Telesat

Telesat Canada

DEPARTMENT OF COMMUNICATIONS
OTTAWA, CANADA

SUBMITTED BY
TELESAT CANADA
OTTAWA, CANADA

Date:

STANDARD TIME BROADCAST USING MSAT

TASK 24

PREPARED FOR
DEPARTMENT OF COMMUNICATIONS
OTTAWA, CANADA

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SUMMARY

This report examines the feasibility of operating a time broadcast service on MSAT. This service may be used to replace NRC's time broadcasting radio station CHU.

The primary focus of the report is on using spread spectrum to transmit the time signals, but conventional transmission methods are also examined briefly.

The use of coding to provide security from unauthorized use of the system is studied. Encryption can be provided economically using the Data Encryption Standard, but the use of encryption is of limited value since timing information is inherently carried by the transmitted signal. Spread spectrum provides a degree of security by means of its low power level.

The accuracy of the satellite time transmission system is examined and it is shown that the computation of path delay to the satellite determines to a large extent the accuracy of the system. It is recommended that predicted information about the satellite location be transmitted along with the time information to aid the receiver in computing this parameter.

Link budgets are computed for a spread spectrum time broadcast system at MSAT UHF and L-band frequencies and at 400.1 MHz. The link budgets are designed so that the interference of the time service into the other MSAT services will degrade the baseline interference budget by only 0.3 dB. The maximum data rate that the spread spectrum system can support for a bit error rate of 10^{-6} is computed. The link budgets for both mobile and fixed receivers are presented.

The link budget results show that low data rates would have to be used for a service operating at MSAT frequencies because of the interference from the voice signals. A data rate of 1.3 bps could be used and a bit error rate of 10^{-6} would be achieved at a UHF fixed terminal if the spread bandwidth was 50 kHz. A data rate of 1.2 bps would be used to achieve the same performance at an L-band fixed receiver. The spread spectrum service at 400.1 MHz could operate with higher bit rates, since there would be no interference from other MSAT services. The data rates would be: 89 bps for mobile service and 240 bps for fixed service.

The effect of the time broadcast service on the payload of the MSAT satellite is examined. It is shown that operation of the service at 400.1 MHz is not attractive because of the reduction in capacity of the other MSAT services due to the additional payload. Similarly, it is not advisable to carry the reference clock on-board the spacecraft since the associated weight and power drain would reduce the capacity of the other MSAT services.

1.0 INTRODUCTION

This is a report of the work performed on Task 24 of the MSAT engineering support contract: "Standard Time Broadcast Using MSAT". The impetus for this contract was a request from the National Research Council to study the feasibility of transmitting standard time signals at 400.1 MHz using MSAT. Transmissions at UHF and L-band are also considered in this report.

The time service on MSAT will be considered as a replacement for radio station CHU. NRC broadcasts radio time signals from station CHU operating at frequencies 3.33, 7.335, and 14.67 MHz. The signals are transmitted using upper single sideband with carrier reinserted. The frequencies are derived from a pair of cesium clocks at the transmitter site. The CHU transmission format basically consists of a voice announcement of the time once a minute and in between the voice announcements the time is transmitted nine times a minute digitally using an FSK code. The format of the time signal is shown in Figure 1 [1].

The accuracy of the time signal at the transmitter is normally within 0.1 ms of a cesium clock at the transmitter site, and the clock itself is accurate to within 10 μs of the international time scale [1].
For most places in Canada, the time signal from station CHU will be received via a skywave. The accuracy of the signal, then, depends on the user's location and current ionospheric conditions.

The cost of operating CHU is approximately $150,000 per year [2]. NRC is considering charging a fee for use of the service on MSAT so that capital and operating costs

CHU DATA TRANSMISSION SEQUENCE

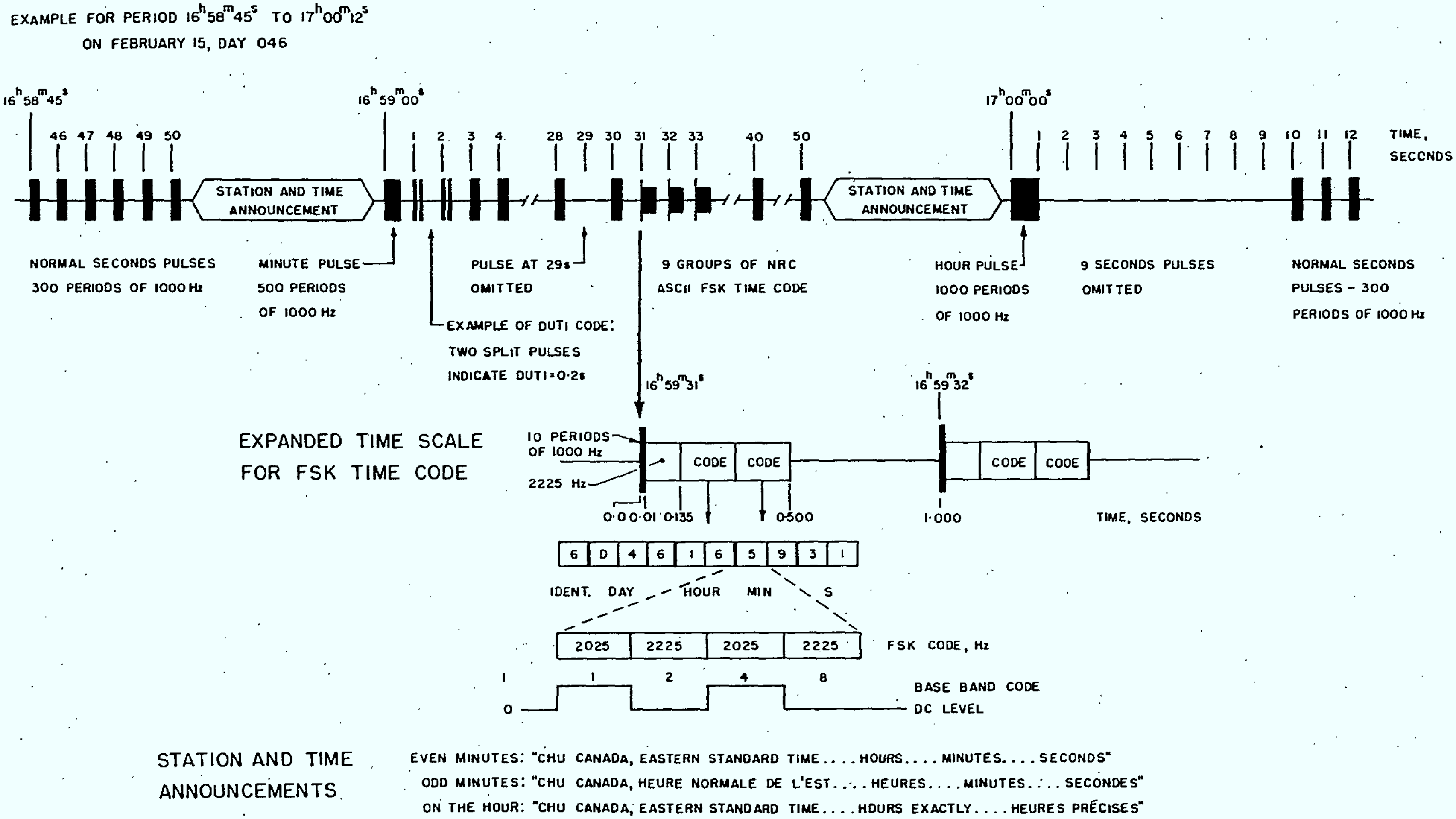


Figure 1

can be recovered In order to deny access to unauthorized users, it is likely that the time transmission via MSAT will be encoded and licenced users will be given the means to decode the transmissions.

There are different methods of transmitting time signals on the MSAT system. The time reference (clock) could be on the ground and the time signal would be transmitted up to the satellite and down to the user. The clock could instead be placed on the satellite so that the time would be broadcast over one link only. However, the provision for periodically correcting the clock on board the satellite should be included.

If the time broadcast service is at 400.1 MHz on MSAT, it would then have its own dedicated transponder chain. If the service is at MSAT UHF (800 MHz) or L-band, the time service could either use the same transponder as the conventional MSAT channels, or it could have its own associated payload.

There is substantial demand envisaged by NRC for a time service broadcast by MSAT. Up to 100,000 users could develop if the cost of a receiver were to be kept below a $50 ceiling [2]. It is estimated that there are 10,000 serious users in Canada.

2.0 USER'S REQUIREMENTS

There are many potential applications for a time reference signal transmitted via the MSAT system. Some examples are: a time of day reference for organizations that operate on a schedule such as radio and television stations; industrial use for controlling processes that must be accurately timed; a time-of-day reference for computer systems; a time display for mobile users, etc. Note that a mobile user with an MSAT terminal may want to add the time service as an option, but it is unlikely that a mobile terminal used only to display the time of day would be economically attractive.

The MSAT time receiver will contain an accurate clock. The time signal received from the satellite will be used to periodically update this clock. Coding will be used to detect and correct errors due to noise. Any detected errors which cannot be corrected will result in the transmission being ignored. Since the receiver will then wait until the next update period to correct its clock, the time accuracy will be degraded and therefore, update cycles must be selected judiciously to result in an acceptable overall accuracy.

Users requiring highly accurate time signals will generally be located at a fixed site. Therefore, they will be using a fixed antenna to receive the time signals. Since they do not require a margin to account for shadowing loss, the performance of their receivers will be better than that for a mobile user.

Mobile users will have to accept a less accurate time signal because shadowing of the satellite signal due to road-side trees will cause errors in the received signal and therefore, increase the time between clock updates. Since mobile users might use the time service as a display of the time of day, this reduced accuracy could be acceptable.

As the time signal will be transmitted via satellite, there will be a delay due to propagation time. This delay can be accounted for if the user knows his location exactly. This will be the case for the user with a fixed earth station, but not for the mobile receiver. Since the position of the mobile receiver will vary with time, the operator will have to use an "average value" for the position of the vehicle when estimating the propagation delay. The error involved with this approximation should not be a problem for the mobile users if the time service is only used as a time of day display.

3.0 TRANSMISSION METHOD

There are a number of factors to consider when determining how to transmit time signals to users. These include: security to ensure that only licenced users access the system; the bandwidth and power required to transmit the signals which determines to a large extent the cost of the system; the complexity of the receiver which affects the cost of the receiver.

Security for the system can be achieved by coding. Encryption methods such as public key encryption can be used to limit access to authorized users. Another method is spread spectrum whereby the data signal modulates a pseudo-random sequence. Only users who know the pseudo-random pattern can demodulate the signals. Although this method may appear to require more bandwidth than the data signal, the spread spectrum signal can be transmitted at an extremely low power level, even below the noise floor of the receiver. The signal can then be transmitted in the same bandwidth as other MSAT signals, effectively reusing the bandwidth. The effect of interference from the spread spectrum signal on normal MSAT channels should be kept to an acceptably low value. A spread spectrum technique is the method preferred by NRC [2].

4.0 CODING

There are two types of coding which could be used with the time broadcasting service: coding for security and coding for error detection.

Coding for security is a technique to change the data so that it cannot be understood by unauthorized users. This may be required if the users are expected to pay a subscription fee to use the service.

Coding for error detection may be implemented so that errors do not cause an incorrect time value to be used. The type of code needed depends on the characteristics of the transmission link, the complexity desired, and the bit error rate desired.

Both types of codes are considered in the next sections. Note that coding for security and coding for error detection are independent of one another. The use of one does not preclude the use of the other.

4.1 CODING FOR SECURITY

Since this service is only intended to be available to users who pay a fee, it is desirable to make the system difficult to access for unauthorized users.

The spread spectrum technique offers a degree of security since the spread spectrum signal is transmitted at such a low level that it is more difficult for an unauthorized user to observe the signal and determine its characteristics. However, the code used to spread the bandwidth of the signal is not designed to provide security. If the security provided by the spread spectrum technique is insufficient to satisfy the requirements of the time service provider, then the message would have to be encrypted. There are many encryption methods that can be used to provide security. The Data Encryption Standard (DES) adopted by the U.S. National Bureau of Standards has also been adopted by many other users. This has resulted in hardware being widely available at low cost [3].

Public key encryption methods eliminate the need for both sender and receiver having a secret key. The sender looks up the receiver's public encryption key, then encrypts the message and sends it. The receiver uses his own private decryption key and is able to decrypt the message. It is very difficult to break the code knowing only the encryption key. This system is very good for setting up communications between parties who have never communicated before. However, this feature is not important for the time broadcast user since communications are one-way and always from the same source.

The DES system seems to be a practical choice for achieving secure time broadcasts.

Adding an encryption technique to the data transmitted by the time service will effectively prevent unauthorized users from receiving time-of-day information from the service. However, regardless of any encryption method used, the time service broadcasts will contain timing information which is impractical to conceal. This information is contained in the transitions of the data stream which are controlled by the reference clock to give the desired precision.

4.2 CODING FOR ERRORS

The transmission of time-of-day information via the time broadcast service creates a need for an error detection capability at the receiver. This need is further increased if longer update periods are chosen.

For mobile receivers, the gain of the code is of little importance since the line-of-sight path to the satellite could be blocked sufficiently to cause the bit error rate to drop below the design value 1% of the time. This limitation is a minor one, since the mobile user will likely use the service only for a display of time. Missed updates due to errors are, therefore, more tolerable.

The utility of coding is highest for the user with a fixed receiver. The signal from the satellite is constant for a fixed receiver.

