

Name: \_\_\_\_\_

Class: \_\_\_\_\_

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## 14 - Bandwidth limiting and restoring digital signals

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## Experiment 14 - Bandwidth limiting and restoring digital signals

### Preliminary discussion

In the classical communications model, intelligence (the message) moves from a transmitter to a receiver over a *channel*. A number of transmission media can be used for the channel including: metal conductors (such as twisted-pair or coaxial cable), optical fibre and free-space (what people generally call the "airwaves").

Regardless of the medium used, all channels have a *bandwidth*. That is, the medium lets a range of signal frequencies pass relatively unaffected while frequencies outside the range are made smaller (or *attenuated*). In this way, the channel acts like a filter.

This issue has important implications. Recall that the modulated signal in analog modulation schemes (such as AM) consists of many sinewaves. If the medium's bandwidth isn't wide enough, some of the sinewaves are attenuated and others can be completely lost. In both cases, this causes the demodulated signal (the recovered message) to be distorted.

Similarly, recall that digital signals are also made up of many sinewaves (called the *fundamental* and *harmonics*). Again, if the medium's bandwidth isn't wide enough, some of them are attenuated and/or lost and this can change the signal's shape.

To illustrate this last point, Figure 1 below shows what happens when all but the first two of a squarewave's sinewaves are removed. As you can see, the signal is distorted.

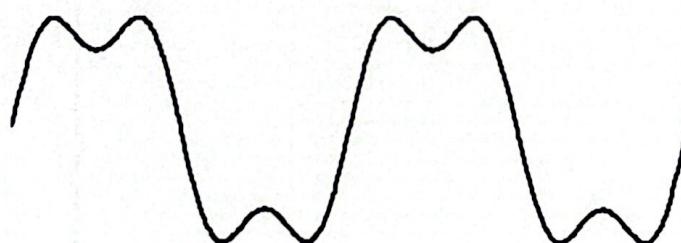


Figure 1

Making matters worse, like a filter the channel shifts the phase of sinewaves by different amounts. Again, to illustrate, Figure 2 below shows the signal in Figure 1 but with one of its two sinewaves phase shifted by 40°.

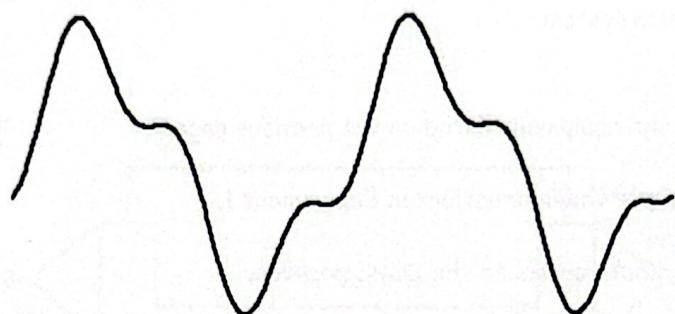


Figure 2

Imagine the difficulty a digital receiver circuit such as a PCM decoder would have trying to interpret the logic level of a signal like Figure 2. Some, and possibly many, of the codes would be misinterpreted and incorrect voltages generated. This makes the recovered message "noisy" which is obviously a problem.

### The experiment

In this experiment you'll use the Emona Telecoms-Trainer 101 to set up a PCM communications system. Then you'll model bandwidth limiting of the channel by introducing a low-pass filter. You'll observe the effect of bandwidth limiting on the PCM data using a scope as well as listening to the effect it has on the recovered message. Finally, you'll use a comparator to restore a digital signal and observe its limitations.

It should take you about 1 hour to complete this experiment.

### Equipment

- Emona Telecoms-Trainer 101 (plus power-pack)
- Dual channel 20MHz oscilloscope
- three Emona Telecoms-Trainer 101 oscilloscope leads
- assorted Emona Telecoms-Trainer 101 patch leads
- one set of headphones (stereo)

## Procedure

### Part A - The effects of bandwidth limiting on PCM decoding

As mentioned in the preliminary discussion, bandwidth limiting in a channel can distort digital signals and upset the operation of the receiver. This part of the experiment demonstrates this using a PCM transmission system.

1. Gather a set of the equipment listed on the previous page.
2. Set up the scope per the instructions in Experiment 1.
3. Set the scope's *Mode* control to the *DUAL* position.
4. Set the scope's Channel 1 and Channel 2 *Input Coupling* controls to the *DC* position.
5. Set the scope's Channel 1 and Channel 2 *Vertical Attenuation* controls to the *1V/div* position.
6. Locate the Variable DCV module and set its *VDC* control to about the middle of its travel.
7. Locate the PCM Encoder module and set its *Mode* switch to the *PCM* position.
8. Connect the set-up shown in Figure 3 below.

