IEC TR 62343-6-9

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TECHNICAL REPORT

colour inside

Dynamic modules –
Part 6-9: Design guide – Study of mechanisms and measurements of crosstalk in wavelength-selective switches

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 62343-6-9, which is a Technical Report, has been prepared by subcommittee SC86C: Fibre optic systems and active devices, of IEC technical committee TC 86: Fibre optics.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
86C/1300/DTR	86C/1321/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62343 series, published under the general title *Dynamic modules*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

A dense wavelength division multiplexing (DWDM) system for fibre optic communication was developed in the late 1990's. The first generation DWDM systems were point-to-point optical networks. In the mid-2000's, second generation DWDM systems, typically ring networks, were developed. One of the key optical components for DWDM systems is a wavelength division multiplexing device. An AWG (arrayed waveguide grating) module has been mainly deployed for first and second generation DWDM systems.

Due to the increasing demand for communication capacity, more flexible optical communication systems, such as mesh networks, have been required. In the past several years, the third generation of DWDM systems, the optical cross-connect system, has been developed and deployed by some communication network carriers and is expected to be deployed worldwide. A wavelength-selective switch (WSS) module plays a key role in realizing the optical switch function in the optical cross-connect system, so that the performance of the WSS directly impacts on the performance of the optical cross-connect systems, such as the capacity, transmission distance, etc.

For AWG modules, only static performance, such as insertion loss, bandwidth, pass-band ripple, polarization dependent loss (PDL), polarization mode dispersion (PMD), coherent crosstalk, etc., has been evaluated. In addition to static performance, dynamic performance during switching or changing attenuation should be taken into consideration for the WSS as a key module of optical cross-connect systems.

For dynamic performance parameters, the influence not only on the controlled channel but also on other channels should be considered.

Considering this background, the influence of WSS dynamic crosstalk on cross-connect system performance and the measurements of dynamic crosstalk has been demonstrated.

This Technical Report is based on Optoelectronic Industry and Technology Development Association (OITDA) – Technical Paper (TP), TP15/TP-2013, "Dynamic crosstalk measurement for wavelength selective switches".

DYNAMIC MODULES –

Part 6-9: Design guide – Study of mechanisms and measurements of crosstalk in wavelength-selective switches

1 Scope

This part of IEC 62343, which is a Technical Report, describes a study of the impact of WSS dynamic crosstalk on the optical network and includes dynamic crosstalk measurement examples for three types of WSS. The generating mechanism and the generation factor of dynamic crosstalk in WSS are clarified, and the evaluation of same-channel crosstalk and different-channel crosstalk is shown to be necessary.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61300-3-21, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-21: Examinations and measurements – Switching time*

IEC 61300-3-29, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-29: Examinations and measurements – Spectral transfer characteristics of DWDM devices*

3 Abbreviations

ADD	add port
AWG	arrayed waveguide grating
COM	common port
CW	continuous wave
DLP	digital light processor
DRP	drop port
DUT	device under test
DWDM	dense wavelength division multiplexing
EXP	express port
LCOS	liquid crystal on silicon
MEMS	micro electro mechanical system
OE	optical-to-electrical
PDL	polarization dependent loss
PMD	polarization mode dispersion
TLS	tuneable laser source
Tx	transmitter
Rx	receiver
WSS	wavelength selective switch

4 Study of dynamic crosstalk for WSS

4.1 Static crosstalk and dynamic crosstalk

WSSs can be considered as the combination of optical spatial switches, variable optical attenuators, and DWDM devices such as AWG modules. For the WSS, dynamic crosstalk, which is the interference between ports and channels during switching and changing attenuation, is generated in addition to static crosstalk.

Static crosstalk has been studied, and the definition and standard measurement methods for WDM devices such as AWG modules have been established. In addition to static crosstalk, dynamic crosstalk for WSSs has to be considered because WSSs vary attenuation and switch ports during operation.

Two types of dynamic crosstalk are considered in this Technical Report: same-channel crosstalk (coherent crosstalk), and different-channel crosstalk (power crosstalk). In this sense, the word of channel refers to the signal at a particular wavelength.

The impact on signal quality of same-channel crosstalk to cross-connect systems is considered to be larger than that of different-channel crosstalk, which may be negligible.

The classification of dynamic crosstalk and static crosstalk and that of same-channel crosstalk and different-channel crosstalk are independent. Therefore, four combinations (dynamic-same-channel crosstalk, dynamic-different-channel crosstalk, static-same-channel crosstalk, and static-different-channel crosstalk) have to be considered.

Table 1 and Table 2 show the features of static and dynamic crosstalk and same-channel and different-channel crosstalk, respectively.

Table 1 – Static crosstalk and dynamic crosstalk

Crosstalk	Description
Static crosstalk	Crosstalk generated during static state, that is without switching ports or changing attenuations
Dynamic crosstalk	Crosstalk generated during dynamic state, such as switching ports and changing attenuations

Table 2 – Same-channel crosstalk and different-channel crosstalk

Crosstalk	Description
Same-channel crosstalk	Crosstalk between same channels. The impact to the cross-connect systems is larger than that of different-channel crosstalk.
Different-channel crosstalk	Crosstalk between different channels. The impact to the cross-connect systems is smaller than that of same-channel crosstalk.

