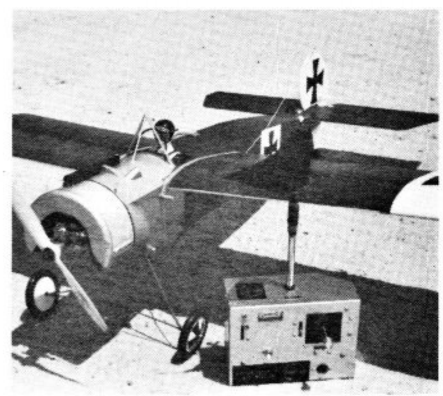
General

Since silicon-controlled switches (SCS) are not found at every corner drugstore, and have just recently found application in the R/C field, I'll attempt to give a basic rundown of how they work. First off, here's a few things of interest.

1. They are not silicon-controlled rectifiers (SCR).
2. They are not new devices.
3. They do not possess magical powers. They have design characteristics that must be considered for proper operation.
4. They are not integrated circuits. They are simply four-layer devices — essentially a diffused base transistor with a third junction.
5. They are versatile devices that can perform a myriad of functions such as a sensitive voltage level detector, bistable memory element, ring counter stage, time-delay generator, pulse and tone generator, relay or motor driver — they can also be used as an SCR.

Since SCR's haven't been given more than cursory attention in the model press I'll start with them and work up to the SCS's (besides, it's easier that way). The SCR is a four-layer device that has the ability to block applied voltage in either direction. In other words, with the device connected in a circuit, such as figure 1a, and with voltage applied it will, in its "off" condition, block current flow and not allow the relay to operate. This is an important characteristic of an SCR but hardly makes it a useful device as



RCM Art Editor Bob Dance's Eindecker and Digitrio. WW I craft is actually a highly modified Falcon. Rig works, despite the fact that Fearless Leader built it!

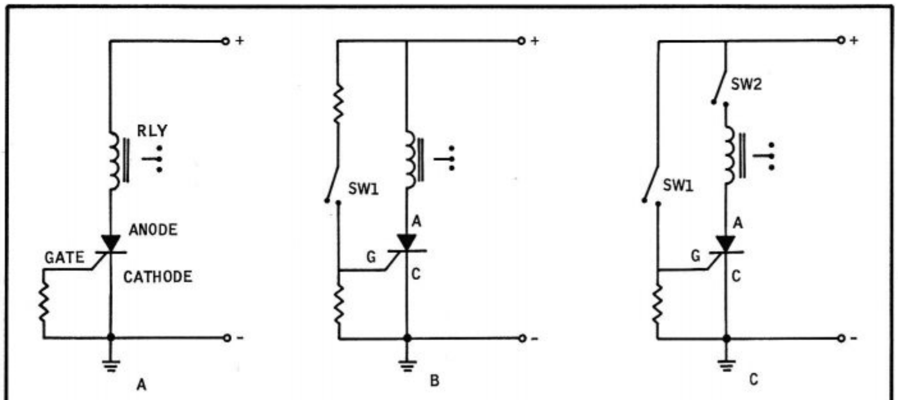


FIG. 1

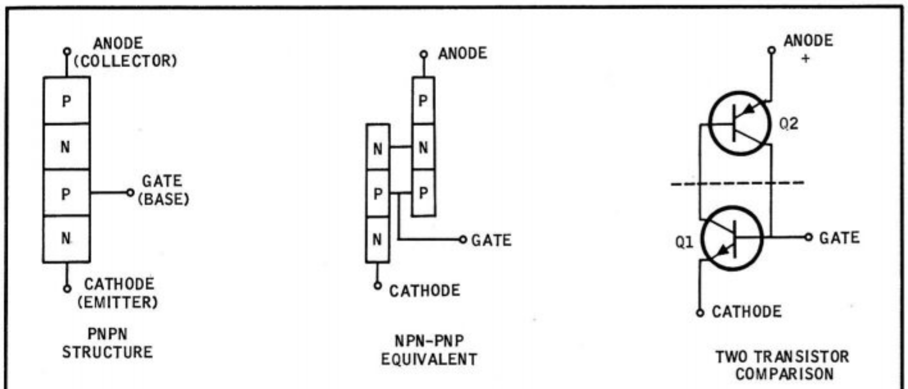


FIG. 2

yet. In order to make it useful we must be able to cause it to draw current through the relay and close the contacts. Figure 1b shows how this can be accomplished. When the switch is closed the SCR will conduct and current will flow through the relay. Here's the selling point to the SCR's existence; when the switch is opened and voltage is removed from the gate it will not cease to conduct. In fact, it will continue to conduct forever if we don't disturb the circuit. It won't do any good to apply a negative voltage to the gate as it has lost control of the device. The only way we can turn the SCR off is to remove the applied voltage. Figure 1c shows a switch in series with the anode voltage that will accomplish this. Let's recap: Once an SCR is "off" or "blocked" it will remain in that state until we apply a forward-biasing voltage to its gate. When we cause an SCR to conduct it will continue to conduct without necessity to maintain forward bias on the gate. In fact, the gate looses all control of the device and we cannot turn it off with reverse bias applied to the gate. The only way the SCR can be turned off is by removing the applied voltage to the circuit. What I have said so far applies to the circuit of figure 1 and should satisfy the average person. To explain a little further for the experimenter it will be necessary to "dig" a little deeper. The SCR is like a rectifier except we can control the "turn-on" by external circuitry. Conduction will continue until the current flowing through the device falls below the "holding current" (I_H). When this happens the device reverts to its "off" state and the gate is again ready to exercise control. This makes the SCR a solid state equivalent to a vacuum tube thyratron.

In order to grasp the turn-on mechanism the SCR can be compared as an NPN and PNP transistor interconnected to provide positive feedback. Figure 2 shows this comparison. Note that the anode, gate and cathode are analogous to collector, base, and emitter respectfully. When the anode is positive, with respect to the cathode, the center junction (corresponding to the two collectors and shown by the dotted line) will be reverse biased as long as neither transistor is conducting and the loop gain is below unity. In this condition the anode to cathode current (I_A) is, for all practical purposes, nil and the device is in its blocking state. It will remain in this state until we cause the loop gain to equal or exceed unity, whereupon it will become regenerative and conduct. Since the conducting state is regenerative the device will turn on at a speed determined by the effective frequency response of the two transistors and current will be limited by the effective saturation resistance of the two devices and the external circuitry. To clarify the regenerative action of the transistor pair assume that the device is in its blocked state and we have just applied a small positive voltage to the gate. This will cause conduction of Q1 which will create a small current flow from the anode through the emitter base junction of Q2 down through collector of Q1 to the cathode. The current flow we caused at Q2's emitter base junction forward biases Q2 and causes it to conduct heavily. This heavy conduction provides a path for Q2 to cause current flow between the emitter base junction of Q1 forward biasing Q1. We no longer need the gate voltage we previously applied to start things off as the collector current flow will sustain conduction.

Let's try again and see if we can condense the operation down to a few sentences. The collector of the NPN transistor drives the base of the PNP transistor and the collector of the PNP transistor drives the base of the NPN transistor. This forms the positive feedback loop and it will have a gain equal to the product of the two transistor gains. The circuit will remain blocked as long as this gain is less than unity and becomes self-regenerative when the loop gain reaches unity. When a positive current is introduced to the gate the NPN transistor conducts. The gain rises with increased current flow and a point will be reached where the loop gain becomes unity and the device will become regenerative. The transistors will drive each other into saturation and the device conduction becomes independent of trigger current. It will remain in conduction until the loop gain is reduced to less than unity. That's the third time I've explained how it works and you're probably growing weary of details. Why don't you read through it again (this time with feeling) and stop at the explanation that fills your needs. If you're the type that needs math for a super-detailed analysis, I recommend Book B-7954 entitled "Silicon-Controlled Rectifier Designer's Handbook" by Westinghouse. The address is Westinghouse Electric Corp., Semiconductor Division, Youngwood, Pa. The cost is $2.00.

Well, now that you understand all about SCR's, and are saying to yourself how you knew it all the time, let's go on to SCS's and see what the difference is between the two devices. To start with, the basic difference is that an SCS cannot only be turned on by a positive current at the gate it can also be turned off with a negative current applied to the gate. Figure 3 shows two circuits with some waveforms.

A is an SCR and B is an SCS. As you can see, the SCR turns on at the leading edge of the first positive going pulse and continues conducting even though the input alternately goes positive and negative. This was explained before and is due to the fact that the gate lost control of the SCR. The only way to turn it off is to remove the voltage to the circuit.

