APPLICATION OF METEOR BURST TELEMETRY TO SNOW HYDROLOGY

652-79

By

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Introduction

During the 43rd annual meeting of 1975, Mr. Barton described the SCS program for acquiring a system to be known as SNOTEL and for which the telemetry network would employ meteor burst communications.

During the 45th annual meeting of 1977, Messrs. Barton and Burke described the characteristics of the SNOTEL system then being implemented and the manner in which these characteristics were influenced by the data acquisition requirements of SCS.

During the 46th annual meeting of 1978, Mr. Farnes described the SNOTEL System in relation to the data user and how it would essentially revolutionize his practices, procedures and capabilities.

At this 47th annual meeting it is our pleasure, as representatives of the Western Union Telegraph Company, to further discuss the telemetry component of SNOTEL from the viewpoint of the contractor who provided it.

We will briefly describe the characteristics of meteor trails as a communication medium, for those of you who may not be familiar with this technique, and the nature of experimental meteor burst systems as contrasted with the now operational SNOTEL system. We will describe some of the problems and challenges we have confronted during the implementation of this precedent setting system and identify some ideas for further exploiting this technology in the same and similar applications. Finally, we will discuss the installation and maintenance aspects which are so important to the success of a program of this type.

Whereas this paper relates principally to the operational SNOTEL system, it should be noted that a second operational system, the Alaskan Meteor Burst Communication System (AMBCS) has been successfully installed in Alaska.

Characteristics of Meteor Trails

The theoretical aspects of communicating by reflection or reradiation of radio waves from ionized meteor trails have been developed during the past twenty five years. Experimental communications systems have been designed and tested. Performance data has been consistent with theoretical predictions.

Table 1 lists the important parameters of meteor trails and their characteristics which influence the design of meteor burst communications systems.

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Parameter	Characteristics
Daily Meteors:	10^7 - Overdense, Forward Reflection 10^{12} - Underdense, Forward Scatter
Annual Variation:	4:1 summer to winter Max. at poles, Min. at equator
Daily Variation:	4:1 AM to PM Max. at equator, Min. at poles
Total Variation:	16:1 over a 1-year period
Height:	93 Km
Range:	to 2000 Km
Trail Duration:	0.1 to 1.0 Sec.
Useable frequencies:	10 to 100 MHz

Table 1. Characteristics of Meteor Trails

A very large number of meteors daily enter the earth's atmosphere. Their high speed collision with air molecules creates short lived trails of electrons. These ionized trails act as a reflecting medium to radio waves. Meteor size and mass ranges from 16 cm and 10 kg to 2 x 10^{-5}m and 10^{-8}gm. The number of meteors varies inversely with size. Electron line density or the number of electrons per meter of trail length also varies inversely with size. Trails with electron line densities of 10^{15} and greater are created by larger meteors, are referred to as overdense and cause a forward reflection of radio waves. Trails with electron line densities of 10^{14} and less are created by smaller meteors, are referred to as underdense and cause a forward scattering of radio waves. Since the daily number of underdense trails exceeds the daily number of overdense trails by a factor of 10^5, system design is normally tailored for the utilization of underdense trails.

At a latitude of 45°, an annual variation in meteor trail activity of approximately 4:1 occurs from summer to winter. This ratio is maximum at the poles and minimum at the equator. In addition, there is a daily variation of approximately 4:1 which is maximum at the equator and minimum at the poles. The total seasonal variation therefore approximates a ratio of 16:1. These variations are always considered in relation to the desired performance capabilities of any meteor burst communications system.

Meteor trails occur at a height of 93 Km thereby establishing the basic geometry for communications links and limiting the range of such links to about 2000 Km or 1200 miles. Beyond this distance the earth's curvature prevents line-of-sight paths between the two stations and a common meteor trail. For viable distances of less than 1200 miles the designer is concerned with antenna propagation characteristics and link power budget to satisfy the required radio performance of the communications link or links being considered. Meteor trail path losses exceed line-of-sight path losses by from 50 to 125 db for trails having electron line densities of from 10^{14} to 10^{10}.

