Technical Brief #4

Optical Fiber Shutters and VOAs

This note is one of a series of technical briefs developed from customer FAQs and intended to answer the majority of questions concerning the operation of Phoenix products. They are targeted at engineers to assist in incorporating Phoenix products into designs. Any detailed technical questions should be forwarded to Phoenix support.

What is an all-fiber VOA and shutter?

The **variable optical attenuator** provides a continuously variable loss to the optical power in the fiber through change of applied voltage.

The **shutter** provides two level operation, high attenuation closed condition with no voltage applied and low loss open condition when biased.

All-fiber evanescent field benefits

- Non-intrusive to the fiber core
- Low insertion loss
- Virtually no reflection
- Wideband of operational wavelengths

Principle of operation

Phoenix shutters and variable optical attenuators (VOA's) are based on the same evanescent field interaction principle. The VOA is a continuously variable attenuation device whilst the shutter is a two level on-off device.

Both component types are fabricated on the optical fiber without impinging the fiber core. Optical power transmission is controlled by modifying conditions in a short section of fiber between guiding and non-guiding, without the necessity for any absorbing materials. Phoenix can fabricate devices on practically any silica fiber type to operate, in principle, over the full working range of the fiber.

A portion of the cladding is removed locally and replaced with a different material, the refractive index of which can be externally controlled to vary from above to below that of the core index. The current range of Phoenix components use thermal modification of the material refractive index.

Figure 1 shows the typical response of a VOA or shutter for increasing refractive index. There are several points to notice about this basic response:

i) Low insertion loss is achieved for indices below the refractive index of the core.

ii) The two curves represent the maximum and minimum loss polarization modes, i.e. the polarization dependent loss (PDL) which is function of the attenuation level.

iii) The maximum attenuation is achieved when the cladding index matches the core index.

iv) Continuing to increase cladding refractive index reduces the attenuation.

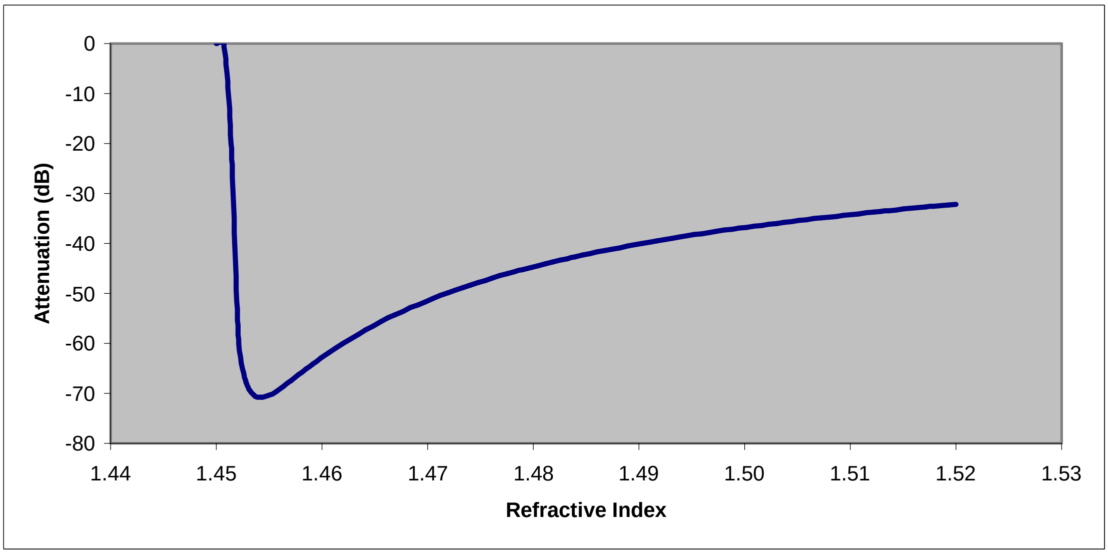


Figure 1 Throughput power attenuation for a VOA or shutter with increasing cladding refractive index.

Phoenix VOAs and shutters use a simple resistive heating method to change the refractive index of the replaced cladding. With no voltage applied across the leads the refractive index is maximum, the device is in the 'off' condition. As current is increased, the refractive index decreases until minimum insertion loss is achieved, the 'on' condition. The current for the 'on' condition is such that the cladding is held at a temperature above 70^0C. Therefore the device will operate over the full specified range of -5^0C to $+70^0$C.Figure 2 shows a typical response as current is increased.

