LJ Technical Systems

ANACOM 2
FM Communications
Trainer
User Manual

MT107/C

DIGIAC

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Contents

ANACOM 2 FM Communications Training System

Features:

- Single-board communications training system;
- On-board audio oscillator, with adjustable amplitude and frequency, for use as an analog signal source;
- Choice of modulators and demodulators allows comparisons to be drawn between different methods of FM modulation and detection;
- Effect of noise on the detection of an FM signal may be investigated;
- On-board amplitude limiter circuit;
- A total of eight switched faults affect the operation of all major functional blocks in the module, allowing the student to investigate thoroughly the operation of all circuits.

POWER SUPPLY REQUIREMENTS

The power supply requirements of the ANACOM 2 module are:

+12 volts at 100mA, -12 volts at 100mA

OUTLINE OF THE ANACOM 2 MODULE

ANACOM 2 is a single-board communications training module, covering the principles of frequency modulation. The layout of the board is shown in Figure 1 overleaf:

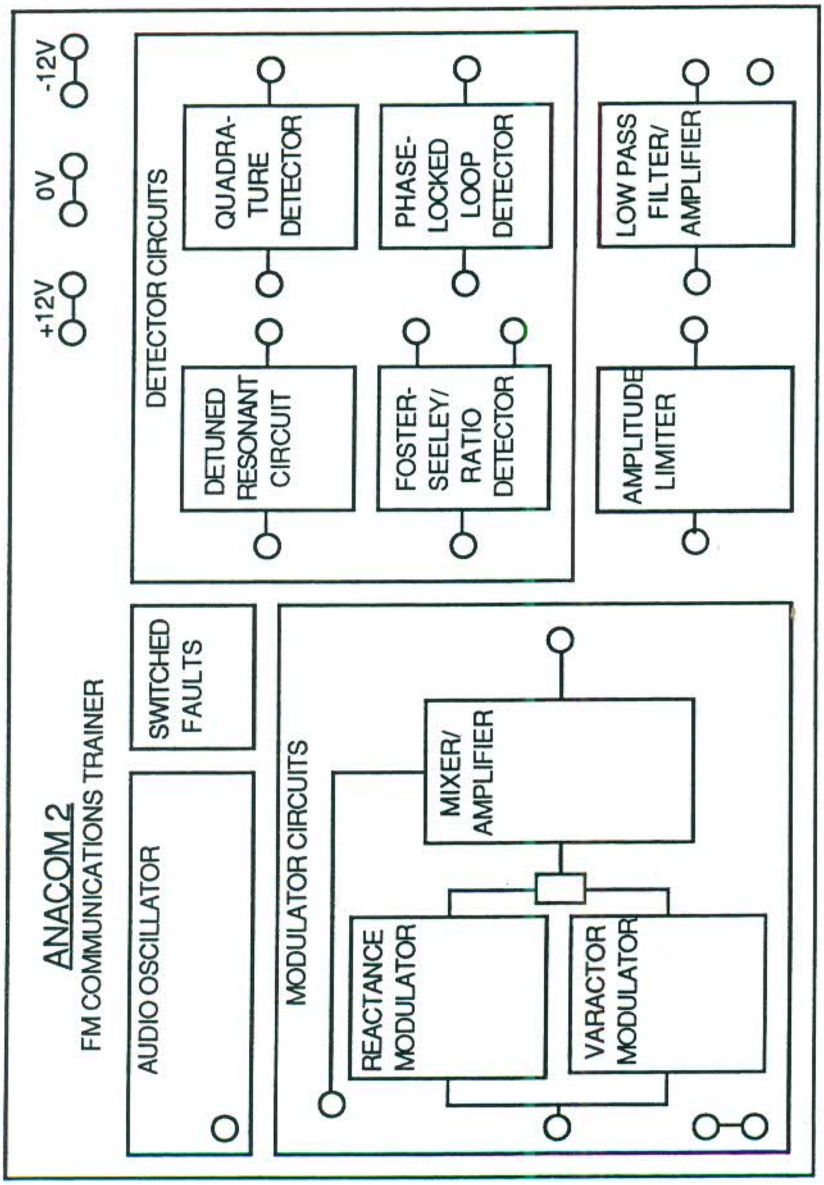


Figure 1

The output from the on-board AUDIO OSCILLATOR block may be used as a modulating signal. The amplitude of this signal is adjustable, as is the frequency (from 300Hz to 3.4kHz). Alternatively, an external audio-frequency signal may be used as the modulating input signal.

Frequency modulation may be performed by using either the REACTANCE MODULATOR circuit or the VARACTOR MODULATOR circuit.

The resulting FM waveform is then passed onto the MIXER/AMPLIFIER block, which:

- amplifies the signal by an adjustable amount, and
- allows an external 'noise' input to amplitude-modulate the FM signal.

The resulting output from the MIXER/AMPLIFIER block may then be passed on to any of the on-board frequency demodulator circuits, in order to recover the audio modulating signal.

The following demodulator circuits are available:

- DETUNED RESONANT CIRCUIT
- QUADRATURE DETECTOR
- FOSTER-SEELEY DETECTOR
- RATIO DETECTOR
- PHASE-LOCKED LOOP DETECTOR

The on-board LOW-PASS FILTER/AMPLIFIER block removes any high-frequency components from the output of the selected demodulator, to recover the original audio modulating signal. This block also provides voltage amplification - the amount of voltage gain can be adjusted by the user.

By amplitude-modulating the FM signal with an external 'noise' input, the student can investigate the effectiveness of different demodulators at rejecting amplitude variations. Alternatively, the on-board AMPLITUDE LIMITER block may be used to remove these amplitude variations from the FM waveform, before frequency demodulation takes place.

Eight switched faults (4 open-circuit, 4 short-circuit) are provided on the board, affecting the operation of the major functional blocks in the module. The fault switches may be concealed behind the lockable cover supplied.

All functional blocks are shown on the PCB mimic, with numbered test points for easy examination of all major signals.

REACTANCE MODULATOR

This experiment investigates how frequency modulation is performed by ANACOM 2's REACTANCE MODULATOR circuit. This circuit modulates the frequency of a carrier sinewave, according to the audio signal applied to its modulating input.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 2 below:

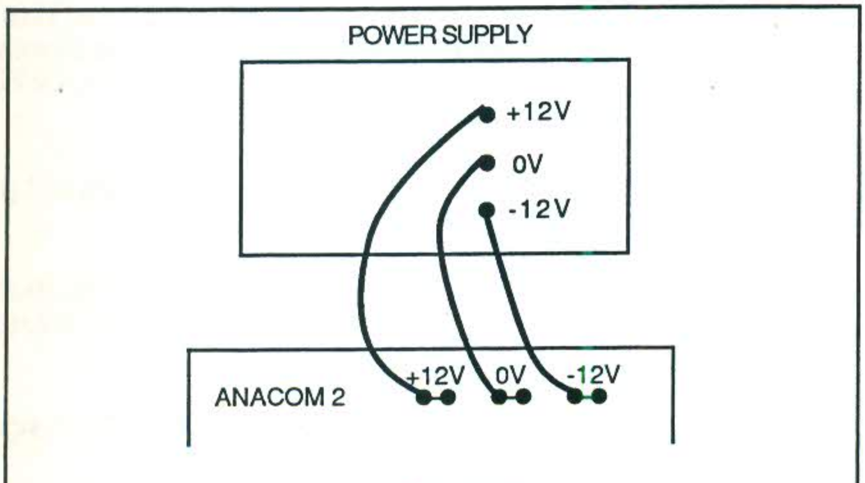


Figure 2

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully **clockwise** position.
   (c) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in **OFF** position.

3. Turn on power to the ANACOM 2 module.

4. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its fully clockwise (MAX) position, and examine the block's output (t.p.1) on an oscilloscope.

This is the audio frequency sinewave which will be used as our modulating signal. Note that the sinewave's frequency can be adjusted from about 300Hz to approximately 3.4kHz, by adjusting the AUDIO OSCILLATOR's FREQUENCY preset.

Note also that the amplitude of this audio modulating signal can be reduced to zero, by turning the AUDIO OSCILLATOR's AMPLITUDE preset to its fully **counter-clockwise** (MIN) position.

Leave the AMPLITUDE preset in its MIN position for the time being.

5. Link the OUTPUT socket of the AUDIO OSCILLATOR block to the AUDIO INPUT socket of the MODULATOR CIRCUITS block, as shown in Figure 5 at the end of this chapter.

6. Put the REACTANCE/VARACTOR switch in the REACTANCE position. This switches the output of the REACTANCE MODULATOR through to the input of the MIXER/AMPLIFIER block, and also switches off the VARACTOR MODULATOR block, to avoid interference between the two modulators.

7. The output signal from the REACTANCE MODULATOR block appears at t.p.13, before being buffered and amplified by the MIXER/AMPLIFIER block.

   Although the output from the REACTANCE MODULATOR block can be monitored directly at t.p.13, any capacitive loading at this point (e.g. due to an oscilloscope probe) may slightly affect the modulator's output frequency.

   In order to avoid this problem, we will monitor the buffered FM OUTPUT signal from the MIXER/AMPLIFIER block, at t.p.34.

8. Put the REACTANCE MODULATOR's CARRIER FREQUENCY preset in its midway position (arrowhead pointing towards top of PCB), then examine t.p.34.

   Note that the monitored signal is a sinewave of approximately 1.2 volts peak/peak, centered around 0 volts d.c.. This is our FM carrier, and it is presently unmodulated since the REACTANCE MODULATOR's AUDIO INPUT signal has zero amplitude.

9. The amplitude of the FM carrier (at t.p.34) is adjustable by means of the MIXER/AMPLIFIER block's AMPLITUDE preset, from zero to its present level. Try turning this preset slowly anticlockwise, and note that the amplitude of the FM signal can be reduced to zero.

   Return the AMPLITUDE preset to its fully **clockwise** position before continuing.

10. The frequency of the FM carrier signal (at t.p.34) should be approximately 455kHz at the moment. This carrier frequency can be varied from 453kHz to 460kHz (approx), by adjusting the CARRIER FREQUENCY preset in the REACTANCE MODULATOR block.

Turn this preset over its range of adjustment, and note that the frequency of the monitored signal can be seen to vary slightly. Note also that the carrier frequency is a maximum when the preset is in its fully clockwise position.

11. The principle of operation of the REACTANCE MODULATOR is shown in Figure 3 below:

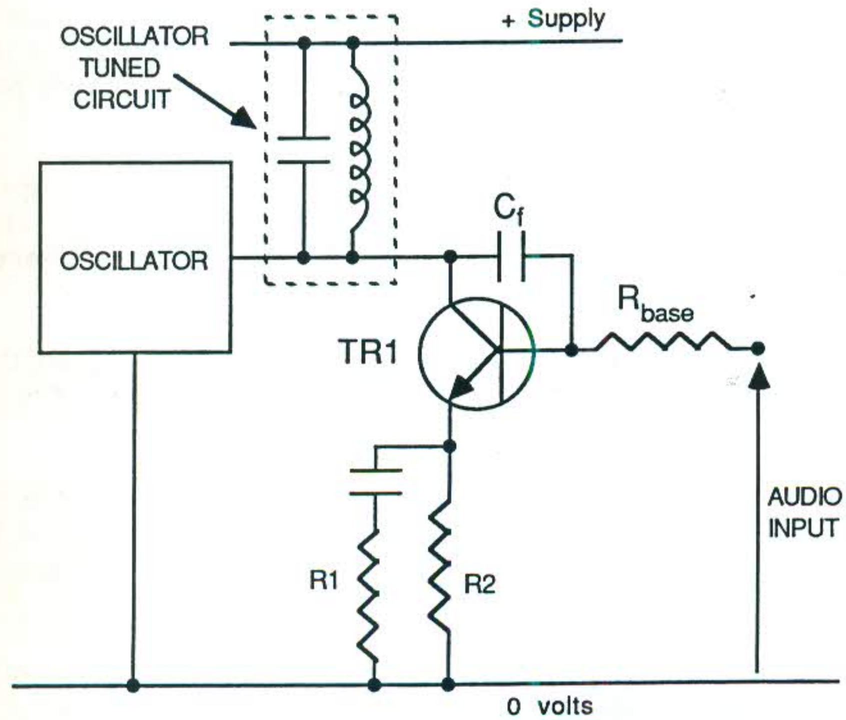


Figure 3

The OSCILLATOR generates a radio-frequency sinusoidal output whose exact frequency is determined by the **inductance** and **capacitance** of the oscillator's tuned circuit.

The circuit to the right of the oscillator's tuned circuit operates as a **voltage-variable capacitance**. This is explained as follows:

The collector of transistor TR1 is connected to the output from the oscillator, so that sinusoidal oscillations occur at the transistor's collector.

Capacitor Cf then passes these oscillations on to the transistor's base. But since Cf is small, its reactance at the oscillator frequency is large, compared with resistor Rbase. Consequently, the voltage seen at the transistor's base is a small-amplitude sinewave which **leads** the voltage at the collector by 90°.

This base signal results in a transistor collector current which also **leads** the collector voltage by 90°, the result being that the transistor circuit appears to the OSCILLATOR as a **capacitance**. This capacitance **adds** to the capacitance of the oscillator's tuned circuit.

The size of this capacitance depends on the change in collector current which occurs for a given change in base voltage, and this is determined by the **transconductance (gm)** of the transistor. The transistor's transconductance depends on the values of resistors R1 and R2, and also on the d.c. bias voltage applied to the transistor's base - the **larger** the bias voltage, the **larger** the value of gm, and the **larger** the capacitance which is added to the capacitance of oscillator's tuned circuit.

Consequently, the transistor circuit shown above behaves as a **voltage-variable capacitance**. The bias voltage applied to the transistor's base (via resistor Rbase) determines the overall capacitance seen by the OSCILLATOR, and hence the frequency at which the oscillator runs.

By modulating the transistor's base bias voltage with an audio signal, the OSCILLATOR's output frequency can therefore be varied. The result is **frequency modulation**.

12. The CARR!ER FREQUENCY preset in the REACTANCE MODULATOR block actually controls the bias voltage applied to the base of the transistor in this **voltage-variable capacitance** circuit, and hence controls the oscillator's running frequency.

    If you have access to a frequency meter, make a plot of **oscillator output frequency** vs. **base bias voltage**. To do this, follow the steps below:

    - Turn the CARRIER FREQUENCY preset to its fully **clockwise** position - this corresponds to minimum base bias voltage.

    - Monitor t.p.34 (the oscillator output frequency) and t.p.11(the base bias voltage).

    - Slowly turn the CARRIER FREQUENCY preset clockwise, and record the frequency at t.p.34 as the d.c. voltage at t.p.11 increases in 0.1 volt intervals.

    - Plot oscillator frequency (at t.p.34) vs. base bias voltage (at t.p.11).

13. If you have plotted oscillator frequency against base bias voltage, you should now have a plot which looks like this:

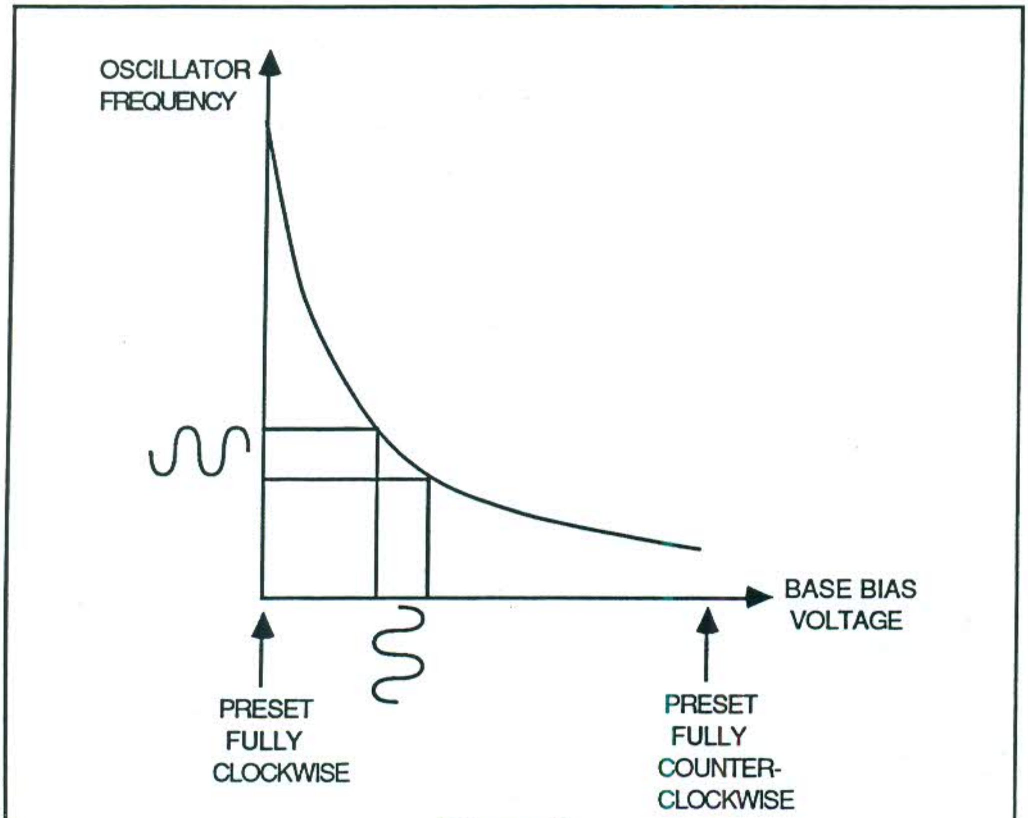


Figure 4

We will now consider what happens when we superimpose a sinusoidal audio-frequency signal onto the d.c. base bias voltage. This is shown on the horizontal axis in Figure 4 above.

Providing the amplitude of this sinusoidal modulating signal is small, the result will be a sinusoidal change in the frequency of the oscillator, as shown on the vertical axis in Figure 4. This is how we perform frequency modulation with the reactance modulator.

If the amplitude of the modulating signal is too large, the portion of the curve traversed by the modulating signal may no longer approximate to a straight line. This will cause the modulator to operate non-linearly - the oscillator's output frequency will no longer change sinusoidally for a sinusoidal modulating input signal. The end result will be distortion of the final demodulated audio signal at the receiver.

We will now investigate frequency modulation using ANACOM 2's reactance modulator, with a sinusoidal modulating signal.

14. Put the REACTANCE MODULATOR block's CARRIER FREQUENCY preset in its fully **clockwise** position.

    Next, monitor the MIXER/AMPLIFIER's FM OUTPUT at t.p.34, and adjust the oscilloscope controls so that there are 15 to 20 cycles of the waveform on the display. Note that the monitored signal is not being frequency-modulated at the moment - this is because no modulating signal is being applied to the REACTANCE MODULATOR block's AUDIO INPUT socket.

    Now turn the AUDIO OSCILLATOR's AMPLITUDE preset to its fully clockwise position, and note what happens to the monitored waveform. You should notice that there is now some ambiguity in the positions of the cycles towards the right-hand side of the display. The carrier waveform is now being frequency-modulated by the audio-frequency sinewave from the AUDIO OSCILLATOR block.

    The greater the ambiguity in the position of the right-most cycles on the oscilloscope, the greater the frequency deviation of the carrier from its center frequency. Decrease the amplitude of the modulating signal by turning the AUDIO OSCILLATOR's AMPLITUDE preset slowly counter-clockwise, and note that the amount of frequency deviation becomes less. This is because the **amplitude** of the modulating signal controls the amount of **frequency deviation** in the FM waveform.

    If you have an X-expansion control on your oscilloscope, use this to 'expand up' the right-most cycles on the display, for a closer look at how frequency modulation affects their appearance.

15. Return the AUDIO OSCILLATOR's AMPLITUDE preset to its fully clockwise position, then vary the **frequency** of the modulating sinewave by adjusting the AUDIO OSCILLATOR's FREQUENCY preset throughout its range.

    Note that varying the modulating frequency has no obvious effect on the monitored FM waveform. This is because the frequency of the modulating signal does **not** affect the **amount** of frequency deviation - it actually determines **how many times per second** the carrier deviates from its center position. The higher the frequency of the modulating signal, the more frequency deviations take place each second.

    Since the oscilloscope cannot show the **rate of change** of frequency deviation, changing the modulating frequency appears to have no effect on the oscilloscope display.

16. Turn the CARRIER FREQUENCY preset in the REACTANCE MODULATOR block slowly counter-clockwise, and note that, in addition to the carrier center frequency decreasing, there is a decrease in the **amount of frequency deviation** that is present.

    This is explained if you look back at the graph of Figure 4. As the CARRIER FREQUENCY preset is turned in a counter-clockwise direction (i.e. as you move towards the right along the X-axis), the slope of the oscillator frequency/base bias curve decreases. Consequently, the same change in base bias results in a smaller change in carrier frequency as the preset is turned.

17. If you plotted oscillator frequency vs. base bias voltage earlier, you can now use your graph to determine the carrier frequency deviation due to the audio modulating signal, for different positions of the CARRIER FREQUENCY preset.

    To do this:

    - Record the minimum d.c. level, and the maximum d.c. level, reached by the modulating signal at t.p.11.
    - Determine from your graph the oscillator frequencies corresponding to these two voltage levels.
    - The difference between these two frequencies is the overall frequency swing of the carrier, and the **frequency deviation** is half of this figure.

