A TRACKING SOLAR CONCENTRATOR

FEATURING

High Efficiency
High Temperature
20,000 Btu output
Simple Construction
Common Materials
Automatic Tracking

Please read the Legal Disclaimer on the home page before continuing.

-i,ii-

Introduction to A TRACKING SOLAR CONCENTRATOR. Alterations and abridgements to the original 1981 text will be italicized

You are about to become one of the solar energy pioneers. In the following pages I will show you in great detail how the very successful solar concentrator and collector designed and built by Teton Engineering can be duplicated with commonly available materials and tools to be found in most well equipped home workshops. We are confident that the purchaser of this manual will make improvements on Teton Engineerings design when you build your own system. Each of you have access to materials, tools and skills that are unique. Our design was restricted to those materials and tools that most home or farm handymen have easy access to. If you follow the Teton design in detail you can be assured of a working system, but we highly encourage you to experiment and add to the pool of knowledge.

Solar concentrators are a rarity in the home or farm solar installations, while flat-plate collectors can be found everywhere. Ever wonder why? There is a lot of reasons- concentrators have to track the sun requiring electronics, bearings, motors and other gadgetry that tends to frighten many folks. It seems that this type of collector should fall in the realm of heavily financed, big energy systems. Indeed, this has been true. You won't find anybody or organization fooling around with flat-plates if they are building a system for serious energy collection. Teton's goal from the beginning was to develope a device that was efficient, usable in very cold weather, hot enough to scald the dishes and still be within the construction abilities of most of Americas back-yard mechanics. Obviously flat-plate is out, simply based on its inability to achieve high temperatures. It is also out based on economics and cold weather performance.

Collecting solar energy is very easy. Retaining it in order to build high- er temperatures for practical use is where the difficulty comes in. We've all gotten into the closed up car in the summer and suffered the effects of collected and retained heat. This phenomenon, commonly called the greenhouse effect works because the collected energy has difficulty es- caping through the glass and insulation of the car body. Open the windows and most of the heat cannot be retained It is lost through re-radiation and convection. An effective solar collector has to be insulated and glazed to permit radiation to enter, while inhibiting the long-wave re-radiation. Frequently, double or triple glazing (like a storm window) is necessary if any energy is to be retained at all when the temperature outdoors is low. This adds to the already expensive collector surface, and now the "high performance" flat-plate is running up to 20 or more dollars per square foot. If we can concentrate the solar radiation with a reflector that can be assembled for about two dollars or less per square foot and hold the active collector area down to a couple of square, then the econ- omics become obvious

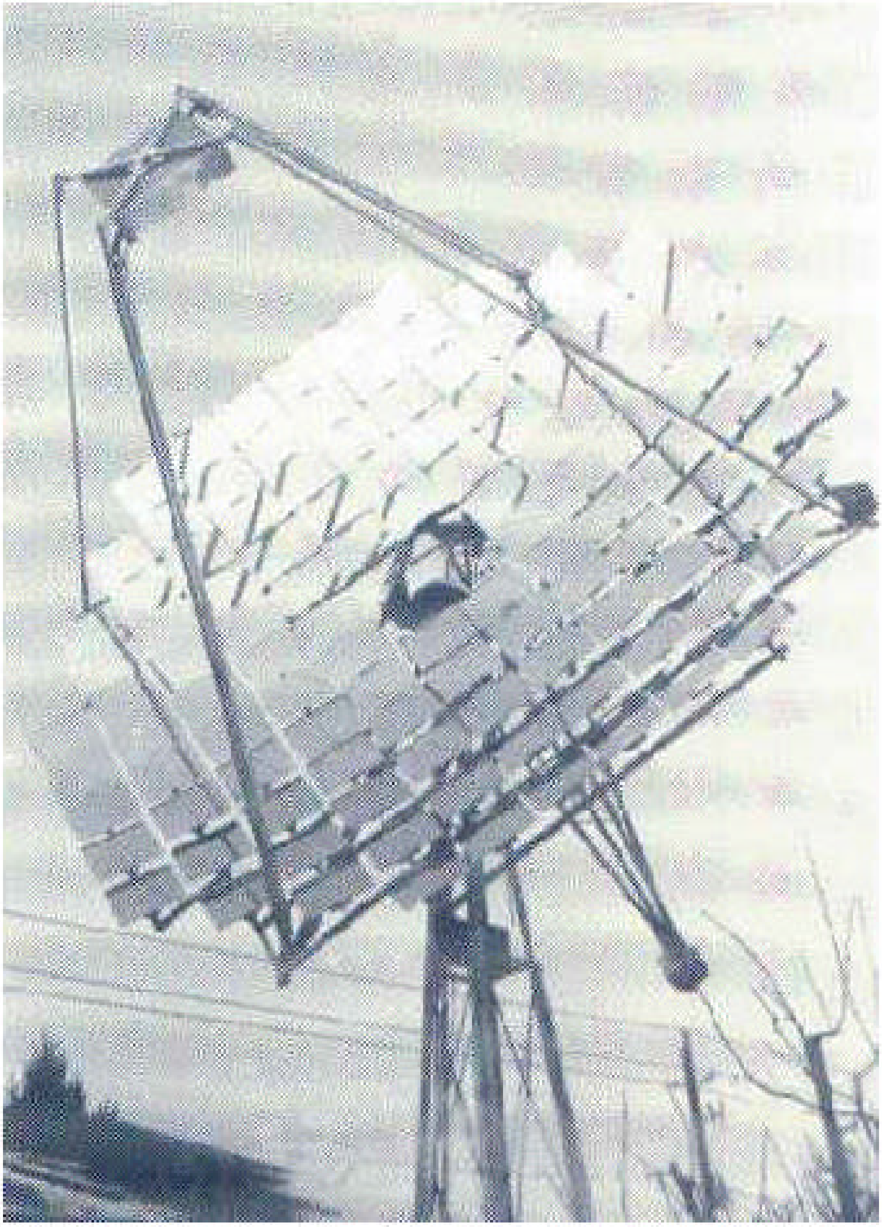
In addition to the economics of construction, there is a big plus. High temperature is easy- even steam if you like. The outdoor temperature is hardly even a consideration. because the area of the collector is so small that the re-radiation and convection losses are very low. In many cases, glazing is simply dispensed with. Recovery efficiency can run up to 60 or 70 percent when the best that flat plates can do is up to 25 percent and down to zero as it gets cold outdoors. These figures are based on the assumption that temperatures of at least 125 F are needed for household use. Of course if you only want to warm the swimming pool on hot summer days, the flat plate will work great and without glazing too.

As we go through the various construction phases, I will toss in a little lightweight mathematics here and there for those who like it. Ignore it if you please or use it to modify the design to suit your needs. We won't get heavy at all. If you want an excellant treatise on the engineering as- pects, I suggest SOLAR ENERGY THERMAL PROCESSES by Duffie and Beckman- published by John Wiley and Sons. My copy was copyrighted in 1974 and was the major engineering referance for this project. They call this system a Fresnel reflector meaning that the reflector (concentrator is made up of many small segments rather than one continuous surface. Further inspiration to use the economical mirror tiles as the segments came from Charles Curnutt, Popular Science, April 1978. The rest of the system is entirely original to the best of my knowledge. The economical bearing and drive systems, and the all weather electronic control system draw heavily upon my years of experience as an electronic engineer with microwave and radar systems. I make no claims to original inventions, but rather I have simply applied basic knowledge of optics, mechanics,thermal processes and electronics to design and fabricate this device. Its uniqueness lies in the fact that you can so easily duplicate it. I cannot assure you that you will not infringe upon the patents of others, although I am aware of none, but traditionally, home construction for personal use is no problem. The only thing We have to sell is this knowledge and a few parts if you should have local procurement problems. *The manual is NOT for sale. Consulation and parts are no longer available*

Wayne Roderick P.E.

Teton Engineering Inc.

Previous Next



cover photo

A Tracking Solar Concentrator for the home experimenter

It's been about twenty years since the USA experienced the big energy crunch and the resulting flurry of alternate energy schemes. Sadly, interest in solar, wind and other sources quickly faded as Americans came to suspect that the crunch was more created than real, and abundant petroleum was again available, but at greatly increased prices. Teton Engineering Inc developed a 20,000 Btu (6000 watt) solar concentrator designed specifically for the backyard mechanic to build using simple construction and basic materials. The design was marketed all around the world while interest was high, but eventually that interest faded away. We continue to receive requests for the manual but it has been withdrawn from the market long ago due to the ever increasing litigious atmosphere in the USA. Searching the internet, we find very little information to help the non professional or hobbyist solar energy experimenter so have decided to contribute the successful design to the public domain without an obligation to provide support or expect compensation. This information is offered for historical interest.

SAFETY WARNING

Working with solar concentrators is VERY DANGEROUS.

- Teton Engineering contributes this lore into the public domain freely and without obligation. You are cautioned that it is experimental, unsafe, and just plain dangerous. You or others may be blinded, maimed or killed while working with this device. We do not certify the design as safe or adequate in any way and must be considered as experimental. We advise you to not undertake construction of this device without professional guidance. It is not the intent of this manual to offer this guidance, but merely to document a successful design that operated continuously from 1980 to 1987.

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I am retired so I'm not available for consulatation, but I'd enjoy hearing from anyone that finds this historical information useful.
Wayne Roderick

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A TRACKING SOLAR CONCENTRATOR

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Table of Contents page

LIABILITY NOTICE- As mentioned in the introduction, you are a pioneer in the solar energy field. You will be working in an area where only limited experience and knowledge is available. There are very few solar concentrators in the home or farm environment. There are many unknowns. Our design is meant to utilize only so far as it may be applicable to your needs. We have no control over your site adaptation or workmanship. We cannot assure you that this design is suitable for your situation. We offer only the experience gained by this project for you to use as you see fit. We encourage you to seek professional service to adapt the design to your situation.

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Previous Next

A TRACKING SOLAR CONCENTRATOR

-1,2-

COST AND PERFORMANCE

We will probably be spending around five or six hundred (1980) dollars, or possibly much less if you're a good scrounger and willing to modify the design to fit available materials. You should achieve around 20,000 Btu of thermal energy which is equivalent to about 6000 watts of electric heat any time you have unobstructed sunshine, summer or winter.

For feel, a quick recovery electric water heater heats at the rate of 4500 watts and costs a bundle to run. Call the power company and ask them for a nominal cost per kilowatt and multiply it by six for the hourly value of the solar collector. If it's gas heat that you want to replace, ask the gas company for a nominal cost per therm (100,000 Btu). Multiply the rate by 1.5 because you only get about two-thirds of the heat when you burn it. Divide this figure by five to get the hourly value of the solar collector. This is a course way to estimate it, but it is only an estimate. We'll continue with an electric comparison

I have relatively cheap electricity from water power here in Idaho costing a nominal 3 cents per Kilo-watt-hour. Thats about 13 cents per hour for a 4500 watt water heater. The sun shines here about 65 percent of the time according to the local Weather Service. Call them in your town or a nearby City and ask for a copy of the Local Climatological Data sheet. It's free and therein you'll find lots of good information in addition to the percent of sunshine. Keeping it simple (see Duffie & Beekman if you don't like it this way) assume an average 12 hour day- subtract a couple hours looking over the neighbors trees, buildings and nearby mountains leaving 10 hours. 65 percent of this time times 365 days per year comes up to about 2400 hours of sun per year. At my 3 cent rate, that's worth about $420 bucks. And I'11 bet your electric rate is higher than mine! Trouble is of course- Summer days are longer than the 10 hour average while the winter days are shorter and likely to be cloudy more of the time. Like me, you'll be short of energy in the winter at times and have an excess in the summer, unless you have a swimming pool or other summer only load.

Another factor to consider in your cost is the benefits available from IRS or your State Taxing Authority.

Now you've seen some typical figures and even if you're sloppy in construction and alignment and lose some, there is probably lots of heat energy to spare. As we go for higher temperatures, above the nominal 140 F water for your domestic use, you'll lose some performance due to collector radiation and convection losses, but it's relatively small,

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A few simple facts and conversions are handy to know:

- A British thermal unit, Btu, is the energy needed raise one pound of water one degree F
- Water weighs about 8 pounds per gallon
    - To raise 40 gallons of water from 50F to 150F takes:
      40 x 8 (150-50) = 32, 000 Btu
- If you want to express that in watt-hours simply divide by 3.4
      32, 000 Btu/3. 4 = about 9,400 watt-hours
      more commonly expressed as 9.4 Kwh

Collector performance is easy to measure before you tie it into a closed loop. Simply hook up a garden hose to it-- allow the water to trickle through until things are stable. Then measure the inlet temperature, the outlet temperature and the flow rate. The easiest way to get the flow rate is to measure the time in seconds to fill a one gallon container.

- gallons per hour = 3600/seconds per gallon
- Btu = 1 gallon x 8 Ibs per gallon x (temp rise)
- Btu per hour = 1 x 8 x 3600 x (temp rise)
- or simply 28, 800 x (temp rise)/time in seconds for one gallon

Collector tests should be made at various flow and temperature rises You will find that the Btu per hour figure falls off with higher temperatures. This is simply because of re-radiation and convection losses and explain why high temperatures are impossible to achieve from large surface flat-plate collectors. If your outlet temperature is nearly equal to the surrounding air temperature, the figures obtained should very nearly indicate the ultimate performance.

Previous Next

A TRACKING SOLAR CONCENTRATOR

GENERAL DESCRIPTION

Teton Engineering's Tracking Solar Concentrator is an array of 116 mirrors, one square foot each mounted on a framework and arranged to reflect sunlight on a "collector", figure 1. The concentrated sunlight can raise the collector temperature to about 1200F, but we will run a cooling fluid, usually automotive type anti-freeze through it to absorb the heat just as it does in your car's engine. The heated fluid will be piped to a heat exchanger where it gives up its heat to another material such as the water you will shower with in the morning. The fluid, now cooled returns to the collector to be heated again and again. The possible uses are limited only by your imagination. We'll suggest some ideas in the chapters that follow, but the most obvious one is to preheat your domestic hot water before you run it into the big gas or electric hog that we call a water heater. Energy left over might be run through a genuine automobile radiator stuck in your space heating system or used to heat a basement or portion of the house that the central heat or stove can't reach.

The mirror frame and the collector will be assembled together with a "tail" that carries a counterweight atop a small tower or post set in the ground and equipped with a drive system that will automatically track the sun from sunrise to sunset. The whole business will weigh in around 600 pounds, but can be assembled in such a way as to never need more than two adults to put it together.

The array as shown in the cover photo is about 13 feet across. The four corner posts forming the pyramid to support the collector are about 10 feet long. The tower you see it mounted on is 16 feet tall, but is not typical of the usual mount. In most cases the array could mounted much closer to the ground.

The mirror array is mounted to the "hub" that contains the support bearings, the drive motor(s) and the simple mechanics for tracking the sun. There is two motor driven sub-systems. One periodically moves the array to follow the sun across the sky throughout the day. The other adjusts the tilt for seasonal variations

The electronic tracking system is the brains of our device and a brain that Teton Engineering is justifiably proud of. If you elect to totally discard the mechanical system in favor of your own design, you still have a bargain in purchasing this manual for the tracking system only. You may have seen other circuits published that look much simpler. They are! Because they are limited in various ways in which they respond to the whims of Mother Nature. Our circuit contains four op'-amplifiers (conveniently mounted in one package) performing multiple functions so that we can ignore wind, clouds and stray light sources. This is not just a fair weather machine, but rather one that you can turn on and forget. The electronic package also determines when the sunlight contains enough energy to justify operation of the circulating pump. It is also adaptable to many types of drive motors and can be operated on battery as well as commercial power

Every part in the electronic tracking system except the limit switches is available at the nearly 8000 Radio Shack Stores around the USA. The parts can easily be assembled by the average hobbyist. A small module containing two photocells and two limit switchs rides on the mirror array where it can see the sunshine and sense the position of the array. The module is wired to a "control box" containing the electronics and relays to actuate the drive motor and fluid pump. The control box can be anywhere within a reasonable distance, preferably indoors.

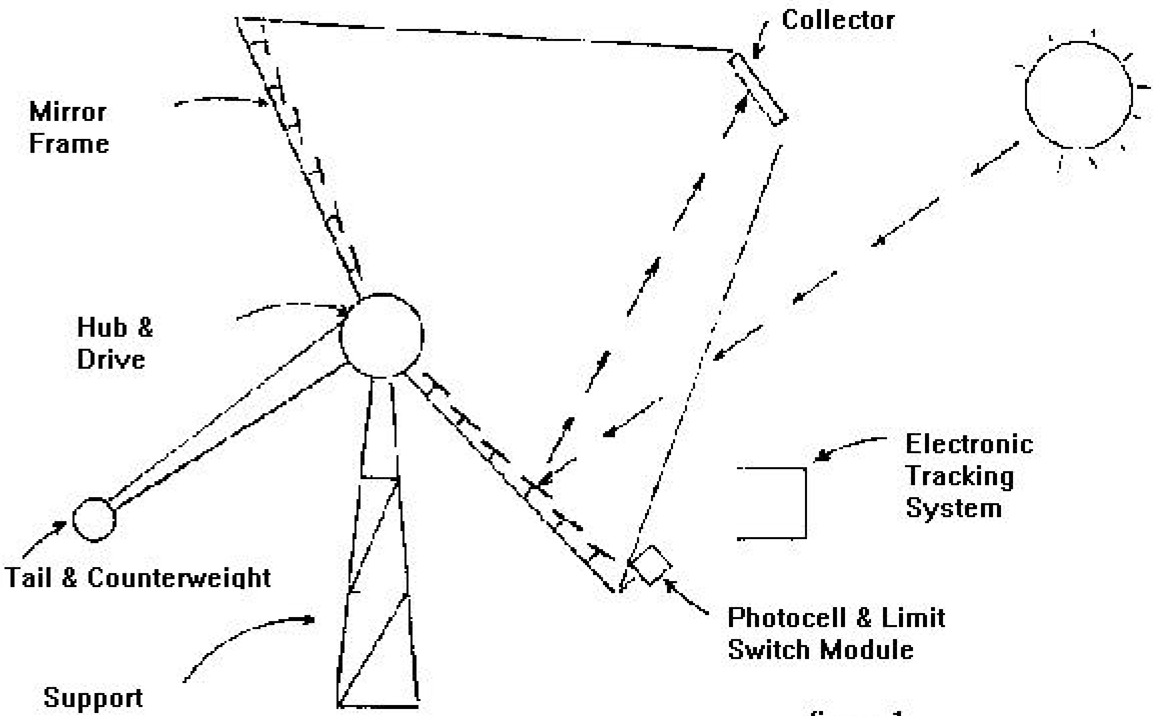


figure 1

MAJOR PARTS

PREV INDEX NEXT

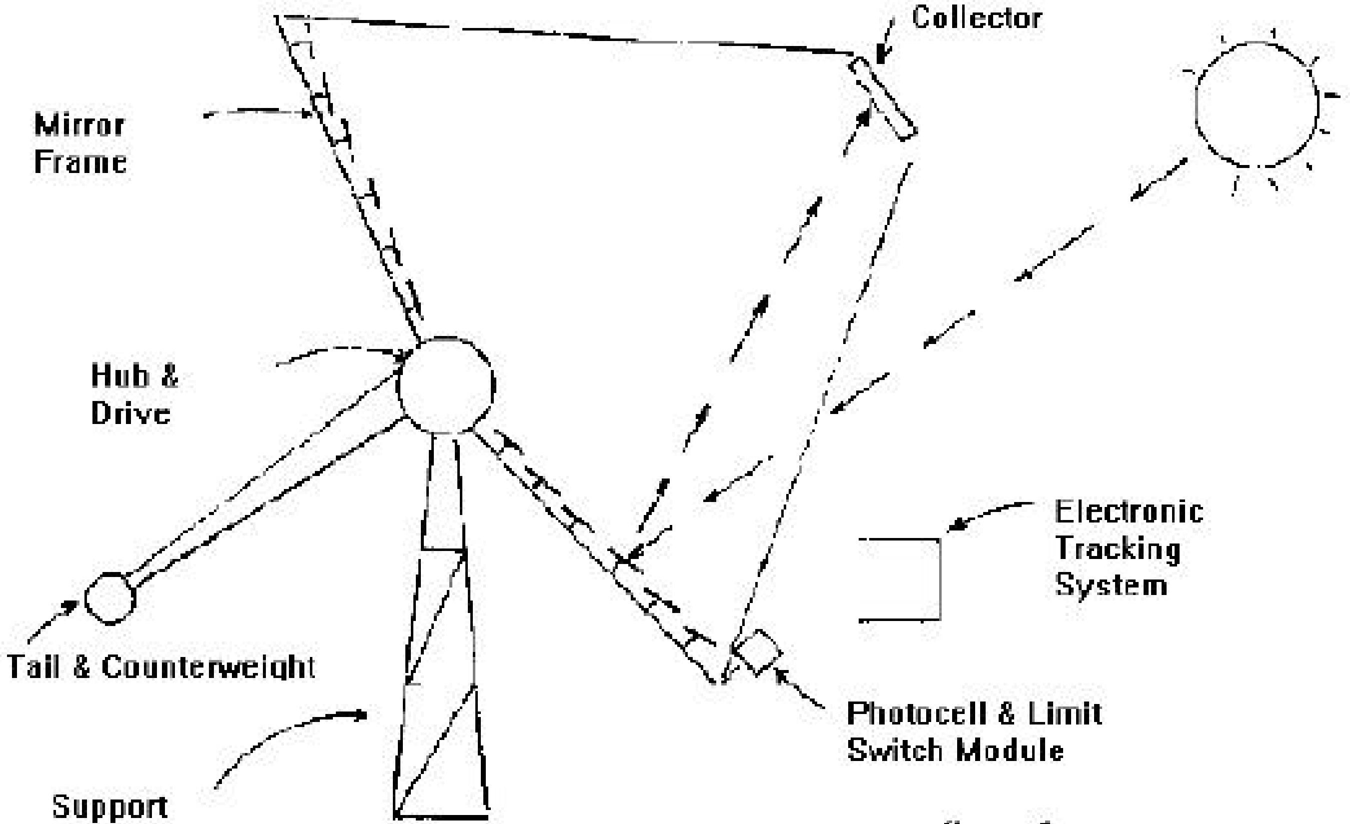


figure 1

MAJOR PARTS

A TRACKING SOLAR CONCENTRATOR

MATERIALS

Our materials where carefully selected and in each case the supplier assured me that these were high volume items available throughout the Nation in small towns as well as large. Higher technology material could greatly reduce the weight, increase reliability some and perhaps even improve the performance a bit. To use these materials in our design would lock out many builders who lacked the resources, the skills and/or the dollars for this. I used very popular structural steel shapes, but you may wish to substitute even then. The two drive motors in the hub assembly and the fluid pump are the only items that I had to go outside my town of 40,000 for. I'll suggest various options for these items and others when we get to the appropriate section. We'll use lots of nuts and bolts, all common mild steel unless otherwise specified. These should cost about a buck a pound at a farm supply store or bolt/nut store like Bosco. I bought my mirror tiles from a local retailer and he gave me a quantity price of 75 cents, so shop around. Small pieces of steel can usually be picked up from the "drop" pile at any steel fabricator at salvage prices.

The electronic tracking system uses parts available at the nearby Radio Shack Store (one of the nearly 8000 should be nearby). An optional circuit board is available from Teton Engineering. It makes assembly easier and a bit more fool-proof, but is not essential. *sorry- the circuit board is no longer available*

I will not provide a detailed list of parts in one grouping because I'm confident that the type of person building our collector will do lots of substituting and innovation. Each chapter will have a list of the parts for that sub-assembly. This way we can update a chapter as the system evolves.

To make sure we are talking about the same parts during construction and any subsequent consultation, all significant pieces will be identified with a unique number in parenthesis, such as (014).

While I encourage you to use imagination and substitution, a few major items will be made available through Teton Engineering to make sure no one is inhibited from building for the lack of parts. *sorry- we can no longer provide support for parts*

Previous Next

A TRACKING SOLAR CONCENTRATOR

-6-

TOOLS AND SKILLS

Like the materials, the tools and skills are basic. There is no machining operations. You will of course need welding facilities. A simple AC welder and a supply of everyday 6011 & 6013 rod will do. Of course an ox-acetylene outfit will do the job, but it's much slower. The welds are arranged to minimize the skill needs. For example, most welds on the .083 x 1 inch steel tube are lap welds to minimize the burn-thru problems that occur when butt welding. For cutting metal a carpenters portable circular saw with a metal cutting abrasive wheel does a great job, but don't forget the safety glasses. A very limited amount of metal cutting will exceed the capacity of the saw and an ox-acetylene outfit will be needed. This is so limited, that it won't be unreasonable to pay someone to do it for you if you're not equipped. Of course, you can always cut with the arc, but its sure messy. You should have a portable grinder to clean up the welds and cuts, but you can get along without it, especially if a bench grinder is available. Lacking these, a course file and wire brush will do.

For hole drilling, nothing beats a drill press, but a half-inch portable will do. Might even get by with a husky 1/4 or 3/8 drill. These are the only major items and if you've got them by now, the hand tools will have been acquired long ago. You could easily justify the purchase of a major tool for this project. Mention this to the wife.

The skills are obvious if you've got the tools and have ever built anything as complicated as a utility trailer or worked on farm machinery. The most useful skill is the one that permits you to adapt the design to your needs and resources. I expect you to build a collector just a little better than the design you're starting with.

The electronic tracking system you will be assembling does require a certain dexterity and the use of small tools including soldering. If you're the all thumbs type, I suggest finding some assistance such as an electronic buff or hobbyist- Check with your local High School- they're all over the place and this kind of project is a real turn on for these guys. No measuring instruments are needed unless you have trouble and I have included enough info so that any capable electronics type can troubleshoot and repair.

Previous Next

A TRACKING SOLAR CONCENTRATOR

-7,8-

SITING

Your tracking solar concentrator should be able to see the sun all day every day. That seems reasonable enough, but can't always be achieved. You'll notice in the cover photo of our prototype, it sits atop a sixteen foot tower. This tower tilts on a hinged base and can be lowered with a winch. We made it tilt because it was a developmental project that would see many tests and changes requiring easy access. It is mounted on the North side of the house and property lines made it impractical to go far enough North to be lower and still see over the house. The South side was impossible because of neighbors trees. This is an extreme situation and most sites we have examined would not require anything like this. *Ultimately we moved it East about 80 feet on a seven foot non-tilting support and piped the hot water underground to a 1000 gallon energy storage tank*

The sun at solar noon will be due South at an angle above the horizon equal to (90 degrees minus your Latitude) at the spring and fall equinox. As

we move through the summer and winter solstice the angle will vary above and below this point.

declination angle = 23. 45 sin 360 (284 + n)/365

where n is the day of the year beginning with Jan. 1st

My latitude is about 43 degrees, so at the equinox, March 21 & September 21 the angle at solar noon is:

90-43=47 degrees

and on June 21st, the longest day of the year, it is:

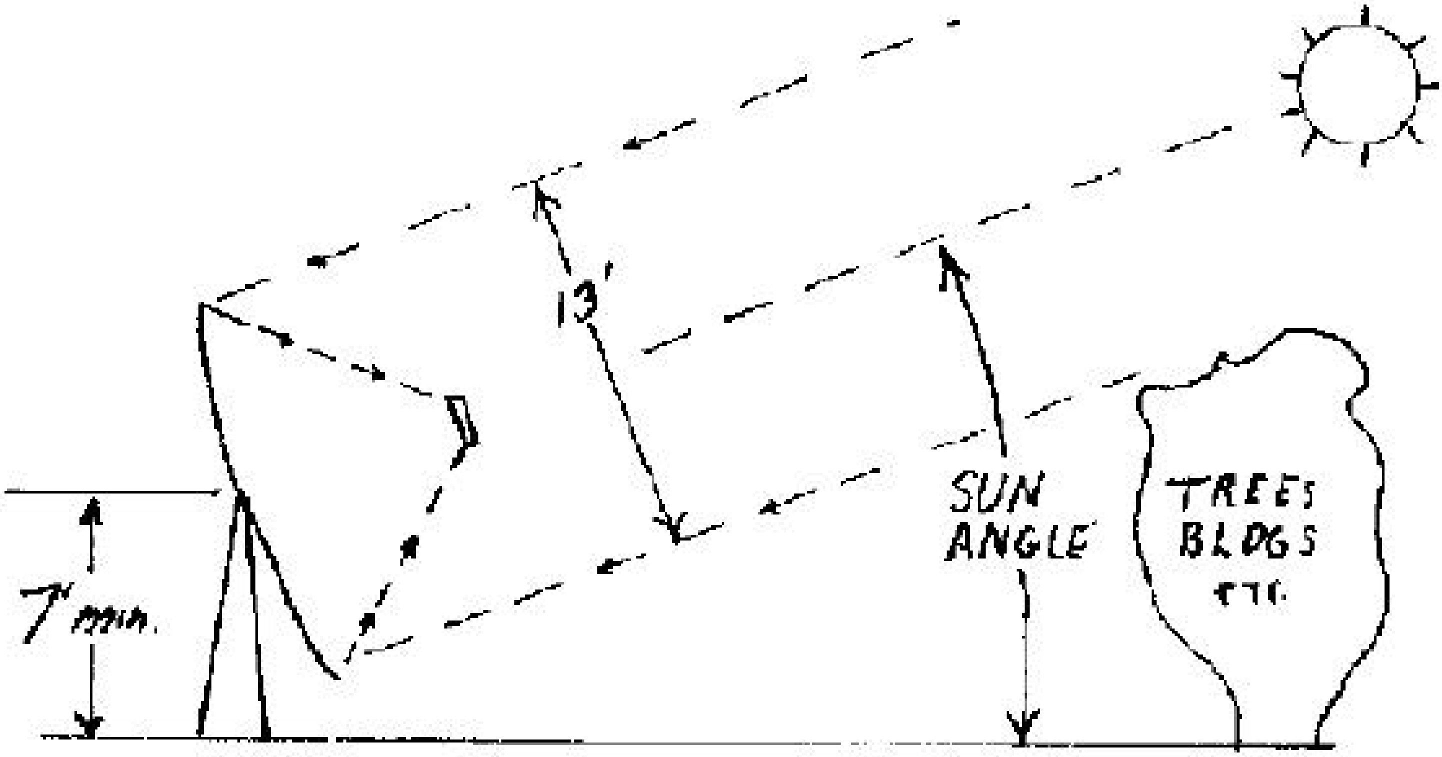
47+23 = 70 degrees

and on December 21st, the shortest day, it is:

47-23=24 degrees

You usually need the heat energy more in the winter, when the day is short, so the 24 degrees is the figure I was after. Find yours in a similar way. During the morning and in the afternoon the sun will be at even lower angles. If you want to get heavier into this, then you better get Duffie & Beekman. Check the neighbors shrubbery and its potential growth and select your location. Consider the problem of piping your heated fluid to its ultimate use point. As long as you don't need a tower, I suggest setting it atop a large pipe or pole buried in the ground. You might also consider a flat top roof. The weight, about 600 pounds will be perfectly centered on the mount, so the only tipping forces will be caused by the winds.

figure02



Sun angle at Winter soltice is (90-latitude-23)

fiaure 2

A TRACKING SOLAR CONCENTRATOR

-9-

SITING SAFETY

The concentrated sunlight can ignite combustibles or cause other damage. At the focal point, temperatures of about 1200 F will be achieved. This point is about eight feet in front of the mirror array. If this concentrated energy does not hit the collector because the array is not properly aligned with the sun, then a hazard exists about another eight feet beyond the missed target. Protect this sixteen foot space ! Beyond this, the energy is dispersed and will simply becomes a lot of bright spots scattered upon surrounding objects, as each mirror has a unique angle with the sun rays. It's a rather pretty effect, especially if the array is lightly dancing in the breeze. The prototype cover photo exemplifies just such a hazard. The energy can hit the nearby roof prior to total dispersal and damage the asphalt shingles. *It did just that so we relocated it for safety reasons*

A piece of sheet metal roofing blocked with a one inch air space between it and the shingles should protect it.