4.2 Generation mechanism of dynamic crosstalk

4.2.1 Configuration example of optical switching functionality

Figure 1 shows an example block diagram of optical switching functionality in optical mesh networks. This node is known as a route and select topology, since incoming data are first routed by the ingress WSS to its correct optical path, where an egress WSS selects the correct data from all its input ports before multiplexing and passing into the transmission fibre. This example configuration of a switching functionality is composed of four WSSs. Using multichannel WSSs, the number of switching optical ports can be increased and can realize cross-connect systems having many paths. Each WSS is connected to each transmission line through WDM IN and WDM OUT ports, and the number of WSS pairs is equal to the number of transmission paths.

Data in the form of DWDM signals are applied to the switching node from the ingress transmission line (transmission fibre) via the WDM IN port into the ingress WSS. This WSS demultiplexes and routes the incoming channels to the correct ongoing path. Some channels are transmitted directly through the switching node so that they pass from the EXP OUT port of the ingress WSS to the EXP IN port of the egress WSS that is associated with the required WDM OUT port. Data that is to be switched out of the transmission fibre within the node are dropped out through the DRP OUT port of the ingress WSS into the associated optical receiver, Rx. Replacement data are then added into the egress WSS from the optical transmitter, Tx, via the add port ADD IN. This added data are subsequently multiplexed with other channels in the egress WSS and then passed into the transmission line via the WDM OUT port.

For the purpose of switching paths, the WSS is controlled to change routing paths and attenuation of any path, if necessary. Dynamic crosstalk is generated in the process.

Multiplexers and demultiplexers can also be composed of optical couplers or splitters rather than WSSs.

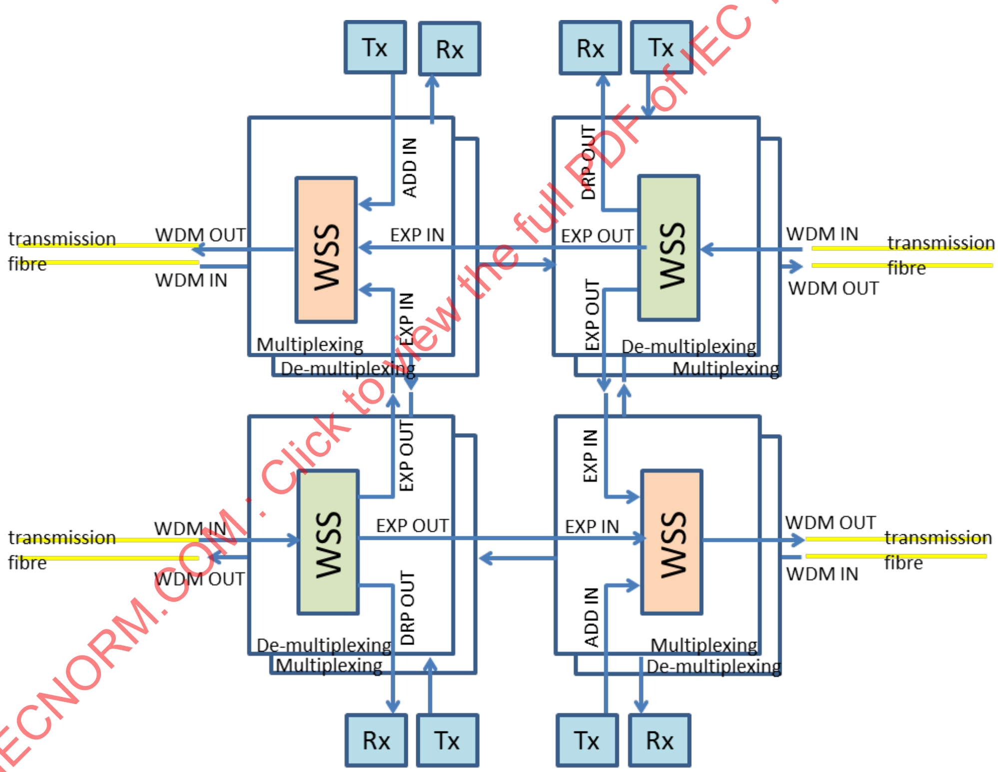

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Figure 1 – Block diagram of optical switching function

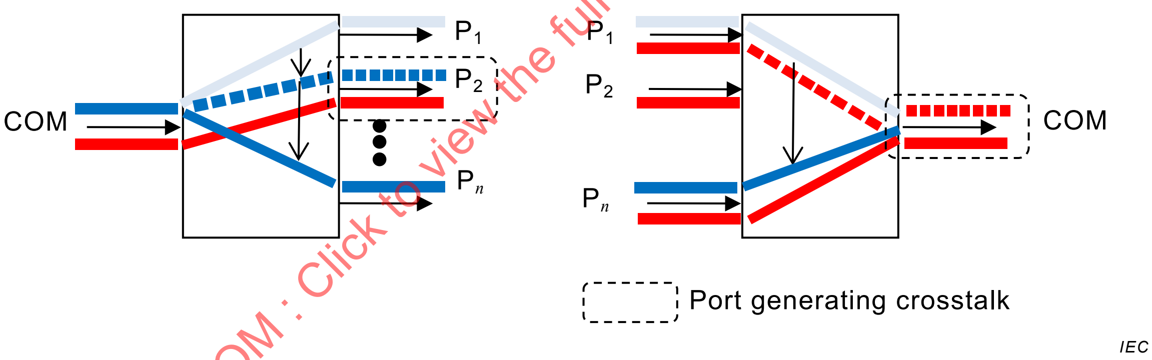
4.2.2 Generation mechanism

Table 3 summarizes the generation mechanisms of same-channel and different-channel crosstalk.

