

Lab Manual:  
Communications Principles  
  
Using the EMONA Communications board for NI ELVIS III



Lab 11: Binary Phase Shift Keying (BPSK)

List of Updates

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# Lab 11: Binary Phase Shift Keying (BPSK)

## Learning Objectives

After completing this lab, you should be able to complete the following activities.

1. Generate a real BPSK signal
2. Describe a BPSK signal in time and frequency domain
3. Explain the use of product demodulation in BPSK
4. Explain the need for data recovery in BPSK demodulation

## Prerequisites

You should have completed Lab 1 and Lab 2 and be familiar with the equipment, its use and the handling precautions for the equipment.

## Required Tools and Technology

|  |  |
| --- | --- |
| Platform: NI ELVIS III Instruments used in this lab:   * Oscilloscope-Time * Oscilloscope-FFT * Function Generator | * Install Instruments: [http://www.ni.com/documentation/en/ni-elvis-iii/latest/getting-started/installing-the-soft-front-panel/](http://www-preview.ni.com/documentation/en/ni-elvis-iii/1.0/getting-started/installing-the-soft-front-panel/) * Access instruments <https://measurementslive.ni.com> * View User Manual <http://www.ni.com/en-us/support/model.ni-elvis-iii.html>   View tutorials <https://www.youtube.com/playlist?list=PLvcPIuVaUMIWm8ziaSxv0gwtshBA2dh_M> |
| Hardware: Emona Communications Board Components used in this lab:   * Four BNC to 2mm banana-plug leads * Assorted 2mm banana-plug patch leads * Set of headphones or earbuds | * View User Manual <http://www.ni.com/en-us/support/model.emona-communications-board-for-ni-elvis-iii.html> |
| Software: NI ELVIS III Function Generator File used in this lab:  ECB\_120k-noise.csv | * Access instrument <https://measurementslive.ni.com> |

## 

## Expected Deliverables

In this lab, you will collect the following deliverables:

* Calculations
* Data from measurements
* Observations

Your instructor may expect you complete a lab report. Refer to your instructor for specific requirements or templates.

## Section 1: BPSK modulation

## Theory and Background

AM and FM modulation schemes can be used to transmit digital signals and this allows for the channel to be shared. As digital data forms the message instead of speech and music, it is preferred that these two systems are called ASK and FSK instead.

Note that ASK uses the digital data’s 1s and 0s to switch a carrier between two amplitudes. FSK uses the 1s and 0s to switch a carrier between two frequencies. An alternative to these two methods is to use the data stream’s 1s and 0s to switch the carrier between two phases. This is called *Binary Phase Shift Keying* (BPSK). Figure 1 shows what a BPSK signal looks like time-coincident with the digital signal that has been used to generate it.



Figure 1: BPSK waveform

Notice that, when the change in logic level causes the BPSK signal’s phase to change, it does so by 180º. For example, where the signal is travelling towards a positive peak the change in logic level causes it to reverse direction and head back toward the negative peak (and vice versa).

You may find it difficult to see at first but look closely and you’ll notice that alternating halves of the BPSK signal’s envelopes have the same shape as the message. This indicates that BPSK is actually *double-sideband suppressed carrier* (DSBSC) modulation. That being the case, BPSK generation and the recovery of the data can be handled by conventional DSBSC modulation and demodulation techniques (explained in Experiments 6 and 9 respectively).

With a choice of ASK, FSK and BPSK you might be wondering about which system you’ll most likely see. All other things being equal, BPSK is the best performing system in terms of its ability to ignore noise and so it produces the fewest errors at the receiver. FM is the next best and AM is the worst. On that basis, you’d expect that BPSK is the preferred system. However, it’s not necessarily the easiest to implement and so in some situations FSK or ASK might be used as they are cheaper to implement. In fact, FSK was used for cheaper dial-up modems.

## 1.2 Implement: Generating an BPSK signal

For this experiment you’ll use the EMONA Communications board to generate a BPSK signal with the Multiplier module to implement its mathematical model. Digital data for the message is modelled by the Sequence Generator module. You’ll then recover the data using another Multiplier module and observe its distortion. Finally, you’ll use a comparator to restore the data.

It should take you about 40 minutes to complete this experiment.

**Powering up the ELVIS III + EMONA Communications Board**

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| --- | --- |
| 1. | Ensure that the NI ELVIS III Application Board power button at the top left corner of the unit is OFF (not illuminated). |

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| 2. | Carefully plug the Emona Communications board (ECB) into the NI ELVIS III ensuring that it is fully engaged both front and back. |

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| 3. | Ensure that you have connected the NI ELVIS III to the PC using the USB cable and that the PC is turned on. |

|  |  |
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| 4. | Turn on the Application Board *Power* button by pressing it once and confirm that it is illuminated. The LEDs on the ECB should also be illuminated. If they are not, then switch the unit off immediately and check for connection or insertion errors. |

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| 5. | Open the Instrument Launcher software in your browser and select the required instruments. |

Table 3 Scope Configuration

|  |  |
| --- | --- |
| Channel Voltage range | 2 V/div |
| Horizontal Timebase | 50us/div |
| Trigger | Analog Edge, Chan 1, Rising |
| Probe Attenuation | 1x |

Table 4 Function Generator Configuration

|  |  |
| --- | --- |
| Channel 1 | Custom |
| Update rate | 500kS/s |
| Waveform file | ECB\_120knoise.csv |

A BPSK signal will be generated by implementing the mathematical model for DSBSC modulation. For more information on this, refer to the preliminary discussion of Lab 6.

