TDRSS LINK BUDGET DESIGN TABLE

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ABSTRACT

The Consultative Committee for Space Data Systems (CCSDS) has issued a Recommendation CCSDS 401.0-B for Radio Frequency and Modulation Systems to be used in Earth stations and spacecraft. Part of this Recommendation is a standardized design tool for link budget computations. This design tool is intended to assist spacecraft designers in preparing the power and performance designs of their spacecraft for communicating with existing standard ground stations. The present CCSDS Recommendation addresses a link design typical for that found with the Deep Space Network (DSN). DSN link analyses use a large subset of link-specific parameters not of any particular use if the space data link passes through the Tracking and Data Relay Satellite System (TDRSS). The link architecture also differs in that the TDRSS parameter set needs to include an extra link through the satellite (two-hop) link versus a DSN-type link which is single-hop. Conversely, the treatment of ranging, PN coding requirements, and TDRSS acquisition and data group formalities are either not of the same format or not present at all on the DSN-type links.

The baseline CCSDS 401 design tool is a Microsoft Excel spreadsheet that can run on an IBM PC or compatible computer. This baseline spreadsheet has been modified to account for the differences between baseline CCSDS model and TDRSS link operations. The paper will discuss the modifications made to the spreadsheet for the TDRSS system details. We will also present example usages of the spreadsheet.

INTRODUCTION

The TDRSS Link Budget Design Table is a modification of the CCSDS Link Design Control Table developed by Anil Kantak of the NASA Jet Propulsion Laboratory (JPL). Kantak based the table on link budgets used by DSN-supported missions. In addition to the basic DSN databases, the CCSDS Link Design Control Table also contains antenna system information for missions supported by the European Space Agency (ESA), French and German national space agencies.

The typical DSN link has one hop, so an uplink signal propagates from the ground station (Goldstone Tracking Station, California) to the DSN user spacecraft while a downlink signal traverses the opposite path. There are no data relay satellites in this kind of network. Consequently, a link budget for a one-hop link will generally specify transmitter powers, antenna gains, and receiver noise temperatures for both ends of the link. If the system includes one or more relay satellites, however, detailed measurements of these link parameters are no longer possible. Instead, multi-hop links such as those in the TDRSS are described in terms of measured ratios such as the effective isotropic radiated power (EIRP) and the G/T figure of merit for the system spacecraft.

In addition to these general discrepancies, DSN and TDRSS links also differ in other respects. DSN missions support a main carrier modulated by subcarriers with separate channels for data and ranging signals. With TDRSS, ranging is carried on a dedicated channel only for forward service links from the ground station (White Sands Ground Terminal, New Mexico) through either of two Tracking and Data Relay Satellites (TDRS) to the user. For the return service links, separate channels may be used for data and ranging or both channels may carry telemetry or payload data. DSN typically uses sine-wave ranging while TDRSS employs special pseudo-random noise (PN) codes for range and Doppler (range rate) tracking as well as signal acquisition by WSGT.

The final important difference between the two space data systems is that DSN supports either S or X-band transmissions with a choice of four different ground station antenna system, while TDRSS supports users transmitting in the S or Ku-bands. Also, TDRSS can handle more than 20 users at a time. DSN is a single-user system. Therefore, TDRSS requires several modes of operation not found in DSN. All these differences must be treated in any adaptation of the CCSDS Link Design Control Table for TDRSS link analysis.

TDRSS LINK BUDGET DESIGN TABLE FORMAT

The link analysis structure used in the TDRSS Link Budget Design Table has been taken from the March, 1983 version of the TDRSS Telecommunication Peformance and Interface Document (TPID) by the TRW Defense and Electronics Group. Specific values used in the Table reflect TDRSS Flight-1 (F1) test results. The CCSDS and TDRSS tables both use the same basic format. This consists of a link budget identification page, a page for general link operating conditions, two data input sheets, and the two link budget worksheets. The modifications made to the CCSDS table in developing the TDRSS link analysis tool will be presented in the context of this format. A flow chart illustrating the basic TDRSS link analysis format is presented below as Figure 1.