The SCS, on the other hand, turns on at the leading edge of the first positive going input pulse and turns off at the trailing edge when it goes negative. It turns on when the input goes positive and turns off when the input goes negative. The output therefore follows the input with a 180 degree phase difference. To achieve turn-off without removing circuit voltages we must adhere to the "holding current" characteristics of the four-layer device. Holding current (I_H) is described as the minimum anode current at which the device will **not** turn off under specified circuit conditions and temperature. Assume that (I_H) for our circuit is 1 MA and in its "on" state the SCS is drawing 5 MA. It's obvious that we could disconnect the anode lead and the current would drop to 0 MA. This would drop the anode current (I_A) below the (I_H) and the device would "turn off." Remembering that we can control the "on" and "off" state of the SCS, it is also obvious that we will be lowering the (I_A) below the (I_H) by the application of reverse bias to the gate. That is the selling point for the existence of the SCS. We can control both the "on" and "off" state of the SCS by application of either forward or reverse bias to its gate without the necessity to sustain the bias for operation in either state.

The foregoing discussion concerning the inability of the SCR to "turn off" with reverse gate bias is theoretical in nature and based on manufacturer's literature. The gain may be reduced below the regenerative point if enough reverse current can be applied. At high anode currents this would not be practical, and even at low anode currents special circuitry would probably be required for consistency. On the other hand the SCS was deliberately designed to be "turned off" with the application of reverse gate bias. The reason for the difference in operating characteristics of the two devices is in their inherent design and they are controlled during manufacture to operate in the different manners I have described. It is beyond the scope of this article to go into all the different parameters of either device or to include typical circuits which could give a better understanding of how they work. If you are interested in digging further into theory or application I suggest you start with the General Electric Transistor Manual. The manual is available at most all electronic, radio, and TV parts outlets.

Before I go on with the decoder, I would like to mention that the particular SCS used is a General Electric 3N84. This SCS has two gates which are designated as (G_C) and (G_A). (G_C) is the gate closest to the cathode and the one used in the foregoing discussion. (G_A) is a gate connected to the collector of Q1 (figure 2). It provides an additional control of the device in basically the same manner as the one we discussed. However, it requires more power and opposite polarity to accomplish the job we will require from the device. The gate we will be using is effective at the current levels used in the decoder and during constructions we will clip the (G_A) lead off. The (G_A) lead is not shown on the schematic for clarity.

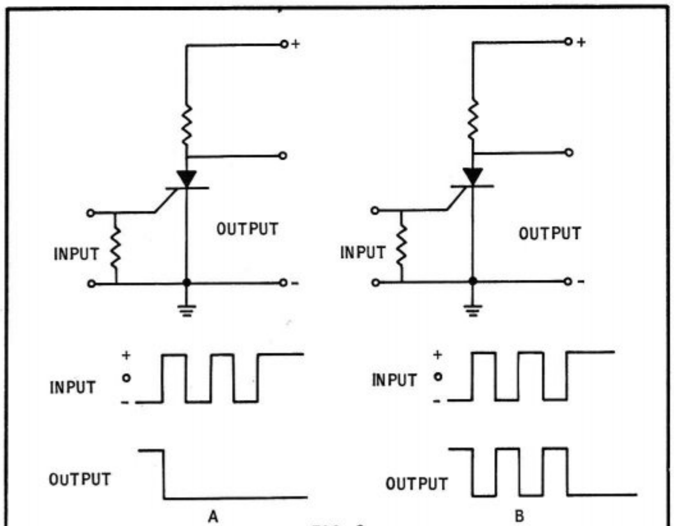
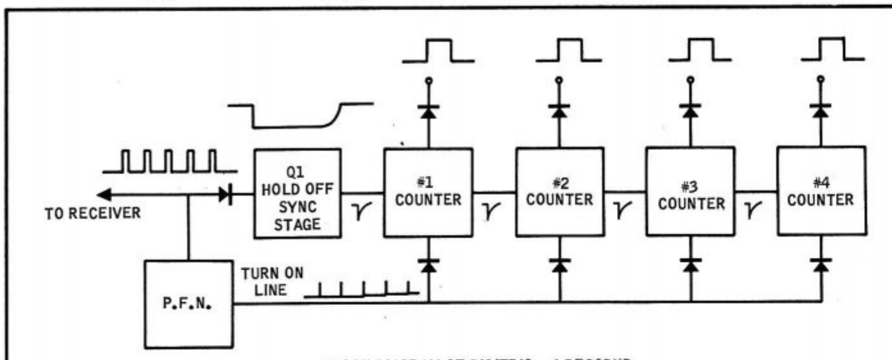


FIG. 3

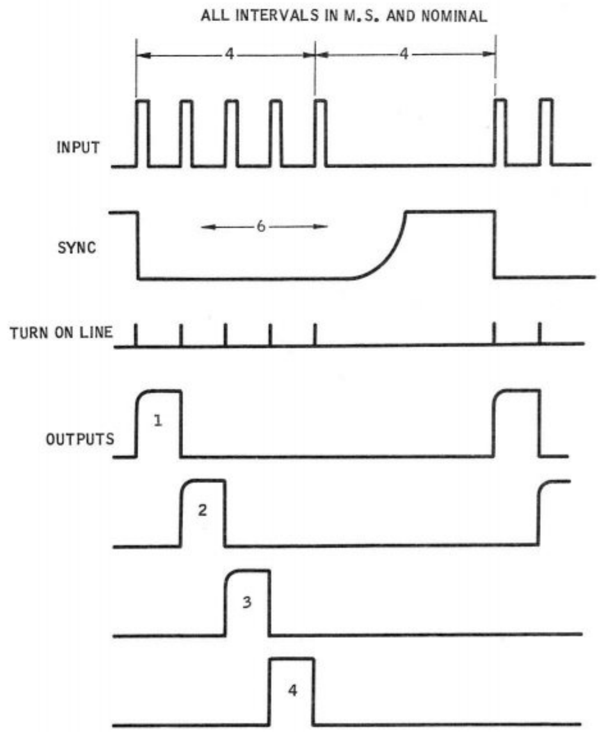
Theory of Decoder

The operation of the decoder is not complicated and even the nontechnical modeler can grasp the basics involved. If the foregoing discussion of silicon-controlled switches left you a little confused I would suggest you re-read it again. The main thing to remember is that positive pulses at the gate will turn one on and negative pulses will turn one off. Your local Einstein type will clear up any remaining questions you may have. The block diagram shows the various stages involved (figure 4). I'll run through the operation quickly for those of you who don't want to get too involved.

The Digitrio-4 transmitter sends five relatively wide pulses which are processed by and through the receiver. These pulses are applied to the decoder at the pulse-forming network (PFN). The pulse-forming network changes these pulses into very short pulses to be used as trigger pulses to turn on the SCS's. The incoming pulses are also applied to the "hold off" sync stage which senses the first pulse of the pulse train and "holds off" until after the pulse train is completed. Once the sync stage is in its hold-off state it does not "see" any further pulses. The first incoming pulse does two things: It causes the sync stage to "hold off" and applies a positive pulse through the PFN to the "turn on" line turning on any SCR that was previously "off." When the sync stage "held off" at the first pulse it also applied a negative pulse to the #1 counter turning it off. This initiated output pulse #1. When the next incoming pulse arrives it will create another turn-on pulse which will turn counter #1 back "on" and complete the #1 output pulse. When the #1 counter stage turns on again it turns off the #2 counter, initiating output pulse #2. The next incoming pulse then applies another turn-on pulse through the PFN and turns on counter #2, completing pulse #2. This action continues until the five incoming pulses have created the four output pulses which command the servos. Remember that the sync stage held off after the first pulse and was blind to the other four. This prevented the #1 counter from turning off on any pulse but the first. However, the sync stage knows when the incoming pulses are no longer present and after waiting for approximately the time it takes to send two pulses