    Repeat this exercise for different positions of the CARRIER FREQUENCY preset, and, if desired, for different modulating signal amplitudes.

18. Return the CARRIER FREQUENCY preset to its midway position, and monitor the AUDIO INPUT (at t.p.6) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on the AUDIO INPUT signal.

    Turn the AUDIO OSCILLATOR's AMPLITUDE preset throughout its range of adjustment, and note that the amplitude of the FM OUTPUT signal does not change. This is because the audio information is contained entirely in the signal's frequency, and not in its amplitude.

19. The complete circuit diagram for the REACTANCE MODULATOR is given at the end of this user manual. If you wish, follow this circuit diagram and examine the test points in the REACTANCE MODULATOR block, to make sure that you fully understand how the circuit is working.

20. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

If you have an AUDIO INPUT MODULE, connect the module's output to the AUDIO INPUT socket in the MODULATOR CIRCUITS block.

The input signal to the AUDIO INPUT MODULE may be taken from an external microphone (supplied with the module), or from a cassette recorder, by choosing the appropriate switch setting on the module.

Consult the User Manual for the AUDIO INPUT MODULE, for further details.

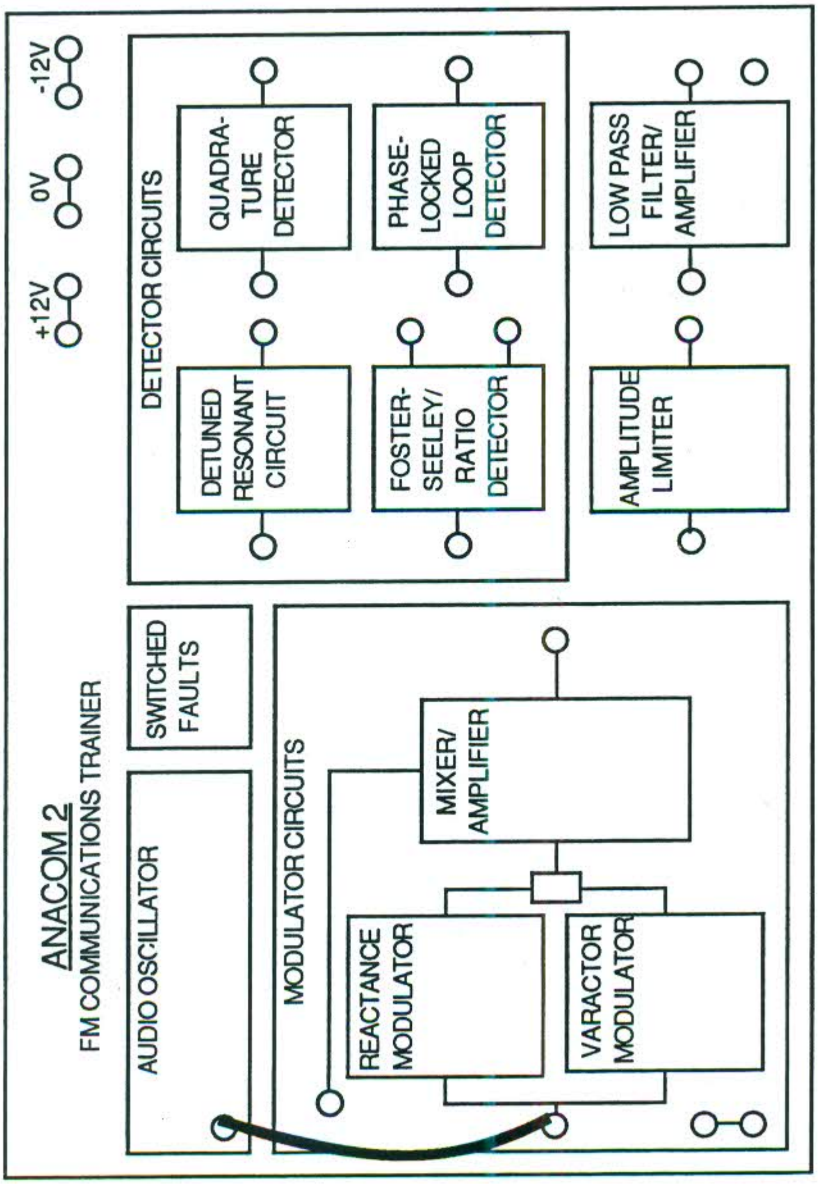

ANACOM 2
FM COMMUNICATIONS TRAINER
+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 5

VARACTOR MODULATOR

This experiment investigates how frequency modulation is performed by ANACOM 2's VARACTOR MODULATOR circuit. Like the REACTANCE MODULATOR investigated in the previous chapter, this circuit modulates the frequency of a carrier sinewave, according to the audio signal applied to its modulating input.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 6 below:

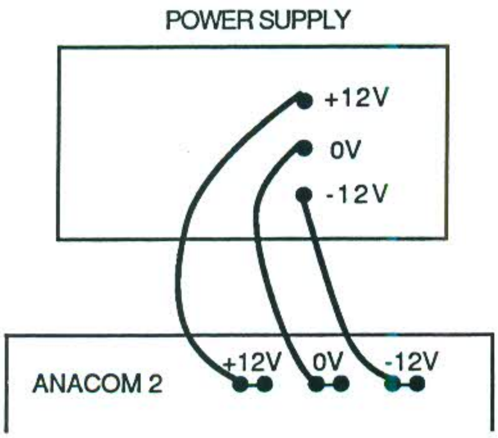


Figure 6

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully **clockwise** position.
   (c) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in **OFF** position.

3. Turn on power to the ANACOM 2 module.

4. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its fully clockwise (MAX) position, and examine the block's output (t.p.1) on an oscilloscope.

This is the audio frequency sinewave which will be used as our modulating signal. Note that the sinewave's frequency can be adjusted from about 300Hz to approximately 3.4kHz, by adjusting the AUDIO OSCILLATOR's FREQUENCY preset.

Note also that the amplitude of this audio modulating signal can be reduced to zero, by turning the AUDIO OSCILLATOR's AMPLITUDE preset to its fully **counter-clockwise** (MIN) position.

Leave the AMPLITUDE preset in its MIN position for the time being.

5. Link the OUTPUT socket of the AUDIO OSCILLATOR block to the AUDIO INPUT socket of the MODULATOR CIRCUITS block, as shown in Figure 9 at the end of this chapter.

6. Put the REACTANCE/VARACTOR switch in the VARACTOR position. This switches the output of the VARACTOR MODULATOR through to the input of the MIXER/AMPLIFIER block, and also switches off the REACTANCE MODULATOR block, to avoid interference between the two modulators.

7. The output signal from the VARACTOR MODULATOR block appears at t.p.24 before being buffered and amplified by the MIXER/AMPLIFIER block.

   Although the output from the VARACTOR MODULATOR block can be monitored directly at t.p.24, any capacitive loading at this point (e.g. due to an oscilloscope probe) may slightly affect the modulator's output frequency.

   In order to avoid this problem, we will monitor the buffered FM OUTPUT signal from the MIXER/AMPLIFIER block, at t.p.34.

8. Put the VARACTOR MODULATOR's CARRIER FREQUENCY preset in its midway position (arrowhead pointing towards top of PCB), then examine t.p.34.

   Note that the monitored signal is a sinewave of approximately 1.2 volts peak/peak, centered around 0 volts d.c.. This is our FM carrier, and it is presently unmodulated since the VARACTOR MODULATOR's AUDIO INPUT signal has zero amplitude.

9. The amplitude of the FM carrier (at t.p.34) is adjustable by means of the MIXER/AMPLIFIER block's AMPLITUDE preset, from zero to its present level. Try turning this preset slowly anticlockwise, and note that the amplitude of the FM signal can be reduced to zero.

   Return the AMPLITUDE preset to its fully **clockwise** position before continuing.

10. The frequency of the FM carrier signal (at t.p.34) should be approximately 455kHz at the moment. This carrier frequency can be varied from 451kHz to 458kHz (approx), by adjusting the CARRIER FREQUENCY preset in the VARACTOR MODULATOR block.

    Turn this preset over its range of adjustment, and note that the frequency of the monitored signal can be seen to vary slightly. Note also that the carrier frequency is a maximum when the preset is in its fully clockwise position.

11. The principle of operation of the VARACTOR MODULATOR is shown in Figure 7 below:

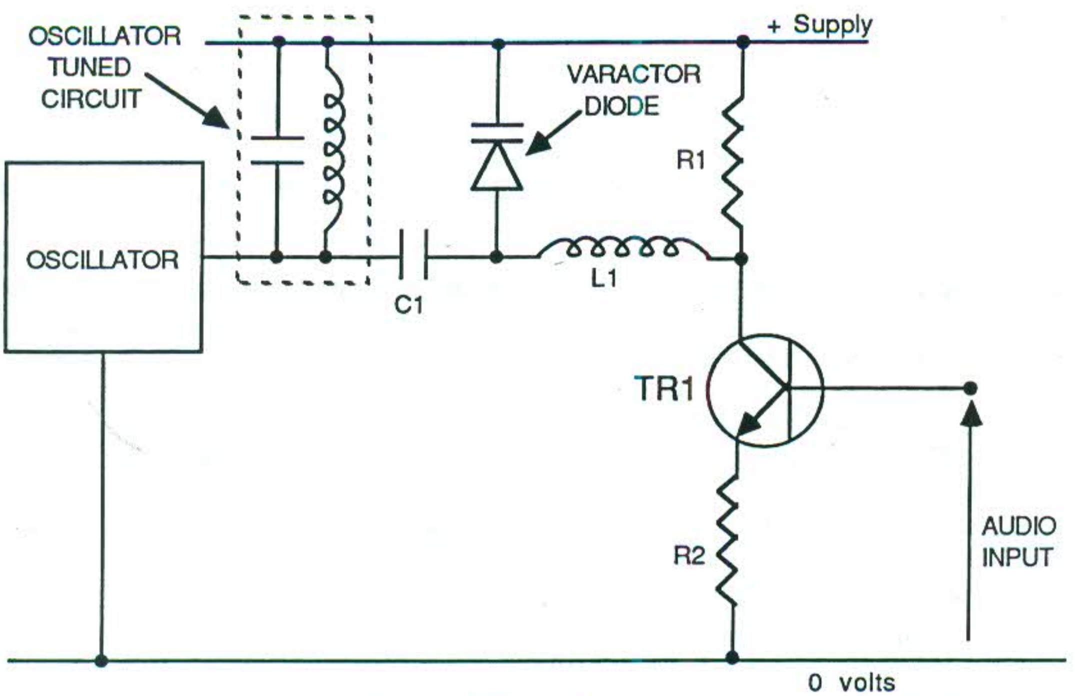


Figure 7

The OSCILLATOR generates a radio-frequency sinusoidal output whose exact frequency is determined by the **inductance** and **capacitance** of the oscillator's tuned circuit.

A VARACTOR DIODE is connected in parallel with the oscillator's tuned circuit, via d.c.-blocking capacitor C1. The characteristic of the varactor diode is such that the application of a **reverse voltage** across the diode makes it behave as a **capacitor**. By varying the applied reverse voltage, the diode's capacitance can be varied - in other words, the varactor diode behaves as a **voltage-variable capacitance**.

Inductor L1 is a radio-frequency choke, passing low-frequency signals but blocking the high-frequency output from the oscillator.

The operation of the varactor modulator circuit is as follows. Consider a positive d.c. bias voltage applied to the base of transistor TR1; this causes current to flow through resistor R1, resulting in a voltage appearing across it. Since L1 is a short-circuit as far as d.c. is concerned, the same voltage appears as a reverse-bias across the varactor diode.

This reverse-bias voltage across the varactor diode causes it to appear as a capacitance, which **adds** to the capacitance of the oscillator's tuned circuit.

The greater the d.c. bias voltage applied to the transistor's base, the **greater** the reverse bias across the varactor diode, the **lower** the diode's capacitance, and the **higher** the frequency at which the oscillator runs.

Now consider an audio modulating signal, which is superimposed on the d.c. bias voltage at TR1's base. This causes a changing voltage across resistor R1, and (since inductor L1 is also a short-circuit at audio frequencies), results in a changing reverse voltage across the varactor diode.

This changing reverse voltage causes the varactor diode's capacitance to vary, which in turn varies the overall capacitance seen by the OSCILLATOR, and hence the frequency at which the oscillator runs.

So, by modulating the transistor's base bias voltage with an audio signal, the OSCILLATOR's output frequency can be varied. The result is **frequency modulation**.

12. The CARRIER FREQUENCY preset in the VARACTOR MODULATOR block actually controls the d.c. bias voltage applied to the base of the transistor in the varactor modulator circuit, and hence controls the oscillator's running frequency.

    If you have access to a frequency meter, make a plot of **oscillator output frequency** vs. **base bias voltage**. To do this, follow the steps below:

    - Turn the CARRIER FREQUENCY preset to its fully **counter-clockwise** position - this corresponds to minimum base bias voltage.
    - Monitor t.p.34 (the oscillator output frequency) and t.p.21 (the base bias voltage).
    - Slowly turn the CARRIER FREQUENCY preset clockwise, and record the frequency at t.p.34 as the d.c. voltage at t.p.21 increases in 0.1 volt intervals.
    - Plot oscillator frequency (at t.p.34) vs. base bias voltage (at t.p.21).

13. If you have plotted oscillator frequency against base bias voltage, you should now have a plot which looks like this:

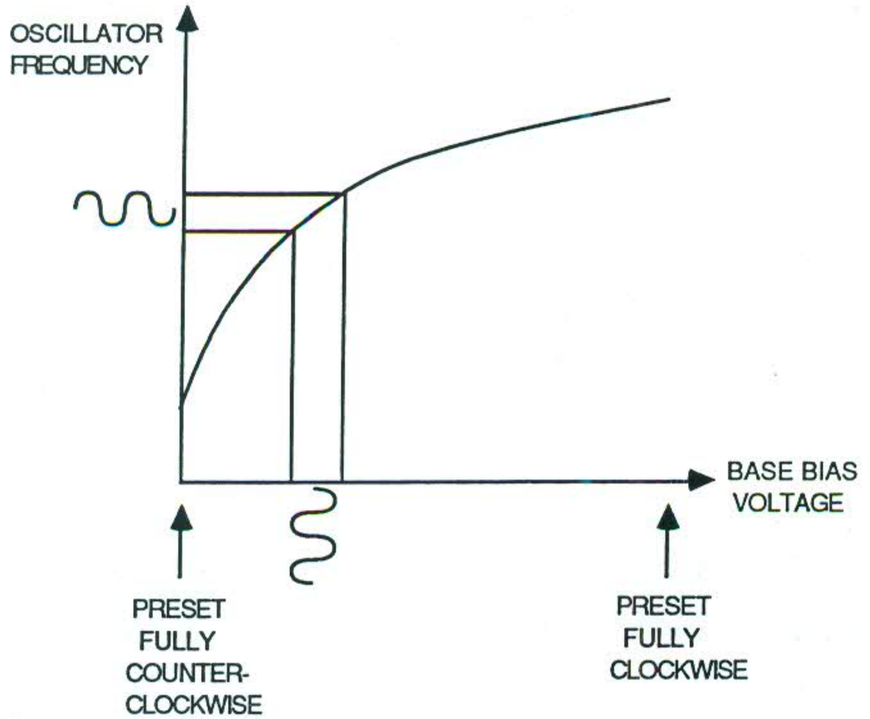


Figure 8

We will now consider what happens when we superimpose a low-amplitude sinusoidal audio signal onto the d.c. base bias voltage. This is shown on the horizontal axis in Figure 8 above.

Providing the amplitude of this sinusoidal modulating signal is small, the result will be a sinusoidal change in the frequency of the oscillator, as shown on the vertical axis in Figure 8. This is how we perform frequency modulation with the varactor modulator.

If the amplitude of the modulating signal is too large, the portion of the curve traversed by the modulating signal may no longer approximate to a straight line. This will cause the modulator to operate non-linearly - the oscillator's output frequency will no longer change sinusoidally for a sinusoidal modulating input signal. The end result will be distortion of the final demodulated audio signal at the receiver.

Note: If you compare the frequency/voltage curves for the varactor and reactance modulators, you should be able to notice that the varactor modulator has the more linear response, for a given frequency deviation around 455kHz. This means that for a given modulating signal amplitude, distortion of the demodulated audio signal will be less for the varactor modulator than for the reactance modulator. You will be able to compare the distortion introduced by the two types of modulator in later experiments, when we investigate FM demodulation.

We will now investigate frequency modulation using ANACOM 2's varactor modulator, with a sinusoidal modulating signal.

14. Put the VARACTOR MODULATOR block's CARRIER FREQUENCY preset in its fully **counter-clockwise** position.

    Next, monitor the MIXER/AMPLIFIER's FM OUTPUT at t.p.34, and adjust the oscilloscope controls so that there are 20 to 25 cycles of the waveform on the display. Note that the monitored signal is not being frequency-modulated at the moment - this is because no modulating signal is being applied to the VARACTOR MODULATOR block's AUDIO INPUT socket.

    Now turn the AUDIO OSCILLATOR's AMPLITUDE preset to its fully clockwise position, and note what happens to the monitored waveform. You should notice that there is now some ambiguity in the positions of the cycles towards the right-hand side of the display. The carrier waveform is now being frequency-modulated by the audio-frequency sinewave from the AUDIO OSCILLATOR block.

    The greater the ambiguity in the position of the right-most cycles on the oscilloscope, the greater the frequency deviation of the carrier from its center frequency. Decrease the amplitude of the modulating signal by turning the AUDIO OSCILLATOR's AMPLITUDE preset slowly counter-clockwise, and note that the amount of frequency deviation becomes less. This is because the **amplitude** of the modulating signal controls the amount of **frequency deviation** in the FM waveform.

    If you have an X-expansion control on your oscilloscope, use this to 'expand up' the right-most cycles on the display, for a closer look at how frequency modulation affects their appearance.

15. Return the AUDIO OSCILLATOR's AMPLITUDE preset to its fully clockwise position, then vary the **frequency** of the modulating sinewave by adjusting the AUDIO OSCILLATOR's FREQUENCY preset throughout its range.

Note that varying the modulating frequency has no obvious effect on the monitored FM waveform. This is because the frequency of the modulating signal does **not** affect the **amount** of frequency deviation - it actually determines **how many times per second** the carrier deviates from its center position. The higher the frequency of the modulating signal, the more frequency deviations take place each second.

Since the oscilloscope cannot show the **rate of change** of frequency deviation, changing the modulating frequency appears to have no effect on the oscilloscope display.

16. Turn the CARRIER FREQUENCY preset in the VARACTOR MODULATOR block slowly clockwise, and note that, in addition to the carrier center frequency increasing, there is a decrease in the **amount of frequency deviation** that is present.

    This is explained if you look back at the graph of Figure 8. As the CARRIER FREQUENCY preset is turned in a clockwise direction (i.e. as you move towards the right along the X-axis), the slope of the oscillator frequency/base bias curve decreases. Consequently, the same change in base bias results in a smaller change in carrier frequency as the preset is turned.

17. If you plotted oscillator frequency vs. base bias voltage earlier, you can now use your graph to determine the carrier frequency deviation due to the audio modulating signal, for different positions of the CARRIER FREQUENCY preset.

    To do this:

    - Record the minimum d.c. level, and the maximum d.c. level, reached by the modulating signal at t.p.21.

    - Determine from your graph the oscillator frequencies corresponding to these two voltage levels.

    - The difference between these two frequencies is the overall frequency swing of the carrier, and the **frequency deviation** is half of this figure.

    Repeat this exercise for different positions of the CARRIER FREQUENCY preset, and, if desired, for different modulating signal amplitudes.

18. Return the CARRIER FREQUENCY preset to its midway position, and monitor the AUDIO INPUT (at t.p.6) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on the AUDIO INPUT signal.

Turn the AUDIO OSCILLATOR's AMPLITUDE preset throughout its range of adjustment, and note that the amplitude of the FM OUTPUT signal does not change. This is because the audio information is contained entirely in the signal's frequency, and not in its amplitude.

19. The complete circuit diagram for the VARACTOR MODULATOR is given at the end of this user manual. If you wish, follow this circuit diagram and examine the test points in the VARACTOR MODULATOR block, to make sure that you fully understand how the circuit is working.

20. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

    If you have an AUDIO INPUT MODULE, connect the module's output to the AUDIO INPUT socket in the MODULATOR CIRCUITS block.

    The input signal to the AUDIO INPUT MODULE may be taken from an external microphone (supplied with the module), or from a cassette recorder, by choosing the appropriate switch setting on the module.

    Consult the User Manual for the AUDIO INPUT MODULE, for further details.

