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Auroræ and the Power System

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Senior Project Engineer
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Halifax Centre

On March 13th 1989, almost all of Québec's power system was knocked out for about five hours, with some customers in the dark for close to two days. The subsequent Québec Hydro press report, blaming the previous night's aurora, was met with a certain degree of scepticism by the general public. Believe it or not, our modern power system **is** at risk from aurorae.

The impact of geomagnetic storms on man-made systems has been chronicled for almost 150 years. It began with spontaneous electric currents being observed on telegraphs in 1846. The first occurrence of a geomagnetic storm affecting a power system was on March 24th, 1940, in New York City.

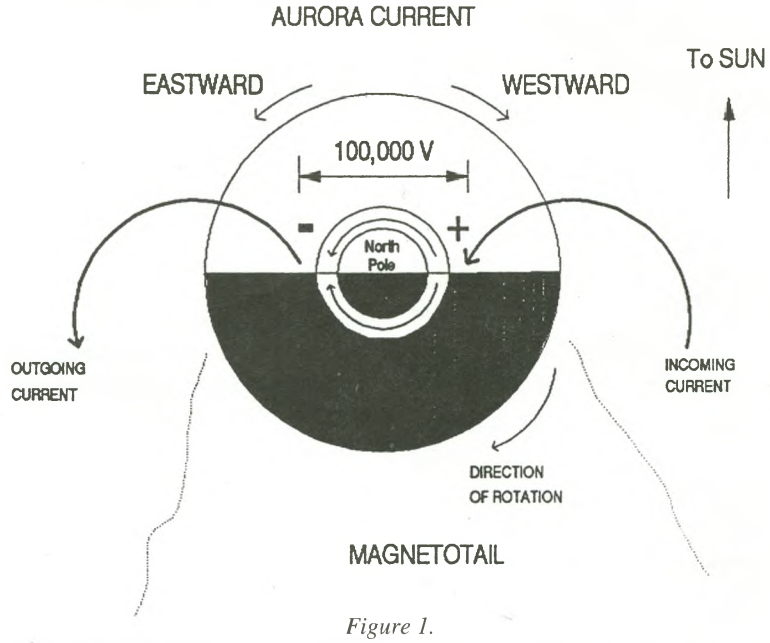

Figure 1.

The explanation begins with the Sun. A flow of charged particles, called the solar wind, is continuously streaming away from the Sun. This solar wind distorts the magnetic field of the Earth and stretches it out as a long cylindrical shaped structure pointing away from the Sun called the magnetotail. In so doing, the positive and negative charged particles of the solar wind are separated, with each type going to opposite sides of the magnetotail. Since opposite charges attract, these particles want to become "unseparated". One path that they can follow to accomplish this is down the magnetic filed lines of the Earth to the upper atmosphere, and through two curved parallel paths to the opposite side of the Earth (and the magnetotail) and then back up to outer space. See figure 1. The high altitude part of this current causes the aurora; the lowest part interaction (altitude≈100 km) affects the power system.

Every electrical current has a magnetic field associated with it. The magnetic field of the auroral current interacts with, and distorts, the Earth's magnetic field. See figure 2. The movement of the Earth's magnetic field lines induces

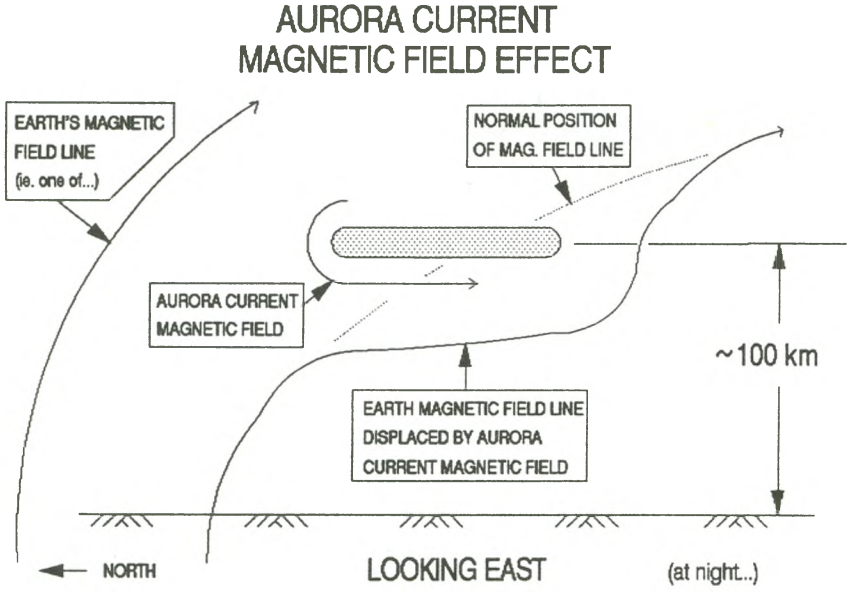

Figure 2.

