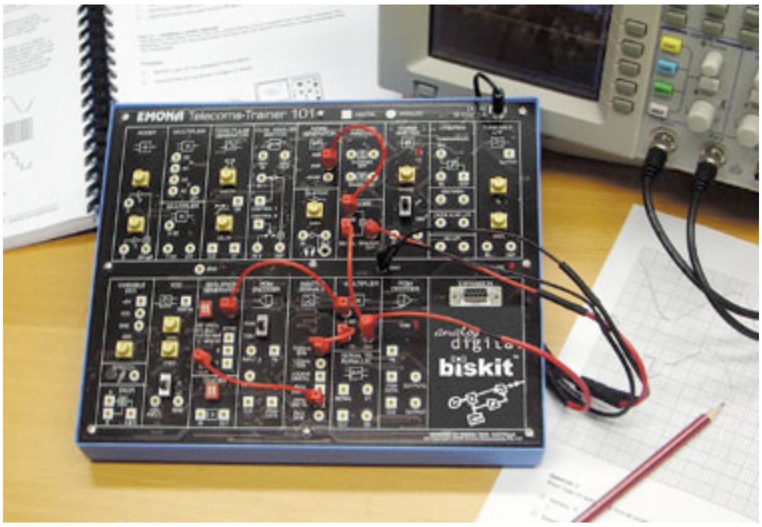
C8

Modulation and Detection

This contributes 5% of the marks for ELEC2220.

In this lab, the EMONA Telecoms-Trainer 101 (ETT-101) is used to investigate Double Sideband Suppressed Carrier (DSBSC) modulation, Frequency Modulation (FM) and Frequency Shift Keying (FSK) schemes. Real-time transmission of speech signals will be experimented and various transmission issues will be studied.



Schedule

Preparation time	:	3 hours
Lab time	:	3 hours

Items provided

Tools	:	None
Components	:	None
Equipment	:	Oscilloscope, EMONA Telecoms-Trainer 101 (ETT-101)
Software	:	Tektronix OpenChoice Desktop

Items to bring

Essentials. A full list is available on the Laboratory website at https://secure.ecs.soton.ac.uk/notes/ellabs/databook/essentials/

Before you come to the lab, it is essential that you read through this document and complete ***all*** of the preparation work in section 2. If possible, prepare for the lab with your usual lab partner. Only preparation which is recorded in your laboratory logbook will contribute towards your mark for this exercise. There is no objection to several students working together on preparation, as long as all understand the results of that work. Before starting your preparation, read through all sections of these notes so that you are fully aware of what you will have to do in the lab.

> **Academic Integrity** – *If you undertake the preparation jointly with other students, it is important that you acknowledge this fact in your logbook. Similarly, you may want to use sources from the internet or books to help answer some of the questions. Again, record any sources in your logbook.*

This exercise uses the standard **mark scheme** available on the Laboratory website at http://secure.ecs.soton.ac.uk/notes/ellabs/markscheme/

Revision History

26 January 2015	Michael Ng (sxn@ecs)	First version of this lab created
1 August 2016	Michael Ng (sxn@ecs)	Version 2.
18 April 2017	Michael Ng (sxn@ecs)	Version 3.
30 Sept 2018	Michael Ng (sxn@ecs)	Version 4.

1 Aims, Learning Outcomes and Outline

This laboratory exercise aims for you to:

- Investigate Double Sideband Suppressed Carrier (DSBSC) modulation and its transmission issues.
- Investigate Frequency Modulation (FM) and Frequency Shift Keying (FSK) schemes.
- Experience real-time transmission of speech signals.

Having successfully completed the lab, you will be able to:

- Understand how DSBSC, FM and FSK work.
- Appreciate how real-time signals are modulated and demodulated in practice.

Section 2 of this document details the preparation that should be completed before attending the corresponding lab session. Every student is expected to complete upto Section 3.2.2, i.e. upto **Question 15**, as detailed in Section 3. Section 3.2.3 provides some additional works that can be completed during the lab session, in order to receive higher marks. Finally, an appendix is provided at the end of this document, in order to explain the conventions adopted by the ETT-101.

2 Preparation

It is essential that you complete **all** the work in this section **before** you come to the lab. If at all possible, prepare for the lab with your usual lab partner. Only preparation which is recorded in your laboratory logbook will contribute towards your mark for this exercise. There is no objection to several students working together on preparation, as long as all understand the results of that work. Before starting your preparation, read through all sections of these notes so that you are fully aware of what you will have to do in the lab. You are advised to refer to your 'ELEC2220 Control and Communications' lecture notes (the communications part) for answering the following questions.

1. Read and understand Section 3.1.1. Assuming a message signal of $s(t) = \cos(\omega_i t)$, sketch the time-domain waveforms before and after $s(t)$ is modulated using the DSBSC modulation at a carrier frequency of ω_c. Sketch the spectrums of the message signal and of the DSBSC-modulated signal.

2. Read and understand Section 3.2.1. Assuming a message signal of $s(t) = \sin(\omega_i t)$, sketch the time-domain waveforms before and after $s(t)$ is modulated using FM at a carrier frequency of ω_c.

3. There are 20 questions in this exercise. You should try to answer as many questions as possible during the preparation stage.

4. Read the appendix and understand the system conventions of the ETT-101 equipment before starting the experiment.

You should allocate 80 minutes on the experiments at Section 3.1 and another 80 minutes on the experiments at Section 3.2.

3 Laboratory Work

3.1 Double Sideband Suppressed Carrier Modulation

3.1.1 Theoretical Background on DSBSC

Double Sideband Suppressed Carrier (DSBSC) modulation is a modulation system similar but different to Amplitude Modulation (AM). Like AM, DSBSC uses a microphone or some other transducer to convert analogue signal (speech and music) to an electrical signal called the message or baseband signal. The message signal is then used to electrically vary the amplitude of a pure sinewave called the carrier. Similar to AM, the carrier usually has a frequency that is much higher than the message's frequency. Figure 1 below shows a simple message signal and an unmodulated carrier. It also shows the result of modulating the carrier with the message using DSBSC.

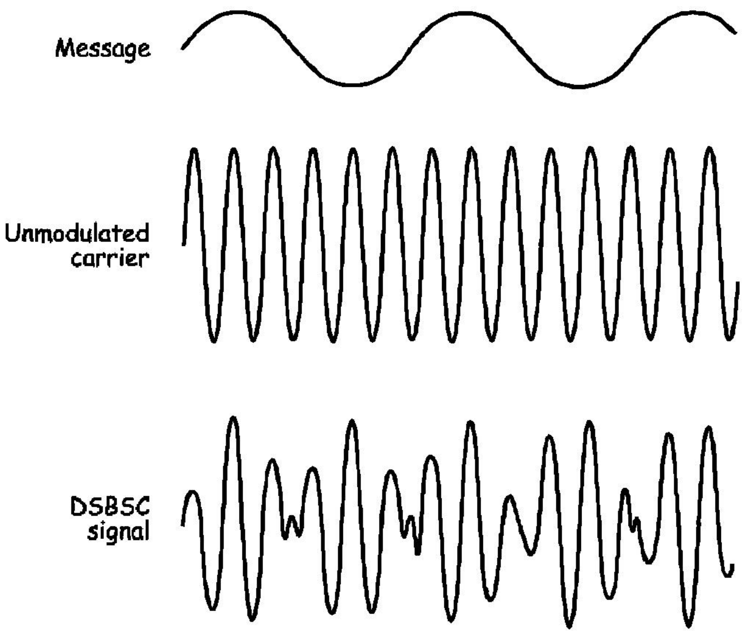


Figure 1:

Figure 2 shows the DSBSC signal with dotted lines added to track the signal's envelopes (that is, its positive peaks and negative peaks). If you look at the envelopes closely you'll notice that they do not have the same shape as the message. Instead, alternating halves of the envelopes form the same shape as the message as shown in Figure 3.

In telecommunications theory, the mathematical model that defines the AM signal is:

$$\text{AM} = (\text{DC} + \text{message}) \times \text{the carrier} \,. \tag{1}$$

By contrast, the mathematical model that defines DSBSC signal is given by:

$$\text{DSBSC} = \text{message} \times \text{the carrier} \,. \tag{2}$$

When the message is a simple sinewave (like in Figure 1) the solution to the DSBSC equation (for example: $\cos(\alpha) \cdot \cos(\beta) = \frac{1}{2}\cos(\alpha + \beta) + \frac{1}{2}\cos(\alpha - \beta)$) tells us that the DSBSC signal consists of two sinewaves:

- One with a frequency equal to the sum of the carrier and message frequencies
- One with a frequency equal to the difference between the carrier and message frequencies

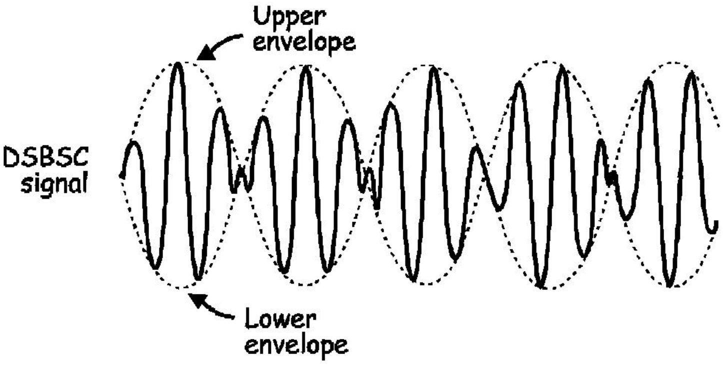


Figure 2:

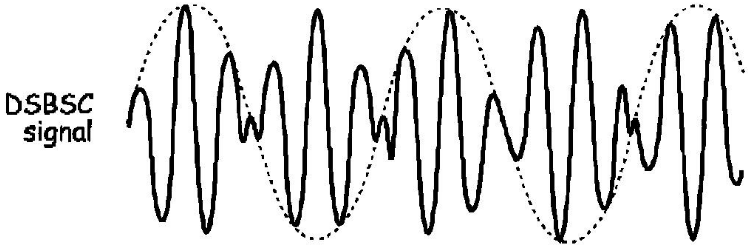


Figure 3:

More importantly, the DSBSC signal doesn't contain a sinewave at the carrier frequency. This is an important difference between DSBSC and AM.