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|  |  |
| 6. | Connect the set-up shown in Figure 2.  **Note:** Insert the black plugs of the oscilloscope leads into a ground (*GND*) socket. | |

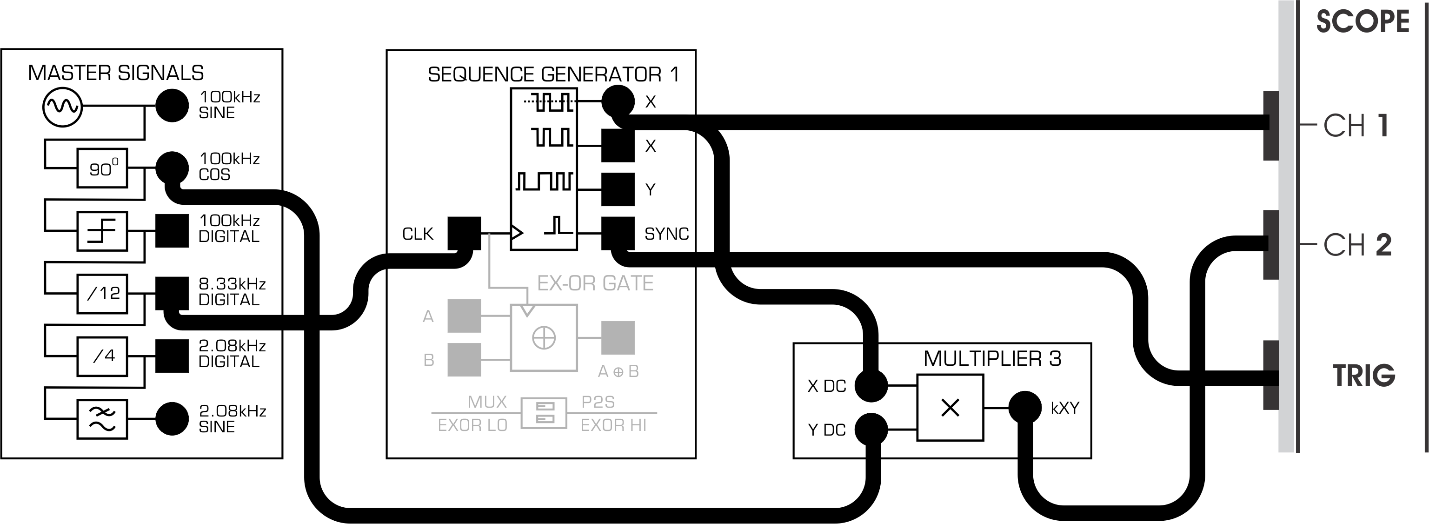


Figure 2: Patching for BPSK generation

This set-up can be represented by the block diagram in Figure 3. The Sequence Generator module is used to model a digital signal and its SYNC output is used to trigger the scope to provide a stable display. The Multiplier module is used to generate the BPSK signal by implementing its mathematical model.

