's ON condition (ground output) causes EX_2 to be held OFF temporarily (Pos. output). R2 continues to charge C2 and EX_2's input rises positive until EX_2 switches ON. This generates a negative transition that is coupled through C1 to EX_1's input turning it OFF. EX_1 remains OFF and EX_2 ON until C1 is charged sufficiently through R1 to turn EX_1 ON. EX_1's turn on forces EX_2 off and thus we have completed one cycle of the multivibrator. It will now continue to run EX_1 and EX_2 turning alternately ON and OFF until power is removed. The multivibrator's cycle time is determined R1C1 and R2C2.

Pulse trains are initiated each time EX_2's output makes the transition from ON to OFF (time T_1, figure 3). Coupling capacitor C3 passes this positive transition to the inputs of $N2_1$ and $N4D_1$ causing both gates to turn ON.

Oscillator keyer one shot: $N2_1$'s turn ON forces EX_3 OFF and EX_3 then drives $N2_2$ ON thus making a loop back to the output of $N2_1$. The keyer one shot will retain this condition until R6 charges C4 sufficiently to turn EX_3 ON causing $N2_2$ to turn OFF ending the keying pulse. The length of the keying pulse is determined by C4 and R6 and is nominally .25 to .30 milliseconds.

The actual oscillator keying (waveform D of figure 3) is done by EX_4. The oscillator in series with R14 form EX_4's collector load. When EX_4 is ON, it provides a current path to ground for Q1's emitter turning the oscillator ON. When EX_4 is OFF, no current path exists and the oscillator is OFF. C8 acts to shape the pulses at D giving a cleaner transmitted pulse. EX_4 has a current capability of 60 ma.

Control one shot: As the pulse through C3 at T_1 keys the oscillator, it simultaneously triggers the channel 1 control one shot by turning $N4D_1$ ON (waveform B). The switch ON produces a negative transition that is coupled to $N4_1$ through control pot R9, trim pot R10 and C6. This turns $N4_1$ OFF thus holding $N4D_1$ ON until R8 charges C6 enough to turn $N4_1$ ON again turning $N4D_1$ OFF. This positive transition at T_2 is coupled through C7 keying the oscillator and activating the channel 2 control one shot.

The time interval between T_1 and T_2 is determined by the width of the control pulse which is determined by the pulse magnitude coupled from $N4D_1$ to $N4_1$. Since the voltage distribution along pot R9 is linear, the pulse magnitude is a linear function of pot position. Moving the pot center tap toward the IC end will increase the control pulse width and moving the center tap toward the supply end will decrease it. R11 and R12 are used to provide isolation between the control and trim pots and also to determine the relative effect of each pot. R12 being approximately four times larger than R11 will allow trim pot R10 one

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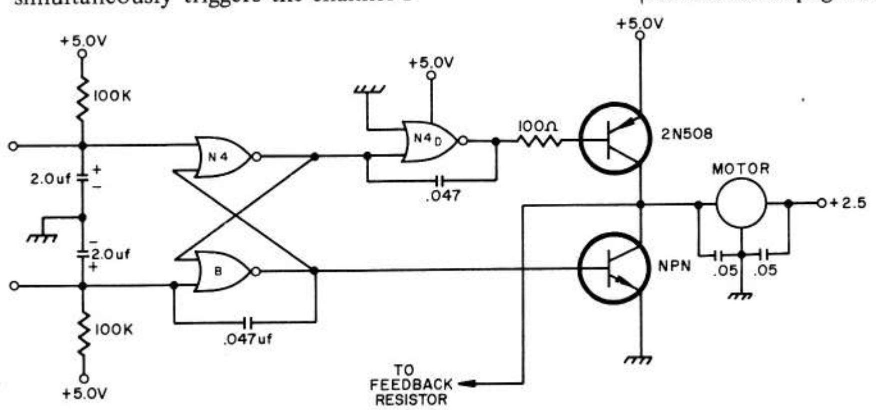
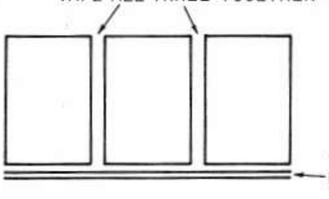


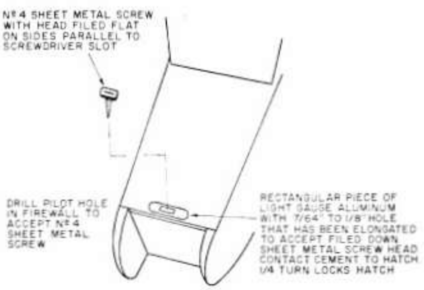
B IS A MC798P
DUAL BUFFER

SERVO DRIVE CIRCUIT FOR
FOUR BATTERY OPERATION
FIGURE 7

Donald Hansen, of Wichita, Kansas, uses Velcro Hook and Pile (Cockleburr) tape for mounting servos, as shown in the accompanying sketch. This also provides some cushioning effect. It is much stronger than double backed tape and can be separated 100,000 times. The cost of this material is $1.38 per yard in 1" width from the Hartwell Corp., 9035 Venice Blvd., Los Angeles, Calif. Don also uses it to secure hatch covers by contact cementing small pieces to the fuselage side and then locking the Velco tape together to hold the hatch in a closed position.