Also consider the hazard to persons, particularly children that may find it fascinating and within reach. You can get one H of a sun- burn, mighty fast with a little horseplay. One look at the array from the focal point might be your last.

I'm not trying to scare you, but we ARE playing with fire. It can be tamed and used like fire, but be careful, please.

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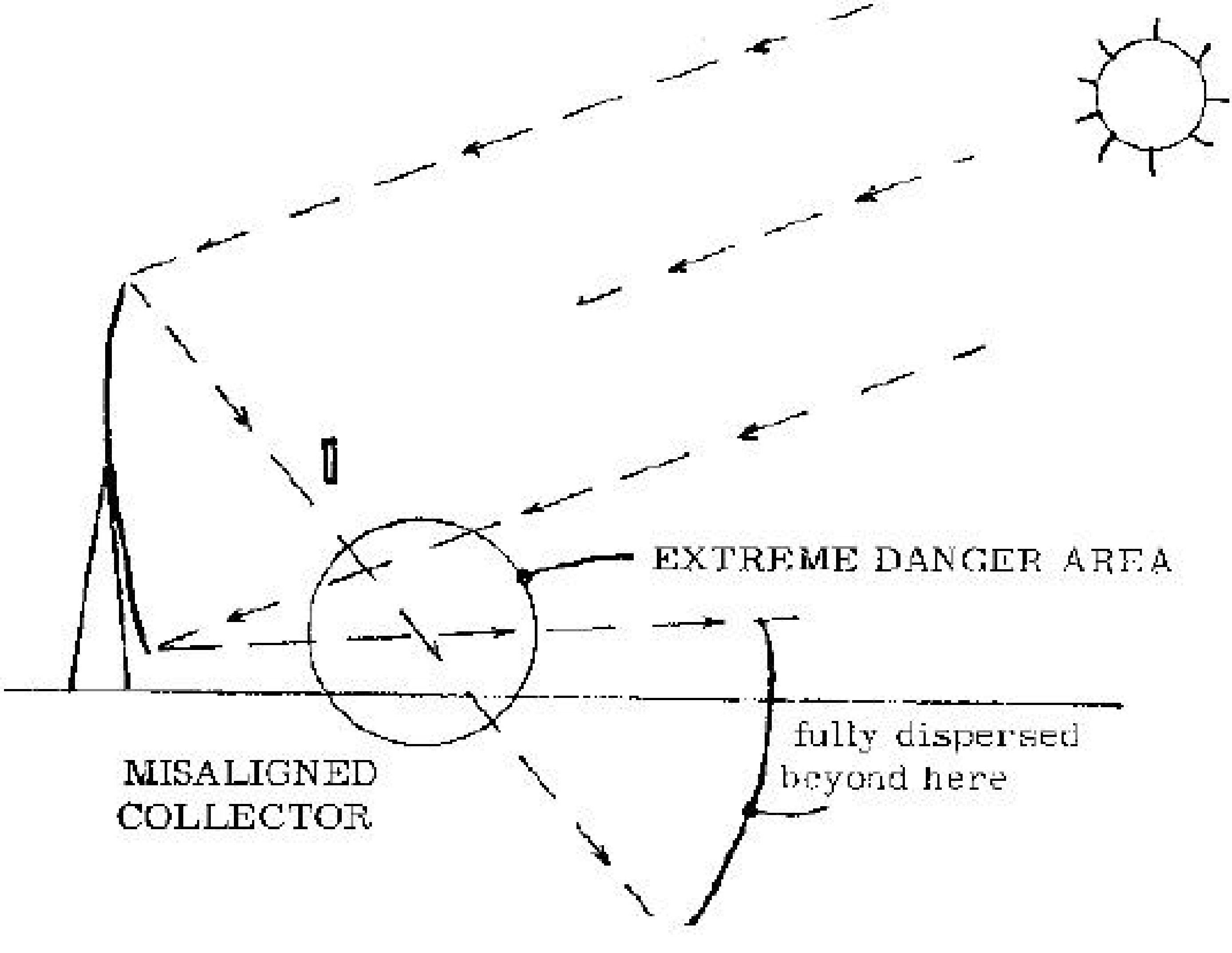
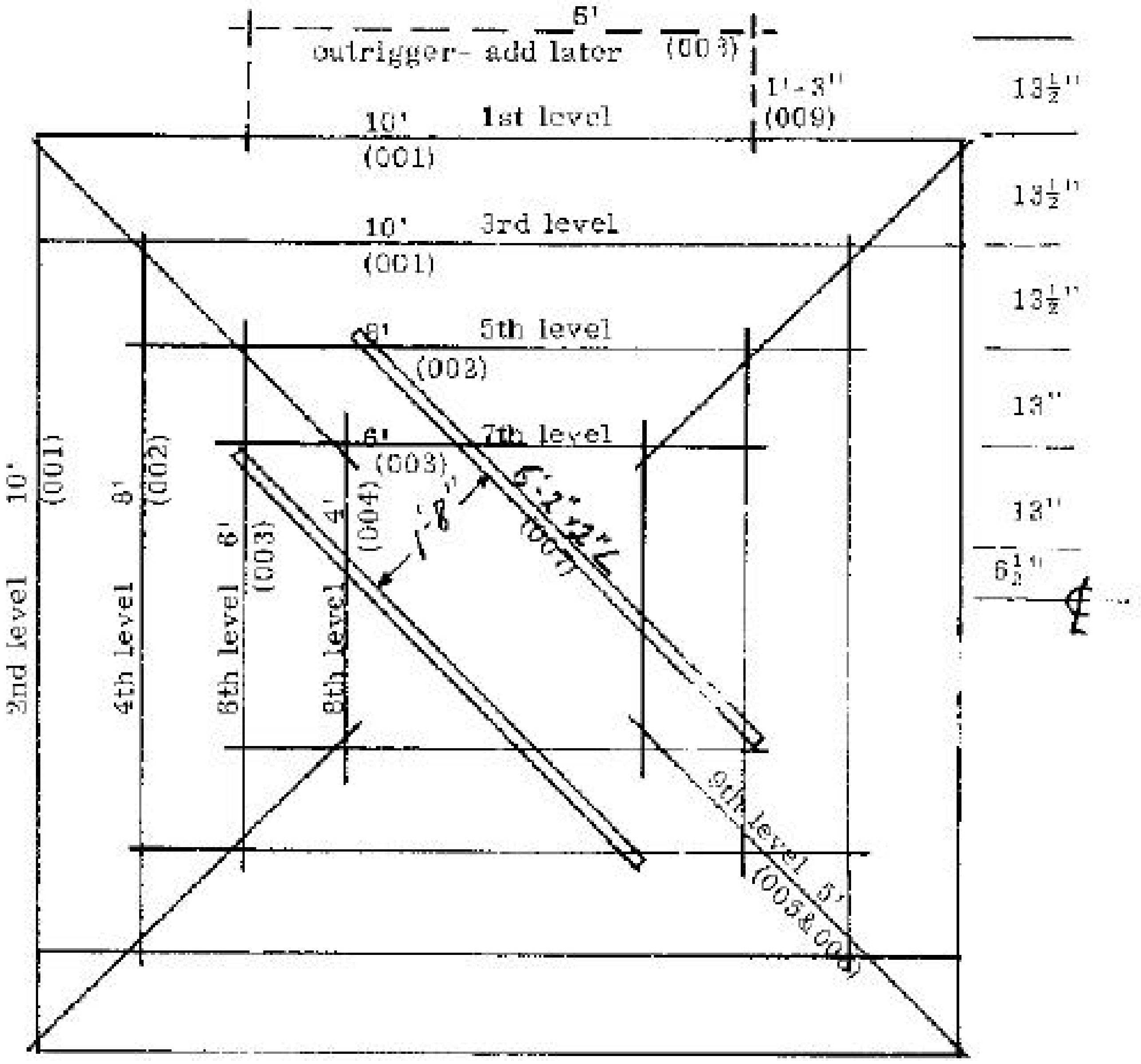
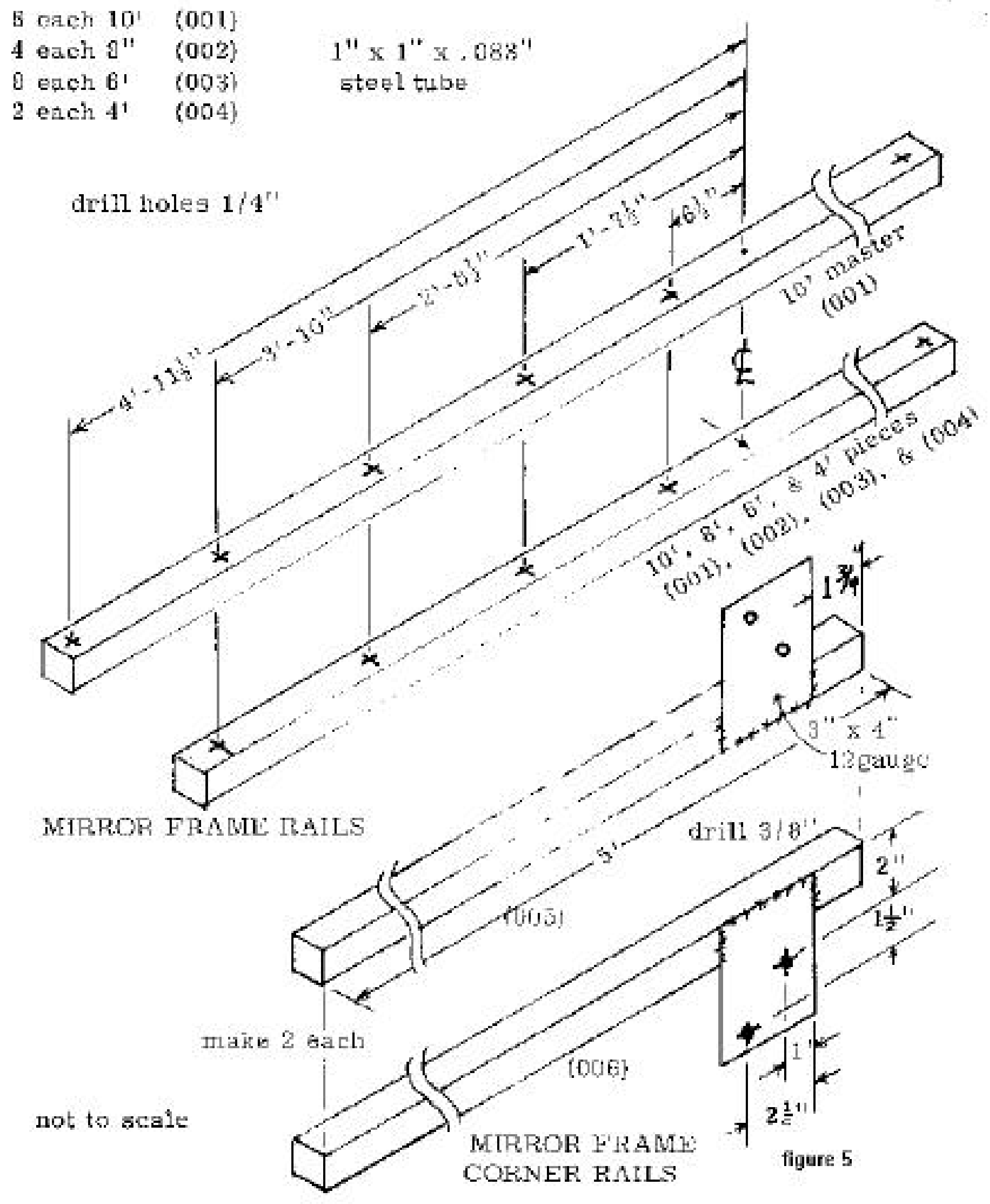
figure03


EXTREME DANGER AREA
fully dispersed
beyond here
MISALIGNED
COLLECTOR



MIRROR FRAME - SCHEMATIC LAYOUT


8 each 10' (001)
4 each 8" (002)
8 each 6' (003)
2 each 4' (004)
1" x 1" x .083"
steel tube
drill holes 1/4"
4'-11½"
2'-5½"
1'-7½"
6½"
10' master
(001)
10', 8', 6', & 4' pieces
(001), (002), (003), & (004)
1¾"
3" x 4"
12gauge
MIRROR FRAME RAILS
drill 3/8"
2"
1½"
(005)
make 2 each
(006)
1"
2½"
not to scale
MIRROR FRAME
CORNER RAILS
figure 5

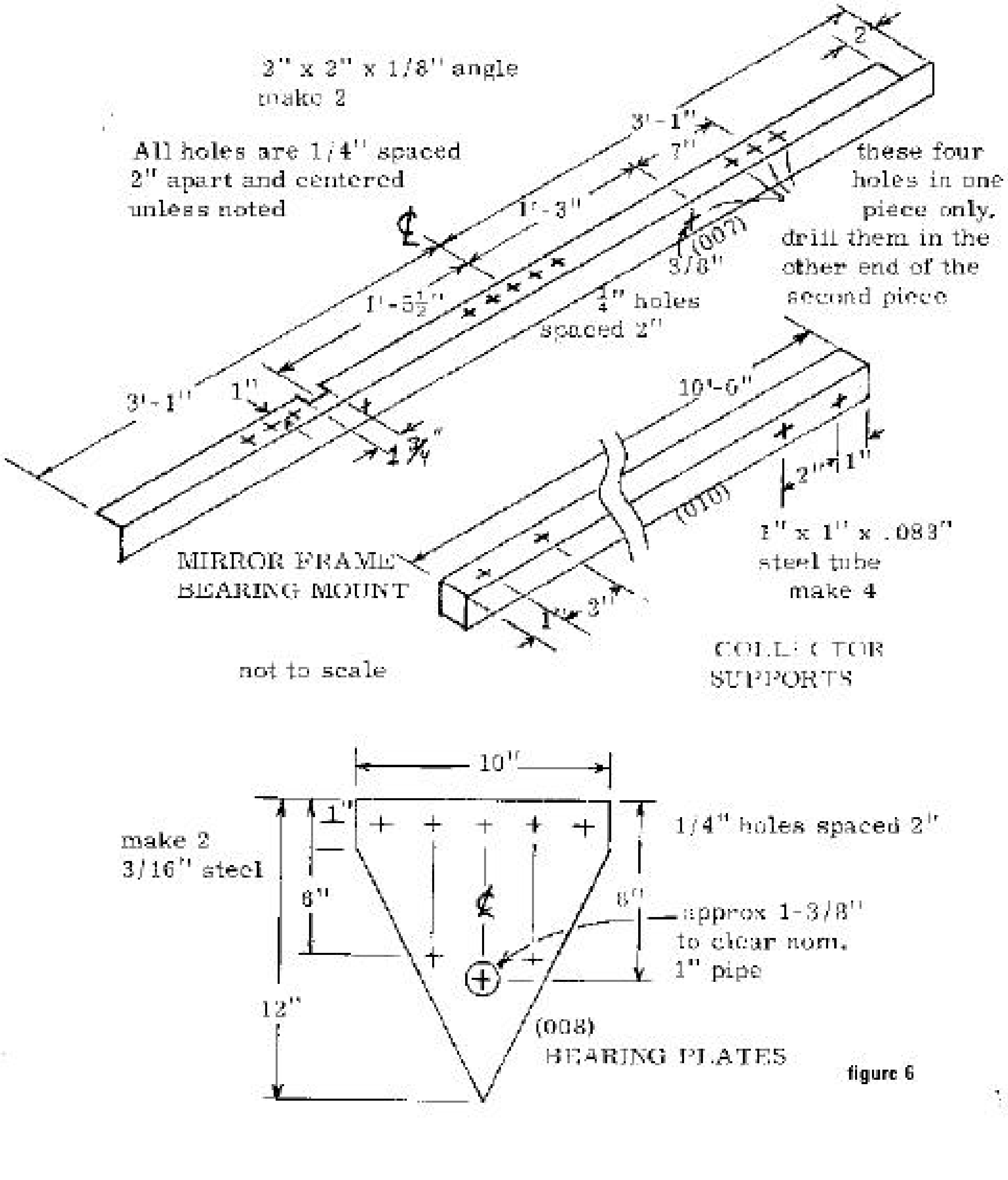

2" x 2" x 1/8" angle
make 2
All holes are 1/4" spaced
2" apart and centered
unless noted
3'-1"
7"
1'-3"
(007)
3/8"
these four
holes in one
piece only,
drill them in the
other end of the
second piece
1'-5½"
¼" holes
spaced 2"
3'-1"
1"
1¾"
10'-6"
2"
1"
(010)
1" x 1" x .083"
steel tube
make 4
MIRROR FRAME
BEARING MOUNT
1"
3"
COLLECTOR
SUPPORTS
not to scale
10"
1"
1/4" holes spaced 2"
make 2
3/16" steel
6"
6"
approx 1-3/8"
to clear nom.
1" pipe
12"
(008)
BEARING PLATES

figure 6

A TRACKING SOLAR CONCENTRATOR

ASSEMBLY- MIRROR FRAME

The steel tubing is usually supplied in slighty over 20 foot lengths so that some waste in cutting is possible and still come up with full 10 foot lengths. Only six of our 10 footers must be a full ten feet, the other eight are nominal 10 feet, so plan your cutting accordingly. All the rest of the tube lengths are also nominals.

Set aside the eight nominal 10 footers, the tail and (010) , four of the 6 footers and all of the 15" pieces for later use. The outriggers shown in the schematic figure 4 will not be mounted until the array is set on the hub. They are too fragile and get in the way while the collector supports are being assembled later.

Next task is to drill the frame rails for the quarter inch bolts that will pin it together and serve to mount the mirrors. Select one of the full ten foot lengths (001) as a master pattern for the remainder. Locate the center and drill the ten holes according to figure 5. Using this master pattern, drill five more full 10 foot lengths (001), four- 8 footers (002), eight- 6 footers (003) and two- 4 footers (004). Center each piece on the master before marking and drilling

Assemble the frame face down by pinning it together with the five inch bolts to form a shallow pyramid. Layout the first and second levels using full ten foot pieces (001) on a flat surface. Block level one up high enough so the bolts can be dropped into it. Carefully level all four corners and measure diagonally across the square to make sure it is square. Continue pinning the remaining levels up through level 8 so as to form the shallow pyramid shape. Figure 7 is a detail of one corner of the frame shown face up. Remember, we are building it face down.

Recheck your level and diagonal measurements and weld everything together. Weld the bolt heads to the tubing.

Fabricate the level nine pieces (005) & (006) according to figure 5. Notice that there is two each, mirror images of each other. This is so they can be offset from the welded bolt heads on the frame and still provide supports to position the 10 foot collector support pieces (010) exactly in the corners. Use a short scrap of tube in place of the (010) pieces to check the positioning of the holes in the 3" x 4" tab on (005) or (006). Then weld in the level nine pieces.

Previous Next

A TRACKING SOLAR CONCENTRATOR

ASSEMBLY- MIRROR FRAME

This would be a good time to pre-fab the outriggers. Temporarily bolt the 15 inch pieces (009) to the outside rails, Figure 7. Pin the four 6 foot pieces (003) to them with 5 inch bolts and weld. Don't weld to the (001) rails yet.

Drop 4 inch bolts into all the remaining holes to form the mirror mounting studs and weld the heads to the rails. Remove the temporary bolts and set the assembled outriggers aside. If you leave them attached you'll very likely bend or twist the (001) rails while handling. We'll reinstall them when the mirror array is mounted on the hub.

Fabricate the two angle irons (007) and the bearing plates (008). Insure that the five bolt holes are aligned for later assembly of the (007) & (008). Set the bearing plate aside and weld the angle irons (007) into the frame assembly according to Figure 9, which is again a face up view. Twenty inchs is the nominal face-to-face spacing, but more important is that they be parallel and symmetrical in the array.

It's time to turn the frame over so our pyramid is now more like a saucer. Block it up on some saw horses to reach a comfortable work level and reduce the risk of falling into the "bed-of-nails", Continue to weld the assembly together from the face side.

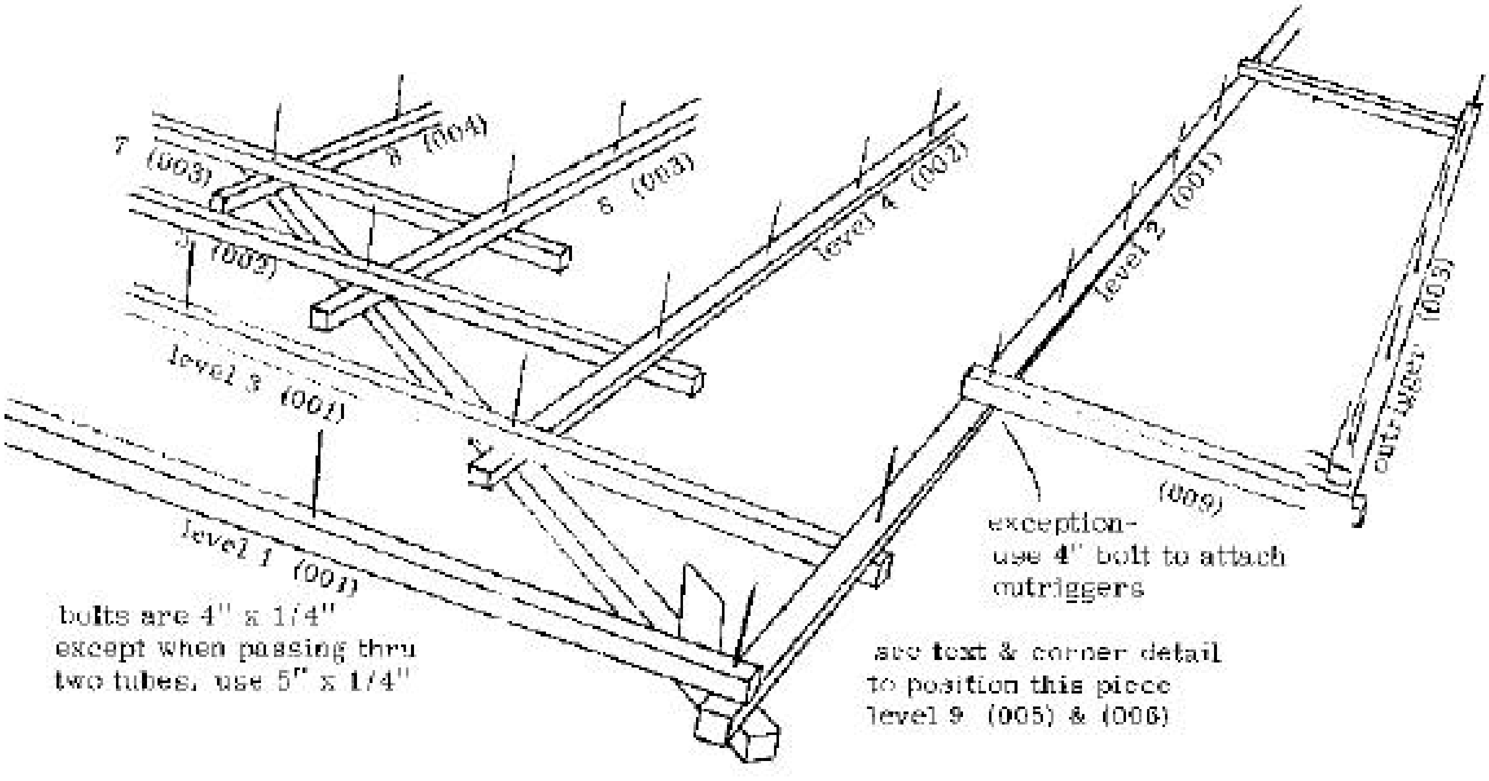
If you've been working indoors, it might be time to move the array outside so we can mount the ten foot collector supports (010) and the collector frame (011).

Drill the collector supports (010) according to Figure 6, Fabricate the collector frame (011) according to Figure 10, Tip the frame up on one side and lash it so you don't have an accident.

Safety tip: Drape the projecting bolts with visible material such as white rags to prevent you or others from walking into them, especially at eyeball level

Attach the collector supports (010) to the corners of the array bringing them together in a pyramid shape where they will tie into the collector frame (011). This is a little awkward to bring all four pieces together with the (011) frame without bending something, so a little extra help might be handy. Lay the array back down- block it up on the saw horses so nobody can fall into the studs that are pointing up, and so you can clean and paint everything. Clean and paint the outriggers too. To keep the weight down, the mirror clips and mirrors will not be installed until the array is mounted on the hub.

