The Higher Institute of Engineering

El-Shorouk City

Communication and Computer Engineering department

SECOND SEMSTER

Optical Communication - CCE 361

For

Fourth year –Academic year 2021/2022

Contents

- ✓ Experiment 1: Fiber Optic Transmission 4
- ✓ Discussion 4
- ✓ Module specifications 4

Transmitter module 4

Receiver module 5

- ✓ Objectives 5
- ✓ Equipment 5
- ✓ Procedure 6
- ✓ Experiment2: Optical signal filtering, splitting, and combining 12
- ✓ Discussion 12
- ✓ Objectives 13
- ✓ Equipment 14
- ✓ Procedure 14
- ✓ Experiment3: Optical Losses 25
- ✓ Discussion 25
- ✓ Objectives 26
- ✓ Equipment 26
- ✓ Procedure 26
- ✓ Experiment4: Fiber Optic Bi-directional Communication 29
- ✓ Discussion 29
- ✓ Experiment5: Wave Division Multiplexing (WDM) 41

Student Name:	
Section:	
Experiments	Grade:
Exp 1: Fiber Optic Transmission	
Exp 2: Optical signal filtering, splitting, and combining	
Exp 3: Optical Losses	
Exp 4: Fiber Optic Bi-directional Communication	
Exp 5: Wave Division Multiplexing (WDM)	

Experiment 1: Fiber Optic Transmission

Discussion

One of the many advantages of using optical fiber over copper cable for transmitting signals over Long distances is the much Lower levels of Loss involved. This means that fewer repeaters are required which provides for enormous cost and energy.

For commercial fiber optic †transmission systems used in telecommunications, Losses are minimized by using Light in the infra-red region of †he electromagnetic spectrum (at wavelength's between 1300nm and 1700nm) and by using laser light sources. However, as you know, infra-red light is not visible to humans and laser light can readily cause injury †o eyes.

So, to demystifies fiber optic transmission and keep learning about it safe, so red and green visible light are used from light-emitting diodes (LEDs) and standard light sensors to model fiber optic transmission in telecommunications.

Module specifications

Transmitter module

Three optical Transmitter modules can be used to “Load" information onto the fiber optic cables. That is, the Transmitter modules can take analog or digital information in electrical form and convert it to light information that can be relatively efficiently transferred into the core of a plastic optical fiber cable. Two of the Transmitter modules use red LEDs as light sources and the third uses a green LED.

There are †wo important points that must be made about the Transmitter modules analog operation. First, analog signals are bipolar which means that they alternate between positive and negative voltages Like the sinewave on the left in Figure 1. However, LEDs only work with voltages in one polarity. So, to allow the entire cycle of the analog input to be converted to light, the transmitter modules level- translate their input about 2.5V (as shown on the right in Figure 1) before using it to drive the LED. This allows analog signals with peaks up to ±2.5V to be converted to light.

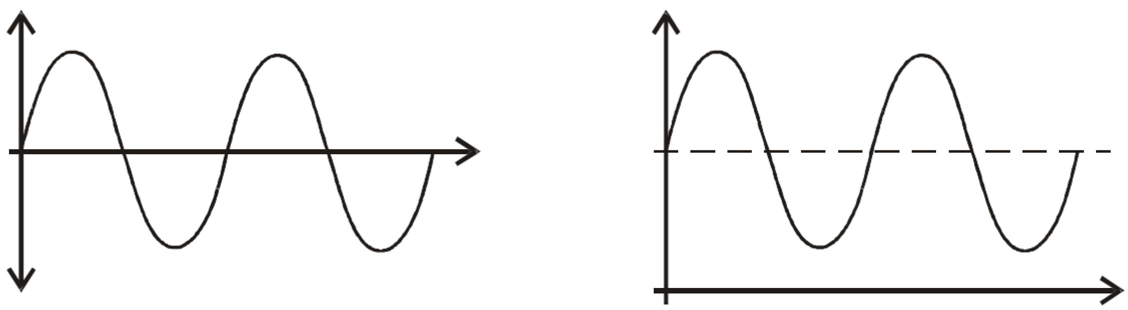


Figure 1 Left) A bipolar analog signal; and Right) A unipolar analog signal †translated about 2.5V

The second point follows on from the first. Once the analog input voltage exceeds 5Vpp, the limits of the LED's operation are exceeded. That is, the LED can'† get† any brighter or darker. This results in clipping at the tops and bottoms of †he waveform on the receiver's output.

Receiver module

Two optical Receiver modules that can be used to “unload" information from fiber optic cables. That is, the Receiver modules can relatively efficiently couple light information from the core of a plastic optical fiber cable to a light sensor that converts the information to electrical signals. As standard light sensors are used, they respond to all visible light and so the Receiver modules can be used to unload both red and green Light from the optical fiber cables. Once the information is converted from Light †o electrical energy, an amplifier is used to increase the signal level. Fine and course gains controls are provided to avoid saturating the signal when the Losses are small but still provide sufficient gain when the Losses are significant (for example, when optical couplers are used).

Importantly, †he conversion of information from Light to electrical energy produces a bipolar signal. This is the signals available on the module's analog output after amplification. This means that, if the transmitted information is a digital data signal, the signal is unsuitable for digital inputs as these work on standard TTL Logic levels which are unipolar (that is, 0V for Iogic-0 and 5V for Iogic-1). To manage this, the Receiver modules also convert the received signal to standard TTL Logic levels which are available on digital outputs for use by PCM Decoder module where appropriate.

Objectives

To investigate the operation of the Transmitter modules in both analog and digital modes. Then, use one of the Transmitter modules to Load analog and digital data onto an optical fiber and investigate the operation of the Receiver modules.

Equipment

- Personal computer with appropriate software installed.
- NI ELVIS II plus USB cable and power pack
- Emona FOTEx experimental add-in module
- Two BNC to 2mm banana-plug Leads.
- Assorted optical patch Leads.
- Assorted 2mm banana-plug patch Leads

Procedure

Part A - The Transmitter modules

The next par† of the experiment, investigate †he operation of †he Transmitter modules using a DC voltage then a Low frequency triangular wave.

1. Ensure that the NI ELVIS II power switch at the back of the unit is off.
2. Carefully plug the Emona UOTEx experimental add-in module into the NI ELVIS II.
3. Insert the holding screws to secure the UOTEx module to the NI ELVIS II.
4. Connect the NI ELVIS II to the PC using the USB cable.
5. Turn on the NI ELVIS II power switch at the rear of the unit then turn on its prototyping Board Power switch at the top right corner near the power indicator.
6. Turn on †he PC and let it boot-up.
7. Launch the NI ELVISmx software.
8. Launch and run The NI ELVIS II Variable Power Supplies VI.
9. Set the Variable Power Supplies' positive output to 0V.
10. Select one of the red LED Transmitter modules and set its Mode control to DIGITAL.
11. Connect the set-up shown in Figure 2 below using the Transmitter module you adjusted for the previous step.

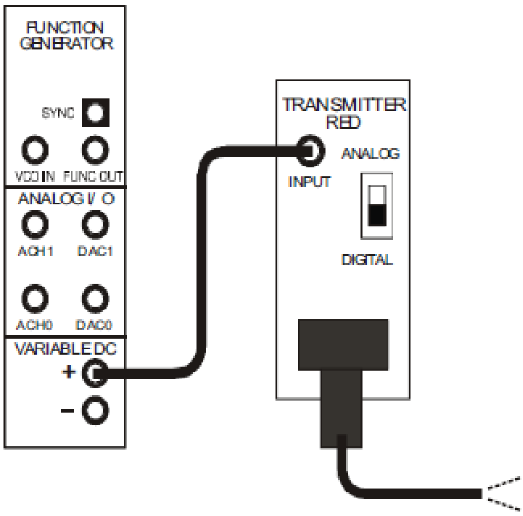


Figure 0-1

The set-up in Figure 2 can be represented by the block diagram in Figure 3 below. The red Transmitter module's input is a variable DC voltage from the Variable Power Supplies.

12. Point the free end of the optical patch lead close to the desk, wall, white paper or the palm of a hand so can see light from the end of the cable shining on it.
13. Increase the Variable Power Supplies positive output voltage until the Transmitter module's LED turns on.
14. Vary the Variable Power Supplies positive output voltage above the level that keeps the LED turned on.

Note: As you do, notice that the Transmitter module's LED light intensity does not change.

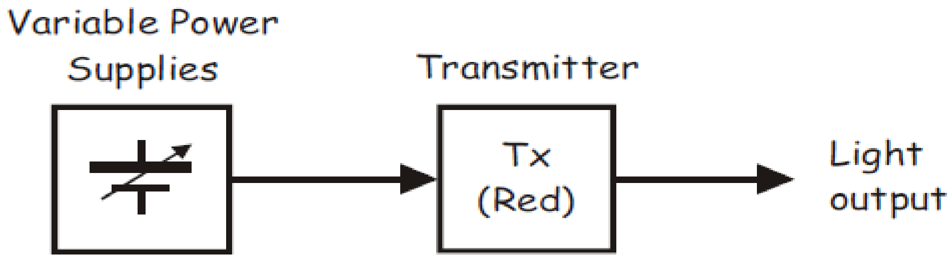


Figure 0-2

15. Return the Variable Power Supplies' positive output to 0V.
16. Increase the Variable Power Supplies positive output in 0.1V increments and identify †he exact voltage that turns the LED on. Record this voltage in Table 1 below.
17. Now reduce the Variable Power Supplies positive output in 0.1V increments and identify.
18. The exact voltage that turns the LED back off. Record this voltage in Table 1 below.

Logic-1 threshold voltage	Logic-0 threshold voltage

19. Close the Variable Power Supplies' VI.
20. Launch and run the NI ELVIS II Function Generator VI.
21. Adjust the function generator using its soft controls for an output with the following specifications.

- Waveshapes: Triangular
- Frequency: 0.5Hz
- Amplitude: 5Vpp
- DC Offset: 0V

22. Set the Transmitter module's Mode control to ANALOG.
23. Connect the set-up shown in Figure 4 below.

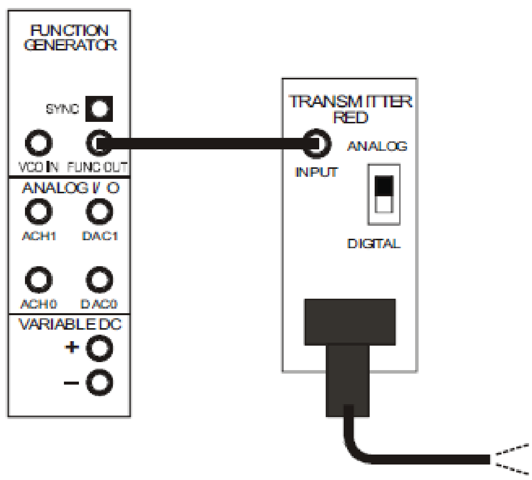


Figure 0-3

This set-up can be represented by the block diagram in Figure 5 below. The red Transmitter module's input is now a Low frequency triangular wave from the function generator.

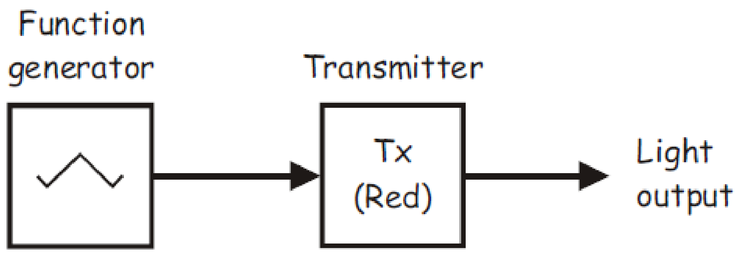


Figure 0-4

24. Point the free end of the optical patch lead close to the desk, wall, etc.

Note: You should see the LED's light intensity vary between minimum and maximum at a constant rate.

25. Increase the function generator's output to the following frequencies 5Hz, 10Hz, 20Hz, 30Hz and 50Hz. Observe the effect on the LED's output between each change.
26. Return the function generator's output to 0.5Hz.
27. Increase the function generator's amplitude to 10Vpp.
28. Return the function generator's amplitude to 5Vpp.
29. Substitute the red Transmitter module for the green Transmitter module.

Note: Make sure that you set the green Transmitter module's mode switch to ANALOG.

30. Repeat Steps 23 to 26 looking for any differences in performance between the red and green Transmitter modules.

Part B - Receiver modules to unload analog signals.

The next part of the experiment lets you investigate the operation of the Receiver modules for unIoading analog information from a fiber optic transmission line.

31. Completely dismantle the current set-up.
32. Adjust the function generator using its soft controls for an output with the following specifications.
    - Waveshape: Sine
    - Frequency:1Hz
    - Amplitude: 5Vpp
    - DC Offset: 0V
33. Select one of the red LED Transmitter modules and set its Mode control to ANALOG.
34. Select one the Receiver modules and set its Gain Range control to LO.
35. Turn the same Receiver module's Variable Gain control fully counterclockwise.
36. Connect the set-up shown in Figure 6 below using the Transmitter and Receiver modules adjusted for Steps 32 to 34.

Note: insert the black plugs of the oscilloscope leads into a ground (GND) socket.

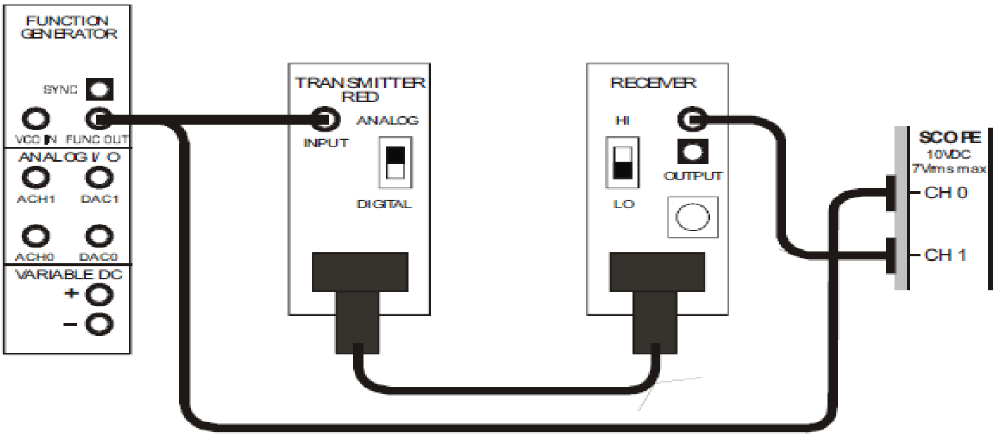


Figure 0-5

This set-up can be represented by the block diagram in Figure 7 on the next page. The function generator is used to model an analog message. The red Transmitter module converts the message to light and transmits it along an optical fiber cable to the Receiver module where it is converted back to an electrical signal.

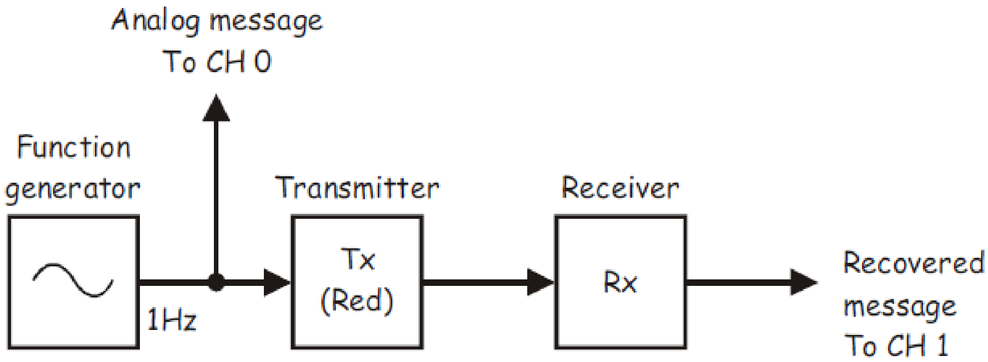


Figure 0-6

37. Look closely at the rear of the optical connectors on the Transmitter and Receiver modules that is in use.
38. Launch and run the NI ELVIS II Oscilloscope VI.
39. Set up the scope per the procedure in Experiment 1 (page 1-12) with the following changes.

- Channel 1 Scale control to the 2V/div position instead of 1V/div position
- Time base control to the 200ms/div position instead of 500µs/div position

40. Activate the scope's Channel 1 input (by checking the Channel 1 Enabled box) to observe the Receiver module's output as well as the original message.

Note: The Receiver module's output should be a copy of the message.

41. Increase the message frequency (†ha† is, increase the function generator's output† frequency) to the following settings 10Hz, 20Hz, 50Hz, 100Hz and 1,000Hz.

Note: After each change in frequency, it will be needed to set the scope's Time base control to a more appropriate setting. Choose a setting that displays only two or so cycles of the signals.

42. Increase the message's amplitude (that is, the function generator's output voltage) in 1V increments up to 10Vpp and observe the effect.

Part C - Using the FOTEx Receiver modules to unload digital signals.

The next part of the experiment lets investigate the operation of the UOTEx Receiver modules for unloading digital information from a fiber optic transmission line.

43. Close the function generator's VI.
44. Dismantle the current set-up.
45. Select one of the red LED Transmitter modules and set its Mode control to DIGITAL.
46. Select one the Receiver modules and set its Gain Range control to LO.
47. Turn the same Receiver module's Variable Gain control fully counterclockwise.
48. Connect the set-up shown in Figure 8 below using the Transmitter and Receiver modules adjusted for Steps 44 to 46.

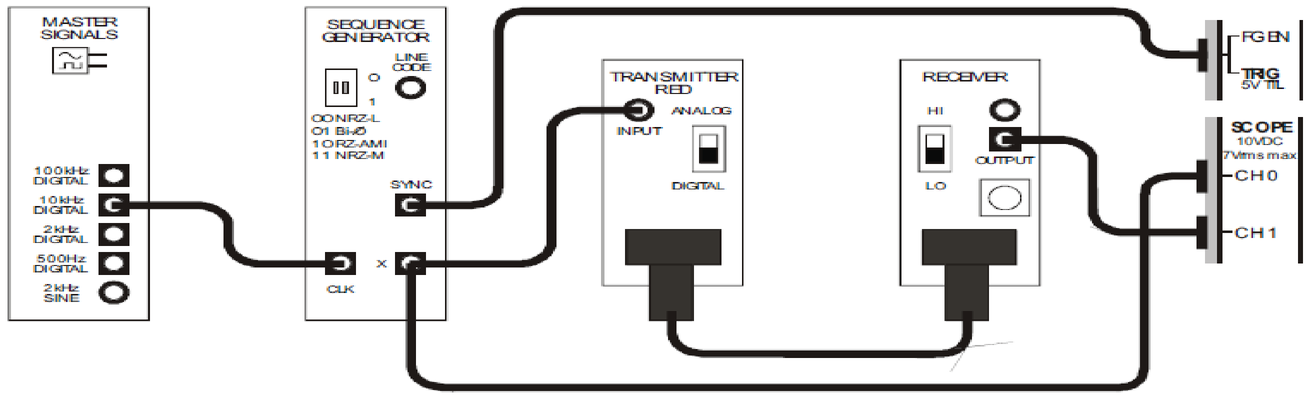


Figure 0-7

This set-up can be represented by the block diagram in Figure 9 on the next page. The Master Signals module's 10kHz DIGITAL output† is used †o clock The Sequence Generator module which models TTL digital data on its X output. This Sequence Generator module repeatedly outputs a 31-bit data sequence allowing the data to be stabilized on the scope's display when it is triggered using the Sequence Generator module's SYNC output as is done here. [Notes it would be impossible to trigger the scope if real digital data were used.] The digital data signal is then used as the message for the red Transmitter module which converts it to light and transmits it along an optical fiber cable for the Receiver module to convert back to an electrical digital signal.

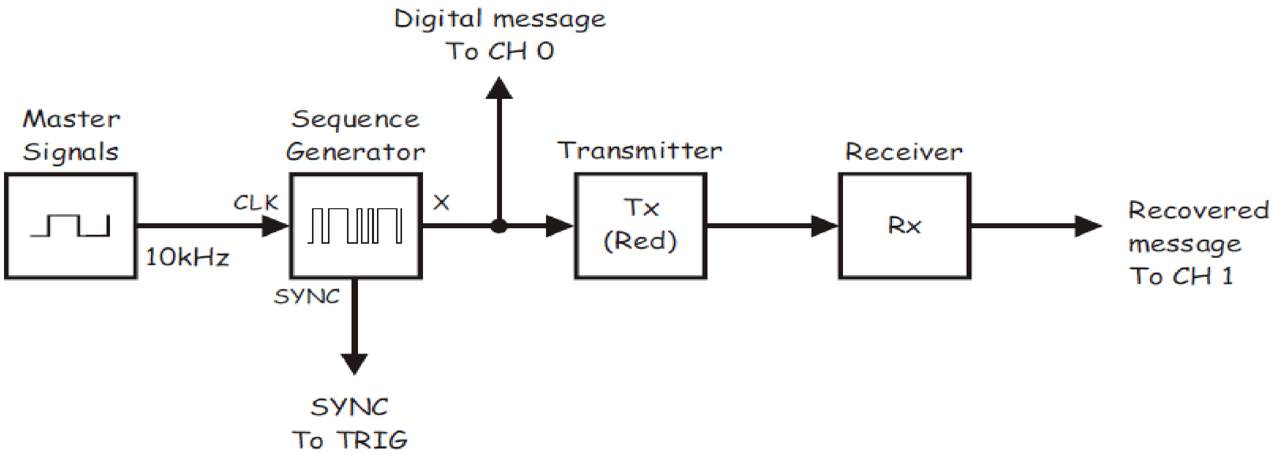


Figure 0-8

49. Make the following changes to the scope's controls:

- Coupling controls for both channels to the DC position instead of the AC position
- Time base control to the 200µs/div position instead of the 500µs/div position
- Channel 1 Vertical Position control to -5V instead of 0V
- Trigger Type to the Digital position

Note: Once done, be able to views a portion of the X output's 31-bit sequence and a copy of it on the Receiver module's output.

