DIRECT BROADCAST SATELLITE-RADIO, SPACE-SEGMENT/RECEIVER TRADEOFFS

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ABSTRACT

This paper looks at the balance between receiver complexity and the required satellite EIRP for Direct Broadcast Satellite (DBS-R) service. In general, the required receiver complexity and cost can be reduced at the expense of higher space-segment cost by allowing a higher satellite EIRP. The tradeoff outcome is sensitive to the total number of active consumer receivers in a given service area, the number of audio programs, and the required audio quality. An understanding of optimum choices of satellite EIRP for DBS-R under various service requirements is a critical issue at this time when CCIR is soliciting input in preparations for the ITU preparatory conference for the service.

1.. INTRODUCTION

There has been considerable international effort in the areas of system studies, system development, and regulatory work for a Broadcast Satellite Service Sound. An important success was the 1992 World Administrative Radio Conference (WARC-92) allocation of L- and S-band spectrum for this service [1]. The Federal Communications Commission (FCC) is active in persuading the regulatory issues for the commercial introduction of this service in the S-band (2.330-2.360 GHz) allocated at WARC-92 for the U.S. Several companies have filed applications before the FCC to provide this type of service [2].

There is an interagency agreement between Voice of America (VOA) and National Aeronautics and Space Administration (NASA) for a coordinated program on DBS-R. This program includes seven tasks: Systems Tradeoffs Study, Propagation Measurements, Satellite Experimentation and Demonstration, Receiver Development, Market Studies, Regulatory Studies, and WARC preparations. All tasks except for the ongoing Receiver Development have been completed.

This paper looks at the balance between receiver complexity and the required satellite EIRP for DBS-R service. In general, the required receiver sensitivity and cost can be reduced at the expense of higher space-segment cost by allowing a higher satellite EIRP. The findings of a completed System Tradeoffs Study [3] and an ongoing DBS-R Receiver Development Task [4] are used to quantify the tradeoffs between the space-segment and the consumer receiver complexity as the satellite EIRP is varied. A number of other parameters (the anticipated number
of receivers in the service area, audio quality, and the number of broadcast programs) are treated as running variables.

11. THE BASE-LINE DHS-R SYSTEM

The base-line system is based on the findings of the Systems Tradeoffs Study Task [3]. The El'ask covered a technical study with regard to identifying and defining viable system options for satellite broadcasting of radio and its reception on consumer-type digital radios. A range of capacity, coverage, and audio quality requirements were considered for both portable and mobile reception in rural, suburban, and urban areas. Important system issues considered include: state of the art digital audio coding, propagation considerations for mobile and indoor portable reception, power and bandwidth efficient channel coding, anti modulation techniques, signal diversity, and cost for DBS-R.

Based on the status of audio coding technology, the following grades of audio quality and bit rates have been identified [3] for DBS-R applications:

- Digital broadcasting of monophonic audio with bit rates in the 16 kbps to 32 kbps range: with subjective audio quality comparable to AM broadcasting.

- Digital broadcasting of monophonic audio with bit rates in the 48 kbps to 64 kbps range with subjective audio quality comparable to monophonic FM broadcasting.

- Digital broadcasting of stereophonic audio with bit rates in the 64-96 kbps range with subjective audio quality comparable to stereophonic FM broadcasting.

- Digital broadcasting of stereophonic audio with bit rates in the 96-328 kbps range with subjective audio quality near to stereophonic CD quality.

- Digital broadcasting of stereophonic audio with bit rates in the 128-160 kbps range with subjective audio quality approaching stereophonic CD quality.

- Digital broadcasting of stereophonic audio with bit rates in the 360-392 kbps range with subjective audio quality comparable to stereophonic CD quality.

11.2. TYPICAL DBS-R LINK BUDGETS

Table 1 gives typical DBS-R link budgets for mobile and indoor portable reception of one near-CD quality audio program at a frequency of 2.35 GHz using a radiated ERP of 40.5 Watts over a 3-degree spot-beam resulting in an EIRP of 50.8 dBW. The mobile link margin of 6.6 dB is appropriate for mobile reception in rural and suburban areas.
areas, mobile reception in urban areas would require either terrestrial boosters or higher K1 RP spot beams. The portable lin ink margin of 12.9 dB is sufficient for indoor reception in most houses. To avoid prohibitive ink margins for portable receivers inside buildings with large penetration loss (more than the line ink margin), the following measures can be taken:

- Attach an antenna to the inside or outside of a window,
- Use higher gain antennas for tabl e-top radios,
- Install the radio in a location of a signal peak of the indoor standing waves.