(continued on page 2)

BULLETIN

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Auroræ and the Power System

(continued from page 1)

a voltage in the ground as if the ground was a wire in a generator. This voltage is about 5 V/km. These voltages are direct current (DC), as opposed to the alternating current (AC) delivered to your home.

Long transmission lines are electrically (and physically) connected to ground through transformers. See figure 3 on page 2. The auroral induced ground voltage causes the ground at each transformer to have a different voltage. It is as if a giant battery was connected between the transformers. The transformer has a high resistance to the normal AC power frequency, but a very low resistance to this DC voltage. The result is a significant flow of DC current into the transformers. The magnitude of this current is proportional to the resistance of the ground beneath the transformers. Québec Hydro's transformers, situated on the high resistance bedrock of the Canadian Shield, are particularly susceptible to this type of current flow.

Transformers have coils of wire wrapped around an iron core which holds the magnetic field. It will not work with DC electricity. Transformers normally carry two types of AC current: load current, and magnetizing current. The magnetizing current is very small (1% of load) and maintains the internal magnetic field necessary for the transformer to work. DC current is magnetizing current only, and for economic reasons transformers are **not** designed for the flow of DC current. Even a small DC current can cause a dramatic increase in the flow of AC magnetizing current, perhaps more than the load current, and possibly more than the coils are capable of carrying. The immediate result to the transformer is the overheating of the internal coils. Also, more magnetic flux is created than the core is capable of holding. This causes core heating plus the excess flux spills into places not normally designed to carry it, such as the steel containment tank. This can cause sufficient heating to blister the tank's paint. A prolonged flow of even a small amount of DC current can destroy a transformer.

In addition to problems caused for transformers, another problem is created in the power system. For complicated reasons, the increase in magnetizing current flow causes the creation of harmonic voltages. Harmonic voltages are multiples of 60 Hz (e.g. 120 Hz, 180 Hz, 240 Hz). Harmonic voltages can cause misoperation of relays in protection schemes resulting in erroneous tripping of healthy equipment.

Harmonic voltages also greatly affect today's most modern high-tech power system device, the Static Var Compensator or SVC. SVC's are very complicated control devices which raise and lower the system voltage at high speed to damp out oscillations in the power system. In so doing, SVC's generate their own harmonic voltages which are removed by filters. The normal level of system harmonics plus those produced by the SVC determines the rating of the filters. Abnormally high levels of system harmonics will overload the filters, causing the SVC to "trip off" when it is needed most. A trip at the wrong time can initiate a total system collapse, just what happened to Québec Hydro.

If SVC's have such problems, then one is tempted to ask "Why are they used?", and "Why are they so heavily depended upon?". Well, strangely enough, the answer lies not in engineering, but in economics. It is an example

(continued on page 7)

ORIGIN OF GROUND INDUCED CURRENTS

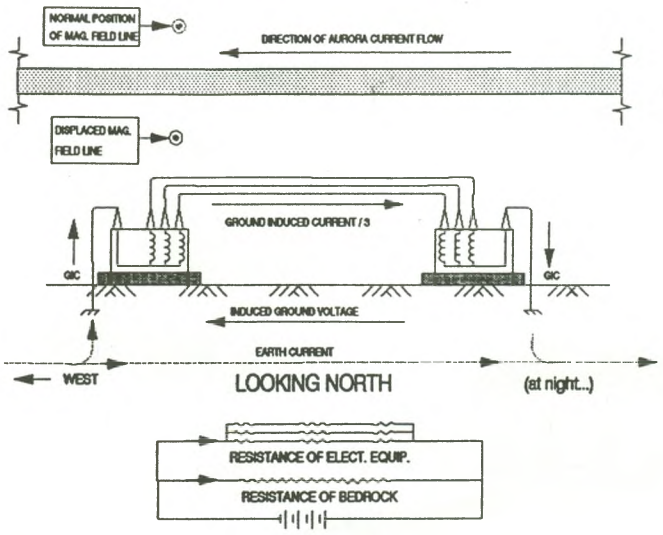

Figure 3.