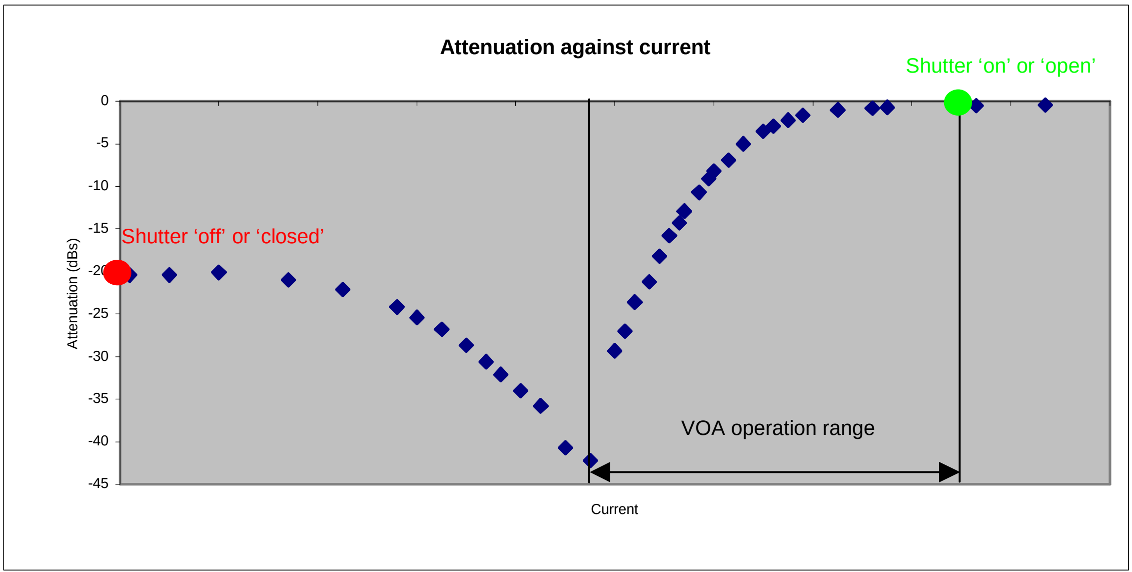


Figure 2 Variation of attenuation with increased drive current

Ambient temperature dependence (TDL)

Thermally controlled devices, such as these, are dependent on the operational ambient temperature, which can fall within the range of –5^{0}C and +70^{0}C for Phoenix standard components.

Figure 3 shows a typical attenuation response curve at two different ambient temperatures of +70^{0}C and 25^{0}C. Operating at lower ambient temperature requires more power and consequently a high drive current to achieve minimum insertion loss. However overall the shape of the response remains the same allowing the specified insertion loss and attenuation levels to be maintained with appropriate feedback control.

