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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-Radio (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 anticipated receivers in a given service area, the number of audio programs, and the required audio quality. An understanding of optimum choice of satellite EIRP for DBS-R under various service requirements is a critical issue at this time when CCIR is soliciting input in preparation for the ITU planning conference for the service.

I. 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 successful international milestone 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 actively perusing the regulatory issues for the commercial introduction of this service in the S-Band (2.310-2.360 GHz) allocated at WARC-92 for the U.S. Several companies have filed applications before the FCC to provide this type of service [2].

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 Tradeoff 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.

II. THE BASELINE DBS-R SYSTEM

The baseline system is based on the findings of the Systems Tradeoffs Study Task [3]. The Task covered a technical study with related tradeoff analysis to identify and define viable system options for satellite broadcasting of radio and its reception by 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 and modulation techniques, anti multipath signaling and diversity techniques, and finally space-segment technology and cost for DBS-R.

II.1 DIGITAL BIT RATE AND Audio QUALITY FOR DBS-R

Based on the status of audio coding technology, the following grades of audio quality and corresponding bit rates have been identified [3] for DBS-R applications: (AM quality, 16-32-kbps), (Monophonic FM quality, 48-64-kbps), (Stereophonic FM quality, 64-96-kbps), (audio quality near to stereophonic CD quality, 96-128-kbps), (audio quality approaching stereophonic CD quality, 128-160-kbps), and (stereophonic CD quality, 160-192-kbps).

II.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 RF power 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, mobile reception in urban areas would require either terrestrial boosters or higher EIRP spot-beams. The portable link margin of 12.9 dB is sufficient for indoor reception in most houses. To avoid prohibitive link margins for portable reception inside buildings with large penetration loss (more than the 12.9 dB link margin), the following measures can be taken: attach an antenna to the inside or outside of a window, use higher gain antennas for table-top radios, or place the radio in a location of a signal peak of the indoor standing waves.

The mobile link 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 time interleaving to mitigate intermittent signal blockage due to roadside objects. The portable reception link budget is based on a table-top portable receiver with a G/T value of -14.7 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 allowing a higher satellite EIRP. Such a tradeoff would make sense if the additional space-segment investment prorated over the number of receivers 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 EIRP.

III. SPACE-SEGMENT COST TRADEOFFS VERSUS RECEIVER COMPLEXITY AS A FUNCTION OF SATELLITE EIRP 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 baseline 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 EIRP of 50.8 dBW. Down-link RF power requirements for other digital audio rates can be estimated by noting 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 EIRP. The numbers of program channels and receivers are treated as running parameters covering a range of 30-150 near-CD-quality channels and 2-20 million (M) receivers. As expected, the prorated space-segment cost is inversely proportional to the number of receivers. For the baseline EIRP, 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 channels 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 follows the same trends as the absolute costs 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 \$6.2 (20 M receivers, 30 channels), \$62 (2 M receivers, 30 channels), \$17 (20 M receivers, 90 channels), and \$170 (2 M receivers, 90 channels).

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 say 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 in satellite 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 table-top portable receiver's front end has a G/T of -14.7 dB/K, with an antenna gain of 12 dBi and a total system noise temperature of 470 K (-26.7 dBK). A 3 dB increase in satellite 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 portions of the receiver can be simplified at the expense of higher Eb/No requirements, for example:

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

   3.b. soft decision decoding can be changed to hard decision decoding to save on deinterleaver 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 values of the front ends of the mobile and portable receivers, are the most promising candidates. The actual cost differential in the manufacture of each simpler receiver is estimated to be in the rough range of $10-$40; a better estimate can be obtained after the ongoing DBS-R receiver development Task [4] has been completed.

Finally we would like to compare the saving in the receiver cost versus the increase in space-segment cost when the satellite EIRP is increased from the baseline value. The outcome of the comparison depends strongly on the number of receivers and the number of program channels. For a system with 20 M receivers and 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 $10-$40 for a 3 dB increase in the satellite EIRP.

On the other hand, for a system with 2 M receivers and 90 near-CD-quality channels, the per-receiver increase of $170 in the space-segment investment cannot be justified by lowering the per receiver manufacturing cost by $10-$40 for a 3 dB increase in the satellite EIRP. For this particular case, it may even make sense to build a receiver with higher sensitivity to reduce the satellite EIRP. It would probably cost $10-$40 to increase the receiver sensitivity about 2 dB beyond the baseline design. It would be technically very difficult to improve the performance of the mobile receiver much more than 2 dB beyond the baseline design unless a lower rate channel code is used instead of the rate 1/2 constraint 7 length convolutional code used in the link budget calculations. The ongoing work in the DBS-R Receiver Development Task [4] indicates that rate 1/3 constraint length 7 convolutional code outperforms the similar rate 1/2 by a couple of dB's in mobile channels with extensive intermittent short signal blockages. 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 roughly 50% more bandwidth). It is anticipated that both code rates will be implemented in the prototype DBS-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 DBS-R system with 20 M receivers and 90 CD-quality channels. The per-receiver premium of $17 in the space-segment investment is in the same range as the $10-$40 estimate in cost savings in production of each receiver for a 3 dB increase in the satellite EIRP. On the basis of this rough tradeoff, the baseline EIRP will be near optimum for this case; a finer tradeoff can be made only when the DBS-R Receiver Development Task has been completed.

