Design of a Low-Cost Data Communications/R.F. System for use with Low Earth Orbiting Store and Forward Satellites.

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Abstract: The functional requirements and system overview for a low cost data communications system for small satellite use are presented. Tradeoffs of system parameters will be discussed such as: cost, transmission speed, power consumption, spectrum useage, and system complexity. Link calculations at 137 MHz, with transmission speeds of 9600 BPS, monopole antennas, and a 50kHz bandwidth show that adequate signal margins can be obtained with 2 Watts of R.F. power for most conditions. Use of low cost, amateur or commercial type radio equipment requires only minor modifications, and creates small reliability and performance risks.

INTRODUCTION

Communications satellites have traditionally been expensive, custom designs and have used high reliability space rated components. Some of this effort towards extreme reliability can be attributed to the high costs of launching such a satellite, and hence, the high replacement cost. Even groups of radio amateurs (hams) which operate with limited capital resources have built their satellites in a similar, high cost manner.

The advent of low cost launch vehicle has required a re-thinking of such an approach. The lower cost satellites which can be flown with such launch vehicles require low cost communications systems to be developed. The overall percentage of communications system to satellite cost may not scale directly with the lower cost, but the range should be similar for both high and low cost satellites. Figure 1 shows a cutaway view of a representative small satellite, the Globesat GS-100 satellite system. The body of the satellite is roughly 19 inches in diameter, and is 37 inches long.

Regardless of the cost, a satellite communications system must meet several functional requirements. The requirements for the Globesat GS-100 communication system are typical of these systems and are given as follows:

- Small size (less than 1 cubic foot)
- Low power
- Inexpensive (less than $1 per bit per second) (BPS)
- Moderate data rates (4800, 9600 BPS)
- Automated data collection from unattended remote terminals
- Operating frequency in experimental satellite band (137MHz)

- ¨ 50 kHz total bandwidth
- Maximum use of off the shelf, existing components and modules.

Such requirements, as a group create a non-trivial problem for the communications engineer. The communications system will operate in a store and forward mode, wherein a store and forward vehicle (in this case a satellite) will be programmed by the control station to collect data from remote terminals. Such a system also may be used to provide remote reprogramming of the satellite or remote terminal computers. Figure 2 shows a conceptual diagram of a store and forward system.

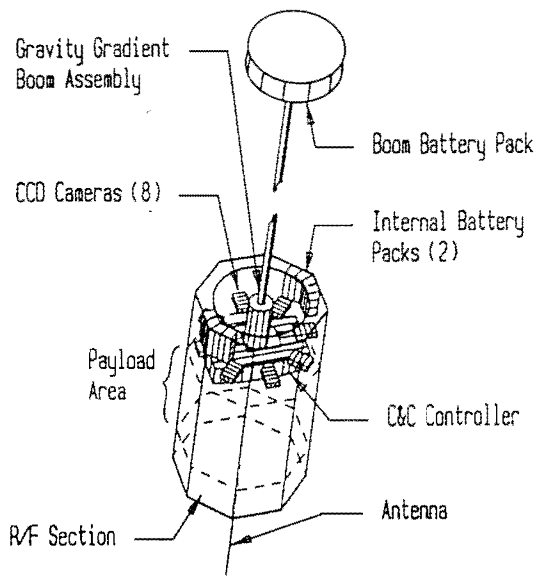

Fig. 1 Globesat GS-100 satellite.