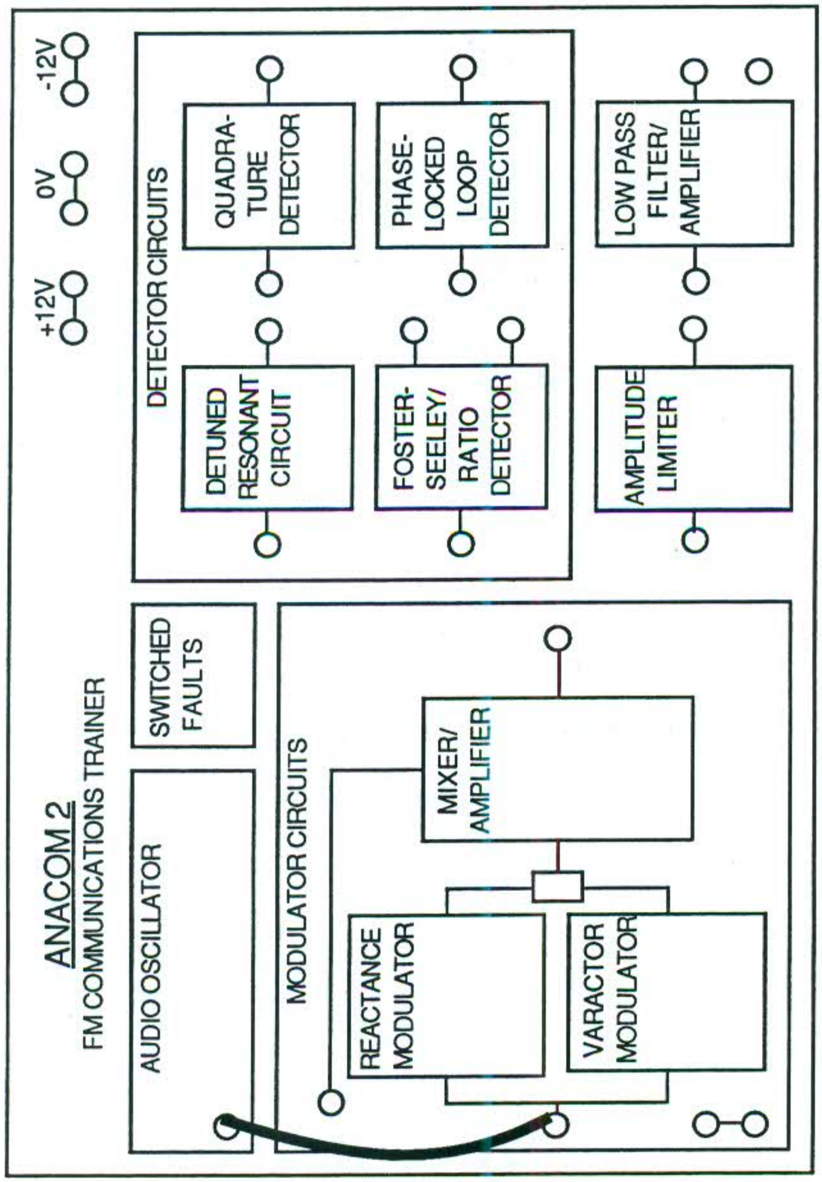

+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
ANACOM 2
FM COMMUNICATIONS TRAINER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 9

DETUNED RESONANT CIRCUIT DETECTOR

This experiment investigates how frequency demodulation is performed by the DETUNED RESONANT CIRCUIT detector block on the ANACOM 2 module.

The operation of this detector circuit will be described in detail, and its sensitivity to noise on the incoming FM signal will be investigated.

The on-board AMPLITUDE LIMITER will then be used to remove any amplitude variations due to noise, **before** they reach the detector. This allows the student to draw conclusions as to whether it is necessary to precede this type of detector with an amplitude limiter stage, in a practical FM receiver.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 10 below:

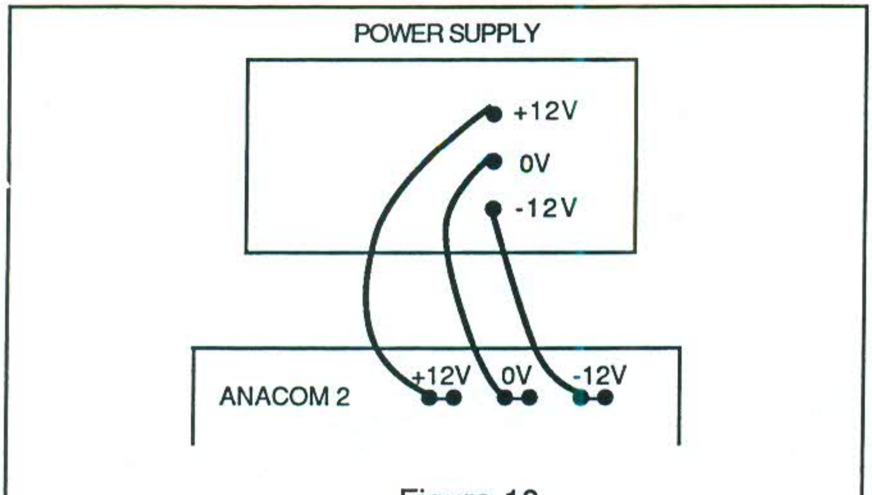


Figure 10

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AUDIO AMPLIFIER block's AMPLITUDE preset in fully clockwise (MAX) position;
   (c) AUDIO AMPLIFIER block's FREQUENCY preset in fully counter-clockwise (MIN) position;
   (d) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully clockwise position;

(e) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in OFF position.

3. Turn on power to the ANACOM 2 module.

4. We will now examine how the DETUNED RESONANT CIRCUIT block is used to demodulate a frequency-modulated signal. The circuit diagram for this block is shown below:

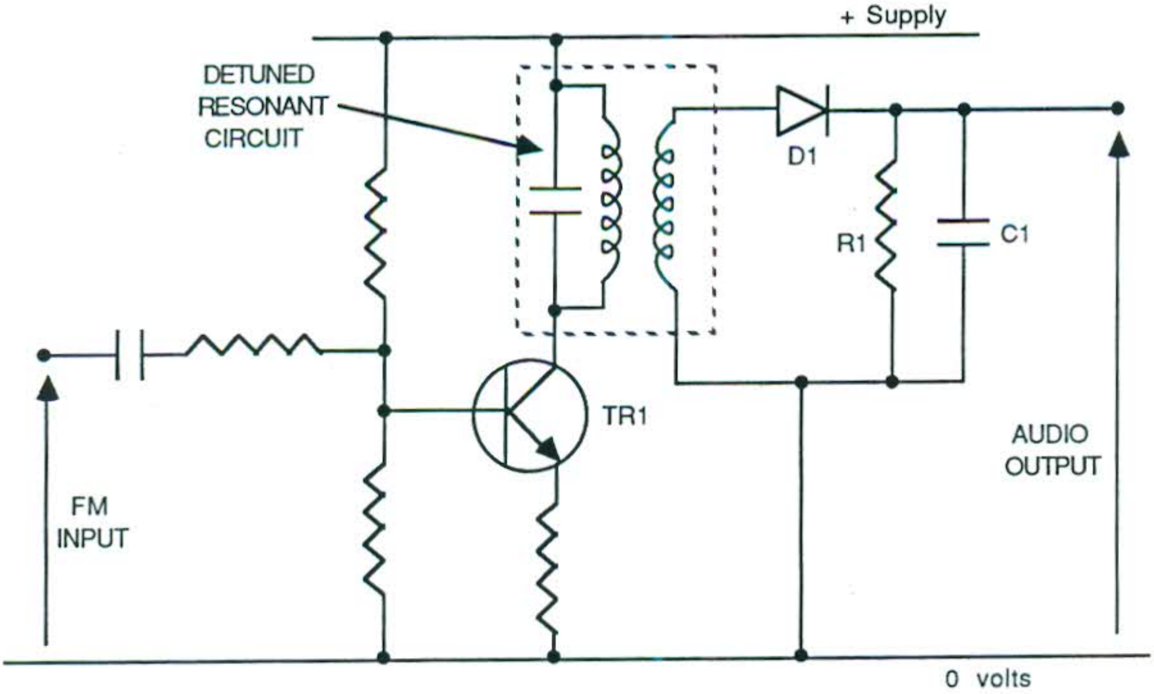


Figure 11

Transistor TR1 is biased for operation in the linear region, and the resonant circuit connected to TR1's collector is deliberately **detuned** so that maximum response occurs **above** the center frequency of the incoming FM signal. The relationship between the **amplitude** of the signal at TR1's collector, and the **frequency** of the FM input signal, is then as shown overleaf:

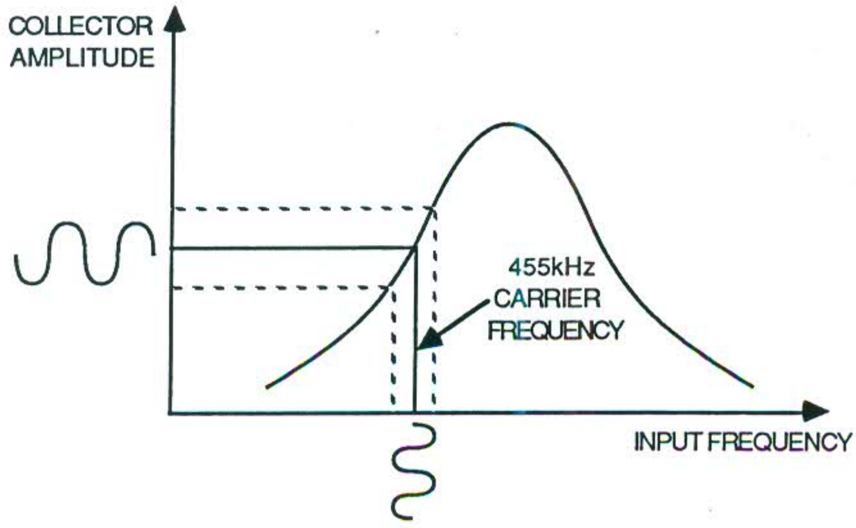


Figure 12

Note that for a small range of frequencies either side of the 455kHz center frequency (as indicated by the vertical dotted lines), the response of the tuned circuit approximates to a straight line. Consequently, if the **frequency** of the incoming FM carrier varies sinusoidally over this range, the **amplitude** of the signal at TR1's collector will also change sinusoidally, as Figure 12 shows.

As a result, the signal at TR1's collector is not only **frequency-modulated**, but is also **amplitude-modulated**. This signal appears, reduced in amplitude, at the transformer's secondary, where it drives an envelope detector circuit comprising diode D1, resistor R1 and capacitor C1.

The envelope detector follows the amplitude changes in the signal, and the final audio output appears at the cathode of diode D1.

5. We will now investigate the operation of the DETUNED RESONANT CIRCUIT block on the ANACOM 2 module.

Set up a signal generator to have a sinusoidal output of amplitude 1 volt pk/pk and frequency 455kHz (approx), then connect it to the INPUT socket of the DETUNED RESONANT CIRCUIT block.

Monitor t.p.39 (the output from the transformer's secondary winding), together with t.p.35 (the input signal to the detector), triggering the oscilloscope from t.p.35.

Vary the frequency of the signal generator's output around its present position, and note that the amplitude of the signal at t.p.39 increases to a maximum close to 455KHz. This is the frequency response shown in Figure 12 above.

6. Monitor t.p.40 (the detector's output signal), together with t.p.35 (the detector's input signal), triggering the oscilloscope from t.p.35.

   Vary the frequency of the signal generator's output around 455kHz, and note that the d.c voltage at t.p.40 changes accordingly. Check that a frequency can be found where this d.c level reaches a maximum.

7. If you have access to a frequency meter, record the d.c. voltage at t.p.40 for incoming frequencies from 20kHz below, to 20kHz above, the resonant frequency of the tuned circuit.

   Plot the d.c. voltage at t.p.40 against frequency, and check that the response is similar to that shown in Figure 12 above.

   Note that the 455kHz carrier frequency used by ANACOM 2's modulator circuits occurs approximately halfway up the left-hand slope of the response. If it does not, it may be that transformer T4 in the DETUNED RESONANT CIRCUIT block needs adjusting. To do this, follow the instructions given in Chapter 9, entitled 'Adjustment of ANACOM 2's Tuned Circuits'

   Disconnect the signal generator from the ANACOM 2 module before continuing.

8. Now that we have investigated the output voltage/input frequency characteristic of the DETUNED RESONANT CIRCUIT detector, we will use the detector to demodulate the FM OUTPUT from ANACOM 2's MODULATOR CIRCUITS block.

   To do this, first make the connections shown in Figure 13 at the end of this chapter.

9. Initially, we will use the VARACTOR MODULATOR to generate our FM signal, since this is the more linear of the two frequency modulators.

   To select the VARACTOR MODULATOR, put the REACTANCE/VARACTOR switch in the VARACTOR position.

   Ensure that the VARACTOR MODULATOR's CARRIER FREQUENCY preset is in the midway position (arrowhead pointing towards top of P.C.B.) before continuing.

10. The AUDIO OSCILLATOR's output signal (which appears at t.p.1) is now being used by the VARACTOR MODULATOR, to frequency-modulate a 455kHz carrier sinewave. As we saw earlier, this FM waveform appears at the FM OUTPUT socket from the MIXER/AMPLIFIER block.

    You may like to examine this FM waveform at t.p.34. However, with the VARACTOR MODULATOR's CARRIER FREQUENCY preset in its present (midway) position, the frequency deviation is quite small. To be able to notice such a small frequency deviation, you will probably need to have an X-expansion control on your oscilloscope.

If you have such a control, display 20-25 cycles of the waveform on the oscilloscope, and then use the X-expansion control to 'expand up' the rightmost cycles of the display. There should be a slight ambiguity in the positions of these cycles, indicating that the sinewave at t.p.34 is being frequency-modulated.

11. Now monitor the audio input signal to the VARACTOR MODULATOR block (at t.p.14), together with the output from the DETUNED RESONANT CIRCUIT block (at t.p.40), triggering the oscilloscope on t.p.14.

    The signal at t.p.40 should contain three components:

    - A positive d.c. offset voltage;
    - A sinewave at the same frequency as the audio signal at t.p.14;
    - A high-frequency ripple component of small amplitude.

    Check that the audio-frequency component is a reasonable sinewave. If it is not, it is likely that the center frequency of the varactor modulator's FM output needs adjusting slightly. To do this, trim transformer T2 in the VARACTOR MODULATOR block, in accordance with the instructions given in Chapter 9 ('Adjustment of ANACOM 2's Tuned Circuits').

12. The LOW-PASS FILTER / AMPLIFIER block strongly attenuates the high-frequency ripple component at the detector's output, and also blocks the d.c. offset voltage. Consequently, the signal at the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73) should very closely resemble the original audio modulating signal.

    Monitor the input (t.p.69) and output (t.p.73) of the LOW PASS FILTER/AMPLIFIER block (triggering on t.p.73), and note how the quality of the detector's output signal has been improved by low-pass filtering. Note also that the d.c. offset has been removed.

13. Monitor the audio input to the VARACTOR MODULATOR (at t.p.14) and the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73), and adjust the GAIN preset in the LOW PASS FILTER / AMPLIFIER block, until the amplitudes of the two monitored audio waveforms are the same.

14. Adjust the AUDIO OSCILLATOR block's AMPLITUDE and FREQUENCY presets, and compare the original audio signal with the final demodulated signal.

    You may notice that the demodulated output suffers attenuation as the audio modulating frequency is increased. This is caused by low-pass filtering, which takes place in the DETUNED RESONANT CIRCUIT's envelope detector, and in the LOW PASS FILTER / AMPLIFIER block.

In spite of this high-frequency limitation to the range of audio frequencies which can be received, the bandwidth of the system is perfectly adequate for normal speech communication.

In the AUDIO OSCILLATOR block, put the AMPLITUDE preset in its MAX position, and the FREQUENCY preset in its MIN position, before continuing.

15. We will now investigate the effect of noise on the system.

    Adjust the signal generator for a sinusoidal output of amplitude 100mV pk/pk, and frequency 2kHz; this will be our 'noise' input.

    Connect the output of the signal generator to the NOISE INPUT socket in ANACOM 2's MODULATOR CIRCUITS block. Then, monitor the NOISE INPUT (at t.p.5) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on t.p.5.

    Note that the FM signal is now being **amplitude-modulated** by the 'noise' input, in addition to being **frequency-modulated** by the audio input from the AUDIO OSCILLATOR block.

    The amplitude modulations simulate the effect that transmission path noise would have on the amplitude of the FM waveform reaching the receiver. This allows us to investigate the effect that transmission path noise would have on the final demodulated audio signal.

16. Monitor the audio modulating signal (at t.p.14), and the output of the LOW PASS FILTER / AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.14.

    Note that there is now an additional component at t.p.73 - a sinewave at the frequency of the 'noise' input. To see this clearly, it may be necessary to slightly adjust the frequency of the signal generator's output, until the superimposed 'noise' sinewave can be clearly seen.

17. Remove the oscilloscope probe from t.p.73, and place it on t.p.40, the output from the DETUNED RESONANT CIRCUIT detector. Note that the 'noise' component is still present, illustrating that this type of detector is very susceptible to amplitude variations in the incoming FM signal.

    Put the oscilloscope probe on t.p.39, the collector of the DETUNED RESONANT CIRCUIT's transistor, to ensure that you fully understand why this type of detector is so sensitive to amplitude variations.

18. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its MIN position, so that no frequency modulation takes place. Then monitor the 'noise' input (at t.p.5), and the output from the LOW PASS FILTER/AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.5.

The signal at t.p.73 is now purely composed of the 'noise' output resulting from amplitude variations occuring at the input to the DETUNED RESONANT CIRCUIT.

Measure and record the peak-to-peak amplitude of the 'noise' output at t.p.73; this measurement will be valuable in allowing us to compare the DETUNED RESONANT CIRCUIT with other types of FM detector, as far as susceptibility to amplitude modulations is concerned.

19. To overcome the problem of the DETUNED RESONANT CIRCUIT detector's susceptibility to noise, we can connect an AMPLITUDE LIMITER block between the FM OUTPUT and the input to the DETUNED RESONANT CIRCUIT.

    The AMPLITUDE LIMITER **removes amplitude variations** from the FM output signal, so that the input signal to the DETUNED RESONANT CIRCUIT detector has constant amplitude.

    Reconnect the AMPLITUDE LIMITER block between the MIXER/AMPLIFIER block and the DETUNED RESONANT CIRCUIT block, as shown in Figure 14 at the end of this chapter.

20. Monitor the AMPLITUDE LIMITER's output at t.p.68, triggering the oscilloscope from t.p.5, the 'noise' input from the signal generator. Note that the amplitude modulations due to to the 'noise' input have been removed.

    Remove the oscilloscope probe from t.p.68, and put it on t.p.73, the output from the LOW PASS FILTER/AMPLIFIER block. Note that the amplitude of any remaining 'noise' component at t.p.73 is now minimal.

21. Return the AUDIO OSCILLATOR block's AMPLITUDE preset to its MAX position, and monitor t.p.73, triggering the oscilloscope on the audio modulating input at t.p.14.

    Note that amplitude variations now have no effect on the final audio output.

    This shows how an amplitude limiter can be used in a practical FM receiver, to remove amplitude variations caused by noise, **before** they reach the detector.

22. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7) and AUDIO OUTPUT MODULE (L.J. Order Code CT8), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

    If you have these modules, make the following connections:

    - Output of AUDIO INPUT MODULE to AUDIO INPUT socket in ANACOM 2's MODULATOR CIRCUITS block;

- Output of ANACOM 2's LOW PASS FILTER / AMPLIFIER block to INPUT socket of AUDIO OUTPUT MODULE.

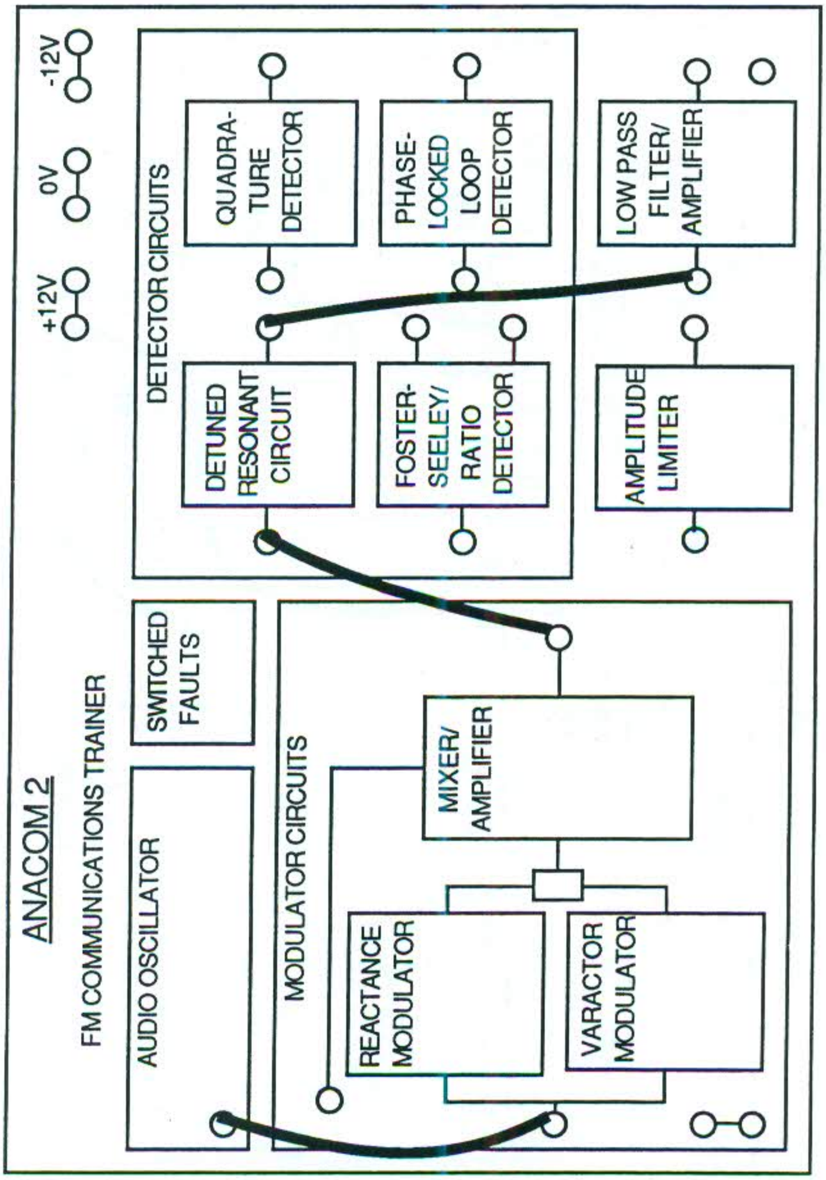
Consult the user manuals for the AUDIO INPUT MODULE and AUDIO OUTPUT MODULE, for further details of how to use them.

