AEROSPACE STANDARD

AS5603™	REV. A
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(R) Digital Fiber Optic Link Loss Budget Methodology for Aerospace Platforms

RATIONALE

The aerospace industry requires precise standards for avionics system design. To ensure that the aerospace fiber optics industry also adopts these same high standards, it is essential that a common set of fiber optic system design procedures be established. This document outlines procedures needed for digital avionics fiber optic link system design that help to assure it complies with aerospace industry best practices.

This document may be used as a stand-alone process but is intended to be used in conjunction with AS5750 which specifies key parameters to be provided by the requesting entity. This revision of the document explicitly describes the process and documentation required to perform a digital fiber optic link loss budget. Theoretical derivation, background material, and additional information provided in the original version of this document have been preserved in AIR6113.

AS5603A has been reaffirmed to comply with the SAE Five-Year Review policy.

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For more information on this standard, visit
https://www.sae.org/standards/content/AS5603A/

1. SCOPE

This document defines the steps and documentation required to perform a digital fiber optic link loss budget. This document does not specify how to design a digital fiber optic link. This document does not specify the parameters and data to use in a digital fiber optic link loss budget.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org

AS5750 Loss Budget Specification for Fiber Optic Links

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org

AIR6113 Guidelines for Design of Digital Fiber Optic Link Loss Budget Methodology

2.2.2 RTCA Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org

DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.2.3 TIA Publications

Available from Telecommunications Industry Association, 2500 Wilson Boulevard, Suite 300, Arlington, VA 22201, Tel: 703-907-7700, www.tiaonline.org/standards/

TIA-440-B Fiber Optic Terminology

TIA-455 Fiber Optic Test Procedures

2.2.4 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

MIL-STD-2052 Fiber Optic Systems Design

2.3 Definitions

ACTUAL MARGIN: This parameter is represented by M_{ACT}. This parameter is the calculated amount of additional optical power in the digital optical link.

ACTUAL SATURATION MARGIN: This parameter is represented by $M_{ACT(SAT)}$. This parameter is the calculated amount of excessive optical power in the digital optical link. This parameter is typically optional in calculating digital fiber optic link loss budgets.

CONFIDENCE LEVEL: This parameter is represented by C. This parameter is the numerical value representing the quality of the data provided and the results of the digital fiber optic link loss budget.

REQUIRED MARGIN: This parameter is represented by M_{REQ}. This parameter is an amount of optical power in the digital optical link set aside to accommodate unknown and unexpected losses.

REQUIRED SATURATION MARGIN: This parameter is represented by $M_{REQ(SAT)}$. This parameter is an amount of optical power in the digital optical link set aside to accommodate losses that have not occurred and unexpected gains. This parameter is typically optional in calculating digital fiber optic link loss budgets.

3. INTRODUCTION

This document details three methods for calculating a digital optical loss budget. These include the Worst Case Method, the Statistical Method, and the Numerical (Simulation) Method. These methods require increasing effort but provide increasing accuracy. Note that AS5750 allows for using a more accurate method over the method selected.

The method to perform a digital optical loss budget is broken down into three general stages: specification, procedure, and documentation. In the specification stage, the high level goal of the digital optical loss budget is captured. In the procedure stage, the steps to accomplish the digital optical loss budget are provided. In the documentation stage, the information generated by the digital optical loss budget is described.

4. SPECIFICATION AND INFORMATION REQUIREMENTS

The following details shall be specified when using this standard:

a. Base loss budget calculation method to be used (I – Worst Case, II – Statistical, or III – Numerical (Simulation)). If no method has been selected, I – Worst Case is selected by default.

b. The specific defined parameter value for required margin, M_{REQ}.

c. The specific defined parameter value for confidence level, C.

If required, the following details shall be specified before using this standard:

d. The specific defined parameter value for required saturation margin, $M_{REQ(SAT)}$.

Note that AS5750 provides the information necessary for this step.