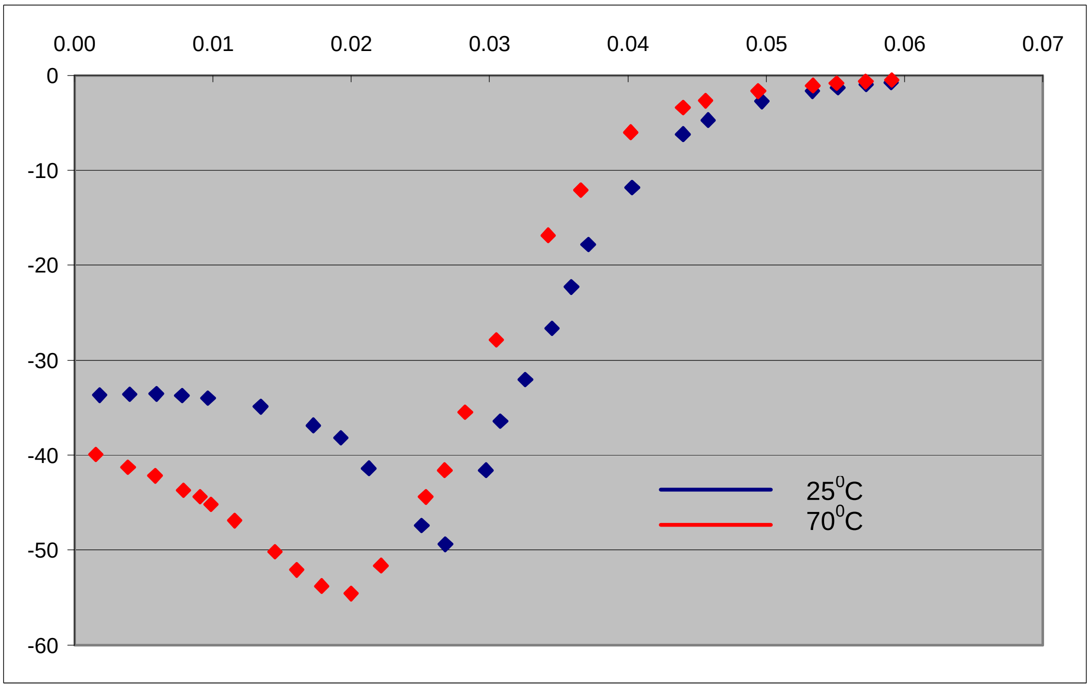


Figure 3 A typical response from a shutter at two ambient temperatures indicating a higher drive current requirement at the lower temperature, these are actual data.

Wavelength dependence (WDL)

Devices will operate at any wavelength for which the fiber is single mode. Increasing wavelength extends the evanescent field further into the cladding therefore the losses of the device are higher at longer wavelengths, giving a WDL (wavelength dependent loss) effect for a fixed drive current.

Figure 4 shows the wavelength dependence, the maximum attenuation peak increases with wavelength.

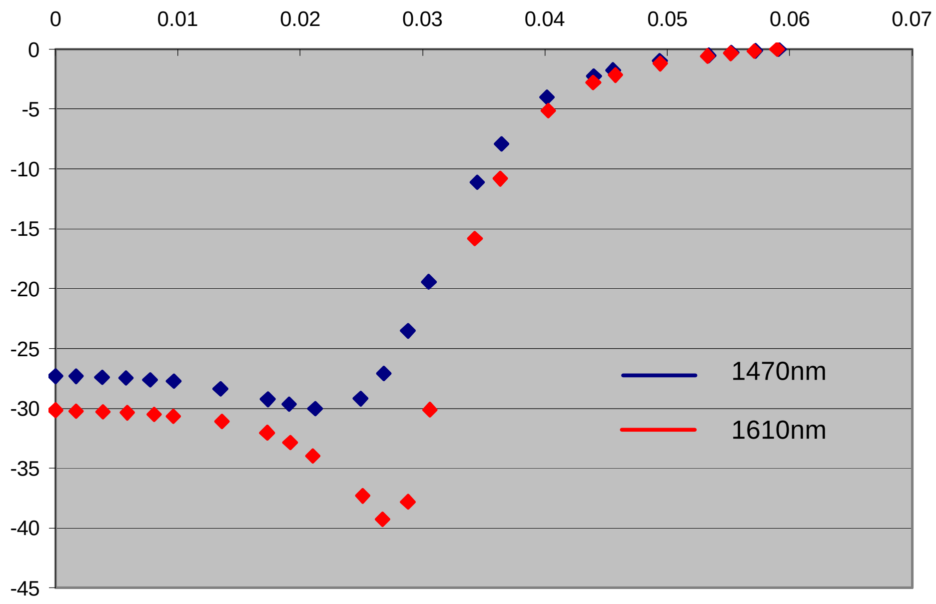


Figure 4 Wavelength response for a shutter or VOA showing higher attenuation at longer wavelengths as the field extends further into the cladding, these are actual data.

Polarization dependence (PDL)

Varying the input polarization state creates a change in the attenuation as a function of the attenuation. Figure 5 shows the attenuation of the TE and TM modes for increasing overlay refractive index. The loss curve is that which would be measured with a depolarized input. The PDL increases with refractive index above the core index, below the core index the PDL is theoretically and practically small.

