METEOR BURST COMMUNICATIONS 1/

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By

Ray E. Leader 2/

Introduction

A growing need exists for a new family of telemetry systems to gather the geophysical environmental data required by the scientific, governmental and industrial communities. Fields of interest include conservation, oceanography, meteorology, public health, hydroelectric power resource management, etc.

The geophysical data acquired by these services in many cases have several common features; usually the rate of change of the phenomena being measured is fairly low; i.e., the data rate associated with the measurement is low. For example, measurements of ocean current, precipitation levels, river or lake water levels, smog content and radiation levels require only modest channel capacity when compared with telephone, television, computer-to-computer communication, etc. In addition to low entropy, the data usually does not require real time transmission. Other characteristics that apply in varying degrees also come to mind. These may be listed as follows:

1. Measurements frequently require placement of sensors in difficult, remote terrain, and beyond line-of-site ranges.

2. Primary power is at a premium.

3. Sensor stations are frequently unmanned, widely separated and sometimes difficult to service.

A frequently overlooked radio propagation medium that is attractive for these applications is that of VHF propagation via scattering from meteor trails. Most previous meteor burst systems have been used for teletype "quasi-continuous" data communications. In many respects, however, it is an ideal medium for low entropy, remote telemetry applications for long ranges. A complete description of forward meteor scatter communication is beyond the scope of this paper as a number of excellent reports exist in the literature.

A meteor burst communication system (MBCS) utilizes as a means of radio signal propagation ionized meteor trails that exist in altitudes of the 80 to 120 Km region of the earth's atmosphere. These trails reflect or actually re-radiate the RF energy (usually in the low VHF range of from 40 to 100 MHz) from a transmitting source to a recovery terminal. The height of the trails allows over-the-horizon communication at distances up to 1200 miles (see Figure 1). However, because the ionized trails exist for only short periods of time (usually from a few milliseconds to a few seconds) communication is intermittent and high speed digital pulse transmission techniques must be used to convey the information. The system is particularly suited to long range, low rate data acquisition applications but it can also support a low speed (100 words/minute) teletype link. Shorter operational ranges, over mountainous terrain, are also a capability due to the height of the reflective meteor trail.

Meteor Trail Ionization

Billions of ionized meteor trails are produced daily in the earth's atmosphere at heights of 80 to 120 Km. These trails diffuse rapidly and usually disappear within a few seconds. However, during their brief existence, they will reflect radio waves in the VHF frequency range.

The meteor, as it enters the upper atmosphere traveling at speeds of 10 to 75 Km/second, possesses a large amount of kinetic energy. As it begins colliding with air molecules, much of this kinetic energy is converted into heat which effectively vaporizes atoms from the surface of the parent meteor. These vaporized atoms, which are traveling at about the same speed as the meteor, are further restricted by air molecules especially as

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2/ The Boeing Company.

they progress further into the atmosphere. This results in the transformation of kinetic energy into the energy of ionization which effectively strips electrons from the atoms leaving a trail of positive charged ions and free electrons. It is the electrons that reflect or re-radiate radio waves.

This ionization is distributed in the form of a long, thin paraboloid of revolution with the particle at the head. The electron line density (electrons/meter) is proportional to the mass of the meteor, and ranges from 10^{18} electrons/meter to about 10^{10} electrons/ meter. Typical trails are 25 Km long and have an initial trail radius of about 1 meter.

Physical Properties of Meteors

In this paper, meteors are defined as extraterrestial objects that travel in orbits (eliptical) around the sun, and at some point in these orbits enter the earth's atmosphere. These objects can be divided into two basic classes:

Shower Meteors - These are groups of particles all moving with the same velocity in fairly well-defined orbits around the sun. To an observer on the earth, they are the most spectacular and appear to radiate from a common point in the sky (called the radiant). Shower meteors account for only a small fraction of the total incidence of meteors.