Figure 2 shows the port that generates dynamic crosstalk for WSS in multiplexing and demultiplexing functions, where COM shows the common port where the multiplexed signals are input or output, and P_1 to P_n shows the branching ports where demultiplexed signals are input or output. Figure 2a) shows the generating mechanism of different-channel crosstalk in port 2, when switching from port 1 (P_1) to port n for a demultiplexing WSS. Figure 2b) shows the generating mechanism of same-channel crosstalk. Figure 3 shows the generating mechanism of same-channel crosstalk in a multiplexer composed of an optical coupler. Figure 4 shows the generating mechanism of different-channel crosstalk in the WSS in the de-multiplexer and Rx.

Table 3 – Generating mechanism of same-channel crosstalk and different-channel crosstalk

Crosstalk	Generating WSS	Generating mechanism
Same-channel crosstalk	WSS for multiplexing	In Figure 2b), same-channel crosstalk is generated for the red channel at the COM port of the multiplexing WSS when switching port 1 (P_1) to port n (P_n) for the blue channel. In Figure 3, same-channel crosstalk is generated at the COM port of the optical coupler used for multiplexing. When a WSS is used instead, same-channel crosstalk can be minimized.
Different-channel crosstalk	WSS for demultiplexing	In Figure 2a), different-channel crosstalk is generated between the dashed blue channel and the red channel at port 2 in the demultiplexing WSS when switching port 1 (P_1) to port n (P_n). In Figure 4, different-channel crosstalk is generated between the dashed blue channel and the red channel at the second Rx, which is connected to port 2 (P_2) of the demultiplexing WSS. In the case of direct signal detection, the different-channel crosstalk influences the performance of the Rx. However, there is no influence for coherent signal detection systems.



a) WSS for demultiplexing b) WSS for multiplexing

Figure 2 – Dynamic crosstalk at WSS

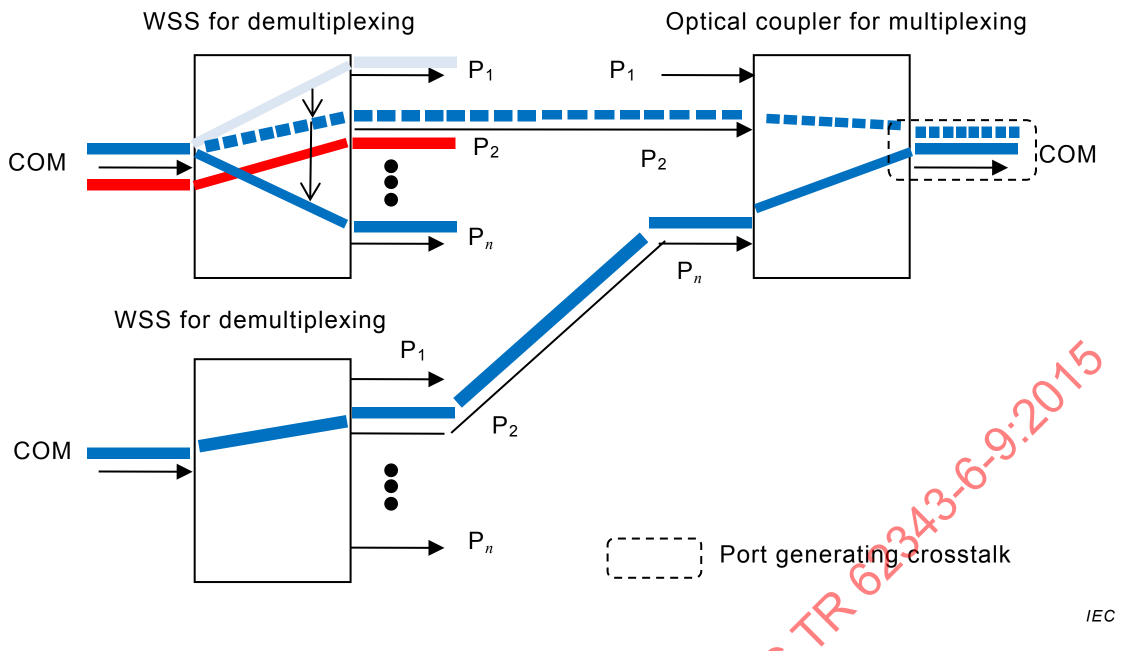


Figure 3 – Dynamic crosstalk at optical coupler for multiplexing

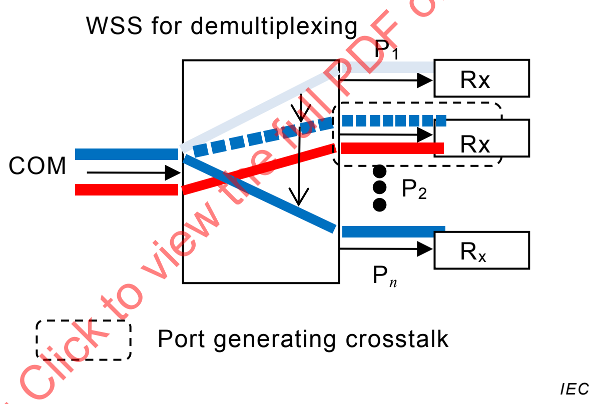


Figure 4 – Dynamic crosstalk at receiver (Rx)

5 Measurement methods of dynamic crosstalk

5.1 Study of measurement methods of dynamic crosstalk

5.1.1 Referenced standard documents

The following standards were referred to when the measurement methods of dynamic crosstalk for WSSs were examined. WSSs can be considered as a combination of optical spatial switches, variable optical attenuators and DWDM devices such as AWG (array waveguide grating) modules, so the method in IEC 61300-3-29 of measuring the transfer function of DWDM devices is referenced, as well as the method in IEC 61300-3-21 for the switching time and bounce time of optical switches. IEC 61300-3-50 for measuring the crosstalk of optical spatial switches relates to static crosstalk and does not apply to the current work.

