

The REVERSER: Servo reversing for Y-cord operation

C. Brent Dane
AMA 345702

Summary

An inexpensive circuit the size of a postage stamp, as shown in Fig. 1, has been designed which reverses the direction of travel of a proportional servo. Its simple design using very commonly available electronic components makes it a great project for any RC modeler.

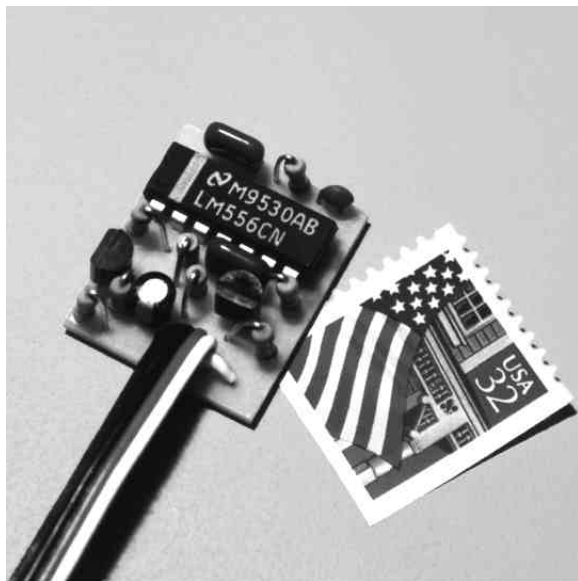


Fig. 1 Photograph of the finished servo reversing circuit.

Why a servo reverser?

"A servo reverser? You have to be kidding! Why would I need that?" If this is your first reaction to this article, you are certainly correct in pointing out that all but the very oldest RC radio systems allow the modeler to reverse the direction of rotation of a servo with just the flip of a switch or, in the case of the newest transmitters, with a couple of simple programming steps. Based on this, one might initially conclude that the need for servo reversing is gone forever. This, however, is certainly not the case. Highly maneuverable and aerobatic planes such as the Extras, Sukhoi, and Caps, just to name a few, are becoming increasingly popular with both the

competition and sport flyer. With the trend toward larger scales and more and more powerful engines, the need for reliable control surface actuation is more critical than ever. A very effective method of controlling highly loaded flying surfaces is to minimize the length and complexity of control linkages by mounting the servos very near the flying surfaces that they control. In the case of split elevators, a popular practice is to mount a servo directly into each side of the fuselage, just below the horizontal stabilizer. A typical installation is shown in Fig. 2. Both servos can then be driven from a single channel using a Y-harness extension cable. If the push rods are attached to the same side of the servo arm (i.e., top or bottom) then the servo motors must rotate in opposite directions for the same control input from the receiver. Therefore, one servo needs to be reversed with respect to the other.

One may be tempted to mount the servos at different vertical positions on each side of the fuselage. In this way the push rods can come off of opposite side of the servos, maintaining a relatively straight path to the elevator control horns. However, carefully comparing Fig. 2a and 2b reveals that this is not an acceptable solution since the two geometries do not provide equal elevator throw at the extremes of travel in each direction. The result is an induced twisting moment at elevator positions away from neutral which is a serious problem for a very roll sensitive aerobatic plane. The only alternative is to maintain mirror-image symmetry in the elevator control installation and force one servo to rotate in a direction opposite to the other. In other words, both control linkages should come off of the bottom of the servo (Fig. 2a) or the top of the servo (Fig. 2a). The control of split elevators is of course just one of a number of situations that could require servo reversing. Other Y-harness applications such as flap actuation and throttle control on multi-engine aircraft are other useful examples.

There are several ways to approach the task of reversing one servo. The first is to physically modify a servo to reverse its rotation. To do this, the servo must be taken apart and the electrical connections to both the motor and to the feedback potentiometer must be reversed. This procedure is often complicated by the fact that the motor can be attached directly to a

printed circuit board. Also, the motor is generally glued into the case for the more expensive ball bearing servos, sometimes requiring that the servo housing be broken away and then replaced. A second approach could be to attach each of the servos to separate channels of a programmable computer radio system. Using electronic mixing, one channel could be reversed and then slaved to the elevator channel. This seems like a great solution and indeed it will be when the manufacturers of our radios figure out the need for this type of dual servo control. However, if you try it now, you will find that the transmitter trim lever, in all of the radio systems that I am aware of, will affect only the master servo, leaving the slave servo unchanged. Finally, a third option would be to insert an electronic device in between the Y-harness and one of the servos which would intercept the electronic control signals and convert them to those necessary to drive the servo in reverse. This is the solution presented here.

