HEWLETT PACKARD

APPLICATION BULLETIN 57

Flux Budget Considerations for Fiber Optic Link Design

This application bulletin is intended to supplement Application Note 1000. Basic information on flux budgeting with specific examples using the Hewlett-Packard HFBR-1002 Fiber Optic Transmitter, HFBR-2001 Fiber Optic Receiver, and HFBR-3000 Series Fiber Optic Cable/Connector Assemblies is presented.

To determine the performance of a fiber optic system, three main areas must be considered:

Transmitter Output Optical Flux
Receiver Input Sensitivity
System Insertion Losses

When designing a fiber optic system, an analysis that includes temperature, humidity, and voltage variations will require using the minimum transmitter output flux and corresponding minimum receiver input sensitivity to ensure the performance of the fiber optic system for the environmental conditions of the system.

Transmitter Output Optical Flux

The transmitter output optical flux, (ϕ_T), is usually expressed in microwatts (μw). For convenience in system calculations, the output flux can be expressed in dBm, allowing all system calculations to be algebraic summations.

When changing microwatts to dBm, the output optical flux is referenced to one milliwatt (1000μW).

$$\text{Transmitter Output Flux, } \phi_T(\text{dBm}) = 10 \log \frac{\phi_T(\mu W)}{\phi_o}$$

$$(\phi_O = 1000\mu W)$$

Receiver Input Sensitivity

The receiver input sensitivity is the minimum input flux that will produce a particular Bit Error Rate (BER) at a specified baud rate. The receiver sensitivity is a function of its internal noise and bandwidth. The receiver sensitivity, ϕ_R, may be expressed in microwatts or in dBm for convenience in system calculations.

$$\text{Receiver Input Sensitivity, } \phi_R(\text{dBm}) = 10 \log \frac{\phi_R(\mu W)}{\phi_o}$$

$$(\phi_O = 1000\mu W)$$

System Insertion Loss

The system insertion loss is defined as the total of all losses of optical flux in the transmission path. The losses at the connector interfaces are caused by reflections, differences in fiber diameter, N.A., and fiber alignment. The system insertion loss also includes losses in the fiber due to scattering and absorption. Each loss is subscripted to correspond to its location in the system and the loss is expressed in decibels. For a worst case design, values should be used taking temperature, humidity, etc. into account for the maximum loss.

A typical system insertion loss includes:

Transmitter to Cable/ Connector Assembly	— α_{TC} (dB)
Steady State Fiber Losses	— $\alpha_0 \cdot \ell$ (dB/km · length)
Cable/Connector Assembly to Receiver	— α_{CR} (dB)
Connector to Connector	— α_{CC} (dB)
Splice	— α_S (dB)
Directional Coupler	— α_{DC} (dB)
Star Coupler	— α_{SC} (dB)

Flux Budget

The flux budget calculation is a method of comparing the ratio of transmitter optical flux and receiver sensitivity to the total loss of the system.

The System Flux Ratio is the ratio of transmitter output flux to the receiver input sensitivity and is expressed in decibels.

$$\text{System Flux Ratio, } \alpha_{FR}(\text{dB}) = 10 \log \frac{\phi_T(\mu W)}{\phi_R(\mu W)}$$

If the transmitter output flux and receiver sensitivity are already expressed in dBm, the System Flux Ratio is merely the difference between ϕ_T and ϕ_R.

$$\text{System Flux Ratio, } \alpha_{FR}(\text{dB}) = \phi_T(\text{dBm}) - \phi_R(\text{dBm})$$

The System Insertion Loss, α_{SL}(dB), is then computed by summing the individual element losses in the transmission path.

$$\alpha_{SL}(\text{dB}) = \Sigma\alpha_i(\text{dB})$$

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For a system to work satisfactorily, the losses must not exceed the System Flux Ratio. The Flux Margin, α_M, is the difference between the System Flux Ratio, α_{FR}, and the System Insertion Loss, α_{SL}. For a system to operate, the flux margin must be greater than zero.

$$\alpha_M(dB) = \alpha_{FR}(dB) - \alpha_{SL}(dB)$$

$$\alpha_M(dB) > 0$$

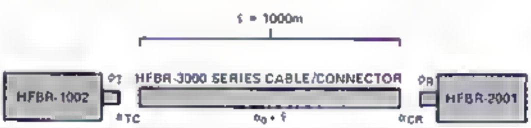
Some designs may require a specific flux margin to account for losses that may increase with time, or to "design-in" a safety margin.

