

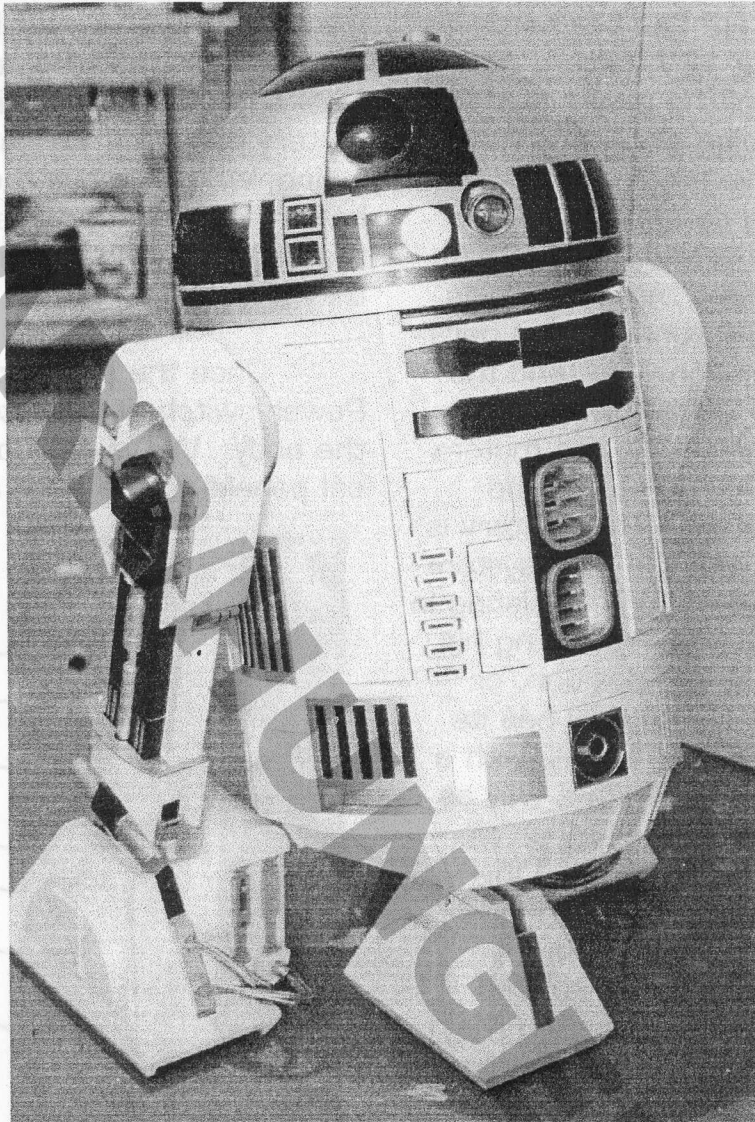
SO... YOU'RE BUILDING A DROID

Most people who start to look into building an R2 will find the task an endless learning process, with structural, mechanical, and electrical engineering problems almost too numerous to mention. While everyone has a different approach to their R2, certain ideas and designs have already been used successfully (after several revisions and failures) and can be incorporated into anyone's design. For this reason, we have collected together many of the ideas we've incorporated into our droid, and published them here for the benefit of fellow builders like yourself.

Again, since everyone's approach (and dimensions/proportions) will be slightly different, we are not providing any structural designs or dimensions. Our drawings are based on our own droid and some dimensions may need to be altered to suit. As well, everyone's frame and shell design will be slightly different, so only a few geometric concepts are provided here, such as shoulder tilt geometry, drive train mechanics, head rotation, etc. Please don't take our designs as a cue to rip your droid apart and start from scratch. Use the ones you feel you need, and by all

means adjust them to suit your own designs.

This book is divided into six sections. The first deals with batteries, charging, and power distribution. Section Two deals with electrical details of the primary control circuitry, including RC and Switch 16 usage. Section Three outlines designs for drive units and 3 Leg Mode actuators. The Fourth section deals with some mechanical designs for hinges, panel servos, and arms. Section Five covers basic designs for head rotation and power transfer (our slip ring). The final section covers some of the devices we've built into the head, including



Periscope and Voice unit.

Please take note that a lot of the motors and components we used were salvaged and/or donated. Trying to find exact matches for everything is nearly impossible, so keep this in mind when using our plans to build your components. Enjoy!

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SECTION ONE: POWER SYSTEMS

Early on in our designs we considered things like battery usage and operational time between charges. We decided then that we would fit as much battery power into him as we realistically could. For this reason, our R2 has five batteries. Each foot has its own 12V battery, independent of the rest of the power system (except for the charging circuits). This means that if his drive batteries run down early, the rest of him can still sit in a corner and flirt with the crowd.

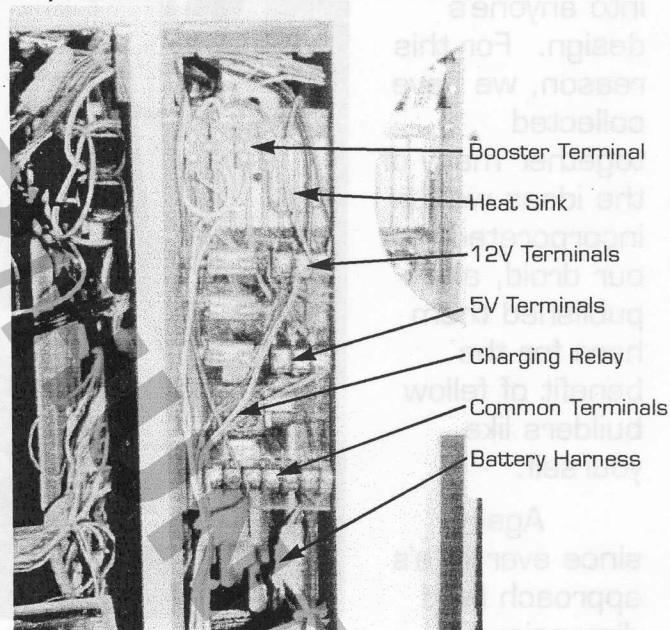
The body contains three batteries. Two of these are 12V, connected in parallel for twice the operational life, and the third is a smaller 6V battery which acts as a booster for intermittent use motors such as the shoulder tilt motors, and some of the arm motors. This battery is connected in series with the 12V system to provide 18V to the motors, assisting in counteracting gravity when returning his weight back to the upright position, or raising an arm. The 6V battery has its own independent charging circuit, with a stereo jack input wired in such a way as to isolate the battery from all other circuits when the charger is plugged in.

The main charging circuit may seem entirely too complicated, but it ensures that all batteries are isolated from the load circuits, whether the Main Power switch is on or off. The charging relays are powered by the voltage from the charger. When activated, they switch the connection to the batteries to allow charge current to pass. A blocking diode (rated 6A minimum) prevents regular battery voltage from keeping the relay coils energized.

This configuration allows you to leave R2 on over the course of an event. When the charger is plugged in, he automatically powers down, and when unplugged, he springs back to life without you having to grope around his private areas for the switch. The only drawback in our system, which we plan to correct

sometime soon, is the fact that the Drive Power switches NEED to be on to charge the drive batteries (not the case for the main batteries). Our design for the foot battery packs uses a CB antenna jack (centre pin only) on each of the braided cables. Our charging relays are in the feet, and the power switches are in the battery packs. If we can rearrange some wiring, we can move the relays into the battery packs and place them between the batteries and power switches where they should be.

Once the power passes the Main Power switch, it is routed to both sides of the body. We've set up the two long vertical panels on the back as access for



power distribution. Each side is divided again in two. One circuit, fused at 7A (an arbitrary value for now) provides 12V to a terminal strip, for distribution throughout that side of the body. The second circuit, also fused at 7A, feeds 6 voltage regulators, rated at 5V, 1A output. These are mounted on a common heatsink, and each one supplies an independent terminal to provide 5V to any control and logic circuits, as well as smaller motors. Remember to divide your circuits up so no combination exceeds 1A. It is also possi-

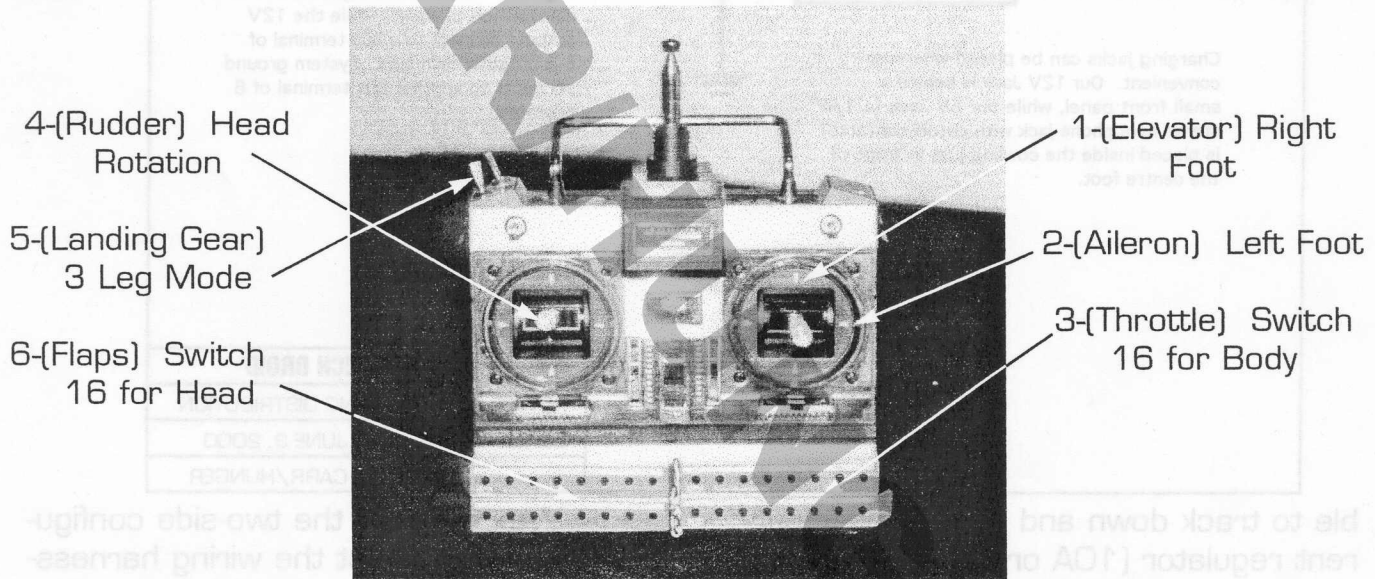
SECTION TWO: CONTROL

We realised that in order to provide a wide range of functions, we would need a lot of radio control flexibility. One of our first ideas was to buy two or three RC sets and divide their functions up using servo/switch combinations, or develop a decoder circuit to divide each channel into a number of outputs. Then someone did it for us. Enter Model Control Devices with the Switch 16. This device solved a lot of control problems.

But first, the basics. We started with an Airtronics Vanguard 6 Channel RC set (usually reserved for aircraft- we'll take our chances). We divided the channels up as follows.

TRANSMITTER

The arrangement of the two axis joystick (Ch1 & 2) works as follows. Each axis controls a foot. They form a control range offset to the upper right by 45



degrees. Moving the joystick to the upper right makes the droid go straight ahead. Upper left makes him rotate on the spot counter clockwise. Lower right, clockwise. Lower left causes him to back up. Any positions in between cause him to arc/turn in the appropriate direction. Speed variation allows you to take him through any of these movements at vari-

ous combinations of speed for both motors. This is similar to the operation of radio controlled tanks. If possible, to make operation a little easier, rotate the control joystick 45 degrees so straight forward is now the top of travel. Most controllers, unless built into custom cases, don't have provision for this modification.

The Channel 3 joystick is replaced with a set of Switch 16 buttons. Follow the instructions with your Switch 16 and all should go well. This modification now leaves the Throttle joystick disconnected and inoperative. This channel will now operate functions in the body.

Channel 4 operates the head rotation. You can set it up for the head to follow the joystick direction when he faces you, or when his back is turned. Most RC units have reversing switches for each channel, as do motor speed controllers.

Channel 5 (operated by the toggle

switch on the upper left) is used to switch R2 from 2 Leg to 3 Leg mode.

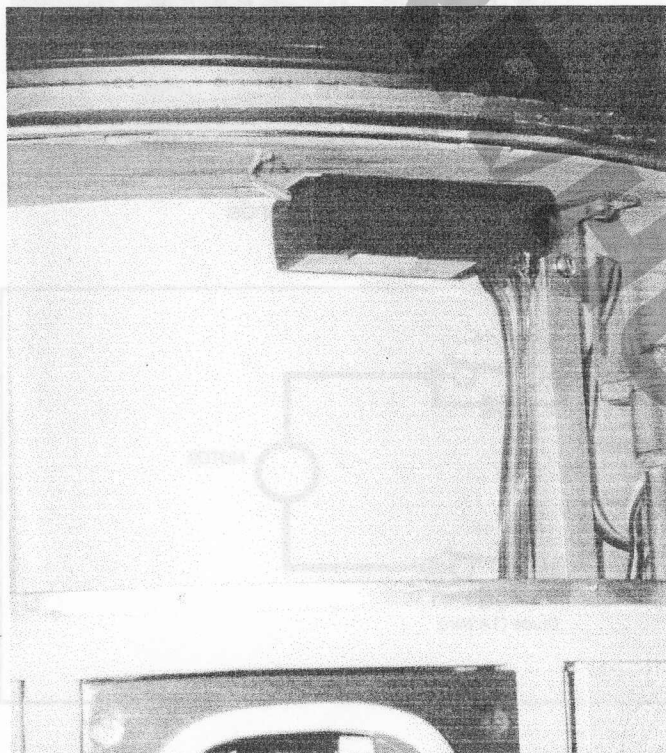
Channel 6 (the upper right switch) is disconnected and replaced with a second set of Switch 16 buttons. These will operate functions in the head.

We mounted the button banks on the hinged cover over the channel reversing switches. These two sets provide us

with 32 additional switchable functions on our droid. This may be more than needed depending on the design, so if desired, Switch 8 units can be used. Our design currently uses about half of the functions, but plans are laid out to add more devices (Arc Welder, Saw, Fire Extinguisher, etc.) and will use up almost all 32 functions.

RECEIVER

We positioned our RC Receiver on the underside of the upper body ring at the front (basically under his chin). The antenna wire is run through a hole and around the top of the upper ring. This keeps the antenna high up in the body. Don't cut the wire short, or place too close to any metal structures, as this



RC Receiver Location

seriously impedes reception.

We wired a harness that plugs into the series of outputs on the Receiver. The harness consists of a common wire(negative), a +5V (from one regulator), and one wire for each channel output. Our harness is routed to the back of the body, where it is divided into the outputs for each channel. Channels 1 and 2

route from there to the two leg harnesses. Channel 3 connects to the input of the Body Switch 16. Channel 4 connects to the input of an MCD Speed Controller in the upper back of the body, to drive the head motor. Channel 5 is routed to a servo in the left side of the body (anywhere convenient is fine). This servo actuates a microswitch by way of a cam, to activate 3 Leg Mode. Channel 6 in our droid is routed to the second Switch 16, which we've placed in the body. We've seriously modified our Switch 16s, including tapping into the outputs to encode them for transfer into the head. This was a provision we made to allow for upgrade to a microprocessor controller, but isn't necessary. A more recommended route that requires no modification to the Switch 16s is to send the Channel 6 signal up into the head, and put the second Switch 16 in the head.

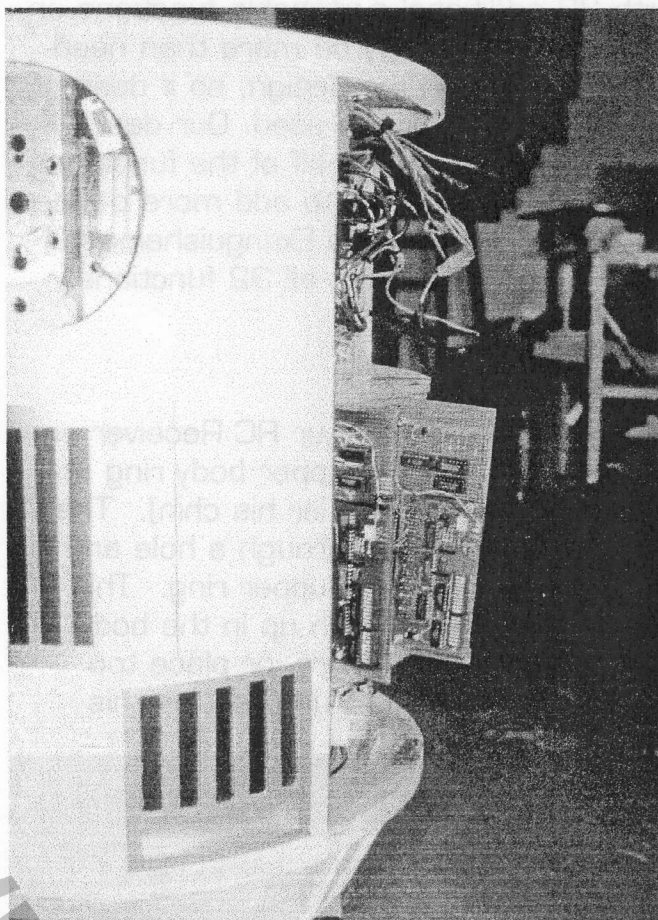
SWITCH 16s

When we discovered the Switch 16s, we realized the potential of how much they could solve. We had one problem. Most of our device logic circuits had already been designed, and weren't quite compatible with the Switch 16s; at least not in their original forms. A lot of our devices required a logic pulse to trigger an action, or an 'active high' signal to operate. The Switch 16 outputs are via transistors to ground (negative- 'active low'). In order to interface the unit properly into our already established design we ended up removing all the transistors and using the logic signals that drove them. These signals were active high and quite able to drive our logic circuits and transistors. Some outputs were set to be momentary, while others toggle on/off each time a controller button is pressed.

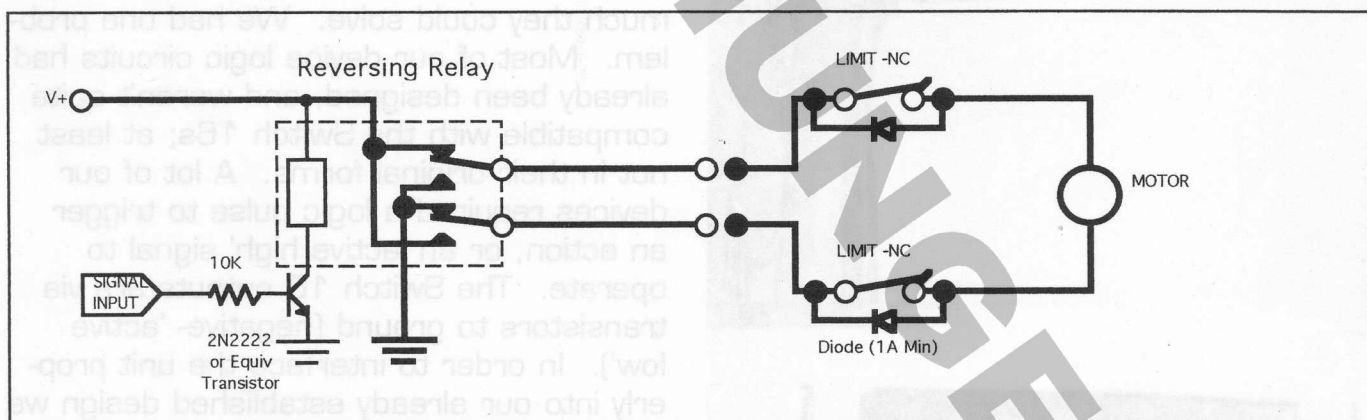
As mentioned earlier, the second Switch 16 was modified further, with an encoder circuit to convert the 16 outputs (all set to momentary) to a four-bit binary signal with one additional control line (a

flag). This meant that only five signals needed to be transferred to the head instead of 16 (see Slip Rings). A switchover circuit allows for future installation of a Microprocessor control in the body, with a four bit binary code operating functions in the head. For those not wanting to get into Microcontrollers, it's much easier to install the second Switch16 in the head itself.

Enough of our overcomplicated design. For those who want just basic control, use the Switch16 outputs to drive motor relays directly (eliminating our transistors from the circuits we've shown in this book). Using a simple reversing relay circuit, with the Switch16 output set to toggle, a device such as a panel or arm can be operated using one controller button. Limit switches with blocking diodes at either end of travel shut off the motor until the direction is reversed by the relay. Smaller loads can be directly driven off the Switch16 (see voice unit), as can be lighting such as the spotlight/holoprojector.



Switch 16 Cards



In the circuit above, the relay is used to reverse the direction of current to the motor. The diodes serve as current blocks, and when a limit switch is reached, it opens and current is blocked by the diode, shutting off the motor. Diodes should be selected based on the motor current. To simplify things, the resistor and transistor can be omitted and the negative terminal of the relay can be directly connected to the Switch 16.

