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

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ABSTRACT

Thi s paper 1 ooks at the bal anew between receiver compl exity anti the requi red satel 1 ite EIRP for Direct. Broadcast Satel 1 i te-Radi o (DBS-R) servi ce . I n general the requi red receiver compl exi ty and costcan be reduced at the expense of' higher space-segment cost by al 1 owi ng a hi gher sat el l ite EIRP. The tradeoff outcome i s sensi tive to the total number of anti cipat ed receivers i n a given service area, the number of audi O prog rams , and the requi red audi o qual ity. An understandi ng of op ti mum choi ce of sat el 1 i te EI RP for DBS-R under vari ous servi ce requi rements i s a crit ical i ssue at. thi s time when CCIR is sol i citing i nput i n preparati ons for the ITU p] anni ng conference for the service.

1. INTRODUCTION

There has. been consi derabl e i nternati onal ef f ort i n t he areas of sys t em studi es , system devel opment and regul atory work for a Broadcast Sat el 1 i te Servi ce Sound. An important. successful i nternati onal mi 1 estone was the 1992 World Admini st rative Radio Con ference (WAR C-92) al 1 ocati on of 1,- and S- band spect rum for thi s service [1] . The Federal Communi cat. i on Commi ssi on (FCC) i s active] y perusi ng the regul at. ory i ssues for the commerci al i ntroduct i on of thi s service in theS-Band (2.330-2.360 GHz) allocated at. WARC-92 for the U.S. Several compani es have fi led appl ications before the FCC to provi de thi s type of servi ce [2].

There i s an i nt eragency agreement. between Voi ce of Ameri ca (VOA) and Nat i onal Aeronauti cs and Spac e Admi ni strati on (NASA) f or a coordi nat ed program on DBS-R. Thi s program i nc l udes seven tasks: Syst ems Trade-of fs Study, Propagati on Measurements, Satel l i te Experi ment ant] Demonst rat i on, Receiver Devel opment, Market Studi es, Regul at ory St udi es , and WARC Preparati ons . Al 1 Tasks except for the ongoi ng Recei ver Devel opment have been compl et ed.

Thi s paper l ooks at the bal ante between receiver compl exi ty ant] the requi red sate] l i te E] RP for DBS-R servi ce. I n general t he requi red receiver sensi tivi ty and cost can be reduced at the expense of hi gher space-segment cost. by al lowing a higher satel l i te E] RP. The f i ndi ngs of a compl eted System Tradeof f Study [3] and an ongoing DBS-R Receiver Devel opment Task [4] are used to quanti fy the tradeof fs between the space-segment and the consumer receiver complexity as the satel] i te E] RP is varied. A number of other parameters (the anti ci pat ed number

of receivers in the service area , audio qua] ity, and the number of broadcast programs) are treated as runni ng vari ah] es.

]]. THE BASE-LINE DBS-R SYSTEM

The base-] ine system j s based on the f i ndings of' the Systems Tradeof fs Study Task [3] . The El'ask covered a technical st udy wi th rel at. ed tradeof f anal ysis to identi fy and define vi able system opt i ons for sat el l it e broadcasting of radio and its recepti on by consumer type digital radios . A range of' capacity, coverage, and audi o qual i ty requi rements were cons i dered for both portabl e and mobi l e recepti on i n rural , suburban, and urban areas. 1 mportant system j ssues considered i nclude: **state** of the art digit al audio coding, propagation consi derati ons for mobi l e and i ndoor portabl e recept i on, power and bandwi dth ef f i ci ent channel codi ng anti modul ati on techni ques, anti mu] ti path signal l ing and diversity techniques, and f inal l y space-segment t echnol ogy and cost for DBS-R.

] I .1 1)1 GI TAL BI T RATE ANI) AUDI O QUAI I TY FOR DBS -1<

Based on the status of audio codi ng technol ogy, the! fol l owi ng grades of audi o qual i ty and bi t rat es have been ident i f i ed [3] for DB S-R appl icati ons:

- Digital broadcasting of monophoni c audio wit, h bit rates i n the 16 kbps to 32 kbps range: wi th subjective audi o qual i ty comparabl e to AM broadcast i ng.

- Digital broadcast ing of monophonic audio with bit. rat es in the 48 kbps to 64 kbps range with subject. ive audi o qual i ty comparabl e to monophoni c FM broadcast. i ng.

- Digital broadcasting of stereophonic audio with bit_ rates in the 64-96 kbps range wi th subjective! audi o qual it. y comparabl e to stereophoni c FM broadcast ng.

- Digital broadcas ti ng of st ereophonic audi o with bit rates in the 96-328 kbps range wi th subject ive audio qual it y near to ste reophoni c CD qua] i t.y.

- Digit al broadcast ing of stereophonic audi o with bi t. rates in the 128-160 kbps range with subjective audi o qua] i ty approachi ng stereophoni c CD qua] i ty.

- Digital broadcasting of stereophoni c audio with bi t. rates i n the 360-392 kbps range wi th subjecti ve audi o qual i ty comparabl e to stereophoni c CD qual i t.y.