The time duration of ionized meteor trails ranges from 0.1 to 1.0 second. Sustained communications between any two points is limited by these durations. To transmit as much information as possible during these brief intervals requires the use of high bit rates and efficient link protocols. Increased bit rates are possible with increased operating frequencies which, in turn, require increased link power budgets.

The useful range of operating frequencies for meteor burst communications extends from 10 to 100 MHz. The lower end of this range is limited by the length of the ionized trail. The upper end of this range is limited by path losses. Mid-range frequencies of from 40 to 50 MHz have been found to be most applicable in relation to cost considerations and information capacity. The bit rate normally utilized at these frequencies is 2000 bits per second.

Point-to-Point Meteor Burst Systems

Excluding the now operational SNOTEL System and its smaller counterpart now operational in Alaska, all other meteor burst systems have been experimental and have been associated with point-to-point communications, i.e., between point A and point B. Considerable effort has been expended in developing successively improved systems by utilizing developing knowledge and experience to achieve optimum performance on a point-to-point basis.

Figure 1 illustrates the geometry of a typical point-to-point system. Experimental systems have been tested in this configuration at various station separation distances D, at various latitudes and in various orientations such as east to west or north to south. Their purpose and use have been for the transmission of narrative information. Design emphasis has been oriented toward the achievement of useful transfer rates of error-free information. Site selection, antenna propagation characteristics and power budgets are optimized in relation to the fixed distance D.

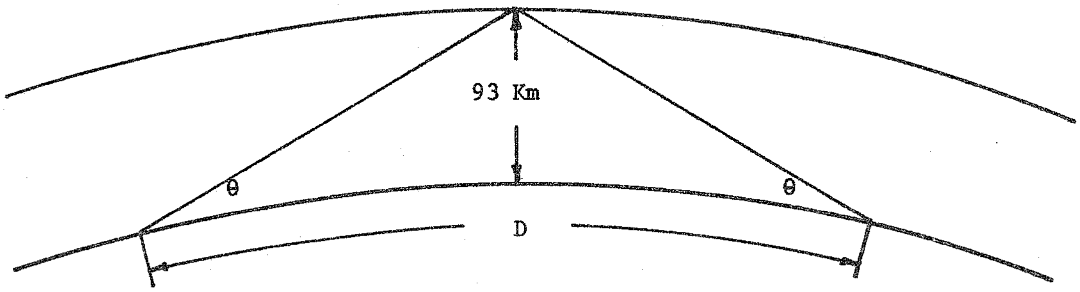

FIGURE 1. Link Geometry of Point-to-Point System

Figure 1a illustrates, in simplified form, an example of the link protocol employed by point-to-point systems. The receiving station repeatedly transmits probes (P) in the direction of the transmitting station. The probe is a request by the receiving station for the distant station to transmit. In addition to the request a probe may contain other information relating to link operation. Whenever a meteor trail occurs to reflect the probe signal to the transmitting station the transmitting station receives this probe and immediately transmits information to the receiving station via the now established meteor path. The transmitting station transmits for a period longer than the expected duration of the meteor trail to assure utilization of the path as long as it persists. The receiving station checks the received information for accuracy. Upon detecting an error the receiving station resumes probe transmission including, within the probe, a pointer which tells the transmitting station the point at which the first error occurred in the previous transmission. When this probe reaches the transmitting station, via a new meteor trail, the transmitting station

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Receiver:        PP               PPPPPPPPPPPPPPP            PP
                   |              |              |             |
Transmitter:       The Quick Brow                n fox jumped ov
                   |              |              |             |
                   |              |              |             |
             Start of     End of       Start of      End of
             1st trail    1st trail    2nd trail     2nd trail
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FIGURE 1a. Simplified Operation of Point-to-Point Link then "rolls back" to the point of error and continues transmission on the newly established meteor path. This technique permits the utilization of all meteor trails, regardless of their duration, to achieve a maximum information transfer rate.

A contemporary system of this type is the European COMET System operated by NATO. This system, operating over a distance of 1000 km, has demonstrated an average information transfer rate of 150 bits-per-second which is equivalent to three 60 words-per-minute teletype circuits. The transmission rate of 2000 bits-per-second results in a link utilization efficiency of 7.5%. It should be noted that the design of this system is enhanced by the use of dual frequency diversity and space diversity. Concurrent signalling on two channels of different frequency and reception by two antennas which are physically separated with signal combining by the receiver improves link performance in relation to single frequency, single antenna systems.

