PREPARATION ........................................................................................................ 62
  the application .................................................................................................... 62
  multi-channel tape recorder ............................................................................. 62
    scheme 1 ......................................................................................................... 63
    scheme 2 ......................................................................................................... 64
  avoid crosstalk ................................................................................................. 64
EXPERIMENT ....................................................................................................... 65
TUTORIAL QUESTIONS ....................................................................................... 67
ACHIEVEMENTS: principle of FDM; appreciation that more than one channel can be recorded on a single track of a domestic tape recorder; demodulation of FDM.

PREREQUISITES: completion of experiments on DSBSC and SSB demodulation eg. Product demodulation - synchronous and asynchronous.

PREPARATION

The principle of frequency division multiplexing - FDM - should be familiar to everyone, since every domestic radio or TV receiver is a frequency de-multiplexer.

You are aware that there are many local radio stations operating without mutual interference. They occupy their own allocated frequency channels without overlap. They have been frequency multiplexed into the radio spectrum.

A de-multiplexer is merely a device which can select one station (channel) from all others. It is a frequency selective device.

the application

Although the above description was indeed of FDM, it is not a typical example of an FDM system. The principle is generally applied when it is required to transmit, simultaneously, more than one message via a particular communications channel, such as a transmission line (say twisted pair or coaxial), and all channels emanate from the same location. Such a medium is thought of as being basically a single channel, but FDM techniques enable it to carry multiple channels simultaneously.

The motivation comes from the observation that a particular transmission medium, say twisted pair, or coaxial cable, has a bandwidth much wider than that of a single voice channel, and so it seems wasteful to use it for one voice channel only.

multi-channel tape recorder

In this experiment the principle of FDM has been used to place several channels on a single track of an audio tape recorder.
The bandwidth of a good quality domestic audio tape recorder is at least 16 kHz, and so is adequate for the purpose of accepting four 3 kHz audio channels side by side, with spaces between to act as ‘guard bands’.

Two schemes are suggested, namely scheme 1 and scheme 2.

**scheme 1**

A possible spectrum is shown in Figure 1.

![Figure 1: FDM scheme 1](image)

There are four channels in the FDM spectrum of Figure 1, each based on independent messages of 3 kHz bandwidth.

Channel A is located in its normal position in the frequency spectrum.

Channels B, C and D have been translated in frequency by individual USSB generators, based on carriers of 4, 8, and 12 kHz respectively.

To recover channel A, a 3 Hz lowpass filter would be sufficient. For the other three channels, SSB receivers would be required. A de-multiplexing scheme is illustrated in Figure 2.

![Figure 2: de-multiplexer for scheme 1](image)

Notice that the three carrier sources might, in practice, be derived, by division, on a master clock of, say, 24 kHz. This is typical of FDM systems.

If only one channel is required at a time, then only one SSB demodulator need be supplied.
**scheme 2**

A less ambitious scheme, but which none-the-less illustrates the principle, is shown in Figure 3.

![Figure 3: FDM scheme 2](image)

This system has only three channels, but requires a less complex de-multiplexer. Instead of SSB demodulators, DSBSC demodulators are adequate.

A suitable de-multiplexer is illustrated in Figure 4.

![Figure 4: demodulation scheme for Figure 3](image)

Unless announced otherwise, it will be assumed below that Scheme 2 is in operation.

**avoid crosstalk**

During the experiment it is important to avoid crosstalk.

In an analog system it is essential to operate in a linear manner to avoid the generation of harmonic and intermodulation distortion. This is especially important in a multi-channel system if interference between channels - *crosstalk* - is to be avoided.

If the crosstalk was introduced at the transmitter there is nothing you can do about it at the receiver ¹. It is your responsibility to avoid circuit overload at the receiver.

If at any time you observe intrusion of the message from another channel into the channel to which you are tuned, check that it is not your circuitry overloading.

¹ do you agree?
The most likely place for intermodulation to occur is in the MULTIPLIER. Check this by reducing the amplitude of the FDM from TRUNKS. This can be done by using a BUFFER AMPLIFIER.