Experiment2: Optical signal filtering, splitting, and combining

Discussion

Filtering

The sophisticated optical fiber systems used in telecommunications allow many thousands of conversations to take place over the network at once. There are several methods of achieving this including time division multiplexing (TDM). Another method involves coupling multiple light sources to the fiber with each operating at a different wavelength. This is known as wavelength division multiplexing (WDM).

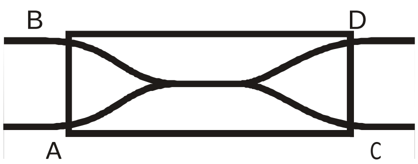
Importantly, filters are needed in WDM systems to pick-out light at one wavelength and reject light at others. For modeling WDM using the Emona FOTEx, red and green WDM Filter modules are available. The red WDM Filter module lets red light pass relatively unaffected but attenuates light at other colors including green. The green WDM Filter module lets green light pass but attenuates the red light.

Splitting and combining

As you know, electrically connecting two uninsulated copper wires together is as simple as bringing them into contact at anyone point along their length. This allows electrical signals traveling along †he wires †o be readily divided and sent to two or more destinations. However, the splitting of light signals traveling along optical fiber is no† so simple. Optical fiber is designed †o contains †he light within †he cores (using total internal reflection) and guide it to the other end. This means †ha† very little of †he light †ha† enters †the fiber can escape along its length. Clearly †hen, splitting light signals cannot be achieved by simply “tapping" into †he fiber at one point in the same way as for copper conductors.

One method of achieving optical splitting relies on †he fac† †ha†, in practice, a small amount of light does escape from small-cored glass fibers. That being †he case, it's possible †o transfer some of †he light from one fiber †o another by placing †hem sufficiently close together over a sufficient length. An obvious variation on †his idea involves increasing †he closeness of †he is coupling (and †hereby reducing †he length over which †he is coupling must be done) by fusing the fibers' cores together. The optical device designed †o split light in †his way is called a fused-fiber coupler and the Emona FOTEx has †wo of †hem.

The construction of fused-fiber couplers is reflected in †heir schematic symbol as shown in Figure 1 below.



The device is said †o has four ports (†ha† is, inputs-outputs) and these are usually denoted alphabetically from A †o D. Ports A and D are †he ends of one of †he fibers and so light coupled †o one of these ports must appear a† the other. That is, light on port A appears a† port D and vice versa. Similarly ports B and C are †he ends of †he other fiber and so light coupled †o one of these ports also must appear a† †he other (†ha† is, B †o C and C †o B).

The fusing of the fibers' cores allows light †o transfer readily between †hem a† the point of coupling. So, this creates four additional signal-paths including A †o C, C †o A, B †o D and D †o B.

Importantly, more light travels through †he fibers directly (e.g., from A †o D) than indirectly (e.g., from A †o C). This means †ha† †here is a difference in light intensity at †he outputs with the direct path being brighter. for †his reason, †he direct signal-paths are known as †he strong paths and †he indirect signal-paths are known as †he weak paths. This is summarized in Table 1 below.

Strong paths	Weak paths
A †o D	A †o C
D †o A	C †o A
B †o C	B †o D
C †o B	D †o B

Interestingly, †here are four undesirable light-paths caused by reflections and scattering at the junction of the fibers. These are A to B, B to A, D to C and C to D. The light intensity at the outputs of these paths is very low but they have †he potential †o cause problems †ha† may need †o be managed depending on what the couplers are used for.

Finally, †he fused-fiber coupler can be used †o combine signals instead of splitting †hem. To explain, consider †he example of a signal connected †o port A. from †he discussion so far we know †ha† †he signal appears on both ports D (strong) and C (weak). Now, if another signal is connected †o port B at †he same time, †ha† signal must also appear on both ports D (weak) and C (strong). Clearly, both of †he output ports consist of light from both of †he sources and have combined.

Objectives

For †his experiment you'll star† by investigating †he operation of †he Emona FOTEx red and green WDM Filter modules. Then, you'll use one of †he Coupler modules to split optical signals and compare †he differences between †he strong and weak signal paths. Finally, you'll use one of

The Coupler modules †o combine optical signals. A† †his stage, all analysis will be qualitative.

A more quantitative analysis of †he performance of these devices will be conducted in a later experiment.

Equipment

- Personal computer with appropriate software installed.
- NI ELVIS II plus USB cable and power pack
- Emona FOTEx experimental add-in module
- Two BNC to 2mm banana-plug Leads.
- Assorted optical patch Leads.
- Assorted 2mm banana-plug patch Leads

Procedure

Part A - Using the Emona FOTEx WDM Filter modules for optical signal filtering

The first part of †he experiments gets you †o qualitatively investigate †he operation of †he FOTEx WDM filter modules.

1. Ensure †ha† the NI ELVIS II power switch a† †he back of the unit is off.
2. Carefully plug †he Emona FOTEx experimental add-in module into †he NI ELVIS II.
3. Insert †he is holding screws †o secure †he FOTEx module †o †he NI ELVIS II.

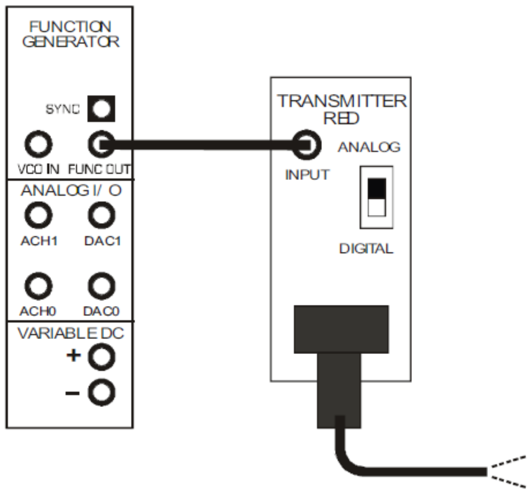
Note: This must be done with †he power off †o avoid damaging †he FOTEx.

4. Connect the NI ELVIS II †o the PC using the USB cable.

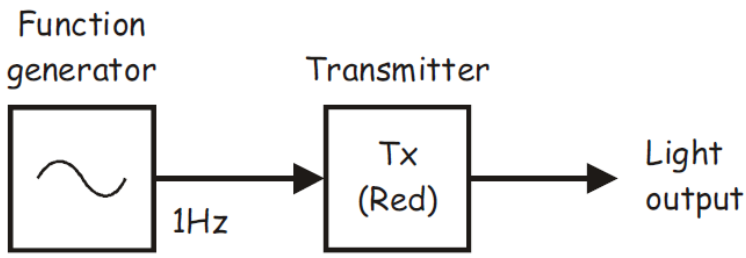
Note: This may already have been done for you.

5. Turn on the NI ELVIS II power switch a† the rear of †he unit then †urn on its Prototyping Board Power switch at †he †op right corner near †he power indicator.
6. Turn on †he PC and let it boo†-up.
7. Launch †he NI ELVISmx software.
8. Launch and run the NI ELVIS II function Generator VI.
9. Adjust †he function generator using its soft controls for an output with the following specifications.
    a. Waveshapes Sine
    b. Frequency 1Hz
    c. Amplitudes 4Vpp
    d. DC Offsets 0V
10. Select one of the red LED Transmitter modules and set its Mode control to ANALOG.
11. Connect the set-up shown in figure below using the Transmitter module you adjusted for the previous step.

Note: Don'† worry †ha† one end of the optical patch lead isn't connected to anything.

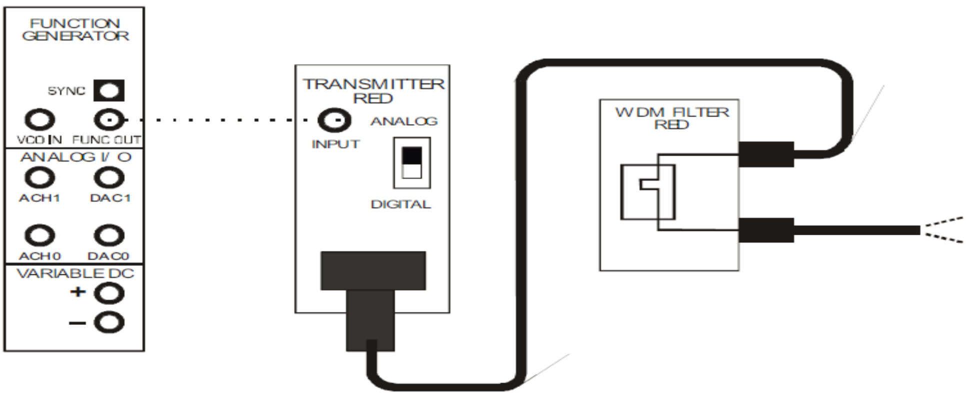


This set-up can be represented by the block diagram in Figure below. The red Transmitter module's input is now a low frequency sinewave from †he functions generator.

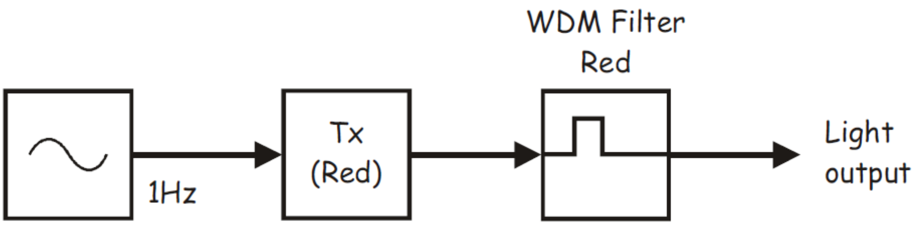


12. Point the free end of the optical patch lead close †o †he desks, wall, white paper or †he palm of your hand so you can see light from the end of †he cable shining on it.
13. Check †ha† †he red light on the end of the fiber is pulsing about once per second.
14. Modify †he se†-up as shown in Figure below.

Note: Remember, dotted lines show leads already in place.



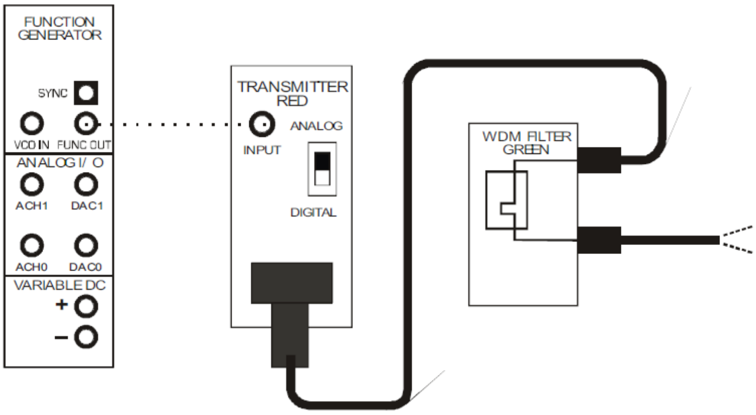
This se†-up can be represented by †he block diagram in Figure below. The Transmitter module's output is now connected †o †he red WDM Filter module's input.



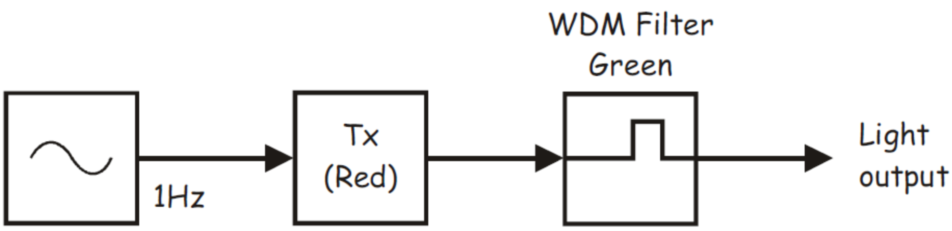
15. Point the free end of the optical patch lead close †o †he desks, wall, etc.

Note: You should again see red light out of the filter pulsing about once per second.

16. Replace the red WDM Filter module for †he green one as shown in Figure below.



This set-up can be represented by the block diagram in Figure below. The Transmitter module's output is now connected to the green WDM Filter module's input.

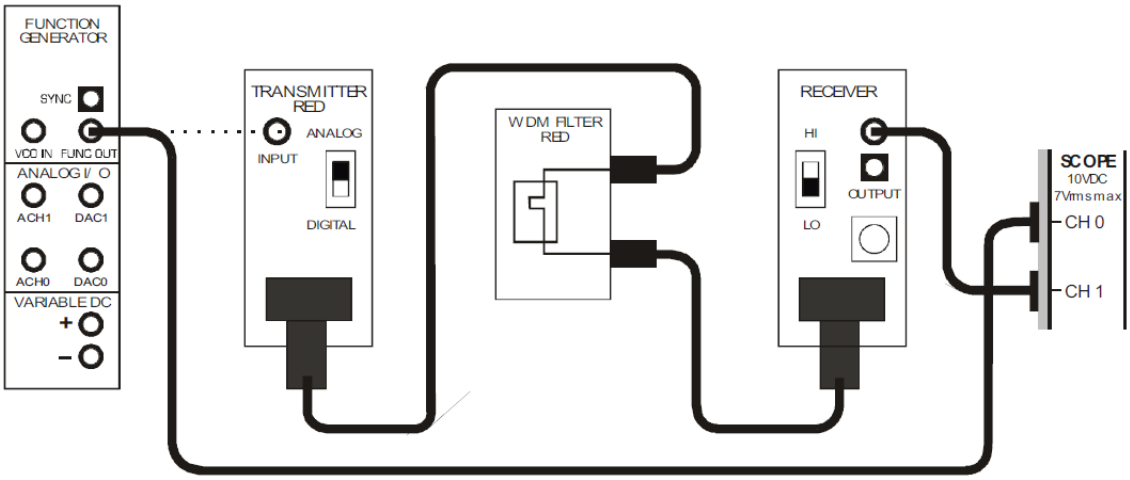


17. Point the free end of †he optical patch lead close †o †he desk, wall, etc to observe †he green WDM Filter module's output.

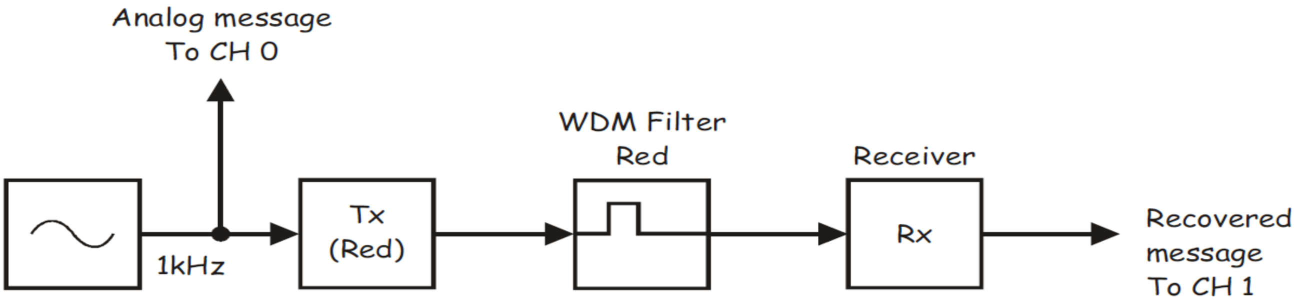
Note: You'll still see a pulsing red light out of †he filter but the brightness should be substantially lower than you saw at Step 15.

18. increase †he messages frequency (†ha† is, increase †he function generator’s output† frequency) †o 1,000Hz.
19. Select one †he Receiver modules and se† its Gain Range control †o LO.
20. Turn †he same Receiver module's Variable Gain control fully clockwise.
21. Connect the set-up shown in Figure below using †he red WDM Filter module and Receiver module you adjusted for Steps 19 and 20.

Note: Insert †he black plugs of the oscilloscope leads into a ground (GND) socket.



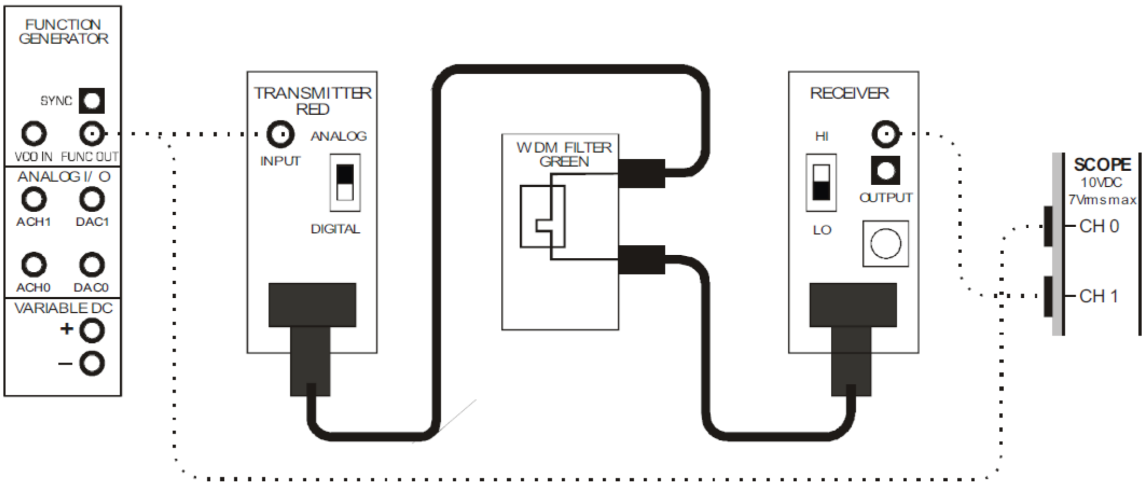
This set-up can be represented by †he block diagram in Figure below. The function generator is used †o model an analog message. The red Transmitter module converts the message to light and transmits it along an optical fiber cable to the red WDM Filter module. The light is filtered and connected to the Receiver module where it is converted back to an electrical signal.



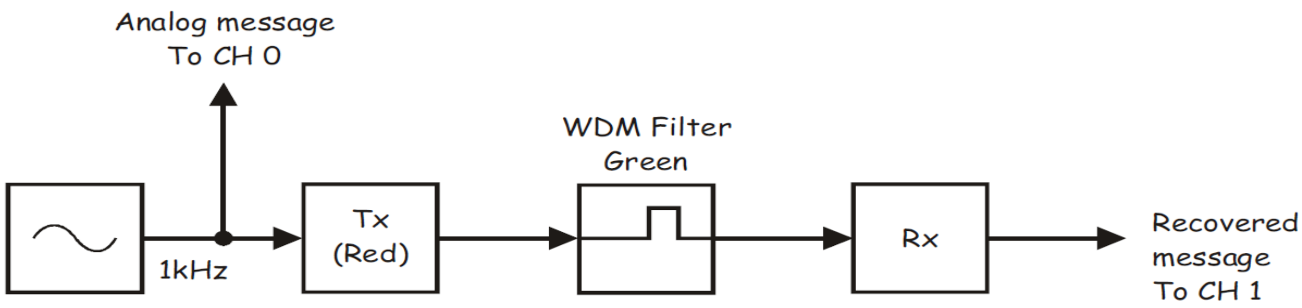
22. Launch and run the NI ELVIS II Oscilloscope VI.
23. Activate the scope's Channel 1 input (by checking †he Channel 1 Enabled box) †o observe the Receiver module's output as well as †he original message.

Note: The Receiver module's output should be a copy of †he message.

24. Replace the red WDM Filter module for †he green one as shown in Figure below.



This set-up can be represented by †he block diagram in Figure below. it's identical to the previous set-up except that †he green WDM Filter module is used †o filters the light between the Transmitter and Receiver modules.



25. Use †he scope †o observe †he Receiver module's new output.
26. Se† the scope's Channel 1 Scale control to the 20mV/div position instead of †he 1V/div position.

Note: You should observe a fairly small copy of †he messages.

27. To confirm †ha† †his signal is a copy of †he message and no† noise, momentarily disconnect one end of any one of †he optical patch leads.