23. Throughout this experiment, frequency modulation has been performed by ANACOM 2's VARACTOR MODULATOR block.

    Equally, frequency modulation may be performed by using the REACTANCE MODULATOR block. If you wish to repeat any of the above experimentation with the REACTANCE MODULATOR, simply put the REACTANCE / VARACTOR switch in the REACTANCE position.

    Note, however, that the linearity of the Reactance Modulator is not as good as that of the Varactor Modulator. This means that, when the Reactance Modulator is used, some distortion of the demodulated audio signal may be noticeable at the detector's output, if the amplitude of the audio modulating signal is too large.

24. Finally, make sure that you fully understand the working of the DETUNED RESONANT CIRCUIT detector, by examining the circuit diagram for the detector at the end of this manual, and monitoring test points within the circuit.


ANACOM 2
FM COMMUNICATIONS TRAINER
+12V
0V
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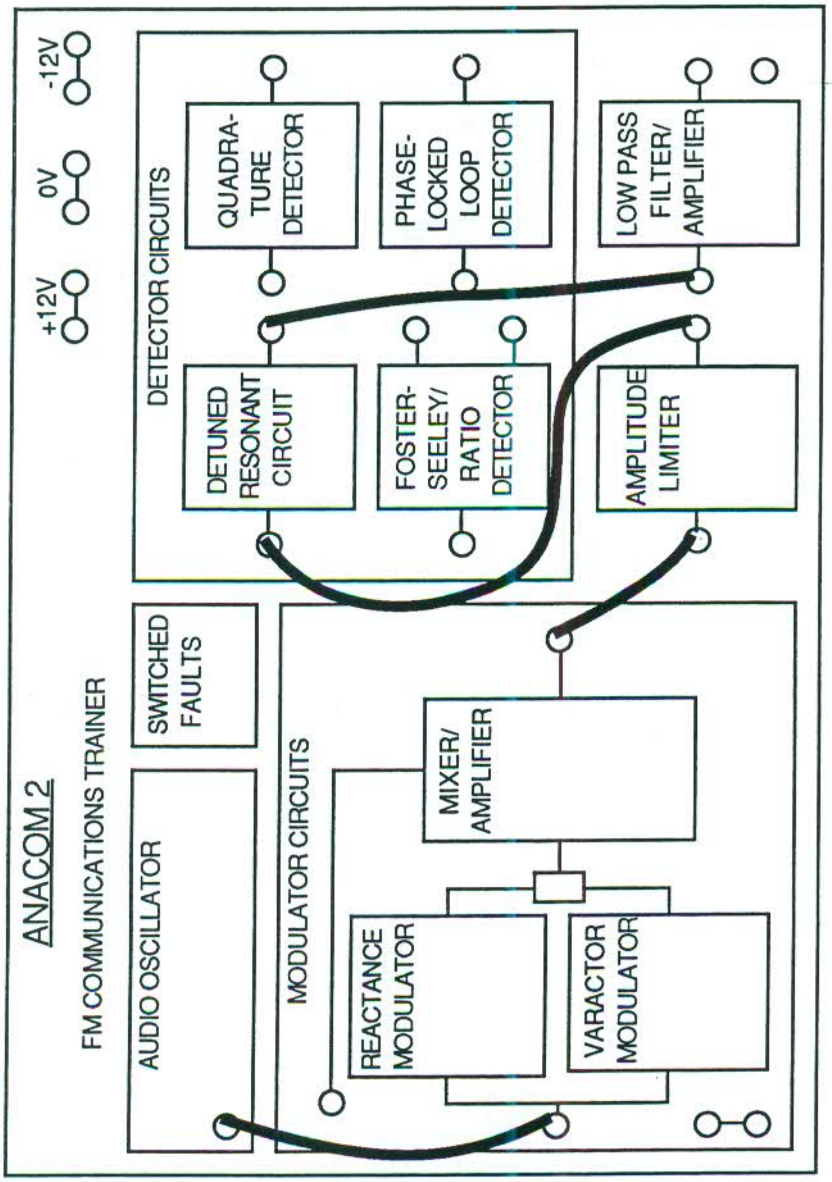
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 13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AMPLIFIER
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RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
ANACOM 2
FM COMMUNICATIONS TRAINER
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 14

QUADRATURE DETECTOR

This experiment investigates how frequency demodulation is performed by the QUADRATURE DETECTOR block on the ANACOM 2 module.

The operation of this detector circuit will be described in detail, and its sensitivity to noise on the incoming FM signal will be investigated.

The on-board AMPLITUDE LIMITER will then be used to remove any amplitude modulations due to noise, **before** they reach the detector. This allows the student to draw conclusions as to whether it is necessary to precede this type of detector with an amplitude limiter stage, in a practical FM receiver.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 15 below:

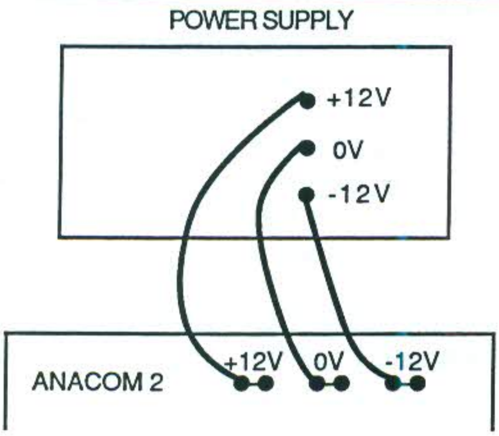


Figure 15

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AUDIO AMPLIFIER block's AMPLITUDE preset in fully clockwise (MAX) position;
   (c) AUDIO AMPLIFIER block's FREQUENCY preset in fully counter-clockwise (MIN) position;
   (d) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully clockwise position;

(e) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in OFF position.

3. Turn on power to the ANACOM 2 module.

4. We will now examine how the QUADRATURE DETECTOR block is used to demodulate a frequency-modulated signal. The block diagram of this circuit is shown below:

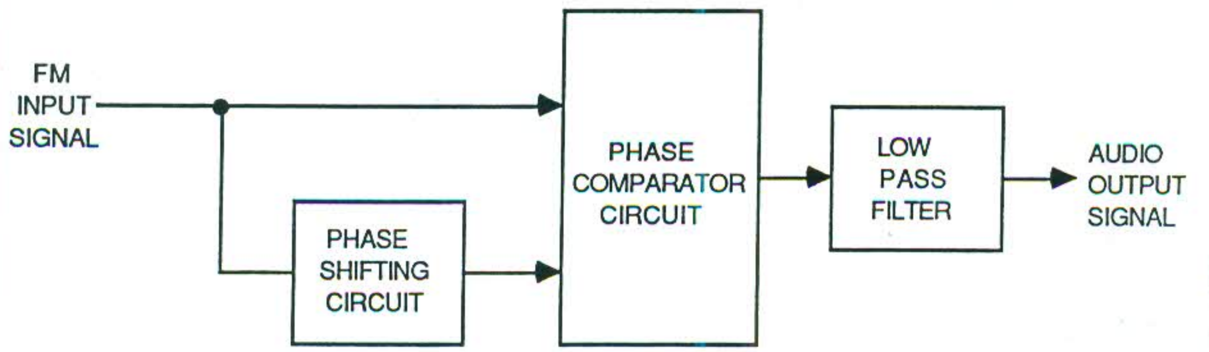


Figure 16

The incoming FM signal is passed through a passive PHASE-SHIFTING CIRCUIT, whose purpose is to shift the phase of the **unmodulated carrier** by exactly 90°.

If the frequency of the FM input signal increases **above** the unmodulated carrier frequency, the phase-shifting circuit will shift the phase of the incoming signal by **more than** 90°. Conversely, if the frequency of the FM input signal decreases **below** the unmodulated carrier frequency, the phase-shifting circuit will shift the phase of the incoming signal by **less than** 90°.

The phase-shifted FM signal is then passed on to a PHASE COMPARATOR CIRCUIT, where its phase is compared with the phase of the original unshifted FM waveform.

The **average voltage level** at the output from the PHASE COMPARATOR **increases** when the phase difference between the shifted and unshifted inputs increases, and **decreases** when this phase difference decreases.

Consequently, an increase in the **frequency** of the incoming FM signal results in an increase in the **average voltage level** at the output of the PHASE COMPARATOR (and vice-versa). A simple low-pass filter, on the output of the phase comparator, helps to remove high-frequency ripple, allowing the average voltage level to be extracted.

It is this relationship between frequency and output voltage which enables the QUADRATURE DETECTOR to demodulate FM.

5. We will now investigate the operation of the QUADRATURE DETECTOR block on the ANACOM 2 module.

   Set up a signal generator to have a sinusoidal output of amplitude 1 volt pk/pk and frequency 455kHz (approx), then connect it to the INPUT socket of the QUADRATURE DETECTOR block.

   Monitor the QUADRATURE DETECTOR block's output at t.p.46, together with its input at t.p.41(trigger the oscilloscope from this signal).

   Vary the frequency of the signal generator's output signal from about 350KHz, to about 550kHz, and note how the d.c. level at t.p.46 changes with increasing frequency.

6. If you have access to a frequency meter, record the d.c. voltage at t.p.46 for incoming frequencies from 400kHz to 500kHz, in 10kHz steps.

   Plot the d.c. voltage at t.p.46 against frequency. The response should be similar to that shown in Figure 17 below:

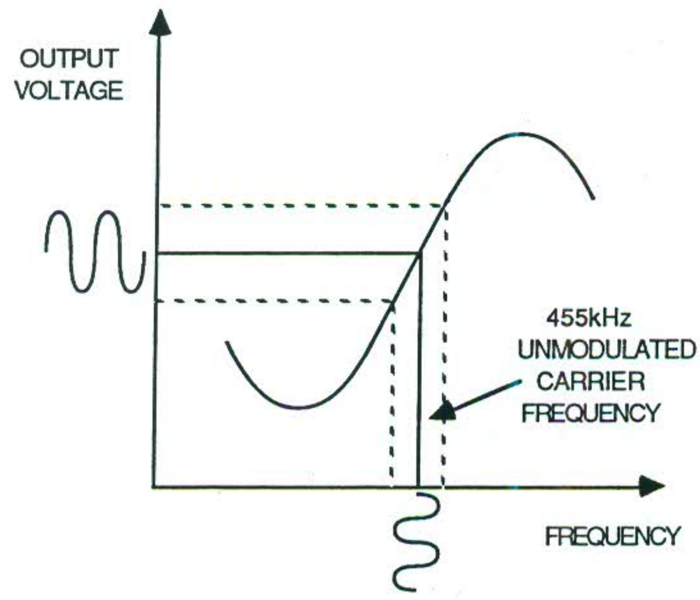


Figure 17

The 455kHz unmodulated carrier frequency should occur at, or close to, the center of the linear part of the response curve, as shown above. If it does not, it may be that transformer T5 in the QUADRATURE DETECTOR block needs adjusting. To do this, follow the instructions given in Chapter 9, entitled 'Adjustment of ANACOM 2's Tuned Circuits'.

It is the linear part of this response curve that is used for frequency demodulation, as shown above. Because of the highly linear voltage/frequency characteristic over this part of the response, little distortion will occur within the quadrature detector, provided that:

- The unmodulated carrier frequency is close to the center of this linear region;
- The frequency deviation of the FM signal is not so great that the incoming frequency goes outside the linear region.

Disconnect the signal generator from the ANACOM 2 module before continuing.

7. Now that we have investigated the output voltage/input frequency characteristic of the QUADRATURE DETECTOR, we will use the detector to demodulate the FM OUTPUT from ANACOM 2's MODULATOR CIRCUITS block.

   To do this, first make the connections shown in Figure 18 at the end of this chapter.

8. Initially, we will use the VARACTOR MODULATOR to generate our FM signal, since this is the more linear of the two frequency modulators.

   To select the VARACTOR MODULATOR, put the REACTANCE/VARACTOR switch in the VARACTOR position.

   Ensure that the VARACTOR MODULATOR's CARRIER FREQUENCY preset is in the midway position (arrowhead pointing towards top of P.C.B.) before continuing.

9. The AUDIO OSCILLATOR's output signal (which appears at t.p.1) is now being used by the VARACTOR MODULATOR, to frequency-modulate a 455kHz carrier sinewave. As we saw earlier, this FM waveform appears at the FM OUTPUT socket from the MIXER/AMPLIFIER block.

   You may like to examine this FM waveform at t.p.34. However, with the VARACTOR MODULATOR's CARRIER FREQUENCY preset in its present (midway) position, the frequency deviation is quite small. To be able to notice such a small frequency deviation, you will probably need to have an X-expansion control on your oscilloscope.

   If you have such a control, display 20-25 cycles of the waveform on the oscilloscope, and then use the X-expansion control to 'expand up' the rightmost cycles of the display. There should be a slight ambiguity in the positions of these cycles, indicating that the sinewave at t.p.34 is being frequency-modulated.

10. Now monitor the audio input signal to the VARACTOR MODULATOR block (at t.p.14), together with the output from the QUADRATURE DETECTOR block (at t.p.46), triggering the oscilloscope on t.p.14.

    The signal at t.p.46 should contain three components:

    - A positive d.c. offset voltage;
    - A sinewave at the same frequency as the audio signal at t.p.14;
    - A high-frequency ripple component of small amplitude.

    Check that the audio-frequency component is a reasonable sinewave. If it is not, it is likely that the center frequency of the varactor modulator's FM output needs adjusting slightly. To do this, trim transformer T2 in the VARACTOR MODULATOR block, in accordance with the instructions given in Chapter 9 ('Adjustment of ANACOM 2's Tuned Circuits').

11. The fact that there is still some high-frequency ripple at the output of the QUADRATURE DETECTOR block, indicates that the passive low pass filter circuit at the block's output (as shown in Figure 16) is not sufficient to remove this unwanted high-frequency component. We use the LOW PASS FILTER / AMPLIFIER block to overcome this problem.

    The LOW-PASS FILTER / AMPLIFIER block strongly attenuates the high-frequency ripple component at the detector's output, and also blocks the d.c. offset voltage. Consequently, the signal at the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73) should very closely resemble the original audio modulating signal.

    Monitor the input (t.p.69) and output (t.p.73) of the LOW PASS FILTER / AMPLIFIER block (triggering on t.p.73), and note how the quality of the detector's output signal has been improved by further low-pass filtering. Note also that the d.c. offset has been removed.

12. Monitor the audio input to the VARACTOR MODULATOR (at t.p.14) and the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73), and adjust the GAIN preset (in the LOW PASS FILTER / AMPLIFIER block) until the amplitudes of the monitored audio waveforms are the same.

13. Adjust the AUDIO OSCILLATOR block's AMPLITUDE and FREQUENCY presets, and compare the original audio signal with the final demodulated signal.

    You may notice that the demodulated output suffers attenuation as the audio modulating frequency is increased. This is caused by low-pass filtering, which takes place in the QUADRATURE DETECTOR's passive low-pass filter, and in the LOW PASS FILTER / AMPLIFIER block.

In spite of this high-frequency limitation to the range of audio frequencies which can be received, the bandwidth of the system is perfectly adequate for normal speech communication.

In the AUDIO OSCILLATOR block, put the AMPLITUDE preset in its MAX position, and the FREQUENCY preset in its MIN position, before continuing.

14. We will now investigate the effect of noise on the system.

    Adjust the signal generator for a sinusoidal output of amplitude 100mV pk/pk, and frequency 2kHz; this will be our 'noise' input.

    Connect the output of the signal generator to the NOISE INPUT socket in ANACOM 2's MODULATOR CIRCUITS block. Then, monitor the NOISE INPUT (at t.p.5) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on t.p.5.

    Note that the FM signal is now being **amplitude-modulated** by the 'noise' input, in addition to being **frequency-modulated** by the audio input from the AUDIO OSCILLATOR block.

    The amplitude modulations simulate the effect that transmission path noise would have on the amplitude of the FM waveform reaching the receiver. This allows us to investigate the effect that transmission path noise would have on the final demodulated audio signal.

15. Monitor the audio modulating signal (at t.p.14), and the output of the LOW PASS FILTER / AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.14.

    You may be able to notice an additional component at t.p.73 - a small amount of 'ripple' at the frequency of the 'noise' input. To see this clearly, it may be necessary to slightly adjust the frequency of the signal generator's output.

16. Remove the oscilloscope probe from t.p.73, and place it on t.p.46, the output from the QUADRATURE DETECTOR block. Note that the small 'noise' component is still visible.

    Note that amplitude variations in the FM waveform has much less effect on the QUADRATURE DETECTOR than they did on the DETUNED RESONANT CIRCUIT detector investigated earlier. This is because the quadrature detector's phase comparator is looking for **phase differences** between the phase-shifted and unshifted FM waveforms, and is consequently fairly insensitive to amplitude variations.

17. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its MIN position, so that no frequency modulation takes place. Then monitor the 'noise' input (at t.p.5), and the output from the LOW PASS FILTER/AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.5.

The signal at t.p.73 is now purely composed of the 'noise' output resulting from amplitude variations occuring at the input to the QUADRATURE DETECTOR.

Measure and record the peak-to-peak amplitude of the 'noise' output at t.p.73; this measurement will be valuable in allowing us to compare the QUADRATURE DETECTOR with other types of FM detector, as far as susceptibility to amplitude modulations is concerned.

Compare your measurement with that recorded for the previous experiment - this will confirm that the susceptibility of the QUADRATURE DETECTOR block to amplitude variations is much less than for the DETUNED RESONANT CIRCUIT.

18. To reduce the effect of amplitude variations even further, we can connect an AMPLITUDE LIMITER block between the FM OUTPUT and the input to the QUADRATURE DETECTOR.

    The AMPLITUDE LIMITER **removes amplitude variations** from the FM output signal, so that the input signal to the QUADRATURE DETECTOR has constant amplitude.

    Reconnect the AMPLITUDE LIMITER block between the MIXER/AMPLIFIER block and the QUADRATURE DETECTOR block, as shown in Figure 19 at the end of this chapter.

19. Monitor the AMPLITUDE LIMITER's output at t.p.68, triggering the oscilloscope from t.p.5, the 'noise' input from the signal generator. Note that the amplitude modulations due to to the 'noise' input have been removed.

    Remove the oscilloscope probe from t.p.68, and put it on t.p.73, the output from the LOW PASS FILTER/AMPLIFIER block. Note that the amplitude of any remaining 'noise' component at t.p.73 is now minimal.

20. Return the AUDIO OSCILLATOR block's AMPLITUDE preset to its MAX position, and monitor t.p.73, triggering the oscilloscope on the audio modulating input at t.p.6.

    Note that amplitude variations now have negligible effect on the final audio output signal.

    This shows how an amplitude limiter can help to minimize the effect of amplitude variations caused by noise, in a practical FM receiver. However, since the QUADRATURE DETECTOR is so good at rejecting amplitude variations anyway, an amplitude limiter may not be needed in many applications where a quadrature detector is used.

21. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7) and AUDIO OUTPUT MODULE (L.J. Order Code CT8), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

    If you have these modules, make the following connections:

    - Output of AUDIO INPUT MODULE to AUDIO INPUT socket in ANACOM 2's MODULATOR CIRCUITS block;

    - Output of ANACOM 2's LOW PASS FILTER / AMPLIFIER block to INPUT socket of AUDIO OUTPUT MODULE.