The mobile lin ink budget is based on a mobile receiver with a G/T of -19.0 dB/K and a near coherent demodulator with soft Viterbi decoding combined with extensive interleaving to mitigate interference from roadside objects. The portable lin ink budget is based on a table e-top portable receiver with a G/T value of -14 dB/K. The development of prototype receivers with such performance objectives is the subject of a companion paper at this conference [4]. In general, the required receiver sensitivity and cost can be reduced at the expense of higher space-segment cost by using higher satellite RF power. Such a tradeoff would make sense if the additional space-segment investment could be spread over the number of receivers, which is more than offset by the savings in the cost of the receiver. First we will look at the variation of the space-segment cost as function of satellite E1 RP.

### III. SPACE-SEGMENT COST TRADEOFFS VERSUS RECEIVER COMPLEXITY AS A FUNCTION OF SATELLITE K1 RP VARIATION FOR TYPICAL S-BAND DBS-R SYSTEMS

The variation of satellite size and cost for DBS-R services has been already reported [3]. Figure 1 shows the space-segment investment as a function of the required down-link RF power for an S-band DBS-R system with 3-degree spot beams.

The base-line per program satellite RF power requirement for broadcasting one 128 kbps digital audio program over one 3-degree spot beam has been given in Table 1 as 40.5 Watts for a nominal K1 RP of 50.8 dBW. Down-link RF power requirements for other digital audio rates can be estimated by not. ing that the needed RF power is proportional to the digital audio rate. The total RF power can be then estimated by summing the power requirement for each channel. Finally the total RF power can be used in conjunction with Figure 1 to estimate the space-segment investment.

Figure 2 shows the variation of space-segment investment (prorated over the number of receivers) as a function of the per channel K1 RP. The number of program channels and receivers are used as running parameters, covering a range of 30-150 near-field disk-quality channels and 2-20 M receivers. As expected, the prorated space-segment cost is inversely proportional to the number of receivers. For the base-line K1 RP, the prorated investment cost varies from $70 to $7 as the number of receivers goes from 2 M to 20 M if the total number of
program channel is 30. The space-segment investment increases with the number of program channels. As an example, when the number of program channels is increased to 70 from the earlier example of 30 channels, the prorated (over the number of receivers) space-segment investment ranges from $17 (20 M receivers) to $170 (2 M receivers).

The variation of prorated space-segment investment as a function of EIRP also shows the same trends as the absolute cost as discussed above with respect to the number of program channels and the number of receivers. For example the per-receiver increase in the space-segment investment for a 3 dB increase in the EIRP over the baseline system is typically $62 (20 M receivers, 30 channels), $17 (20 M receivers, 30 channels), $170 (2 M receivers, 90 channels), and $170 (2 M receivers, 90 channels). Figure 3 shows a detailed picture of the incremental increases in the Space-Segment investment (prorated over the number of receivers) over the baseline system as the satelite EIRP is increased by 1, 2, and 3 dB over the baseline EIRP.

Next we examine how a 3 dB increase in satellite EIRP over the baseline design can be used to lower the cost of the receiver. First let us identify those parts of the baseline receiver design where potential cost savings are likely to be realized if the satellite EIRP is increased by 3 dB.

1. In the baseline design, the mobile receiver's front end has a G/T of -19 dB/K, with an antenna gain of 4.5 dBi and a total system noise temperature of 224 K (-23.5 dBK). A 3 dB increase is satelite EIRP will allow a lower cost front end with a G/T of -22 dB/K (for example an antenna gain of 3 dBi and system noise temperature of 317 K).

2. In the baseline design, the top portable receiver's front end has a G/L of -14.7 dB/K, with an antenna gain of 12 dBi and a total system noise temperature of 470 K (-26.1 dBK). A 3 dB increase is satelite EIRP will allow a lower cost front end with a G/T of -17.7 dB/K (for example an antenna gain of 10 dBi and system noise temperature of 589 K).

3. The signal processing portion of the receiver can be simplified at the expense of higher Kb/No requirements, for example:

3a. the near coherent demodulator can be changed to differential detection for the mobile receiver,

3b. soft decoding can be changed to hard decision decoding to save on decoder memory.

