VIDEO REPEATER FOR THE DRY VALLEYS REGION OF ANTARCTICA

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ABSTRACT

A repeater is being designed to provide a telemetry and compressed video link from a remote robot located in the Dry Valleys Region of Antarctica, over a mountain range to California via McMurdo Antarctica. In return a command link is provided for control. A simple task normally, but a bit more difficult when considerations include the unforgiving elements of Antarctica itself. Even with a design using the most robust equipment, tradeoffs must always be made for the effects of the isolation and the weather. This paper describes one approach to the design of equipment capable of insuring the proper bandwidth, power output, and receive sensitivity that can use the energy provided by Mother Nature to continually charge the primary power source, and the engineering struggle to use electronic equipment in the severe and harsh environment of Antarctica.

KEYWORDS

Antarctica, Digital Communications, Solar Power

INTRODUCTION

Modem day solid state electronic equipment is very reliable. As long as the power source is stable and the operating environment is reasonably normal, shock and vibration are minimal, and a system operator can interface and provide preventative maintenance, the equipment will operate with a prolonged life. The same is true in Antarctica. The difference comes when all these "normal" services cannot be provided and sacrifices in performance must be made. Stable power itself is difficult when Mother Nature refuses to cooperate. Equipment allowed to freeze in its un-powered state down to minus 60 degrees over a long period of time, will become "cold soaked" and could be damaged if powered up in that state. Equipment installed in locations so remote that access is only by helicopter, cannot be operationally verified by a technician during preventative maintenance. Portable equipment must be shock mounted for transport by helicopter. Because Antarctica is the most windy continent on earth, portable equipment in remote locations must be designed for survival in winds of 175 miles per hour. Outriggers and tie downs become standard procedure. Blowing gravel and other projectiles must be considered in all mechanical designs.

APPROACH

A communications repeater prototype was fabricated which demonstrated some of the new technology in batteries and solar cells. The system was transported to Antarctica for testing during the 1992-1993 season. The prototype was designed for a communications problem, but lessons learned are being used in the design of the video repeater. This paper will use the test results of the prototype as the basis for the capability of the remote video repeater.

The video repeater design will use the physical dimensions of the prototype system. The prototype is constructed of 2.5 inch diameter aluminum tubing with aluminum "I" beams as supports for the bottom and the vertical standing tubing. The dimensions are 5 feet by 5 feet on the base, and 5 feet high. The top two foot portion of the cube is tilted back at an angle of 20 degrees to allow for installation of the solar cells and provide the proper tilt for the average sun angle. The equipment is self contained in a removal shelter that is located in the center of the cube at the bottom. The electronic equipment and the batteries are installed in the shelter and wired to operate immediately when an external switch is thrown. The prototype system is designed for helicopter lift with four lifting eyes on the top. The video repeater will use the identical design with more electronic equipment, larger solar cells, and more batteries. All electronic equipment and batteries for the video repeater will be located inside the removal shelter. The total weight of the prototype is 910 pounds, but the video repeater is estimated to be 1250 pounds because of the extra batteries and equipment.

In the prototype an Omega OM220, Portable Data Logging System (3)* was used to record solar charging current, battery discharge current, battery voltage, temperature outside, and temperature inside the protective equipment shelter. Results for a 10 percent duty cycle showed that the temperature difference between outside and inside was about 10 degrees when the outside temperature was minus 10 degrees Fahrenheit (F). Originally it was intended to use the heat generated by the equipment to warm the interior of shelter, but as it turned out the low duty cycle reduced the equipment operating heat dissipation. This in turn reduced the heat build-up in the equipment shelter. The batteries used in the prototype were lead acid gel cells and the specifications stated that the batteries will take a charge until the battery temperature reaches minus 4 degrees F. Also, the batteries can be discharged as long as the temperature remains above minus 76 degrees F. The battery system was designed to be discharged for a long period of time without charge. A problem develops if the temperature drops down inside the shelter to below minus 4 degrees F and stays there any length of time. However, in this solar power system it is not as much a problem as it seems. That is because this solar system was designed to operate only during the Antarctic spring and summer when the days and nights both have sunshine and the temperature is not severe. The winter systems that use wind power are the subject for another paper.

The prototype was transported to Mt. Discovery, 42 miles south of McMurdo, and set up with the OM220 Data Logger installed to record the operating environment and parameters. After a week, the system was removed from Mt. Discovery and placed on Mt. Erebus where it remained until the end of the season. The lowest temperature recorded was minus 10 degrees F, and the prototype performed flawlessly.