That said, as the solution to the equation shows, DSBSC is the same as AM in that a pair of sinewaves is generated for every sinewave in the message, where one is higher than the unmodulated carrier's frequency and the other is lower. As message signals such as speech and music are made up of thousands of sinewaves, thousands of pairs of sinewaves are generated in the DSBSC signal that sit on either side of the carrier frequency. These two groups are called the sidebands.

So, the presence of both sidebands but the absence of the carrier gives us the name of this modulation method - double-sideband, suppressed carrier (DSBSC). The carrier in AM makes up at least 66% of the signal's power but it doesn't contain any part of the original message and is only needed for tuning. So by not sending the carrier, DSBSC offers a substantial power saving over AM and is its main advantage. The DSBSC modulation can be denoted by Figure 4.

The envelope detector can be used to recover(or demodulate) the original message from an AM signal. Unfortunately, the envelope detector cannot be used to demodulate a DSBSC signal since a DSBSC signal's envelopes are not the same shape as the message. Instead, DSBSC signals are demodulated using a circuit called a product detector (also known as a synchronous detector or switching detector). Its basic block diagram is shown in Figure 5. As its name implies, the product detector uses multiplication and so mathematics is necessary to explain its operation. The incoming DSBSC signal is multiplied by a pure sinewave that must be the same frequency as the DSBSC signal's suppressed carrier. This sinewave is generated by the receiver and is known as the local carrier. To see why this process recovers the message, let's describe product detection mathematically as follows:

$$\text{DSBSC demodulator's output} = \text{the DSBSC signal} \times \text{the local carrier} \,. \tag{3}$$

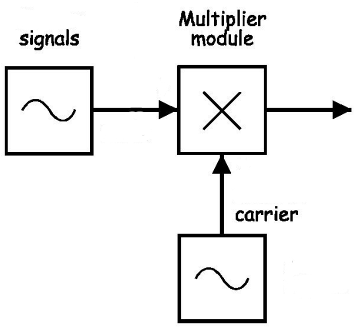


Figure 4:

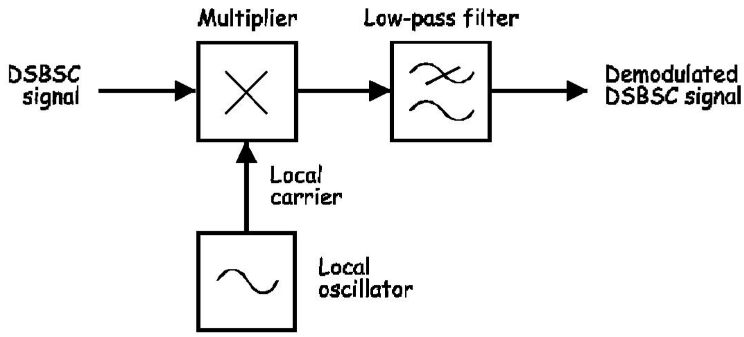


Figure 5:

More importantly, DSBSC generation involves the multiplication of the message with the carrier which produces sum and difference frequencies. That being the case, this information can be substituted for the DSBSC signal and the equation can rewritten as:

$$\text{DSBSC demodulator's output} = [(f_c + f_m) + (f_c - f_m)] \times f_c \ , \tag{4}$$

where f_c and f_m are the carrier frequency and message frequency, respectively. When the equation is solved, we get four sinewaves with the following frequencies:

- $f_c + (f_c + f_m) = 2f_c + f_m$
- $f_c + (f_c - f_m) = 2f_c - f_m$
- $f_c - (f_c + f_m) = -f_m$; (which simplifies to just the message frequency)
- $f_c - (f_c - f_m) = f_m$; (which also simplifies to just the message frequency).

(It's important to remember that for every pair of pure sinewaves that are multiplied together, two completely new sinewaves are generated. One has a frequency equal to the sum of the original sinewaves' frequencies and the other has a frequency equal to their difference.)

Notice that two of the products are sinewaves at the message frequency. In other words, the message has been recovered. As the two message signals are in phase, they simply add together to make one larger message. Notice also that two of the products are non-message sinewaves. These sinewaves are unwanted and so a low-pass filter is used to reject them while keeping the message.

In this experiment you'll use the ETT-101 to generate a DSBSC signal by implementing its mathematical model. Then you'll set up a product detector by implementing its mathematical model too. Once done, you'll connect the DSBSC signal to the product detector's input and compare the demodulated output to the original message and the DSBSC signal's envelopes. You'll also observe the effect that an over-modulated DSBSC signal has on the product detector's output. You'll investigate the effect on the product detector's performance of an unsynchronised local carrier. The effects of the channel attenuation and noise corruption on the received signal will also be investigated.

3.1.2 Setting up the DSBSC modulator

The first part of the experiment gets you to set the DSBSC modulator.

1. Gather a set of the equipment: an ETT-101 trainer set and an oscilloscope.
2. Set up the scope[1]. Ensure that:
   - the Trigger Source control is set to the Channel 1 (CH1) position at the oscilloscope.
   - the Mode control is set to the CH1 position.
3. Connect the setup as shown in Figure 6.
   Note: Insert the black plugs of the oscilloscope leads into ground (GND) sockets.

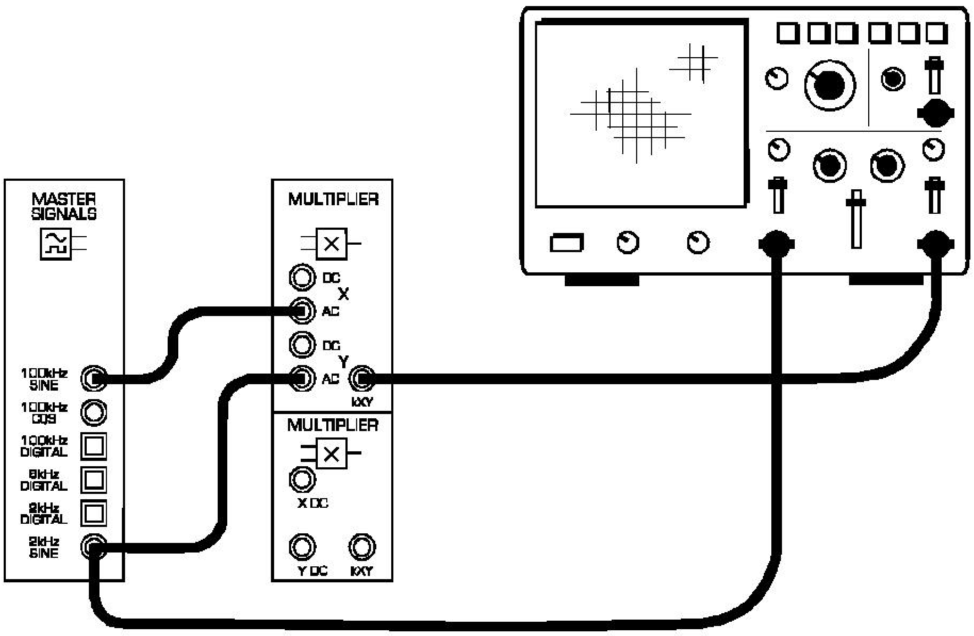


Figure 6:

   The setup in Figure 6 can be represented by the block diagram in Figure 7. It generates a 100kHz carrier that is DSBSC modulated by a 2kHz sinewave message.

4. Adjust the scope's Timebase control to view two or so cycles of the Master Signals module's 2kHz SINE output.
5. View both the DSBSC signal out of the Multiplier module as well as the message signal[2].
   Note: If you have connected the setup correctly, the Multiplier's output should be a carrier modulated by a sinewave to produce a DSBSC signal.
   Tips: You may need to adjust the scope's two Vertical Attenuation controls.

[1]You may use the 'AUTOSET' function for this setting if you are using a digital scope.
[2]If you are using the **Tektronix TDS 2024B Oscilloscope**, you can turn on 'CH 2' by pressing its 'CH2 MENU' button.

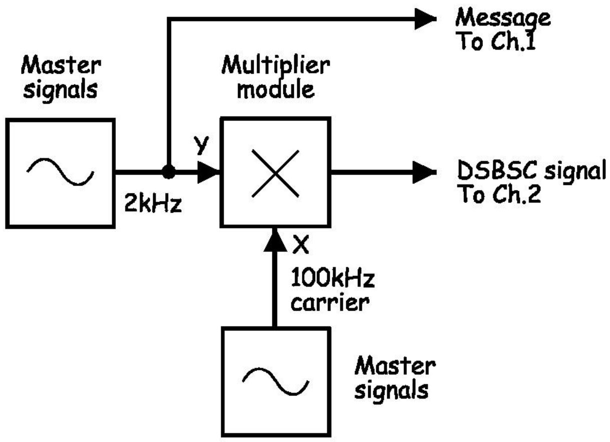


Figure 7:

3.1.3 Recovering the message using a product detector

1. Modify the setup as shown in Figure 8.
   Remember: Dotted lines show leads already in place.

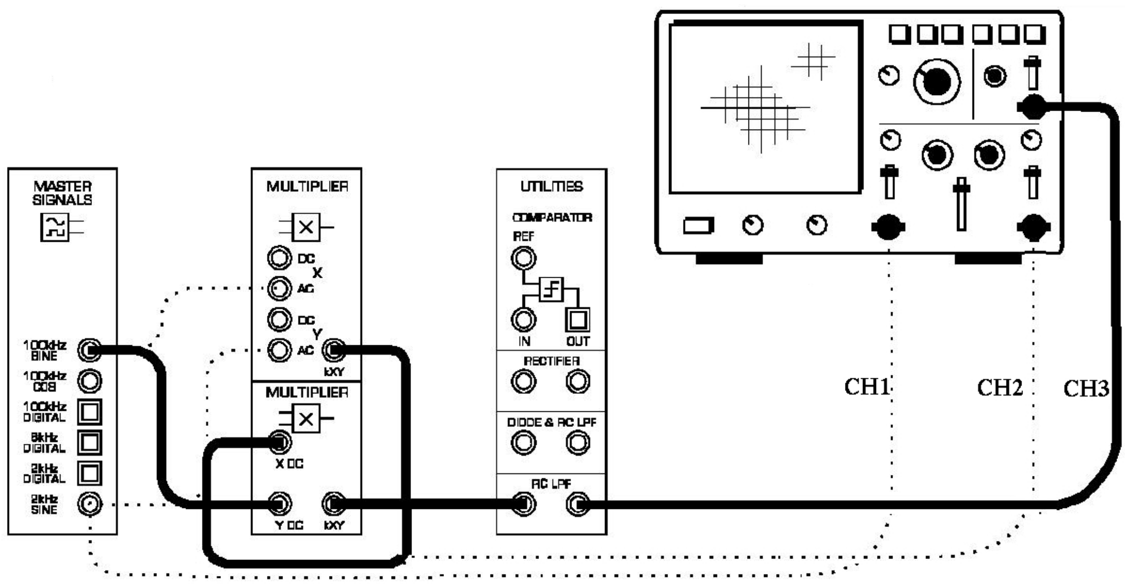


Figure 8:

The Multiplier module and the RC Low-pass Filter on the Utilities module are used to implement a product detector which demodulates the original message from the DSBSC signal. The entire setup is represented by the block diagram in Figure 9. It highlights the fact that the modulator's carrier is 'stolen' to provide the product detector's local carrier. This means that the two carriers are synchronised which is necessary for DSBSC communications to work.

