Telesat

Telesat Canada

THE USE OF MSAT FOR A RADIO BROADCAST CHANNEL

TASK 25

PREPARED FOR

DEPARTMENT OF COMMUNICATIONS

Submitted By: Telesat Canada

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1.0 Background

Satellite application for the provision of mobile communication services has proven to be a dynamic study topic over the past few years. Various applications in the broad categories of voice and data communications which constitute the primary modes of service for MSAT have already been exposed to various levels of technical and economic studies with promising results. As an extension to these basic applications, other services such as radio broadcasting, location detection, paging, and standard time broadcasting have recently been proposed and are currently under active study to assess their commercial potential.

This report is specifically directed towards a radio broadcasting application via MSAT. The study was initiated as a result of the interest expressed by the Canadian Broadcasting Corporation (CBC) in utilizing MSAT as a vehicle for radio broadcasting over areas where terrestrial means are either not adequate or too costly. In a letter to the Department of Communications on January 30, 1985, the Corporation indicated a desire to explore the MSAT potential for providing a means for continuous newscast, distribution of other programs of interest as well as quality stereo programming to the national audience regardless of their location on the Canadian territory. CBC's specific interests were stated to be the desire for:

a) providing useful and sometimes vital information to Canadians on the roads, and
b) reaching the Corporation's goal of providing quality programming to all areas of Canada.

In response to this request, the Department of Communications (DOC) commissioned Telesat to briefly investigate the technical and economic factors associated with the use of MSAT for the direct broadcast of radio programs to vehicular, portable, and fixed receivers. This report is intended to summarize the results of the studies to date on the technical feasibility of the basic concept, alternative system designs in terms of signal quality, system resource requirements, and the relative cost impact of various design options.

1.1 General Outline of the Study

In view of the limited time made available to this preliminary study, a detailed treatment of the subject matter was not deemed feasible. For this reason, the following elements of the study were identified to be of primary importance and as such required immediate attention:

i) suitable modulation techniques within the means of an MSAT system
ii) signal quality analysis and adoption of a set of suitable performance criteria for the assumed modes of service
iii) link analysis for mobile, fixed and portable terminals in both UHF (866-870 MHz) and L-band (1544-1559 MHz), having feeder links at SHF frequencies (13.20 - 13.25 GHz)
iv) a brief analysis of the ground terminal options and the associated cost
v) estimation of satellite resource requirements for various options
vi) estimation of the relative cost impact of various options

The primary mission of an MSAT system, as defined to date, is to provide a nation-wide voice and data communication capability. For this reason and within the context of the present study, radio programming via MSAT is assumed to be a peripheral service offering. Accordingly, the system parameters assumed for this application are defined within a range which will not lead to a significant departure from the basic system design envisaged for MSAT. Although a rough order of magnitude cost estimation has been carried out, no attempt has been made to perform a formal commercial viability analysis for the following reasons. Given the characteristics of an MSAT system and the alternative means for radio program distribution, the most likely revenue generating base for full or partial recovery of the cost of an MSAT-based radio broadcast network appears to be national advertisement. The degree of viability of such a concept is, therefore, keenly related to the magnitude of such a revenue potential as well as the acceptable level of subsidization by the network operator. Due to the lack of sufficient information in this area, a parametric approach has been adopted. Characterizing system parameters are varied over a limited range to investigate the relative cost of various service delivery options. The bounds for this range are selected based upon Telesat's current perception as to what may constitute the cost-threshold of a radio program network operator and what could possibly be viewed as an acceptable signal quality.

Since the technology involved in the receiver design is relatively well understood and could be implemented with predictable costs, the thrust of the study is towards the main areas of uncertainty such as performance criteria development, link budgeting, identification of the satellite resource requirements and estimation of the cost impact of the various options.

2.0 Modulation Techniques

This section presents a comparison of various modulation techniques which could be used to transmit radio programming via MSAT. There are three types of programming considered:

a) news and information services consisting of voice only;

b) news and information services plus acceptable quality monophonic music; and,

c) high-fidelity stereo transmission.

The audio bandwidth required for (a) would be 3 kHz. The audio bandwidth for (b) would be 5 kHz, and for (c), 12.5 kHz per channel for a total of 25 kHz.

Only analog modulation techniques are considered. The scarcity of the spectrum in MSAT would preclude the use of digital modulation techniques because of their wide bandwidth requirements.

Channels in MSAT are expected to be spaced 5 kHz apart. Therefore, the radio broadcasting bandwidth will occupy an integral number of 5 kHz channels.

2.1 Amplitude Modulation

Amplitude modulation can take several forms:

1) double sideband with carrier (commonly called AM);
2) double sideband suppressed carrier (DSBSC);
3) single sideband (SSB); and,
4) vestigial sideband (VSB).

2.2 Double Sideband with Carrier

Double sideband amplitude modulation with carrier is the modulation scheme used by commercial AM broadcasting stations. Since both upper and lower sidebands are transmitted, the transmission bandwidth is $2f_x$, where f_x is the highest modulating frequency. The output SNR of an AM receiver demodulating with envelope detection is [1]:

$$S/N = A_c^2 k_a^2 P_m / (2 f_x N_o)$$

where A_c is the carrier amplitude, k_a is a constant when multiplied by the maximum value of the message signal determines the percent modulation, P_m is the average power in the message, and $N_o/2$ is the double sided noise spectral density.

The transmitted signal power is:

$$P_T = P_c + P_c P_m$$

where $P_c = A_c^2/2$ is the power of the carrier. The maximum power efficiency for an arbitrary signal is 50%.

2.3 Double Sideband Suppressed Carrier (DSBSC)

Double sideband suppressed carrier modulation is the same as AM except that the carrier is not transmitted. Therefore, all the power of the transmitter can be used to send the information signal. However, demodulation is more complex because the carrier must be recovered. The bandwidth of a DSBSC signal is $2f_x$. The output SNR of a receiver using coherent detection is:

$$S/N = A_c^2 P_m / (2 f_x N_o)$$

The transmitted signal power is:

$$P_T = P_c P_m$$

Therefore, for DSBSC, the power efficiency is 100%.

2.4 Single Sideband (SSB)

Single sideband modulation is more bandwidth efficient than either of the two previous amplitude modulation techniques. It uses a bandwidth of f_x. The disadvantage of SSB modulation is that it is more difficult to generate and demodulate.

The output SNR of a receiver demodulating SSB is:

$$S/N = A_c^2 P_m/(4f_x N_o)$$

The transmitted signal power is:

$$P_T = 1/2 P_c P_m$$

Thus, it can be seen that an SSB signal requires twice the power of a DSBSC signal to produce the same SNR. But SSB requires half the transmitted power of DSBSC since only one sideband is transmitted. Therefore, for the same transmitted power, SSB and DSBSC have the same performance.

2.5 Vestigial Sideband (VSB)

Practical SSB systems have poor low-frequency response. DSB systems have good low frequency response, but are bandwidth inefficient. A modulation scheme that has good low frequency response, high bandwidth efficiency, and high power efficiency is VSB modulation. VSB signals consist of one sideband, as SSB signals do, but they also include a trace of the other sideband. The bandwidth of a VSB signal is:

$$B_T = f_x + \alpha, \ \alpha < f_x$$

where α is the frequency content of the partial sideband. The SNR for VSB is the same as the SNR for SSB.

It is not easy to derive an expression for the power transmitted in a VSB signal, but bounds can be obtained as:

$$P_c + 1/2P_cP_m \leqslant P_T \leqslant P_cP_m + P_c$$

where P_c is the carrier power and P_m is the average message power. We have assumed here that a pure carrier term is transmitted with the modulated signal. This simplifies demodulation. However, a VSB signal can be sent without any carrier component.

2.6 Frequency Modulation

Frequency modulation systems can provide better discrimination against noise and interference at the expense of bandwidth. The modulation is described by the deviation ratio:

$$D = \Delta f/f_x$$

where Δf is the frequency deviation and f_x is the highest modulating frequency.

If D is less than 0.3, the modulation is called narrowband FM, and it is a linear modulation. The bandwidth is $2f_x$, which is the same as for AM.