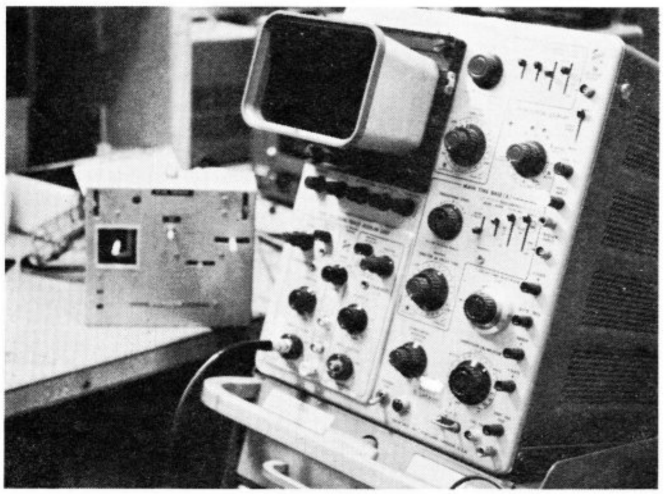


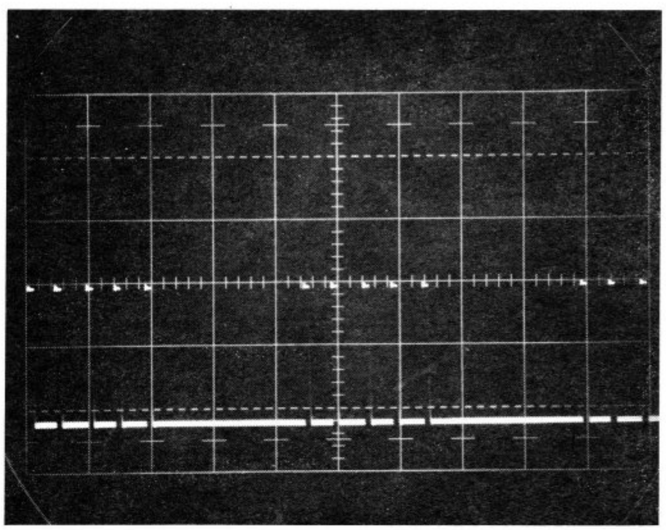
BLOCK DIAGRAM OF DIGITRIO - 4 DECODER
FIG. 4

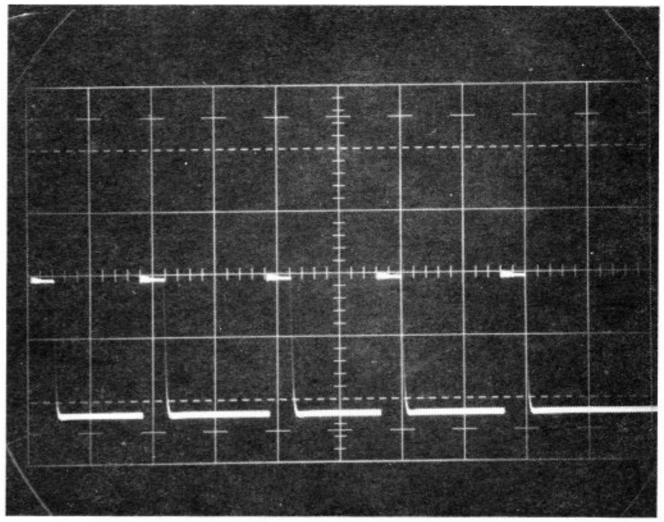


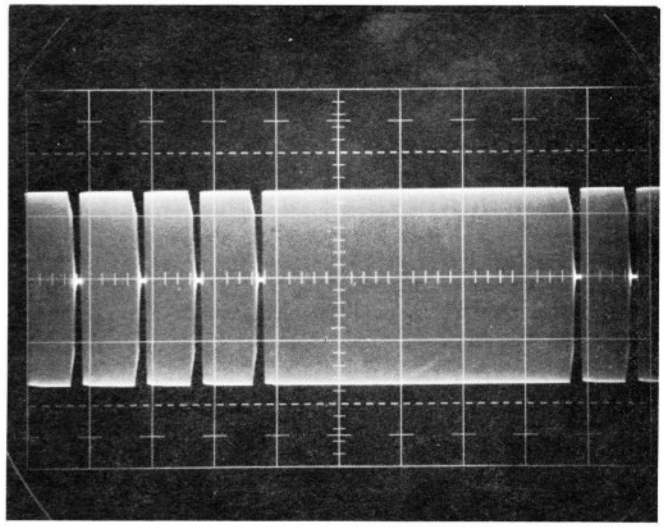
WAVE FORMS FOR DIGITRIO - 4 DECODER

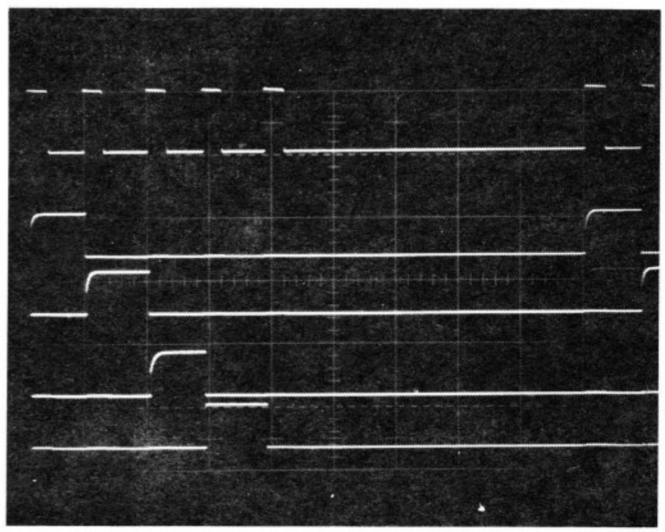
FIG. 5



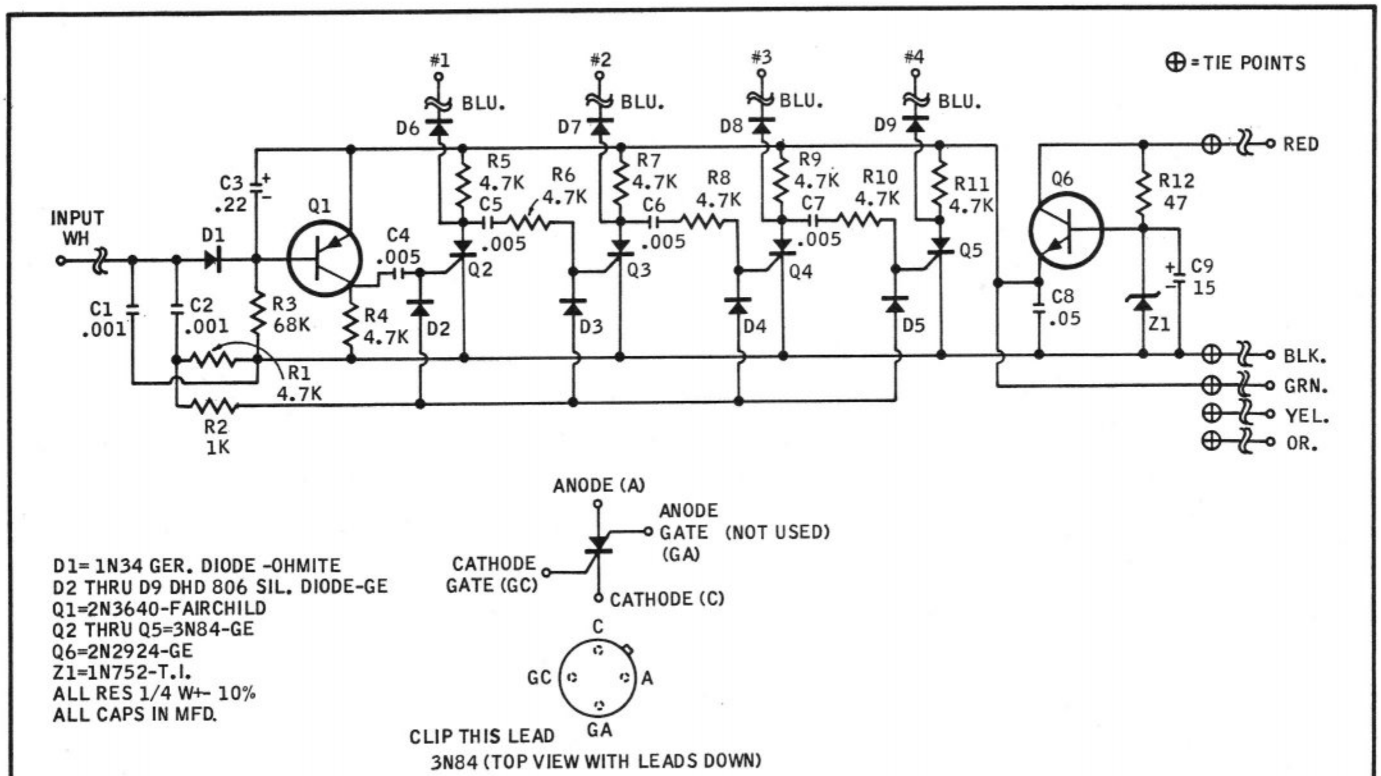








Left, middle: A portion of Dick Carman's workshop in Mountain View, Calif., and the equipment on which Dick made the accompanying scope traces. Left: 2V/CM 2 MS/CM; Collector Q11 transmitter. Frame rate 9MS. Above, top: 2V/CM, .5 MS/CM, collector Q11 transmitter. Above, middle: RF out 1 MS/CM using pick-up coil. Above: Top equals input to decoder. Channel 1 through 4 1 MS/CM 5V/CM.