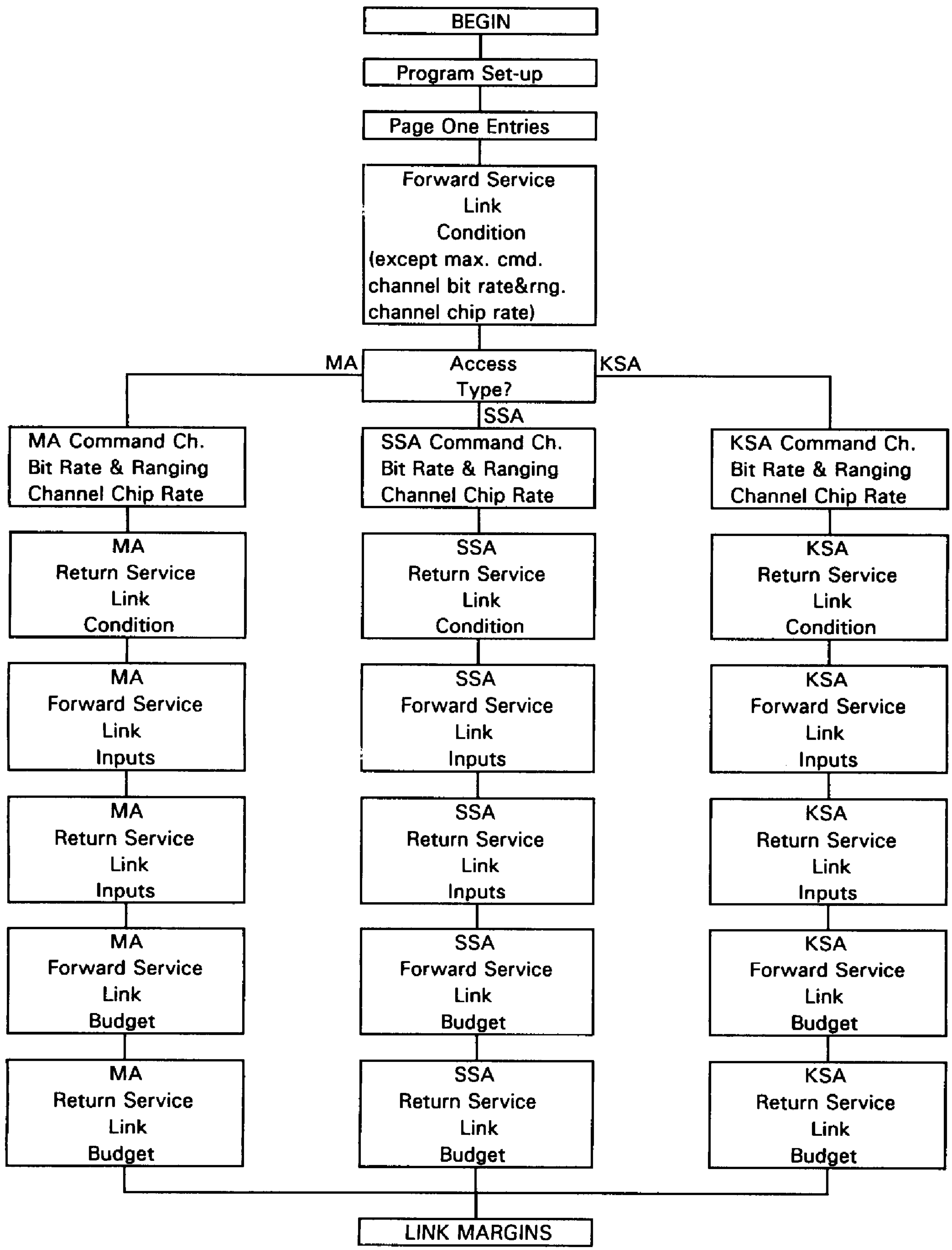
GENERAL INFORMATION

The first page of the CCSDS Link Design Table contains information to identify a particular link budget associated with any mission using CCSDS Recommendations. This information includes the CCSDS member agency responsible for the mission, the names of mission and spacecraft, any link budget identification, the date of the analysis, the computer file for the analysis, the individual directly responsible for the mission or project, and the person responsible for the proper operation of the network supporting the mission. Few changes were made on this page of the TDRSS Link Budget Design Table, since the identifying information supplied here suffices for practically any space data system project.

LINK OPERATING CONDITIONS

For both link design tools, the second page list basic signal characteristics over all relevant links within the system under study. For the DSN-type links treated by the CCSDS Recommendation, there are only two links, an Earth-to-Space Link and a Space-to-Earth Link. Because of this, the operating conditions for DSN-supported missions can be conveniently divided by link. The left half of the page details RF carrier modulation, baseband data, data subcarrier, and ranging signal formalities for the Earth-to-Space Link along with data on weather availability and spacecraft distance from the Earth station. The right side of the page does the same for the Space-to-Earth Link. TDRSS does not consist of single-hop links, but it does have very well-defined links between each TDRS and WSGT. As such, the space-to-space links between the user and the two TDRS spacecraft are the only ones really requiring characterization in the TDRSS table. As with the CCSDS table, the left half of the second page summarizes qualities of signals directed toward the user (forward service) while the right half lists those for signals from the user (return service).

Figure 1: TDRSS Link Analysis Flow Diagram



Except for TDRSS-supported space shuttle communications, which are not supported by the TDRSS table, the space data system does not use subcarriers to modulate data, so this page of the worksheet provides no such information. Also, being space-to-space links there is no need for weather availability entries on the TDRSS table, so only average user-to-TDRS spacecraft distance appears in this section. The main TDRSS link characteristics required for the link operating condition characterization are listed in Tables 1-4 below.