There are two main categories of codes: block codes and convolutional codes. Block codes operate on a block of bits. Convolutional codes operate on a continuous stream of bits. Bits are fed into a shift register and each baud interval a number of the shift register outputs are combined to form one or more output bits. Convolutional codes are not especially suited to applications in which the messages are transmitted in bursts. Convolutional codes are complex to decode at the receiver. Therefore, they are not suited for a time broadcast application where the receiver cost should be kept low.

There are many different block codes, with different data rates and error correction abilities. Some are designed to reduce the effects of random errors and some correct burst errors.

The environment in which fixed receivers will operate is assumed to be such that the signal received from the satellite is constant. Therefore, thermal noise in the electronic equipment is expected to be the major source of errors and they are expected to occur randomly.

Probably the most important consideration in choosing a code is that it should be simple to decode to minimize the decoder cost for the receiver.

The correction of errors by the code is less important than the detection of errors. Likewise, the code should provide for a very low probability of not detecting an error.

A simple parity check code is a practical means of solving the coding problem. The data can be divided into blocks with a parity check bit added to each block. Since 4 bit blocks are used to transmit decimal digits, parity checks based on multiples of 4 bit blocks would be a logical implementation. Table 1 shows some parity check error probabilities for different block lengths.

Code	P_1	P_2	P_3
1 parity for 4 bits	5×10^{-6}	1×10^{-11}	1×10^{-6}
1 parity for 8 bits	9×10^{-6}	3.6×10^{-11}	1×10^{-6}
1 parity for 16 bits	1.7×10^{-5}	1.36×10^{-11}	1×10^{-6}
1 parity for 32 bits	3.3×10^{-6}	5.28×10^{-11}	1×10^{-6}

P_1 = Probability of an error which is detected

P_2 = Probability of an error which is not detected

P_3 = Probability of an error in the parity bit
= Probability of detecting an error which is not in the data bits

Table 1 : Error Events for a Simple Parity Check Code

5.0 SPREAD SPECTRUM

A spread spectrum technique introduces redundancy into the data signal which, therefore, allows the signal to be detected at extremely low levels. The signal can be placed below the noise floor of the receiver.

There are two primary methods of spreading the spectrum of a data signal: direct sequence encoding and frequency hopping encoding. Direct sequence encoding involves multiplying the data signal by a higher rate pseudo-random sequence. The resulting signal, which requires a wider bandwidth to transmit, is modulated and transmitted over a channel. At the receiver, the demodulated signal is multiplied by the pseudo-random sequence to recover the original data sequence. This multiplication process spreads the spectrum of any interference which is received with the signal.

A frequency hopping system multiplies the data signal by a frequency which is produced by a frequency synthesizer. The frequency synthesizer selects its output frequency depending on a code word produced by a pseudo-random code generator. The frequency of the signal is then randomly hopped within the frequency range of the synthesizer. At the receiver, a frequency synthesizer is driven by the same pseudo-random code sequence which returns the signal to baseband and spreads any interference which is present with the received signal.

The ratio of the pseudo-random code rate to the data rate is called the processing gain. The output signal-to-noise ratio can be increased above the input signal-to-noise ratio by the amount of the processing gain.

5.1 COMPARISON BETWEEN DIRECT SEQUENCE AND FREQUENCY HOPPING

Direct sequence encoded and frequency hopped encoded spread spectrum systems are similar in the results they achieve but they use different methods to achieve them.

A direct sequence receiver usually uses coherent demodulation. Coherent operation can be used with the time service because long preambles to provide acquisition of the recovery circuits is practical for this service. In fact, it is probably advisable that the time service not use burst operation, but rather always transmit something. In between timing updates, a continuous stream of 'ones' and 'zeros' could be sent so that the receiver remains locked.

Frequency hopped systems generally use incoherent processing since phase coherence is difficult to maintain between hops.

One disadvantage of a frequency hopped system is that it requires a frequency synthesizer capable of generating many frequencies. Therefore, it is complex as compared with a direct sequence system which uses shift registers and multipliers to generate or demodulate the spread spectrum.

Rather than using a frequency synthesizer at the receiver to demodulate a frequency hopped system, an FFT can be performed each chip period to estimate the generated frequency. Although this eliminates the costly frequency synthesizer, the cost of the hardware to perform the FFT is likely to be high.

The most practical method to use for the time broadcast system is, hence, direct sequence encoding because of its lower complexity and, as a result, lower cost receiver.

5.2 SPREAD SPECTRUM PARAMETERS

The spread spectrum signal can be broadcast on MSAT over normal MSAT voice or data channels. The level of the spread spectrum signal can be made small enough so that its effect on the voice or data channels is small. Ideally, the spread spectrum signal should be lower than any other interference source. The level chosen for the spread spectrum signal depends on the bit error rate required at the receiver, the noise level of the receiver, the interference levels tolerable in the MSAT system, and the processing gain of the spread spectrum system. The processing gain depends on the data rate of the source and the data rate of the pseudo-random code. The bandwidth of the spread signal should be kept to as low a value as possible because the spread spectrum signal will cause some interference into other MSAT services. The effect of interference from the spread spectrum time signal will have a greater effect on data communication channels than for voice channels since it takes considerably more noise to make a sound unintelligible than to cause a bit error.

The rate of the pseudo-random sequence suggested for a 400.1 MHz spread spectrum system is 25 kbps [2]. This will be taken as a baseline value for the other bands.

The bit rate of the data source can be quite low, since the amount of information to be transmitted is low. We can examine the effect of using bit rates as low as 1 bps. This rate will place a limit on the maximum frequency of time update. The bit error rate depends on the modulation technique used, the processing gain of the system, and the level of the spread spectrum signal relative to the other signals in the MSAT system. Any bit error performance can be improved with the use of coding.

The time broadcast service involves the link from the SHF base station to the MSAT terminal. Note that we have assumed that the main time clock is at a base station rather than at the satellite. The smallest interference level produces a 32 dB C/I in the uplink for both UHF and L-band service. We want the spread spectrum signal to have a small effect on the other MSAT services. Therefore, we will design the spread spectrum system so that it changes the normal MSAT interference level by no more than 0.3 dB. The interference power of the spread spectrum signal should then be 32 dB below the power of the normal MSAT carrier. The power of an MSAT carrier received at the mobile terminal depends on the type of terminal. The power received 99% of the time at a mobile terminal would be less than that received at a fixed terminal.

5.3 SURFACE ACOUSTIC WAVE TECHNOLOGY

One of the problems encountered when implementing a spread spectrum system is synchronization of the pseudo random noise generator to the received waveform. The synchronization problem is especially difficult for spread spectrum receivers because of the high noise levels.

One solution to this problem is the use of surface acoustic wave (SAW) devices. A surface acoustic wave is an elastic wave that travels along the surface of a solid. A device usually consists of a set of metal strips place on a piezoelectric substrate. Alternate strips are connected together and form the electrical input to the device. The overlap of the metal strips determines the characteristics of the generated wave. A device of this type can be used to generate a pseudo-random code. The length of the code would correspond to the number of metal strips on the device. In the receiver an equivalent device could be used as a matched filter. If the received signal is fed into the device, a pulse will appear at the output when the input signal is the same as the pseudo-random sequence. Synchronization is therefore, inherent. This is slightly different from conventional spread spectrum systems as two pseudo-random codes would be used, one to represent binary '1' and one to represent binary '0'. It should be noted, however, that the codes may be inverses of one another. One limitation of SAW technology is that the pseudo-random code would have to be short so that it would fit on a substate. This would reduce the difficulty of unauthorized decoding of the signal.

Another limitation is frequency. SAW devices have a minimum practical frequency of around 10 MHz, since the spacing between metal strips is usually $\lambda/2$.

The length of the pseudo-random code produced by a SAW device can be increased by connecting a number of them in parallel. The length of the code would then be the sum of the individual code lengths. At the receiver, the same number of parallel devices would be used and their outputs would be connected to a tapped delay line (another SAW device) so that they added coherently.

6.0 PROPAGATION DELAY

The time it takes the time signal to travel from the transmitter to the satellite and then to the receiver must be accurately computed if the receiver is to make an accurate estimate of the time.

The total propagation delay depends on the following factors:

- total length of the path which depends on the satellite location as well as the transmitter and receiver locations

- propagation effects of the signals in the ionosphere and troposphere.

The one-way signal delay caused by the troposphere and ionosphere is plotted in Figure 2 (from [4]) for frequencies from 100 MHz to 1.1 GHz. As can be seen, the ionospheric delay is less than 0.1μs for 400 MHz and decreases for higher frequencies. The ionospheric delay is latitude dependent, since high latitude transmissions will intercept more of the ionosphere, but the additional delay should be small. The tropospheric delay is constant with frequency, but is less than 0.1μs for elevation angles of 10° or greater.

Accurate positions of the satellite must be known to calculate the path delay. Orbital ephemeris will normally be computed for MSAT, and if this information is made available to the time service users, then accurate path delay corrections can be made.

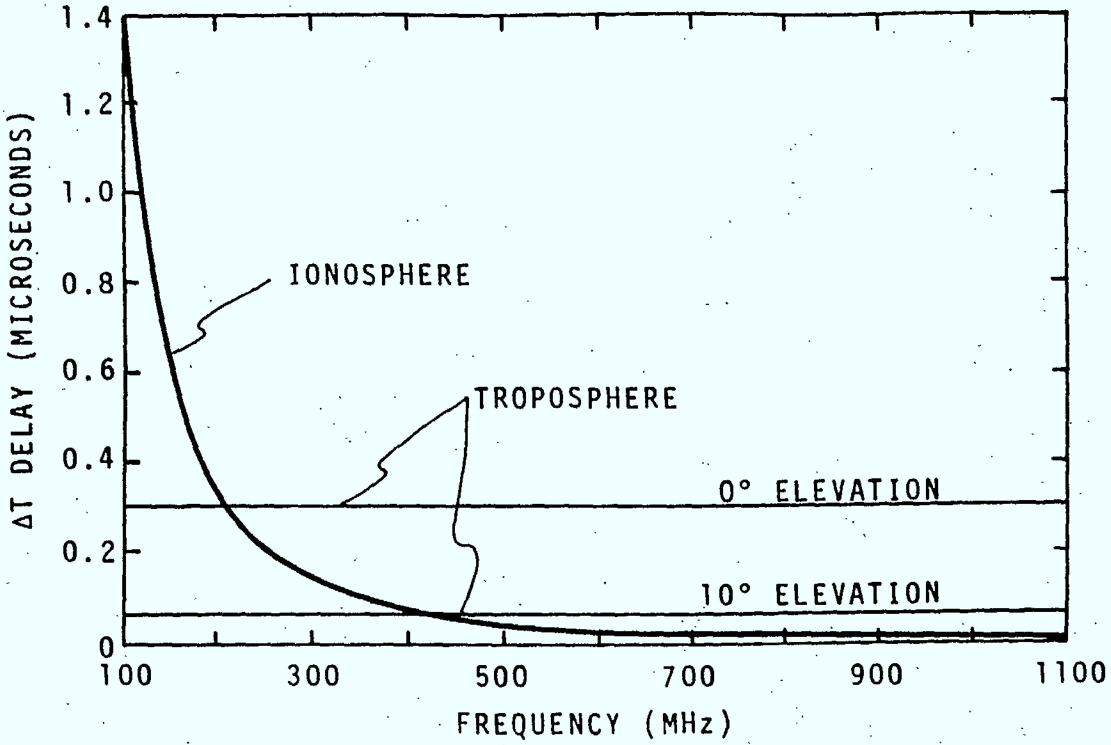


Figure 2

One-way signal delay caused by the troposphere and ionosphere.

NBS time signals were broadcast over the ATS-3 satellite. Accurate path delay calculations were computed at the receiver with the aid of satellite ephemerides which were sent along with the time signals [4]. The longitude and latitude of the sub-satellite point and the height of the satellite above the centre of the earth was transmitted. This method is also used by NBS to send time signals via the GOES system [5].

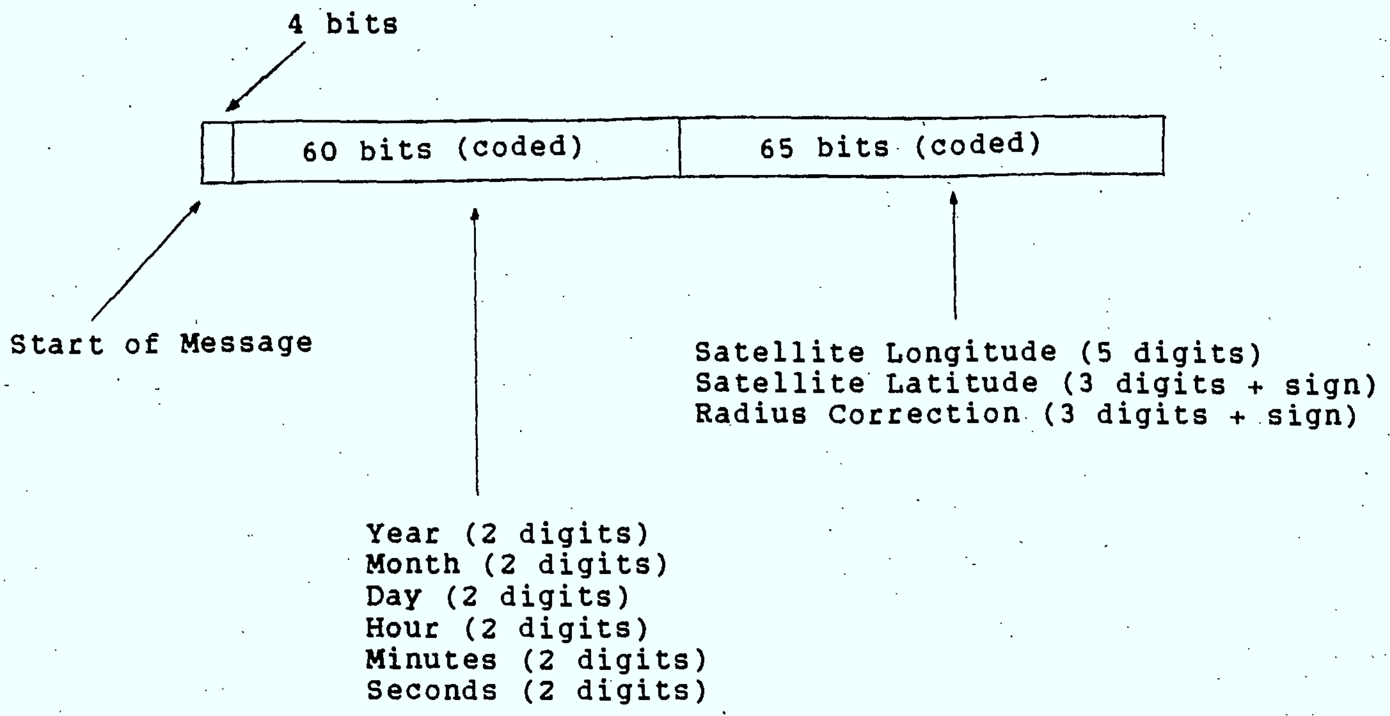
The accuracy of the NBS system using ATS-3 satellite was approximately 25μs [4].