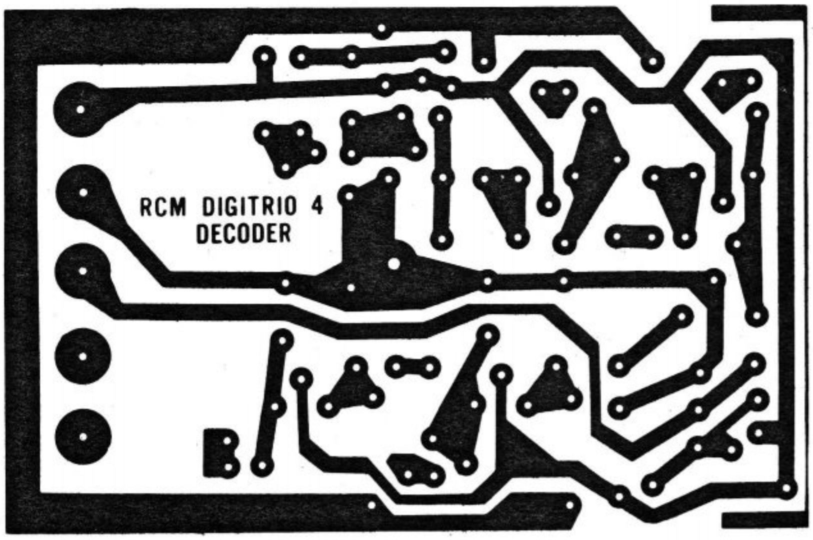
DIGITRIO - 4 DECODER

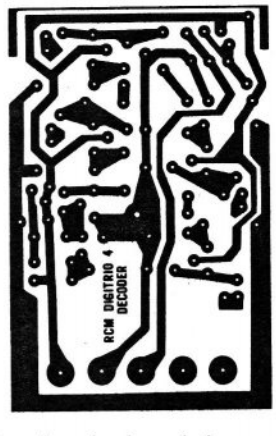
comes "on" again. This occurs during the sync pause between pulse trains and the decoder is ready to process the next pulse train that arrives. This action continues at approximately an 8 MS repetition rate. For the nontechnical that is basically how it works and I would advise you to read it over a couple of times to help you in case you have to troubleshoot the system after a prang. If the rest of you Einsteins will follow the schematic and waveforms we'll have another go at it. (One more time with apathy.)

The five incoming pulses are differentiated by C2 and R1 which make up the pulse-forming network. The pulses are then applied to the turn-on line through R2 which limits the positive gate current to the SCS's. Diodes D2 through D5 pass the positive pulses on to the individual SCS's and isolates the stages from each other. While we're at this corner of the schematic let's get rid of C1. Its only function is to ground the decoder end of the input wire for RF so that it doesn't radiate the sharp wavefronts of the pulses back into the receiver. The input pulses are also applied to Q1 (sync stage) through D1. Normally this stage will be conducting being forward biased by R3. C3 is charged by R3 also. The inverted appearance of Q1 is due to the schematic drawing and a close look will reveal that polarities are correct. The first incoming pulse causes D1 to conduct discharging C3 — this causes Q1 to cutoff. The time constant of R3 and C3 will keep this stage cutoff for the duration of approximately two input pulses. Therefore as long as pulses are present this stage will "hold off." As soon as the pulses are removed R3 will charge C3 and Q1 will conduct. At the end of each pulse train it does just that and prepares the decoder to accept the next pulse train. When the pulse train arrives and Q1 turns off its collector going negative allows C4 to discharge through R4. (Its left side was charged positive while Q1 was conducting.) This transfers a negative pulse via C4 to Q2's gate turning it

PARTS LIST

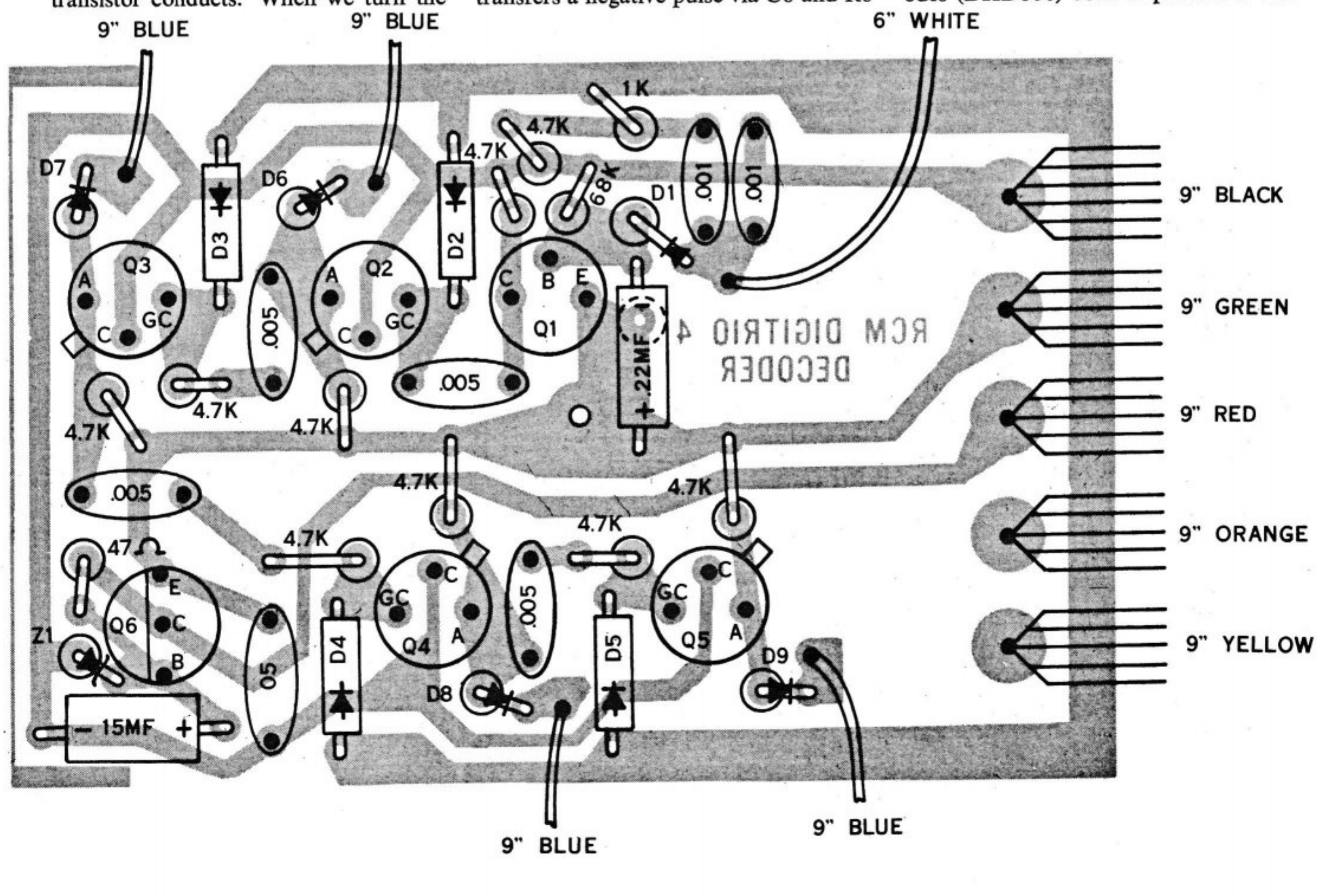
QUANTITY	DESCRIPTION	MANUFACTURER OR SOURCE	MANUFACTURERS NUMBER
2	.001 Disc. Capacitor	Erie	831-000-Z50-102P
4	.005 Disc. Capacitor	Erie	851-006-Z5UO-502P
1	.22 MFD Tantalytic Condenser 25 VDC	World Engines	CT-224
1	.05 MFD Disc. Capacitor	Erie	5635-000-Z5E-5032
1	15 MFD Tantalytic Condenser 15 VDC	World Engines	CL-156
1	1N 752 Zener Diode	Texas Inst.	1N 752
1	1N34 Germanium Diode	Sylvania	1N 34
8	DHD 806 Silicon Diode	General Elec.	DHD 806
1	2N 3640	Fairchild	2N 3640
1	2N 2924	General Elec.	2N 2924
4	3N84 SCS	General Elec.	3N 84
1	1K ¼ watt 10% resistor	Ohmite	
9	4.7K ¼ watt 10% resistor	Ohmite	
1	68K ¼ watt 10% resistor	Ohmite	
1	47 ohm ¼ watt 10% resistor	Ohmite	
4	Servo Connector Set	World Engines	
1	Battery Connector Set	World Engines	
1	4PDT Switch	R/C Craft	
5	¼" Rubber Grommet	World Engines	
1	#2 x ¼ Self-Tapping Screw — Type A		
1	9" length Heat-Shring Tubing (Large)	⅛" Alpha	FIT-105
1	16" length Heat-Shrink Tubing (Small)	Alpha	FIT-105
1	Insulation Sheet 2 — ⅛" x ⅜"	World Engines	
1	Prefabricated Circuit Board	World Engines	
7	9" Black Wires	#26 Hookup Wire — World Engines, Bonner, Ace, etc.	
5	9" Green Wires		
6	9" Red Wires		
6	9" Orange Wires		
6	9" Yellow Wires		
4	9" Blue Wires		
1	6" White Wire		