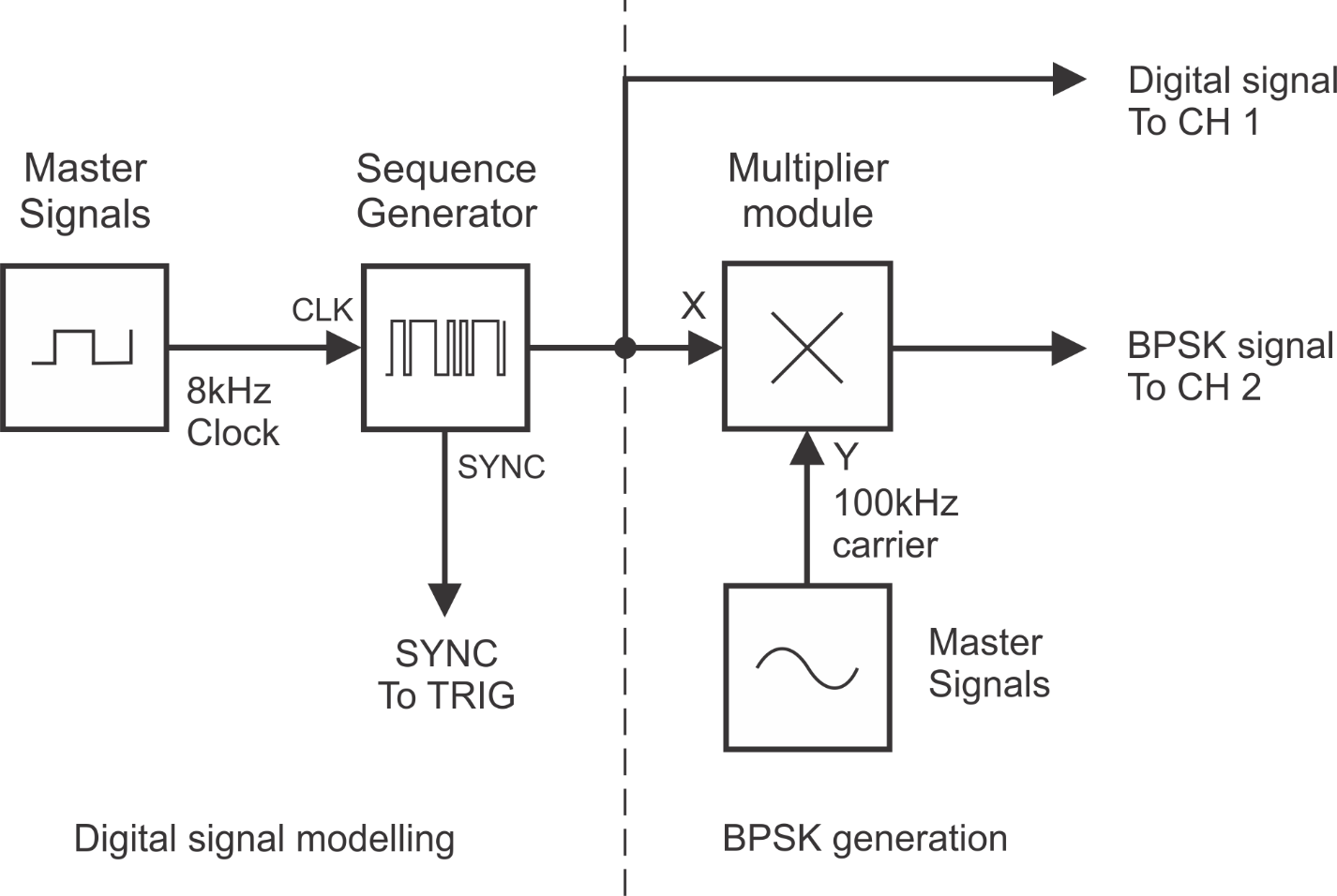


Figure 3: Block diagram for BPSK generation

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| --- | --- |
| 7. | Launch and run the NI ELVIS III Oscilloscope instrument. |

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| 8. | Set up the scope per the procedure in Experiment 1 with the following changes:   1. *Scale* control for Channel 2 to *2V/div* instead of *1V/div* 2. *Input Coupling* controls for both channels to *DC* instead of *AC* 3. *Timebase* control to *100µs/div* 4. *Trigger Type* control to *Digital* *Edge* 5. *Trigger Source* control to *TRIG* |

|  |  |
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| 9. | Activate the scope’s Channel 1 and Channel 2 inputs to observe the Sequence Generator module’s output and the BPSK signal out of the Multiplier module. |

|  |  |
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| 10. | Compare the signals. |

* 1. What feature of the BPSK signal suggests that it’s a DSBSC signal? **Tip:** If you’re not sure, see the preliminary discussion.

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It’s clear that something happens when the Sequence Generator’ module’s output changes logic level but it’s difficult to see exactly what it is at this resolution. The next few steps allow you to get a better look.

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| 11. | Modify the set-up as shown in Figure 4. |