The accuracy with which the orbit ephemerides of the MSAT system can be predicted will determine the accuracy of the propagation delay calculation. This accuracy cannot be predicted currently since the spacecraft bus has not been chosen, but it is safe to assume that an accuracy at least as good as that obtained with the ATS-3 satellite can be achieved.

7.0 MESSAGE FORMAT

The message format depends on the amount of data to be transmitted. The format currently used by NRC for radio station CHU is shown in Figure 1 [1]. The information contained is: day (from the start of the year), hour, minute, and second. NRC also wants the satellite time system transmission to include the year [2]. If we assume that two decimal digits are used to transmit seconds, two for minutes, two for the hour, two for the day of the month, two for the month, and two for the year (i.e. 86 rather than 1986), then 12 decimal digits are required. If we use 4 binary digits to transmit each decimal digit, then 48 bits are required to send the time information.

In order to allow precise computation of the path delay from the satellite, satellite ephemerides and the height of the satellite above earth centre will be transmitted with the time message. Five decimal digits are needed to specify the satellite longitude to a precision of hundredths of a degree, and three digits are needed to specify the satellite latitude to a precision of hundredths of a degree plus a sign indicator for the latitude. NBS specified the satellite height above earth centre in hundreds of microseconds from a value of 119,300 μs [4]. Three digits were used plus a sign indicator. Therefore, if 4 bits are used to specify a decimal digit, then 52 bits will be needed for the satellite path correction information, assuming that we use 4 bits for a sign indicator (this is for simplicity). An additional 4 bits are used to indicate the start of the message. A 4 bit all 'ones' sequence will indicate the start. The proposed message format is shown in Figure 3. In this figure we have assumed that one parity bit for every 4 data bits is used for error detection.



Code: One Parity Bit Per 4 Data Bits

Figure 3: Proposed Message Format

8.0 UPDATE FREQUENCY

The update frequency partly determines the achievable accuracy of the time service. It is affected by the amount of data to be transferred and the data rate.

As shown in Section 7, the system requires 100 bits of data to be sent plus a 4 bit start-of-message block. If a parity bit is added for every 4 bits of the message (excluding the start-of-message) block, then the total message length is 129 bits (including the start-of-message block).

The update frequency should be chosen so that a low-cost oscillator can be used in the receiver and the desired accuracy can be maintained.

The oscillator stability has two components: The drift due to aging and the drift due to temperature variations. The drift due to temperature variations is not considered to be significant since fixed receivers will be located indoors, and the temperature will not vary much. The temperature range that mobile receivers are subjected to will be significant, but the accuracy of the mobile receiver is not required to be high if the mobile receiver is used as a time-of-day display.

The allowable drift due to aging depends on the length of time between updates. This is determined by the amount of information to be transmitted and the data rate. Section 12 discusses this point further.

9.0 ACCURACY

The accuracy with which the time signal can be sent to the user depends on how accurately the receiver can estimate the path delay from the satellite as well as the delays as the signal passes through the satellite and the receiver. The accuracy also depends on the resolution of the spread spectrum system. If the time signal is defined as occurring at the start or end of one of the data bits, then this signal can be resolved to within one chip period (a chip period is the duration of a bit of the pseudo-random code).

The effect of electronic equipment delay on the accuracy of the system depends on the variance of the delay of the equipment. The variance of the delay in the receiver will vary slightly from unit to unit due to drift in the values of the components. The need to keep the tolerances close in the manufacturing process is a requirement which may increase the cost of a receiver.

The accuracy desired by NRC for the satellite time system was specified as 100μs [2]. The resolution of the spread spectrum system is no worse than 40μs, if the chip rate is 25 kbps.

The measured delay variations in the receive equipment used in the time broadcast experiments of [4] were small. The mean delay was 133μs with an rms deviation of 2.6μs. The authors stated that this value could be reduced since the equipment that they used was not explicitly designed to minimize the delay variations.

The satellite time system operated by the National Bureau of Standards using the ATS-3 satellite achieved an accuracy of 25μs [4]. This accuracy level should be achievable on the MSAT satellite as well. Adding the resolution error of the spread spectrum system (40 μs) and the variance in the delay of the signal in the equipment should produce an accuracy within the required 100μs.

10.0 LINK MARGINS

This section presents a comparison of environmental effects on propagation at 400 MHz, 800 MHz, and 1500 MHz and considers the relevance of these effects on the communication system design.

10.1 CASE A: LINE OF SIGHT

The use of a geostationary satellite at the lower part of the UHF band suffers especially from a unique propagation effect due to ionospheric disturbances which are particularly more pronounced in the region of high latitudes. Irregular structures in the ionosphere are thought to occur in two ionospheric regions. These are the E-region between about 90 and 120 km and the F-region between about 200 and 600 km and higher.

Canadian measurements of fading signals received from synchronous satellites have covered a wide range of frequencies over a range of latitudes varying from Ottawa up to Resolute Bay, N.W.T., and including experimental measurements at Churchill, Manitoba located near the visual auroral zone maximum [6].

The experimental results showed that although at high latitudes the required fade margin for 99% of propagation reliability could be as much as 3 dB at 400 MHz, versus about 1 dB at 800 MHz, the scintillation of received signal decreases significantly at lower latitudes and it is expected to be less than 1 dB at 400 MHz.

A map of the elevation angles from Canada to a geostationary satellite at 106.5° W longitude is shown in Figure 4.

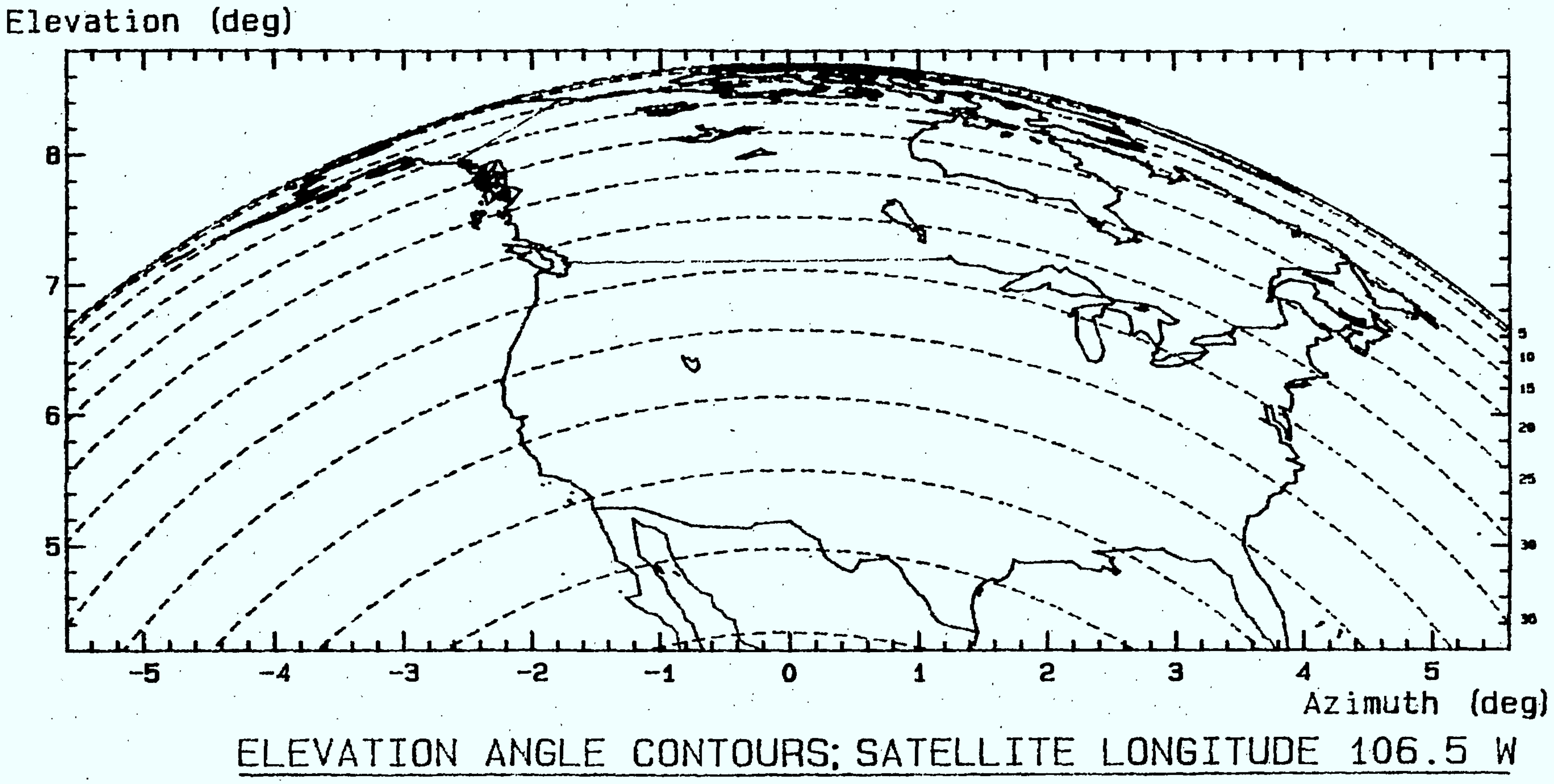


Figure 4 : Elevation Angles to the MSAT Satellite
from North America

10.2 CASE B: MULTIPATH AND SHADOWING

There are no known measured data on the margin required for fading due to multipath and shadowing for a mobile receiver operating at 400 MHz. The margin required is estimated by extrapolating a curve of measurements of the propagation losses at 1542 MHz and 870 MHz [7] (see Figure 5). The frequency change from 1542 MHz to 870 MHz is approximately a factor of 2, and the change from 870 MHz to 400 MHz is also approximately a factor of 2, so the change in margin required from 1542 MHz to 870 MHz is assumed to be the same as the change from 870 MHz to 400 MHz. Using this assumption, the margin required to account for multipath and shadowing is approximately 8 dB for 99% of the time.

Note that the required margin for the multipath only case is expected to be about 4 dB for all three frequency bands. This margin appears to be adequate, especially for fixed or transportable terminals which would be employed in locations free from any shadowing losses.

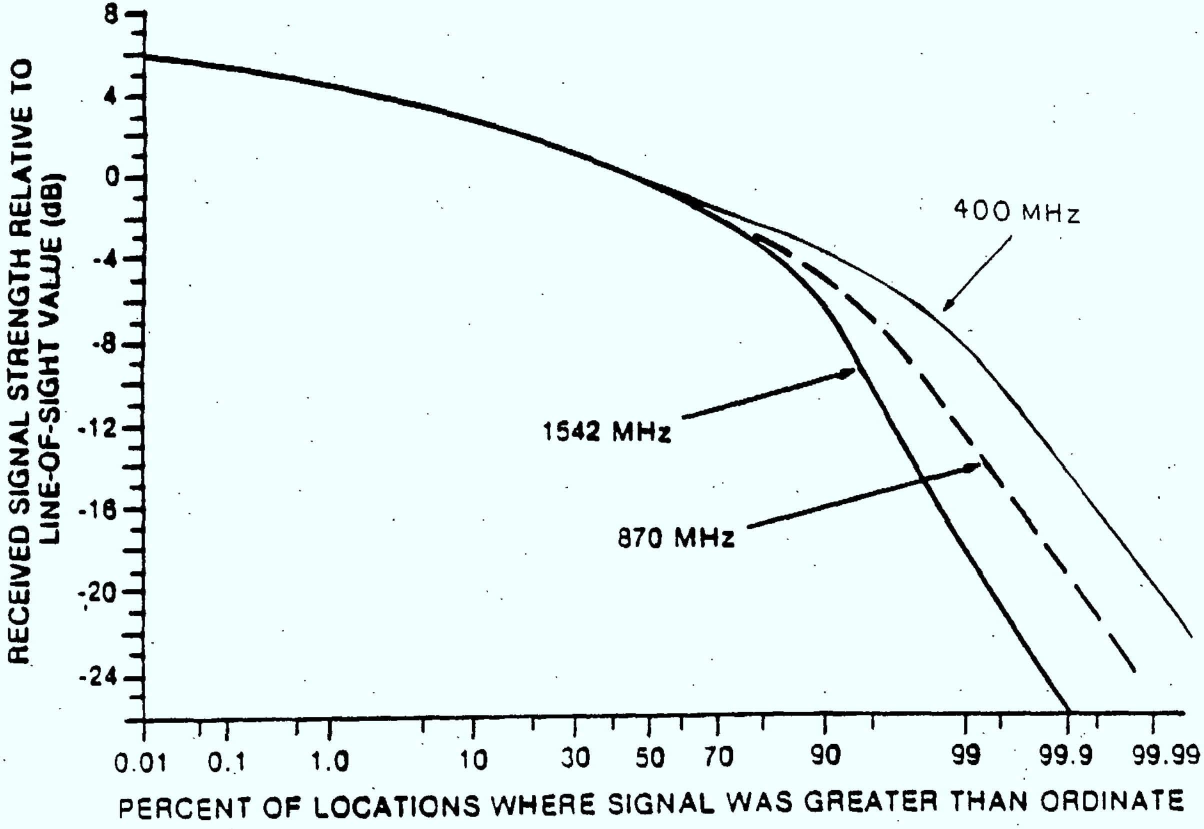


Figure 5 : Comparison of L-Band and UHF (800 MHz) Fading Data and Extrapolated 400 MHz Data

11.0 LINK BUDGETS

As was mentioned earlier, there are two different methods of broadcasting time via MSAT:

Method a):	The time reference (clock) is on the ground and the time signal would be transmitted up to the satellite and down to the user.
Method b):	The clock on board the satellite and the ground station would correct the clock periodically.

