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MICROWAVE PHOTONIC PRODUCTS

PSI-1600 Series 12 GHz Link

PSI-2600 Series 20 GHz Link

PSI-3600 Wide Dynamic Range Components and Systems

PSI-0204 Modulator Controller

PSI-0303 Digital Modulator Controller

BENEFITS OF FIBER OPTIC TRANSMISSION:

- BEST SPACE UTILIZATION
- LOWEST SIGNAL LOSS
- HIGHEST SIGNAL INTEGRITY
- HIGHEST SIGNAL SECURITY
- LOW MAINTENANCE COST
- SIMPLE INSTALLATION
- APPLICATION FLEXIBILITY
- EMI/RFI PROTECTION

Photonic Systems, Inc (PSI) offers a broad range of microwave photonic products designed for simple installation, operation and best-in-class performance. We offer our customers photonic solutions designed by leading microwave photonic technologists to solve unique signal transmission problems. Our customers include defense, research and commercial entities in all corners of the world.

PSI is pleased to offer the microwave photonic products outlined in this brochure. These standard products include direct and externally modulated fiber optic transmitters for bandwidths ranging from 2 to 40 GHz. We also offer components including modulators, light sources, and modulator bias controllers. PSI can modify these products to fit your particular system needs. Please contact us for more details.

Applications

- RF over fiber
- GPS timing distribution
- Antenna remoting
- Signal concentration
- Video distribution
- Radio Astronomy
- Satellite ground stations
- Wireless service enhancement
- ELINT

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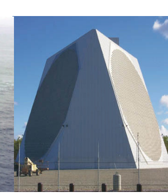
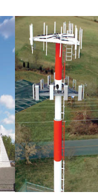
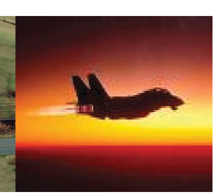
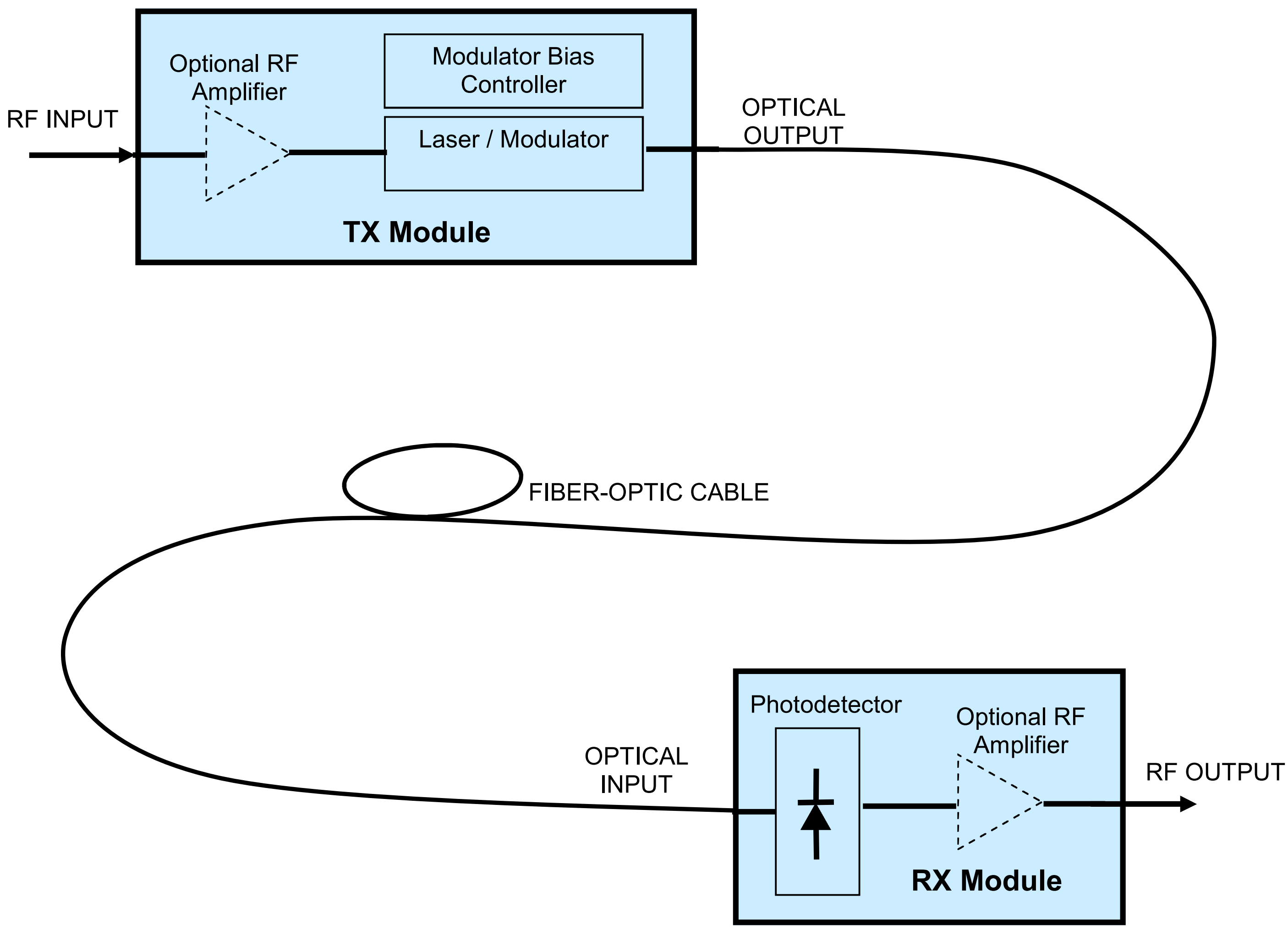




Elements of a Photonic Link



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PSI-1600 Series Microwave Photonic Links

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Product Description

The PSI-1600 series is a family of high-performance microwave photonic links intended for antenna remoting or RF/IF signal distribution in military systems, satellite communications, radio astronomy, optical delay lines, cellular/wireless base stations or other applications. The PSI-1601 is a unique amplifierless link offering wide dynamic range at a modest price. Also available are amplified versions; the PSI-1602 includes amplification at the TX module to optimize noise figure, the PSI-1603 employs amplification only at the RX module and the PSI-1604 includes amplification at both link ends, yielding +34dB of insertion gain. All links feature very wide bandwidth of up to 12 GHz and low power consumption. This performance is achieved through a transmitter employing a precisely controlled electro-absorption modulator laser. The separate receiver module contains a sensitive, microwave bandwidth InGaAs photodiode. All modules are constructed in laboratory-grade housings and shipped with AC power supplies. Custom packaging and gain configurations are also available. For more information, please contact us at info@photonicsinc.com.

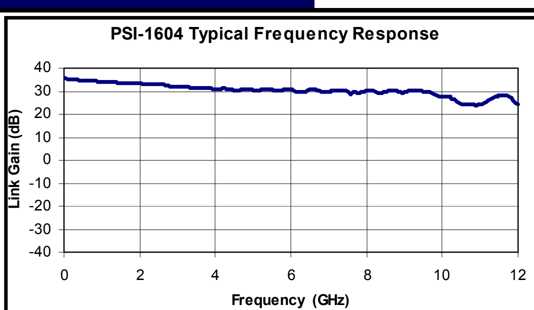
PSI-1600 Features	Benefit
Microwave bandwidth, low noise figure, wide dynamic range	Application flexibility and signal integrity; enables replacement of lossy, heavy copper transmission lines
Signal transport over low-loss (0.25dB/km) optical fiber	Optimizes system size, weight and power
Compact size, low power consumption and high reliability	Lowest total cost to install and operate

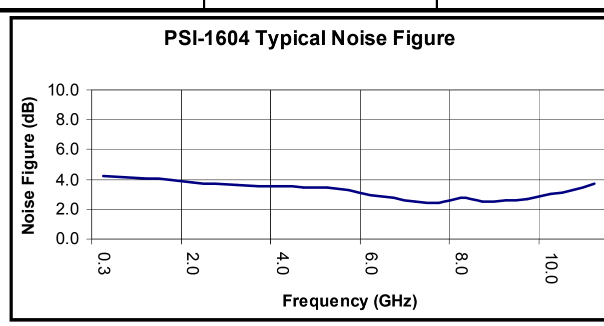
Applications

- **Radio over fiber**
- **Radio Astronomy**
- **Remote antenna distribution**
- **Phased array radar**
- **Cellular antenna farms**
- **Optical delay lines**
- **SATCOM**
- **TCDL**

Typical Performance, 25°C @ Mid-band

Parameter	*PSI-1601 Link*	*PSI-1602 Link w/ pre-amp*	*PSI-1603 Link w/ post-amp*	*PSI-1604 Link w/ pre & post-amp*
Operating bandwidth	.045-12 GHz	.1-12 GHz	.1-12 GHz	.1-12 GHz
Noise figure	35 dB	6 dB	36 dB	7 dB
Gain	-30 dB	2 dB	2 dB	34 dB
1-dB compression output	-25 dBm	-25 dBm	7 dBm	7 dBm
IP3 output power	0 dBm	-6 dBm	24 dBm	22 dBm
Spur-free dynamic range (in 1 Hz)	112 dB	106 dB	106 dB	103 dB
VSWR	<2:1	<2.2:1	<2.2:1	<2.2:1
Bias power, TX module	<8 W	<11 W	<8 W	<11 W
Bias power, RX module	35 mW	35 mW	3.5 W	3.5 W





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PSI-1600 Series Microwave Photonic Links

RF and Electrical Characteristics

Parameter	Min	Max	Units
Bandwidth	0.045	12	GHz
RF port impedance	50, all ports		Ohms
Receiver input equivalent noise		20	pA/Hz
Amplitude flatness, any 100 MHz		± 0.5	dB
AC power (60 Hz)	100	240	VAC