Actual size decoder board shown above. A 2X enlargement at left for your convenience in having a negative made.

off. For those sharpies who caught it, the fact that both a positive pulse from the PFN and a negative pulse via C4 are present at Q2's gate at the same time has already been allowed for. The pulse duration of the positive pulse is made considerably shorter and the negative pulse wins every time. The next incoming pulse (#2) doesn't affect Q1, which is still "holding," but it does turn Q2 back on. Let's pause here and discuss the output pulses to the servos. Q2 through Q5 are normally conducting and their anodes are at their cathodes potential. Since the input transistors in the servos are NPN's they are cutoff. When we turn off one of the SCS's its anode goes positive and the servo input transistor conducts. When we turn the SCS back on the servo input transistor cuts off again and we have produced a decoder output pulse (or servo input pulse). Since Q1 "holds" throughout the pulse train Q2 cannot be turned off again (Thank God!) until the sync pause. So it stays conducting until turned off again by Q1 conducting on the first incoming pulse and repeats the action just described. When the first output pulse is completed and Q2 conducts, it transfers a negative pulse via C5 and R6 to Q3's base turning it off. Although we again have two pulses of opposite polarity present at the gate the negative pulse wins due to its longer duration. The next incoming pulse (#3) after being differentiated, turns Q3 back on and it transfers a negative pulse via C6 and R8 to Q4's gate turning it off, etc., etc., etc. As each output pulse is completed the associated SCS remains on. Each SCS stage can only be turned off by the preceding stage turning on (except in the case of Q2 which turns off when Q1 cuts off) so the circuit counts the pulses down. As you can see the duration of each decoder output pulse is dependent upon the time between the leading edges of the adjacent pulses in the incoming pulse train which control it. R5, R7, R9 and R11 are the SCS anode load resistors. C5, C6, C7, R6, R8 and R10 are for interstage coupling. Their values were selected for both the proper time constant and gate current to allow optimum results. D6 through D9 are silicon diodes (DHD806) used to provide a volt-



age drop and are necessary for proper operation. The SCS has a slightly higher saturation voltage than the threshold voltage necessary to cause the servo input transistors to conduct. Without them the servos could conduct continuously even though the decoder was working properly otherwise. I might mention here also that D1 is a germanium diode (1N34). Don't substitute silicon for germanium or vice versa or you will be in trouble. I hope you read that advice the first time around and are not just now finding it after tearing your hair out looking for your trouble. If so it serves you right for not following instructions. Q6 and associated parts make up the voltage regulator and is a duplicate of the original Digitrio regulator. I know some of you are getting sick of my standard warning not to substitute parts — if so, get out the "belch bag" because here it comes again. **DON'T SUBSTITUTE PARTS.** You will notice that I didn't use my familiar Mickey Mouse phrase. Bernie Murphy didn't mention the Digitrio so why should I mention him? I need a new phrase anyway. Anyone have a suggestion except the obvious, "why don't you just shut up"? I wouldn't do it anyway!

CONFIDENTIAL TO B.M.

I'll meet **you** at the field, in the street, or on the "green" anytime you're ready.

WIRING DECODER BOARD

Make sure your board fits the case properly and the mounting hole lines up with hole in case. Drill all holes with #65 drill.

( ) Clip off GA lead of 3N84's (see drawing and overlay). Be careful! Bend GA lead out and check by placing SCS over drawing before cutting. Use tab for alignment **not** writing on case.

( ) Mount all 4.7K's (9 ea.) as shown on overlay.

( ) Mount the 68K as shown on overlay.

( ) Mount the 47 ohm as shown on overlay.

( ) Mount the 1K as shown on overlay.

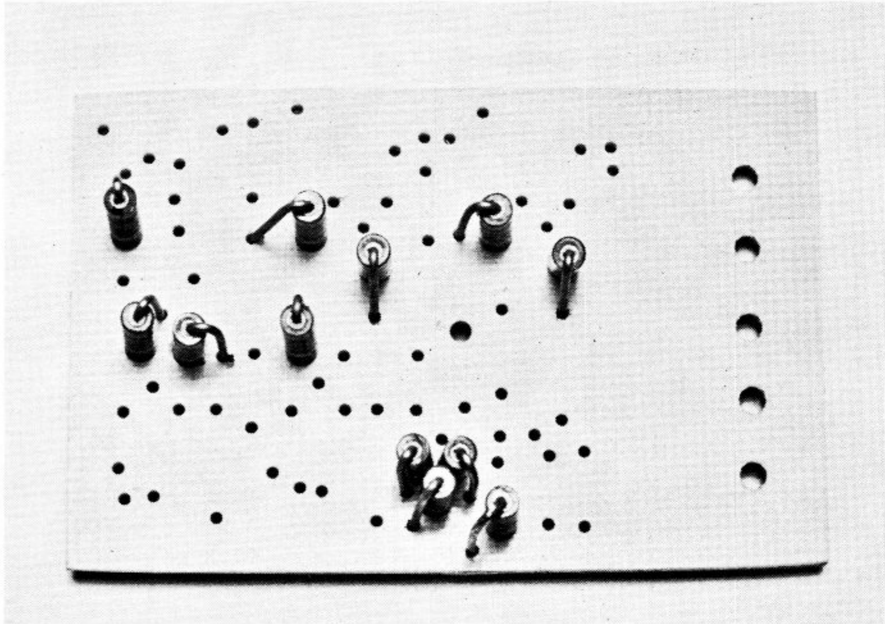
( ) Install Z1. The bar will be up on this zener diode.

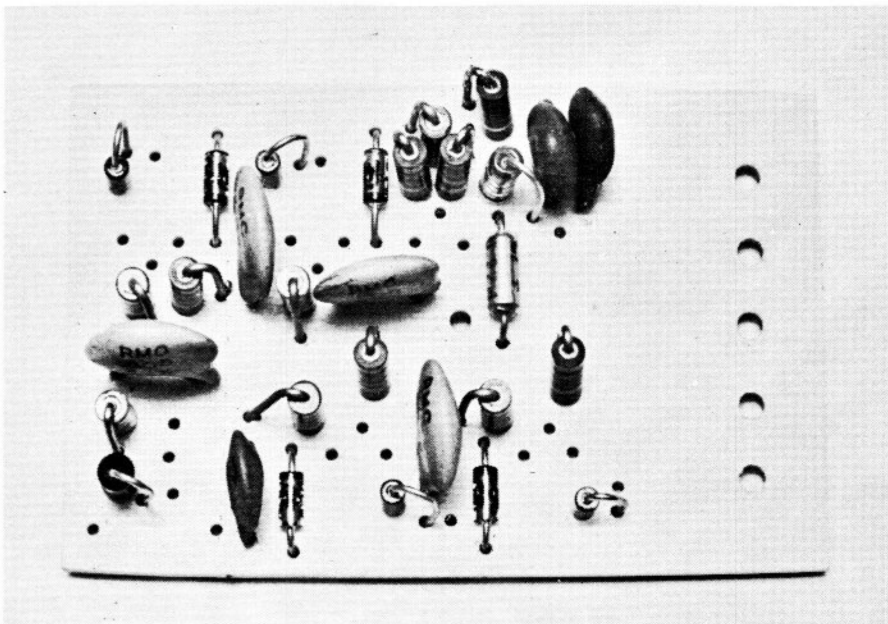
( ) Install 1N34 **germanium** diode (D1). The bar will be down on this diode.