2. Display the message signal (2kHz sinewave), modulated signal and demodulated signal (after RC LPF) on the scope. Set the scope's Timebase control to 100μs/div. Print these three waveforms and stick them onto your logbook. If you prefer not to print, you may sketch the waveforms directly into your logbook.

   Question 1
   How much are the time shift (in μs) and the phase shift (in radian) between the original

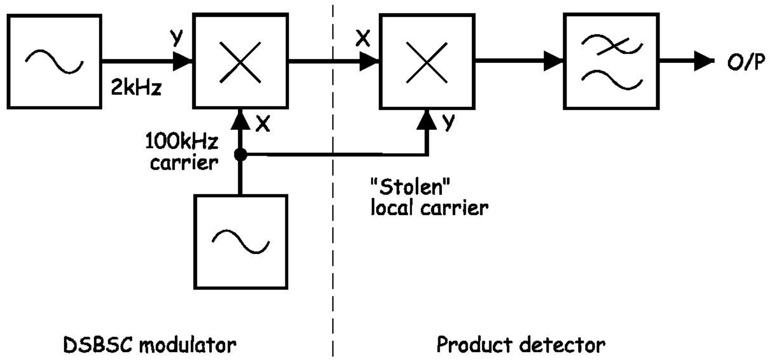


Figure 9:

and demodulated signals in terms?
(Tips: a 2kHz sinewave has a period of 500 μs, which corresponds to 2π radians. A phase shift of x μs would correspond to $x/500 \times 2\pi$ radians.)

Question 2
Why must a product detector be used to recover the message instead of an envelope detector?

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3. Press the 'MATH MENU' button on your scope and select the 'FFT' operation in order to display the spectrum of the three signals. Set the scope's Frequency base (Timebase) control to 12.5kHz/div and use the 'Rectangular window' for the FFT operation. Display and print, one by one, the spectrum of the message signal, modulated signal and demodulated signal. Stick your printouts onto your logbook. You may choose to sketch the waveforms directly into your logbook if your prefer not to print.

Question 3
Identify the locations of the spectrum of the original signal, the modulated signal and the demodulated signal from your printouts (or sketches). What are the frequencies at these locations.

Question 4
Compare the width of the spectrum when using the Rectangular window and Hanning window for the FFT operation. Which window type would produce a thinner spectrum width?

Return to the normal display (time domain) of the scope by pressing the 'MATH MENU' button once.

3.1.4 Transmitting and recovering speech using DSBSC

You have set up a DSBSC communication system to "transmit" a 2kHz sinewave. In this section you will use it to modulate, transmit, demodulate and listen to speech.

1. Modify the setup as shown in Figure 10.

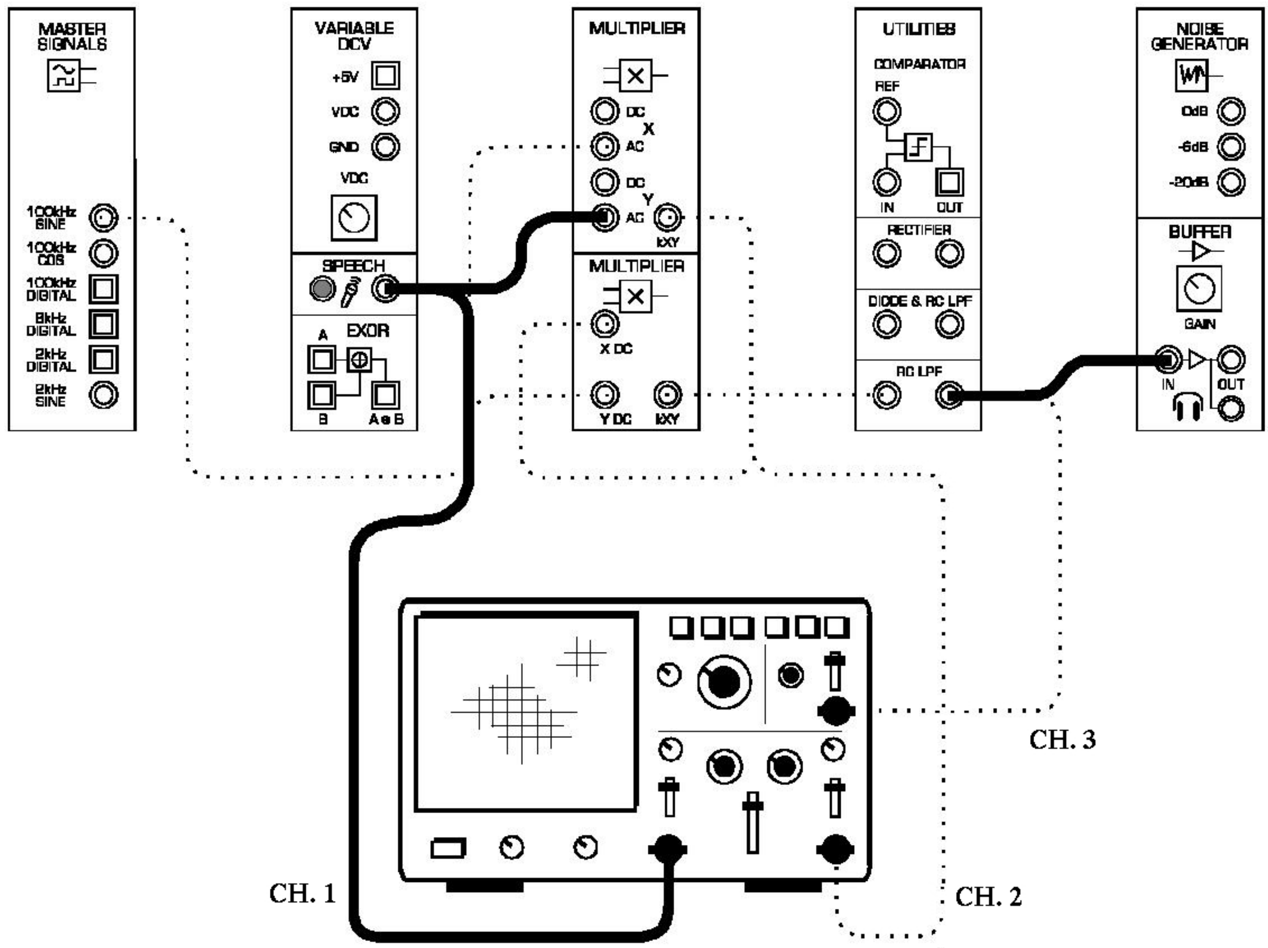

Figure 10:

2. Set the scope's Timebase control to the 1ms/div position.
3. Turn the Buffer module's Gain control fully anti-clockwise.
4. Without wearing the headphones, plug them into the Buffer module's headphone socket.
5. Put the headphones on.
6. As you perform the next step, set the Buffer module's Gain control to a comfortable sound level.
7. Talk, sing or hum while watching the scope's display and listening on the headphones.
   Question *
   Print or sketch one of the scope's display.

3.1.5 Carrier synchronisation

Crucial to the correct operation of a DSBSC communications system is the synchronisation between the modulator's carrier signal and the product detector's local carrier. Any phase or frequency difference between the two signals adversely affects the system's performance.

The effect of phase errors

Recall that the product detector generates two copies of the message. Recall also that they're in phase with each other and so they simply add together to form one bigger message. However, if there's a phase error between the carriers, the product detector's two messages have a phase error also. One of them has the sum of the phase errors and the other the difference. In other words, the two messages are out of phase with each other.

If the carriers' phase error is small (say about 10°) the two messages still add together to form one bigger signal but not as big as when the carriers are in phase. As the carriers' phase error increases, the recovered message gets smaller. Once the phase error exceeds 45° the two messages begin to subtract from each other. When the carriers phase error is 90° the two messages end up 180° out of phase and completely cancel each other out. The next part of the experiment lets you observe the effects of carrier phase error.

1. Turn the Buffer module's Gain control fully anti-clockwise again.
2. Return the scope's Timebase control to about the 0.1ms/div position.
3. Locate the Phase Shifter module and set its Phase Change control to the 180° position.
4. Set the Phase Shifter module's Phase Adjust control to about the middle of its travel.
5. Modify the setup as shown in Figure 11.