Sporadic Meteors - These are particles that move in random orbits around the sun and account for the vast majority of meteors that are used in radio work. Their radiants and times of occurrences are random and cannot be cataloged as shower meteors can; however, it is known that they are not uniformly distributed in the sky but are mostly confined to within about 20° of the ecliptic plane (the plane of the earth's orbit about the sun). Also, the intersection of the meteor orbits with the earth's orbit are not uniformly distributed but are concentrated so as to produce a maximum of intersections in August and a minimum in February, with about a 4:1 variation. The rate of incidence of sporadic meteors is further dependent upon the time of day with the morning hours being more active. On the morning side of the earth, meteors are swept up by the forward motion of the earth in its orbit around the sun. On the evening side, the only meteors reaching the earth are those which overtake it. A daily variation of about 4:1 can be expected.

Characteristics of Reflected Signals

Radio signals received on a meteor-burst link are basically of two forms. The most prevalent of which is the underdense trail reflection. In this case, the reflecting meteor is characterized by a relatively low electron line density (q 10^{14} electrons/meteor). An underdense trail does not actually reflect energy, instead the radio waves pass through the trail exciting individual electrons as it does. These excited electrons act as small dipoles re-radiating the signal at an angle equal but opposite to the incident angle of the trail and radio signal.

Signals from underdense trails rise to an initial peak value in a few hundred microseconds then decay exponentially in amplitude. Decay times from a few milliseconds to a few seconds are typical. The decay in signal strength is due to distructive phase interference caused by the radial expansion or diffusion of the trail's electrons.

Meteor trails with electron line densities greater than 10^{14} electrons/meter actually reflect signals and are called overdense. Here the line density is so great that radio signals cannot penetrate them and are actually reflected instead of re-radiated. There are no distinctive patterns associated with overdense trails except they usually reach higher amplitudes than underdense and usually last longer. Signal fading often occurs due to reflections from two parts of the trail destructively interfering. Ionosphere winds blow these trails around causing some of the fading. The period of the fading is usually greater than a few hundred milliseconds and thus does not affect the typical intermittent MBCS. A fairly good illustration of this type of trail is the contrail left by a high altitude jet and the effects of wind on it. Due to the unpredictable nature of the signals, no useful theory has been developed to describe them.

Other means of communication over the typical MBCS are airplane reflection at distances of less than 100 miles. These usually last many seconds and are characterized by a great deal of signal fading. Sporadic E also contributes long periods of communication time.

As stated above the typical MBCS will utilize all methods of propagation but will mainly rely on underdense meteor reflection.

System Description

A MBCS system is composed of two types of terminals, a base or master, and remote stations. Normally, one master station communicates with a number of remote stations. Fig. 2 is a block diagram of the two stations. Boeing has recently developed, fabricated and field tested such a system. The specific hardware is described below.

Master Station

I. Communication Unit - The receiver/modulator assemblies are completely transistorized and are of modular construction. The receiver is solid state of modern design. The transmitter has a controlled output up, to 2000 watts of RF power. The communication unit modulates the carrier with information obtained from the control unit and will transmit the data via the antenna. Furthermore, the signal from the remote unit is received, demodulated and clocked to the control unit for processing.

The unit is of modular construction using an integrated packaging technique. Components are mounted on 9.25 x 4.5 edge connector cards that are housed in a card file that fits a standard 19-inch rack.

II. Control Unit - The control unit consists of a minicomputer that is interfaced with the communication unit of the master. station. Through software, the control unit formats and processes the codes that are transmitted and received by the communication unit. A teletype printout is used to display the received data and the keyboard is used to input the different command sequences to the selected remote station. The computer is programmed to automatically control the entire sequence.

III. Power Unit - The master station transmitter is powered with 220 VAC single phase power. In the mobile configuration, the 110 VAC is obtained from one side of the 220 VAC line and is used to power the various power supplies and test equipment. The power supply produces the required voltage for the electronics of the various modules.

IV. Antenna Unit - The antenna unit is comprised of two (2) stacked five (5) element yagi antennas and a duplexer designed to operate continuous duty. The antennas feed a high power duplexer section allowing full duplex operation at the base station.

Remote Station

I. Communication Unit - The transmitter/receiver assembly is completely transistorized and is of modular construction. The electronics are designed for minimum power consumption. The receiver is a modern solid state design. The modular construction of the power amplifier section offers a selection of RF power outputs. The remote station can transmit from 20 watts to 300 watts of RF power.