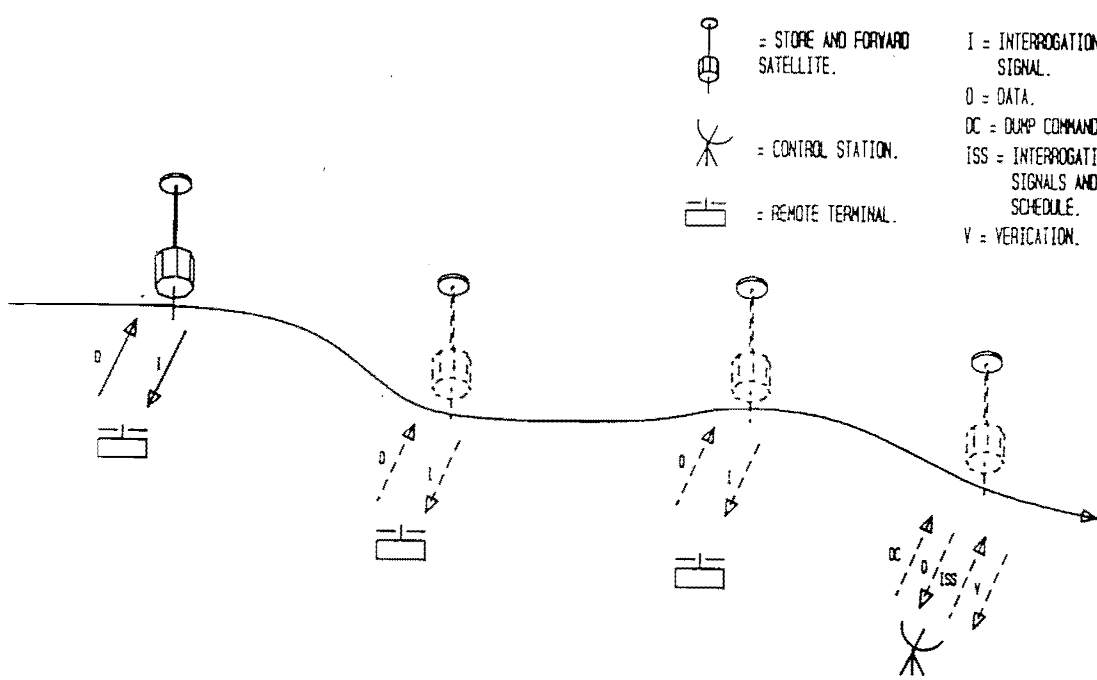

Fig. 2 Store and forward data retrieval system.

SYSTEM OVERVIEW

In order to meet the overall requirements, communications systems are typically constructed by combining a number of modules into a single unit. Ideally each module within the overall unit or system accomplishes a specific purpose or function. Some systems may have several of these modules integrated into a single larger module, or have some functional overlap between modules. A block diagram of a generic store and forward system is given in Figure 3 The block diagram can be divided into two major portions: designer independent and design dependent.

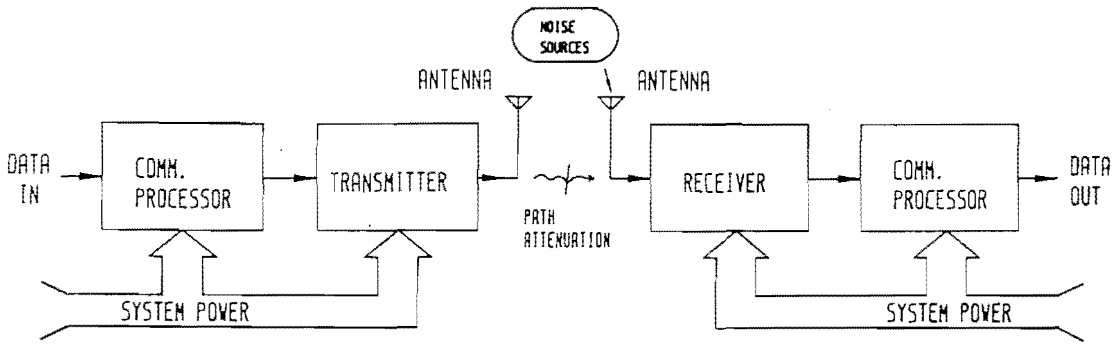

Fig. 3 System block diagram.

Design Independent Portion

The designer independent portions of such a system are those items over which the designer has little or no control. Some of these items are noise sources, noise source distribution, RF channel/link, link variations, link attennation, and electrical power limitations. One can estimate the system feasibility from a determination of these factors and a knowledge of the overall system design.

The noise sources which typically affect communications system are grouped in astronomical and terrestrial sources. Probably the strongest astronomical noise source is the sun. However, a ground observer will encounter very few times in which the satellite position is close enough to the sun so as to block the satellite transmissions due to noise. The moon can also cause increased noise, but due to lower surface temperature, the noise levels are much lower. Sky noise, which is mostly a result of the stellar distribution in the galaxy, can create high noise levels. The small angular distribution of such high noise areas or "hot spots" at 137 MHz should cause only a limited number of retransmissions to be required from the satellite.

The modern lifestyle has created an ever increasing number of terrestrial noise sources. In many locations, automobile ignition noise is the main component in the noise background. The typical patterns of automobile useage can be seen in the daily and weekly noise level variations. Power lines, electric fences, electronic equipment, radio trqansmitters, and rotating machinery are additional sources which contribute to the overall noise background at any given location and time. The worst case (maximum) noise levels are very difficult to design a communications system around. Most satellite communications systems have some flexibility in the locations of the remote terminals and the control stations. If a particular location is found to have a high noise level, the station can be moved to a new location. This new location may need to be a suburban or even a rural site for acceptable noise levels. The Globesat system is designed to operate in a maximum equivalent sky temperature, and maintain a 3dB saftety margin.