11.2. TYPI CAI DBS-R I] NK BUDGETS

Tabl e] gives typi cal DBS-R] ink budgets for mobi l e and j ndoor portabl e recepti on of one near-CD qua] i ty audi o program at a frequency of 2.35 GHz using a radi ated RF powe r of" 40.5 Watts over a 3-degree spot -beam resul ti ng in an E] RP of 50.8 dBW. The mobi l e l ink margin of 6.6 dB i s appropri ate for mobi 1 e recepti on j n rural and suburban

areas , mobi 1 e recepti on i n urban areas woul d requi re ei ther terrestrial boosters or hi gher EI RP spot. -beams. The portabl e 1 i nk margi n of 12.9 dB i s suf f i ci ent f or i ndoor recept i on i n most. houses. To avoid prohibitive] ink margins for port. abl e recepti on i nside bui 1 di ngs with I arge penetrati on 1 oss (more than the 1 ink margi n) , the fol 1 owi ng measures can be taken:

- Attach an antenna to the inside or outside of a window,
- Use hi gher gai n antennas for tab] e-top radi os,
- 1)1 ace the radio in a 1 ocat i on of' a signal peak of' the indoor st andi ng waves.

The mobi 1 e] i nk budget, i s based on a mobil e receiver with a G/T of -19.0 dB/K and a near coherent demodul ator wi th soft. Vi terbi decodi ng combi ned wi th extensive t i me i nterl eavi ng to mi ti gate i nt ermi ttent si gnal bl ockage due to roadside objects. The portabl e recepti on] i nk budget. is based on a tab] e-top portabl e receiver wi th a G/Tvalue of -14 .-/ dB/K. The devel opment of prot otype receivers wi th such performance objectives i s the subject of a companion pape r at. thi s conference [4] . 1 n general the requi red receiver sensit ivi t y and cost can be reduc ed at the expens e of higher space-segment cost by a] 1 owi ng a hi ghe r satel l i te EI RP. Such a tradeoff wou1 d make sense i f the addi ti onal space-segment i nvestment prorat ed over the number of receivers is more than of fset by the savi ngs i n the cost of the receiver. First we wi 11 look at the vari ati on of the space -segment cost as function of satel l ite El RP.

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 satel l ite si ze and cost for DBS-R servi ces have been al ready reported [3] . Fi gure] shows the space -segment i nvestment a s a functi on of the requi reel down-] i nk RF power for an S- Band DBS-R syst em wi th 3-degree spot -beams.

The base- 1 i ne per program satel 1 i te RF power requi rement for broadcasti ng one 128 kbps di gi tal audi o program over one 3-degree spot -beam has been given i n tabl e] as 40.5 Watts for a nominal EI RP of 50.8 dBW. Down-1 ink RF power requirements for other digital audio rat es can be estimated by not. i ng that the needed RF power i s proport i onal to the digi tal audi o rate . The total RF power can be then est i mat ed by summi ng the power requi rement for each channe l . Fi nal 1 y t he t ot al RF power can be used in conjunction with Figure] t o est imate the space -segment i nvestment.

Figure 2 shows t he vari ati on of space-segment i nvestment (prorated over the number of receivers) as a function of the per channel EI RP. The number of program channel s and receivers are t rest.ecl as runni ng parameters, covering a range of 30-150 near- CD-qual ity char-l n e 1 s and 2-20 M receivers. As expected, the prorated space-segment. cost is inversely proport.ions] to the number of receivers. For the ba se- 1 i ne EI RP, the prorated i nvestment cost vari es from $70 to $7 as t he number of recei vers go from 2 M to 20 M i f the total number of

program channel s i s 30. The space - segment i nves tment i ncreases with t he number of program channel s. As an exampl e, when the number of program channel s i s i ncreased to "/0 from the earl i er exampl e of 30 channel s, the prorated (over the number of receivers) space -segment i nvestment ranges from $17 (20 M receivers) to $170 (2 M receivers) .

The vari ati on of prorated space-segment investment as a functi on of EI RP al so f o] 1 ows the same trends as the absol ute cost s di scussed above wi th respect to t-he, number of program channel s and the number of rec eive rs. For exampl e the per-receiver increase i n the space--segment i nves tment for a 3 dB i ncrease i n the EIRP over t he base-l i ne syst em is typ icall y $ 6.2 (20 M receivers, 30 channels) , $ 62 (2 M receivers, 30 channels) , $ 17 (20 M receivers, 90 channels) , and $ 170 (2 M rec eivers , 90 channels) . Figure 3 shows a detai 1 ed picture of the i ncremental i ncreas e i n the **Space-Segment** i nvestment (prorat ed o ver t he number of recei vers) over the base-l ine system as the sat, e] l ite EI RP is i ncreased 1 , 2, and 3 dB over t-he base-1 i ne EI RP.

Next we examine how a 3 dB increase in sat el l ite EI RP over the base-l i ne design can be used to l ower the cost of the receiver. Fi rst. l et us iden ti f y those parts of the base-l ine receiver design where pot enti al cost savings are l ikely to be real ized if the satel l ite EI RP is i ncreased say by 3 dB.

1. 1 n the base-l ine design, the mobi le receiver ' s front. end has a G/T of -19 dB/K, with an antenna gai n of 4.5 dBi and a tot al system noi se temperature of 224 K (-23 .5 dBK) . A 3 dB i ncrease i s sat el l i te EIRP wi 11 al l ow a l ower cost f rent. end with a G/'J' of -22 dB/K (f or exampl e an antenna gai n of 3 dBi and sys tem noi se temperature of 317 K) .

2. in the base-l ine design, the tab] e-top portabl e receiver ' s front end has a G/l' of -14 .7 dB/K, with an antenna gain of 12 dBi and a tot al system noise temperature of 470 K (-26. -I dBK) . A 3 dB i ncrease i s satel l i te EI RP wi]] al l ow a 1 ower cost front end wi th a G/T of -1 7 .7 dB/K (for example an antenna gain of 10 dBi and system noise temperature of 589 K) .