INPUT DATA SHEETS

There are two input data sheets included with both the CCSDS Link Design Control Table and the TDRSS Link Budget Design Table. The first input sheet forms the third page of the link budget worksheet in both tables. In the CCSDS table this is the Earth-Space Link Input Data Sheet which lists Earth station transmitting as well as spacecraft receiving carrier, data, and ranging channel parameters. In addition, Earth-to-Space path input data appears on this page. Since the command, telemetry, and payload data for TDRSS missions is transmitted on one forward service channel and ranging PN codes on the other, the TDRSS table input sheet splits into columns corresponding to these two channels instead of dividing groups of rows into sectors for each of the four DSN-type signal channels as is done in the CCSDS table. Also, because the payload services addressed in the TDRS S table do not use subcarriers nor have atmospheric conditions generally associated with their operation, the forward service input sheet does not carry such information, unlike the CCSDS table. However, the TDRSS table still uses the basic link subdivisions of TDRS transmitting parameters, TDRS-to-user path inputs, and user spacecraft receiving characteristics which correspond to the Earth station and spacecraft system parameters found in the CCSDS Recommendation.

Table 1: TDRS-to-User Link (Forward Service) Parameters

Link Parameter	MA	SSA	KSA
Command, Range Channel Type	Unbalanced QPSK	Unbalanced QPSK	Unbalanced QPSK
Command, Range Channel Format	NRZ (L, M, S)	NRZ (L, M, S)	NRZ (L, M, S)
Command Channel Bit Rate, kb/s	0.1 - 10	0.1-300	1 - 25,000
Transmitting Freq. F, in Mhz	2106.4	2025.8 - 2117.9	13775
Range Channel Chip Rate, chips/s	1461 * F	1461 *F	

Table 2: MA User-to-TDRS Link (Return Service) Parameters

Link Parameter	Value or Entry
Channel I, Q Type	BPSK (balanced or unbalanced)
Channel I, Q Format	NRZ (L, M, S), Biphase-L
Channel I, Q Bit Rate, kb/s	DGl Mode 1: 0.1 - 50; DGl Mode 2: 1 - 50 (total rate from I and Q should not exceed 50kb/s)
Channel I, Q Rate	1/2
Channel I, Q Constraint Length	7

Table 3 : SSA User-to-TDRS Link (Return Service) Parameters

Link Parameter	Value or Entry
Channel I Type	DG1: BPSK (balanced or unbalanced) DG2: BPSK, SQPSK (single data channel), QPSK(dual data channels)
Channel Q Type	DGl Modes 1 & 2: BPSK DGl Mode 3, DG2: BPSK, SQPSK (single data channel) QPSK (dual data channels
Channel I, Q Format	NRZ (L, M, S), Biphase-L
Channel I Bit Rate, kb/s	DG1: Modes 1 & 3: 0.1 - 150; Mode 2: 1 - 150 DG2: 1 - 3000 (must use BPSK for bit rates under 50 kb/s with either channel)
Channel Q Bit Rate, kb/s	DGl Mode 1: 0.1 - 150; Mode 2 or DG2: 1 -150; Mode 3: 1 - 3000
Channel I, Q Rate	1/2 for DGl Modes 1 & 2, Mode 3 (dual channels), DG2 (single BPSK or SQPSK), or DG2 (dual QPSK) 1/3 for DG2 (single BPSK or dual QPSK) {for Channel Q only, 1/3 also for DGl Mode 3 (dual channels)}
Channel I, Q Constraint Length	7

Table: 4. KSA User-to-TDRS Link (Return Service) Parameters

Link Parameter	Value or Entry
Channel I Type	DG1: BPSK (balanced Or unbalanced) DG2 : BPSK, SQPSK (single data channel); QPSK (dual channels)
Channel Q Type	DGl Modes 1 & 2: BPSK DGl Mode 3, DG2: BPSK, SQPSK (single data channel) QPSK (dual data channels)

Channel I Data Rate, kb/s	DGl: 1 - 300; DG2: 1 - 150,000
Channel Q Data Rate, kb/s	DGl Modes 1 & 2: 1 - 300; DGl Mode 3, DG2: 1 - 150,000 (may use BPSK on single uncoded channel up to 100 Mb/s or 50 Mb/s on single coded data channel)
Channel I, Q Rate	1/2
Channel I, Q Constraint Length	7