Of the designer independent portion, the RF channel or link is the most unpredictable. The overall path attenuation can change due to weather, ionospheric effects, or other causes. The general practice is to take the known or expected path losses, and then add some safety margin to the overall attenuation.

This total attenuation is what the system must be designed to handle. Most systems are sufficiently robust to be able to handle the repeats or retries of the path attenuation is worse than expected. The channel must also be designed within the national and international agreements for frequency selection and useage. For example, 137 MHz is an internationally allocated frequency for experimental satellite use

The power required for the satellite communications system must be minimized. While reception may only consume small amounts of power, transmission consumes large amounts of power. The Globesat communications system minimizes power consumption in two ways. First, the transmit/receive duty cycle will be controlled within the power resources of the satellite, remote terminal or control station. Second, power will be continuously applied only to those portions of the receiver which are necessary to detect the presence of a signal. This is similar to the squelch on feature on many modern radios. When a signal is detected, the remainder of the receiver and the communications processor are powered up. Such a system design can cut the overall power communication of the receiver to about one-fourth of the un-squelched level. The cost is the additional system complexity required to do the necessary power switching. To reduce the power draw further would require that the system completely power down the receiver, which was judged to present an unacceptable risk.

Designer Dependent Portions

Link calculations are the point at which the designer must consider both the designer independent and dependent portions of the overall system. Figure 4 shows the results of a sample link calculation. Sucessful radio link designs require a balance between the tradeoffs in many areas. The required system bandwidth can be calculated from a knowledge of the modulation method, the encoding scheme (with the resultant signaling rate), and the bit rate to be transmitted. The received signal power level is calculated by knowing the transmitter output power, the antenna gains, the seperation distance between the

SATELLITE TO RT LINK BUDGET BPSK (RATE 1/2 CODING)

4/3 Earth model:				
Ground Elevation angle (E)	7.0	deg		
Earth Radius (r), in 4/3 model	8,500	km		
Satellite Elevation angle (B)	20.4	deg		
Satellite altitude (h)	500	km		
Slant Range (S)	2,098	km		
Frequency	137.5	MHz		
Transmitter:				
Transmitter output power	2.0	w	33.0	dBm
RF Line losses	-1.2	dB	-1.2	dB
Antenna gain	3.0	dBi	3.0	dBi
EIRP			34.8	dBmi
Channel:				
Free space loss	-141.6	dB	-141.6	dB
Atmospheric losses	-8.0	dB	-8.0	dB
Signal strength at receiver			-114.8	dBm
Receiver RF:				
Antenna gain	3.0	dBi	3.0	dBi
RF line loss (L)	-0.7	dB	-0.7	dB
Total RF carrier power (S)			-112.5	dB
Receiver Demodulator:				
Rec. noise figure (F) @ 290 K	2.0	dB		
Total sky temp (Ta)	2,000	K		
Treceiver (Trec)	170	K		
Tsys	1,915	K		
kT	-165.8	dBm/Hz		
Symbol rate (Rs)	19.2	ks/s		
Es/N0 available (S/(kT*Rs))	10.4	dB	10.4	dB
Es/N0 required (w/coding)	4.5	dB	4.5	dB
Signal Margin	5.9	dB	5.9	dB

Fig. 4 Sample link calculation.

transmitter and receiver, the transmission medium characteristics (including attenuation), and the receiver sensitivity. The received noise power depends directly on the background noise levels, and the system bandwidth. If the link calculations show that the system does not provide adequate signal strength or link margins, the designer must consider ways of obtaining a stronger signal. Directional antennas can be used, but either incur an access time penalty, or place a tracking requirement on the system. The transmitter power can be increased at the cost of additional power consumption. Only a small improvement (if any) in the overall system performance can be obtained by improving the receiver internal noise levels, since most of the received noise results from the enviroment. This may require a relocation of the ground stations to a less noisy enviroment. The path length from the satellite to a given ground station changes with time. Simply waiting to establish communications with the satellite until the satellite has moved closer may be sufficient. Additional system gain may be obtained by encoding, at the expense of increased power consumption and system complexity.

The designer dependent portions of the communications system are the communications procesesors, transmitter, receiver and antennas. Both the transmitter and receiver consist of a number of modules connected together. The transmitter for the GS-100 system consists of an encoder, modulator, power amplifer and directional couples. A transmit/receive switch may be included if the same antenna is used for both transmit and receive functions. The corresponding receiver consists of a low noise amplifier, RF amplifier, demodulator and decoder.