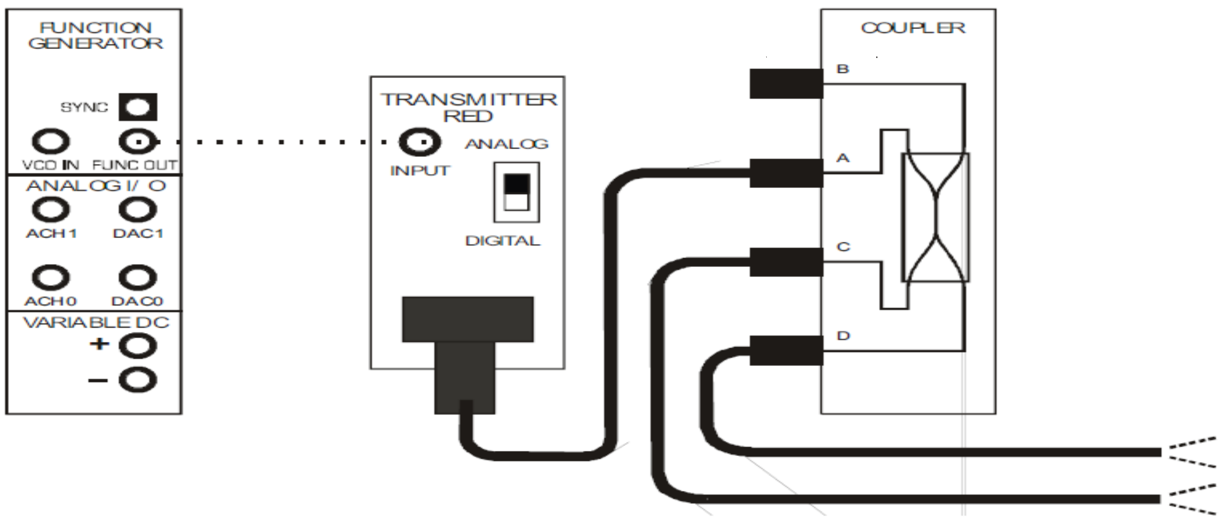
Note 1: When you do, †he small copy of the message should disappear.

Note 2: Be sure †o reconnects the optical patch lead before continuing.

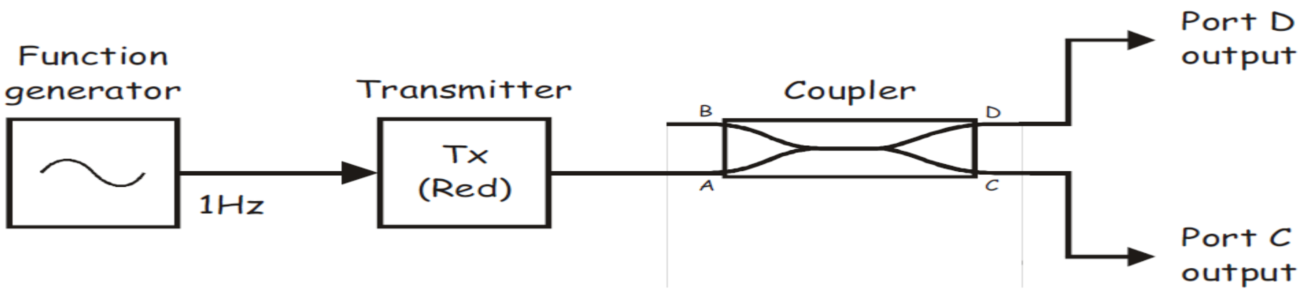
Part B - Using the Emona FOTEx Coupler modules for splitting optical signals

The next part of †he experiment gets you to qualitatively investigate the signal-splitting action of †he FOTEx fiber-fused Coupler modules.

28. Se† †he function generator's output frequency †o 1Hz.
29. Check that the function generator's other options are still set to the followings
    a. Waveshapes Sine
    b. Amplitudes 4Vpp
    c. DC Offsets 0V
30. Use †he left-side Coupler module to modify †he se†-up as shown in Figure below.



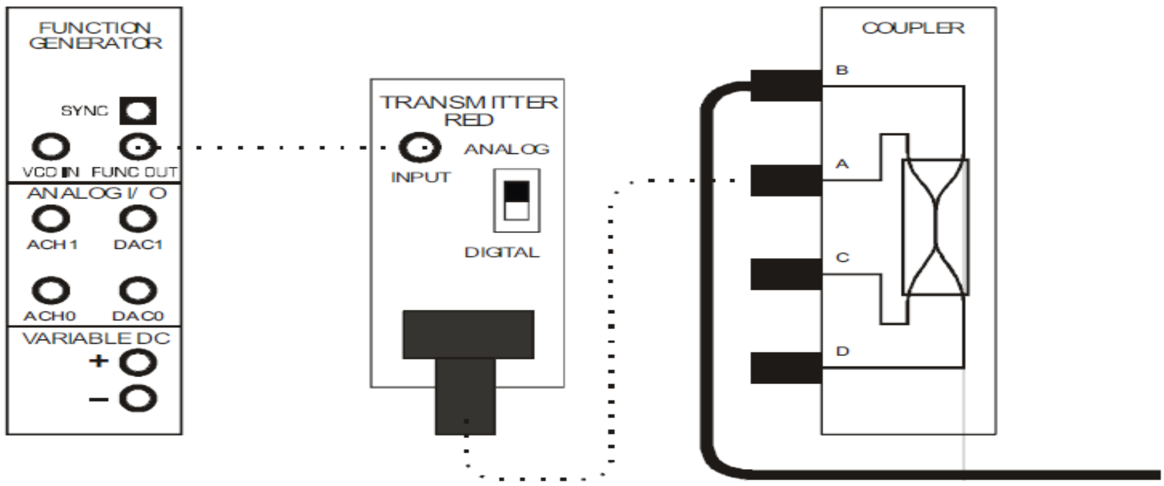
This set-up can be represented by †he block diagram in Figure on †he next page. The red Transmitter module's input is a low frequency sinewave from †he function generator. The Transmitter module's output is connected to port A on a Coupler module.



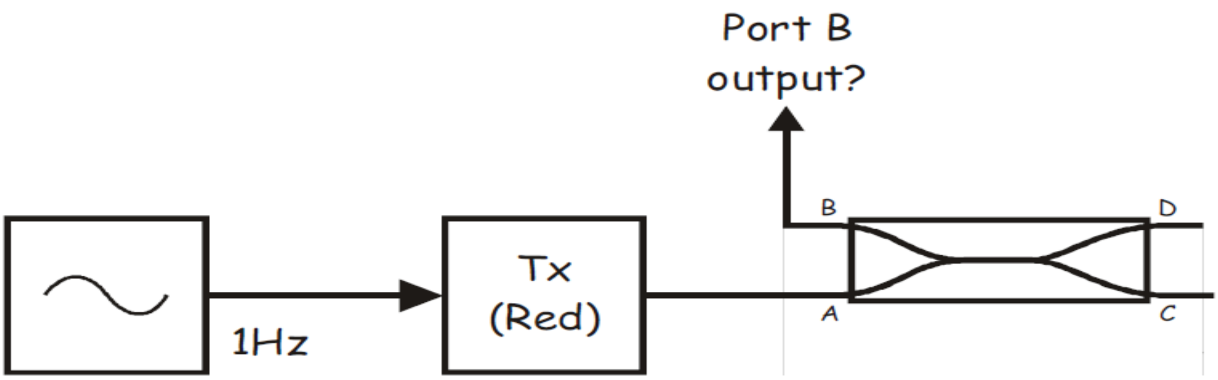
31. Point the free end of †he †wo optical patch leads close †o †he desk, wall, etc.

Note: You should see red light pulsing about once per second from †he output of both ports C and D. This is †he split light energy from port A.

32. Compare †he brightness of †he outputs. is it possible †o distinguish between †he strong and weak paths by visual inspection?
33. Modify †he se†-up as shown in Figure below.



The se†-up in previous Figure can be represented by †he block diagram in Figure below. it's basically †he same as before except you're now looking a† †he port B output.



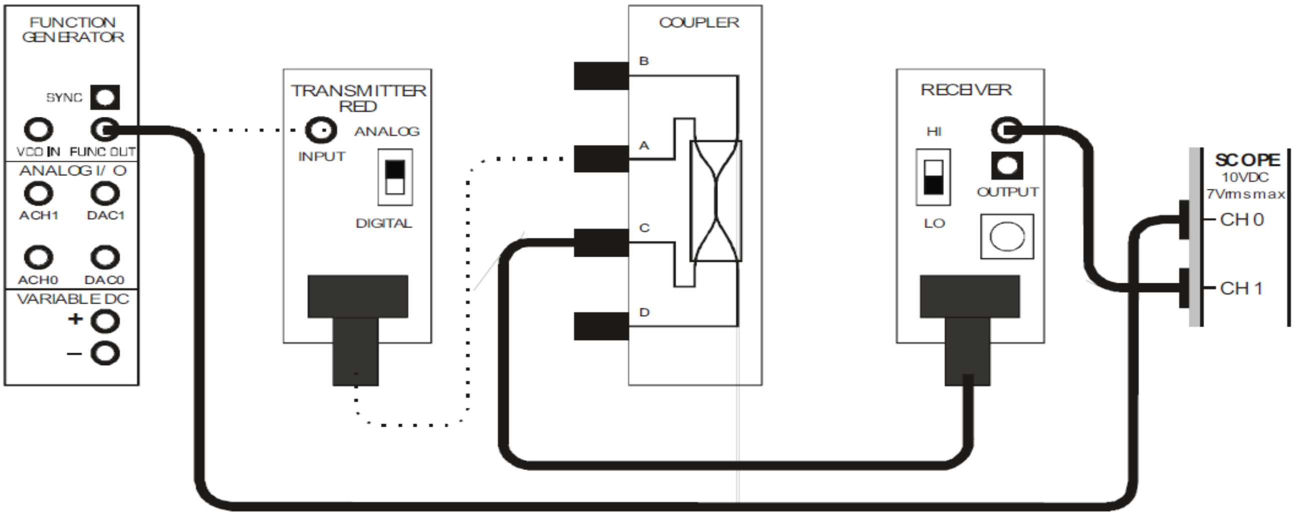
34. Point the free end of the optical patch lead close †o †he desks, wall, etc.

Note: You should see red light pulsing about once per second from port B

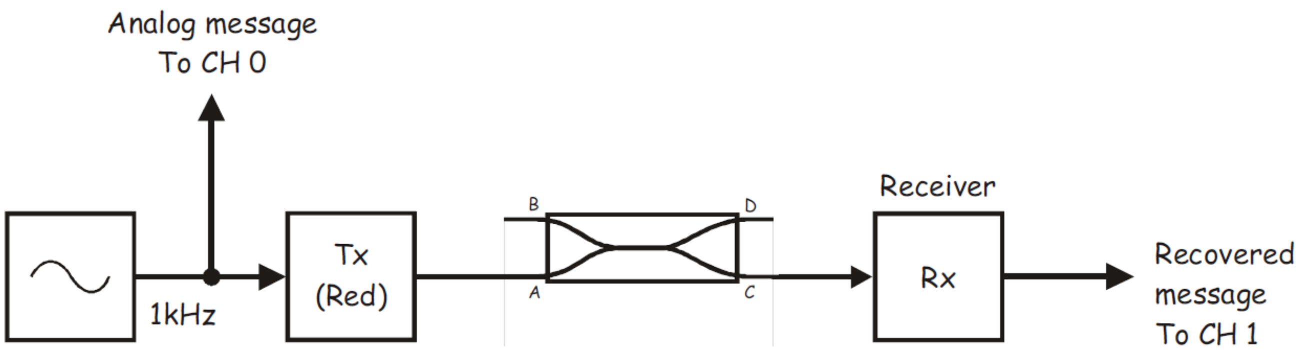
35. Se† †he Gain Range control of one of †he Receiver modules to LO.
36. Turn †he Variable Gain control of the same Receiver module fully clockwise.

Note: These †wo adjustments to the Receiver modules set their gains to the same level.

37. Increase the message frequency (that is, increase †he function generator's output frequency) to 1,000Hz.
38. Use †he Receiver module you adjusted for Steps 35 and 36 †o modify †he se†-up as shown in Figure below.



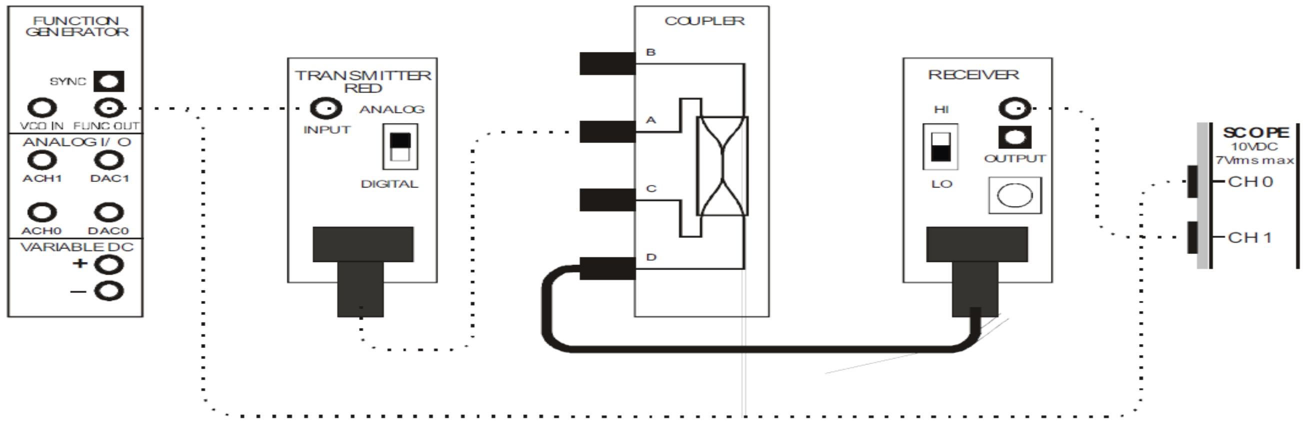
This se†-up can be represented by †he block diagram in Figure below. The analog signal modeled by †he function generator is converted to light by the red Transmitter module and is connected to port A of the Coupler module. The Coupler module splits the light signal into two signals available at ports C and D. The port C output is connected to the Receiver module.



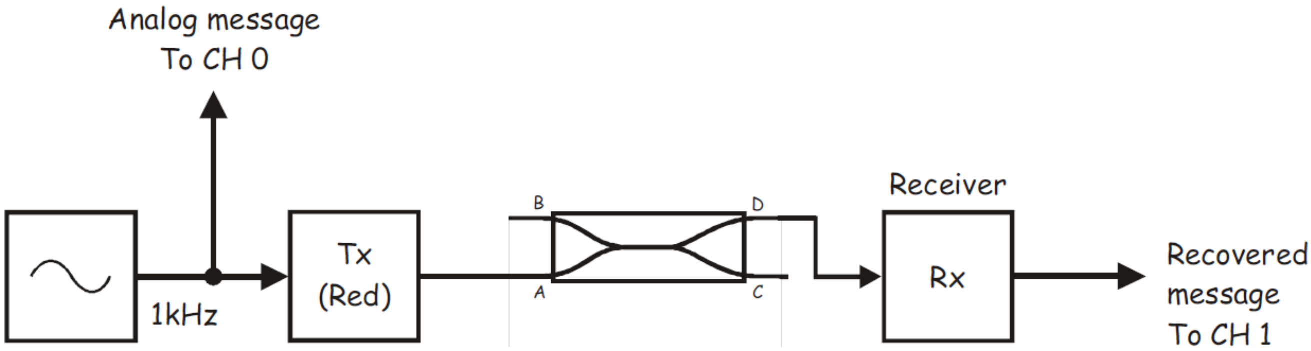
39. If the scope's Channel 1 input is not displayed †hen activate it.

Note: The scope should display †he original message and †he copy of it on the Receiver module's output. This is †he signal via †he Coupler module's port C.

40. Measure †he amplitude (that is, †he peak-†o-peak voltage) of †he Receiver module's output. Record your measurement in Table 2 on †he next page.
41. Modify †he scope's Channel 1 connection as shown in Figure below using †he same Receiver module.



The change †o †he scope's connection is shown on †he block diagram in Figure below.



42. Observe †he message and its copy on †he scope's display.

Note: The signal on this Receiver module's output is a copy of †he message via †he Coupler module's port D.

43. Measure †he amplitude of †he Receiver module's output. Record your measurement in Table 2 below.

Copy of message via port C	Copy of message via port D

Part C- Using the Emona FOTEx Coupler modules for combining optical signals

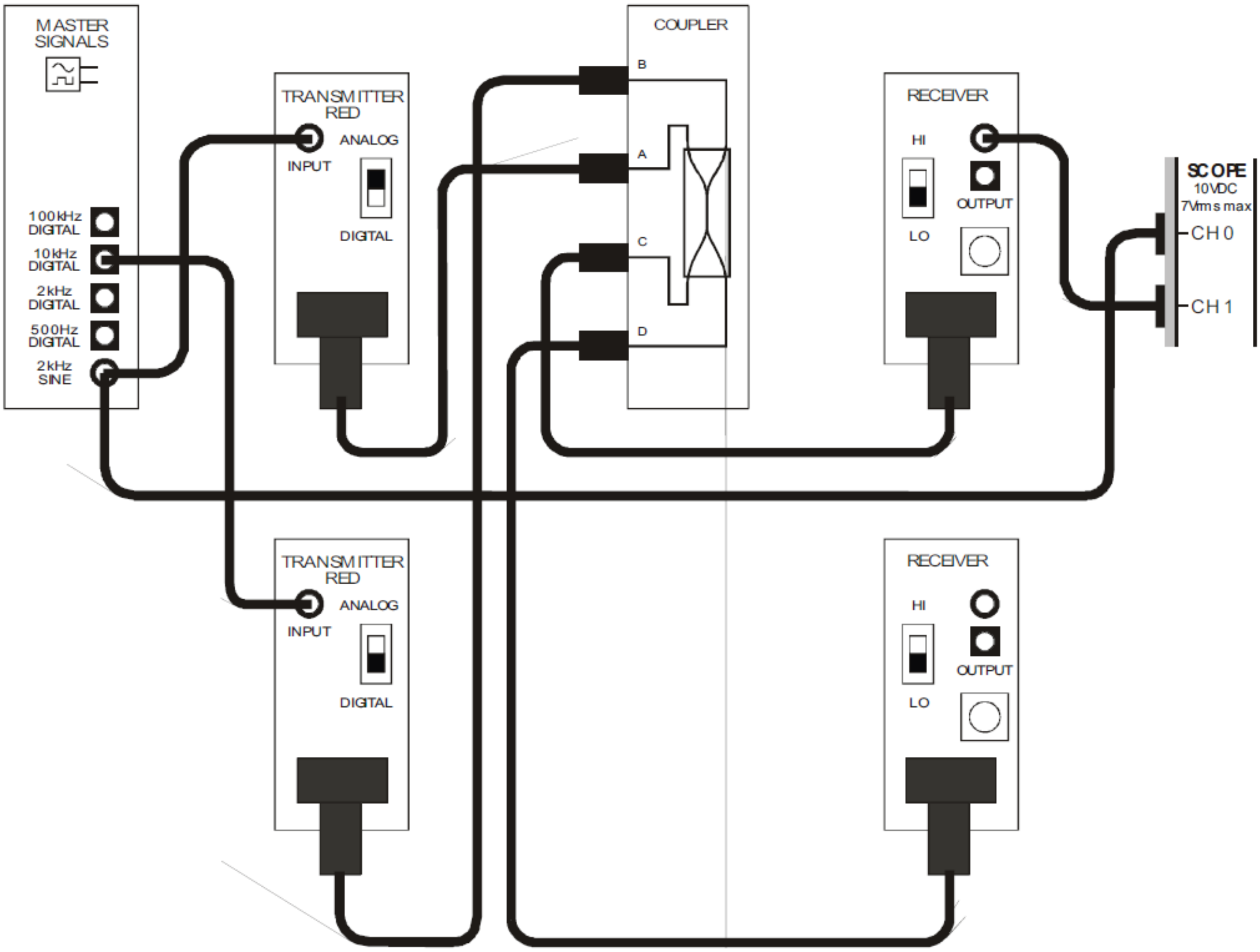
The next part of †he experiment gets you †o qualitatively investigate the signal-combining action of the FOTEx fiber-fused Coupler modules.

44. Completely dismantle †he current set-up.

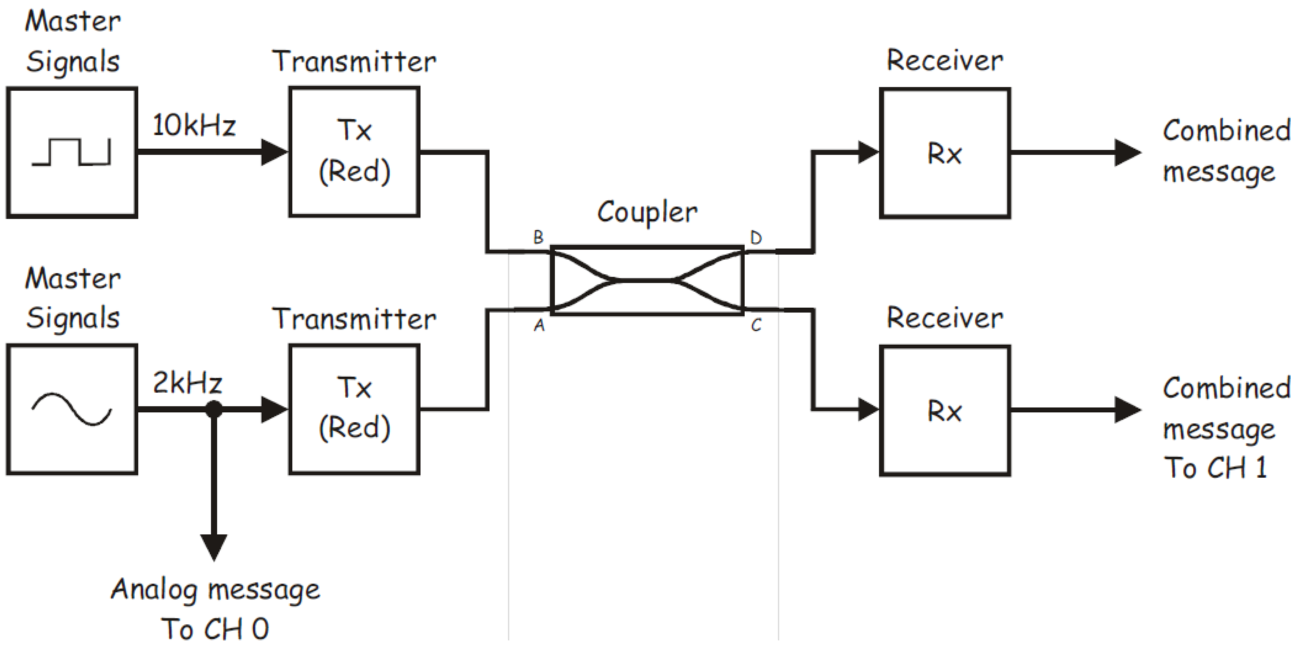
Note: You don't necessarily have to perform this step if you're confident that you can modify †he current set-up to obtain the set-up in Figure below (there are a few similarities). However, you'll still need to read the following instructions to make sure that all modules are adjusted correctly.