Sample Flux Budget Calculation

DATA SHEET PARAMETERS			MIN	TYP	MAX	UNITS	NOTES
HFBR-1002 Transmitter	Output Optical Flux		50	100		μW	*
			−13	−10		dBm	
HFBR-2001 Receiver	Input Optical Sensitivity		0.8	0.5		μW	*
			−31	−33		dBm	
HFBR-3000 Series Cable/Connector	Insertion Loss	Length Dependent		7	10	dB/km	$^*\lambda$ = 820nm ℓ > 300m
		Fixed		5.4	8.4	dB	$^*\lambda$ = 820nm $\ell \le$ 300m

*NOTE: Guaranteed specifications 0°C-70°C, ±5% Voltage, 10^{-9} BER @ 10 Mbaud.

A sample "flux budget" calculation is presented for a Hewlett-Packard 1000 metre point-to-point fiber optic system. The system uses a Hewlett-Packard HFBR-1002 Transmitter, HFBR-2001 Receiver, and an HFBR-3000 series 1000 metre Cable/Connector Assembly with no intermediate connector or splice.



1. System Flux Ratio

The System Flux Ratio is the ratio of the transmitter output flux to the receiver input sensitivity.

System Flux Ratio, α_{FR} =

$$10 \log \frac{\phi_T(\mu W)}{\phi_R(\mu W)} = 10 \log \frac{50\mu W}{0.8\mu W} = 18dB$$

OR $\alpha_{FR} = \phi_T(dBm) - \phi_R(dBm) = -13dBm - (-31dBm)$ = 18dB

2. System Insertion Loss

$$\alpha_{SL} = \Sigma\alpha_i = \alpha_{TC} + \alpha_0 \cdot \ell + \alpha_{CR}$$

The loss from the Transmitter to Cable, α_{TC}, is not directly measurable and is shown as a "typical" value on the HFBR-1002 data sheet.

More easily measurable and convenient to state is a maximum insertion loss from the Transmitter to the end of a connectored cable of length, ℓ, called $\alpha_{T\ell}$, for use in system flux budgeting calculations. The insertion loss then includes α_{TC}, the loss of the cable, and α_{CR}. This approach is convenient for systems where the propagation characteristics of the cable have not reached a steady state, and values of both α_{TC} and α_0 are a function of the cable length.

The insertion loss $\alpha_{T\ell}$ may be easily expressed as the difference between two measurable quantities:

ϕ_T — Transmitter Output Flux
ϕ_ℓ — Flux Measured at the end of a cable of length, ℓ

$$\alpha_{T\ell}\ (dB) = \phi_T(dBm) - \phi_\ell(dBm)$$

Using this measurement method, under worst-case conditions, the maximum insertion loss is 15.4dB for a Hewlett-Packard 1000 metre fiber optic system.

The System Insertion Loss can then be expressed as:

$$\alpha_{SL} = \alpha_{T\ell} = 15.4dB$$

3. System Flux Margin

Flux Margin, α_M, is the difference between the System Flux Ratio and the System Insertion Loss.

