Measurement of the temperature dependence of the common fiber-optic components

Russian Quantum Center

Tiurnikov Alexey

1. Annotation

Purpose of the work:

In general, the goal of the work is the analysis of impact of environmental conditions (temperature) on QKD security.

In order to achieve these goals, it is necessary to measure the impact of temperature on beamsplitters, isolators and circulators.

The work uses:

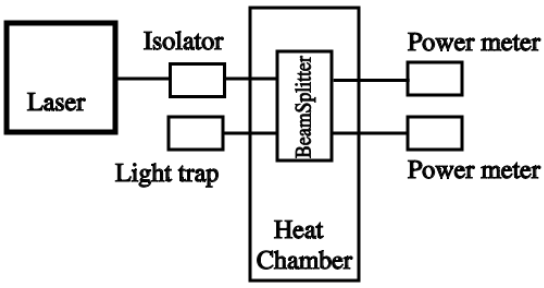
Heat Chamber (Binder MK53),
Laser 14 DFB,
Laser diode controller (CLD1015 ThorLabs),
Fiber isolator (ThorLabs IO-H-1550APC ThorLabs)
Optical Power Meter (ThorLabs S154C),
Optical Power Meter (ThorLabs S155C),

Samples:

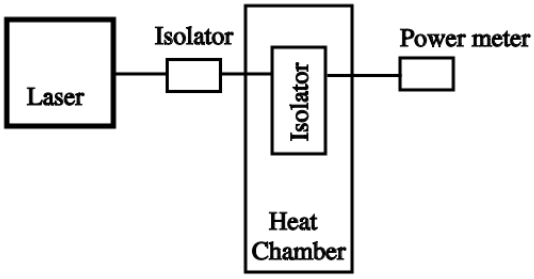
Beamsplitter 99/1 (ThorLabs TW1550R1A2),
Beamsplitter 90/10 (ThorLabs TW1550R2A2),
2 unknown beamsplitters 90/10,
Russian beamsplitter 90/10,
Fiber isolator (ThorLabs IO-H-1550APC),
Circulator (AC Photonics)

2. Experimental Setup

The laser operates at a wavelength of 1550 nm. The isolator in the circuit is necessary to protect the laser diode from the reflected emission. Also, the light trap on the 2nd input channel of the splitter avoids the situation of accidental eye contact with the reflected emission.



Scheme of experimental setup for beamsplitters



Scheme of experimental setup for isolators

3. Measurement results and data processing

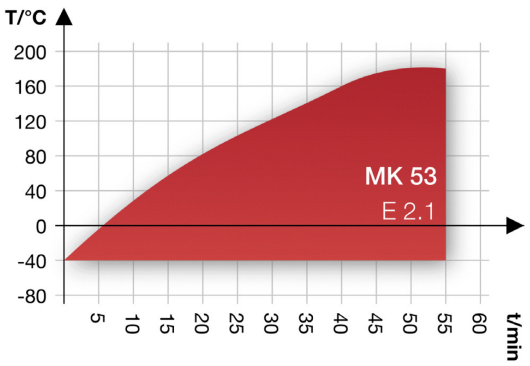
During the operation, the temperature of the heat chamber varied from -30 to +120 degrees Celsius. The Binder MK53 heat chamber can be programmed. The following program was used during the work:

time, minutes	00:00 - 20:00	20:00 - 40:00	40:00 - 60:00	60:00-80:00	80:00-100:00	100:00 - 120:00
set temperature, degrees	-30	-20	0	40	80	120