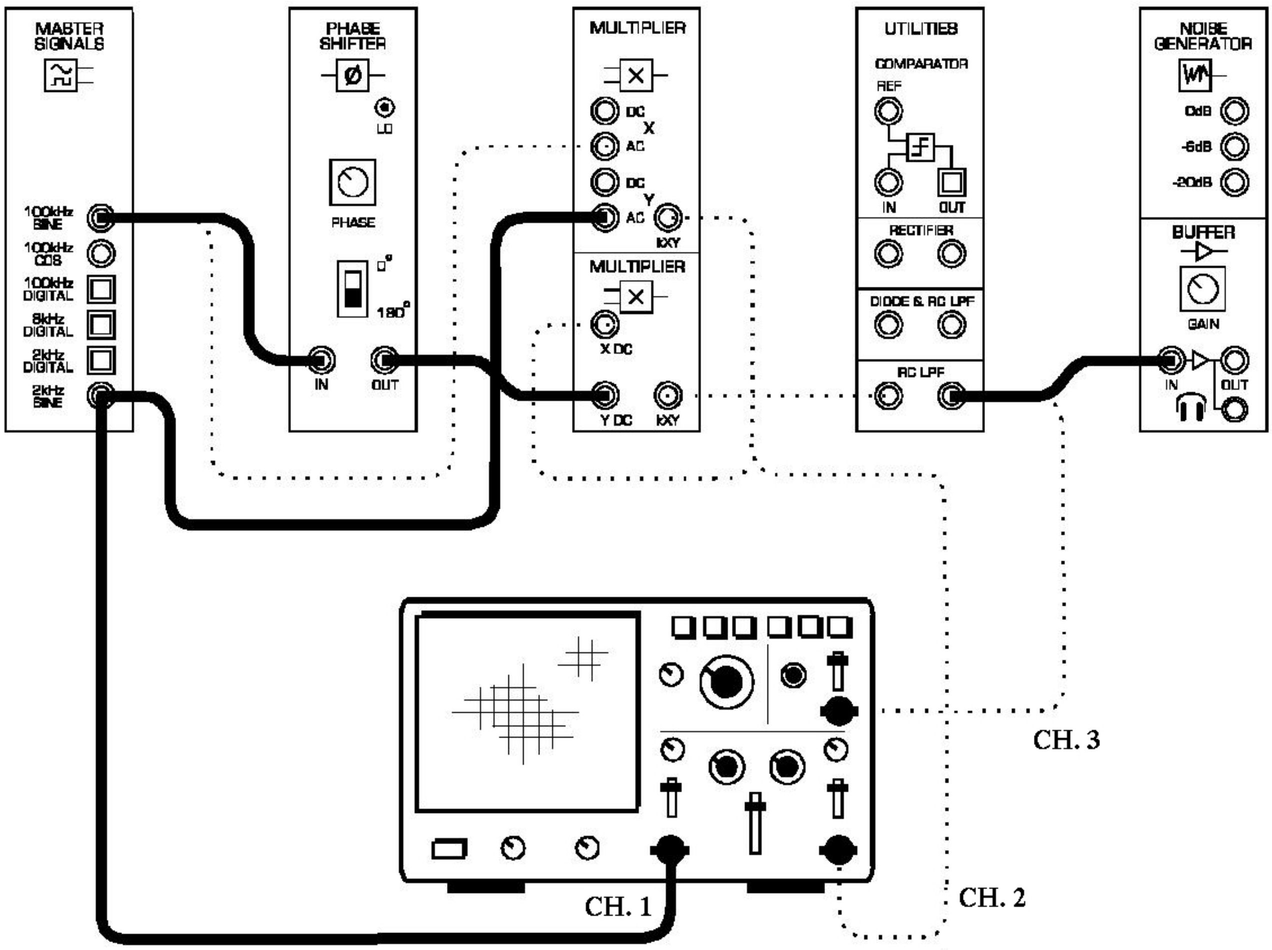

Figure 11:

The entire setup can be represented by the block diagram in Figure 12. The Phase Shifter module allows a phase error between the DSBSC modulator's carrier and the product detector's local carrier to be introduced.

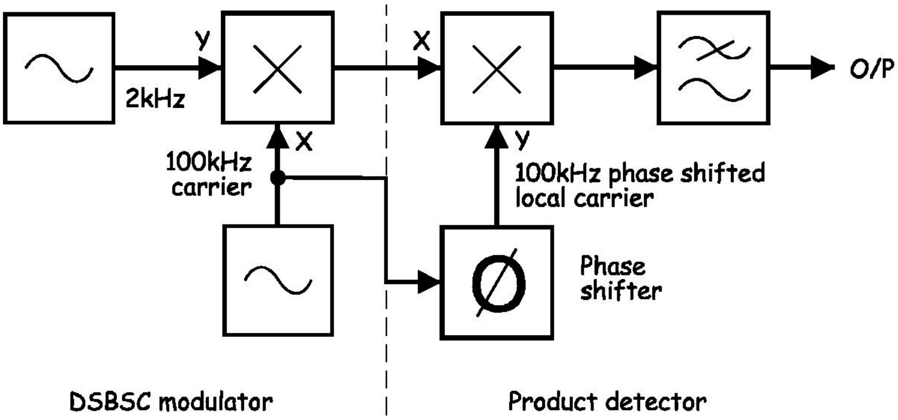

Figure 12:

6. Slowly increase the Buffer module's gain until you can comfortably hear the demodulated 2kHz tone.
7. Vary the Phase Shifter module's Phase Adjust control left and right while watching and listening to the effect on the recovered message.
8. Adjust the Phase Shifter module's Phase Adjust control until the amplitude of the recovered message is the biggest.

   Question 5
   Given the size of the recovered message's amplitude, what is the likely phase error between the two carriers?

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9. Adjust the Phase Shifter module's Phase Adjust control until the amplitude of the recovered message is the smallest.

   Question 6
   Given the size of the recovered message's new amplitude, what is the likely phase error between the two carriers?

The effect of frequency errors

When there's a frequency error between the DSBSC signal's carrier and the product detector's local carrier, the product detector generates four sinewaves instead of two. Two of them are at the message frequency reinforcing each other as normal. The other two are at frequencies lower and higher than the message by the error between the two carriers.

Ironically, the problem caused by a frequency error between the carriers is worst when the error is relatively small. This is because the additional sinewaves are close in frequency to the message and so pass through the low-pass filter with it and so can be heard by the listener. The next part of the experiment lets you observe the effects of carrier frequency error.

1. Locate the VCO module and set its Range control to the HI position.

2. Set the VCO module's Frequency Adjust control to about the middle of its travel (the middle corresponds to zero frequency offset).

3. Modify the setup as shown in Figure 13.

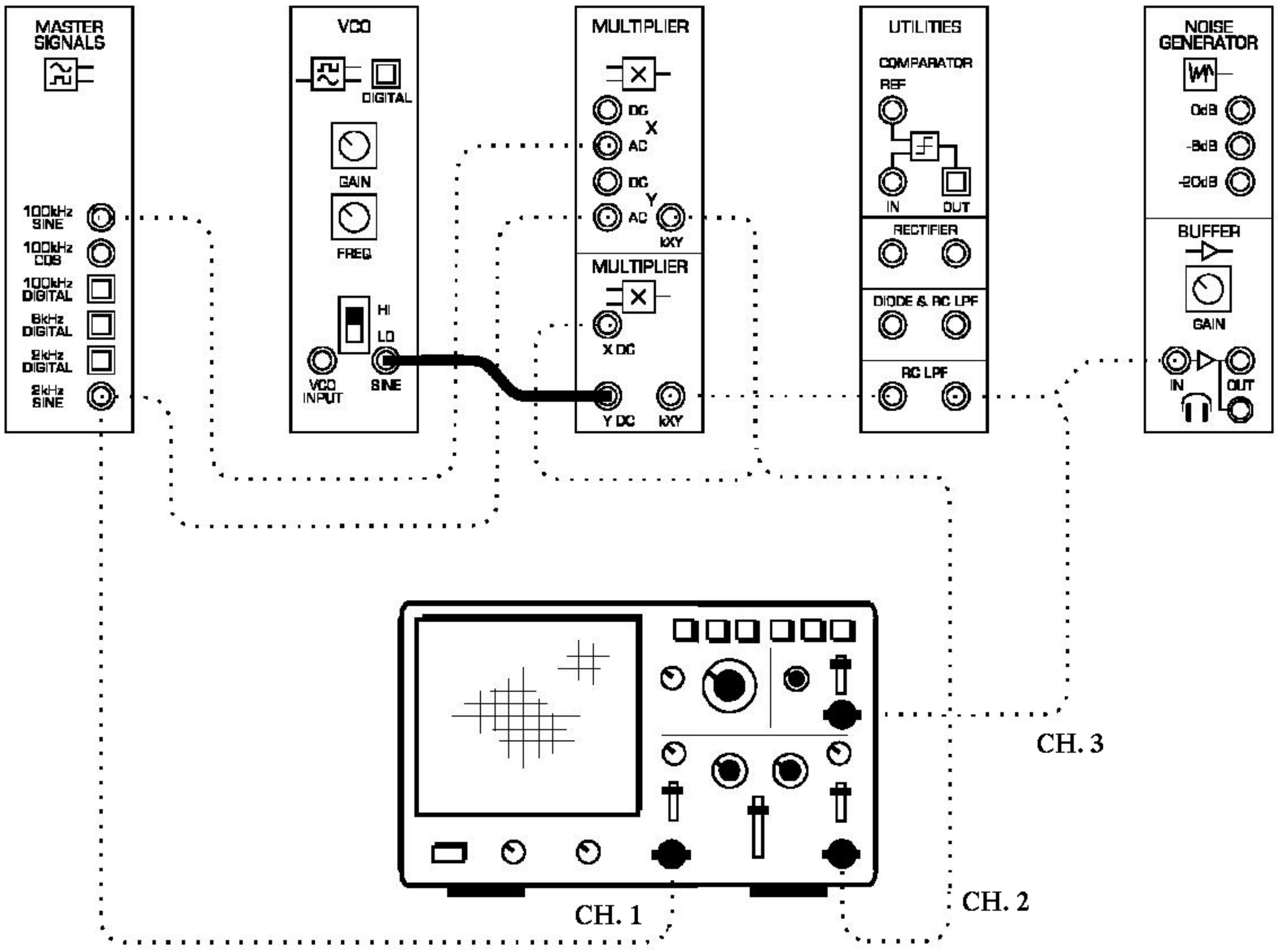

Figure 13:

The entire setup can be represented by the block diagram in Figure 14. The VCO module allows the local oscillator to be completely frequency (and phase) independent of the DSBSC modulator.

4. Vary the VCO module's Frequency Adjust control left and right and observe the effect on the recovered message.

5. If you're not doing so already, listen to the recovered message using the headphones.

6. Use the display of the recovered message on the scope and your hearing to try to get VCO module's frequency as close as possible to the transmitter's carrier frequency.

   Tips: If you can't remember what 2kHz sounds like, disconnect the plug to the VCO module's output and connect it to the Master Signals modules 100kHz SINE output for a couple of seconds. This will mean that the two carriers are the same again and the message will be recovered.

