# Satellite Sound Broadcasting System Study, Mobile Considerations

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## ABSTRACT

There is an ongoing study at JPL to investigate a Satellite Sound Broadcast System in the UHF or L bands. The study considers program reception both by portable and mobile receivers. This paper reports on the mobile reception part of the study. Existing propagation and reception measurements for the Land Mobile Satellite channel are used with proper interpretation to evaluate the signalling, coding, and diversity alternatives suitable for the system. Signal attenuation in streets shadowed by buildings appear to be around 20 db, considerably higher that the 10 db adopted by CCIR. With the marriage of proper technologies, an LMSS class satellite can provide substantial direct satellite audio broadcast capability in UHF or L Bands for high quality mobile and portable indoor reception by low cost radio receivers. This scheme requires terrestrial repeaters for satisfactory mobile reception in urban areas. A specialized bandwidth efficient spread spectrum signalling technique is particularly suitable for the terrestrial repeaters.

## INTRODUCTION

There has been considerable international effort in the areas of system studies, system development and regulatory work towards enabling a Satellite Sound Broadcast System (SSBS) [1]-[5]. An important milestone will be the 1992 World Radio Administrative Conference (WARC 1992) consideration of frequency allocation for such a service.

There is an ongoing effort at JPL to study a SSBS for reception in the UHF or L bands by portable and mobile receivers. Portable reception considerations have been discussed in [4]. The current paper presents preliminary results of the study concerning mobile reception. A flexible multilayered system is developed with each layer relatively independent of internal workings of other layers to facilitate the orderly evolution of the system, and allow adaptation of technologies from other communication systems either existing or under development. Important system issues include: state of the art digital audio coding, power and bandwidth efficient channel coding and modulation techniques, anti multipath signalling and diversity techniques, and finally the space segment.

## AUDIO CODING

There has been considerable work and progress in digital coding of 20 KHz audio due to ISO (International Standards Organization ) activity towards achieving bit rates under 256 kbps for Compact Disk (CD) quality stereo music. Systems developed towards these objectives use either sub-band or transform coding and rely on the noise masking threshold of the human auditory system for efficient adaptive bit allocation schemes [6]-[9]. With these technologies, digital coding of music is feasible at bit rates in the order of 200 kbps to 256 kbps. Such systems can find immediate application in the recording industry, studio facilities, as well as in terrestrial and satellite audio transmission systems. One can safely assume that official or defacto standards for CD quality audio at bit rates of 256 kbps (4 times the basic 64 kbps ISDN channel) will be firmly in place before SSBS will be implemented. The use of this standard for high quality SSBS is one obvious option. Development of a more compact bit rate around 192 kbps (3 time the basic 64 kbps) is also likely. Based on the properties of the human ear, it is unlikely to achieve significantly lower bit rates without impairing the desired CD quality for this application. Thus we will assume bit rates of 192 kbps to 256 kbps as the lower and upper limits for CD quality audio.

One can significantly reduce the required bit rate by choosing a monophonic system and or allowing degradation of the audio quality in bandwidth and dynamic range. A typical bench mark is monophonic FM quality audio rated 4 on the subjective Mean Opinion Score (MOS) at 64 kbps [7], using the same audio coding techniques discussed above. We have

adopted the 64 kbps as the upper limit for a monophonic SSBS system. To allow for future advances in the technology, 48 kbps is used as the lower limit for such a systems. At present technology one can expect an audio quality somewhat lower than monophonic FM at the 48 kbps. There is already a CCITT (standard G.722) audio coder optimized for high quality speech (slightly higher than 4 on the MOS quality scale) at the 64 kbps digital rate. The quality is slightly below 4 (on the MOS scale) for music signals. However one cannot rule out the possibility that the same system can be modified to give satisfactory performance for music.

Based on the status of audio coding technology, we will consider two grades of service quality for SSBS:

o Digital broadcasting of monophonic audio with bit rates in the 48 kbps to 64 kbps.

o High fidelity digital Stereo Broadcasting at bit rates in the 192 kbps to 256 kbps range with quality approaching that of CD. The four fold increase in bit rate requirements from monophonic to CD quality audio is partially due to stereophonic requirements (factor of 2). The higher dynamic range and wider spectrum of CD quality audio result in an additional doubling of the bit rate requirements.