For D greater than 1, the modulation is called wideband FM. This modulation technique is non-linear. Wideband FM has an infinite number of sidebands which decrease in magnitude away from the carrier frequency. The bandwidth can be approximated by Carson's Rule:

$$BW = 2(\Delta f + f_x)$$

The larger the value of D, the better the performance is relative to AM.
The output SNR is

$$S/N = 3A_c^2 \, k_f^2 \, P_m \, / \, (2N_o \, f_x^3)$$

where P_m is the average message signal power
$N_o/2$ is the double sided noise spectral density
k_f is the frequency sensitivity of the modulator in Hz/V

For a sinusoidal modulating signal, the improvement over AM is proportional to D^2.

Wideband FM is an unlikely choice for broadcasting radio program material on MSAT because the spectrum is so scarce that the cost would be very high. Terrestrial stereo FM broadcasting stations use a value of 5 for D and 15 kHz for f_x. This requires a bandwidth of 180 kHz, which represents 36 MSAT channels.

The power in an FM modulated signal is independent of the message. Therefore,

$$P_T = 1/2A_c^2 = P_c$$

where A_c is the amplitude of the carrier.

2.7 Amplitude Companding

An amplitude compander compresses the input baseband signal in the transmitter by amplifying low level signals more than high level signals. The operation is therefore, non-linear. The dynamic range of the input signal is reduced. This prevents low-level signals from being masked by noise. In the receiver, the signal is expanded. Low level signals receive small amplification and high level signals receive large amplification. The result of this signal processing technique is an increase in the subjective signal-to-noise ratio as perceived by the listener. Amplitude companding can be used with any modulation technique.

2.8 Recommended Modulation Technique

Due to the extremely limited bandwidth available, the recommended technique is amplitude companded single sideband (ACSB). This permits the smallest bandwidth to be used, and the amplitude companding will reduce the satellite power required to achieve a given quality of service. The use of ACSB is also advantageous in that the mobile radio service and mobile telephone services are expected to use ACSB. This should reduce the cost of the receiver. If the broadcast material is voice only, then a single MSAT channel should suffice. Broadcasting monophonic music will require a bandwidth larger than can be accommodated by a single MSAT channel. Since we want the radio programming service bandwidth to be a multiple of 5kHz in order not to disrupt the MSAT channel spacing, two channels will be used, which will allow an audio bandwidth of around 8 kHz. To transmit stereophonic program material requires a minimum audio bandwidth of 25 kHz plus guard band, and would require six MSAT channels.

Because of the difficulty of demodulating SSB transmissions, a pilot tone should be transmitted in order to achieve an acceptable signal quality. The pilot tone will provide a reference for automatic tuning. This would eliminate the problem of frequency translation error. It also provides a reference for AGC circuitry. Ordinary SSB transmits power only when modulation takes place. Therefore, pauses in speech look like signal fades to the AGC circuit and the resulting gain varies rapidly, unnecessarily. The pilot signal also provides a reference to correct for fast fading.

The use of single sideband modulation may prove to be undesirable for high fidelity broadcasts because of its poor low frequency response. However, since the SSB transmitter is at the base station, and there is only one of them, it is feasible to use a more expensive filter with a better low frequency response. Otherwise, VSB modulation can be used. A pilot tone should be used with VSB, to improve demodulation as with SSB.

Compatability with existing car radios is likely to be important only if high fidelity stereo broadcasts are made using MSAT. In this case, the user may want to use existing high fidelity equipment in the car. For the other two types of services, the sound quality achievable using the MSAT receiver is likely to be sufficient. Compatability can be achieved if the MSAT radio signal is demodulated in the down-converter to baseband and then remodulated into the AM or FM broadcast band. A switch should be provided to disconnect the car radio antenna, to avoid interference from a local station which may occupy the same channel.

Note that the required number of channels given here for the services will have to be doubled if the MSAT radio service is to cover all of Canada, assuming the MSAT satellite covers Canada with two spot beams. Also, another doubling of the number of channels would be required for services to be broadcast in both French and English. Therefore, for all-Canada coverage in French and English, the number of MSAT channels required would be:

a) voice-only service: 4 channels
b) voice/monophonic music: 8 channels
c) high fidelity stereophonic broadcasts: 24 channels

Using two MSAT channels for the broadcasting of voice/monophonic music programming is wasteful since only 5 kHz of audio bandwidth is needed. We can reduce the waste if we place French and English services adjacent to each other and assign each 1.5 MSAT channels. This will not disrupt the MSAT channel spacing, since the two services together occupy 3 channels. The same technique can be used for a high fidelity stereophonic broadcast service to reduce the number of occupied MSAT channels. By placing the French and English services adjacent to one another, the number of MSAT channels required would be:

a) voice-only service: 4 channels
b) voice/monophonic music: 6 channels
c) high fidelity stereophonic broadcasts: 22 channels

Note that two spot beams cover Canada for the UHF system. If the radio broadcast service is at L-band, then another doubling of the number of channels would be required, since there are expected to be 4 spot beams covering Canada at L-band.

3.0 Signal Performance Requirement

We will assume that the CBC elects to implement a broadcast service containing monophonic music. Simple voice-only broadcasts can be made on an existing MSAT MRS channel. High quality stereophonic broadcasts will require so much power or bandwidth that it will not be economically viable.

The signal-to-noise ratio at the output of the demodulator of the receiver determines the quality of the received signal as perceived by the listener. In order to determine a target SNR for the radio program service on MSAT, we must examine the signal-to-noise ratios of similar systems.

A proposed satellite program distribution system intended to provide a national program service for U.S. public radio stations uses a 70 dB SNR as its objective [2]. The program material is transmitted using wideband FM with 15 kHz audio bandwidth.

RCA has designed a satellite distribution system to distribute a wide range of program audio, data, and voice-grade services [3]. They offer program audio channels with bandwidths ranging from 3.5 kHz to 15 kHz with 50 dB to 60 dB signal-to-noise ratios. The audio channels use wideband FM.

The specifications for a news collection and distribution system proposed by Broadcast News specifies a signal-to-noise of 55 dB to provide technical quality comparable with normal FM broadcasting [4]. The audio bandwidth is 15 kHz.

Telesat's performance specifications for transmitting audio material at C-band require a weighted signal-to-noise ratio of 57 dB at the receiver output [5]. The modulation is wideband FM with a 15 kHz audio bandwidth. The increase in SNR from the weighting network is not known exactly, but it is estimated at 7 dB, so that the unweighted SNR at the receiver output is approximately 50 dB.

A proposed system for broadcasting Voice of America signals at L-band to mobile and transportable receivers aims for a signal-to-noise ratio of 40 dB [6]. This system uses wideband FM.

A proposed CCIR satellite sound broadcasting service to portables in the UHF band recommends a 40 dB weighted signal-to-noise ratio for service to automobiles [7]. This system uses FM with parameters compatible with terrestrial FM broadcasting to allow reception with conventional FM receivers with an additional frequency conversion. The unweighted SNR value was not specified, but it is believed that it would be in the range of 33-35 dB.

The CCIR recommendation for low-cost sound broadcasting receivers for areas where radio service is not available for economic, geographic, or technical reasons, specifies 30 dB as the minimum SNR for a service with 5 kHz fidelity [8].

The results of subjective tests of sound quality as a function of SNR are shown in Figure 1 [9]. Three results are shown. The CCIR results are from a U.S.S.R. contribution to Study Group X. Over 1100 subjective evaluations were made. The BBC results involved only 4 listeners. The RCA results involved 17 subjective evaluations of noise. The CCIR and RCA results agree