SECTION THREE: LEGS AND DRIVE

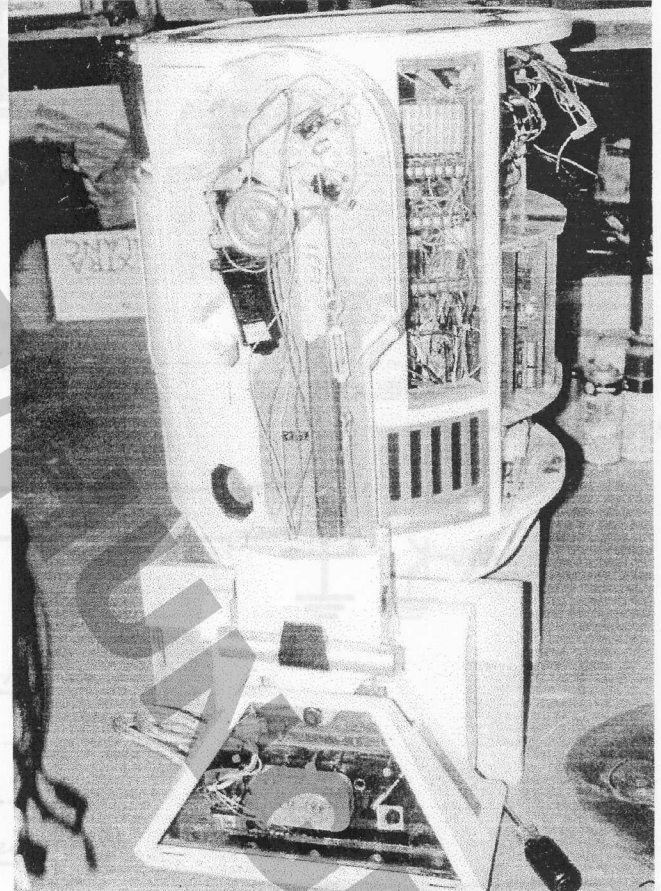
From a mechanical point of view, Three Leg Mode is probably the most difficult function in the droid. The combination of geometry, load bearing, mechanics, and timing is a very critical mix. We tried several variations, some with abysmal failure, one resulting in his almost falling on his face. Many people have studied footage of R2 switching over and are trying to do it this way. The problem is that this method only works in the movies, where a stop motion or CGI model can be manipulated. He seems to tilt forward as the centre leg extends, then settles into position on the centre foot. If we had a few years and a budget, as well as space inside for gyrostabilizers etc., we could probably do it this way without him falling over forward in the process.

OPERATION

Our design incorporates a sequence, controlled by the limit switches on his leg/tilt mechanisms. When first activated, the centre leg extends to reach the floor. When it reaches the bottom of travel it engages two limit switches, one to switch off the motor, and the second to signal a control circuit that the centre foot is in position. A slight time delay now ensures the foot is firmly in place before activating the motors in the shoulders. These tilt the legs about 30 degrees. As they do this, he rolls forward on his centre foot, so the legs and body are both now at 15 degrees from vertical. Transfer is now complete. As has been mentioned and measured, his tilt is actually 15/22.5. This is probably closer, but would require the centre leg to extend below the floor, or continue extending as he tilts. It would also require an extra couple of inches of travel from the centre leg. Ours is already as long as it can be with everything else inside the body. I can't think of an easy way to do this con-

sidering the weight and design of our droid.

When deactivated, the shoulder motors are reversed, and operating now

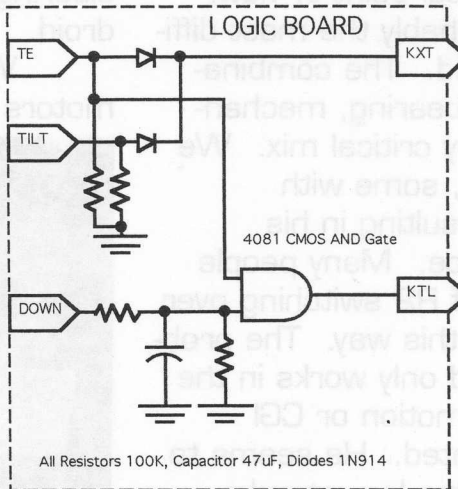


First Operational Leg Design

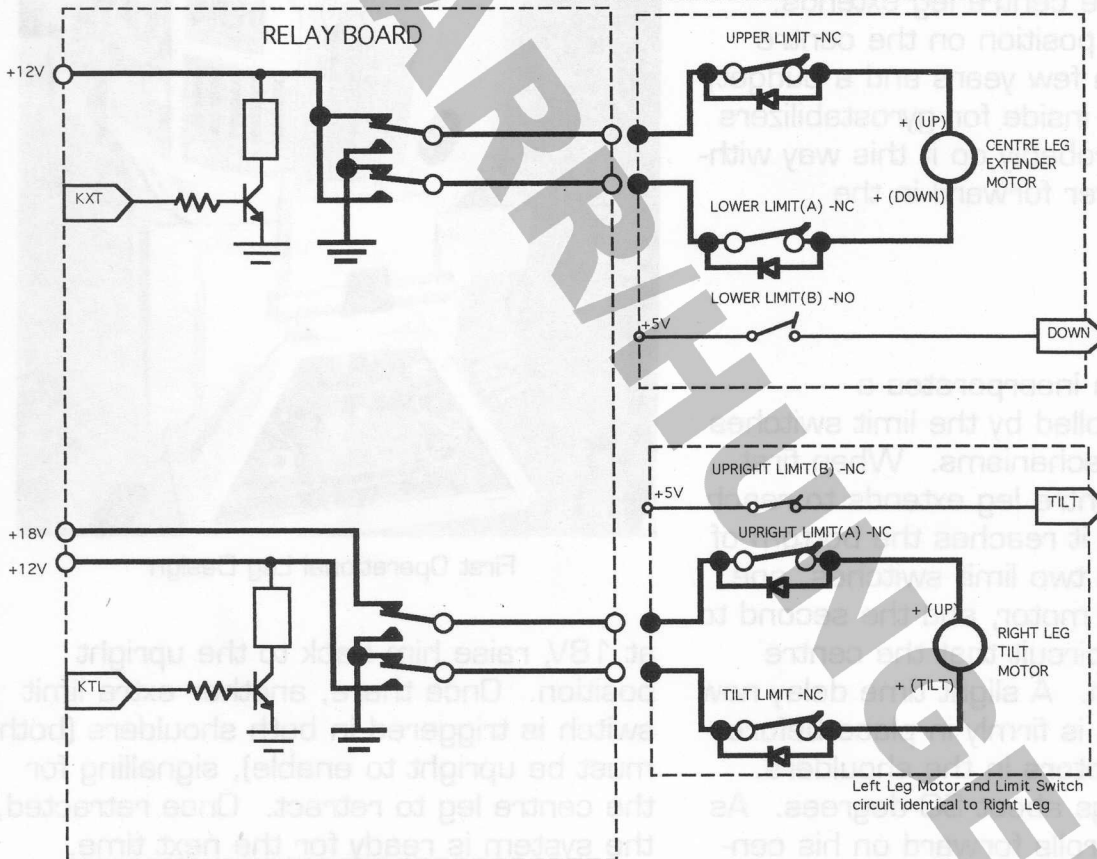
at 18V, raise him back to the upright position. Once there, another extra limit switch is triggered in both shoulders (both must be upright to enable), signalling for the centre leg to retract. Once retracted, the system is ready for the next time.

We used power window motors for our Three Leg Mode drives. They are compact, durable, and the worm drive prevents backlash, locking the legs into position when the motors are stopped. This seems to work well, despite the weight of our R2.

Microswitch actuated by Ch 5 Servo



All Resistors 100K, Capacitor 47uF, Diodes 1N914



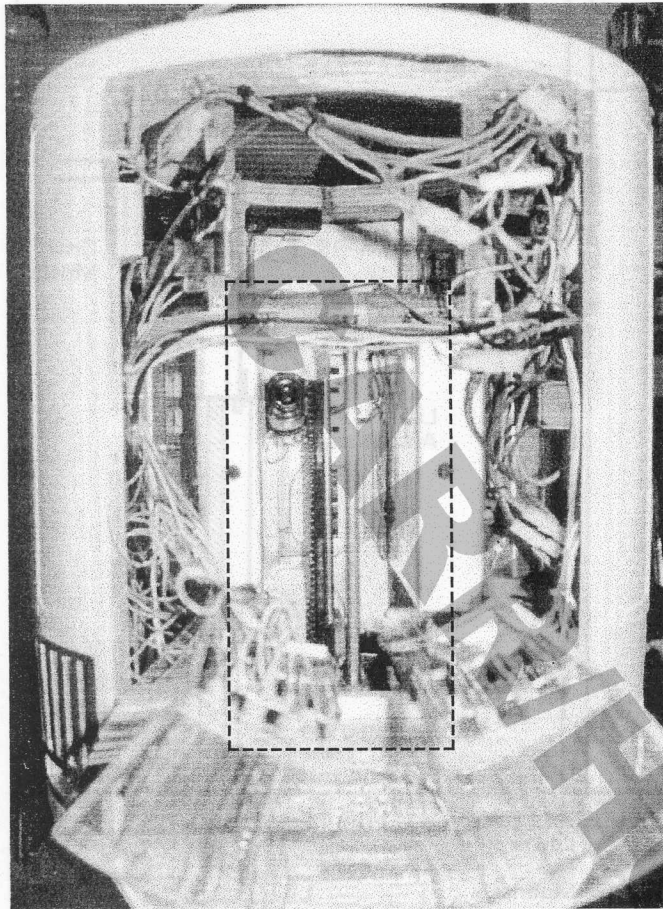
LEGEND

- TE= Tilt Enable (from Microswitch)
- TILT= Tilt notification
- DOWN= Leg down notification
- KXT= Leg extend relay signal
- KTL= Tilt relay signal

R2 ASTROMECH DROID	
TILT/3 LEG MODE SCHEMATIC	
SCALE: NONE	JUNE 3, 2000
	CARR/HUNGER

MECHANICS

The centre leg is supported on two steel rods at the front and back. We had to place them far enough apart to allow



Body with card rack open. Centre leg rails and motor can be seen.

the foot to fit between them as they extend to the base of the body. The leg itself slides along these via two brass tube bushings. The drive motor is mounted at the top, on the underside of the head support deck. A 1.5" sprocket is attached directly to the spline shaft on the motor.

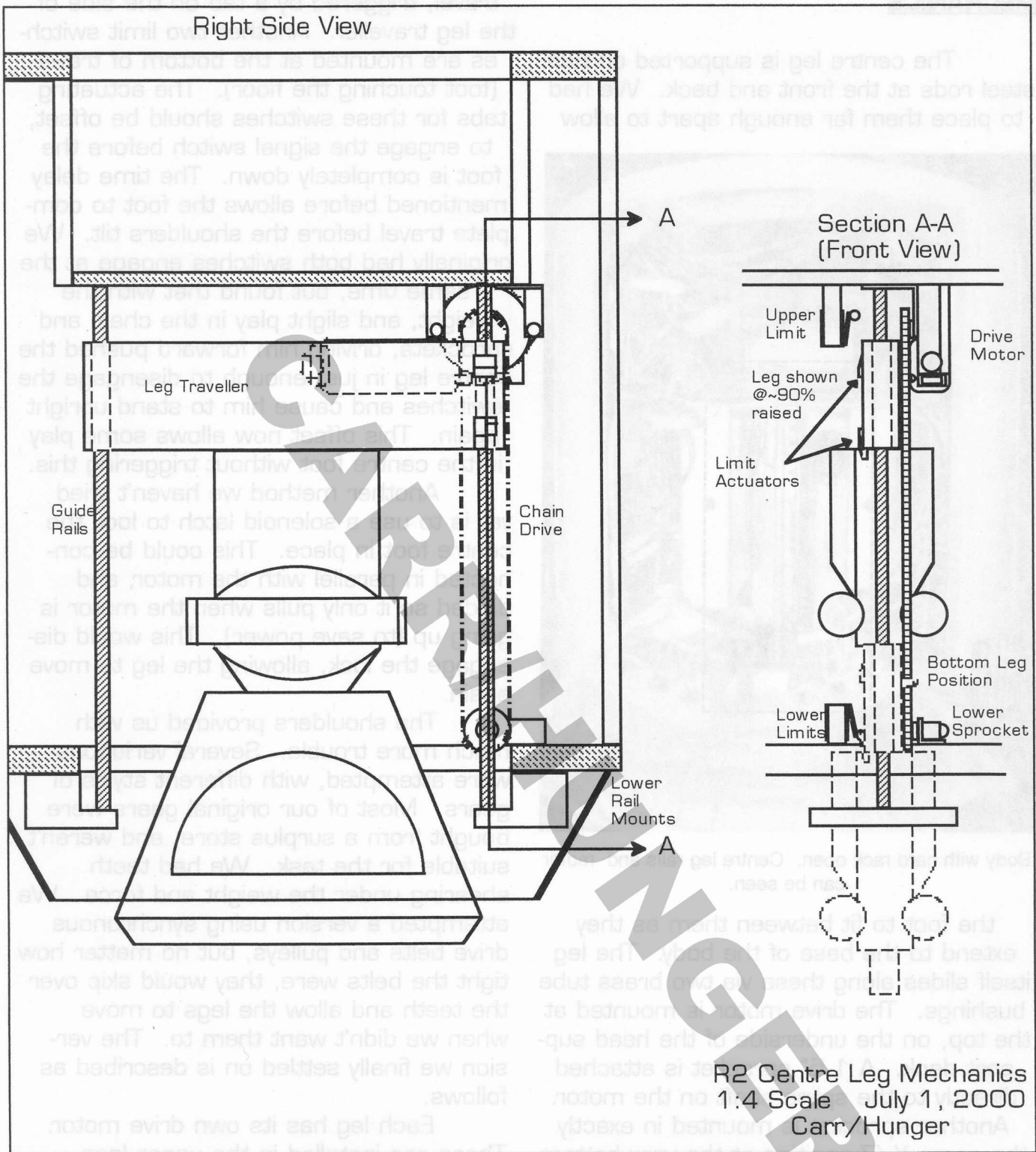
Another sprocket is mounted in exactly the same X/Z position at the very bottom of the body. A rollerchain is snugly fit between them. Make it quite tight with no play, otherwise it will allow the centre leg to move a bit when you don't want it to. A small bracket is fitted to the side of the leg traveller, which captures one link on the chain. As the motor runs, the leg is dragged up or down by the chain. A limit switch is mounted at the very top of

travel, triggered by a tab on the side of the leg traveller. Another two limit switches are mounted at the bottom of travel (foot touching the floor). The actuating tabs for these switches should be offset, to engage the signal switch before the foot is completely down. The time delay mentioned before allows the foot to complete travel before the shoulders tilt. We originally had both switches engage at the same time, but found that with the weight, and slight play in the chain and sprockets, driving him forward pushed the centre leg in just enough to disengage the switches and cause him to stand upright again. This offset now allows some play in the centre foot without triggering this.

Another method we haven't tried yet is to use a solenoid latch to lock the centre foot in place. This could be connected in parallel with the motor, and dioded so it only pulls when the motor is going up (to save power). This would disengage the lock, allowing the leg to move again.

The shoulders provided us with much more trouble. Several variations were attempted, with different styles of gears. Most of our original gears were bought from a surplus store, and weren't suitable for the task. We had teeth shearing under the weight and force. We attempted a version using synchronous drive belts and pulleys, but no matter how tight the belts were, they would skip over the teeth and allow the legs to move when we didn't want them to. The version we finally settled on is described as follows.

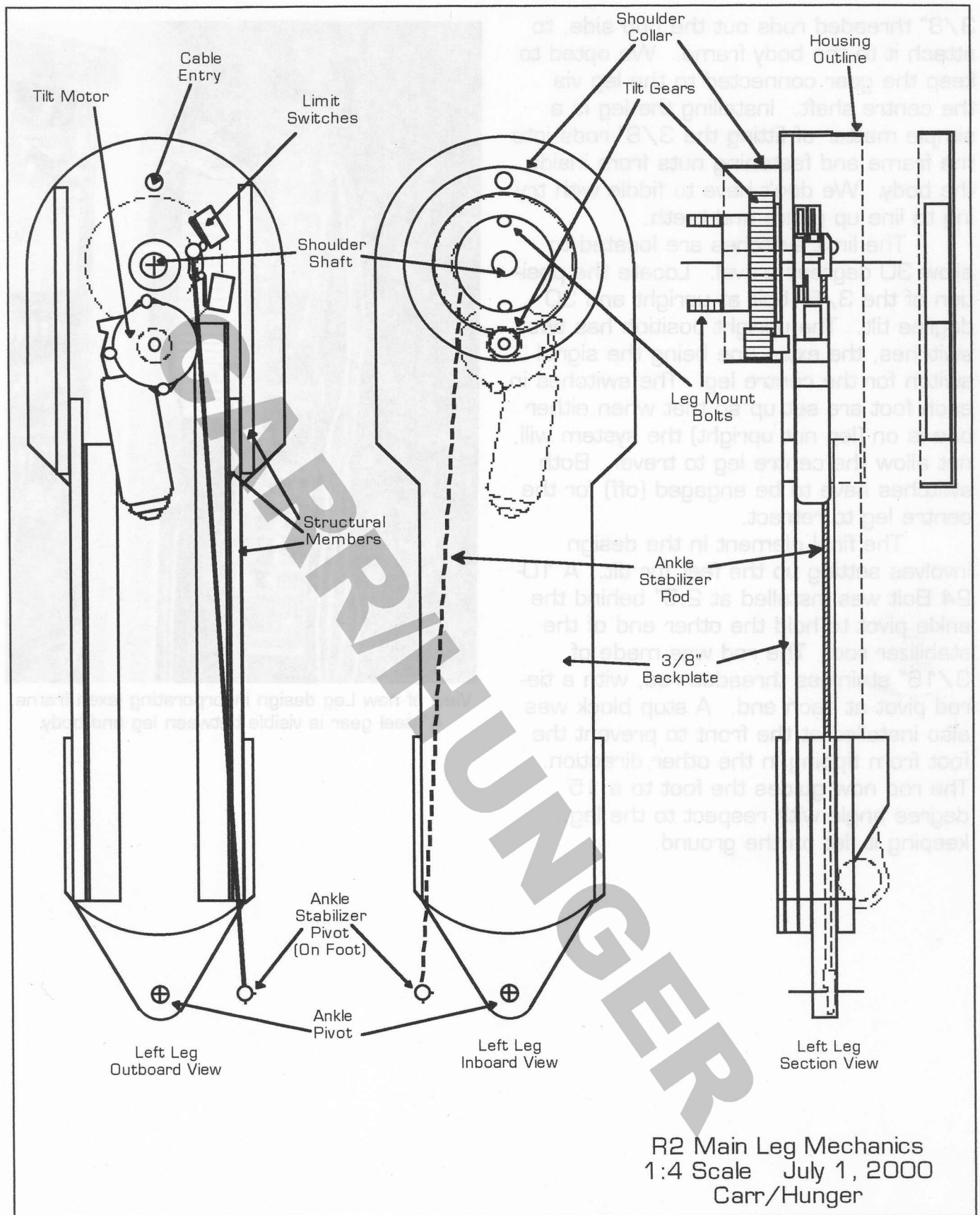
Each leg has its own drive motor. These are installed in the upper legs themselves (as there was no room left in the body). We mounted them with the spline shaft extending inboard towards the body, at the bottom of the shoulder ring. A 12 tooth (3/4" dia) steel gear is attached to the spline shaft. We actually had to remove the shafts and grind the ends (they are case-hardened) so we could centre drill them for 3/8" shafts to



accommodate the gears. The adjoining gear is a 64 tooth (4" dia) steel gear approximately 3/4" thick, with an additional hub. Its centre bore is 3/4", so that's the size of shoulder shaft we used. We laid out our gearing positions, angle of travel, etc, and drilled the holes in the legs.

In order to stabilize R2's feet so

they don't move in the upright position, we devised a rod assembly that ties the foot to the body. As seen in the drawing, we needed a 1:2 ratio for foot movement vs total travel. Picking a radius for the ankle pivot that was useable (2.5"), we needed half that at the shoulder pivot. A hole was drilled on the face of each large gear, and a 3/8" bolt installed. This bolt has



no head, but is centre drilled to accept a 10-24 Machine Screw. This screw will hold the rod at the top. An arced slot also had to be milled into the leg plate to

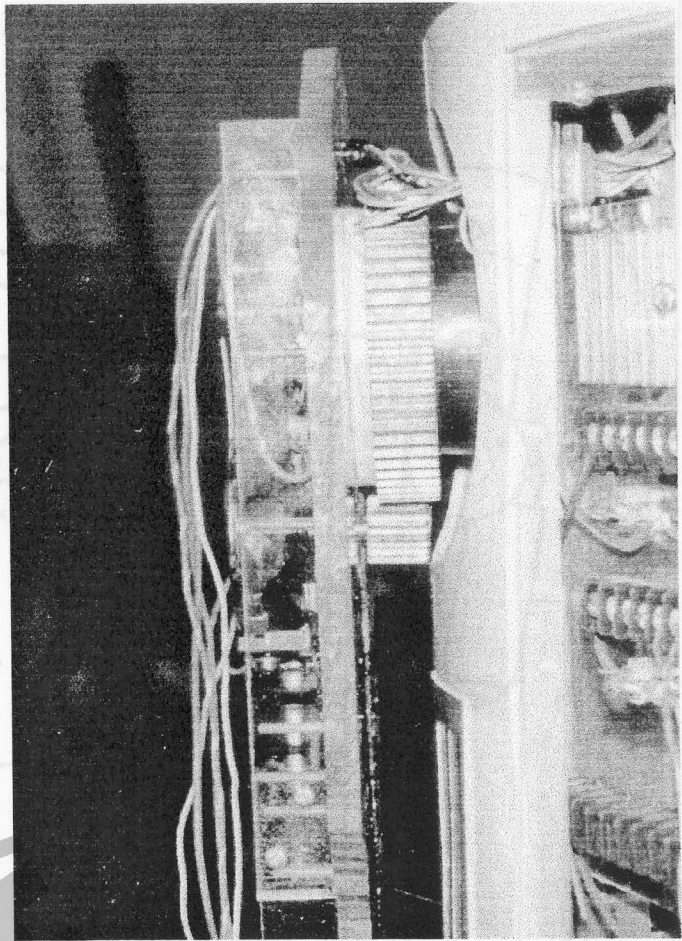
accommodate this 3/8" bolt and its travel range. This 3/8" bolt also engages the limit switches for the leg travel.