The video repeater will use some of the same basic components of the prototype except in a higher frequency range. The prototype was in the VHF band (150 megahertz [MHz]), and the video repeater system will be in the UHF band (450 MHz). This way the use of existing, off-the-shelf wide band-width equipment will be an advantage. The band-width will be approximately 2 MHz to accommodate a maximum digital data stream of a T-1 link, which is 1.544 Mega bits per second (Mb/s).

The video and telemetry will be digitized at the remote site prior to being transmitted. The two video channels will be compressed and multiplexed with the telemetry into one carrier. Presently the estimates for the video are for two full motion, compressed digital images represented by 512 Kb/s (Kilo Bits Per Second) per image. The composite signal containing both the video and the telemetry will then be transmitted to a nearby mountain where the Video Repeater will re-transmit it to McMurdo. At McMurdo the signal will go via a microwave link to the Black Island Unattended Satellite Earth Station (USES), and then via the INTELSAT geosynchronus satellite to California.

Command signals will come from California via the satellite to USES, to McMurdo, to the repeater, and into the valley to the remote site.

DISCUSSIONS

The RF (Radio Frequency) link must be designed first to decide the amount of energy required to deliver the signals to their respective destinations, and what quality of the signals to expect. This will provide insight to what transmitter power output will be required to overcome the losses and provide adequate signal to noise at the remote site and McMurdo. Using the following digital link equation, we can determine the carrier-to-noise density power ratio (C/N), where the noise is measured in a normalized one Hertz bandwidth.

(1)* C/N = EIRP - SPACE LOSS + G/T - BOLTZMANN'S CONSTANT, in dBW/Hz (decibels above a watt per Hertz).

Where: C/N is the carrier-to-noise density ratio.
EIRP is the Effective Isotropic Radiated Power.
SPACE LOSS based on frequency and distance.
G/T is the Figure of merit gain-to-equivalent noise temperature ratio.
BOLTZMANN'S Constant is - 228.6 dBW / K / Hz (dB watts per degree Kelvin per Hertz).

Yagi antennas with a gain of 12 dBi (Decibels above the gain of an Isotropic Antenna) are planned for two sites, McMurdo and the video repeater. Both receivers will have a preamplifier to provide at least a 2 dB noise figure, at UHF frequencies of 425 and 455 MHz. The return command signals will come to the remote site at VHF (150 MHz) on separate omni directional antennas. Separation of these frequencies will eliminate the need to use physically large filters to prevent de-sensing during the time when the transmitter and receiver are on at the same time. The Block Diagram of Figure 1 provides a signal flow for the video repeater system. The continuous digital data signal from the remote robot will provide telemetry and two video channels from the remote site via McMurdo to California. This link has a band-width of approximately 2 MHz and a repeater continuous power output of 2 to 4 watts. The VHF side is for command signals provided by the operator in California, and because of its narrow band-width of 25 KHz and a frequency of 150 MHz, does not present much of a problem.

Calculations for the long UHF link of 62 miles using 4 watts continuous power output provides the following carrier-to-noise density ratio (C/N).

EIRP for 4 watts power output, 0.5 dB cable loss, and antenna gain of 12 dBi is 17.5 dBW.

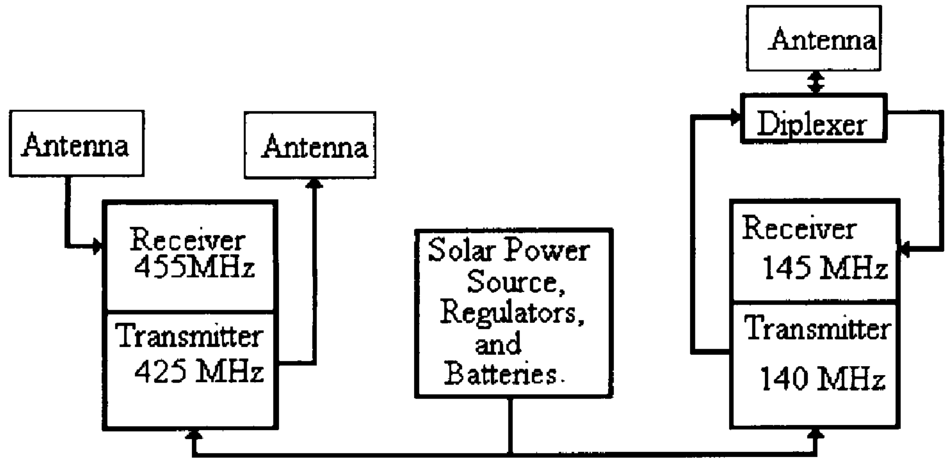

Figure 1
Block Diagram of Video Repeater

The space loss for 62 miles at 425 MHz is 125 dB, calculated by the standard equation:

dB = 36.6 + 20 log f (MHz) + 20 log d (miles)
= <u>125 dB</u>

G/T is calculated for both identical receiving systems by defining the temperature.