MOBILE RECEPTION AND PROPAGATION CONSIDERATIONS

There is a significant body of experimental, theoretical, and modelling work on the Land Mobile Satellite Service (LMSS) channel. Available information includes experimental data obtained with the ATS-6, Marecs, and ETS satellites as well as a number of terrestrial simulations of the LMSS channel using balloons, towers and aircraft. [10]-[22].

The coarse structure of the LMSS channel is determined by the intermittent blockage of the line of sight by roadside objects (shadowing). Such shadowing can be extensive in urban areas. It is illustrative to look at mobile reception propagation experiments with the ATS-6 [10].

The ATS-6 experiments provide information on the excess path Loss for the LMSS channel as a function of local environment, vehicle heading, and link frequency (860 MHz, 1550 MHz) in several cities with satellite elevation angle ranging from 19 degrees, in Chicago, to 43 degrees, in San Francisco. At the frequency of 860 MHz and satellite elevation angle of 32 degrees, the median signal attenuation exceeded 20 db for 4% of

sectors for example in urban Denver. Each sector has been chosen as a "few hundred wavelengths long" (order of 100 meters). The shadowing effect is particularly sensitive to the street bearing. The median signal attenuation exceeded 20 db for 10% of sectors in the streets running perpendicular to the satellite azimuth. Measurements obtained in the same environment at a frequency of 1550 MHz indicate the same phenomenon but at attenuation levels a few db's higher.

The ATS-6 experiments show that severe urban shadowing effects have only a modest dependence on satellite elevation angle over the measured range(19 degrees to 45 degrees). This can be explained by the fact that severe shadowing is generally occurring in streets at right angle to the satellite azimuth, which remain shadowed anyway within these range of satellite elevation angles. Satellite elevation angles need to reach around 60 to 70 degrees to reduce this type of shadowing to an insignificant percent of the sectors [5]. Thus to provide urban coverage in urban setting one has three alternatives:

o Provide massive link margins (about 20 db) to compensate for shadowing losses and use a signal structure consistent with the fine structure of the shadowed signal. An example of this system is given by CCIR [23] defined as Advanced Digital System II, albeit with a link margin of only 10 db for 99% sector coverage. Such a link margin is insufficient and should be increased to at least 20 db based on the experimental results discussed above.

o Keep the satellite elevation angle very high (at least 60 to 70 degrees). This option is feasible with geostationary orbits only for locations with very low latitudes. For other locations one needs a non geostationary orbit. Under this scenario one can provide a link margin typical of a Rician channels, with short shadows mitigated by diversity techniques.[5].

o Provide enough link margin for a Rician channel, augmented with terrestrial retransmission to fill in urban shadowed areas. Short term signal blockage in rural and suburban areas can be mitigated by diversity techniques. One such system has been proposed based on the Eureka DBS-audio system developed in Europe [1]. We will explore this alternative using spread spectrum signalling techniques for the urban coverage.

Shadowing effects in rural and suburban areas have been studied extensively [10]-[22]. Roadside trees have

been identified as the most significant cause of signal blockage with shadowing depths as high as 20 db for the 1% probability level for some severely shadowed routes in Australia [12]. Tree trunks and branches are the major cause of deep shadowing, while the foliage on the trees has a modest additional contribution of 1 to 3 db's of attenuation [12]. Tree shadowing in SSBS can be mitigated by the use of diversity techniques to overcome deep but short shadows caused by trunks and branches. The same solution would also mitigate shadowing caused by utility poles. A few db's of extra link margin would also be needed to cover the shallow but long foliage shadowing. Rural and suburban overpasses, tunnels, and occasional buildings would result in deep and wide shadows which cannot be combated with this combined scenario. However such shadowing would be infrequent in rural areas and has to be tolerated.

We need to consider fade duration statistics to evaluate the effectiveness of various diversity techniques against tree shadowing. Measurements taken in central Maryland [11] with a helicopter based transmitter to simulate a satellite signal at 30 degrees elevation angle show some interesting results for tree shadowing. These measurements show that in the case of fades deeper than 5 db, 12 % lasted longer than 5 wavelengths (1 meter), and only 2% lasted more than 20 wavelengths (20 x 20 cm = 4 meters).