The 4" gear is also fitted with two

3/8" threaded rods out the hub side, to attach it to the body frame. We opted to keep the gear connected to the leg via the centre shaft. Installing the leg is a simple matter of fitting the 3/8" rods into the frame and fastening nuts from inside the body. We don't have to fiddle with trying to line up gears and teeth.

The limit switches are located to allow 30 degrees travel. Locate the position of the 3/8" bolt at upright and 30 degree tilt. The upright position has two switches, the extra one being the signal switch for the centre leg. The switches in each foot are set up so that when either one is on (leg not upright) the system will not allow the centre leg to travel. Both switches have to be engaged (off) for the centre leg to retract.

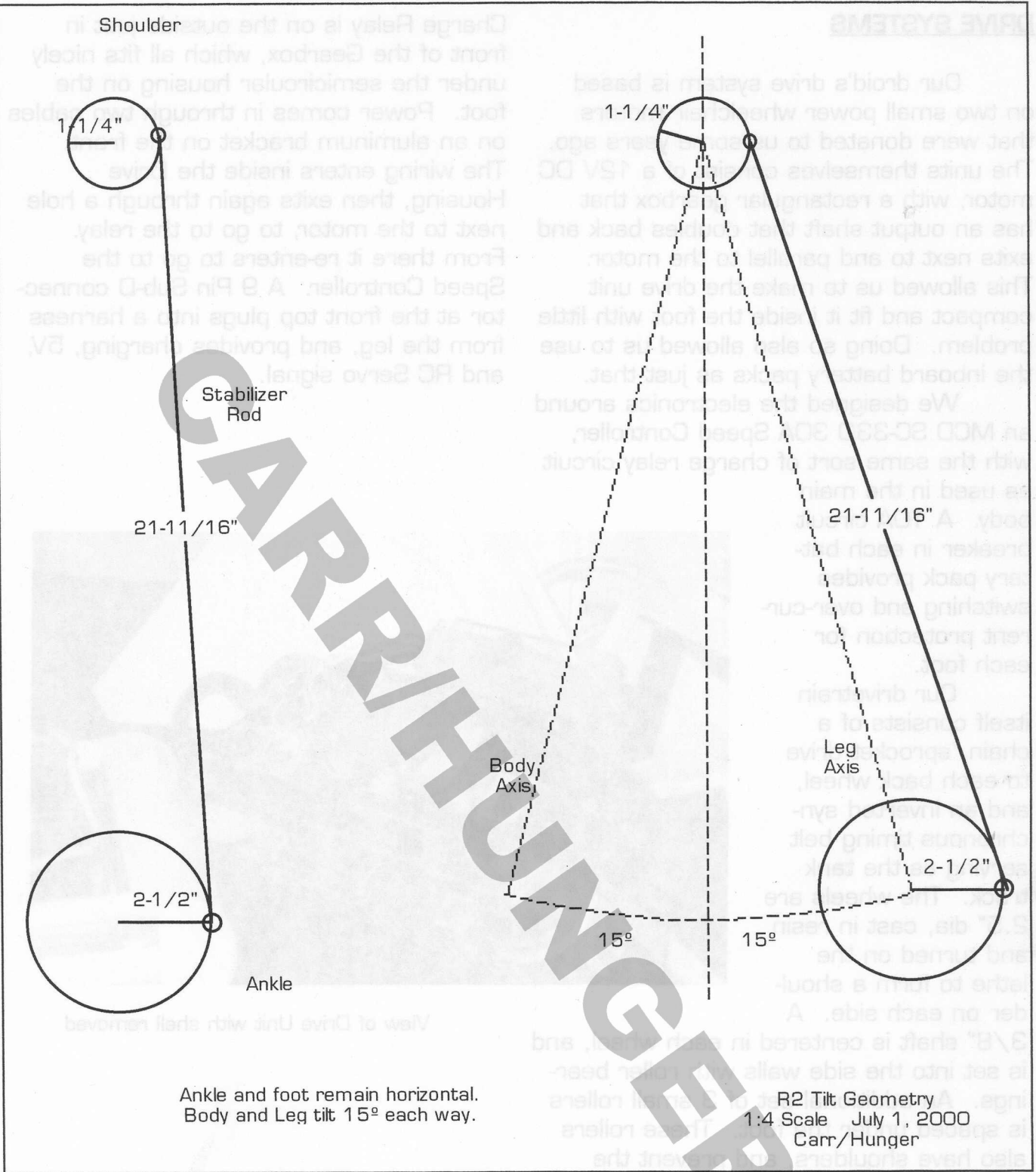
The final element in the design involves setting up the feet for tilt. A 10-24 Bolt was installed at 2.5" behind the ankle pivot to hold the other end of the stabilizer rod. The rod was made of 3/16" stainless threaded rod, with a tie-rod pivot at each end. A stop block was also installed at the front to prevent the foot from tipping in the other direction. The rod now guides the foot to a 15 degree angle with respect to the leg, keeping it flat on the ground.



View of new Leg design incorporating lexan frame. 4" steel gear is visible between leg and body.



RS Main Leg Mechanics
1:4 Scale July 1, 2000
Cam/Hunger



DRIVE SYSTEMS

Our droid's drive system is based on two small power wheelchair motors that were donated to us some years ago. The units themselves consist of a 12V DC motor, with a rectangular gearbox that has an output shaft that doubles back and exits next to and parallel to the motor. This allowed us to make the drive unit compact and fit it inside the foot with little problem. Doing so also allowed us to use the inboard battery packs as just that.

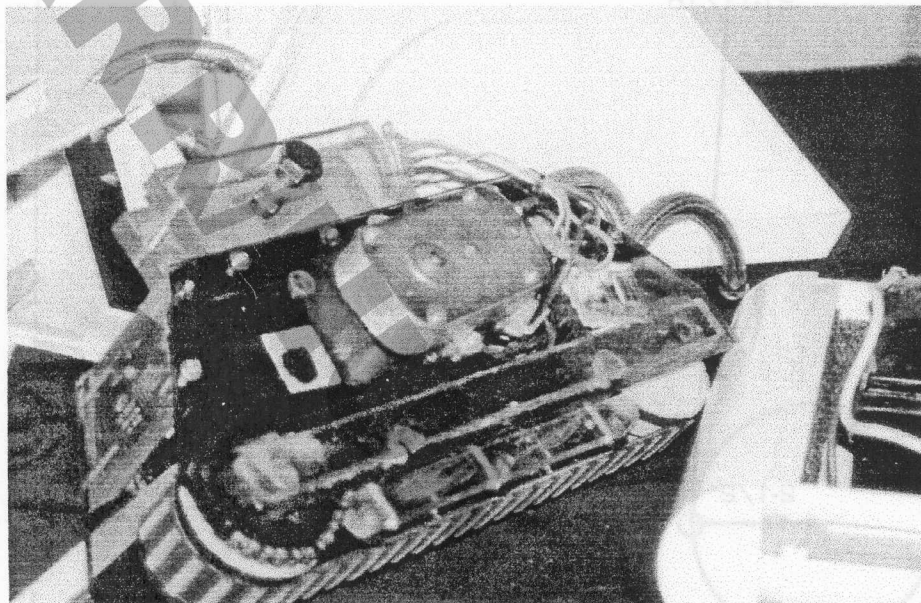
We designed the electronics around an MCD SC-330 30A Speed Controller, with the same sort of charge relay circuit as used in the main body. A 10A circuit breaker in each battery pack provides switching and over-current protection for each foot.

Our drivetrain itself consists of a chain/sprocket drive to each back wheel, and an inverted synchronous timing belt serving as the tank track. The wheels are 2.5" dia, cast in resin and turned on the lathe to form a shoulder on each side. A 3/8" shaft is centered in each wheel, and is set into the side walls with roller bearings. An additional set of 3 small rollers is spaced under the foot. These rollers also have shoulders, and prevent the track from being dragged sideways when R2 is turning.

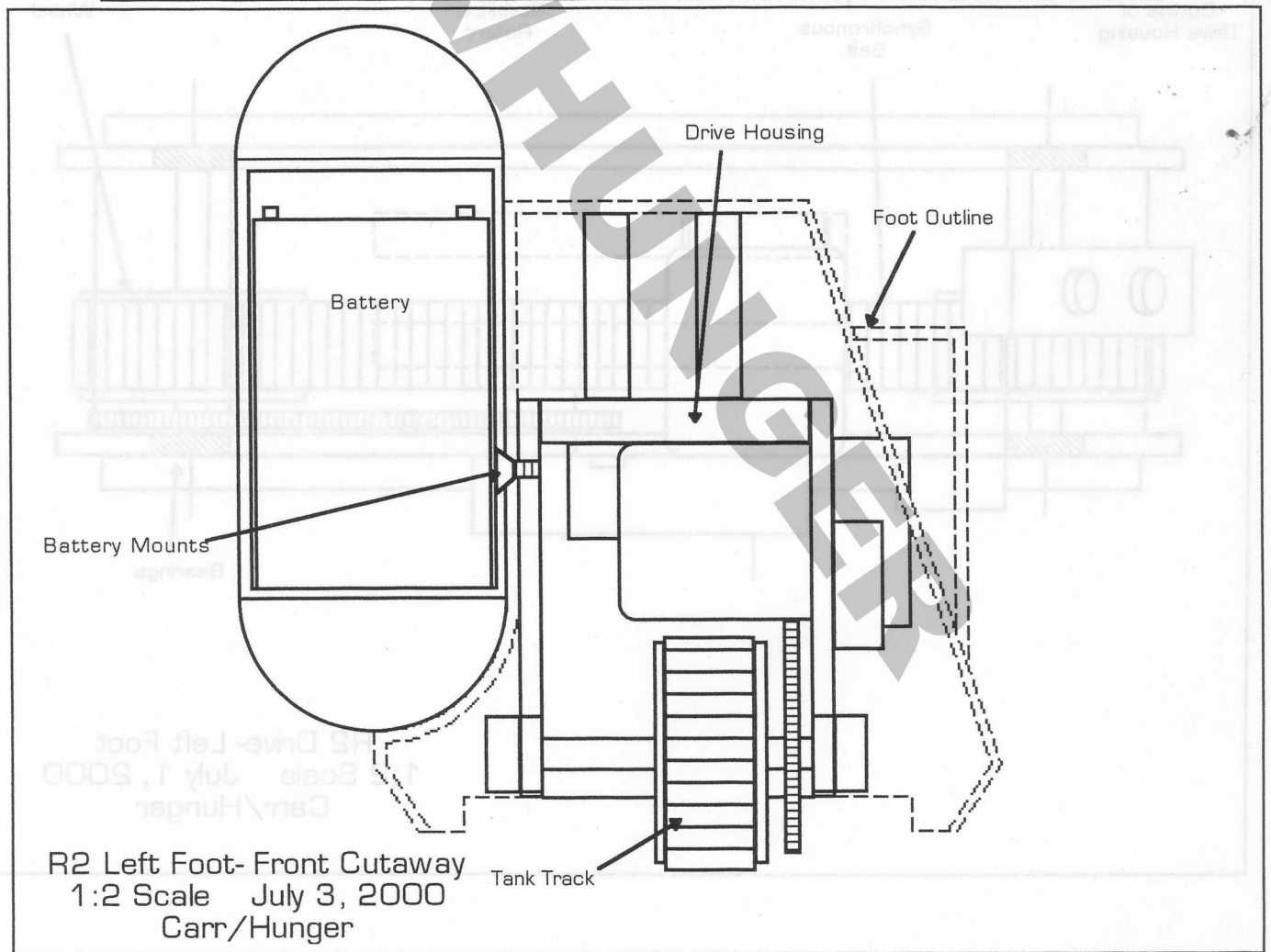
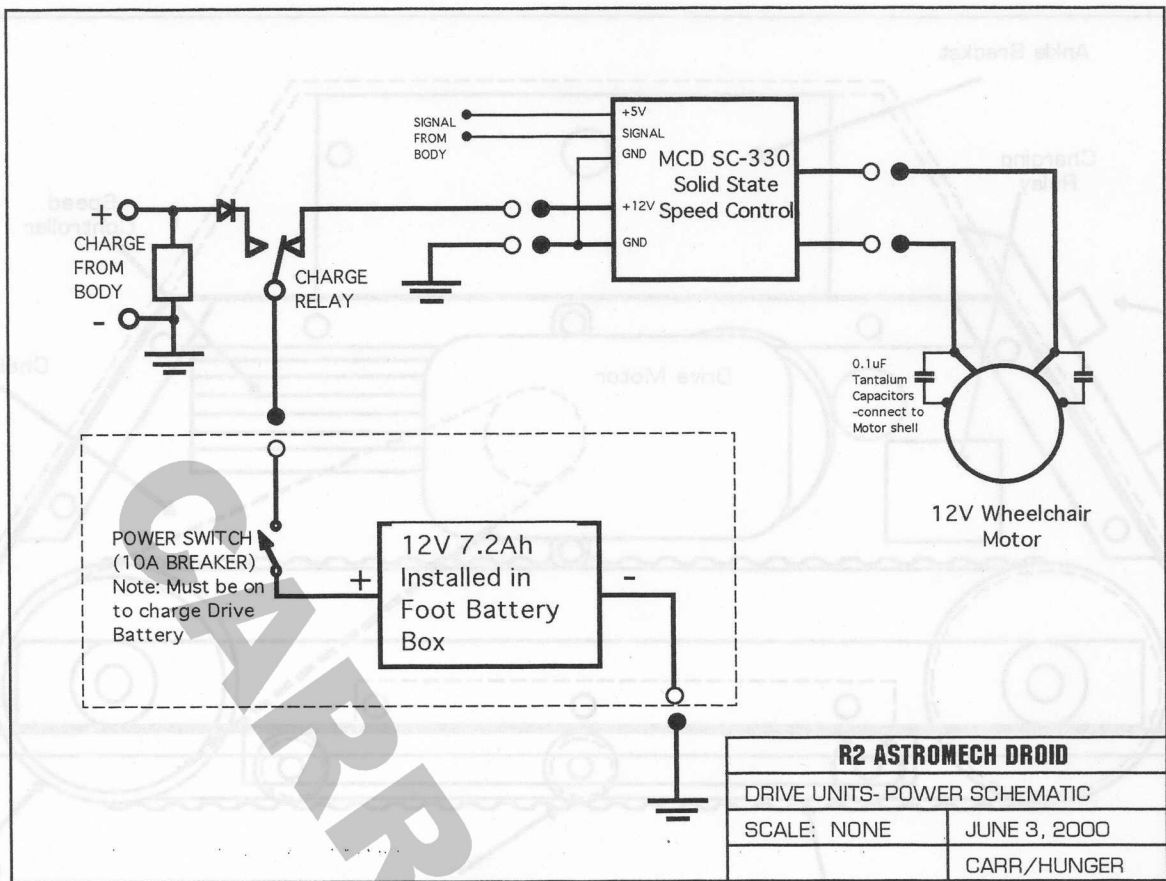
The foot shell itself is only attached to the inboard side of the housing, and provides no structural support. The battery pack is screwed through the inboard shell wall, into the housing wall, holding the whole unit together.

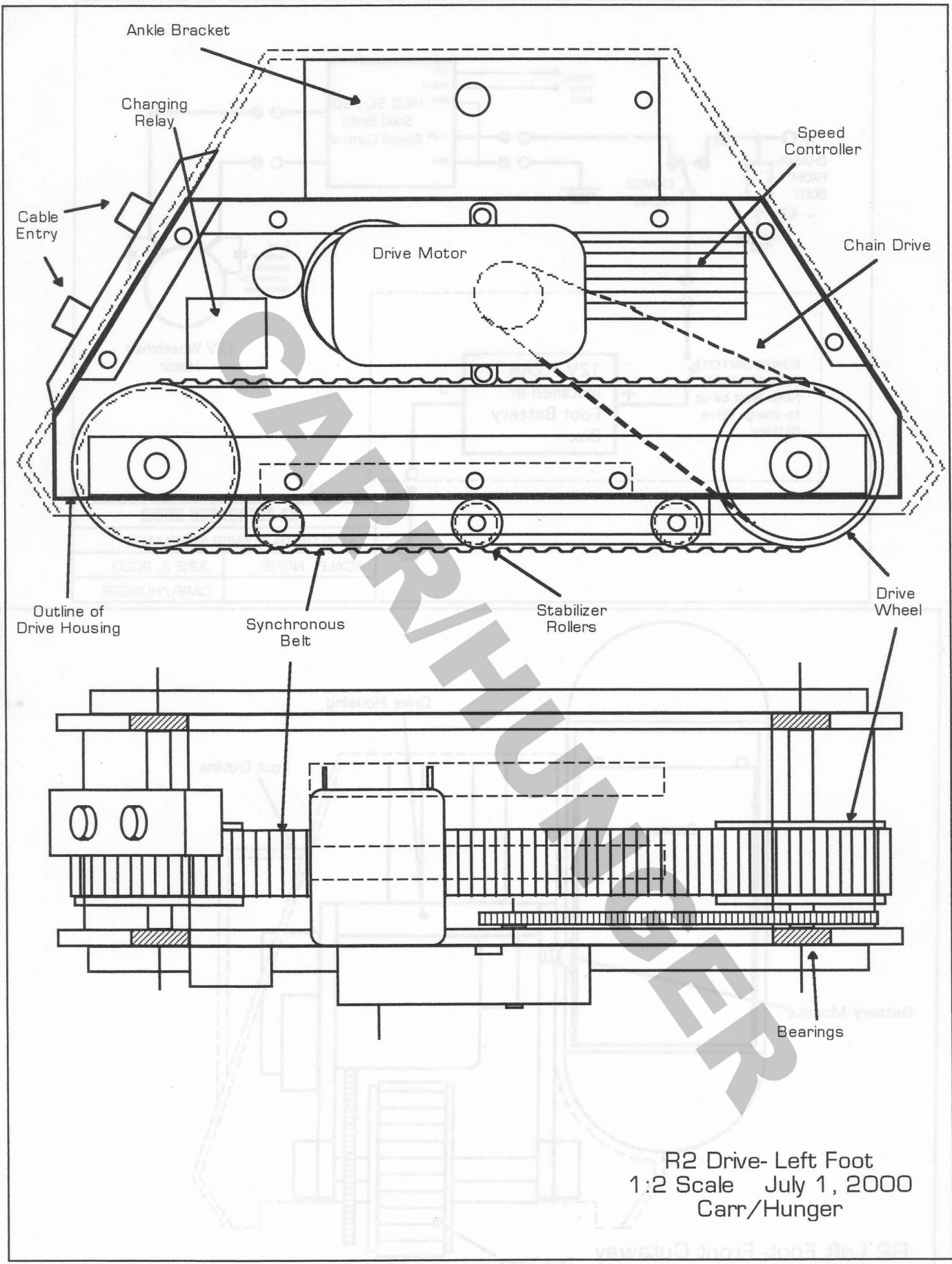
The Speed Controller is installed inside the Drive Housing at the back. The

Charge Relay is on the outside just in front of the Gearbox, which all fits nicely under the semicircular housing on the foot. Power comes in through two cables on an aluminum bracket on the front. The wiring enters inside the Drive Housing, then exits again through a hole next to the motor, to go to the relay. From there it re-enters to go to the Speed Controller. A 9 Pin Sub-D connector at the front top plugs into a harness from the leg, and provides charging, 5V, and RC Servo signal.