45. Select one of the red Transmitter modules and set its Mode control †o ANALOG.
46. Set the Mode of the other red Transmitter module †o DIGITAL.
47. Set the Gain Range control of both Receiver modules to LO.
48. Turn the Variable Gain control of both Receiver modules fully clockwise.
49. Connect the set-up shown in Figure below.

Note: Use †he position of †he Mode switches in †he diagram †o determine which Transmitter module is connected †o which output on the Master Signals module.



This set-up can be represented by †he block diagram in Figure below. Two red Transmitter module’s are being used †o convert †wo model message signals (one analog and one digital) †o light signals. These signals are connected †o ports A and B of †he Coupler module and so are simultaneously available at both ports C and D.



50. Check †hat the scope is set up per †he procedure wi†h †he following changes
    - Time base control to †he 100µs/div position instead of 500µs/div position

51. if the scope's Channel 1 input is not displayed then activate it.

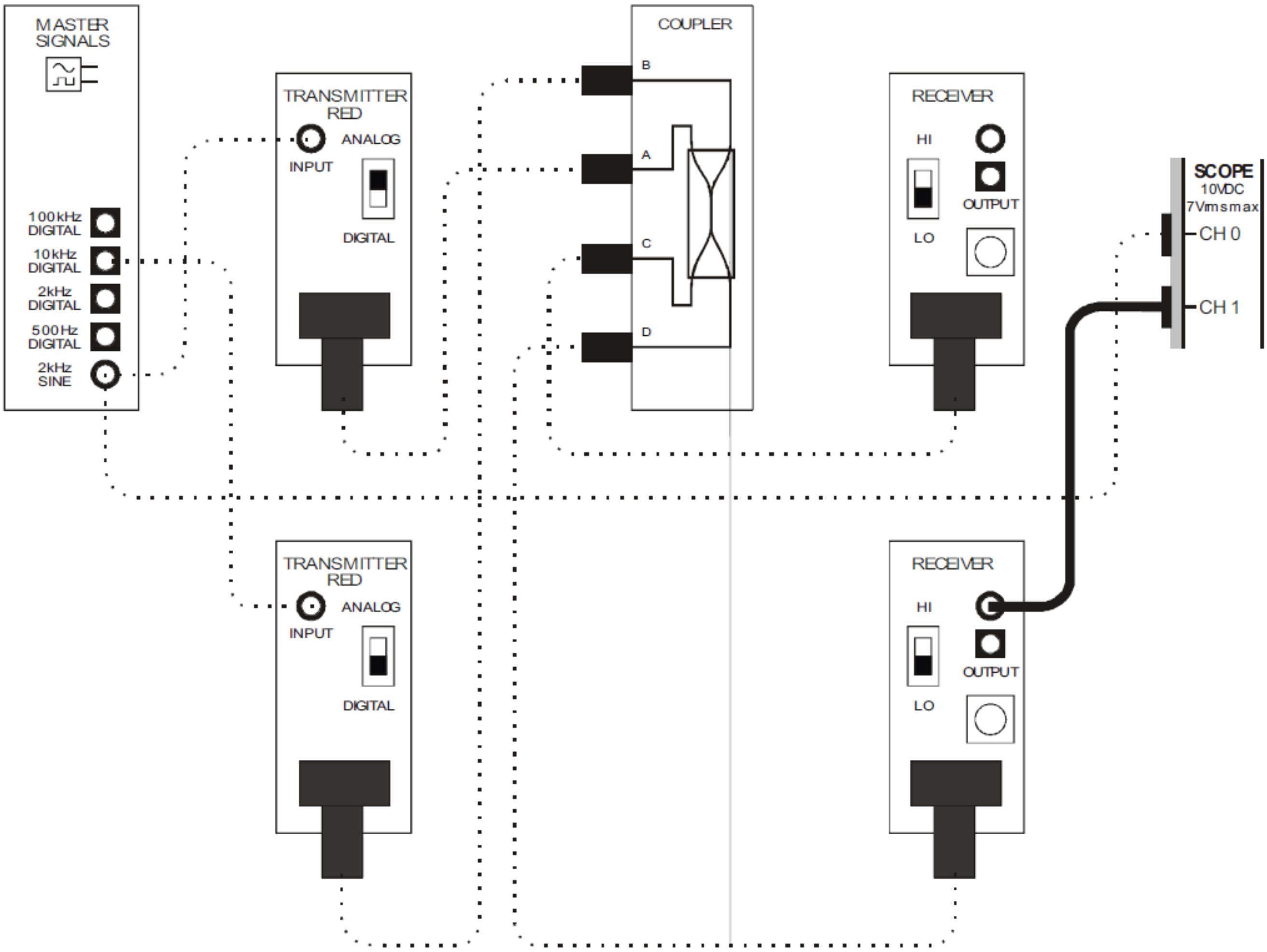
Note: The scope should display the original message and the combined messages on †he Receiver module's output. This is †he signal via †he Coupler module's port C.

52. To prove †ha† †he Receiver module’s output† is †he combination of †he †wo message signals, momentarily disconnect the optical patch lead from †he Transmitter modules one at a time.

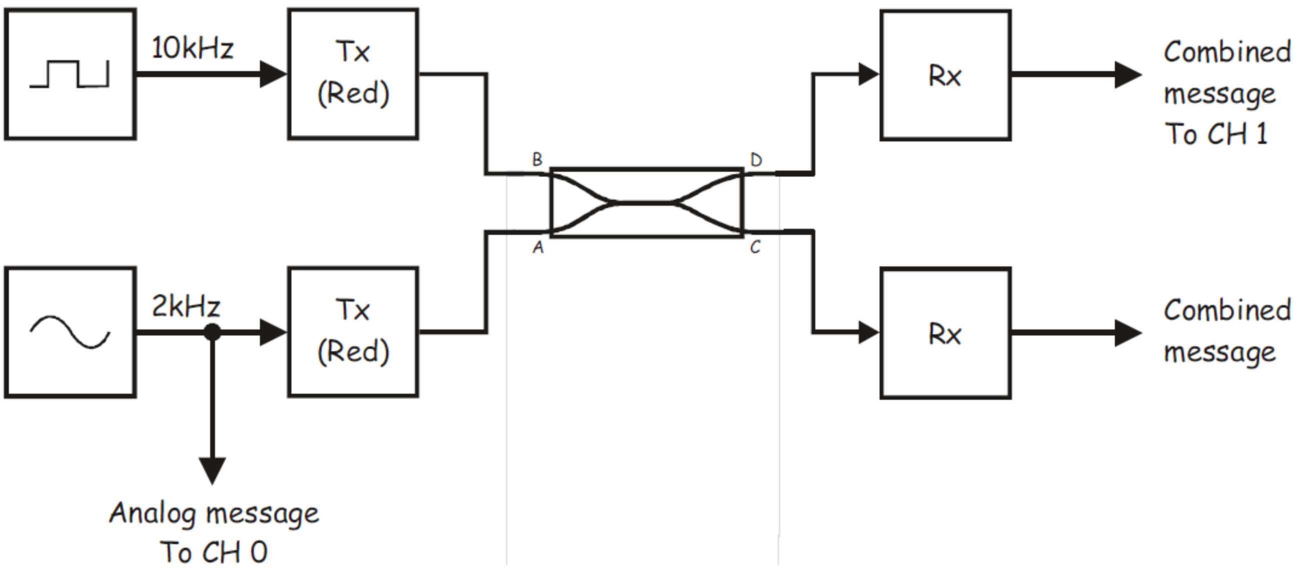
Note 1: When you do, you should obtain a copy of one message or the other.

Note 2: Be sure †o reconnect the optical patch leads before continuing.

53. Modify the scope's Channel 1 connection as shown in Figure below.



The change to the scope's connection is shown on the block diagram in Figure below.



Experiment3: Optical Losses

Discussion

Minimizing Losses is an important part of the implementation of all communications systems including optical. There are several advantages to doing so and significant among them is the benefit of increasing transmission distances before the need to repeat the signal. That being the case, as †here is a great deal of discussion in optical communication

theory about the losses of different types of fiber materials and construction, their losses at various wavelengths, the losses involved in the different methods of connecting and splicing fibers, and the differences in losses between different types of filters, couplers, circulators and so on.

Loss (or attenuation) is generally expressed in decibels (dB) and is calculated using †he equations.

$$Loss = 10\log_{10}\frac{P_1}{P_2}$$

Where P_1= is a signal power, and P_2= is the reference signal's power.

As voltage measurements are usually more convenient to take than power measurements, loss can also be calculated using the equations.

$$Loss = 20\log_{10}\frac{V_1}{V_2}$$

Where V_1= is a signal's amplitude, and V_2= is the reference signal's amplitude.

Plastic fiber has attenuation levels ranging from tens to hundreds of times greater than those for glass fiber. As such, plastic fiber use is largely restricted to distances of 100m or less. However, the lengths of plastic fiber provided for use are short enough for the loss to be insignificant and so can be ignored. A loss is significant if the change it introduces is audible and this occurs when changes exceed ±3dB. The worst-case losses for the shorter of the optical patch leads is approximately 1dB which is sufficiently below this.

Connections between optical fibers can introduce a significant source of IOSs that is affected by physical factors Likes over-lap of fiber cores, alignment of fiber axes, fiber spacing, and end- reflection loss. Losses due to these factors can be minimized by careful splicing of the fibers and so it is the preferred method. However, splicing is time-consuming and permanent and so connectors. These connectors have a typical insertion loss (that is, the loss that they introduce to the signals that would not have occurred otherwise) of 2dB. That said, this can vary substantially due to connector orientation. To explain, as a connector is a mechanical joint, simply rotating the connector can vary some or all the physical factors listed above which, in turn, can vary the connector's loss. While the loss introduced by one connector is insignificant, devices with an input and output require two connectors. This means that the total typical connector losses exceed the 3dB threshold and so they become audibly noticeable and therefore significant.

Objectives

To investigate the variation in the optical patch lead's losses due to connector orientation by observing the effect this has on the output voltage of a Receiver module.

Equipment

- Personal computer with appropriate software installed.
- NI ELVIS II plus USB cable and power pack
- Emona UOTEx experimental add-in module
- Emona UOTEx User manual
- Two BNC †o 2mm banana-plug leads.
- Assorted 2mm banana-plug patch leads
- Assorted optical patch leads.

Procedure

Part A - Investigating the variation in connector losses due to connector orientation.

Several physical characteristics of optical connections cause variations in connector losses due to connector orientation. The next part of the experiment lets you investigate this issue.

1. Ensure that the NI ELVIS II power switch at the back of the unit is off.
2. Carefully plug the Emona UOTEx experimental add-in module into the NI ELVIS II.
3. Insert the holding screws to secure the UOTEx module to the NI ELVIS II.

Note: This must be done with the power off to avoid damaging the UOTEx.

4. Connect the NI ELVIS II to the PC using the USB cable.
5. Turn on the NI ELVIS II power switch at the rear of the unit then turn on its Prototyping Board Power switch at the top right corner near the power indicator.
6. Turn on the PC and let it boot-up.
7. Launch the NI ELVISmx software.
8. Select one of the red LED Transmitter modules and set its Mode control to ANALOG.
9. Select one the Receiver modules and set its Gain Range control to LO.
10. Turn the same Receiver module's Variable Gain control fully clockwise.
11. Connect the set-up shown in Figure 1 below using the Transmitter and Receiver modules adjusted for Steps 8 to 10.

Note: Use one of the short optical patches leads between the Transmitter and Receiver modules

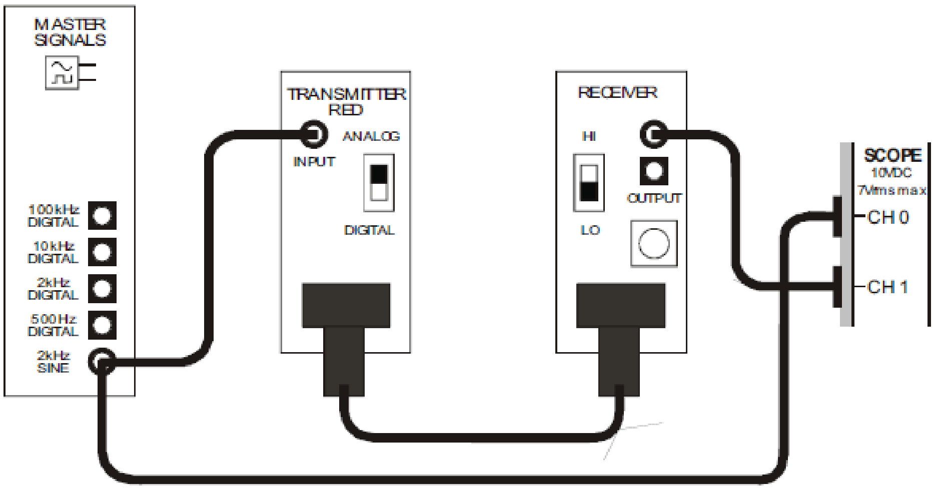


Figure 1

This set-up can be represented by the block diagram in Figure 2 below. The Master Signals module's 2kHz SINE output is used to model an analog message. The red Transmitter module converts the message to light and transmits it along an optical fiber cable to the Receiver module where it is converted back to an electrical signal.

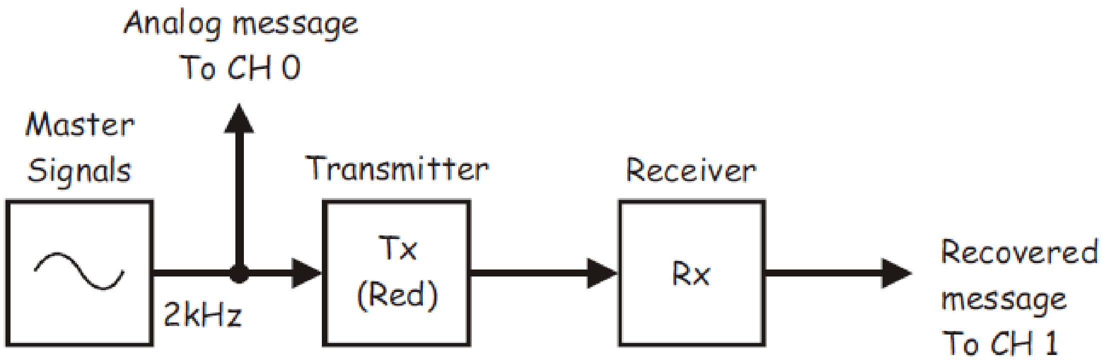


Figure 2

12. Launch and run the NI ELVIS II Oscilloscope VI.
13. Set up with the following:
    - Channel 1 Scale control to †he 2V/div position instead of the 1V/div position
14. Activate the scope's Channel 1 input to observe the recovered message as well as the original version of it.

Note: if the set-up has been wired correctly, you should see two 2kHz sinewaves.

15. Check to make sure that the recovered message is not clipped.

Note: if it is, reduce the Receiver module's gain by turning its Variable Gain control counterclockwise until the clipping is gone.

16. Measure the recovered message's RMS voltage. Record your measurement in the first free column in Table 1 on the next page.

Note: The RMS voltage is indicated at the left end of the row of measurements for each channel.

17. Disconnect the optical patch lead's connector at the Transmitter module, rotate it 90°, reconnect it then repeat Step 16.
18. Repeat Step 17 two more times.
19. Repeat Step 17 but this time don't measure the voltage.

Note: This final rotation has taken you back to the connector's original orientation.

20. Disconnect the optical patch lead's connector at the Receiver module, rotate it 90°, reconnect it then repeat Step 16.
21. Repeat Step 20 two more times.
22. Identify the biggest voltage in Table 1 (Vmax) and the smallest (Vmin) and use these figures in the equation below to determine the difference between them in decibels. Record your calculation in the final cell in Table 1.

$$Difference = 20\log_{10}(\frac{V_{min}}{V_{max}})$$

Measurement 1	Measurement 2	Measurement 3	Measurement 4
Measurement 5	Measurement 6	Measurement 7	Diff. between V_{max} & V_{min} in dB

Part B - Choosing two optical patch leads for further optical loss measurements.

Part A has indirectly shown that the optical patch leads' losses can vary significantly depending on connector orientation. This is problematic when taking and comparing measurements of signals on the input and output of the other optical devices. Unless you always keep †he connector orientations the same the measurements may be incorrect making comparisons less valid. To avoid having to worry about this as an issue, the next part of the experiment gets you identify two appropriate short optical patch leads that can be used for the remainder of the experiment.

23. Replace the optical patch lead in the set-up for the other short leads one at a time and repeat Steps 15 †o 22 until you have found two leads with a worst-case difference between the biggest and smallest voltages below 3dB.

Note: if time permits, test all of the short optical patch leads and pick the best two.

Experiment4: Fiber Optic Bi-directional Communication

Discussion

An interesting feature of optical fibers is that light traveling in one direction is largely unaffected by light traveling in the opposite direction along the same fiber. This makes sense when you think about it. If you were to shine two torches at each other, their beams wouldn't interfere with one another.

The ability of light to travel in both directions along optical fibers without interfering allows us to use them for bi-directional communications. That said, the loading and unloading of the signals at each end is more involved because both ends of the fiber must be connected to both a transmitter and a receiver. In telecommunications, this is usually managed by a device called a *circulator*. However, circulators for plastic fiber systems are expensive (defeating the purpose of using plastic in the first place). A cheaper alternative involves using two optical couplers but the trade-offs include increased losses and cross-talk.

Recall that an optical coupler is a 4-port device with the ports usually denoted alphabetically from A to D. Recall also that a signal injected in to one port is literally split and becomes available on the two ports at the opposite end of the coupler (though one port's output is significantly stronger than the other). For example, a signal injected in to port A is split between port D (the strong path) and port C (the weak path). Importantly, the optical coupler is a bi-directional device. So, a signal injected in to ports C or D is split between ports A and B and this is true even if a signal is connected to ports A and/or B at the same time. It's this property that allows us to use optical couplers to implement bi-directional fiber optic communications.

Figure 1 below shows the basic implementation of bi-directional fiber optic communications between two stations using optical couplers.

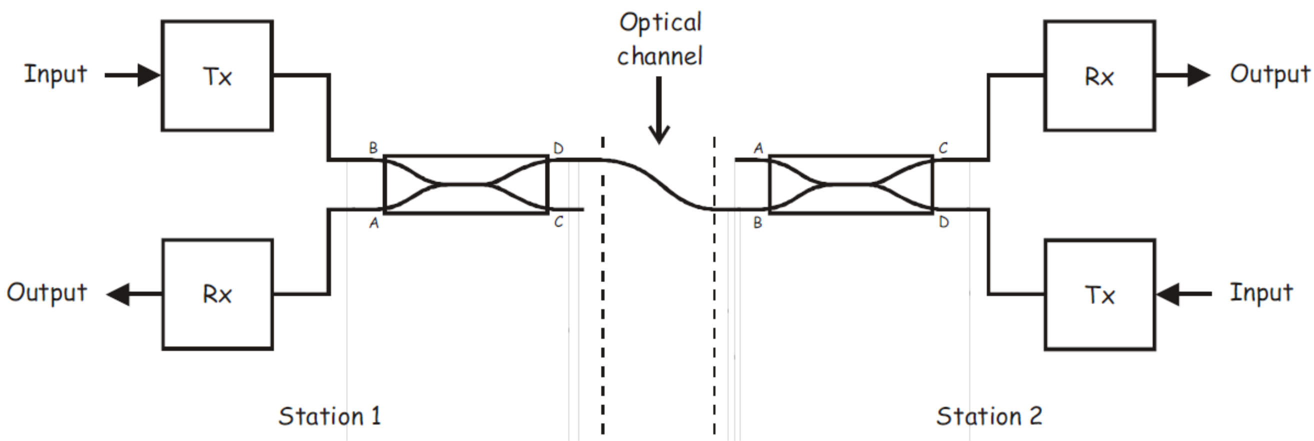


Figure 1

As you can see, the transmitter (Tx) of Station 1 is connected to the channel via the weak path of its optical coupler (that is, from port B to D). This transmitted signal is connected to the receiver (Rx) at Station 2 via the strong path of its optical coupler (that is, from port B to C). At the same time, the transmitter of Station 2 is connected to the channel via the weak path of its optical coupler (that is, from port D to B) and this signal is directed to the Station 1 receiver via its optical coupler's its strong path (that is, from port D to A).