The following sections present the link budgets for the above methods of time broadcasting via MSAT when the operating frequency is either MSAT UHF frequencies, MSAT L-band frequencies, or the ITU-assigned 400.1 MHz frequency for time broadcasting.

Note that the MSAT parameters used here are currently under revision. The small changes resulting from the revisions should not have a large effect on the conclusions of this report.

11.1 METHOD (a): MSAT UHF LINK BUDGETS

The satellite system temperature is 876 K at SHF [8]. This corresponds to a noise density of -199.2 dBW/Hz. The C/N_o of the uplink for the voice or data services is 58.9 dB-Hz as shown in Tables 2 and 3. Therefore, the voice or data carrier power is -140.3 dBW. We will design the system so that the spread spectrum power will be 32 dB less than the voice or data carrier power. Thus, the spread spectrum power in the voice or data channel bandwidth is -172.3 dBW.

TABLE 2

SHF/800 MHz LINK BUDGET
BASE STATION TO MOBILE
MSAT VOICE/DATA SERVICE

<u>Uplink</u>		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	40.1	dBW
Path Loss	206.8	dB
C/N_o Thermal	58.9	dB-Hz
<u>Downlink</u>		
EIRP/Carrier	26.5	dBW
Path Loss	183.2	dB
Receive G/T (2)	-19.1	dB/K
Availability	99%	
Fade Margin	13	dB
C/N_o Thermal	39.8	dB-Hz
<u>Interference</u> (C/I)		
Intermod and Energy Spread		
Uplink	32	dB
Downlink	22	dB
Other Sources		
Uplink	32	dB
Downlink	-	
Bandwidth	3	kHz
C/I_o Total	56.0	dB-Hz
Total C/N_o	39.6	dB-Hz

Notes:

(1) Satellite receive gain (EOC) 26.4 dBi. Satellite system temperature 876 K.
(2) Mobile receive gain 8 dBi. Mobile system temperature 509 K.

TABLE 3

SHF/800 MHz
BASE STATION TO FIXED TERMINALS
MSAT VOICE/DATA SERVICE

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	40.1	dBW
Path Loss	206.8	dB
C/N_0 Thermal	58.9	dB-Hz
Downlink		
EIRP/Carrier	26.5	dBW
Path Loss	183.2	dB
Receive G/T (2)	-12.8	dB/K
Availability	99%	
Fade Margin	4	dB
C/N_0 Thermal	55.1	dB-Hz
Interference		
Intermod and Energy Spread		
Uplink	32	dB
Downlink	22	dB
Other Sources		
Uplink	32	dB
Downlink	-	
Bandwidth	3	kHz
C/I_0 Total	56.0	dB-Hz
Total C/N_0	51.6	dB-Hz

Notes:

(1) Same as Table 1.

(2) Fixed terminal receive gain 12 dBi. System temperature 300 K.

If we assume that PSK modulation is used to transmit the spread spectrum signal and that the PSK spectrum is filtered after the first null, then we can compute the spread spectrum power in the MSAT voice channel bandwidth (3000 Hz). The power in a PSK signal contained in the first null is 90.3% of the total power. The power in a 3000 Hz bandwidth about the centre frequency is 12% of the total, assuming a 50 kHz bandwidth between the first nulls (see Figure 6). Therefore, 13.3% of the filtered signal energy is contained in a 3000 Hz bandwidth. Thus, the total spread spectrum power is 7.5 times the power in the 3000 Hz bandwidth.

From the above discussion, it is clear that the total spread spectrum power received at the satellite is 7.5 x (-172.3 dBW) or -163.5 dBW. The C/N_o for the uplink spread spectrum signal is, therefore, 35.7 dB-Hz.

The EIRP transmitted from the base station for the spread spectrum signal is:

$$-163.5 \text{ dBW} + 206.8 \text{ dB} - 26.4 \text{ dBi} = 16.9 \text{ dBW}$$

assuming that the satellite antenna gain is 26.4 dBi.

If we assume that a UHF mobile receiver used for the normal MSAT voice services has a system temperature of 509 K [9], this corresponds to a noise density of -201.5 dBW/Hz. The link budget for a MSAT UHF voice or data channel, forward link to mobile terminals is shown in Table 2. The downlink C/N_o is 39.8 dB-Hz for an availability of 99%. The carrier power at the receiver is, therefore, -161.7 dBW. If the spread spectrum power is 32 dB below the voice or data carrier power in

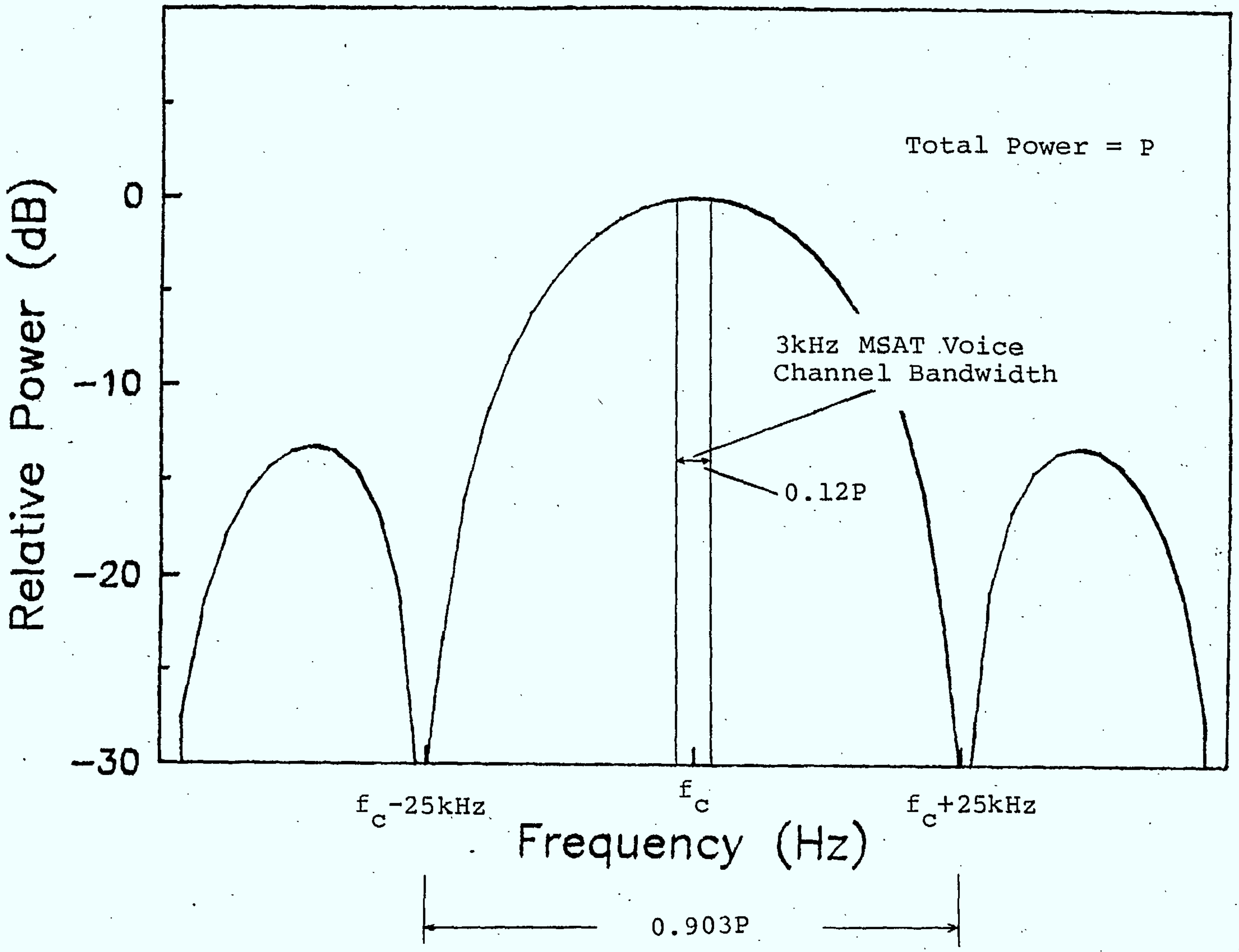


Figure 6 : BPSK Spectrum Showing Power Between First Nulls and Power in an MSAT Voice Channel Bandwidth

the 3000 Hz voice bandwidth, then the spread spectrum power would be -193.7 dBW in a 3 kHz bandwidth. The total spread spectrum power is 7.5 x (-193.7 dBW) or -184.9 dBW. The EIRP from the satellite is computed as:

-184.9 dBW + 183.2 dB + 13 dB - 8 dBi = 3.3 dBW

For an MSAT fixed receiver used for normal voice services, the system noise temperature is 300 K (currently under review). This corresponds to a noise density of -203.8 dBW/Hz. The link budget for a fixed terminal, UHF voice or data channel from base station to MSAT terminal is shown in Table 3. The downlink C/N_o for the voice or data channel is 55.1 dB-Hz. Therefore, the voice or data carrier power at the receiver is -148.7 dBW. Since the spread spectrum power is to be 32 dB below the voice or data carrier power, the spread spectrum power is -180.7 dBW in a 3 kHz bandwidth. The total spread spectrum power is 7.5 x (-180.7 dBW) or -171.9 dBW. The EIRP from the satellite is:

-171.9 dBW + 183.2 dB + 4 dB - 12 dBi
= 3.3 dBW

For a fixed spread spectrum receiver, the receiver temperature is estimated as 682 K (see Appendix B). This represents a noise density of -200.3 dBW/Hz.

The C/N_o of the downlink for fixed spread spectrum is -171.9 dBW/-200.3 dBW/Hz or 28.4 dB-Hz. For the mobile service, the C/N_o at the receiver is -184.9 dBW/-201.5 dBW/Hz or 16.6 dB-Hz.

The interference noise budget as shown in Tables 2 and 3 must be recalculated for the spread spectrum system. We will assume that the interfering spectra are flat and extend over the spread spectrum bandwidth. In the uplink, there is no interference from other MSAT carriers into the spread spectrum system, since we assume that the time service provider has an SHF base station at its site and transmits a single carrier.

The downlink (UHF) intermodulation C/I is 22 dB for an MSAT voice or data channel [10]. Therefore, this represents a C/I_o of 56.8 dB-Hz for a channel bandwidth of 3 kHz. We will assume that the intermodulation interference density is constant across the bandwidth of the spread spectrum signal. Since the spread spectrum carrier power is 23.2 dB below the power of an MSAT voice or data carrier for both mobile and fixed service, the spread spectrum C/I_o for intermodulation interference is 56.8 dB-Hz - 23.2 dB or 33.6 dB-Hz.

Using the same analysis for uplink interference from other sources, we start with a 32 dB C/I for a voice or data carrier. This corresponds to a C/I_o of 66.8 dB-Hz, which gives a C/I_o of 43.6 dB-Hz for the spread spectrum signal.

We now compute the ratio of the voice or data carriers into the spread spectrum signal. The power of the voice or data carriers at a mobile receiver is -161.7 dBW. We will assume that this power is constant across the 3 kHz bandwidth. This corresponds to a noise density of -161.7 dBW/3 kHz or -196.5 dBW/Hz.

The C/I_o for the mobile spread spectrum system due to voice or data carrier interference is -184.9 dBW/ -196.5 dBW/Hz or 11.6 dB-Hz.

The overall C/N_o of the spread spectrum for mobile receivers is the power sum of every C/N_o term:

$$\begin{aligned} C/N_o &= 35.7 \text{ dB-Hz} \oplus 16.6 \text{ dB-Hz} \oplus 33.6 \text{ dB-Hz} \\ &\oplus 43.6 \text{ dB-Hz} \oplus 11.6 \text{ dB-Hz} \\ &= 10.4 \text{ dB-Hz} \end{aligned}$$

where $\oplus$ represents a power sum.