Obviously, antenna diversity with separation of a few meters, or time interleaving with a length of about one second can mitigate a significant number of tree shadowing fades. Frequency diversity will not work because these fades are due to shadowing and not due to the multipath phenomenon. Antenna diversity is particularly attractive on the basis of link budget, but has the drawback that not all car manufactures may want to incorporate such schemes in their cars. Time interleaving does not have this problem, but would put a few db's of burden on the link budget. Within the scope of our design, modest additional link margin is not a significant problem as we are providing excess link margin of 10 to 12 db's for portable reception inside buildings anyway. Another problem with time interleaving is its sensitivity to the speed of the mobile. With a car stopped within a shadow, time interleaving does not work. However this problem is somewhat mitigated in the rural and suburban case where stoppage is less frequent than urban areas. Given these facts, one can include time interleaving as a system solution and leave antenna diversity as an elective option that the car manufacturer or the mobile user can exercise. Quantitative study of time interleaving parameters, including the FEC coding structure to be

used, is currently being carried out at JPL. Antenna diversity improvements will also be considered.

In urban areas, where there is frequent deep and lengthy shadowing of the satellite signal, satisfactory reception will be practical with the help of terrestrial repeaters. Suburban areas would be borderline cases between urban and rural areas as candidates for terrestrial boosters. Next we will look at a tentative system architecture for such a hybrid system.

## SYSTEM ARCHITECTURE AND LINK BUDGETS

The proposed system architecture is based on the use of a satellite with modest link margins to provide country wide coverage, with a signal structure to mitigate deep short fades encountered due to roadside tree trunks and branches and such other objects as utility poles and traffic signs in an otherwise Rician channel. Detailed link budget and satellite power and spectrum requirements are given in Figure 1 for a typical configuration to cover the CONUS with 4 beams of 3 degrees width. Sixteen programs per beam of digital sound at 48 kbit is assumed in this table. Based on indoor portable reception requirements [4], 10 watts of radiated satellite power per program has been assumed which results in 5.5 db of surplus link margin for mobile rural/suburban reception under unfavorable conditions.

For the typical system of Figure 1, the spectrum requirement is 1.54 MHz per beam resulting in 4.61 MHz per CONUS if the first and fourth beams share the same frequency. Let us name the three frequency blocks F1, F2, and F3, and the four beams B1, B2, B3, B4. Then the frequency assignments will be (F1,B1), (F2,B2),(F3,B3), and (F1,B4). Within each beam the two unassigned spectrum blocks can be used by spread spectrum terrestrial boosters to provide urban coverage. Figure 2 gives detailed analysis on the number of spread spectrum channels that can be supported in each urban area by such a scheme using terrestrial boosters. The analysis is based on the use of a specialized spread spectrum technique developed for the urban LMSS channel [24]. This spread spectrum coding system combines a very low-rate almost orthogonal convolutional code with a pseudo noise (PN) sequence. The very low rate code provides FEC capability with very low decoder $Eb/No$ threshold, 3.65 db's, for example for a BER of 1.0E-5 for rate 1/32 coding. The coder also acts to spread the bit rate, in this case by a spreading factor of 32. The PN sequence has a chip rate equal to the symbol rate of the coder and merely acts to randomize the output symbols. As coding is almost orthogonal, decoding implementation is very

Figure 1.    LINK BUDGET FOR RURAL/SUBURBAN MOBILE RECEPTION

MONOPHONIC DIGITAL SOUND AT 48 KBPS
Transmission frequency= 1 GHz
FDM, Same frequency reused every 3rd beam.
R=1/2 , Conv. code,  soft decoding,    BER=1.0E-4