Multi-Station Network

The SNOTEL telemetry network represents a significant departure from the point-to-point systems from which most test data and experience has derived. In one sense it can be thought of as a very large party line network with up to 511 stations, each required to talk to one master station. It can also be thought of as up to 511 point-to-point systems each comprised of the master station and one remote station at a given point in time. In actuality, there are two master stations in the SNOTEL network but we will assume that there is but one for purposes of this discussion.

The SNOTEL System utilizes one transmit frequency for the master station which is the receive frequency of the remote stations. A second frequency is employed for transmission by the remote station and reception by the master station. The master station transmits and receives simultaneously whereas the remote stations transmit or receive alternately. The master station is equipped with four antennas, necessary for system wide coverage. All four antennas are keyed simultaneously with the same probe patterns. However, each antenna is equipped with a separate receiver which is independently connected to the master station computer. Two or more messages from different remote stations which may arrive simultaneously at different master station receivers will be processed by the master station computer without contention. Remote stations transmit only when they receive a probe from the master station provided that the received probe contains an address to which they may validly respond and only if they have not already responded during a preset time interval.

Each Remote Station of the SNOTEL network is assigned a unique address. If, however, the master station were to probe for each remote station in rotation the elapsed time to obtain data reports from all stations in the network would be unacceptable. To illustrate this, it requires from about 0.4 minutes at 6:00 AM during the summer to about 6.4 minutes at 6 PM during the winter to establish an effective meteor path between the master station and any given remote station. The ratio of these delays is consistent with the 16:1 annual variance previously described. If data were to be obtained from the 160 initially installed remote stations by uniquely addressing each in turn, the elapsed time to obtain data from all stations would range from about 64 minutes to about 17 hours.

The elapsed time to acquire data from all stations in the network is minimized by probing for groups of stations with a group address to which any station of the group will respond upon receiving the probe. The liklihood of two or more stations receiving the probe simultaneously is very low due to the random occurrence and location of meteor trails and the resultant low probability of establishing simultaneous meteor paths to two or more stations in a group. To further reduce the liklihood of simultaneous responses, each remote station assumes a quiescent state for a preset period after successfully transmitting. For SNOTEL, this period is 30 minutes and during this time the station will not answer an otherwise valid probe. However, the probability of establishing multiple meteor paths increases with the occurrence of meteor showers or with sporadic E layer activity. Whenever two or more stations respond simultaneously to the same master station receiver their data is received in error after which they continue to be probed for correct data.

Figure 2 illustrates the vertical link geometry of the SNOTEL system in relation to one of the master station antennas. Unlike the point-to-point systems at fixed distances, this system requires that useable meteor paths be established at all distances up to a maximum range of about 850 miles. To accomplish this requires that the master station antenna have a uniform vertical power lobe extending over elevation angles of from 4° to 50°. To achieve this imposes certain conditions on the antenna design, its mounting height and angle and on the site terrain. It is also required that remote station antennas have a vertical power lobe at the take-off angle to meteor trails which is appropriate to their range.