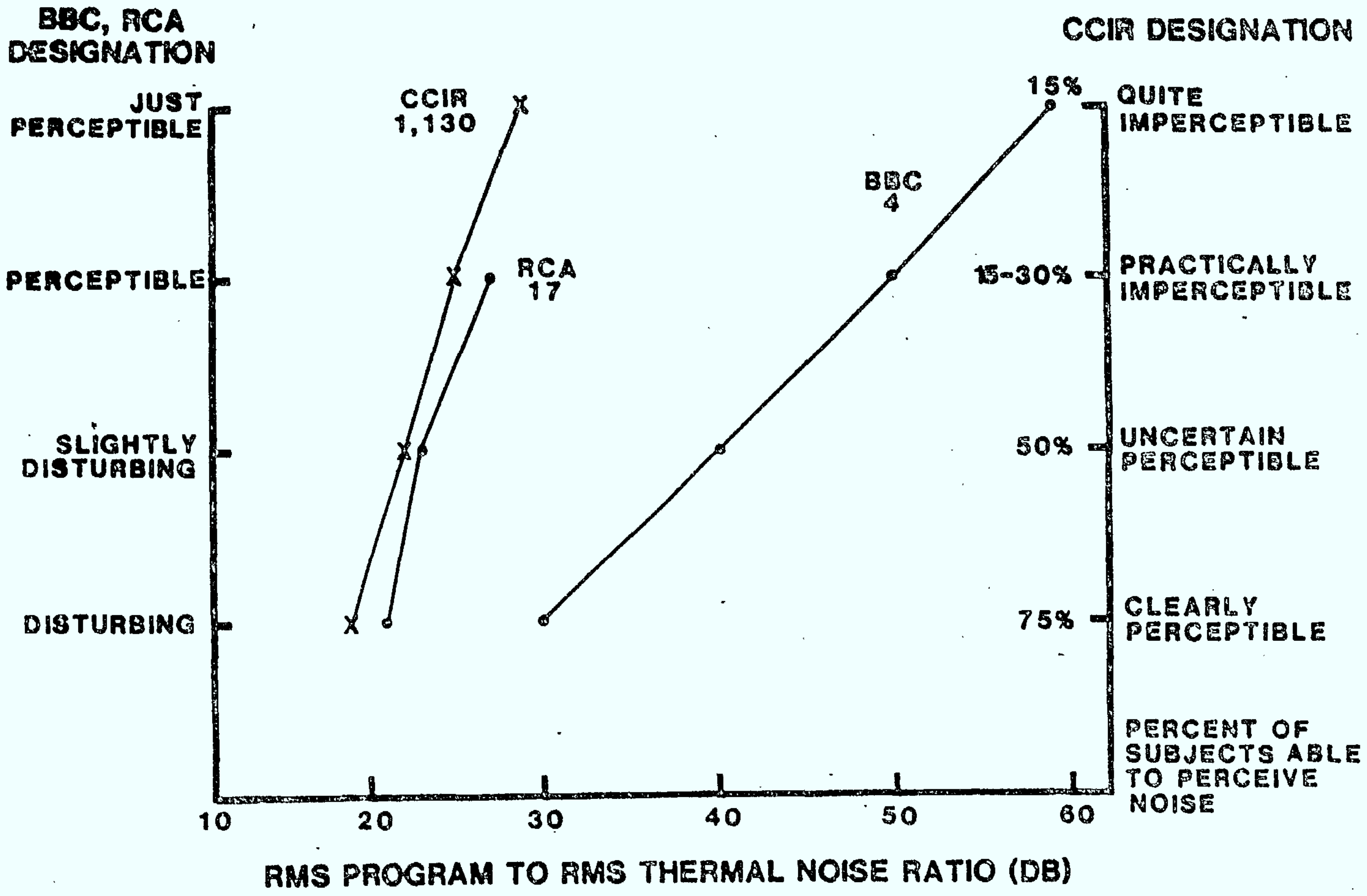


Figure 1: Subjective vs. Objective Evaluation of Noise

closely. The BBC results differ considerably from the other two. The reasons for the differences may be:

1) the small number of listeners in the BBC tests may be insufficient to give confidence in the results
2) the BBC results were obtained in a quiet laboratory, whereas the CCIR and RCA tests were made in environments with noise levels close to that of a normal household, and
3) a difference in interpretation of the meaning of the subjective designations.

Considering these factors, it appears that the CCIR or RCA results should be used. Using these results, RCA aimed for a SNR of 26 to 32 dB in their study.

We note that most of the sound quality specifications in the open literature are for FM systems. It is not known if these SNR values can be applied directly to other modulations such as SSB. The determination of the minimum SNR value for acceptable quality sound from an MSAT radio broadcasting service can only be achieved by field tests of the system with listeners subjectively judging the sound quality.

Ideally, the radio broadcast service provided by MSAT should offer service comparable to that of the terrestrial broadcasting system. Therefore, a signal-to-noise ratio of 40 dB at the receiver output for service to fixed or portable terminals would be desirable. For service to mobiles, since the receiver would be placed inside a vehicle, the extra ambient noise surrounding the listener would permit a lower SNR to be acceptable, since the listener's expectations would be less due to the vehicle noise. A minimum signal-to-noise ratio of 35 dB would be desirable for an ideal system.

Since the MSAT system is power and bandwidth limited, the above SNR objectives may not be realizable. In addition, since the radio programming service on MSAT is intended for remote areas that are not currently served by terrestrial radio broadcasting services, the potential audience would probably accept a lower quality service than that expected by listeners of terrestrial radio services. In this vein, we will place the lower limit of SNR at 30 dB, the value recommended by the CCIR for service to remote areas. If this level of SNR is not achievable, then the service will not be considered acceptable.

The quality of the sound at the output of the receiver depends, in part, on the gain of the amplitude compandor. The subjective gain of a speech compander used in an FM-SCPC communications system varied from 16-18 dB [10]. The subjective gain of a compandor used in a radio broadcasting system may be different, because listeners may be more critical when they are listening to music. This may tend to lower the noise improvement value a listener assigns to a companded system. On the other hand, compandors generally improve the noise performance of high frequency signals more than low frequency signals because high frequency signals usually have a lower average value. Since the radio broadcasting service will have a wider bandwidth than a voice circuit, this effect may improve the subjective noise improvement of a compandor.

Reference [2] refers to an audio processor for high fidelity program material which gives a subjective improvement in SNR of 29 dB. Due to the smaller bandwidth of the MSAT radio programming service, less gain is likely to be realized by a compandor. We will assume a subjective increase in SNR of 20 dB. We must note that at very low signal-to-noise ratios, although the effect of a compander will be quite pronounced, the intelligibility of the signal will be low, and it would therefore be unreasonable to assume that the compandor improves the SNR by 20 dB.

We will assume no loss from the antenna to the detector input.

4.0 Link Budgets

This section presents the link budgets of the possible scenarios for the radio broadcasting service. Both UHF and L-Band link budgets are presented. Three types of receiving terminal are considered: mobile terminals, fixed or transportable terminals, and portable terminals.

4.1 UHF Mobile Terminals

Using the results of [11], a fade margin of at least 13 dB is required to account for multipath fading and shadowing 99% of the time at an elevation angle of 20°. To achieve an availability of 95%, a 7 dB fade margin is required, and for an availability of 90%, a fade margin of 5 dB is necessary. The link budget including fading is shown in Table 1. The parameters used in the UHF link budgets were obtained from [12]. An overall C/N_o of 39.7, 45.4, and 47.1 dB-Hz is obtained for availabilities of 99%, 95%, and 90%, respectively. Assuming a companding gain of 20 dB, the S/N values are 22.7, 28.4, and 30.1 dB for availabilities of 99%, 95%, and 90%, respectively. However, because the SNR at the input to the receiver is only 2.7 dB for 99% availability, it is unrealistic to equate the quality of the output signal with a signal of 22.7 dB SNR.

Note, that since we assume that the U.S. and Canadian spectrum allocations are separate, there are no downlink interference sources.

The carrier power for the radio broadcast signal may be increased to improve the signal quality at the receiver. The cost charged for the service would be increased since the increased carrier power represents a larger utilization of the satellite capacity. We will assume that the radio broadcast carriers have been placed so that intermodulation interference into lower power carriers is not objectionable. Increasing the radio broadcasting carrier power will reduce the effect of intermodulation interference of the other MSAT carriers into the radio broadcast signal. For the current MSAT system design, an increase in the power of the radio broadcast carrier of x dB will result in an improvement in the intermodulation C/I value of approximately x dB for the radio service, as long as the power increase is not significant.

We will consider two cases: a power increase in the radio broadcast carrier of 3 dB and a power increase of 6 dB.

The link budget assuming a 3 dB increase in carrier power and fade margins of 13 dB, 7 dB, and 5 dB appears in Table 2. A C/N_o of 42.7 dB-Hz, 48.3 dB-Hz and 50.1 dB-Hz, respectively is the result. A companding gain of 20 dB would produce an S/N of 25.7 dB, 31.3 dB, and 33.1 dB for availabilities of 99%, 95%, and 90%, respectively.

For an increase in carrier power of 6 dB, and availabilities of 99%, 95%, and 90%, the resulting C/N_o is 45.7 dB-Hz, 51.3 dB-Hz, and 53.0 dB-Hz, respectively as shown in Table 2. For a companding gain of 20 dB, the signal-to-noise ratio is 28.7 dB, 34.3 dB, and 36.0 dB, for availabilities of 99%, 95%, and 90%, respectively.