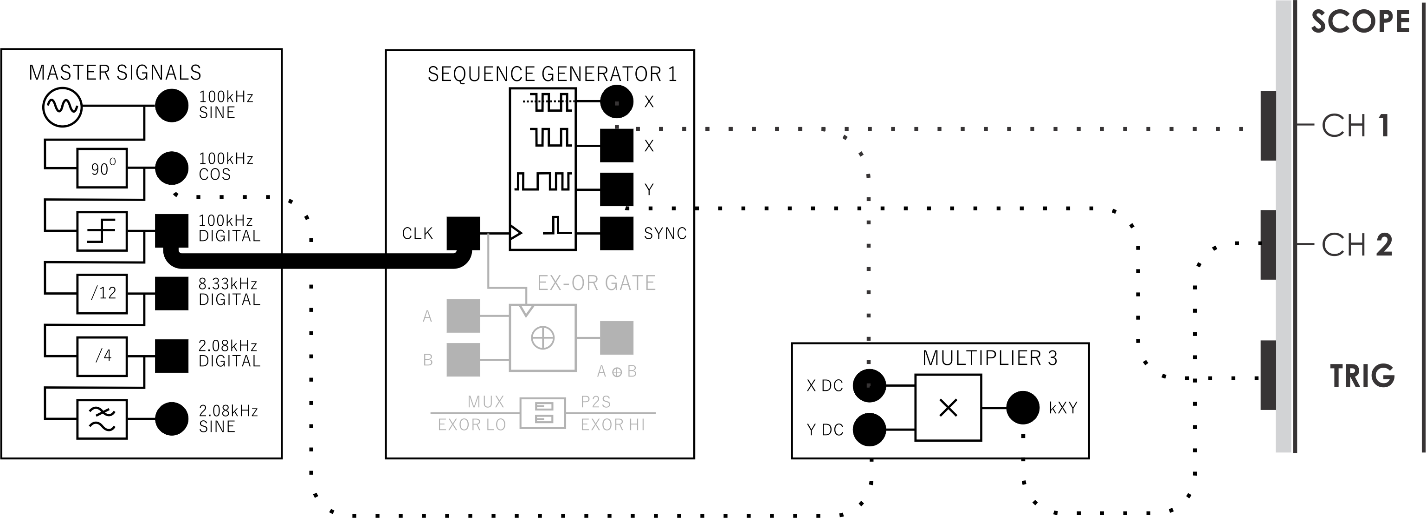


Figure 4: Patching for modified BPSK

|  |  |
| --- | --- |
| 12. | Set the scope’s *Timebase* control to the *10µs/div* position. |

* 1. What happens to the BPSK signal on the data stream’s logic transitions?

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| 13. | Switch the carrier source from 100k Cos to be 100kHz Sine for a moment and notice the difference at the transition points. Ensure that you understand why this difference occurs. Change it back to 100kHz Cos once you do. |

* 1. Why does the BPSK signal look different at the transitions for the 100kHz Sine carrier?

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## 1.3 Implement: Investigating the spectrum of BPSK

In an earlier Lab experiment you have understood the basis for the spectrum of a digital data stream (or PN data stream). In this experiment you will explore how that complex signal appears when shifted up to the carrier passband during modulation, as well as what happens in the frequency domain during product demodulation.

|  |  |
| --- | --- |
| 1. | Return the Sequence Generator module’s *CLK* input to the Master Signals module’s *8.33kHz Digital* output. |

|  |  |
| --- | --- |
| 2. | Enable the FFT mode of the Oscilloscope instrument. Change the scope’s timebase to 1ms/div. View the spectrum from 0Hz to 200kHz, set the FFT Source channel to Channel 2 and use the Blackman-Harris window rather than the default Rectangular window. |

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| 3. | Set the frequency span for the FFT displayed from say 70kHz to 130kHz for a closeup of the frequency domain of interest. |

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| 4. | Capture a screenshot of the FFT and append to your report. Annotate your report appropriately so as to identify the waveforms captured. Use the cursors to highlight important levels and transition points in the waveform if necessary. |

1-4 What frequency does the first null in the spectrum occur at? What does this correspond to?

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## Section 2: Demodulating a BPSK signal using a product detector

As BPSK is really just DSBSC (with a digital message instead of speech or music), it can be recovered using any of the DSBSC demodulation schemes. The next part of the experiment lets you do so using a product detector.

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| --- | --- |
| 1. | Set the scope’s *Timebase* control to the *200µs/div* position. |

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| 2. | Locate the Tuneable Low-pass Filter module on the board and turn its *TUNE* control fully clockwise. |

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| 3. | Set the Tuneable Low-pass Filter module’s *GAIN* control to about the middle of its travel. |

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| 4. | Modify the set-up as shown in Figure 5. |

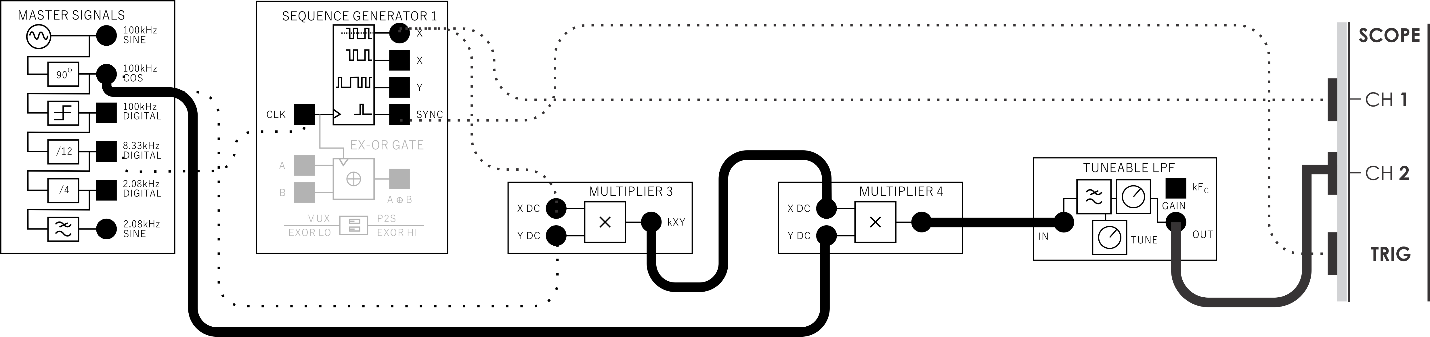


Figure 5: Patching for product demodulation

The BPSK generation and demodulation parts of the set-up can be represented by the block diagram in Figure 6. The second Multiplier and the Tuneable Low-pass filter module are used to implement a product detector to recover the digital data from the BPSK signal.