7. Disconnect the plugs to the Master Signals module's 2kHz SINE output and connect them to the Speech module's output.

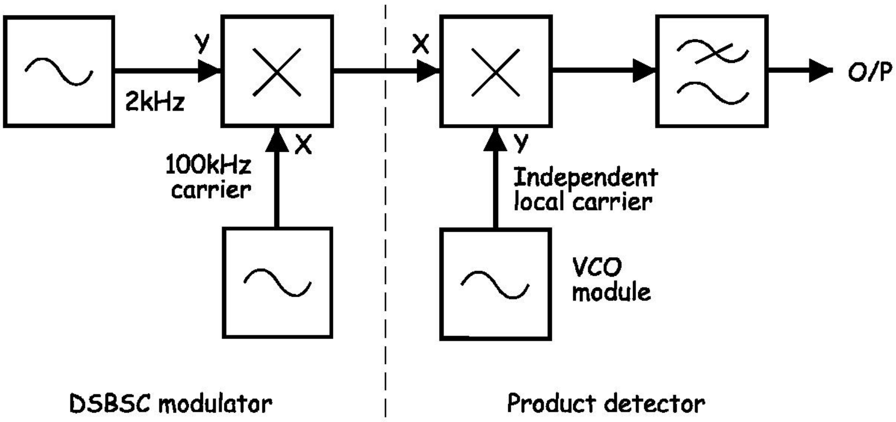

Figure 14:

8. Talk, sing, etc into the microphone while varying the VCO module's Frequency Adjust control and listen to the effect of an unsynchronised local carrier on speech.

   Question 7
   How does the recovered speech sound like when you vary the VCO modules Frequency Adjust control left and right?

3.1.6 Channel distortion and noise

A channel is the space (or medium) between the transmitter and the receiver. Two types of channels are provided in the CHANNEL MODULE of ETT-101. CHANNEL BPF is used to model a wireless channel, such as a satellite link, radio or TV channel. BASEBAND LPF is used to model a wire or cable channel, such as a telephone or modem link, or hardwired link between computer networks.

- CHANNEL BPF is a bandpass filter used for signals which are modulated at the ETT-101 carrier frequency of 100kHz. The filter is centred at 100kHz with a bandwidth of 20kHz.
- BASEBAND LPF is a lowpass filter used for data signals which are not modulated. The cut-off frequency of the filter is 2kHz.

The NOISE GENERATOR module provides a wide source of electrical noise. Three different amplitudes of noise level are provided. Electrical noise model the effects on a signal due to real-world disturbances. Examples of disturbances are other nearby signals, static, nearby electrical machines, electrical transformers and so on.

Connect the setup shown in Figure 15 but don't disconnect any of your existing wiring in Figure 13. This setup can be represented by the block diagram in Figure 16. It models the behaviour of a real channel by adding noise to communications signals. The amount of noise can be varied by selecting either the -20dB output (noise is about one-tenth the size of the signal), the -6dB output (noise is about half the size of the signal) or the 0dB output (noise is about the same size as the signal).

Now modify your setup in Figure 13 in order to transmit the DSBSC signal across the channel module so that Figure 14 is changed to Figure 17.

1. Unplug the patch lead which connects the modulator output (the 'kXY' of the upper Multiplier in Figure 13) to the demodulator input (the 'X DC' of the lower Multiplier in Figure 13).

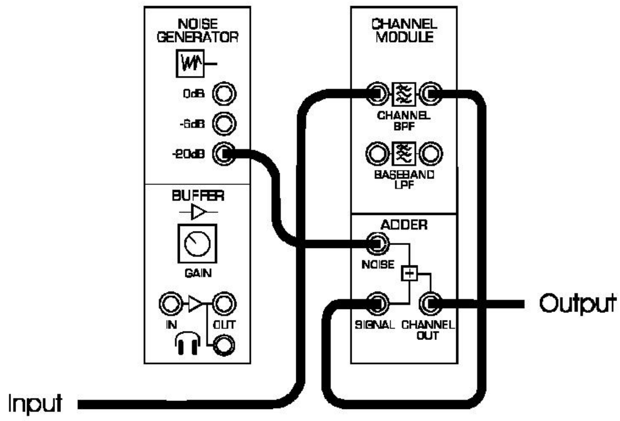

Figure 15:

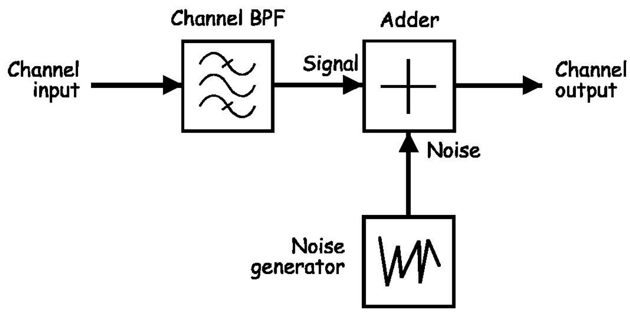

Figure 16:

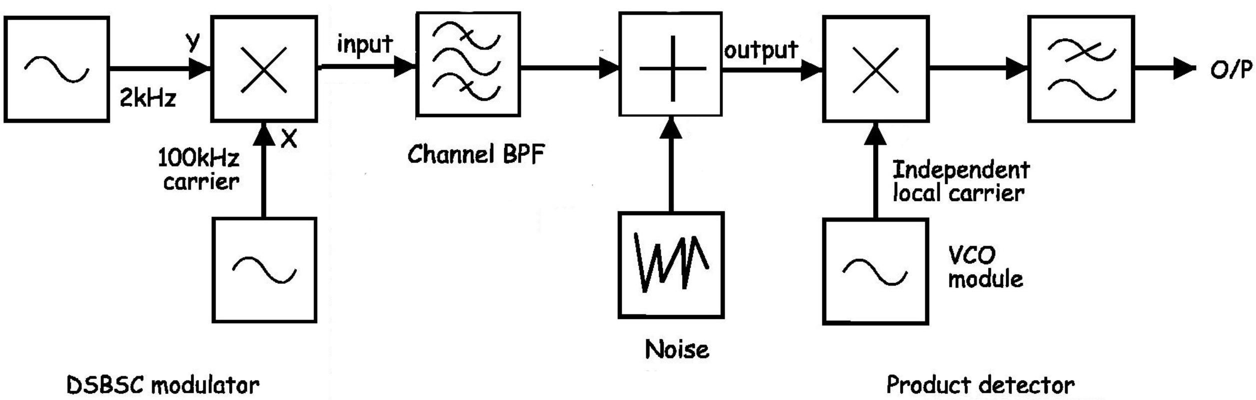

Figure 17:

2. Connect the modulator output (the ‘kXY’ of the upper Multiplier in Figure 13) to the channel input (the ‘Input’ of Figure 15).

3. Connect the channel output (‘Output’ of Figure 15), to the demodulator input (the ‘X DC’ of the lower Multiplier in Figure 13).
   Note: Once done, the transmitter’s DSBSC signal travels to the receiver’s input (the demodulator) via the model of a noisy channel.

4. Compare the original and recovered data under three different noise sources of -20dB, -6dB and 0dB.

   Question 8
   Which of these noise sources causes the worst corruption to the transmitted signal?

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5. Now change the source from sine wave to speech signals. The only thing to change in your current setup is to unplug the connection at the ‘2kHz SINE’ output of the MASTER SIGNALS module and plug it to the output of the SPEECH module.

6. Talk, sing or hum while watching the scope’s display and listening to the decoded speech signal.

   Question 9
   Can you still hear the speech signal when the noise sources are -20dB, -6dB and 0dB, respectively?

   Question 10
   How does the recovered speech sound like when you vary the VCO modules Frequency Adjust control left and right, assuming a noise source of -20dB?

3.2 Frequency Shift Keying Modulation

3.2.1 Theoretical Background on FSK Modulation

Frequency Shift Keying (FSK) modulation is the digital version of Frequency Modulation (FM). FM uses the amplitude of the message to vary the frequency of a carrier. Hence, the amplitude of the FM signal is held constant while its frequency changes according to the amplitude of the message as seen in Figure 18. Since noise affects the amplitude of the modulation signal, FM is less susceptible to noise compared to AM. Furthermore, AM requires linear amplifier to produce the final AM signal, while linear amplifier is not necessary for FM.

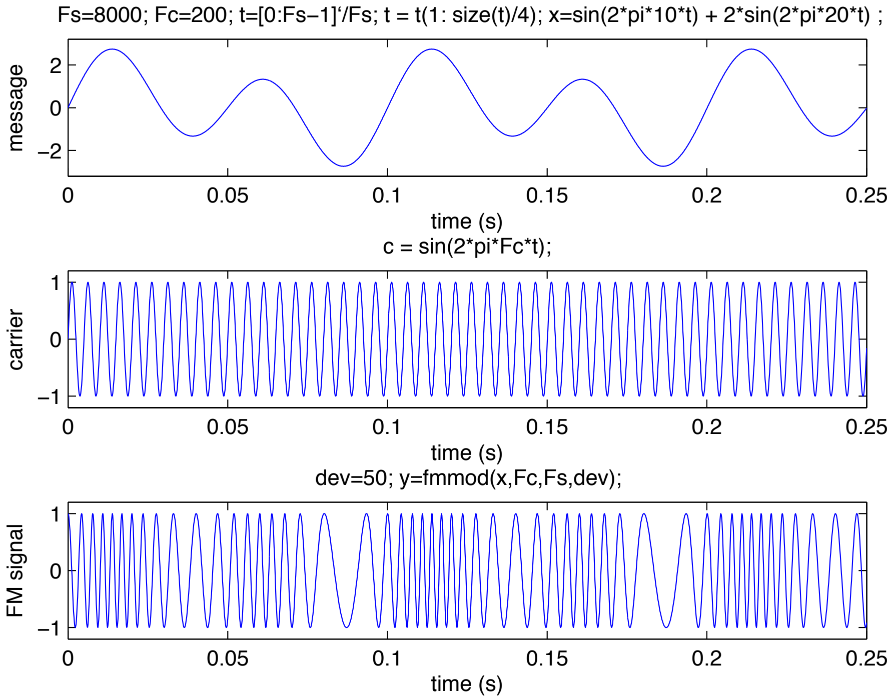

Figure 18:

FM signals can be generated using an oscillator with an electrically adjustable frequency. For example, Voltage Controlled Oscillator (VCO) can be used to generate FM signals. More specifically, the instantaneous frequency of an FM signal is given by:

$$f_i = f_c + Gm(t) \ , \tag{5}$$

where f_c is the carrier frequency (also known as the *rest* frequency), G is the VCO gain and $m(t)$ is the message signal. The higher the VCO gain, G, the higher the deviation between f_i and f_c for a given message signal amplitude. Typically, when the message amplitude is at 0V, the oscillator would output a signal at its rest frequency. When the message amplitude is higher (lower) than 0V, the oscillator would output a higher (lower) frequency signal. Hence, the bigger the magnitude of the message, the greater the deviation between the frequency of the FM signal and that of the carrier, as seen in Figure 18.