Alberta Star Party 1991

Glen Hawley
Calgary Centre

The 1991 Alberta Star Party was a joint effort of the Lethbridge Astronomy Club, and the Calgary and Edmonton Centres of the Royal Astronomical Society of Canada. In past years, each of these groups had taken turns hosting the event at different locations in southern Alberta. The once and future permanent site is now the Waterton Heritage Campground, a private facility just north of the Waterton Park gates, off Highway 6. Lethbridge handled local logistics, Calgary the registrations, and Edmonton the speakers, and this arrangement seems to have worked very well. We intend to continue our cooperative efforts in years to come.

The party is held each year in late August near the time of the New Moon; typically on the weekend following the Mount Kobau Star Party. If the Waterton site lacks the superb skies of Kobau, it does have some little conveniences that Kobau lacks, such as hot showers, a small grocery store, heated outdoor pool, and flush toilets (a particular relief after the rather aromatic "one-hole-long-drop" facilities at Kobau) Daytime activities in the park are only a few minutes drive away. These things make astronomy more fun for the rest of the family.

Most of the participants camped in the campground overflow area, which the campground management set aside for our exclusive use. Serious dark sky fanatics had their own area, outside the campground and up the hill a little ways, while lovers of civilized amenities could set up their RV's in the main campground, where they could have electricity and water hook-ups for a modest extra fee. Registration of $20.00 for the star party did not cover camping fees, which started at $8.00 per night. Those who did not wish to actually camp out could go to the town of Waterton, which is located right inside the park, to stay in one of the motels there.

Around 150 registrants showed up this year, and T-shirt sales were brisk. The traditional Saturday supper was cooked on a four metre long barbecue-on-wheels which showed up towed behind a pick-up truck full of groceries. A good two dozen volunteers were recruited holus-bolus from the three sponsoring groups, to supplement the Lethbridge cooking team. There were burgers for the kids, steaks for the adults, corn-on-the-cob, baked potatos, an enormous vat of salad, and an excellent selection of various home baked desserts.

The weather, while not perfect, was reasonable. Afternoon thundershowers cleared off in the evenings, only annoying us slightly with some dewing problems. A large group of sunspots was slowly creeping out of sight around the limb of the Sun, but enough of them remained to make a worthwhile view through solar filters during the day. The sky brightness caused by the high sunspot levels did have a deleterious effect on the nighttime views, as one might expect.

While most of the attendees were from Alberta, some came from B.C., Montana, Saskatchewan and Manitoba. We hope to be able to welcome more people from eastern Canada and the United States, and plan on a bit more publicizing of what has been till now a basically local event. ✪

Mount Kobau '91

Dave Clyburn
Edmonton Centre
reprinted from *Stardust*

After two wet Mount Kobau Star Parties in a row, why would 140 or so people drive hundreds of miles to take the chance of getting drenched again? The place seems to get in your blood. The mountain can offer tranquil beauty one hour and raging thunderstorms the next. The sky at our observing site, well east of Edmonton can get very dark, but the brilliant Milky Way spilling across the heavens at Kobau is another matter entirely. For long periods, my telescope is abandoned; its field of view is much too narrow for what can be seen here.

After a couple of years of attending, the confusion of tents, R.V.'s and telescopes reveals its own order: Craig McCaw's 17.5 inch joins the Calgary group, near Ted Pigeon's 20 inch Cassegrain. Lucien Kemble, Dan Lazar and Murray and Joanne Paulson are also in their familiar spots on the second tier. John Casino's 36 inch is below. Above, on the road to the summit, the Vancouver observers are on the west side (joined by the Breckenridges) on the concrete pad while Bryce Heartwell's 14 inch and my tepee are in their usual places to the east. Linda and Robin Utter are everywhere at once. The American group who form Refractor Alley are missing this year as the Table Mountain Star Party is on at the same time south of the border, but appropriately, their spot remains vacant throughout the week.

On Monday night, I wander down the hill to check out the 36 inch. John Casino is busy doing something else but graciously offers me, a stranger, its use. Now, where else do you get a 36 inch telescope to yourself for an hour? Much later, John Dobson comes out to see what we're looking at. Someone at the eyepiece describes NGC 6888, the Crescent Nebula, as a big egg. John scurries (and I mean scurries) up the ladder to see for himself. After a moment, he announces definitively, "This is no hen's egg - it's a snake's egg!" That settles that.