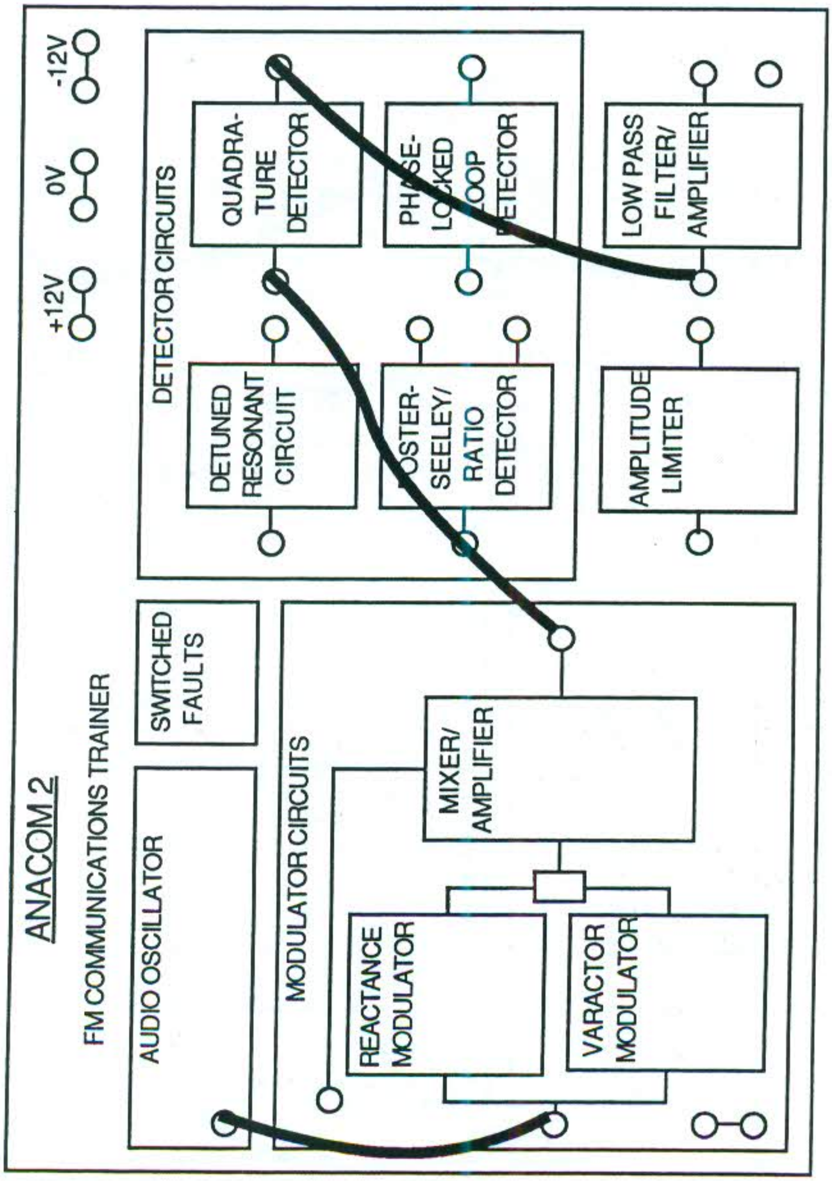
    Consult the user manuals for the AUDIO INPUT MODULE and AUDIO OUTPUT MODULE, for further details of how to use them.

22. Throughout this experiment, frequency modulation has been performed by ANACOM 2's VARACTOR MODULATOR block.

    Equally, frequency modulation may be performed by using the REACTANCE MODULATOR block. If you wish to repeat any of the above experimentation with the REACTANCE MODULATOR, simply put the REACTANCE / VARACTOR switch in the REACTANCE position.

    Note, however, that the linearity of the Reactance Modulator is not as good as that of the Varactor Modulator. This means that, when the Reactance Modulator is used, some distortion of the demodulated audio signal may be noticeable at the detector's output, if the amplitude of the audio modulating signal is too large.

23. Finally, make sure that you fully understand the working of the QUADRATURE DETECTOR, by examining the circuit diagram for the detector at the end of this manual, and monitoring test points within the circuit.



+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
ANACOM 2
FM COMMUNICATIONS TRAINER
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 18

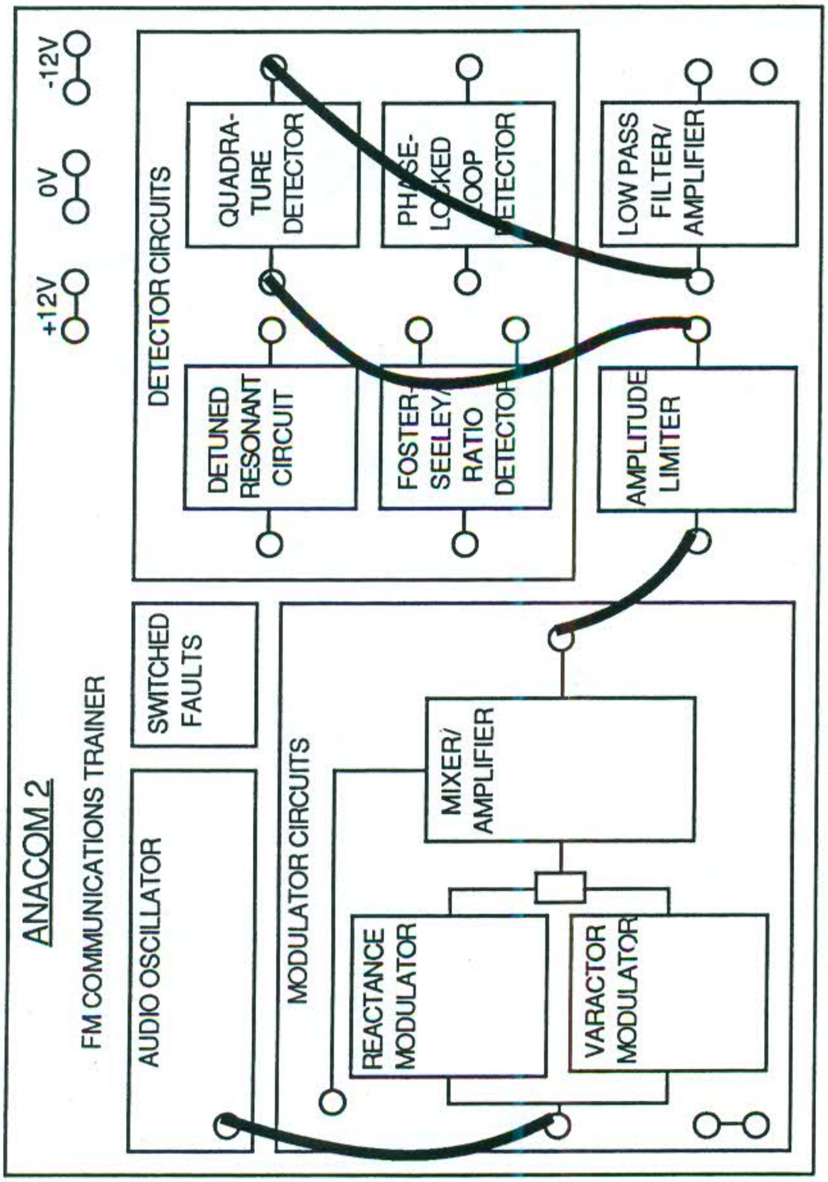

ANACOM 2
FM COMMUNICATIONS TRAINER
+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-TURE DETECTOR
PHASE-LOCKED LOOP DETECTOR
LOW PASS FILTER/ AMPLIFIER
DETUNED RESONANT CIRCUIT
FOSTER-SEELEY/ RATIO DETECTOR
AMPLITUDE LIMITER
SWITCHED FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/ AMPLIFIER
REACTANCE MODULATOR
VARACTOR MODULATOR

Figure 19

FOSTER-SEELEY DETECTOR

This experiment investigates how frequency demodulation is performed by the FOSTER-SEELEY detector on the ANACOM 2 module.

The operation of this detector circuit will be described in detail, and its sensitivity to noise on the incoming FM signal will be investigated.

The on-board AMPLITUDE LIMITER will then be used to remove any amplitude modulations due to noise, **before** they reach the detector. This allows the student to draw conclusions as to whether it is necessary to precede this type of detector with an amplitude limiter stage, in a practical FM receiver.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 20 below:

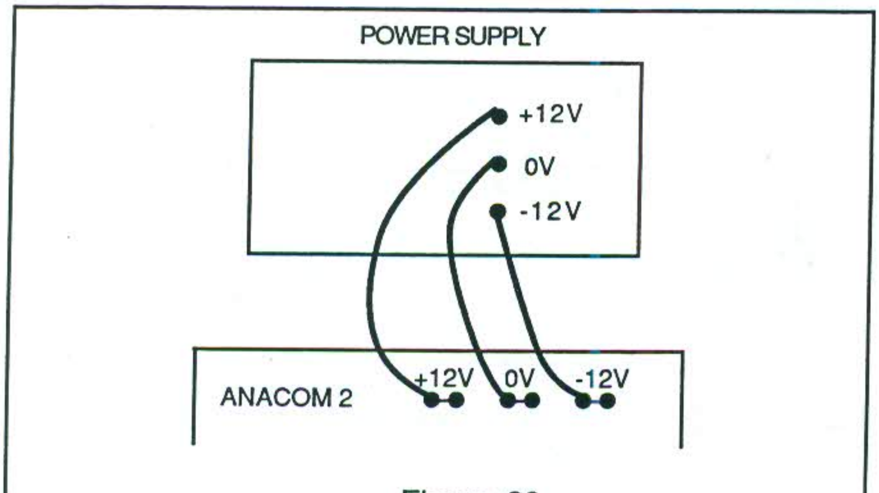


Figure 20

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AUDIO AMPLIFIER block's AMPLITUDE preset in fully clockwise (MAX) position;
   (c) AUDIO AMPLIFIER block's FREQUENCY preset in fully counter-clockwise (MIN) position;
   (d) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully clockwise position;

(e) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in OFF position.

3. Turn on power to the ANACOM 2 module.

4. We will now examine how the FOSTER-SEELEY DETECTOR is used to demodulate a frequency-modulated signal. An outline of the circuit given below:

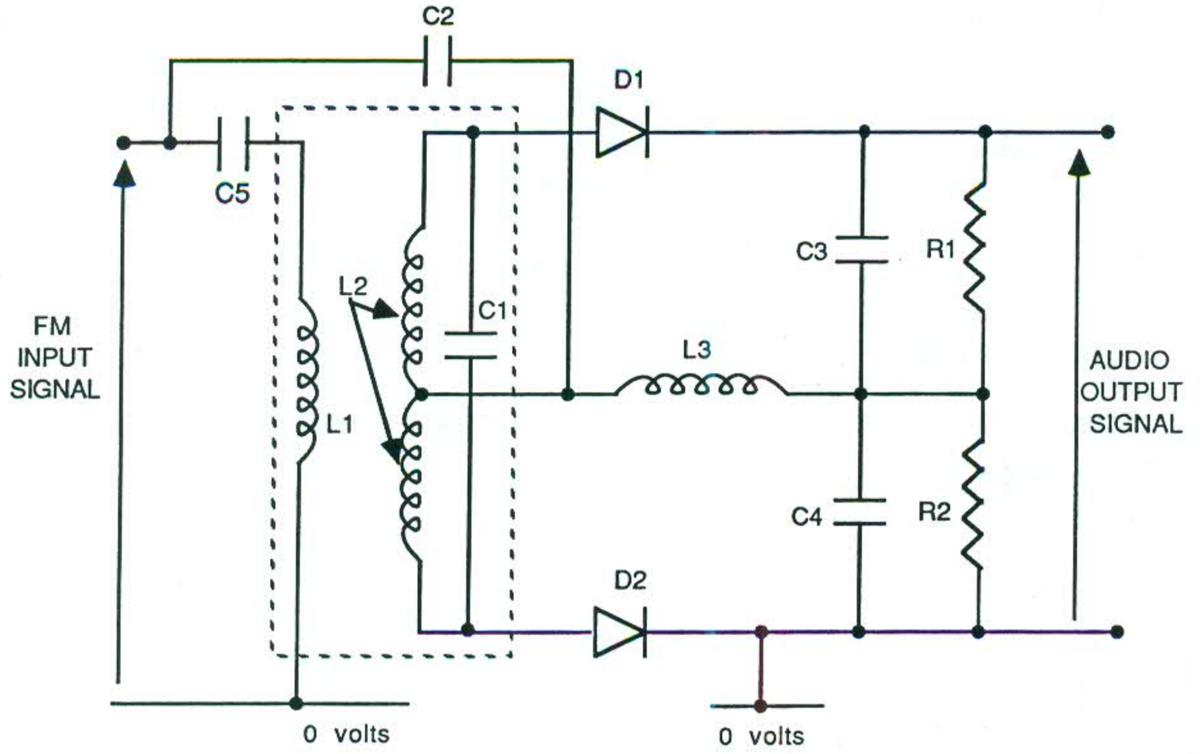


Figure 21

The tuned circuit comprising center-tapped inductor L2 and capacitor C1 is tuned to resonate at the unmodulated FM carrier frequency.

Diodes D1 and D2 and their respective low-pass filters (C3 and R1, C4 and R2) form envelope detectors.

Capacitors C2, C3 and C4 all have negligible reactance at radio frequencies, so that the FM input signal also appears across L3.

The operation of the FOSTER-SEELEY DETECTOR is as follows.

When the incoming FM signal is at the unmodulated carrier frequency, the tuned circuit comprising L2 & C1 will be at resonance. At this resonant frequency, capacitor C5 introduces a phase shift of exactly 90° between the incoming FM signal (**V_{FM}**) and the voltage across L1 (which we will call **Va**).

Since L1 and L2 are tightly coupled magnetically, the voltage across L2 (which we will call **Vb**) will also be 90° out of phase with V_{FM}, as shown in Figure 22:

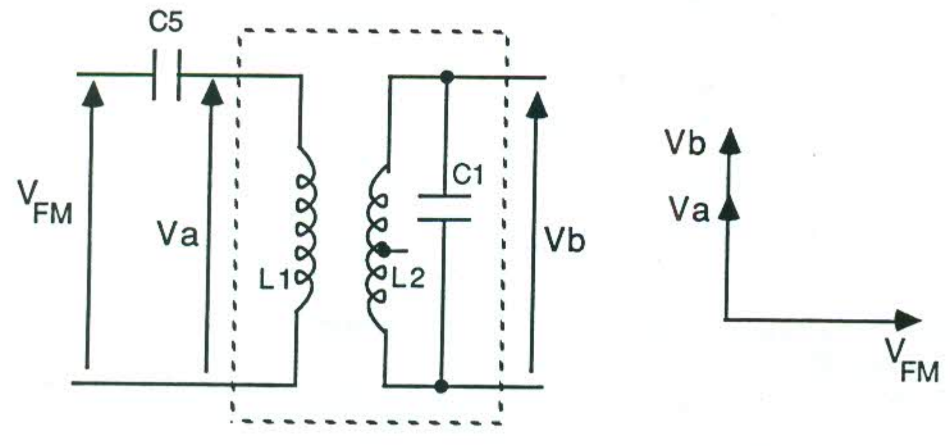


Figure 22

You will also note that inductor L2 is center-tapped. If the voltage across the upper half of L2 is **V1**, and that across the lower half is **V2** (where V1 and V2 are referenced to the center-tap), then the phase relationships between V1, V2, and the incoming FM signal (V_{FM}) will be as shown in Figure 23:

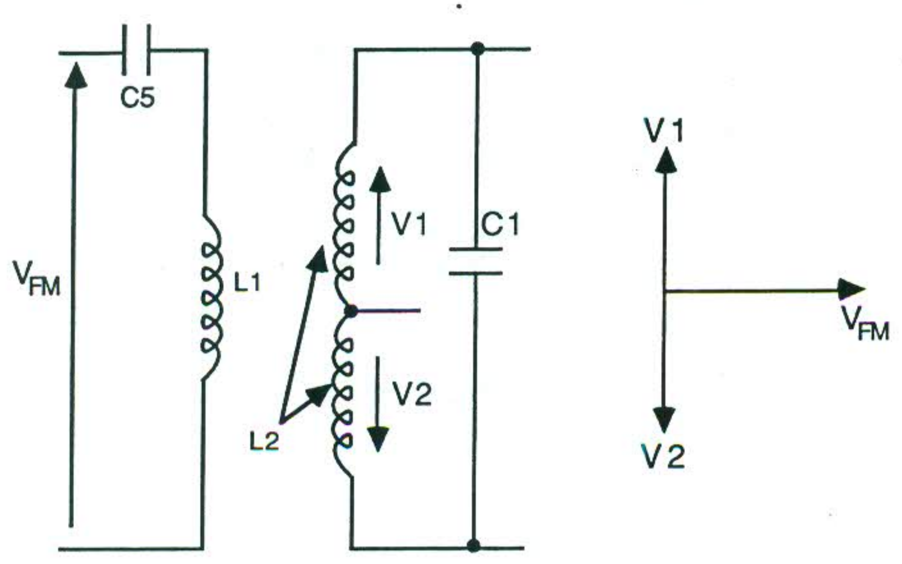


Figure 23

You will recall from Figure 21 that VFM also appears across inductor L3. Consequently, when the tuned circuit is at resonance, the voltages at the anodes of diodes D1 and D2 can be represented by vectors **Vd1** and **Vd2** in the vector diagram below:

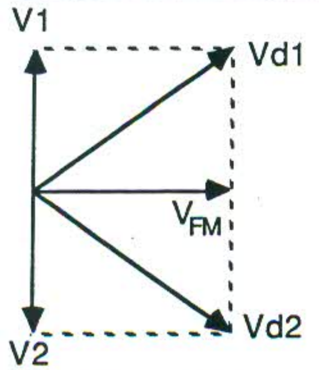


Figure 24

Note that at resonance, Vd1 and Vd2 are equal, resulting in equal and opposite d.c. levels at the cathodes of the two diodes in Figure 21, relative to the center-tap of L2. These equal and opposite voltages cancel, to give 0 volts d.c. at the detector's audio output, relative to ground.

Now suppose that the frequency of the FM signal increases **above** the unmodulated carrier frequency. This causes the phase shift due to capacitor C5 to fall **below** 90°.

This results in V1 leading V_{FM} by less than 90°, and V2 lagging V_{FM} by more than 90°, as shown in Figure 25 (a) below:

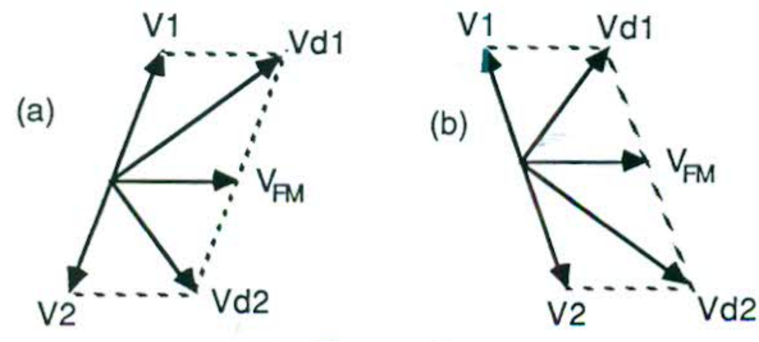


Figure 25

Consequently, the amplitude of Vd1 is greater than that of Vd2, resulting in a larger voltage appearing across R1 than R2. This gives rise to an overall **positive** voltage at the detector's audio output.

Conversely, if the frequency of the FM input signal decreases **below** the unmodulated carrier frequency, the phase shift due to capacitor C5 increases **above** 90°. This causes voltage V1 to lead V_{FM} by more than 90°, while V2 lags V_{FM} by less than 90°, as shown in Figure 25 (b) above. As a result, Vd2 is greater than Vd1, and the final detector output voltage is **negative**.

It is in this way that the output voltage from the detector changes to follow frequency changes in the incoming FM signal.

5. We will now investigate the operation of the Foster-Seeley Detector on the ANACOM 2 module.

   In the FOSTER-SEELEY/RATIO DETECTOR block, select the Foster-Seeley detector by putting the switch in the FOSTER-SEELEY position. This configures the circuit to be as shown in Figure 21 above.

   Set up a signal generator to have a sinusoidal output of amplitude 1 volt pk/pk and frequency approximately 400kHz, then connect it to the INPUT socket of the FOSTER-SEELEY/RATIO DETECTOR block.

   Monitor the block's FOSTER-SEELEY output at t.p.52, together with its input at t.p.47 (trigger the oscilloscope from this signal).

   Vary the frequency of the signal generator's output signal from about 400KHz, to about 500kHz, and note how the d.c. level at t.p.52 changes with increasing frequency.

6. If you have access to a frequency meter, record the d.c. voltage at t.p.52 for incoming frequencies from 430kHz to 480kHz, in 5kHz steps.