The communication unit will receive, demodulate, and clock the data to the control unit. The communication unit also receives data from the control unit and modulates it on the remote unit carrier frequency, and forwards it to the antenna unit via the T-R switch.

II. Control Unit - The control unit formats and processes messages that are transmitted and received. The logic module is designed with COS-MOS logic for minimum power consumption when in the operational mode. Jumper wires are used to program the station address.

III. Power Unit - The remote power unit is powered by battery, and can either be continually trickle charged, or operated in isolation. The length of isolation time and interrogation rate will determine the battery size requirements.

IV. Antenna Unit - The antenna unit is comprised of one (1), five (5) element yagi (or a dipole) and a T-R switch. The antenna feeds the T-R switch section allowing only simplex operation at the remote station.

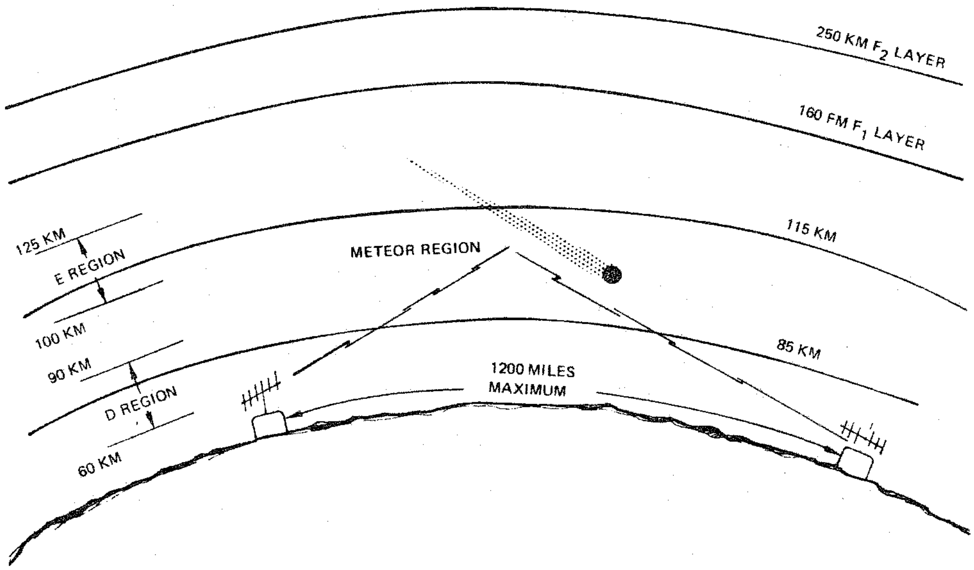


Figure 1: METEOR BURST COMMUNICATION SYSTEM

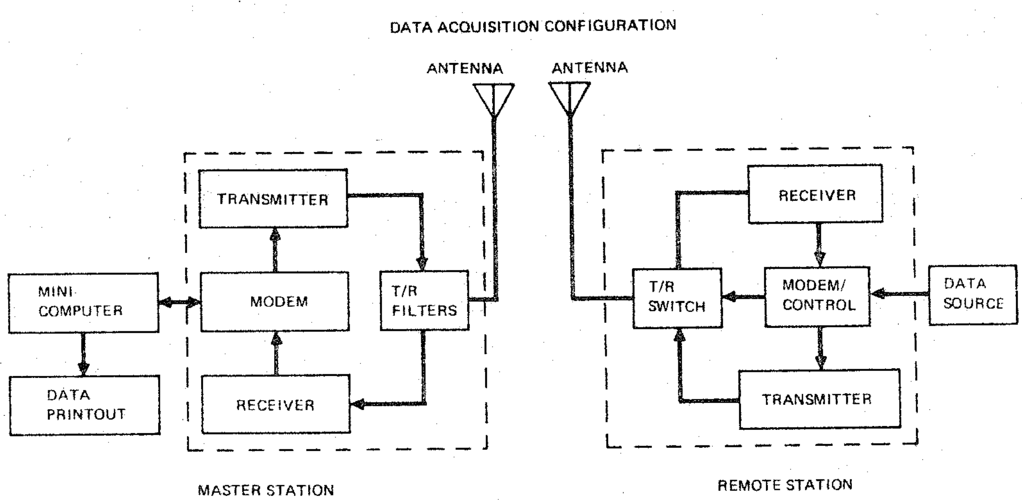


Figure 2: METEOR BURST COMMUNICATION SYSTEM

Operational Sequence

A typical operational sequence starts when the master station continually probes the sky for a suitable meteor trail. The probe consists of digital information that is modulated on the master station VHF carrier frequency and is continually being transmitted. The information includes a preamble, recognition code, and a remote station address code. The coded digital signal is received at the remote station when the meteor trail is properly oriented and is suitably ionized. The remote station is in the standby configuration for maximum battery life. When the signal is received, the remote station becomes operational and the digital information decoded. If during the decoding it is determined that the addressing is incorrect, the station will return to the standby mode. However, if correct, the remote station will transmit a block of data to the base station over the same meteor trail. When the master station receives the remote signal, the computer will examine the addressing and, if correct, will accept the data.

Performance

Performance of a MBCS is measured in the number of error free data receptions at the master station. The following performance was obtained by field testing the system described in this paper over the past one and one half years.

Performance will vary with a number of parameters which include transmitter power, operating RF frequency, receiver sensitivity, and antenna gains. The following performance data is based on parameters which reflect a reasonable hardware configuration. That is, no high power transmitters or large antenna configurations.