We will design the system for a bit error rate of 10^{-6}. Therefore, we require an E_b/N_o of 10.5 dB for coherent BPSK [11]. If the data rate of the time signal is R bps, then:

$$R = (C/N_o)/(E_b/N_o)$$

$$= 10.4 \text{ dB-Hz} / 10.5 \text{ dB}$$

Therefore, the mobile terminal spread spectrum system can support a data rate of R = 0.98 bps. The link budget for the spread spectrum service to mobile terminals appears in Table 4.

If an omni-directional antenna is used, the gain would be less. The G/T of the receiver in this case would be -22.4 dB/K (see Appendix B). A change in G/T affects the downlink C/N_o and the C/I_o due to voice carrier interference. These two values determine the performance of the link. Since the G/T for the omni-directional antenna is 3.3 dB less, the overall

TABLE 4

SHF/800 MHz LINK BUDGET
BASE STATION TO MOBILE
SPREAD SPECTRUM RECEIVER

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	16.9	dBW
Path Loss	206.8	dB
C/N_0 Thermal	35.7	dB-Hz
Downlink		
EIRP/Carrier	3.3	dBW
Path Loss	183.2	dB
Receive G/T (2)	-19.1	dB/K
Availability	99%	
Fade Margin	13	dB
C/N_0 Thermal	16.6	dB-Hz
Interference (C/I)		
Voice Carriers	-35.4	dB
Intermod and Energy Spread		
Uplink		
Downlink	-13.4	dB
Other Sources		
Uplink	-3.4	dB
Downlink	-	
Bandwidth	50	kHz
C/I_0 Total	11.6	dB-Hz
Total C/N_0	10.4	dB-Hz

Notes:

(1) Same as Table 1.
(2) Mobile receive gain 8 dBi. Mobile system temperature 509 K.

C/N_o would be 3.3 dB less, or 7.1 dB-Hz. The maximum data rate which could be used would be 0.46 bps.

For service to fixed terminals, the interference of voice or data carriers into the spread spectrum signal would be different than that for mobile terminals. The power of a voice or data carrier at a fixed receiver was computed to be -148.7 dBW. We assume that this power is constant across a 3 kHz bandwidth. The power density is, therefore, -148.7 dBW/3 kHz or -183.5 dBW/Hz. The carrier power for the spread spectrum signal at a fixed receiver was computed as -171.9 dBW. Therefore, the C/I_o due to voice or data carrier interference is -171.9 dBW/-183.5 dBW/Hz or 11.6 dB-Hz.

The overall C/N_o of the spread spectrum service to fixed terminals is computed as:

$$\begin{aligned} C/N_o &= 35.7 \text{ dB-Hz} \oplus 28.4 \text{ dB-Hz} \oplus 33.6 \text{ dB-Hz} \oplus 43.6 \text{ dB-Hz} \\ &\oplus 11.6 \text{ dB-Hz} \\ &= 11.5 \text{ dB-Hz} \end{aligned}$$

The data rate which can be used with this service is computed as:

$$R = (C/N_o)/(E_b/N_o)$$

$$= 11.5 \text{ dB-Hz} / 10.5 \text{ dB}$$

Solving for R yields a value of 1.3 bps.

The link budget for spread spectrum service to fixed terminals appears in Table 5.

TABLE 5

SHF/800 MHz LINK BUDGET
BASE STATION TO FIXED SPREAD SPECTRUM RECEIVER

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	16.9	dBW
Path Loss	206.8	dB
C/N_0 Thermal	35.7	dB-Hz
Downlink		
EIRP/Carrier	3.3	dBW
Path Loss	183.2	dB
Receive G/T (2)	-16.3	dB/K
Availability	99%	
Fade Margin	4	dB
C/N_0 Thermal	28.4	dB-Hz
Interference (C/I)		
Voice Carriers	-35.4	dB
Intermod and Energy Spread		
Uplink		
Downlink	-13.4	dB
Other Sources		
Uplink	-3.4	dB
Downlink	-	
Bandwidth	50	kHz
C/I_0 Total	11.6	dB-Hz
Total C/N_0	11.5	dB-Hz

Notes:

(1) Same as Table 1.
(2) Fixed terminal receive gain 12 dBi. System temperature 682 K.

11.2 METHOD (a): L-BAND LINK BUDGETS

The spread spectrum service operating at L-band will now be considered. The method of calculation is the same as that for UHF. Only the results are presented here. The derivation appears in Appendix A.

The link budget for L-band spread spectrum service to a mobile terminal appears in Table 6. The overall C/N_o is -3.5 dB-Hz. The data rate which this system can support is 0.04 bps. If an omni-directional antenna is used, then the G/T of the receiver is 6.6 dB less (see Appendix B), and the overall C/N_o is -10.1 dB-Hz. The maximum bit rate is 0.009 bps.

The bit rates which can be supported by L-band mobile terminals is low. It may be desirable to increase the bit rates by increasing the spread spectrum bandwidth. If the bandwidth is increased to 500 kHz, then this will increase the overall C/N_o by 10 dB. For a mobile receiver with a high-gain antenna, the C/N_o would be 6.5 dB-Hz. This would allow a data rate of 0.40 bps. For a mobile receiver with an omni-directional antenna, increasing the spread bandwidth to 500 kHz would allow a data rate of 0.09 bps. These low data rates may be acceptable for mobile systems if they do not require high accuracy.

The link budget for L-band spread spectrum service to a fixed terminal appears in Figure 7. The overall C/N_o is 11.2 dB-Hz. A data rate of 1.2 bps can be supported.

TABLE 6

SHF/L-BAND LINK BUDGET
BASE STATION TO MOBILE SPREAD SPECTRUM RECEIVERS

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	16.9	dBW
Path Loss	206.8	dB
C/N_o Thermal	35.7	dB-Hz
Downlink		
EIRP/Carrier	-4.6	dBW
Path Loss	188.2	dB
Receive G/T (2)	-15.8	dB/K
Availability	99%	
Fade Margin	18	dB
C/N_o Thermal	2.0	dB-Hz
Interference (C/I)		
Voice Carriers	-49.1	dB
Intermod and Energy Spread		
Uplink	-	
Downlink	-13.4	dB
Other Sources		
Uplink	-3.4	dB
Downlink	-	
Bandwidth	50	kHz
C/I_o Total	-2.1	dB-Hz
Total C/N_o	-3.5	dB-Hz

Notes:

(1) Same as Table 5.
(2) Mobile receive gain 10.4 dBi. System temperature 421 K.

TABLE 7

SHF/L-BAND LINK BUDGET
BASE STATION TO FIXED SPREAD SPECTRUM RECEIVERS

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	16.9	dBW
Path Loss	206.8	dB
C/N_0 Thermal	35.7	dB-Hz
Downlink		
EIRP/Carrier	-4.6	dBW
Path Loss	188.2	dB
Receive G/T (2)	-9.1	dB/K
Availability	99%	
Fade Margin	4	dB
C/N_0 Thermal	22.7	dB-Hz
Interference (C/I)		
Voice Carriers	-35.4	dB
Intermod and Energy Spread		
Uplink	-	
Downlink	-13.4	dB
Other Sources		
Uplink	-3.4	dB
Downlink	-	
Bandwidth	50	kHz
C/I_0 Total	11.6	dB-Hz
Total C/N_0	11.2	dB-Hz

Notes:

(1) Same as Table 5.
(2) Fixed terminal receive gain 17 dBi. System temperature 404 K.

TABLE 8

SHF/400.1 MHz LINK BUDGET

BASE STATION TO MOBILE

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	27.2	dBW
Path Loss	206.8	dB
C/N_0 Thermal	46.0	dB-Hz
Downlink		
EIRP/Carrier	10.6	dBW
Path Loss	177	dB
Receive G/T (2)	-23.1	dB/K
Availability	99%	
Fade Margin	9	dB
C/N_0 Thermal	30.1	dB-Hz
Interference (C/I)		
Intermod and Energy Spread		
Uplink	-	
Downlink	-	
Other Sources		
Uplink	6.9	dB
Downlink	-	
Bandwidth	50	kHz
C/I_0 Total	53.9	dB-Hz
Total C/N_0	30.0	dB-Hz

Notes:

(1) Satellite receive gain (EOC) 26.4 dBi. Satellite system temperature 876 K.
(2) Mobile receive gain 4 dBi. Mobile system temperature 518 K.

TABLE 9

SHF/400.1 MHz
BASE STATION TO FIXED TERMINALS

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	27.2	dBW
Path Loss	206.8	dB
C/N_0 Thermal	46.0	dB-Hz
Downlink		
EIRP/Carrier	10.6	dBW
Path Loss	177	dB
Receive G/T (2)	-22.5	dB/K
Availability	99%	
Fade Margin	5	dB
C/N_0 Thermal	34.7	dB-Hz
Interference		
Intermod and Energy Spread		
Uplink	-	
Downlink	-	
Other Sources		
Uplink	6.9	dB
Downlink	-	
Bandwidth	50	kHz
C/I_0 Total	53.9	dB-Hz
Total C/N_0	34.3	dB-Hz

Notes:

(1) Same as Table 9.
(2) Fixed terminal receive gain 10 dBi. System temperature 1780 K.

11.3 METHOD (a): 400.1 MHz LINK BUDGETS

The derivation of the link budgets for 400.1 MHz operation appears in Appendix A. The link budget for service to mobile terminals is shown in Table 8. The total C/N_o is 30 dB-Hz which can support a data rate of 89 bps. The link budget for fixed terminals is shown in Table 9. The total C/N_o is 34.3 dB-Hz which can support a data rate of 240 bps.

11.4 METHOD (b): LINK BUDGETS

For the case when the clock is on board the satellite, the spread spectrum system is generated on board the satellite. This means that the uplink signal is not a spread spectrum signal and it is only used to periodically correct the satellite clock. Therefore, the uplink signal has no effect on the link budget. Since, in each of the link budgets computed so far, the uplink C/N_o is greater than that for the other links, the link budgets for the method (b) cases can be considered to be the same as for the method (a) cases.

12.0 DATA RATE FOR SPREAD SPECTRUM SERVICES

From Section 7, the number of bits transmitted each update period would be 129. From Section 10, for a bit error rate of 10^{-6} and an interference degradation caused by the spread spectrum signal on the normal MSAT interference budget of less than 0.3 dB, the different services can support the following data rates:

- 0.98 bps for high-gain mobile UHF (800 MHz)
- 0.46 bps for omni-directional mobile UHF (800 MHz)
- 1.3 bps for fixed UHF (800 MHz)
- 0.04 bps for high-gain mobile L-band
- 0.009 bps for omni-directional mobile L-band
- 1.2 bps for fixed L-band
- 89 bps for mobile 400.1 MHz
- 240 bps for fixed 400.1 MHz

The update period would be approximately once every 2 minutes for the service to fixed receivers using MSAT frequencies. The fixed 400.1 MHz service would allow updating every 0.54 seconds. The mobile services would allow less frequent updating for the same performance.

The choice of data rate depends in part on the type of oscillator used in the receiver. The types of crystal oscillator available are, in increasing order of cost: clock oscillators, medium stability crystal oscillators, temperature-compensated crystal oscillators, and ovenized crystal oscillators. Temperature compensated oscillators and ovenized oscillators provide high stability as a function of temperature. Temperature stability likely will not be a concern for time receivers, since most services will operate indoors. Temperature variation is not likely to be a concern for mobile receivers, since a reduced accuracy should be acceptable.

If the accuracy of the time at the receiver is to be 100 μs, the error will be divided between drift in the receiver clock and error in the transfer of time over the satellite link. We will assume that the clock drift and accuracy of the time transfer contribute equally to the inaccuracy of the system.

If the drift of the receiver clock updates is limited to 50 μs and updates occur once every 2 minutes, then the accuracy of the receiver clock would have to be 4×10^{-7}.

The service to mobile terminals will not be able to update their clocks as often to achieve the same performance as fixed receivers. If the time broadcast service is designed so that mobiles can achieve a bit error probability of 10^{-6}, then the resulting low data rate would require an extremely high accuracy clock if fixed receivers are to meet the desired system accuracy. For example, for service to high-gain antenna L-band mobile receivers, a data rate of 0.04 bps maximum could be used. This would allow an update once every 3225 seconds or once every 54 minutes. The required oscillator accuracy would be 1.6×10^{-8} which would require an expensive oscillator. Although the severity of this problem could be reduced by increasing the spread bandwidth of the system, there is a limit as to how much the accuracy requirement could be relaxed this way. It is therefore recommended that the data rate be chosen to provide acceptable service to fixed receivers.

By using data rates chosen to reduce the fixed receiver oscillator accuracy requirements, performance at mobile receivers will be degraded. For example, if the MSAT

UHF data rate is 1.3 bps, then the E_b/N_o at a mobile receiver using an omni-directional antenna would be 6.0 dB. This would result in a bit error rate of 2.4×10^{-3}. The E_b/N_o at a mobile receiver using a high-gain antenna would be 9.3 dB. The resulting bit error rate would be 2.0×10^{-5}.

For an L-band system, using a data rate of 1.2 bps would provide unacceptable service to mobiles ($E_b/N_o < 0dB$). The reason for this is that we have assumed that L-band will only be used to provide service to fixed terminals, and therefore, will use a lower EIRP from the satellite.

13.0 TIME BROADCAST BY NON-SPREAD SPECTRUM

Rather than transmitting time signals in a spread bandwidth, below the level of the MSAT voice or data carriers, the signal could be broadcast using the minimum bandwidth necessary in a dedicated channel.