The communications processors at each end function to create a reliable RF link for computer to computernetworking. This is accomplished via packet radio using a modified version of the X.25 computer networking protocol[1,2.] The transmitter must encode and modulate the data to be transmitted on the RF carrier, and then boost this carrier level to the required RF power output. The directional coupler is to allow measurement of forward and reflected power on the antenna feedline for system diagnostics. The overall DC to RF efficiency of transmitters generally decreases with frequency. At 137MHz, the expected effiency is approximately 30%. The receiver must amplify the weak signal received from the transmitter (without addition of harmful noise), demodulate the encoded data from the carrier, decode the data, and finally store the data in the appropriate location.

The modulation/demodulation and encoding/decoding processes are distinctly different. The encoding/decoding process via a convolutional encoder and a Viberbi decoder gives up to a theoretical 6dB processing gain. This processing gain is acchieved by sending multiple symbols for each bit to be transmitted. The actual symbols transmitted depend on a known algorithm, and the n previous bits to be transmitted. Certain patterns or sequences of symbols are not allowed. The receiver can from a knowledge of the encoding process and the received symbols, reconstruct the original bit stream. This is true even if certain of the symbols are received incorrectly. The processing gain (using rate 1/2 encoding) is achieved at the expense of doubling the information rate, or halving the throughput, based on a non-coded system.

The modulation/demodulation process is to allow the information to be transmitted more efficiently over long distances and to minimize the signal attenuation. Typically, data transmission is done using Frequency Shift Keying (FSK) or Phase Shift Keying (PSK). The GS-100 system uses a Binary Phase Shift Keying (BPSK) modulation, and realizes 5dB coding gain with convolutional encoding. The demodulation of BPSK signals, and the decoding of the encoded information are the most difficult tasks in the entire communications system. Correspondingly, the cost of these two modules will typically be about one-third of the total communications system cost.

The antennas used for the satellite, remote terminal and control stations must be designed in accordance with the requirements for each station. The satellite antenna must be stored for launch. The remote terminal antenna must have an omni directional pattern or suffer the reduced view angle (and hence satellite passes) of a directional antenna. The control station must be able to communicate with the satellite under adverse conditions. The polarization of the transmitted signals must also be considered as part of the station requirements. Circular polarization is less resistant to ionospheric losses, but requires more complex antenna systems for each station. For the satellite, the launch storage and small size requirements led to a choice of an omni directional quarter wave stub antenna. This was judged to be a reasonable comprimise of size, complexity, gain and antenna patterns. The remote terminal antenna is also a quarter wave stub. The comprimise for this antenna was based on mechanical stability, gain and antenna patterns. The antenna system for the GS-100 control station will be a high gain directional array mounted on a azimuth-elevation tracking system. The primary concern for the control station antenna system was to maximize the transmitted and received signal strength. In doing so, the directional antennas will help to minimize the noise received from directions other than the direction to the satellite.

Equipment Types

Many of the modules and system components for such communications system have been developed for use in commercial land mobile radios. Another group of manufactures produces similar modules for purchase by radio amateurs. While these designs are not built to the usual aerospace specifications, the commercial market place effectively provides rigorous testing. If the small reliability and performance risks of such components (when considered against the moderate replacement cost of the satellite) can provide a large cost savings for such satellite systems. Some systems may truely require the standard aerospace, modules constructed of class S devices. For such systems, the high cost of such a traditional approach must be tolerated. The overall risk assessment, cost and performance tradeoffs are left for the system designer to consider.

The transmission bandwidth of the system must be matched to the data transmission rate and the choice of modulation. Different types of modulation schemes require different spectral bandwidths to transmit the same information. For FSK, roughly 4Hz minimum is required to send 1 bit per second. Using BPSK, roughly 2Hz is required to send the same 1 bit per second. The modulation types and required bandwidths are well documented in many communications references[3]. If the required information bandwidth is equal to or less than the typical 2700Hz bandwidth for voice radios, one may consider using such radios as part of the overall system. Special purpose designs of moderate cost, dedicated information transmission radios are now becoming available on the commercial market.

CONCLUSION

The design of a satellite based store and forward communications system must meet the system design requirements in order to be useful. The system must integrate the portions over which the designer has little control with those the designer can control. Such an integration must be based on the system requirements and assumptions, as well as the calculated and measured performance of the designer specified modules. Special consideration by the designer should be given to the computer networking protocol implemented in the system, not only with regards to the performance, but also to the availability of dedicated networking processors. The antennas specified for each station must provide the needed signal gain in the desired direction, and if possible signal rejection in undesired directions. The overall choices for equipment specification in the satellite communications system must be based on the system specification and the designers judgement. Several system designs can meet the same set of requirements.

ACKNOWLEDGEMENTS

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