System noise will follow the standard equation of Antenna noise, plus noise contributions caused by losses, and the noise of the preamplifier, or:

System noise T = Ta/Lr + Tl + Te

Where :

Ta = Antenna noise based on look angle elevation.
Lr = Cable losses.
Tl = Noise contributions by losses (1 - 1/Lr)290.
Te = Noise Figure of the Preamplifier.

For this system, Ta, antenna noise at zero degrees elevation is approximately 150 Kelvin. Lr, cable losses of 0.5 dB (1.12). Tl, noise contributions by losses of (1 - 1/Lr)290 is 152.5 Kelvin, and 2 dB noise figure makes Te 170 Kelvin. Results for system noise Is <u>335</u> Kelvin. Now divide antenna gain by the temperature.

G/T = (12 dBi - 0.5 dB) - (10 log 335 Kelvin)
= 11.5 - 25.3 = <u>-13.8 dB/K.</u>

The carrier-to-noise density ratio then becomes:

C/N = EIRP - Space loss + G/T - BOLTZMANN'S constant
= [17.5 dBW - 125 dB + (-13.8 dB/K) - (-228.6 dBW/K/Hz)]
= <u>107.3 dBW/Hz</u>

Now that the carrier-to-noise density ratio is known, we can calculate the bit energy-to-noise ratio so a determination of the threshold can be made. The bit energy, E, is the product of the carrier power and the bit duration. The bit energy-to-noise density ratio, (E/N) of the total link is obtained by solving :

(2)* E/N = (C/N)Tb   Where: Tb is the bit duration , or (l/data rate). For a T-l link this is 1/1544000 seconds.

So, the link bit energy for a 1.544 Mb/s data rate is:

(E/N) = (C/N)Tb
= 107.3 dBW/Hz + 10 log (1/1544000)(seconds per bit)
= 107.3 + (- 61.9) = <u>45.4 dB</u>

This margin will provide a more than adequate BER (Bit Error Rate) for the digital signals being passed from the remote site to McMurdo. Experience has shown that a bit energy ratio of 15 dB will provide a BER of one part in ten to the minus eighth with no problem. As can be seen, there will be no problem operating at even 2 watts power output if desired to conserve primacy power.

The short link from the robot to the repeater is less than 2 miles, so it is assumed that no problems will be encountered with the RF link. The repeater receiver will have a 2 dB noise figure and will be receiving with a 12 dBi gain antenna, and the remote robot system will use a 2 watt transmitter with an omni directional antenna.

On the VHF side the problem is not as severe. Command signals are on an as needed basis and will only generate a carrier on a duty cycle of approximately 10 percent. A PM (Phase Modulated) carrier will be used to provide a 9600 baud modem signal. The antennas will be omni-directional and the transmitter power will be 2 to 4 watts. A diplexer and filters will be used to maintain isolation between transmit and receive signals coming from the common antenna.

Power for the system will consist of solar cells with lead acid gel cell storage batteries. All design features are based on using the system during the Antarctic summer when ambient temperatures are above minus 20 degrees F.

Because the sun never sets during the spring and summer months in Antarctica, it provides an excellent opportunity to exploit the capability of solar cells for primary power. New technology in storage batteries and solar cells lends itself nicely to the power requirements for remote equipment. The prototype system contained 4 storage batteries and was designed for a duty cycle of 25 percent with three days storage capacity with no charge. The end result was that the actual charge rate allowed the batteries to stay at full charge for the entire summer. This was partly due to the true duty cycle which was less than 10 percent. With the video repeater things are different. The discharge rate of this repeater will be a continuous 1.5 amps, with intermittent 3 amps during command cycles. Of course this will be for 8 hours each day. No data is available yet on what the duty cycle will be for the command signals. Our design presently uses a 10 percent duty cycle during the 8 hour day as a best guess for the command signal.