Previous Next



MIRROR FRAME - CORNER VIEW
face up

figure 7

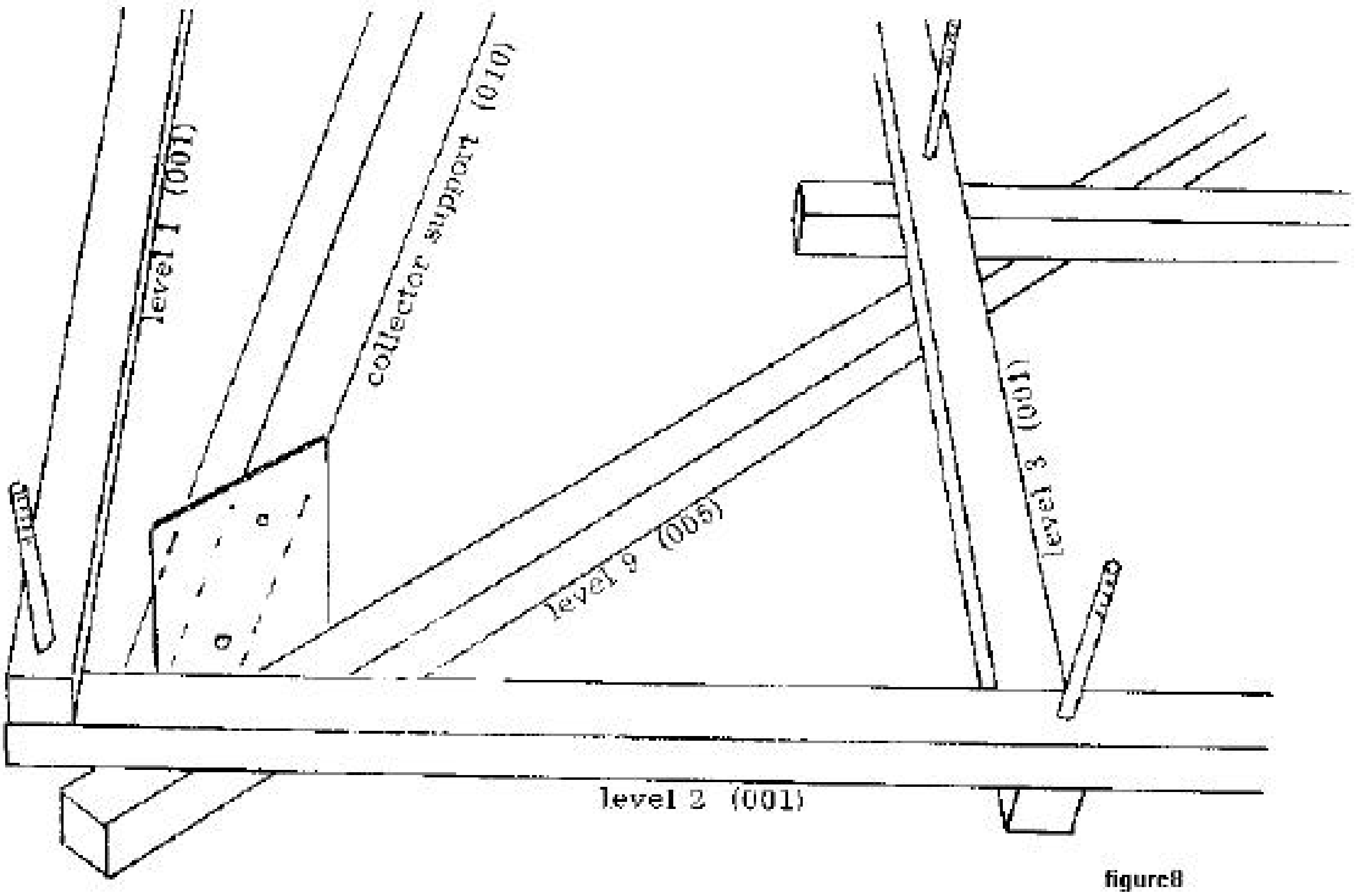


figure8

MIRROR FRAME - CORNER DETAIL
face up

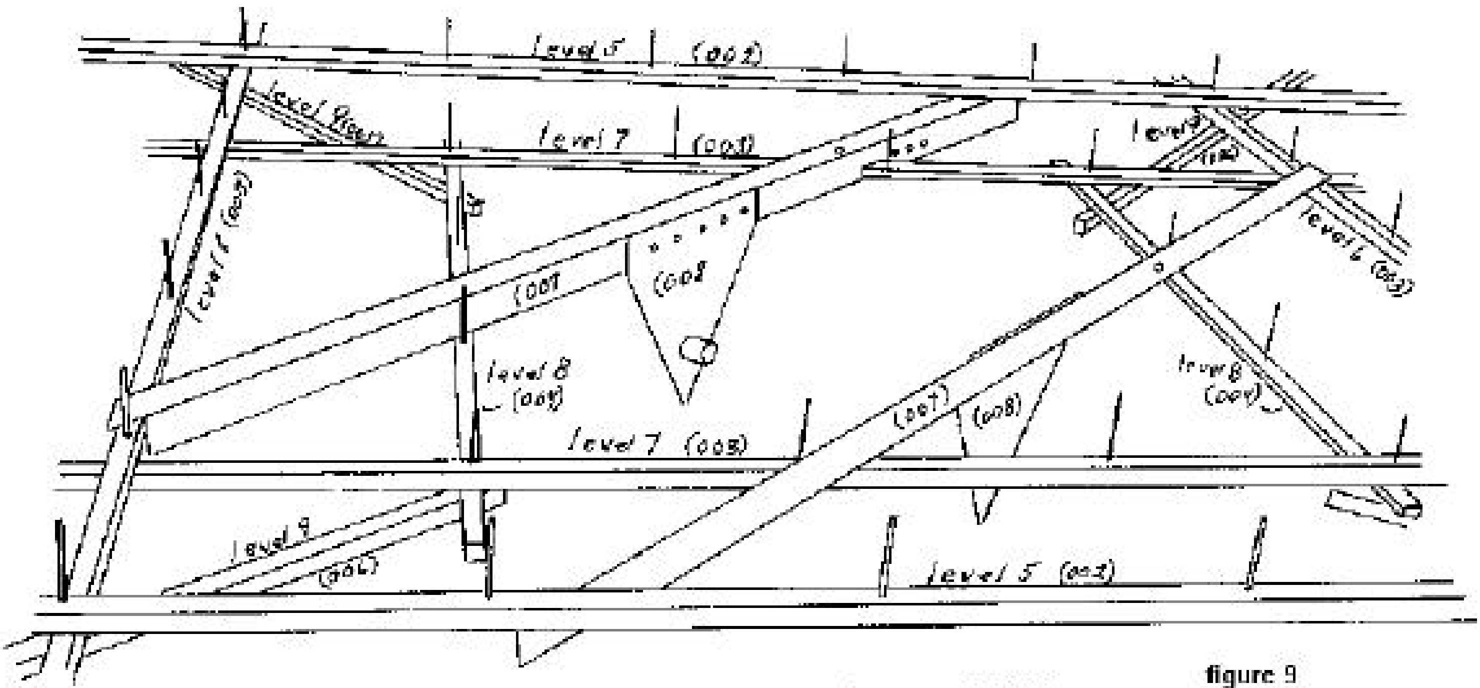
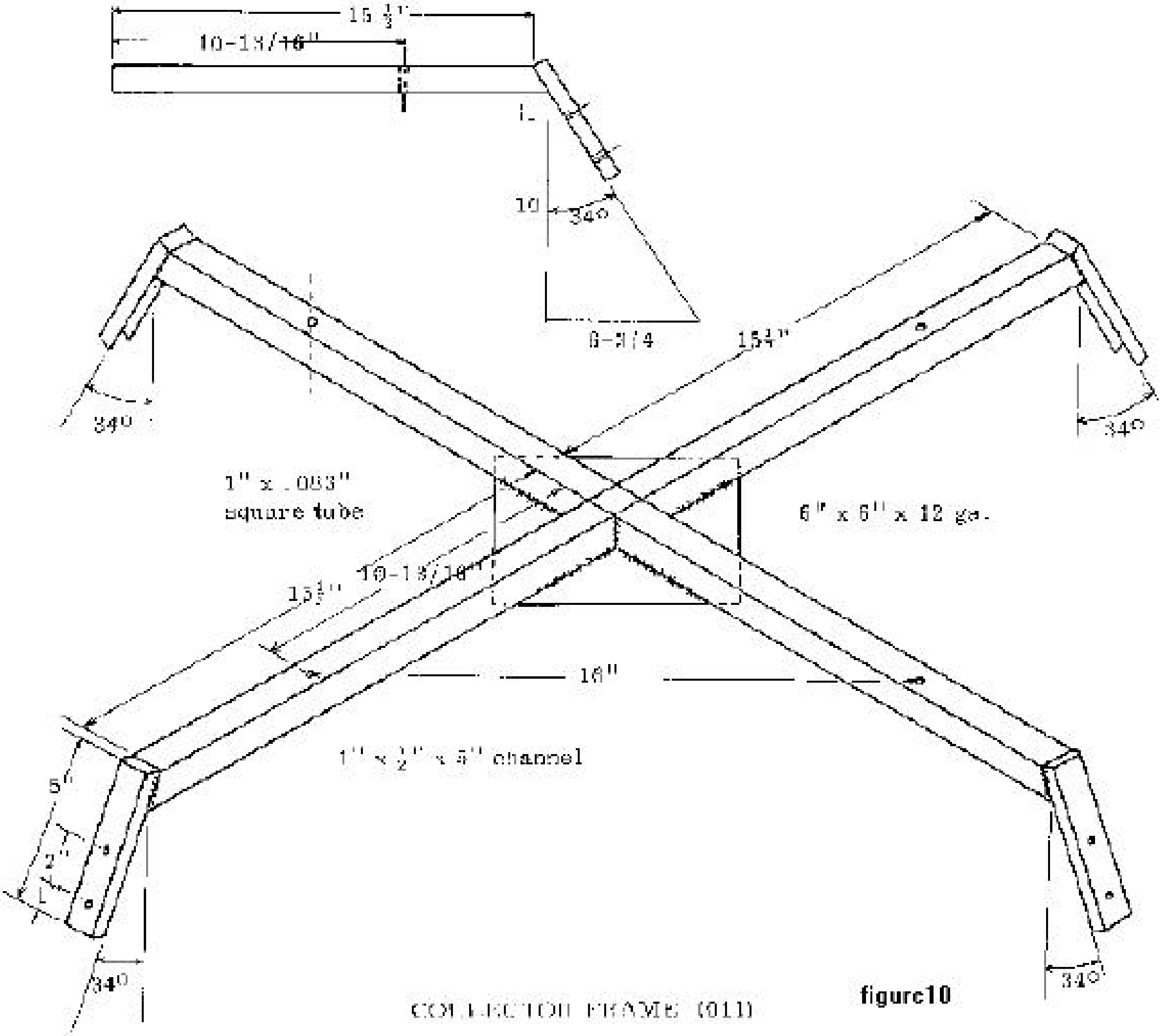


figure 9

MIRROR FRAME - CENTER DETAIL - FACE UP



COLLECTOR FRAME (011)

figure10

A TRACKING SOLAR CONCENTRATOR

-20, 21-

THE HUB

The hub must carry the entire weight of the array and provide the bearings to permit it to follow the sun. The tracking drive system will be mounted here as well as part of the tilt drive system. This chapter will define the requirements of the hub and show you how to economically assemble it from discarded automobile parts thereby eliminating expensive machine work. The following chapter will describe the the drive system.

Figure 11 shows how an old Chevy 1/2 ton pickup front wheel, hub, brake drum and spindle where used to provide the bearing system. The 15 inch diameter plate (101) is intended to mount on your support structure which should have a similar plate (201) mounted dead flat. The mirror array will have its bearing plates (008) rotating on the one inch shaft (109). This shaft should be located exactly over the center of the plate (101) in order to properly center the weight of the array.

The spindle (104) forms an angle to the surface of the Earth that is equal to your latitude. This makes it parallel with the Earths axis. The mirror array will now rotate about the spindle towards the West at 15 degrees per hour while the Earth rotates toward the East at the same rate. The result is that the mirror array remains steadily fixed upon the sun. This mounting system greatly reduces the tracking requirements.

second bearing system, consisting of the bushed bearing plates (008) riding on the one inch shaft (109) provides adjustment for the 23-1/2 degree tilt of the Earth. The array will be adjusted over this range only one cycle per year For this reason, we did not set fit to make it automatic, but a motor drive has been provided to make it easy to adjust once in a while. You may desire to save the cost of the motor drive and make it manual if the system is mounted in a convenient location.

THE HUB - MAJOR MATERIAL LIST

- Two discs of 1/4" steel plate cut and drilled per figure 14.
- scrap iron similar to (102), (103) & (108)
- Automobile or light truck front wheel assembly (104), (105), (106), & (107).
- 24"x 1" steel rod (109)
- Four bushings, (110) cut from 1" black pipe- 2" long

When selecting your front wheel assembly, you have many choices, so you'll probably do better at a scrap yard buying by the pound rather than at the auto salvage dealer. The requirements are:

- The brake drum should have flanges suitable to wrap a #40 roller chain around for our drive system per Figure 11. The old Chevy drum used on the prototype had a raised ridge that the chain rides upon just as it would on a sprocket but this is not essential.
- The spindle (104) should be designed so it is convenient to attach to the channel iron (102) by bolting. This is preferable to welding as minor adjustments can be made with shim washers.
- A six hole wheel bolt pattern is nice as the symmetry makes for less clearance problems with the one-inch rode (109) that will be welded into the wheel, but this

also is not essential.

Previous Next

A TRACKING SOLAR CONCENTRATOR

THE HUB - FABRICATION

The brake drum will be used as a sprocket for a #40 roller chain later. This saves us the expense of mounting a large sprocket. It works great without teeth because it will rotate considerably less than a full turn and so the chain can be bolted into the drum. Of course this trick won't work if you live far enough North where the Summer days get very long. To clear the chain you'll have to take some metal off of the back rim of the wheel. The sketchs and photos show both rims cut off, but this may not be necessary

The hub requires some customized design to suit your latitude and the wheel assembly that you have salvaged. The ultimate requirements are:

- The spindle must form an angle to the horizontal that is equal to your latitude, Therefore the channel iron (102) that it mounts upon must form an angle of (90-latitude) with the steel plate (30.1).
- The one inch shaft (109) must be directly above the center of the steel plate (101),

Obviously the place to start is with the 1/4" plate (101), figure 13. Might as well make the second plate (201) at the same time and set it aside for attachment to your support structure. Because the hub must be oriented exactly in a North-South line, the mounting bolt holes are elongated to allow for later adjustment in case you are not a precision surveyor. You could get by with square plates of about 12" x 12" if you can get them sheared to save labor, but the lay the bolt pattern out in a circular form so that some rotation is possible later.

Make up items (102) and (103) and weld them at the proper angle for your latitude onto the plate (101). If you're handy with angles, I need say no more, but if trig' makes you nervous, use a carpenters framing square and the chart in figure 12. Item (102) should he no wider than is necessary to mount the spindle as the space along side it will be needed later for the motor drive. If you prefer to do careful planning and layout and are working with a drill press instead of a portable drill and cutting torch, you may prefer to delay the welding of these pieces until all the holes are cut for the Tracking Motor Drive described in the next Chapter.

With the wheel (107) off of its hub, notch its face about a half-inch deep so the one-inch shaft (109) can lay into it. Select a piece of pipe or pipe coupling (108) large enough to clear the hub (106) when the wheel is in place, but small enough to avoid interferance with the lug nuts. *continued on page 24*

Previous Next

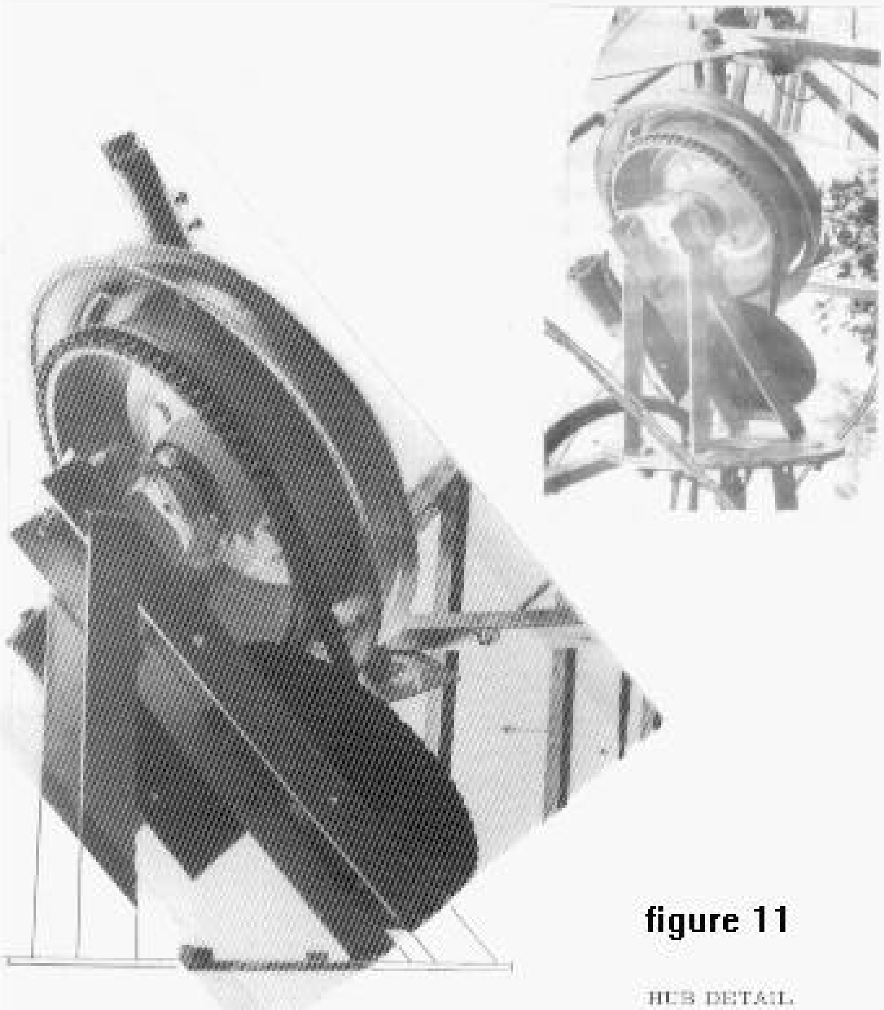


figure 11

HUB DETAIL

A TRACKING SOLAR CONCENTRATOR

THE HUB - FABRICATION *continued*

Burn a hole through it for the one-inch rod (109) as shown in Figure 13 and Figure 14 Work on a flat surface and be precise about positioning the three pieces. Both ends of the rod should be the same distance above your work surface and it should be dead center in the wheel and pipe piece while not interfering with access to the lug nuts. When you've tacked it and are sure of the quality, weld the three pieces (107), (108) & (109) together. Finally, burn the rod out of the center of the pipe piece so the hub (106) can fit through. This procedure assures that the two pieces of shaft are properly aligned with each other.

Mount the spindle (104), positioning it so that when all parts are assembled the one inch shaft (109) when held in a horizontal position is directly above the center of the plate (101). This is not important for tracking purposes but will reduce the stresses on you support structure by causing the center of gravity of the array to fall in its center. Also, in positioning the spindle, you may have to space it on washers or shims so that the drum will be in position for the chain drive per Figure 14.

Make up the four bushings (110) approximately two inchs long from nominal one inch black pipe. Drill and tap two of them for a couple of 3/8" set screws. Weld the other two into the bearing plates (008) on your mirror array using the newly made wheel and shaft assembly to align and position them. You'll notice the bearing plates (008) seem to be rather non-rigid due to flex in the array. Don't be alarmed, the tail assembly will fix this.

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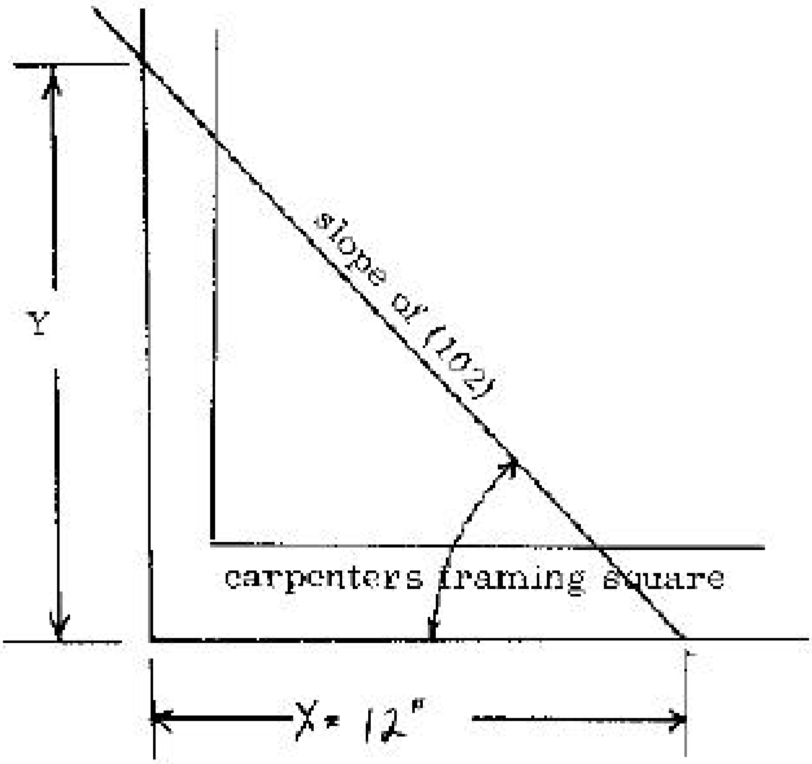
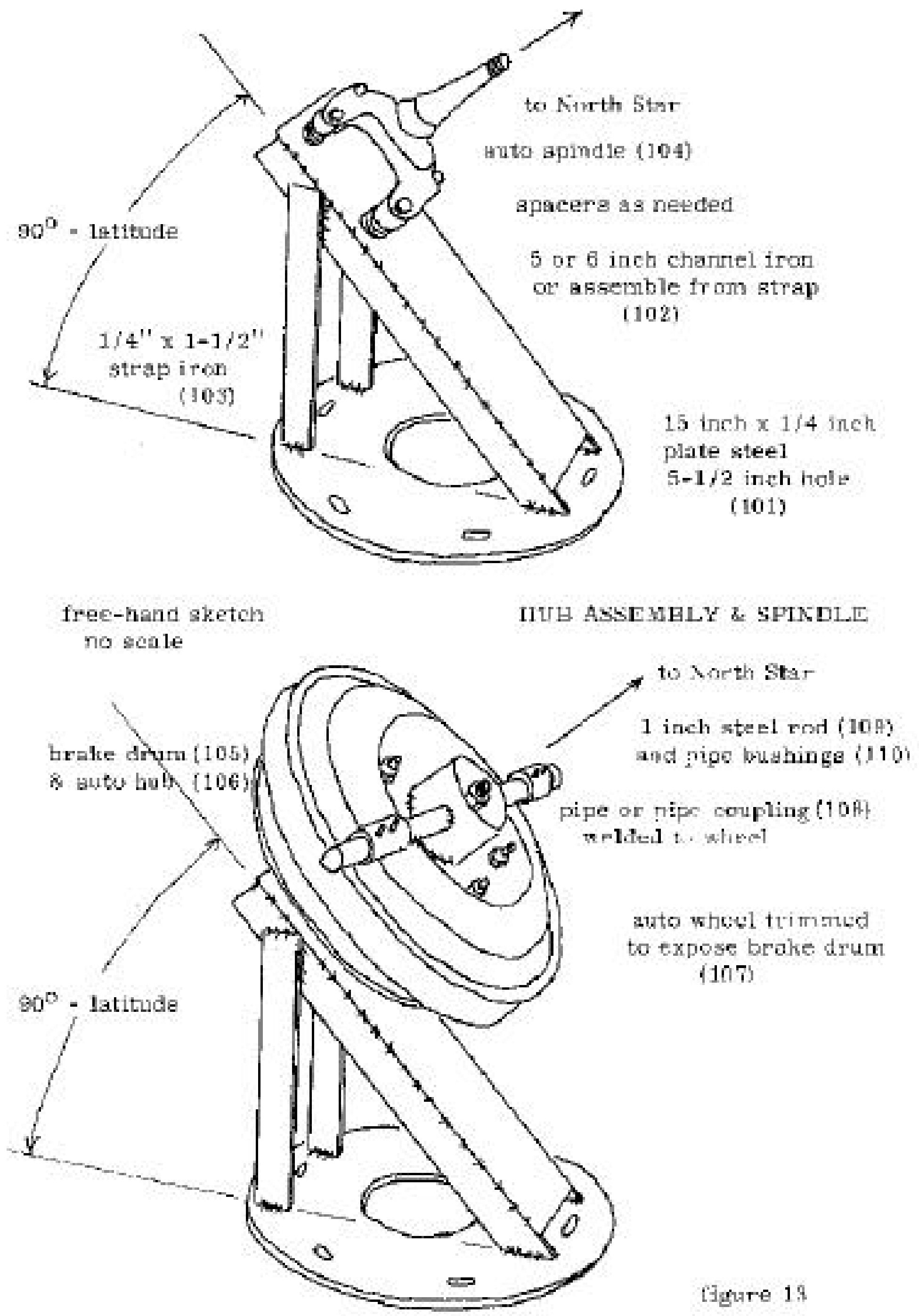
figure12



latitude	Y=12 tan (90-lat)
28	22-9/16"
30	20-13/16"
32	19-3/16"
34	17-13/16
36	16-1/2"
38	15-3/8"
40	14-5/16"
42	13-5/16"
44	12-7/16"
46	11-9/16
48	10-13/16"

figure 12



to North Star
auto spindle (104)
spacers as needed
90° - latitude
5 or 6 inch channel iron
or assemble from strap
(102)
1/4" x 1-1/2"
strap iron
(103)
15 inch x 1/4 inch
plate steel
5-1/2 inch hole
(101)
free-hand sketch
no scale
HUB ASSEMBLY & SPINDLE
to North Star
1 inch steel rod (109)
and pipe bushings (110)
brake drum (105)
& auto hub (106)
pipe or pipe coupling (108)
welded to wheel
auto wheel trimmed
to expose brake drum
(107)
90° - latitude

figure 13

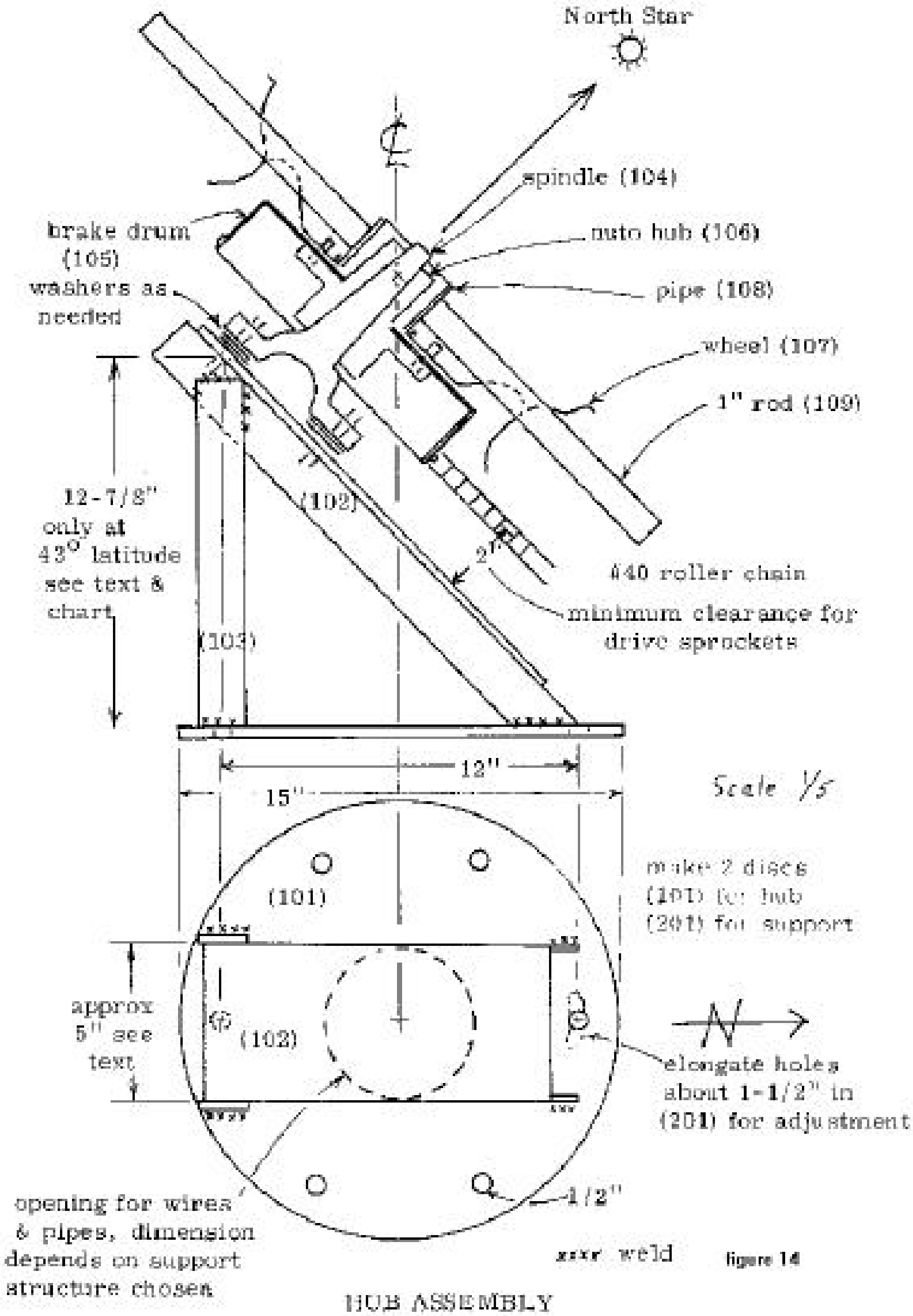


figure 14

HUB ASSEMBLY

A TRACKING SOLAR CONCENTRATOR

SUPPORT STRUCTURE - REQUIREMENTS

Your support structure will be unique to your location and siting problems. The prototype system uses a sixteen foot tilting tower assembled with 2" x 2" angle iron legs, one-inch cross members and 3/8" rod lacing. It is set in concrete pilings 43 inches in the ground, below frost level with a total mass of 2000 pounds. This is suitable for this site, but probably overkill for yours. In most cases a large piece of pipe set in the ground will probably suffice. If you're not confident in designing your own support system, by all means consult with local experts who will consider your soil conditions, frost depth, wind problems and above all-safety. Go back and review the Chapter on Siting Safety

The only requirement we will impose is that the steel plate (201) be mounted dead flat with one set of opposite holes exactly on a North-South line and that the structure be not wider than 15 inches at the top tapering to not wider than 30 inches, five feet below the top.

A height of about 5-1/2 feet to the mounting plate (201) is the least you can get by with, providing you mow the grass short, but I'd suggest a bit more to reduce hazards to the array and most of all to make it harder for some idiot to burn himself. Remember also the hazard area pointed out in the Siting Safety Chapter. It'd be a rotten shame to burn the house or garage down.

Previous Next

A TRACKING SOLAR CONCENTRATOR

DRIVE SYSTEM, TRACKING

The drive system that swings the array to track the sun will be assembled on the Hub previously built. A reversible electric motor will drive it through a set of reduction chain & sprockets to give us a very powerful system that can easily cope with the wind.*1999 note: obviously, we mean nominal winds. We usually steered the collector toward the noon time position, disabled the drive and tied the tail down when winds felt intuitively hazardous after an incident when high winds snapped the #50 drive chain! The collector still stands, with the tail tied down and was never again been damaged by wind.* Even with this reduction, the array can be swept from one limit to the other in two or three minutes with the recommended motor. When actually tracking in full automatic mode, it will move a fraction of a degree every couple minutes. The prototype uses a readily available gear-motor with a built in reduction of 1787:1, but we encourage you to seek out others for the sake of economy. You should consider slow speed motors salvaged from the auto or farm machinery areas if operation from battery is important.