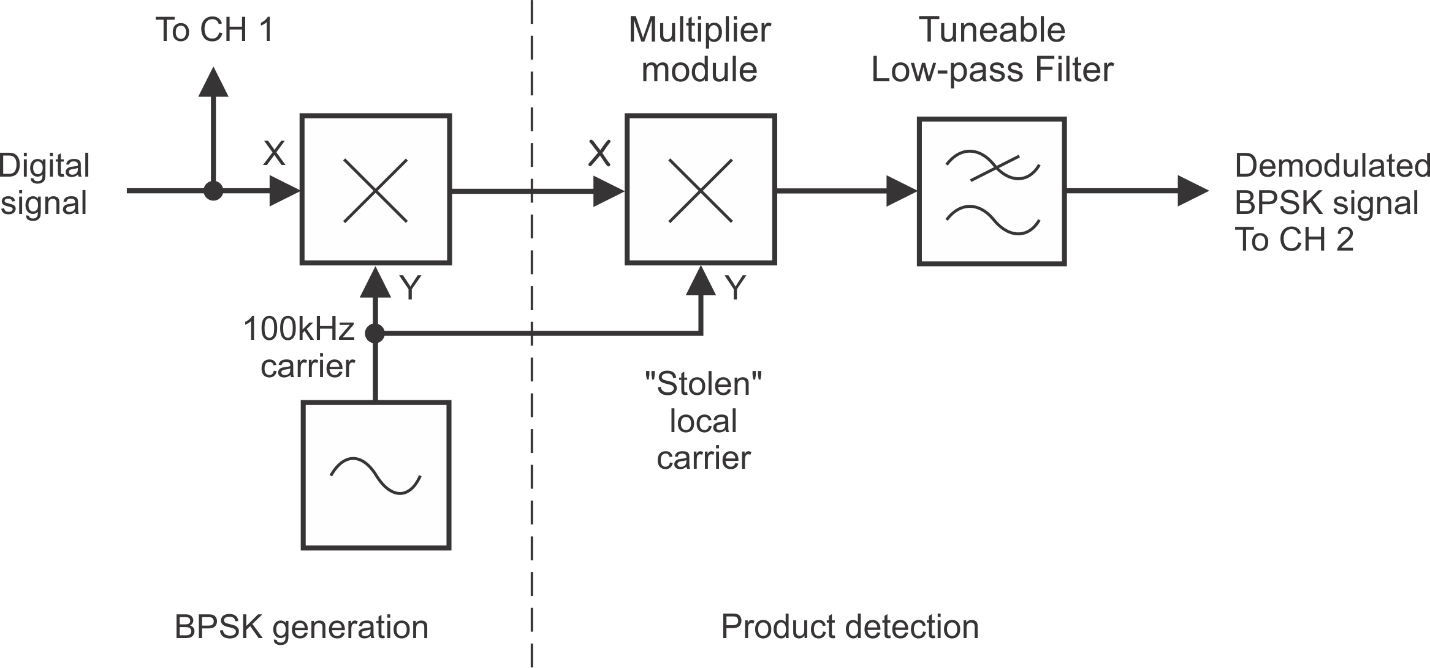


Figure 6: Block diagram for product demodulation

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| 5. | Compare the digital signal with the recovered digital signal. |

* 1. Why is the recovered digital signal not a perfect copy of the original?

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* 1. What can be used to “clean-up” the recovered digital signal?

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## 2.1 Implement: Investigating the spectrum of BPSK during product demodulation

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| 1. | Enable the FFT mode of the Oscilloscope instrument. Change the scope’s timebase to 1ms/div. |

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| --- | --- |
| 2. | Set the frequency span for the FFT displayed from 0kHz to 250kHz to capture the entire area of interest. |

|  |  |
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| 3. | View the signal at the **input** to the TUNEABLE LPF with one channel of the scope. Capture a screenshot of the FFT and append to your report. Annotate your report appropriately so as to identify the waveforms captured. Use the cursors to highlight important levels and transition points in the waveform if necessary. |

2-3 Why is there signal at around 200kHz?

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* 1. Why is there signal around 0 Hz?

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## 2.2 Implement: Restoring the recovered data using a comparator

A comparator is a useful circuit for restoring distorted digital signals. The next part of the experiment lets you use a comparator to clean up the demodulated BPSK signal.