Based on the measurement configurations described in IEC 61300-3-21 and IEC 61300-3-29, two measurement methods have been examined: a method using a tuneable laser source with an optical power meter and a method using a tuneable laser source with an optical-to-electrical (OE) converter and an oscilloscope.

5.1.2 Test configuration of tuneable laser source (TLS) and optical power meter

Figure 5 shows the typical example of this test configuration. The light of wavelength λ is input to the common port of the WSS from the tuneable laser, and the output optical power from each branching port (port 1 to n) is monitored simultaneously and continuously with a multiport optical power meter. Optical power variations are recorded while executing port switching of the WSS.

The wavelength range of the tuneable laser should cover the operating wavelength range of the WSS. The optical power meter(s) should have as many input channels as the number of WSS branching ports and be able to measure and record the power synchronously and continuously on all channels. The response time and sampling rate of the power meter should be sufficient to detect events much shorter than the switching time of the device under test, and the dynamic range during continuous measurement shall be sufficient to accurately detect the maximum acceptable level of transient crosstalk power.

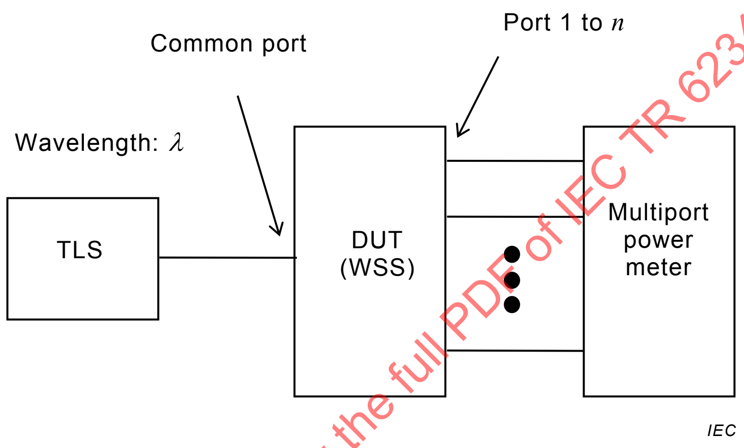


Figure 5 – Test configuration of tuneable laser source (TLS) and optical power meter

5.1.3 Test configuration of tuneable laser source, OE converter and oscilloscope

Figure 6 shows a typical example of this test configuration. The light of wavelength λ is input to the common port of the WSS from the tuneable laser, and the output optical power from each branching port (port 1 to n) is converted to an electrical signal by the OE converter and monitored simultaneously and continuously with the oscilloscope. Voltage variations are recorded while executing port switching of the WSS.

The wavelength range of the tuneable laser should cover the operating wavelength range of the WSS. The oscilloscope(s) should have as many input channels as the number of WSS branching ports and be able to measure and record the voltage synchronously and continuously on all channels. The dynamic range of the OE converter and oscilloscope shall be sufficient to detect the maximum acceptable level of transient crosstalk.

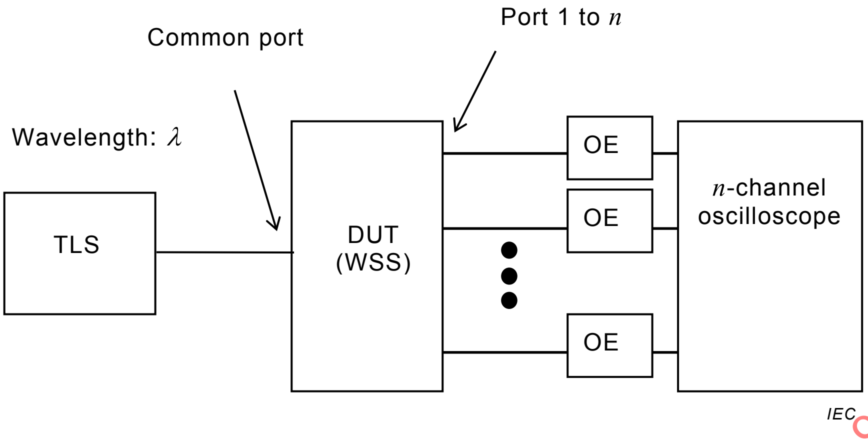


Figure 6 – Test configuration of tuneable laser source and oscilloscope

5.1.4 Comparison of the measurement methods

Because the WSS port count is often high, for example a 1 × 9, the generally available 4-channel oscilloscope may not be sufficient for these tests. Moreover, it requires careful selection to design the OE-converter and scope combination to achieve sufficient dynamic range and low polarization dependency. Recently, multiple port optical power meters have been available with fast sampling, for example 10 µs averaging time and 60 dB wide dynamic range, during continuous logging. This method of combining such an optical power meter and the tuneable laser is attractive.