DRIVE SYSTEM, TRACKING - MAJOR MATERIAL LIST

- #40 roller chain, approx 7 feet (301)
- #40 sprocket, 12 tooth, 3/4" bore (302) Martin 40BS12-3/4
- #40 sprocket, 60 tooth, 3/4" bore (303) Martin 40BS60-3/4
- #40 sprocket, 10 tooth, 1/2" bore (304) Martin 40BS10-1/2 this item matches the recommended motor
- Bushing, 2" long, 5/8" id x 3/4" od (305)

- above items are generally available at a bearing supply store such as Kaman Bearings

- 5/8" x 3" hardened steel bolt and 2 nuts (306)

- scrap steel per figure (307) &- (308)
- Gear-motor, Dayton 22797 (309)
  - Available at motor supply stores throughout the USA or order from Teton Engineering- Order blank at rear of manual *sorry- we no longer provide support*

Previous Next

A TRACKING SOLAR CONCENTRATOR

DRIVE SYSTEM, TRACKING -ASSEMBLY

Seefigure 15 for the sprocket layout used on the prototype. Because your hub is tailored to your latitude and your drum (105) may be of a different dimension, use the figure and dimensions for general guidance only. Elongated holes are cut in the spindle support (102) so that the chain adjusting plate (307) can be moved to tighten the chain. The hardened bolt (306) is welded to the plate (307) to form a shaft for the reduction sprocket set.

Press the bushing (305) through the sprockets (302) and (303) and then weld them together. Don't overheat and damage the bushing.

Grease the shaft (306) and surface that the big sprocket will run against and double nut the bolt (306) to retain them. Make any slight adjustment to the spindle mounting washer/shims to properly align the drum (105) and the sprocket (302) and install the chain (301) with a master link or half-link as needed. Mark the shaft (109) position on the drum (105) according to figure 15 and drill four 3/ 16" holes between adjacent chain rollers and through the drum. Bolt the chain down with high quality bolts torqued tight. These four bolts are your sprocket "teeth" and will take some pretty high stresses in the wind

Fabricate the motor mounting plate (308) and mount the motor similar to the photo, figure 11. Install the (304) sprocket and chain. Adjust the plate (308) to remove slack.

Fabricate and install a rain shield that will permit free air flow through the motor.

Previous Next

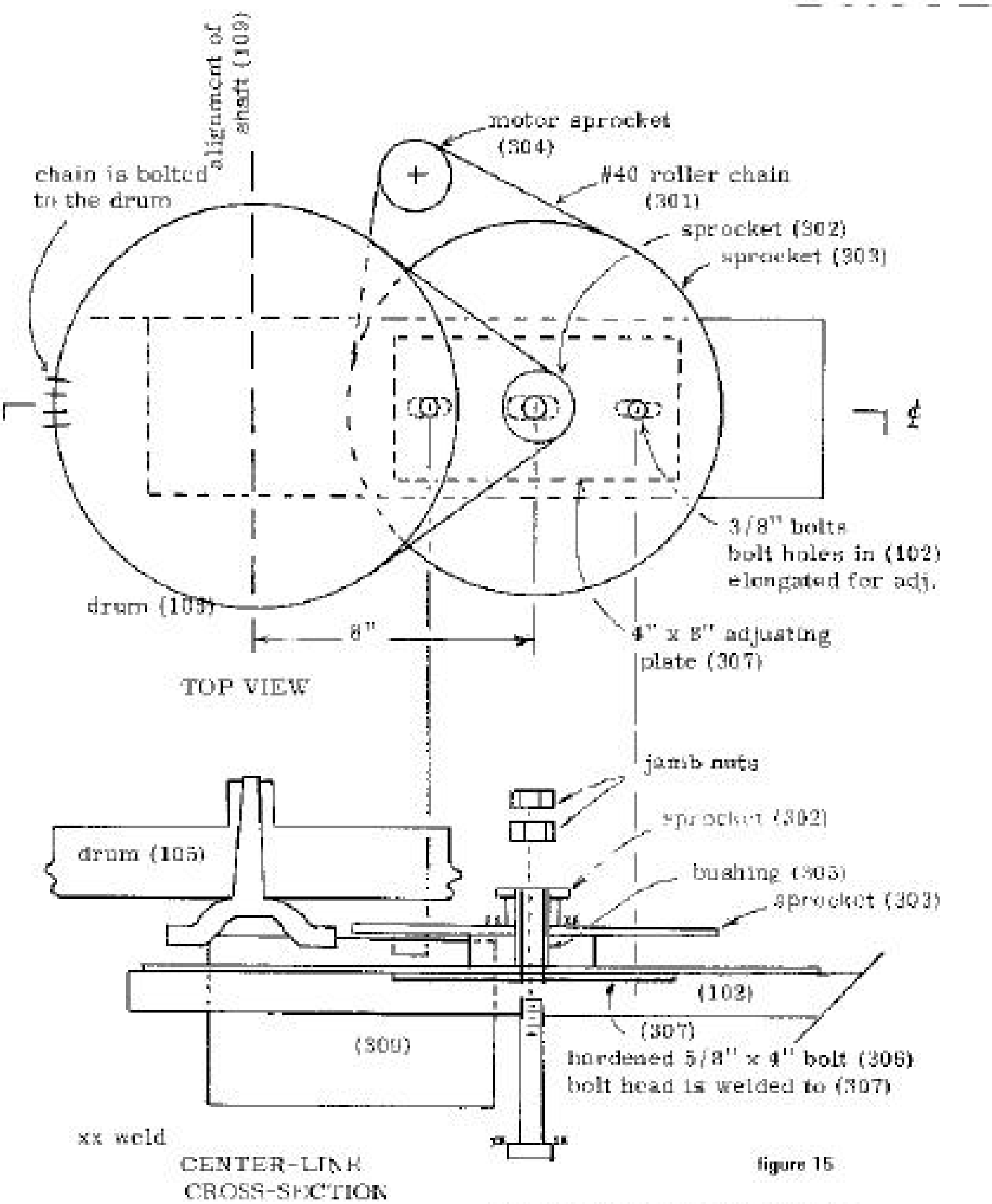


figure 15

DRIVE SYSTEM - TRACKING SPROCKET/CHAIN LAYOUT

A TRACKING SOLAR CONCENTRATOR

HUB AND ARRAY MOUNTING

Mount the hub assembly complete with its drive system on your support structure. Remember, the spindle (104) points North. In fact, if it had a hole bored through its length you would be able to sight through it to the North Star. If you have made an error in alignment, it will become obvious when we try to track the sun later and this is where the elongated holes will come in handy.

Unless you have access to hoisting facilities, I recommend mounting the mirror array at this time before we make it heavier. There is still a bit of welding to do on the wheel (107) for the tilt drive system, but we found it more convenient to have things bolted down when installing it.

If you have been following the order of assembly, the wheel and shaft (109) were left assembled to the mirror array bearing plates (008). Adjust the bushings (110) to center the wheel and lock the set screws down. Find some help and set the mirror array on the hub after you have made sure that the shaft (109) is aligned to the mark previously put on the drum and bolt it down with the lug nuts. At this time the array is unbalanced and feels a bit insecure because of the lack of a tail assembly. Don't try the motor drive yet. Next, we'll build a tail and counterweight system

Previous Next

A TRACKING SOLAR CONCENTRATOR

TAIL AND COUNTERWEIGHT

tail and counterweight are very important in reducing stresses on the hub, support and drive systems. It also adds needed rigidity to the array bearing plates (008). With this, we can completely balance out all static forces except the total weight which will appear centered over the support structure. When the system is properly balanced, the drive systems can be removed and the array can be easily positioned in either axis with gentle hand pressure.

TAIL AND COUNTERWEIGHT - MAJOR MATERIAL LIST

- 4 each 10 foot lengths .083" x 1" square steel tube (401) these were cut and set aside earlier.
- approx 18" - 3/4" threaded rod, 3 nuts, 2 lock-washers (402)
- 2 each - 3/16" gusset plates per figure . (403)
- scrap steel or other material for weight - see text (404)
- approx 20 feet - 3/8" steel rod (405)

TAIL AND COUNTERWEIGHT - ASSEMBLY

There is little to be said about the tail system that is not apparent from the photos. The prototype is overbuilt, having been made in two pieces for removal of the tail/counterweight section, while leaving enough to rigidize the bearing plates (008). This was for developmental reasons only and is not recommended. The four pieces (401) are tapered to a common connection point figure 16and figure 17. It will be necessary to make a slight bend in them in order that the bearing plates (008) remain parallel. Unlike the prototype, a much simpler set of cross ties with 3/8" rod should be sufficient. The counterweights are six inch squares of scrap steel with a 3/4" hole through the middle. A one-inch piece weighs about 10 Ibs. The total requirement will be in the neighborhood of 60-70 Ibs. A way to determine it is to hang a bucket of sand filled to balance and then weigh the bucket and sand on the bathroom scales. You will notice that the weights are suspended slightly below the centerline of the array. This effectively counteracts the tail pieces (401) which are above the centerline

Previous Next

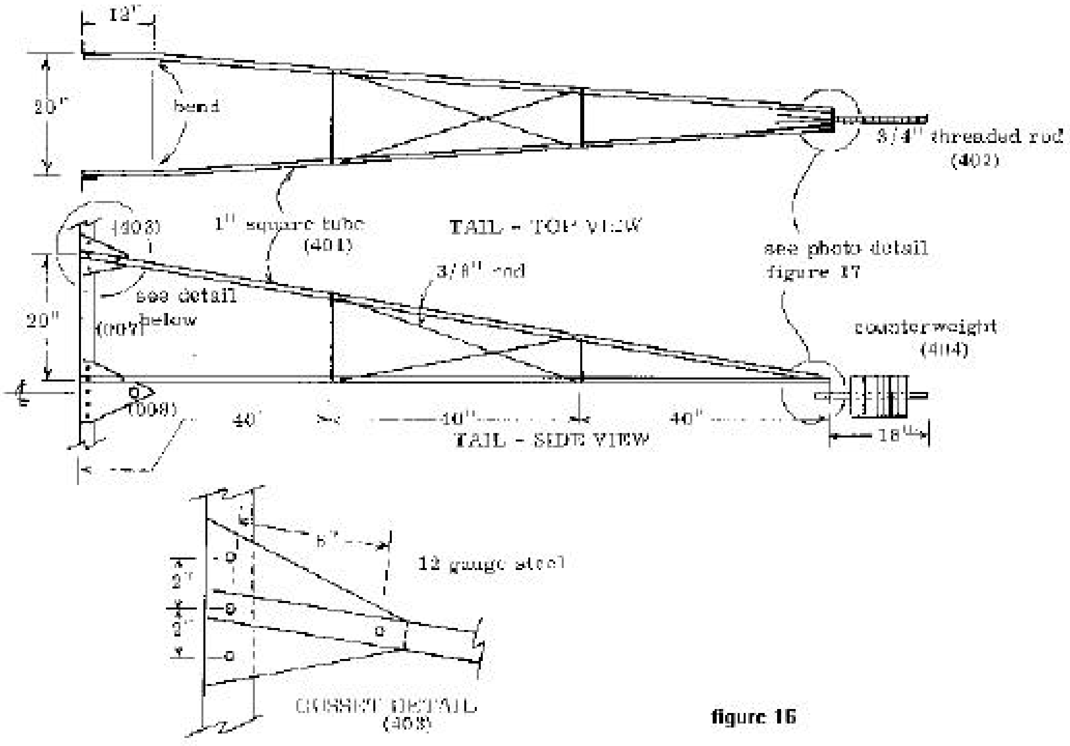


figure 16

TAIL AND COUNTERWEIGHT

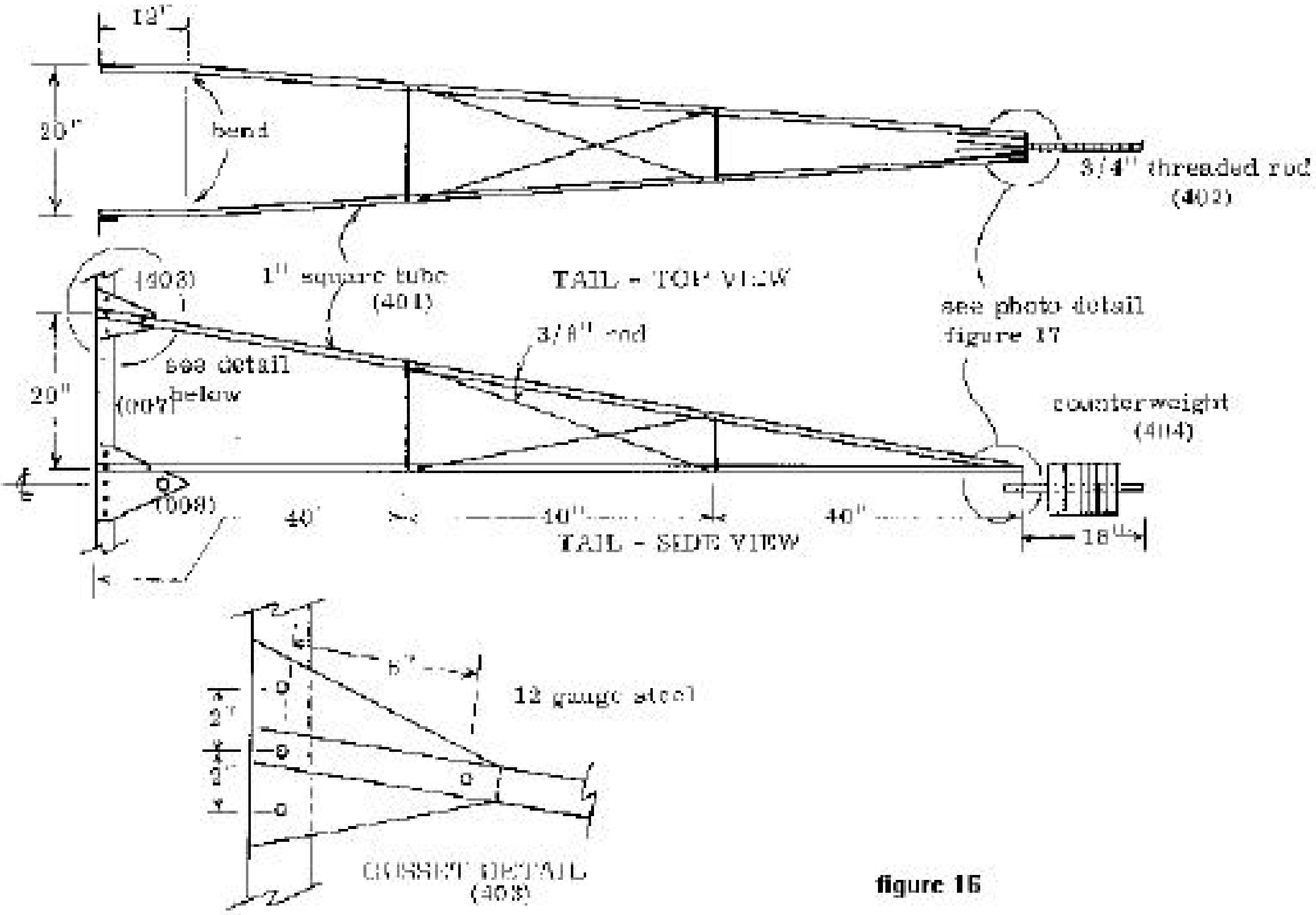
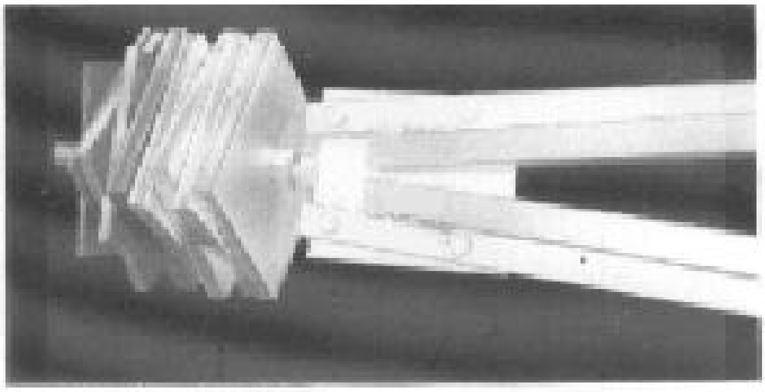


figure 16

TAIL AND COUNTERWEIGHT



COUNTERWEIGHT - TOP VIEW

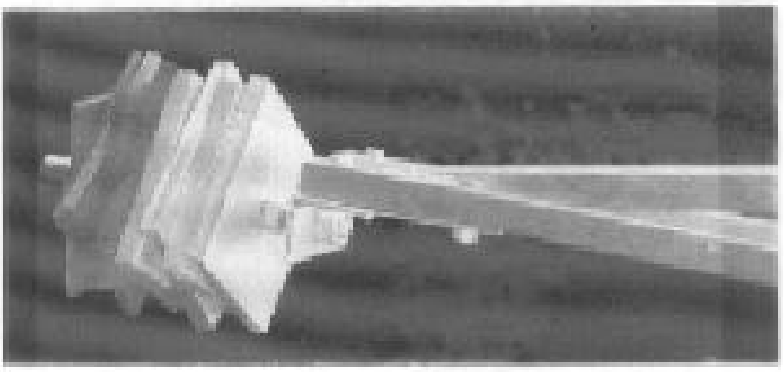


figure 17

COUNTERWEIGHT - SIDE VIEW

A TRACKING SOLAR CONCENTRATOR

DRIVE SYSTEM, TILT

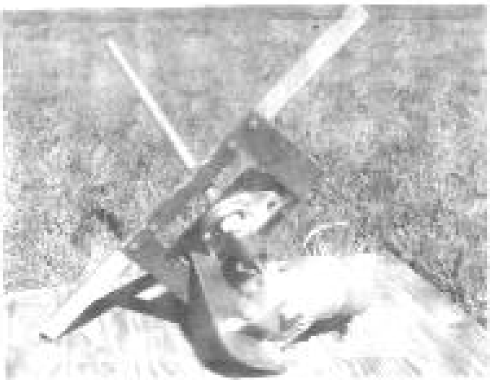
The array must be tilted + 23-1/2 degrees from its nominal angle at the spring and fall equinox. This ability has been provided with the bearings (008) and shaft (109). It remains to build a system to anchor the array to the hub and provide this adjustment.

Back in the Chapter on Siting, it was shown that the suns declination angle was a sinusoidal function of time, going through a complete cycle once per year. There is several weeks around December 21 and again around June 21 when the declination angle changes very slowly and the array can go long periods without adjustment. The angle changes at the greatest rate at the spring and fall equinox and adjustments will have to be made every few days. The adjustment could be made manually or full automatic. We compromised with a manually switched reversible motor drive. It requires you to observe the array for a moment while the sun is shining and operate the switch for a few seconds to make the adjustment. At this time, we are not offering an automatic control system for this.

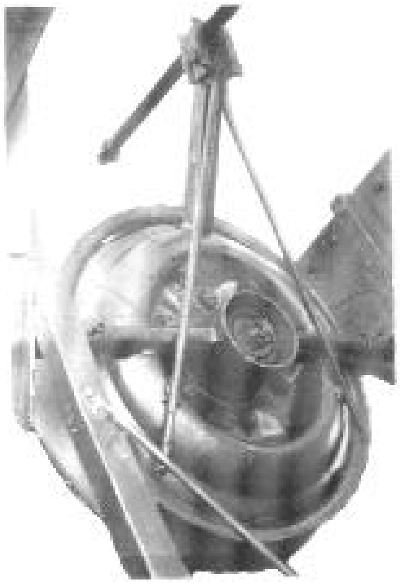
The motor drive uses the same gearmotor that was selected for the tracking drive system. This choice provides a spare that can be diverted to the higher need in case of failure, leaving the tilt system fully manual. The motor drives a long threaded rod in a screw jack arrangement as shown in the functional sketch figure 19. The motor and its pivoting support assembly is bolted to the mirror array rails (007) through holes you should have drilled previously. The threaded rod (505) is made captive with a thrust bearing at the motor end. The other end of the rod turns in a nut pivoted to the wheel (l07) on the hub assembly.

Previous Next

TILT DRIVE - SHAFT SIDE



TILT DRIVE - MOTOR SIDE (note rain shield)



PIVOT ARM (509) & DRUM (105)

figure 18

A TRACKING SOLAR CONCENTRATOR

DRIVE SYSTEM, TILT - MAJOR PARTS LIST

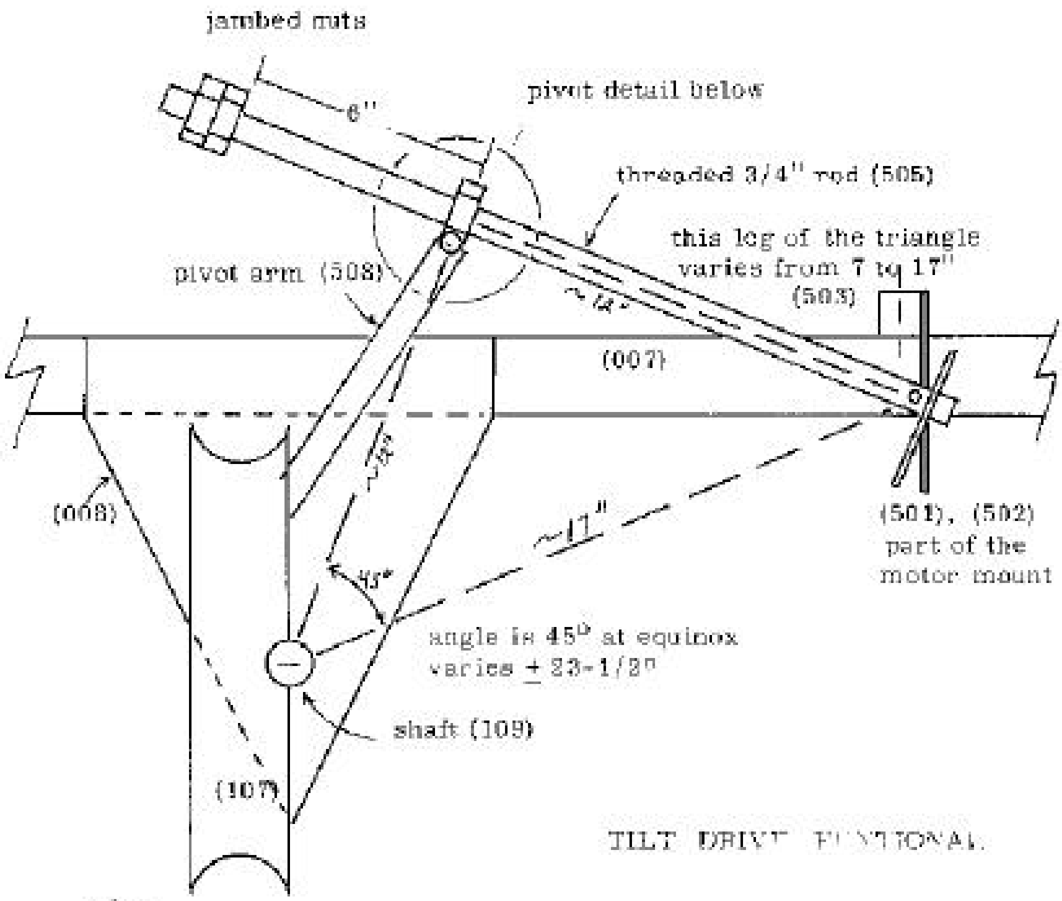
- 3/6" plate steel 5" x 10-1/2" (501)& (502)
- 24" x 1" square steel tube (503) & (502)
- Thrust bearing, 3/4" bore. The bearing in the photo is a Fafnir PBS pillow block. Suitable & economical, it has adequate thrust rating (504)
- approx. 24" x 3/4" threaded rod, 5 nuts and a lock washer. (505)
- Flexible coupling, 1/2" one end, 3/4" on the other from motor supply store (506)
- Gear-motor, Dayton 2X797, (507) same as (309)
- Pivot Arm per figure 18 and 19 from scrap (508)

DRIVE SYSTEM, TILT - ASSEMBLY

The assembly is shown in figures 18, 19, and 20 except for the pivot arm . (508) which we will comment on. In figure 19, you will notice that a triangle is formed by three pivot points. One side of the triangle, the threaded rod, is adjustable in length As a result, all three corners of the triangle must pivot to permit this change. At the equinox, two adjacent sides are about twelve inches long and form a right (90 degree) angle. You must adjust your pivot arm (508) length and attachment to the wheel (107) for this condition. The array is in the equinox position when the wheel (107) forms a right angle with the rails (007) as shown in the functional diagram. The threaded rod will travel about five inches both directions from here throughout the year.

The pipe/bolt hinge connecting (501) & (502) is aligned by threading a single piece of 3/8" rod through all pieces before welding. The 3/8" bolt pins are held in place with the bearing mounting bolts.

Previous Next


jambed nuts
6"
pivot detail below
threaded 3/4" rod (505)
this leg of the triangle
varies from 7 to 17"
(503)
pivot arm (508)
(007)
(008)
(501), (502)
part of the
motor mount
~17"
45°
angle is 45° at equinox
varies ± 23-1/2°
shaft (109)
(107)
TILT DRIVE

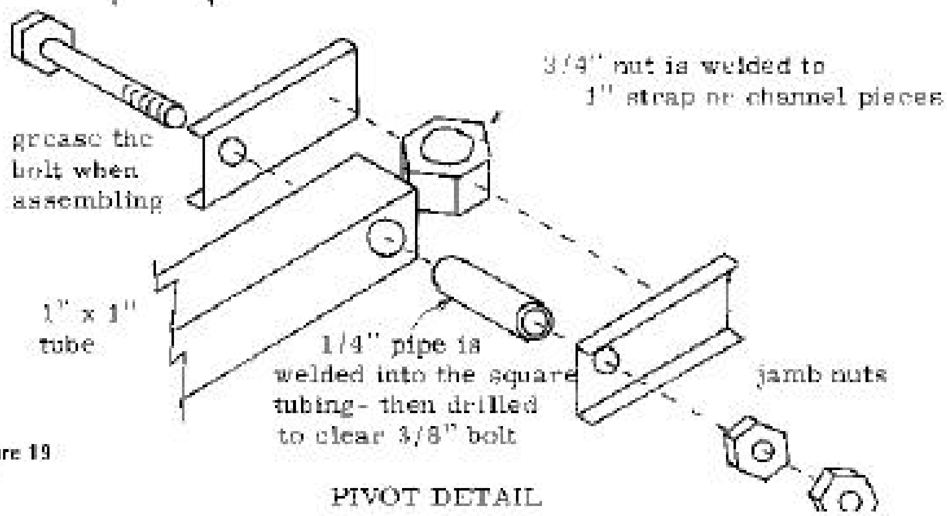
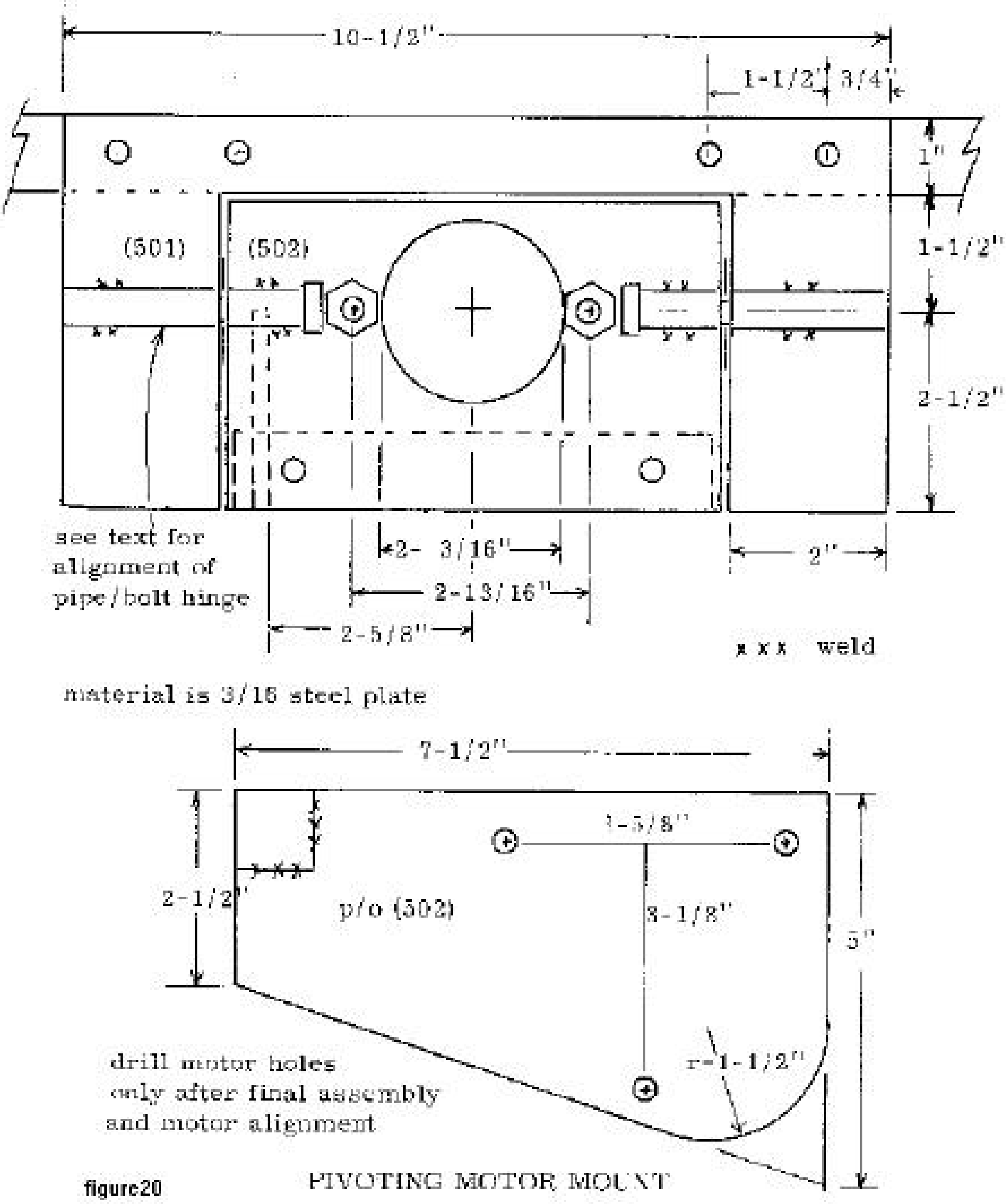

3/4" nut is welded to
1" strap or channel pieces
grease the
bolt when
assembling
1" x 1"
tube
1/4" pipe is
welded into the square
tubing- then drilled
to clear 3/8" bolt
jamb nuts
PIVOT DETAIL

figure 19



figurc20 PIVOTING MOTOR MOUNT

A TRACKING SOLAR CONCENTRATOR

-40-

MIRROR INSTALLATION

Each of the 116 12" x 12" mirrors will be cemented into a spring clip which is in turn attached to the studs protruding from the array frame. Spring clips may be made from a number materials, each with its own advantages. In selecting your material, consider cost, weight, strength, springiness and maintenance. We chose to use .040" hard aluminum. It is light, has suitable mechanical characteristics and most important, it requires no painting. Periodic cleaning and painting of these would be a miserable chore that we can do without. The mirrors are simply mirror tiles available at most "home supply" stores. They are a very popular item for interior dec- orating. We use them without treatment, simply cementing them into the spring clips with a bead of silicon sealer. At this time, we'll also mount the outriggers that were built earlier.