The fact that the two signals travel through a weak path of one of the optical couplers is responsible for the higher losses involved in this method of loading and unloading the signals (compared with using a circulator).

Also, recall from your investigations into the operation of the Coupler modules in Experiment 10, that the input signal to an optical coupler is actually split three ways not just two. A small amount of light is reflected to the port on the same end as the input. For example, a signal injected in to port A results in a very small signal on the output of port B. This is responsible for the cross-talk mentioned earlier and may need to be managed.

The experiment

For this experiment you'll use the Emona FOTEx to set up a uni-directional communication system over a fiber optic channel. Once you've established that the set-up is working, you'll modify it to implement a full fiber optic bi-directional communications system and investigate its operation.

Procedure

Part A – Setting up a uni-directional fiber optic communications system
Before experimenting with bi-directional fiber optic communications, it's useful to set up a uni-directional link first.

1. Ensure that the NI ELVIS II power switch at the back of the unit is off.

2. Carefully plug the Emona FOTEx experimental add-in module into the NI ELVIS II.

3. Insert the holding screws to secure the FOTEx module to the NI ELVIS II.

   Note: This must be done with the power off to avoid damaging the FOTEx.

4. Connect the NI ELVIS II to the PC using the USB cable.

   Note: This may already have been done for you.

5. Turn on the NI ELVIS II power switch at the rear of the unit then turn on its *Prototyping Board Power* switch at the top right corner near the power indicator.

6. Turn on the PC and let it boot-up.

7. Launch the NI ELVISmx software.

8. Select one of the **red** LED Transmitter modules and set its *Mode* control to *ANALOG*.

9. Select one the Receiver modules and set its *Gain Range* control to *HI*.

10. Turn the same Receiver module's *Variable Gain* control fully clockwise.

11. Connect the set-up shown in Figure 2 below using the Transmitter and Receiver modules you adjusted for Steps 8 to 10.

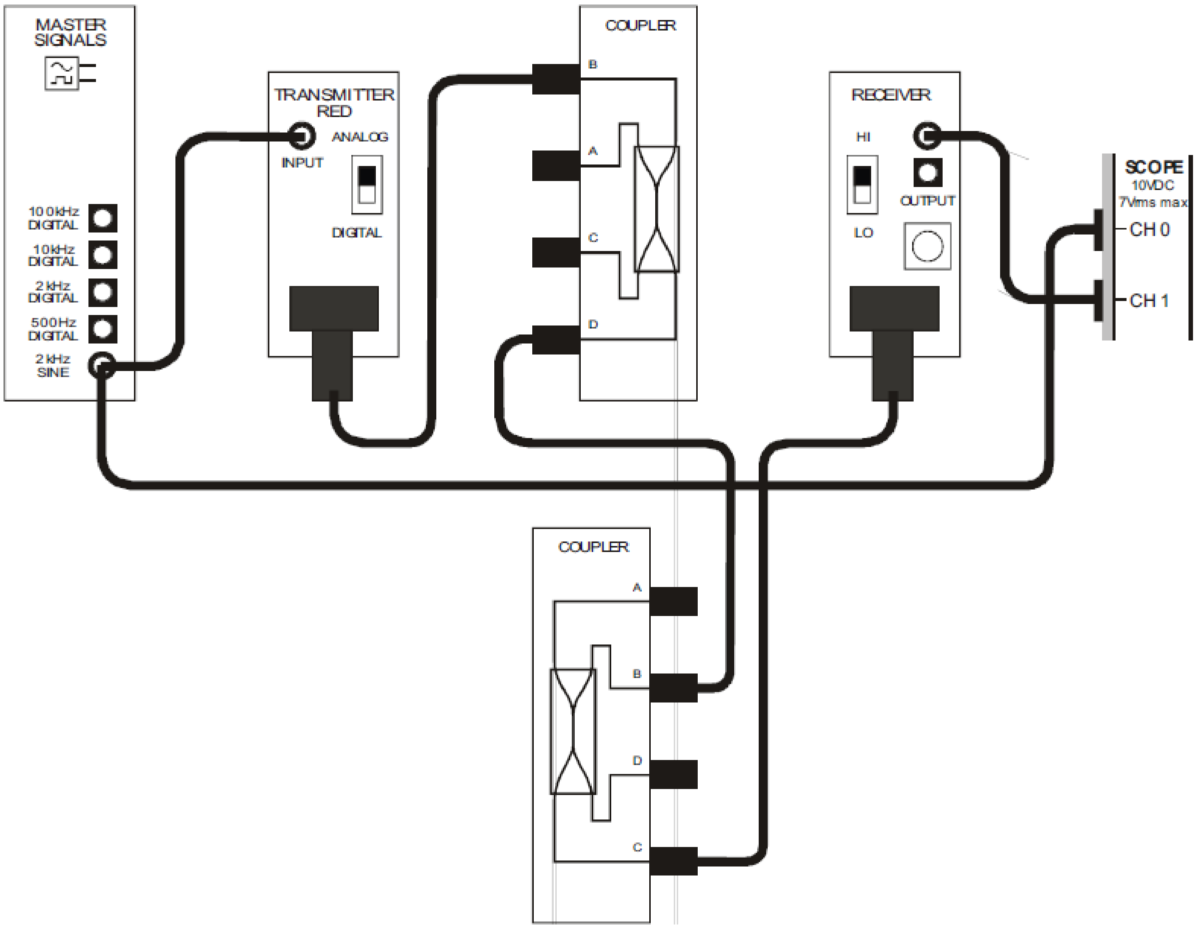


Figure 2

This set-up can be represented by the block diagram in Figure 3 on the next page. Station 1 is the transmitter in a uni-directional communications system and Station 2 is the receiver. An analog message is modeled by the Master Signals module's *2kHz SINE* output. The channel between the stations is modeled by the optical patch lead between the left and right couplers. The optical patch leads between the couplers and the Transmitter and Receiver modules are internal station connections and do not model the channel.

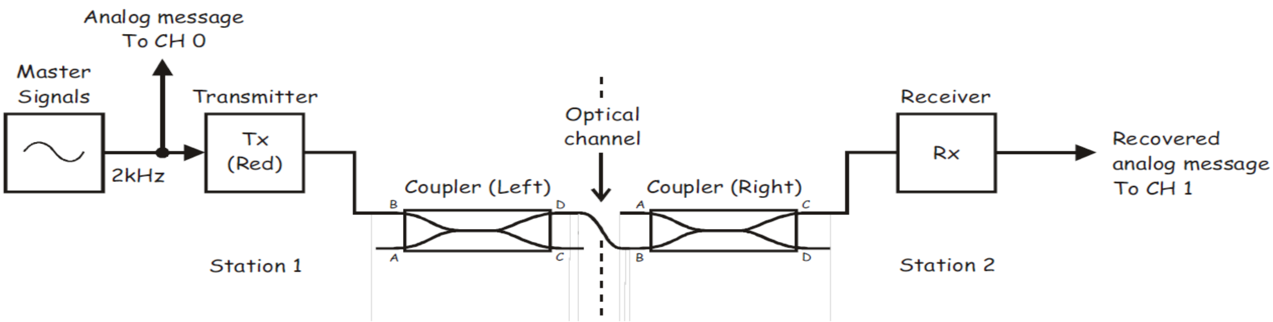


Figure 3

12. Launch and run the NI ELVIS II Oscilloscope VI.

13. Set up the scope per the procedure in Experiment 1 (page 1-12) with the following change:

    - *Timebase* control to *100μs/div* instead of *500μs/div*

14. Activate the scope's Channel 1 input to observe the recovered version of the analog message on the output of Station 2.

    Note: If the set-up has been wired correctly, you should observe a copy of the message at about the same amplitude.

Part B – Converting the set-up to a fiber optic bi-directional communications system
An additional Transmitter and Receiver module can be used to readily convert the current set-up to a bi-directional link. The next part of the experiment gets you to do so.

15. Set the *Mode* control of the other red Transmitter module to *DIGITAL*.

16. Set the *Gain Range* control of the other Receiver module to *LO*.

17. Turn the same Receiver module's *Variable Gain* control to about the middle of its travel.

18. Make the following changes to the scope's set-up:

    - *Input Coupling* controls for both channels to the *DC* position instead of the *AC* position
    - Channel 1 *Vertical Position* control to *-5V* instead of *0V*
    - *Timebase* control to the *50μs/div* position instead of the *100μs/div* position
    - *Trigger Type* control to the *Digital* position instead of the *Edge* position

19. Modify the set-up as shown in Figure 4 below.

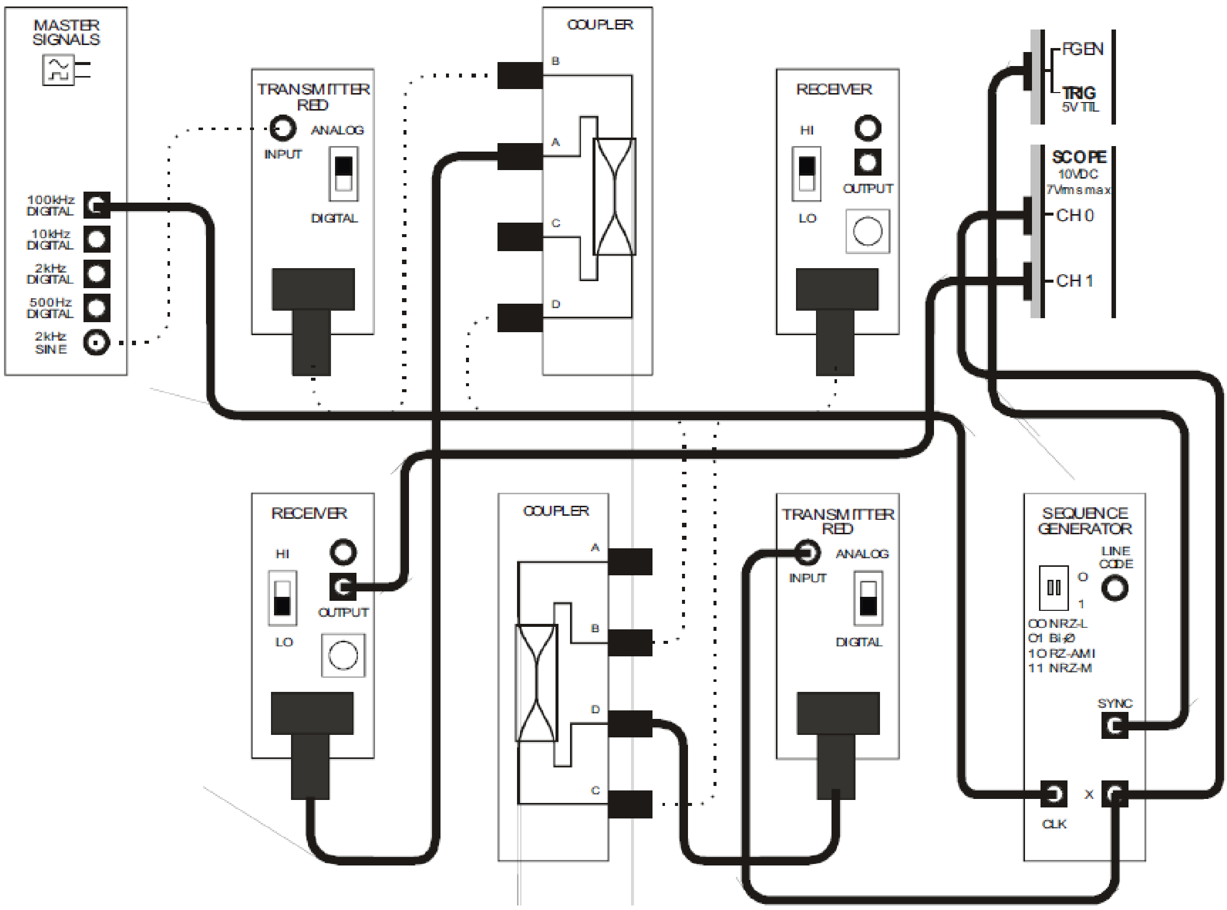

MASTER SIGNALS
100kHz DIGITAL
10kHz DIGITAL
2kHz DIGITAL
500Hz DIGITAL
2kHz SINE
TRANSMITTER RED
INPUT
ANALOG
DIGITAL
COUPLER
A
B
C
D
RECEIVER
HI
LO
OUTPUT
FGEN
TRIG
5V TTL
SCOPE
10VDC
7Vrms max
CH 0
CH 1
SEQUENCE GENERATOR
LINE CODE
0
1
00 NRZ-L
01 Bi-Ø
10 RZ-AMI
11 NRZ-M
SYNC
CLK
X

Figure 4

The set-up in Figure 4 can be represented by the block diagram in Figure 5 below. Both stations can now transmit and receive information. For contrast, the Station 2 message is a digital data signal modeled by the Sequence Generator module with a 100kHz bit-clock. The channel (modeled by the optical patch lead between the left and right couplers) now carries information in both directions.

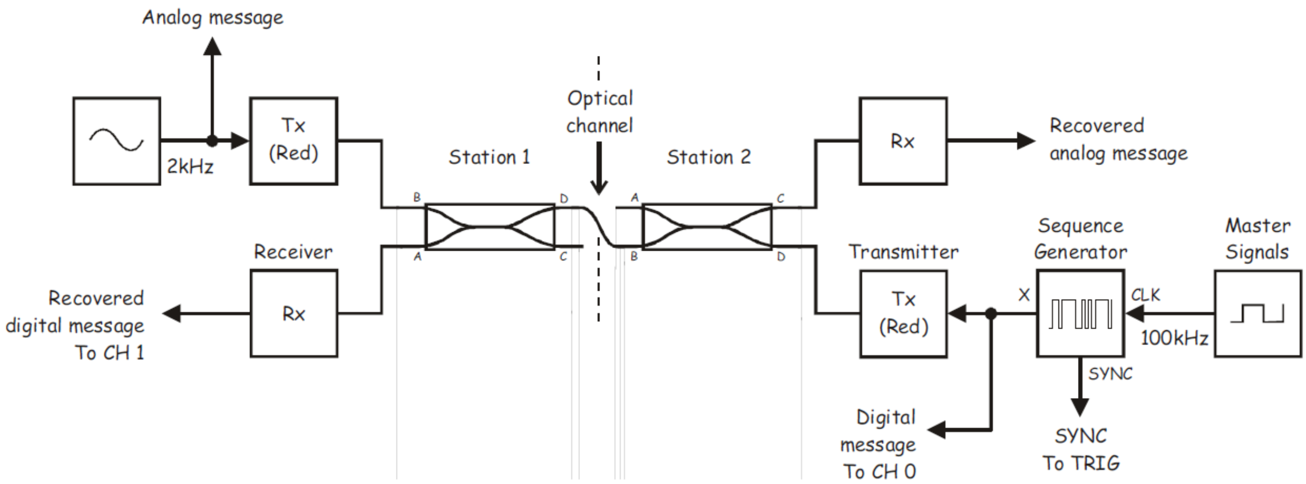


Figure 5

20. Observe digital data message and the recovered version of it on the output of Station 1.

Note: If the set-up has been wired correctly and the scope is adjusted correctly, you should observe two digital data signals with the same amplitude.

Question 1

In which direction does the analog message travel?

☐ From Station 1 to Station 2 ✓

☐ From Station 2 to Station 1

Question 2

In which direction does the digital message travel?

☐ From Station 1 to Station 2

☐ From Station 2 to Station 1 ✓

Question 3

How many of the optical patch leads are used to model the channel?

Only one (the lead between the left and right couplers).

21. Modify the scope's connections to the set-up as shown in Figure 6 below.

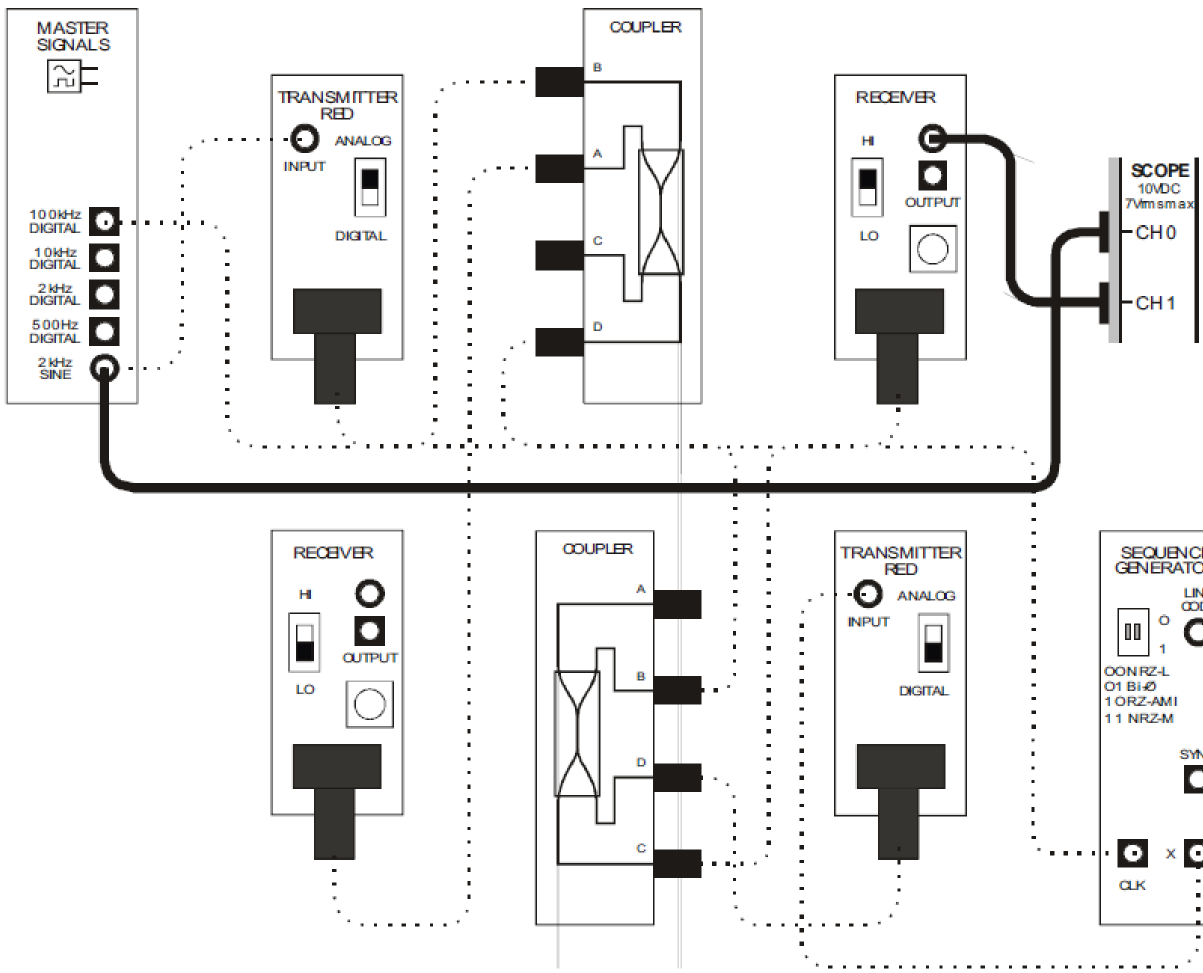


Figure 6

The changes to the scope's connections in Figure 6 can be represented by the block diagram in Figure 7 below. The change has been made to observe the analog message and the recovered version of it.

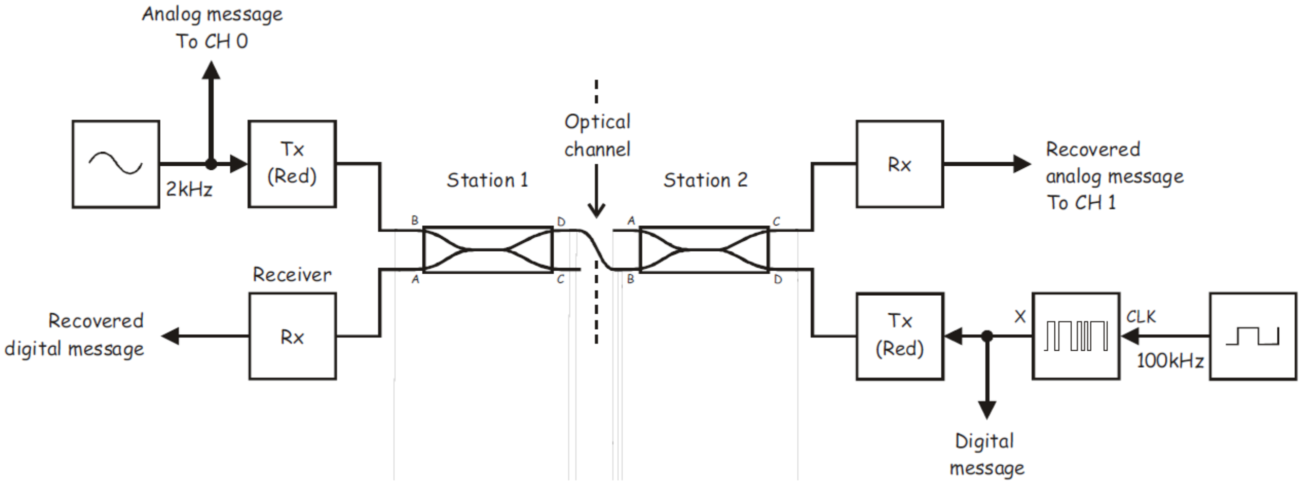


Figure 7

22. Make the following changes to the scope's set-up:

- *Input Coupling* controls for both channels back to the *AC* position
- Channel 1 *Vertical Position* control back to *0V*
- *Timebase* control back to the *100µs/div* position
- *Trigger Type* control back to the *Edge* position

23. Observe the analog message and the recovered version of it.

Note: You should see that the recovered version of the analog message is now distorted.