5. PROCEDURE

5.1 Describe the Digital Optical Link

The first step is to generate a complete description of the digital optical link. This description starts with the optical source of the digital optical link where the digital information is first converted to light, for example, a directly modulated laser. The description ends with the optical destination where the light is converted back to digital information, for example, a photodiode. For complex optical systems where the light from one optical source may reach more than a single optical destination, each significantly different optical path between a single optical source and multiple optical destinations should be treated as different digital optical links and should have separate digital optical loss budgets calculated for each resulting digital optical link.

5.1.1 Description List

A description list of the digital optical link shall be generated.

5.1.1.1 Describe Optical Source

The optical source of the digital optical link shall be included in the description list of the digital optical link. The optical source shall be identified uniquely. An example of unique identification is “Unit A, laser 3.” The type of optical source and manufacturer should be noted.

5.1.1.2 Describe Optical Elements

The optical elements of the digital optical link shall be included in the description list of the digital optical link. Typically these optical elements are part of an optical cable plant. Optical elements are components or interfaces that may significantly affect the propagation of light along with the optical source and optical destination. Table 1 is a list of items that shall be included if present in the digital optical link. For example, include a connector if the digital optical link has a connector between the optical source and the optical destination but do not include a wavelength demultiplexer if the digital optical link does not have a wavelength demultiplexer. Note that some of these elements may have negligible effects on the digital optical link. If there are duplicate optical elements in the digital optical link, each duplicate optical element shall be listed separately in the description list. Note that some optical systems have optical elements not listed in Table 1. These optical elements unlisted in Table 1 shall be included in the description list. Each optical element included in the description list shall be identified uniquely. An example of unique identification is “Unit B, filter 2, port 1 to port 3.” The type of optical element and manufacturer should be noted.

5.1.1.3 Describe Optical Destination

The optical destination of the digital optical link shall be included in the description list of the digital optical link. The optical destination shall be identified uniquely. An example of unique identification is “Unit B, PIN diode 4.” The type of optical destination and manufacturer should be noted.

TABLE 1 – OPTICAL ELEMENTS TO INCLUDE IN DESCRIPTION LIST

Optical Element	**Comment**
Connector	There may be a variety of connector types in an optical link. This optical loss value is based on the insertion loss of a mated pair of optical termini.
Attenuator	
Mode Conditioning Cable	
Wavelength Filter	Include multiplexing and demultiplexing elements
Optical Isolator	Typically used with lasers and optical amplifiers to suppress the reverse flow of light
Optical Switch	This device routes light from a select input to a select output and does not convert to an electrical signal
Coupler	Also referred to as combiner, star coupler, power splitter, and monitor tap
Modulator	
Optical Amplifier	
Optical Fiber	Loss measured over planned length of the optical fiber
Optical Waveguide	Loss measured over planned length of the optical waveguide
Splices	Mechanical splices are more likely to have significant losses to merit inclusion in the optical element list while fusion splices are typically negligible
Mode Field Adapters	These devices are typically used in single-mode fiber optic systems to adjust between sections of differing mode fields
Extreme Optical Fiber Bends	Bends that are permanently planned in the design and not transitory

5.1.2 Environmental Conditions

The expected environmental conditions for the digital optical link shall be documented. The environmental conditions for different parts of the link should be documented separately if the environmental conditions for different parts of the link are significantly different. Environmental conditions shall include temperature range and vibration spectrum. There are many other environmental conditions that should be included. See AIR6113, MIL-STD-810, or RTCA DO-160 for a more complete list and descriptions of potential environmental conditions. As a guideline, environmental conditions would be documented if they significantly impact any item in the description list. Note that a seemingly insignificant impact in a single item in the description list may become significant when grouped with other items that are impacted in the same fashion.