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

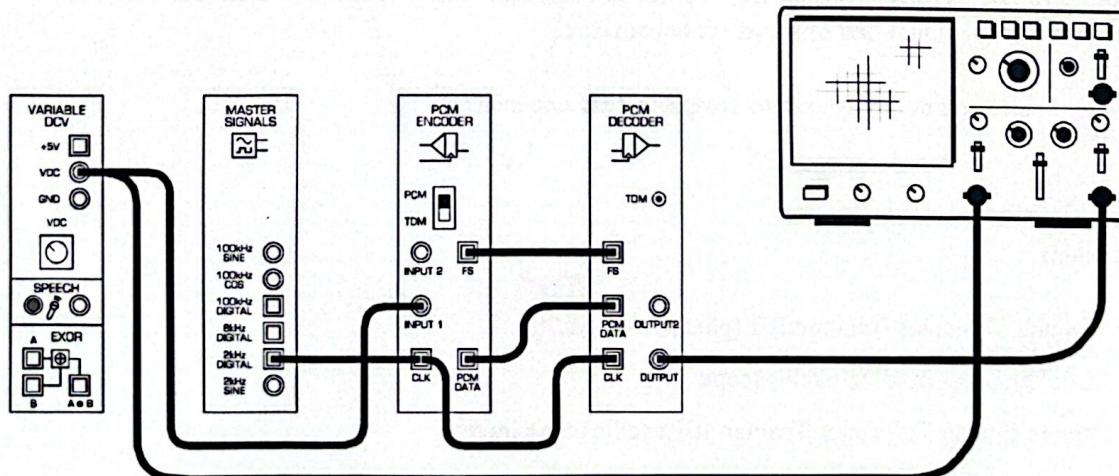


Figure 3

The set-up in Figure 1 can be represented by the block diagram in Figure 4 below. The PCM Encoder module converts the Variable DCV module's output to a digital code that the PCM Decoder decodes and returns to a (sampled) DC voltage. Importantly, the patch lead that connects the PCM Encoder module's *PCM DATA* output to the PCM Decoder module's *PCM DATA* input is the communication system's "channel".

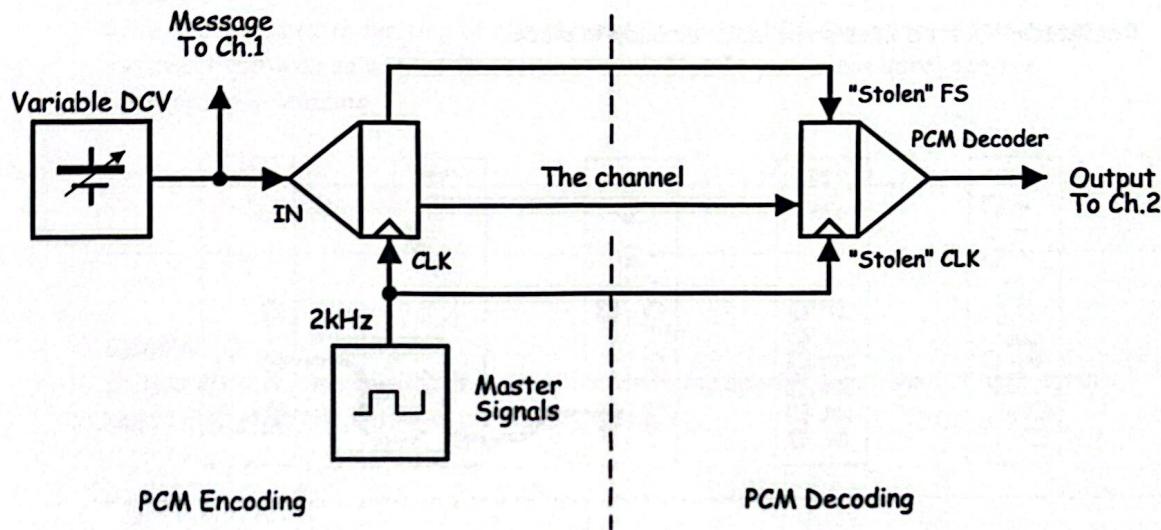


Figure 4

- Vary the Variable DCV module's *VDC* control left and right.

**Note:** If the set-up is working, you should see the DC voltage on the output of both the Variable DCV and PCM Decoder modules move up and down.



Ask the instructor to check  
your work before continuing.

10. Locate the Tuneable Low-pass Filter module and set its *Gain* control to about the middle of its travel.
11. Turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control fully clockwise.
12. Modify the set-up as shown in Figure 5 below leaving the scope connections as they are.