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| --- | --- |
| 1. | Connect the Comparator module *REF* input to 0V (GND terminal). |

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| 2. | Modify the set-up as shown in Figure 7. |

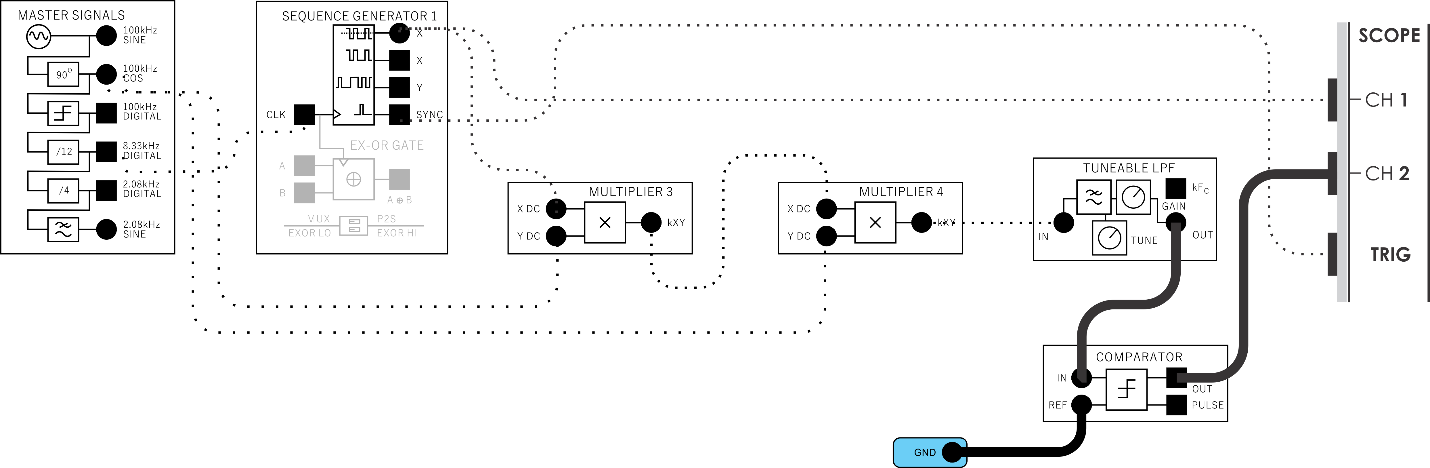


Figure 7: Patching for data recovery

The BPSK generation, demodulation and digital signal restoration parts of the set-up can be represented by the block diagram in Figure 8.

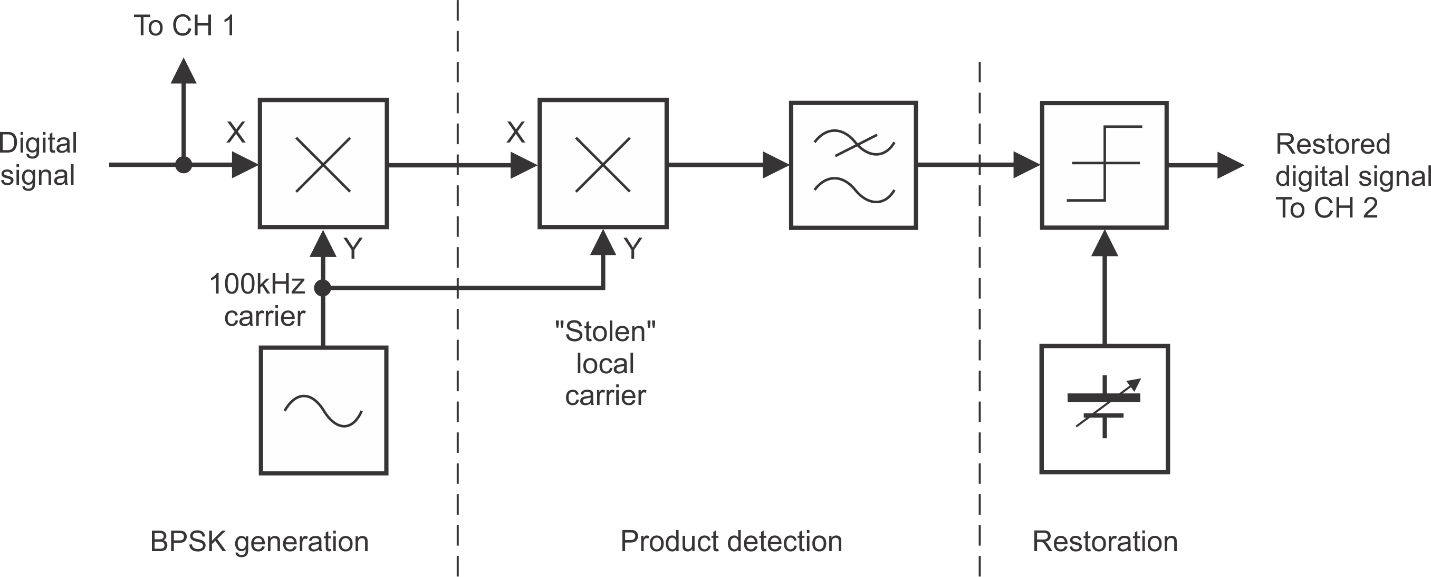


Figure 8: Block diagram for data recovery

## Section 3: Introducing the noisy channel

It’s common for radio frequency communications systems to be upset by unwanted electromagnetic radiation called *noise*. Some of this radiation occurs naturally and is generated by the Sun and atmospheric activity such as lightning. Much of the radiation is human-made - either unintentionally (the electromagnetic radiation given off by electrical machines and electronics equipment) or intentionally (other peoples’ communication transmissions that we don’t want to receive).