Of course, the concept of an in-line electronic servo reverser is not a new one. These can be purchased from a number of RC manufacturers and generally work pretty well. The purpose of this article, however, is both to illustrate the important role that these devices still play in RC modeling and to present a simple, inexpensive design that can be readily built by most modelers. A fairly significant shortcoming that is shared by most commercially available reversers is the use of an onboard centering adjustment. This usually takes the form of a carbon film potentiometer which is particularly susceptible to temperature drift. This can cause unwanted changes in trim for the reversed servo as the ambient temperature changes. This is avoided in this design and will be a topic of further discussion later in the article.

Theory of Operation

To understand how the electronic servo reverser works, it is first necessary to review the control signals sent from the receiver to a servo. There are three wires connecting each servo to the receiver. The first two supply the plus and minus voltage from the battery pack and are often red and black, respectively (see Table 3). The third wire carries pulses which direct the motion of the servo. These positive pulses

occur at a rate of about 60 per second and vary in width between about 1 and 2 ms (milliseconds, or thousandths of a second). A pulse width of 1ms sends the servo output to the limit of rotation in one direction and 2ms to the limit in the other. For example, the pulse width supplied to a servo near the center position is approximately 1.5 ms. A servo reverser must therefore convert a 1ms pulse to 2ms and a 2ms pulse to 1ms. A 1.5ms pulse should remain approximately unchanged. A very nice way of doing this is to generate a 3ms reference pulse and then subtract the duration of the incoming pulse from this reference pulse in order to produce the output pulse. Mathematically, this is simply $T_{out}=3-T_{in}$ where T_{out} and T_{in} are, respectively, the duration of the output and input pulses in milliseconds.

The REVERSER circuit is based on the very common and easily available 555 timer chip. Actually, the 556 version is used, which is two independent 555's in a single 14 pin package. An approximate description of the REVERSER is that the first half of the 556 is used to generate the 3ms reference and the second half performs the previously described pulse width subtraction operation. Fig. 3 shows the schematic of the servo reverser design and Fig. 4 presents a timing diagram useful for understanding how it operates.

Servo motors tend to draw current in many small "gulps" lasting only 1-2 milliseconds each. This places a small ripple on the receiver battery voltage when a servo is in motion. This is particularly noticeable when using high torque ball bearing servos. Although the REVERSER will continue to work over a wide battery voltage range without trim changes, if these rapid voltage fluctuations are not filtered, they could occasionally cause a small amount of mechanical chatter to be observed on the servo output when another servo is moved. This, in addition to the previously mentioned temperature drift, has been a common complaint associated with some commercially available designs. Referring to the schematic shown in Fig. 3, resistor R1, capacitor C1, and transistor Q1 form a filtered voltage source which supplies the entire circuit and suppresses any rapid voltage flutter. Resistor R2 acts as a current limit to protect Q1 in the case of an accidental short circuit.