5.2 Evaluation of the measurement methods

In order to confirm the availability of the measurement methods for dynamic crosstalk as described in 5.1.2, different-channel crosstalk and same-channel crosstalk were measured on WSS samples with three different operation principles. The following WSS were used in this test:

– Micro electro mechanical system (MEMS) type 1 × 9 WSS (100 GHz spacing)
– Liquid crystal on silicon (LCOS) type 1 × 4 WSS (flexible grid)
– Digital light processor (DLP) type 1 × 2 WSS (50 GHz spacing)

Figure 7 shows a photograph of the experimental set-up. This consists of a tuneable laser, an 8-channel optical power meter and control software. When the measurement is executed, the optical power meter is continuously monitored at all input ports synchronously. The update of the measuring data is stopped by the software when a power change of 20 dB or more (arbitrary setting) is observed on any port, and the data for the event is saved. Moreover, the WSS is operated on an evaluation board with control software. The main measurement specification is the following:

– Wavelength window: C band and L band
– Number of measurement channels: 8 channels (maximum 100 channels)
– Power meter averaging time: 1 µs minimum
– Measurement dynamic range: > 60 dB depending on the averaging time

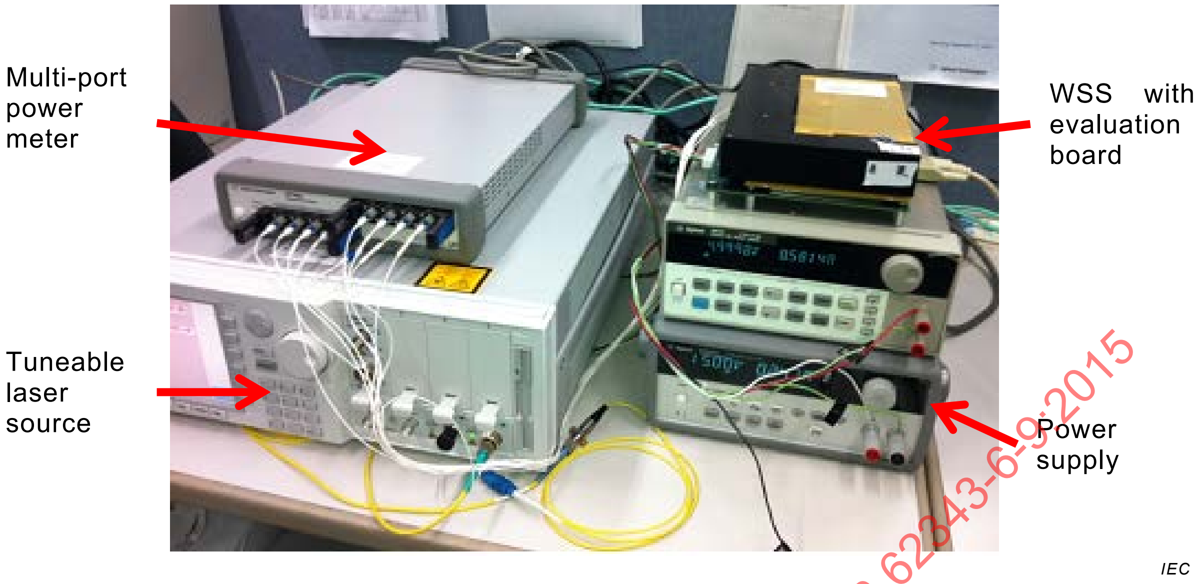


Figure 7 – Experimental set-up

6 Measurement result of dynamic crosstalk

6.1 MEMS type WSS

6.1.1 Measurement conditions

The following measurement conditions were used:

– WSS: MEMS type 1 × 9 WSS (100 GHz spacing)
– Test frequency: f_1 = 193,4 THz (1 550,116 nm) and f_2 = 193,3 THz (1 550, 918 nm)
– Measured ports: port 1 to port 8
– Power meter averaging time: 25 μs
– Number of acquisition points for optical power meter: 10 000 points (25 ms × 10 000 = 2,5 s)

6.1.2 Measurement of different-channel crosstalk

As shown in Figure 2a), different-channel crosstalk is observed for a demultiplexing WSS. The measurement set-up is shown in Figure 8.

The measurement procedure is as follows:

a) Set the attenuation value to the maximum value for all ports and all channels;
b) Input the CW light of the channel with frequency f_1 (channel f_1, later) from the TLS to the common port, and configure the WSS connecting the common port to port 8 for channel f_1;
c) Switch from port 8 to port 1 for channel f_1. During the switch, measure the output power for port 1 to port 8 continuously and synchronously. The leakage light observed in each port can be considered as different-channel crosstalk.

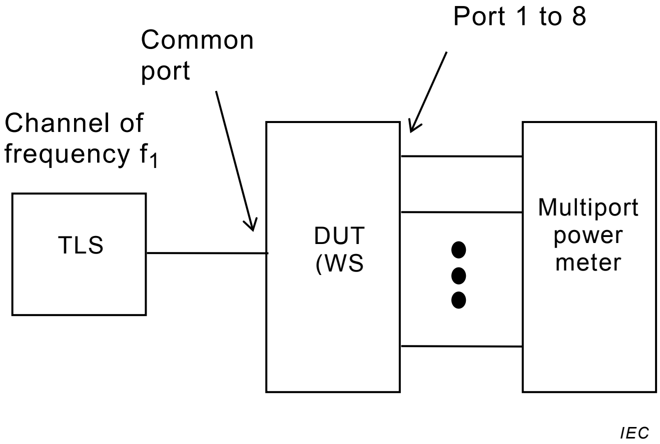


Figure 8 – Measurement set-up of different-channel crosstalk

Figure 9 shows the measurement result of different-channel crosstalk. The X-axis indicates time in units of seconds; the Y-axis indicates the relative optical power level in decibels. Port 1 to port 8 indicate port numbers. Different-channel crosstalk of around 40 dB was generated for all ports.