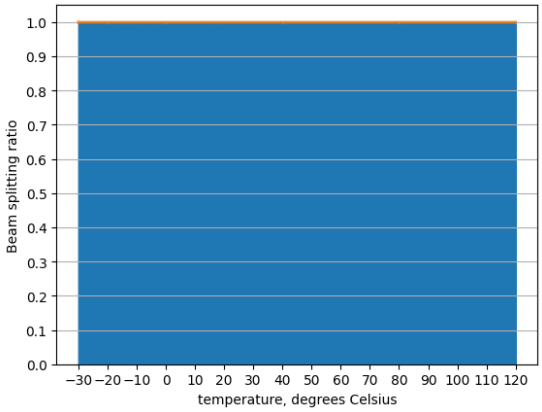
Accordingly, the change in temperature was as follows: The sample is immersed inside, the heat chamber is turned on, cooled from room temperature to -30 degrees Celsius in ~10 minutes, then maintains the set temperature of -30 degrees Celsius for ~10 minutes, then switches to the next step. Because of this, we used the following approximation: cooling/heating to the set temperature occurs in 10 minutes, after that the set temperature is maintained for another 10 minutes. We also used the approximation that the temperature varies locally linearly, that is, we can consider that from 40 to 80 degrees Celsius the temperature varies linearly, also from 80 to 120 degrees Celsius the temperature varies linearly, but with a different slope coefficient.

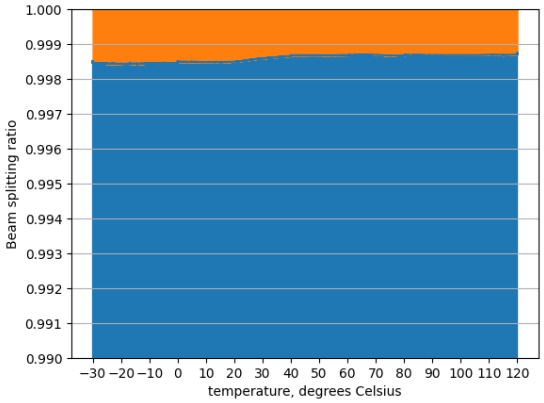
Beam splitters operating parameters are in the range from -40 to +70 degrees (for different models). The power is injected into the samples is 15.13 mW, obtained during the calibration of the setup.

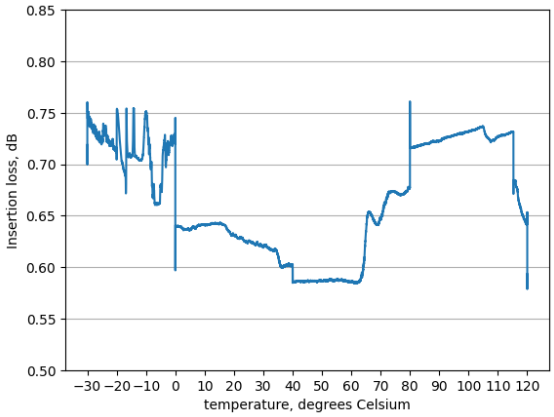
Heating-up times MK 53:



3.1. ThorLabs TW1550R1A2 (99/1)

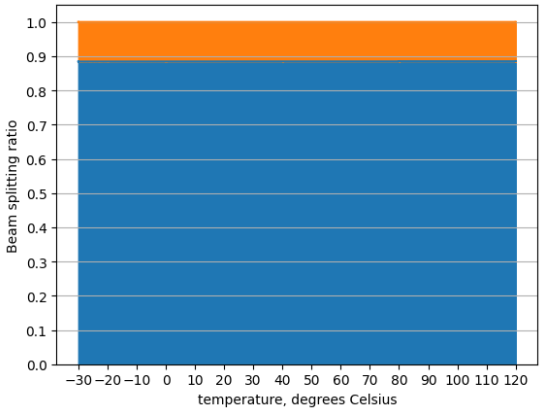


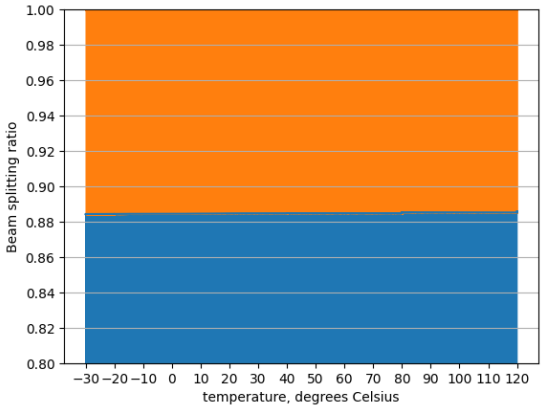


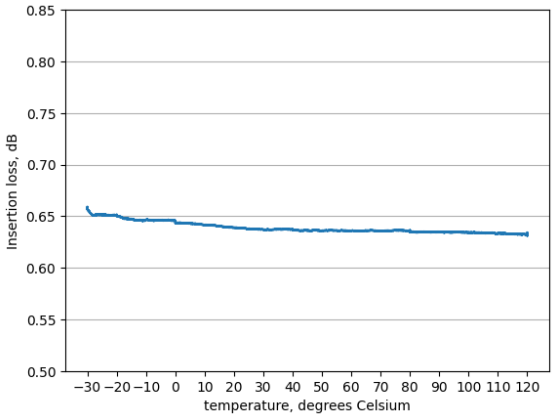


No dependence of the beam splitting ratio on temperature was observed in this measurement.