   Plot the d.c. voltage at t.p.52 against frequency. The response should be similar to that shown in Figure 26 below:

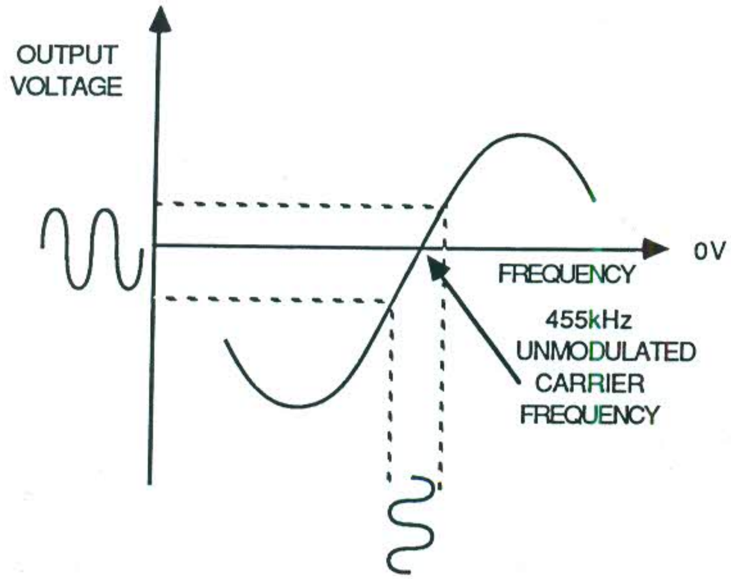


Figure 26

Note the similarity between the voltage/frequency characteristic of the Foster-Seeley Detector and that of the Quadrature Detector used in the previous experiment. This type of response is known as an **S-curve**, since it resembles a letter 'S'.

The 455kHz unmodulated carrier frequency (used by ANACOM 2's frequency modulators) should occur at, or close to, the 0 volts axis, as shown above. If it does not, it may be that transformer T6 in the FOSTER-SEELEY / RATIO DETECTOR block needs adjusting. To do this, follow the instructions given in Chapter 9, entitled 'Adjustment of ANACOM 2's Tuned Circuits'

It is the linear part of the response curve that is used for frequency demodulation, as shown above. Because of the linear voltage/frequency characteristic over this part of the response, little distortion will occur within the Foster-Seeley detector, provided that:

- The unmodulated carrier frequency is close to the center of this linear region;

- The frequency deviation of the FM signal is not so great that the incoming frequency goes outside the linear region.

Disconnect the signal generator from the ANACOM 2 module before continuing.

7. Now that we have investigated the output voltage/input frequency characteristic of the FOSTER-SEELEY DETECTOR, we will use the detector to demodulate the FM OUTPUT from ANACOM 2's MODULATOR CIRCUITS block.

   To do this, first make the connections shown in Figure 27 at the end of this chapter.

8. Initially, we will use the VARACTOR MODULATOR to generate our FM signal, since this is the more linear of the two modulators, as far as its frequency/voltage characteristic is concerned.

   To select the VARACTOR MODULATOR, put the REACTANCE/VARACTOR switch in the VARACTOR position.

   Ensure that the VARACTOR MODULATOR's CARRIER FREQUENCY preset is in the midway position (arrowhead pointing towards top of P.C.B.) before continuing.

9. The AUDIO OSCILLATOR's output signal (which appears at t.p.1) is now being used by the VARACTOR MODULATOR, to frequency-modulate a 455kHz carrier sinewave. As we saw earlier, this FM waveform appears at the FM OUTPUT socket from the MIXER/AMPLIFIER block.

   You may like to examine this FM waveform at t.p.34. However, with the VARACTOR MODULATOR's CARRIER FREQUENCY preset in its present (midway) position, the frequency deviation is quite small. To be able to notice such a small frequency deviation, you will probably need to have an X-expansion control on your oscilloscope.

   If you have such a control, display 20-25 cycles of the waveform on the oscilloscope, and then use the X-expansion control to 'expand up' the rightmost cycles of the display. There should be a slight ambiguity in the positions of these cycles, indicating that the sinewave at t.p.34 is being frequency-modulated.

10. Now monitor the audio input signal to the VARACTOR MODULATOR block (at t.p.14), together with the FOSTER-SEELEY OUTPUT from the FOSTER-SEELEY/RATIO DETECTOR block (at t.p.52), triggering the oscilloscope on t.p.14.

    The signal at t.p.52 should contain two components:

    - A sinewave at the same frequency as the audio signal at t.p.14;
    - A high-frequency ripple component of small amplitude.

Note: Any d.c. offset should be small, compared with the amplitude of the audio-frequency component. If it is not, it is likely that the center frequency of the incoming FM signal needs adjusting. To do this, trim transformer T2 in the VARACTOR MODULATOR block, in accordance with the instructions given in Chapter 9 ('Adjustment of ANACOM 2's Tuned Circuits').

11. The high-frequency ripple which is present at the FOSTER-SEELEY OUTPUT is due to the envelope detection process that takes place in the Foster-Seeley Detector (see Figure 21).

    The LOW-PASS FILTER / AMPLIFIER block strongly attenuates this high-frequency ripple component, and also blocks any small d.c. offset voltage that might exist at the detector's output. Consequently, the signal at the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73) should very closely resemble the original audio modulating signal.

    Monitor the input (t.p.69) and output (t.p.73) of the LOW PASS FILTER / AMPLIFIER block (triggering on t.p.73), and note how the quality of the detector's output signal has been improved by further low-pass filtering.

12. Monitor the audio input to the VARACTOR MODULATOR (at t.p.14) and the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73), and adjust the GAIN preset (in the LOW PASS FILTER / AMPLIFIER block) until the amplitudes of the monitored audio waveforms are the same.

13. Adjust the AUDIO OSCILLATOR block's AMPLITUDE and FREQUENCY presets, and compare the original audio signal with the final demodulated signal.

    You may notice that the demodulated output suffers attenuation as the audio modulating frequency is increased. This is mainly due to the low pass filter in the LOW PASS FILTER / AMPLIFIER block, which has a break frequency of 3.4kHz.

    In spite of this high-frequency limitation to the range of audio frequencies which can be received, the bandwidth of the system is perfectly adequate for normal speech communication.

    In the AUDIO OSCILLATOR block, put the AMPLITUDE preset in its MAX position, and the FREQUENCY preset in its MIN position, before continuing.

14. We will now investigate the effect of noise on the system.

    Adjust the signal generator for a sinusoidal output of amplitude 100mV pk/pk, and frequency 2kHz; this will be our 'noise' input.

    Connect the output of the signal generator to the NOISE INPUT socket in ANACOM 2's MODULATOR CIRCUITS block. Then, monitor the NOISE INPUT (at t.p.5) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on t.p.5.

Note that the FM signal is now being **amplitude-modulated** by the 'noise' input, in addition to being **frequency-modulated** by the audio input from the AUDIO OSCILLATOR block.

The amplitude modulations simulate the effect that transmission path noise would have on the amplitude of the FM waveform reaching the receiver. This allows us to investigate the effect that transmission path noise would have on the final demodulated audio signal.

15. Monitor the audio modulating signal (at t.p.14), and the output of the LOW PASS FILTER / AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.14.

    You will notice an additional component at t.p.73 - a considerable amount of 'ripple' at the frequency of the 'noise' input. To see this clearly, it may be necessary to slightly adjust the frequency of the signal generator's output.

16. Remove the oscilloscope probe from t.p.73, and place it on t.p.52, the FOSTER-SEELEY OUTPUT from the FOSTER-SEELEY/RATIO DETECTOR block. Note that the 'noise' component is still visible.

17. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its MIN position, so that no frequency modulation takes place. Then monitor the 'noise' input (at t.p.5), and the output from the LOW PASS FILTER/AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.5.

    The signal at t.p.73 is now purely composed of the 'noise' output resulting from amplitude variations occuring at the input to the FOSTER-SEELEY DETECTOR.

    Measure and record the peak-to-peak amplitude of the 'noise' output at t.p.73; this measurement will be valuable in allowing us to compare the FOSTER-SEELEY DETECTOR with other types of FM detector, as far as susceptibility to amplitude modulations is concerned.

    Compare your measurement with those recorded for the previous experiments.

18. To reduce the effect of amplitude variations even further, we can connect an AMPLITUDE LIMITER block between the FM OUTPUT and the input to the FOSTER-SEELEY DETECTOR.

    The AMPLITUDE LIMITER **removes amplitude variations** from the FM output signal, so that the input signal to the FOSTER-SEELEY DETECTOR has constant amplitude.

    Reconnect the AMPLITUDE LIMITER block between the MIXER/AMPLIFIER block and the FOSTER-SEELEY/RATIO DETECTOR block, as shown in Figure 28 at the end of this chapter.

19. Monitor the AMPLITUDE LIMITER's output at t.p.68, triggering the oscilloscope from t.p.5, the 'noise' input from the signal generator. Note that the amplitude modulations due to to the 'noise' input have been removed.

    Remove the oscilloscope probe from t.p.68, and put it on t.p.73, the output from the LOW PASS FILTER/AMPLIFIER block. Note that the amplitude of any remaining 'noise' component at t.p.73 is now minimal.

20. Return the AUDIO OSCILLATOR block's AMPLITUDE preset to its MAX position, and monitor t.p.73, triggering the oscilloscope on the audio modulating input at t.p.14.

    Note that amplitude variations in the FM waveform now have no effect on the final audio output.

    This shows how an amplitude limiter can remove the effect of amplitude variations caused by noise, in a practical FM receiver. Since the FOSTER-SEELEY DETECTOR is quite susceptible to these amplitude variations, it is usual to precede this type of detector with an amplitude limiter.

21. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7) and AUDIO OUTPUT MODULE (L.J. Order Code CT8), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

    If you have these modules, make the following connections:

    - Output of AUDIO INPUT MODULE to AUDIO INPUT socket in ANACOM 2's MODULATOR CIRCUITS block;

    - Output of ANACOM 2's LOW PASS FILTER / AMPLIFIER block to INPUT socket of AUDIO OUTPUT MODULE.

    Consult the user manuals for the AUDIO INPUT MODULE and AUDIO OUTPUT MODULE, for further details of how to use them.

22. Throughout this experiment, frequency modulation has been performed by ANACOM 2's VARACTOR MODULATOR block.

    Equally, frequency modulation may be performed by using the REACTANCE MODULATOR block. If you wish to repeat any of the above experimentation with the REACTANCE MODULATOR, simply put the REACTANCE / VARACTOR switch in the REACTANCE position.

Note, however, that the linearity of the Reactance Modulator is not as good as that of the Varactor Modulator. This means that, when the Reactance Modulator is used, some distortion of the demodulated audio signal may be noticeable at the detector's output, if the amplitude of the audio modulating signal is too large.

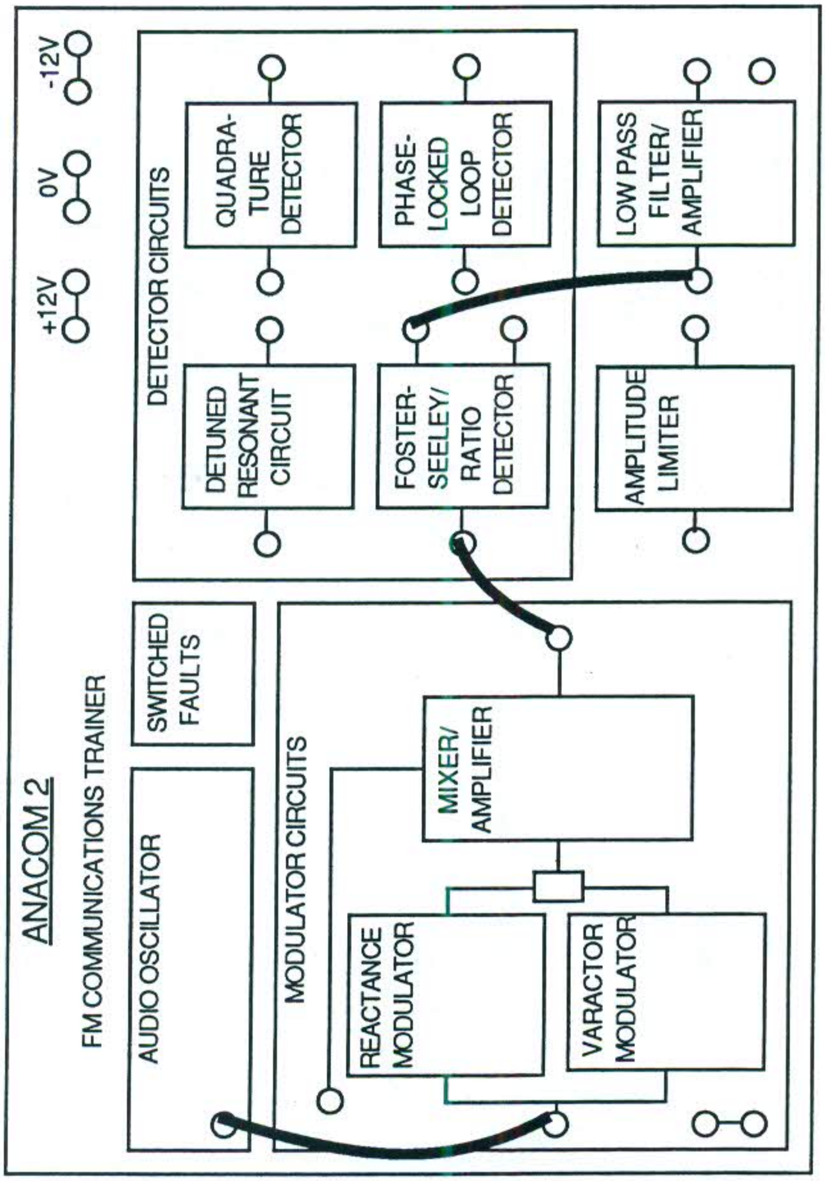
23. Finally, make sure that you fully understand the working of the FOSTER-SEELEY DETECTOR, by examining the circuit diagram for the detector at the end of this manual, and monitoring test points within the circuit.

24. As you will have noticed, one problem with the FOSTER-SEELEY DETECTOR is its sensitivity to amplitude variations in the incoming FM signal.

This is eaiest to see if you look back at Figure 25 (a) and (b). Note that the output from the FOSTER-SEELEY DETECTOR is proportional to the **difference** between diode voltages Vd1 and Vd2. This voltage difference depends on the absolute amplitudes of Vd1 and Vd2, which in turn depend on the **amplitude** of the incoming FM signal.

Any changes in the amplitude of the FM signal will therefore cause changes in the output voltage from the detector.

As we shall see in the next experiment, this disadvantage is overcome by a slight modification of the FOSTER-SEELEY circuit. The modified detector is known as a RATIO DETECTOR.


+12V
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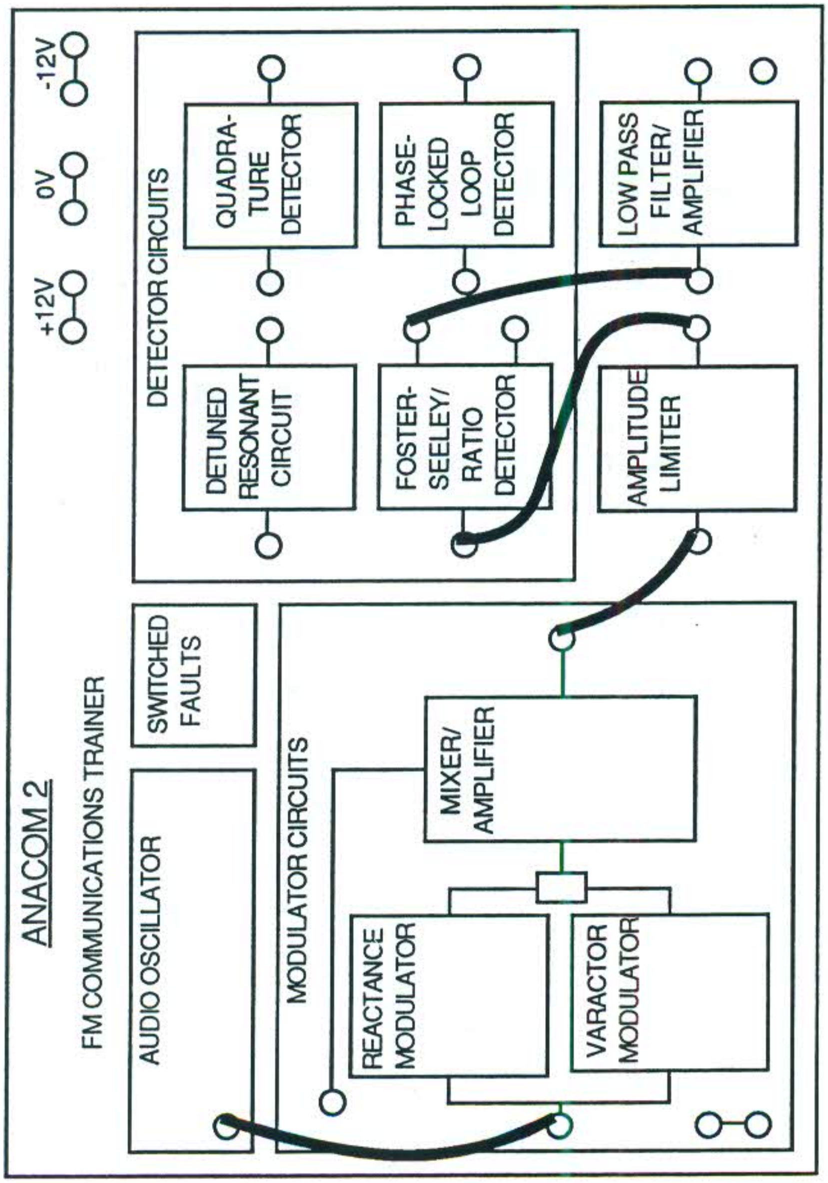
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
ANACOM 2
FM COMMUNICATIONS TRAINER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 27


ANACOM 2
FM COMMUNICATIONS TRAINER
+12V
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DETECTOR CIRCUITS
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RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 28

RATIO DETECTOR

This experiment investigates how frequency demodulation is performed by the RATIO DETECTOR on the ANACOM 2 module.

The operation of this detector circuit will be described in detail, and its sensitivity to noise on the incoming FM signal will be investigated.

The on-board AMPLITUDE LIMITER will then be used to remove any amplitude modulations due to noise, **before** they reach the detector. This allows the student to draw conclusions as to whether it is necessary to precede this type of detector with an amplitude limiter stage, in a practical FM receiver.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 29 below:

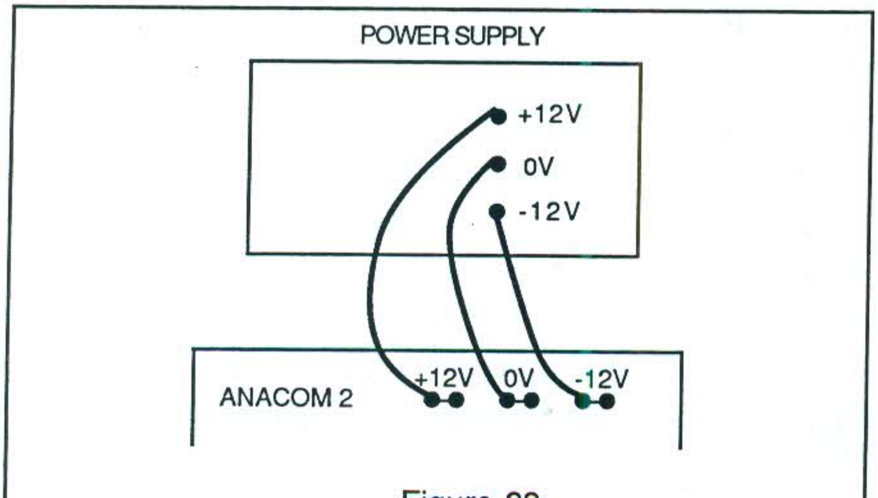


Figure 29

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AUDIO AMPLIFIER block's AMPLITUDE preset in fully clockwise (MAX) position;
   (c) AUDIO AMPLIFIER block's FREQUENCY preset in fully counter-clockwise (MIN) position;
   (d) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully clockwise position;

(e) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in OFF position.