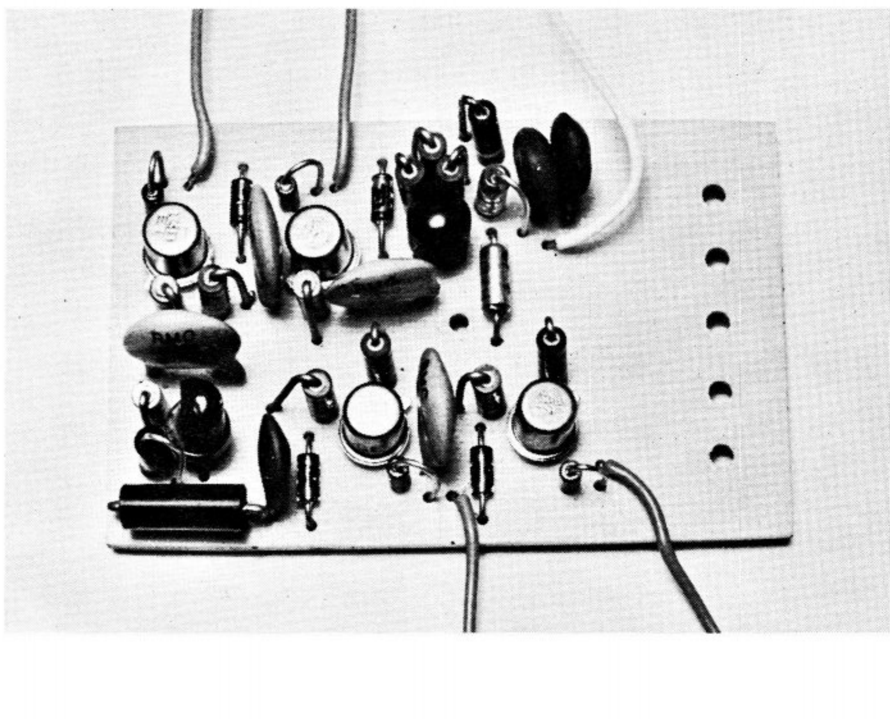
( ) Mount all DHD806 **silicon** diodes (8 ea.) observing polarity. It would be a good idea to check these individually with an ohmmeter to insure that they are good and properly marked. The bar end of all diodes standing up will be up. The bar end of all diodes laying down will be toward the center of the board.

( ) Mount the 15MFD capacitor. Observe polarity. Bend Z1 lead so it doesn't touch this capacitor's case.

( ) Mount the .22 capacitor. If you are using the old one mount it vertically as shown by dotted lines — observe polarity.







( ) Mount the two .001 capacitors.
( ) Mount the four .005 capacitors.
( ) Mount .05 capacitor.
( ) Mount the 2N3640 transistor as shown on overlay.
( ) Mount the 2N2924 transistor as shown on overlay.
( ) Mount the 3M84 SCS's as shown on overlay (4 ea.). See note #1.
( ) Add wires as shown on overlay: Twist ⅜" bare end of the groups together, insert into proper hole and solder. Solder the four blue wires as shown. Solder white wire as shown.
( ) FLAT solder mounds with fine file and clean board with acetone or dope thinner.
( ) Bevel edges of board to prevent shorting to case.

PRELIMINARY CHECKOUT

( ) Inspect copper side of board carefully for BRIDGED solder lands.
( ) Inspect component side of board for proper parts mounting and insure that component leads don't touch. Also insure that 3N84 cases don't touch adjacent leads or components.
( ) Measure resistance between black (negative) land and green (positive reg. 5.1V) land. You should read approximately 3K with proper polarity and on the X100 scale — this reading depends on the meter you use and can vary. (I used a 20K/V multi-meter.)

PREPARING RECEIVER/DECODER

These steps apply only if you have a three-channel decoder already built:

( ) Remove receiver and decoder from case.
( ) Unsolder white/green/black wires from receiver. Set the receiver board aside as it will not require any changes.
( ) Completely dismantle decoder removing all components and wires. If you are going to use all new parts, of course this step doesn't apply.

NOTE: Your best bet on servo/power wiring is to salvage the old plugs and completely rewire. You can use your old wiring harness but it gets pretty exasperating.

( ) Prepare decoder case for five grommets as per original Digitrio article and drill antenna and mounting hole.

NOTE: A shield is not required on the decoder. To obtain a good ground, melt a solder mound around decoder mounting hole, drill it with an undersize drill and let sheet-metal screw tap into it.

( ) Mount decoder, with the insulating sheet, in its case half with mounting screw and install grommets.
( ) Route one each blue, yellow, orange, red, green and black wire through grommet for each servo.
( ) Route one each red, orange, yellow and black through grommet for power wiring to switch.
( ) Twist all servo groups together and clip to length desired.
( ) Slip a 1" piece of large heat-shrink tubing over each of the servo wire groups.
( ) Twist the remaining white/black/green and cut to 3".
( ) Untwist 1" and tin each wire 3/16" in the servo groups and slip a ½" piece of small heat-shrink tubing over each lead.
( ) Solder each servo plug as shown in original wiring diagram.
( ) Slip a 1" piece of large heat-shrink tubing over the four power wires.
( ) Tin each power lead 3/16", slip a ½" piece of small heat-shrink tubing over each lead and solder to switch connections.
( ) Solder the battery plug and wires to switch in the same manner.
( ) Solder the receiver leads to the receiver board as per original overlay.
( ) Mount receiver in its case half and slide the two case halves together while checking for pinched wires.

NOTES:

1. When soldering in the SCS's it would be advisable to use a heat sink on the leads (a pair of long nose pliers will do). Also unplug the soldering iron to prevent capacitive voltage coupling which could damage or change the characteristics of the SCS's.
2. The motor control servo must be returned to original circuitry if it was modified.

GENERAL

Later in the article I'll cover final testing of the Digitrio-4 modification. From the phone calls I have received so far, many of these systems have been built from the articles and are flying with excellent results. All of these systems were operating properly before they were modified. If you were having difficulty before the mod, you may carry over your problems to the four channel. Remember, all we have changed is the decoder. If your trouble was in your decoder the new decoder may solve your problems. On the other hand if your problems were elsewhere, the -4 mod will not clear them up. When you troubleshoot the system keep in mind that we have only changed the decoding method and added two more pulses at the transmitter.

I have received many letters inquiring about repair service on the Digitrio. There are many places around the country that can repair your Digitrio. I have received several letters from different firms and individuals asking if they have my permission to service the Digitrio. Although it is impossible for me to vouch for the quality of the service rendered by all these people, I encourage them to perform repair service. My feeling is that I would like to see as many Digitrios flying as possible, and since the system is basically simple in concept to a qualified technician, careful selection of your repairman should yield satisfactory results. If you are having trouble beyond your capabilities, or just want to know that your rig is performing properly, I would suggest, first of all, that you get with your technician friend. He can probably tell you whether your problems are serious or minor in nature. If he can't, try your dealer, he should know the **really** sharp technicians in the area. If your problems were minor they should have been cleared up by that route. If you can't get satisfaction locally, your problems may be of a complex nature and require expensive test equipment for a solution. Even simple troubles often defy detection. I have repaired many Digitrios for my friends that had improperly installed components. Some of these sets required many hours to correct. When told that their trouble was one of parts installation their reply was essentially the same, "I checked it over at least a dozen times and would swear it was right!" The problem here is evident — when checking back they simply repeated the same mistake they made originally. This could be due to reading the instructions improperly or having a "mental block." I have made this mistake many, many times myself. One improperly installed component can usually be found by observing symptoms and applying circuit knowledge along with common sense. However, two or more improperly installed components can lead to many hours on the test bench and involve expensive test equipment, as well as the best efforts of the technician for a cure. By the same token, one or more defective parts could be present in the system giving approximately the same symptoms and troubleshooting problems. On several occasions I have been subjected to a Digitrio builder displaying a temper tantrum because this system didn't work properly. This type person usually possessed occult powers because he had applied his mystic powers of electronic's knowledge to his built-in, "brain-powered" computer and came up with the revelation that the "Digitrio could never work properly! In a few cases a simple "tweak" of the alignment tool caused replacement of his crystal ball with a book on electronic theory. You'd be surprised how many people fail to peak their receiver and end up with a P.C. board full of useless parts.

