**Department of Electronic and Information Engineering**

**Communication Laboratory**

**Amplitude Modulation**

**Objective**
To study the operation of an AM Modulator and of two types of detectors – an envelope detector and a synchronous demodulator.

**Background Knowledge**

(1) **Amplitude Modulation Basics**

A simple form of information transfer is Morse code, where the signal at the frequency selected for transmission is switched off and on in dots and dashes. The transmission frequency is mainly selected by consideration of the transmission medium and has nothing to do with the information it has to carry.

In order to carry any information, some characteristics of the carrier must be changed, or modulated with that information, hence the term modulating signal. In the Morse code example where the carrier is switched off and on, it is the amplitude of the carrier that is carrying the information. This is very crude form of Amplitude Modulation (AM) because there are only two states: zero amplitude and full amplitude. In order to carry more complex information such as speech or television, the amplitude is varied linearly so that the instantaneous carrier amplitude is proportional to the amplitude of the modulation signal. When the modulating signal is varying the carrier from zero to twice its amplitude, the carrier is said to be fully, or 100%, modulated. Modulation depth, or modulation index, is calculated from the formula:

\[ m = \frac{(v_{\text{max}}-v_{\text{min}})}{(v_{\text{max}}+v_{\text{min}})} \]

where \( v_{\text{max}} \) is the maximum instantaneous carrier amplitude and \( v_{\text{min}} \) is the minimum one. The resulting fraction is often expressed as a percentage. If the fraction exceeds 1 (modulation depth greater than 100%), then the carrier is said to be over-modulated.

100% modulation
The maximum voltage \( v_{\text{max}} \) is 2V and the minimum voltage \( v_{\text{min}} \) is 0V.
\[ \therefore \text{the modulation index} = \frac{(2 - 0)}{(2 + 0)} = 1.0 \]

50% modulation
The maximum voltage \( v_{\text{max}} \) is 3V and the minimum voltage \( v_{\text{min}} \) is 1V.
\[ \therefore \text{the modulation index} = \frac{(3 - 1)}{(3 + 1)} = 0.5 \]
Amplitude modulated signals in the time domain
One of the easiest methods of examining a signal is by the oscilloscope. This is the time domain. The amplitude variation of the carrier in time with the modulation and the operation of a system analysed can be seen easily. In the practicals, we use a sine wave as the modulation source, as this makes the oscilloscope pattern clearest; the modulating signal could be very complex in a practical system. The modulating frequency would probably be lower. In order for the oscilloscope trace to be stable, it must be triggered from the modulation source.

Amplitude modulated signals in the frequency domain
The use of a spectrum analyser for examining signals in the frequency domain is a very powerful tool. The spectrum analyser shows the modulated signal to have three components:
1. The Carrier, at the same frequency as the carrier source.
2. A lower side frequency at the carrier minus the modulation frequency.
3. An upper side frequency at the carrier plus the modulation frequency.

The amplitude of the carrier is independent of the modulation, while the amplitude of the side frequencies depends entirely on modulation depth. In the practical, the modulation source is a sine wave, containing only one frequency, and therefore is represented by a narrow line in the frequency spectrum. In practice, where the modulating signal is more complex, there would be a range, or band, of side frequencies above the carrier frequency and a band below it. They extend either side of the carrier to an extent equal to the maximum modulating frequency.

Note: The instrumentation is triggered from the modulating signal. It will not work if that signal is reduced to zero. So, to observe the effect of low signal levels, reduce the modulating signal slowly and not too far.

(2) Envelope Detector
The purpose of any detector or demodulator is to recover the original modulating signal with the minimum of distortion and interference. The simplest way of dealing with an AM signal is to use a simple half-wave rectifier circuit. If the signal were simply passed through a diode to a resistive load, the output would be a series of half-cycle pulses at carrier frequency. So the diode is followed by a filter. Typically a capacitor and resistor in parallel.

This is essentially just a half-wave rectifier which charges a capacitor to a voltage \( \approx \) to the peak voltage of the incoming AM waveform. When the input wave's amplitude increases, the capacitor voltage is increased via the rectifying diode. When the input's amplitude falls, the capacitor voltage is reduced by being discharged by a resistor R. Hence the term “envelope detector”.