**Remember:** Dotted lines show leads already in place.

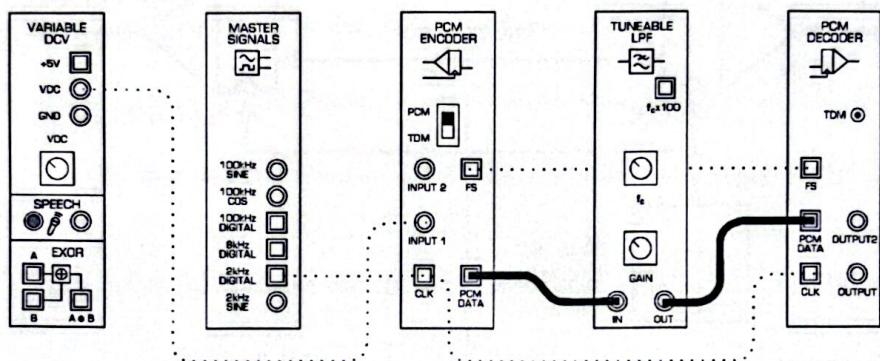


Figure 5

The set-up can be represented by the block diagram in Figure 6 below. The Tuneable Low-pass Filter module models bandwidth limiting of the channel.

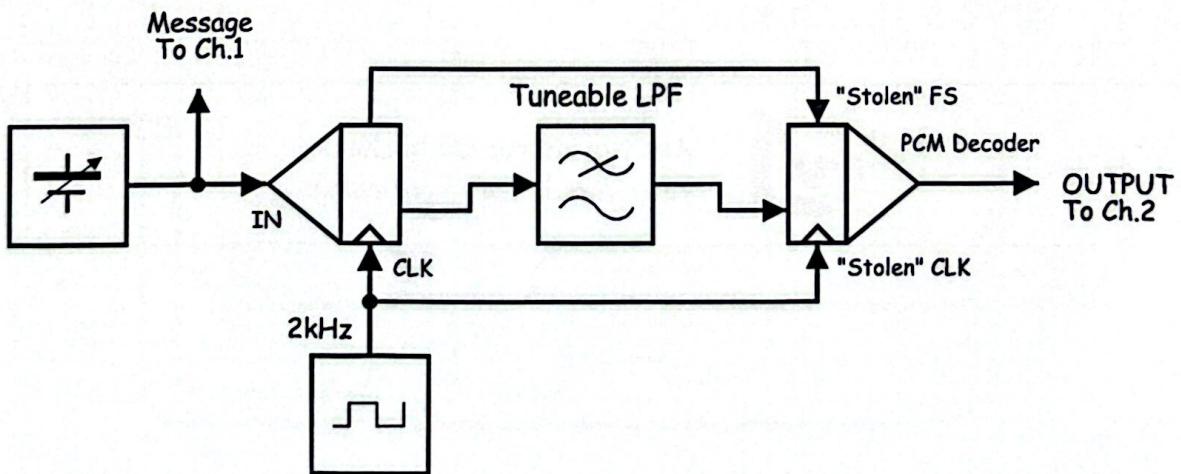


Figure 6

13. Vary the Variable DCV module's *VDC* control left and right. At the same time, slowly turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control anti-clockwise.
14. Stop turning the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control once the PCM Decoder module's output becomes corrupted.

**Question 1**

Why does bandwidth limiting of the channel cause the PCM Decoder module to output incorrect voltages as well as the correct one? Tip: If you're not sure, see the preliminary discussion.

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**Question 2**

If this were a communications system transmitting speech, what would these errors sound like when the message is reconstructed?

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Ask the instructor to check  
your work before continuing.

## Part B - The effects of bandwidth limiting on a digital signal's shape

You've seen how a channel's bandwidth can upset a receiver's operation. Now let's have a look at how it affects the shape of the digital signal at the receiver's input.

Importantly, digital signals that are generated by a message such as a sinewave, speech or music cannot be used for this part of the experiment. This is because the data stream is too irregular for the scope to be able to lock onto the signal and show a stable sequence of 1s and 0s. To get around this problem the Sequence Generator module's 32-bit sequence is used to model a digital data signal.

15. Completely dismantle the previous set-up.
16. Set the scope's *Mode* control to the *CH1* position.
17. Set the scope's *Trigger Source* control to the *EXT* position.
18. Set the scope's *Trigger Source Coupling* control to the *HF REJ* position.
19. Set the Tuneable Low-pass Filter module's *Gain* control to about the middle of its travel.
20. Turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control fully clockwise.
21. Locate the Sequence Generator module and set its dip-switches to 00.  
**Tip:** To do this, push both switches up.
22. Connect the set-up shown in Figure 7 below.