Then, there's the type that starts changing parts values at the first sign of trouble. This type is doomed from the start unless he truly understands what he is doing. An example of this was a fellow to whom I loaned my original decoder so that he could get his system in the air. My decoder had been through well over 200 flights and performed flawlessly. At the first sign of difficulty a modification was made to my decoder, followed by some passable and some impassable flights. Of course, all the problems experienced were blamed on my decoder. As it turned out, my friend forgot to install the zener diode in his transmitter. The moral here, is: If you can't pin-point your trouble don't experiment with the circuitry!

One quick way to determine where your problem lies would be to swap your defective sub-systems with a friend whose rig is working properly. This is an often overlooked, but highly accurate, way to pinpoint your trouble. Say, for instance, you suffer from lack of range. It's easy to swap transmitter crystals with your buddy in order to check your transmitter against his airborne equipment. It's a little more involved to swap receiver crystals, but can quickly tell you whether your airborne equipment is at fault. This same reasoning applies to the decoder and servos. All parts of the system were designed to be built separately and can be interchanged — just remember to go through alignment of the transmitter and receiver if you swap crystals. Also, if you have to resort to the parcel post route, send the entire system to your repairman — including antenna, batteries, battery charger, etc. A lot of troubles are quite minor such as failure to resonate the antenna as described in the articles, bad batteries, improper polarity of battery charger, etc. Performing the modifications I recommend may clear up a problem for you, also. If there are any doubts about system performance, perform the recommended mods. These were worked out from actual case histories and won't degrade the performance so you have nothing to lose.

Another often overlooked item is interwiring errors, especially at the servo plugs. I know of several cases where the switch was improperly wired so that there was current drain on one or more batteries with the switch turned off. Check all wiring carefully and look for loose strands of hook-up wire that may be causing shorts, especially at the switch. One other place to check is where stranded wires are inserted in the P.C. boards. It is possible for one or two strands to "push" away from the hole and "short" to an adjacent component lead. This has happened on two known occasions with the white wire at the receiver causing failure of Q7.

Whatever your problems and regardless of how complex they may seem to you, systematic checking by a good technician should be routine, so seek help if you get over your head. World Engines prints on each kit they sell that they will repair systems built from their kits. By the time this is in print or because of this article others should offer repair service so check the ads in RCM and check with your dealer. I'll try to compile a list of those offering this service for later publication. Now that the -4 mod is completed I'm undecided where to go next. Frankly, I'm glad it's over and I can assure you that the letters I received kept me going. I received more letters of encouragement than I could count and only a few critical ones. To you who wrote letters of encouragement I would like to say thanks again and urge you to let the other model editors know when you enjoy or are interested in an article. I am sure you don't realize what a profound impact you make on a writer's morale and incentive to do his best. To the critical writers, I'd like to say thanks also — you taught me a valuable lesson and expanded my knowledge of human nature.

A long overdue acknowledgment of patience and well wishing is due to our friends "down under." The Australian chaps have many Digitrios flying in spite of difficulty in obtaining parts and extra delay of magazine delivery.

From the letters received there seems to be a need for comprehensive Digitrio troubleshooting instructions which I am considering. Also the mail indicates a desire for a simple pulse system with which I am experimenting. I also have been working on some 72 MC gear which works well. Perhaps some of this will be published later on. The problems I encountered so far with these new frequencies are small and I foresee no problems except the type approval tests required. While the type approval will require a little more effort on the part of the designer the largest hurdle lies in compiling the information required by the F.C.C. It also appears that this new band of frequencies could develop into an "appliance operator's band" with the restrictions of type approval which is/was apparently overlooked and/or endorsed by the AMA. Since most of what has been written about this new "blessing" is either premature or in the form of publicity, I have no significant comments except that the "high desirability of these new frequencies" remains to be proven. Further, the restrictions placed on equipment at these frequencies will, in all probability, severly hinder state of the art advancement in the future.

TROUBLESHOOTING THE -4 MODIFICATION — TRANSMITTER

The transmitter mod only added two one-shots which are identical to those previously covered. I therefore don't have any troubleshooting advice here except to recheck your modification installation. If possible look at the sync pause duration (adjustable by R13) on a scope. This can be viewed between the collector and emitter of Q11. Adjust R13 to 8-9 MS between the leading edges of the #1 pulses in the pulse train. This will provide a nominal 4 MS sync pause. To calibrate your scope, display one or two cycles of 60 cycles AC. Each cycle will have a time period of 16⅔ MS. Eyeball a half cycle (either a positive or negative alternation) and you will have 8⅓ MS. With your horizontal gain and horizontal centering control adjust this half cycle to occupy four divisions on the scope. Your scope is now adjusted to approximately 2 MS/DIV. Display the pulse train at Q11 and adjust R13 so that the leading edges of the #1 pulses are separated by four divisions on the scope face without adjusting either the horizontal sweep frequency or horizontal gain. The above procedure, while not super-accurate, will get you within design limits. The same procedure can be used by European and other countries that use 50 cycles for household voltage. The only difference is the period of one cycle being 20 MS. In that case, adjust ½ cycle for five divisions so that each division still represents approximately 2 MS and set up the #1 pulses between four divisions. For those of you who don't have a scope or easy access to one simply set R13 to midrange.

DECODER

It would be advisable to check the decoder for upper temperature limits before flying in hot weather. This can be as simple as exposing it to direct sunlight on one of the hottest days you anticipate flying or placing it in the oven. Since winter is coming on and the hotter days won't be with us for a while the oven is your best best. CAUTION: Don't depend on the oven temperature dial for this test. Buy or borrow a centigrade thermometer if you want to go above 120° F. The normal household type only goes to 120° F. Decide what would be the hottest day on which you anticipate flying and add 30° F (20° F for direct sunlight effect and 10° F for insurance). By experimenting with the heat control and opening the oven door to varying degrees adjust the heat to your predetermined upper limit temperature. Insert the complete airborne system along with the thermometer and let it soak up the heat for at least 15 minutes after the thermometer stops rising or total of 30 minutes whichever is longest. Keep the bulb of the thermometer close to the decoder and use a piece of wood or cardboard (a small cutting board is fine) to support the equipment. Operate the equipment as it soaks up the heat and if it stops you can estimate what the upper temperature was when it failed. Also you can check servo drift with heat by marking the output arms with a pencil. The drift should be no more than the width of a pencil line to about 140° F. If you are satisfied with the test, place your transmitter in the oven and check it also. Since you have gone this far you might as well go the deepfreeze route too. You can either let the equipment cool to room temperature first or give it the shock treatment and go directly to the deepfreeze. If you don't anticipate flying with the eskimos, use the refrigerator. It will take awhile to get it down to temperature due to previous heating, so be prepared to wait awhile. Your equipment should work between 20° F to 140° F. I checked five systems and one worked to 170° F, three to 160° F and one to 110° F which was corrected to 160° F. The lower limits were below 20° F (limit of my deepfreeze) on four and 30° F on the one I corrected. Before I get into correcting for temperature I'll explain what factors influence temperature range.

As explained earlier in the theory of operation the turn-on line provides a positive pulse through a diode to each SCS gage. The circuit constants were chosen to provide a 200 ua positive pulse of approximately 2 us duration for this purpose. The turn-off pulse for each stage is provided by the preceding stage and circuit constants provide a 300 ua negative pulse with a 10 us duration. The difference in pulse duration and strength account for proper commutation by allowing the negative pulse to overcome the positive pulse when they arrive simultaneously at a gate and the selected stage is turned off.