3. The signal processing port i ons of the receiver can be simpl i fied at t he expense of hi gher Eb/No requi rements, for exampl e:

   3a. the near coherent. demodul ator can be changed t o di f ferenti al det ecti on for the mobi le receiver,

   3.b. soft deci si on decodi ng can be changed to hard dec i si on decodi ng to save. on de-int erl eaver memory.

Of the possi b) e opti ons to decrease receiver cost at. the! expense of hi gher satel l i te EI RP, i tems 1 and 2 above, namely l oweri ng the G/T Value's. of the f rent ends of the mobi l e. and port. abl e re ceivers , are the most promi si ng candidates. The actual cost di fferenti al i n the manufacture of each simpler receiver i s est. i mat ed to be i n the rough range of $10-$40, a better estimate can be obtai ned after t hc! ongoi ng DBS-R receiver devel opment Task [4] has been compl et ed.

Finally we like to compare! the saving in the receiver cost versus the increase in space- segment cost when the satellite EIRP is increased from the base-line 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 satellite EIRP.

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 -justified by the 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. 3 t would probably cost $10-$40 to increase the! receiver sensitivity about 2 dB beyond the base-line design. It. would be technically very difficult. to improve the. performance of the mobile receiver much more than2dBbeyondthe base?-] inc! design unless a 1 ower rate channel code is used instead of the rate 1/2 constraint 7 length convolutional code used in the link budget calculat. ions. 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 signalblockages. 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 $ 1 '/ 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 satellite EIRP. On the basis of this rough tradeoff, the base!-line EIRP will be near optimum for t.his case; a finer tradeoff can be made only when the DBS-R Receiver Development Task has been completed.

For some applications, space-sc:cjment. costs cannot be compared in par with receiver manufacturing costs. 1 f the two cat. egories 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 SO I iciting input in preparations for the 1 TU p] anning conference for the servicc.

1 n **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 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 base--line EIRP of 50.8 dBW per 3-degree spot-beam appears to be near optimum.

- If the **number of** receivers **are** significantl **y 1** ess **than above, say** around 2 M, then it. wou1 d 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) .

- 1 f 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. woul d 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-1 ine design, as the cost savings in receiver manufacturing will hit diminishing returns beyond 3 dB increase in the per channel EIRP.