Four solar cells of 83 watt capacity will be installed in the video repeater located on all four sides of the cube at the top covering north, east, south, and west. This will allow at least one solar panel to be facing the sun at all times. Each solar panel is tilted back 20 degrees to face the average inclined sun. During the month of November the sun is inclined at about 30 degrees at noon and about 15 degrees at midnight. Six, 90 ampere-hour storage batteries will be installed in the video repeater designed to operate and be charged during the times when the temperature inside stays above minus 4 degrees F.

Using 6 batteries at 90 ampere-hours and 12 volts each in parallel, will produce a system battery capacity of 6480 watt-hours. This value must be de-rated by 0.6 to provide a maximum discharge depth (approximately 11.25 volts minimum), and de-rated another 0.6 for a low operating temperature of minus 4 degrees F. The result is a usable battery capacity of 2333 watt-hours. The load power is 1.5 ampere x 12 volts x 8 hours, or 144 watt hours, + 1.5 amps x 12 volts x 0.8 hours (10 percent duty cycle of 8 hours operating time), or 14.4 watt hours. So the combination of 144 + 14.4 is 158.4 watt-hours, and with a total capacity of 2333 watt-hours of system battery capacity, the batteries should maintain primary power for approximately 15 days without additional charge. This over-design allows the operation of the remote site during longer days if necessary. For 24 hour operation, the total drain would be 475.2 watt-hours for almost 5 days of no charge. The no charge time is for overcast, bad weather days that could last for 4 or 5 days in Antarctica.

De-rating is an important factor that provides a safety factor for the batteries. In the power system, a device will be included to cut off all power when the battery voltage gets down to 11.25 volts. This serves to protect the battery from too deep a discharge that adds to the battery life and as long as it has some charge, keeps it from freezing. After solar charge returns the batteries to 12 volts, the cutoff device is de-activated.

Solar cell charging provided with 360 degree coverage can be calculated using measured sun data for Antarctica austral summer. As an example, the daily sun hours during the month of November shows 5.9 hours of sun available on a solar panel facing the north, 3.7 hours facing the south, and 4.8 hours facing east and west. Even though there is 24 hours of sun, the system is a square rather than a circle so the corners facing the sun will be omitted. In real conditions this is not true but this provides another conservative design point. Actually, tests with the prototype proved that some charge current was acquired from all solar panels whether they faced the sun or not. At one site the background was ice and snow and charge currents of 8 amps were observed from four 60 watt panels during the peak of the sunshine. Again, with batteries it is best to over design and accept extra power as a bonus. So on the video repeater design, adding these hours for a total of 19.3 useful direct sun hours, multiply by 83 watts for the solar panel maximum output, gives 1602 watt-hours available per day during the month of November.

High winds are common in Antarctica so all portable systems must be able to operate in over 100 mile per hour winds and survive in 175 mile per hour winds. The surface area of the system facing the maximum direct wind is only 21 square feet of cylindrical and flat combination surfaces. Considerations for drag coefficients and a centroid of 2.4 feet above the ground produce a total overturning force of 3200 foot pounds for 100 mile an hour gusts. Surface tension of the wind on a flat surface was disregarded to provide additional design margin. The system moment is 1000 pounds at 2.5 feet, or 2500 foot pounds as the opposing force. To keep the system from overturning, outriggers will be constructed at the four corners of the base and stored in the existing base tubing. At the site, the outriggers will be positioned and any nearby rocks of sufficient size that can be moved, will be placed on the outriggers for added stability. The outriggers alone provide an additional 3 feet to the moment arm so the opposing force will exceed 5000 foot pounds.

No precautions against "cold soaking" were taken on the prototype because it was to be kept inside during the winter and used only during the warm months when the temperature will never be below minus 20 degrees. However, the video repeater will have heat strips of 15 to 20 watts for warming the equipment prior to applying power after storage in very cold temperatures for any length of time. Once the equipment has been warmed by the strips to an operating temperature according to its specifications, the power can be applied. Warming the equipment is a precaution to prevent damage to the electronic components at power up.

SUMMARY

Having experienced the results provided by the prototype, the major video repeater problems are considered to be solved. One problem still exists that was not mentioned, sun noise. When the sun is in a westerly direction, it will pass behind the video repeater during certain times of the year. The receiver has to discriminate between the signal and the noise. It may not be a problem as the condition will only exist during certain times of the year and the signal-to-noise ratio is quite high. This particular problem is to be investigated during the 1993-1994 season.

The end result of combating the elements to provide modern day communications is that small problems become very large ones because of Mother Nature and the remoteness of the operation. Every day new technologies produce equipment and components that makes the job easier and provides new solutions to operations in the extreme environment. As long as the Antarctic beckons to be explored, communications will be provided to the explorers.

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