Absolute Maximum Ratings

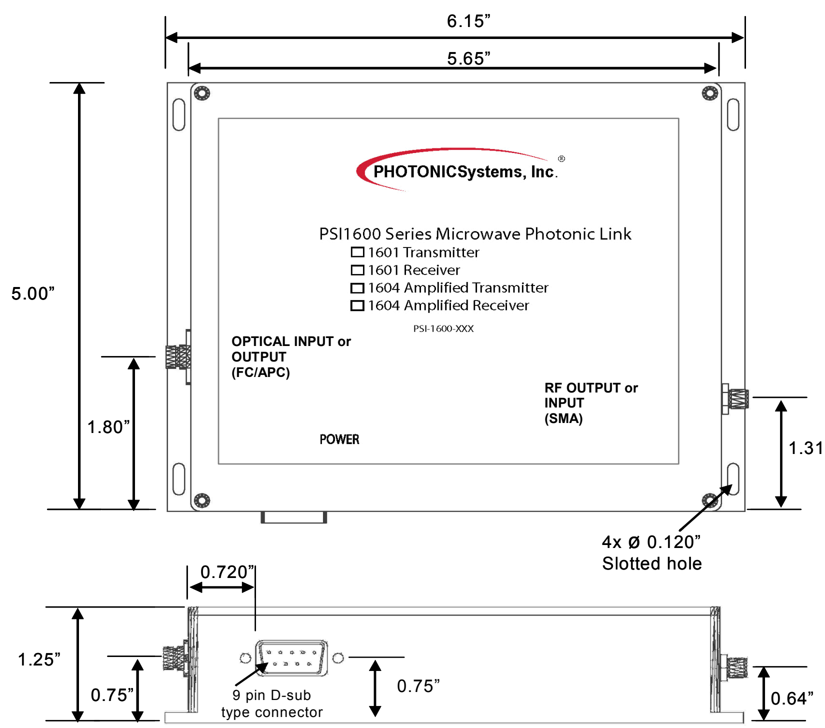
Parameter	Min	Max	Units
Operating Temperature (within specs)	0	50	°C
Operating Temperature (no damage)	-20	60	°C
Storage Temperature	-40	80	°C
Humidity	0	95	%
RF input (Amplified TX at max gain)		-6	dBm
RF input (Unamplified TX)		+25	dBm
Optical power into receiver		+13	dBm

Optical Characteristics

Parameter	Min	Max	Units
Wavelength	1520	1575	nm
TX optical power	0.5	10	mW
RX optical input power	0	20	dBm
Receiver responsivity	0.85		A/W
Connector return loss		-40	dB
Fiber type between TX and RX (user supplied)	Single mode; Corning SMF-28 or equivalent		--
Fiber span @ 1dB degradation in noise figure	3		km

Physical Characteristics

Parameter	Attribute
RF Connectors, all ports	SMA Female
DC connector	9 pin D-sub
Fiber optic connector	FC/APC



PSI-1600 Series Modules

This module is used for both transmitter and receiver photonic link modules, including amplified and amplifierless versions.

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PSI-2600 Series Microwave Photonic Links

Product Description

The PSI-2600 series is a family of high-performance microwave photonic links intended for antenna remoting or RF/IF signal distribution in military systems, satellite communications, radio astronomy, optical delay lines, cellular/wireless base stations or other applications. The PSI-2601 is an amplifierless link with wide spur-free dynamic range and high input intercept point for difficult RF environments. Also available are amplified versions; the PSI-2602 includes amplification at the TX side to optimize noise figure the PSI-2603 employs amplification only at the RX module and the PSI-2604 includes amplification at both link ends, yielding 27 dB of insertion gain. All links feature very wide bandwidth of up to 20 GHz and low power consumption. This performance is achieved through a transmitter employing a precisely controlled lithium niobate modulator and a low noise DFB laser. The separate receiver module (identical to the module used in PSI-1600 series links) contains a sensitive, microwave bandwidth InGaAs photodiode. All modules are constructed in laboratory-grade housings and shipped with AC power supplies. Custom packaging and gain configurations are also available. For more information, please contact us at info@photonicsinc.com.

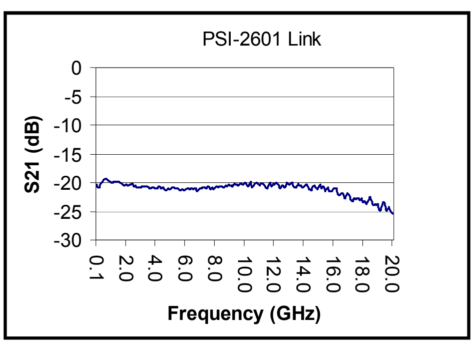
PSI-2600 Features	Benefit
High performance fiber optic link	Enables replacement of lossy, heavy copper transmission lines
Lithium niobate modulator with precision bias control	Long service life
High input power tolerance	Will not overload when close to high RF sources
Compact, low power consumption and high reliability	Low total cost to install and operate

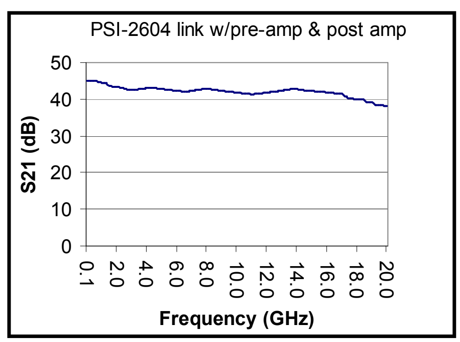
Applications

- **Radio over fiber**
- **Radio astronomy**
- **Remote antenna distribution**
- **Phased array radar**
- **Cellular antenna farms**
- **Optical delay lines**
- **SATCOM**
- **ELINT/EW**

Typical Performance, 25°C @ mid-band

Parameter	PSI-2601 Link	PSI-2602 Link w/ pre-amp	PSI-2603 Link w/ post-amp	PSI-2604 Link w/ pre & post-amp
Operating bandwidth	.045-20 GHz	.1-20 GHz	.1-20GHz	.1-20 GHz
Noise figure	32 dB	5 dB	32 dB	5 dB
Gain	-21 dB	11 dB	11 dB	43 dB
1-dB compression output power	-9 dBm	-10 dBm	20 dBm	20 dBm
IP3 output power	0 dBm	-2 dBm	26 dBm	26 dBm
Spur-free dynamic range (in 1 Hz)	108 dB	104 dB	104 dB	101 dB
VSWR	<2:1	<2.2:1	<2.2:1	<2.2:1
Bias power, TX module	<20 W	<23 W	<20 W	<23 W
Bias power, RX module	35 mW	35 mW	4 W	4 W





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PSI-2600 Series Microwave Photonic Links

RF and Electrical Characteristics

Parameter	Min	Max	Units
Bandwidth	0.10	20	GHz
RF port impedance	50, all ports		Ohms
Receiver input equivalent noise		20	pA/Hz
Amplitude flatness, any 100 MHz		± 0.5	dB
AC power (60 Hz)	100	240	VAC

Absolute Maximum Ratings

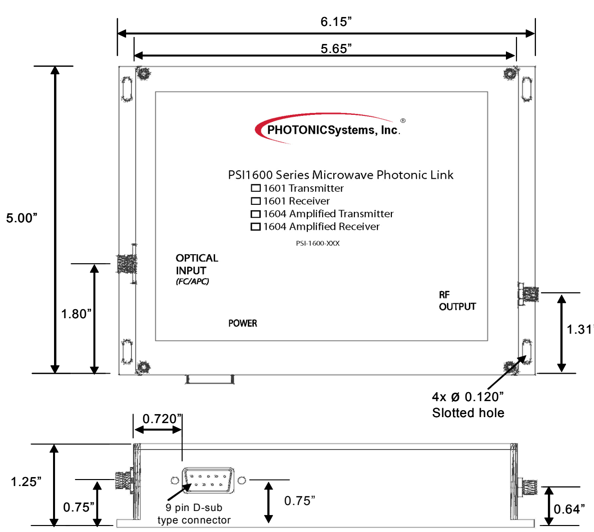
Parameter	Min	Max	Units
Operating Temperature (within specs)	0	50	^{0}C
Operating Temperature (no damage)	-20	60	^{0}C
Storage Temperature	-40	80	^{0}C
Humidity	0	95	%
RF input (Amplified TX at max gain)		-6	dBm
RF input (Unamplified TX)		+25	dBm
Optical power into receiver		+13	dBm

Optical Characteristics

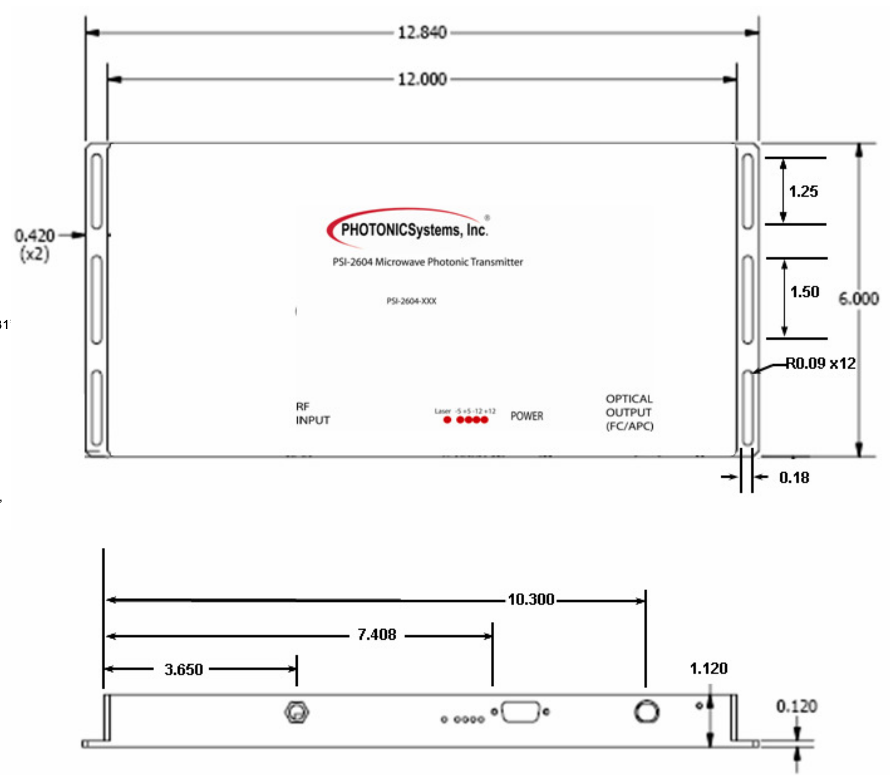
Parameter	Min	Max	Units
Wavelength	1520	1575	nm
TX optical power	0.5	10	mW
RX optical input power	0	20	dBm
Receiver responsivity	0.85		A/W
Connector return loss		-40	dB
Fiber type between TX and RX (user supplied)	Single mode; Corning SMF-28 or equivalent		--
Fiber span @ 1dB degradation in noise figure	6		km

Physical Characteristics

Parameter	Attribute
RF Connectors, all ports	SMA Female
DC connector	9 pin D-sub
Fiber optic connector	FC/APC



PSI-1600 & 2600 Series Receiver Module-
This module is used for both families of photonic links, including amplified and amplifierless versions.