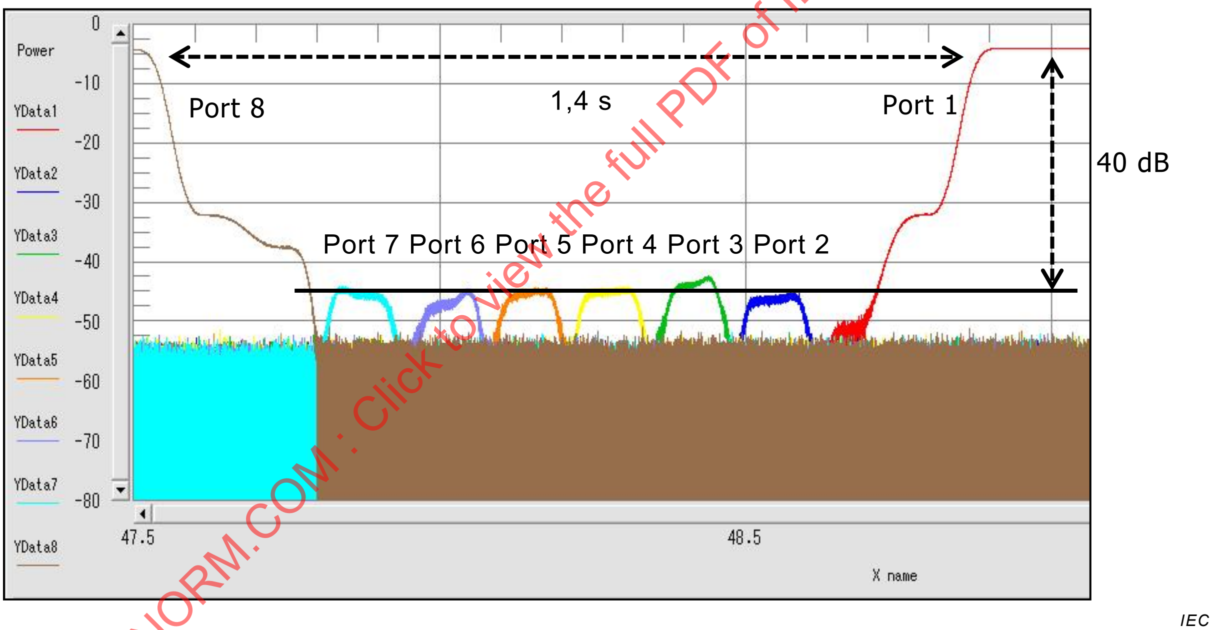


Figure 9 – Measurement result of different-channel crosstalk for MEMS type WSS

6.1.3 Measurement of same-channel crosstalk

As shown in Figure 2b), same-channel crosstalk is generated at the common port for a multiplexing WSS. However, the same measurement set-up as for different-channel crosstalk was used. As a WSS is bidirectional, it is possible to measure same-channel crosstalk.

The measurement procedure of same-channel crosstalk is as follows:

a) Set the attenuation to the maximum value for all ports and all channels;

b) Input the CW light of channel f_1 from the TLS to the common port of the WSS, and set the WSS connecting the common port to port 1 for channel f_1;

c) Switch channel f_2 from port 1 to port 8. During the switch, measure the output power for all ports for channel f_1. The leakage light observed can be considered as same-channel crosstalk, because the light of channel f_2 is not applied.

Figure 10 shows the measurement result of same-channel crosstalk for the MEMS type WSS. X and Y axes indicate the same as in Figure 9. Port 1 to port 8 indicate the same as in Figure 9. For port 1, the influence of switching for channel f_2 was not observed as the power level of port 1 is constant. For port 2 to 8, the influences of switching for channel f_2 were observed. These leakage levels are considered as same-channel crosstalk. When the frequency of channel f_2 was changed to a non-adjacent channel of f_1, the influence for port 2 to port 7 was not observed. Therefore, this same-channel crosstalk is considered to be relating to the adjacent-channel crosstalk performance, and the leakage power level was changed when the switching ports and switching direction were changed. These dependencies of the switching ports and switching direction are due to the internal structure of this WSS.