These results show that for radio broadcasts to a UHF mobile terminal, increased carrier power above the MSAT baseline is desirable.

Note that 99% availability means that, on average, for 99% of the time (or locations) the signal level will be higher than 28.7 dB. For vehicles roaming in areas with sparely populated trees, e.g. in the Prairies and Northwest Territories, the signal level would be considerably higher and, therefore, a better availability would be provided. A higher availability for areas with foliage blockage could also be obtained assuming that the broadcaster is willing to pay for the extra power and assuming that the power is available.

4.2 UHF Fixed or Transportable Terminals

We define transportable terminals to be terminals with a fixed antenna which can be easily disassembled and transported to another site. The fixed or transportable terminal has a higher antenna gain as compared with a mobile terminal. Also, since the antenna is not moving, there is no margin required to overcome shadowing from foliage blockage. Considering only multipath, a 4 dB margin gives 99% availability [11]. Lower fade margins are not considered since the difference in fade margin between 99% availability and 95% availability is only a fraction of a dB.

The link budget with a 4 dB fade margin appears in Table 3. The overall C/N_o achieved is 52.3 dB-Hz. Assuming a companding gain of 20 dB, the resulting SNR is 35.3 dB.

Since the resulting SNR for fixed or transportable terminals is fairly low, we will examine the effect of increasing the radio broadcast carrier by 3 dB and 6 dB. The link budget for the fixed antenna, assuming a 4 dB fade margin and an increased carrier power appears in Table 4. For an increase in carrier power of 3 dB, the overall C/N_o is 55.2 dB-Hz. With a companding gain of 20 dB, a receiver SNR of 38.2 dB is achieved.

With the radio carrier signal power increased by 6 dB, the resulting C/N_o is 58.0 dB-Hz. With a companding gain of 20 dB, the resulting receiver SNR is 41.0 dB.

With the lower fade margin required by a fixed service, better received signal quality is realized. With increased carrier power, fairly good performance is achievable.

4.3 UHF Portable Terminals

Portable terminals are small enough to be carried by a man. They are designed to be set up and taken down quickly. Because they are small they have a smaller gain. But because they can be set up anywhere, the site can be chosen such that there is no blockage loss. Therefore, the same fade margin is used as for fixed antenna service. This type of portable terminal has the same performance as the fixed or transportable terminal considered in the previous section. Here, we consider a portable antenna of the type which would be permanently attached to a small radio set. We assume that the portable antenna has a gain of 8 dBi.

The link budget with the carrier power boosted is shown in Table 5. For a 3 dB increase, the resulting C/N_o is 52.7 dB-Hz. With a companding gain of 20 dB, this would give a receiver SNR of 35.7 dB. With the carrier power increased by 6 dB, the total C/N_o is 55.6 dB-Hz which gives an SNR of 38.6 dB, assuming a companding gain of 20 dB.

4.4 L-Band Mobile Terminals

The L-band link budget is quite similar to the UHF link budget. The SHF link from base station to satellite is identical. The L-band mobile antenna could be designed to achieve a G/T higher than the corresponding UHF mobile G/T. However, the free space loss would also be higher in L-band by as much as 5 dB. The EIRP from the satellite has been shown to be higher at L-band than for the UHF design [13].

We must allow for a fade margin to account for propagation losses. Using the results of [11], a fade margin of 18 dB is necessary to overcome multipath fading 99% of the time at an elevation angle of 20°. For an availability of 95%, a fade margin of 10 dB would be required whereas the necessary margin for an availability of 90% would be 6 dB. The faded L-band link budget appears in Table 6. The parameters of the L-band link budget are taken from [13]. The overall C/N_o is 38.8 dB-Hz for an availability of 99%, 46.3 dB-Hz for an availability of 95%, and 49.6 dB-Hz for an availability of 90%. The receiver SNR is 21.8 dB, 29.3 dB, and 32.6 dB, for availabilities of 99%, 95%, and 90%, respectively, assuming a 20 dB companding gain. Note that the service at a C/N_o of 38.8 dB-Hz is likely to be unusable, since the SNR at the input of the compandor will be only 1.8 dB.

The service to L-band mobile terminals could be improved by boosting the carrier. We will assume two cases of increased carrier power: 3 dB and 6 dB. The increase in carrier power will reduce the amount of intermodulation interference into the radio broadcast carriers. Increasing the carrier power by 3 dB (or 6 dB) will result in an increase in the intermodulation value of at least 3 dB (or 6 dB). The value is not expected to be much above 3 dB (or 6 dB), so we will use a C/I value increased by 3 dB (or 6 dB).

The link budget for L-band mobile service with the carrier power increased by 3 dB appears in Table 7. The overall C/N_o is 41.8 dB-Hz, 49.3 dB-Hz, and 52.6 dB-Hz for fade margins of 18 dB, 10 dB and 6 dB, respectively. With a companding gain of 20 dB, receiver output signal-to- noise ratios of 24.8 dB, 32.3 dB, and 35.6 dB are realized for availabilities of 99%, 95% and 90%, respectively.

As shown in Table 7, with the carrier power increased by 6 dB, for availabilities of 99%, 95%, and 90%, the resulting C/N_o values are 44.8 dB-Hz, 52.3 dB-Hz, and 55.5 dB-Hz, respectively. For a companding gain of 20 dB, the signal-to-noise ratios are 27.8 dB, 35.3 dB, and 38.5 dB, respectively.

Service to L-band mobile terminals would require significantly increased carrier power levels to achieve acceptable performance. In the next section, we examine radio service to L-band fixed terminals.

4.5 L-Band Fixed or Transportable Terminals

If the L-band system is used for service to mobile terminals, then the capacity will be low due to the increased power requirements to overcome free space loss and multipath fading and shadowing. Therefore, an alternative L-band system has been proposed. This system will serve transportable, fixed, and portable terminals only. Mobile terminals will operate at UHF only. Therefore, the satellite L-band power can be reduced because there is no margin required for blockage due to foliage.

The L-band fixed or transportable terminal G/T is -7.8 dB/K. From [11], the fade margin to account for multipath fading only is estimated to be 4 dB for an availability of 99%. As for the UHF case, this is the only availability considered as a small decrease in fade margin would result in a large change in the availability. Because of the reduced margins required, only 13.6 dBW EIRP from the satellite is needed.

The faded L-band link budget for this service appears in Table 8. The overall C/N_o is 42.0 dB-Hz for a 4 dB margin. Assuming a companding gain of 20 dB, the receiver SNR is 25.0 dB.

Since the SNR at the receiver for L-band fixed or transportable service is so low, we will examine the effect of increasing the radio carrier power by 3 dB and 6 dB.

For L-band service to fixed or transportable terminals, because of the reduced power requirement from the satellite, the capacity of the satellite is increased. There will be 104 or 275 carriers per transponder, depending on the spacecraft chosen [14]. In this case, the same argument used in computing the effect of intermodulation interference with increased carrier power for UHF applies to L-band. We will use uplink and downlink carrier-to-intermodulation interference density ratios increased by 3 dB for a 3 dB increase in carrier power and an increase in intermodulation C/I_o of 6 dB for a 6 dB increase in carrier power.

The L-band fixed or transportable service link budget assuming that the carrier power is increased is shown in Table 9. For an increase in carrier power of 3 dB, the resulting C/N_o is 45.0 dB-Hz which yields a receiver output SNR of 28.0 dB, assuming a companding gain of 20 dB. If the radio broadcasting carrier power is increased by 6 dB, then the resulting C/N_o is 48.0 dB-Hz. For a companding gain of 20 dB, the receiver SNR is 31.0 dB.

The performance of fixed service at L-band is quite poor unless the carrier power is greatly increased. Radio broadcasting service to L-band fixed or transportable terminals does not seem practical.

4.6 L-Band Portable Terminals

The link budget for service to an L-band portable terminal with the carrier power increased above the MSAT baseline level is shown in Table 10. As before, the type of portable antenna assumed here is that for a portable radio set. For carrier power increased by 3 dB, the overall C/N_o is 41.1 dB-Hz. Assuming a companding gain of 20 dB gives a receiver output SNR of 24.1 dB. For a 6 dB increase in carrier power, the total C/N_o is 44.1 dB-Hz. With a companding gain of 20 dB, the receiver SNR is 27.1 dB. Therefore, this type of receiver does not provide acceptable quality service.