3.2. First unknown beamsplitter 90/10

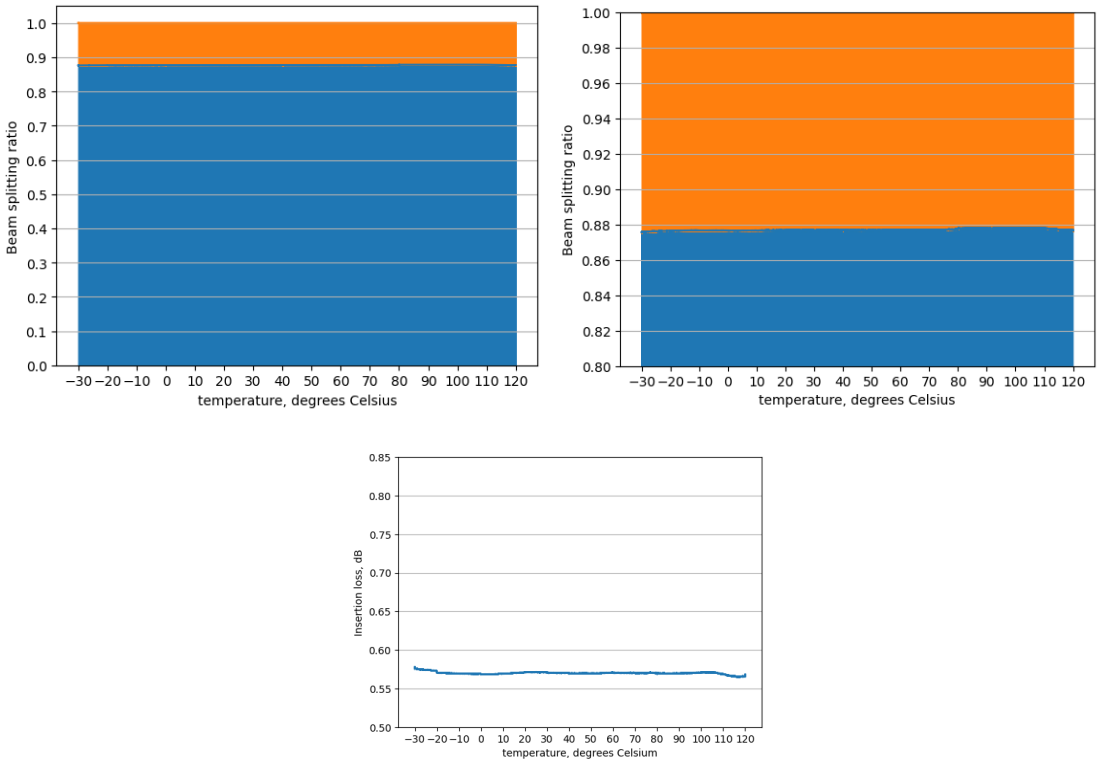






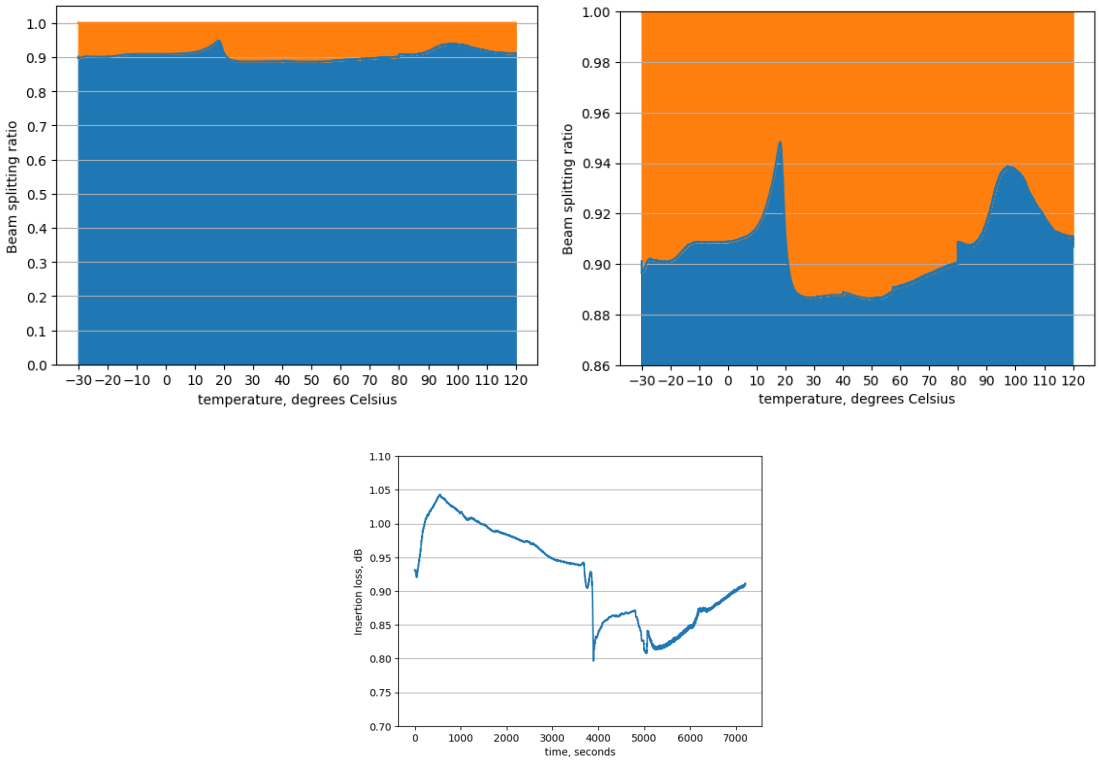
No dependence of the beam splitting ratio on temperature was observed in this measurement.