Question 4

It's clear that some of the digital message is super-imposed on the recovered version of the analog message? What's the name for this problem?

Cross-talk.

Question 5

Which one of the Coupler modules is causing this problem and why?

The right side Coupler module that forms part of Station 2. This is because some of the signal on its port D is reflected back to its port C due to the optical properties of the fiber fusion coupling.

Question 6
How can the analog message be cleaned up?

Pass the Station 1 receiver's output through a low-pass filter with a cut-off frequency above the highest frequency in the message but below the digital data signal's bit-clock frequency.

Question 7
Under what conditions would this solution be unsuitable for this set-up?

If the bit-clock for the digital data is too close the highest frequency in the analog message or even below it (and therefore the digital data signal consists of harmonics inside the LPF's pass-band as well) or; if the digital message is a baseband analog signal.

Question 8
Why didn't the recovered version of the digital message (on the output of Station 1) experience this problem?

As the signal is digital the Receiver module's digital output must be used. This output uses a comparator or decision making circuit of some sort to clean-up digital signals.

Question 9
Which optical patch lead or leads in the set-up are carrying information in both directions?

Only the lead between the left and right couplers (which we are using to model the channel between the stations).

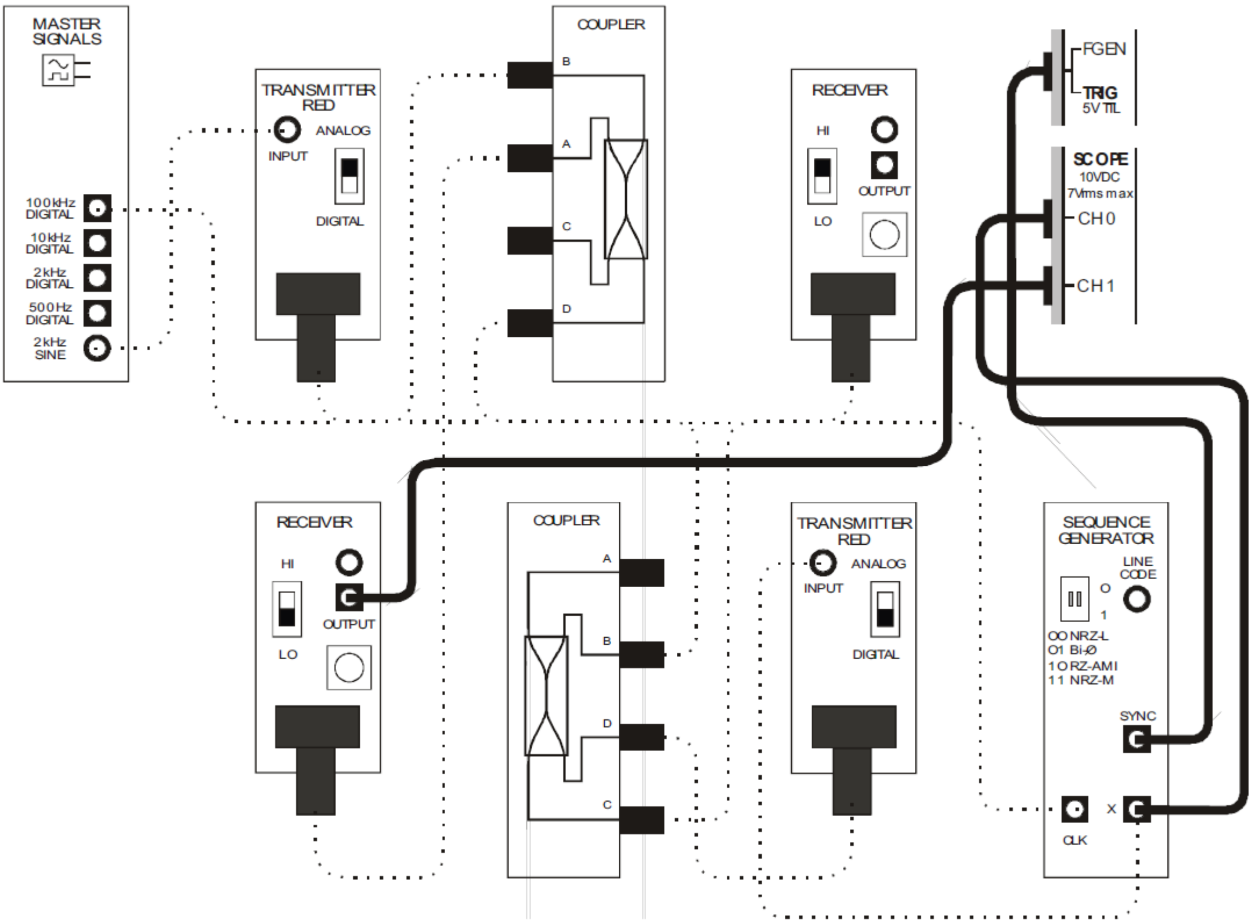
The next part of the experiment lets you verify your answer to Question 9.

24. Disconnect one end of any one of the optical patch leads and observe the effect on the recovered message.

25. Reconnect the optical patch lead.

26. Repeat Steps 24 and 25 for the rest of the optical patch leads. Make a note of all the patch leads that, when disconnected, cause the recovered analog message to be lost.

27. Modify the scope's connections to the set-up as shown in Figure 8 below.



The changes to the scope's connections return the set-up to the block diagram in Figure 5.

28. Make the following changes to the scope's set-up:

- *Input Coupling* controls for both channels back to the *DC* position
- Channel 1 *Vertical Position* control back to *-5V*
- *Timebase* control back to the *50µs/div* position
- *Trigger Type* control back to the *Digital* position

29. Repeat Steps 24 to 26.

Note: As you do, note which optical patch lead or leads from Steps 24 to 26 also cause the recovered digital message to be lost.

Question 10

Explain how your observations prove your answer to Question 9.

Only the patch lead between the left and right couplers would have caused the recovered message to be lost at the output of both receivers. Therefore, it must be the only optical patch lead carrying information in both directions.

Think about the physical nature of this optical medium and consider how it differs from electrical signals traveling in a channel made of an electrical conductor. With the bi-directional electrical signal, the opposing currents (made up of electron flow) subtract from one another and the individuality of the signals is lost. In the case of the optical medium, the photons of light are independent elements and do not interact significantly with other elements in the channel.

Importantly, this is true even when both optical signals are operating in the same frequency band as long as they're traveling in opposite directions. However, if they are operating at the same frequency band but traveling in the same direction, it's impossible to separate them at the receiver. This issue is explored in Experiment 11 on wave division multiplexing (WDM).

Experiment5: Wave Division Multiplexing (WDM)

Experiment 9 (on PCM-TDM 'T1' implementation) shows that a single light source can be used to allow multiple users to share a fiber optic channel. This is achieved by time division multiplexing (TDM) the channel using pulse code modulation (PCM).

Usefully, a fiber optic channel can be multiplexed in another way instead of (or, more likely, in addition to) using TDM. It involves coupling multiple users to the channel via independent light sources operating at different wavelengths and is known as *wavelength division multiplexing* (WDM). Naturally, the equivalent number of receivers must be connected to the other end of the channel. However, as optical receivers respond to light of all wavelengths, the light must first be separated by wavelength using optical filters and directed to the appropriate receiver.

In telecommunications, the loading and unloading of signals is performed by equipment designed specifically for the infra-red light sources that are commercially used. As similar devices for the visible light used on the Emona FOTEx are not readily available, WDM can instead be modeled using its two optical couplers as shown in Figure 1 below.

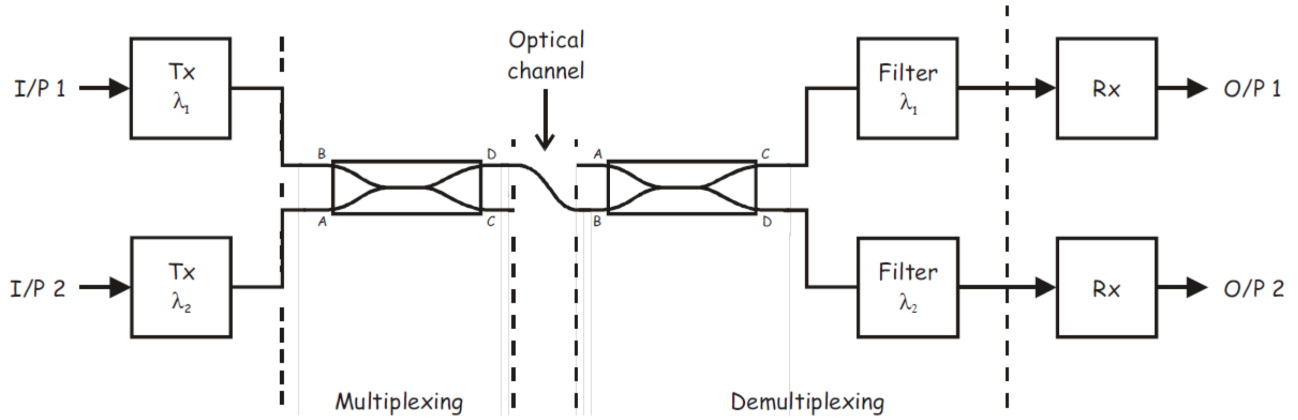


Figure 1

As you can see, a transmitter connects a user to port B of an optical coupler and another transmitter connects a second user to port A. As you know, the light for both signals appears on both ports C and D due to the coupler's optical combining characteristic.

Importantly, whichever of ports C or D connect to the channel (port D in Figure 1 but port C could have been used) the signal on it can be considered WDM when the transmitters use light at different wavelengths and the receivers are able to discriminate between them. This is the case here because after a second coupler directs the combined light to two outputs (ports C and D) optical filters are used to let light at only the appropriate wavelength through to the appropriate receiver.

If you study Figure 1 closely, you'll notice that the two light signals travel through the strong path of one of the optical couplers but also through the weak path of the other. Passage of the light via one of the optical coupler's weak paths is responsible for losses greater than normal for devices used in the commercial implementation of WDM.

The experiment

For this experiment you'll use the Emona FOTEx to transmit two discrete message signals along an optical fiber in the same direction using wave division multiplexing (WDM). You'll use the set-up to investigate the need for filtering to recover just one of the messages. Then you'll modify it to implement a complete two-channel WDM communication system and investigate its operation. Finally, you'll convert the set-up to combine WDM with TDM to transmit and receive three channels of information.

Procedure

Part A – Investigating wave division multiplexing

The first part of this experiment gets you to transmit two discrete message signals along an optical fiber in the same direction using wave division multiplexing. A complete two-channel WDM communications system is **not** modeled at this stage.

1. Ensure that the NI ELVIS II power switch at the back of the unit is off.

2. Carefully plug the Emona FOTEx experimental add-in module into the NI ELVIS II.

3. Insert the holding screws to secure the FOTEx module to the NI ELVIS II.

   Note: This must be done with the power off to avoid damaging the FOTEx.

4. Connect the NI ELVIS II to the PC using the USB cable.

Note: This may already have been done for you.

5. Turn on the NI ELVIS II power switch at the rear of the unit then turn on its *Prototyping Board Power* switch at the top right corner near the power indicator.

6. Turn on the PC and let it boot-up.

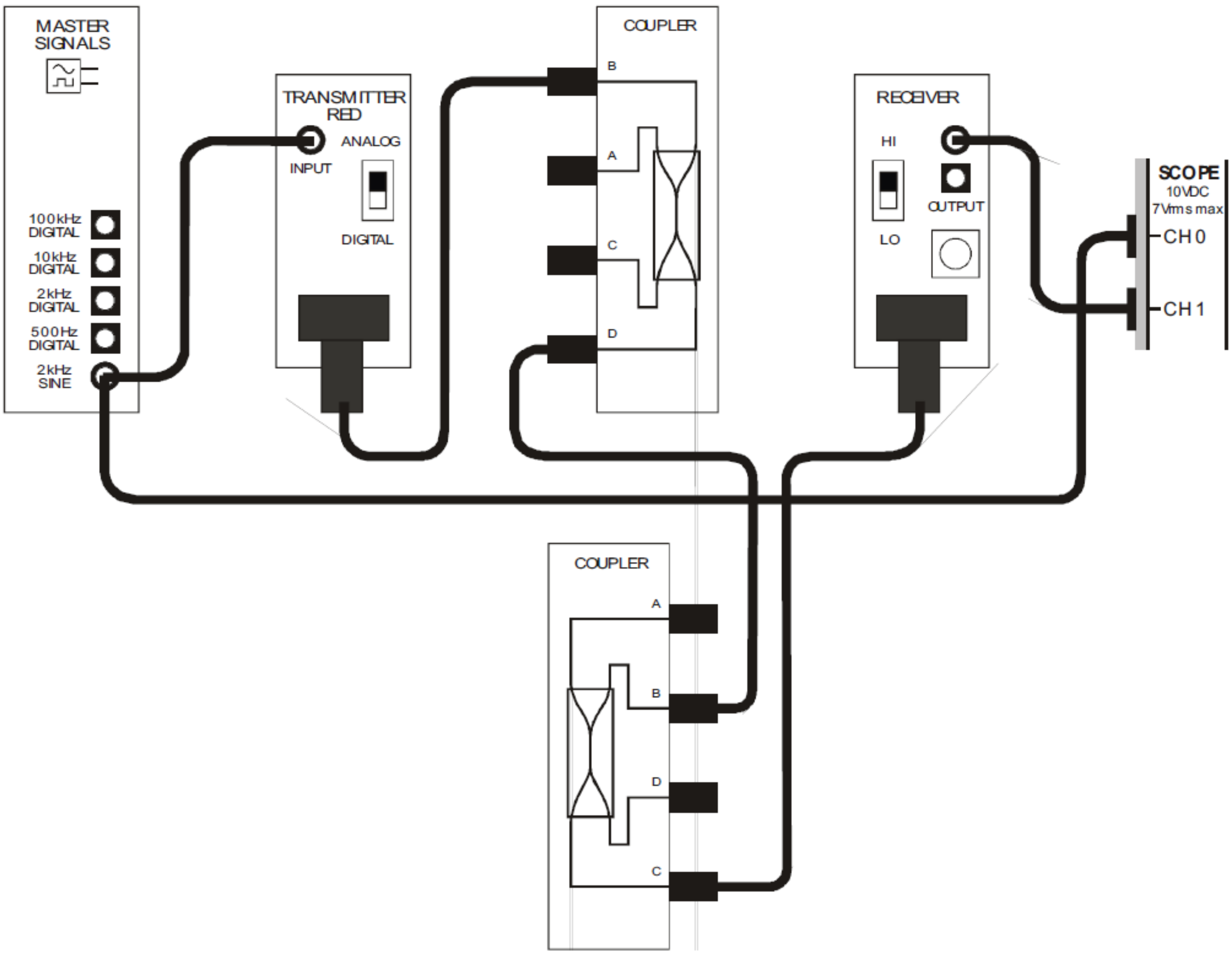
7. Launch the NI ELVISmx software.

8. Select one of the **red** Transmitter modules and set its *Mode* control to *ANALOG*.

9. Select one the Receiver modules and set its *Gain Range* control to *HI*.

10. Turn the same Receiver module's *Variable Gain* control fully clockwise.

11. Connect the set-up shown in Figure 2 on the next page using the Transmitter and Receiver modules you adjusted for Steps 8 to 10.



This set-up can be represented by the block diagram in Figure 3 below. The arrangement is a single-channel fiber optic transmission system. The Master Signals module's *2kHz SINE* output is used to model an analog message. Coupler modules are used to facilitate the remainder of the experiment.

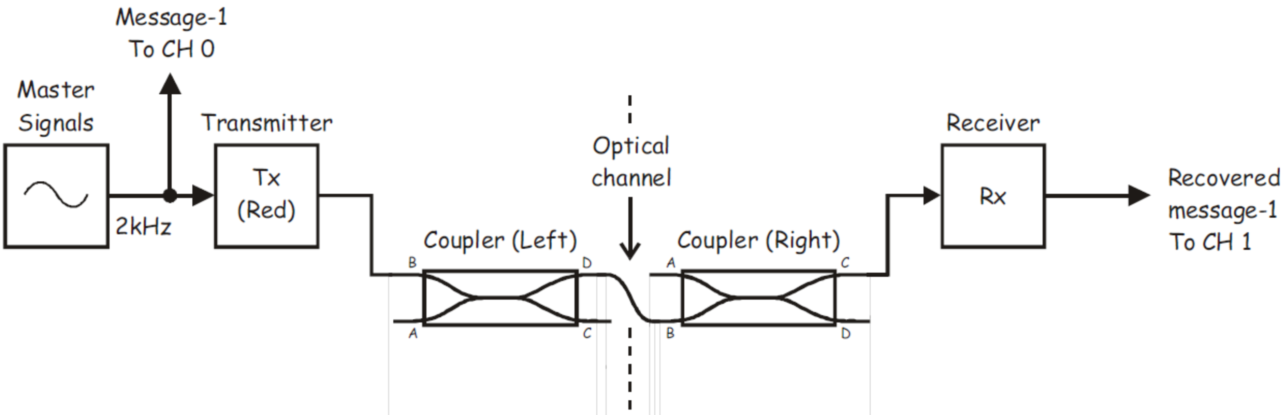


Figure 3

12. Launch and run the NI ELVIS II Oscilloscope VI.

13. Set up the scope per the procedure in Experiment 1 (page 1-12) with the following change:

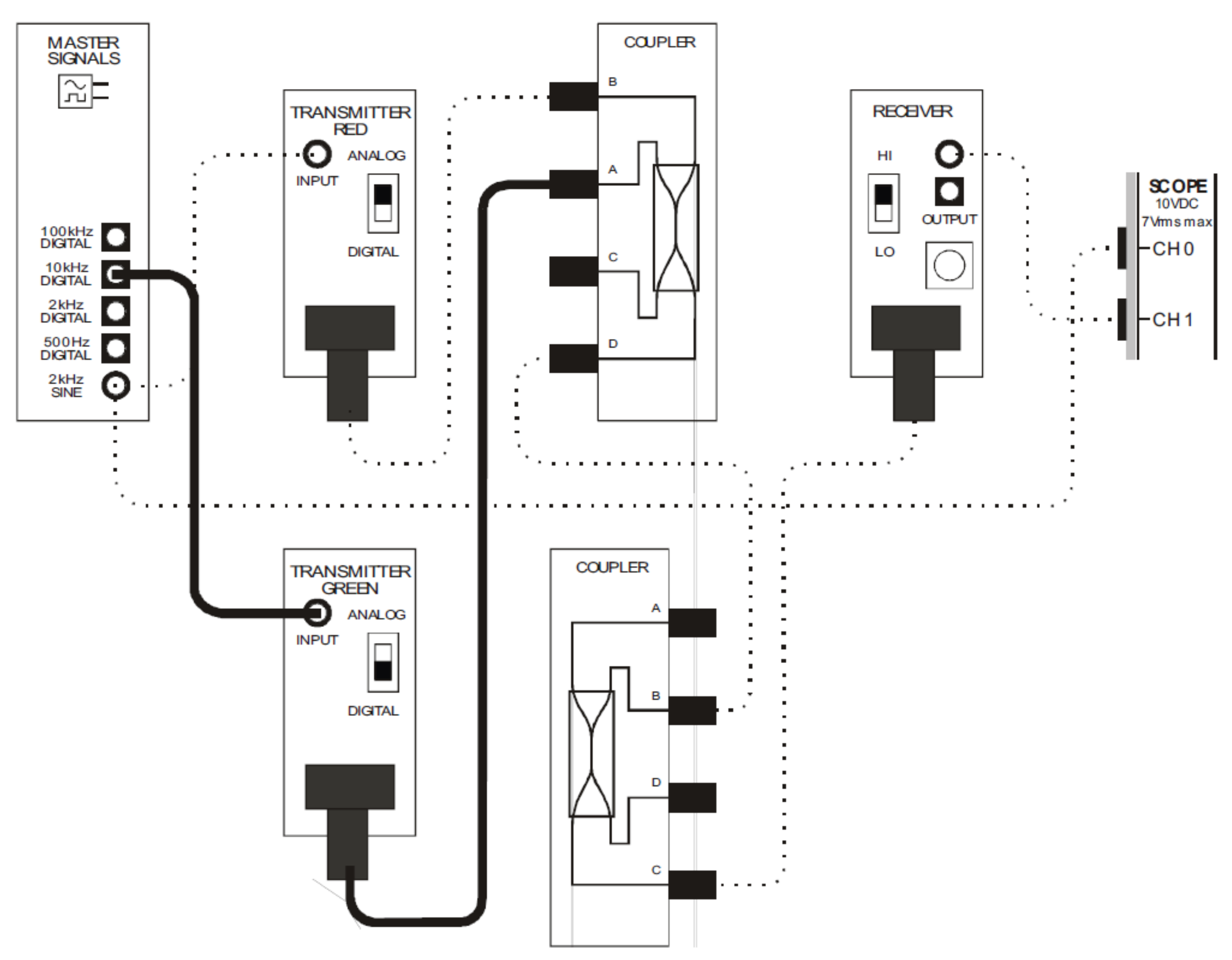
    - *Timebase* control to the *100μs/div* position instead of the *500μs/div* position

14. Activate the scope's Channel 1 input to observe the recovered message-1 as well as the original version of it.

    Note: If the set-up has been wired correctly, the two signals should be the same amplitude and phase.