![Envelope Detector Circuitry.](image)
The time constant of the RC network is very important because if it is too short, the output will contain a large component at carrier frequency. However if it is too long it will filter out a significant amount of the required demodulated output.

In this practical, the output of the AM generator that you used previously is fed to an envelope detector. You can monitor the output and compare it with the original modulation source. The time constant of the filter following the detector can be adjusted. This filter is often called a post-detection filter. It also introduces a phase shift between the original signal and the output.

(3) Product Detector
In this practical, you will investigate an alternative demodulator called a product detector. It has certain advantages over the simple envelope detector but at the expense of some complexity.

It is not often used for AM but is the only type of detector that will demodulate the suppressed carrier amplitude modulations that are investigated in the next assignment. It is important to appreciate that a product detector will demodulate all forms of AM.

If the AM signal is mixed with (i.e. modulated by) a frequency equal to that of its carrier, the two sidebands are mixed down to the original modulating frequency and the carrier appears as a d.c. level. The mathematics of the process show that this will only happen if the mixing frequency is equal not only in frequency to that of the carrier, but also in phase, i.e. the two signals are synchronous. This is why a product detector when used for AM is sometimes called a synchronous detector. For AM the effect is very similar to a full-wave rectifier rather than the half-wave of the envelope detector.

The output still needs a post-detection filter to remove the residual ripple, but this time the ripple is at twice the carrier frequency and is therefore further away from the modulation and hence easier removed.

In general terms the product detector gives less distortion, partly because it uses both positive and negative peaks of the carrier.

Generating the Mixing Frequency
This is produced by an oscillator, which is usually referred to as a Beat Frequency Oscillator or BFO. This is because if it is not at the same frequency as the carrier the output of the product detector is a frequency equal to the difference between the two which is called a beat frequency, or envelope frequency.

As previously described, it is vital that the BFO be synchronised to the carrier. In practice, this is achieved with a special recovery circuit but there for simplicity a sample of the carrier is fed directly to the BFO and when the free running frequency of the BFO is near to that of the carrier it locks into synchronism.
Reference
1. Ferrel G. Stremler, Introduction to Communication Systems 3rd, Addison Wesley
2. Amplitude Modulation
3. Single-side-band Demodulation
4. The Envelope Detector

Equipment
1. PC Interface Box (RAT 53-100)
2. AM Board 53-130
3. Oscilloscope (optional)
4. Feedback Power Supply 01-100
5. PC with Discovery Software

Preliminary Preparation
1. Connect the equipment as the following Figure 2 and DO NOT turn on any power at this moment.

![Figure 2: Setting.](image)

2. Switch on the Oscilloscope and set it as follows:
   Vert. Amp 0.2V/Div
   Hori. Amp 5μs/Div
3. Turn on the Computer first and connect AM Board to the Interface before switching on the FEEDBACK Power Supply 01-100.
   Note: Connect the voltages of the AM Board to that of the Interface carefully, otherwise, the Board will be burnt!
4. In DOS Prompt mode, type `<CD\FBTP>` and then `<START>`.
5. Turn on the power.
6. Use the Mouse to click at the `<System>` in the Menu Bar and then select `<Index>`.
7. Click `<1>` in the list for Assignment 1 and then select `<Yes>` for this experiment.
8. Click at the `<Practicals>` in the Menu Bar, and select `<Practical 1>` for Practical 1 experiment and so on.
9. Click at `<Conditions>` in the Menu Bar and select `<Spectrum Analyser>`.
10. Click at `<Conditions>` in the Menu Bar and select `<Change size>`. Then the `<spectrum analyser>` will be in large size.
11. Use Channel 1 of the Oscilloscope to monitor any point on the AM Board if necessary.
Experimental Procedures & Questions
(1) Practical 1 (Amplitude Modulation with Full Carrier)
Practical 1 introduces the generation of the amplitude-modulated signal.