In describing the operation of the servo reverser the two halves of the 556 dual timer will be referred to as timer 1 (pins 1-6) and timer 2 (pins 8-13). Each incoming pulse from the receiver (Fig. 4a) is inverted by transistor Q2. When the signal goes high, the npn transistor conducts, dropping the supply voltage to zero across resistor R5. R3 limits the transistor base current and R4 assures that the transistor current shuts off cleanly at the end of the pulse. The falling leading edge of this inverted pulse (Fig 3b) triggers timer 1. This opens the discharge pin 1 and capacitor C2 begins to charge through resistor R6 (Fig. 4c). Under normal circumstances, C2 would continue to charge until a voltage of $\frac{2}{3} V$ is reached at the threshold pin 2. This would produce an output pulse whose duration is given by $1.1 \times R6 \times C2$ which in this case is set very near 3 ms. However, the voltage at control pin 3 of timer 1 is raised above its normal value of $\frac{2}{3} V$ by R7. This same charge signal (Fig. 4c) is also applied to the threshold pin 12 of timer 2. Its control pin 11 is sitting at the normal $\frac{2}{3} V$ causing the output of timer 2 to shut off at the end of the 3 ms interval. The input pulse from the receiver is also passed through a high pass filter (R8 and C4) generating a falling edge at the end of the pulse (Fig. 4d) which triggers the output of timer 2. The output of timer 2 (Fig. 4e) is therefore exactly the desired signal: it begins at the end of the input pulse and finishes at the end of the 3 ms reference period. Its duration is $3 \text{ ms} - T_{in}$.

It is important that the high pass filter on timer 2 trigger is referenced to $\frac{2}{3}V$ from pin 11 of timer 2 rather than to the full supply voltage. This is due to the much discussed and often misunderstood "PCM problem." Many PCM receivers operating on a standard 4 cell NiCd battery pack have output control pulses with an amplitude of less than 3V. In this case, if the filter is referenced against the full battery supply voltage, the resulting falling edge at the end of the pulse does not go below the threshold of $\frac{1}{3}V$ required to trigger the timer. Biasing the filter at $\frac{2}{3} V$ ensures that the triggering level is reached even for lower amplitude pulse trains. A second point is that R7 is theoretically not required since without it, one might reason that the charging signal would reach threshold for both timers simultaneously, shutting them off together. In practice this is not a good idea since if timer 1 happened to shut off just ahead

of timer 2, the charging voltage would fall to zero and the output of timer 2 would then never shut off. For this reason, R7 makes sure that timer 2 always reaches threshold well before timer 1.

Finally, what about a centering adjustment? As stated earlier, most commercial units include this feature at the expense of trim settings that may vary excessively with changing temperature. I chose to use a fixed value of 274k for R6 believing that to provide an adjustment would be redundant to the centering method (electronic trim or mechanical adjustment) that would have been used if the servo reverser circuit were not in place. The great advantage is that a fixed setting allows a 1% metal film resistor to be used which has excellent temperature stability. To verify this, I built a version of the circuit with both a metal film resistor and a standard 5% carbon composite resistor. I carefully wrapped each circuit in plastic cling wrap tied off tightly with a rubber band around the electrical leads. The circuits were alternately placed in hot water at 130°F and a salted ice slurry at 30°F. The input and output pulse widths were digitally measured using a Radio Shack Pro-Servo Master.¹ After letting the temperature of the circuits stabilize in each bath, I found that the output of the version with the metal film resistor varied by less than 0.5% over this 100° temperature range. The pulse width from the reverser circuit with the carbon resistor varied by more than 4% (almost 10 times worse) which could constitute a significant and noticeable change in trim even over smaller temperature ranges! A carbon film adjustable potentiometer, such as those sometimes found in other reversing circuits, would certainly have behaved even worse although I did not perform this test.

Fig. 6 presents the results of the measurements for the temperature stabilized version. The graph shows the output pulse width versus the input pulse width. As can be seen, the REVERSER has a very linear response over the entire servo control range. The measurements at 30°F and 130°F are also shown in the data table.

Construction

An important goal during the design of this circuit was to be able to completely build it from components that can easily be purchased at an

electronics supply such as Radio Shack.² I was successful except for one component: resistor R6 which is a 274k 1% metal film resistor. Even so, this should be easily obtained from another local electronics supply. Table 1 is a complete parts list with the Radio Shack catalog numbers and quantities required. Note that the resistors are sold in packets of 5 so that the builder will have some left over. Fig. 5 is an exact size pattern for the printed circuit board. The best way, I believe, of making this board is with a product called "Press-n-Peel."³ It is a blue plastic film which can be run through a conventional photocopy machine or printed onto directly with a laser writer computer printer. Following the instructions supplied with the film, the image in Fig. 5 should be copied onto the dull side. It is then ironed onto a copper clad board (Radio Shack 276-1499) using a household or your airplane film sealing iron. When experimenting with the best temperature, I found it useful to securely tape the film to the board along one edge. I could then carefully peel back a small portion to test the adhesion of the pattern to the board. If the transfer was incomplete, the film was let back down and additional pressure at a higher temperature used.