ACKNOWLEDGEMENT

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

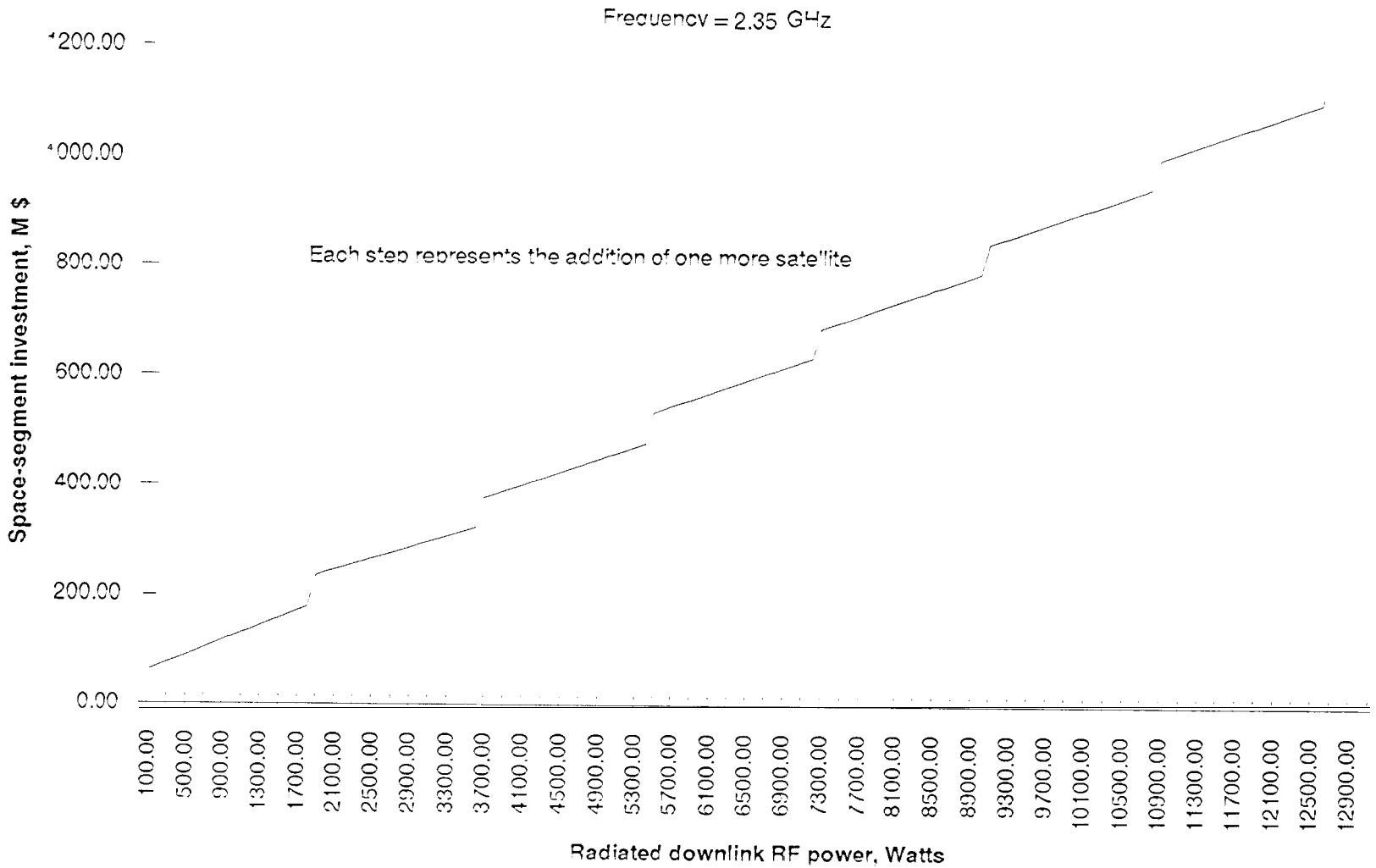

Figure 2.a Space-segment investment as a function of per channel EIRP. (Number of program channels, C, and number of receivers, R, are running parameters).

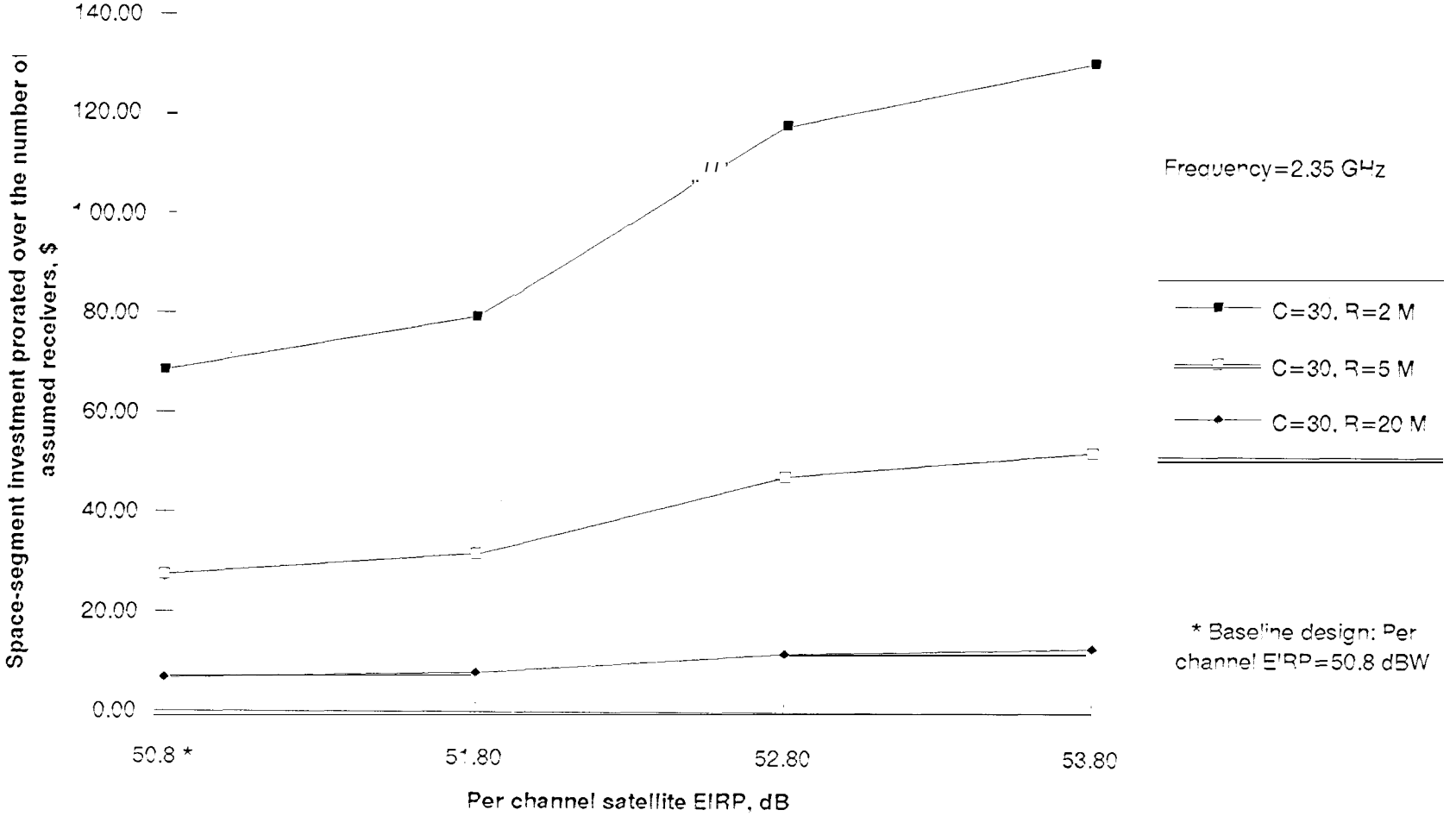

Figure 2.b Space-segment investment as a function of per channel EIRP. (Number of program channels. C, and number of receivers, I?. are running parameters)