Midweek, the air is steady: Murray sees Encke's Division in his 12.5 inch and Bryce has the central star in the Ring at 620x in his 14 inch. Thursday night is calm and clear all night. Murray finds an arc of the Veil Nebula in his 6x30 Zeiss binoculars, unfiltered. Laced with dark tentacles, M24, the great star cloud in Sagittarius, is magnificent in my 12.5 inch. True to form Alister Ling and Steve (a friend visiting from Australia) spend three hours on an almost invisible planetary with an even more invisible galaxy superimposed on its edge. Dawn offers the subtlest of colours; greens, yellows, blues, violets. We try out Steve's 8x50 Fujinon binoculars and know what we want for Christmas.

Friday night is cloudy, but after an all-nighter, no one seems too upset. Showers on Saturday afternoon threaten the telescope-making competition, but they abate. Bob Drew's 20 inch f/4 aluminium "Heavy Metal Thunder" takes a prize. The evening is cloudy; it's starting to feel like last year again. A few people pack up and leave. Around 11:00 P.M., skies clear and the air is very transparent. The 36 inch is back in the States, but it's replaced by a splendid 25 inch f/5 with a Galaxy Optics mirror brought by the MacMillan Planetarium in Vancouver.

We try out Bob's new 20 inch. The Veil is stunning. Guest speakers Al Dyer and Terence Dickinson share that view. Near NGC 891, the field is riddled with galaxies. NGC 7008 shows a wealth of detail. The dawn comes all too early, but then provides its own rewards. For the dark of the Moon in August, Mount Kobau was again the place to be. ✪

One board member found perplexing the scientific view that the north and south poles have changed places several times in the history of our planet. She wondered why scientists couldn't make up their minds! She also found evolution unconvincing because she could not imagine how asexual life forms could evolve into male and female forms. Nonetheless, she said that she was in favor of science because it had made possible cosmetics and skin creams.

National Science Foundation, Conference on Science Education (1986)

MICRO-GUIDER: A Computerized Setting Circle/Database Device

David J. Lane
Halifax Centre

INTRODUCTION:

Micro-Guider, as I have named it, is a device which I have designed and built to provide a telescope with digital setting circles, complete with a database of 7 975 celestial objects. It is designed to provide many of the features provided by commercially available units.

As well as describing the Micro-Guider's functionality and software, this article will also discuss a future project which will enhance the Micro-Guider's capability. The author would be more than pleased to provide more detailed information than is provided here, for readers who wish to consider building the device themselves. A blank printed circuit board and EPROM (electrically programmable read-only memory) chips are available at cost from the author. I can be reached at the following "addresses":

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B3M 1E2
Phone: (902) 443-5989
Compuserve ID: 71601,247
Internet: 71601.247@compuserve.com

DESCRIPTION:

The Micro-Guider is a self-contained device which connects to a telescope by using two optical shaft encoders, one attached to each rotational axis. The optical encoders translate the movement of the telescope into electrical signals which are interpreted by the Micro-Guider's on-board microprocessor.

The Micro-Guider is very user-friendly, incorporating a large two line by twenty column liquid crystal display (LCD), and a sixteen button keypad for the user to interact with. In addition, the built-in software is entirely menu-driven.

As is normal practice with modern digital setting circles, the Micro-Guider uses two initially known coordinates to align itself. This allows it to work equally well with equatorial or alt-azimuth mounted telescopes, since it does not require polar alignment or mount levelling. Once aligned, it uses the elapsed time and the azimuth and altitude to calculate the current right ascension and declination based on a complex trigonometric algorithm.

In addition to just the right ascension and declination display, the Micro-Guider also has a built-in database of celestial objects. The database contains 17 bright alignment stars, the 110 Messier objects, the entire 7 840 object NGC database, and the eight planets. Five "user" objects also allow for the storage of transient objects such as comets or minor planets.