View of Drive Unit with shell removed



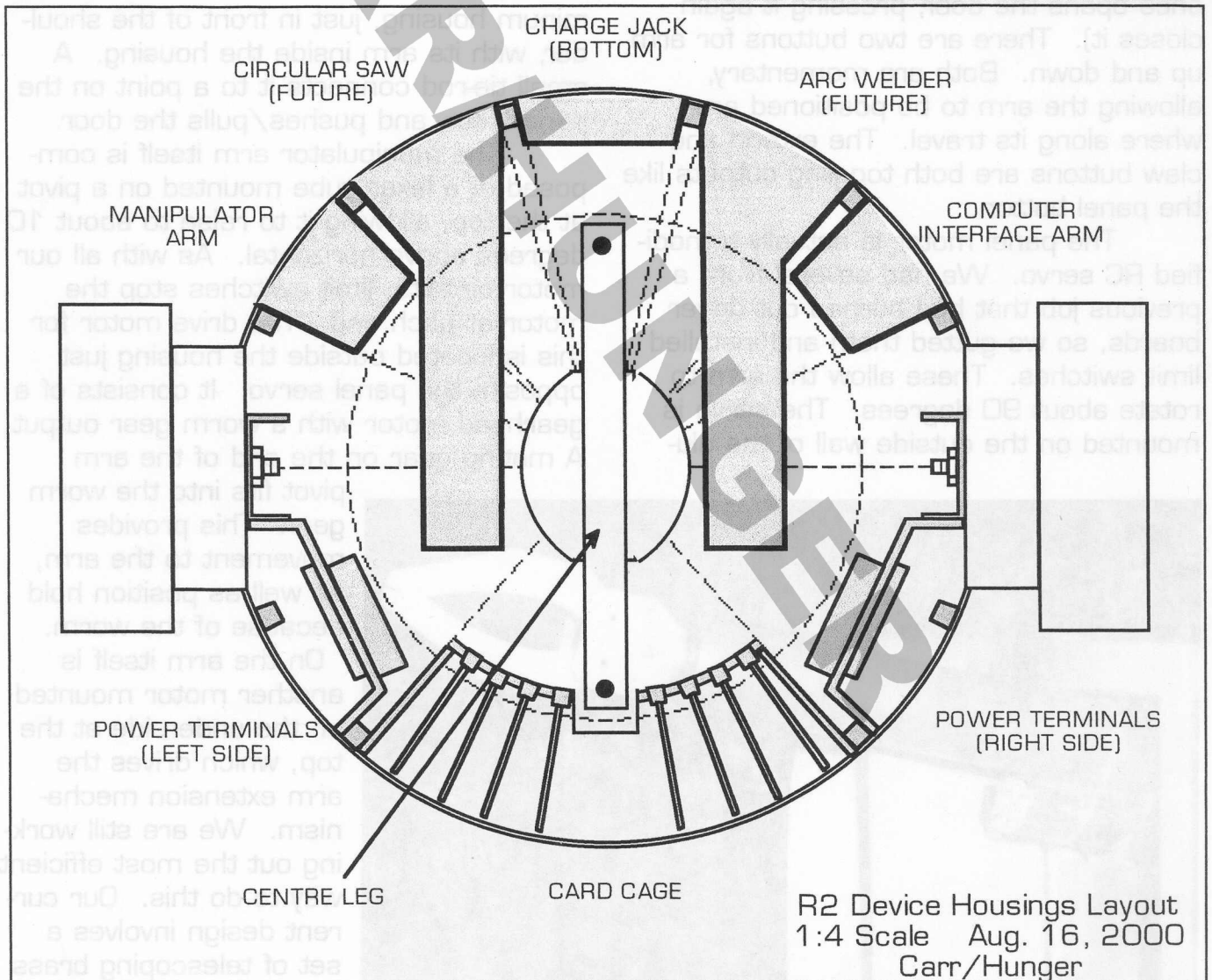


R2 Drive- Left Foot
 1:2 Scale July 1, 2000
 Carr/Hunger

SECTION FOUR: PERIPHERAL DEVICES

When we decided to equip our droid with all the functions seen in the movies, we knew we had our work cut out for us. Of course, some of the functions just aren't possible, so we decided to pick the most feasible. Our droid still isn't fully equipped, but provisions have been made to expand him. We've built housings for the existing devices we have, as well as for future upgrades. This means that almost every cubic inch of space inside is spoken for. This section outlines how we've built the housings, hinges, servos, and devices.

All of our devices are contained in aluminum enclosures, which are permanently fastened to the frame. The design of our body shell makes them impossible

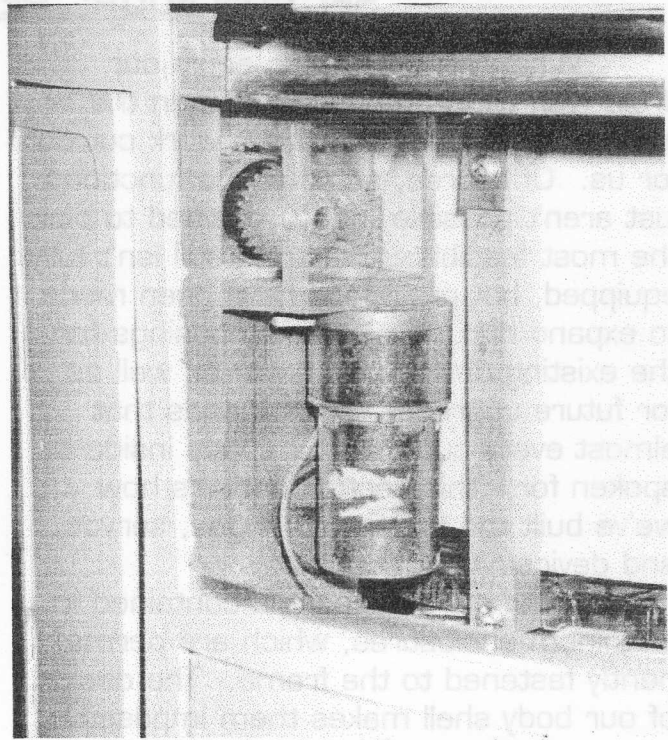


to remove, so we had to consider other methods of serviceability. The individual drive motors, servos, and components are removable through the device opening, or through access from inside the body. The two primary devices we've focused on are of course, the main manipulator arm, and the computer interface probe. Both are designed to be fully operational, with up/down movement, extension, etc.

MANIPULATOR ARM

All of the functions on this device are independent of each other. There are separate buttons for panel open/close, arm up, down, extend/retract, and claw open/close. The panel output from the Switch 16 is set to toggle (pressing it once opens the door, pressing it again closes it). There are two buttons for arm up and down. Both are momentary, allowing the arm to be positioned anywhere along its travel. The extend and claw buttons are both toggling outputs like the panel button.

The panel motor is actually a modified RC servo. We had several from a previous job that had burned out driver boards, so we gutted them and installed limit switches. These allow the arm to rotate about 90 degrees. The servo is mounted on the outside wall of the alu-



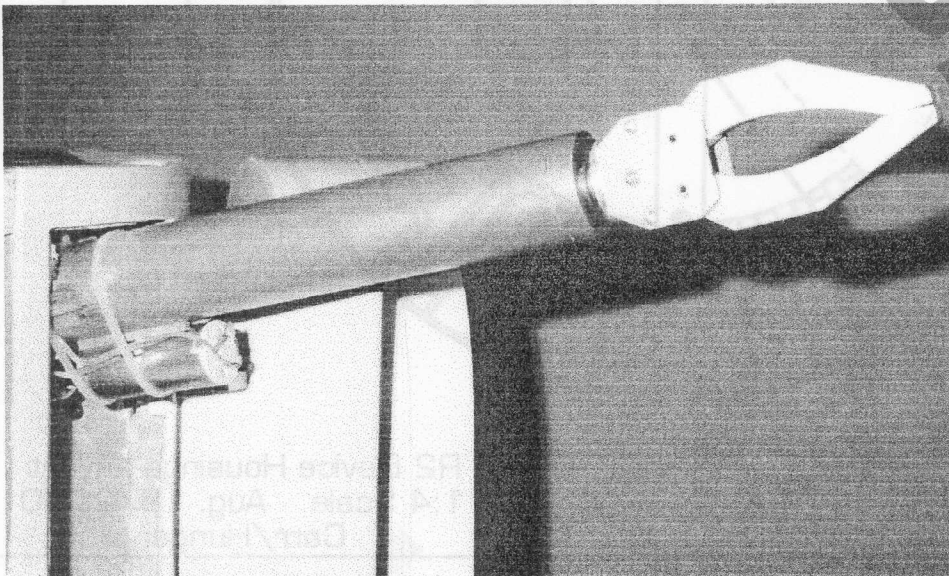
View showing Arm Lifter mechanism

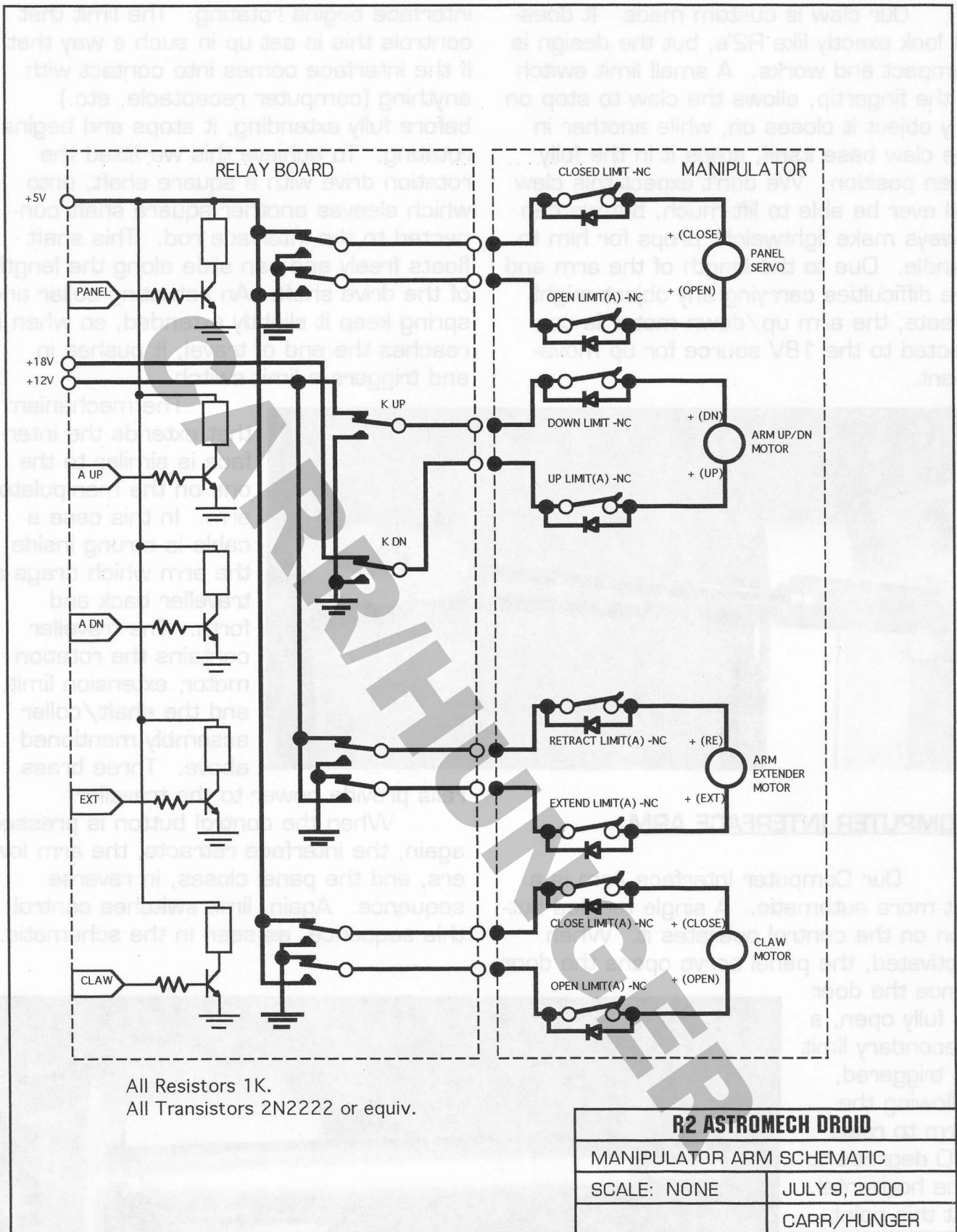
minum housing, just in front of the shoulder, with its arm inside the housing. A small tie-rod connects it to a point on the panel door, and pushes/pulls the door.

The manipulator arm itself is composed of a lexan tube mounted on a pivot at the top, allowing it to raise to about 10 degrees above horizontal. As with all our motor circuits, limit switches stop the motor at each end. The drive motor for this is located outside the housing just opposite the panel servo. It consists of a gearhead motor with a worm gear output. A mating gear on the end of the arm

pivot fits into the worm gear. This provides movement to the arm, as well as position hold because of the worm.

On the arm itself is another motor mounted on the underside at the top, which drives the arm extension mechanism. We are still working out the most efficient way to do this. Our current design involves a set of telescoping brass



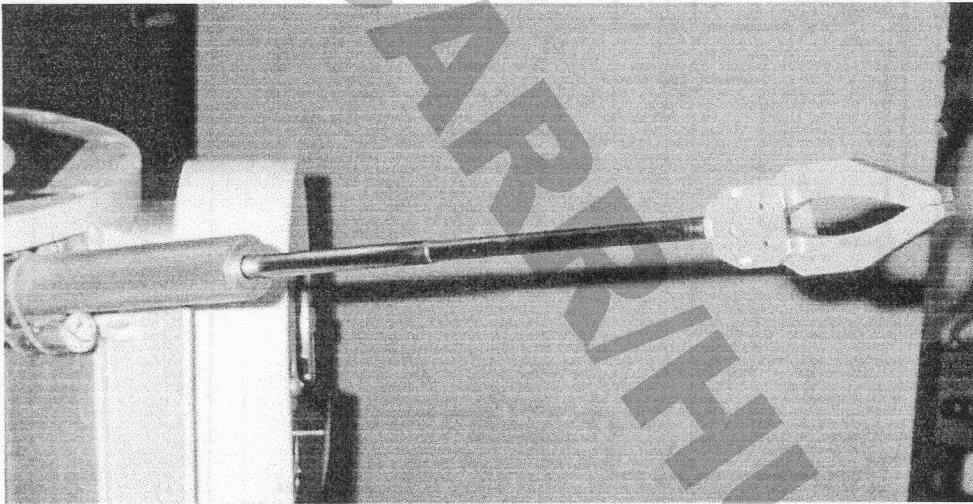


tubes, with a stiff band running down the centre. The band is fed out from a spool at the top of the arm, much the same way a power car antenna works, but

smaller. This design, once perfected, can extend the arm from 12" long to about 25".

Our claw is custom made. It doesn't look exactly like R2's, but the design is compact and works. A small limit switch in the fingertip, allows the claw to stop on any object it closes on, while another in the claw base itself, stops it in the fully open position. We don't expect this claw will ever be able to lift much, but we can always make lightweight props for him to handle. Due to the length of the arm and the difficulties carrying any object might create, the arm up/down motor is connected to the 18V source for up movement.

interface begins rotating. The limit that controls this is set up in such a way that if the interface comes into contact with anything (computer receptacle, etc.) before fully extending, it stops and begins rotating. To achieve this we fitted the rotation drive with a square shaft, onto which sleeves another square shaft connected to the interface rod. This shaft floats freely and can slide along the length of the drive shaft. An actuating collar and spring keep it slightly extended, so when it reaches the end of travel, it pushes in and triggers a limit switch.



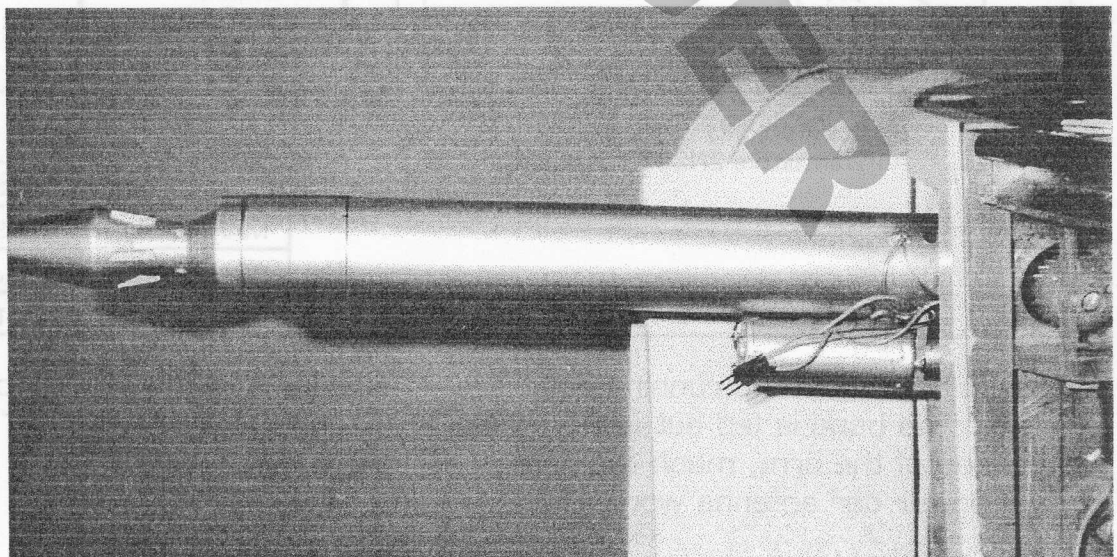
The mechanism that extends the interface is similar to the one on the manipulator arm. In this case a cable is strung inside the arm which drags a traveller back and forth. The traveller contains the rotation motor, extension limit, and the shaft/collar assembly mentioned above. Three brass

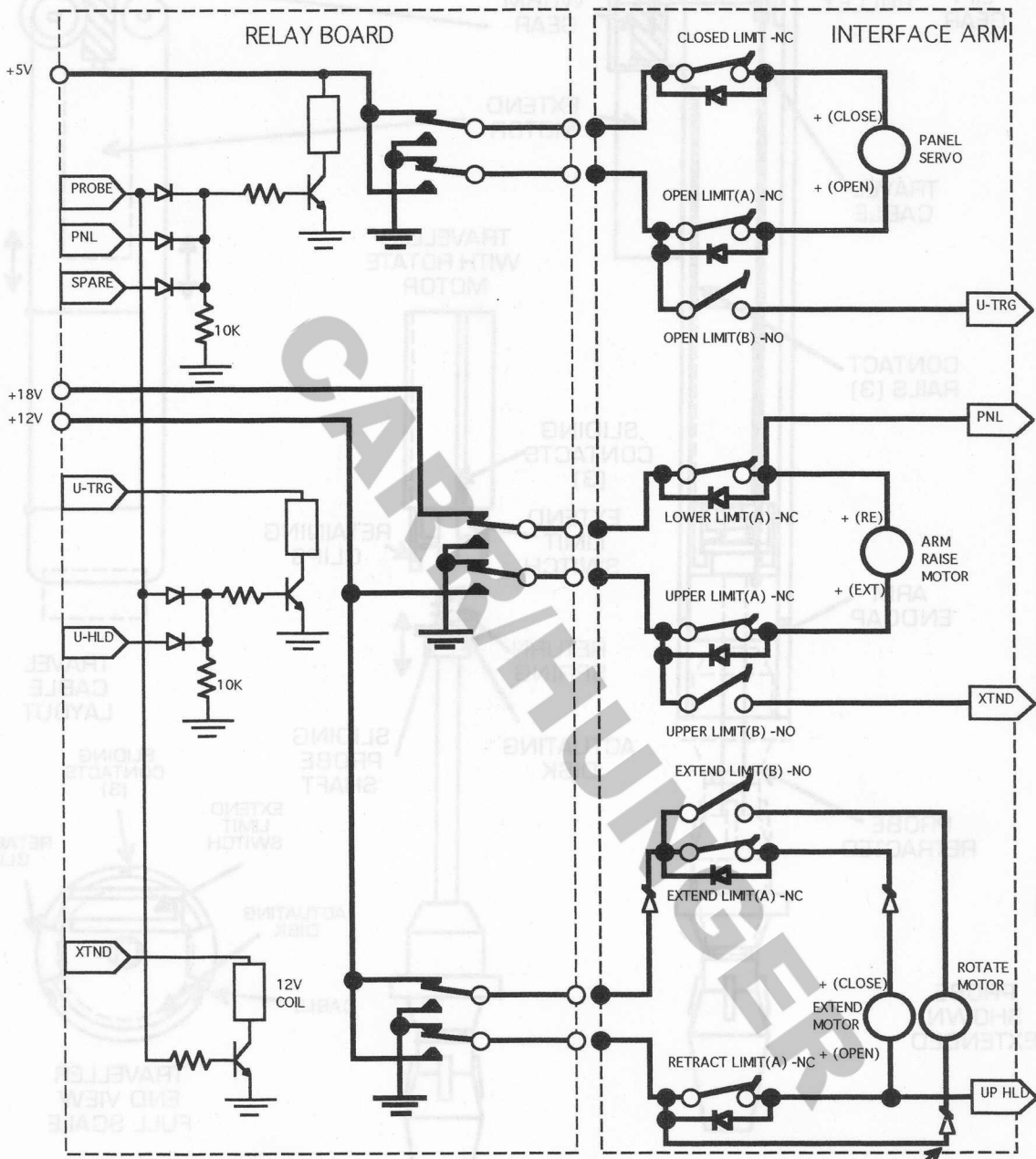
COMPUTER INTERFACE ARM

Our Computer Interface Arm is a bit more automatic. A single toggled button on the control operates it. When activated, the panel servo opens the door. Once the door is fully open, a secondary limit is triggered, allowing the arm to raise 90 degrees to the horizontal. At this point another limit is triggered to extend the interface. When fully extended, the