When the message signal is binary, with two possible amplitudes, the FM signal would oscillate between two frequencies. The frequency of the FM signal that corresponds to logical-0s (or at low amplitude) is normally referred to as the *space frequency*, while that corresponds to logical-1s (or at high amplitude) is referred to as the *mark frequency*. The resultant FM signal, as shown in Figure 19, is called binary FSK or simply as FSK. As expected, FSK is more robust to noise and amplifier non-linearity, compared to Amplitude Shift Keying (ASK). Note further that, the frequency of the message signal affects the rate at which the FM (or FSK) signal deviates from the carrier's rest frequency.

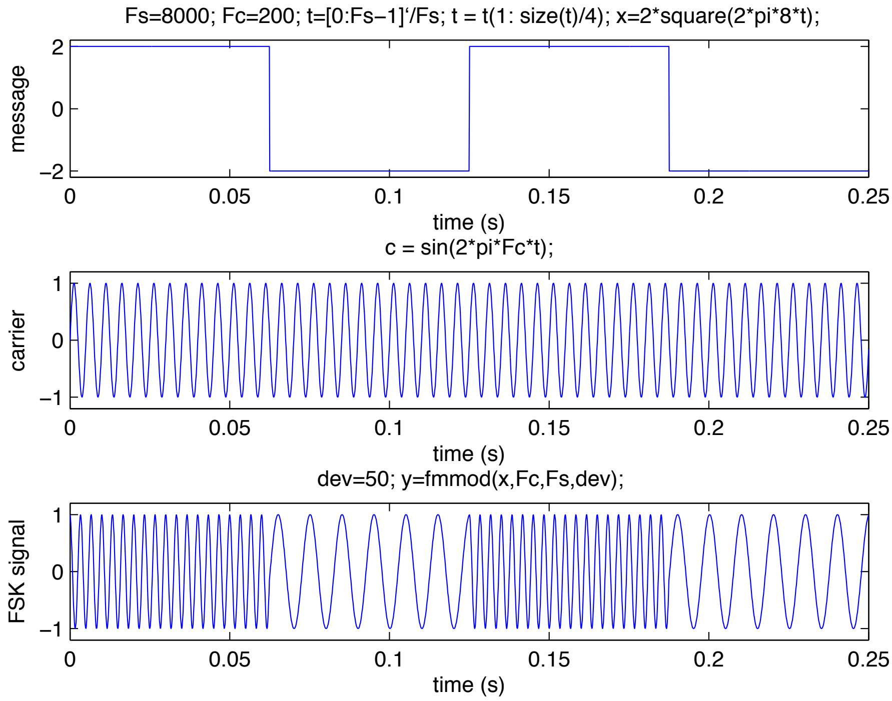

Figure 19:

FSK signal can be generated using conventional FM modulator circuits and the VCO is commonly used. FSK demodulation can be handled by conventional FM demodulators such as the zero crossing detector and the phase-locked loop. Alternatively, if the FSK signal is passed through a sufficiently selective filter, the two sinewaves that make it up can be individually picked out. Considered on their own, each signal is an ASK signal and so the data can be recovered by passing either one of them through an envelope detector.

In this experiment, you will use ETT-101 to generate FM and FSK signals. Firstly, you will set up the VCO module to investigate the unmodulated carrier. Then, you will do FM on squarewave and speech signals. Secondly, you will use the Sequence Generator module to produce digital data for FSK modulation. Then, FSK demodulation will be investigated.

3.2.2 Frequency Modulation

1. Gather a set of the equipment: an ETT-101 trainer set and an oscilloscope.

2. Set up the scope. Ensure that:

   - the Trigger Source control is set to the Channel 1 (CH1) position at the oscilloscope.
   - the Mode control is set to the CH1 position.

3. Locate the VCO module on ETT-101 and turn its Gain control to about two third of its travel (about the position of number 2 on a clock face).

4. Set the VCO module's Frequency Adjust control to about the middle of its travel.

5. Set the VCO module's Range control to the LO position.

6. Connect the setup as shown in Figure 20.

7. Set the scope's Timebase control to the 20 μs/div position.

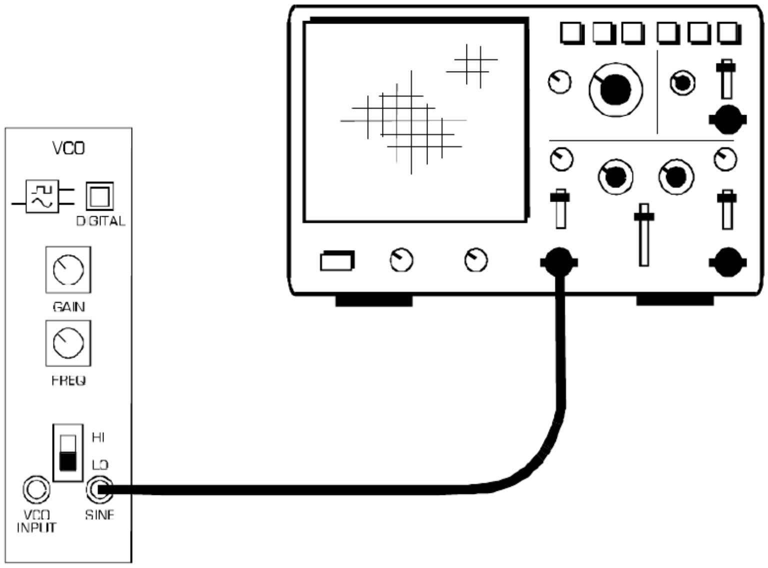

Figure 20:

8. Adjust the VCO module's Frequency Adjust control so that one cycle of its output is exactly 5 divisions.

   Question 11
   What is the VCO module's rest frequency? Explain how you measure it.

   ---

9. Now modify the setup according to Figure 21. Note that the scope's connection to the VCO module's output has changed.

10. Try to obtain an output from the VCO that is similar to the FM signal shown in Figure 19. You may need to tweak the VCO module's Gain control.

    Question 12
    How many sinewaves does the VCO module produce?

    Question 13
    Why do the sinewaves have different frequencies?

    Question 14
    What do the FM signal's sinewaves tell you about the message signal, i.e. bipolar or unipolar?

    ---

11. Next, modify the setup as seen in Figure 22 in order to generate an FM signal using speech.

12. Set the scope's Trigger Source control to the CH2 position. Then talk, sing or hum while watching the scope's display.

13. Set the scope's Timebase control to about $20\mu s$/div. Slowly make your hum louder and louder without changing its pitch.

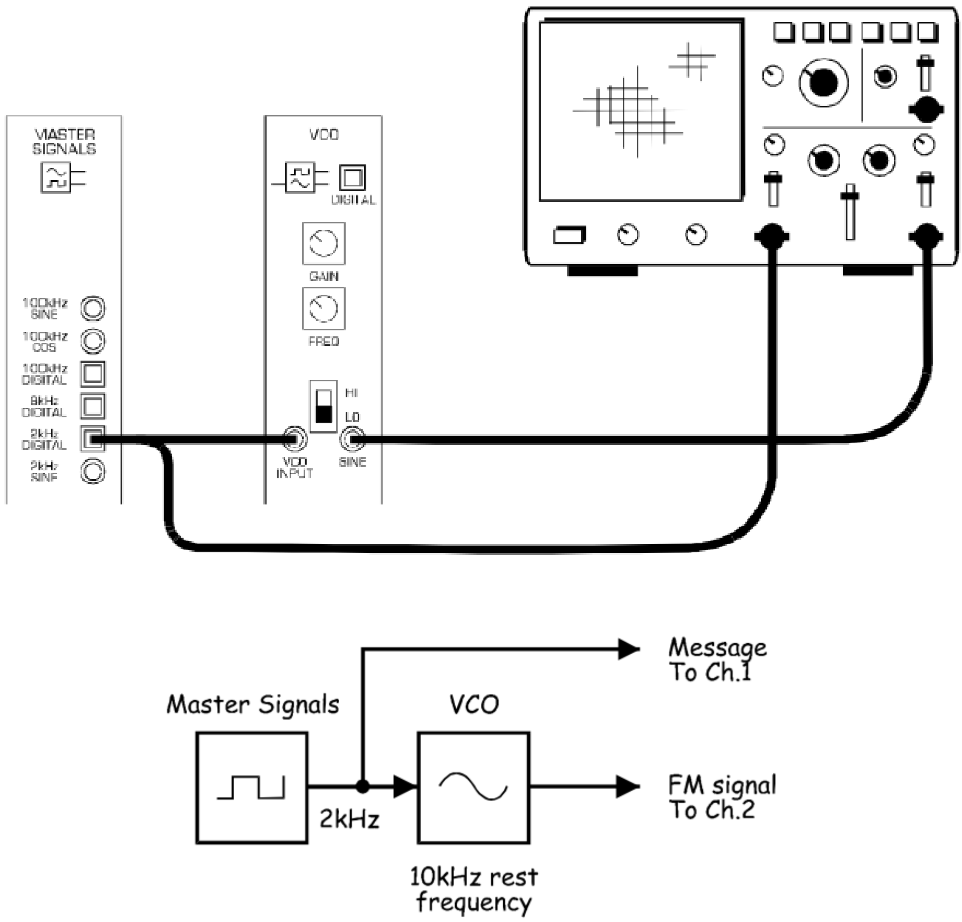

Figure 21:

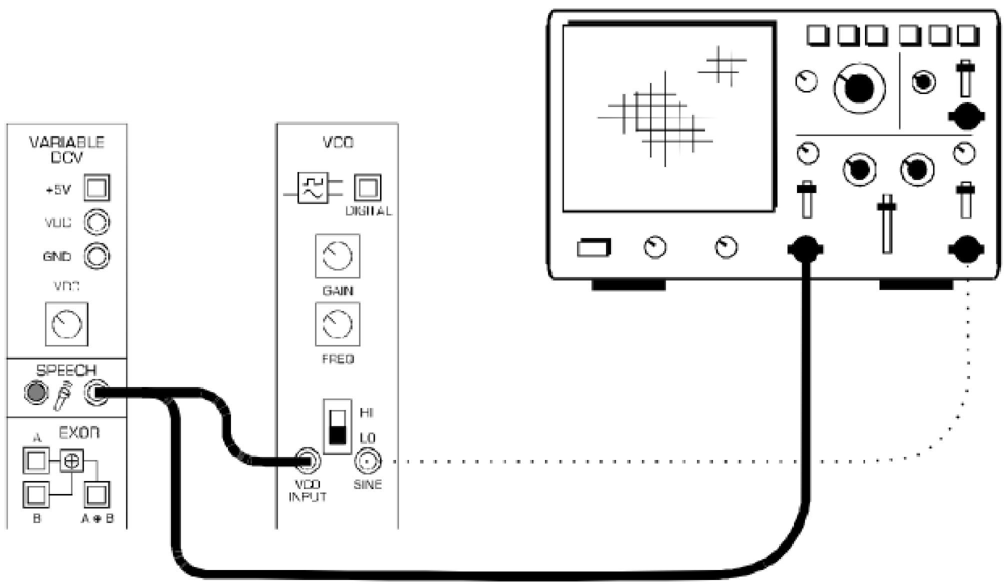

Figure 22:

Question 15
What happens to the VCO module's output as you talk louder? Why?

3.2.3 FSK Modulation and Demodulation

1. Gather a set of the equipment: an ETT-101 trainer set and an oscilloscope.
2. Set the scope's Trigger Source control to the EXT position. (Some scopes do not need this step)
3. Set the scope's Channel 1 and Channel 2 Input Coupling controls to the DC position.
4. Locate the VCO module and set its Gain control to about half its travel.
5. Set the VCO module's Frequency Adjust control to about a quarter of its travel (about the position of the number 9 on a clock face).
6. Set the VCO module's Range control to the LO position.
7. Locate the Sequence Generator module and set its dip-switches to 00 (push both switches up).
8. Connect the setup as shown in Figure 23.

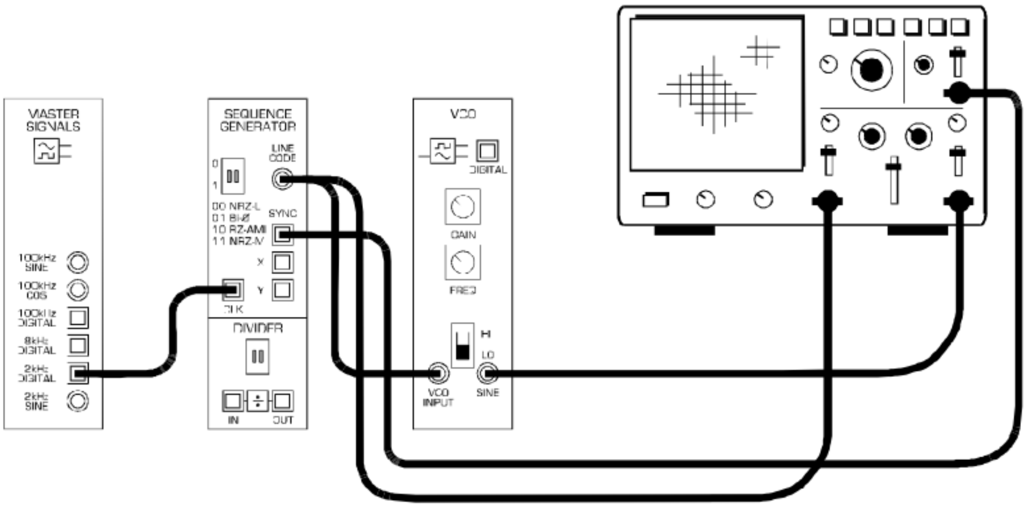

Figure 23:

9. The setup shown in Figure 23 can be represented by the block diagram seen in Figure 24. 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 VCO module is used to generate the FSK signal.
10. Set the scope's Timebase control to the 500μs/div position.
11. View the Sequence Generator module's output and the FSK signal.
12. Compare the signals. Sketch (or print out the scope screen) part of the Sequence Generator module's output and its FSK signal. Note: if the sinewaves in the FSK signal roll too

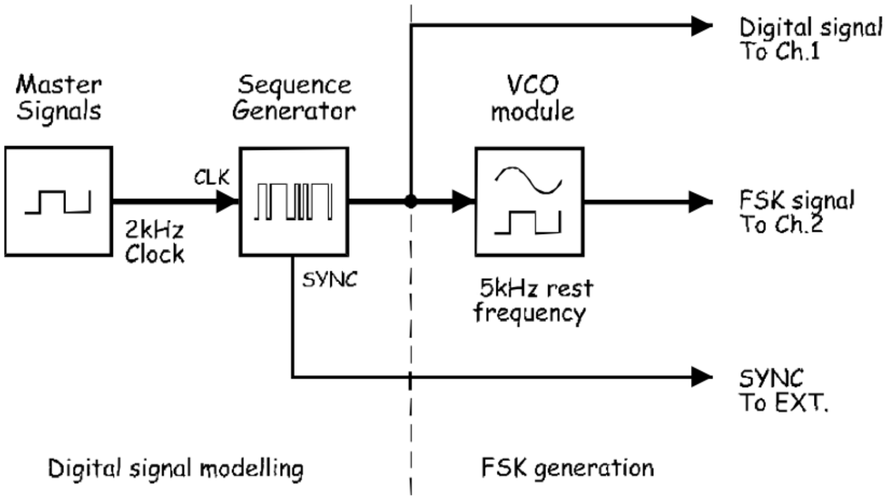

Figure 24:

much, turn the VCO module's Frequency Adjust control a little left or right to stabilise it. You may want to use the stop/start button of the oscilloscope to look at the signals.

Question 16
What is the name of the VCO output frequency that corresponds to logical-1 in the digital data? Similarly, what is the name of the VCO output frequency that corresponds to logical-0?

---

13. Now, you are going to do an FSK demodulation using simple filtering and envelope detection.

14. Turn the VCO module's Frequency Adjust control to about the position of the number 2 on a clock face.

15. Locate the Tuneable LPF module and turn its Cut-off Frequency Adjust control to about 3 quarter of its travel (about the position of the number 3 on a clock face).

16. Turn the Tuneable LPF's Gain control fully clockwise.

17. Modify the setup as shown in Figure 25. Remember that the dotted lines show leads already in place. Also, the left most modules have been cut-off to fit the drawing on the page.

    The FSK generation and demodulation parts of the setup can be represented by the block diagram in Figure 26. The Low-pass filter module is used to pick out one of the FSK signal's two sinewaves, while the DIODE and RC LPF on the Utilities module form the envelope detector to complete the FSK signals demodulation.

18. Compare the digital signal and the filter's output. Sketch them on your logbook or print out the scope screen.

    Question 17
    Which of the FSK signal's two sinewaves is the filter picking up?

Question 18
What does the filtered FSK signal look like?

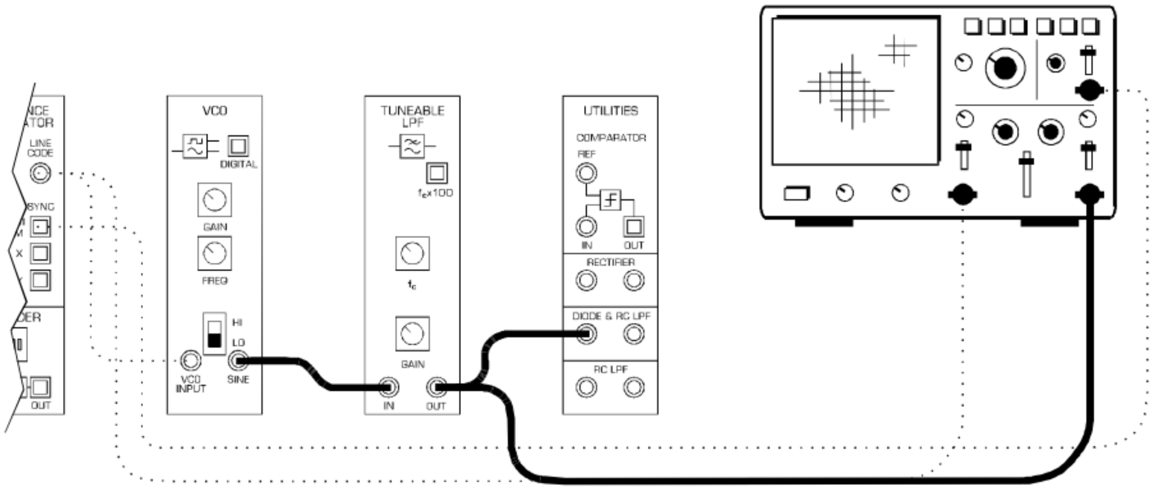

Figure 25:

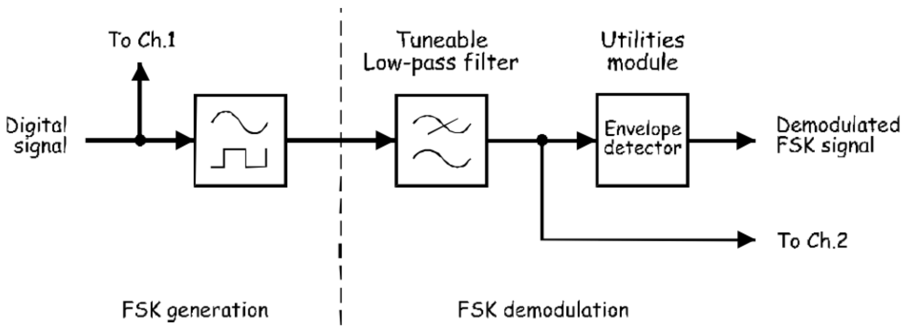

Figure 26:

19. Connect the scope's Channel 2 input to the envelope detector's output as shown in Figure 27. Compare the original digital signal with the recovered digital signal. Sketch them on your logbook or print out the scope screen.