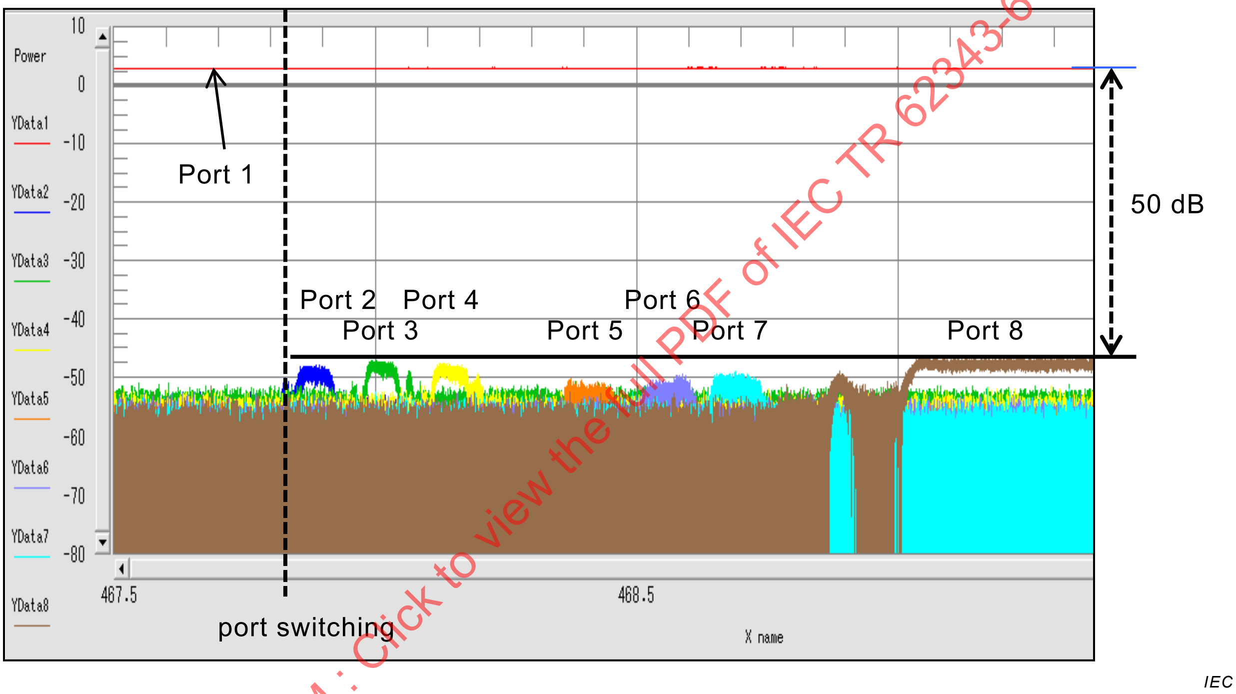


Figure 10 – Measurement result of same-channel crosstalk for MEMS type WSS

6.2 LCOS type WSS

6.2.1 Measurement conditions

The measurement conditions are as follows:

– WSS: LCOS type 1 × 4 WSS (flexible grid)
– Width of the grid of WSS: 100 GHz spacing (set)
– Test frequency: f_1 = 193,4 THz (1 550,116 nm) and f_2 = 193,3 THz (1 550,918 nm)
– Measured ports: port 1 to port 4
– Power meter averaging time: 25 µs
– Number of acquisition points for power meter: 10 000 points (25 µs × 10 000 = 2,5 s)

6.2.2 Measurement of different-channel crosstalk

The measurement procedure is the same as in 5.1.2. The power levels for port 1 to port 4 were measured during switching from port 1 to port 4 for channel f_1.

Figure 11 shows the measurement result of different-channel crosstalk for the LCOS type WSS. X and Y axes indicate the same as in Figure 9 and Figure 10. Port 1 to port 4 indicate port numbers. The switching time from port 1 to port 4 was approximately 0,17 s. During switching, a different-channel crosstalk of around 30 dB for port 2 and around 35 dB for port 3 were observed. The phenomenon of decreasing the leakage power for all ports in the middle of the switching time was not due to the WSS performance but to the control software used.