Most noise gets added to signals while they’re in the channel. This changes the signals’ shape which in turn changes how the signals sound when demodulated by the receiver. If the noise is sufficiently large (relative to the size of the signal) the signal can be changed so much that it cannot be demodulated.

It’s possible to model noise being added to a signal in the channel of a communications system using the board. If time allows, this activity gets you to do so.

## 3.1 Implement: Model the noisy AWGN band-limited channel

|  |  |
| --- | --- |
| 1. | Connect the set-up shown in Figure 9 but **don’t** disconnect any of your existing wiring. Set the Amplifier module’s gain to minimum to start with (fully anti-clockwise). |

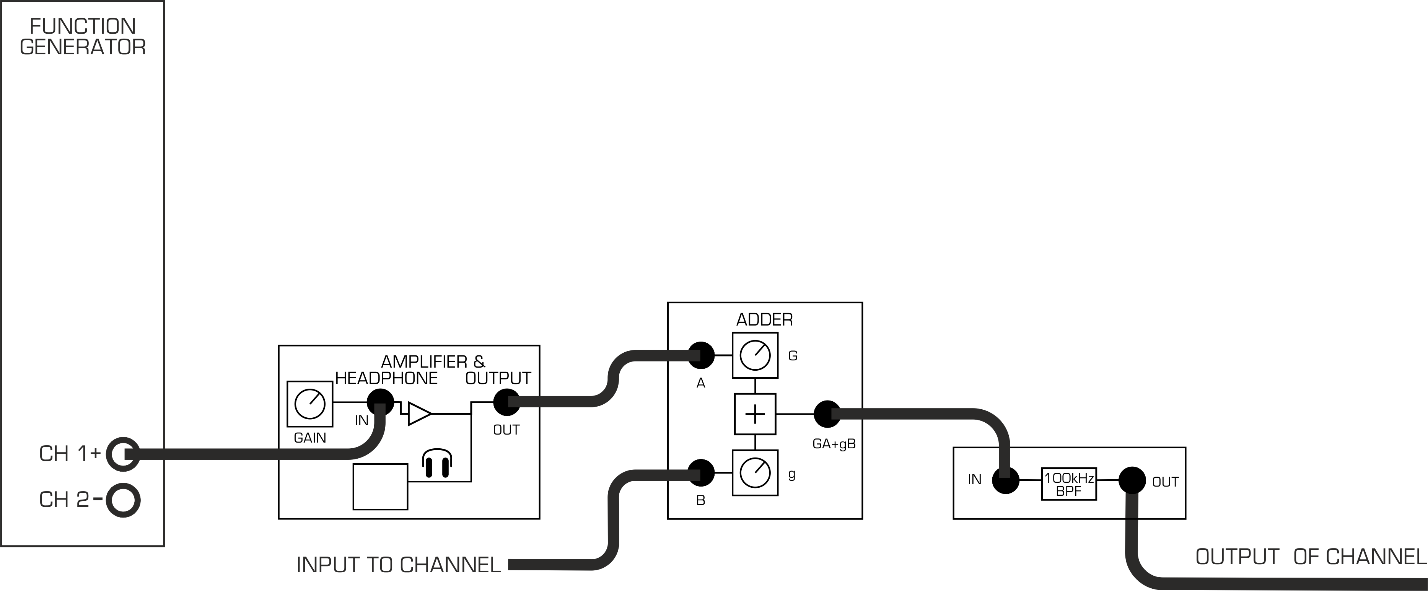


Figure 9: Patching up the noisy bandlimited channel

This set-up can be represented by the block diagram in Figure 10. It models the behavior of a real channel by adding noise to communications signals such as BPSK, as well as band-limiting.

Usefully, the amount of noise can be varied with the Amplifier module. Selecting different levels of noise such as *-20dB* output (noise is one-tenth the size of the signal), the *-6dB* output (noise is half the size of the signal) or the *0dB* output (noise is the same size as the signal) is worth investigating and documenting.