| AUDIO LINK BUDGET | UNITS | Fav. valu | Unfav. |
|---|---|---|---|
| Inf. bit rate/program | KBPS | 48.00 | 48.00 |
| Inf. bit rate/program | DB | 46.81 | 46.81 |
| XMITTER  PWR  per program | WATTS | 10.00 | 9.00 |
| XMITTER PWR  per program | DBW | 10.00 | 9.54 |
| FREQUENCY | GHZ | 1.00 | 1.00 |
| SATELLITE ANTENNA DIA | M | 7.00 | 7.00 |
| XMIT ANT GAIN | DB | 34.71 | 34.71 |
| ANT BEAMWIDTH | DEG | 3.00 | 3.00 |
| EIRP | DBW | 44.71 | 44.25 |
| RANGE | KM | 40000.00 | 40000.00 |
| FREE SPACE LOSS | DB | 184.48 | 184.48 |
| RCV ANT DIA | M | 0.23 | 0.18 |
| RCV ANT GAIN | DB | 5.00 | 3.00 |
| RCV ANT BEAMWIDTH | DEG | 91.70 | 115.58 |
| RCVD SIG PWR | DB | -134.77 | -137.24 |
| RCV SYST TEMP | K | 200.00 | 400.00 |
| RCV SYST TEMP | DB | 23.01 | 26.02 |
| RCV SYST G/T | DB | -18.01 | -23.03 |
| No | DBW/HZ | -205.59 | -202.58 |
| C/No | DBHz | 70.82 | 65.35 |
| | | | |
| Eb/No Available At Beam Center | DB | 24.01 | 18.53 |
| Eb/No At Beam Edge | DB | 21.01 | 15.53 |
| Implementation loss | DB | 1.00 | 2.00 |
| | | | |
| Req. Eb/No | DB | 6.00 | 8.00 |
| Surplus link margin | DB | 14.01 | 5.53 |
| | | | |
| Spot Beams/CONUS | | 4.00 | 4.00 |
| Numb of Prog/Spot Beam | | 16.00 | 16.00 |
| SAT Radiated Power/CONUS | Watts | 640.00 | 576.00 |
| | | | |
| Code Rate | | 0.50 | 0.50 |
| Modulation Rate QPSK, | Bit/Hz | 0.50 | 0.50 |
| | | | |
| Bandwidth/Program | KHz | 96.00 | 96.00 |
| Bandwidth/SpotBeam | MHz | 1.54 | 1.54 |
| Bandwidth/CONUS | MHz | 4.61 | 4.61 |
| Spectral Efficiency/CONUS | Bit/Hz | 0.67 | 0.67 |

Figure 2. CHANNEL CAPACITY CALCULATIONS FOR URBAN TERRESTRIAL SYSTEM

spread-spectrum signaling with FEC.,

| | | | | | units |
|---|---|---|---|---|---|
| conv. code constraint length | 7 | 7 | 7 | 7 | |
| code rate | R=1/32 | R=1/32 | R=1/32 | R=1/32 | ratio |
| spread factor | 32 | 32 | 32 | 32 | ratio |
| assumed Eb/No ratio, excluding interference | 20.00 | 20.00 | 20.00 | 20.00 | db |
| assumed No/Eb ratio, excluding interference | 0.01 | 0.01 | 0.01 | 0.01 | ratio |
| program channels/frequency block | 8 | 12 | 8 | 12 | channels |
| spread spectrum pilot channel/ frequency block | 1 | 1 | 1 | 1 | channels |
| interfering channels/frequency block | 8 | 12 | 8 | 12 | channels |
| Ni/Eb | 0.25 | 0.38 | 0.25 | 0.38 | ratio |
| Eb/Ni, signal to interference ratio | 4.57 | 2.91 | 4.57 | 2.91 | ratio |
| combined noise and interference to signal ratio | 0.26 | 0.38 | 0.26 | 0.38 | ratio |
| available Eb/(No+Ni) | 5.85 | 4.15 | 5.85 | 4.15 | db |
| decoder Eb/(Ni+No) threshold for BER=1.0E-4 | 2.85 | 2.85 | 2.85 | 2.85 | db |
| data margin for BER=1.0E-4 | 3.00 | 1.30 | 3.00 | 1.30 | db |
| decoder Eb/(Ni+No) threshold for BER=1.0E-5 | 3.65 | 3.65 | 3.65 | 3.65 | db |
| data margin for BER=1.0E-5 | 2.20 | 0.50 | 2.20 | 0.50 | db |
| number of spread spectrum chanells/frequency block | 8 | 12 | 8 | 12 | channels |
| number of frequency blocks /location | 2 | 2 | 2 | 2 | |
| number of spread spectrum chanells/location | 16 | 24 | 16 | 24 | channels |
| satellite broadcast programs/location | 16 | 16 | 16 | 16 | programs |
| terrestrial channels surplus to satellite programs | 0 | 8 | 0 | 8 | channels |
| bit rate/Channel | 48.00 | 48.00 | 256.00 | 256.00 | kbps |
| chip rate | 1536.00 | 1536.00 | 8192.00 | 8192.00 | kcps |
| spectrum per frequency block | 1.54 | 1.54 | 8.19 | 8.19 | MHz |
| frequency blocks/CONUS | 3 | 3 | 3 | 3 | |
| spectrum/CONUS | 4.61 | 4.61 | 24.58 | 24.58 | MHz |