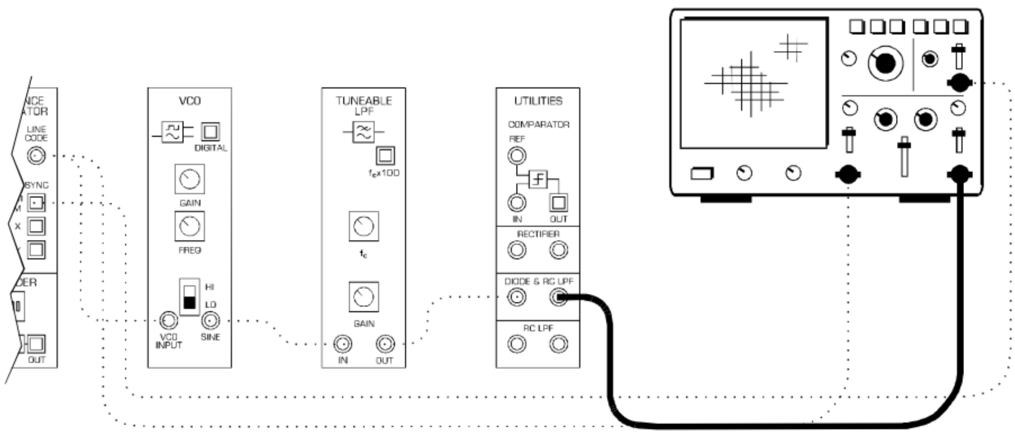

Figure 27:

20. The comparator is a useful circuit for restoring distorted digital signals. You will now use a comparator to "clean-up" the demodulated FSK signal.

21. Modify the setup as shown in Figure 28.

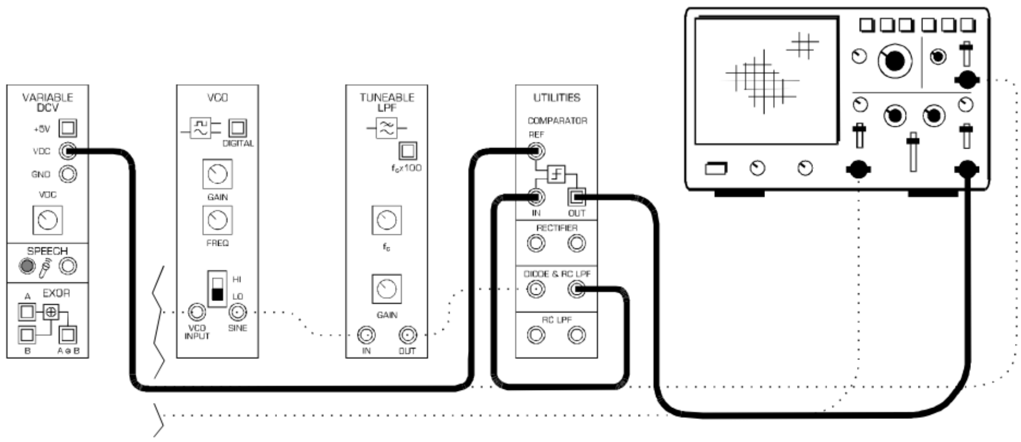

Figure 28:

The FSK generation, demodulation and digital signal restoration parts of the setup can be represented by the block diagram in Figure 29

22. Set the Variable DCV module's Variable DC control to about the middle of its travel. Compare the signals. Note: If they are not the same, vary the Variable DCV module's Variable DC control until they are.

23. Now add noise to the FSK signal based on the additional setup shown in Figure 30.

    First, disconnect the lead between the VCO output and the Tuneable LPF input. Then, locate the Channel Module and connect the VCO output to the 'SIGNAL' input of the ADDER(under the Channel Module), while connect the 'CHANNEL OUT' of the ADDER to the Tuneable LPF input.

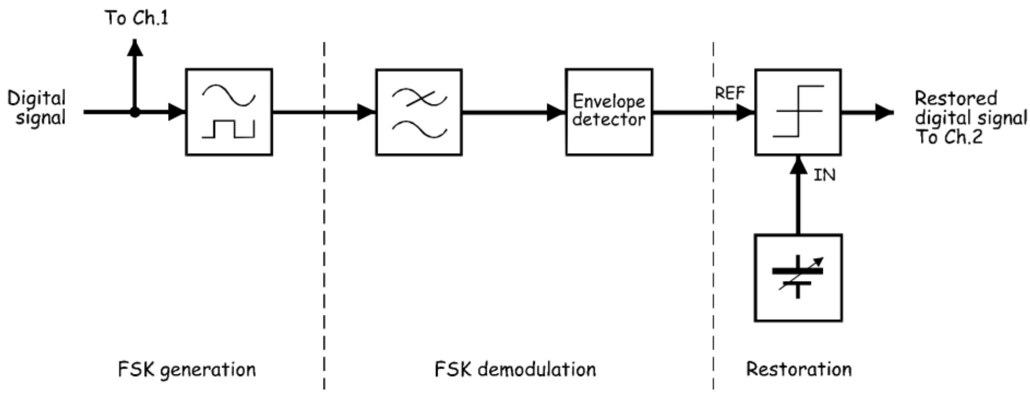

Figure 29:

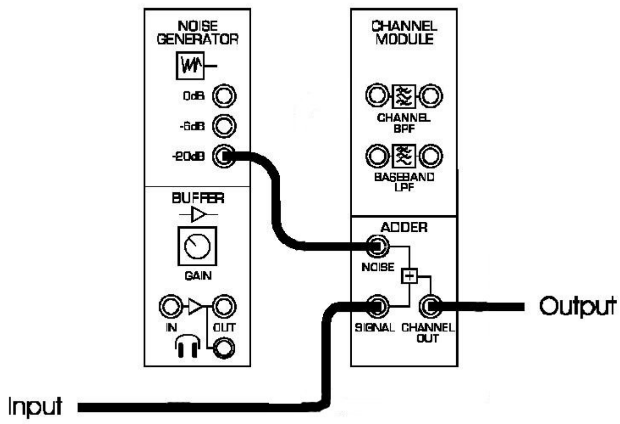

Figure 30:

24. Locate the Noise Generator module and investigate the effect of the noise on the restored digital signal.

Question 19
How does the -20dB noise affect the restored digital signal?

Question 20
How does the -6dB noise affect the restored digital signal?

Appendix: ETT-101 System Conventions

The front panel of the EMONA Telecoms-Trainer 101 (ETT-101) has been laid out following a series of front panel conventions. All ETT-101 modules, for example the module shown in Figure 31, conform to the following mechanical and electrical conventions:

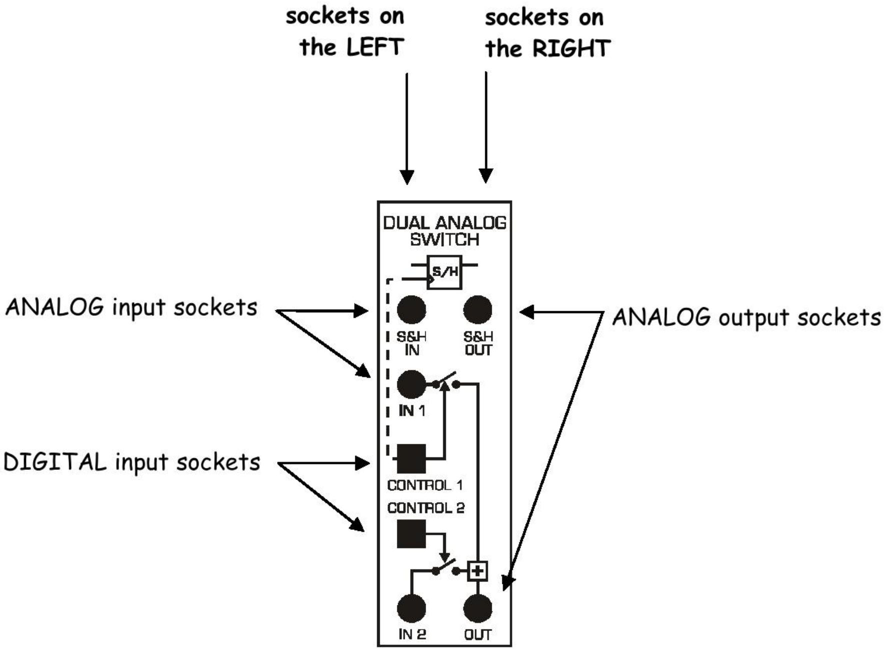

Figure 31:

- Signal interconnections are made via front panel, 2mm sockets.
- Sockets on the **LEFT HAND SIDE** are for signal **INPUTS**. All inputs are high impedance, either 10k ohms or 56k ohms depending on the module, in order to reduce effects when connections are made and broken.
- Sockets on the **RIGHT HAND SIDE** are for signal **OUTPUTS**. All analog outputs are low impedance, typically 330 ohms. Again, this is to reduce effects when connections are made and broken. Digital outputs are typically 47 ohms.
- ROUND sockets, "○", are only for ANALOG signals. ANALOG signals are typically held near the ETT-101 standard reference level of 4V pk-pk.
- SQUARE sockets, "□", are only for DIGITAL signals. DIGITAL level signals are TTL level, 0 to 5 V.
- ROUND sockets labelled GND, "○", are common, or system GROUND.

⇨ **Warning:** Each of the scope probe has a red lead and a black lead. Plug the **black lead** to the ground (GND) socket. It will not work if you plug the red lead to the GND.

⇨ **Note:** There are two GND sockets at the middle of the trainer and one GND socket at the 'Variable DCV' module. It is possible to create more than 3 GNDs using the jumpers provided.

If you are using a digital scope, you may use the 'AUTOSET' button for most of the scope settings or use the 'AUTOSET' button for attaining the initial scope setting[3].

[3]Please contact Michael Ng at sxn@ecs.soton.ac.uk for further comments and feedbacks. ©2015