PSI-2600 Series Transmitter Module-
This module is used for all PSI-2600 transmitters.

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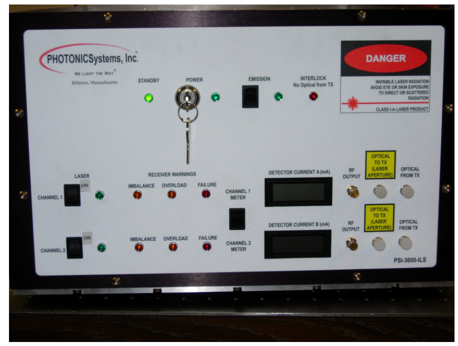
Preliminary

PSI-3600 Series Microwave Photonic Components

PSI-3600-LNLS
High Power Low Noise Light Source Module



System Description

The PSI-3600 microwave photonic system consists of a family of components that offer unparalleled performance in a wide range of applications. Components of the system include a high power optical light source, PSI-3600-LNLS, a transmitter module, PSI-3600-TX and a receiver module, PSI-3600-RX. These modules may be purchased individually or as a complete photonic system depending upon application requirements. When operated as a complete photonic link, the PSI-3600 offers the widest dynamic range and best noise figure performance of any commercially available product.

Low Noise Light Source

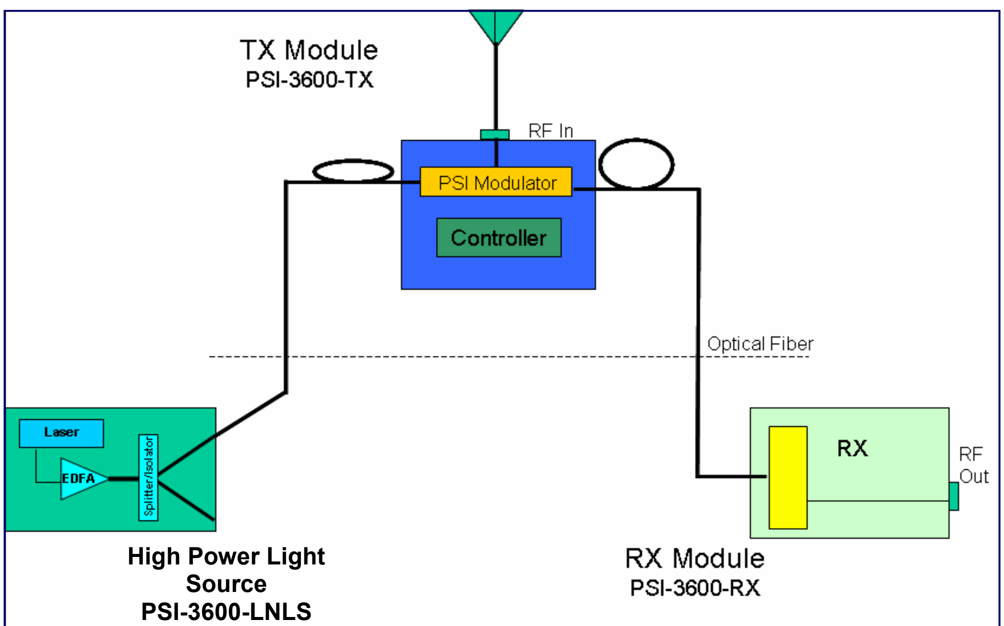
The PSI-3600-LNLS high power, low noise light source provides an optical carrier for use in extremely high performance photonic transmission links. The source may used with the PSI-3600-TX and PSI-3600-RX to reach previously unattainable performance or used independently in other applications. This product is available with optical power output levels optimized for specific application requirements. Multiple optical output taps are available to support light source sharing among multiple links. The PSI-3600-RX may optionally be built into the light source for applications where the light source and detector are co-located.

Benefits

- ✓ Eliminates high transmission line loss
- ✓ Reduces electronic amplification noise figure penalty
- ✓ Microwave bandwidth transmission over long distances through optical fiber
- ✓ Offers signal security and integrity
- ✓ Allows future system growth through wavelength multiplexing

Applications

- Antenna remoting
- Phased array radar
- Optical delay lines
- Signal concentration
- Remote imaging



Example of a high performance microwave photonic transmission system with PSI-3600 components

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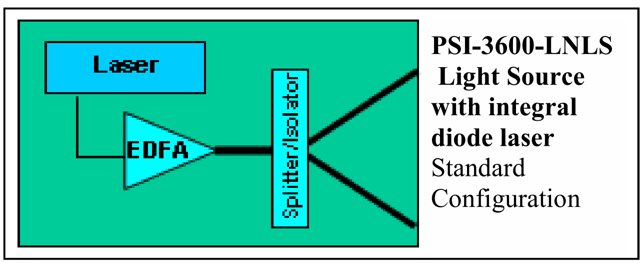
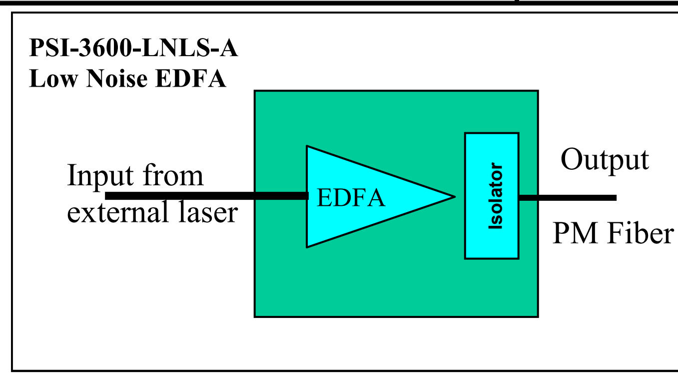
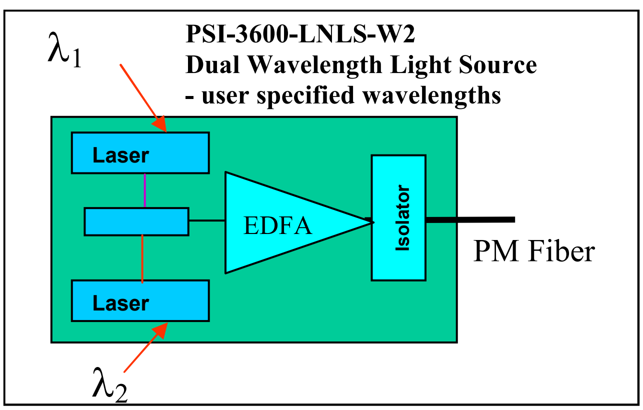
PSI-3600-LNLS Light Source Module

Light Source Module Specification Highlights

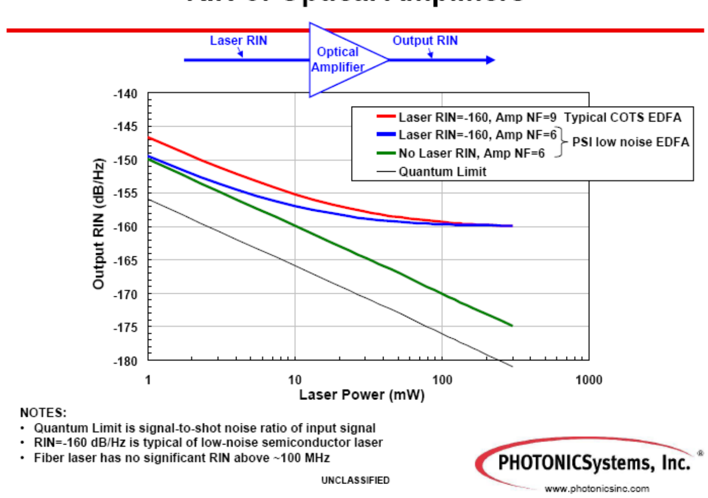
Parameter	Typical Value	Units
Optical Output Power	1-10, defined by user application	Watts
Operating Wavelength	1545-1565, user specified on ITU 100GHz grid	nm
Relative Intensity Noise (of source laser)	<-150, 100MHz to 10GHz	dBHz
Source Laser	Diode laser	—
Amplifier Technology	EDFA	--
Optical Fiber Type	Polarization maintaining, PANDA Fujikura SM-15P or equivalent	—
Optical Output Connectors	FC/APC, Slow axis	—
Unit Dimensions	19" W, height and depth dependent on power	inches
Operating Temperature Range	0 to 50	Deg C
Power Requirements	120	VAC







RIN of Optical Amplifiers



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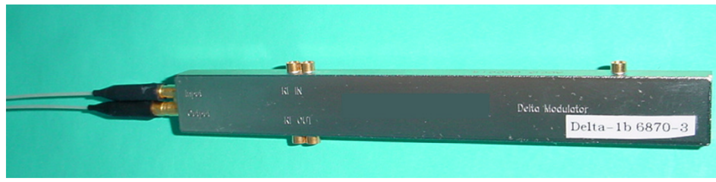
PSI-3600 Series Microwave Photonic Components

PSI-3600-D1 Low Vπ Modulator

Description



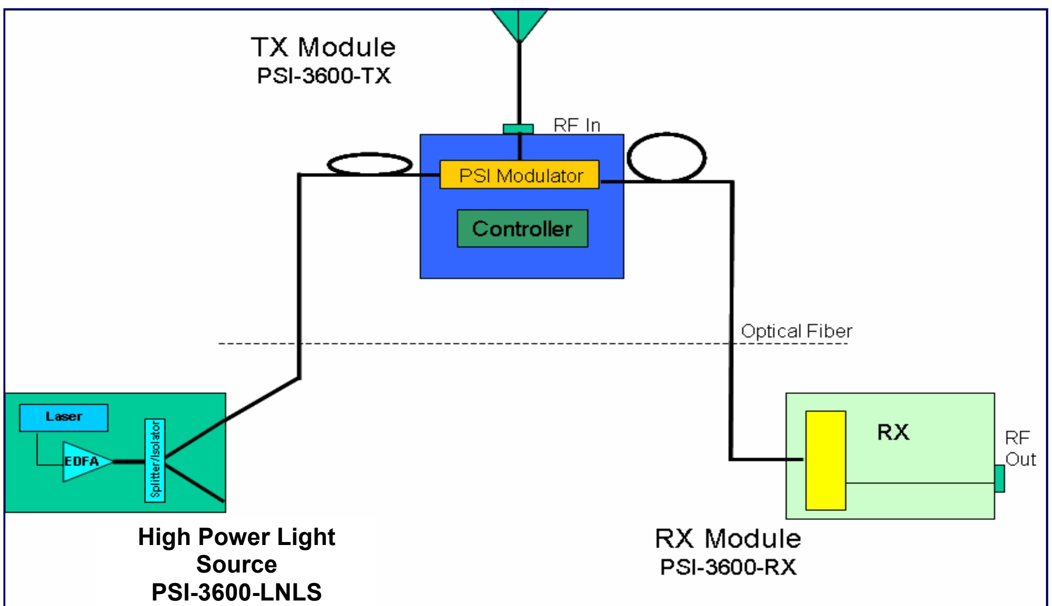
The PSI-3600-MOD-D1 Lithium Niobate, Mach-Zehnder interferometer modulator provides intensity modulation of light in the 1550 nm region for use in very low noise figure, wide dynamic range photonic systems. Offering the lowest drive voltage (Vπ) on the market, this modulator serves a critical role in defense antenna remoting, phased array radar, radio astronomy and other applications that demand the highest level of system performance. With a Vπ of 1.2V at 1 GHz, this modulator may be used to construct microwave photonic links with unprecedented positive intrinsic link gain, low noise figure and wide dynamic range. These modulators are available in versions capable of operation to 6, 12 or 18 GHz. The PSI-3600-MOD-D1 includes complementary optical outputs and may used in either single or dual RF drive configurations.