The receiver used to access this system would be less expensive than a spread spectrum receiver since the demodulator would be simpler. However, since dedicated MSAT channel bandwidth would be used, the cost to operate this service would likely be higher.

Since a conventional modulation scheme would not use a high-rate pseudo-random code generator, an important consideration would be the accuracy with which the signal could be measured. From [12], the rms error in measuring the zero crossings of a sine curve is given by:

$$\delta t = T/(2\pi\sqrt{2E_b/N_o})$$

where T is the period of the sine wave.

We will examine the case for a UHF fixed terminal. From the MSAT link budget, Table 3, the overall C/N_o is 51.6 dB-Hz. For a bit rate of 2400 bps, this corresponds to an E_b/N_o of 17.8 dB. The corresponding rms error in measuring the zero axis crossings is 6.0 μs. This degree of accuracy indicates that a lower bit rate (and, therefore, bandwidth) could be used and an acceptable level of performance would result.

If we use 100 bps, the corresponding E_b/N_o at the receiver would be 31.6 dB. The rms error in measuring the zero axis crossing is calculated to be 29 μs. This value should be acceptable. When the error in computing the path delay calculation from the satellite (25 μs) is added, the total error should be less than 54 μs which is within the 100 μs accuracy specified by NRC [2].

An advantage of using a low bit rate such as 100 bps is that it allows for the possibility of sharing a channel, and therefore, would lower the cost of the space segment assigned to the time broadcasting service.

14.0 PAYLOAD SUBSYSTEM REQUIREMENTS

This section will consider the communication payload requirements for time broadcasting via MSAT at 400.1 MHz, UHF MSAT spectrum, and L-band MSAT spectrum. As has been indicated by NRC [2], the desired service area is the area covered by an antenna with 3 dB beamwidth of 17° x 17°. This coverage area has direct implications on the design of the required payload subsystem for time broadcasting. In order to establish the associated space segment cost, it is necessary to allocate the required resources discussed in the link budget study of this report (Section 11). That is, the resources in terms of spacecraft mass and power should be carefully examined for each band. In addition, the viability and compatibility of each design should be assessed against excess resources available on the candidate MSAT spacecraft. It should be borne in mind that the time broadcasting payload, as a very small part of the total communication payload, should by no means jeopardize or reduce the reliability of the spacecraft.

As was mentioned earlier, time broadcasting via MSAT can be achieved in two ways: (1) the reference clock can be on the ground and the time signal transmitted up to the satellite and down to the user, or (2) the reference clock can be on board the satellite so that the time signal is transmitted down to the user.

The payload requirements for the above methods of time broadcasting and for all three frequency bands of interest should be examined in detail in order to determine the most cost effective and reliable configuration for the overall system operation. The effect of these two methods on the payload will be considered in this section.

14.1 The Reference Clock on the Ground

If the reference clock were to be on the ground, then time signals would be transmitted via the SHF link to the satellite and then using an appropriate frequency conversion they would be broadcasted back to earth. If the broadcasting frequency is at 400.1 MHz, then a separate RF chain with its associated circuit components such as power splitter, filters, upconverter, amplifiers, as well as a separate antenna are required. For time broadcasting at MSAT UHF or L-band frequencies, it is advisable to share the same RF chain with other MSAT services. If the system design is based on spread spectrum, then the system study in Section 11 showed that the interference from the time broadcasting service into other MSAT services is negligible. Although the interference from MSAT services into the time broadcasting service is of concern, however, adding a separate chain for time broadcasting will only complicate the hardware design and provides no significant improvement in interference as long as the time broadcasting is re-using the same frequency band as the other MSAT services. Assigning a portion of MSAT spectrum to this service does not seem wise due to the fact that MSAT spectrum is at a premium. However, in order to have a hemispherical coverage, the spectrum which has the time signal should be separated from the rest of the spectrum and fed to an appropriate antenna. When the separation of the time signal is done after the SSPA, the additional RF components include a power splitter, bandpass filter and hemispherical coverage antenna. However, the penalty associated with the payload required for the added components does not make this scheme interesting.

Thus, this approach will not be pursued further. That is, no change in the baseline payload design is recommended when time broadcasting is at MSAT frequencies and the clock is on the ground. However, additional payload is required when transmitting the time signal at 400.1 MHz, as is discussed below.

The received signal should be split after the downconverter, then filtered, amplified, upconverted, again amplified, and then fed to the 400.1 MHz hemispherical antenna. The additional payload is shown in Figure 7. Note that since the required SSPA power for the time signal is about 1 Watt, the total mass of the components for the time broadcasting signal, excluding the antenna, is expected to be less than 1 kg.

The weight and the size of the antenna with hemispherical coverage depends on the choice of the antenna. Since, in addition to the weight, the volume is the key driver for the choice of the antenna, it appears that for maximum gain within the available space, a deployable helical antenna is the most suitable candidate for time broadcasting signals. Further investigation revealed that Canadian Astronautic Limited (CAL) had designed a deployable Transmit/Receive helical antenna operating at about 300 MHz, to be flown on a military communication satellite (see Appendix C).

When the CAL antenna is stowed, it lies in a flat spiral, like a watch spring, held down by pressure applied through a composite material top cone. The design of the antenna at 400.1 MHz is expected to be about 1.8 m in length when deployed. The earth coverage gain is at least 12 dBic (axial gain is about 13 dBic) with a total weight of about 7 kg. Note that

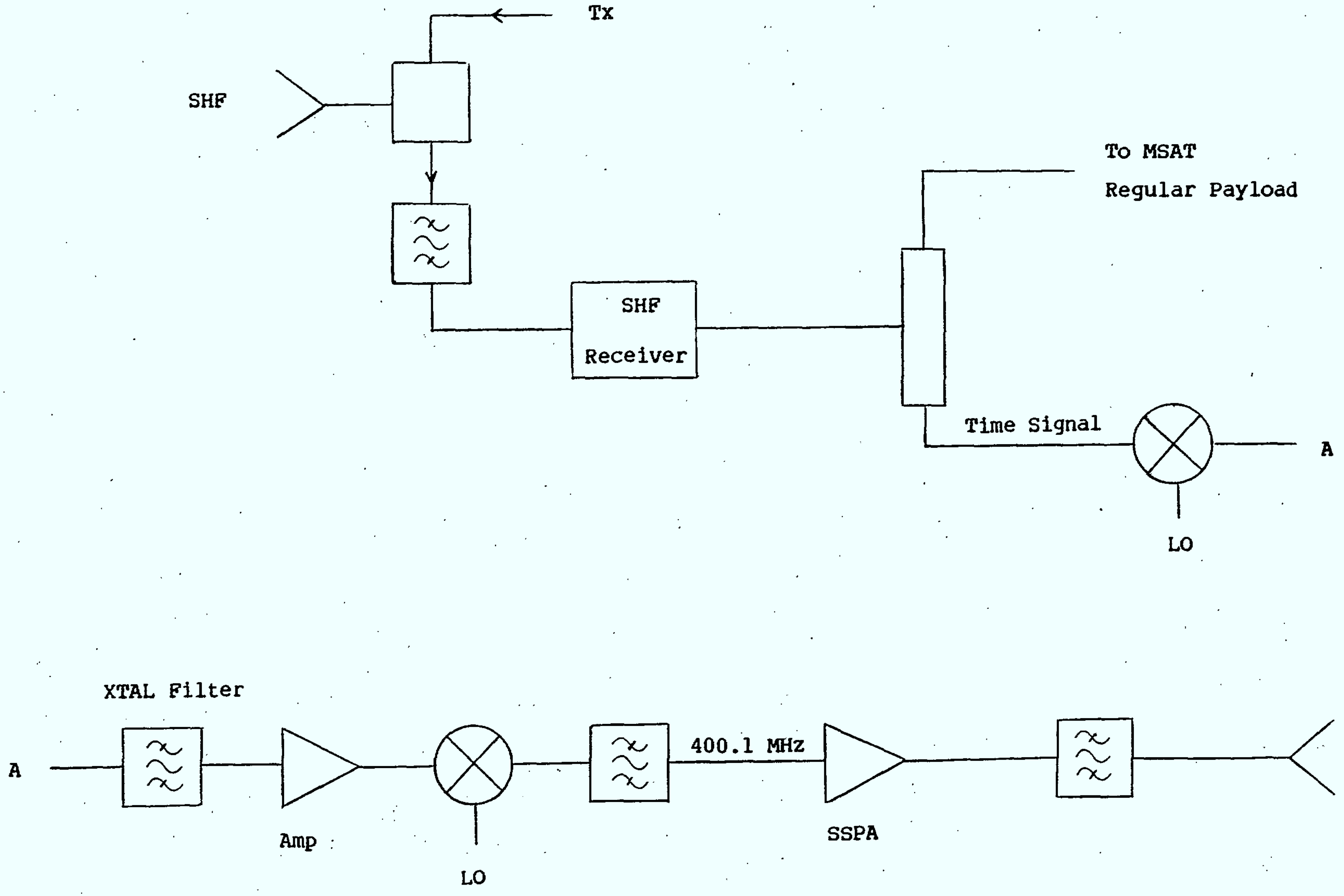


Figure 7: Satellite Payload for 400.1 MHz Time Broadcasting

most of the total antenna mass is due to the motor to deploy the helix. The envelope of the antenna when stowed is expected to be about 60 cm in diameter and 30 cm in height. Although this deployable antenna seems very attractive both from size and weight considerations, still the availability of the required volume on the candidate bus for the antenna and its subsystem is uncertain.

Table 10 shows the expected mass and power budget of the payload at 400 MHz.

<u>Power</u>	
400 MHz 1 Watt SSPA with 50% efficiency	2 W
Power for local oscillators, amplifier, etc.	1.0 W
<u>Mass</u>	
Deployable helical antenna with motor	7 kg
Mass of the other components such as local oscillators, amplifier, etc.	1 kg

Table 10: The Required Mass and Power Budget for Time Broadcasting at 400.1 MHz When the Clock is on the Ground.

Telesat's baseline design is based on a spacecraft with 27% STS occupancy. The payload envelope of this bus, shown in Figure 8, reveals that about 120 Watts of end-of-life power would be reduced with the addition of the time broadcasting signal payload. Although this is only a small fraction of the total available DC power, (≤5%) its impact on the UHF and L-band services should be assessed. If the required power by the time signal is shared evenly by the UHF and L-band payloads, then the impact on the UHF power would be 14.4 Watts RF

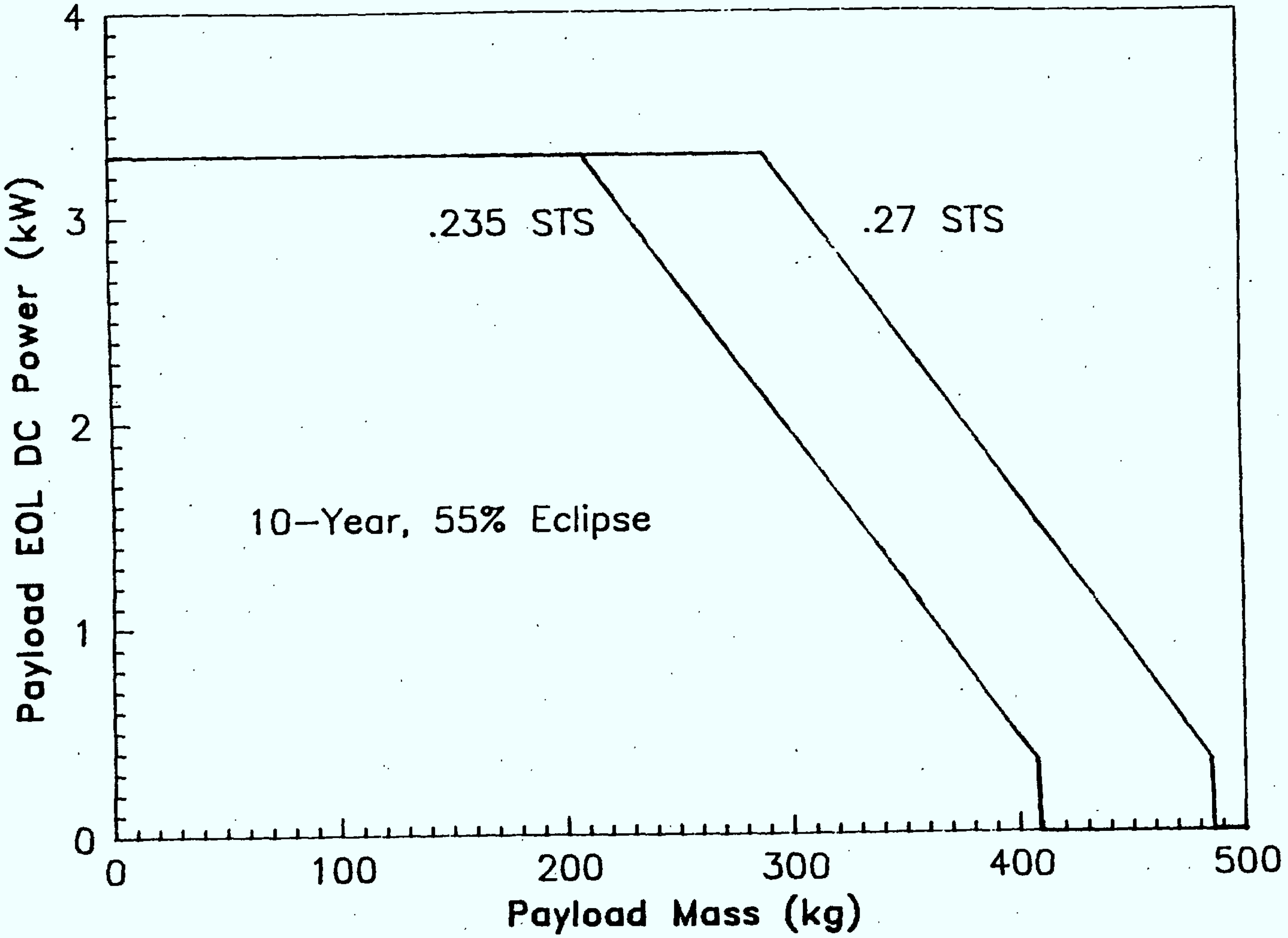


Figure 8: Payload Envelope of Proposed MSAT Bus

power reduction (24% SSPA efficiency) whereas the effect on the L-band power would be a reduction of about 12 Watts (20% SSPA efficiency). These reductions of RF power means that either the number of active carriers or their levels should be reduced. For the UHF case, it means a reduction of the number of active carriers by 12 (from 90 to 78) or reducing their level to 1.01 Watts, a reduction of 0.13 Watts per carrier. That is, the EIRP/carrier would be reduced by 0.7 dBW (from 26.5 dBW to 25.8 dBW for UHF). Similarly, for L-band, either the number of active carriers should be reduced by 12 (from 38 carriers to 26), or the EIRP per carrier should be decreased by 1.5 dB (from 28.5 dBW to 27 dBW). Either of the approaches is detrimental to the overall MSAT services.