It is the ratio of unwanted-to-wanted signal power that you are trying to reduce.

\[ \text{In a typical overloaded system it can be shown that a 6 dB reduction of signal level should result in a reduction of the unwanted signal power by more than 6 dB} \]

This phenomenon is demonstrated in the experiment entitled Amplifier overload in this Volume.

**EXPERIMENT**

An FDM signal is available at your TRUNKS panel.

You will note that the demodulators of Figure 4 are not true SSB demodulators. This is not necessary, since, although each channel is in fact an SSB signal, there is no signal on the opposite sideband. Secondly, not being DSBSC there is no need to include a phase changer in the carrier paths.

The two carrier signals can be obtained from an AUDIO OSCILLATOR and VCO modules. Note that, in both schemes, the receiver for channel A is in principle the same as that for the other channels, with a local oscillator on zero kHz. This can be simulated by replacing the oscillator signal with a 2 volt DC signal from the VARIABLE DC module. Alternatively, for channel A, dispense with the MULTIPLIER altogether, and use the LOWPASS FILTER only (as in Figures 2 and 4).

Since you have only one HEADPHONE AMPLIFIER you will only be able to listen to one channel at a time, by connecting the input of the HEADPHONE AMPLIFIER to the appropriate MULTIPLIER output (for channel B and C), or the FDM itself (for channel A).

**T1** patch up the de-multiplexer scheme of Figure 4. For the two carriers use an AUDIO OSCILLATOR and a VCO. You will have to share the HEADPHONE AMPLIFIER (with its 3 kHz LPF) between channels.

**T2** locate the FDM signal at the TRUNKS panel.

**T3** initially set the peak amplitude of the FDM signal into your demultiplexer at the TIMS ANALOG REFERENCE LEVEL.
T4 show that it is possible to separate the individual channels with your demultiplexer. Record their carrier frequencies (nominally 0, 8, and 12 kHz in the scheme of Figure 3, but the signal at TRUNKS could differ from this). Remember that, if there is significant crosstalk, check the effect of a reduction of the amplitude of the FDM signal from TRUNKS by using a BUFFER AMPLIFIER.

T5 make sure you investigate both methods of recovering channel A. That is, without the MULTIPLIER, or with the MULTIPLIER and a zero frequency local oscillator signal.

T6 from your results draw the spectrum, in the format of Figure 3, of the FDM signal you have been sent.

T7 introduce crosstalk. This can be done by connecting, if not already done so, a BUFFER AMPLIFIER between TRUNKS and the input to your demultiplexer. Initially set the gain of the BUFFER AMPLIFIER to unity, and re-confirm that crosstalk is low (or non-existent). Then increase the BUFFER AMPLIFIER gain, by say a factor of two, and check the crosstalk. This crosstalk 'measurement' can only be an estimate whilst all channels are carrying speech. You should make some comments on how this estimate was made and recorded.

Record the peak amplitude of the FDM signal into your demultiplexer when it is set just below the onset of crosstalk.
**TUTORIAL QUESTIONS**

**Q1** draw a block diagram and describe its use to make a tape recording of the FDM signal you have been sent.

**Q2** assuming you have a DSBSC demodulator only (not an SSB demodulator) could you separate the channels of the scheme illustrated below?

![Diagram](image1)

**Q3** you have shown that a true SSB demodulator is not necessary in order to recover each channel from the scheme of Figure 3. In principle, however, there is an advantage in using a true SSB demodulator. Explain.

**Q4** to avoid the need for SSB generators to make the FDM signals, an alternative scheme could generate the spectrum shown below. Could a DSBSC demodulator be used in principle to recover the three channels independently? Can you suggest a possible practical problem(s) with this scheme?

![Diagram](image2)

**Q5** discuss the meaning and significance of the term ‘guard band’ in the present context.

**Q6** in the last Task, was the peak amplitude of the FDM signal above or below the TIMS ANALOG REFERENCE LEVEL when the crosstalk became unacceptable (this will have to be a qualitative judgement). Comment.
Frequency division multiplex