15. Set the *Mode* control of the **green** Transmitter module to *DIGITAL*.

16. Modify the set-up as shown in Figure 4 below.


MASTER SIGNALS
100kHz DIGITAL
10kHz DIGITAL
2kHz DIGITAL
500Hz DIGITAL
2kHz SINE
TRANSMITTER RED
INPUT
ANALOG
DIGITAL
COUPLER
A
B
C
D
RECEIVER
HI
LO
OUTPUT
SCOPE
10VDC
7Vrms max
CH 0
CH 1
TRANSMITTER GREEN
INPUT
ANALOG
DIGITAL
COUPLER
A
B
D
C

The set-up in Figure 4 can be represented by the block diagram in Figure 5 below. The arrangement transmits two signals over the channel – an analog message and a digital message (modeled by the Master Signals module's *10kHz DIGITAL* output).

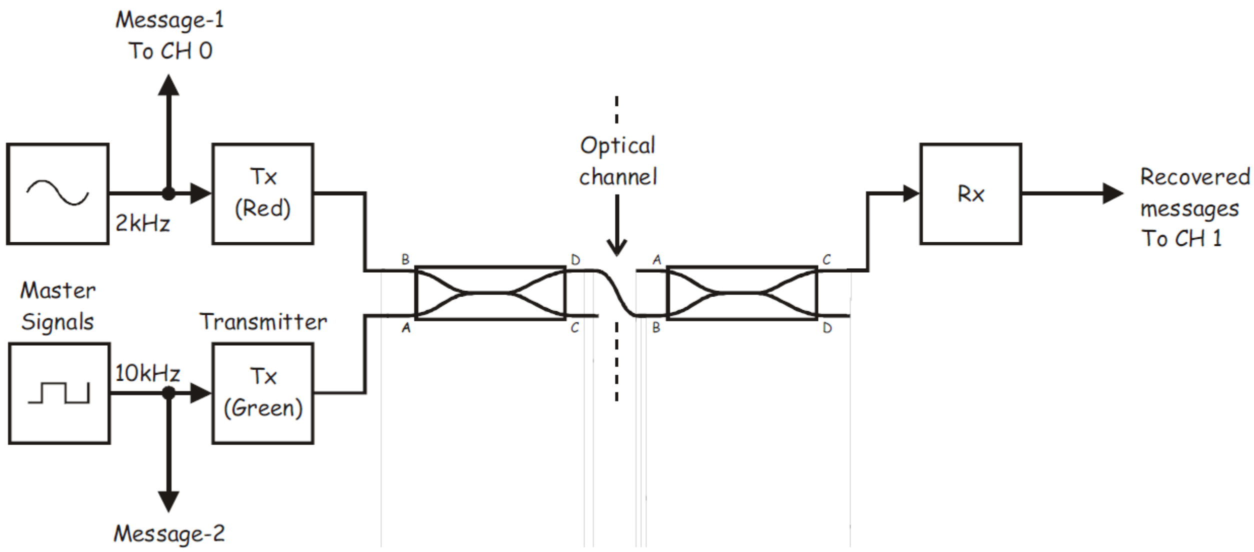


Figure 5

17. Observe the signal on the Receiver module's output.

Note: You should see a distorted version of the signal that you observed for Step 14.

Question 1

Describe the signal that you observe.

It's a sinewave with a squarewave superimposed on it.

Question 2

How does the operation of the Coupler modules create this distortion?

A light signal on either of the Coupler module's input ports appears on both output ports (weak & strong). So, when signals are connected to both input ports, the signals must be added together.

To verify your answer to Question 2…

18. Disconnect the optical patch lead at the Receiver.

19. Point the free end of the optical patch lead close to the desk, wall, white paper or the palm of your hand so you can see light from the end of the cable shining on it.

20. **Momentarily** disconnect the optical patch lead to the Red Transmitter and observe the effect.

    Note: Look closely as the change is subtle.

21. **Momentarily** disconnect the optical patch lead to the Green Transmitter and observe the effect.

22. Reconnect the optical patch lead at the Receiver and check to make sure that you've reconnected the other two leads as well.

Question 3
Why isn't the Receiver module able to select just one of the two light signals and reject the other?

The optical device used for the Receiver module's input responds to light at all wavelengths.

Question 4
What device must be used to allow the Receiver module to convert just one of the light signals back to an electrical signal instead of both of them?

A red or green optical filter.

To verify your answer to Question 4…

23. Modify the set-up as shown in Figure 6 below.

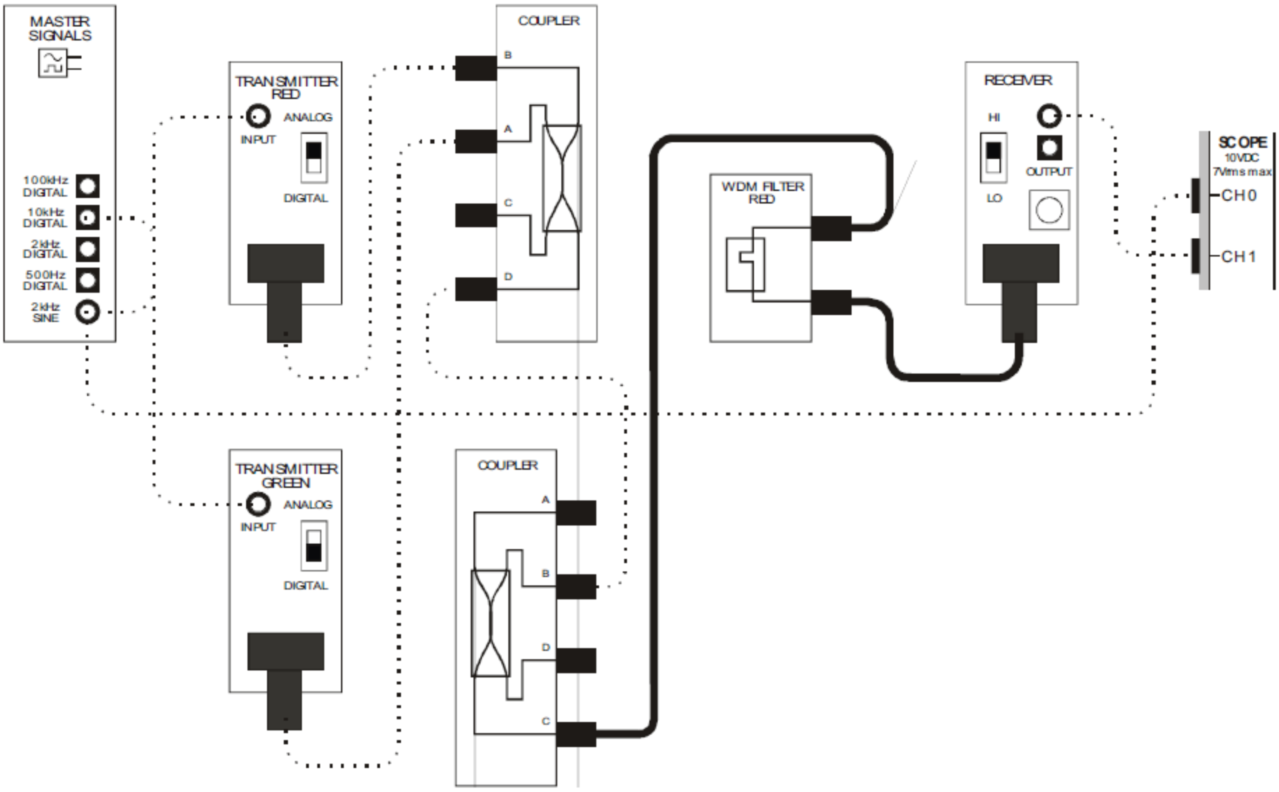


Figure 6

This set-up can be represented by the block diagram in Figure 7 on the next page. A filter has been introduced between the right-side Coupler module's C output and the Receiver module's input. This has been done to allow the Receiver module to recover only the analog message (that is, message-1).

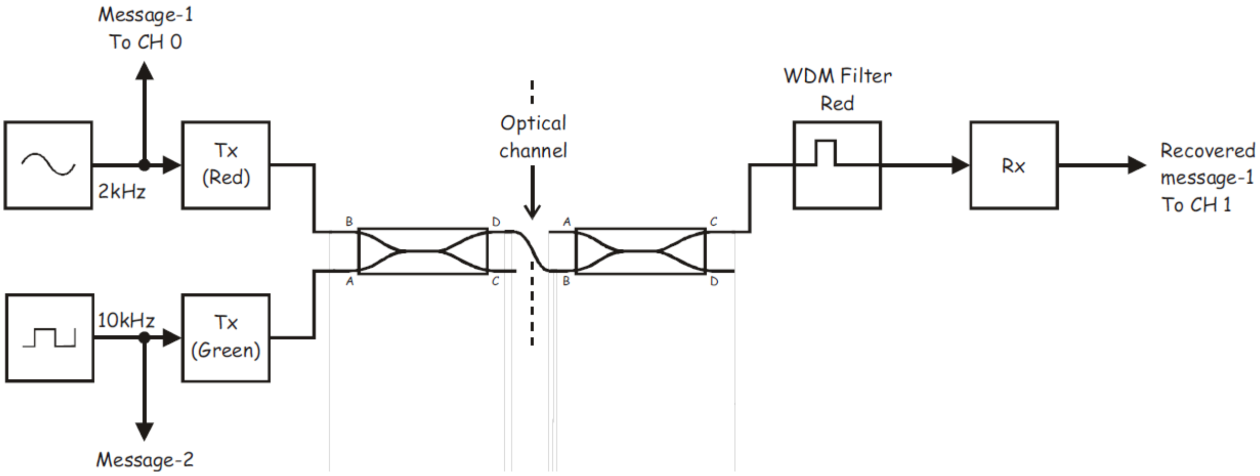


Figure 7

24. Set the scope's Channel 1 *Scale* control to the *200mV/div* position.

25. Observe the signal on the Receiver module's output.

    Note: The set-up should only be recovering message-1.

Part B – Converting the set-up to a complete two-channel WDM communications system

An additional filter and receiver can be used to readily convert the current set-up to a complete two-channel wavelength division multiplex (WDM) communications system. This is only true if the filter used for the receiving the second channel blocks red light and lets green light pass to the receiver. The next part of the experiment gets you to do this.

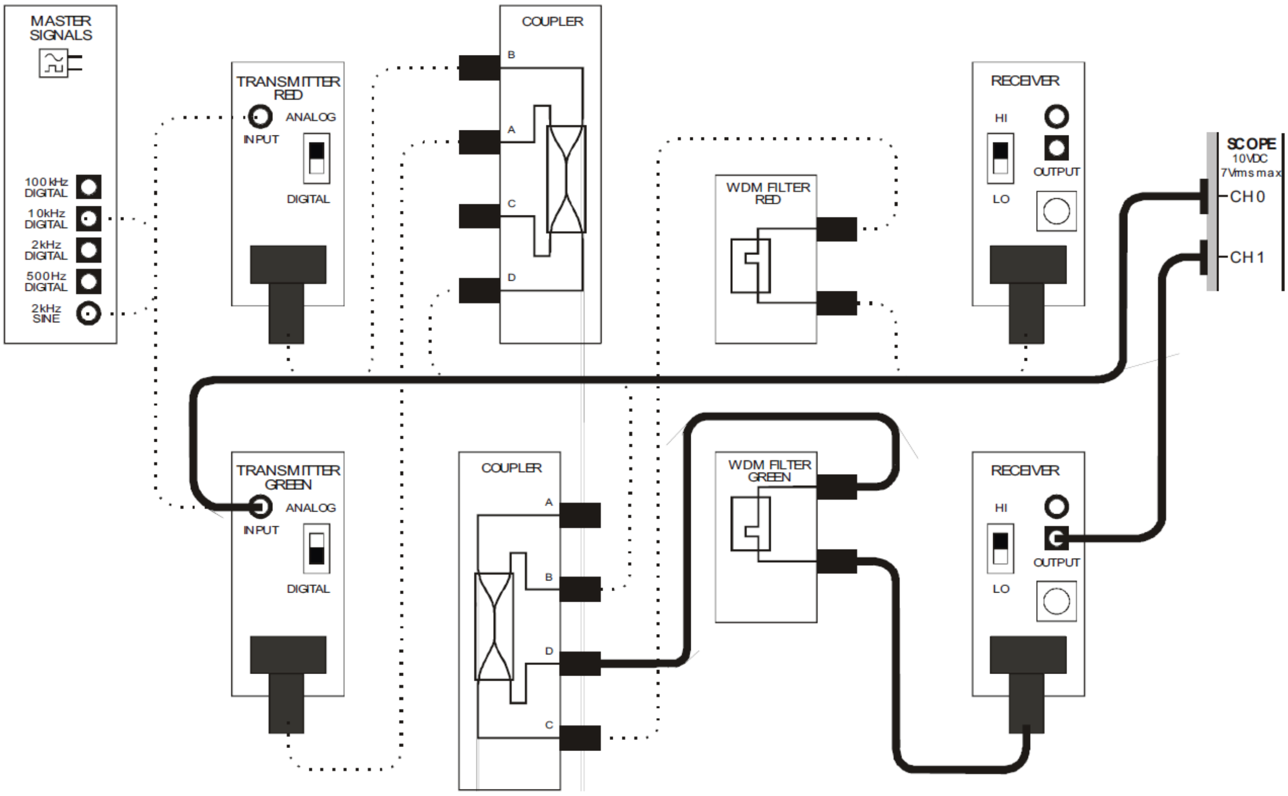
26. Set the *Gain Range* control of the unused Receiver module to *HI*.

27. Turn the same Receiver module's *Variable Gain* control fully clockwise.

28. Make the following changes to the scope's set-up:

- *Input Coupling* controls for both channels to the *DC* position instead of the *AC* position
- Channel 1 *Scale* control to the *1V/div* position instead of the *200mV/div* position
- Channel 1 *Vertical Position* control to *-5V* instead of *0V*
- *Trigger Level* control to *2V* instead of *0V*

29. Modify the set-up as shown in Figure 8 below.



The set-up in Figure 8 can be represented by the block diagram in Figure 9 below. The previously unused port D output of the right Coupler module is connected to the green WDM Filter module which lets only green light pass through to a second Receiver module. This Receiver module's output is a copy of message-2.

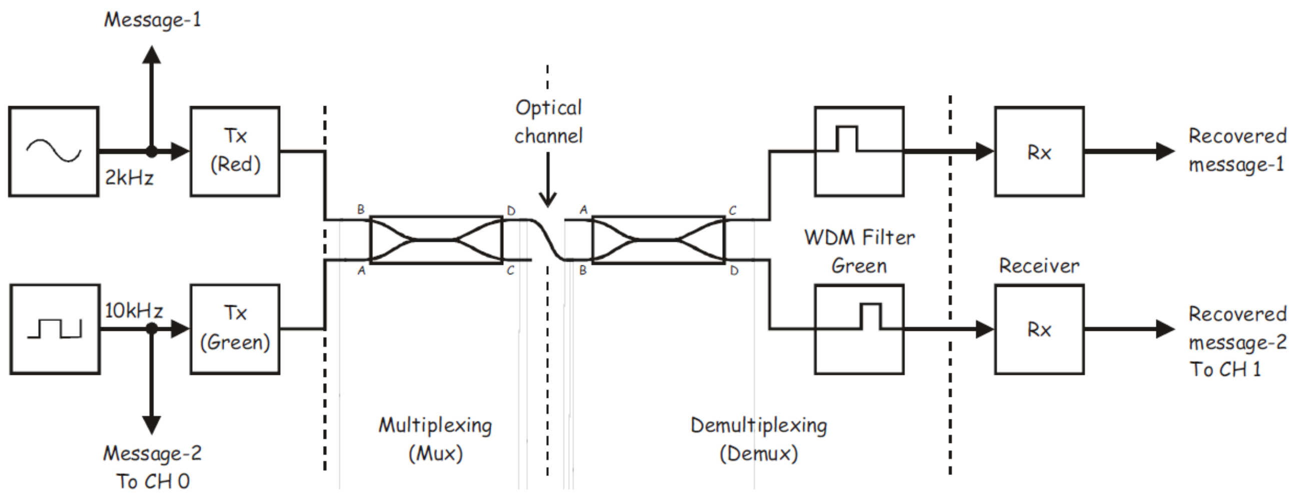


Figure 9

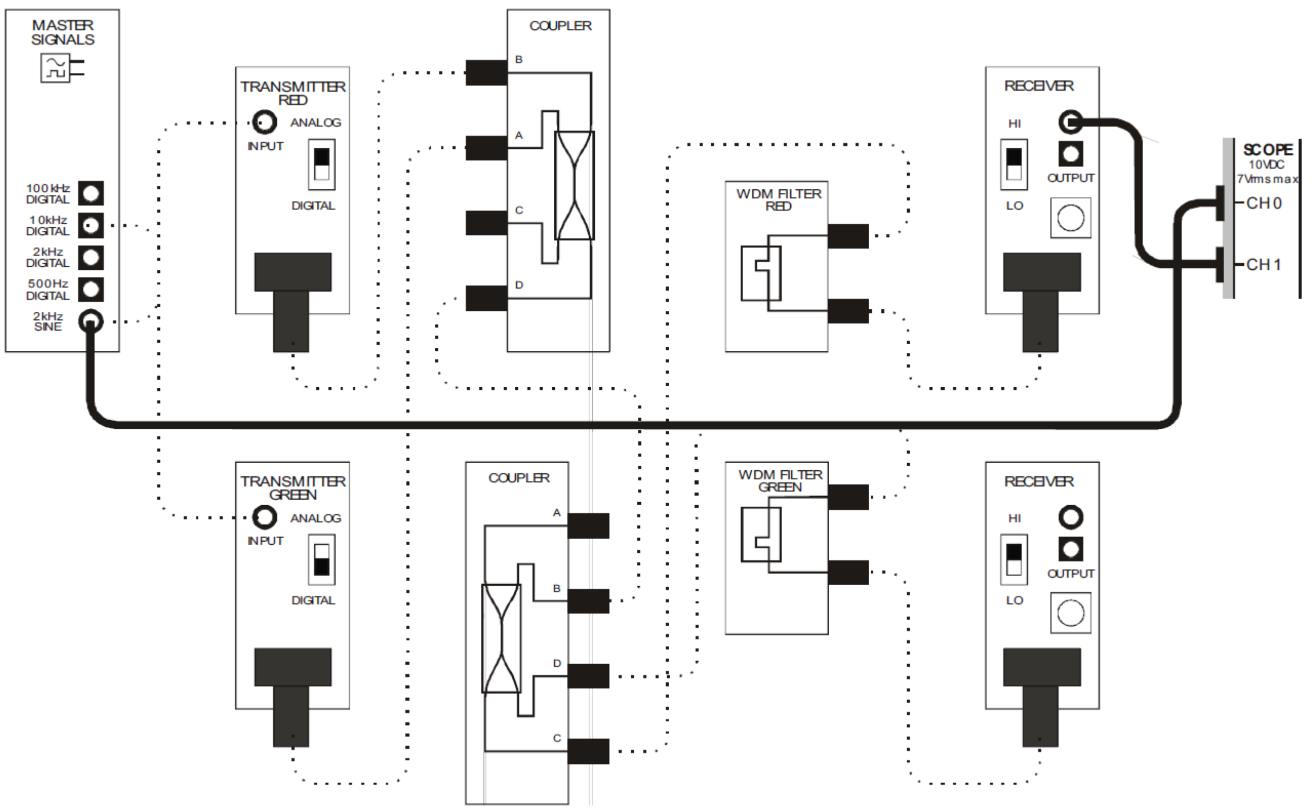
30. Observe message-2 and the recovered version of it on the output of second Receiver module.

    Note: If the set-up has been wired correctly, you should observe two 10kHz squarewaves with the same amplitude.

31. Make the following changes to the scope's set-up:

    - *Input Coupling* controls for both channels back to *AC*
    - Channel 1 *Scale* control back to *200mV/div*
    - Channel 1 *Vertical Position* control back to *0V*
    - *Trigger Level* control back to *0V*

32. Modify the scope's connections to the set-up as shown in Figure 10 below.



33. Disconnect the optical patch to the **red** Transmitter module's output.

34. Set the scope's Channel 1 *Scale* control to *50mV/division*.

35. Observe the signal on the Receiver module's output.

    Note: You should see a low-level copy of message-2.

Question 5
Why is this signal present?

Filters aren't perfect – They "reject" signals outside their pass-band (that is, attenuate them) but cannot remove them altogether.

Question 6
What potential problem can the presence of message-2 on the output of the message-1 Receiver module cause?

Cross-talk.

Question 7
Although a low-level copy of message-1 also appears on the message-2 Receiver module's output, this is unlikely to cause the same problem for digital signals. Why?