PSI-3600-D1 Feature	Benefit
Very low Vπ: 1.2 V at 1 GHz, 2.7 V at 18 GHz	Enables highly linear intensity modulation with minimal drive components
Available in 18, 12 or 6 GHz versions	Flexibility for various system applications
Dual complementary outputs	Enables balanced fiber links for optimum link noise figure

When used in conjunction with the PSI-3600-DET detector, PSI-3600-LNLS low noise light source, PSI-2600-11 photonic controller and PSI-0204-11 modulator bias controller, the PSI-3600-D1 completes a best-in-class microwave photonic system, capable of record-setting photonic link dynamic range, noise figure and positive intrinsic link gain.

Applications

- Antenna remoting
- Phased array radar
- Signal Distribution
- Remote imaging
- ELINT/EW



Example of a high performance microwave photonic transmission system with PSI-3600 components

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PSI-3600-MOD -D1
Low Vπ Modulator

PSI-3600-MOD-D1-18/-12/-6 Specifications

Parameter	Typical Value			Units
Operating Wavelength	1525- 1605			nm
Optical Insertion Loss	9			dB
Optical Return Loss	40, min			dB
Optical Output	Dual complementary			--
Extinction Ratio	20, min			dB
Vπ , DC	0.9			V
RF Vπ; 18, 12 or 6 GHz model	*-18*	*-12*	*-6*	
Vπ , 1GHz (single drive)	< 1.2	< 1.2	< 1.2	V
Vπ , 6GHz (single drive)	< 1.7	< 2	< 2	V
Vπ , 12GHz (single drive)	< 2.2	< 3	-	V
Vπ , 18GHz (single drive)	< 2.7	-	-	V
Storage Temperature Range	-40 to +85			°C
Operating Temperature Range	0 to 70			°C
RF Port Connectors (dual drive)	GPO			--
Bias Connector	GPO			--
Optical Connector	FC/APC			--
Output Optical Fiber	SMF (PMF available)			--

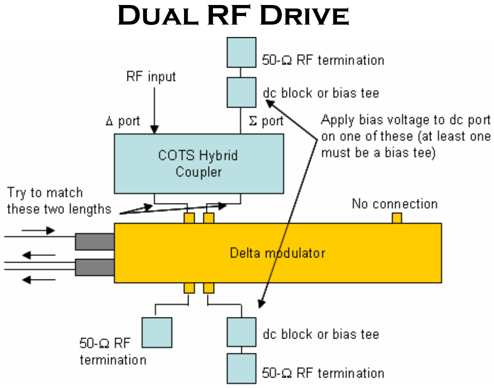
Using the PSI-3600-MOD-D1 Modulator

These modulators may be used in a variety of high performance microwave photonic applications. With dual RF drive inputs as well as dual complementary optical outputs, the modulator offers application flexibility that allows the user to optimize link performance.

In applications where the lowest possible drive voltage is required, users may take advantage of the dual RF drive capability to realize a ~30% Vp reduction. Dual drive requires the use of a hybrid 180° coupler connected in conjunction with a bias-T and 50W terminations as shown below. Single drive operation is achieved with fewer components and results in a more practical solution for wideband link applications.

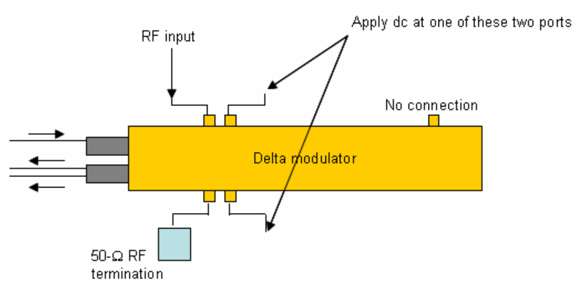
In order to minimize the effects of source laser RIN, the dual complementary optical outputs may be used in conjunction with the PSI-3600-BPD balanced detector. This link arrangement requires careful matching of optical fiber lengths but offers substantial in wideband link noise figure. Contact PSI for more information on balanced detection.

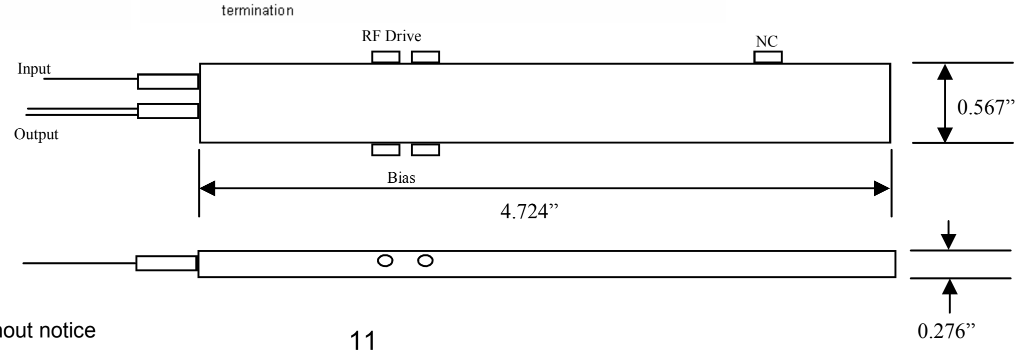
Dual RF Drive



= user supplied component

Single RF Drive





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PSI-0204 Series
PSI-204-11 Chip-scale Bias Controller

Product Description

The PSI—0204-11 chip-scale optical modulator bias controller (MBC) offers comprehensive control of external optical modulators from a single, small form factor circuit board. When operated with lithium niobate ($LiNbO_3$) modulators, the PSI-0204-11 provides automatic or manual bias control. Users may select automatic tracking of Quad +, Quad -, Minimum or Maximum bias points as shown in Figure 1.
Operation at an externally set manual bias point may also be selected.

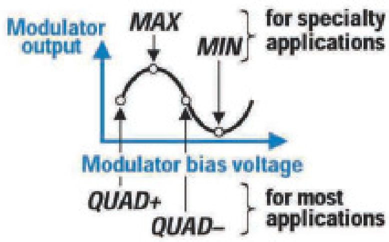
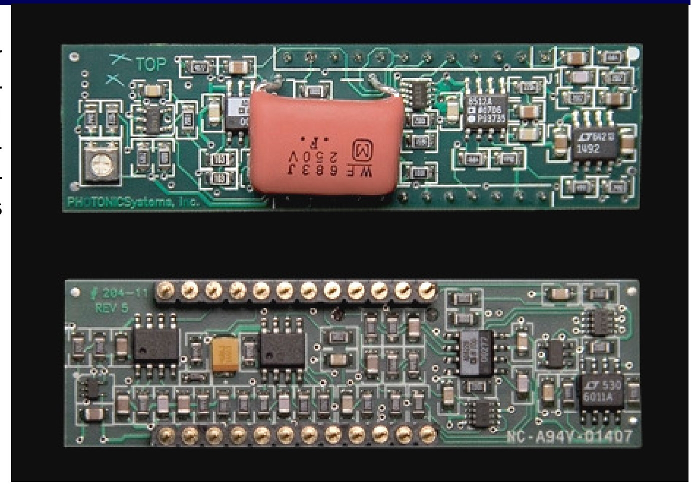


Figure 1– Modulator Transfer Function

Using a dither tone, the PSI-0204-11 tracks a user selected operating point to within +/- 1° at 1% dither of V_{π} when operating at quadrature. Dither frequency is set at 1 KHz and dither amplitude is user defined between 20 and 200mVpp. Bias point accuracy is maintained over a wide operating temperature range of 0° to +50° C. Using a common photodetector, bias point accuracy is easily maintained over a 10dB range of optical power. Wider dynamic range controllers are available upon request.

Designed for easy integration into the user's optical system, these controllers maintain constant bias point operation by compensating for drift in a modulator's transfer function. An external modulation fiber optical transmitter is shown in Figure 2 to illustrate how the controller is typically used. A dither tone is applied to the modulator bias voltage and sampled at the modulator optical output. Through use of an optical coupler and photodetector, a portion of the transmitted light is detected and fed to the MBC. User settings determine bias point and amplitude.

Beyond standard specifications, PSI can modify the PSI-0204-11 to meet the exact requirements of your application, such as specific dither frequency, wide temperature range or very large optical input range. Smaller package sizes are offered for operation at a single bias point; other designs may also result in micro-miniature packages.
An optional evaluation kit is available to aid with design-in and proof of concept activities. The evaluation board provides a convenient means to power, control and test the MBC in a laboratory setting. Electrical connections are provided through either a DB9 or Molex plug. An optical photodetector completes the feedback loop. Included in the kit are an evaluation board with photodetector, AC power adapter and an MBC device.