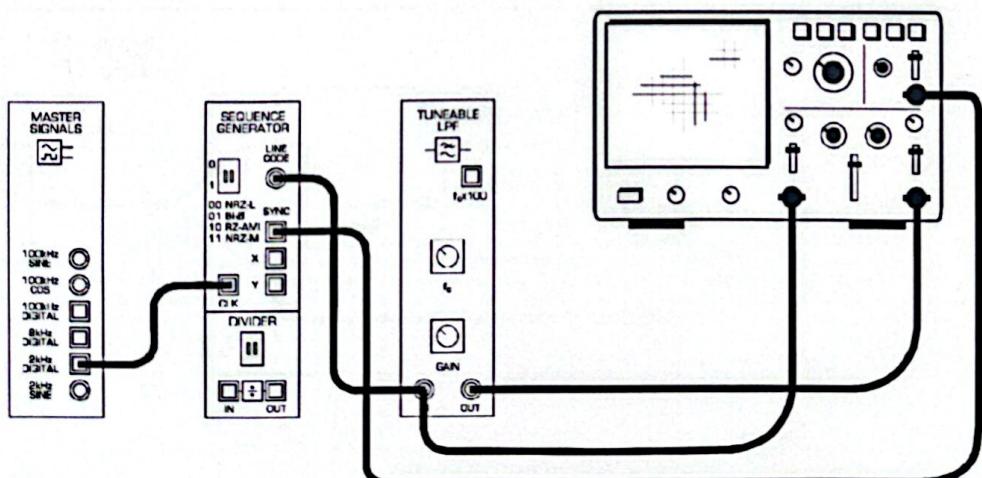


Figure 7

The set-up in Figure 7 can be represented by the block diagram in Figure 8 below. 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.

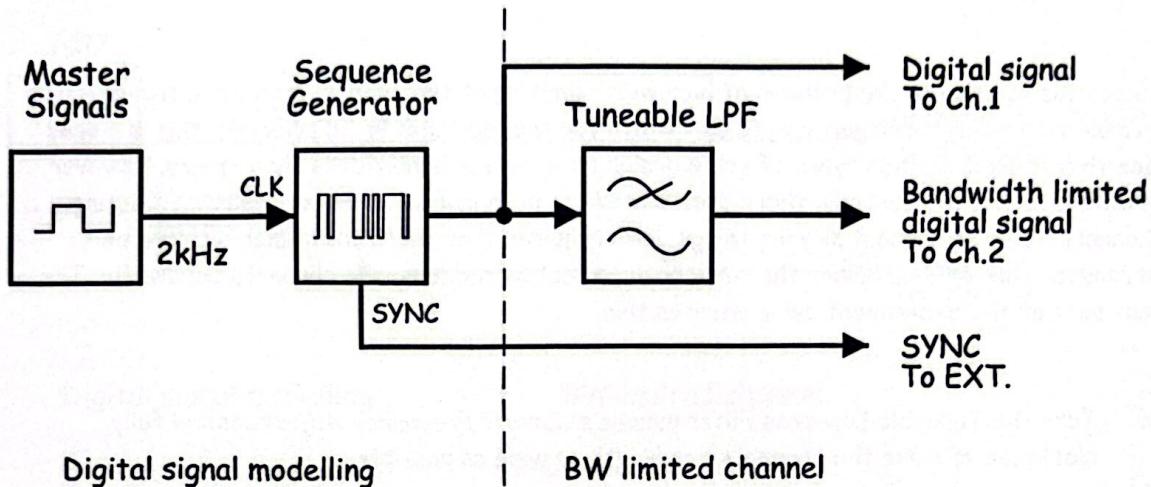


Figure 8

23. Set the scope's *Timebase* control to the *1ms/div* position to view about twenty bits of data.

**Note:** It probably doesn't look like twenty bits of data because some of the bits are the same logic level as adjacent bits.

24. Set the scope's *Mode* control to the *DUAL* position and compare the signals.
25. Note the effects of making the channel's bandwidth narrower by turning the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control anti-clockwise.

### Question 3

What two things are happening to cause the digital signal to change shape? Tip: If you're not sure, see the preliminary discussion.

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Ask the instructor to check  
your work before continuing.

An obvious solution to the problem of bandwidth limiting of the channel is to use a transmission medium that has a sufficiently wide bandwidth for the digital data. In principle, this is a good idea that is used. Certain types of cable design have better bandwidths than others. However, as digital technology spreads, there are demands to push more and more data down existing channels. To do so without slowing things down requires that the transmission bit rate be increased. This ends up having the same basic effect as reducing the channel's bandwidth. The next part of the experiment demonstrates this.

26. Turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control fully clockwise to make the channel's bandwidth as wide as possible.
27. Turn the VCO module's *Frequency Adjust* control to about a quarter of its travel (the control's arrowhead should be pointing to where the number nine is on a clock's face).
28. Set the VCO module's *Range* control to the *LO* position.
29. Modify the set-up as shown in Figure 9 below.

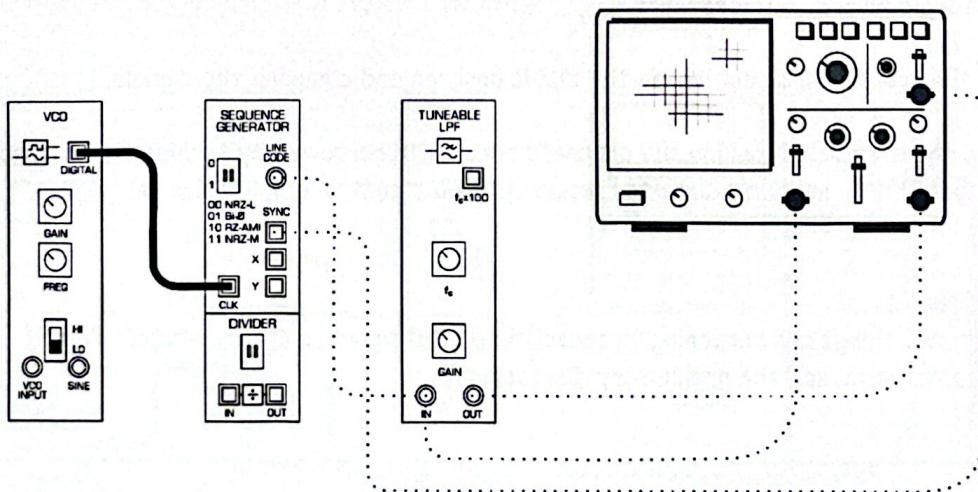


Figure 9

The set-up in Figure 9 can be represented by the block diagram in Figure 10 below. Notice that the Sequence Generator module's clock is now provided by the VCO module's *DIGITAL* output and so it is variable.

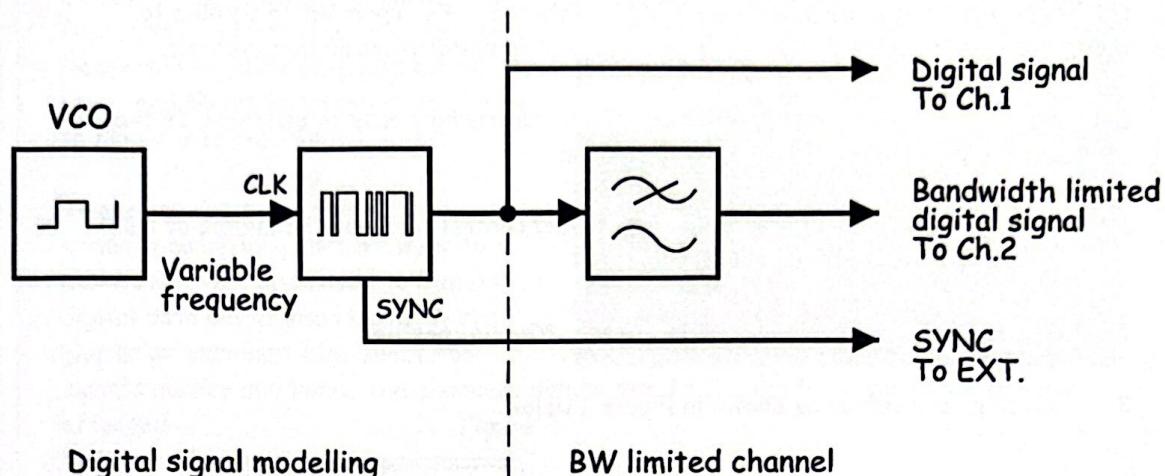


Figure 10

30. If the scope's display is unstable, turn the VCO module's *Frequency Adjust* control clockwise a little until it settles down.
31. To model increasing the transmission bit-rate, continue to turn the VCO module's *Frequency Adjust* control clockwise while watching the scope's display.

**Tip:** As you do this, you'll need to turn the scope's *Timebase* control clockwise as well so that you can properly see the digital signals.

#### Question 4

What other change to your communication system distorts the digital signal in the same way as increasing its bit-rate?

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Ask the instructor to check  
your work before continuing.

## Eye diagrams

As you've just seen, bandwidth limiting distorts digital signals and this means that they can be misinterpreted by the receiver. Obviously then, it's important to be able to inspect and test the performance of the channel in digital transmission systems.