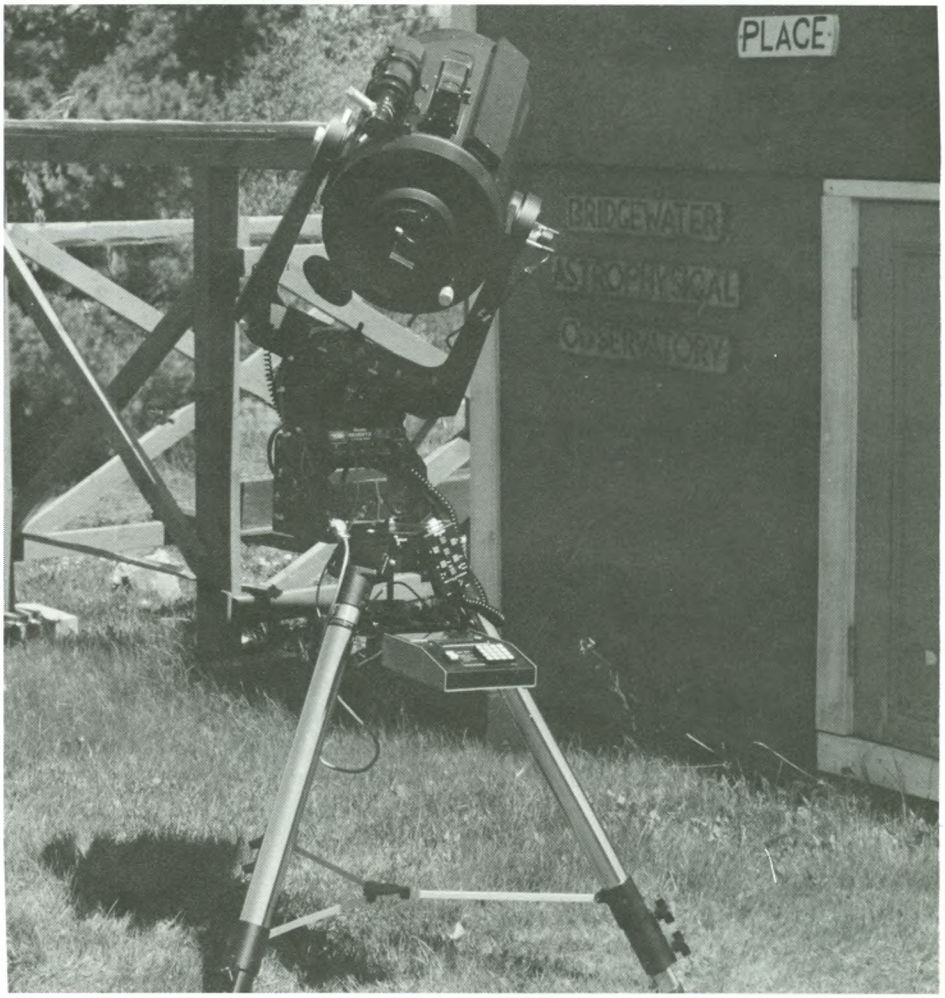
OPERATION:

The operation of the Micro-Guider is very straightforward because it is entirely menu driven. When the Micro-Guider is turned on, the MAIN MENU becomes active. The MAIN MENU is used to access four functions, the first being the SET MENU.

The SET MENU is used to align the Micro-Guider, set the built-in clock, and also to control several programmable settings. The alignment function asks the user to select two objects from the built-in database and to point the telescope to these two objects. After this procedure is complete, the Micro- Guider is able to determine the right ascension and declination that the telescope is pointed to, until the mount base is moved or the Micro-Guider is turned off.

The second selection accessed from the MAIN MENU is the SELECT MENU. The SELECT MENU is used to select an object to find (it is also used by the alignment function described above). It consists of a sub-menu used to enter whether a star, deep sky object, or a planet is to be selected. If a star is selected, the user is to enter the number of the star (as shown on the front of the Micro-Guider) directly on the keypad. The star database is mainly used in the alignment function of the SET MENU. If a planet is selected, the Micro-Guider uses the date and time from the built-in clock to calculate the planet's position. All nine planets are supported; if the user enters a 3 (meaning the Earth), the calculated position is somewhat inaccurate as Micro-Guider simply instructs the user to look down! The deep sky database is subdivided into Messier and NGC objects, with the object's catalogue number entered directly on the keypad.

The third selection accessed from the MAIN MENU is the INFO screen. It displays the known information (object number, right ascension, declination, object type, and magnitude) for the currently selected object.



The Micro-Guider, shown attached to the author's Meade 2120 telescope. Photo by the author.

The last selection of the MAIN MENU is the GUIDE MODE. The GUIDE MODE is the main operational screen of the Micro-Guider. This is the screen where the telescope's coordinates are shown. The GUIDE MODE has two screens: right ascension/declination screen and azimuth/altitude screen. The first screen displays the right ascension and declination in which the telescope is currently pointed and the right ascension and declination of the currently selected object. The telescope's coordinates are updated whenever the telescope is moved or if a sufficient amount of time has elapsed which makes a re-calculation necessary. The selected object is brought into the telescope's field of view by moving the telescope such that the telescope's coordinates equal that of the selected object. The second screen does the same thing, only using altitude and azimuth instead of right ascension and declination.