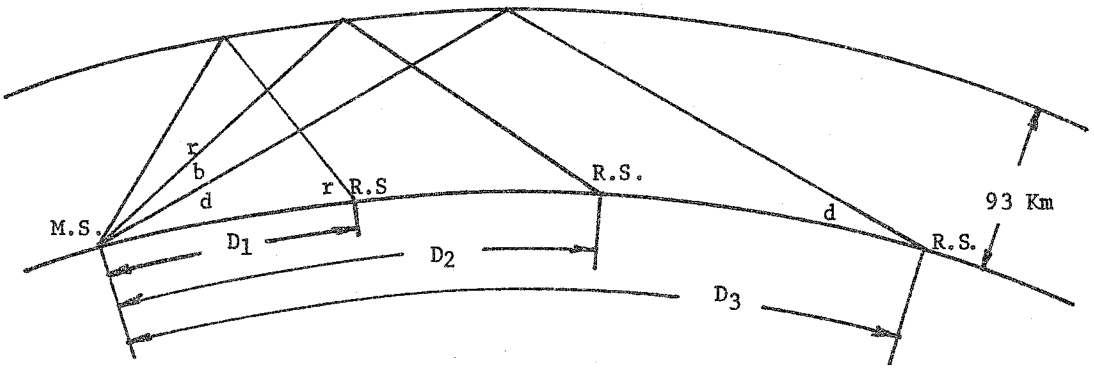

FIGURE 2: Link Vertical Geometry of Snotel System

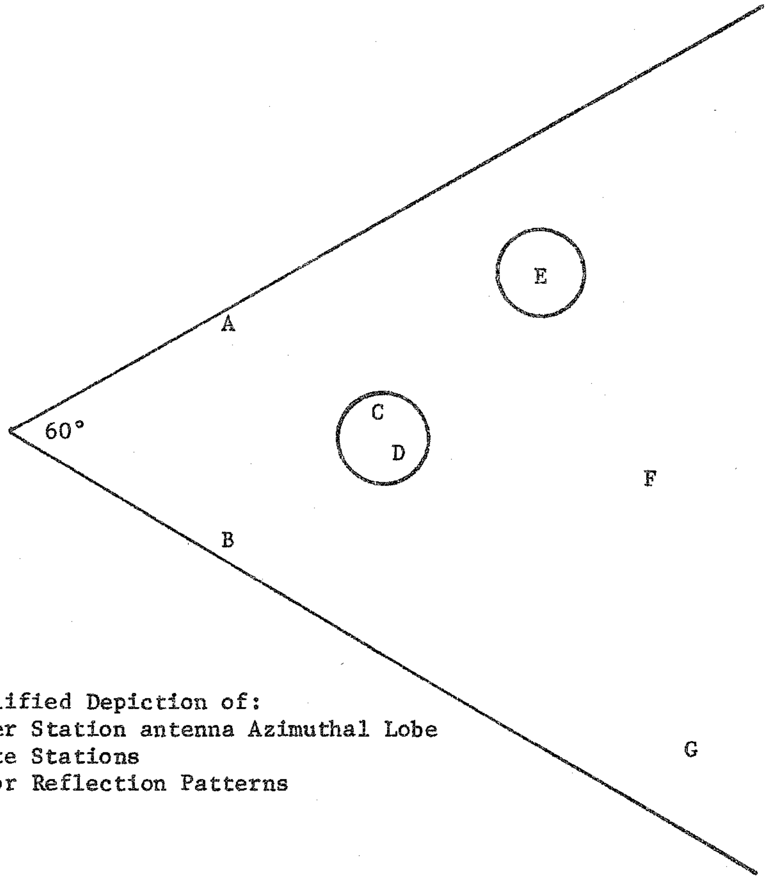

FIGURE 3: Simplified Depiction of:
Master Station antenna Azimuthal Lobe
Remote Stations
Meteor Reflection Patterns

Figure 3 illustrates the horizontal link geometry of the SNOTEL System in relation to the horizontal lobe, between 3 db points, of one of the master station antennas. Remote stations, indicated by letters, are geographically dispersed within this covered area. Since meteor trails occur on either side of the great circle path between any two points, the effective coverage of the master station antenna exceeds that which is shown. The circled areas indicate meteor reflection patterns which occur randomly throughout the covered area whenever the master station probes for the remotes. The pattern shown covering stations C and D can be predicted to occur in accordance with the range of stations C and D from the master station and their separation distance. For this situation, stations C and D are assigned to different probe groups to avoid simultaneous probe reception and response.

Figure 3a illustrates, in simplified form, the sequence of communications between the master station and the remote station. The remote station is normally in a listening mode with its receiver on. Upon receiving a probe containing an address to which it can validly respond it switches its transmitter on and transmits already accumulated current data. It then switches its transmitter off and its receiver on in preparation for receiving the master station acknowledgement. If the data has been received correctly by the master station an acknowledgement will be received after which the remote station will enter the quiescent state previously described.