3. Turn on power to the ANACOM 2 module.

4. We will now examine how the RATIO DETECTOR is used to demodulate a frequency-modulated signal. An outline of the circuit given below:

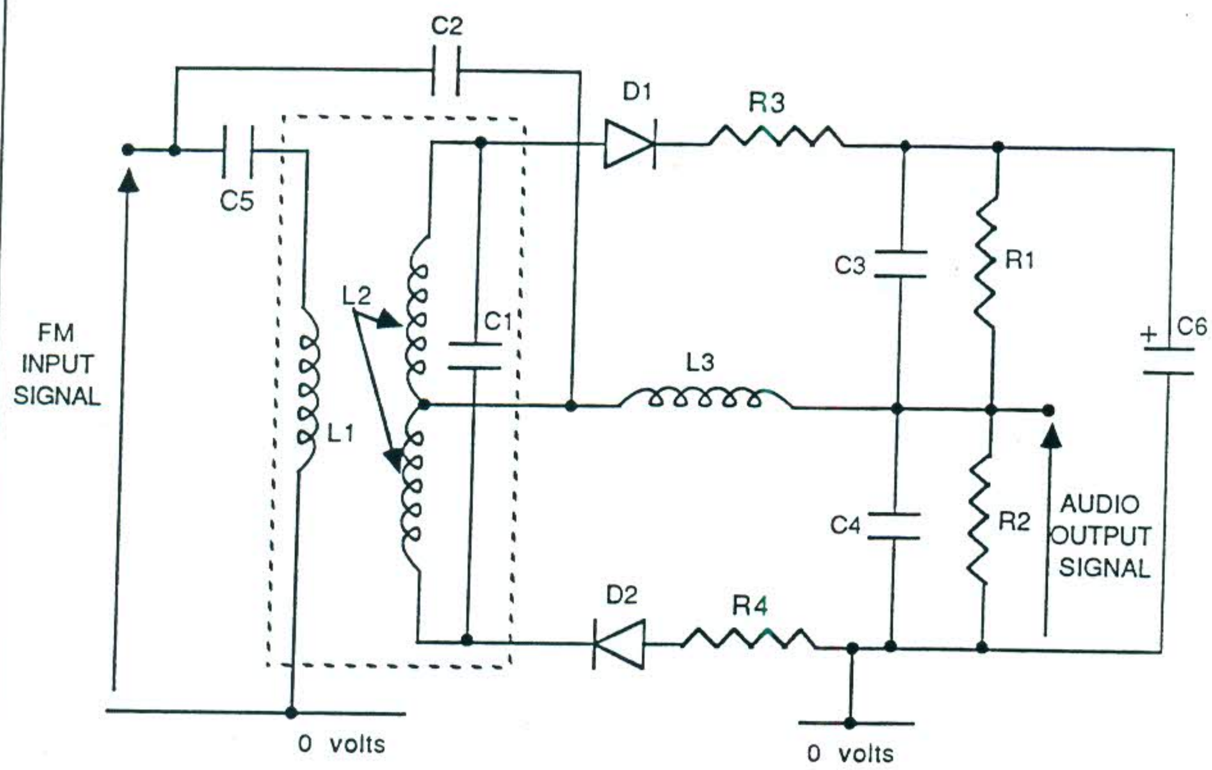


Figure 30

You will notice that the RATIO DETECTOR circuit is very similar to the FOSTER-SEELEY DETECTOR circuit shown in Figure 21 of the previous chapter. In fact, the only things that have changed in the above circuit are:

- Diode D2 has been reversed;
- Resistors R3 and R4 have been added in series with the diodes;
- A large electrolytic capacitor (C6) has been connected across the series combination of R1 and R2;
- The final demodulated audio output is taken from across **one** of the output resistors (R2 in the above diagram), rather than from across both of them.

The operation of the RATIO DETECTOR is similar in many respects to that of the FOSTER-SEELEY DETECTOR. However, the RATIO DETECTOR circuit has the advantage of being less susceptible to amplitude variations in the incoming FM signal.

Since the 'front end' of the RATIO DETECTOR (comprising L1, L2, L3, C1, C2 and C5) is the same as that of the FOSTER-SEELEY DETECTOR, the voltages Vd1 and Vd2 applied to the two diodes are identical to those for the FOSTER-SEELEY DETECTOR, as shown in Figure 31 below.

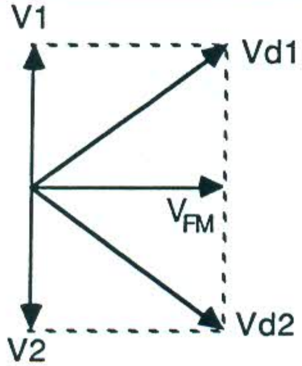


Figure 31

In Figure 31, V1 is the voltage across the top half of L2, V2 is the voltage across the bottom half, and V_{FM} is the original FM signal which appears across L3. For a detailed explanation of how these voltages are produced, refer to that given in the FOSTER-SEELEY DETECTOR experiment.

Note that when the tuned circuit is at resonance, Vd1 and Vd2 are equal. in the case of the FOSTER-SEELEY DETECTOR, this resulted in equal and **opposite** d.c. levels across resistors R1 and R2.

However, since diode D2 has been reversed in the RATIO DETECTOR circuit, the result is equal and **additive** voltages across R1 and R2 in the ratio detector. This results in a d.c. voltage appearing across the series combination of R1 and R2, when the incoming frequency is the resonant frequency of the tuned circuit.

Since C6, a large electrolytic capacitor, is connected across R1 and R2, it will charge up to this d.c. voltage.

As was the case with the FOSTER-SEELEY DETECTOR, if the frequency of the FM signal increases **above** the unmodulated carrier frequency, the vector diagram of V1, V2, Vd1 and Vd2 becomes as shown in Figure 32 (a).

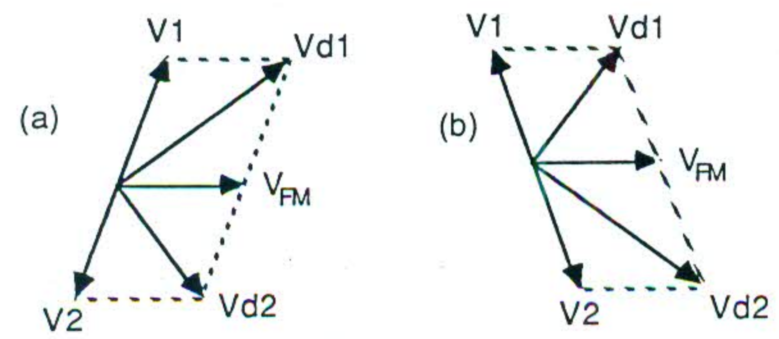


Figure 32

This results in an **increase** in the d.c. voltage across resistor R1, and a **decrease** in the d.c. voltage across R2. However, the **total voltage** across the two resistors is fixed, because the large time constant formed by C6 and (R1+R2) prevents this voltage from changing with the audio modulating signal.

If the frequency of the FM input signal now falls **below** the unmodulated carrier frequency, the vector diagram of V1, V2, Vd1 and Vd2 becomes as shown in Figure 32 (b) above. This results in a **decrease** in the d.c. voltage across resistor R1, and an **increase** in the d.c. voltage across R2. But once again the total voltage across the two resistors remains fixed.

The final demodulated audio output voltage is taken from across R2, and this voltage changes to follow frequency variations in the incoming FM signal.

Since the sum of the voltages across R1 and R2 remains constant, the **ratio** of the voltage R2, when referenced to this constant voltage, changes with the FM signal's frequency. It is this changing volatge ratio which gives the RATIO DETECTOR its name.

Now consider what happens if the **amplitude** of the incoming FM signal suddenly increases. Voltages Vd1 and Vd2 will both try to increase, and these in turn will try to increase the voltages across **both** R1 and R2.

However, since capacitor C6 is large, the overall voltage across R1 and R2 will **not respond** to the fast change in input amplitude. The result is that the demodulated audio output (taken from across R2) is unaffected by fast changes in the amplitude of the incoming FM signal.

Ratio detector circuits can sometimes become 'overstabilized', so that if the incoming signal suddenly increases in amplitude, the ratio detector's output actually **drops** momentarily. This problem is overcome by connecting **compensation resistors** (R3 and R4 in Figure 30) between the diodes and capacitor C6.

5. We will now investigate the operation of the RATIO DETECTOR on the ANACOM 2 module.

   In the FOSTER-SEELEY/RATIO DETECTOR block, select the Ratio detector by putting the switch in the RATIO position. This configures the circuit to be as shown in Figure 30 above.

   Set up a signal generator to have a sinusoidal output of amplitude 1 volt pk/pk and frequency approximately 400kHz, then connect it to the INPUT socket of the FOSTER-SEELEY/RATIO DETECTOR block.

   Monitor the block's RATIO OUTPUT at t.p.53, together with its input at t.p.47 (trigger the oscilloscope from this signal).

   Vary the frequency of the signal generator's output from about 400kHz to about 500kHz, and note how the d.c. voltage at t.p.53 changes with increasing frequency.

6. If you have access to a frequency meter, record the d.c. voltage at t.p.53 for incoming frequencies from 430kHz to 480kHz, in 5kHz steps.

   Note: Each time the incoming frequency is changed, it may be necessary to wait a few seconds for the output voltage to stabilize, before measuring the detector's output voltage. This gives the voltage across the large output capacitor (C6 in Figure 30) a chance to settle before each reading is taken.

   Plot the d.c. voltage at t.p.53 against frequency. The response should be similar to that shown in Figure 33:

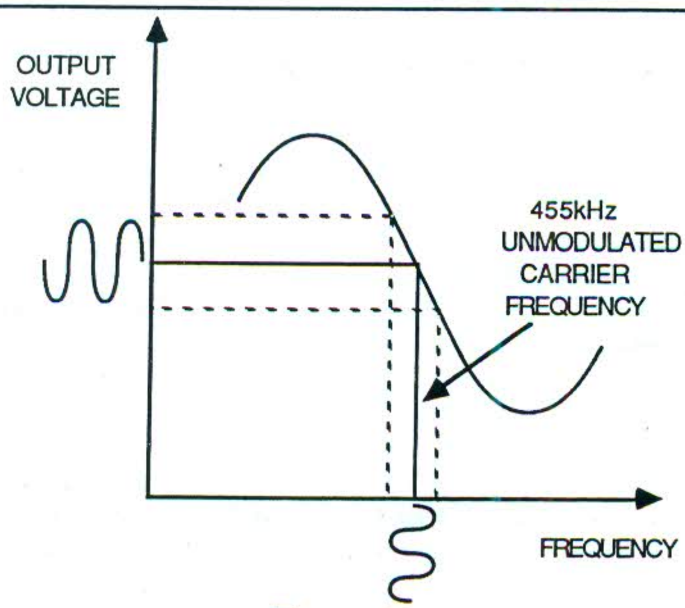


Figure 33

Note that, unlike the S-curve for the FOSTER-SEELEY DETECTOR, the linear region slopes downward from left to right, i.e. the output voltage in this region **decreases** with increasing frequency.

The 455kHz unmodulated carrier frequency (used by ANACOM 2's frequency modulators) should occur at , or close to, the center of the linear part of the response curve, as shown above. If it does not, it may be that transformer T6 in the FOSTER-SEELEY / RATIO DETECTOR block needs adjusting. To do this, follow the instructions given in Chapter 9, entitled 'Adjustment of ANACOM 2's Tuned Circuits'

It is the linear part of the response curve that is used for frequency demodulation, as shown above. Because of the linear voltage/frequency characteristic over this part of the response, little distortion will occur within the Ratio detector, provided that:

- The unmodulated carrier frequency is close to the center of this linear region;
- The frequency deviation of the FM signal is not so great that the incoming frequency goes outside the linear region.

Notice also that, unlike the FOSTER-SEELEY DETECTOR, there is always a positive offset voltage at the output of the RATIO DETECTOR, even when the incoming FM signal is at the unmodulated carrier frequency.

Disconnect the signal generator from the ANACOM 2 module before continuing.

7. Now that we have investigated the output voltage/input frequency characteristic of the RATIO DETECTOR, we will use the detector to demodulate the FM OUTPUT from ANACOM 2's MODULATOR CIRCUITS block.

   To do this, first make the connections shown in Figure 34 at the end of this chapter.

8. Initially, we will use the VARACTOR MODULATOR to generate our FM signal, since this is the more linear of the two modulators, as far as its frequency/voltage characteristic is concerned.

   To select the VARACTOR MODULATOR, put the REACTANCE/VARACTOR switch in the VARACTOR position.

   Ensure that the VARACTOR MODULATOR's CARRIER FREQUENCY preset is in the midway position (arrowhead pointing towards top of P.C.B.) before continuing.

9. The AUDIO OSCILLATOR's output signal (which appears at t.p.1) is now being used by the VARACTOR MODULATOR, to frequency-modulate a 455kHz carrier sinewave. As we saw earlier, this FM waveform appears at the FM OUTPUT socket from the MIXER/AMPLIFIER block.

   You may like to examine this FM waveform at t.p.34. However, with the VARACTOR MODULATOR's CARRIER FREQUENCY preset in its present (midway) position, the frequency deviation is quite small. To be able to notice such a small frequency deviation, you will probably need to have an X-expansion control on your oscilloscope.

   If you have such a control, display 20-25 cycles of the waveform on the oscilloscope, and then use the X-expansion control to 'expand up' the rightmost cycles of the display. There should be a slight ambiguity in the positions of these cycles, indicating that the sinewave at t.p.34 is being frequency-modulated.

10. Now monitor the audio input signal to the VARACTOR MODULATOR block (at t.p.14), together with the RATIO OUTPUT from the FOSTER-SEELEY/RATIO DETECTOR block (at t.p.53), triggering the oscilloscope on t.p.14.

    The signal at t.p.53 should contain two main components:

    - A positive d.c.offset voltage;
    - A sinewave at the same frequency as the audio signal at t.p.14, but shifted in phase by 180°.

    Note that the amount of high-frequency ripple present on the signal is very small - this is due to the smoothing effect of the large output capacitor (C6 in Figuro 30).

11. The LOW-PASS FILTER / AMPLIFIER block removes the d.c. offset voltage at the detector's output, and strongly attenuates any residual high-frequency ripple that may be present.

    Consequently, the signal at the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73) should very closely resemble the original audio modulating signal.

    Monitor the input (t.p.69) and output (t.p.73) of the LOW PASS FILTER / AMPLIFIER block (triggering on t.p.73), and note how the two signals differ.

12. Monitor the audio input to the VARACTOR MODULATOR (at t.p.14) and the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73), and adjust the GAIN preset (in the LOW PASS FILTER / AMPLIFIER block) until the amplitudes of the monitored audio waveforms are the same.

13. Adjust the AUDIO OSCILLATOR block's AMPLITUDE and FREQUENCY presets, and compare the original audio signal with the final demodulated signal.

You may notice that the demodulated output suffers attenuation as the audio modulating frequency is increased. This is mainly due to the low pass filter in the LOW PASS FILTER / AMPLIFIER block, which has a break frequency of 3.4kHz.

In spite of this high-frequency limitation to the range of audio frequencies which can be received, the bandwidth of the system is perfectly adequate for normal speech communication.

In the AUDIO OSCILLATOR block, put the AMPLITUDE preset in its MAX position, and the FREQUENCY preset in its MIN position, before continuing.

14. We will now investigate the effect of noise on the system.

    Adjust the signal generator for a sinusoidal output of amplitude 100mV pk/pk, and frequency 2kHz; this will be our 'noise' input.

    Connect the output of the signal generator to the NOISE INPUT socket in ANACOM 2's MODULATOR CIRCUITS block. Then, monitor the NOISE INPUT (at t.p.5) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on t.p.5.

    Note that the FM signal is now being **amplitude-modulated** by the 'noise' input, in addition to being **frequency-modulated** by the audio input from the AUDIO OSCILLATOR block.

    The amplitude modulations simulate the effect that transmission path noise would have on the amplitude of the FM waveform reaching the receiver. This allows us to investigate the effect that transmission path noise would have on the final demodulated audio signal.

15. Monitor the audio modulating signal (at t.p.14), and the output of the LOW PASS FILTER / AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.14.

    You may be able to notice an additional component at t.p.73 - a small amount of 'ripple' at the frequency of the 'noise' input.

16. Remove the oscilloscope probe from t.p.73, and place it on t.p.53, the RATIO OUTPUT from the FOSTER-SEELEY/RATIO DETECTOR block. Note that the 'noise' component is equally visible at this output.

17. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its MIN position, so that no frequency modulation takes place. Then monitor the 'noise' input (at t.p.5), and the output from the LOW PASS FILTER/AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.5.

    The signal at t.p.73 is now purely composed of the 'noise' output resulting from amplitude variations occuring at the input to the RATIO DETECTOR.

Measure and record the peak-to-peak amplitude of the 'noise' output at t.p.73; this measurement will be valuable in allowing us to compare the RATIO DETECTOR with other types of FM detector, as far as susceptibility to amplitude modulations is concerned.

Compare your measurement with those recorded for the previous experiments. Note especially the improvement in the rejection of amplitude variations which is offered by the Ratio Detector, compared with the Foster-Seeley Detector.

Note: The measured output amplitude due to the 'noise' input should be substantially less for the Ratio detector than for the Foster-Seeley detector - an improvement by a factor of about 5 can be expected. If this is not the case, it is likely that the center frequency of the incoming FM signal is not the same as the resonant frequency of the ratio detector's tuned circuit. To overcome this problem, adjust the following transformers in accordance with the instructions given in Chapter 9 ('Adjustment of ANACOM 2's Tuned Circuits'):

- Transfomer T2 in the VARACTOR MODULATOR block;
- Transfomer T6 in the FOSTER-SEELEY/RATIO DETECTOR block.

18. To reduce the effect of amplitude variations even further, we can connect an AMPLITUDE LIMITER block between the FM OUTPUT and the input to the RATIO DETECTOR.

    The AMPLITUDE LIMITER **removes amplitude variations** from the FM output signal, so that the input signal to the RATIO DETECTOR has constant amplitude.

    Reconnect the AMPLITUDE LIMITER block between the MIXER/AMPLIFIER block and the FOSTER-SEELEY/RATIO DETECTOR block, as shown in Figure 35 at the end of this chapter.

19. Monitor the AMPLITUDE LIMITER's output at t.p.68, triggering the oscilloscope from t.p.5, the 'noise' input from the signal generator. Note that the amplitude modulations due to the 'noise' input have been removed.

    Remove the oscilloscope probe from t.p.68, and put it on t.p.73, the output from the LOW PASS FILTER/AMPLIFIER block. Note that the effect of amplitude variations on the signal at t.p.73 is now negligible.

20. Return the AUDIO OSCILLATOR block's AMPLITUDE preset to its MAX position, and monitor t.p.73, triggering the oscilloscope on the audio modulating input at t.p.14.

    Note that amplitude variations in the FM waveform now have no effect on the final audio output.

This shows how an amplitude limiter can remove the effect of amplitude variations caused by noise, in a practical FM receiver. This is why, in spite of the fact that the ratio detector can be made to be relatively insensitive to amplitude variations, it is quite common to precede this type of detector with an amplitude limiter.

21. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7) and AUDIO OUTPUT MODULE (L.J. Order Code CT8), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

    If you have these modules, make the following connections:

    - Output of AUDIO INPUT MODULE to AUDIO INPUT socket in ANACOM 2's MODULATOR CIRCUITS block;
    - Output of ANACOM 2's LOW PASS FILTER / AMPLIFIER block to INPUT socket of AUDIO OUTPUT MODULE.

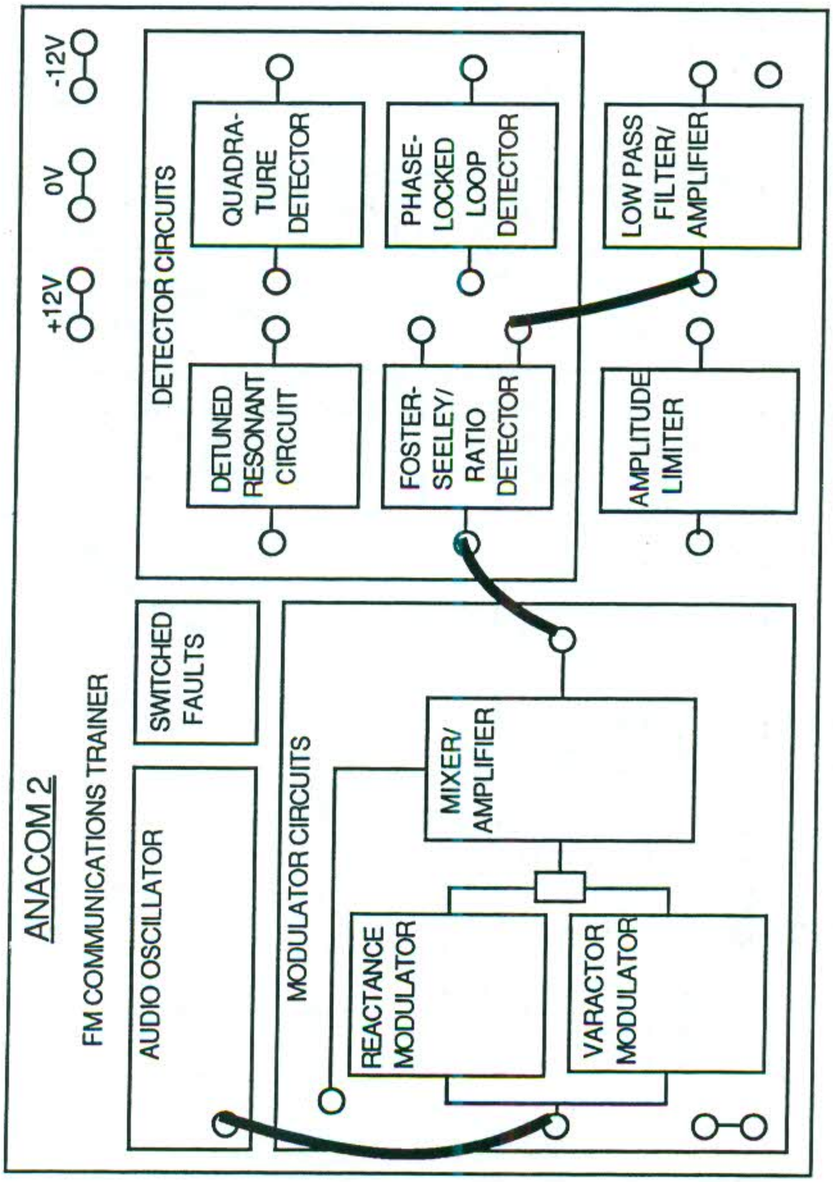
    Consult the user manuals for the AUDIO INPUT MODULE and AUDIO OUTPUT MODULE, for further details of how to use them.