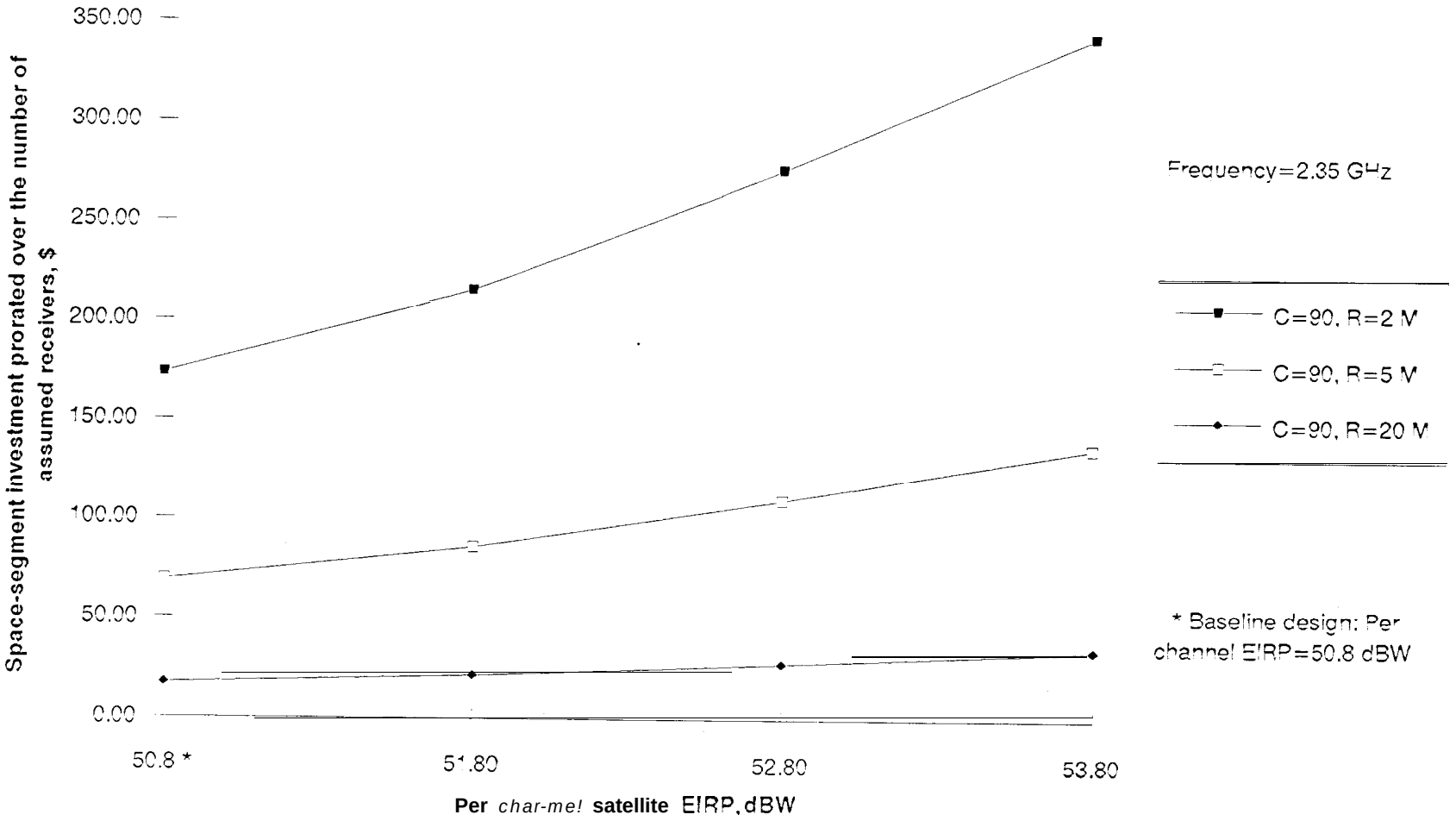

Figure 2.c Space-segment investment as a function of per channel EIRP. (Number of program channels, C, and number of receivers. F?, are running parameters).