Fig. 8 Photograph of the assembled servo reversing circuit from the trace side of the printed circuit board.

After successful image transfer, the board is etched in a solution of ferric chloride (Radio

Shack 276-1535) for 30-60 minutes or until all of the unwanted copper is gone. Note that the blank board is two-sided so the copper will be completely removed from the back side. This board is large enough to simultaneously make up to 20 printed circuit boards. After etching, the mounting holes should be drilled with a #65 drill bit. This is easily accomplished since the copper surrounding each hole location accurately guides the drilling. Those modelers interested in building a circuit but who do not want to manufacture a PC board or need the 274k resistor may contact the author. Alternatively, a complete unassembled kit, minus servo connectors, can be obtained.⁴

Fig. 7 shows a schematic of the installation of the components onto the board. They should be inserted from the side opposite from the copper circuit pattern. Table 2 is a list of the components with their required values. All of the resistors should be mounted vertically as shown in the photograph in Fig. 1. Pay special attention to IC1, C1, Q1, and Q2 since the direction they are installed is very important. Capacitor C1 should have one lead marked with a "+" or a "-." Carefully solder the installed components to the copper circuit pattern, taking care to avoid solder bridges across gaps between the traces. Be sure to use a good quality resin core electronics-grade solder and brighten the copper traces with fine steel wool or a scotch-brite pad before starting. Advice and/or instruction from a fellow modeler with circuit assembly experience could be useful here. Fig. 8 shows the completed soldering job on the trace side of the board. The excess resin left from soldering can be easily removed with a solvent such as lacquer thinner (I use K&B Superpoxy thinner since that's what I have in my shop) and an epoxy brush with the bristles cut back to 1/4". Input/output leads can be obtained by cutting a servo extension cable appropriate to your particular radio system in half. Table 3 summarizes the wire color codes typically used for some common radio systems. Using Fig. 7, carefully attach the leads according to this chart. Note that wires from both the input and output leads are attached at points A and B. Airtronics⁵ users should be cautioned that the V+ and V- wires are reversed in the servo harness from those for Futaba,⁶ JR,⁷ and RCD⁸ radio systems. Since the Airtronics harness has two wires of the same color (black), carefully note

which one is denoted as the center wire in Table 3.

Installation and operation

To use the REVERSER, the circuit is simply plugged in between the receiver (or one arm of a y-harness) and the servo. A nice touch is achieved by sliding the finished circuit into a short length of 1" heat shrinkable tubing. Be careful not to overheat the circuit when shrinking. If desired, a second set of output leads can be attached to points A, B, and C, resulting in a built-in Y-harness. I like to wrap the finished circuit in a layer of 1/4" latex foam held with a couple of rubber bands to shield it against engine vibration.

The author

Brent Dane has been an AMA member and an R/C model pilot since 1990. He is a member of both the Livermore Flying Electrons and the East Bay Radio Controllers, two AMA sanctioned clubs which have flying fields near Livermore, CA. Brent is a physicist in the laser program at Lawrence Livermore National Laboratory. For answers to questions or for additional information about the REVERSER, Brent can be contacted on the internet at e-mail address cbdane@pacbell.net or visit his web site at <http://www.cliftech.com/>.

End notes

1. Radio South, 3702 N. Pace Blvd., Pensacola, FL 32505, (800) 962-7802.
2. Radio Shack, a Division of Tandy Corporation, Fort Worth, TX 76102
3. Press-n-Peel is manufactured by Techniks and can be ordered from All Electronics Corp., Van Nuys, CA 91411, (818) 997-1806. All Electronics Corp. is also an alternate source for the electronic components required for the GOSLOW.