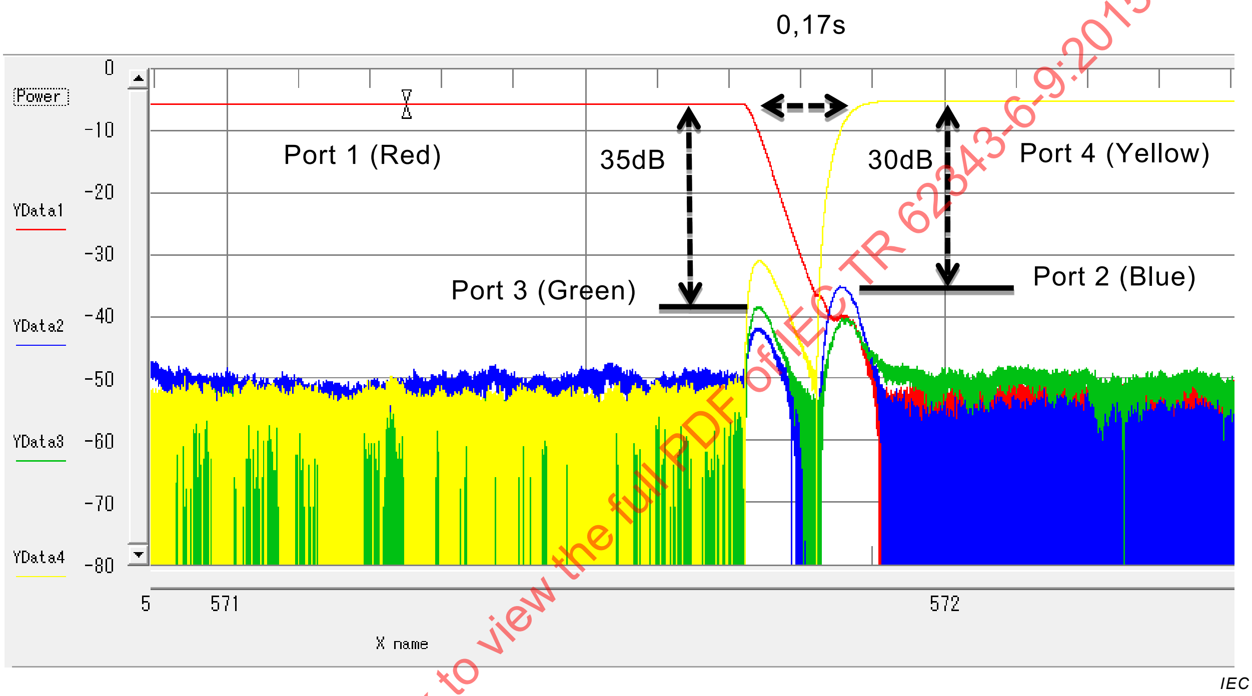


Figure 11 – Measurement result of different-channel crosstalk for LCOS type WSS

6.2.3 Measurement of same-channel crosstalk

The measurement procedure is the same as for the MEMS type WSS. The change of power levels for port 1 to port 4 were observed during switching from port 1 to port 4 for channel f_2.

Figure 12 shows the measurement result of same-channel crosstalk for the LCOS type WSS. The X and Y axes indicate the same as in Figure 9, Figure 10 and Figure 11. Port 1 to port 4 indicate the same as in Figure 11. The influence of switching channel f_2 to port 1 was not observed as the power level of port 1 for channel f_1 was stable. After switching, the power level of noise for port 4 increased. This change is considered as same-channel crosstalk. This phenomenon was observed for the MEMS type WSS and it was considered to be due to adjacent-channel crosstalk. On the other hand, this kind of phenomenon was not observed at port 2 and port 3.

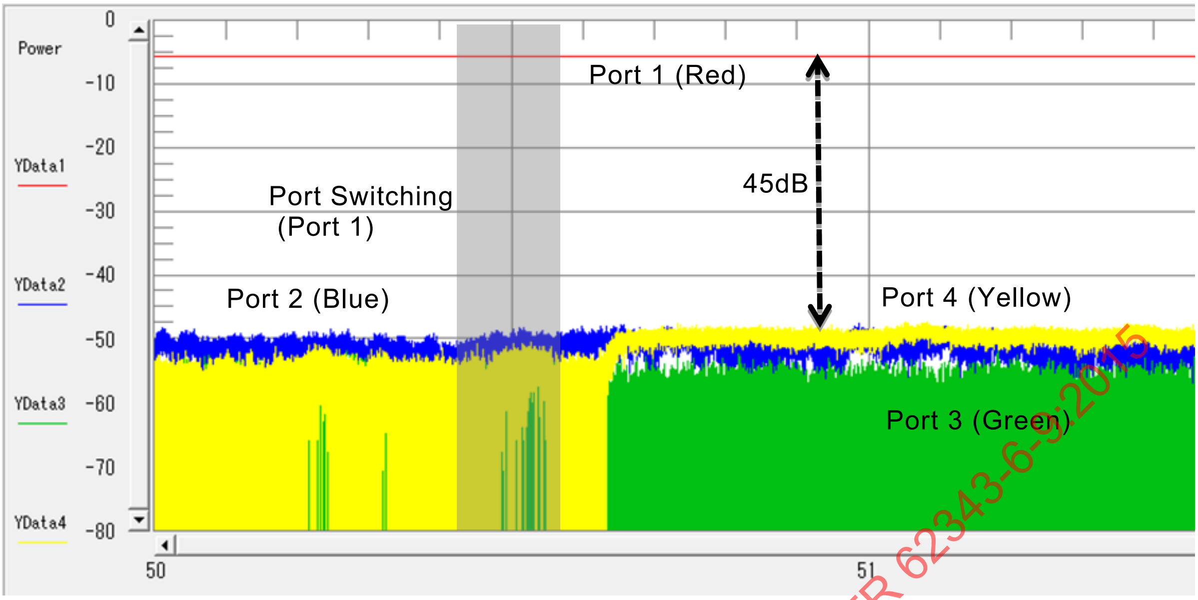


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Figure 12 – Measurement result of same-channel crosstalk for LCOS type WSS

6.3 DLP type WSS

6.3.1 Measurement conditions

The measurement conditions are the following:

– WSS: DLP type 1 × 2 WSS (50 GHz spacing)

– Test frequency: f_1 = 193, 4 THz (1 550,116 nm) and f_0 = 193, 45 THz (1 549,715 nm)

– Measured ports: port 1 and port 2

– Power meter averaging time: 25 µs

– Number of acquisition points for power meter: 10 000 points (25 µs × 10 000 =2,5 s)

As the measured DLP type WSS was 1 × 2, it was impossible to measure different-channel crosstalk and same-channel crosstalk as for the MEMS type and the LCOS type WSS. Therefore the following measurement procedure given in 6.3.2 was carried out.

6.3.2 Measurement procedure and result

6.3.2.1 Switching characteristics of the 1x2 DLP type WSS

The CW light of channel f_1 from TLS was input to the common port of the WSS and the power levels of port 1 and port 2 were observed during switching from port 1 to port 2. The measurement result is shown in Figure 13. X and Y axes are the same as in Figure 9 to Figure 12. The red line shows optical power of port 1 and the blue line shows port 2. The switching time for the DLP type WSS was approximately 0,2 s. The power level (attenuation of WSS) changed gradually compared with other types of WSS.