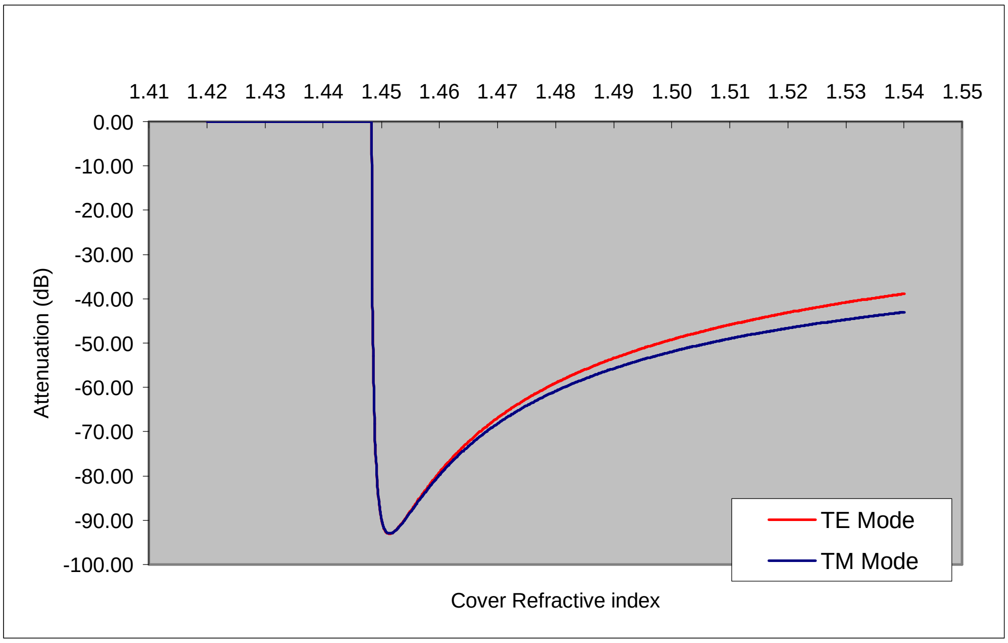


Figure 5 Theorectical curves showing the throughput loss in a VOA or shutter for the TE and TM modes. Increasing the refractive index above that of the core increases the PDL observed. Actual devices follow the same response as shown by the model.

Shutter operation and specifications

The shutter is a very simple device to operate:
? Zero current 'off' – closed condition
? Apply current 'on' – open condition

The specified performance is 'worst case' combination of parameters for operation at the extremes of the specified operational ranges.

Isolation
Isolation specifies the 'off' state and is the **minimum** level of attenuation from the device under any, wavelength, ambient temperature and polarization state combination with the specified ranges.

Insertion loss
Insertion loss specifies the 'on' state and is the **maximum** level of attenuation from the device under any, wavelength, ambient temperature and polarization state combination with the specified ranges. PDL is included in the specified insertion loss.