From the above discussion it appears that time broadcasting via MSAT at 400.1 MHz is not economically viable on the candidate bus and it should be ruled out.

14.2 The Clock On-Board the Spacecraft

Rather than having the reference clock on the ground, an alternative is to have a clock on-board the satellite which serves as the timing reference. Although the clock on-board the satellite would be very accurate, it would still have to be periodically corrected from the ground since the ground clocks would be more accurate. The effect of this method on the MSAT payload is now considered.

The principal considerations in designing a clock for on-board a spacecraft are low weight, small size, low power consumption, high reliability and high frequency stability.

In the last two decades, the satellite frequency standards have progressed from quartz oscillators used in the Navy Navigation satellite system (NNSS) satellites and early TIMATION launches to rubidium units used in the NTS-1 of NAVSTAR GPS, cesium units in NTS-2, and hydrogen maser units for NTS-3 [13].

Table 11 shows the sequence of different clocks used in various flight programs [13]. It is seen that the hydrogen maser clock used for NTS-3 has a stability 3000 times better than the quartz clock used for TIMATION-I satellite. The rubidium clock used on NTS-1 apparently weighed about 1.3 kg with dimensions of 10 x 10 x 11 centimeters and required about 13 Watts of power. The cesium clock used on NTS-2 weighed about 4 kg with dimensions 7.6 x 7.6 x 30.5 cm. Subsequent cesium clocks designed for use on the Navigation Development Satellites (NDS) have a better frequency stability with dimensions 12.8 x 19.5 x 38.1 cm.

The cesium clocks still require updating to maintain a specified error budget in the satellite system. Since it is desirable for the space system to be made less dependent on the ground system, then the hydrogen maser could be the best frequency standard, offering a significant improvement over the cesium beam.

As was mentioned earlier, having a clock on board the spacecraft means that there is a requirement for updating the clock, where the frequency of this updating depends on the initial stability of the clock and the tolerable error in the time broadcasting signal. This requirement indicates an additional payload for the updating signal excluding the clock itself. The additional payload should separate the

	TIMATION-I	TIMATION-II	NTS-1	NTS-2	NTS-3
Launch Date	May/67	Sept./69	July/74	June/77	Oct./81
Frequency	UHF	VHF/UHF	UHF/L	UHF/L_1/L_2	UHF/L_1/L_2
Clock	Qtz	Qtz	Qtz/Rb	Qtz/Cs	Cs/H-M
$\Delta f/f(PP10^{13}/day)$	300	100	5-10	1-2	0.1

Table 11: Technology Satellites

time updating signal from the rest of the MSAT services, and after downconverting and filtering, it would feed the clock. The signal from the clock should then be upconverted to the desired time broadcast frequency, filtered, amplified, and then fed to the antenna. It is clear that the required payload would be similar to the one given in Figure 7 with the addition of the clock before the upconversion stage. Therefore, the weight of the required added payload would be 1 kg plus the weight of the clock which we assume here to be 4 kg. From Figure 8 it appears that a 5 kg increase in payload weight would cause a decrease of about 85 Watts of the end-of-life DC power of the candidate bus. If we assume that the clock would require 13 Watts of power and the rest of the additional payload for time broadcasting would need about 2 Watts, then the total reduction of the end-of-life power of the baseline system is 100 Watts. Again, if we assume that this power reduction would be shared evenly by the UHF and L-band payloads, the impact on the UHF power would be a reduction of 12 Watts of RF power (24% SSPA efficiency), and the reduction of the L-band RF power would be 10 Watts (20% SSPA efficiency). As has been discussed in Section 14.1, these reductions of RF power are detrimental to the overall MSAT services and are not economically viable. Therefore, it is recommended that the use of the clock on board the spacecraft be ruled out and option (1), which is the clock on the ground, be used for this service. Note that option (1) also has a higher reliability than option (2) when the clock is on-board the satellite.

15.0 CONCLUSIONS

This section presents the conclusions of the study carried out on time broadcasting at present.

Spread spectrum, as suggested by NRC, seems to be a useful technique for broadcasting time signals over the MSAT system. It is particularly useful as a method to reuse bandwidth of voice or data channels. However, the use of spread spectrum is likely to increase the cost of the receiver.

One way of lowering the cost of the receivers may be achieved by using surface acoustic wave technology, to simplify the synchronization circuits, but the use of large scale integration in implementing conventional carrier recovery techniques may also be attractive.

The use of the spread spectrum technique would probably not be necessary if the time service were to be implemented at 400.1 MHz since there are no other MSAT signals at this frequency.

Conventional transmission methods could also be used to transmit the time signals at MSAT frequencies rather than a spread spectrum technique. This would require dedicated channel bandwidth for the time service, so the cost of the service would probably be higher. The required bit rate would be low, however, so the necessary bandwidth would be small and therefore, the time service could possibly share a channel with another user in order to reduce the cost of the service.

Coding can be used to provide security for the system or for the detection of errors. The encryption of the time signal will prevent unauthorized users from receiving time-of-day information. However, there is timing information in the waveform of the transmitted signal which cannot be concealed by encryption. If a spread spectrum technique is used to transmit the time signals, a degree of security will be provided by the spread spectrum technique which may make encryption unnecessary.

The use of coding to detect errors is an important feature to include with a time broadcasting system. Coding can reduce the possibility of receiving the incorrect time due to a noise-induced error. A simple parity check code gives error detection and is very simple to decode at the receiver.

The data rate which could be supported by a time broadcast system operating at MSAT frequencies would be fairly low. It is recommended that data rates be chosen to minimize the oscillator accuracy requirement for fixed receivers, since most of the serious users would likely use fixed receivers.

For a spread bandwidth of 50 kHz, an MSAT UHF fixed-antenna system could operate at 1.3 bps and an L-band system could operate at 1.2 bps. Performance would be degraded for mobile receivers, but their requirements should be less stringent. UHF mobile receivers with a high-gain antenna operating at 1.3 bps would experience a bit error rate of 2×10^{-5}. For UHF mobiles with omni-directional antennas, the bit error rate would be 2.4×10^{-3}.

The L-band system analyzed here uses a low EIRP value, since it is assumed that only fixed receivers will operate at L-band. Therefore, mobile receiver operation for the time service is not practical at L-band. Note that the values calculated here could be changed by increasing the spread bandwidth or by reducing the bit error rate requirement.

A spread spectrum service operating at 400.1 MHz could support higher data rates because there is no interference from voice carriers in this frequency band. A data rate of 89 bps could be used and a bit error rate of 10^{-6} or better would be achieved for both mobile and fixed services.

The accuracy achievable by a satellite time broadcast service depends on the accuracy with which the receiver can estimate the delay of the signal over the satellite link. The accuracy of this estimation depends on the accuracy with which the orbit of the MSAT satellite can be predicted.

The variance of the signal delay through the transmitter, satellite, and receiver also affects the accuracy of the time transfer. The magnitude of these effects depends on the design of the equipment. Although the accuracy cannot be predicted exactly, similar time broadcast systems by satellite have been able to achieve an accuracy of better than 100 μs. Information about the satellite position should be transmitted in the data to the receiver to allow accurate path delay calculations.

If the time service is operated at 400.1 MHz, then a separate RF chain is required at the satellite since 400.1 MHz is not within the normal MSAT frequencies.

The weight of the additional payload, excluding the antenna, for the 400.1 MHz RF chain would be small, but the weight due to the antenna would be significant. The reduction in capacity for UHF and L-band due to the requirements of the 400.1 MHz overall payload would be unacceptable. Therefore, operation of the time service at 400.1 MHz is not recommended.

The use of a separate chain for the time service, if it is operated at the MSAT frequencies, is not recommended since the reduction in interference achieved by using a separate chain does not justify the increased hardware complexity as well as the reduced resources available for regular MSAT services.

The weight and power drain of the frequency references assumed here are typical of the clocks used on the NTS satellites. For these numbers, the reduction in capacity of the MSAT primary payload (service to mobiles) due to adding a reference clock on-board the MSAT satellite is expected to be too severe for the candidate bus, so this is not considered to be a viable option.

The placement of the reference clock on the ground will reduce the redundancy required for reliable system operation and generally will simplify the design of the system.

APPENDIX A

LINK BUDGET DETAILS

L-BAND

The spread spectrum service operating at L-band will now be considered. The SHF uplink is the same as for the UHF link budgets [14].

For a mobile receiver used for normal MSAT voice services, the system temperature is 421 K [14]. This corresponds to a noise density of -202.4 dBW/Hz. The link budget for an L-band voice or data channel, base station to mobile terminal appears in Table A.1. As can be seen, the downlink C/N_o is 38.9 dB-Hz for an availability of 99%. The voice or data carrier power at the mobile receiver is, therefore, -163.5 dBW. For the spread spectrum power to be 32 dB below the voice or data carrier power (degradation to Telesat baseline design is again limited to 0.3 dB), the spread spectrum power would be -195.5 dBW in the 3 kHz bandwidth. The total spread spectrum power would be 7.5 times larger or -186.7 dBW. The EIRP required from the satellite is then:

$$-186.7 \text{ dBW} + 188.2 \text{ dB} + 18 \text{ dB} - 10.4 \text{ dBi} = 9.1 \text{ dBW}$$

where it was assumed that the mobile receive antenna gain is 10.4 dBi. We now compute the EIRP required from the satellite for service to fixed terminals. The system temperature for a fixed receiver for normal MSAT voice services is 300 K (currently under review). The noise density is, therefore, -203.8 dBW/Hz. The link budget for L-band voice or data service to fixed

TABLE A.1

SHF/L-BAND LINK BUDGET
BASE STATION TO MOBILE
MSAT VOICE/DATA SERVICE

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	40.1	dBW
Path Loss	206.8	dB
C/N_0 Thermal	58.9	dB-Hz
Downlink		
EIRP/Carrier	32.3	dBW
Path Loss	188.2	dB
Receive G/T (2)	-15.8	dB/K
Availability	99%	
Fade Margin	18	dB
C/N_0 Thermal	38.9	dB-Hz
Interference (C/I)		
Intermod and Energy Spread		
Uplink	32	dB
Downlink	22	dB
Other Sources		
Uplink	32	dB
Downlink	-	
Bandwidth	3	kHz
C/I_0 Total	56.0	dB-Hz
Total C/N_0	38.8	dB-Hz

Notes:

(1) Satellite receive gain (EOC) 26.4 dBi. Satellite system temperature 876 K.
(2) Mobile receive gain 10.4 dBi. System temperature 421 K.

terminals appears in Table A.2. The downlink C/N_o is 47.2 dB-Hz. Therefore, the voice or data carrier power at the receiver is -156.6 dBW. The spread spectrum power in a 3 kHz bandwidth is 32 dB below this, or -188.6 dBW. The total spread spectrum power is 7.5 x (-188.6 dBW) or -179.8 dBW. The required EIRP from the satellite is:

-179.8 dBW + 188.2 dB + 4 dB -17 dBi
= -4.6 dBW

assuming that the fixed antenna gain is 17 dBi.

We must use the smaller of the two calculated EIRP values so that the spread spectrum interference is no more than 32 dB into a voice or data channel. Therefore, at L-band, the EIRP from the satellite is -4.6 dBW.

We now recompute the spread spectrum power received at a mobile receiver. The power received is:

-4.6 dBW -188.2 dB -18 dB + 10.4 dBi
= -200.4 dBW

The C/N_o for a mobile receiver is then:

-200.4 dBW/-202.4 dBW/Hz or 2.0 dB-Hz.

The receiver noise temperature for a fixed receiver used for time broadcasts is 404 K (see Appendix B). The noise density is -202.5 dBW/Hz.

The C/N_o for a fixed receiver is -179.8 dBW/ -202.5 dBW/Hz or 22.7 dB-Hz.