rails provide power to the traveller

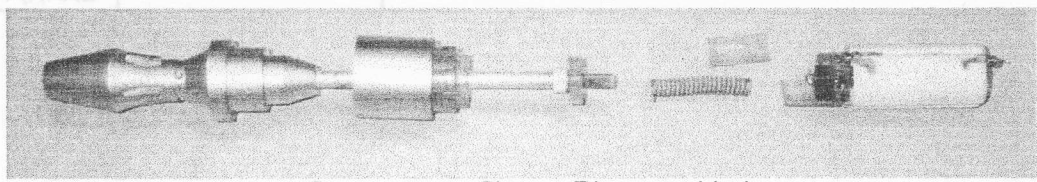
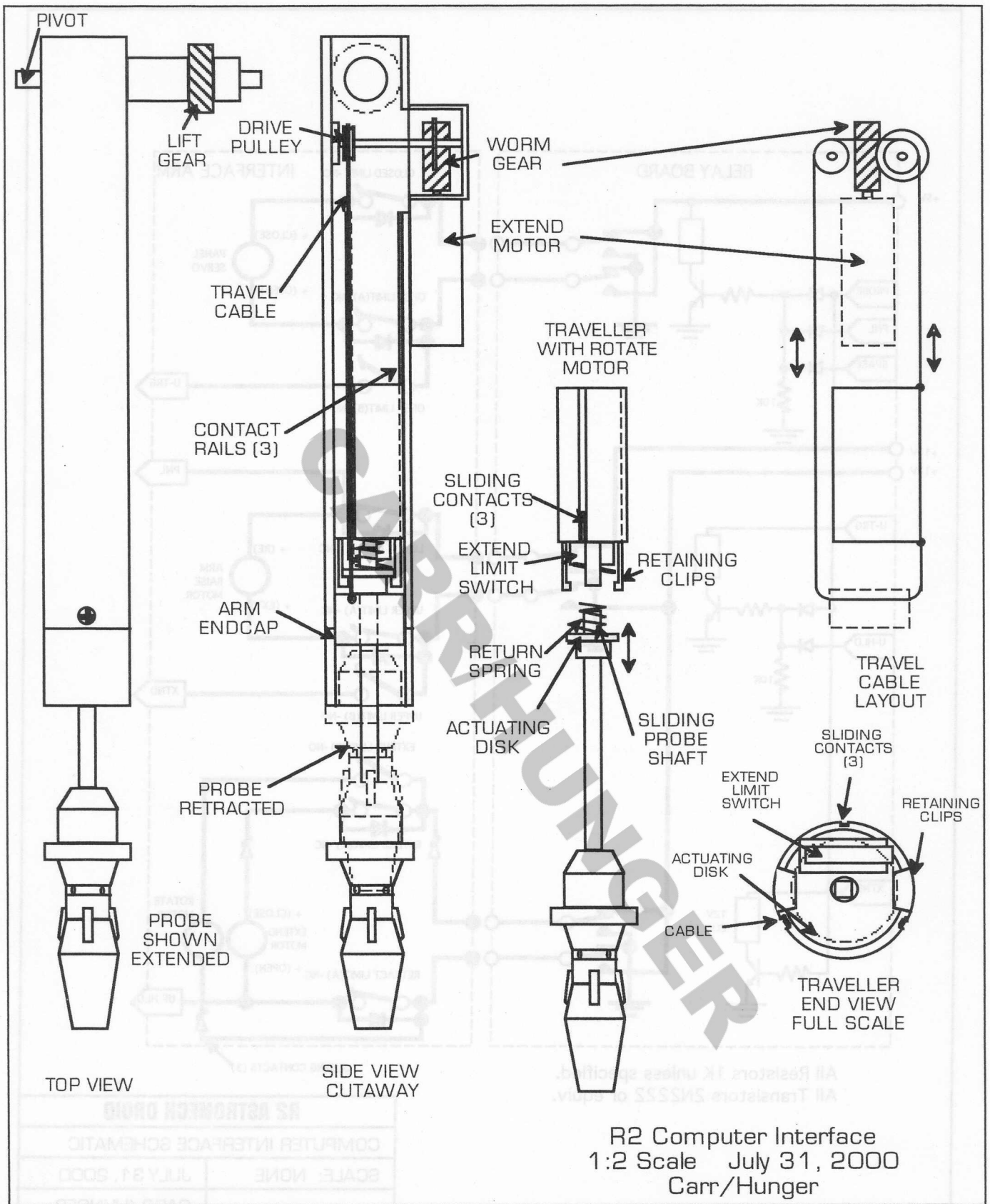
When the control button is pressed again, the interface retracts, the arm lowers, and the panel closes, in reverse sequence. Again, limit switches control this sequence, as seen in the schematic.



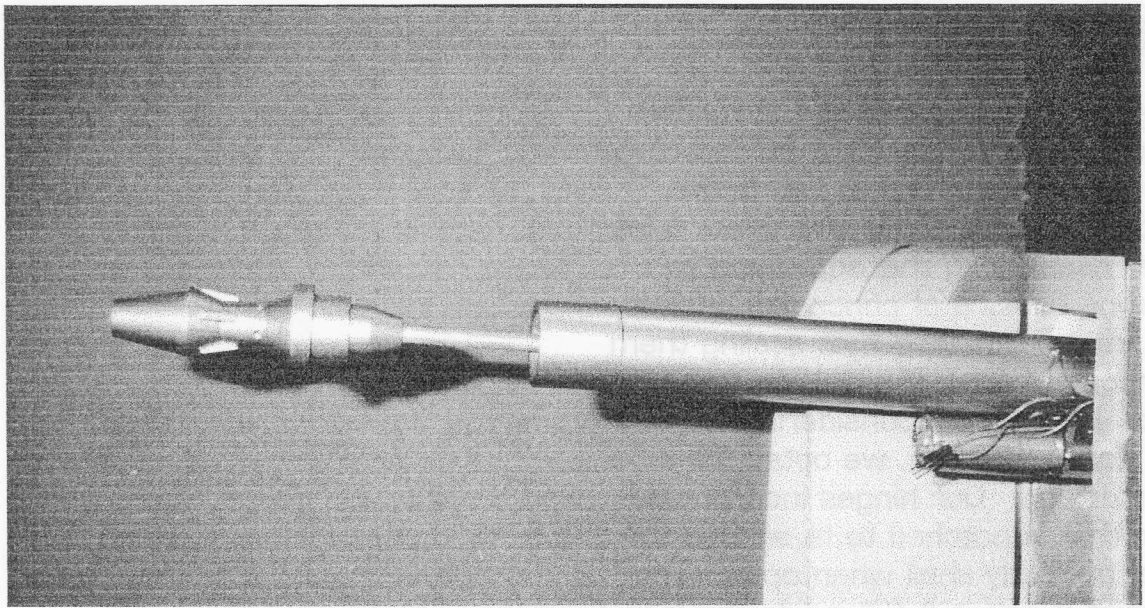


All Resistors 1K unless specified.
 All Transistors 2N2222 or equiv.

R2 ASTROMECH DROID	
COMPUTER INTERFACE SCHEMATIC	
SCALE: NONE	JULY 31, 2000
CARR/HUNGER	



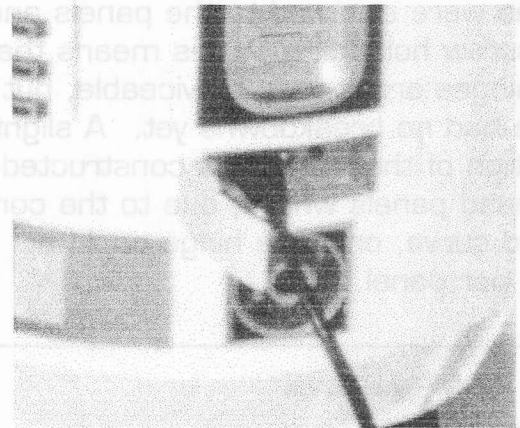
Components Shown Disassembled



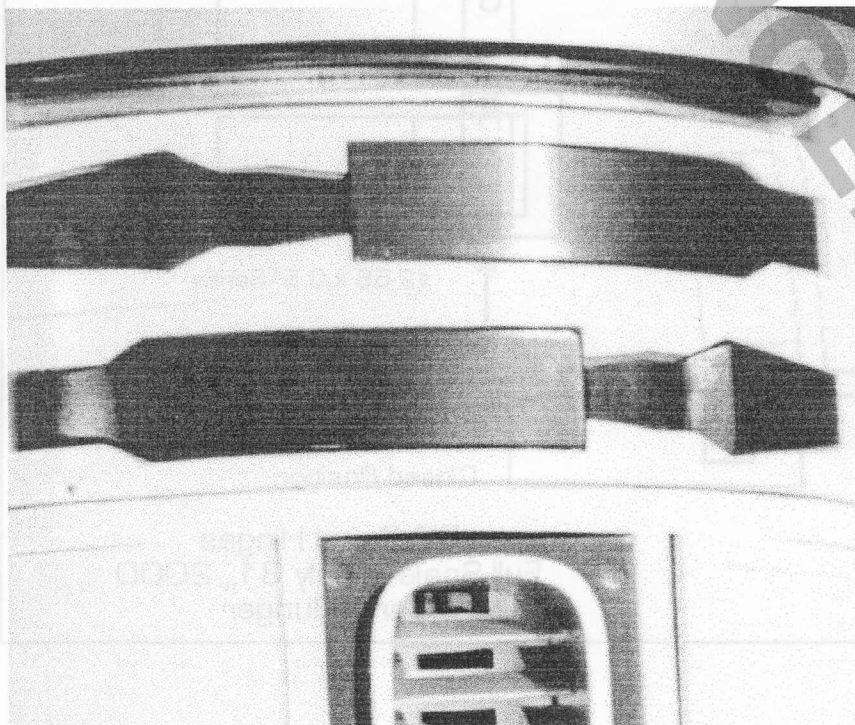
OTHER DEVICES

As mentioned, we've made provision for other devices, such as the circular saw and arc welder, as well as the blue actuator arms, which only need driver motors installed. The housings are installed, with mounting brackets and wiring harnesses. We haven't designed the other future devices yet, but sometime soon we hope to do so. Two other panels in use are the panel immediately below the front cooling ducts, and the one

to its left. The centre one is his 12V charging port, which consists of a heavy



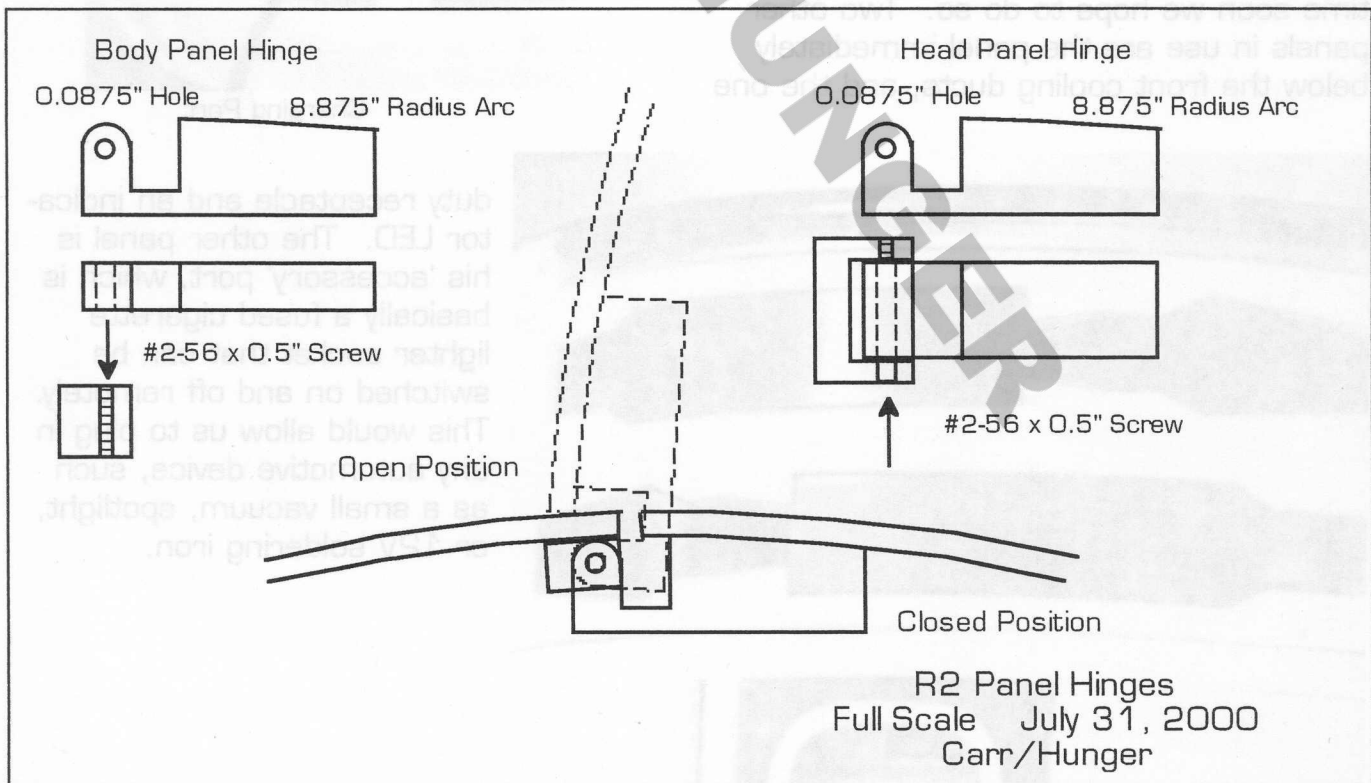
Charging Port



duty receptacle and an indicator LED. The other panel is his 'accessory' port, which is basically a fused cigarette lighter socket that can be switched on and off remotely. This would allow us to plug in any automotive device, such as a small vacuum, spotlight, or 12V soldering iron.

HINGES

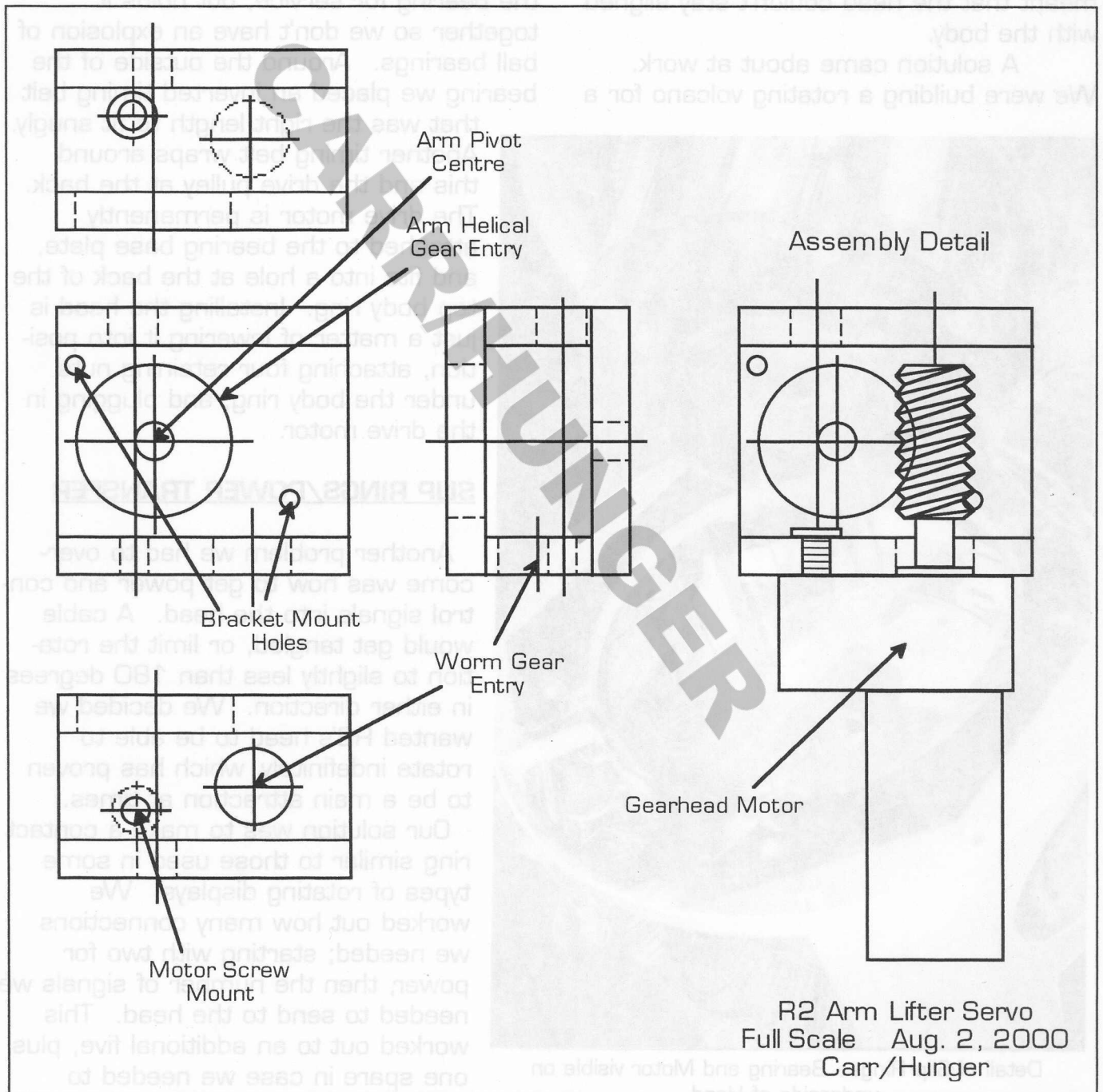
Another problem that R2 builders are encountering is finding a hidden hinge that is compact enough to use in the close quarters available. We spent a lot of time researching this and trying to copy some designs of concealed cabinet hinges, and discovered that scaling them down required a lot of precision to get them to work right. Considering we had over a dozen to make, we opted for a simpler design. Our hinges incorporate an arm that is notched to fit around the edge of the body shell when open. The pivot point is about $1/8$ " inside the frame next to the panel opening, and is mounted via one screw to a lexan block. The hinges were screwed to the panels and the screw holes filled. This means that the hinges aren't very serviceable, but we've had no breakdowns yet. A slight variation of the hinge was constructed for the head panels where, due to the compound curve, only one hinge could be used per panel.



ARM LIFTERS

We designed our arm lifter servos around a cheap gearhead motor from our local surplus store. We made an adapter bracket in 1/4" Lexan. The motor was fitted with a worm gear salvaged from an old VCR eject mechanism. The mating gear with helical teeth was attached to the pivot shaft of the arm. The whole servo assembly is mounted outside the device housing, towards the front of the body. Installing the arm is a matter of fitting it through the 1" clearance hole until

the 1/4" shaft fits into the pivot hole in the servo bracket and the helical gear meshes with the worm gear. A second bracket, made from 1.5" aluminum L-channel is then fitted over the 1/4" shaft at the other end and fastened to the top of the device housing (in our case, the 3/4" plywood top ring). The limit switches are mounted where they can be triggered by the actuator on the side of the arm at the appropriate positions.



SECTION FIVE: HEAD ROTATION AND POWER TRANSFER

HEAD ROTATION BEARING

When we originally designed the head, it was going to be supported at the very bottom (6 inches inside the body) using a commercially available 'Lazy Susan' bearing. This led to two major problems. First, the motor was going to be in the centre under the head, for which there was no room due to the centre leg. Second, the bearing had as much as 1/4" side to side play, which meant that the head couldn't stay aligned with the body.