Features and Benefits

- ✓ Dither based control compatible with most optical modulators
- ✓ Adjustable Dither amplitude: 20 to 200mVpp
- ✓ Power supply range: +/-12 to +/-18volts
- ✓ Low operating current: <12mA typical
- ✓ Small size: 2.5"x 0.7", 24pin, 0.6" width DIP
- ✓ Customized Designs available in micro-sized packages
- ✓ Evaluation kit available for simple test and design

Applications

- **Modulator design**
- **Integrated Modulator/Transmitters**
- **Fiber optic component evaluation**
- **Photonic Test Systems**
- **Spectroscopy systems**
- **Analog communications systems**

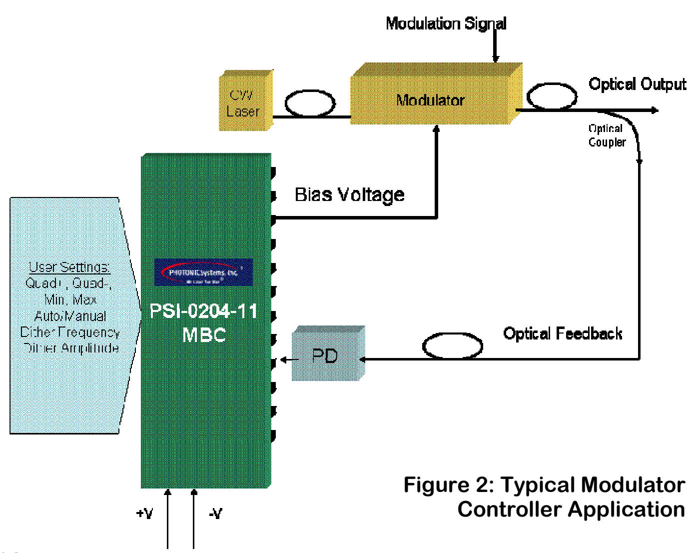


Figure 2: Typical Modulator Controller Application

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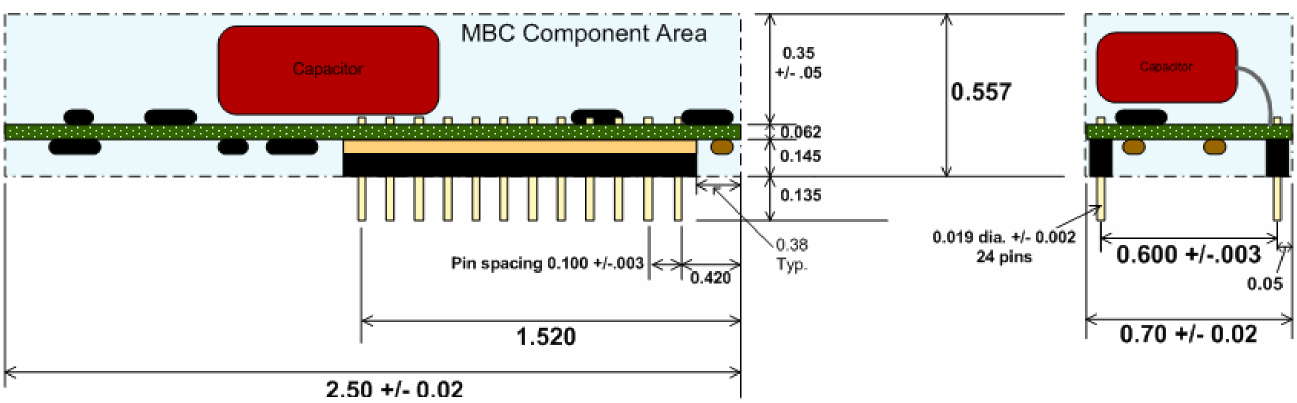
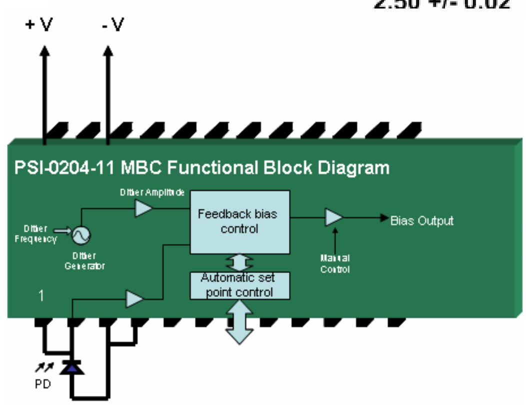
PSI-0204 Series
PSI-204-11 Chip-scale Bias Controller

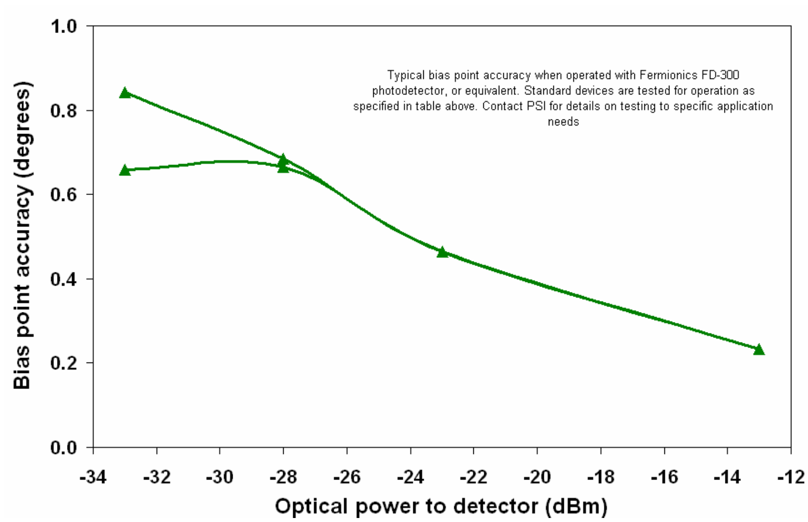
Specifications

Parameter	Typical Value	Units
Modulating Signal	Analog small or large signal or DPSK	—
Modulators Supported	$LiNbO_3$	—
Modulator/Bias-T Load Capacitance	< 0.2	μ F
Output DC Bias Port Impedance	100	ohms
Output DC Bias Voltage	0.3 less than supply voltage	Volts
Dither Frequency	1	KHz
Dither Amplitude	20 to 200; user defined	mVpp
Bias Point Error @Quad + or Quad - point, 5 to 50 μa photo detector current [1]	1 @1% dither of V_π	degrees
Bias Point Error @Max or Min point, 10 to 100 μa photo detector current [1]	< 0.1	degrees
DC Power Supply	+/- 12 to +/-18	Volts
DC Operating Current	< 12	mA
Operating Temperature Range	0 to +50	°C
MBC Board Dimensions	2.5 x 0.7 (6.4 x 1.7cm) ; 24 pin dual in-line package, 0.6" width	inches

1. Equivalent to -23 to -13 dBm of optical power (at quadrature) applied to Fermionics FD-300 or equivalent photo detector. Wider dynamic range controllers available at additional cost; contact PSI for details.







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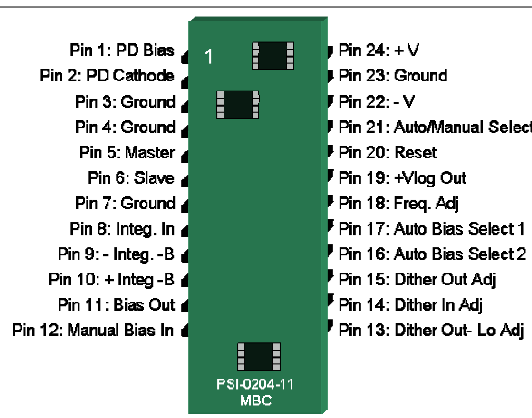
Device Function and Pin Descriptions

Pin	Function	Description
1	PD Bias	Provides internally generated bias voltage for photodetector. Normally connected together with Pin 2 to the PD cathode.
2	PD Cathode	Photodetector cathode connection. Normally connected to Pin 1 for PD bias.
3	PD Anode (Common)	Photodetector anode connection.
4	PD Anode (Common)	Photodetector anode connection.
5	Master	Output of PD preamplifier. Normally connected to pin 6. May be used for control of slaved bias controllers.
6	Slave	Input to dither detection circuitry. Normally connected to pin 5. May be used for control from a master bias controller.
7	Ground	Device Ground
8	Intg. In	Control loop integrator input. Normally unused, this input allows for modification of the bias control response time.
9	-Intg. –B	Control loop integrator output. Normally connected to pin 10, this output allows for modification of the bias control response time.
10	+Intg. +B	Control loop integrator output. Normally connected to pin 9, this output allows for modification of the bias control response time.
11	Bias Out	Bias output
12	Manual Bias In	Input for control of bias in manual mode. Input voltage ranges from –V to + V for control of bias voltage over Max to Min.
13	Dither Out– Lo Adj	Low dither voltage output. May be used for fine adjustment of dither amplitude. Normally not used.
14	Dither In	Dither input. Normally connected to pin 15 through a user selectable resistance to set dither amplitude. May be used to implement adjustable dither in conjunction with pin 15.
15	Dither Out Adj	Dither generator output. Normally connected to pin 14 through a user selectable resistance to set dither amplitude. May be used to implement adjustable dither in conjunction with pin 14.
16	Auto Bias Select 2	Input to set auto bias point in conjunction with pin 17. See table 1 below. Device employs internal 200k pull up resistor.
17	Auto Bias Select 1	Input to set auto bias point in conjunction with pin 16. See table 1 below. Device employs internal 200k pull up resistor.
18	Freq. Adj (future use)	No connection- Dither frequency control in future release; not supported at this time.
19	+Vlog Out	4.5 volt reference output. Normally not used.
20	Reset	Control loop reset input. Ground for normal operation, allow high for reset; device employs 200k pull up resistor.
21	Auto/Manual Select	Selects Automatic or manual bias point control. Connect to ground for automatic control; open for manual control. Device employs internal 200k pull up resistor.
22	-V	Negative power supply connection. Acceptable range from –4.75 to –18 volts
23	Ground	Device Ground
24	+V	Positive power supply connection. Acceptable range from 4.75 to 18 volts



MBC Pin / Bias Point	Pin 17	Pin 16
Q+	Open	Open
Q-	Ground	Open
Max	Open	Ground
Min	Ground	Ground

Table 1: Auto bias control point settings.

PSI-0204 Series
PSI-204-99 Evaluation Kit
For use with PSI-0204-11 chip-scale MBC

Product Description

The PSI—0204-99 optical modulator bias controller (MBC) evaluation kit provides a complete laboratory solution for evaluation of the PSI-0204-11 chip-scale MBC. The chip-scale controller provides control of external optical modulators from a single, small form factor circuit board. When operated with lithium niobate ($LiNbO_3$), modulators, the PSI-0204-11 provides automatic or manual bias control. Users may select automatic tracking of Quad +, Quad -, Minimum or Maximum bias points as shown in Figure 1. Operation at an externally set manual bias point may also be selected.