Unlike the point-to-point systems, which employ link protocols for the dynamic segmenting of information, the SNOTEL system utilizes a single meteor trail for transmission of the entire transaction consisting of probe, data message and acknowledgement. The total time required for this transaction with a data message containing the maximum of 16 data words is 0.175 sec. at the transmission rate of 2000 bits per second. This time is consistent with the effective duration of the meteor trails for which the system link power budget has been designed. Shorter duration meteor trails are avoided by requiring, at the remote station, that the signal level of received probes exceed a threshold value before their acceptance and before transmission of data by the remote station.

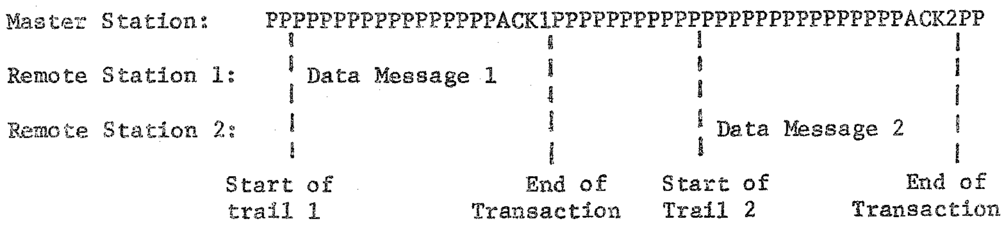

FIGURE 3a: Snotel System-Simplified Operation

Performance of SNOTEL

The SNOTEL I System, consisting of the master stations and 160 remote stations was formally tested during the period January 15 to February 12, 1978 which is the period of lowest meteor activity during the year. The average system-wide response performance during sixteen consecutive days was as follows: 72% within 30 minutes, 93% within one hour, 96% within two hours and 97% within three hours.

The test period included, in addition to evaluation of response performance, a number of tests designed to assure the government that system capabilities are commensurate with requirements of the contract. All tests during this period were successfully completed.

Problems and Challenges

When Western Union initially embarked on the SNOTEL program its greatest concern related to the application of meteor trail communications theory and techniques for a system of this type. This concern stemmed from the fact that while much was known and understood about meteor trail communications, there was no previous experience for a system having the characteristics and vastness of SNOTEL. Ironically, perhaps, most of the major problems encountered during this program have not been related to adverse discoveries associated with basic meteor burst theory. Such theories have proven to be sound and meteors, except for a few brief periods of near total absence, have continued to arrive as expected.

Among the major problems and resulting challenges has been the implementation of reliable remote station power supplies. These power supplies consist of storage batteries which are charged from a photovoltaic or solar panel source. Since the terrestrial application of solar panels is essentially in its infancy and since there was no known experience factor relating to their application at locations with the peculiarities of SNOTEL sites, Western Union has had continuing difficulty in establishing a cost effective design. Experience has proven to be an effective but costly teacher. We have now, we believe, become experts in this field.

The operating environment of the master station located at Ogden, Utah is suspected of being less than ideal. This location is subject to higher than desired ambient noise levels. Additionally, its location on a hill composed largely of volcanic residue is undesirable in relation to that required for optimum antenna propagation patterns. Significant efforts to analyze these problems and achieve improvement have been made. The station performs satisfactorily but hindsight tells us that a more favorable site should have been initially selected.

Link power budgets were initially calculated for utilization of unity gain dipole antennas at most remote station locations. These antennas also provided the wide beam patterns appropriate to the requirement for communicating with either of two master stations located 300 miles apart. It has been necessary to modify a majority of these antennas to obtain an additional 3-5db of gain.

Within a radius of about 200 miles of the master station there is a cross-over between line-of-sight or spacewave paths and meteor trail paths. Antenna modification and/or adjustment at a number of sites has been necessary to reduce this problem.

For each of these technical problems, solutions have been developed. Identification of these problems should not be interpreted as having negative implications in regard to the SNOTEL system since it must be remembered that this system is a first of its kind. To have had no problems during its implementation would have been little short of miraculous. Its success has now been proven by the wealth and timeliness of the data obtained during the winter season of 1978-79. We believe that SNOTEL clearly demonstrates the superiority of this technology for the acquisition of environmental data.