The overall SNR performance at the various UHF and L-band terminals is summarized in Table 11.

5.0 The Portable and Vehicle Receivers

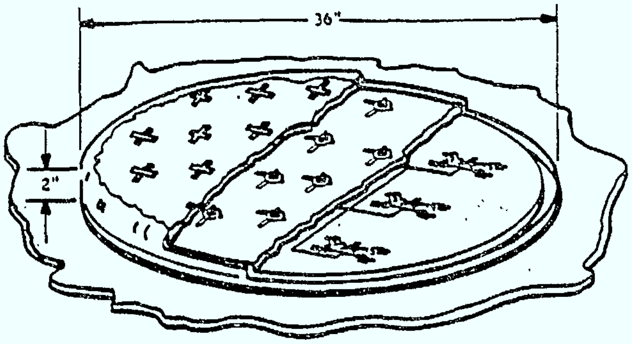
The receiver concept could be built upon conventional designs currently in production in North America, with the addition of a suitable antenna and a converter to extract and reformat the radio program signal in a manner compatible with existing radios. The incremental cost of this modification, assuming a large quantity production, is projected to be small. One approach could be similar to the solution used in direct broadcasting of video to home receivers. That is, the radio signal is first brought to baseband and then remodulated into a format suitable for direct reception by conventional sets. A switch would be necessary to disconnect the conventional radio antenna in order to avoid interference from a local station transmitting on the same frequency.

As will become evident in the following, one of the critical elements of an MSAT receiver is the UHF or L-Band antenna. The utilization of high gain antennas will improve the signal quality and/or reduce the space segment cost associated with a particular service offering. However, the requirement for a higher gain generally translates into more complex antenna designs which are inherently more costly, particularly in a true mobile environment. For these reasons, selection of the proper antenna for a particular receive terminal is intimately related to the desired mode of operation, number of distinct services to be provided via the same antenna as well as the relative impact on the overall end-user cost.

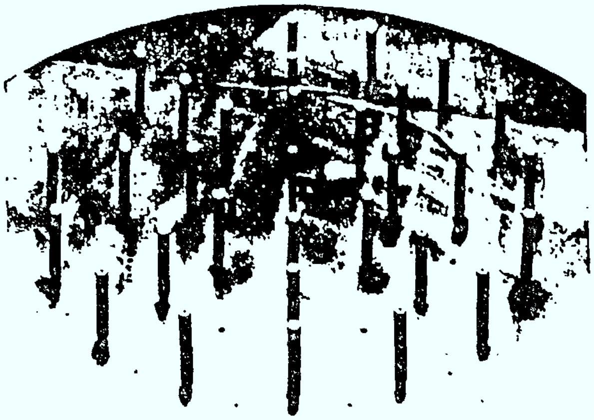
Three different types of terminals are currently envisaged to be employed by MSAT users:

i) Vehicular terminals
ii) Portable terminals
iii) Fixed terminals

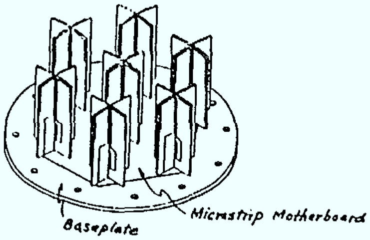
The antenna for vehicular application, is expected to be the most expensive one. Figure 2 shows some of the candidate antennas. Table 12 compares the expected receive gains and G/T of these terminals. The most suitable antennas for portable and fixed applications appear to be Helices, Yagi-Uda arrays, Microstrip arrays or short backfire antennas: Examples of these antennas are shown in Figure 3. Another type of receiving terminal that could be assumed for radio broadcast application via MSAT is a portable radio set as shown in Figure 4. Due to the limitation imposed by the size and the cost of the set, the gain of the antenna at UHF is expected to be about 8 dBic which is 4 dB smaller than that of UHF portable receivers.



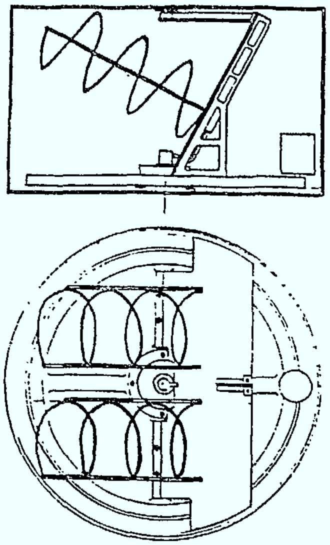
a) Microstrip Phased Array



b) Adaptive Array (CRC Design)



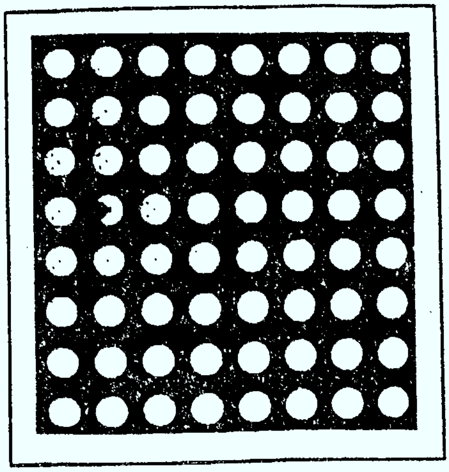
c) Marconi Phased Array of
Crossed Drooping Dipoles



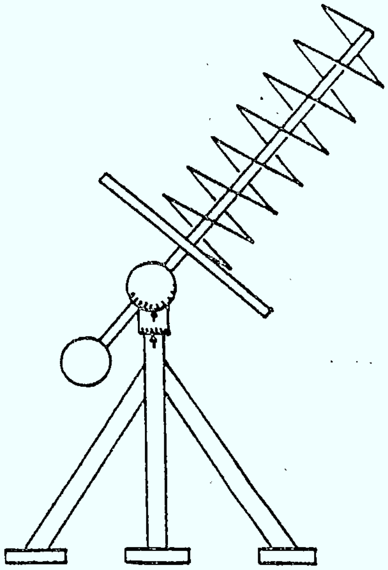
d) Comm Dev Double Helix

Figure 2: Candidate Antennas For MSAT Use

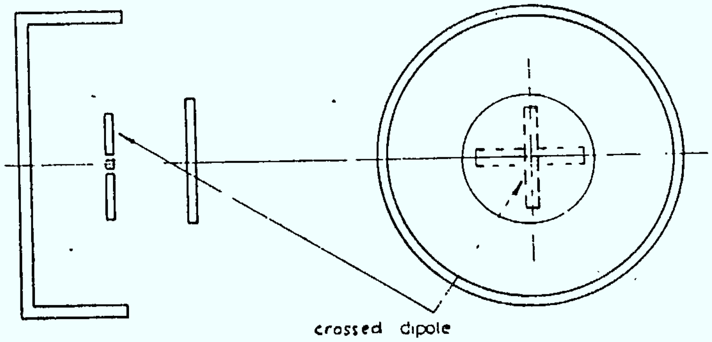
Note: a), b), and c) are electronically scanning arrays whereas d) is a mechanically rotatable antenna.



Microstrip Array of Circular Elements



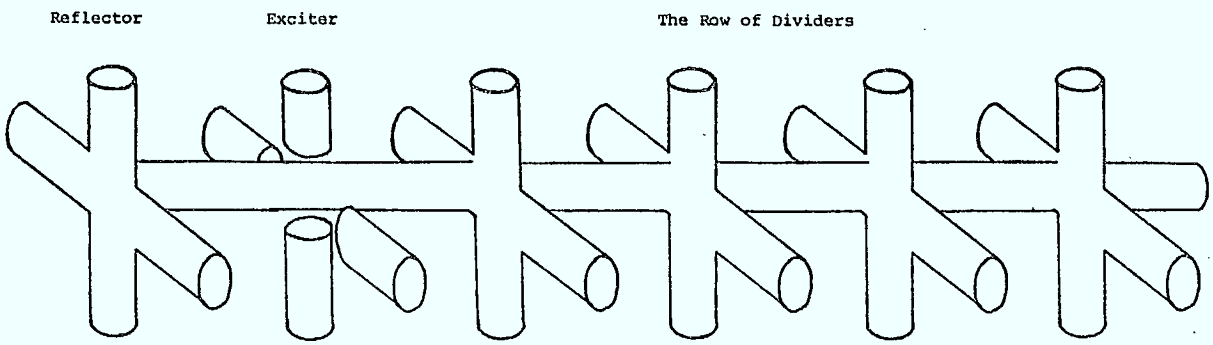
Helix Antenna with Mount and Positioner



Short Backfire Antenna

Figure 3: Antennas For Portable and Fixed Applications

Cont'd . . .