4. To receive an etched printed circuit board, send a check or money order for \$10.00 per board to Brent Dane, 678 Crane Ave, Livermore, CA 94550. A complete unassembled kit without servo connectors can be obtained for \$15.00 (includes postage and handling). If you simply need the 274k 1% resistor, send a self-addressed stamped envelope (SASE) to the above address and one will be sent at no charge.

5. Airtronics Inc., 11 Autry, Irvine, CA 92718; (714) 830-8769.

6. Futaba Corporation of America, P. O. Box 19767, Irvine, CA 92713-9767.

7. JR Radio Control Systems, Horizon Hobby Distributors, Inc., 4105 Fieldstone Rd., Champaign, IL 61821.

8. Hitec/RCD, 10729 Wheatlands Ave., Suite C, Santee, CA 92071; (619) 258-4940.

Table 1

# parts	Description	Radio Shack	Digi-Key
1	47 resistor	271-1105	47QBK-ND
3	10k resistor	271-1335	10KQBK-ND
3	47k resistor	271-1342	47KQBK-ND
1	274k 1% metal film resistor	N/A	274KXBK-ND
1	470pF ceramic disk capacitor	272-125	P4045A-ND
2	.01 μ F PC-mount capacitor	272-1065	P4513-ND
1	22 μ F radial-lead electrolytic capacitor	272-1026	P960-ND
2	MPS2222A npn transistor	276-2009	PN2222-ND
1	556 dual timer	276-1728	LM556CN-ND

Table 2**Resistors**

R1	10k	brown, black, orange*
R2	47	yellow, purple, black
R3	10k	brown, black, orange
R4	47k	yellow, purple, orange
R5	47k	yellow, purple, orange
R6	274k	red, purple, yellow, orange**
R7	10k	brown, black, orange
R8	47k	yellow, purple, orange

Capacitors

C1	22 μ F
C2	.01 μ F***
C3	.01 μ F
C4	470pF****

Transistors

Q1	MPS2222A
Q2	MPS2222A

* The last resistor color band is gold for $\pm 5\%$ resistors.

** The last resistor color band is brown for $\pm 1\%$ blue resistors.

*** .01 μ F capacitor is labeled 103.

**** 470pF capacitor is labeled 471.

Table 3

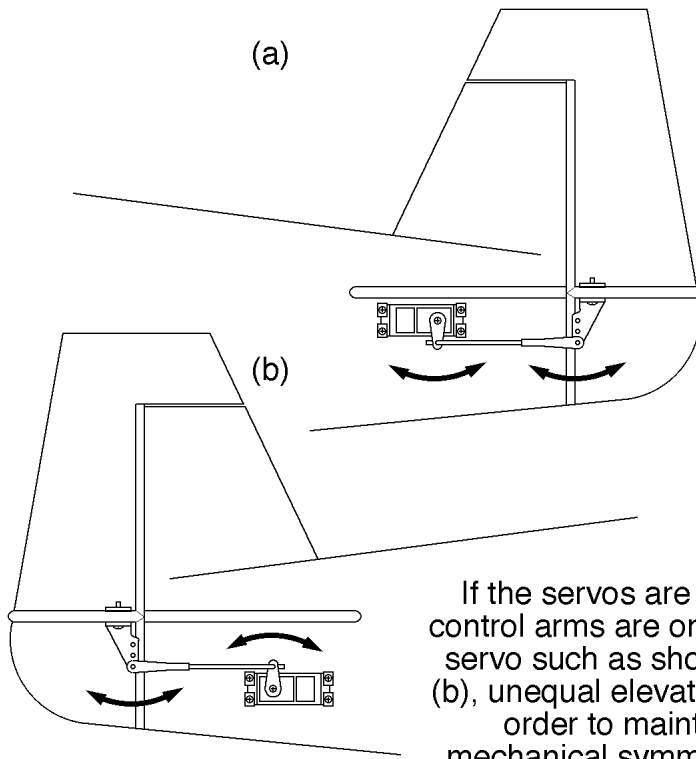
Manufacturer	Positive voltage (B)	Negative voltage (A)	Signal (C, D)
Airtronics	black / red	black (center wire)	black
JR	red (center wire)	brown	orange
RCD/Hitec	red (center wire)	black	yellow
Futaba	red (center wire)	black	white