Ongoing SNOTEL Growth and New Applications

We are presently preparing, with SCS, for the installation of additional remote stations on the SNOTEL network during 1979 with the expectation that approximately 400 remote stations will be ready for operation during the 1979-80 snow season. This will double the number of snow sampling sites, as compared to the 1978-79 season, from which real time data will be available to the government.

Each remote station is capable of sixteen 12-bit data words per transmission. Most stations are currently monitoring station battery, temperature, precipitation and snow water content thus utilizing only four of the sixteen data words. Available additional capacity is expected to be utilized for 1) obtaining comparative data in an operational environment from sensors measuring the same parameter but employing different technologies and 2) sensors measuring additional parameters of interest such as wind speed, wind direction and soil moisture.

Development efforts, some of which have related to SNOTEL and to the Alaskan Meteor Burst System, have resulted in a repertoire of logic modules suitable for interconnecting the remote station equipment with a wide variety of analog and digital sensors. In addition a modular family of simplified, low power VHF equipment has been designed for extending the distance over which the meteor burst remote station can be connected to sensing devices. Whereas this distance is presently limited by the use of metallic cable, low power, line-of-sight VHF will extend such distances to from 3-5 miles. With such equipment, it will be possible to obtain data from sensing devices located within a 3-5 mile radius of the meteor burst remote station and then to transport this data over long range meteor burst links to the destination user.

An item of some concern to those who first learn of meteor burst technology is the delay factor associated with the establishment of meteor paths and the impact of such delays on the total response period to obtain data from all or part of a network. Such concerns frequently arise in relation to a need, for example, for data reports from a number of stations every 10 to 15 minutes. Many such requirements can be met by tailoring the master station probing patterns to provide fast or emergency response from a community of remote stations. Response time can be further reduced by utilizing higher gain antennas, faster data rates and increased transmitter power. By employing multiple frequencies, in relation to the geographic and density distribution of remote stations, response intervals can be significantly shortened.

In summary, the designer of meteor burst communications systems has considerable flexibility at his disposal for the design of automated data acquisition systems to meet a wide range of requirements.

Installation and Maintenance Aspects

With much of the meteor burst telemetry equipment by necessity collocated with the data collection instrumentation in remote, often difficult to reach mountainous terrain, continuity of service and economics dictate that the functions of installation and maintenance be carefully planned and carried out. Critical to these functions are the feasibility of all-weather access and the ability of the site to support meteor burst transmission/reception. Consequently, the initial I&M activity beyond planning is the confirmation of site acceptability from all viewpoints. The following discussion pertains to the I&M of remote stations; master station aspects are discussed separately.

Site Survey

The selection of a data site for automation must not only meet the needs of a representative hydrologic and climatic location in a watershed, but must also support the radio propagation characteristics of the meteor burst system. Radio path characteristics vary with the specifics of the desired link such as distance from the master station, the elevation angle along the link path, and the directional orientation of the link. A standardized system/network design is commonally used to meet the broadest possible range of these parameters to insure adequate performance from all points in the network, including optimization of transmitter radiated power, receiver sensitivity, and antenna gain and bandwidth. However, the conditions at the data site must allow for a vertical horizon angle which varies on a scale of approximately 20° at a range of 300 miles to 5° at 800 miles, no interposing significant natural or manmade obstructions in the radio path, and a freedom from radio interference from such sources as other radio systems, power lines, or industrial broadband noise. The telemetry system power source can also impose some limitations on site selection. The fire hazard of fossil fuel generators require appropriate site preparation and maintenance for such a system. The commonally used solar cell (photovoltaic effect) - storage battery combination introduces the need for adequate solar exposure. The solar cell array (panel) must be mounted in a position which provides unobstructed open sky over an azimuth angle of ±40° from true south and above an elevation angle equivalent to the sun's position at 9:00 a.m. and 3:00 p.m. on December 21, at the latitude of the site, as dipicted in Figure 4.