5.1.3 Additional Characteristics

If there are any additional characteristics to be separately accounted for in the digital optical link, they shall be documented. These characteristics may be additional penalties or adjustments that capture the interaction between the components in the optical link. The effects of these additional characteristics are typically accounted for in the optical loss data and do not need to be extracted and included separately. See AIR6113 for a list and descriptions of potential additional characteristics.

5.1.4 Review Description

Once the description list, environmental conditions, and additional characteristics are documented, they shall be provided to the entity requesting the loss budget. Ideally, this information should be reviewed with the entity before continuing. This step ensures completeness and agreement on the description list and the included environmental conditions before investing further effort.

5.2 Prepare Optical Data

Optical data is needed for every item in the description list. This information may come from a variety of sources. These sources are listed in Table 2.

TABLE 2 – SOURCES FOR OPTICAL DATA

Optical Data Source	**Comment**
Field data	This is data collected from fielded components
Test data	This is data taken with a test setup in a laboratory
Manufacturer specification	
Calculated	

The optical data needs to be prepared differently due to the differences in the loss budget calculation methods. If method I – Worst Case was selected, the optical data shall be prepared as described in Section 5.2.1. If method II – statistical was selected, the optical data shall be prepared as described in Section 5.2.2. If method III – numerical (simulation) was selected, the optical data shall be prepared as described in Section 5.2.3.

Optical data prepared for an optical source shall be recorded in absolute terms on a logarithmic scale (dBm). Optical data prepared for an optical destination shall be recorded in absolute terms on a logarithmic scale (dBm). Optical data prepared for optical elements shall be recorded in relative terms on a logarithmic scale (dB). For an optical element that has an optical loss, the optical data shall be positive. For an optical element that has an optical gain, optical data shall be shall be negative. Optical data prepared for additional characteristics shall be recorded in relative terms on a logarithmic scale (dB). For additional characteristics that have an optical loss, the optical data shall be positive. For additional characteristics that have an optical gain, the optical data shall be negative.

5.2.1 Method I – Worst Case Data Preparation

For every item in the description list, a worst case value shall be determined based on the type of item.

5.2.1.1 Data for Optical Source

The worst case value of the optical source shall be the minimum (weakest) optical output power over the documented environmental conditions with a confidence level of *C*. Note that this worst case value should not be a value where the optical source would be considered broken or non-functional. This worst case value shall be documented for the uniquely identified optical source in the description list. The source of the optical data (from Table 2) for the uniquely identified optical source shall be documented.

5.2.1.2 Data for Optical Elements

The worst case value shall be documented for each uniquely identified optical element in the description list. The worst case value of each optical element shall be the maximum optical loss over the documented environmental conditions with a confidence level of *C*. If an optical element provides optical gain, then its worst case value shall be the minimum optical gain over the documented environmental conditions with a confidence level of *C*. Note that this worst case value should not be a value where the optical element would be considered broken or non-functional. The source of the optical data (from Table 2) for each uniquely identified optical element shall be documented.

5.2.1.3 Data for Optical Destination

The worst case value of the optical destination shall be the maximum (weakest) sensitivity over the documented environmental conditions with a confidence level of *C*. Note that this worst case value should not be a value where the optical destination would be considered broken or non-functional. This worst case value shall be documented for the uniquely identified optical destination in the description list. The source of the optical data (from Table 2) for the uniquely identified optical destination shall be documented.

5.2.1.4 Data for Additional Characteristics

If there are any additional characteristics documented for the digital optical link, the worst case values for each additional characteristic shall be documented. The worst case value of each additional characteristic shall be the maximum optical loss over the documented environmental conditions with a confidence level of *C*. If an additional characteristic provides optical gain, then its worst case value shall be the minimum optical gain over the documented environmental conditions with a confidence level of *C*. The source of the optical data (from Table 2) for each additional characteristic shall be documented.

5.2.1.5 Optional Saturation Method I – Worst Case Data Preparation

If the required saturation margin is specified for the worst case method, the steps in this subsection shall be followed. This optional method is also referred to as the best case scenario. A best case value shall be determined based on the type of item for every item in the description list.