Servo Reverser updates

1. There is a small but very significant type setting error in the Model Aviation article. In Table 2, the value of resistor R2 is listed at 47k. It should read 47. The color codes describing this resistor are correct and should be followed.
2. The Model Aviation article describes a 270k 1% metal film resistor. I have updated the design to a 274k resistor. This value is more commonly available (I purchase it from DigiKey Corp.) and also comes closer to providing an exact 3ms reference pulse.
3. I have found that the ultimate temperature stability results from using not only a metal film resistor for R6 but also a polypropylene film capacitor (instead of the more common polyester film) for capacitor C2. This is the capacitor that I am supplying in the kit and for best results, I have decided to throw one of these in the envelope for everyone requesting a resistor. If you receive one of these and feel generous, drop me a dollar in the mail. Otherwise, please enjoy.
4. In the text of the article, it is explained that a complete kit, without servo leads, is available from the author. However, the reference at the end of the article states only that a "complete kit" is available. I hope that there is no confusion and that it is clear that I do not supply leads with the kit. I cannot of course anticipate what style connectors you would require and it would be difficult to keep all the different varieties in stock. As explained in the article, leads can be obtained easily by cutting an aileron servo extension in half.
5. I want you to succeed in assembling the REVERSER circuit. For this reason, just as with the GOSLOW last year, I will debug any circuits that I receive which you have been unsuccessful at making work. Please give it a good try before giving up and dropping it in the mail. If you find that you absolutely need for me to look at it, return postage would be greatly appreciated.
6. Although I receive many requests, I cannot provide any assembled and tested circuits. Between a very demanding job and three wonderful young children, I have chosen not to build any circuits and will remain firm in this decision. If you would like a REVERSER circuit, I would encourage you to try to assemble one. I believe that you will find that it is much easier than you perhaps have guessed!
7. To download much more complete plans, instructions, and theory of operation than what appeared in Model Aviation, refer to web site <http://www.cliftech.com/>.

C. Brent Dane
cbdane@pacbell.net

Figure 2



If the servos are installed so that the control arms are on opposite sides of the servo such as shown in figures (a) and (b), unequal elevator throw will result. In order to maintain mirror image mechanical symmetry, one servo must be electronically reversed.