Failure of the mirrors brought about the final shutdown after seven years of service. The reflective (silver) backing peeled off, starting at the mirrors edge. A few that failed early were replaced with a bead of silicon sealer added all the way around the edge and this did seem to extend the life.

The mirrors weigh about 145 pounds, the aluminum clips about 28 pounds, and the outriggers another 35 pounds. Consider this, if you have elected to not mount the array on the hub yet.

MIRROR INSTALLATION - MAJOR MATERIAL LIST

- mirror tiles, 12" x 12" x 3/32" 116 each (601)
- spring clips, drilled & bent per figure 23. 116 each (602)
- silicon sealer, 2 caulk gun size tubes

MIRROR INSTALLATION- ASSEMBLY

Refer to figure 7 and mount the outriggers (003) & (009) that you previously assembled. Weld them in place.

Drill a 1/4" hole through the center of the 116 4" x 15" pieces of sheet metal (602). Stack up a number of them and drill all at once so that only the top and bottom ones will need to be de-burred. Bend according to figure 23 . If you're using the hard aluminum make a gentle radius bend to avoid cracking it. It doesn't take much to hold the mirrors so don't overdo it. Before you mount the clips, I recommend taking a few 1/4" bolts and nuts and destroying them in the course of learning.

Mount a bolt in your vise and turn a nut right on up to the shank with a torque wrench. It strips the threads real easy, doesn't it?. Try a couple more noting the torque limits. Now assemble another bolt & nut but don't ruin it. Stack up the washers and clip, holding the first nut

Previous Next

A TRACKING SOLAR CONCENTRATOR

with an open end wrench and twisting the second with your torque wrench, while aligning the clip, to the point of destruction. Note that this torque limit is much higher than the previous one. With lessons learned, lets mount the clips without ruining any of the studs on the mirror array frame.

We have no good arguments as to which way to orient the clips, so do what pleases you. Figure 22 shows how we done it on the prototype, putting them crosswise to the rail they are mounted on. Run a small bead of silicon sealer on both edges of the mirror clip and mount the mirror. Be careful to center it in the clip, measure - don't guess or you'll be sorry when it comes to aligning (focusing) them. Don't be tempted to leave out the sealer. We have made controlled tests and found that the wind will make some of the mirrors walk right out of the clips if you depend solely on friction. It doesn't seem to make much matter what the orientation of the clip is, because they all move through vertical and horizontal positions throughout the day.

Go back and touch up the clip alignment to correct any mirrors that are not square with the rest. A recheck of the torque on all of them would be a good idea. Done this way, we have never had one come loose. *1999- this is still a valid statement, 20 years later.*

Add weight to the tail to maintain balance You may have to remove the roller chain (301) bolts from the drum (105) to determine that the balance is OK.

MIRROR INSTALLATION- FOCUSING

This is the fun part, because now you will begin to appreciate the energy that you have at your command. We'll do this now, rather than after the collector is mounted as the dummy target Is expendable while the collector should be protected with fluid running through it. Mount up the dummy target, a scrap of sheet metal, 20 inches square on the collector frame (011). Paint it flat black with a heat resistant paint such as Derusto #760 barbecue black. This will reduce the reflections to help you avoid eyeball burnout.

The dummy target like the real one will cast a shadow directly into the center of the array. Locate this center, and make permanent marks on the rails (007) where the shadow must fall, figure 26. These marks can be seen in the cover photo and are used for the periodic adjustment of the tilt drive in normal operation, so make them visible.

Previous Next

A TRACKING SOLAR CONCENTRATOR

Provide a temporary system for controlling at least the tracking drive motor from a convenient position where the target shadow can be observed. The tilt drive can be manually adjusted if desired as it will not change during the days focusing operation, unless you have an error in the angle or orientation of the hub!! Figure 25 is the hook-up for the recommended motor. Adjust the drive systems so that the target shadow falls on your marks in the center of the array. Check out the tracking drive motors and mechanical systems and we're ready to focus.

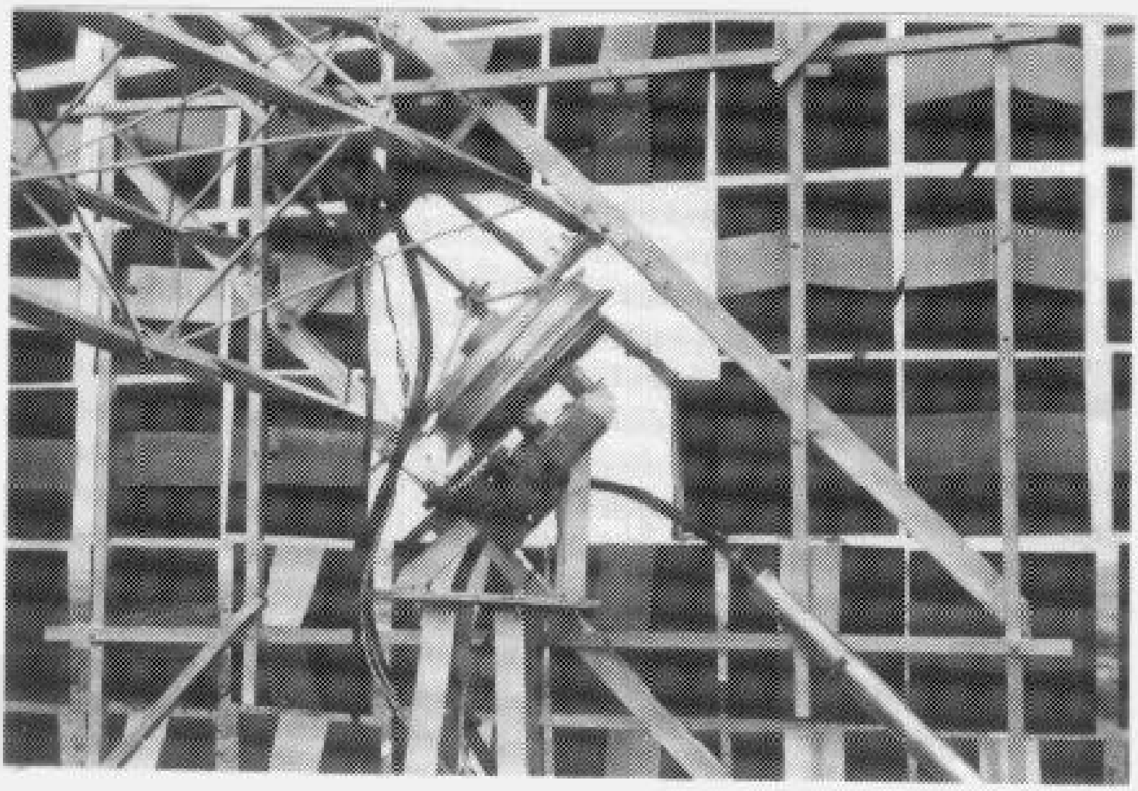
Make up a bending tool similar to figure 24. This is used to bend the studs on the array for each mirror, making its reflected sunlight fall on the target center. You must have someone controlling the drive motor and adjusting its position every few minutes as you do this. Stay behind the array, peering at the target edges through the gaps between the mirrors. Try welding goggles if they help. Because of the intense light in the target center, you cannot see when a mirror is aligned, but you can see when the square of light is off center on the cooler edges of the target. When you think one is on target, put pressure on it to move it up, down, left & right and observe its light on the target edges. Using this system, you should be able to focus a third to half of the mirrors before the reflections become too intense. Drape the aligned mirrors with sheets or other light weight material and continue with the rest.

Steer the array away from the sun towards its limits to a position that you can bore sight it from in front of the array, if possible. The dummy target will be reflected with its edges visible in the center mirrors and gradually filling the entire array as you move away. Mis-focused mirrors will be very obvious discontinuities. Looking into a flashlight reflector gives you a similar effect. The cold lamp filament seems to fill the reflector as you move away, Both are parabolic reflectors This check is not essential if it is difficult or impossible to do.

Your dummy target got mighty hot! If you had used aluminum with an inch of fiberglass insulation behind it, it would have probably would have been destroyed. Without cooling, the targets temperature will approach 1200 F before its re-radiation losses will balance the incident energy. Obviously, now the kid will come out in you, and you'll have to play with the fire by testing a few items at the focal point. You'll find it easy to burn but not ignite materials. This is because the high temperature expands the air in the immediate vicinity so greatly, that their is insufficient oxygen for combustion.

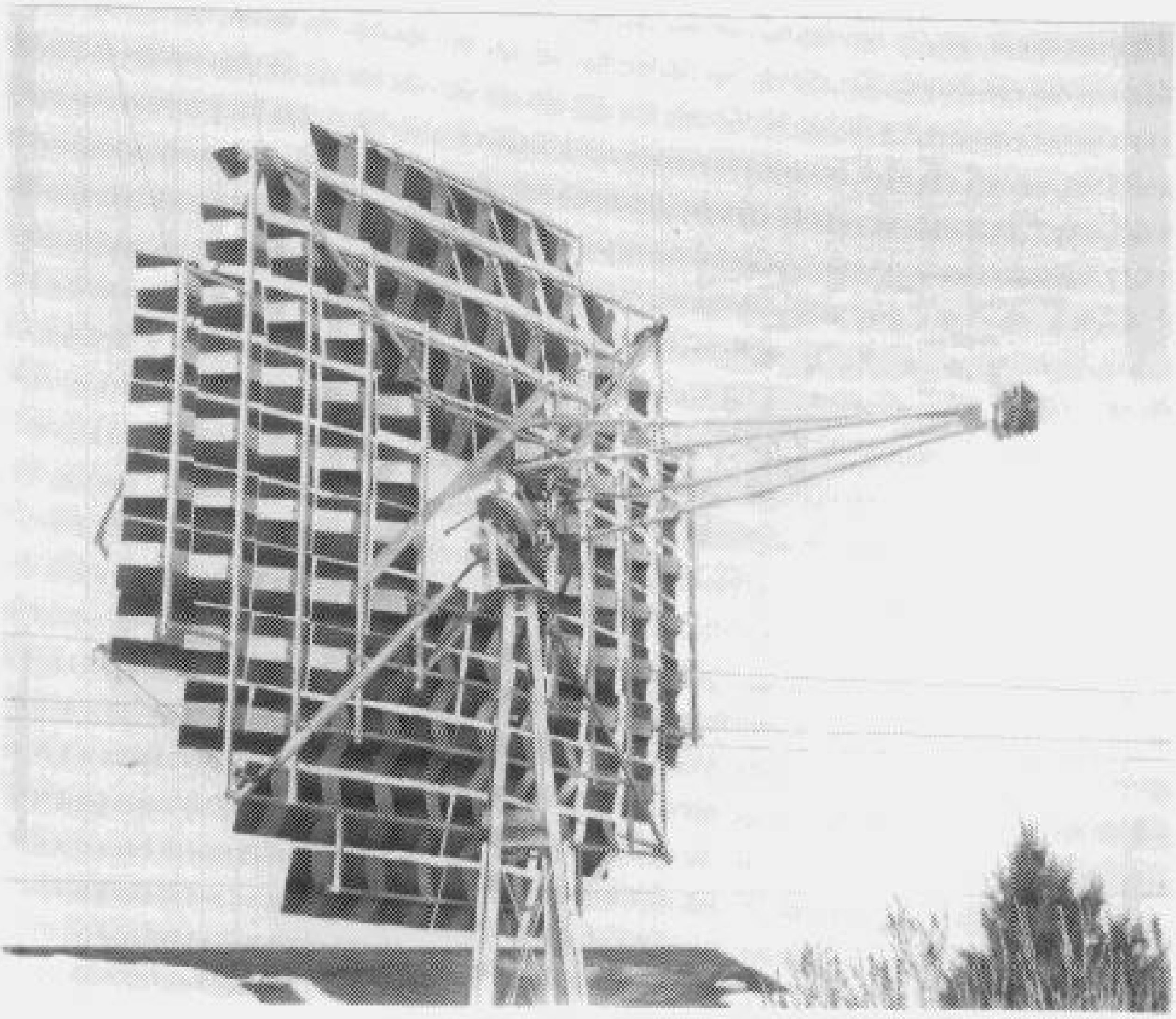
Playtime is done, lets build a collector.

Previous Next

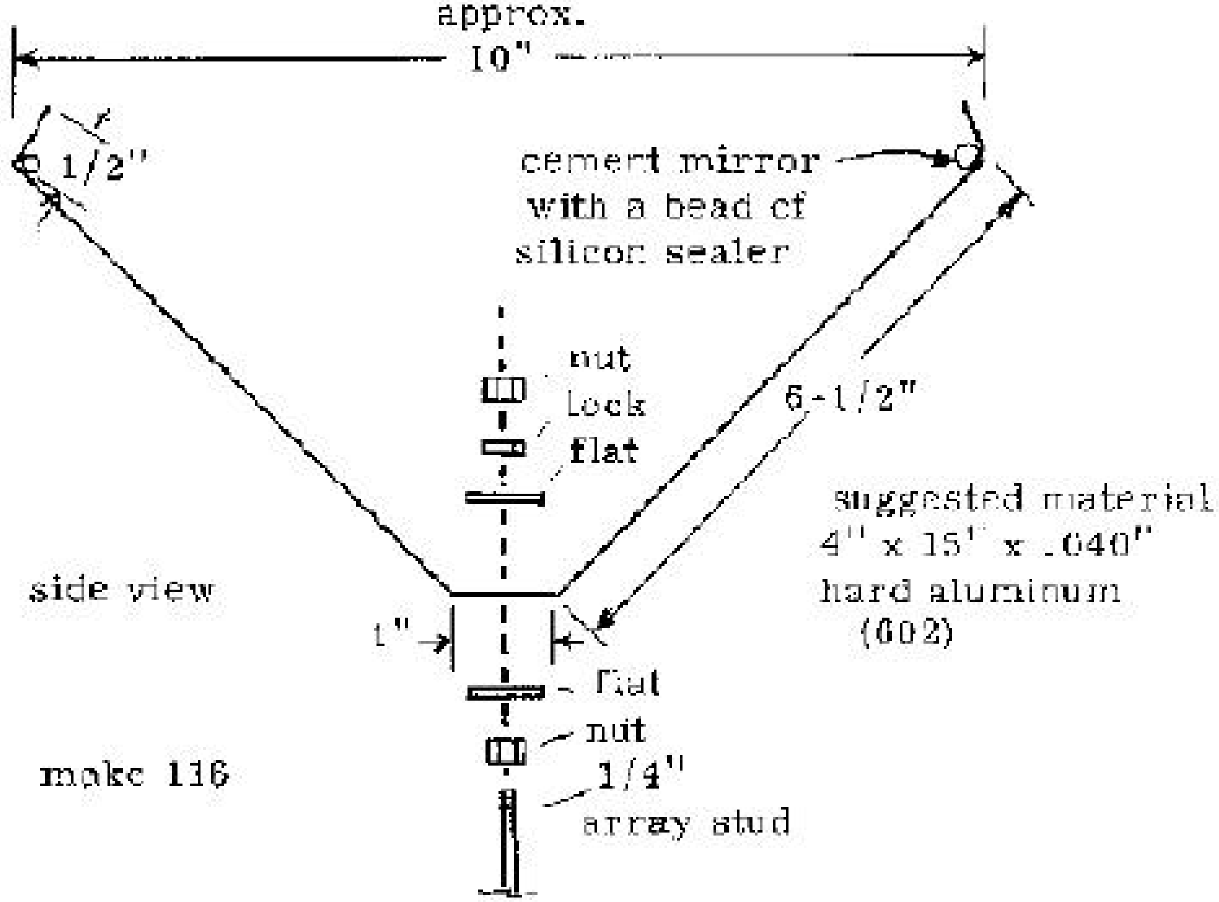


REAR VIEW - COMPLETE & IN SERVICE
array is facing East

figure 21

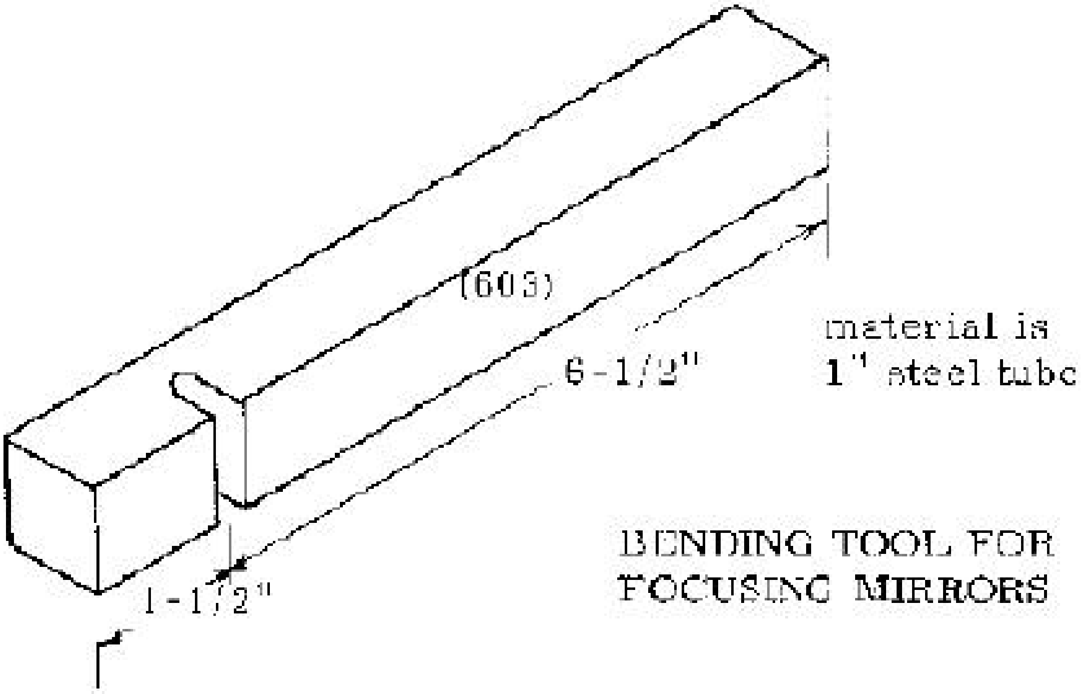


REAR VIEW - OVERALL- COMPLETED
array is facing West at sunset, January
figure 22



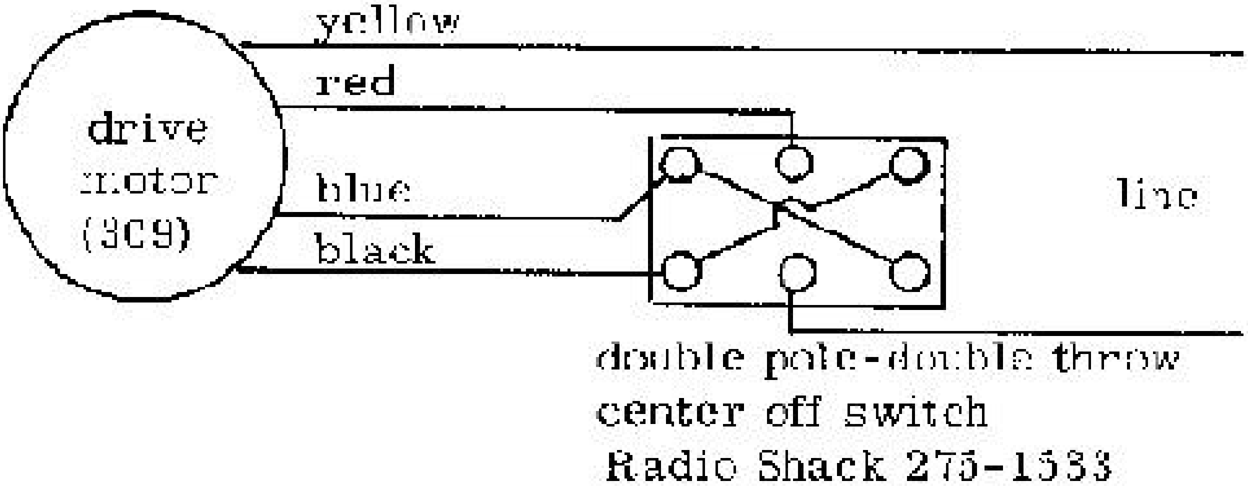
MIRROR CLIP

figure 23



BENDING TOOL FOR
FOCUSING MIRRORS

figure 24



TEMPORARY HOOKUP
TRACKING DRIVE SYSTEM

figure 25

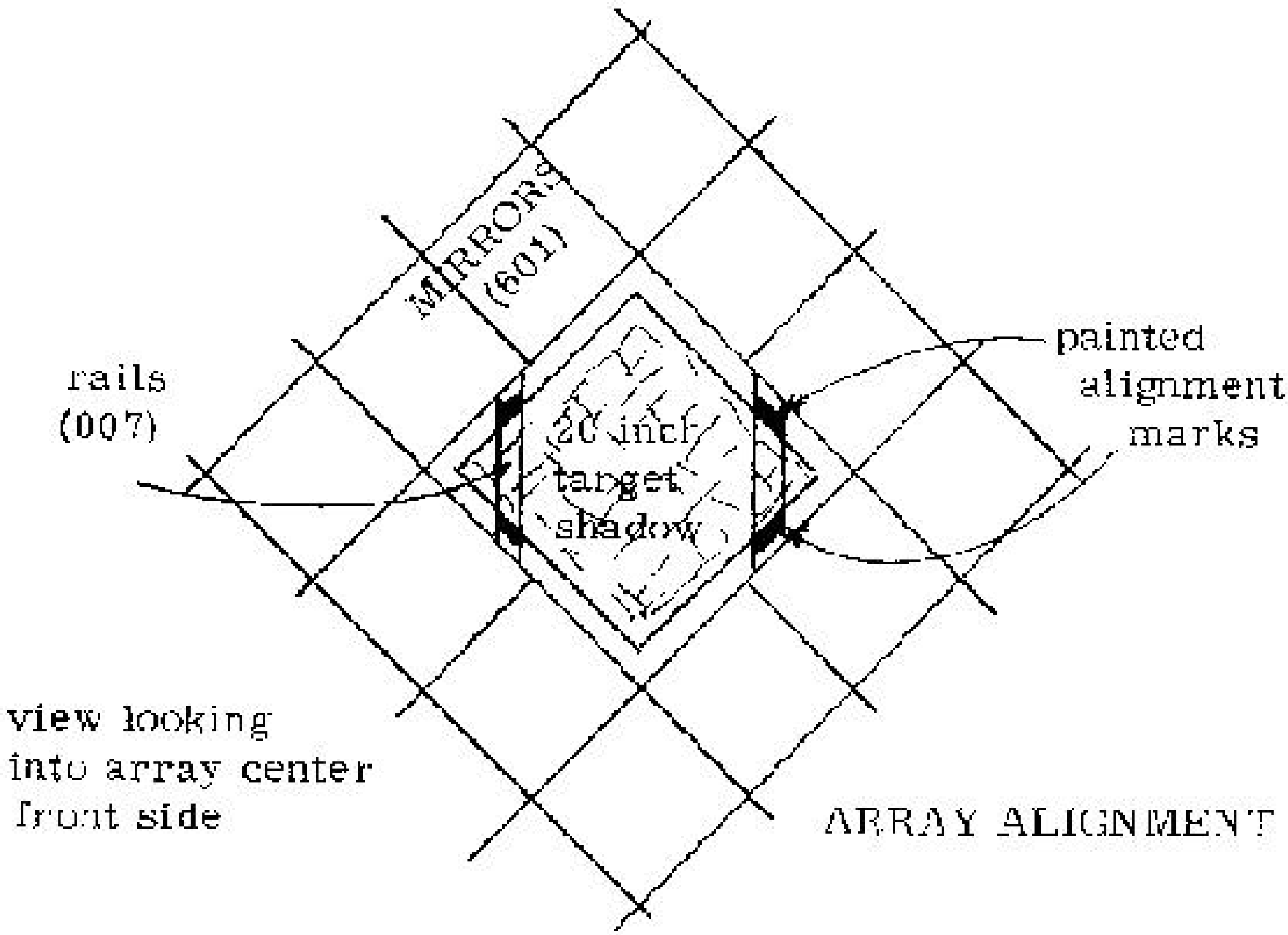

MIRRORS
(601)
rails
(007)
20 inch
target
shadow
painted
alignment
marks
view looking
into array center
front side
ARRAY ALIGNMENT

figure 26

A TRACKING SOLAR CONCENTRATOR

THE COLLECTOR

collector must be a rugged device, capable of surviving a loss of fluid, in which case it will heat to about 1200 F before its losses equal the solar energy input. It must be designed to handle the fluid flow rate and pressure to satisfy your application. The first idea that comes to mind, is to use copper tubing, perhaps attached to a flat metal plate similar to the construction of most flat plate collectors. This indeed has been tried and found unsatisfactory. The tubing cannot be soft soldered because of the high temperatures and hard soldering creates monstrous warpage problems. Mechanical attachment such as clamping fails when the copper loses its temper, and oxides form when it overheats, resulting in poor thermal connection. The plate cannot be eliminated, unless you can figure out a way to cover the entire target area with tubing and still manage to have low flow resistance. Tests were made with collectors using aluminum which simply melted and ran like molasses when overheated.

The satisfactory design that was adopted for the prototype is very easy for you to duplicate. Two plates of 14 gauge steel are sandwiched to- gether and the fluid is ran through the space between them. The heat has only a few thousandths of an inch to travel to reach the fluid. The resistance to fluid flow is very low and the design has survived many deliberate dry runs for hours at a time. It is necessarily heavier than some others we tested, weighing in at 23 pounds, but this is acceptable. The collector is built somewhat like a steam boiler with stay bolts to strengthen it, figure 28.

- Caution: It is not a steam boiler and we have made no attempt to test or prove its capabilities under high pressure steam.

The collector is intended to work in a low pressure loop, not to exceed twenty psi. If you need higher pressure, then you should seek out persons skilled in boiler design for advice.