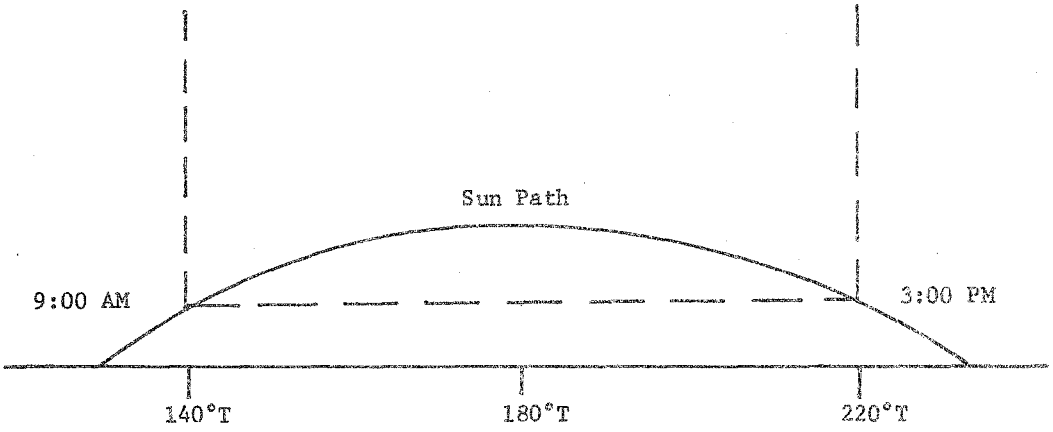

Figure 4. Solar Panel Exposure Requirement

To establish the acceptability of a data collection site from the telemetry system aspect, a site survey, quantitatively noting pertinent site conditions, is essential. A survey can be completed with relatively unsophisticated handheld instruments such as a good compass and an Abney level. The surveyor must also carefully note the presence of potentially harmful RFI sources. If solar electricity is selected as the power source, the site survey must determine the availability of an adequate "window". A carefully prepared check list with space for annotation of observed data provides a record for subsequent analysis and ongoing maintenance activities. Sketches with significant site features, distances, type and height of canopy, etc. are extremely useful and should be included in the survey data. If information regarding site access has not previously been documented, it should also be included in the survey record.

Recognizing that appropriate snow measuring sites, by their inherent character, require extraordinary access means for installation and maintenance activities, particularly the latter as service restoral may be necessary at any time of year, careful transportation planning is critical. The constraints to access, which can only be judged as to degree of difficulty on a site-by-site basis, include;

- Legally protected or restricted areas.
- Lack of road and trail availability and/or maintenance
- Ill-defined maps and markers
- Geographical features such as steep slopes, overhangs offering avalanche threat, large boulder incidence, etc.
- Climatic conditions which obsure visibility
- Canopy, terrain features, altitudes, or severe weather, which preclude helicopter operations.

In surveying access, worst case transportation requirements should be determined. In many cases oversnow machines, either the large heavy duty types or the smaller, open, single passenger type, in combination with snow shoes for foot travel is adequate for wintertime travel to a site; however, a small fully tracked vehicle for seasons other than winter is essential for traversing alternating snow, shallow water, mud, or bare ground conditions. Helicopter - only access is an alternative, but this approach also requires careful evaluation in terms of cost effectiveness and availability. The cost element may be affected by availability, considering type of craft (pay load, operating altitude, and landing attitude), pilot qualifications, ferry time and inclement weather. For any transportation means, planning for a significant amount of equipment, in addition to the I&M crew, must be considered. Items such as batteries or propane tanks, test equipment, replacement assemblies, survival gear, and communication equipment weighing up to 100 pounds will have to be transported to the site each visit.

Installation

To provide for the environmental protection of the electronics package at a data site, a waterproof enclosure is employed, a battery pack can be accommodated in the same enclosure or housed in a separate one. This enclosure(s) can be mounted in any convenient open location at the site, but is often installed in a larger enclosure or in a shelter constructed for the purpose as a matter of human comfort and convenience, as well as to insure access to the equipment when the snowpack builds. With expected temperatures in the very low range (> - 30°C), the enclosures housing both the electronics and batteries should be designed to afford some protection such as snow burial, heavy insulation, or an external heat source. An external antenna must be cabled to the equipment, along with an additional cable for interconnecting the power source. Antenna arrays (typically a dual element dipole) and solar panels require a mounting structure 20-30 feet in height, which may be a convenient tree or an installed self-supporting tower or mast. Assuming completed construction and instrumentation, a single days effort of two technicians is normally required for the installation and test of the telemetry system at a remote data site.