3.3. Second unknown beamsplitter 90/10



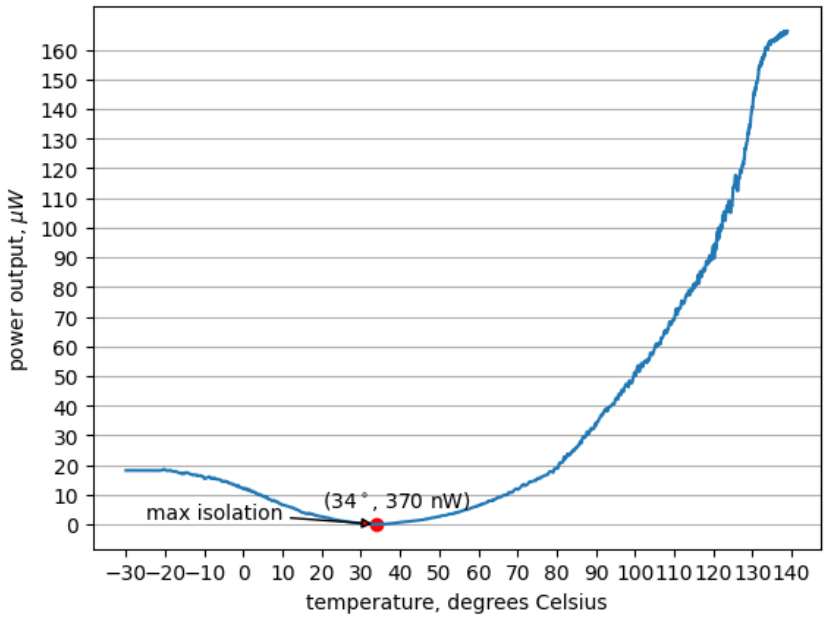
No dependence of the beam splitting ratio on temperature was observed in this measurement.

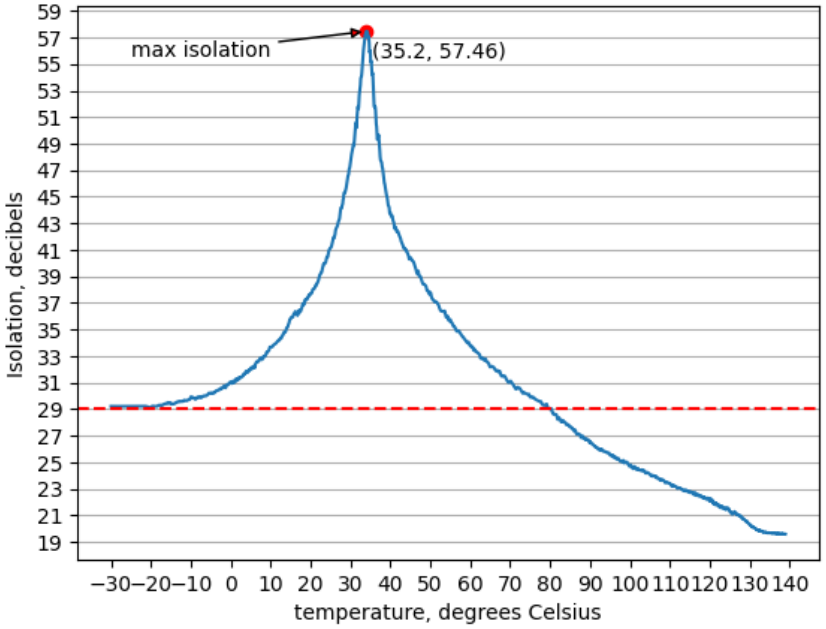
3.4. Russian unknown beamsplitter 90/10



This sample is a little different. It is worth noting that between -10 and +10 degrees Celsius there is a step that turns this beam splitter from 90/10 to 91/9, which is a significant and stable change. Also near a temperature of 25 degrees Celsius, a peak is observed, the nature of which is unknown. At temperatures above 80 degrees Celsius, which is clearly beyond the use temperature (most of the measured samples have a use temperature of -40 to +85 degrees Celsius), a change in beam splitting ratio is observed.
From the insertion loss plots, the situation is also different. The insertion loss in ThorLabs samples is at the level of 0.5-0.6 dB. In this sample the losses are about 0.8-1.0 dB. Also the plot behaves ”strangely”, the reason is unknown.