The other input data sheet found in the two link budget spreadsheets models the telecommunications link between a transmitting user and a receiving relay satellite or ground station, as the case may be. Input parameters are sectioned for both tables similarly to that of the preceding page of the respective worksheets. Of course, the CCSDS link budget tool characterizes a Space-to-Earth Link as opposed to the space-to-space User-to-TDRS link of the TDRSS table. In both the TDRSS forward and return input sheets, however, user spacecraft link characteristics have maintained the CCSDS format as far as possible, since the user is thought to desire the more detailed system description possible with the basic CCSDS Recommendation format. Hence, for the user receiving parameters on the TDRSS forward input sheet the user may specify design values for user spacecraft receiver noise temperatures and antenna gains even though these values cannot be measured independently for an operating TDRS-to-user forward service link. A similar case exists for user transmitting characteristics on the TDRSS return input sheet. Transmitter power, transmitting antenna gain, and even design antenna circuit losses can be listed for a user-to-TDRS link, in spite of the fact that the two-hop nature of the TDRSS return service link does not permit direct measurement of such user satellite transponder features.

LINK COMPUTATIONS

As with the input data sheets, a pair of link computational or link budgeting spreadsheets appear in both link design tables. The first link computation sheet forms the fifth page of both the CCSDS Link Design Control Table and the TDRSS Link Budget Design Table. The CCSDS table evaluates Earth-to-Space Link performance in terms of carrier, data, and ranging channel conditions for the transmitting Earth station as well as the receiving user spacecraft. Earth-to-Space path performance is also determined on this sheet. The presence of subcarriers as well as four interacting channels for DSN-type link signals means that detailed calculations for fractional powers and signal degradations on particular channels due to interference from other channels are needed with the CCSDS table. On the contrary, the forward service link budget for TDRSS only requires the transmitting power of the command channel to be specified relative to that of the ranging channel. This is a fixed ratio regardless of the type of TDRSS mode or service offered. Also, no link analysis results for rain attenuation or molecular absorption loss performance appears in TDRSS link budget calculations, further simplifying the forward service link budget sheet. The TDRSS table models interference, channel loss, and Eb/No performances at the user spacecraft receiver and forward signal processors as close to the CCSDS Recommendation as possible, the main discrepancies arising from the differing channel structures between TDRSS and DSN noted above.

The last page of the CCSDS and TDRSS link budgeting tools consists of the computations for links where the user spacecraft is transmitting signals to the ground station or a TDRS, respectively. The format for each link budget parallels that for the link going to the user from the preceding page of each worksheet. Again, for the CCSDS table several fractional power calculations are needed to characterize the effect of using subcarriers to modulate the transmitted data on Space-to-Earth link performance. TDRSS only specifies the ratio of the orthogonal return service data channels relative to one another. As with the forward service, this ratio is standardized to either 1:1 or 4.1, thus significantly reducing the scope of TDRSS fractional power computations.

The TDRSS Link Budget Design Table includes one last section for the overall or end-to-end TDRSS return link performance which accounts for signal processing of the received signal at WSGT. Through open-loop tests conducted at the TDRSS Ground Terminal the carrier-to-noise ratio for the overall link can be found with respect to the point at which the received signal from the user spacecraft enters the demodulator. This C/N ratio at WSGT can be specified rather exactly due to the automatic gain control circuitry onboard the two TDRS spacecraft. With this system feature, the TDRS-to-WSGT links can be said to be strongly defined, thus eliminating the need for a four-part link budget for TDRSS as one might expect to see for a two-hop link.

PROGRAM FEATURES

Most of the Excel spreadsheet macros used in the CCSDS Link Design Control Table were preserved, albeit in a modified form, in the TDRSS Link Budget Design Table. The CCSDS uplink and downlink power ratio computation macros count as major exceptions to this rule, however, since the relative forward and return service channel power constraints with TDRSS serve to simplify fractional power calculations. Because the TDRSS may choose from a rather extensive variety of services and signal configurations, a mode selection dialog box was also constructed using the Excel dialog editor as a user-friendly feature. With this dialog box, the link engineer may examine several user link design possibilities by selection options offered on the box. Depending on the options chosen, a command macro attached to the bax may also enter preset data into some of the entries on the TDRSS table worksheet, thus saving link analysts some time and effort. Lastly, sample databases for all major non-shuttle TDRSS user operational modes have been included with the spreadsheet package. The user can access these databases through Excel command macros or place database values directly onto the link budget sheet by selecting the appropriate modes on the mode selection dialog box.

CONCLUSION

The CCSDS Link Design Control Table developed by Kantak works quite adequately for DSN-supported missions since its structure directly addresses DSN link configurations, thereby containing link budget entries corresponding to the kind of link measurements possible with this space data system. With TDRSS, it is not possible to make such detailed measurements of transponder conditions on the two hops of the space link, so the CCSDS table parameters in general cannot be expressed in terms of TDRSS link values. This fact necessitates a link budget structure different from that addressed by the CCSDS table, though a TDRSS link budget tool certainly can make use of Kantak's basic structure to the greatest extent feasible with accepted TDRSS link analysis practice, which has been the main product of the study presented here.

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