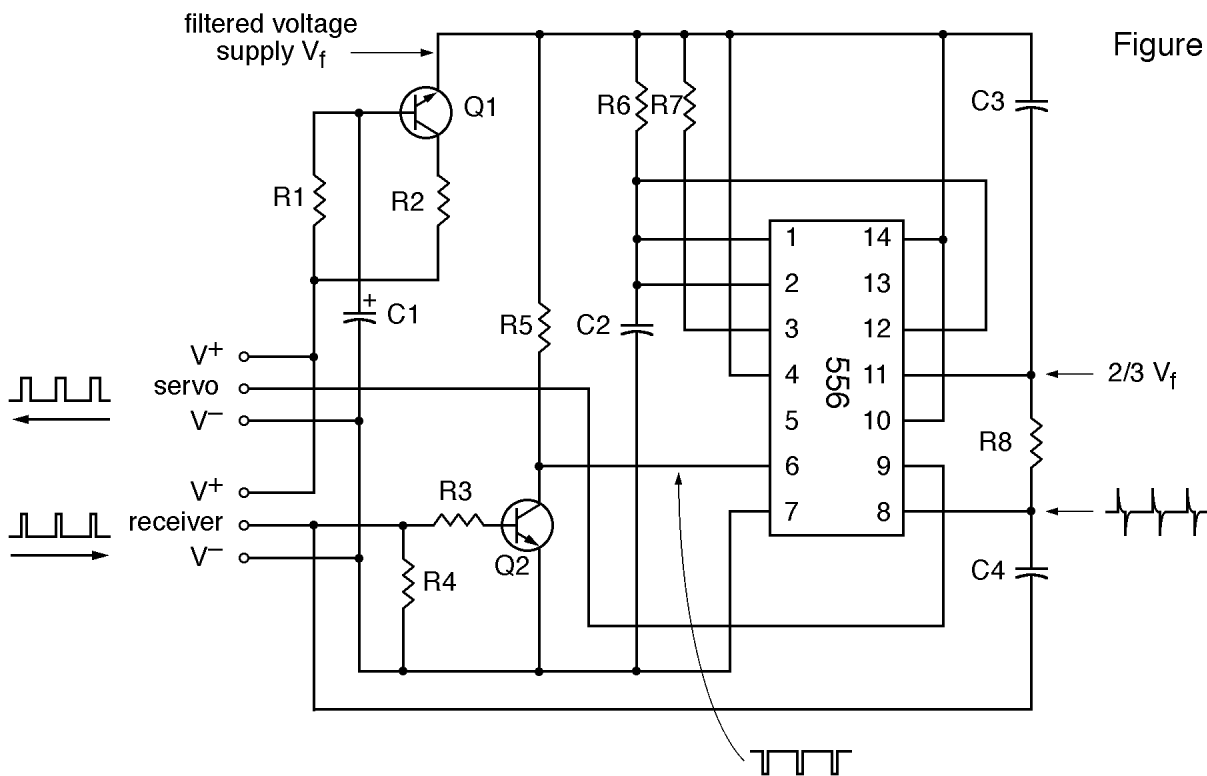


Figure 3

Timing diagram

Figure 4

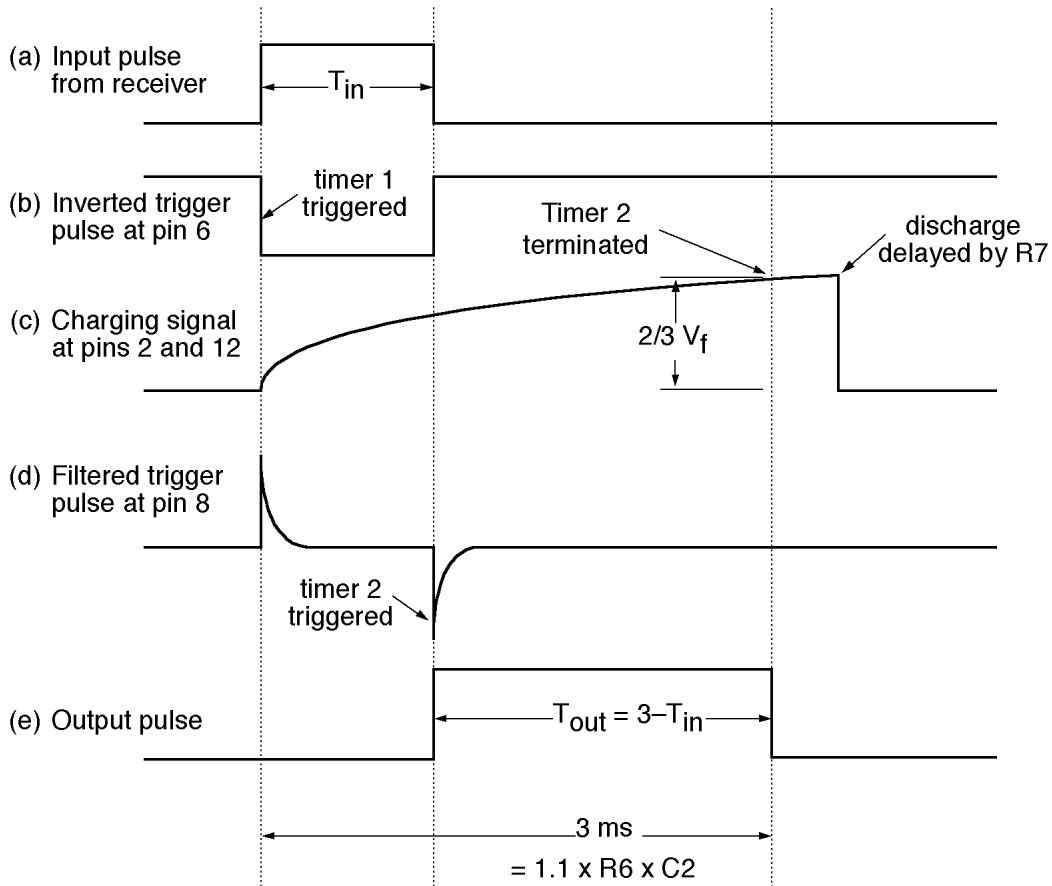
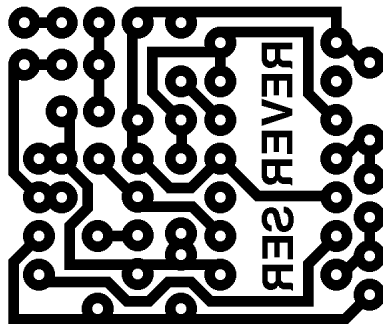
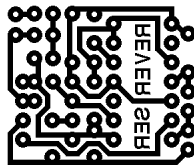
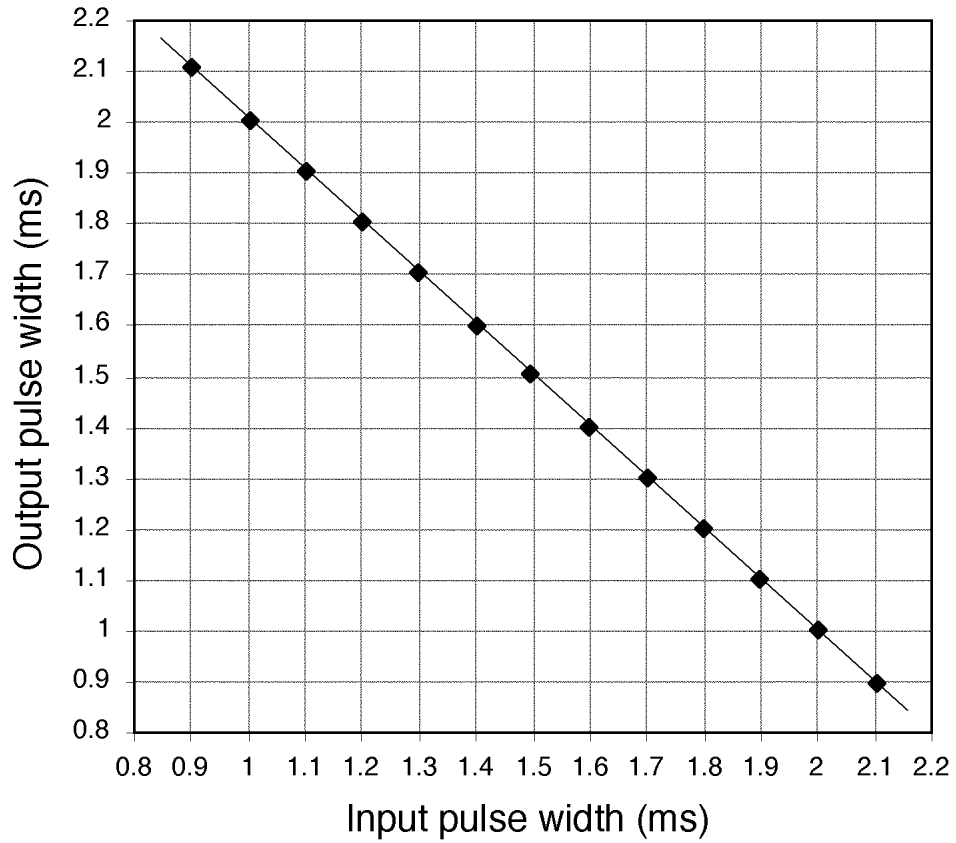


Figure 5



2X enlargement

Figure 6



30° F		70° F		130° F	
Input	Output	Input	Output	Input	Output
1.002	2.001	0.901	2.104	1.002	2.008
		1.005	2.000		
		1.106	1.899		
		1.203	1.801		
		1.303	1.701		
1.501	1.498	1.406	1.597	1.504	1.504
		1.500	1.503		
		1.603	1.399		
		1.702	1.299		
		1.801	1.200		
2.005	0.994	1.902	1.099	2.003	1.001
		2.002	0.998		
		2.106	0.894		

Figure 6