1. Select <Practical 1> from the <Practicals> menu in Assignment 1.
2. On AM Board, set the <carrier level> to maximum and the <modulation level> to minimum.
3. Use the Mouse to click at point <6> on the screen.
4. Click <Conditions> and then select <Oscilloscope> and <Change size> for easy observation.
5. Increase the <modulation level> until the minimum instantaneous carrier amplitude $v_{\text{min}}$ just reaches zero. This is 100% modulation. If the <modulation level> is still increased after $v_{\text{min}}$ have already reached zero, then over-modulation occurs.
6. Try to adjust the <modulation level> and observe the signals at point <6> with the <oscilloscope> and the <spectrum analyser> at various modulation levels.

**Question 1:** What happens to the positive and negative envelopes when over-modulation occurs?

**Question 2:** How would you recognise over-modulation on the spectrum analyser display when comparing with full modulation?

7. Re-connect point <6> to the <oscilloscope> display.
8. Adjust the <modulation level> and calculate the modulation index until 50% modulation is achieved. Then record the maximum and minimum instantaneous carrier amplitudes of point <6>.

**Question 3:** Calculated the modulation depth from the data obtained above. Comment on the calculated modulation depth with the theoretical value.

9. Change to observe the signal by the <spectrum analyser> and measure the sidebands.

**Question 4:** What is the amplitude of the two sidebands relative to the carrier expressed in dB for 50% modulation?

10. Adjust the <carrier level> with a fixed <modulation level> and then use spectrum analyser to observe the changes in signals at point <5> and <6>. 

Figure 3: Practical 1 configuration.
(2) **Practical 2 (Demodulation using an Envelope Detector)**
Practical 2 aims to demodulate the signal from the amplitude modulator by using an envelope detector. The hardware is configured as shown below:

![Practical 2 configuration diagram]

1. Select <Practical 2> from the <Practicals> menu in Assignment 1.
2. Set the <carrier level> to maximum.
3. Set the <modulation level> to about half scale.
4. Set the <time constant> to minimum.
5. Use the <oscilloscope> to monitor the detector output <16> and adjust the <time constant> on the AM Board. If the time constant is too short, a large carrier component is present.
6. Increase the <time constant> and observe the amplitude of the detected output from the <oscilloscope> at large size.

**Question 5:** What happens to the waveform of the detected output when the time constant is increasing? Explain the observation with the aid of diagrams.

7. Use the <spectrum analyser> to observe the carrier component amplitude.
8. Compare the original modulating signal at point <4> with the detector output at point <16> in both shape and phase at various time constants using the <oscilloscope>.

**Question 6:** Draw the waveforms observed at point <4> and <16>.

**Question 7:** Is the phase shift caused by the post-detection filter a lead or lag?

**Question 8:** Why does the filter cause a phase shift?

**Question 9:** What problems could be caused if the range of modulating frequencies was quite large?

**Question 10:** Does the demodulated signal be distorted when over-modulation occurs? Explain.
(3) Practical 3 (Demodulation using a Product Detector)
Practical 3 aims to demodulate the signal from the amplitude modulator by using a product detector. The hardware is configured as shown below:

![Practical 3 Configuration Diagram]

Figure 5: Practical 3 configuration.

1. Select <Practical 3> from the <Practicals> menu in Assignment 1.
2. Set the <carrier level> to maximum and the <modulation level> to about half scale.
3. Monitor the BFO output at <13> with the <oscilloscope> at large size.
4. Adjust the <BFO Frequency> control slowly until a clear stationary trace is shown on the <oscilloscope> display. This means that the BFO frequency is locked to the carrier. Both are in phase.
5. Use the <oscilloscope> to look at the output of the detector <15> before the filter.

**Question 11:** Draw the waveform and explain its phenomenon.

6. Use the <spectrum analyser> to compare the output of the detector with the carrier in terms of the frequency of the ripple, which is at twice the carrier frequency.
7. Use the <oscilloscope> to examine the output of the filter <14> and then compare it with the modulation source <4>.
8. Examine the filtered output <14>, using the <spectrum analyser> at large size, with the BFO synchronised. The trace should show three points where the level is above the background ripple.

**Question 12:** Explain what the three points represent.

9. Again examine the filtered output <14>, using the <spectrum analyser> at large size.
10. Decrease the amplitude of the modulation signal as far as possible without the instrument trigger failing.
11. Vary the <BFO Frequency> control.

**Question 13:** How wide is the available range of the beat frequency approximately?