Yagi-Uda Array of Crossed Dipoles

Figure 3 (cont'd): Antennas for Portable and Fixed Applications

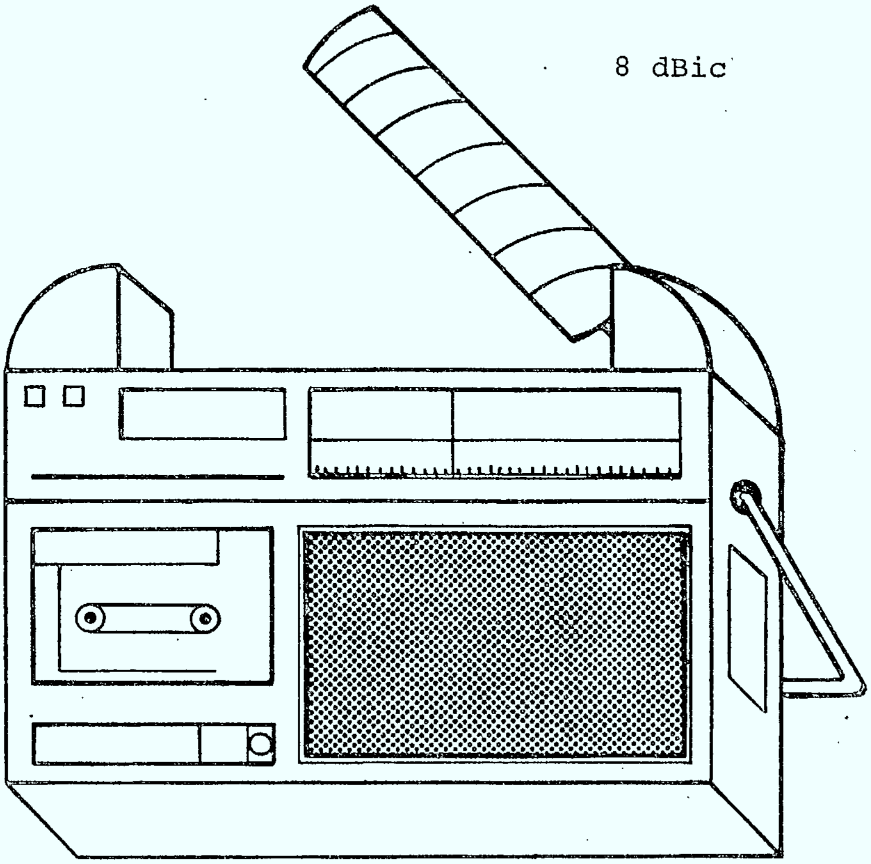


Figure 4: Portable Radio Set With Antenna

6.0 Space Segment Study and Costing

The increase in the satellite EIRP of the broadcast carrier is achieved by having a higher uplink EIRP on that channel as opposed to isolating the channel in the satellite receiver and adjusting its gain. The latter would lead to problems due to the loss in combining before transmitting, in addition to increased spacecraft mass.

Since there are many active carriers (90 in the UHF case) boosting the power of one or two carriers by a few dB's would not have a significant effect on the other carriers. Suppose we have N carriers in a transponder each with an EIRP of E_1. If we wish to increase the EIRP of n of these carriers by Δ dB each and not change the total output power of the transponder, the EIRP of each of the other carriers (E_2) is then obtained from:

$$E_2 = E_1 + 10 \log_{10} \left(\frac{N - n10^{0.1\Delta}}{N - n} \right)$$

This is illustrated in Figure 5.

For example, if $N = 90$, $n = 2$, $\Delta = 3$ dB,

$E_2 = E_1 + 10 \log_{10} (86/88) = E_1 - 0.099$ dB

that is, if 2 carriers are increased by 3 dB, the rest of the carriers have to be reduced by 0.1 dB each in order to maintain the total power constant. If the two carriers are increased by 5 dB, the rest have to be reduced by 0.2 dB. For the L-band system where the total number of active carriers in a transponder is 23, an increase of 3 dB for two of the carriers will result in about 0.4 dB EIRP reduction for the rest of the carriers. A reduction in satellite EIRP per carrier of

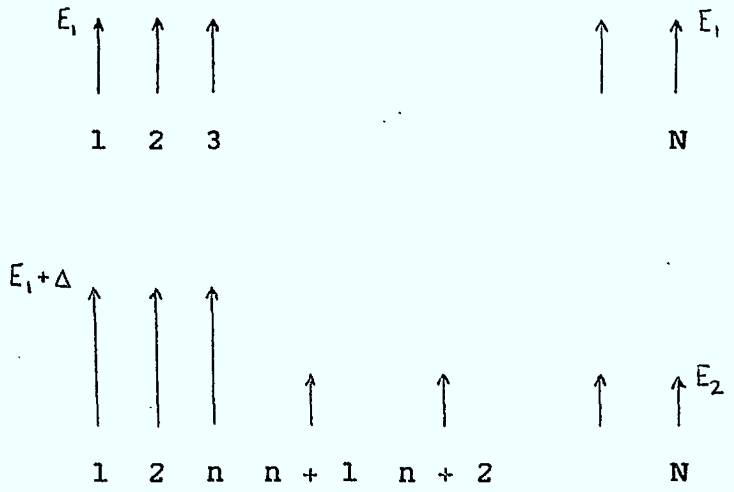


Figure 5: EIRP of Carrier for Equal Carrier Case (top) and Boosted Carrier Case (bottom)

this magnitude is negligible especially considering the uncertainties in fade margins etc. Hence the consideration in increasing the power of one or two carriers would be based mainly on intermodulation degradation.

It is clear then that there is no significant change in the spacecraft transponder due to the presence of a broadcast carrier. It should be pointed out, however, that if the transponder design includes an AGC to protect the amplifier against overload, in the event of increased power, the smaller carriers would suffer much more degradation than the higher power carrier(s).

6.1 Cost of a Radio Program Channel on MSAT

The estimate of the cost of a channel is a complex exercise that must take many factors into account. The very cursory cost estimate given here is only meant to give one an idea of the rough order of magnitude involved and should be restricted to this use only. We first assume that CBC will want to have a channel or channels on a 24 hour basis. Even in the case when they do not require a channel for the full 24 hours, they would presumably release the channel only at night when its availability would not greatly benefit the rest of the users. For this reason, it is reasonable to assume that the CBC channel(s) will be dedicated.

The quickest way to estimate an upper bound on the cost of a channel is to assume that Telesat would charge for the actual airtime. In the CVS, the airtime charges collected by Telesat were $1.25 per minute. Hence, for a dedicated channel, one would assume 24 hours airtime per day. This yields a yearly charge of

$1.25 x 60 x 24 x 365
= $657,000 per channel per year

The charges for each service (assuming both English and French broadcasts) would be:

voice only	$2.63 million per year
voice & monophonic music	$3.94 million per year
high-fidelity stereo	$14.45 million per year

The above charges assume that the broadcast carriers have levels that are not significantly different from the levels of the other carriers. In case the broadcast carrier power is increased well above the nominal power per carrier, the charges would likely be adjusted to reflect the increased power utilization.

Note that these charges represent an upper bound on the broadcast channel charges. The air time charge of $1.25 per minute was arrived at by taking into consideration the slow market build up expected in the early years of the program and also the bursty nature (low utilization) of the mobile traffic. For long-time or permanent users of a channel, a discount mechanism would have to be worked out.

A better method of estimating the charges for dedicated channels may well be to charge according to the RF resource utilization (bandwidth and power) of a particular service. Since there are 90 active carriers per beam (of equal power), the resource utilizations for each service assuming English and French broadcasts are:

voice only	2/90 = 2.2%
voice & monophonic music	3/90 = 3.3%
high-fidelity stereo	11/90 = 12.2%

In cases where the broadcast carrier power is increased to provide a better service, the resource utilization would increase commensurately with the power increase. For example, a voice-only service with the carrier increased by 6 dB would have a resource utilization of (4 x 2)/90 = 8.9%.