Eye diagrams are ideal for this purpose and are surprisingly easy to generate. If the instructor allows, this activity gets you to do so.

1. Return the VCO module's *Frequency Adjust* control to about the middle of its travel to reduce the bandwidth limiting.
2. Set the scope's *Timebase* control to the  $20\mu\text{s}/\text{div}$  position.
3. Modify your set-up as shown in Figure 1 below.

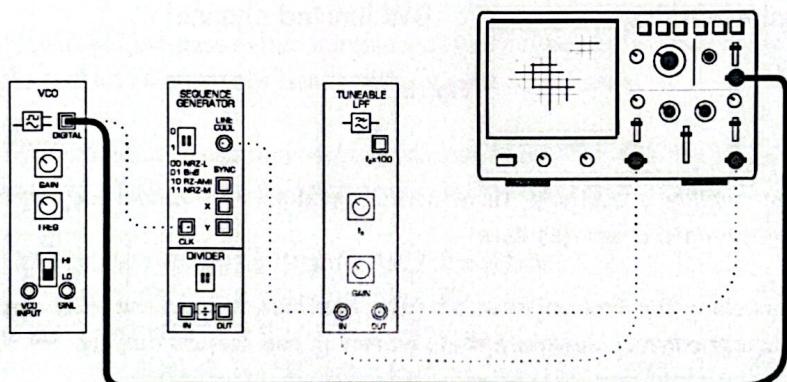


Figure 1

This set-up can be represented by the block diagram in Figure 2 below.

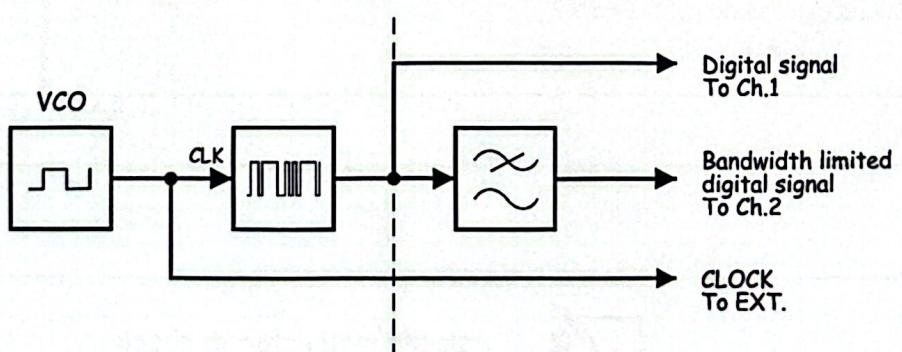


Figure 2

The scope is now being triggered by the system clock instead of the Sequence Generator module's *SYNC* signal. This forces the scope to draw the Sequence Generator module's data bits over each other and should look something similar to Figure 3 to the right.

Triggering the scope this way is normally something that we want to avoid. However, when used to inspect digital data out of the channel it can give us an excellent idea about the signal's quality and hence the channel's bandwidth. If the digital signal is not greatly affected by bandwidth limiting, the spaces between the traces (called the "eyes") are wide-open. As bandwidth limiting degrades the signal's quality, the eyes begin to close. See this for yourself by following the next few steps.

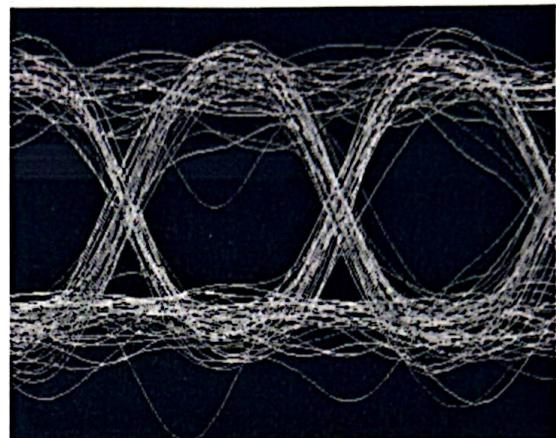


Figure 3

4. While watching the eye diagram on the scope, slowly turn the VCO module's *Frequency Adjust* control fully-clockwise to increase the clock frequency and hence the data's bit-rate.

**Note:** As you do this, you may need to change the scope's *Timebase* control to the  $10\mu\text{s}/\text{div}$  position.

5. Slowly turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control anti-clockwise to increase the channel's bandwidth limiting.



Ask the instructor to check your work before continuing.

6. Return the VCO module's *Frequency Adjust* control to about the middle of its travel
7. Turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control fully clockwise
8. Return the scope's *SYNC* input to the Sequence Generator module's *SYNC* output.