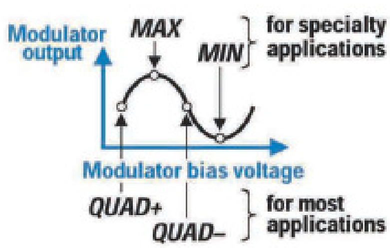
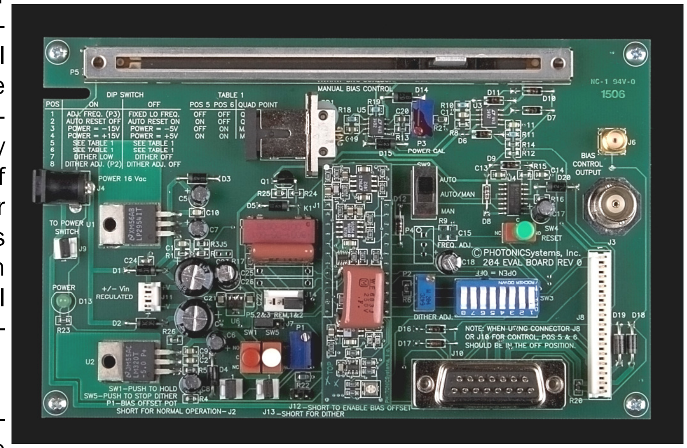


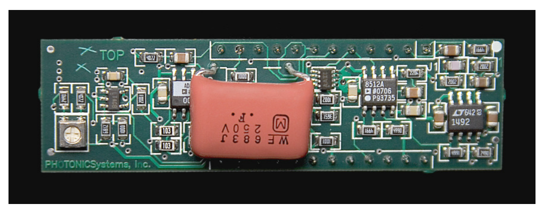
Figure 1– Modulator Transfer Function

The chip-scale device evaluation board provides a simple means to make all necessary electrical and optical connections to an MBC under evaluation. A 24 pin socket on top of the board hosts the device under test. All electrical and optical connections are made to the device including power, user-defined settings and bias voltage output. An on-board photodetector completes the optical feedback loop from a user's modulator and laser system. Controls are provided to set manual bias point, automatic bias point, bias offset, dither amplitude and dither frequency. Push buttons allow for temporary hold of a bias point, dither disable and forced reset. A bias monitor port is provided as are connections through either a D-type or Molex connector. The kit is shipped complete with a sample MBC, AC power supply, and connectors.



Features and Benefits

- ✓ Complete evaluation kit for PSI-0204-11 Modulator Bias Controller
- ✓ Includes all control components to test MBC with your application
- ✓ Dither based control compatible with most optical modulators
- ✓ Includes sample MBC, AC power supply and DC electrical connectors.



About the PSI-0204-11 Chip-scale MBC

Designed for easy integration into the user's optical system, these controllers maintain constant bias point operation by compensating for drift in a modulator's transfer function. An external modulation fiber optical transmitter is shown in Figure 2 to illustrate how the controller is typically used. Through use of an optical coupler and photodetector, a portion of the transmitted light is detected and fed to the MBC. The dither tone is applied to the bias voltage output and sampled as a control mechanism. User settings determine bias point selection, dither frequency and amplitude.

Beyond standard specifications, PSI can modify the PSI-0204-11 to meet the exact requirements of your application. Smaller package sizes are offered for operation at a single bias point; other designs may also result in micro-miniature packages.

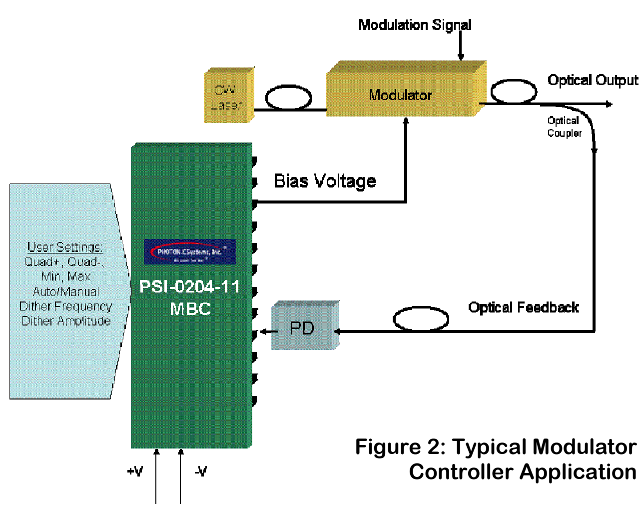


Figure 2: Typical Modulator Controller Application

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Using the Evaluation Board-

Most functions of the PSI-0204-99 Modulator Bias Controller evaluation board are set up through an 8 position DIP switch bank (SW3) located at the lower right of the board. These switches enable the dither generator at a fixed frequency and amplitude, enable automatic reset, set the automatic bias control point and determine set +/-15 volt supply operation. Prior to applying power to the evaluation board, ensure that the switches are set according to your application and the tables below.

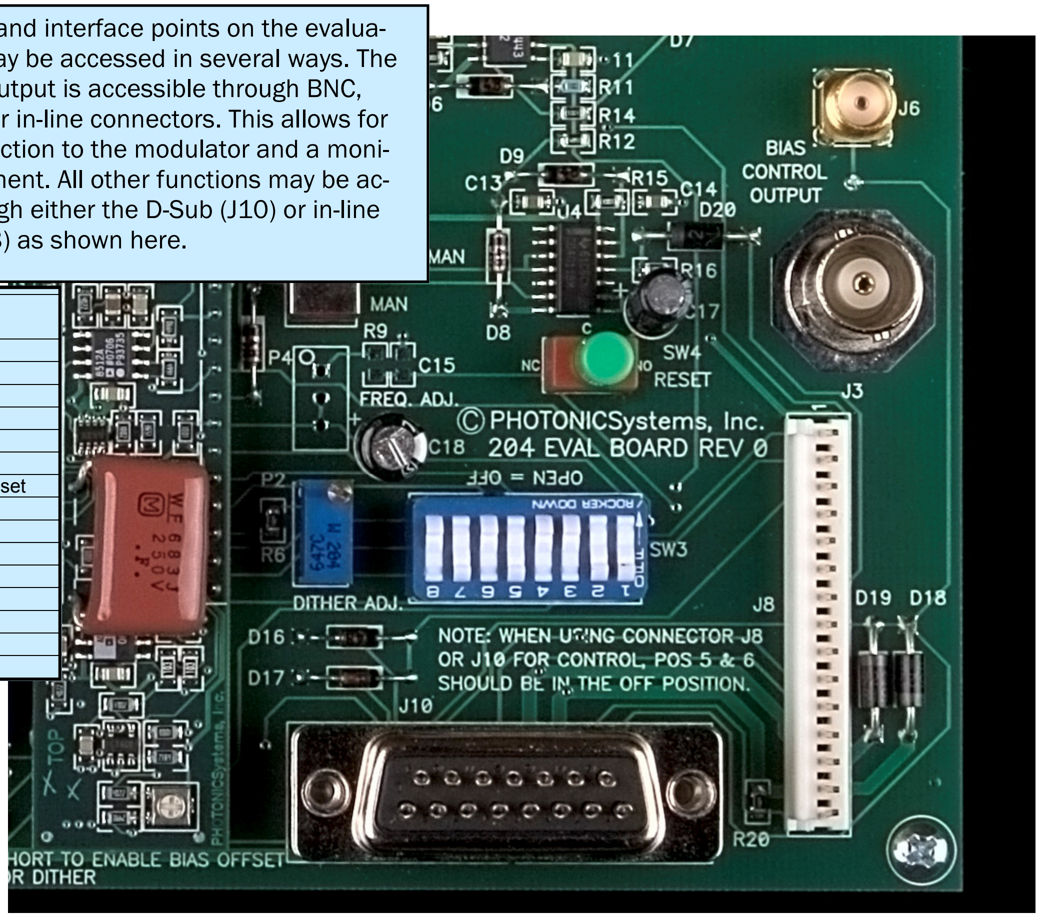
POS	ON	OFF (CLOSED)
1	Adjustable Dither Frequency	Fixed Frequency (1KHz)
2	Auto Reset Off	Auto Reset On
3	Power= -15V	Power= -5V
4	Power=+15V	Power=+5V
5	Bias Mode (See Table 2)	Bias Mode (See Table 2)
6	Bias Mode (See Table 2)	Bias Mode (See Table 2)
7	Dither Low	Dither Off
8	Dither Adj. (P2)	Dither Adj. Off

MBC Pin / Bias Point	Pin 17	Pin 16
Q+	Open	Open
Q-	Ground	Open
Max	Open	Ground
Min	Ground	Ground

Auto bias control point settings.

All functions and interface points on the evaluation board may be accessed in several ways. The controller's output is accessible through BNC, SMA, D-sub or in-line connectors. This allows for simple connection to the modulator and a monitoring instrument. All other functions may be accessed through either the D-Sub (J10) or in-line connector (J8) as shown here.

J8 or J10 pin	*Description*
1	Q+/-
2	Min/Max
3	Min
4	+5 volts
5	Power Switch 1
6	Power Switch 2
7	Reset Input; Ground to force reset
8	Bias Output
9	Power Meter
10	Auto/manual Select
11	Ground
12	Bias Wiper (Manual Control)
13	V-
14	V+
15	Power LED



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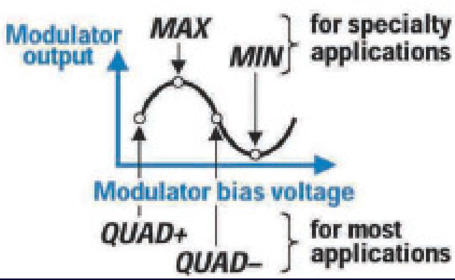
PSI-0303 Digital Modulator Bias Controller

Product Description

The PSI—0303 digital modulator bias controller is a full featured laboratory instrument designed for precise control of Mach-Zehnder interferometer fiber optic modulators. Designed to operate in the presence of a digital modulation signal, these controllers accurately prevent bias point drift from any of four preset or one user set modulator transfer function points. Through use of a proprietary control algorithm, the controller maintains bias control without the use of a dither signal.