SOFTWARE:

The Micro-Guider's hardware is basically a dedicated computer, thus the software formed a major part of the effort in designing this device and thus reflects greatly in its functionality. The software was written primarily in the C programming language.

When writing the software for this project, I did not have many of the luxuries available to most programmers when using a conventional desktop computer. I had to start from absolute scratch, by writing all of the software which scans the keypad, outputs to the LCD display, and other functions most programmers take for granted.

The first major part of the software is the optical encoder and coordinate conversion routines. The optical encoders are read by the software at a rate of 2 048 times per second. Each optical encoder produces two signals which are used to determine the direction of motion of each shaft. These two signals when combined, form a "grey code". A grey code is a binary sequence whereby only one bit (or signal) can change from one state to the next. The software detects a change in the encoder signals, then interprets the grey codes to determine the new azimuth and altitude of the telescope given the current and previous grey codes.

Given the azimuth and altitude of the telescope, the Micro-Guider then uses the trigonometric algorithm described by Toshimi Taki of Japan in *Sky and Telescope's* Astronomical Computing column (February 1989). This algorithm, given two initial coordinates at known times, can be used to convert a telescope's azimuth and altitude into right ascension and declination and vice-versa. Consult the article for details of this algorithm.

Another major part of the program is the object database and planet calculation functions. As mentioned earlier, there is a permanent database of alignment stars (seventeen), Messier objects (110), and NGC objects (7 740). The database contains the Epoch 2000.0 coordinates to a precision of 1/20 of a degree, the object type, and the brightness of the object (if known) to the nearest tenth of a magnitude.

The Messier database was obtained from the Compuserve computer network's ASTRO FORUM (provided by Darrell Green). The NGC database was derived from the NGC2000.0 disk marketed by Sky Publishing. In all cases the databases had to be compressed into a size of 6 bytes per object in order to allow all of the objects to fit into the 64k of available object memory. There is space available for about 3000 more objects, which in the future I may use for the brightest Index Catalogue objects.

The planets are calculated using the algorithm described in the book: "Practical Astronomy With Your Calculator" (equation 50). The algorithm is not "super" accurate, but was a trade off between speed, program size, and accuracy. The user objects are entered by the user and stored in non-volatile memory.

Using the basic software functions just described, a menu structure was created to act as the user interface for the Micro- Guider, completing the software.

FUTURE PROJECT:

A future project which I intend to undertake is to enhance the Micro-Guider's capabilities by adding the ability for it to drive a Dobsonian telescope in right ascension so that it will track the stars. For obvious reasons, the Micro-Guider cannot drive a Dobsonian telescope in right ascension with a single motor in one axis (as is done with an equatorially mounted telescope), thus it must be accomplished by controlling two independent motors. The motors that I intend to use are stepping motors attached to the azimuth and altitude axis driven at calculated rates of speed and direction to simulate a single motion in right ascension. This is the method used by most modern professional observatories.

The motors will be controlled based on the following method. The Micro-Guider always *(continued on page 7)*

A close-up view of the Micro-Guide. Note that for entering negative declinations the "D" key is used as the keypad has no minus key. Photo by the author.

Canadian "Starfest" Comes of Age

Cathy Cresswell
Ottawa Centre

This year's August 10th weekend marked the celebration of the tenth year for Starfest, one of the most popular Canadian amateur astronomical conventions. Starfest saw first light in 1982 with about twenty-five participants from southern Ontario. It was conceived by Andreas Gada and Bonnie Bird, founders of the North York Astronomical Association. The N.Y.A.A. is an active observing group started in 1980 in Toronto and currently has about forty-five members. Club equipment includes 16" f/5 and 12.5" f/6 Newtonians, a CCD camera and a surplus Baker Schmidt meteor camera.

The Starfest convention is held annually at the River Place Campground near Mount Forest, Ontario. The Friday evening program consists of informal slide talks under the marquis tent and observing until dawn. Saturday has tent talks morning and afternoon, a swap table, commercial vendors, a catered dinner at the site, door prize draws and a special evening talk followed by observing. For other family members there is a pool and playground.