Previous Next

A TRACKING SOLAR CONCENTRATOR

THE COLLECTOR- MAJOR MATERIAL LIST

- 2 pieces 18" x 18" x 14 gauge steel(701)
- 6-1/2 feet of 1/2" square steel tube (702)
- 2- 1/2" pipe to 1/2" flare tube-brass union (703)
- 5- 1" x 5/16" bolts and 15 nuts (704)
- light gauge sheet metal box- 20" x 20" x 5" with one inch of insulation liner (705)

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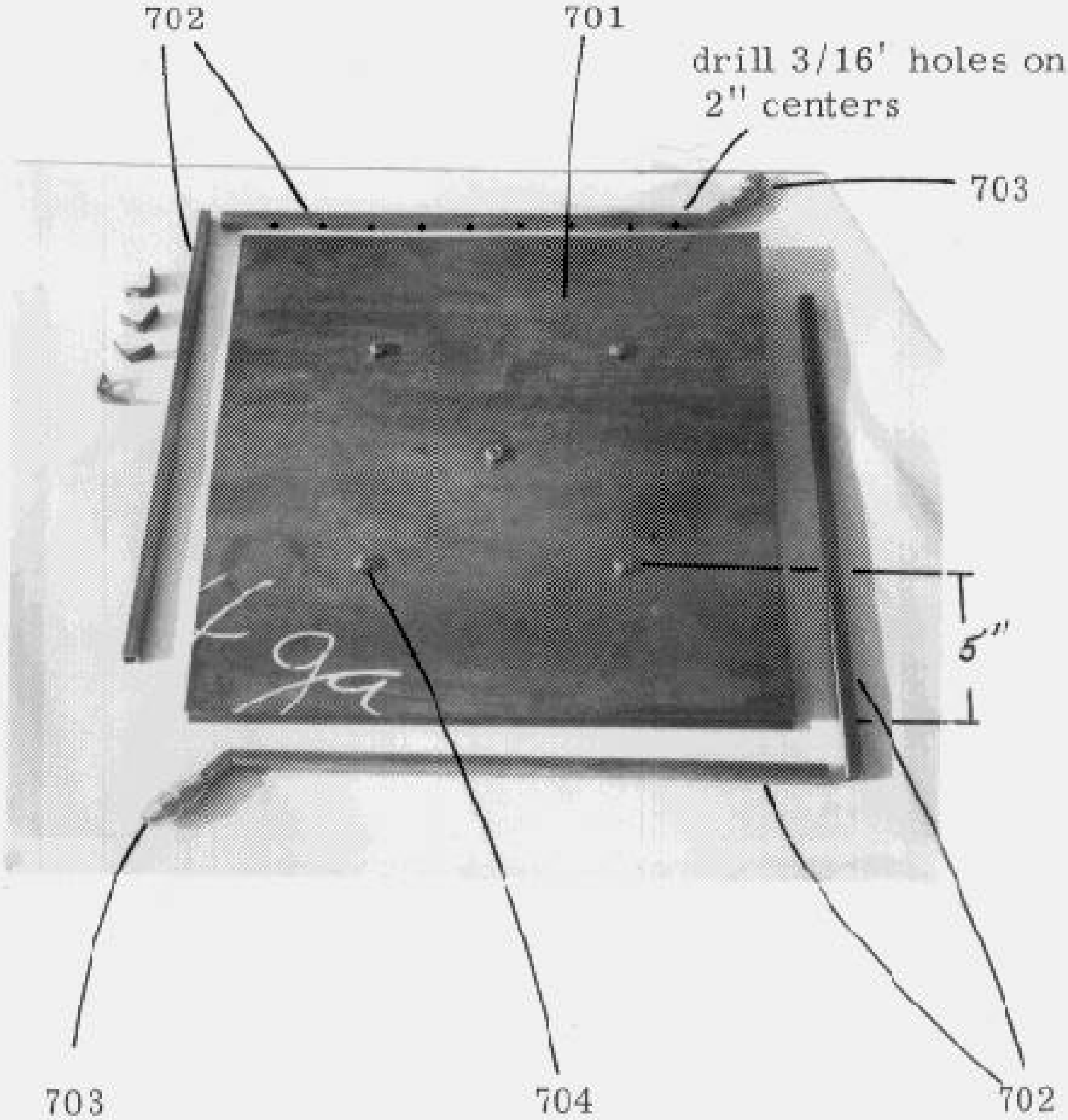
figure27

Previous Next



COLLECTOR ASSEMBLY- PRIOR TO WELDING

figure 27

A TRACKING SOLAR CONCENTRATOR

-48-

COLLECTOR CONSTRUCTION P>The construction is clearly shown in the photos, figure 27 and figure 28.

Two of the 1/2" square steel tube frame pieces serve as manifolds to distribute the fluid across the face of the sandwich. The other two are simply gap fillers so you have something to weld to. Notch and bend the manifold pieces according to figure 27. Drill the holes as shown. If you choose to weld the notched bends at this time, then grind the weld flat, so as to maintain the 1/2" spacing. Deform the square ends of the manifold pieces a bit and file a bit on the round brass fitting so that they loosely mate, and braze them together as shown.

Drill the two plates (701) together for the 5/16" stay bolts and bolt them together, using two nuts between them for spacers. The two nuts should provide very close to the desired 1/2" space. Don't weld the stay bolts until the edges are done-it will warp the plates. Clamp the 1/2" square frame/manifold pieces (702) between the plates and tack weld them at the center of each side only.

Weld in two or three inch passes, both plates to the frame/manifold pieces, starting at the center of one side. Do the same on the opposite side, then the other two sides. Continue working out, two or three inches at a time toward the corners, keeping the clamps just ahead of your weld. This will result in a warp free job.

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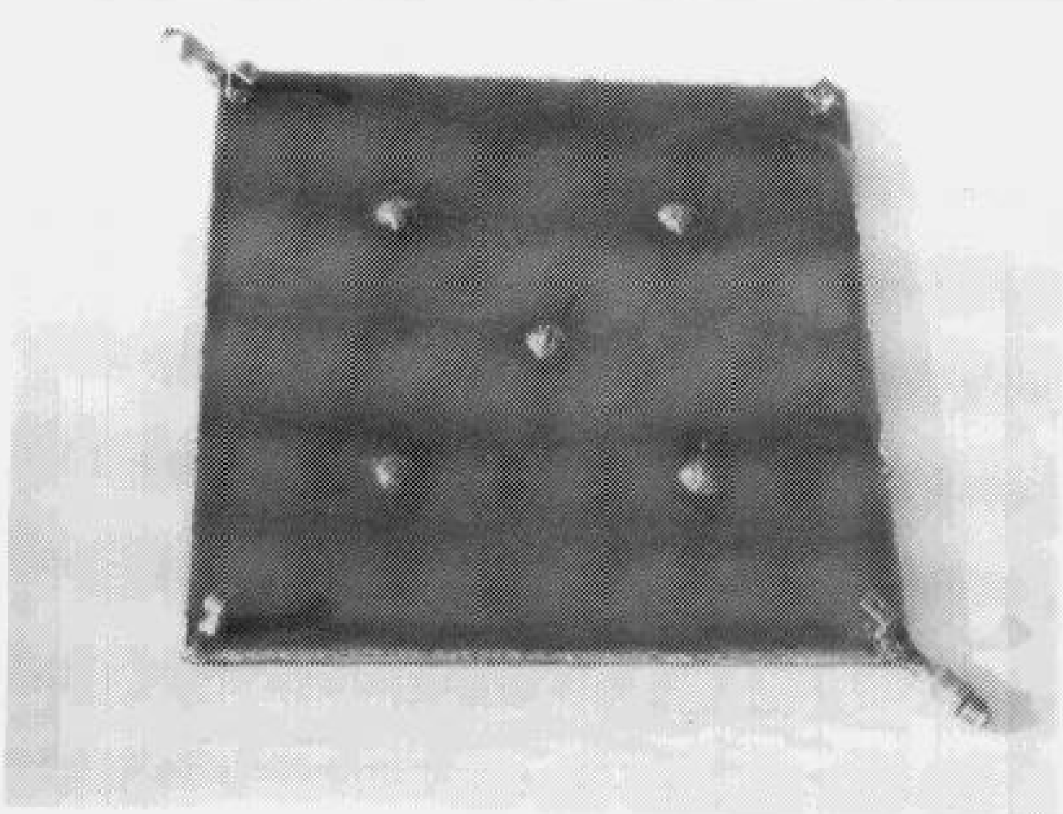
figure28

Previous Next



COLLECTOR - WELDING DONE figure 28

A TRACKING SOLAR CONCENTRATOR

With the edge welding complete, the stay bolts & nuts can be welded for a water tight seal. This will warp the faces somewhat, but they can't go very far. Pressure test it with about 30 pounds of air, about all you want to pump on a simple hand tire pump, under water for leaks.

- *WARNING! Don't use a compressor- You're likely to have a very deadly or maiming rupture*

Weld on four mounting ears, made from scrap strap or angle stock as shown in the figure 28. Make sure they line up with the holes in the collector frame (011) figure 10.

Clean and paint your collector with the high temperature silicone base paint that we used on the test collector earlier. This paint reduces reflection and increases the energy absorption while protecting the collector from rust. It should survive until you accidently run the collector dry. When this happens, you'll have to wire brush the white residue off and repaint it. We have not found a readily available dull black coating that will survive the high temperatures of a dry run. Even acetylene smoke sluffed off.

Fabricate a 20" x 20" box 5" deep (705), of light gauge sheet metal, clearly visible in the cover photo, to mount the collector in. Its sole purpose is to protect the one inch layer of fiberglass insulation from wind and storm. Aluminum will survive because it is not broadside to the concentrated sunlight as the collector is. Line the box with one inch duct insulation- if you can't find it, use scraps of fiberglass backed/vinyl skinned ceiling tile. Mount the collector, box and insulation with 1/4" threaded rods or spacers so that the insulation is not compressed.

An area you may find interesting to explore is the addition of glazing over the collector. We made some tests and gained about 15% recovery, up to about 23,000 total Btu/hr. The glass, spaced one inch from the collector and being of no special quality shattered as we went for higher fluid temperatures. It may be very difficult to find material that will survive a dry run. Such materials certainly do not meet the criteria for this "common material" project, and further research was abandoned.

Previous Next

A TRACKING SOLAR CONCENTRATOR

-50-

PIPING & CONTROLS

The piping to get the fluid into and out of the collector is routed along the top and bottom collector support rails (010). With insulation it is two inches wide and with the other one inch rails, only obstructs about 2% of the incident or unreflected energy. As you consider options to this rather circuitous routing, forget about the idea of running from the open center of the array to the collector. Such systems obstruct a significant portion of the energy reflected from every mirror, resulting in losses of 20 to 25%. Even if such piping is left uninsulated, most of the energy hitting the pipe would be reflected from it due to the low angle of incidence.

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figure29

The top and bottom rails were chosen over the side rails as the top is always the high, in the morning or evening, and so it is the logical place to put the pressure release and recovery system figure 31.

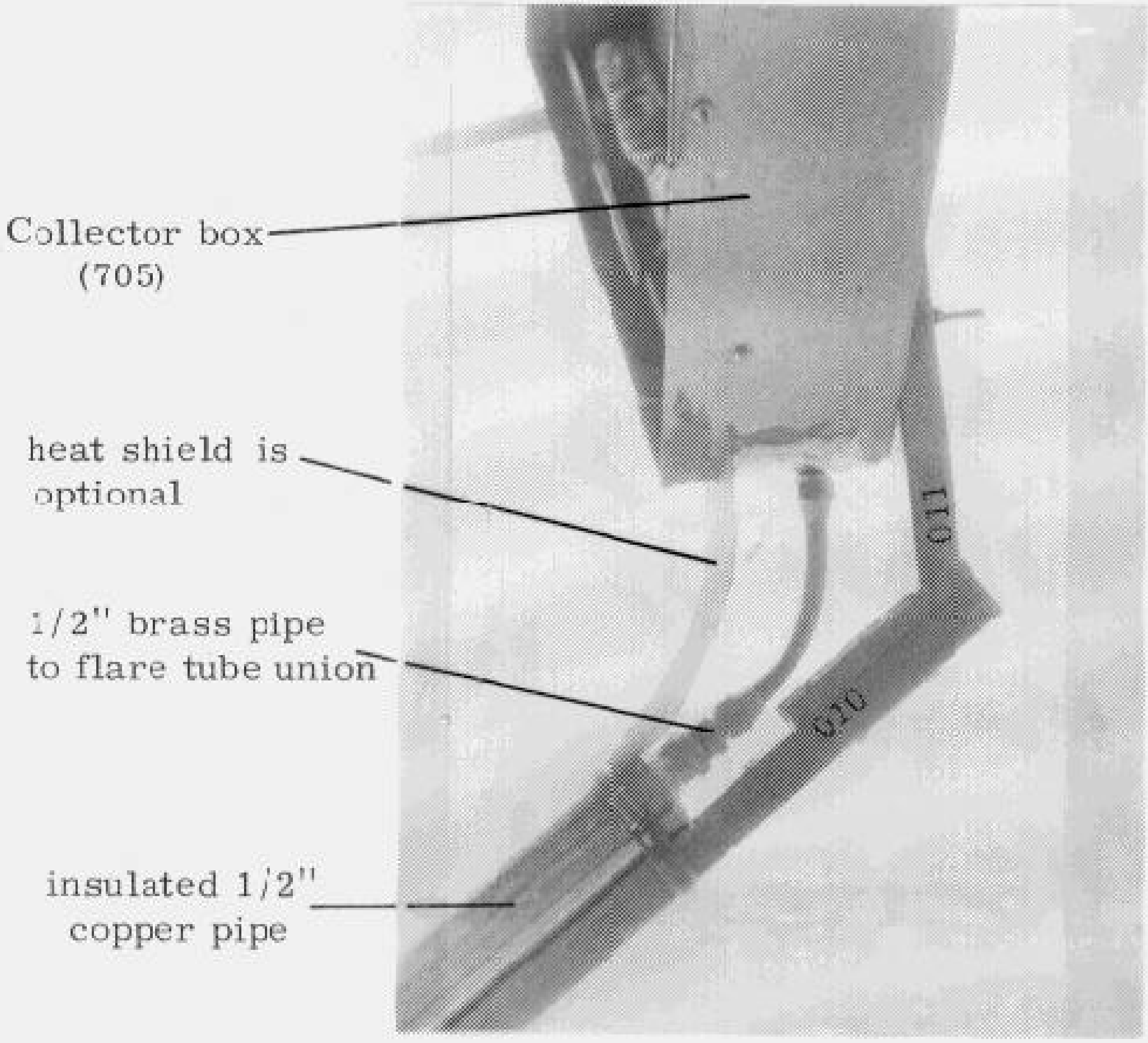
The longer outdoor runs, on the collector system as well as the lines to your use/storage system are assembled from 1/2" rigid copper pipe wrapped with fiberglass and slid into a light gauge 2" downspout pipe to keep it dry. A doughnut cut from any convenient sheet material is cemented in the ends with silicon sealant to keep the pipe centered. figure 30.shows one end of one of these lines where it connects with the collector. Make sure that water that might seep into the fiberglass has a drain at the low end.

Flexible lines passing through the hub array are 5/8" automobile heater hoses. If you're using water/antifreeze mix, the pressure and temperature conditions are very much like the situation is in an automobile cooling system. The hose is wrapped with fiberglass tape that will get wet when it rains, but sure dries out fast when the sun comes out and the system starts working. An alternative would be to use the foam insulation used on air conditioning pipes, but it is rather expensive.

Your system must include provision for expansion if a closed loop is used as is done on the prototype. We circulate a 50/50 mix of automobile antifreeze and water. Because the operating conditions are so similar to conditions in the auto and there is simply not sense (cont pg 52)

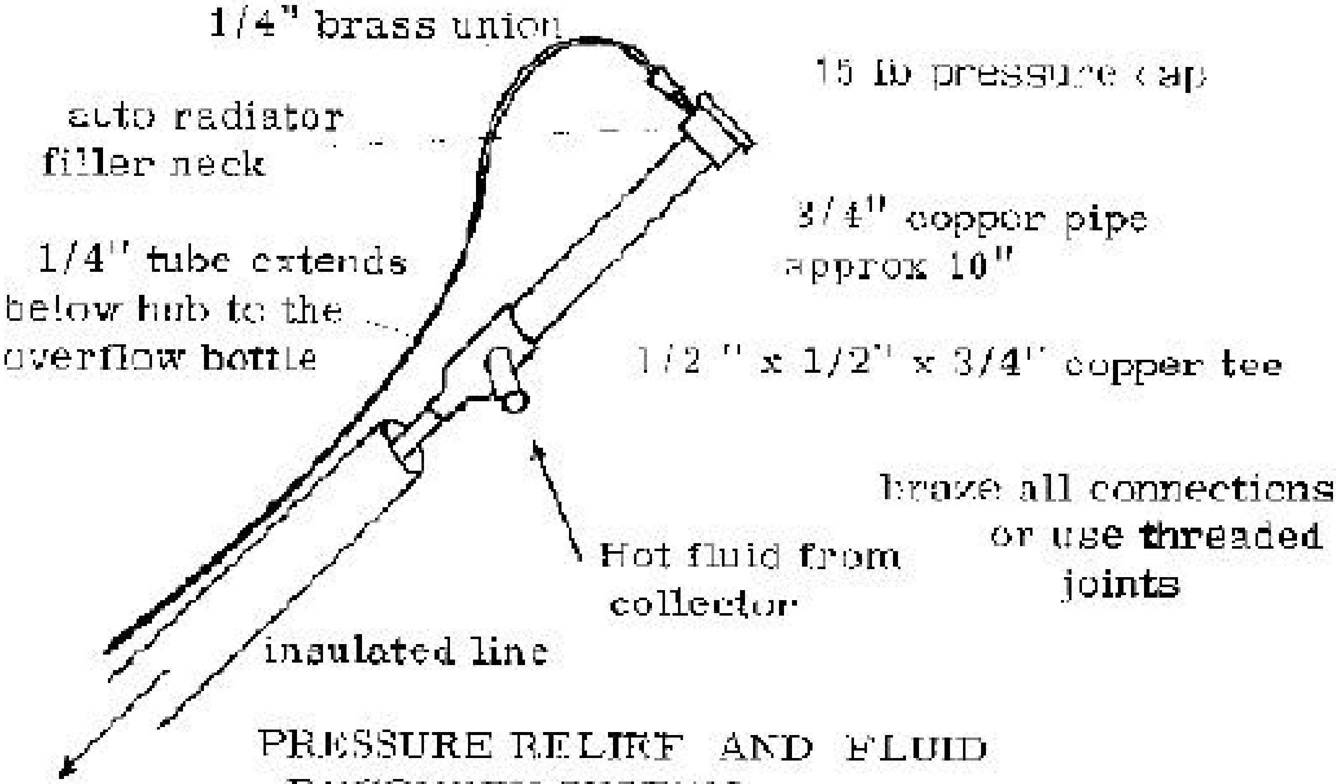
Previous Next

figure 29



COLLECTOR TO INSULATED PIPE CONNECTION

figure 30



PRESSURE RELIEF AND FLUID
RECOVERY SYSTEM

figure 31

A TRACKING SOLAR CONCENTRATOR

in re-inventing the wheel, we followed Detroits lead. A fluid recovery system, complete with a 15 pound:pressure cap does a fine job. If you have a boil-over, you save the anti-freeze and it simply siphons back into the system when it cools off. Install an automotive radiator filler cap in the piping at the top of the array as shown in figure 31. Bring the overflow tube, down to the support structure, just below the hub and install a one or two gallon container with the tube reaching into the bottom of it.

Don't soft solder any connections between the collector and the relief system. Some day, in your experiments or when the power fails to the pump, super-heated steam will blow the soft solder out of every joint. Believe this!! If you can't find a new filler neck at the corner radiator shop, use a salvaged one, but be sure to scrape away the soft solder down to clean brass before you braze or the joint will fail.

The automotive pressure cap makes it easy to fill the system if it's a closed loop. You can simply pour in from the top while the pump circulates bringing air to the high point or as we do, the fluid is pumped in at a low level with sufficient pressure to lift the 15 pound cap and expel the air. As the system heats, air will be released from the fluid at the high point and normal expansion will force it out. The alternate heat and cool cycles will eventually purge the air almost completely if you make sure the expansion tank always has some fluid available to be sucked back in.

We cannot comment much on the rest of your piping as it depends on what you have elected to do with your system. Our solar concentrator is like an electric motor with hundreds of potential uses.

Unless you live in a frost free area, for most applications you will want to circulate a water/antifreeze solution. Other materials to con- sider, if you want higher temperatures are various oils and some of the silicon compounds.

- Caution: If you are using a toxic material as your heat transfer fluid, then you must use a double heat exchanger system in contact with potable water. Some local laws require this as does good common sense

Figure 32 shows how a heat storage tank open to atmospheric pressure can serve as a double heat exchanger. A leak of toxic fluid from the pressurized collector system is diluted in the tank and could not enter the city/well water unless its exchanger leaked AND it was below atmospheric pressure at the same time.

Previous Next

A TRACKING SOLAR CONCENTRATOR

Several pumps are available varying greatly in cost, performance and noise. We have selected a very satisfactory one for the prototype, a Grundfos model UPS20-42 available from heating and plumbing suppliers around the country.

An optional, but recommended safety device that you should consider at this time is a high temperature limit control that will direct the electronic tracking system to get off the sun to prevent a boil-over. We used a Ranco C30-C1250 remote bulb temperature controller with an adjustable range of 120 to 250 F. It has a six foot lead and bulb that can be strapped to the piping at the top of the array while the control is mounted near the hub where you have easy access to it. An alternative is a Honeywell L6008C1206-30 to 270F. Others, who have built copies of our system have elected to install a snap action limit switch, 300F right behind the collector so it can sense an over- heat with no fluid in the system, to transmit heat to the previous device.

Other controls might sense the temperature in a storage tank and direct the array to get off the sun when the desired limit is reached. Any one or all of these controls can be wired into the electronic track- ing system providing they open a circuit when the limit is reached.

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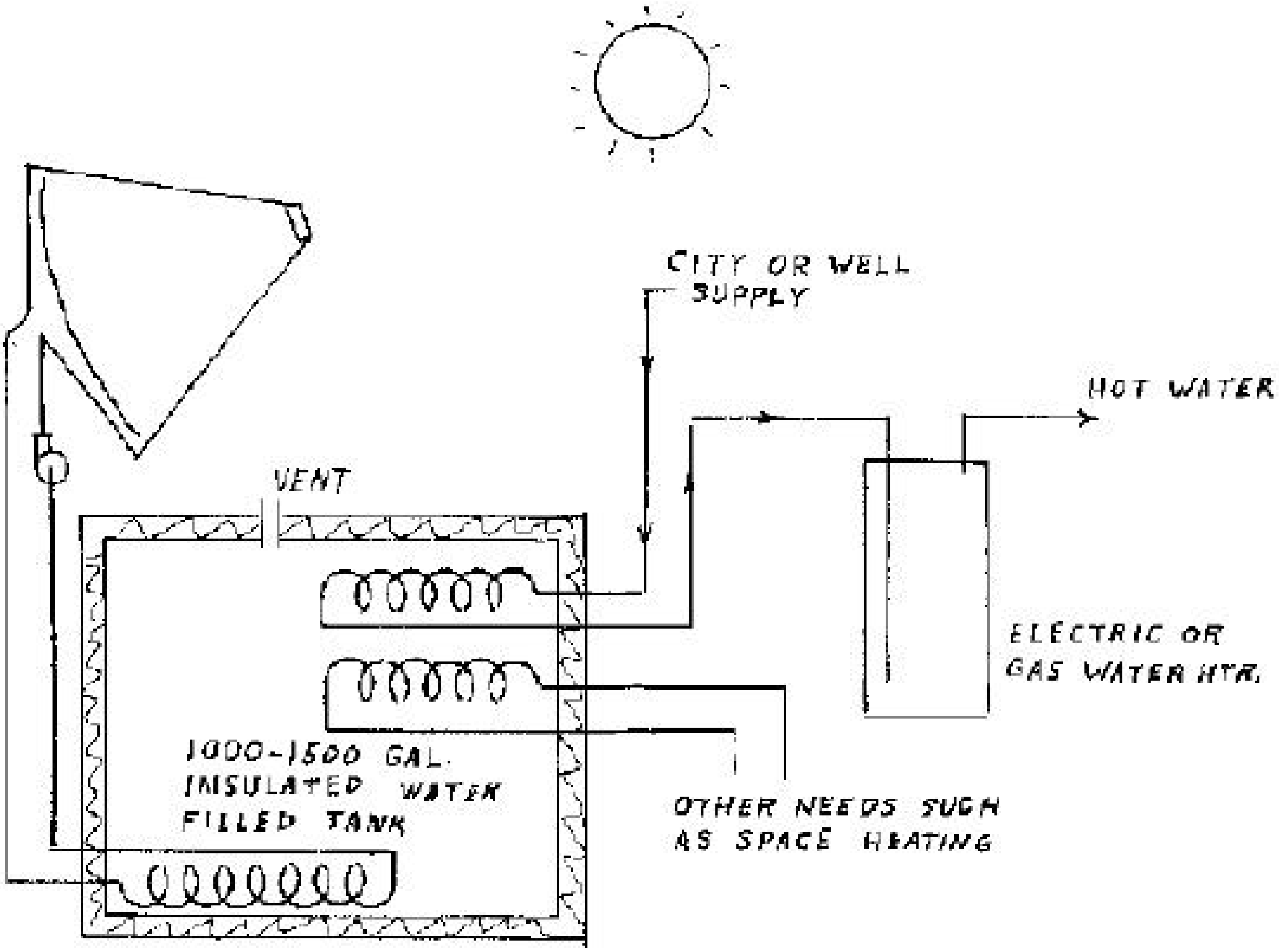
figure52



DOUBLE WALL HEAT EXCHANGER & TANK

figure 32

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC TRACKING SYSTEM

Teton Engineerings electronic solar tracker is a sophisticated device that does far more than just track the sun. You might call it a Function Manager or some other space age name like that. What it does:

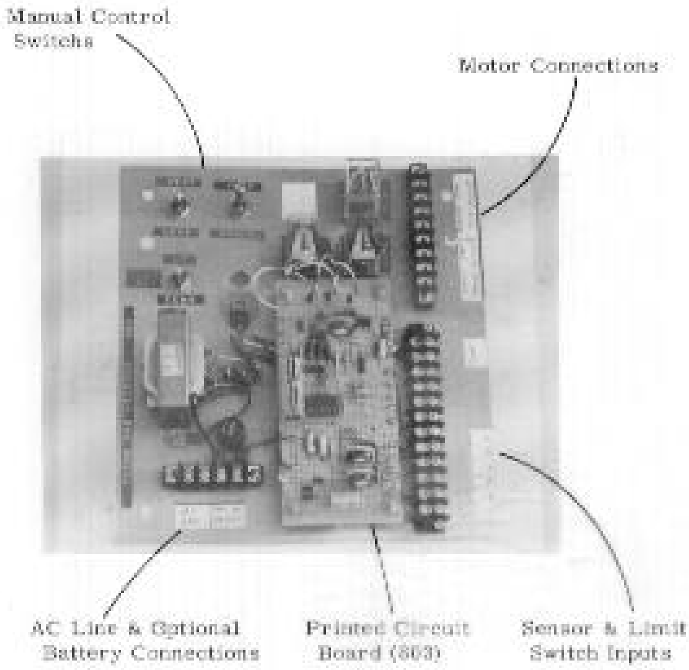
1. It must determine when the sunlight is adequate to produce usable energy and then turn on the fluid pump and permit the tracking circuits to work
2. It must track the sun while ignoring transient shadows & lights from fast moving sources such as clouds, shrubbery, birds, autos etc. It must also ignore oscillations of the array caused by wind.
3. It must recognize the end of day and return the array to its home position in anticipation of the next sunrise.
4. It must.protect the system upon command by removing the array from focus and returning to its home position. The commands may come from any number of devices such as temperature limit controls.
5. It must be adaptable to the users choice of drive motors.
6. It should be capable of operating from, and charging a battery if the user chooses this option.

In spite of the degree of sophistication, we have chosen to not use state-of-the-art microprocessor techniques but like the rest of the system, the design uses readily available materials. You may elect to upgrade it by substitution of some industrial grade components particularly the motor control relays and switches, although the specified components should result in adequate reliability.

As shown in figure 33 all the electronics, relays and manual switches are neatly assembled on an aluminum plate that will be mounted in an appropriate container. The small stuff is laid out on a 3" x 6" circuit board that you can make, or buy or replace with "perf" board.

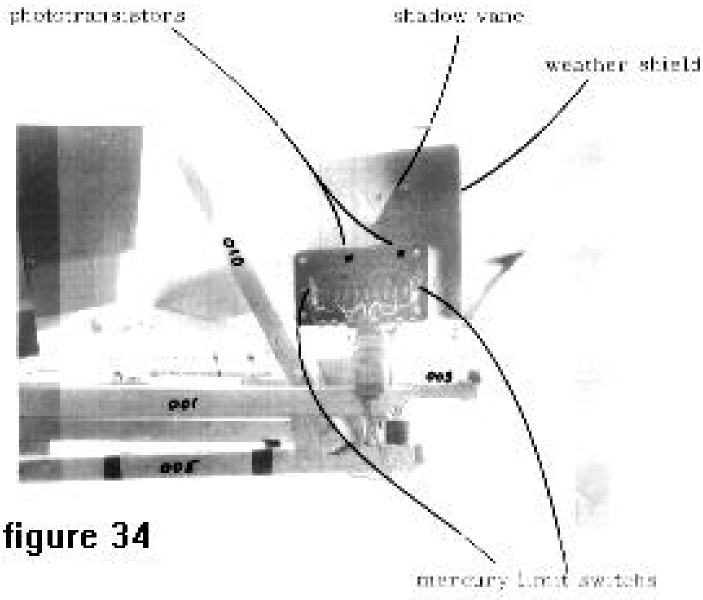
Remotely located is a small module that rides a corner of the mirror array, figure 34. It contains two phototransistors to sense the sun and two mercury switches to sense the physical position of the array. The mercury limit switches were chosen over other types because they are impervious to weather and contact corrosion. An optional thermostat may be mounted near the collector output to protect the system from overheating.

Previous Next



CONTROL PANEL (802)

figure 32



phototransistors
shadow vane
weather shield
mercury limit switchs

figure 34

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC TRACKING SYSTEM
THEORY OF OPERATION

The following section is not essential for construction and alignment of the tracker. It is provided in case the builder has difficulty and needs further information. See figure 38.