Of the possible options to decrease receiver cost at the expense of higher satellite EIRP, items 1 and 2 above, namely lowering the G/T Value's of the front ends of the mobile and portable receive candidates, are the most promising candidates of the mobile and portable receivers, are the most promising candidates of the mobile and portable receive candidates. The actual cost differential in this manufacture of each simpler receiver is estimated to be in the range of $10-$40, a better estimate can be obtained after the ongoing DBS-K receiver development Task [4] has been completed.
Finally we like to compare! the saving in the receiver cost versus the increase in space- segment cost when the satell ite K1RP is increased from the base-1 nc value. The outcome of the comparison depends strongly on the number of receivers anti the number of program channels. For a system with 20 M receivers anti 30 near CD quality channels, the per-receiver premium of $6.2 in the space-segment investment is more than offset in the lower per-receiver manufacturing cost of $30-$40 for a 3 dB increase in the satell ite K1RP.

On the other hand, for a system with 2 M receivers and 90 near -- CD quality channels, the per-receiver increase of $1 "?0 in the space- segment investment cannot be -just. i f i ed by the lowering the per receiver manufacture ng cost by $10-$40 for a 3 dB increase in the satell ite K1RP. For this part icular case, it may even make sense to build a receiver with higher sensitivity to reduce the satell ite K1RP. It would probably cost $10-$40 to increase the receiver sensitivity about 2 dB beyond the base-1 nc base design. It would be technica lly very difficult to improve the performance of the mobile receiver much more than2dBbeyond the base-1 nc! design unless a 1 over rate chan nel code is used instead of the rate 1/2 constraint 7 length convolutional code used in the 1 ink budget calculation ions. The ongoing work in the DHS-R Receiver Development Task [4] indicates that rate 1/3 constra int 7 length convolutional code outperforms the simi lar rate 1/2 by a couple of dB's in mobile channels with extensive intermit tent short signal blocks. Hence, it is expected that a mobile receiver with a rate 1/3 code will require a smaller link margin than one with a rate 1/2 (at the expense of rough] y %50 more bandwidth). It is anticipated that both code rates will be implemented in the prototype DHS-R receiver [4] and field tested. The results, when available, can be used to provide a tradeoff between space-segment cost versus spectrum requirements for the two code rates.

As a third example we look at a DH S-R system with 20 M receivers and 90 CD-quality channels. the per-receiver premium of $1 "?0 in the space-segment investment is in the same range as $30-$40 estimate in cost savings in production of each receiver for a 3 dB increase in the satell ite K1RP. On the basis of this rough tradeoff, the base-1 nc K1RP will be near optimum for this case; a finer tradeoff can be made only when the DHS-R Receiver Development Task has been completed.

For some applications, space sc jment costs cannot be compared in par with receiver manufacturing costs. If the two cat. egories of costs need to be dealt separately weighted, the comparisons made above should be modi ed accordingly, al though the separate cost trades for receiver and space?-segment as a function of satell ite K1RP would still be valid.

Finally one should note that the quantative results given above are valid only for S-Band DHS-R. A separate but simi lar tradeoff analysis is required for L-Band DHS-R.

SUMMARY AND CONCLUSIONS

An understanding of optimum choice of satellite K1RP for DHS-R under various service requirements is a critical issue at this time.
when CCI\textsuperscript{R} is SO I cit ing i nput i n preparations for the 1 TU pl anni ng con ference for the service.

In summary the per channel EIRP for optimum balance between space-segment investment and receiver manufacturing cost depends on the number of receivers anti the number of program channel s. The following findings are tentative and will be updated when the DNS-R Receiver Task has been completed:

- For a typical S-Band DNS-R system with 90 near-CD-quality channel s and 20 M receivers, the base-\textsuperscript{1} inc. EIRP of 50.8 dBW per 3-degree spot-beam appears to be near optimum.

- If the number of receivers are significantly less than above, say around 2 M, then it would be advantageous to increase the receiver sensitivity to reduce the satellite EIRP. However it would be very difficult to increase the receiver sensitivity beyond around 2 dB from the base-line design without reducing the channel coding rate (and hence the spectrum efficiency of the system).

- If the number of program channels is reduced say from 90 to 30 near-CD-quality channels, with a large number of receiver rs, say 20 M, then it would make sense to increase the per channel EIRP to allow a lower G/L' for receiver front-end to reduce receiver cost. The increase in satellite EIRP should be limited to roughly 3 dB over the base-line design, as the cost savings in receiver manufacturing will hit diminishing returns beyond 3 dB increase in the per channel EIRP.