A solution came about at work. We were building a rotating volcano for a

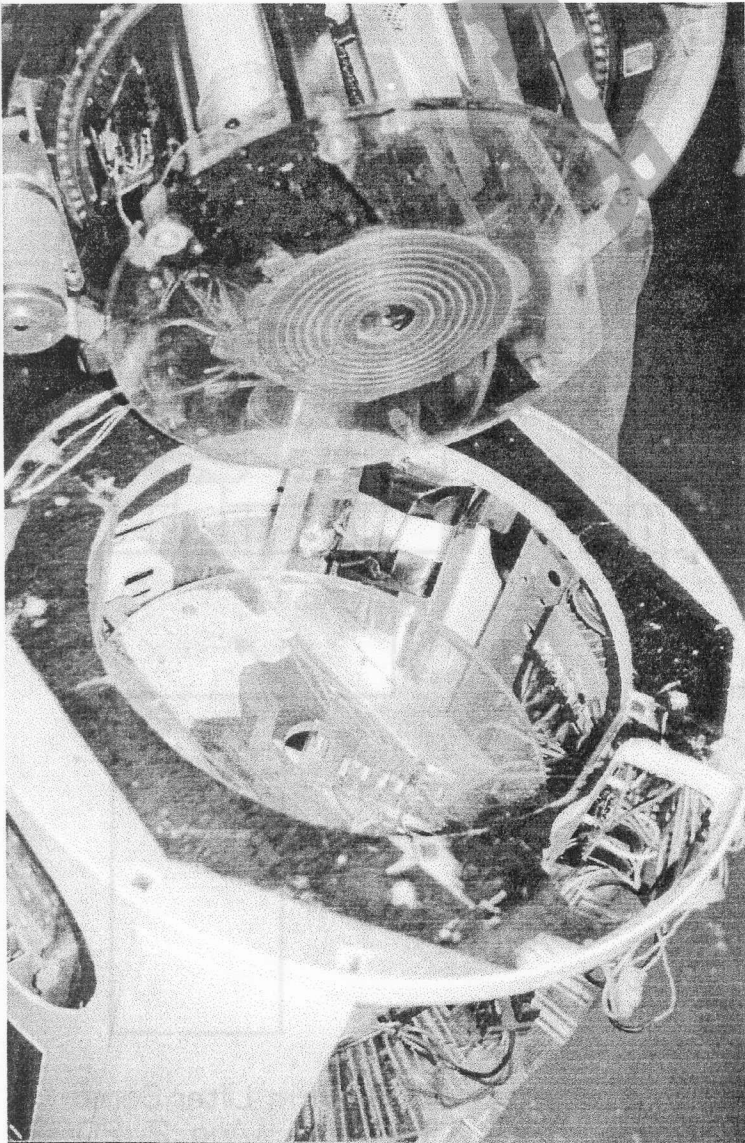
store display. This required us to use a large ring bearing. No appropriate bearing being available, we had to design and build one. Once I saw that the idea worked, I incorporated it into R2.

Essentially, the bearing consists of a top plate, a bottom plate, and acrylic rings. Sandwiched in between are about 100 3/8" ball bearings. Tolerances had to be precise, we still have a couple of tight spots we're trying to work out. A series of retaining clips allows us to open the bearing for service, but holds it together so we don't have an explosion of ball bearings. Around the outside of the bearing we placed an inverted timing belt that was the right length to fit snugly. Another timing belt wraps around this and the drive pulley at the back. The drive motor is permanently attached to the bearing base plate, and fits into a hole at the back of the top body ring. Installing the head is just a matter of lowering it into position, attaching four retaining nuts under the body ring, and plugging in the drive motor.

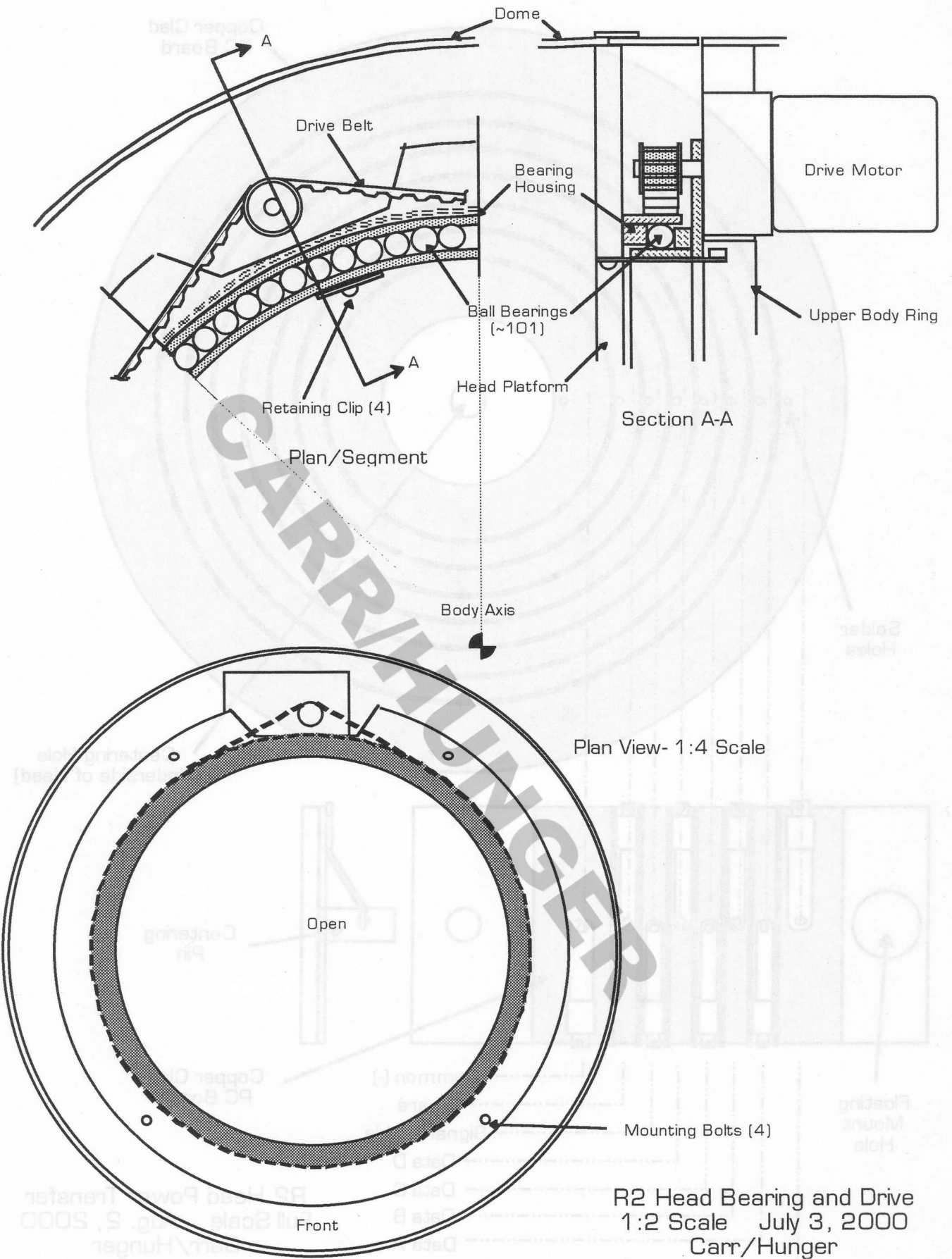
SLIP RINGS/POWER TRANSFER

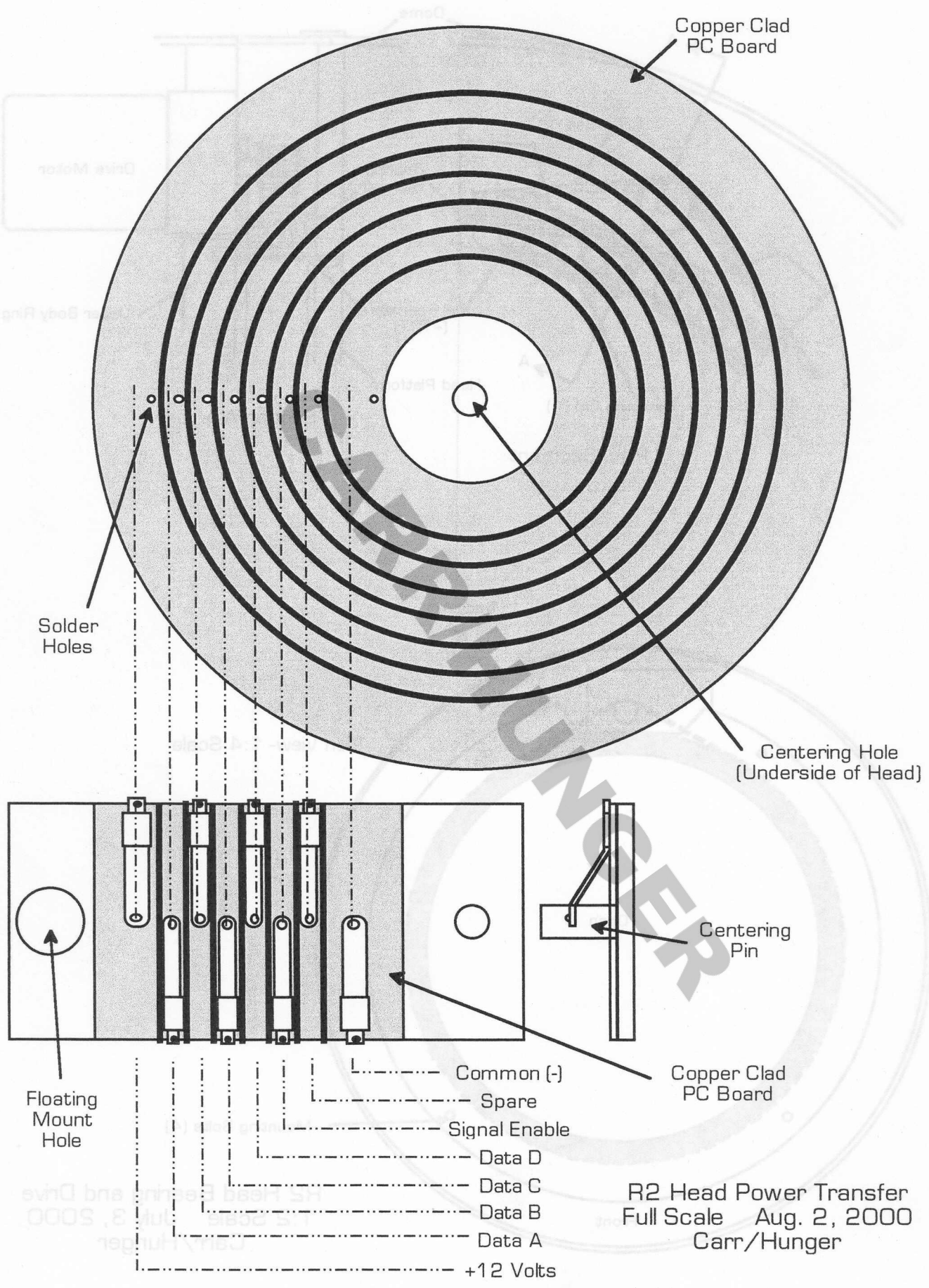
Another problem we had to overcome was how to get power and control signals into the head. A cable would get tangled, or limit the rotation to slightly less than 180 degrees in either direction. We decided we wanted R2's head to be able to rotate indefinitely, which has proven to be a main attraction at times.

Our solution was to make a contact ring similar to those used in some types of rotating displays. We worked out how many connections we needed; starting with two for power, then the number of signals we needed to send to the head. This worked out to an additional five, plus one spare in case we needed to



Detail of Slip Rings - Bearing and Motor visible on underside of Head





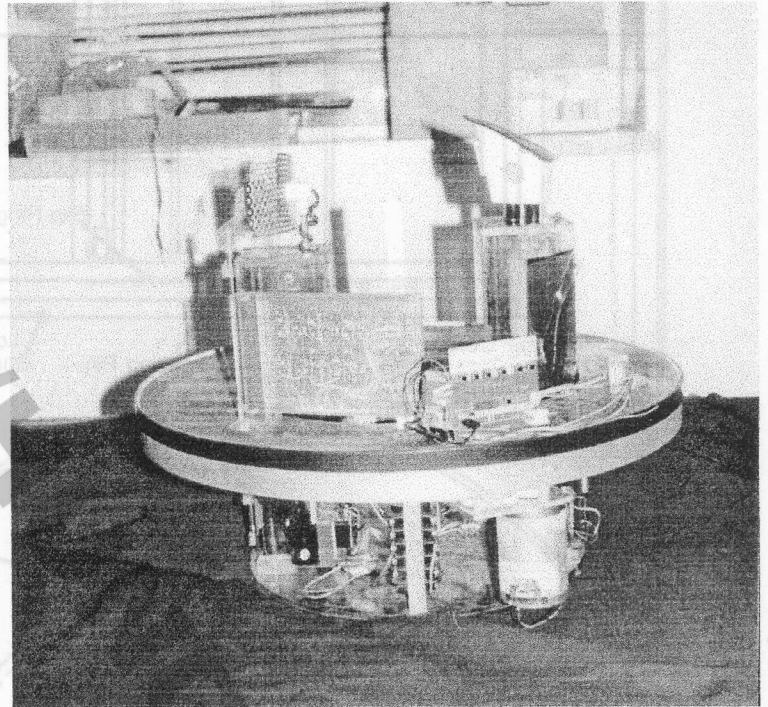
R2 Head Power Transfer
 Full Scale Aug. 2, 2000
 Carr/Hunger

expand at a later date (always a good idea to make provisions where possible). We scribed the grooves on our disk on the lathe, but a good compass point with a few passes works well, too. Etching is also a good way, but takes much more prep, and chemicals. Holes were drilled in each ring, to allow wires to be soldered, and passed through corresponding holes in the base of the head. The wires are to the edge of the rings to avoid the sliding contacts as they pass. The disk itself is contact cemented to the bottom of the head.

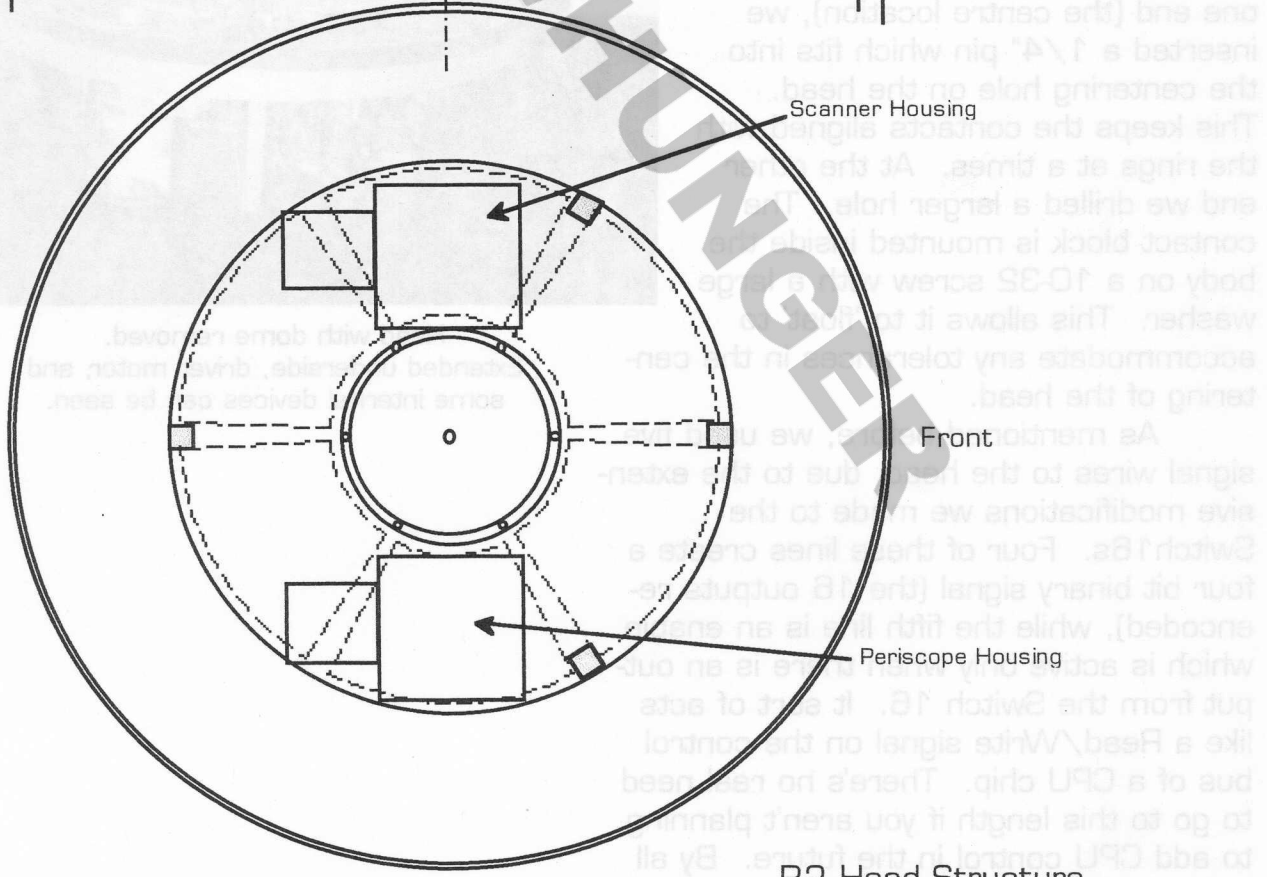
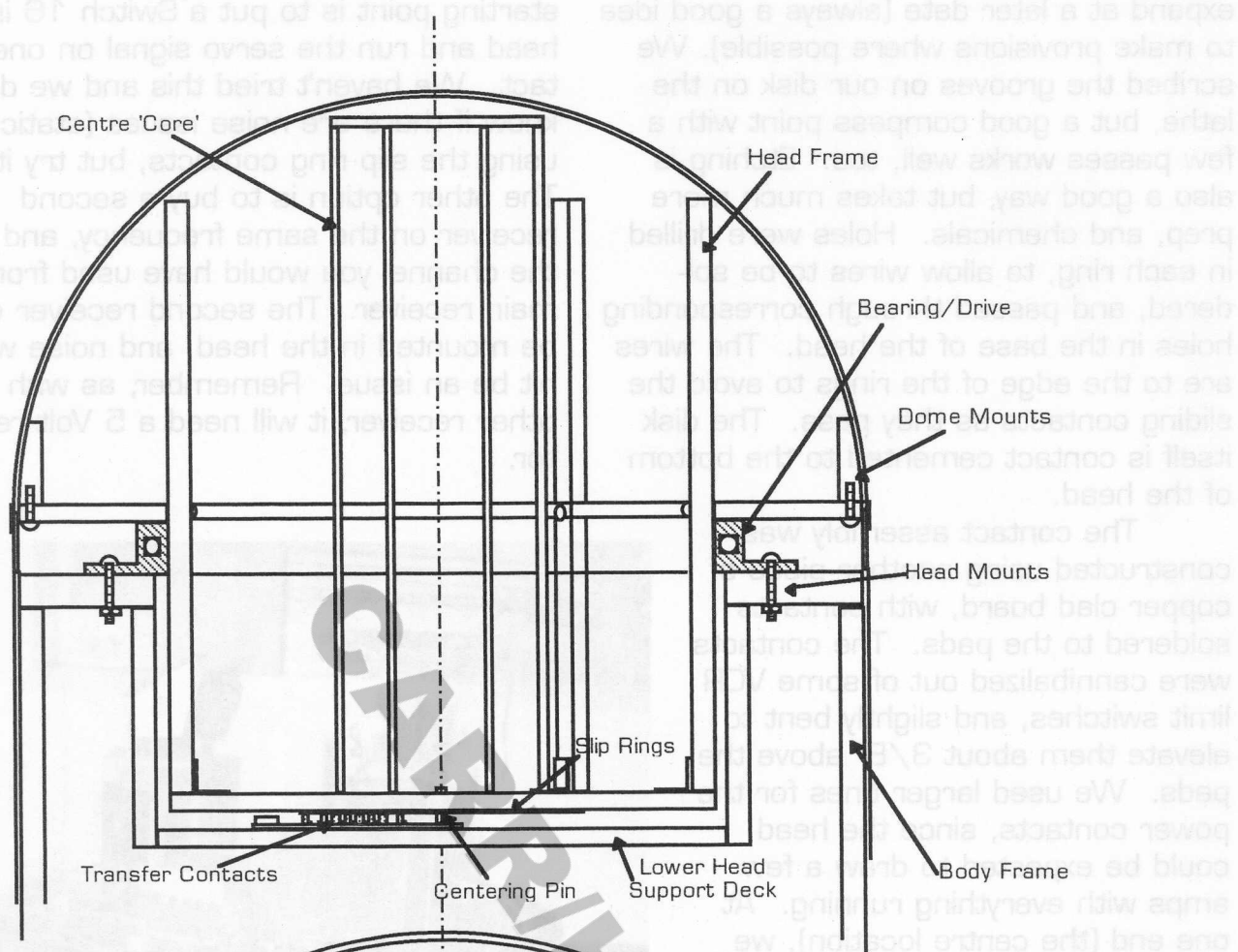
The contact assembly was constructed using another piece of copper clad board, with contacts soldered to the pads. The contacts were cannibalized out of some VCR limit switches, and slightly bent to elevate them about $3/8$ " above the pads. We used larger ones for the power contacts, since the head could be expected to draw a few amps with everything running. At one end (the centre location), we inserted a $1/4$ " pin which fits into the centering hole on the head. This keeps the contacts aligned with the rings at a times. At the other end we drilled a larger hole. The contact block is mounted inside the body on a 10-32 screw with a large washer. This allows it to 'float' to accommodate any tolerances in the centering of the head.

As mentioned before, we used five signal wires to the head, due to the extensive modifications we made to the Switch16s. Four of these lines create a four bit binary signal (the 16 outputs re-encoded), while the fifth line is an enable which is active only when there is an output from the Switch 16. It sort of acts like a Read/Write signal on the control bus of a CPU chip. There's no real need to go to this length if you aren't planning to add CPU control in the future. By all means, make all the contacts, you never know when you'll need them, but a good

starting point is to put a Switch 16 in the head and run the servo signal on one contact. We haven't tried this and we don't know if there are noise issues (static, etc) using the slip ring contacts, but try it. The other option is to buy a second receiver on the same frequency, and use the channel you would have used from the main receiver. The second receiver could be mounted in the head, and noise wouldn't be an issue. Remember, as with the other receiver, it will need a 5 Volt regulator.