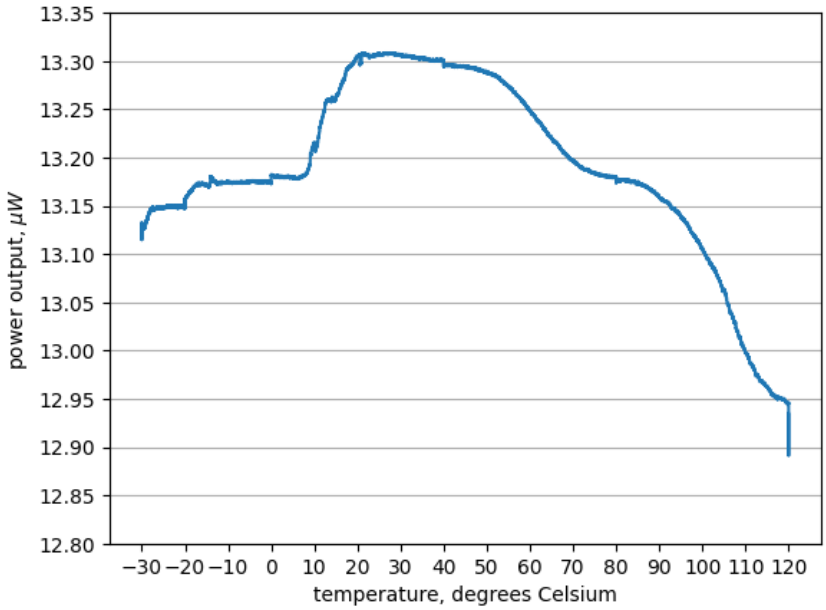
3.5. ThorLabs IO-H-1550APC (backward)

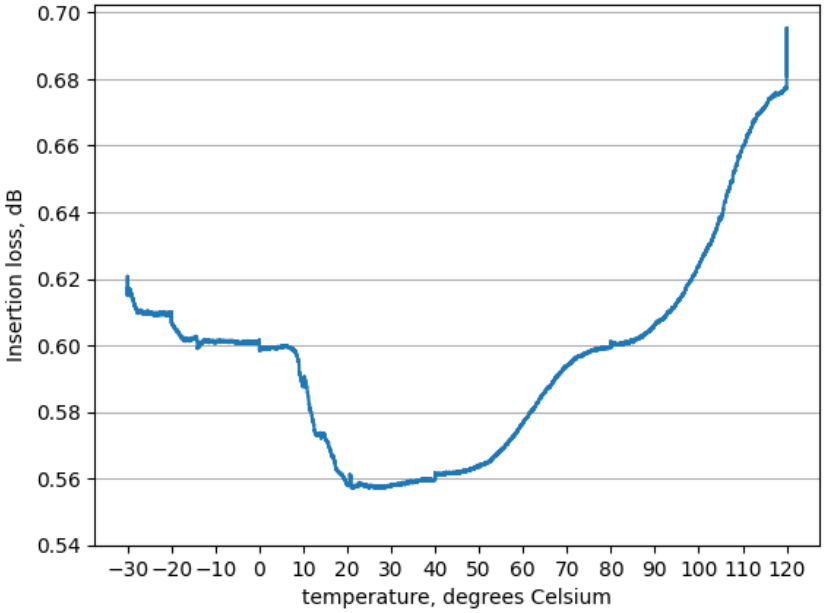




The ThorLabs isolator was involved in this measurement, it was plugged into the setup in backward direction to study its isolation. In order to get a better plot, 1 measurement was performed with non-stop heating from -30 to +140 degrees Celsius. From the plot it can be seen that there is an inverse dependence on temperature. The peak of values is at temperatures just above room temperature - about 35 degrees Celsius. The red line indicates the value of minimum insulation from the specification. ThorLabs claim that the insulation value will not be lower than this at temperatures from -40 to +85 degrees Celsius, which agrees with the results obtained. At higher temperatures (80-140 degrees Celsius) the dependence remains the same.