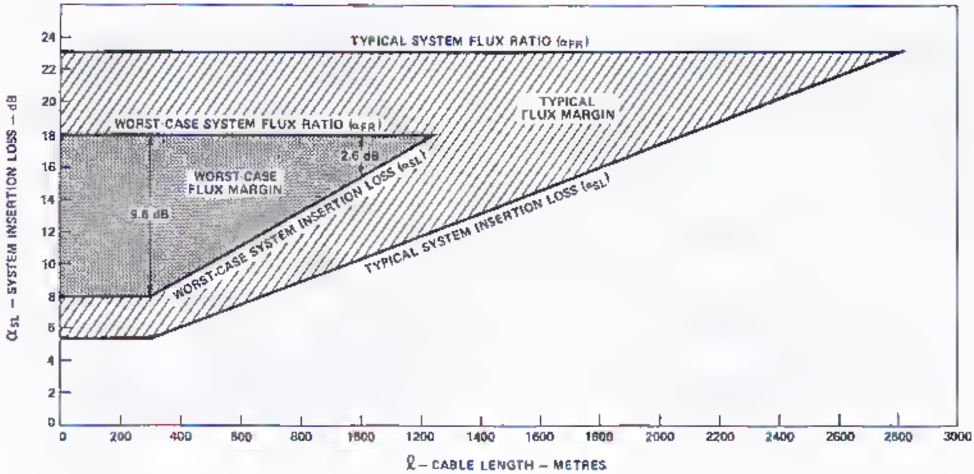
Flux Margin = System Flux Ratio—System Insertion Loss

$$\alpha_M = \alpha_{FR} - \alpha_{SL}$$

$$\alpha_M = 18.0dB - 15.4dB$$

$$\alpha_M = +2.6dB$$

In this example, the Flux Margin, α_M, represents the worst case margin: 0–70°C, 10^{-9} BER @ 10Mbaud for a 1000 metre system.



Graphical Representation

The insertion loss for a Hewlett-Packard point-to-point system (using the HFBR-1002, HFBR-2001, and HFBR-3000 Series Cable/Connector) can be represented graphically. The graph is a convenience for readily determining the flux margin for systems less than 1000 metres and also is a guide for determining the flux margin available when splices, connectors, and couplers are a proposed part of a fiber optic system.

For the HFBR-1002 Transmitter and the HFBR-3000 series Cable/Connector Assembly steady state propagation occurs at distances greater than 300 metres from the transmitter. Therefore the system insertion loss for a Cable/Connector Assembly less than or equal to 300 metres is defined as a single insertion loss, α_F(dB). For lengths greater than 300 metres the system insertion loss is composed of two parts: 1) the fixed loss, α_F(dB), $\ell \leq 300$ metres; and 2) a length dependent loss, α_0(dB/Km), the linear cable attenuation, valid where optical flux is in equilibrium ($\ell > 300$m).

Two cases will be graphed, one using typical data sheet values, the second using worst case insertion losses.

1. Typical System Insertion Loss

$\alpha_{SL} = \alpha_F$ (typ) , ($\ell \leq 300$m)

$\alpha_{SL} = 5.4$dB

$\alpha_{SL} = \alpha_F$ (typ) + α_0 (typ) · ($\ell - 300$) , ($\ell > 300$m)

$\alpha_{SL} = 5.4\text{dB} + 0.007\ (\text{dB/m}) \cdot [\ell\ (\text{m}) - 300]$

2. Typical Flux Ratio

$$\alpha_{FR} = 10 \log \frac{100\mu W}{0.5\mu W} = 23\text{dB}$$

3. Worst Case Insertion Loss

$\alpha_{SL} = \alpha_F$ (max), ($\ell \leq 300$m)

$\alpha_{SL} = 8.4$dB

$\alpha_{SL} = \alpha_F$ (max) + α_0 (max) · ($\ell - 300$) ,($\ell > 300$m)

$\alpha_{SL} = 8.4\text{dB} + 0.010\ (\text{dB/m})\ [\ell\ (\text{m}) - 300]$

4. Worst Case Flux Ratio

$$\alpha_{FR} = 10 \log \frac{50\mu W}{0.8\mu W} = 18\text{dB}$$

As shown on the graph, the Flux Margin is the number of dB between the System Flux Ratio line and the System Insertion Loss. Hewlett-Packard system performance (worst case*) guarantees a minimum Flux Margin at 1000 metres of 2.6dB, while typical performance is greater than 12dB. For a 300 metre system worst case Flux Margin is 9.6dB and typical performance is greater than 17dB.

As demonstrated by the graph, the H-P system can be expected to function at distances considerably beyond 1000 metres under *typical* operating conditions.

*0-70°C, 10^{-9} BER @ 10Mbaud

APPLICATION NOTES