For the automation of a candidate snow measuring site, the elements and sequence of the installation effort should then be:

- Site access determinations
- Site survey and analysis
- Supporting structures construction
- Instrumentation (sensor installation)
- Telemetry equipment installation
- System checkout and testing

Maintenance

In maintenance concept and practices planning, the reliability of the equipment to be maintained is a key factor. Too frequent service restoral visits present the dual problems of data loss and uneconomical operation. To achieve this reliability for meteor burst systems it is not only necessary to insure that basic design and production quality control meet stringent guidelines, but it may also be necessary to provide a second and third level of quality assurance testing as the equipment is shipped and staged for installation.

A second key factor which contributes to the reduction of the demand maintenance rate is good preventative maintenance practices applied during the snow-free season. Experience has shown that carefully completed PM's provide a significant degree of additional assurance that a station will not become inoperative during the critical data gathering period. Preventative maintenance includes a close examination of all system elements subject to physical damage incurred from snow movement, lightening, wildlife, etc. Each element of the system then must be tested for proper operation. The antenna system must have the VSWR and radiated power output determined and directional orientation checked. All electronics must have idle, update, and transmission currents and voltages checked for proper value. The power system, all-important to station operability, must receive detailed attention with all expendables replenished to capacity (fully charged batteries in the case of their use). Finally, the total operability of the station must be determined, both by means of local test equipment and transactions with the master station. Demand maintenance includes the detection and correction (usually subassembly or major element replacement due to expected climatic conditions) as well as all of the steps of the preventative maintenance routine. For both maintenance activities, a complete record is required for management purposes. The site log and a maintainers notebook should be annotated with complete and detailed information. Additional data concerning access or specific site conditions should also be recorded in the maintainers notebook as such information can be extremely useful for triggering correction of deteriorating conditions and future site visit planning. Equipment removed from a site as a result of field maintenance will be subsequently tested and repaired in a field shop, or returned to the central repair facility which has the necessary test equipment and facilities to handle depot-type repair work.

A successful maintenance program depends upon the proper selection, training, and equipping of the personnel who will participate in it. Meteor burst systems require a unique set of qualifications. The job classification must specify a degree of physical fitness in addition to competency in the test and repair of electronic, logic, and radio equipment; as well as basic vehicle maintenance. The training necessary to achieve this competence must be both formal and practical, beginning with technicians possessing the basically required skills. In addition to technical training, a survival orientation or a specialized course is mandatory.

Master Station I&M Aspects

Meteor burst master stations are installed and maintained in a more convential manner than remote stations, with siting criteria the critical factor. These criteria include:

- Freedom from manmade electrical interference
- Clear horizon (azimuth and elevation)
- Antenna field
- Utility availability (power, telephone, and communication lines)
- All weather access road

Additional siting considerations include the availability of a suitable structure to house the station, the proximity of a maintaintenance force, and accommodation of a system maintenance management function.

Although meteor burst telemetry systems can be designed for unattended operation, the quality of system performance is greatly enhanced by a maintenance management capability which provides an ongoing evaluation of operations with immediate attention to service requirements. Master station software is designed to produce diagnostic and statistical information for system management, accesible through the control console, which may be remotely located as desired.

Summary

With recent acceptance and current operation of the SNOTEL and AMBCS meteor burst transmission systems, based on both summer and winter testing, theoretical postulations in regard to multi-station networks have been confirmed. During the implementation of these systems engineering design revisions were applied to assure operability. In the course of this effort additional application possibilities were explored and found to be technically feasible. The implementation phase of these projects also fully defined the practical implications of installation and maintenance. Therefore, it can now be stated that meteor burst technology has been proven in both design and operation, and is an economical approach to data acquisition, particularly for the automation of snow surveys.

References

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3. Farnes, P.E., "Future Snow Survey Operations With SNOTEL", Western Snow Conference Proceedings 1978, pp. 15-20.