Head with dome removed. Extended underside, driver motor, and some internal devices can be seen.



Plan View-Head Frame

R2 Head Structure
 1:4 Scale July 3, 2000
 Carr/Hunger

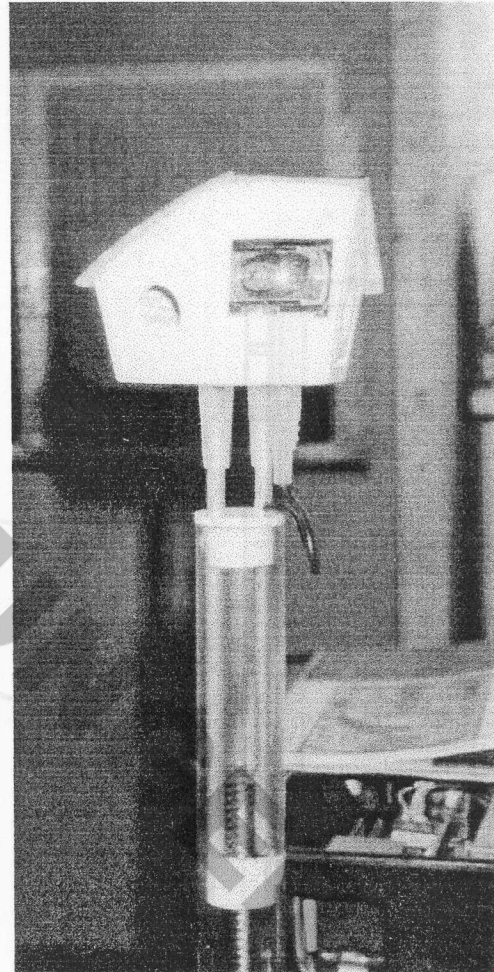
SECTION SIX: HEAD DEVICES

As seen in the previous section, our head extends some distance inside the body. This allows us to install things like the periscope and scanner antenna, as well as future devices. As in the body, we've made provision for adding future devices such as a variation on the lightsaber launcher, a small repair arm, fire extinguisher, and 'holoprojector'.

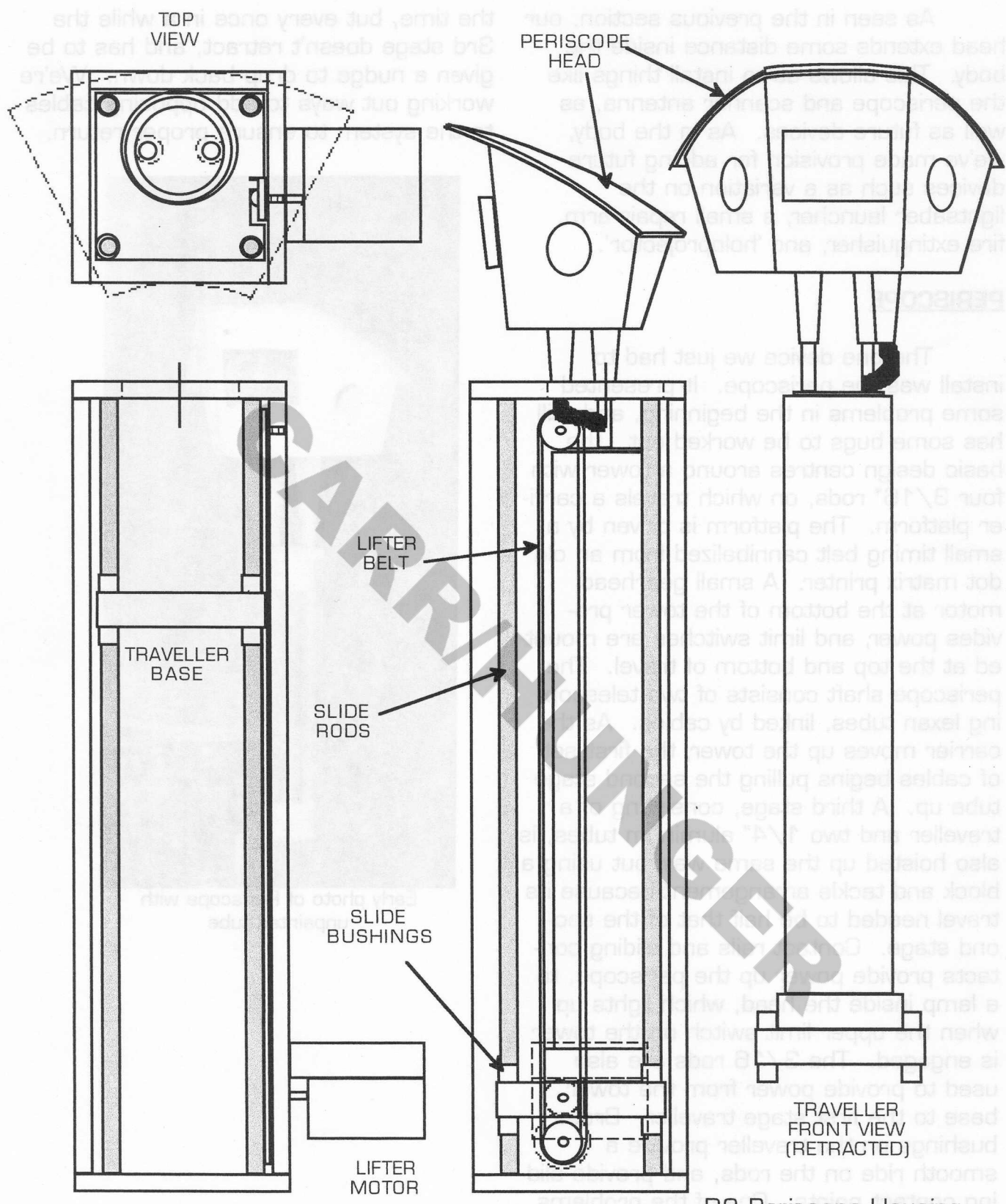
PERISCOPE

The one device we just had to install was the periscope. It presented some problems in the beginning, and still has some bugs to be worked out. The basic design centres around a tower with four 3/16" rods, on which travels a carrier platform. The platform is driven by a small timing belt cannibalized from an old dot matrix printer. A small gearhead motor at the bottom of the tower provides power, and limit switches are mounted at the top and bottom of travel. The periscope shaft consists of two telescoping lexan tubes, linked by cables. As the carrier moves up the tower, the first set of cables begins pulling the second stage tube up. A third stage, consisting of a traveller and two 1/4" aluminum tubes, is also hoisted up the same way, but using a block and tackle arrangement because its travel needed to be half that of the second stage. Contact rails and sliding contacts provide power up the periscope, to a lamp inside the head, which lights up when the upper limit switch on the tower is engaged. The 3/16 rods are also used to provide power from the tower base to the first stage traveller. Brass bushings on the traveller provide a smooth ride on the rods, and provide sliding contact points. One of the problems we're still encountering is positive retraction of the Periscope. Our system employs gravity to retract the tubes when the traveller lowers. This works most of

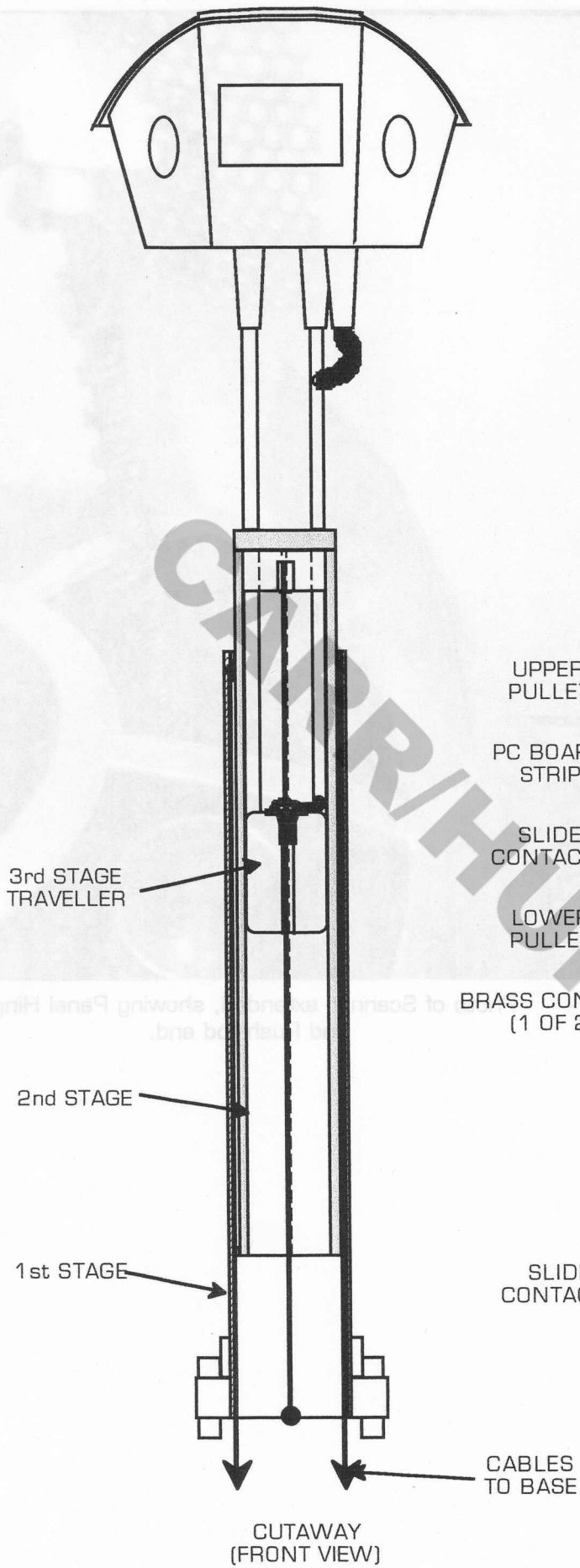
the time, but every once in a while the 3rd stage doesn't retract, and has to be given a nudge to drop back down. We're working out ways to add opposing cables to the system to ensure proper return.



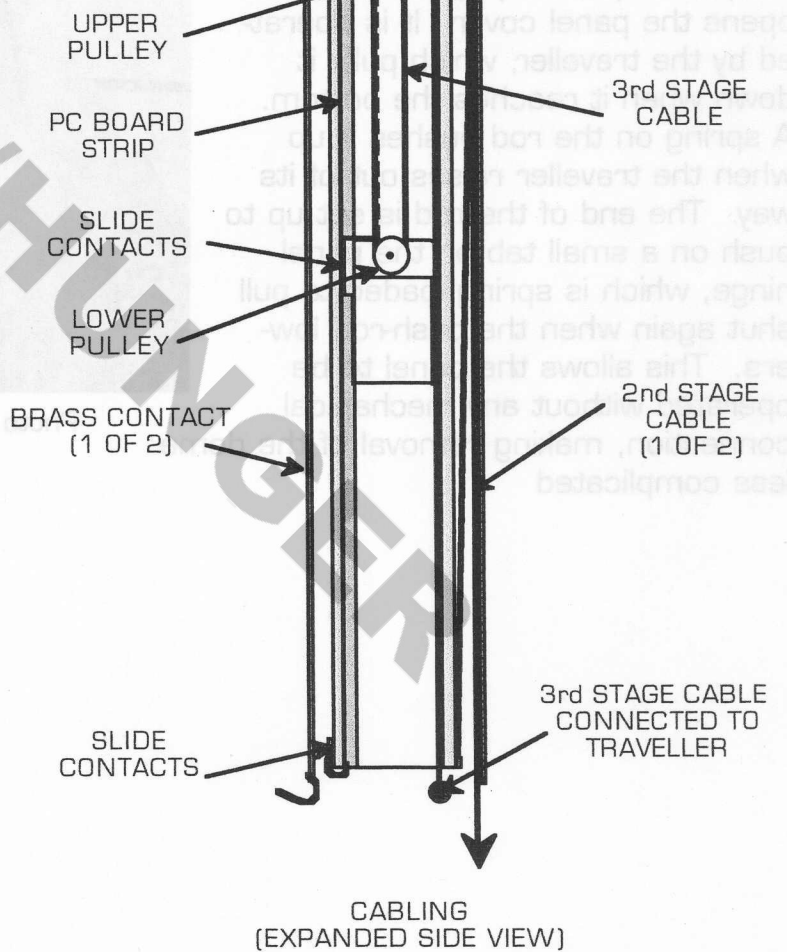
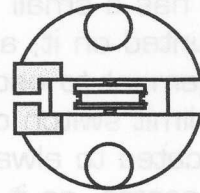
Early photo of Periscope with unpainted tube



R2 Periscope Housing
 1:2 Scale Aug. 8, 2000
 Carr/Hunger



3rd STAGE TRAVELLER FULL SCALE (TOP VIEW)



R2 Periscope Mechanism
1:2 Scale Aug. 12, 2000
Carr/Hunger

SCANNER ANTENNA

The scanner antenna works in much the same way as the periscope. It has the same tower, although slightly shorter, and the same first stage traveller and drive motor. The traveller has a small gearhead motor mounted on it, and a crank shaft arrangement to oscillate the antenna. A limit switch on this crank shaft is located to always stop the antenna at centre, so it clears the panel opening on the way down. The oscillation motor activates once the antenna is fully extended, and centres the antenna just as it starts retracting.

An addition not required on the periscope is a push-rod which opens the panel cover. It is operated by the traveller, which pulls it down when it reaches the bottom. A spring on the rod pushes it up when the traveller raises out of its way. The end of the rod is set up to push on a small tab on the panel hinge, which is spring loaded to pull shut again when the push-rod lowers. This allows the panel to be operated without any mechanical connection, making removal of the dome less complicated

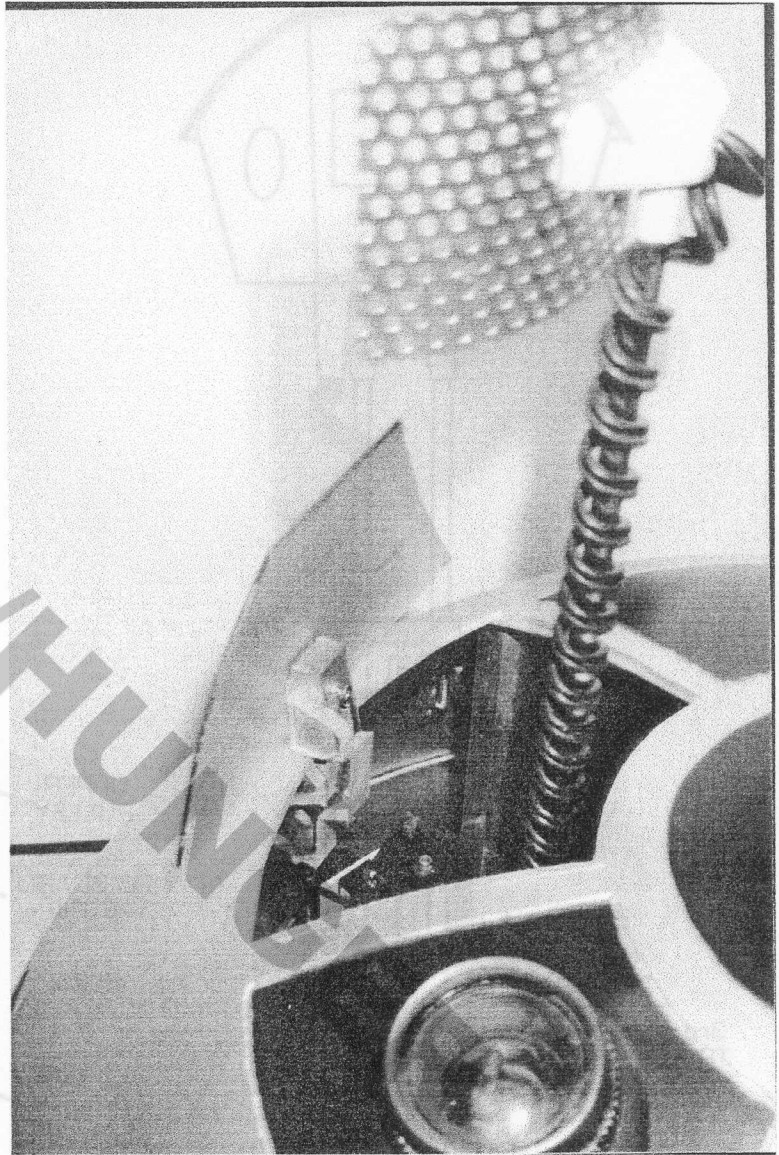
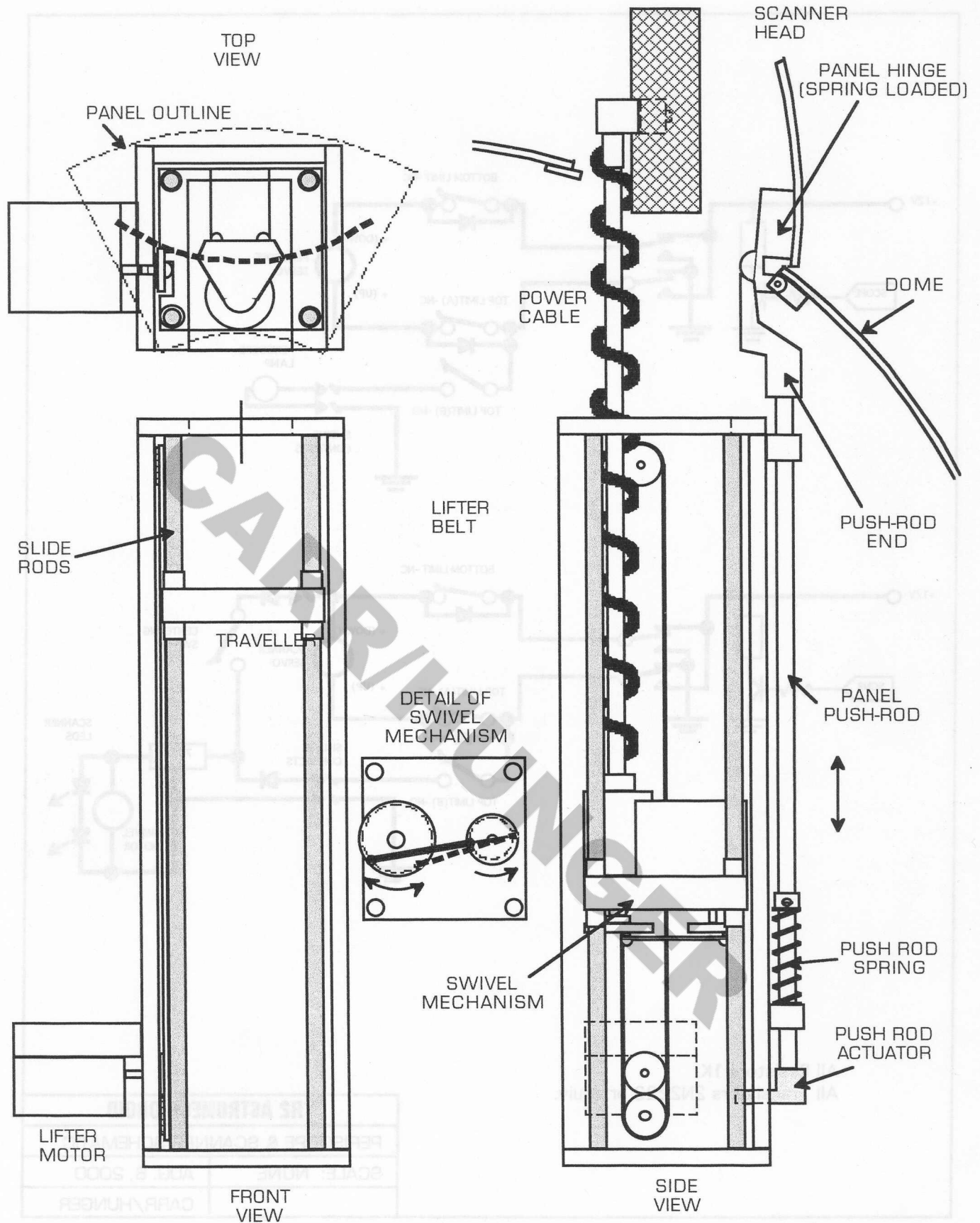
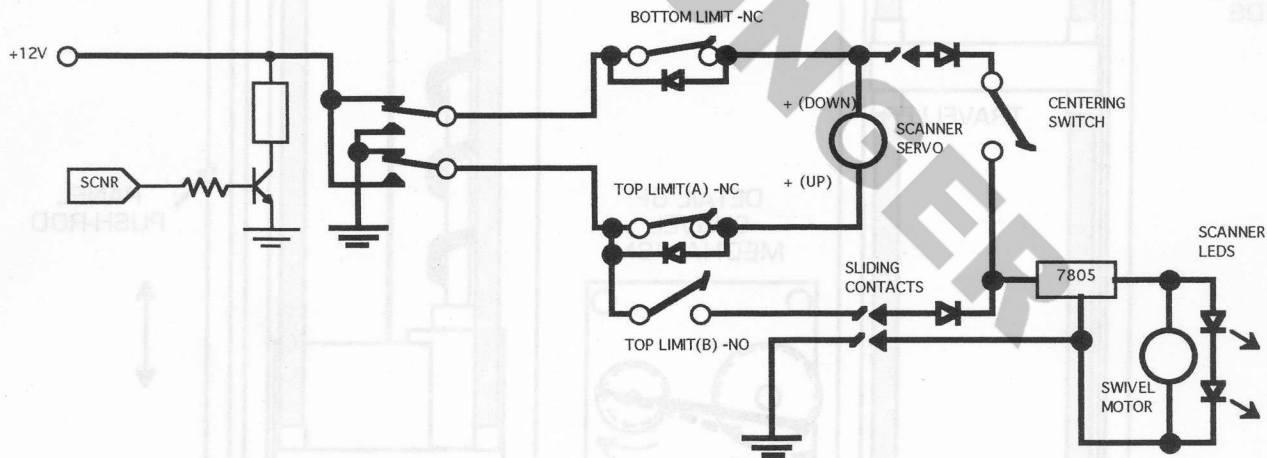
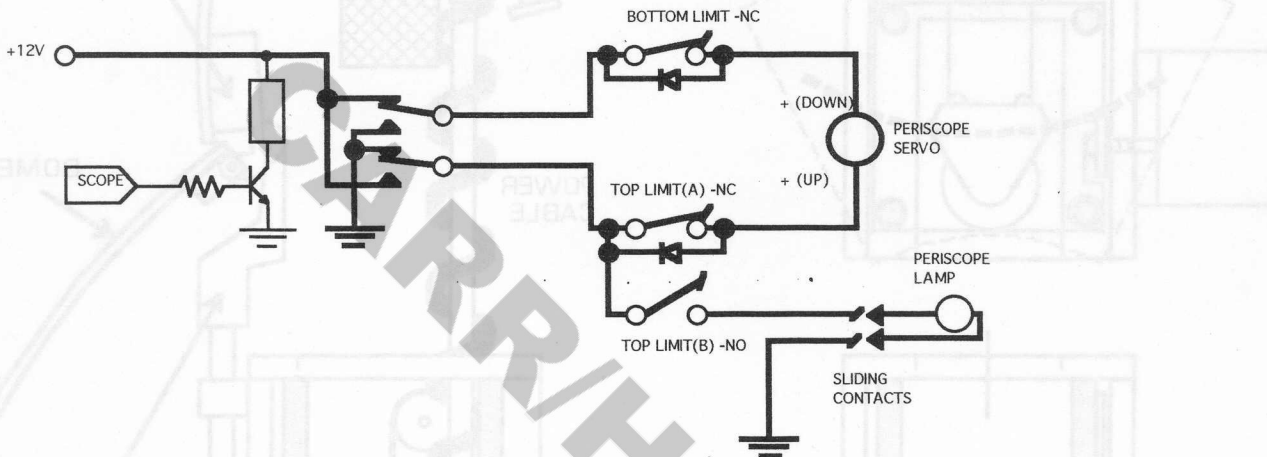