While on the subject of hatches, Jack Lang of Decatur, Ill., not being satisfied with rubber bands, dowels, hooks, for hatch hold-downs, came up with the following idea which is quite simple and efficient and is self-explanatory in the accompanying drawing.



MINI–QUAD

(continued from page 27)

fourth the control of pot R9 for the same pot movement. R8 is physically a miniature trim pot and is used to control the resolution of the control and trim pots. The higher the resistance setting of R8 the greater will be the change in the control pulse width per degree of pot movement. C5 provides noise immunity to the high impedance input of $N4_1$.

In operation, the pulse width is varied from 1.0 to 2.0 milliseconds with 1.5 milliseconds being neutral. However, due to the versatility that R8 adds almost any time combination can be achieved out to about 4.0 milliseconds.

Control one shot channel two: The circuit shown for channel 2 is for stick assemblies with trimmable control pots. This simplifies the one shot circuit because R11 and R12 of channel one are not needed. Waveform C, channel 2's control pulse, begins at T_2 and ends at T_3 generating another keying pulse through C9 and activating channel 3. Channel 3 produces the keying pulse at T_4 and activates channel 4. Channel 4's control pulse keys the oscillator at T_5 ending the transmitter's information cycle. The keying process is initiated again each time EX_2 turns OFF.

Expansion to six channels: Since the N2 contains inputs for channel 5 and channel 6, expansion to six channels requires the addition of only one N4 and its associated components.

Decoder

The decoder consists of four functional circuit groups: (1) An input amplifier that is a standard transistor circuit and acts as a buffer between the receiver's output and the first IC; (2) a sync circuit that provides the shift register with a sync input each time the transmitter sends a pulse train; (3) the shift register which decodes the receiver pulses and drives the servo control logic; (4) an optional fail safe that drives the motor servo to idle, or OFF, position if a failure occurs in the transmitter or receiver.

Amplifier: The receiver's output is coupled through the step up transformer T_1 (figure 4) to the base of Q1. Q1 provides the drive necessary for $N4D_1$ and also provides a D.C. bias point as determined by the setting of R1. When R1 is adjusted to give Q1 a D.C. output of 1.0 volts and Q1 receives inputs from the receiver, waveform A appears as shown in figure 5A. $N4D_1$, $N4D_2$, $N4D_3$ and $N4D_4$ all serve to amplify the signal from Q1, drive the sync circuit and provide the shift pulses to the shift register's flip-flops. C4 removes any RF or IF components from the shift pulses that might be passed by the receiver.

Sync circuit: The sync circuit determines when the transmitter's pulse train has been completed and provides this signal to CFF_1 readying the shift register for the next transmitted pulse train. Each receiver pulse turns $N4D_2$ ON (ground output) discharging C2 through D1 generating the waveform of figure 5B. During intervals when no pulses are received for 4 milliseconds or longer, R4 charges C2 sufficiently positive to **steer** CFF_1's top output positive when the first pulse of the transmitted pulse train is received. Confused? Well, now is the time to explain the CFF. The clocked flip-flop (CFF) is designed to store whatever level is presented to the Sync input (called steer input logically) when a transition from positive to ground is received on its shift input. This means that when CFF_1's sync input is positive (.8 volts or higher) and a negative transition is received at its shift input, CFF_1's output at 1 will be positive. If CFF_1's sync input is ground or lower than .6 volts and a negative transition is received at its shift input, CFF_1's output at 1 will be ground. In addition, CFF_1's bottom output (1) **will always be opposite in level to that at 1**.

Shift register (decoder): At T_1 (shown on figure 5A) CFF_1's sync input is positive when the negative shift pulse transition occurs (waveform C). This causes CFF_1's 1 output to go positive until the next negative sync transition at T_2. Notice that CFF_1's sync input is below .6 volts at T_2 therefore its 1 output goes to ground. Channel 1 is now decoded with the resulting waveform D exactly the same width as the originally transmitted channel one pulse.

At T_2 the sync input of CFF_2 is held positive by CFF_1 and the shift pulse at T_2 causes CFF_2's 2 output to go positive. The pulse at T_3 switches CFF_2's 2 output back to ground thus channel two is decoded (waveform E). Channel three is decoded by CFF_3 with shift pulses at T_3 and T_4 and channel 4 by CFF_4 at T_4 and T_5.