For some applications, space-segment costs cannot be compared in par with receiver manufacturing costs. If the two categories of costs need to be differently weighted, the comparisons made above should be modified accordingly, although the separate cost trades for receiver and space-segment as a function of satellite EIRP would still be valid.

Finally one should note that the quantitative results given above are valid only for S-Band DBS-R.

A separate but similar tradeoff analysis would be required for L-Band DBS-R.

SUMMARY AND CONCLUSIONS

An understanding of optimum choice of satellite EIRP for DBS-R under various service requirements is a critical issue at this time when CCIR is soliciting input in preparation for the ITU planning conference 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 and the number of program channels. The following findings are tentative and will be updated when the DBS-R Receiver Task has been completed:

- For a typical S-Band DBS-R system with 90 near-CD-quality channels and 20 M receivers, the baseline EIRP of 50.8 dBW per 3-degree spot-beam appears to be near optimum.

- If the number of receivers is 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 baseline 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 receivers, say 20 M, then it would make sense to increase the per channel EIRP to allow a lower G/T for receiver front-end to reduce receiver cost. The increase in satellite EIRP should be limited to roughly 3 dB over the baseline design, as the cost savings in receiver manufacturing will hit diminishing returns beyond 3 dB increase in the per channel EIRP.

Acknowledgment

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TABLE 1. DBS-R LINK BUDGET FOR MOBILE AND INDOOR 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, soft decoding
Coherent demodulation for portable reception, near coherent demodulation for mobile reception

AUDIO LINK BUDGET (DOWN-LINK)	Mobile Mean Value	Portable Mean Value	Units	Comments
Digital audio quality (stereophonic)	Near-CD	Near-CD		1
Audio bit rate	128.00	128.00	kbps	
Transmitter power per program	40.50	40.50	watts	
Frequency	2.35	2.35	GHz	
Satellite antenna diameter	2.98	2.98	m	
Satellite antenna gain	34.71	34.71	dBi	
Satellite antenna beamwidth	3.00	3.00	deg	
EIRP	50.79	50.79	dBW	
Satellite Elevation angle	30.00	30.00	deg	
Slant Range	38687	38687	Km	
Free space loss	191.61	191.61	dB	
Atmospheric losses	0.25	0.25	dB	
Pointing loss	0.5	0.5	dB	
Receiver noise temperature	224	470	K	
Receiver Antenna gain	4.5	12	dBi	
Receiver G/T	-19.00	-14.72	dB/K	
C/No	68.03	72.31	dBHz	
Eb/No available (beam center)	16.95	21.24	dB	
Theoretical Eb/No for BER=1.0E-4	3.30	3.30	dB	
Degradation mobile channel	2.00	0.00	dB	
Receiver implementation loss	1.50	1.50	dB	
Interference degradation	0.50	0.50	dB	
Receiver Eb/No Requirement	7.30	5.30	dB	
AVAILABLE LINK MARGIN, LINE OF SIGHT, Beam Center	9.65	15.94	dB	
AVAILABLE LINK MARGIN, LINE OF SIGHT, Beam Edge	6.65	12.94	dB	2 & 3

COMMENT 1.	Higher audio quality may become possible at this bit rate due to ongoing work by industry
COMMENT 2.	Direct mobile reception will be feasible in rural and suburban areas
COMMENT 3.	Direct indoor table-top portable reception will be feasible in most houses

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

Frequency = 2.35 GHz

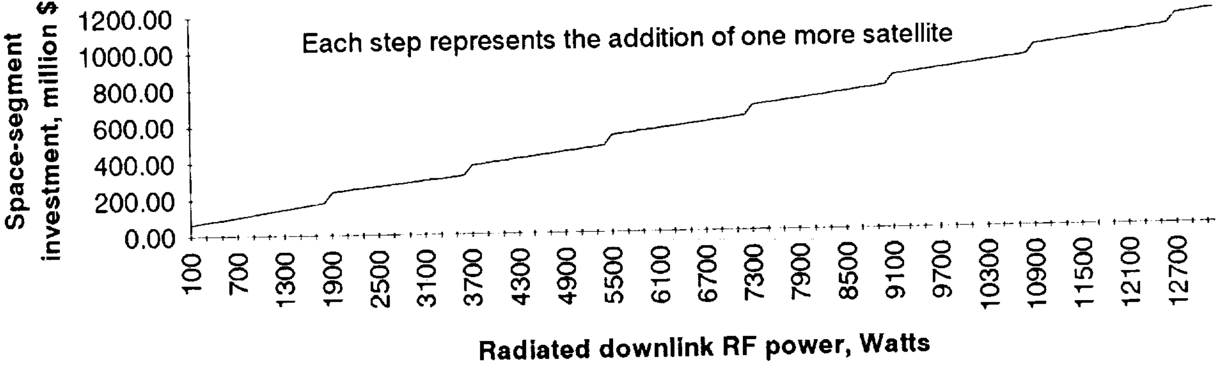

Figure 2. Space-segment investment as a function of per channel EIRP. (Number of program channels, C, and number of receivers, R, are running parameters). Frequency = 2.35 GHz