The best case value of the optical source shall be the maximum (strongest) optical output power over the documented environmental conditions with a confidence level of *C*. Note that this best case value shall not be a value where the optical source would be considered broken or non-functional. This best case value shall be document for the uniquely identified optical source in the description list. The source of the optical data (from Table 2) for the uniquely identified optical source shall be documented.

The best case value shall be documented for each uniquely identified optical element in the description list. The best case value of each optical element shall be the minimum optical loss over the documented environmental conditions with a confidence level of *C*. If an optical element provides optical gain, then its best case value shall be the maximum optical gain over the documented environmental conditions with a confidence level of *C*. Note that this best case value shall not be a value where the optical element would be considered broken or non-functional. The source of the optical data (from Table 2) for each uniquely identified optical element shall be documented.

The best case value of the optical destination shall be the minimum (weakest) saturation over the documented environmental conditions with a confidence level of *C*. Note that this best case value shall not be a value where the optical destination would be considered broken or non-functional. This best case value shall be documented for the uniquely identified optical destination in the description list. The source of the optical data (from Table 2) for the uniquely identified optical destination shall be documented.

If there are any additional characteristics documented for the digital optical link, the best case values for each additional characteristic shall be documented. The best case value of each additional characteristic shall be the minimum optical loss over the documented environmental conditions with a confidence level of *C*. If an additional characteristic provides optical gain, then its best case value shall be the maximum optical gain over the documented environmental conditions with a confidence level of *C*. The source of the optical data (from Table 2) for each additional characteristic shall be documented.

5.2.2 Method II – Statistical Data Preparation

For every uniquely identified item in the description list, a mean value and a standard deviation shall be documented. Each mean value and standard deviation shall be over the documented environmental conditions. Note that this mean and standard deviation should be based on data from functional items. The source of the optical data (from Table 2) for each uniquely identified item shall be documented.

If there are any additional characteristics documented for the digital optical link, the mean and standard deviation shall be documented for each additional characteristic. The source of the optical data (from Table 2) for each additional characteristic shall be documented.

Note that optional saturation data preparation is not necessary for the statistical method as saturation is accounted for in the calculation.

5.2.3 Method III – Numerical (Simulation) Data Preparation

For every uniquely identified item in the description list, a distribution curve shall be documented. Each distribution curve shall account for the range of documented environmental conditions. If necessary, accounting for environmental conditions may be accomplished through parametric adjustments to the distribution curve or having alternate distribution curves at different environmental condition ranges. Note that this distribution curve should be based on data from functional items. The source of the optical data (from Table 2) for each uniquely identified item shall be documented.

If there are any additional characteristics documented for the digital optical link, a distribution curve shall be documented for each additional characteristic. The source of the optical data (from Table 2) for each additional characteristic shall be documented.

Note that optional saturation data preparation is not necessary for the numerical (simulation) method as saturation is accounted for in the calculation.

5.2.4 Review Optical Data

Once the optical data is documented, it shall be provided to the entity requesting the loss budget. Ideally, this information should be reviewed with the entity before continuing. This step ensures completeness and agreement on the optical data before investing further effort.

5.3 Perform Calculations

The calculation of the actual margin of the digital optical link needs to be performed differently due to the differences in the loss budget calculation methods. If method I – worst case was selected, the calculation shall be performed as described in Section 5.3.1. If method II – statistical was selected, the calculation shall be performed as described in Section 5.3.2. If method III – numerical (simulation) was selected, the calculation shall be performed as described in Section 5.3.3.