What? You can't read the poor resolution? Click here for a bigger picture

Solar sensing is done with two phototransistors forming voltage dividers with adjustable collector load resistors figured 35 The base connections are not used. The circuit is linear only over a limited range, putting out nearly zero voltage in bright sunlight and a nominal 12 volts in subdued light or darkness. The collector resistors will be adjusted for linear operation at a sunlight level that is marginal for heating.

One phototransistor PCI will be referred to as the REFerance input and is in unobstructed view of the sun. The second one PC2 will be referred to as the VARiable input and will have a shadow cast upon it when the array falls behind the sun.

Position sensing is done with hermetically sealed mercury switches. They are mounted so that the West switch opens just prior to sunset and the East switch opens when the array has returned to its HOME position.

The low-level signals from the sensors will be processed with the popular LM3900 Norton op' amps, eventually driving three relays. One will control the PUMP, another will drive the TRACKing motor and a third will reverse the tracking motor to drive the array HOME.

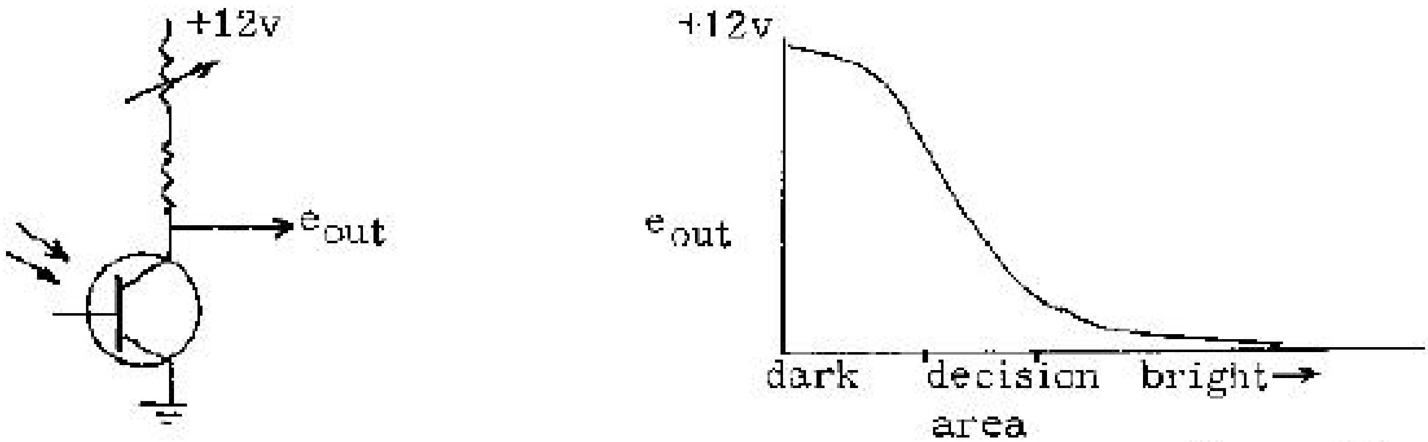
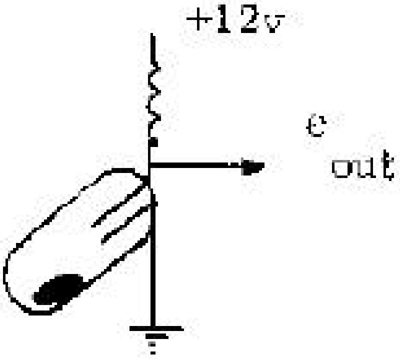


figure 35



12 volt - limit of travel

0 volt = not at limit

figure 36

A TRACKING SOLAR CONCENTRATOR

The Norton current differancing amplifiers operate similiar to voltage op' amps except that you must think in terms of current input rather than voltages. The output, figure 37, simply goes high, toward +12v when the current into the + terminal exceeds the current into the - terminal. It goes low when the - input current exceeds the + input current. Both inputs look like a forward biased diode to ground. Simply use ohms law for each input resistor to determine the total current into each of the two inputs. Unless the source voltages are very low, the diode drop can be ignored.

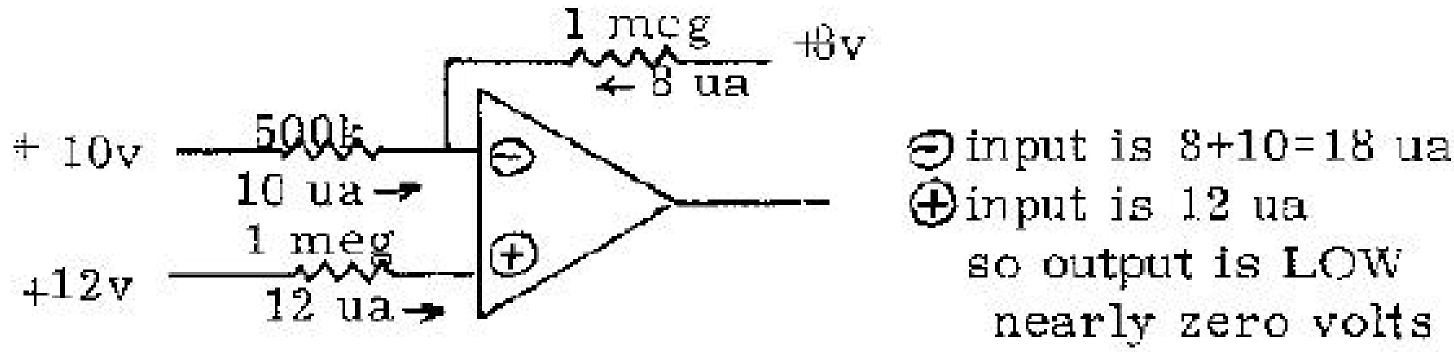
figure37

Amplifier U1a, a schmitt trigger configuration, is biased low with 24 ua via R8 when the array is traveling between its limits. At the WEST limit (end of day) the switch LS-2 opens permitting 50 ua into the + input via R2 and R5. When U1a-5 goes high, the + current input is reinforced with another 50 ua via R7. The high output of U1a-5 turns on Q1 activating the relay RLY1. The track motor now drives the array toward HOME. The WEST limit switch LS-2 closes as soon as the array starts moving, but the feedback resistor R7 maintains U1a-5 high. When the array reaches HOME the EAST limit switch LS-I opens permitting 240 ua via R3 and R6 to be added to the original 24 ua bias via R8 into the - input. U1a-5 goes low turning off Q1, releasing the relay RLY1 and stopping the motor. This status will continue until the array is driven away from its EAST limit by the TRACK circuit.

Other safety or control switches, such as a temperature limiter can be wired in series with the WEST limit. When one of these open, the array will return to HOME, the PUMP will shut down and the TRACK circuit will be disabled and remain that way until it is closed again.

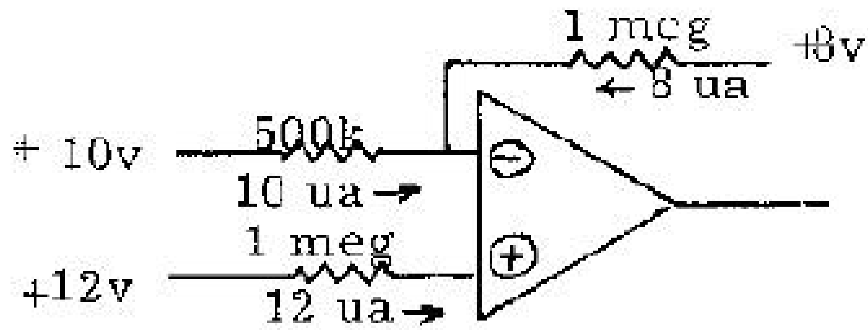
Amplifier U1b with capacitor C2 is an integrator. It is biased low with 24 ua via R13. When darkness sets in the REFerance input goes high enough so that the current through R11 and R12, totalling 420 kohms exceeds that through R13, 470 kohms. The integrating capacitor prevents switching upon transient conditions that might block the light into PCI, thus insuring that it is indeed nightime. The high from U1b-lO supplies

Previous Next



EXAMPLE - NORTON OP' AMP BIASING

figure 37



⊖ input is 8+10=18 ua
⊕ input is 12 ua
so output is LOW
nearly zero volts

EXAMPLE - NORTON OP' AMP BIASING

figure 37

A TRACKING SOLAR CONCENTRATOR

about 50ua to the + input of U1a via R4 causing it to switch into the HOME function as described earlier. This circuit is needed because cloud cover may stop the normal TRACKing and the array will not reach its WEST limit at sunset. In such a case, the DARK circuit takes over to return the array HOME.

The phototransistors PC1 and PC2 have variable collector load resistors R14 and R22 permitting them to be matched to each other and made sens- itive to the range of sunlight where we must decide to operate or shutdown. Diodes D2 and D3 in a logic OR circuit and the LED1 make this adjustment easy without meters.

In darkness the REFerance and VARiable inputs are high, back biasing diodes D2 and D3 so that no current flows through them. Amplifier U1c, a schmitt trigger configuration, is biased low with 36 ua via R16 and R17 which exceeds the bias of 12 ua via R18. When the sun rises and the cloud cover is not too great the REFerance input goes toward a low, forward biasing D2 and diverting current from R16 away from the U1lc - input. When the U1c - input current drops below the 12 ua bias into U1c +, the amplifier switchs high, driving another 12 ua into its own U1c + input via feedback resistor R19. This provides a hysterisis to insure positive action. Ulc switchs on with about 3-1/2 volts at TB2-1 or TB2-3. It switchs off with about 6 volts or more at both TB2-1 and TB2-3. When the sunlight is adequate and U1c-4 is high, the PUMP is activated by Q2 and relay RLY2. A high is also furnished to U2-4 permitting the TRACK circuit to function. Resistor R10 provides 50 ua to turn off the PUMP and disable the TRACK circuit whenever a WEST limit switch of safety switch is opened.

If R14 and R22 are adjusted properly and if both PC 1 and PC 2 are fully exposed to the sunlight, then the voltages at the REFerance and VARiable terminals will be very nearly equal. In this case the additional 12 ua via R26 drives the integrating comparator U1d-9 to a high output, which has no effect on the 555 timer, U2. As the array focus lags the suns position, a shadow will be cast upon PC2 causing the VARiable voltage to go higher. When the increased current into U1d - goes higher than the current into U1d +, the comparator will attempt to go low. The integrating capacitor C3 will cause the comparator to ignore rapid changes of the VARiable input caused by wind disturbances to the array.

When the comparator U1d-9 goes low, the timer U2 is triggered and generates a pulse to drive the TRACK relay and in turn the TRACK motor to advance the array a small increment. The integrating comp- arator is simultaneously driven back to a high condition with a positive pulse via D4 and R27. It will take Beveral seconds for it to recover and trigger the timer again, even if the PC2 is totally in shadow.

Previous Next

A TRACKING SOLAR CONCENTRATOR

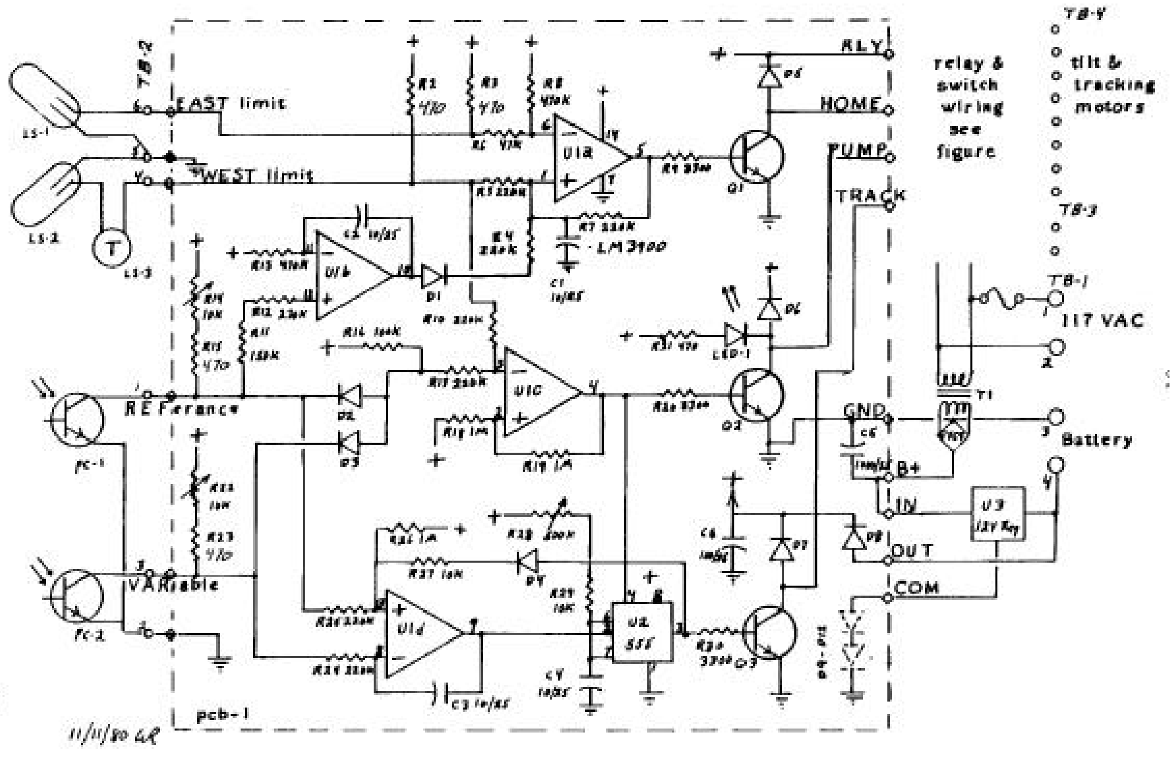
The pulse time and hence the duration of the motor run is controlled with capacitor C4 and the series combination of R28 and R29. It can be computed by: time=l. 1 RC. For example, if R28 were adjusted for a total resistance of 200 kohms, then 1. 1 x 0. 2 meg x 4 ufd = 0. 8 seconds. This is a typical run time for the recommended motor and will advance the array about every two minutes. If you elect to use a battery powered motor, the economy of the pulsed operation is obvious.

The power supply is designed to operate from and charge a 12 volt storage battery if you so choose. The 12 volt regulator U3 voltage output is increased by adding diodes D9-D12 in its common lead. Each diode raises the voltage by about 0.6 volts. Use as many as needed to match the float voltage of your selected battery and regulator. A good place to start, for an automotive type lead/acid battery is with two diodes for about 13.2 volts. If a battery is not to be used, the the COM lead is simply grounded. The regulator will self limit its current output, so no further control is needed.

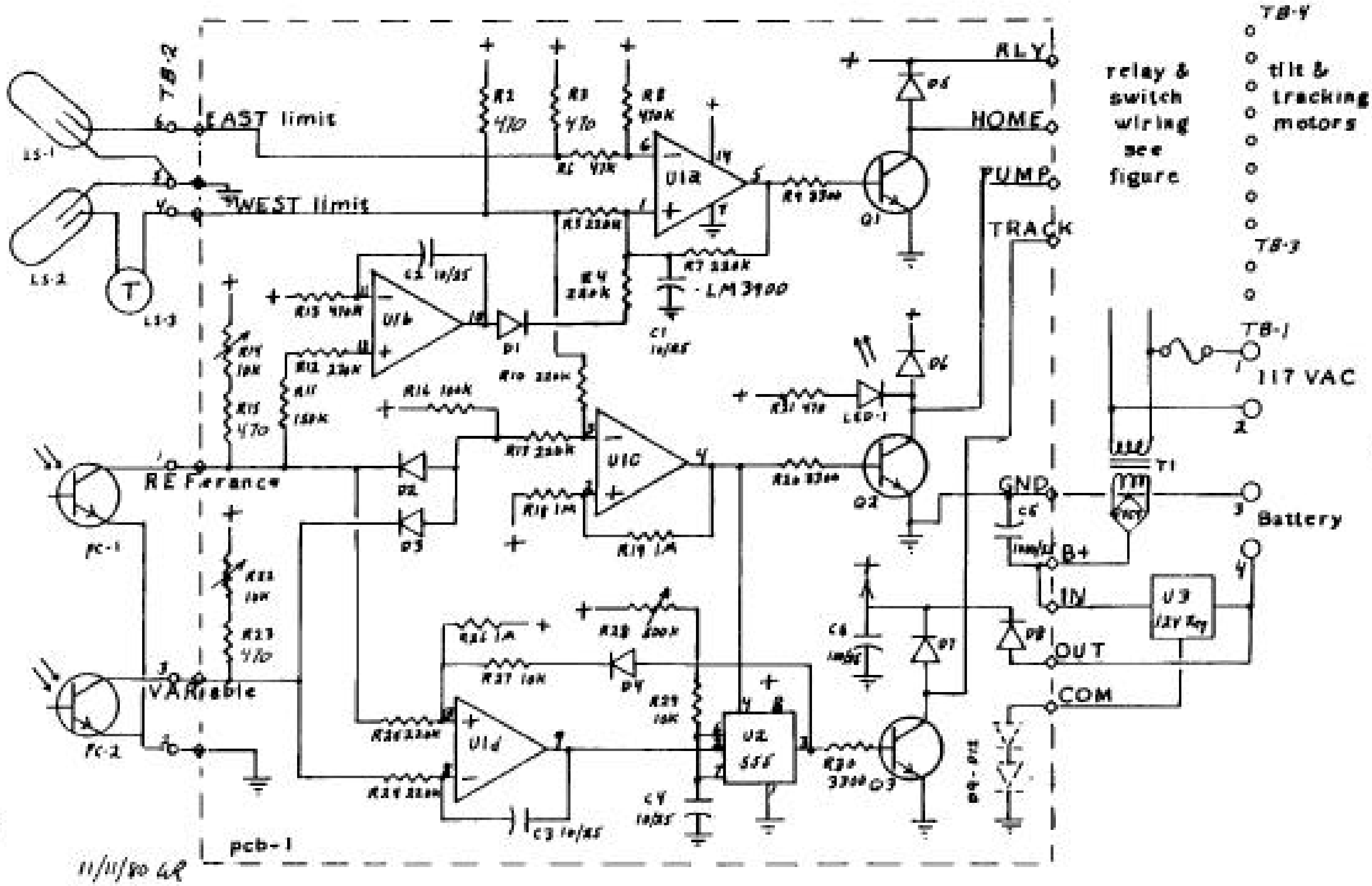
The relay and switch circuits, figure 38 are designed to drive and reverse a two winding motor such as the one recommended, but can easily be re-wired as needed for permanent magnet, split winding or other types. With S1 in AUTO position, the system operates unattended except for an occasional adjustment of the TILT motor with switch S3 every few days. With S1 in MANUAL position, S2 can be operated to move the array toward the WEST, or toward the EAST (HOME position) for testing or other maintenance. The fuse Fl is selected for the recommended motor and electronics.

Previous Next

figure 38



ELECTRONIC TRACKING SYSTEM- SCHEMATIC DIAGRAM



ELECTRONIC TRACKING SYSTEM- SCHEMATIC DIAGRAM

figure 38

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC TRACKING SYSTEM- MAJOR PARTS

- Array mounted sensors per figure 40 (801)
- Control panel per figure 41 (802)
- Circuit board per figures 42 and and 43 (803)

Parts for the Array mounted sensor package (801)

```
                                                    Radio Shack #
      2 phototransistors, FPT-100 or equal                276-130
      Experimenter box, plastic                           270-233
      Barrier terminal strip                              274-653
      2 mercury switchs, cannibilized from the popular
             round thermostats, Honeywell T87F series
             ask any heating dealer for a junker or two
      misc. aluminum sheet, bolts, spacers & nuts

Parts for the Control Panel (802)

      S1,S2,SS-Switchs, DPDT, Center off                  275-1533
      RLY1,RLY2, RLY3-Relays, DPDT, 12volt DC             275-218
      Sockets for the relays                              275-220
      Fuseholder for Fl                                   270-364
      TB1, TB3-Feedthru barrier strip, 4 term.            274-651
      TB2-barrier strip, 6 term.                          274-659
      TB4-feedthru barrier strip, 8 term.                 274-653
      T1-transformer, 12.6 vac                            273-1505
      RECT-rectifier, 50v, 6 amp, bridge                  276-1180
      U3 -12volt regulator, 7812 or equal                 276-1771
      insulated mounting kit for regulator
      misc.-aluminum plate 9" x 9-1/2", bolts
             spacers & nuts, container suitable for
             the environment such as 10x12x4-1/2
             raintite electrical J-box
```

This 1980 parts list is obviously going to be obsolete

Previous Next

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC TRACKING SYSTEM- MAJOR PARTS cont.

Parts for the circuit board (803)

Part	Value	Radio Shack#
Clthru C4- 10 ufd, 35 volt electrolytic cap.		272-1013
C5- 1000 ufd, 35 volt electrolytic cap.		272-1019
C6- 100 ufd, 35 volt electrolytic cap.		272-1016
Dlthru D4- diode, 11';14148 or equal		276-1122
D5 thru D12- diode, 1N4000 or equal		276-1101
U1- LM3900, quad, Norton op'amp		276-1713
U2- 555 timer		276-1723
Q1,Q2,Q3- 2N2222 transistor or equal		276-1617
IC sockets, package of two, cut one down for U2		276-1999
Resistors are 1/4 watt, lO"/o or better, 1/2 watt may be substituted		
R2, R3, R15,R21, R23, 470 1/2 watt only		271-019
R4, R5, R7, R10, R17, R24, R25 220k		271-1350
R6	47k	271-1342
R8,R13	470k	271-1354
R9,R20,R30	3300	271-1328
R11	150k	271-047
R12	270k	271-050
R14, R22	10k trim pot	271-218
R16	100k	271-1347
R18,R19,R26	Imeg	271-1356
R27, R29	10k	271-1335
R28	500k trim pot	271-221
PCB printed circuit board per figure 42		

note symbol R1 is not used

Previous Next

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC SOLAR TRACKER- CONSTRUCTION

WARNING. This device uses voltages (120 VAC) that are dangerous to life. It was not designed to meet todays stringent safety standards. Persons unfamiliar with safe wiring and electrical practices should seek skilled help.

The tracker is assembled in three pieces, the array mounted sensor package (801), the control pane1 (802) and the electronic circuit board (803).

The array mounted sensor package is simply a mechanical assembly as shown in figure 40 In the prototype, a terminal strip was first used to connect the external wiring, but later a watertight connector was added for convenience during research. It is an unnecessary expense, not recommended for your use. The connector is obvious in the photo, figure 34. The mercury switches as mentioned in the parts list, were cannibalized after we found new ones too expensive or hard to locate. The cost of a new thermostat with two switches was cheaper than the price quoted by others for two switches. The metal clips that held the switches in the thermostat can be soldered to the small tabs and the switch clipped back in. The tabs can be bent for adjustment but the switch attachment might have to be modified some also when you make the first course alignment. If your switches are double throw type with three wires, hook up the pair that is closed when the box is in the position shown in the figure 40. Wire it according to figure 38. If you wish, the terminal strip connections can duplicate those of TB2 in the control panel. This package bolts on an unused stud of the mirror array in one of the corners. Avoid the bottom corner if you're in ice and snow country. The top is great if its convenient to reach. The East side can be shadowed by nearby mirrors if the array falls behind the sun due to clouds. The West is good also, but we couldn't use it on the prototype because of afternoon obstructions. A small piece of mirror is cemented on the REFerance side of the shadow vane to increase the angle that the phototransistor can see. This aides in capturing the sun and catching up after clouds have had the system stopped for a few hours.

Note the orientation toward the North Star in figure 40. The open side of the box is always looking below the horizon so that rain & snow will not enter it. You can leave the cover off, unless you suffer blowing storm conditions, until the alignment is complete.

The control panel (802) is assembled on a 9" x 9-1/2" piece of aluminum plate. A suggested layout is shown in figured 41. Quarter inch holes in the corners will be used to mount it on some studs attached to the rear of an appropriate container such as a rain-tite electrical junction box. Use the components to determine to determine the exact size and location of holes. If you have elected to use the recommended motors, then wire it according to figure 39. Make sure your wiring of the array is protected from damage in the moving parts area of the hub. Shielded two-

Previous Next

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Previous Next

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Previous Next

A TRACKING SOLAR CONCENTRATOR

conductor wire is suggested for the sensor and limit switch wiring.

- Caution: This panel and the motors use voltages that are hazardous or lethal, 120 VAC. Make sure that your wiring conforms with local codes.
- *Do not attempt the line voltage (120 volt) wiring unless you are qualified to do it safely and legally*.

The electronic circuitry is most easily assembled on a printed circuit board. figure 42. *The pc board is 3" x 6", page 69 will link to a higher resolution, 300 pixels/inch, suitable for many printers.* The parts placement guide is The parts placement guide is in figure 43. The circuit can of course be assembled on "perf" board, as the prototype originally was, but there is a much higher risk of error in this approach. Be sure to observe polarities and pin basing when you mount parts other than the resistors. For gosh sakes, use high grade 63/37 electronic quality solder. Mount the board on your control panel spaced sufficiently high to prevent interferance with other components and wire the 4 lines to the relays according to figure 38. Connect the sensor inputs to TB2 according to figure 38. Connect the power supply and regulator according figure 38 also.