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REFERENCES


Figure 1. **Space-segment** investment as a function of radiated downlink RF power

Frequency = 2.35 GHz

Each step represents the addition of one more satellite.
Figure 2.a Space-segment investment as a function of per channel EIRP. (Number of program channels, C, and number of receivers, R, are running parameters.)
Figure 2.5 Space-segment investment as a function of per channel EIRP. (Number of program channels, C, and number of receivers, R, are running parameters)
Figure 2.c Space-segment investment as a function of per channel EIRP. (Number of program channels, C, and number of receivers, F?, are running parameters).
Figure 3. Increase in space-segment investment to allow higher EIRP than the baseline design. (Number of program channels, C, and number of receivers, R, are running parameters).
Figure 3.b  Increase in space-segment investment to allow higher EIRP than the baseline design. (Number of program channels, C, and number of receivers, R, are running parameters)
TABLE 5. DBS-R LINK BUDGET FOR MOBILE AND TABLE-TOP PORTABLE RECEPTION AT A FREQUENCY OF 2.35 GHz

For broadcasting one audio program over one 3-degree spot-beam with coverage of about one million square miles
QPSK modulation, \( r=1/2 \), Conv. code,

Coherent demodulation for portable reception, near coherent demodulation for mobile reception; soft decoding for both types of reception.

<table>
<thead>
<tr>
<th>AUDIO LINK BUDGET (DOWN-LINK)</th>
<th>Mobile Reception</th>
<th>Portable Reception</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Value</td>
<td>TOL (+/-)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital Audio Quality (Stereo)</td>
<td>NEAR CD</td>
<td>NEAR CD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Audio Bit Rate</td>
<td>28.00</td>
<td>28.00</td>
<td>kbps</td>
<td></td>
</tr>
<tr>
<td>Mitter power per program</td>
<td>40.50</td>
<td>40.50</td>
<td>watts</td>
<td></td>
</tr>
<tr>
<td>Frequency range</td>
<td>16.07</td>
<td>16.07</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>2.35</td>
<td>2.35</td>
<td>GHz</td>
<td></td>
</tr>
<tr>
<td>Satellite antenna diameter</td>
<td>2.98</td>
<td>2.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satellite antenna gain</td>
<td>34.7</td>
<td>34.7</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Satellite antenna beamwidth</td>
<td>3.00</td>
<td>3.00</td>
<td>deg</td>
<td></td>
</tr>
<tr>
<td>EIRP</td>
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<td>50.79</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>2.35</td>
<td>2.35</td>
<td>GHz</td>
<td></td>
</tr>
<tr>
<td>Satellite elevation angle</td>
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<td>3.00</td>
<td>deg</td>
<td></td>
</tr>
<tr>
<td>Slant Range</td>
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<td>35867</td>
<td>km</td>
<td></td>
</tr>
<tr>
<td>Free space loss</td>
<td>7.6</td>
<td>7.6</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Atmospheric losses</td>
<td>0.25</td>
<td>0.25</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Pointing loss</td>
<td>0.5</td>
<td>0.25</td>
<td>dB</td>
<td></td>
</tr>
</tbody>
</table>

Receiver noise temperature, indoors for portable reception

| Receiver Antenna gain         | 224             | 470               | K     |          |
| Receiver Gain                 | 4.5             | 4.5               | dB    |          |
| Receiver Gain                 | 19.00           | 19.72             | dB/K  |          |
| C/No                           | 68.00           | 72.31             | dB/K  |          |
| BIT RATE                       | 5.07            | 5.07              | dB    |          |
| Eb/No available (beam center) | 16.95           | 21.24             | dB    |          |

Theoretical Eb/No for BER = 10^-4

| Degradation (mobile channel)  | 3.30            | 3.30              | dB    |          |
| Receiver implementation loss  | 2.00            | 2.00              | dB    |          |
| Interference degradation      | 1.50            | 1.50              | dB    |          |
| Receiver Eb/No Requirement    | 0.50            | 0.50              | dB    |          |
| Receiver Eb/No Requirement    | 3.30            | 5.30              | dB    |          |

AVAILABLE LINK MARGIN, LINE 2, Sight, Beam Center

| 9.65                          | 1.52            | 9.94              | 1.44  | dB 2 & 3 |

AVAILABLE LINK MARGIN, LINE 3, Sight, Beam Center

| 6.65                          | 1.52            | 12.94             | 1.44  | dB 2 & 3 |

**Comments:**

1. Higher audio quality may become possible at this bit rate due to ongoing work by industry
2. Direct mobile reception will be feasible in rural and suburban areas
3. Direct indoor table-top portable reception will be feasible in most houses.
Figure 3.c  Increase in space-segment investment to allow higher EIRP than the baseline design. (Number of program channels, C, and number of receivers, R, are running parameters).