3.6. ThorLabs IO-H-1550APC (forward)

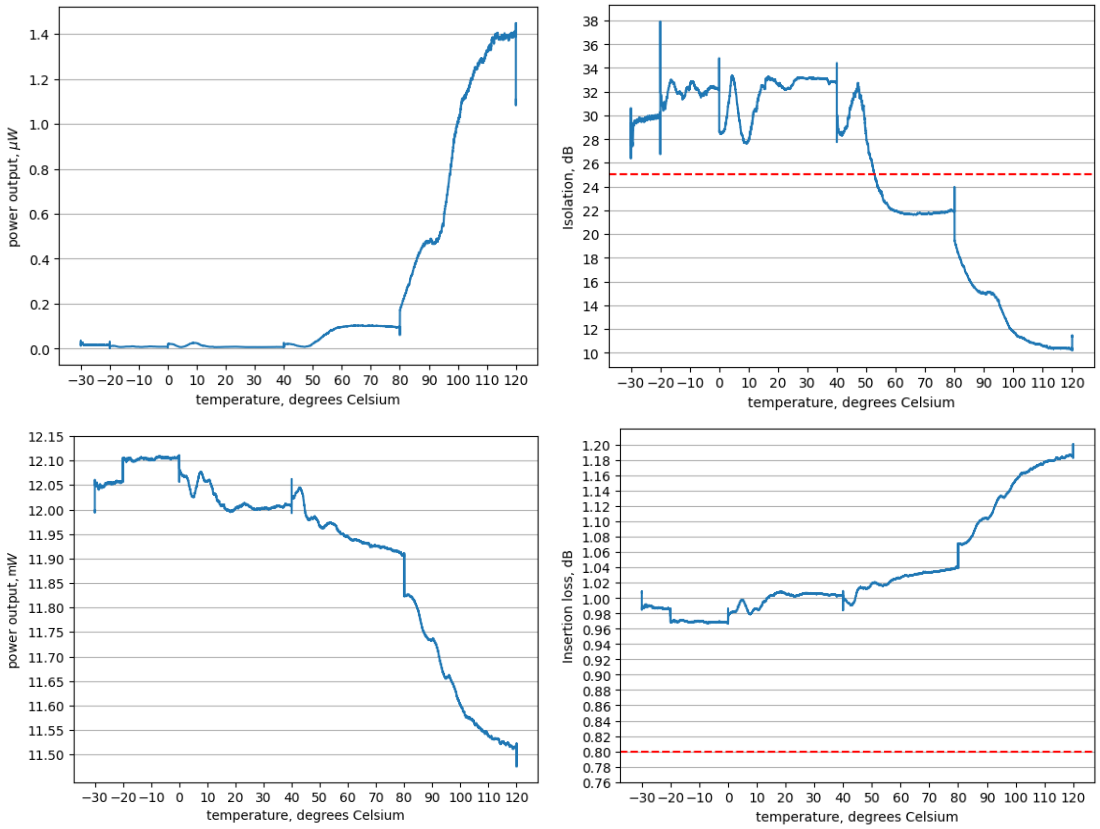




In this measurement, the isolator was placed in the forward direction and the power at the output after it was measured. The temperature dependence is also noticeable here, but less significant.

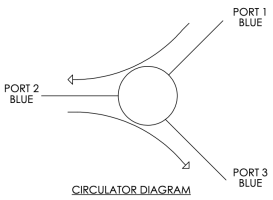
3.7. AC Photonics circulator

The top two graphs are for forward direction, the bottom two graphs are for backward direction.



In this measurement, the setup was the same as for the beam splitters, but without the light trap, since the circulator has only 3 outputs. The values were measured from ports 2 → 1 (forward) and 2 → 3 (backward). The installation components and the measurement scheme remained the same. The red line shows the insulation and insertion loss values from the documentation.

The temperature dependence is also present, but it appears beyond the temperature of use (above 80 degrees Celsius). The insertion losses in the circulator are increased, relative to those specified in the documentation, the reason is unknown.