Over the past ten years, Starfest speakers have included many well-known amateurs and professionals: Terry Dickinson, noted Canadian observer and author of the popular *Nightwatch* and other books; Dr. Fred Lossing of the Ottawa Centre, a Stellafane judge for many years and a designer of the 16" Newtonian telescope that was used to discover five Canadian comets; Dr. Tom Bolton of the David Dunlap Observatory, discoverer of the X-ray source Cygnus X-1; Steve Dodson of the acclaimed Science North center in Sudbury, Ontario, who is currently building what may be Canada's largest amateur telescope; and David Levy, Canadian comet hunter extraordinaire, now up to twelve comets at the time of writing. Special treats have been the continuous forty-eight hour coverage of Voyager's Neptune encounter with live telephone linkage with Terry Dickinson at the Jet Propulsion Laboratories; the comet panel discussion with Canadian comet discoverers David Levy, Rolf Meier and Doug George; and the on-site optical quality survey and testing marathon by Peter Ceravolo of *Telescope Making* magazine.

This 10th year celebration brought a very special program and about 275 registrants. The guest speakers for the Saturday evening talk were Tony Hallas and Daphne Mount of Oakview, California, who delighted us with their incredible astrophotos. The daytime program included special talks on optical design by Roland Christen of Astro-Physics and on telescope fabrication by Rocky Cimarusti of Celestron International. Other presentations were given by Andreas Gada on the successful N.Y.A.A. Baja eclipse trip; Michael Watson on the R.A.S.C. eclipse trip; comet discoverer Doug George and electronics engineer Bob Sandness on CCD comparisons; and Dr. John Percy, Dean of Science and Erindale Campus of the University of Toronto on contributions that serious amateurs can make to astronomy.

There was a commemorative cake cutting ceremony Saturday evening and a number of special award presentations were made to Starfest contributors from the past decade. Prize certificates were awarded to winners of Starfest's first astrophotography competition. Best of Show honours went to Ottawa's Doug George.

Both Friday and Saturday nights were cool and clear and afforded everyone spectacular observing through a myriad of telescopes ranged throughout the campground. It was a special ending to a special celebration. ✪

Starfest founders Andreas Gada and Bonnie Bird with the anniversary cake. Photo by the author.

NOVA EAST '91

Doug Pitcairn
Halifax Centre

This year's Nova East was held on the Labour Day weekend, August 30th to September 2nd in New Brunswick's Fundy National Park. It was hoped that the late date would increase our chances of a clear sky. For the last three Nova Easts, the skies have been poor until the last night, and then fate has allowed everyone a night of prime observing. This year saw a continuation of this somewhat perplexing trend. Sunday night was indeed clear, and until the twenty-three day old moon rose about midnight, Fundy's legendary dark sky allowed a feast of observing.

Friday saw a so-so day turn into a cloudy night. Several dozen people showed up for public viewing anyway. You've got to admire their enthusiasm! Then it was back to the campsite for several slide talks.

Saturday was rather wet with intermittent dry spells. The corn boil and whatever roast was postponed until the more promising Sunday, as was the scope set up. We did get everybody to fill out a registration form, and there was a brisk sale of NE '91 T-shirts, featuring artwork by our very own Mary Lou Whitehorne. The scene depicted was a typical NE '91 one: two raccoons, eating corn and playing inside some hapless astronomer's Dobsonian scope! In addition, the members of the Cape Breton Astronomy Club (Motto: "We put the party back in Star Party!") sold anyone and everyone a famous and very rare (till next printing) C.B.A.S. hat.

Sunday the sky was broken cloud until midday, when the clouds departed and left us a classic clear sky. The corn was consumed and astronomical babble was the order of the day. The telescopes were displayed, along with assorted gidgets and gadgets. The "Coulter gang" dominated one section of the field, while the large refractors towered overhead. The aperture range was two to thirteen inches, with Tom Anderson's (Saint John Astronomical Society) King Kong taking first place in the monster category (12" f/9 on an equatorial mount). The clear skies were no accident. A Styrofoam and cardboard telescope was burned in effigy that evening as a sacrifice to the cloud gods, while amateurs stood around chanting "Clear skies!". Laugh, oh ye of little faith, but the clouds parted and the photons were good.

The slide talks do a nice job of filling in the cloudy nights. This year's talks included cover-

age of the eclipse in Baja, Stellafane and the G.A., stamps with an astronomical theme, as well as an assortment of astrophotos from several amateurs. We also distributed several small door prizes, including an excellent framed photo of Comet Levy (taken at last year's Nova East) by Greg Palman of Maine's Penobscot Valley Amateur Astronomers. Also given away was a year's subscription to *The Starry Messenger*. We hope to expand upon the door prizes next year as we are considering starting a small registration fee.