5.3.1 Method I – Worst Case Calculation

The actual margin for the worst case method shall be calculated by the following equation:

$$M_{ACT} = P - R - E - A \tag{Eq. 1}$$

where:

P is the documented worst case value for the optical source from the description list

R is the documented worst case value for the optical destination from the description list

E is the sum of the documented worst case values for all of the optical elements from the description list

A is the sum of the documented worst case values for all of the documented additional characteristics

5.3.1.1 Optional Saturation Method I – Worst Case Calculation

The optional actual saturation margin in the worst case method shall be calculated by the following equation:

$$M_{ACT(SAT)} = R' - P' + E' + A' \quad \text{(Eq. 2)}$$

where:

P' is the documented best case value for the optical source from the description list

R' is the documented best case value for the optical destination from the description list

E' is the sum of the documented best case values for all of the optical elements from the description list

A' is the sum of the documented best case values for all of the documented additional characteristics

5.3.2 Method II – Statistical Calculation

The actual margin for the statistical method shall be calculated by the following equation:

$$M_{ACT} = P_m - R_m - E_m - A_m - K\,\sigma \quad \text{(Eq. 3)}$$

where:

P_m is the documented mean value for the optical source from the description list

R_m is the documented mean value for the optical destination from the description list

E_m is the sum of the documented mean values for all of the optical elements from the description list

A_m is the sum of the documented mean values for all of the documented additional characteristics

K is the confidence multiplier determined by Eq. 4

σ is the total standard deviation calculated in Eq. 5

The confidence multiplier satisfies the following equation:

$$\mathrm{C} = 100 \times \frac{1}{\sqrt{2\,\pi}} \int_{-\infty}^{\mathrm{K}} \mathrm{e}^{-\mathrm{z}^2/2} \mathrm{dz} \quad \text{(Eq. 4)}$$

where typical values of K, the confidence multiplier, for given values of C, the confidence level, are documented in APPENDIX A.

The total standard deviation is calculated by the following equation:

$$\sigma = \left(\sigma_P^2 + \sigma_R^2 + \sigma_{E1}^2 + \sigma_{E2}^2 + \cdots + \sigma_{Ej}^2 + \sigma_{A1}^2 + \sigma_{A2}^2 + \cdots + \sigma_{Ak}^2\right)^{\frac{1}{2}} \quad \text{(Eq. 5)}$$

where:

σ_P is the documented standard deviation for the optical source from the description list

σ_R is the documented standard deviation for the optical destination from the description list

σ_{Ej} is the documented standard deviation for the *j*th optical element from the description list

σ_{Ak} is the documented standard deviation for the *k*th documented additional characteristic

5.3.2.1 Optional Saturation Method II – Statistical Calculation

The optional actual saturation margin in the statistical method shall be calculated by the following equation:

$$M_{ACT(SAT)} = R_m - P_m + E_m + A_m - K\,\sigma \quad \text{(Eq. 6)}$$

where:

P_m is the documented mean value for the optical source from the description list

R_m is the documented mean value for the optical destination from the description list

E_m is the sum of the documented mean values for all of the optical elements from the description list

A_m is the sum of the documented mean values for all of the documented additional characteristics

K is the confidence multiplier determined by Eq. 4

σ is the total standard deviation calculated in Eq. 5

5.3.3 Method III – Numerical (Simulation) Calculation

This method simulates the digital optical link *n* times, calculating the margin of the link each time. The resulting statistics on the interim margins are then used to calculate the actual margin and optional actual saturation margin.

The digital optical link shall be simulated a minimum number of times to provide a sufficiently stable actual margin within the required confidence level. This may be accomplished by monitoring the results of an iterative analysis of the interim margin until the results fall within the desired range of the final asymptotical value. Alternatively, the number of repetitions may be determined through statistical theory.