TABLE A.2

SHF/L-BAND LINK BUDGET
BASE STATION TO FIXED TERMINALS
MSAT VOICE/DATA SERVICE

Uplink		
Satellite G/T (1)	-3.0	dB/K
EIRP/Carrier	40.1	dBW
Path Loss	206.8	dB
C/N_o Thermal	58.9	dB-Hz
Downlink		
EIRP/Carrier	18.6	dBW
Path Loss	188.2	dB
Receive G/T (2)	- 7.8	dB/K
Availability	99%	
Fade Margin	4	dB
C/N_o Thermal	47.2	dB-Hz
Interference (C/I)		
Intermod and Energy Spread		
Uplink	32	dB
Downlink	22	dB
Other Sources		
Uplink	32	dB
Downlink	-	
Bandwidth	3	kHz
C/I_o Total	56.0	dB-Hz
Total C/N_o	46.4	dB-Hz

Notes:

(1) Same as Table 5.
(2) Fixed terminal receive gain 17 dBi. System temperature 300 K.

The effect of interference from other MSAT sources on the L-band spread spectrum system is the same as that calculated for the UHF system, previously.

The C/I_o for intermodulation interference from other MSAT carriers into the spread spectrum system on the downlink is 33.6 dB-Hz.

The C/I_o from other sources of interference into the spread spectrum system is 43.6 dB-Hz.

For a mobile receiver, the voice or data carrier power at the receiver is -163.5 dBW as computed previously. We assume that this power is constant across the 3 kHz bandwidth, and represents a noise density of -198.3 dBW/Hz. The spread spectrum power was computed to be -200.4 dBW, so the C/I_o caused by voice or data carriers interfering into the spread spectrum signal is -200.4 dBW/-198.3 dBW/Hz or -2.1 dB-Hz.

The total C/N_o for a mobile receiver is then:

$$35.7 \text{ dB-Hz} \oplus 2.0 \text{ dB-Hz} \oplus 33.6 \text{ dB-Hz} \oplus 43.6 \text{ dB-Hz} \oplus (-2.1 \text{ dB-Hz})$$
$$= -3.5 \text{ dB-Hz}$$

where $\oplus$ indicates a power sum.

The data rate which can be used by this system is calculated assuming that a bit error rate of 10^{-6} is the goal. This requires an E_b/N_o of 10.5 dB for a coherent BPSK system. Therefore,

$$R = (C/N_o)/(E_b/N_o)$$

$$= -3.5 \text{ dB-Hz} / 10.5 \text{ dB}$$

Therefore, a data rate of up to 0.04 bps can be used with mobile receivers. The link budget for the L-band spread spectrum service to mobile terminals is shown in Table 6.

If an omni-directional antenna is used, the G/T would be -22.4 dB/K (see Appendix B). The overall C/N_o would be -10.1 dB-Hz. A data rate of up to 0.009 bps could be used.

For a fixed receiver, the power received from a voice or data carrier is -156.6 dBW. If we assume that the power is constant across the 3 kHz bandwidth, this corresponds to a noise density of -156.6 dBW/3 kHz or -191.4 dBW/Hz. The spread spectrum power received at a fixed terminal was computed to be -179.8 dBW. Therefore, the C/I_o of the voice or data carriers interfering into the fixed spread spectrum service is -179.8 dBW/-191.4 dBW/Hz or 11.6 dB-Hz.

The total C/N_o for a fixed receiver is then:

$$35.7 \text{ dB-Hz} \oplus 22.7 \text{ dB-Hz} \oplus 33.6 \text{ dB-Hz} \oplus 43.6 \text{ dB-Hz} \oplus 11.6 \text{ dB-Hz}$$
$$= 11.2 \text{ dB-Hz}$$

For a bit error rate of 10^{-6}, we require an E_b/N_o of 10.5 dB. Therefore,

$$R = (C/N_o)/(E_b/N_o)$$

$$= 11.2 \text{ dB-Hz} / 10.5 \text{ dB}$$

Therefore, this system can support a data rate of 1.2 bps.

The link budget for spread spectrum service to fixed terminals is shown in Table 7.

400.1 MHz

Operation of the time broadcast service at 400.1 MHz would be quite different from operation at 800 MHz or L-band because there are no other MSAT services that the time broadcast service would interfere with. Operation at extremely low power levels is not necessary in order to minimize interference, but low power levels are desirable to reduce the size of the 400.1 MHz power amplifier in the satellite.

We will assume the link to the satellite from the base station will be at SHF. The power level of the uplink signal is not critical since it is assumed that the signal emanates from the user's SHF base station, so there is no intermodulation interference from other carriers. As shown in the MSAT voice or data link budgets (Tables 2, 3, A.1, and A.2) there is no significant interference into SHF signals. Therefore, the SHF power from the time service provider's base station could be quite low. We want the uplink C/N_o to be large enough so that the overall C/N_o is not significantly affected. Since the specified overall C/N_o is 30 dB-Hz for the time broadcast service [2], if if we specify the uplink C/N_o to be 46 dB-Hz, then it will affect the overall C/N_o by less than 0.1 dB. This allows the downlink, which is the critical link, to use the smallest power possible to achieve a C/N_o of 30 dB-Hz.

The uplink EIRP is, therefore:

46 dB-Hz - 228.6 dBW/K-Hz + 206.8 dB + 3 dB/K
= 27.2 dBW

where 3 dB/K is the satellite G/T [10].

For a mobile terminal operating at 400.1 MHz, the receiver noise temperature is estimated to be 518 K. For a fixed receiver operating at 400.1 MHz in urban areas, the receiver noise temperature is estimated to be 1780 K (see Appendix B).

The 518 K noise temperature for a mobile receiver corresponds to a noise density of -201.5 dBW/Hz. The 1780 K noise temperature for a fixed receiver produces a noise density of -196.1 dBW/Hz. To compute the performance of the overall link, we must include the effect of interference.

For operation at 400.1 MHz, there are few interfering sources. There are no other known transmissions of time signals at 400.1 MHz. It will be assumed that there are no other sources of interference in the downlink.

For the uplink, in the 800 MHz and L-band link budgets, an interference in the uplink from other sources was considered. We will use the same value here. For a voice or data channel, the C/I was taken to be 32 dB.

Over a 3 kHz channel, this is equivalent to a C/I_o of 66.8 dB-Hz. The SHF uplink EIRP for an MSAT voice or data channel is 40.1 dBW. For the uplink of the 400.1 MHz service, the EIRP is 27.2 dBW. Since the carrier power is lower, the uplink C/I_o from other sources will be lower. The value used is:

$$\begin{aligned} C/I_o &= 66.8 \text{ dB-Hz} - 40.1 \text{ dBW} + 27.2 \text{ dBW} \\ &= 53.9 \text{ dB-Hz} \end{aligned}$$

The uplink C/N_o is 46 dB-Hz and the overall C/N_o is 30 dB-Hz. Therefore, the downlink C/N_o must be 30.1 dB-Hz. Since the receiver noise density is -201.5 dBW/Hz for a mobile terminal, in order to produce a C/N_o of 30.1 dB-Hz, the power at the receiver must be -171.4 dBW. For a fixed receiver, the noise density is -196.1 dBW/Hz, so the power at the receiver is -166.0 dBW.

As discussed in Section 10, a margin of 1 dB is required for the effect of scintillation. The margin required for multipath and fading for 99% of the time is estimated to be 8 dB. Adding the 1 dB margin for scintillation produces a total margin of 9 dB for mobile terminals. A fixed receiver required a 4 dB margin for multipath so the total margin is 5 dB when the effect of scintillation is included.

For a fixed antenna, the gain is specified as 10 dBi. The gain for a mobile terminal would be less; we assume a value of 4 dBi.

The EIRP required from the satellite for operation with a mobile receiver is:

-171.4 dBW + 177 dB + 9 dB - 4 dBi
= 10.6 dBW

The EIRP required from the satellite for operation with a fixed receiver is:

-166.0 dBW + 177 dB + 5 dB -10 dBi = 6 dBW

Since the spread spectrum signal will not interfere with other MSAT services, we can use the higher EIRP value, i.e., 10.6 dBW.

The data rate which can be used for mobile service is calculated as:

$R = (C/N_o)/(E_b/N_o)$

$= 30$ dB-Hz / 10.5 dB

Solving for R yields a data rate of 89 bps.

The power received at a fixed terminal is:

10.6 dBW - 177 dB - 5 dB + 10 dBi = -161.4 dBW

Therefore, the downlink C/N_o is 34.7 dB-Hz. The overall C/N_o is given as

46 dB-Hz $\oplus$ 34.7 dB-Hz $\oplus$ 53.9 dB-Hz = 34.3 dB-Hz

where $\oplus$ indicates a power sum. We can compute,

$R = (C/N_o)/(E_b/N_o)$

$= 34.3$ dB-Hz / 10.5 dB

Solving for R produces a value of 240 bps.

The link budgets for 400.1 MHz operation are shown in Tables 8 and 9.

APPENDIX B

RECEIVER SYSTEM TEMPERATURE

The noise temperature of a receiver is a function of the antenna noise temperature, the losses from the antenna to the LNA, and the LNA noise figure. The system temperatures computed in this section are referenced to the input of the LNA.

The antenna noise temperature varies depending on the location of the receiver. For mobile terminals, since they will operate mainly in rural areas, the level of man-made noise received by the antenna will be low. The antenna noise temperature is estimated using the data presented in [15] for rural areas. The data for 850 MHz is read from one of the plots given in the report, and the values for 400 MHz and 1550 MHz are extrapolated. The noise temperature for 400 MHz is estimated to be 213 K. For 850 MHz, it is estimated as 152 K, and for 1550 MHz, it is estimated as 142 K.

The LNA noise temperature for 850 MHz and L-band is assumed to be the same value as that used for the normal MSAT receivers, i.e. 170 K. For 400.1 MHz operation, the NRC-specified value is 289 K [2].

For 850 MHz and L-band operation there could be two types of mobile antennas used. If the time service is used as an additional service for an existing MSAT receiver, then the associated antenna would be a high-gain type (8 dBi for 850 MHz and 11.3 dBi for L-band). If the receiver is used only to receive the time service, then the antenna will likely be a low-cost omni-directional one with a gain of approximately 4 dBi for both frequencies. An omni-directional antenna is likely to be the only type used for operation at 400.1 MHz for mobile terminals. For applications using a high-gain mobile antenna, we will use the G/T values currently used in the MSAT link budgets, i.e. -19.1 dB/K for UHF and -15.8 dB/K for L-band. The receiver noise budgets for omni-directional antennas are shown in Table B.1.

The antenna noise temperature for a fixed receiver used for time broadcasts is likely to be higher than that for a fixed receiver used for normal MSAT services. The reason for this is that typical users of the time service will likely be located in urban areas and, therefore, the antenna would be exposed to higher levels of man-made noise.

The antenna noise temperatures are estimated using the results of [15]. Measured and predicted results agree quite closely for a typical business area. The predicted value for 850 MHZ is 2.9 dB above 290 K or 570 K. The predicted results are extrapolated for 400 MHz and 1550 MHz. At 400 MHz, the predicted value is 8.1 dB above 290 K or approximately 1800 K. For 1550 MHz, the predicted value is -1.2 dB from 290 K or 220 K.

The total system temperature also depends on the LNA noise figure and the loss between the antenna and the LNA. The LNA noise figure is assumed to be 2 dB for 850 MHz and 1550 MHz and 3 dB for 400.1 MHz.

The antenna gain is assumed to be 10 dBi for 400.1 MHz, 12 dBi for 850 MHz, and 17 dBi for L-band.

The noise budgets for fixed receivers are shown in Table B.2.

	400.1 MHz	850 MHz	1550 MHz
LNA N.F. (dB)	3	2	2
Losses (dB)	1	1	1
Antenna Temperature (K)	213	152	142
System Temperature (K) (LNA input)	518	350	343
Antenna Gain (dBi)	4	4	4
G/T (dB/K)	-24.1	-22.4	-22.4

Table B.1: Noise Budgets for Mobile Receivers with Omni-directional Antennas

	400.1 MHz	850 MHz	1550 MHz
LNA N.F. (dB)	3	2	2
Losses (dB)	1	1	1
Antenna Temperature (K)	1800	570	220
System Temperature (K) (LNA input)	1780	682	404
Antenna Gain (dBi)	10	12	17
G/T (dB/K)	-23.5	-17.3	-10.1

Table B.2: Noise Budgets for Fixed Receivers

APPENDIX C

CAL DEPLOYABLE HELICAL ANTENNA

PROJECT SYNOPSIS

Deployable U.H.F. Spaceborne Helical Antenna

Description

Canadian Astronautics has designed a deployable, transmit/receive, helical antenna to be flown on a military communication satellite that will be launched on the STS. The antenna will provide earth coverage radiated patterns, from a geostationary orbit over two narrow frequency bands.

Stowed, the antenna helix lies in a flat spiral, like a watch spring, held down by pressure applied through a composite material top cone.

Deployed, the antenna reaches 2.4 m (8 ft.) in length maintained by a tip tensioning mechanism.

Performance

• Axial Gain	>13 dBI from 250 Mhz to 310 Mhz
• Earth Coverage Gain	>12 dBI for cone of 9.1° semi-angle
• Axial Ratio (Earth Coverage)	<2 dB
• Return Loss	>18 dB
• Mass	7kg (15½ lb.)
• Life	>7 years at geostationary orbit
• Qualification Environment	Compatible with STS launch
• Envelope: Stowed	65 cm diameter 31 cm height
• Envelope: Deployed	2.4 m height 36 cm base diameter

For further information on this or other CAL projects contact: The Marketing and Sales Manager, Space Division at Canadian Astronautics Limited, 1050 Morrison Drive, Ottawa, Ontario K2H 8K7. Telephone (613) 820-8280 or Telex 053-3937.

CAL CANADIAN ASTRONAUTICS LIMITED

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