The actual costs based on this method of estimation are presently in the process of generation at Telesat.

In the L-band case, since there are 23 active carriers per beam, the resource utilizations for each service assuming English and French broadcast are:

voice only	2/23 = 8.7%
voice & monophonic music	3/23 = 13.0%
high-fidelity stereo	11/23 = 47.8%

The resource utilization for the L-band system seems extremely high (about 3.9 times higher than the UHF ones) mainly because the system accommodates only 23 channels compared to 90 channels for UHF. The major reason for this lower number of carriers is the required higher fade margins in L-band [11, 13], due principally to foliage. If the system were designed for a lower service availability, the required margin would be reduced thus increasing the channel capacity and hence lowering the resource utilization by the broadcast service. This ultimately would lead to lower per channel costs and hence a lower cost of the broadcast channel.

7.0 Conclusions

A satellite-based radio broadcasting network has several distinct advantages relative to its terrestrial-only alternative. In a radio program network, a number of transmitters are required to be fed with program material not generated locally. In a large network, securing an efficient and cost effective program delivery system is of utmost importance and satellite transmission could certainly be an elegant solution for this particular function. Such a satellite-based radio program network could further be complemented by the ability to broadcast over the areas which are either out of the reach of the existing terrestrial distribution network or poorly served due to a low population density. Direct sound broadcasting by MSAT to mobile, portable, and fixed receivers could effectively provide total coverage of the Canadian territory.

However, a considerable number of interrelated factors must be analyzed in much more detail before one can fully appraise the full potential and relative merits of radio broadcasting via MSAT. Some of the relevant areas yet to be fully investigated are the end user's threshold of acceptability in terms of a given signal quality standard, the size of the potential market and its susceptibility to the terminal cost, and most importantly, advertising revenue potential.

The results of this study have shown that amplitude modulation is the recommended modulation to transmit radio programming material by MSAT. The limited bandwidth available forces us to dismiss the possibility of using wideband FM with its inherent SNR improvement relative to AM. To further reduce the portion of the

MSAT spectrum that the radio broadcast channel would use, we propose that SSB modulation be used. In order to improve the demodulation of SSB, a pilot tone should be transmitted with the carrier. The suitability of SSB modulation for broadcasting music is unclear, as no commercial SSB music broadcasting service exits. VSB modulation may prove to be a better choice because of its better low frequency response.

Because the MSAT system is also power limited, amplitude companding will have to be used on the SSB signal, to improve the subjective SNR at the receiver output.

Compatability with existing car radios can easily be achieved by demodulating the received signal to baseband and then remodulating the signal with AM or FM onto the terrestrial radio band. Another option is to down convert the signal to baseband and apply it to the input of the car radio audio amplifier. This would require that the car radio be modified to allow the signal to be applied directly to its internal circuitry.

The number of MSAT channels required to cover-all of Canada with French and English services is 4 for a voice-only service, 6 for a voice/monophonic music service and 22 for a high-fidelity stereo service.

Signal quality is an issue which cannot be resolved analytically. The minimum level of signal quality that users will find acceptable will have to be determined by field trials of the radio broadcast service. The results of this study have aimed for a minimum receiver output signal-to-noise ratio of 30 dB.

High quality radio broadcasting to mobile terminals is difficult to achieve without greatly increasing satellite power or using a significant portion of the MSAT bandwidth. Even with a reduced availability criterion, the SNR at the receiver is slightly above the minimum limit.

Service to UHF fixed or transportable terminals with a Boosted Carrier is significantly above the minimum acceptable level.

The service quality for UHF portable terminals is slightly below that of UHF fixed or transportable service due to the smaller antenna gain. The service performance is below the minimum acceptable level for L-band portable terminals even with the carrier power increased 6 dB.

The service to L-band fixed or transportable terminals is not practical for a system consisting of L-band service to fixed and transportable terminals only. Service to L-band fixed terminals would be practical in an L-band system that served mobile terminals.

Therefore, it can be concluded that with the current envisaged MSAT system design, radio broadcasting via MSAT to mobile terminals will not offer service quality comparable with terrestrial services available near urban centres. However, since the MSAT radio broadcast service is intended for areas not currently served by any type of radio service, a lower quality service, as compared with urban areas, may be acceptable. Further study is needed in the area of what level of quality the end-user would find acceptable.

TABLE 1

UHF/SHF LINK BUDGET
BASE STATION TO MOBILE

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		26.5		dBW
Path Loss		183.2		dB
Receive G/T (2)		-19.1		dB/K
Availability	99%	95%	90%	
Fade Margin	13	7	5	dB
C/N_o Thermal	39.8	45.8	47.8	dB-Hz
Interference				
Intermod and Energy Spread				
Uplink		32		dB
Downlink		22		dB
Other Sources				
Uplink		32		dB
Downlink		-		
Bandwidth		5		kHz
C/I_o Total		58.2		dB-Hz
Total C/N_o	39.7	45.4	47.1	dB-Hz
SNR assuming a companding gain of 20 dB.	22.7	28.4	30.1	dB

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 2

UHF/SHF LINK BUDGET
BASE STATION TO MOBILE
BOOSTED CARRIER

Uplink		+ 3 dB			+6 dB		
Satellite G/T (1)		-3.0			-3.0		dB/K
EIRP/Carrier		43.1			46.1		dBW
Path Loss		206.8			206.8		dB
C/N_o Thermal		61.9			64.9		dB-Hz
Downlink							
EIRP/Carrier		29.5			32.5		dBW
Path Loss		183.2			183.2		dB
Receive G/T (2)		-19.1			-19.1		dB/K
Availability	99.0%	95.0%	90.0%	99.0%	95.0%	90.0%	
Fade Margin	13.0	7.0	5.0	13.0	7.0	5.0	dB
C/N_o Thermal	42.8	48.8	50.8	45.8	51.8	53.8	dB-Hz
Interference							
Intermod and Energy Spread							
Uplink		35			38		dB
Downlink		25			28		dB
Other Sources							
Uplink		32			32		dB
Downlink		-			-		
Bandwidth		5			5		kHz
C/I_o Total		60.9			63.2		dB-Hz
Total C/N_o	42.7	48.3	50.1	45.7	51.3	53.0	dB-Hz
SNR assuming a companding gain of 20 dB.	25.7	31.3	33.1	28.7	34.3	36.0	dB

Notes: Same as Table 1 notes

TABLE 3

UHF/SHF LINK BUDGET
BASE STATION TO FIXED OR TRANSPORTABLE TERMINALS

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	5	kHz
C/I_0 Total	58.2	dB-Hz
Total C/N_0	52.3	dB-Hz
SNR assuming a companding gain of 20 dB	35.3	dB

Notes

(1) Same as Table 1.
(2) Fixed terminal receive gain 12 dBi. System temperature 300 K.

TABLE 4

UHF/SHF LINK BUDGET
BASE STATION TO FIXED OR TRANSPORTABLE TERMINALS
BOOSTED CARRIER

Uplink	+3.0 dB	+6.0 dB	
Satellite G/T (1)	-3.0	-3.0	dB/K
EIRP/Carrier	43.1	46.1	dBW
Path Loss	206.8	206.8	dB
C/N_o Thermal	61.9	64.9	dB-Hz
Downlink			
EIRP/Carrier	29.5	32.5	dBW
Path Loss	183.2	183.2	dB
Receive G/T (2)	-12.8	-12.8	dB/K
Availability	99.0%	99.0%	
Fade Margin	4.0	4.0	dB
C/N_o Thermal	58.1	61.1	dB-Hz
Interference			
Intermod and Energy Spread			
Uplink	35	38.0	dB
Downlink	25	28.0	dB
Other Sources			
Uplink	32	32.0	dB
Downlink	-	-	
Bandwidth	5	5	kHz
C/I_o Total	60.9	63.2	dB-Hz
Total C/N_o	55.2	58.0	dB-Hz
SNR assuming a companding gain of 20 dB.	38.2	41.0	dB

Notes: Same as Table 3.