Photo of Scanner extended, showing Panel Hinge and Push-rod end.





R2 Scanner
 1:2 Scale Aug. 11, 2000
 Carr/Hunger



All Resistors 1K.
 All Transistors 2N2222 or equiv.

R2 ASTROMECH DROID	
PERISCOPE & SCANNER SCHEMATIC	
SCALE: NONE	AUG. 6, 2000
CARR/HUNGER	

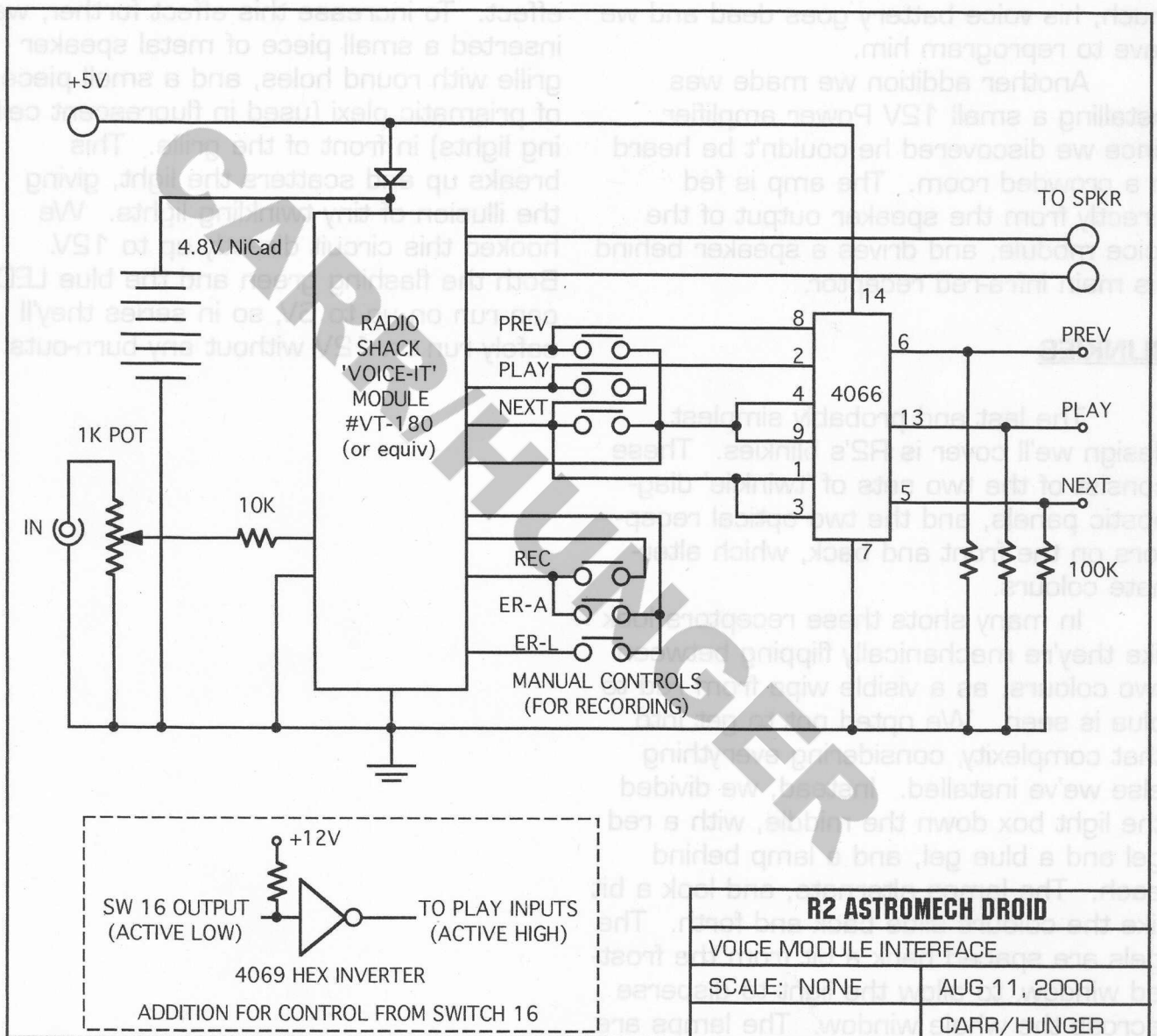
VOICE MODULE

We wanted our R2 to have a good range of voices. Short of having an entire Switch 16 dedicated to voices, we came up with the next best thing. Many places now sell digital message recorders at quite reasonable prices. We picked up one that is capable of an indefinite number of entries up to a total of 3 minutes of recording time. At a couple of seconds per voice/sound, this meant we could easily store a few dozen sounds if we wanted. Our final number is around 24, including his famous scream, and whistle.

In order to use the voice recorder, we had to modify it first. Opening it up, we located the traces and noted how the

playback/record buttons were arranged electrically. Most devices like this employ a keypad matrix of sorts. We patched into this matrix, and 'duplicated' the buttons using a CMOS analog switch IC. This provides four isolated switches, each controlled by a separate gate pin. We used three of these for PREVIOUS, PLAY, and NEXT. These were then controlled from our Switch 16 interface circuit and assigned three buttons on the transmitter. To control them directly from a Switch 16, use the inverter addition shown.

The voice module is removable, and has a connection port to allow us to plug it into the audio output from our computer. We duplicated the RECORD, ERASE



LAST, and ERASE ALL buttons using small pushbuttons on the interface board. With practice, clicking on the sound you want while simultaneously pressing the RECORD button allows you to record each voice cleanly. A small speaker on our recording interface allows you to play back from the voice module, to ensure proper recording (the playback buttons were also duplicated with small pushbuttons).

A small battery is mounted on the voice module, as the model we found needs power to maintain its memory. A charging diode (to isolate the voice recorder from the interface circuit) allows the battery to trickle charge whenever R2 is on. We have found, however, that after a few months, if he hasn't been used much, his voice battery goes dead and we have to reprogram him.

Another addition we made was installing a small 12V Power amplifier, since we discovered he couldn't be heard in a crowded room. The amp is fed directly from the speaker output of the voice module, and drives a speaker behind his main infra-red receptor.

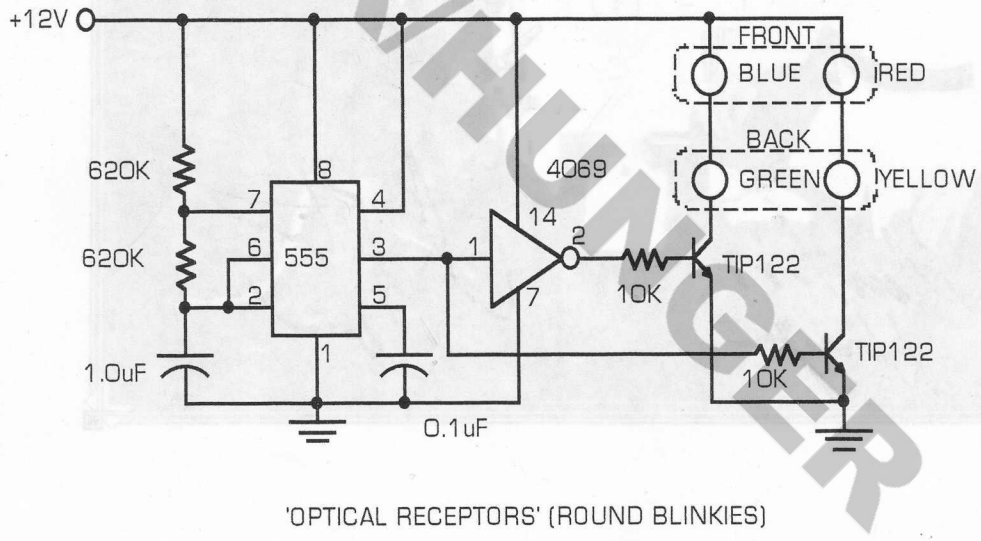
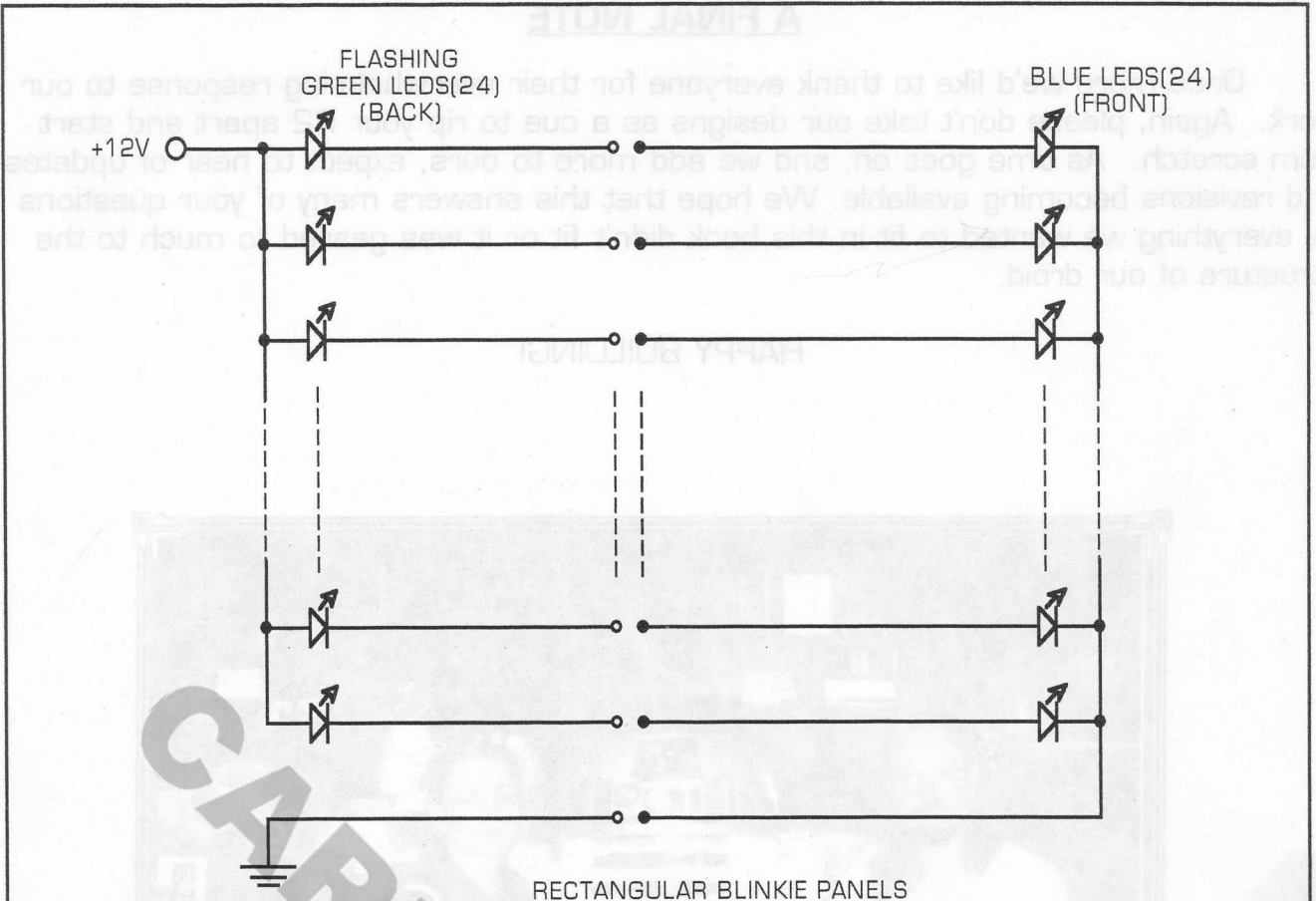
BLINKIES

The last and probably simplest design we'll cover is R2's blinkies. These consist of the two sets of 'twinklie' diagnostic panels, and the two optical receptors on the front and back, which alternate colours.

In many shots these receptors look like they're mechanically flipping between two colours, as a visible wipe from red to blue is seen. We opted not to get into that complexity, considering everything else we've installed. Instead, we divided the light box down the middle, with a red gel and a blue gel, and a lamp behind each. The lamps alternate, and look a bit like the colours slide back and forth. The gels are spaced back a bit from the frosted window, to allow the light to disperse across the whole window. The lamps are driven using a 555 Timer circuit, with a

couple of transistors for the output stage. We chose 6V lamps and connected them in series. 12V lamps in parallel would work just as well, but we wanted a certain brightness and lower current draw.

The diagnostic panels were a slightly different approach. Our design incorporates LEDs. The long rectangular panel near the back contains two rows of twelve flashing green LEDs. These are connected in series with two groups of twelve blue LEDs, set up in 3x4 groups, behind the two small displays. The series connection makes the blue LEDs flash in unison with their green partners. All are wired randomly between the two groups, and when running, the slight variation in flash rates causes a random twinkling effect. To increase this effect further, we inserted a small piece of metal speaker grille with round holes, and a small piece of prismatic plexi (used in fluorescent ceiling lights) in front of the grille. This breaks up and scatters the light, giving the illusion of tiny twinkling lights. We hooked this circuit directly up to 12V. Both the flashing green and the blue LEDs can run on up to 6V, so in series they'll safely run on 12V without any burn-outs.

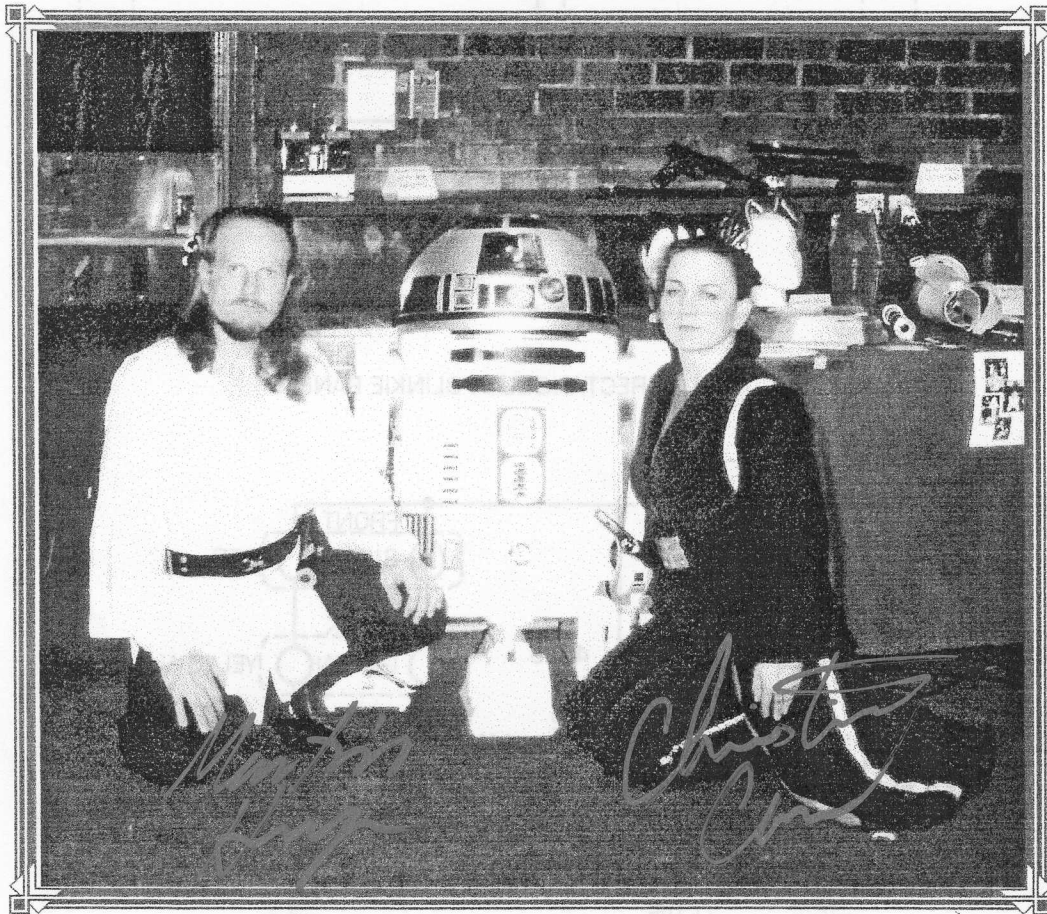


R2 ASTROMECH DROID	
HEAD BLINKIES SCHEMATIC	
SCALE: NONE	AUG. 13, 2000
CARR/HUNGER	

A FINAL NOTE

Once more we'd like to thank everyone for their overwhelming response to our work. Again, please don't take our designs as a cue to rip your R2 apart and start from scratch. As time goes on, and we add more to ours, expect to hear of updates and revisions becoming available. We hope that this answers many of your questions as everything we wanted to fit in this book didn't fit or it was geared too much to the structure of our droid.

HAPPY BUILDING!



Martin Hunger and Christina Carr

Turning two dimensions into three.

email: infinity@pathcom.com

webpage: <http://www.pathcom.com/~infinity>

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R2D2 is copyrighted Lucasfilm ©.

SPECIFICATIONS (OUR DROID)

Body Diameter: 18.0 inches
Body Height: 20.0 inches
Overall Height: 42.75 inches
Overall Width: 29.5 inches
Overall Weight: 135 pounds

Drive Batteries: Yuasa 12V 7.2Ah
Body Batteries: Yuasa 12V 7.2Ah
Booster Battery: Yuasa 6V 4Ah

Drive Motors: 12V Power Wheelchair Motors (type unknown)
Tilt Motors: 12V Power Window Motors (type unknown)

Radio Control: Airtronics Vanguard 6 Ch Aircraft System

Operable Functions:

- Twin Drive Motors (tank style drive)
- Two leg/three leg modes
- Head rotation (full indefinite rotation)
- Manipulator arm
- Computer interface arm
- Switchable accessory outlet
- Periscope
- Scanner antenna
- Spotlight
- 24 R2 Voices (sequential/skip playback)

Planned Functions:

- Circular saw
- "Arc welder"
- Blue actuator arms
- "Holo projector"
- Moving projector lens
- Lightsaber launcher
- Repair arm in head
- Misc devices from centre of head