Previous Next

A TRACKING SOLAR CONCENTRATOR

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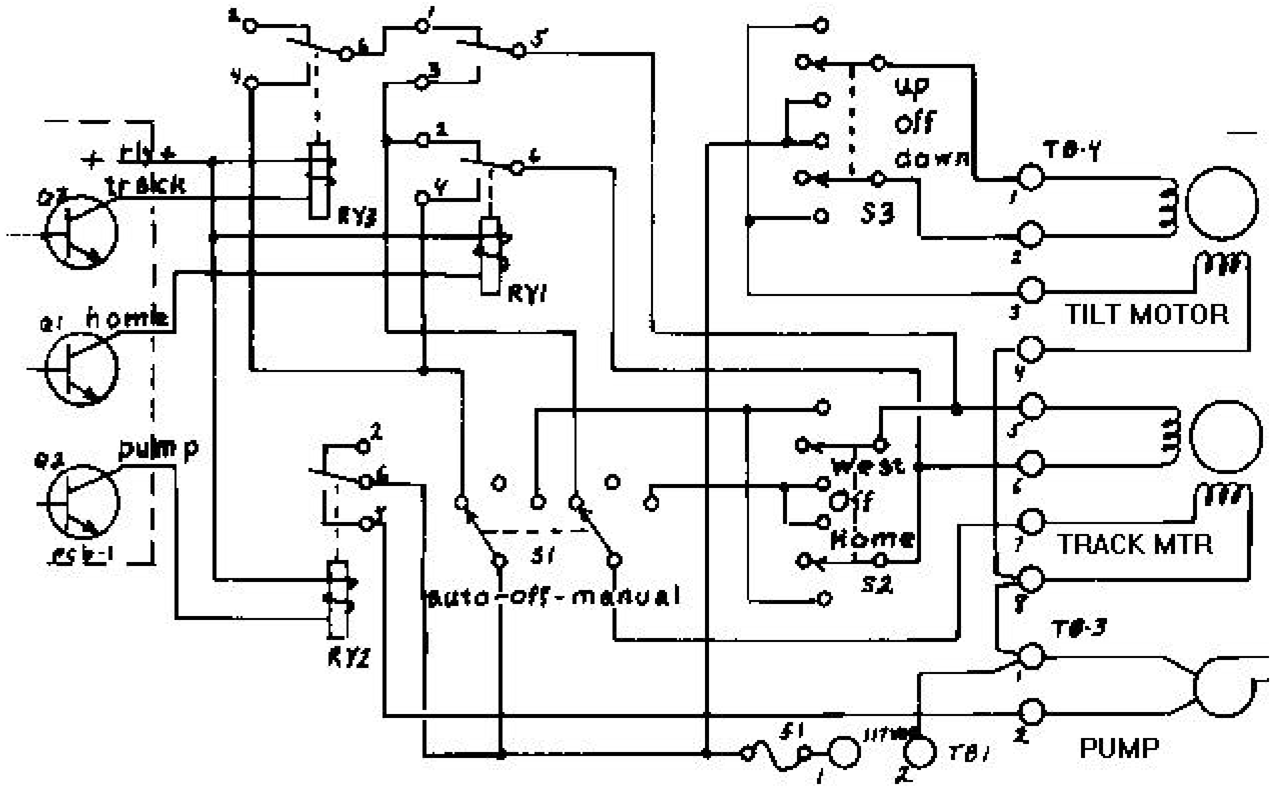
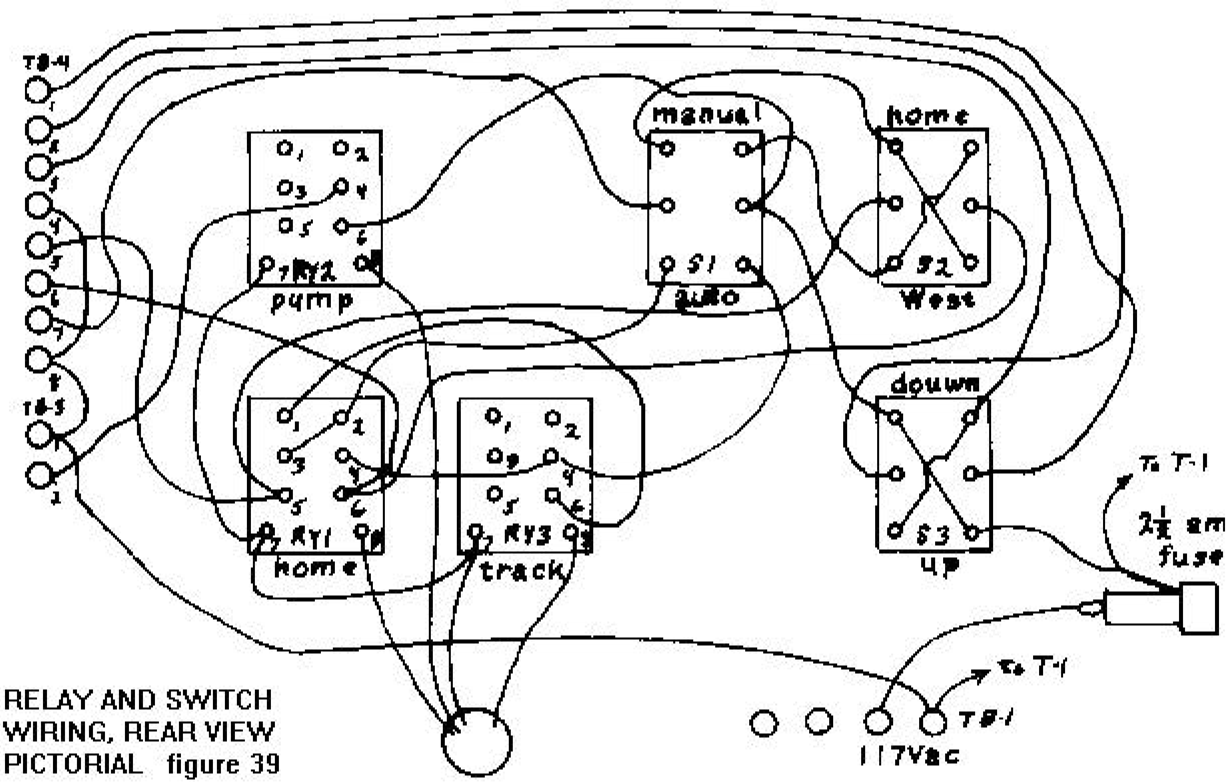
Previous Next

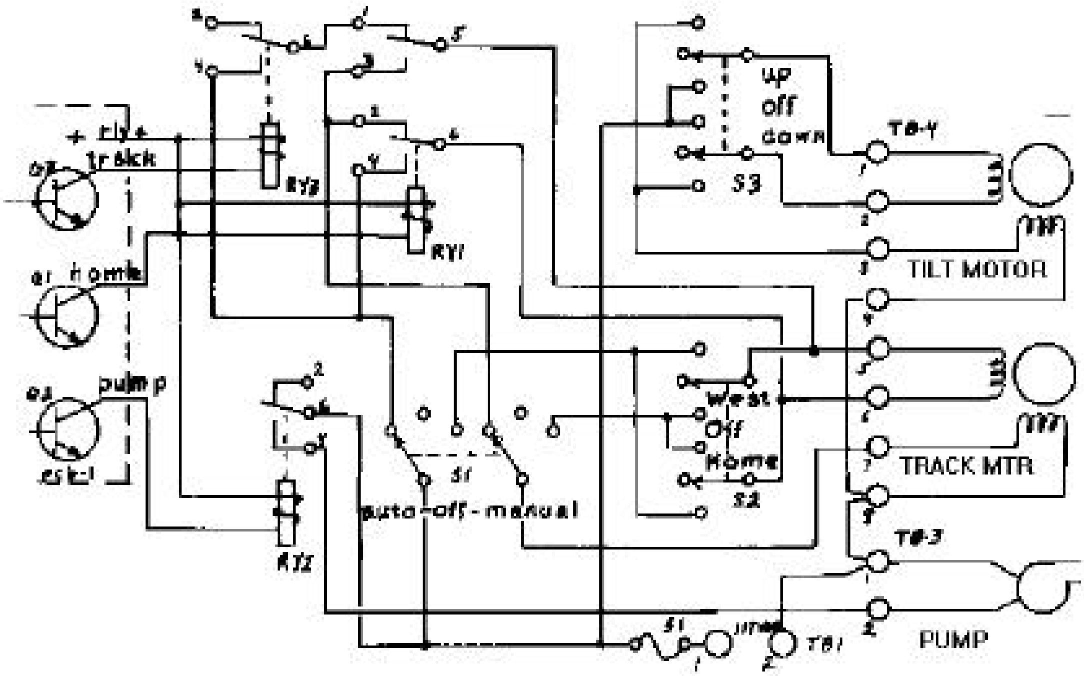
A TRACKING SOLAR CONCENTRATOR



RELAY & SWITCH WIRING - SCHEMATIC



RELAY AND SWITCH WIRING, REAR VIEW PICTORIAL figure 39



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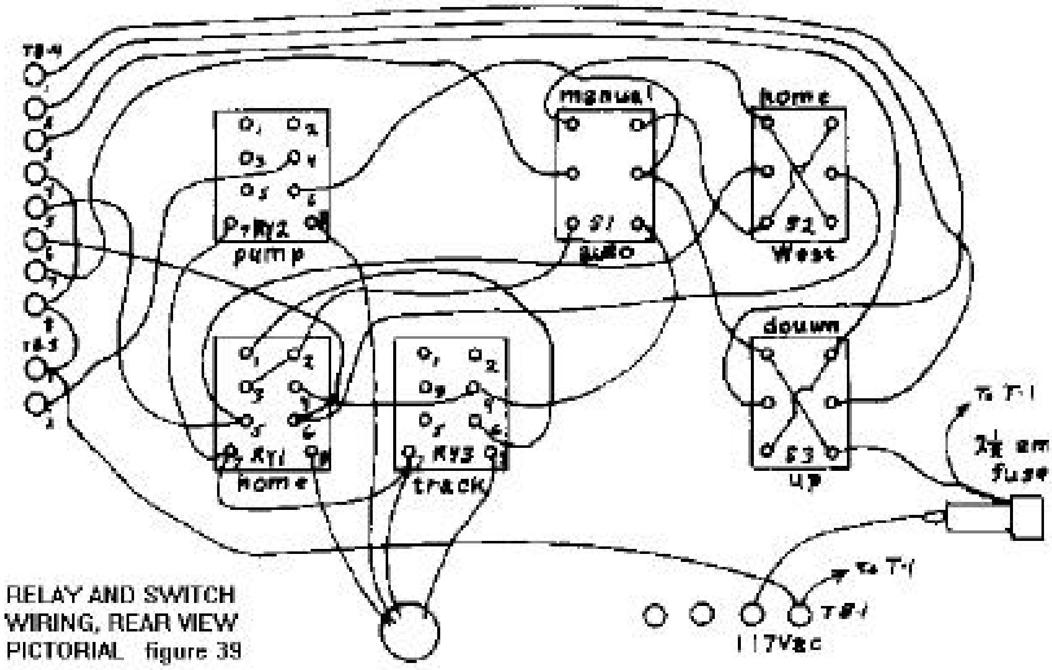
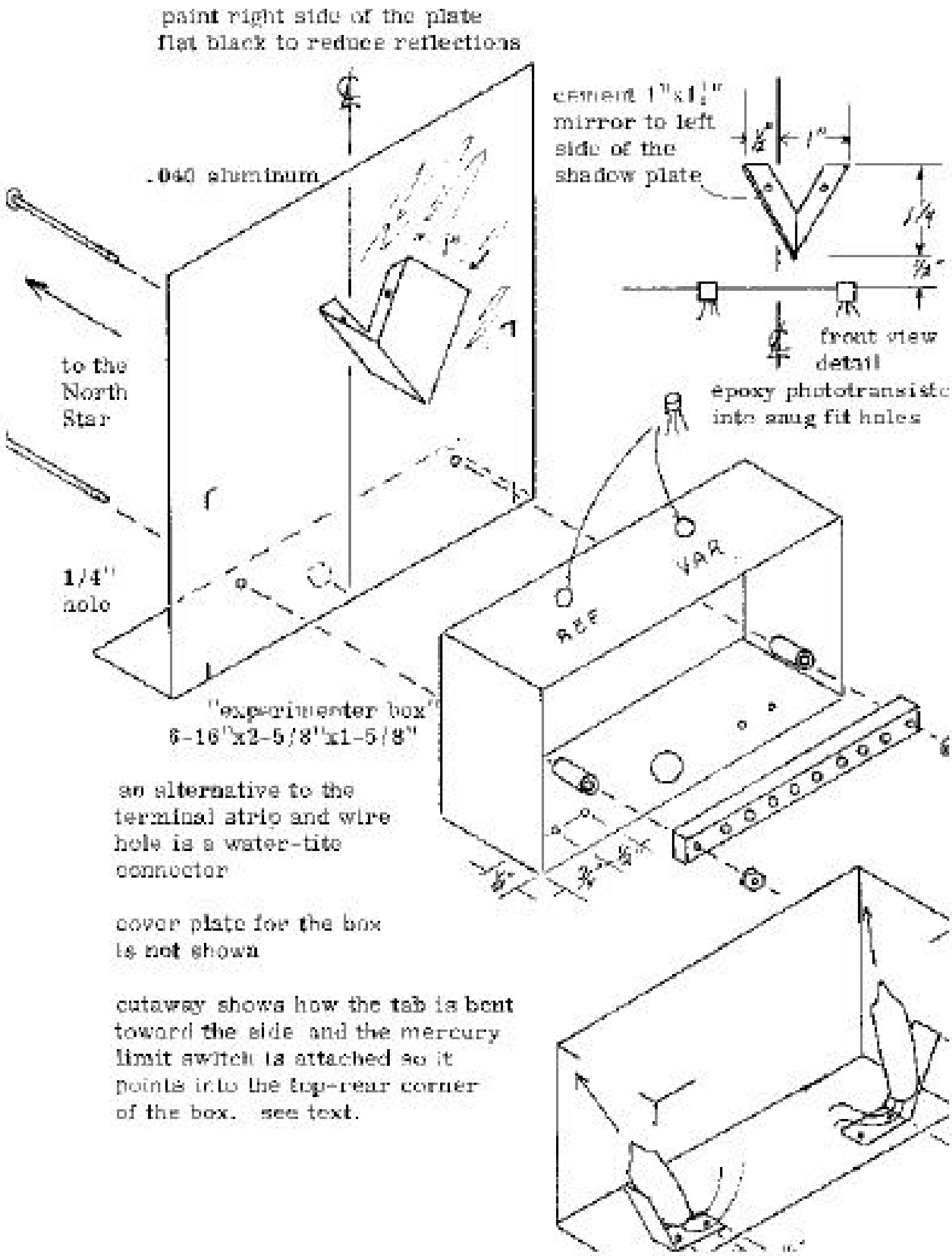
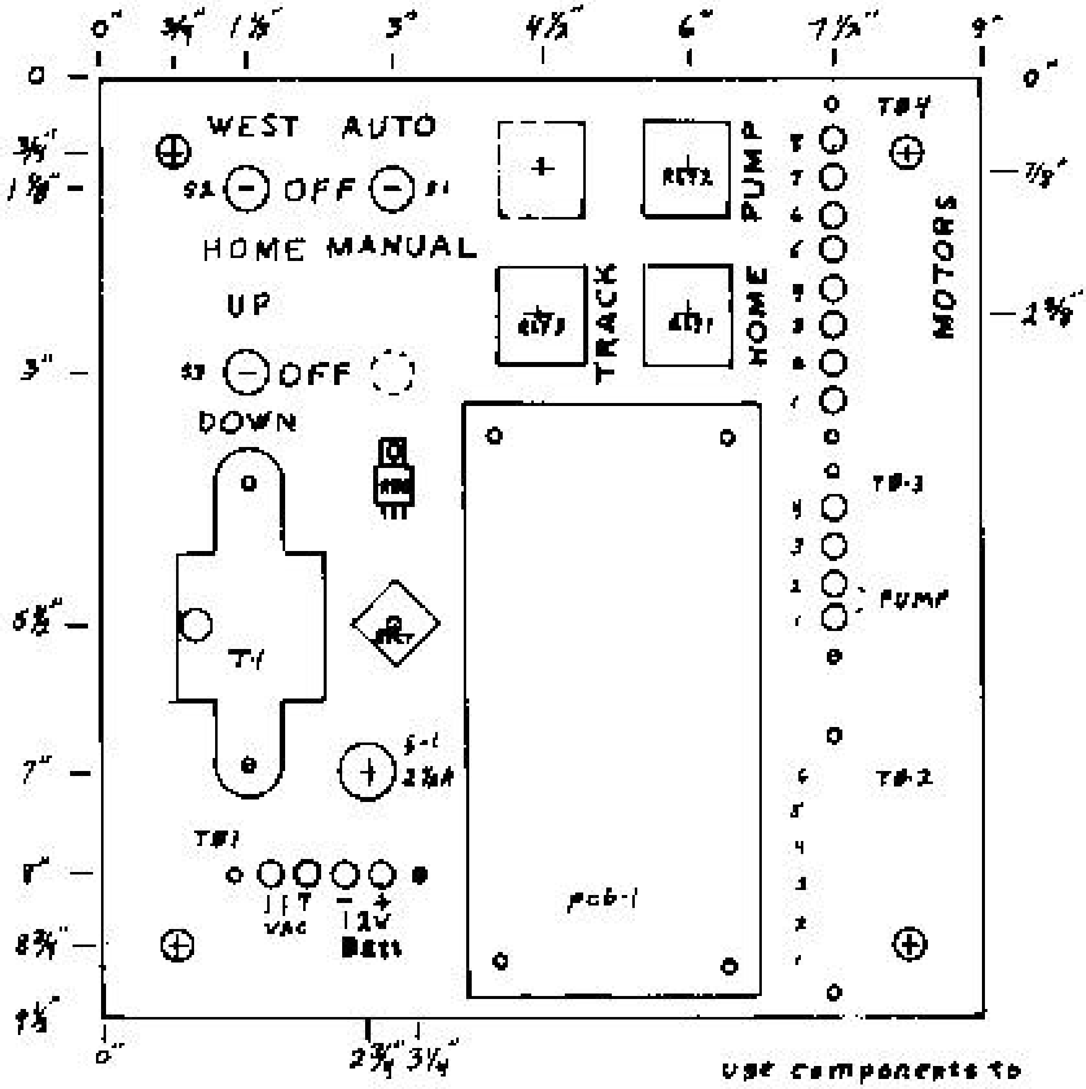


RELAY AND SWITCH WIRING, REAR VIEW PICTORIAL figure 39



paint right side of the plate
flat black to reduce reflections
.040 aluminum
to the
North
Star
1/4"
hole
cement 1"x1½"
mirror to left
side of the
shadow plate
1"
1/4
front view
detail
epoxy phototransistor
into snug fit holes
REF
VAR
"experimenter box"
6-16"x2-5/8"x1-5/8"
an alternative to the
terminal strip and wire
hole is a water-tite
connector
cover plate for the box
is not shown
cutaway shows how the tab is bent
toward the side and the mercury
limit switch is attached so it
points into the top-rear corner
of the box. see text.



use components to determine exact size and location of holes

figure 41

CONTROL PANEL - LAYOUT

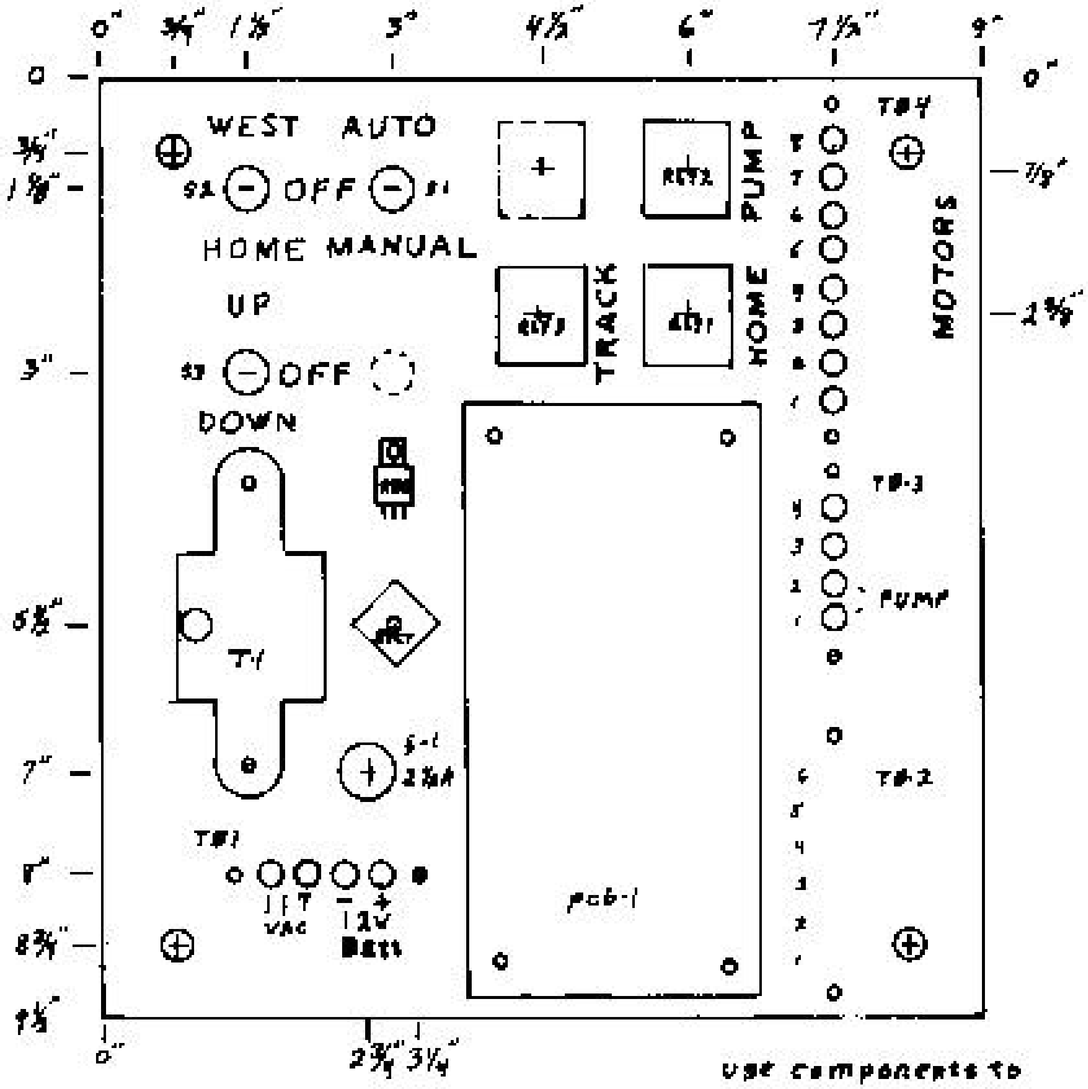
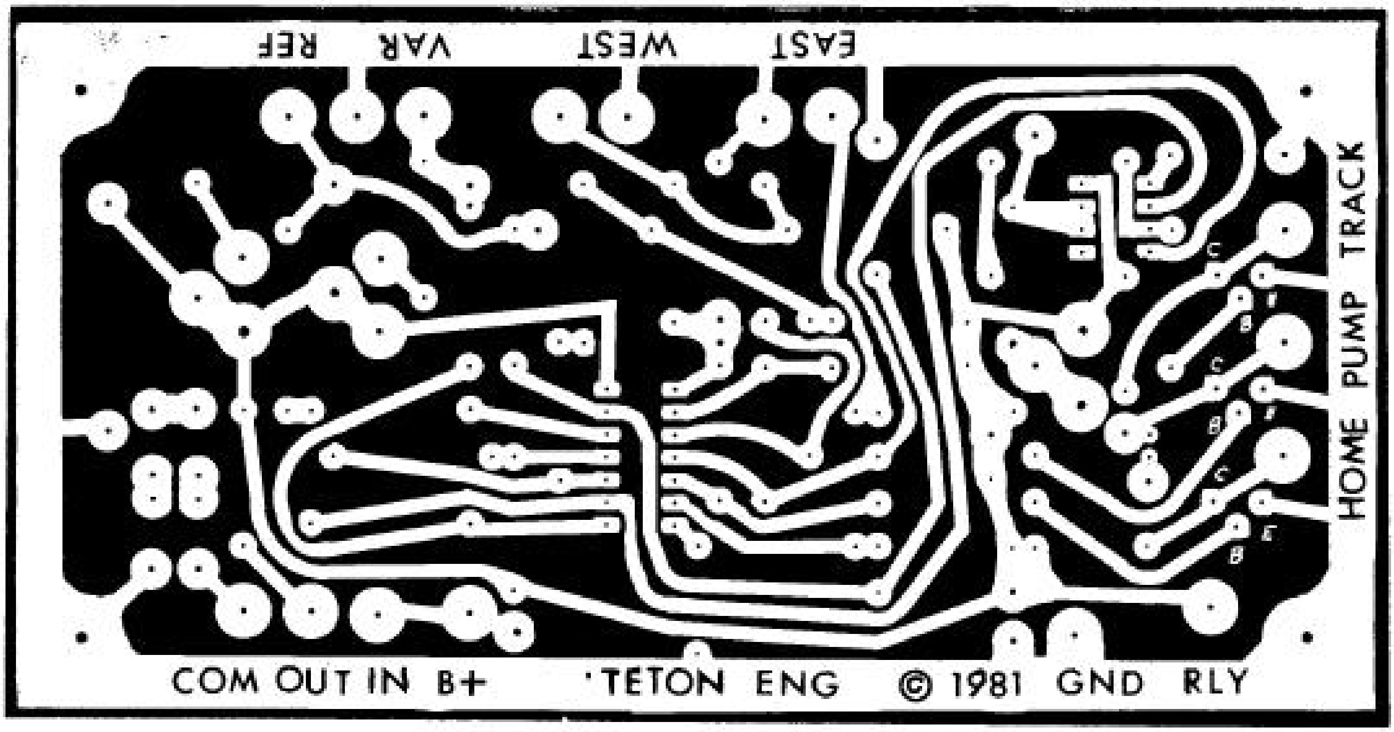


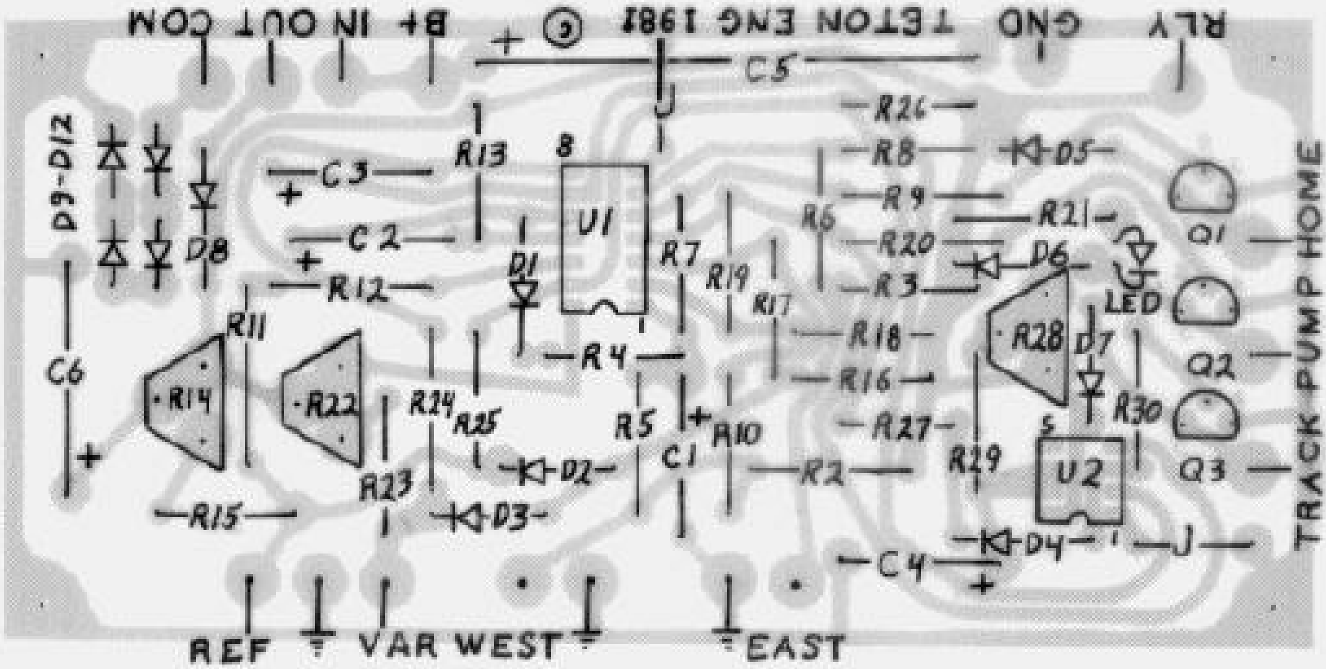
figure 41

use components to determine exact size and location of holes

CONTROL PANEL - LAYOUT



NEGATIVE LAYOUT- CONDUCTOR SIDE figure 42



COMPONENT LAYOUT- TOPSIDE figure 43

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC SOLAR TRACKER- ALIGNMENT

With all wiring installed, determine that the WEST-HOME switch S2 will control the TRACK motor when the AUTO-MANUAL switch S1 is in the MANUAL position. If it doesn't, the most likely problem is an error in connecting the motor wires to TB-4. To sort them out is easy. Remove the wires from TB4-5, TB4-6 & TB4-7 leaving the wire on TB4-8. S1 in MANUAL & S2 in WEST positions. Take any one of the loose three wires and touch it to TB4-5. The one that sparks is the mate to the one still connected- hook it to TB4-7. The other two go on TB4-5 and TB4-6. It doesn't matter one bit which is the field pair and which is the armature pair. It should work now, but if the directions are backward, simply turn over the pair on TB4-5 and TB4-6. While you're at it, check out the TILT motor in a similiar way.

Manually steer the array WEST of the focus so that both PC 1 and PC2 are fully illuminated by the sun. Now if you've got a cloudy overcast where the shadows are barely perceptible, we have it made. Of course this isn't likely, so assuming the sun is shining, simulate the marginal condition by placing two layers of common window screen a few inchs in front of the PC1 and PC2 sensors. The window screen makes a fine, non-selective filter to simulate cloudy conditions.

Adjust R14, REFcalibration and R22, VAR calibration alternately to first turn on the LED and then to just barely turn it off. Go slowly ! It should turn on with about 3-1/2 volts and off with about 6 volts on TB2-1 or TB2-3. Notice the logic here: either control can turn it on, but it takes both of them to turn it off! When you are done, you should have about 6 volts DC above ground at both terminals. If the LED won't light, the WEST limit switch may be open. put a temporary jumper on TB2-4 and TB2-5. The controls should be within about 45 degrees of each other. Further suggests a very bad match in the photo- transistors. In this case it would be wise to buy a third one and match it up with one of the other two. Remove the window screen.

Move:the array back a bit EAST of the sun so that the shadow vane casts a shadow on PC2. The REF voltage at TB2-1 should be very low and the LED should be on. The PUMP relay should be closed. The VAR voltage at TB2-3 should be high and the TRACK relay should be pulsing every few seconds. Check the pulse control R28 and deter- mine that it varies the length of the pulses. Set it for about one second pulses. With the switch S1 in the AUTO position, the array should step ahead to track the sun. Now we'll get it right on target.

Previous Next

A TRACKING SOLAR CONCENTRATOR

ELECTRONIC SOLAR TRACKER- ALIGNMENT cont.

During the next operation, keep someone close to the controls, in case you trigger a HOME function. The array might return to the EAST without a limit switch to stop it. You could trigger this action by obscuring PC1 thereby simulating a DARK condition or by accidently opening the WEST limit switch. A HOME function can only be stopped by opening the EAST limit switch or removing power from the control panel.

- Caution: Did you understand what you just read?

The tracking is adjusted by bending the stud supporting the sensor package in the same manner as you did to align the mirrors. It may be necessary to back up the array with the MANUAL controls several times and let it step up to the sun on AUTO before you get the position just right. At this time, you should adjust the TILT also, so that the collector shadow falls on your alignment marks, figure 26.

Adjusting the limit controls is a matter of bending the tabs, figure 40 and possibly unsoldering and rotating the mercury switchs a bit, so that they open before the array can be driven to a mechanical jam-up. Don't crowd it, there isn't much energy in the first and last hour of the day because the sun is looking through so much atmosphere, so don't insist on tracking the sun right down to a desert horizon. The array is MANUALly driven to its limits while observing the HOME relay. The relay will activate at the WEST limit and release at the EAST limit even though the array is under MANUAL control. If you have obstructions to look over, adjust the limits accordingly.

To make repeated tests at the WEST limit; briefly remove AC power to release the HOME function. To make repeated tests at the EAST limit; remove the WEST input at TB2-4 which will initiate the HOME function.

Keep in mind--If you bend the stud for a TRACK alignment, you must re-check and perhaps adjust the WEST and EAST limits again. You can avoid this dependency by putting the limit switchs in another place, anywhere on the array that you may choose. We found it convenient to make one package. The initial mechanical adjustments just described have never had to be repeated on the prototype, they are stable, in spite of some very high winds, greater than 55 mph that have occurred as well as snow and ice conditions. *They remained stable during the years of operation (1980-1987).*

Your final check is the DARK function. Wait until night or simply cover up PC1. The REF voltage will go to about 12 volts. Some long seconds later, the integrator is convinced that it is truly dark and a HOME function is activated. R14 and R22 should be re-adjusted under actual conditions when the system is put in service. END

Previous