4. Conclusion

In this work, common optical components such as isolators, beam splitters, and circulators were analyzed for changes in their characteristics under the influence of temperature.

In this work it was found that isolators and circulators depend on temperature, beam splitters theoretically also depend on temperature, but all manufacturers except for the Russian one take this into account in production. In isolators the temperature dependence is obvious, with all other components it is not observed. The insertion loss does not increase significantly with temperature.

5. Specifications

TW1550R2A2	
Coupling Ratio[a]	90:10
Coupling Ratio Tolerance	±2.5%
Center Wavelength	1550 nm
Minimum Bandwidth	±100 nm
Insertion Loss[a]	≤0.8 dB / ≤11.5 dB
Excess Loss[a]	<0.15 dB (Typ.)
Uniformity[a]	≤0.6 dB
Polarization-Dependent Loss (PDL)[a]	≤0.15 dB
Optical Return Loss (ORL) / Directivity[a]	≥60 dB

Beamsplitter 90/10

TW1550R1A2	
Coupling Ratio[a]	99:1
Coupling Ratio Tolerance	±0.6%
Center Wavelength	1550 nm
Minimum Bandwidth	±100 nm
Insertion Loss[a]	≤0.3 dB / ≤24.2 dB
Excess Loss[a]	<0.15 dB (Typ.)
Uniformity[a]	≤0.8 dB
Polarization-Dependent Loss (PDL)[a]	≤0.15 dB
Optical Return Loss (ORL) / Directivity[a]	≥60 dB

Beamsplitter 99/1

Parameter	Sym.	Condition	Min	Max	Unit
Storage Temperature	T_{STG}		-40	+85	°C
Operating Case Temperature	T_{OP}		-20	+70	°C
Laser Forward Current	I_F			350	mA@40-63mW
				500	mA@80-100mW
Laser Reverse Voltage	V_R			2	V
Photo Diode Photo Current	I_{PD}			10	mA
Photo Diode Reverse Voltage	V_{PD}			20	V
TEC Current	I_{TEC}			4	A
TEC Voltage	V_{TEC}			4	V
Thermistor Current				2	mA
Thermistor Voltage				5	V
Lead Soldering Time				10	s
Lead Soldering Temperature				250	°C
ESD		HBM		500	V

14 DFB Laser

ISOLATOR SPECIFICATIONS	
OPERATING WAVELENGTH	1550±20nm
POWER	≤ 300mW
MINIMUM ISOLATION (@ 25°C)	30dB
TYPICAL INSERTION LOSS (@ 25°C)*	≥ 0.5dB
MAXIMUM INSERTION LOSS 0~70°C	≤ 0.50dB
PDL (@ 23°C)	< 0.1dB
RETURN LOSS (INPUT/OUTPUT)	≥ 60/50dB
OPERATING TEMPERATURE (°C)	0 ~+70
STORAGE TEMPERATURE (°C)	-40 ~+85

Fiber isolator IO-H-1550APC ThorLabs,

Item #[a]	S154C	S155C
Sensor Image (Click the Image to Enlarge)		
Wavelength Range	800 - 1700 nm	
Power Range	100 pW to 3 mW (-70 dBm to +5 dBm)	1 nW to 20 mW (-60 dBm to +13 dBm)
Detector Type	InGaAs Photodiode	
Linearity	±0.5%	
Resolution[b]	10 pW (-80 dBm)	100 pW (-70 dBm)
Measurement Uncertainty[c]	±5%	

Fiber Photodiode Power Sensors S154C and S155C

Parameter	Unit	Specifications	
Number of Ports		3	
Operating Wavelength	nm	1550	
Configuration		P1 – P2, P2 – P3	
Typical Peak Isolation	dB	40	
Minimum Isolation	dB	≥25	≥25
Insertion Loss	dB	Typ.: 0.6 Max.: ≤0.8	Typ.: 0.8 Max.: ≤1.0

AC Photonics Polarization Maintaining Optical Circulator