Enter HEAT—the turn-on sensitivity rises with heat and the turn-off sensitivity decreases with heat. As heat is raised a point will be reached where the device will not turn-off with the presence of the turn-on pulse. A further increase in temperature will not allow turn-off even without the presence of the turn-on pulse and eventually the temperature will rise where the gate loses all control and the device is held conducting by minority carrier current flow. As temperature is lowered the trigger requirements will react in an opposite manner as far as circuit operation is concerned. This circuit was designed for proper operation between conservative limits of 20-140 F by selection of circuit constants. Some of the causes for premature failure could be that one of the SCS's trigger parameters has changed either by excessive heat or capacitive voltage coupling during P.C. board assembly. Or, possibly that one of the SCS's was on the parameter border line when you received it. If temperature effects cause failure before the upper temperature limit is reached a solution can be affected in one of two ways. Either replace the SCS that is failing or increase the turn-off/turn-on pulse ratio. Replacement of the SCS is the most expensive of the two methods and in most cases is unnecessary if you don't mind an increased lower temperature limit. If we increase the amplitude of the turn-off pulse the total temperature spread will shift upwards although the rise of the extremes won't be directly proportional. In other words, say our temperature spread was 20°-110° F. We may cause an increase of our upper limit by 50° up to 160° F and our lower limit may only rise 8° up to 28° F. As you can see this can get complicated since the discussion so far pertains to only one stage and we will be working with four. Actually the temperature checking procedure is rather simple if done in a systematic manner and I'll outline it for you as follows:

1. Select your minimum upper temperature limit as described previously.
2. Adjust your oven or place the equipment, with the receiver case open, in the direct sunlight on an extremely hot day. If your servos were not marked as to which output they are controlled by, mark them before you go any further. Mark them from #1 to #4.
3. With all the equipment hooked up (all servos) operate the equipment and look for a servo failure as the temperature rises. If the failure occurs in the oven, estimate as best you can the equipment temperature when the failure occurred. If you believe the failure occurred at an acceptable temperature (say within 5°-10° F of your target temperature) run further tests to insure that the failure temperature is not within your specifications. NOTE: Your first tests will probably be on the hot side until you are used to the procedure. Also there may be hot spots in the oven. If the failure occurs in direct sunlight of course the results will be unacceptable.
4. The next step is to decide which stage is failing. If more than one stage failed during the test concern yourself with only the first to fail. The failure of one stage will cause the following higher-numbered stages to fail also. For instance, if #3 stage failed, both stages #3 and #4 would be inoperative, but if #4 failed it wouldn't affect the other three. However. if #3 failed at a higher temperature then #4 would be the second one to go out. The objective here is to fix them one at a time systematically and prevent confusion. Keep notes of failures for further reference.
5. Fix the stage that failed. Here you have your choice of methods. Either replace the SCS or increase the value of the .005 coupling capacitor from the preceding stage to a .01. This can be done by paralleling the existing .005 with another .005 at the copper side of the P.C. board until the tests are completed. The coupling capacitors are C4, 5, 6 and 7. If #4 output failed (Q5) you would increase C7, #3 C6, #2 C5 and #1 C4.
6. Run another test to determine if any other stages will fail within your upper limit specifications and correct them as above.
7. When you are satisfied with the upper limit tests, run the lower limit tests in the refrigerator or deepfreeze. Here again you can use one of your coldest days and set the equipment outside but don't set it in the direct sunlight. If a failure occurs higher than your lower temperature specification check your notes to see if you added a capacitor to correct the upper limit of that stage. If so you will have to replace the SCS to maintain both high and low temperature extremes.
8. Replace the SCS's or the .005's with 0.1's and recheck the temperature range for insurance.

Here's another way to make a quick check. Although it won't tell you the temperature extremes accurately it will let you know whether you're in the ball park or not:

1. Heat the oven to what you feel is about twice as hot as you expect the equipment to operate.
2. Place the equipment in the oven and operate the servos until the cases get hot to the touch (not warm). At about 140° F the cases will be uncomfortable to hold but not hot enough to burn the skin. Or, you can wait until you have a failure and remove the equipment noting the case temperatures when the equipment starts operating again. A WORD OF CAUTION HERE: Your equipment could go beyond 160° F without failure and chances for heat damage to component parts will increase, so stay within reason on the touch test.
3. Run the deepfreeze test. Here the lower test limit will be determined by the temperature setting and the freezer's ability to recover from the added heat of the equipment. At about 20° F the servo wires will get stiff and servo response may slow down slightly due to the cold. It should be easy to obtain a household thermometer for this test.

The above "quick" check will depend a lot on your ability to determine temperature by symptoms.

Troubleshooting follows the same logic as the heat checks to pin-point a defective stage. Determine which stage is defective by observing servo action and repair as necessary. Don't run the heat checks until you are sure the system is functioning properly as it will be a waste of time. From the letters received and personal observations I know there will be many cases of germanium and silicon diode swapping. Also diodes installed backwards or marked improperly. If you don't know for sure what type diode you have (hunches are sure to get you into trouble) don't use it. Also a check of each diode before installing them may prevent later problems. If you use a scope and want to look at the outputs you will either have to connect the servos or simulate them. They can be simulated by placing a 22 K resistor and a silicon diode in series across the decoder output with the diode arrow pointing to ground (SCS cathode). Don't check the SCS's with an ohmmeter unless you've got a lot of money for replacements. All the components used have been identified for you and if you make substitutions you know my favorite saying. I'll spare you the nausea this time and just say "good luck!"

One thing should be obvious at this point. Since each SCS stage is identical it would be an easy matter to increase the number of channels. I have gone to six without any circuit changes other than SCS stage addition. Beyond this R2 may have to be decreased to maintain on/off pulse ratio. 500 ohms should be about right for 8 channels. If I get enough letters I may publish a board for additional channels. How many depends on the requests. The same goes for a new transmitter board. If you write in please state your desires and spare me the lectures on why I should have done it in the first place. Also fellows, no more lectures on the number or content of articles it's taken to complete the system. When you write articles on the system you design I promise not to tell you how to do it. O.K.! Fair enough.

Here are a couple of notes on the Digitrio that may answer a few letters. Ed Means and Jack Albrecht of Colorado Springs were up last Saturday. Ed brought along a Digitrio-4 that he is building, for a look-see on the scope. The equipment worked well as checked with a FSM and multimeter. The transmitter scoped out perfectly and the power output was measured as higher than average. When we scoped the receiver, however, it also appeared a little "hotter than average." However something didn't seem quite right. At certain signal levels we would get double output pulses. Also the diode load output had a "rabbit" running through the pulse trains. This "rabbit" had no direct relationship to either the individual pulses or the sync pause. It just drifted through the pulse train at a very slow rate. This led to several hours of trouble shooting, and finding nothing wrong, it seemed obvious that our problem was in the scope connections. But, regardless of how we isolated the scope leads the problem persisted. By this time all the desire to "play" with this "damned Digitrio" was dissipated. Ed and Jack left for Colorado Springs mumbling something about sticking something somewhere!

The next couple of days I would turn the receiver on occasionally and check to see if the trouble had cured itself. My prayers to the "Electronic Fairy" were not working and the "radio rabbit" was still running. I tried ignoring it for a couple more days by "de-mothballing" the Digifli and installing a new ringed Max 40. After a successful day of flying the Digifli (bringing it home in one piece), a thought struck me — "Thompson, when was the last time you brought a plane home in one piece?" I thought for awhile and said to myself, "I don't remember, it's been so long!" I checked with my neighbor, Tom Wyatt, and he said, "It must have been when you were still in Phoenix." After a few calls to Phoenix Bob Burand reminded me that one time last February I had forgotten to take my transmitter to the field.

What I'm getting at is this. With what I had just accomplished I knew that a simple receiver problem would be "duck soup." First of all I pulled the receiver out of the Digifli and looked at it with the scope. I saw the "rabbit" but it was insignificant. I took it out of the case to look at the IF stages and the "rabbit" came on strong. There was my answer, the receiver should be in the case for testing. But then I remembered that this hadn't happened before so I got out my old scope and ran similar checks. The "rabbit" was gone, whether it was in the case or not. I then tried to figure out what was causing the problem when I used the new scope. I never really came to a concrete conclusion although several things were contributing:

1. A local broadcast station was entering my new scope — apparently through the A.C. line and modulating the scope trace.

2. A power line leak was emitting a pulse-type electrical noise with a 20 DB over S9 signal on my communication's receiver. I later verified that it was showing up in the Digitrio receiver output. I did find a way to eliminate the problem though. With the receiver in the case and grounded to the case no trace of the "rabbit" is evident on either scope. The receiver case is grounded when the case halves are together because the decoder board is grounded to its case half. However with the case halves separated there is no ground between the receiver board and its case half. The easiest way to supply a ground is to notch the mounting hole in the receiver board case half. Solder a bare piece of wire to the +5.1V land at the junction of the two 40 mfd electrolytics and let it stick through the notch in the mounting hole. Insert the mounting screw and wrap the wire around it one turn and tighten it down. The "rabbit" appeared to be causing the double-pulse output and was cured before the grounding process by replacing R15 (10K) with a 47K. Whether this was necessary or not I don't know as Ed has his receiver back now and I didn't change it back. A check of my receiver indicates no change in resistors is necessary but I am passing it on as something to try in case you have similar trouble. Based on the fact that the trouble I experienced is possible, whether real or induced, I recommend that the receiver board be grounded as described to preclude troubleshooting confusion.

Russ Johnson, Palmerston North Aeroneers MAC, New Zealand, with his OS .19 powered Falcon and Digitrio.