Diurnal Characteristics - Operation varies over the daily cycle as shown in Figure 3. Nearly 400 receptions per hour were received in the early morning hours, and 100 per hour in the evening hours. This 4:1 daily variation has been demonstrated to be consistent throughout the year.

Yearly Characteristic - Performance over a yearly cycle also has a four to one variation, with a maximum in August and a minimum in February. If the curve of Figure 3 were plotted with data during February, the morning maximum would be approximately 100 receptions per hour and the evening minimum at 25 receptions per hour.

Range Characteristics - Performance over the possible operating range of 0 to 1200 miles varies as shown by the curve in Figure 4. Actual testing was not performed beyond 1000 miles. Data was sampled at the same time of day to provide comparable results for the ranges measured. The 160 messages per hour shown are not indicative of the maximum daily message rate. The basic reason for the reduced performance at short and long ranges was the reduction of common sky at the 80 to 100 Km altitude region between the two stations. Therefore, the number of usable meteor is reduced as compared to mid-range (400 to 800 mile) operation.

At some range, as the two stations become closer and closer together in range, a continuous master station signal can be detected at the remote station. The range at which this can occur is highly dependent on the nature of the horizon angle of each of the stations. This range was detected to be as far as 150 miles given a fairly low (less than two degrees) horizon profile between the stations.

Message Waiting Time - An important consideration in the application of Meteor Burst Communications is the expected waiting time between messages. Figure 5 plots this statistic during the daily minimum performance hours, 1600-2000, and the peak hours from 0400 to 0800. Ninety percent of the wait intervals are less than two minutes during the least active period of the day (1600-2000).

Arctic Operation

The effects of the aurora on low VHF communication have been investigated by the Institute of Space and Atmospheric Studies at the University of Saskatoon. Scatter tests indicate that signal fade rates occur in the 5 to 50 Hertz range. A meteor burst system, by its short term operation (less than 0.1 second), would operate successfully on these scatter signals. The communication rates will be greatly enhanced whenever the aurora conditions exist,