Benefits

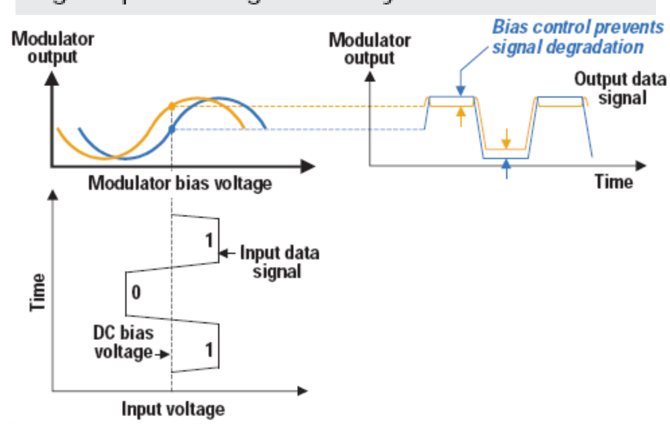
- ✓ **Complete-** includes optical coupler and photo-detector
- ✓ **Accurate-** maintains drift to within 2° at Quad points; +/- 0.2° at Max and Min points
- ✓ **Easy to use–** front panel optical and bias connections, LCD read-out of bias voltage and optical power

Measurements are simplified through use of the PSI-0303 in your link or component evaluation set-up. With an internal optical coupler and photo-detector an internal feedback path automatically establishes lock on the desired bias point.

Automatic control modes allow the operator to select Quad+, MAX, Quad– or MIN bias points. A 10-turn potentiometer provides manual control for fine tuning to a specific bias point. An LCD display shows the bias voltage and optical output power. All features allow for simplified characterization of a modulator's Vπ, optical insertion loss, optical extinction ratio and rate of bias point drift.

Why use a Modulator Bias Controller?

Ideally, the desired Mach-Zehnder modulator bias point—in this example, the blue point on the curve shown here—would occur at a specific DC voltage that remains constant despite any variation of environmental conditions. However, effects in the modulator's electro-optic material can cause the transfer function to "drift" to the left or right—see, for example, the orange curve—such that a specific DC bias voltage may yield a QUAD+ point on the transfer function curve now and a different point on the curve after a slight change in the environmental conditions. As the figure at right shows, this small bias point drift can have a large impact on signal fidelity.



Applications

- **Modulator design**
- **Fiber optic component evaluation**
- **Laboratory control**
- **Data communications systems**

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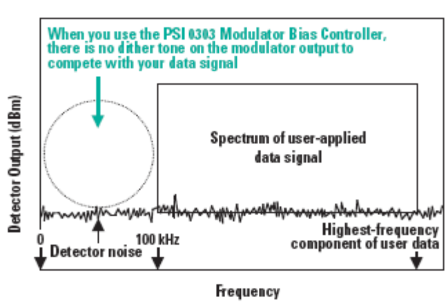
PSI-0303 Digital Modulator Bias Controller

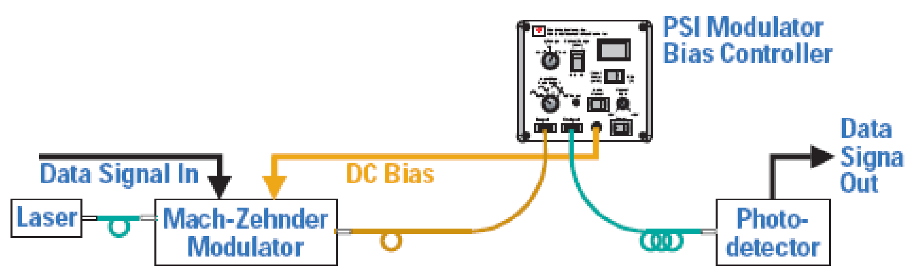
Specifications

Parameter		Typical Value	Units
Fiber Type		SMF-28	—
Wavelength		1300-1550	nm
Optical Insertion Loss		0.8	dB
Input Optical Power	***Quad + or -*** ***Max or Min***	0 to –15 0 to –10	dBm
Output DC Bias Voltage		+/-15	V
DC Bias Port Impedance		<1	Ω
Modulator Vπ standard Range; unit may be factory set for other values as needed		2.4– 7.6	V
Dither Frequency		n/a	
Bias Point Error	***Quad+ or –*** ***Max or Min***	+/- 5 +/-3	Deg.
Initial Auto Bias Point Acquisition Time		10	sec.
Drift Compensation Response Time	***0 to -10 dBm input power*** ***-10 to –20 dBm input power***	5 5	sec. sec.
Case Dimensions (WxHxD)		5.75x5.25x8.75	In.
Optical Connectors		FC/APC	---
Storage Temperature		-25 to +60	°C
Power		115v @25mA	—

The PSI 0303 Digital Signal Modulator bias controller (U.S. Patent pending) has a desirable spectral output: *none at all.*

When you apply digital data (at 2.5Gbps, 10Gbps, or any other data rate) to a modulator controlled by the PSI 0303, its output light is modulated by your digital data only: *there is no dither tone present!*





Options

P/N suffix	Description
-019-xxxx	Custom Optical Wavelength (user specified, nm)
-003	High Optical Power
-018	Polarization maintaining fiber, coupler and connectors
-024	Polarization maintaining coupler & connectors combined with high optical power; input range 100uW to 10mW

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Introduction

Since the development of low-loss optical fiber in the late 1960s [1], designers of all sorts of systems for transmitting, detecting, and processing electronic signals have sought to exploit its uniquely advantageous characteristics. To do this has required the development of devices that generate light at the optical wavelengths that propagate best in the fiber, devices that allow the electronic signal of interest to modulate this light at one end of the fiber, and devices that restore the signal to electronic form at the other end of the fiber. The interconnection of these devices in a configuration that results in the conveyance of the electronic signal of interest from one point to another by means of the optical fiber is what is known as a *fiber-optic link*.

Figure 1 illustrates an example of how a fiber-optic link conveys a radio-frequency (*RF*) microwave signal [2]. In the example shown, a signal consisting of a single frequency f_{RF} modulates a single-frequency optical carrier at frequency f_{opt} for propagation in the optical fiber as sidebands at frequencies $f_{opt} \pm f_{RF}$, which beat against the carrier in the photodetector to produce an output electronic signal at the original frequency f_{RF}. Figure 1 specifically depicts the spectral patterns of signals in a link that employs *intensity modulation* and *direct detection*.

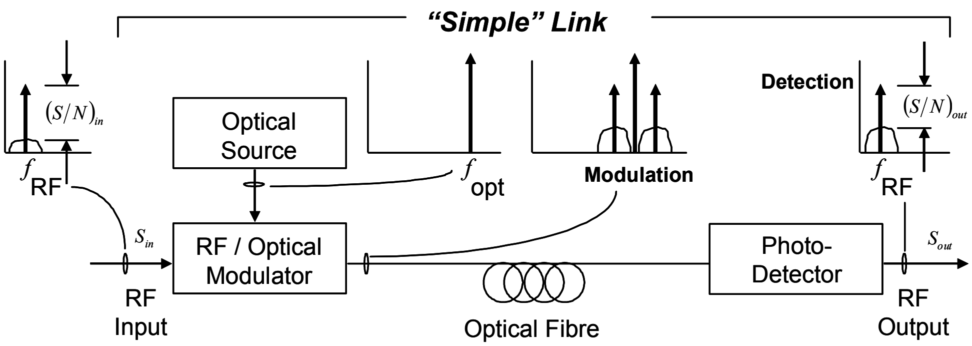

Fig. 1 Definition of an "intrinsic" analog fiber-optic link (after [2]).

Also, for the purposes of discussion, a straightforward or "intrinsic" link is defined here to include the optical source, modulator, fiber, and optical receiver, but not any electronic amplifiers. The link has electronic input and output ports, and as such can include passive circuits that transform the impedances of these ports to match those of the modulation and detection device impedances, respectively.

Requirements

The most common figures of merit that quantify the analog performance of a fiber-optic link are:

• Gain	• Minimum detectable signal
• Signal-to-noise ratio	• Compression dynamic range
• Noise figure	• Spurious-free dynamic range

Figure 2 shows how several of the figures of merit commonly used to quantify the performance of microwave components are defined.

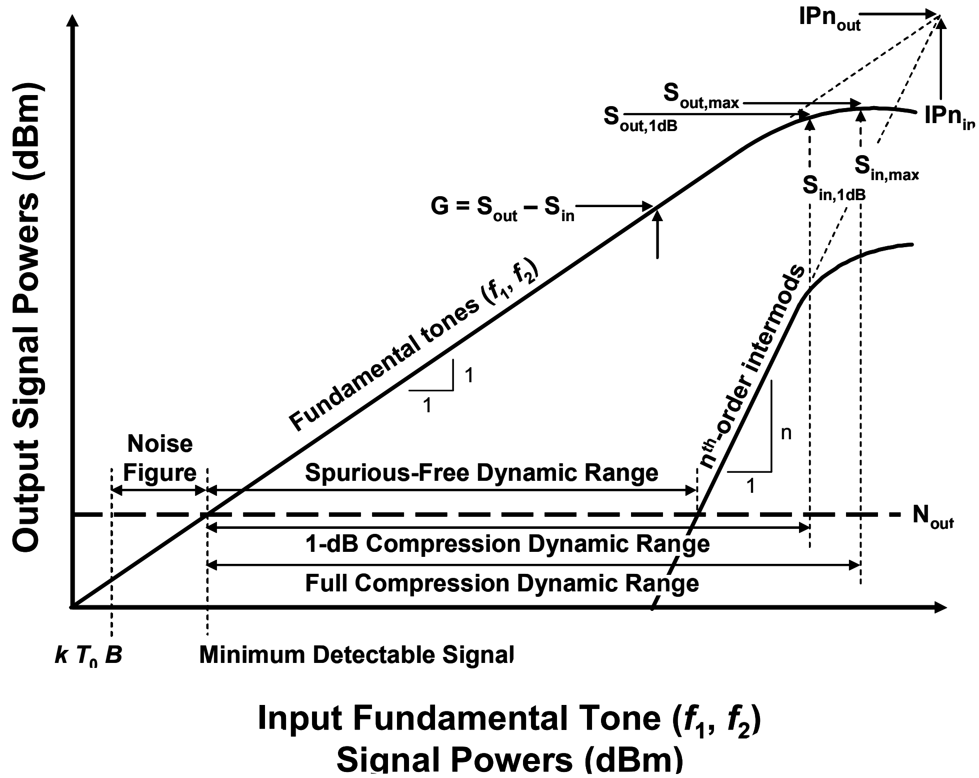

Fig. 2 Principal figures of merit for analog two-port devices, including analog fiber-optic links.