Fail safe: The fail safe is optional and functions much the same as the sync. When no pulses are received for 25 milliseconds, $N4D_6$ goes ON forcing $N4D_7$ OFF. $N4D_7$ drives CFF_1 set and CFF_2, CFF_3 and CFF_4 reset. This has the effect of driving the number one servo to one extreme and controlling the engine to idle or OFF.

Zenor supply: The Zenor supply shown in figure 4 provides a regulated voltage for the critical voltage points as shown. All IC's not shown directly tied to V_{zcc} are driven by a direct 3.75 volt battery tap or as shown on the diagrams.

Servo Control Logic

The servo control logic of figure 6 consists of a one shot ($N4_1$ and $N4_2$), two comparison gates ($N4_3$ and $N4_4$), two pulse stretchers (EX_1, $N4_5$, EX_2 and $N4_6$) and two transistor drivers ($N4D_1$ and $N4D_2$).

One shot: When channel 1 is decoded at T_1 the positive transition from CFF_1 is coupled through C1 to $N4_2$. This turns $N4_2$ ON providing a negative transition through C3 to $N4_1$. $N4_1$ goes off holding $N4_2$ ON until R2 charges C3 sufficiently positive to switch $N4_1$ ON. Waveform G on figure 3 is a typical $N4_2$ output. Since the one shot's pulse width is determined by the servo pot's wiper position, the pulse width is an electrical indication of the servo's mechanical output position. R4 provides the "narrow" pulse width limit of about 1 millisecond when the pot wiper is at the R4 end and can be selected to provide desired servo travel. C2 provides noise immunity to the high impedance input of $N4_1$.

Error gates: The one shot's pulse is compared with the decoded pulse by gates $N4_3$ and $N4_4$. Any difference results in an error pulse that provides corrective drive to the servo through the pulse stretcher, transistor driver and servo drive transistor. For the pulses shown on figure 3 the one shot pulse G is longer than the decoded pulse F presenting an input condition to $N4_3$ where both inputs are simultaneously at ground for the duration of the difference between the two pulses. This turns $N4_3$ OFF generating error pulse H. $N4_3$ remains OFF driving EX_1 ON until pulse G returns positive. If the **decoded** pulse had been longer than the one shot pulse, $N4_4$ would have generated the error pulse.

Pulse stretcher: EX_1 is turned on by error pulse H discharging C4. When the junction at R5 and C4 goes below .6 volts, $N4_5$ switches OFF driving $N4D_1$ ON. $N4_5$ remains OFF until R5 charges C4 sufficiently to turn it ON again. The pulse stretching effect comes from C4 discharging rapidly through EX_1 but recharging slowly through R5. This allows error pulses of .02 milliseconds to generate servo drive pulses of 5 milliseconds or more. $N4_5$ and $N4_6$ are interlocked so only one can be OFF at a time.

Transistor drivers: $N4D_1$ and $N4D_2$ provide amplification of the stretched error pulses and drive the servo drive transistors Q1 and Q2. Servo feedback is provided by R3 and prevents servo oscillation. C6 slows the switching speed of $N4D_1$ and limits switching noise.

Figure 7 shows an optional servo drive circuit for use with 4 batteries. If 4 batteries are used ALL IC's would receive their voltage from the Zenor supply.

Servos

I used the Graupner, Varioprop servos in both systems for the following reasons: (1) I was in Germany at the time of construction and these servos were available and cheap ($9.75); (2) they contain no circuits, only the pot, and the mechanics are small, light, powerful and efficient. The second reason is they were very compatible with the construction technique used as I consider it desirable that all electronics are in one package. This is so because the same IC package is shared electronically by two servos. Varioprop servos are not to my knowledge available in the USA, however, they can be ordered directly from Johannes Graupner, 7312 Kircheim/Teck, Germany. There are several American servos available without electronics that will work just as well. Actually I would like to see one produced under 1 oz. in weight and about 1.5 x 1.0 x 1.0 inches in dimensions. With servos of this size and the IC logic presented here, a four channel system should weigh around 10 ounces with batteries.

Construction: All circuits were built on fiberglas Vectorboard with holes on tenth inch centers matching the IC pin spacing. IC interconnections were made by wrapping No. 30 wire around the pins being connected, then soldering. Of course, printed circuits could be generated, however, to achieve good IC packing density the printed circuits could become difficult to lay out.

The transmitter's Vectorboard was 2¼ by 4¼ inches and had plenty of room for all circuits including RF.

All airborne circuits were constructed on three 2 x 3 inch Vectorboard cards. On card one, I constructed the receiver, sync, shift and fail safe circuits. Card two contained the decoder shift register, servo one shots, error gates and the EX half of the pulse stretchers. Card three contained the N4 half to the pulse stretcher, the transistor drivers and servo drive transistors. The cards are first individually constructed, then interwired and stacked making a package of 1¾ x 2 x 3 inches weighing less than 5 oz. This weight includes servo and battery connectors.

One hint I'd like to pass along is that some components can be mounted across the top of the IC's thereby conserving Vectorboard surface area.