TABLE 5

UHF/SHF LINK BUDGET
BASE STATION TO PORTABLE TERMINAL
BOOSTED CARRIER

Uplink	+3.0 dB	+6.0 dB	
Satellite G/T (1)	-3.0	-3.0	dB/K
EIRP/Carrier	43.1	46.1	dBW
Path Loss	206.8	206.8	dB
C/N_0 Thermal	61.9	64.9	dB-Hz
Downlink			
EIRP/Carrier	29.5	32.5	dBW
Path Loss	183.2	183.2	dB
Receive G/T (2)	-16.8	-16.8	dB/K
Availability	99.0%	99.0%	
Fade Margin	4.0	4.0	dB
C/N_0 Thermal	54.1	57.1	dB-Hz
Interference			
Intermod and Energy Spread			
Uplink	35	38.0	dB
Downlink	25	28.0	dB
Other Sources			
Uplink	32	32.0	dB
Downlink	-	-	
Bandwidth	5	5	kHz
C/I_0 Total	60.9	63.2	dB-Hz
Total C/N_0	52.7	55.6	dB-Hz
SNR assuming a companding gain of 20 dB.	35.7	38.6	dB

Notes:
1) Same as Table 1.
2) Portable terminal receive gain 8 dBi. System temperature 300 K.

TABLE 6

L-BAND/SHF LINK BUDGET
BASE STATION TO MOBILE

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%	95%	90%	
Fade Margin	18	10	6	dB
C/N_0 Thermal	38.9	46.9	50.9	dB-Hz
Interference				
Intermod and Energy Spread				
Uplink		32		dB
Downlink		22		dB
Other Sources				
Uplink		32		dB
Downlink		-		
Bandwidth		5		kHz
C/I_0 Total		58.2		dB-Hz
Total C/N_0	38.8	46.3	49.6	dB-Hz
SNR assuming a companding gain of 20 dB.	21.8	29.3	32.6	dB

Notes

(1) Same as Table 1.

(2) Mobile receive gain 11.3 dBi. System temperature 510 K.

TABLE 7

L-BAND/SHF LINK BUDGET
BASE STATION TO MOBILE
BOOSTED CARRIER

Uplink		+ 3 dB			+6 dB		
Satellite G/T (1)		-3.0			-3.0		dB/K
EIRP/Carrier		43.1			46.1		dBW
Path Loss		206.8			206.8		dB
C/N_0 Thermal		61.9			64.9		dB-Hz
Downlink							
EIRP/Carrier		35.3			38.3		dBW
Path Loss		188.2			188.2		dB
Receive G/T (2)		-15.8			-15.8		dB/K
Availability	99.0%	95.0%	90.0%	99.0%	95.0%	90.0%	
Fade Margin	18.0	10.0	6.0	18.0	10.0	6.0	dB
C/N_0 Thermal	41.9	49.9	53.9	44.9	52.9	56.9	dB-Hz
Interference							
Intermod and Energy Spread							
Uplink		35			38		dB
Downlink		25			28		dB
Other Sources							
Uplink		32			32		dB
Downlink		–			–		
Bandwidth		5			5		kHz
C/I_0 Total		60.9			63.2		dB-Hz
Total C/N_0	41.8	49.3	52.6	44.8	52.3	55.5	dB-Hz
SNR assuming a companding gain of 20 dB.	24.8	32.3	35.6	27.8	35.3	38.5	dB

Notes

Same as Table 6.

TABLE 8

L-BAND/SHF LINK BUDGET
BASE STATION TO FIXED OR TRANSPORTABLE TERMINALS

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	13.6	dBW
Path Loss	188.2	dB
Receive G/T (2)	-7.8	dB/K
Availability	99%	
Fade Margin	4	dB
C/N_0 Thermal	42.2	dB-Hz
Interference		
Intermod and Energy Spread		
Uplink	32	dB
Downlink	22	dB
Other Sources		
Uplink	32	dB
Downlink	-	
Bandwidth	5	kHz
C/I_0 Total:	58.2	dB-Hz
Total C/N_0	42.0	dB-Hz
SNR assuming a companding gain of 20 dB.	25.0	dB

Notes:

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

TABLE 9

L-BAND/SHF LINK BUDGET
BASE STATION TO FIXED OR TRANSPORTABLE TERMINALS
BOOSTED CARRIER

	+3 dB	+6 dB	
Uplink			
Satellite G/T (1)	-3.0	-3.0	dB/K
EIRP/Carrier	43.1	46.1	dBW
Path Loss	206.8	206.8	dB
C/N_0 Thermal	61.9	64.9	dB-Hz
Downlink			
EIRP/Carrier	16.6	19.6	dBW
Path Loss	188.2	188.2	dB
Receive G/T (2)	-7.8	-7.8	dB/K
Availability	99.0%	99.0%	
Fade Margin	4.0	4.0	dB
C/N_0 Thermal	45.2	48.2	dB-Hz
Interference			
Intermod and Energy Spread			
Uplink	35	38	dB
Downlink	25	28	dB
Other Sources			
Uplink	32	32	dB
Downlink	-	-	
Bandwidth	5	5	kHz
C/I_0 Total	60.9	63.2	dB-Hz
Total C/N_0	45.0	48.0	dB-Hz
SNR assuming a companding gain of 20 dB.	28.0	31.0	dB

Notes

Same as Table 8

TABLE 10

L-BAND/SHF LINK BUDGET
BASE STATION TO PORTABLE TERMINAL
BOOSTED CARRIER

Uplink	+3 dB	+6 dB	
Satellite G/T (1)	-3.0	-3.0	dB/K
EIRP/Carrier	43.1	46.1	dBW
Path Loss	206.8	206.8	dB
C/N_0 Thermal	61.9	64.9	dB-Hz
Downlink			
EIRP/Carrier	16.6	19.6	dBW
Path Loss	188.2	188.2	dB
Receive G/T (2)	-11.8	-11.8	dB/K
Availability	99.0%	99.0%	
Fade Margin	4.0	4.0	dB
C/N_0 Thermal	41.2	44.2	dB-Hz
Interference			
Intermod and Energy Spread			
Uplink	35	38	dB
Downlink	25	28	dB
Other Sources			
Uplink	32	32	dB
Downlink	-	-	
Bandwidth	5	5	kHz
C/I_0 Total	60.9	63.2	dB-Hz
Total C/N_0	41.1	44.1	dB-Hz
SNR assuming a companding gain of 20 dB.	24.1	27.1	dB

Notes

1) Same as Table 1
2) Portable terminal receive gain 13 dBi. System temperature 300 K.

TABLE 11

UHF S/N PERFORMANCE

Terminal	Nominal EIRP	+3 dB EIRP	+6 dB EIRP	Availability
Mobile	22.7 dB	25.7 dB	28.7 dB	99%
	28.4 dB	31.3 dB	34.3 dB	95%
	30.1 dB	33.1 dB	36.0 dB	90%
Fixed or Transportable	35.3 dB	38.2 dB	41.0 dB	99%
Portable	-	35.7 dB	38.6 dB	99%

L-BAND S/N PERFORMANCE

Terminal	Nominal EIRP	+3 dB EIRP	+6 dB EIRP	Availability
Mobile	21.8 dB	24.8 dB	27.8 dB	99%
	29.3 dB	32.4 dB	35.3 dB	95%
	32.6 dB	35.8 dB	39.2 dB	90%
Fixed or Transportable	25.0 dB	28.0 dB	31.0 dB	99%
Portable	-	24.1 dB	27.1 dB	99%

Table 12

Comparison Between
Different UHF/L-Band MSAT Terminal Antennas

	Vehicular Antenna	Portable Antenna	Fixed Antenna
Type	Electronically phased array, mechanically rotated array.	Helix, Yagi array, short backfire ant. Microstrip array.	Helix, Yagi array Microstrip array short backfire.
Cost	$650 - $2500 depending on design	$800 or less	$800 or less
Receiver Gain:			
UHF	8 dBic	12 dBic	12 dBic
L-Band	11 dBic-13 dBic	17 dBic	17 dBic
LNA Noise Figure	2 dB	2 dB	2 dB
System Noise Temperature	400 K - 500 K*	300 K**	300 K
G/T:			
UHF	-19 dB/K	-13 dB/K	-13 dB/K
L-Band	-16 to -14 dB/K	-8 dB/K	-8 dB/K

* 500 K for microstrip array due to high circuit loss, 400 K for CRC or Comm Dev antennas.

** It is expected that these antennas will be used in places with considerably less man-made noise.

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