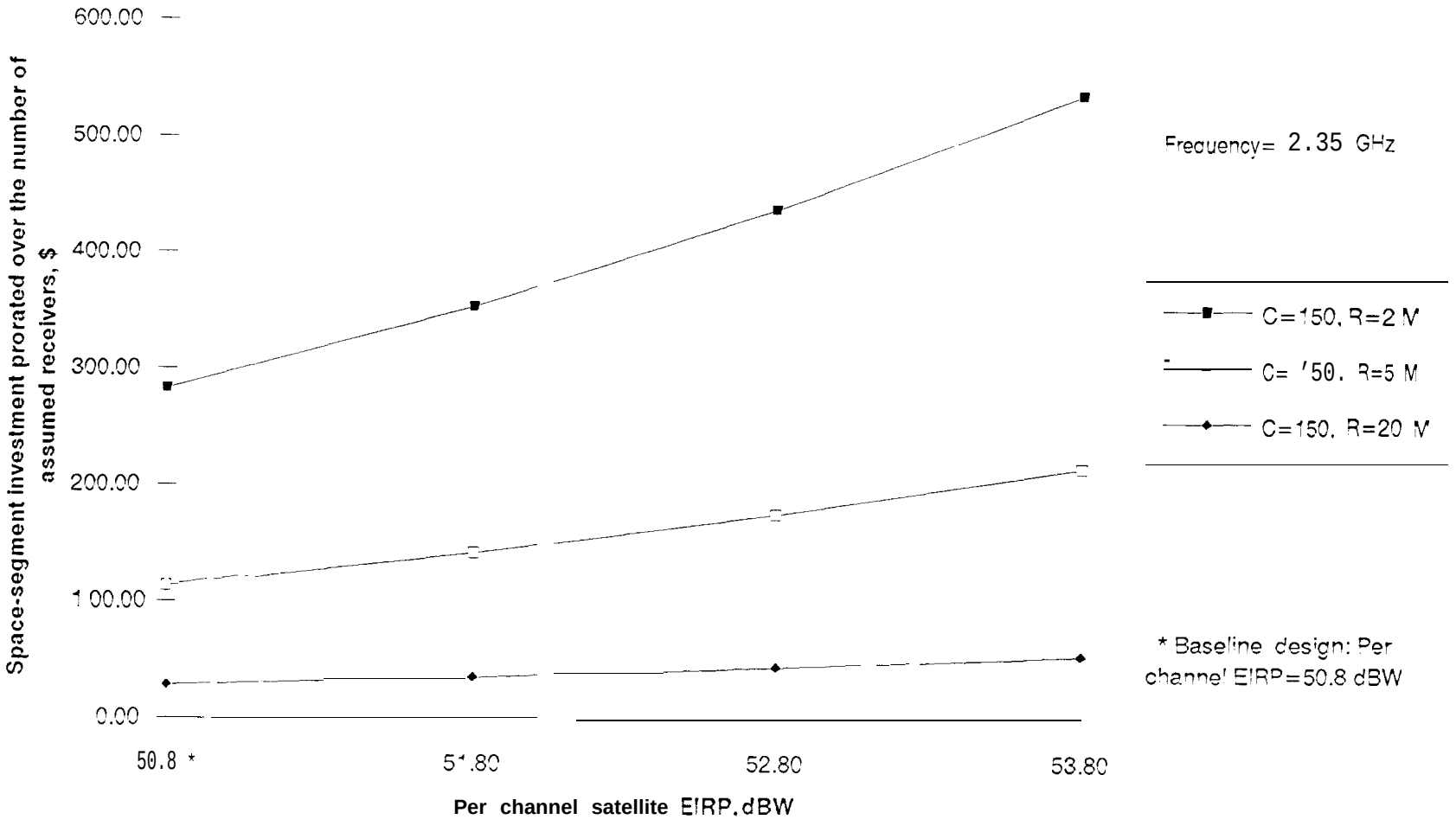

Figure 3.a Increase in space-segment investment to allow higher EIRP than the baseline design. (Number of program channels, C, and number of receivers, R, are running parameters).