In a single iteration, the following steps shall occur:

a. Each unique item in the description list shall have a value randomly chosen according to the distribution curve documented for that item and the environmental conditions of that item.

b. Each additional characteristic documented for the digital optical link shall have a value randomly chosen according to the distribution curve documented for that additional characteristic.

c. The interim margin of this iteration shall be calculated by the following equation:

$$M_i = P_i - R_i - E_i - A_i \quad \text{(Eq. 7)}$$

where:

i is the number of the current iteration

P_i is this iteration's random value for the optical source from the description list

R_i is this iteration's random value for the optical destination from the description list

E_i is the sum of this iteration's random values for all of the optical elements from the description list

A_i is the sum of this iteration's random values for all of the documented additional characteristics

d. The interim margin of this iteration shall be stored such that a mean and standard deviation may be obtained once the iterations are complete.

e. The optical interim saturation margin of this iteration shall be calculated by the following equation:

$$M_{i(SAT)} = R_i - P_i + E_i + A_i \quad \text{(Eq. 8)}$$

where:

i is the number of the current iteration

P_i is this iteration's random value for the optical source from the description list

R_i is this iteration's random value for the optical destination from the description list

E_i is the sum of this iteration's random values for all of the optical elements from the description list

A_i is the sum of this iteration's random values for all of the documented additional characteristics

f. The optional interim saturation margin of this iteration shall be stored such that a mean and standard deviation may be obtained once the iterations are complete.

Once the above steps have been repeated a sufficient number of times, the actual margin for the numerical (simulation) method shall be calculated by the following equation:

$$M_{ACT} = M_m - K\,\sigma_M \quad \text{(Eq. 9)}$$

where:

M_m is the mean value of the interim margin values stored in the above step d.

σ_M is the standard deviation of the interim margin values stored in the above step d.

K is the confidence multiplier determined by Eq. 4

The optional actual saturation margin for the numerical (simulation) method shall be calculated by the following equation:

$$M_{ACT(SAT)} = M_{m(SAT)} - K\,\sigma_{M(SAT)} \quad \text{(Eq. 10)}$$

where:

$M_{m(SAT)}$ is the mean value of the interim margin values stored in the above step f.

$\sigma_{M(SAT)}$ is the standard deviation of the interim margin values stored in the above step f.

K is the confidence multiplier determined by Eq. 4

5.4 Review Results

Once the actual margin has been calculated, the actual margin for the digital optical link shall be documented. If the actual margin is less than the required margin, the digital optical link does not meet and fails the requirements of the design according to the selected method. If the actual margin is greater than or equal to the required margin, the digital optical link meets and passes the requirements of the design according to the selected method. This pass / fail result for the loss budget shall be documented for the digital optical link.

If the optional actual saturation margin has been calculated, the optional actual saturation margin shall be documented. If the actual saturation margin is less than the required saturation margin, the digital optical link does not meet and fails the requirements of the design according to the selected method. If the actual saturation margin is greater than or equal to the required saturation margin, the digital optical link meets and passes the requirements of the design according to the selected method. This pass / fail result for saturation shall be documented for the digital optical link.

6. DOCUMENTATION

Unless otherwise specified, the following data shall be reported:

a. Title of results: Digital Fiber Optic Loss Budget Methodology

b. Identification of standard used (AS5603)

c. Identification of the digital optical link being analyzed

d. Date the digital fiber optic loss budget was performed

e. Methodology used: I – worst case, II – statistical, or III – numerical (simulation)

f. Description list of the digital optical link

g. Environmental conditions of the digital optical link

h. Additional characteristics of the digital optical link

i. The optical data prepared for the items in the description list and for the documented additional characteristics

j. The required margin, M_{REQ}

k. The confidence level, C

l. The actual margin, M_{ACT}, calculated

m. The pass / fail results of the loss budget

If specified, the following data shall be reported:

n. The optical required saturation margin, $M_{REQ(SAT)}$

o. The actual saturation margin, $M_{ACT(SAT)}$, calculated

p. The pass /fail results of the saturation calculation

United States military applications require that the following information shall also be reported for each test. For other (nonmilitary) applications, this information need not be reported but shall be available for review upon request.

q. Responsible entity performing the loss budget calculation

7. NOTES

7.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications nor in documents that contain editorial changes only.

PREPARED BY SAE COMMITTEE AS-3, FIBER OPTICS AND APPLIED PHOTONICS