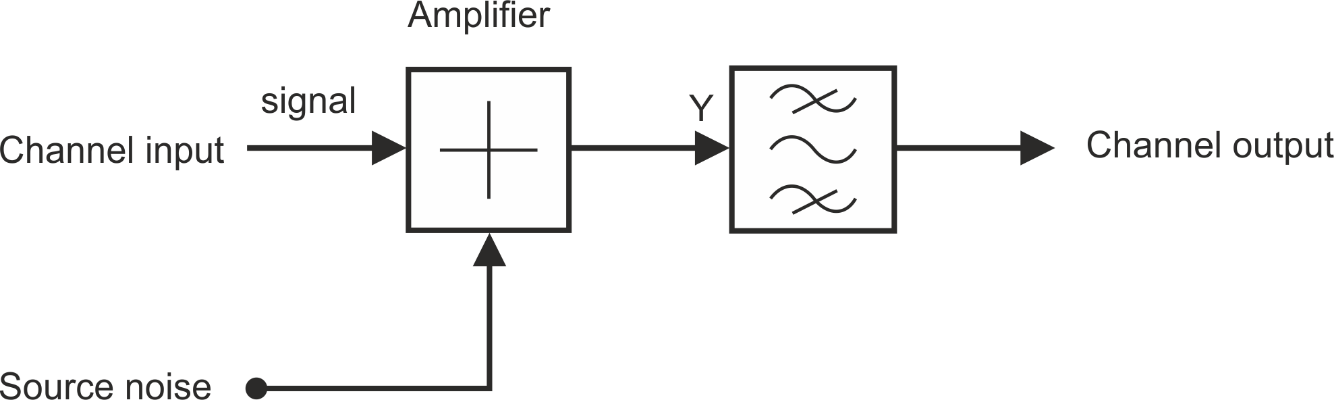


Figure 10: Block diagram for noisy AWGN band limited channel

The noise source is from the Function Generator module. Select Channel 1 to use a CUSTOM signal and load the file “ECB\_120k-noise.csv”. Select an update rate of 500kS/s.

This will output a wideband noise signal with 120kHz bandwidth: enough to provide a noisy channel at the passband frequency of 100kHz.

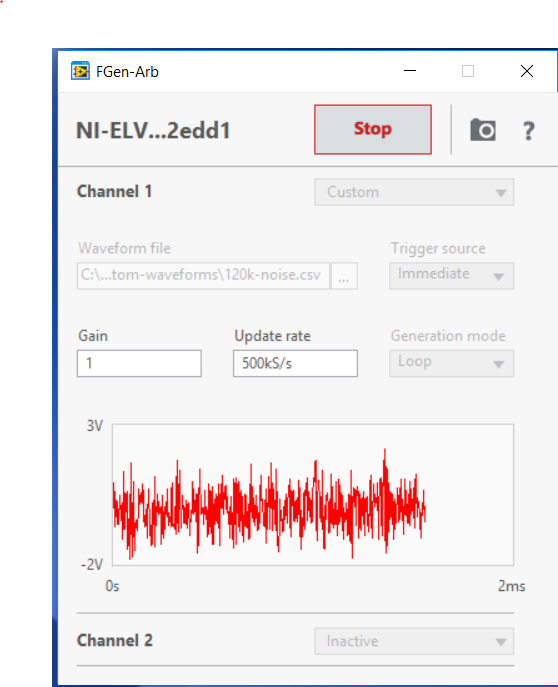


Figure 11: 120kHz noise signal for AWGN channel

|  |  |
| --- | --- |
| 2. | Turn the *G* and *g* gain controls on the Adder module to midway ie: around 12 o’clock. This gives each channel an approximate gain of unity. |
| 3. | Unplug the patch lead from the output of the Multiplier 3 module (the upper Multiplier) and connect it to the noisy channel’s input “Input to Channel” (as per Figure 9).. |
| 4. | Connect the noisy channel’s output to the input of the Multiplier 4 (the lower Multiplier).  **Note 1:** Once done, the transmitter’s signal (the upper Multiplier module’s output) travels to the receiver’s input (the lower Multiplier module’s input) via the model of a noisy channel.  **Note 2:** A Bandpass Filter is a tuned circuit with a high Q and can become unstable under certain condition. If it does, then it may oscillate independently of the input. If this does occur, simply power cycle the board by briefly switching it off and on again via the Application board pushbutton. |
|  |  |
| 5. | Compare the original and recovered data. |
|  |  |
| 6. | Unplug the scope’s Channel 2 input from the Comparator’s output and connect it to the Adder module’s output to observe the noisy BPSK signal. |
|  |  |
| 7. | Vary the Amplifier module’s *GAIN* slightly to increase the noise in the channel. You can measure the level of noise using the Measurement feature of the Scope instrument. |
|  |  |
| 8. | Observe the effect that this has on the BPSK signal. |
|  |  |
| 9. | Reconnect the scope’s Channel 2 input to the comparator’s output. |
|  |  |
|  |  |
| 10. | Capture screenshots of various noise levels on the scope and append to your report. Annotate your report appropriately so as to identify the waveforms captured. Use the cursors to highlight important levels and transition points in the waveform if necessary |

11. View the level of noise before and after the Channel BPF.

3-1 Why is the level of noise after the Channel BPF lower than before the BPF?

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| 11. | Capture a screenshot of the FFT of signals including the noise and append to your report. Annotate your report appropriately so as to identify the waveforms captured. Use the cursors to highlight important levels and transition points in the waveform if necessary. |