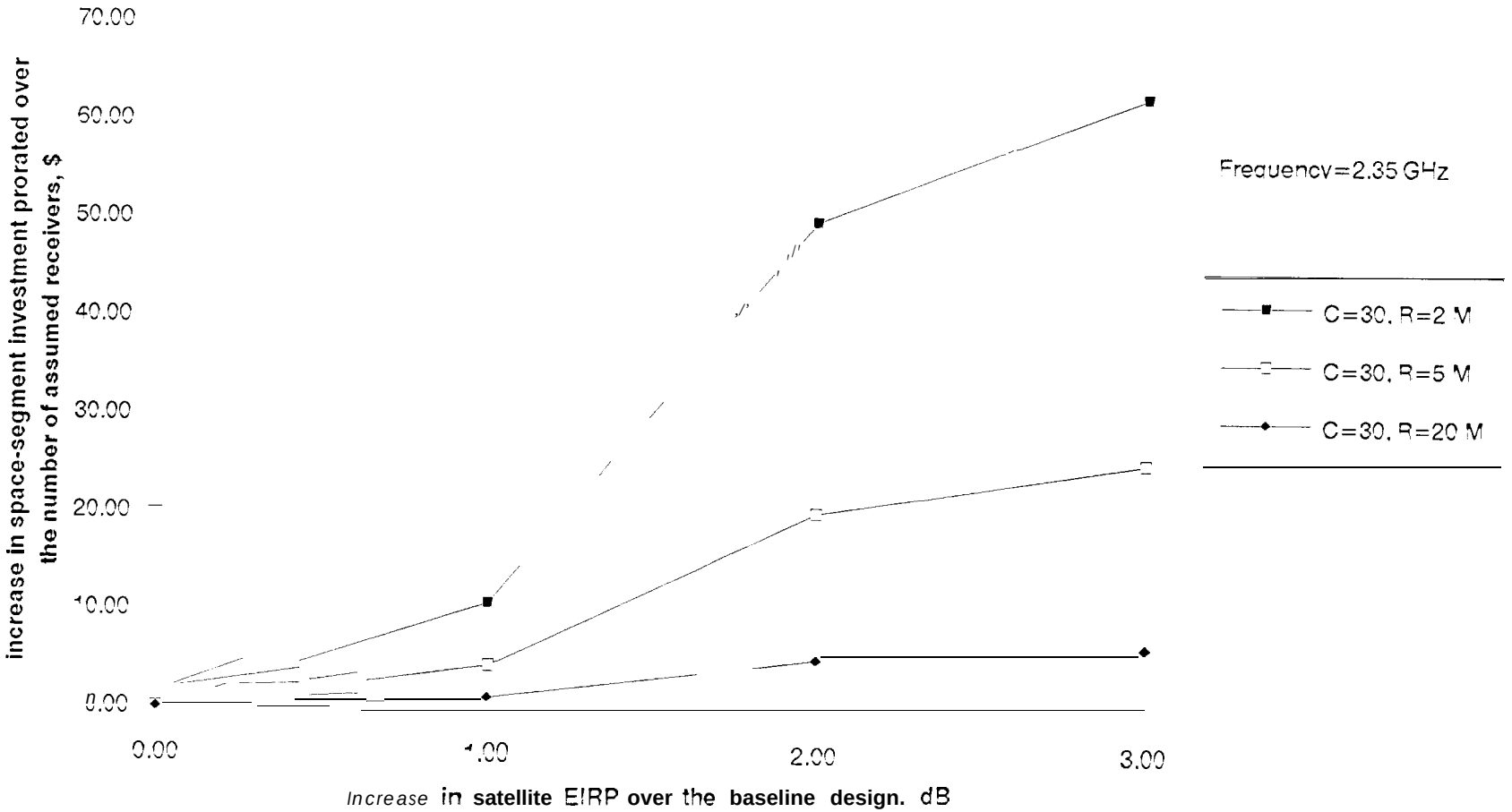

Figure 3.b Increase in space-segment investment to allow higher EIRP than the baseline design. (Number of program channels, C, and number of receivers, R, are running parameters)

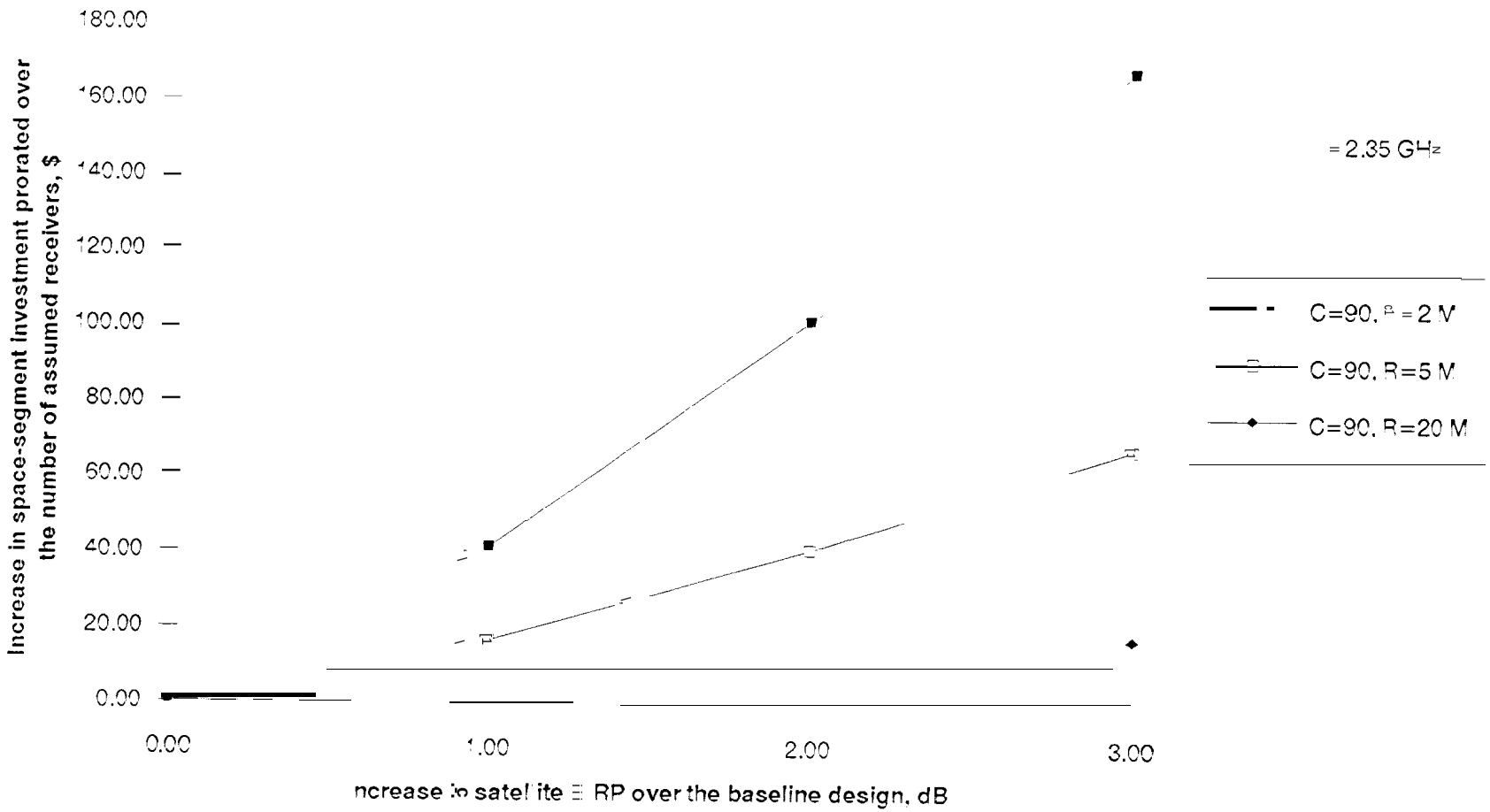

TABLE 1. DBS-R LINK BUDGET FOR MOBILE AND TABLE-TOP PORTABLE RECEPTION AT A FREQUENCY OF 2.35 GHz
For broadcasting one audio program over one 3-degree spot-beam with coverage of about one million square miles
QPSK modulation, R=1/2, Conv. code,
Coherent demodulation for portable reception, near coherent demodulation for mobile reception; soft decoding for both types of reception