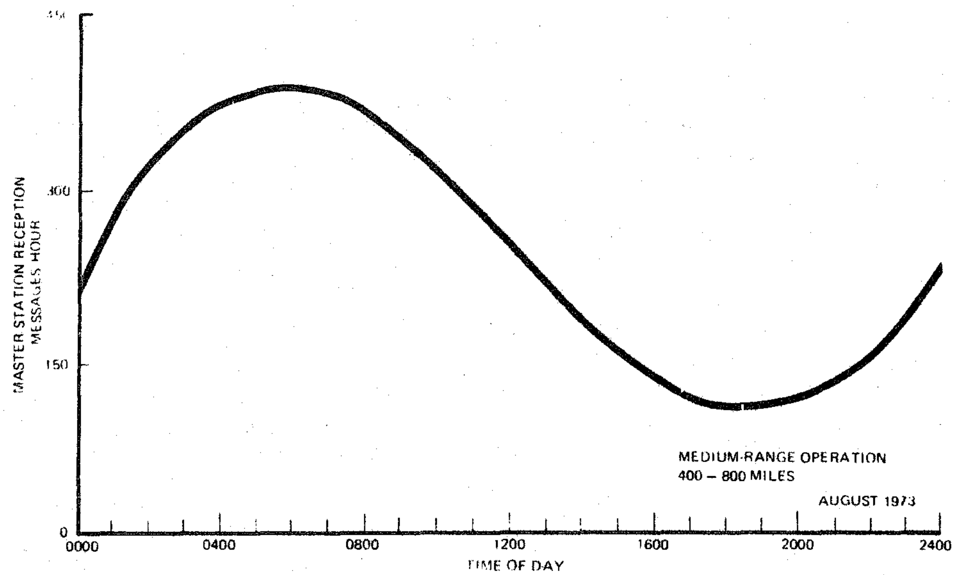


Figure 3: ***METEOR BURST COMMUNICATION SYSTEM DIURNAL DATA RATE VARIATION***

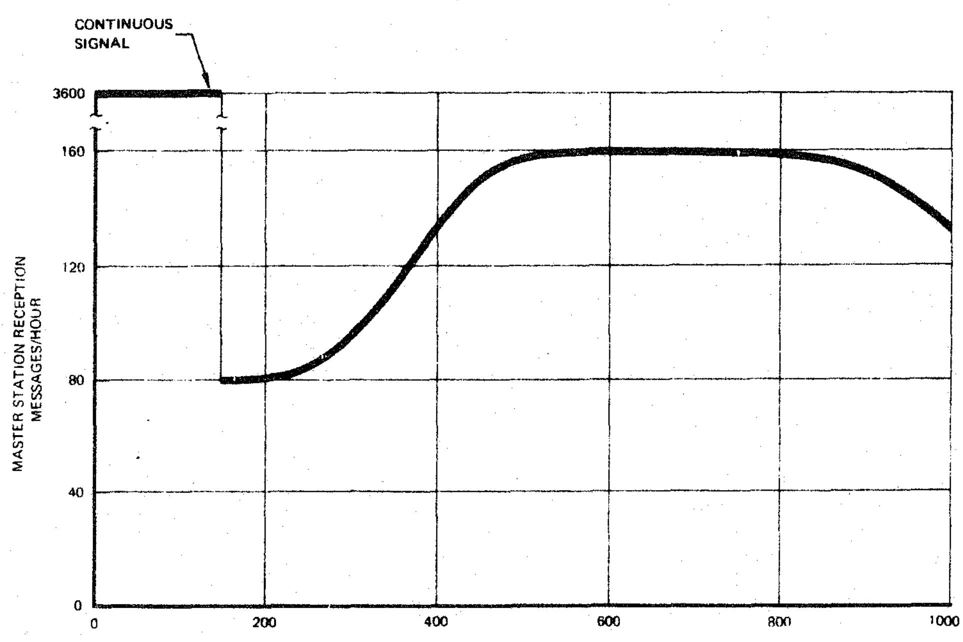
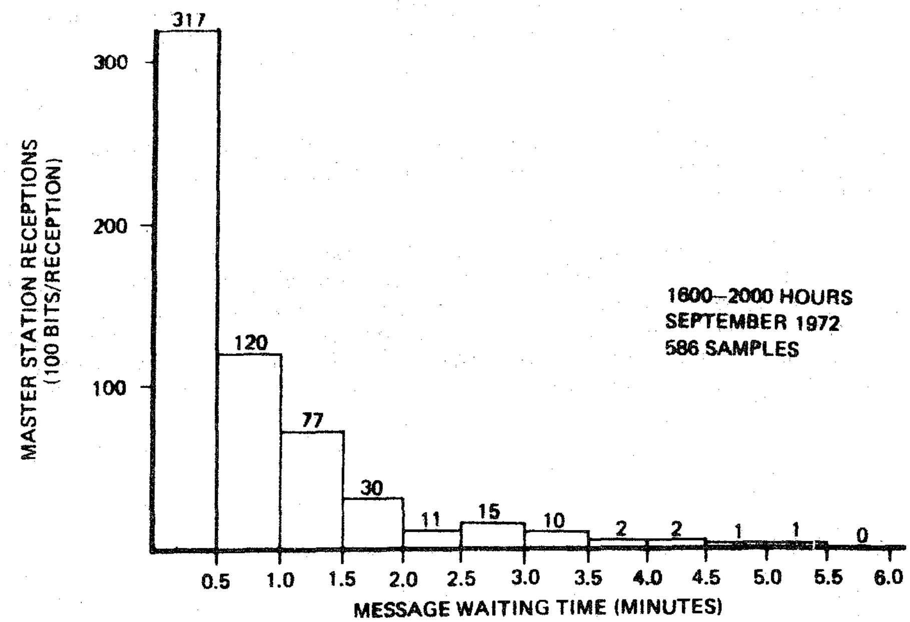