One thing noticed this year was a drop in the attendance from the Halifax Centre. The weather no doubt was a contributing factor. Also conspicuous by their absence were any members from the two P.E.I. clubs, Charlottetown and Athena. The attendance from both south of the border and from the Saint John club were both up. Next year's Nova East, (August 28th - 31st), is ideally timed with a three day crescent moon showing off to the public, then getting out of the way for an all night observing session. ✪

Micro-Guider

(continued from page 5)

knows the current right ascension and declination (coordinates on the sky) and the azimuth and altitude (coordinates of the telescope). It also can calculate a future azimuth and altitude of the telescope for a fictitious object placed at the current declination but with an increased right ascension (thus at a time in the near future). Knowing the current azimuth and altitude and a future azimuth and altitude and the time difference between them, the Micro-Guider can calculate the rate and direction at which to drive each of the two motors.

If this approach proves successful and tracks sufficiently well to allow for time exposure photography, the next logical step is to add a third axis at the eyepiece to correct for field rotation at the film plane. This final step would open up some exciting possibilities by allowing portable and stable large aperture telescopes to be used for deep sky astrophotography without their normal massive equatorial mountings.

The author would be very interested in hearing from Dobsonian owners who would like to collaborate on this project.

ACKNOWLEDGEMENTS:

I would like to acknowledge my employer, OCEANROUTES SEIMAC where I work as electronics design manager, for allowing me to use their computer-aided design system. I would also like to thank Nathan Cohen, for designing and machining the encoder mounts. ✪

Auroræ and the Power System

(continued from page 2)

where a complicated, but elegant solution is cheaper then the brute force approach.

The modern power system has evolved into one where generating equipment is remote from load centres and interconnected by long transmission lines. On any system, the power that can flow is inversely proportional to transmission resistance. That is to say, the lower the resistance (i.e. more lines), the greater the power flow. However, on an AC system, things are a little more complicated. Power flow is also proportional to the angle between the sending and receiving voltages. On an AC system, sixty times per second, the voltage rises from zero to a maximum in one direction, decreases back to zero, rises to maximum in the opposite direction and decreases to zero again. Believe it or not, when the AC voltage is at a maximum at your house, it is not at a maximum at the generating station. There, it is actually past maximum and on its way back to zero! This time difference between the voltage at your house and the generating station can be described as the "angle" between the sending and receiving voltages. Power flow is regulated by controlling this angle. There is a practical maximum at which this angle can be maintained, however a larger angle can be tolerated if an SVC is used.

This is where the economics come in. There are two choices available to provide increased power flow: build more lines, or build an SVC. A high voltage transmission line typically costs about $300,000 per km, plus the substation at each end. For a typical line length of 400 km, that's $120,000,000 for the lines plus several million for the two substation terminals. An SVC giving a similar increase in transmission capacity costs about $12,000,000. Although the SVC option results in higher system losses, the SVC is still more attractive economically.

To date, the worst power system disruption occurred at 2:45 A.M. on March 13th, 1989, when virtually all of the province of Québec was plunged into darkness. Québec Hydro's system collapse can be attributed to the loss of SVC's due to high levels of harmonic voltages. At that time, the Québec system was sustaining a connected load of 21 350 MW. Nine hours later, 83% of its forecast load had been restored. The remaining 17% represents about 3 600 MW, a little more than twice the peak load for Nova Scotia Power!

The Sun goes through cycles where the average strength of the solar wind varies. The last strong cycle was in the late 1950's, during a time when power systems were small and weakly interconnected. This made them relatively insensitive to the effects of the aurora. Today's power system spans thousands of kilometres, depends on SVC's to damp out instability, and is much more sensitive to the aurora.

The aurora problem is not new, but high solar activity in recent years has demonstrated how susceptible the modern power system has become. Currently, we are at the mercy of magnetic storms, but the next period of low solar activity will provide time for continuing research to offer possible solutions. ✪

Professor Emeritus J.E. Kennedy at the podium in the lecture theatre of the Convention Centre, Montevideo, Uruguay, participating in the official opening ceremonies of the International Colloquium on the Astronomical Culture in Modern Society on July 16th, 1991. Claude Hareau de Estrada, on his left, served as the official English-Spanish translator.
The following evening, Professor Kennedy, a former President of the R.A.S.C. and currently the representative of the Saskatoon Centre on National Council, delivered the invited main lecture.

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Note that the individual issues are identified by letters as follows: F=February, Ap=April, J=June, Au=August, O=October, D=December. Thus a page reference of J7 refers to page 7 of the June issue.