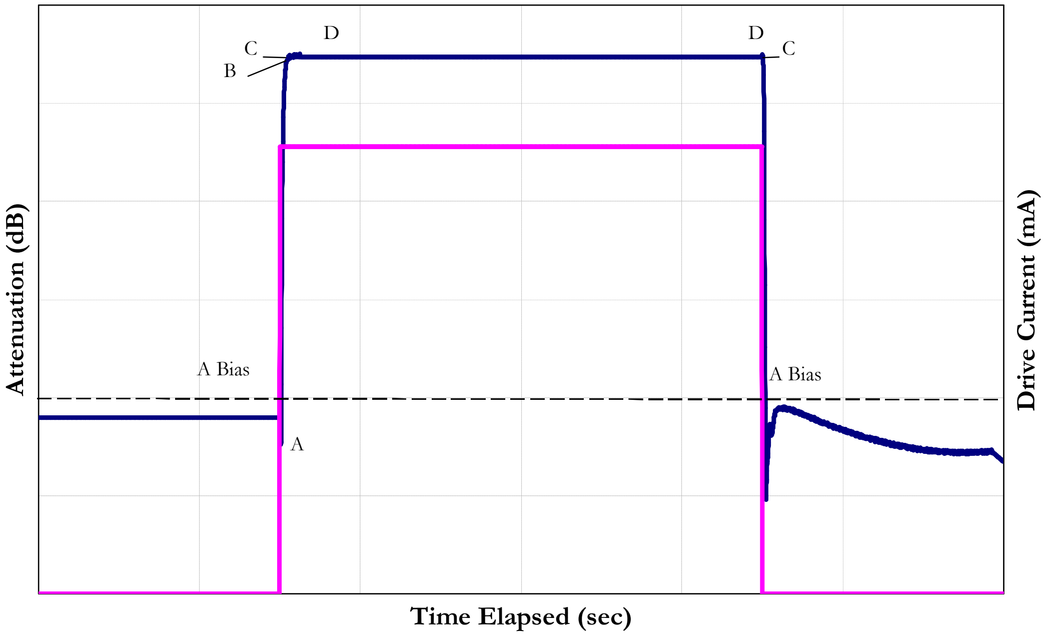
Switching times

The switch on time is defined as the time taken to reach minimum insertion loss when applying current from 0mA to maximum drive current under worst case wavelength and ambient temperature conditions.

Switch on time can be improved by biasing the device at the attenuation maximum.

Switch off time is defined as the time taken to reach and maintain attenuation equal to, or greater than, the specified isolation from the 'on' condition under worst case wavelength and ambient temperature conditions.

Figure 6 shows the switching and the effect on times for alternative definitions.



Switching On (-10?C)

A to A Bias = 300ms
A Bias to B= 300ms
B to C = 150ms
C to D =250ms
A to D = 1000ms

Switching Off (70?C)

D to C = 300ms
C to A Bias= 450ms
D to A Bias = 750ms

A - is the attenuation when no current is applied to the heater. (>40dB)
A Bias - is the attenuation of the switch under bias (40dB)
B =3dB, C= 1dB D= 0.5dB

Figure 6: On-off switching time definition and typical values for Phoenix shutter.

VOA operation and specification

The VOA is a continuously variable device operating on the slope between minimum insertion loss and maximum attenuation.

Stability is a critical issue for these devices and under constant, temperature, wavelength and input SOP (state of polarization), the VOAs are very stable and repeatable. However variation of any of the mentioned parameters causes fluctuations in attenuation. Therefore the VOA requires a feedback control system to operate effectively. Figure 7 shows one option for constant output power control.

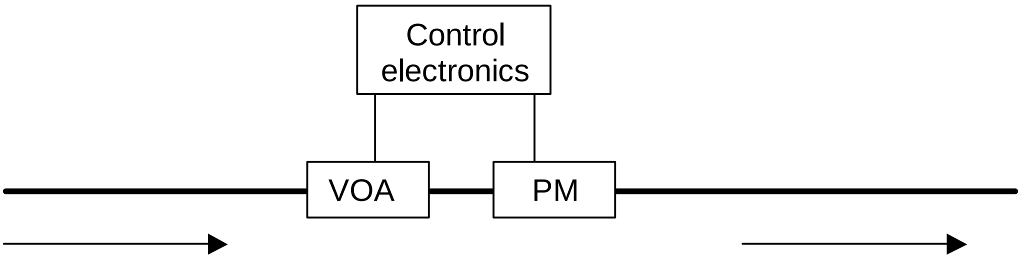


Figure 7: VOA control using an in-line power monitor to maintain constant output power

The power monitor (see tech brief #4) detects the power in the fiber at the VOA output to provide a control signal for the VOA drive current. Any variations in power output from the VOA will be corrected within the performance characteristics of the selected power monitor. This approach removes power fluctuation created by the entire optical circuit prior to the power monitor.

These VOA's can be calibrated to operate at any wavelength for which the fiber is single mode. The VOAs operate over a single wavelength or group of close wavelength channels.

Integration

The VOAs and shutters are among the range of Phoenix components which can be integrated to provide multi-functional and multi-channel modules in a compact footprint.

Multimode and polarization maintaining fiber devices

The evanescent field technology enables most fiber types to be used.

Multimode fiber VOAs and shutters operate over a very wide range of wavelengths and can be made with graded index and step index fibers.

Polarization maintaining fiber VOAs and shutters provide the option to incorporate power control in a polarization maintaining system.

Alternative wavelengths and high power operation

The manufacturing process is applicable to other silica fiber types, and shorter wavelength devices can be fabricated offering similar performance characteristics.

The principle of operation is to modify the cladding material to alter from guiding to non-guiding condition, therefore there are no in-line attenuators to absorb power. In the non-guiding condition the power is coupled to radiation modes and the energy dissipated in the packaging and not the optical materials. With correct packaging design this technique can be used for high power fiber operation without damage to the optical elements.