Gain performance

The first to be examined here is the *intrinsic small-signal gain, g_i*, because several of the other figures of merit depend in some way upon this one. For an input RF signal power expressed in W (or mW or μW), g_i is the dimensionless ratio of the output RF power to this input power. When this ratio is less than unity, it is called loss rather than gain. Similarly, for powers expressed in dBm, G_i is the difference between these and is expressed in dB, with a negative difference representing loss rather than gain:

$$g_i\ (\text{dimensionless}) = \frac{s_{out}(\text{in W})}{s_{in}(\text{in W})} \quad (1a)$$

$$\begin{aligned} G_i\ (\text{in dB}) &= 10\ \log(g_i) \\ &= S_{out}(\text{in dBm}) - S_{in}(\text{in dBm}) \end{aligned} \quad (1b)$$

Signal-to-noise performance and Noise figure

The ratio of signal output power to noise output power, usually expressed in dB, is almost always one of the most important figures of merit in any system design. For many communications systems, the input signal strength is controlled and therefore known, in which case the output signal-to-noise ratio might be designed to always meet or exceed a specified value at this input power. In sensing systems such as radars, however, this input signal strength is unknown, and so the output signal-to-noise ratio cannot be readily specified. For such systems a useful figure of merit is the *noise figure* (*nf* or *NF*), which is defined as the extent to which the signal-to-noise ratio degrades:

$$nf(\text{dimensionless}) = \left[\frac{(s/n)_{in,a}}{(s/n)_{out}}\right]_{n_{in}=kT_0B} = \frac{n_{out}}{kT_0B \cdot g_a}. \quad (2a)$$

$$\begin{aligned} NF(\text{in dB}) &= 10\ \log(nf) = (S/N)_{in,a}(\text{in dB}) - (S/N)_{out}(\text{in dB}) \\ &= N_{out}(\text{in dBm}) - 10 \cdot \log(kT_0B)(\text{in dBm}) - G_a(\text{in dB}). \end{aligned} \quad (2b)$$

In equation (2a), s/n is the dimensionless ratio of signal power s to noise power n (both expressed in W), and in equation (2b) S/N is the difference in dB between these two powers (both expressed in dBm). The input noise is specified as only the noise arising from thermal sources. This input noise is the product of k (Boltzmann's constant), T_0 (room temperature, standardized by the IEEE as 290 K [3]), and B (the instantaneous bandwidth of the electronic receiver, sometimes called the "resolution bandwidth" or "noise bandwidth"). Because the output noise term n_{out} is also proportional to B, the noise figure is independent of B.

Minimum detectable signal

Figure 2 shows how, using equation (2b), *NF* can be determined graphically from measurable quantities. It also shows how to graphically determine another important figure of merit that expresses the signal-to-noise performance of a link, which is the minimum detectable signal (*mds*). This quantity, which is defined as the smallest signal power appearing at the link input that can be distinguished from the noise at the link output, is related to the noise figure as follows (and as shown in Figure 2):

$$mds(\text{in W}) = \frac{n_{out}}{g_a} = kT_0B \cdot nf\ . \qquad \text{(3a)}$$

$$\begin{aligned} MDS(\text{in dBm}) &= N_{out}(\text{in dBm}) - G_a(\text{in dB}) \\ &= kT_0B(\text{in dBm}) + NF(\text{in dB}). \end{aligned} \qquad \text{(3b)}$$

Dynamic range

Just as the existence of noise sets a lower limit on the link's input signal power, there is also an upper limit on the input signal power. This upper limit exists because of the nonlinear characteristics of the link components that give rise to phenomena such as output signal compression (sometimes called gain compression) and the generation of harmonic and/or intermodulation distortion, as will be explained further below. The link's *dynamic range* is defined as the ratio of the largest input power (expressed in W) that it can usefully convey to the smallest such input power, which is the *mds* (or as the difference in dB between these two powers if they are both expressed in dBm, which is the *MDS*). How one defines the largest input power that the link can usefully convey depends upon the application. In some applications this is simply the input signal power that causes full compression of the output signal, such that further increases of the input power do not cause the output power to increase (and may even cause it to decrease), and for these applications the *full-compression dynamic range* (cdr_{full}) is defined as follows (and as shown in Figure 2):

$$cdr_{full}(\text{dimensionless}) = \frac{s_{in,\max}(\text{in W})}{mds(\text{in W})}. \qquad \text{(4a)}$$

$$CDR_{full}(\text{in dB}) = S_{in,\max}(\text{in dBm}) - MDS(\text{in dBm}). \qquad \text{(4b)}$$

Sometimes the largest input power that the link can usefully convey is considered to be that at which the output power has been compressed by 1 dB. This input signal power, $S_{in,1dB}$, is the power for which the output power $S_{out,1dB}$ satisfies the following equation:

$$S_{out,1dB}(\text{in dBm}) = S_{in,1dB}(\text{in dBm}) + G_a(\text{in dB}) - 1\text{ dB}. \qquad \text{(5)}$$

From this relationship the *1-dB-compression dynamic range* as shown in Figure 2 is defined as follows:

$$CDR_{1dB}(\text{in dB}) = S_{in,1dB}(\text{in dBm}) - MDS(\text{in dBm}). \qquad \text{(6)}$$

In many applications, the generation of harmonic and/or intermodulation distortion by nonlinear components in the link sets the upper limit on the useful input signal power and therefore dictates the dynamic range. If a signal consisting of a single tone at frequency f_1 is present at the input to the link, harmonic distortion products caused by the link's nonlinearity appear at the output at frequencies $p \cdot f_1$, where p is the set of all positive integers. If the input signal instead consists of two tones f_1 and f_2, then the resulting output harmonics at $p \cdot f_1$ and $p \cdot f_2$ will be accompanied by intermodulation distortion products at $p \cdot f_1 \pm q \cdot f_2$ and $p \cdot f_2 \pm q \cdot f_1$, where both p and q are both positive integers.

Intermodulation distortion products are generally more problematic than harmonics for two reasons: (1) for two equal-strength input tones at f_1 and f_2, the resulting output intermodulation tones at $p \cdot f_1 \pm q \cdot f_2$ and $p \cdot f_2 \pm q \cdot f_1$ are stronger than the output harmonics at $(p+q) \cdot f_1$ and $(p+q) \cdot f_2$ for any given positive integers p and q for which $p \pm q$, and; (2) in applications covering less than an octave of bandwidth (*i.e.*, those in which the maximum frequency of operation is less than twice the minimum frequency), all harmonics fall out of band and can therefore be filtered out, whereas, for f_1 and f_2 sufficiently close to one another, many of the intermodulation products whose "order" $n=p+q$ is an odd number can fall within the band of operation and therefore preclude being filtered out.

In sensing applications, in which spurious output tones at the intermodulation distortion frequencies give rise to false detections, the upper end of the *spurious-free dynamic range (SFDR)* is defined as the input power that causes any output intermodulation product to exceed the output noise. The dominant order of distortion, n, determines this maximum input power, and a somewhat complicated set of considerations determines n. Generally, the lower the order of distortion, the lower the input power must be to generate an intermodulation product of a given strength. Therefore, unless there is a reason not to begin with the assumption that $n = 2$, that is the starting assumption one should make. However, if the system operates over less than one octave of bandwidth, second-order distortion products will always fall out of band and therefore permit being filtered out, so that it instead makes sense to begin with the assumption that $n = 3$.

For an input signal consisting of two equal-power tones of small magnitude, the output intermodulation distortion products will be negligible because they will fall very far below the output noise. However as the two-tone input signal power is increased, the output power at the intermodulation frequencies will increase as the input power to the n^{th} power, so that on Figure 2's plot of output vs. input power in dBm the slope of the intermodulation products is n, compared to a slope of 1 for the fundamental signal tones. A useful figure of merit is the input power at which these two slopes would hypothetically intersect were they to not compress as shown in the figure. This input power is known as the n^{th}-order intercept IPn_{in} and the corresponding output power is IPn_{out}.

From the geometric arrangement of the lines in Figure 2, it can be seen that the *SFDR* is limited by the n^{th}-order distortion products to:

$$\begin{aligned} SFDR_n(\text{in dB}) &= \frac{n-1}{n}\left[IPn_{in}(\text{in dBm}) - MDS(\text{in dBm})\right] \\ &= \frac{n-1}{n}\left[IPn_{out}(\text{in dBm}) - N_{out}(\text{in dBm})\right]. \end{aligned} \tag{7}$$

Other figures of merit

Microwave components are often additionally characterized in terms of their frequency-dependent scattering matrix [S_{mn}], where S_{mn} is the complex ratio of signal intensity out of port *m* to the signal intensity into port *n* when all ports other than port *n* are terminated by the complex conjugates of their input impedances. For a two-port microwave component in which the input and output ports are denoted ports 1 and 2, respectively, the squares of the amplitudes of the four scattering parameters have particular significance:

$|S_{11}|^2$ = input return loss
$|S_{12}|^2$ = backwards isolation
$|S_{21}|^2$ = insertion loss (or insertion gain if $|S_{21}|^2 > 1$)
$|S_{22}|^2$ = output return loss

The importance of the gain ($|S_{21}|^2$) has already been explained. The backwards isolation ($|S_{12}|^2$) is identically zero in most fiber-optic links, in that most modulators cannot detect light and most detectors cannot modulate light; notable exceptions are the dual-function electro-absorption modulator/detector devices demonstrated in the laboratories of the U.S. Navy and the University of California [4]. Because other microwave signal components are not essentially unidirectional, microwave signal reflections at the input and output ports of a link that functions in a chain of microwave components can have adverse effects on the performance of the complete chain. Therefore a link must often be designed such that its input and output return losses ($|S_{11}|^2$ and $|S_{22}|^2$, respectively) lie below a specified level.

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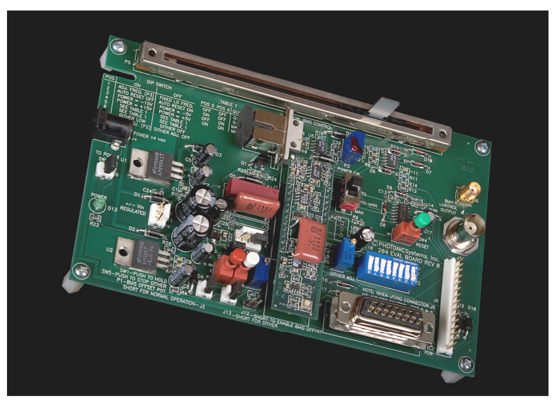

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