AUDIO LINK BUDGET (DOWN-LINK)	Mobile Reception		Portable Reception		Units	Comments
	Mean Value	TOL (+/-)	Mean Value	TOL (+/-)		
DIGITAL AUDIO QUALITY (STEREOPHONIC)	NEAR CD		NEAR CD			1
AUDIO BIT RATE	128.00		128.00		kbps	
Xmitter power per program	40.50		40.50		watts	
Xmitter power per program	16.07		16.07		dBW	
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	
Frequency	2.35		2.35		GHz	
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	0.25	0.25	dB	
Pointing loss	0.5	0.25	0.5	0.25	dB	
Receiver noise temperature, (indoors for portable reception)	224		470		K	
Receiver Antenna gain	4.5		12		dBi	
Receiver G/T	-19.00	1.00	-14.72	1.00	dB/K	
C/No	68.03		72.31		dBHz	
BIT RATE	51.07		51.07		dB	
Eb/No available (beam center)	16.95		21.24		dB	
Theoretical Eb/No for BER=1 OE-4	3.30		3.30		dB	
Degradation mobile channel	2.00	0.50	0.00		dB	
Receiver implementation loss	1.50	0.50	1.50	0.50	dB	
Interference degradation	0.50	0.50	0.50	0.50	dB	
Receiver Eb/No Requirement	7.30	0.87	5.30	0.71	dB	
AVAILABLE LINK MARGIN, LINE O. SIGHT, Beam Center	9.65	1.52	15.94	1.44	dB	
AVAILABLE LINK MARGIN, LINE O. SIGHT, Beam Edge	6.65	1.52	12.94	1.44	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
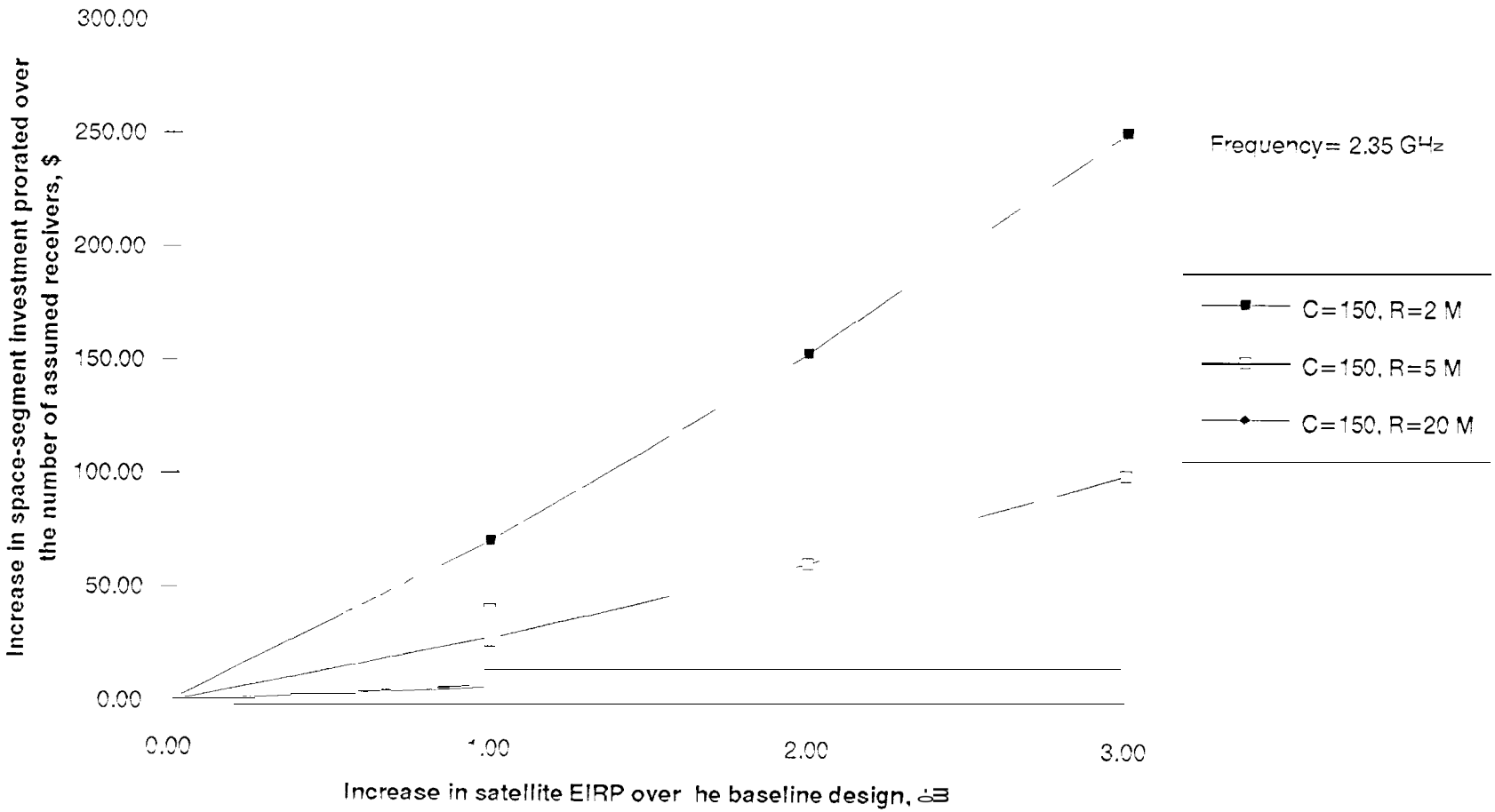
Figure 3.c ncrease in space-segment investment to allow higher EIRP than the baseline design. (Number of program channels, C, and number of receivers, R, are running parameters).