Digital signals can be cleaned-up using a comparator or decision maker. The cross-talk would have to be substantial for it to cause problems.

Part C – Converting the set-up to a three-channel TDM-WDM communications system

As mentioned in the preliminary discussion, WDM is used to increase the number of users operating on a channel. Recall that TDM is used for the same purpose. Unsurprisingly, these techniques can be combined and this is widely done in commercial telecommunications. The next part of the experiment gets you to convert the current set-up to a three-channel TDM-WDM communications system.

36. Reconnect the optical patch to the **red** Transmitter module's output.

37. Launch and run the NI ELVIS II Function Generator VI.

38. Adjust the function generator for an output with the following specifications:

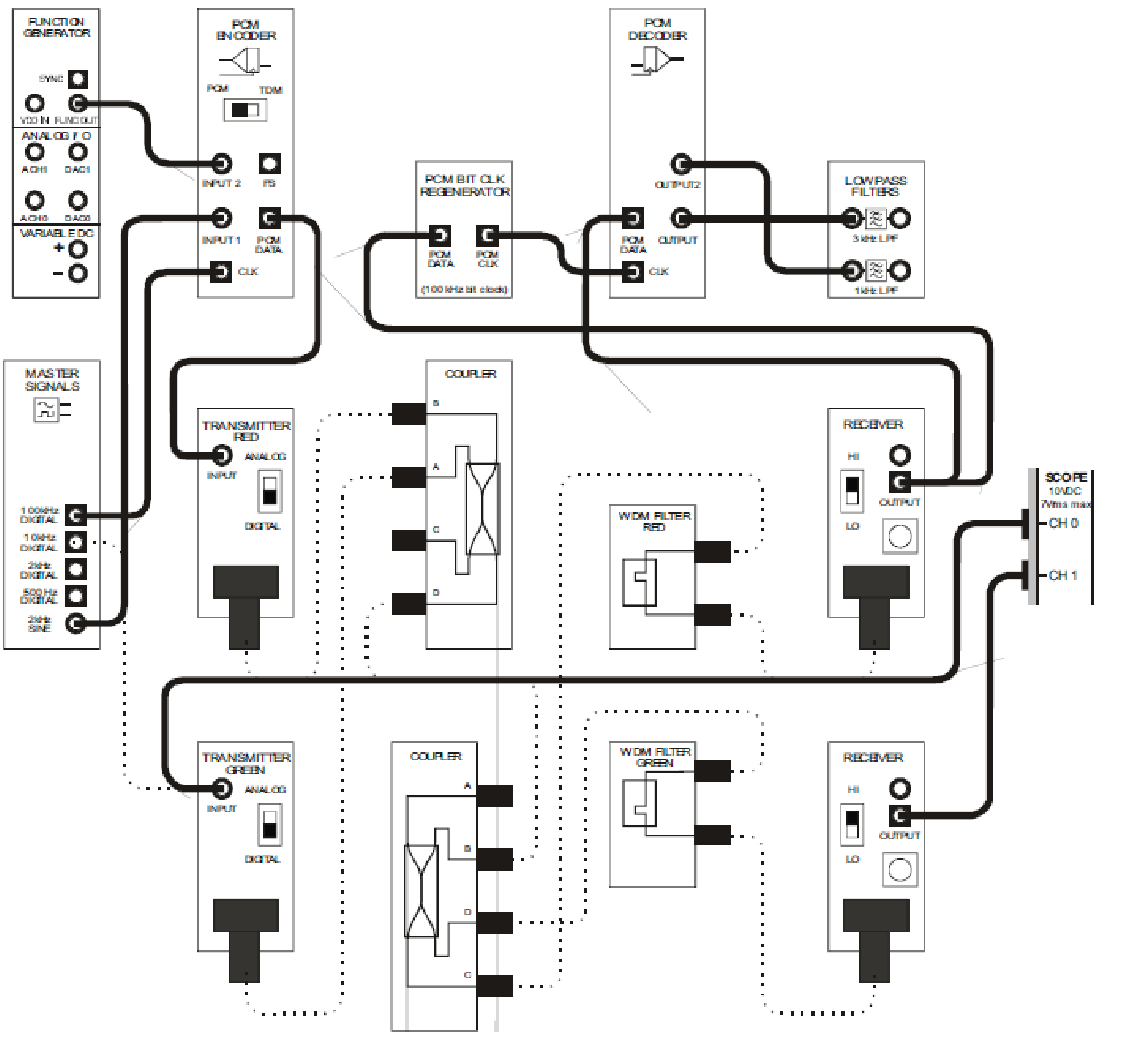
    - Waveshape: Sine
    - Frequency: 1kHz
    - Amplitude: 4Vpp
    - DC Offset: 0V

39. Set the *Mode* control of the **red** Transmitter module that is currently in the set-up to the *DIGITAL* position.

40. Make the following changes to the scope's set-up:

    - *Input Coupling* controls for both channels back to *DC*
    - Channel 1 *Scale* control back to *1V/div*
    - Channel 1 *Vertical Position* control back to *-5V*
    - *Trigger Level* control back to *2V*

41. Modify the set-up as shown in Figure 11 below.



FUNCTION GENERATOR
SYNC
VCO IN
FUNC OUT
ANALOG I/O
ACH1
DAC1
ACH0
DAC0
VARIABLE DC
PCM ENCODER
PCM
TDM
INPUT 2
FS
INPUT 1
PCM DATA
CLK
PCM BIT CLK REGENERATOR
PCM DATA
PCM CLK
(100 kHz bit clock)
PCM DECODER
OUTPUT2
PCM DATA
OUTPUT
CLK
LOW PASS FILTERS
3 kHz LPF
1kHz LPF
MASTER SIGNALS
100kHz DIGITAL
10kHz DIGITAL
2kHz DIGITAL
500Hz DIGITAL
2kHz SINE
TRANSMITTER RED
ANALOG
INPUT
DIGITAL
COUPLER
WDM FILTER RED
RECEIVER
HI
LO
OUTPUT
SCOPE
10VDC
7Vrms max
CH 0
CH 1
TRANSMITTER GREEN
COUPLER
WDM FILTER GREEN
RECEIVER

The set-up in Figure 11 can be represented by the block diagram in Figure 12 below. There are now three message signals being transmitted over the optical channel. Messages 1 and 2 are analog signals modeled by the Master Signals module's *2kHz SINE* output and the function generator (set for a 1kHz sinewave) respectively. These messages are encoded to PCM-TDM by the PCM Encoder module and this digital data signal is sent over the channel using red light. The third message is modeled by the Master Signals module's *10kHz DIGITAL* output and sent over the channel using green light as before.

At the receiving end, the red light containing the PCM-TDM data is filtered using the red WDM Filter module and sent to the PCM Decoder module where it is demultiplexed and decoded then sent to reconstruction filters to recover the original analog messages. The PCM Decoder module's local bit-clock is derived from the PCM data signal using the PCM Bit-clock Regenerator module.

The green light carrying message-3 over the channel is filtered using the green WDM Filter module and is available on the output of the Receiver module connected to it.

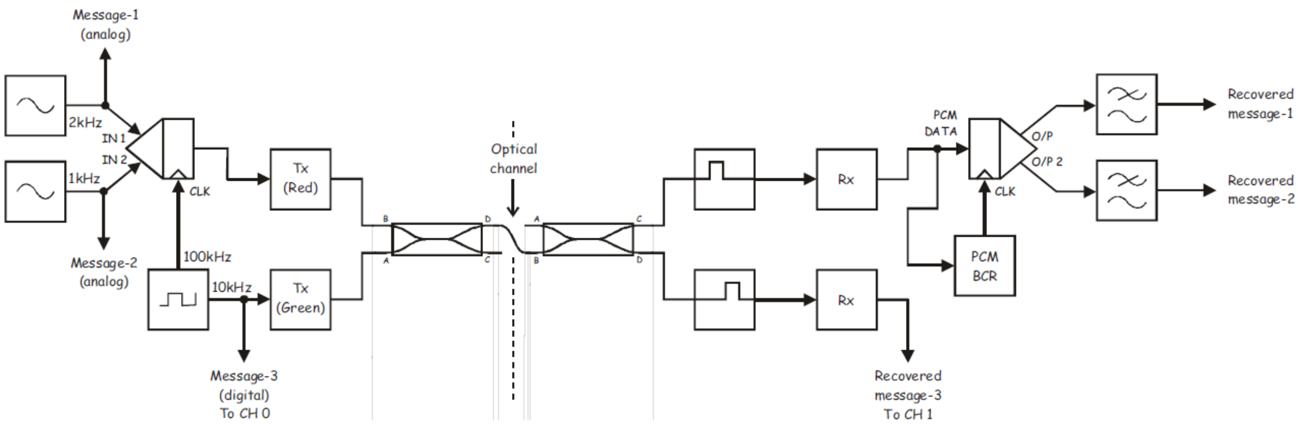


Figure 12

42. Check that the set-up is still recovering the model of a digital message (message-3).

43. Make the following changes to the scope's set-up:

- *Input Coupling* controls for both channels back to *AC*
- Channel 1 *Vertical Position* control back to *0V*
- *Timebase* control to the *200μs/div* position instead of the *100μs/div* position
- *Trigger Level* control back to *0V*

44. Modify the scope's connections to the set-up as shown in Figure 13 on the next page.

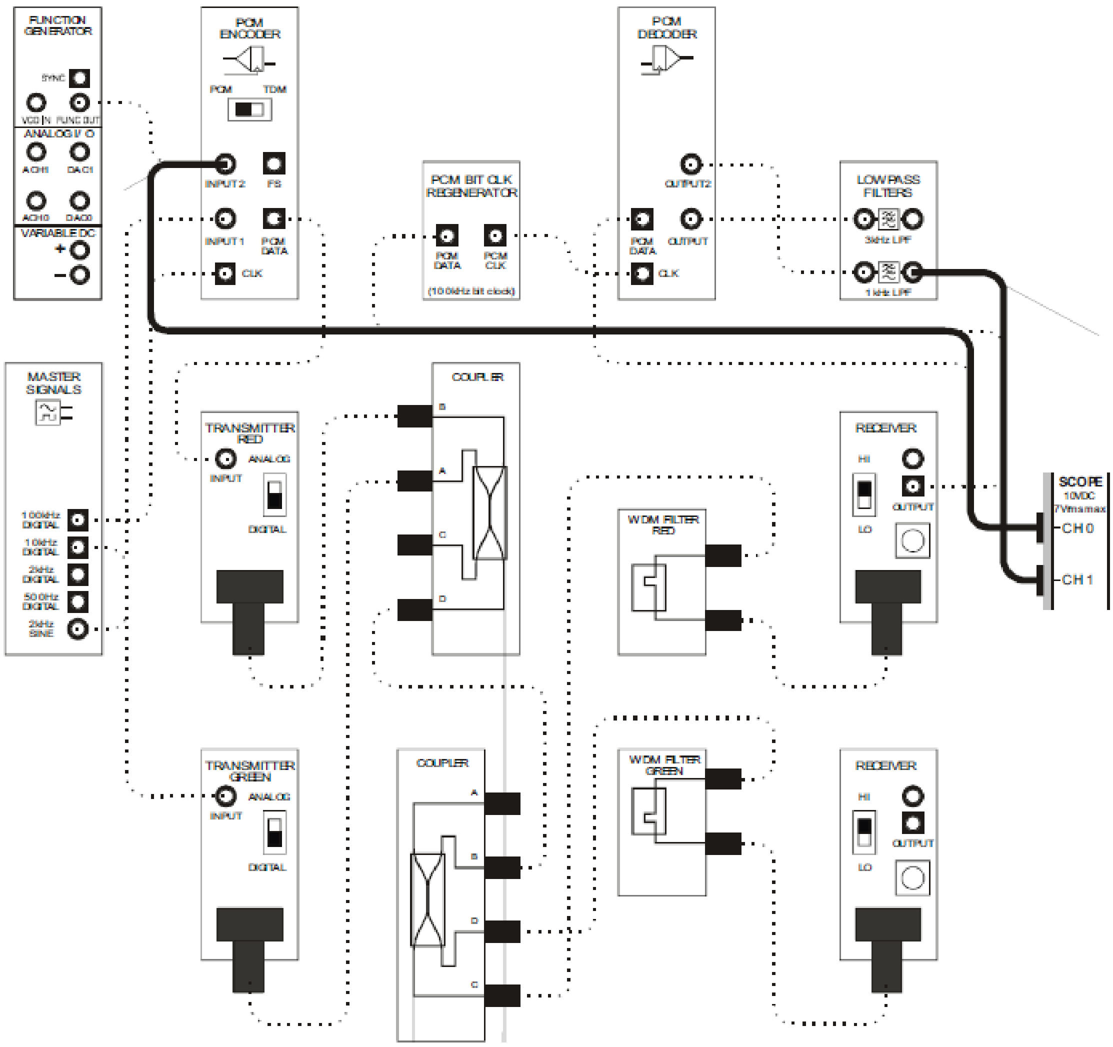


Figure 13

45. Observe the analog message-2 and the recovered version of it on the 1kHz LPF's output.

Note: If the set-up has been wired correctly and the scope is adjusted correctly, you should observe two 1kHz sinewaves.

46. Modify the scope's connections to the set-up as shown in Figure 14 below.

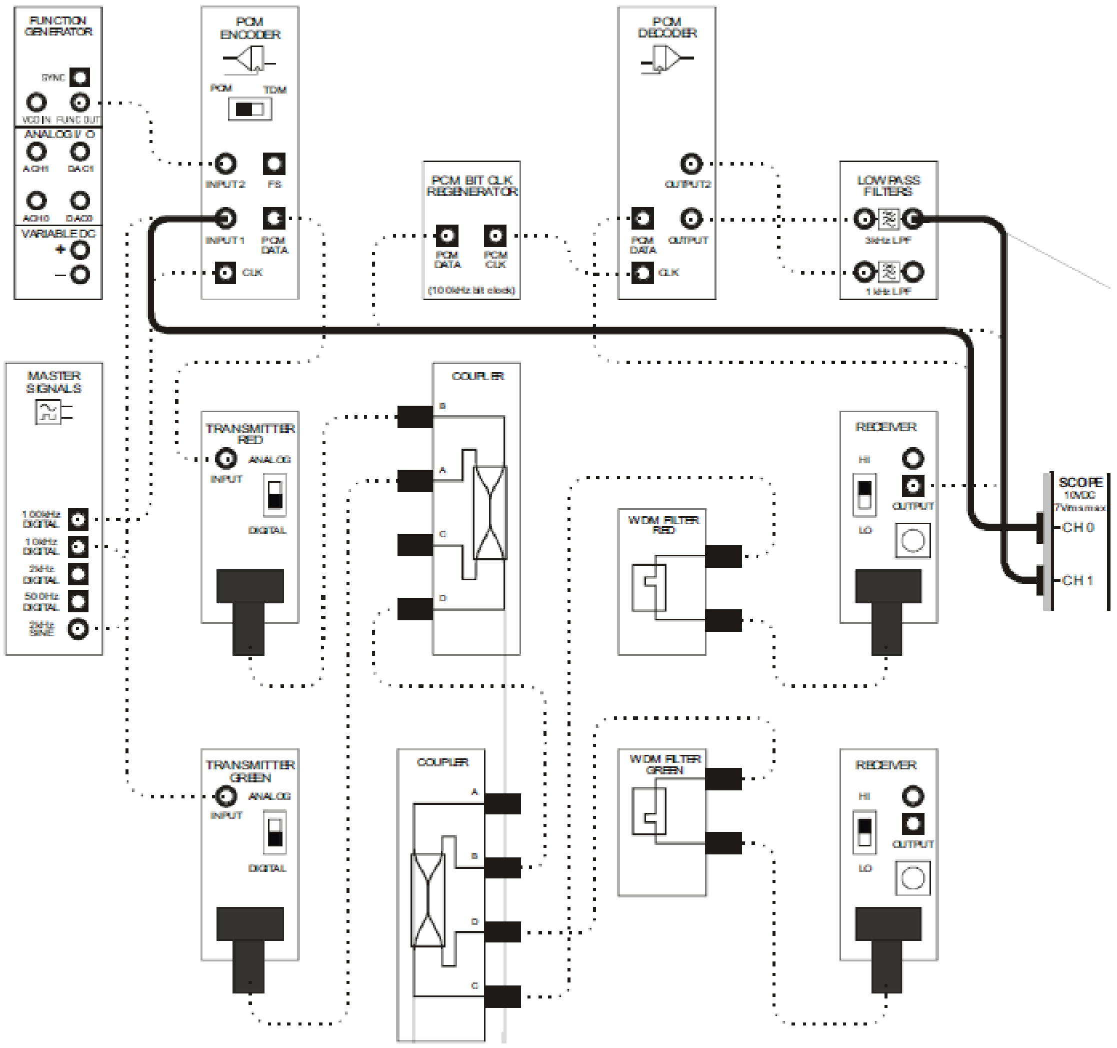


Figure 14

47. Observe the analog message-1 and the recovered version of it on the 3kHz LPF's output.

Note: If the set-up has been wired correctly and the scope is adjusted correctly, you should observe two 2kHz sinewaves (though the recovered version of it will be a little distorted).

Given the amount of information being transmitted over the channel, can you imagine the complexity of the light signal? The next part of the experiments gets you to look at it.

48. Modify the set-up as shown in Figure 15 below.

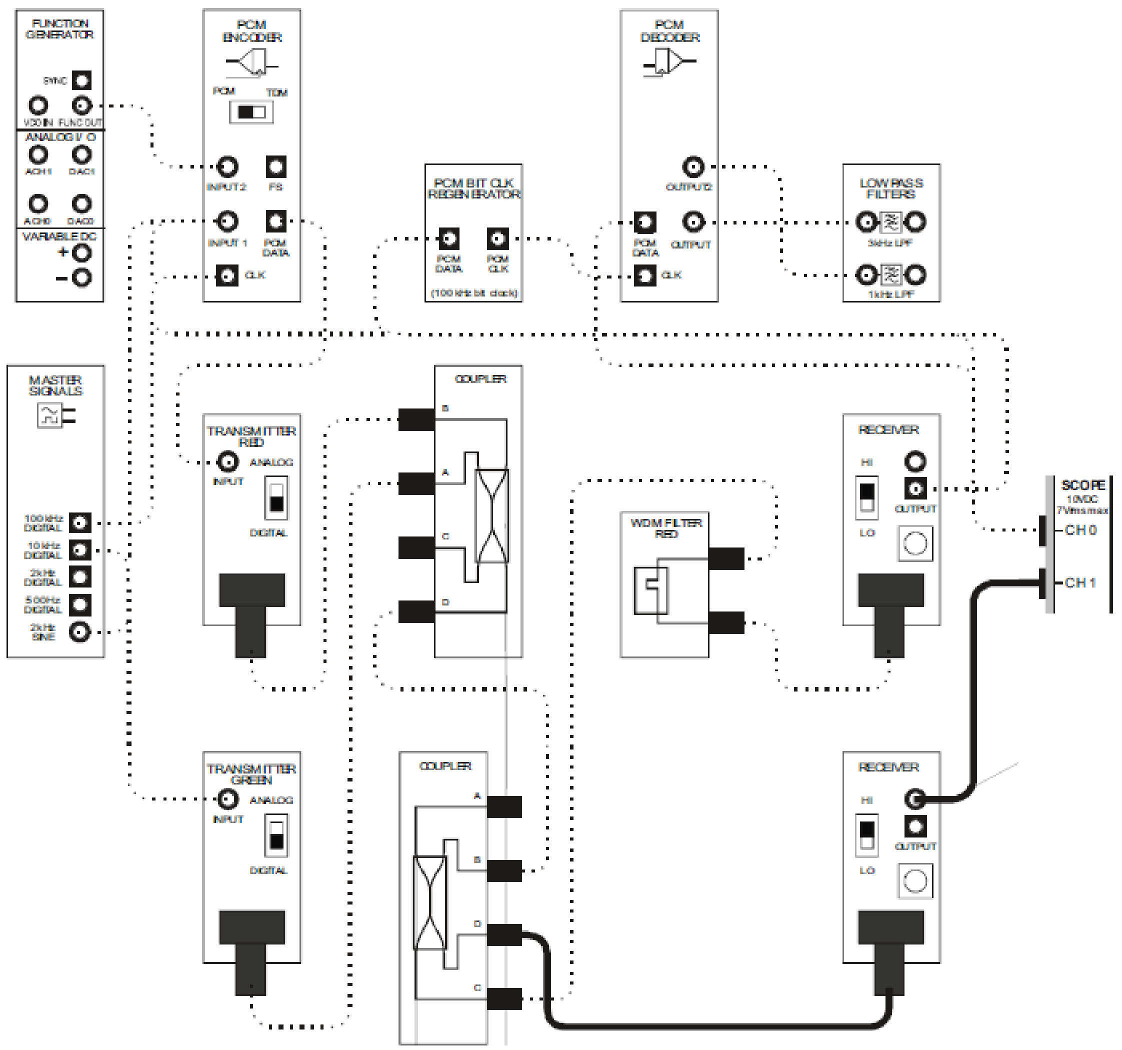


Figure 15

49. Set the scope's *Timebase* control to the *50μs/div* position.

50. Observe the signal on the lower Receiver module's output.

Note: This signal is the electrical equivalent of the raw light information being transmitted over the channel.