simple. As the decoder has a very low Eb/No threshold, the channel can tolerate the interference from a relatively large number of other spread spectrum channels using the same spectrum. In the example of Figure 2, twelve spread spectrum channels with equal power can share the same spectrum. Excluding spread spectrum interference, the signal to system noise ratio, Eb/No, is assumed to be 20 db. One also should account for the interference from the other 11 program channels and from one pilot channel. We note that the signal to interference ratio, Eb/Ni, is given by the spread factor, 32, divided by the number of interfering channels, 12, resulting in Eb/Ni=2.67 or 4.26 db's. There is a slight signal degradation due to system noise. The overall signal to noise ratio, Eb/(No+Ni), is 4.15 db's, giving us a data margin of 0.5 db above the decoder threshold of 3.65 db's for a BER of 1.0E-5.

For this specific system configuration, the two unused frequency blocks in each beam footprint can support 24 terrestrial spread spectrum program channels, resulting in eight surplus programs over the 16 satellite based programs. This extra capacity can be used to support local programs. One can also operate the spread spectrum system below capacity just to retransmit the satellite based programs. This back off of the spread spectrum capacity results a further improvement in the data margin to 2.2 db's over the 3.65 db threshold for BER of 1.0E-5.

The spread spectrum channels can use multiple repeaters on the same frequency to provide ideal coverage of urban areas. Rake type receivers can combine signals received from multiple transmitters resulting in very effective diversity techniques. Such a system has been demonstrated in the US for cellular mobile telephony applications [25]. A completely different system, that does not use spread spectrum

signaling, developed by Eureka project in Europe has somewhat similar capabilities as long as the multiple signals received from different repeaters do not differ in path length by more than 5 kilometers. The spread-spectrum system discussed here does not suffer from this limitation and can provide very flexible coverage of urban areas.

Figure 3 shows system requirements for a number of broadcast quality options for CONUS coverage.

## CONCLUSIONS

ATS-6 experiments at 860 MHz and at satellite elevation angles in the range of 19-43 degrees indicate typical 20 db median signal attenuation for urban streets shadowed by buildings. Signal attenuation is a few db's higher at 1.5 GHz. The 10 db link margin adopted by CCIR [23] for urban shadowing needs to be accordingly revised.

With the marriage of proper technologies an LMSS class satellite can provide substantial direct audio broadcast capability in UHF or L Bands for high quality mobile and portable indoor reception by low cost radio receivers. This scheme requires terrestrial repeaters for satisfactory mobile reception in shadowed urban streets. A specialized spread spectrum technique developed for the urban LMSS channel [24] is particularly suitable for the terrestrial repeaters.

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Figure 3. TYPICAL SYSTEM PARAMETERS FOR A NUMBER BROADCAST QUALITY OPTIONS

| Carrier frequency = 1 GHz | Almost mono FM | Mono FM | Almost CD | CD | |
|---|---|---|---|---|---|
| Digital sound quality comparable to: | | | | | units |
| Bit rate/Channel | 48 | 64 | 192 | 256 | kbps |
| programs /locations | 16 | 16 | 16 | 16 | channels |
| Urban booster channels/location | 24 | 24 | 24 | 24 | channels |
| Surplus urban booster channels | 8 | 8 | 8 | 8 | channels |
| Spectrum requiremen/CONUS | 4.61 | 6.14 | 18.44 | 24.6 | MHz |
| Satellite radiated RF power/program | 10 | 13.4 | 40 | 53.4 | watts |
| Satellite radiated RF power/CONUS | 640 | 854 | 2560 | 3414 | watts |
| Surplus mobile link margin, Fav. | 14 | 14 | 14 | 14 | db |
| Surplus mobile link Margin, unfav. | 5.5 | 5.5 | 5.5 | 5.5 | db |

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