### Part C - Restoring digital signals

As you have seen, bandwidth limiting distorts digital signals. As you have also seen (and heard) digital receivers such as PCM decoders have problems trying to interpret bandwidth limited digital signals. The trouble is, bandwidth limiting is almost inevitable and its effects get worse as the digital signal's bit-rate increases.

To manage this problem, the received digital signal must be cleaned-up or "restored" before it is decoded. A device that is ideal for this purpose is the comparator. Recall that the comparator amplifies the difference between the voltages on its two inputs by an extremely large amount. This always produces a heavily clipped or "squared-up" version of any AC signal connected to one input if it swings above and below a DC voltage on the other input.

As you know, ordinarily we avoid clipping but in this case it's very useful. The bandwidth limited digital signal is connected to one of the comparator's inputs and a variable DC voltage is connected to the other. The bandwidth limited digital signal swings above and below the DC voltage to produce a digital signal on the comparator's output. Then, the variable DC voltage is adjusted until this happens at the right points in the bandwidth limited digital signal for the comparator's output to be a copy of the original digital signal.

Unfortunately, this simple yet clever idea has its limitations. First, bandwidth limiting can distort the digital signal too much for the comparator to restore accurately (that is, without errors). Second, the channel can cause the received digital signal (and hence the restored digital signal) to become phase shifted. For reasons not explained here this can cause other problems for receivers.

This part of the experiment lets you restore a bandwidth limited digital signal using a comparator and observe these limitations.

32. Set the scope's *Timebase* control to the *0.5ms/div* position.
33. Set the Variable DCV module's *Variable DC* control to about the middle of its travel.
34. Disconnect the patch lead to the VCO module's *DIGITAL* output then modify the set-up as shown in Figure 11 on the next page.

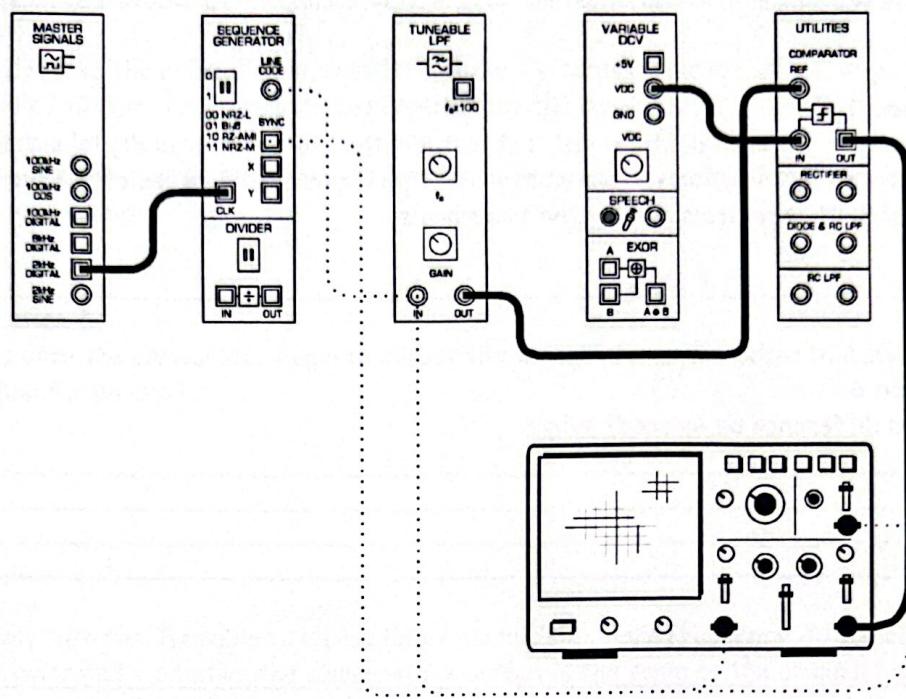


Figure 11

The entire set-up can be represented by the block diagram in Figure 12 below. The comparator on the Utilities module is used to restore the bandwidth limited digital signal.