Figure 4: ***METEOR BURST COMMUNICATION SYSTEM DATA RATE VS RANGE***



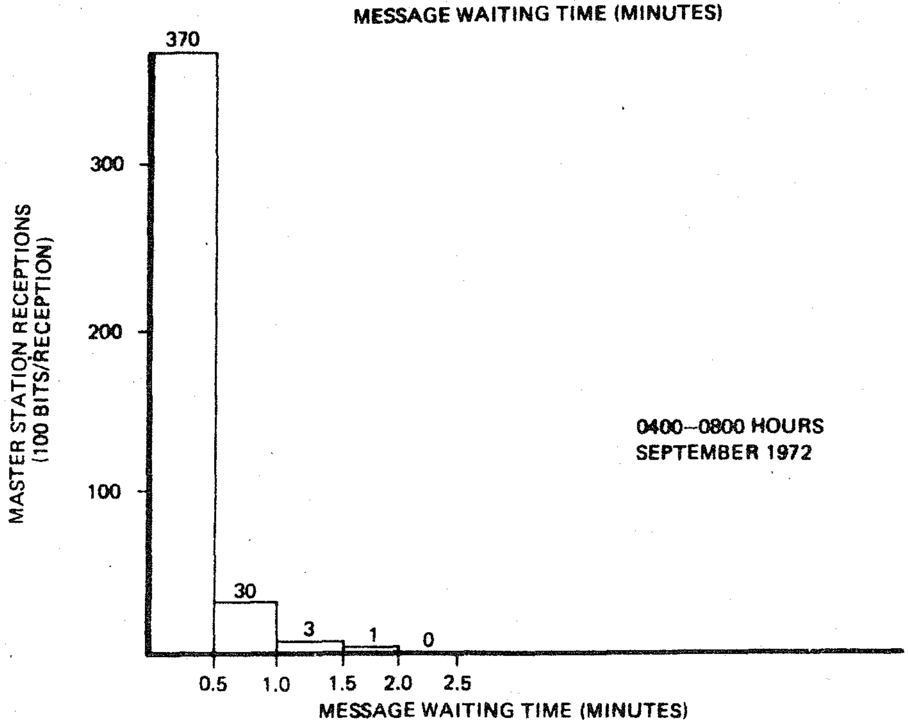


Figure 5: METEOR BURST COMMUNICATION SYSTEM MESSAGE WAITING TIME

A similar type of scatter has *been* observed in the Far East, and is known as the Far Eastern anomily or F-Scatter. A meteor burst system has been demonstrated to operate effectively on this F scatter. The Institute of Space and Atmospheric Studies plans to conduct additional forward scatter tests in 1974.

Summary

Application of Meteor Burst Communication technique to remote data collection provides a very cost competitive approach where the requirements fit within the Meteor Burst statistical capabilities.

An example of an ideal application is the communication link to remote stations being installed in the Northwest mountain areas to gather hydrological and meteorological data. The Bonneville Power Administration (BPA) plans to install meteor burst communications to a number of their hydromet remote stations. BPA can thus monitor remotes throughout their mountainous domain (Washington, Oregon, Idaho, and Montana) from a single central control station. No relays or intermediate communication means will be required.