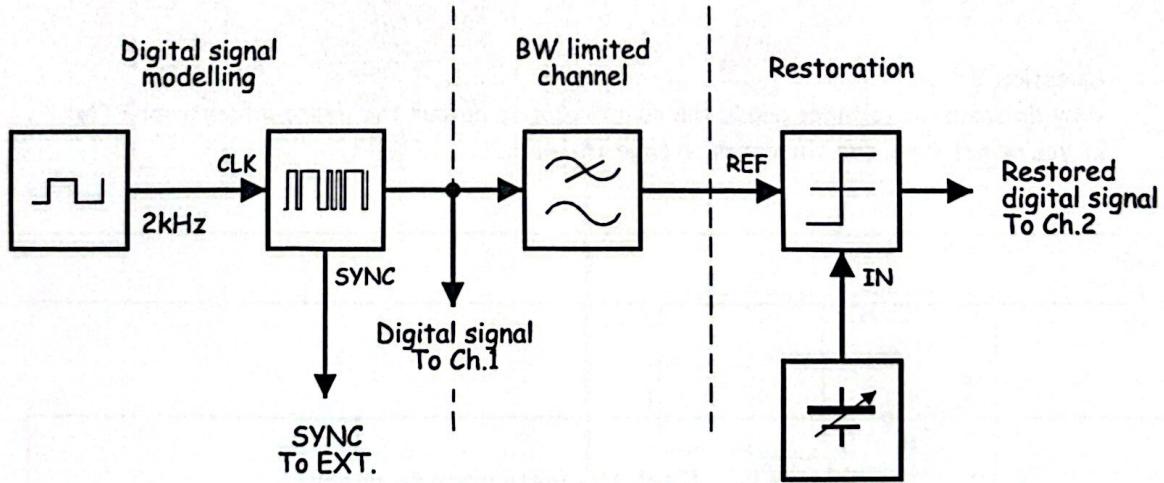


Figure 12

35. Compare the signals.

**Question 5**

Although the restored digital signal is almost identical to the original digital signal, there is a difference. Can you see what it is? Tip: If you can't, use one of the scope's Vertical Position controls overlay the two signals.

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**Question 6**

Can this difference be ignored? Why?

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Ask the instructor to check  
your work before continuing.

36. Slowly turn the Variable DC module's *DC Voltage* control fully clockwise and fully anti-clockwise and observe the effect.

**Question 7**

Why do some DC voltages cause the comparator to output the wrong information? Tip:  
If you're not sure, see the notes on page 14-14.

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Ask the instructor to check  
your work before continuing.

37. Return the Variable DCV module's *Variable DC* control to about the middle of its travel.
38. Slowly make the channel's bandwidth narrower by turning the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control anti-clockwise.

**Note:** As you do this, the phase difference between the two digital signals will increase but ignore this.

#### Question 8

Why does the comparator begin to output the wrong information when this control is turned far enough?

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39. Slowly turn the Tuneable Low-pass Filter module's *Cut-off Frequency Adjust* control clockwise and stop when the comparator's output is the same as the original digital signal (ignoring the phase shift).
40. Compare the restored digital signal with the bandwidth limited digital signal by modifying the set-up as shown in Figure 13 below.

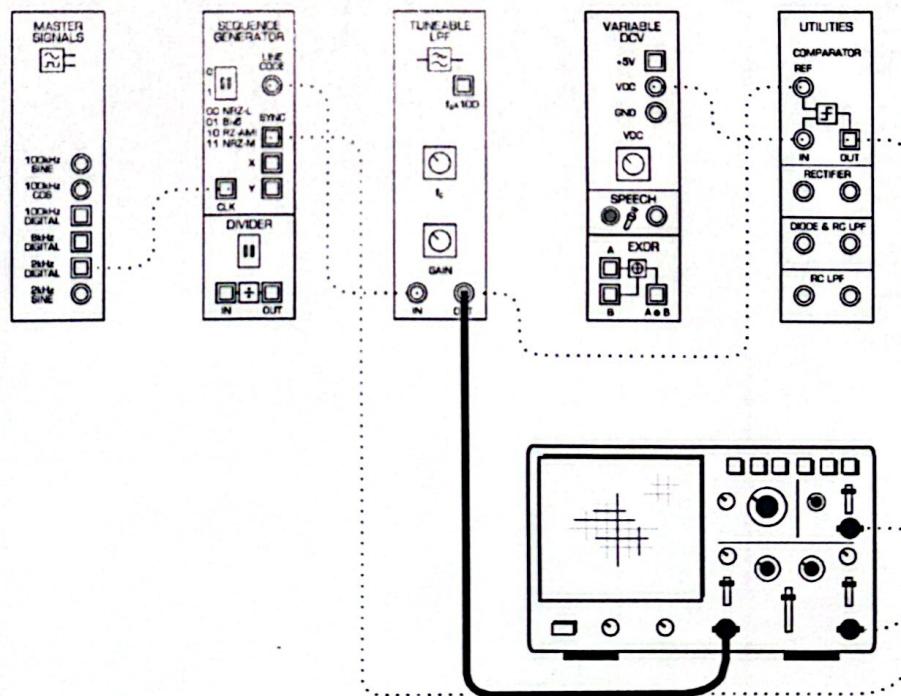


Figure 13

**Question 9**

How can the comparator restore the bandwidth limited digital signal when it is so distorted?

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Ask the instructor to check  
your work before finishing.