22. Throughout this experiment, frequency modulation has been performed by ANACOM 2's VARACTOR MODULATOR block.

    Equally, frequency modulation may be performed by using the REACTANCE MODULATOR block. If you wish to repeat any of the above experimentation with the REACTANCE MODULATOR, simply put the REACTANCE / VARACTOR switch in the REACTANCE position.

    Note, however, that the linearity of the Reactance Modulator is not as good as that of the Varactor Modulator. This means that, when the Reactance Modulator is used, some distortion of the demodulated audio signal may be noticeable at the detector's output, if the amplitude of the audio modulating signal is too large.

23. Finally, make sure that you fully understand the working of the RATIO DETECTOR, by examining the circuit diagram for the detector at the end of this manual, and monitoring test points within the circuit.



+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
ANACOM 2
FM COMMUNICATIONS TRAINER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 34

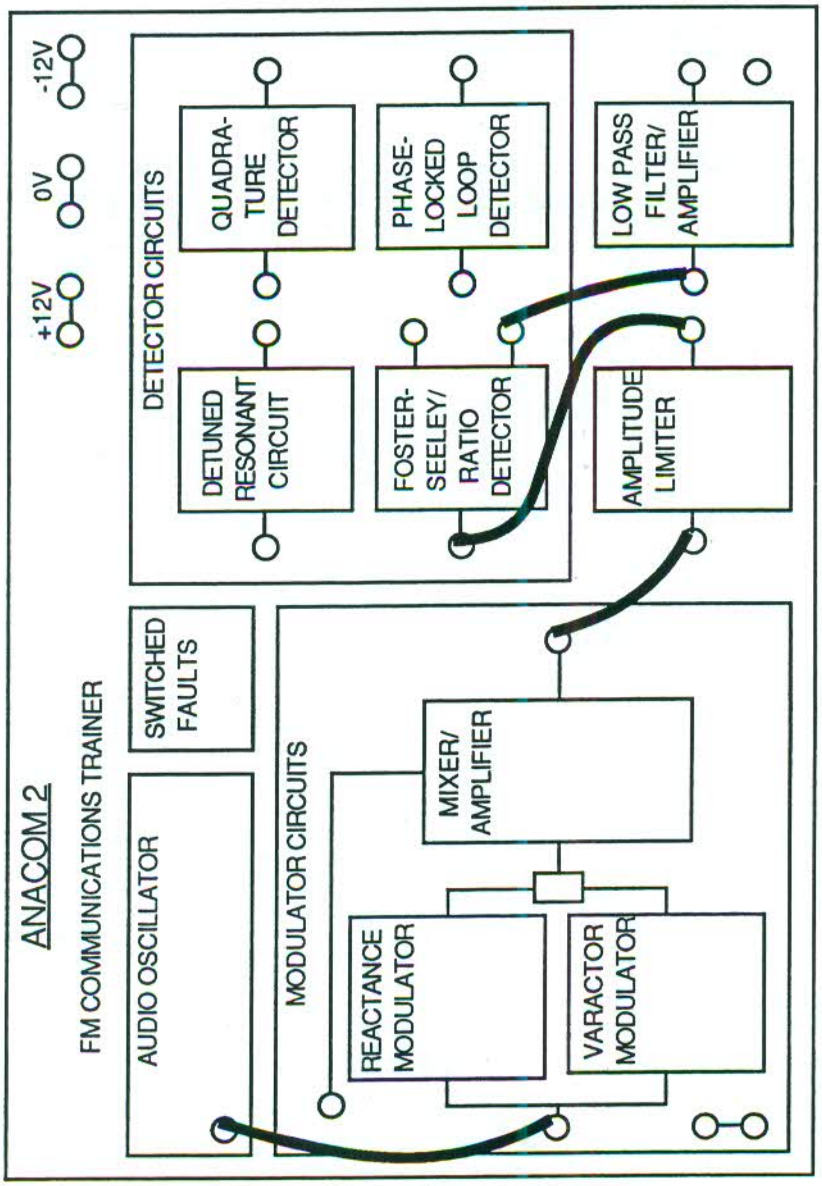

ANACOM 2
FM COMMUNICATIONS TRAINER
+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 35

PHASE-LOCKED LOOP DETECTOR

This experiment investigates how frequency demodulation is performed by the PHASE-LOCKED LOOP DETECTOR block on the ANACOM 2 module.

The operation of this detector circuit will be described in detail, and its sensitivity to noise on the incoming FM signal will be investigated.

The on-board AMPLITUDE LIMITER will then be used to remove any amplitude modulations due to noise, **before** they reach the detector. This allows the student to draw conclusions as to whether it is necessary to precede this type of detector with an amplitude limiter stage, in a practical FM receiver.

To avoid unnecessary loading of monitored signals, X10 oscilloscope probes should be used throughout this experiment.

EXPERIMENTATION

1. Connect the ANACOM 2 module to the power supply as shown in Figure 36 below:

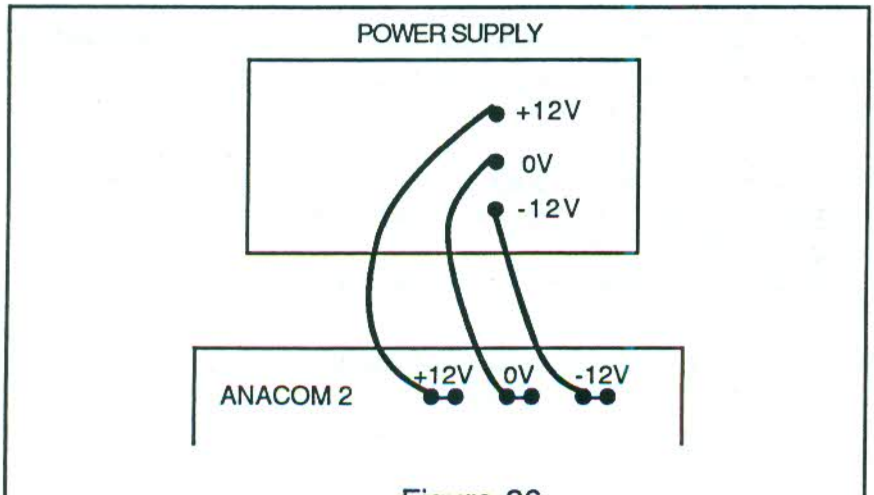


Figure 36

2. Ensure that the following initial conditions exist on the ANACOM 2 module:

   (a) All switched faults OFF;
   (b) AUDIO AMPLIFIER block's AMPLITUDE preset in fully clockwise (MAX) position;
   (c) AUDIO AMPLIFIER block's FREQUENCY preset in fully counter-clockwise (MIN) position;
   (d) AMPLITUDE preset (in the MIXER/AMPLIFIER block) in fully clockwise position;

(e) VCO switch (in PHASE-LOCKED LOOP DETECTOR block) in **ON** position.

3. Turn on power to the ANACOM 2 module.

4. We will now examine how the PHASE-LOCKED LOOP DETECTOR block is used to demodulate a frequency-modulated signal. The block diagram of this circuit is shown below:

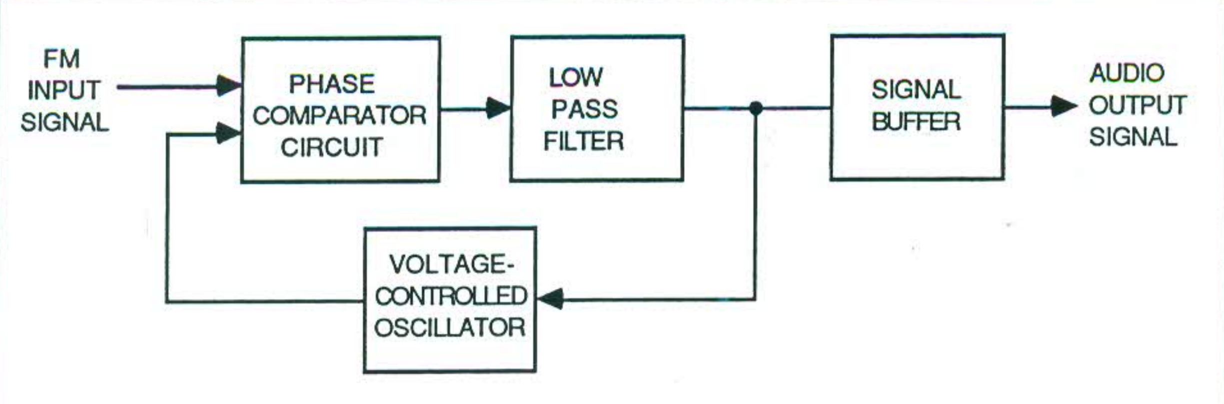


Figure 37

The incoming FM signal is taken to one input of the PHASE COMPARATOR CIRCUIT, where its phase is compared with the square-wave output from the VOLTAGE-CONTROLLED OSCILLATOR (VCO).

This comparison is performed in two stages within the PHASE COMPARATOR block. First, the sinusoidal FM input signal is converted into a square wave, and then it is compared with the VCO's square wave output by means of an Exclusive-OR gate. The output of the Exclusive-OR gate is the final output from the PHASE COMPARATOR , as shown in Figure 38:

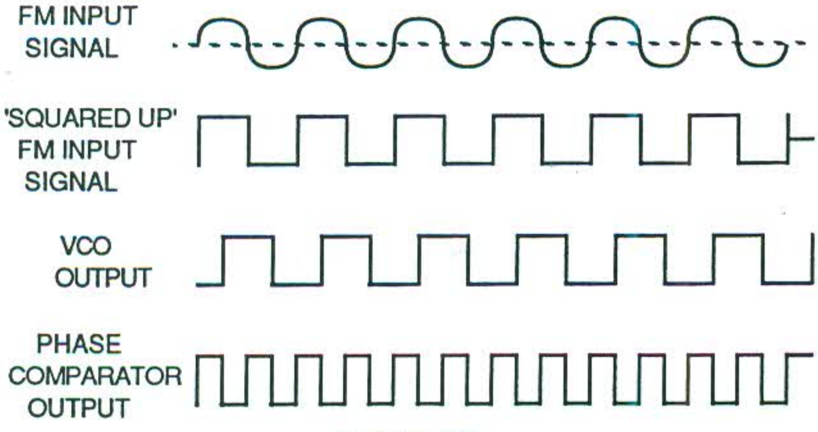


Figure 38

The output signal from the PHASE COMPARATOR is passed on to a low-pass filter, which extracts the **average voltage level** from the phase comparator's output.

The output voltage from the LOW PASS FILTER drives the input of the VCO, where it controls the **frequency** of the VCO's output signal. The higher the VCO's input voltage, the higher the frequency at its output.

The output signal from the VCO is then connected back to PHASE COMPARATOR, to complete the loop.

The overall action of the phase-locked loop is to try to ensure that the VCO's output frequency is always equal to the frequency of the incoming FM signal, and that the VCO lags the FM input signal by a phase angle of 90°.

Once this has been achieved, we say that the VCO output is **phase-locked** to the FM input signal. This situation is illustrated in Figure 38 above.

The phase-locked loop maintains this 'phase-lock' situation in the following way.

If the frequency of the incoming FM signal starts to increase, the phase difference between the two signals will increase above 90°. This will cause the mark:space ratio at the output of the PHASE COMPARATOR will **increase**, increasing the average voltage level at the input to the VCO, and causing the VCO to run **faster**.

Conversely, if the frequency of the incoming FM signal starts to decrease, the phase difference between the two signals will drop below 90°. This will cause the mark:space ratio at the output of the PHASE COMPARATOR will **decrease**, lowering the average voltage level at the input to the VCO, and causing the VCO to run **more slowly**.

This continuous compensation ensures that the VCO's output frequency follows frequency changes in the FM input signal.

Note that the average voltage level at the low pass filter's output will rise and fall as the frequency of the incoming FM signal increases and decreases about the unmodulated carrier frequency. In other words, the signal at the low pass filter's output is the required demodulated audio signal.

This signal is buffered to avoid loading the output of the low pass filter, so that the final demodulated output from the PHASE-LOCKED LOOP DETECTOR appears at the output of the SIGNAL BUFFER (see Figure 37).

5. We will now investigate the operation of the PHASE-LOCKED LOOP DETECTOR block on the ANACOM 2 module.

   Set up a signal generator to have a sinusoidal output of amplitude 1 volt pk/pk and frequency 455kHz, then connect it to the INPUT socket of the PHASE-LOCKED LOOP DETECTOR block.

6. Monitor the PHASE-LOCKED LOOP DETECTOR block's output at t.p.60, together with its input at t.p.54 (trigger the oscilloscope from this signal).

   Vary the PHASE-LOCKED LOOP DETECTOR block's FREQUENCY ADJUST preset throughout its adjustment range, noting that:

   - In the middle of the adjustment range, the signal at t.p.60 is a d.c. level with a small amount of high-frequency ripple superimposed on it;
   - At the extremes of the adjustment range, the average level of the signal at t.p.60 is no longer constant.

   Then trim the FREQUENCY ADJUST preset until the signal at t.p.60 is d.c. level of +6 volts.

   The VCO's center frequency is now set up to be 455kHz.

7. Now vary the frequency of the signal generator's output signal either side of 455kHz, noting that:

   - for a small range of frequencies around 455kHz, the average d.c. level at t.p.60 increases with increasing frequency. It is over this frequency range that FM demodulation takes place.
   - both above and below this frequency range, the average level of this signal is no longer constant. The signal generator's frequency is now outside the range of frequencies which the VCO can produce, so that the VCO can no longer match the incoming signal frequency. Consequently, phase lock is lost.

8. If you have access to a frequency meter, record the average d.c. level at t.p.60, for different signal generator frequencies, over the frequency range for which this level is constant.

   Plot the d.c. voltage at t.p.60 against frequency. The response should be similar to that shown in Figure 39:

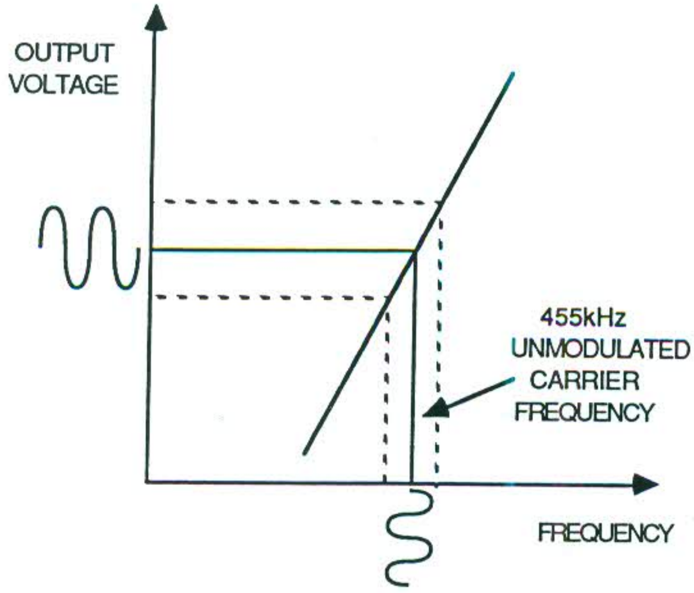


Figure 39

Your graph of output voltage vs. input frequency should be a straight line, indicating that the PHASE-LOCKED LOOP DETECTOR is a highly linear frequency demodulator. This means that the PHASE-LOCKED LOOP DETECTOR will demodulate an FM signal with negligible distortion of the audio output waveform.

The demodulation of an FM signal, which has been modulated by a sinewave, is shown in Figure 39 above.

Disconnect the signal generator from the ANACOM 2 module before continuing.

9. Now that we have investigated the output voltage/input frequency characteristic of the PHASE-LOCKED LOOP DETECTOR, we will use the detector to demodulate the FM OUTPUT from ANACOM 2's MODULATOR CIRCUITS block.

   To do this, first make the connections shown in Figure 40 at the end of this chapter.

10. Initially, we will use the VARACTOR MODULATOR to generate our FM signal, since this is the more linear of the two modulators, as far as its frequency/voltage characteristic is concerned.

    To select the VARACTOR MODULATOR, put the REACTANCE/VARACTOR switch in the VARACTOR position.

    Ensure that the VARACTOR MODULATOR's CARRIER FREQUENCY preset is in the midway position (arrowhead pointing towards top of P.C.B.) before continuing.

11. The AUDIO OSCILLATOR's output signal (which appears at t.p.1) is now being used by the VARACTOR MODULATOR, to frequency-modulate a 455kHz carrier sinewave. As we saw earlier, this FM waveform appears at the FM OUTPUT socket from the MIXER/AMPLIFIER block.

    You may like to examine this FM waveform at t.p.34. However, with the VARACTOR MODULATOR's CARRIER FREQUENCY preset in its present (midway) position, the frequency deviation is quite small. To be able to notice such a small frequency deviation, you will probably need to have an X-expansion control on your oscilloscope.

    If you have such a control, display 20-25 cycles of the waveform on the oscilloscope, and then use the X-expansion control to 'expand up' the rightmost cycles of the display. There should be a slight ambiguity in the positions of these cycles, indicating that the sinewave at t.p.34 is being frequency-modulated.

12. Now monitor the audio input signal to the VARACTOR MODULATOR block (at t.p.14), together with the output from the PHASE-LOCKED LOOP DETECTOR block (at t.p.60), triggering the oscilloscope on t.p.14.

    The signal at t.p.60 should contain three components:

    - A positive d.c. offset voltage;
    - A sinewave at the same frequency as the audio signal at t.p.14;
    - A high-frequency ripple component.

13. You will note that the amplitude of the high-frequency ripple component at t.p.60 is actually higher than that of the required sinewave component. This indicates that the simple, passive low pass filter circuit within the detector (as shown in Figure 37) is not sufficient to remove this unwanted high-frequency component from the required audio component.

    We use the LOW PASS FILTER / AMPLIFIER block to overcome this problem.

    The LOW-PASS FILTER / AMPLIFIER block strongly attenuates the high-frequency ripple component at the detector's output, and also blocks the d.c. offset voltage. Consequently, the signal at the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73) should very closely resemble the original audio modulating signal.

    Monitor the input (t.p.69) and output (t.p.73) of the LOW PASS FILTER / AMPLIFIER block (triggering on t.p.73), and note how the quality of the detector's output signal has been improved by further low-pass filtering. Note also that the d.c. offset has been removed.

14. Monitor the audio input to the VARACTOR MODULATOR (at t.p.14) and the output of the LOW-PASS FILTER / AMPLIFIER block (at t.p.73), and adjust the GAIN preset (in the LOW PASS FILTER / AMPLIFIER block) until the amplitudes of the monitored audio waveforms are the same.

15. Adjust the AUDIO OSCILLATOR block's AMPLITUDE and FREQUENCY presets, and compare the original audio signal with the final demodulated signal.

    You may notice that the demodulated output suffers attenuation as the audio modulating frequency is increased. This is caused by the low pass filter in the LOW PASS FILTER / AMPLIFIER block, which has a break frequency of 3.4kHz.

    In spite of this high-frequency limitation to the range of audio frequencies which can be received, the bandwidth of the system is perfectly adequate for normal speech communication.

    In the AUDIO OSCILLATOR block, put the AMPLITUDE preset in its MAX position, and the FREQUENCY preset in its MIN position, before continuing.

16. We will now investigate the effect of noise on the system.

    Adjust the signal generator for a sinusoidal output of amplitude 100mV pk/pk, and frequency 2kHz; this will be our 'noise' input.

    Connect the output of the signal generator to the NOISE INPUT socket in ANACOM 2's MODULATOR CIRCUITS block. Then, monitor the NOISE INPUT (at t.p.5) and the FM OUTPUT (at t.p.34), triggering the oscilloscope on t.p.5.

    Note that the FM signal is now being **amplitude-modulated** by the 'noise' input, in addition to being **frequency-modulated** by the audio input from the AUDIO OSCILLATOR block.

    The amplitude modulations simulate the effect that transmission path noise would have on the amplitude of the FM waveform reaching the receiver. This allows us to investigate the effect that transmission path noise would have on the final demodulated audio signal.

17. Monitor the audio modulating signal (at t.p.14), and the output of the LOW PASS FILTER / AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.14.

    You may be able to detect a very small amount of 'ripple' at t.p.73, at the frequency of the 'noise' input. This is because the PHASE-LOCKED LOOP DETECTOR cannot perfectly reject amplitude variations in the transmitted FM signal.

Nevertheless, the PHASE-LOCKED LOOP DETECTOR is very good at ignoring amplitude variations in the FM signal, which is why the effect of the 'noise' input is much less than for most of the other FM demodulators we have examined. In fact, for many applications the noise rejection offered by the PHASE-LOCKED LOOP DETECTOR is quite acceptable.

18. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its MIN position, so that no frequency modulation takes place. Then monitor the 'noise' input (at t.p.5), and the output from the LOW PASS FILTER/AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.5.

    The signal at t.p.73 is now purely composed of the 'noise' output resulting from amplitude variations occuring at the input to the PHASE-LOCKED LOOP DETECTOR.

    Measure and record the peak-to-peak amplitude of the 'noise' output at t.p.73; this measurement will allow you to compare the PHASE-LOCKED LOOP DETECTOR with other types of FM detector, as far as susceptibility to amplitude variations is concerned.

    Compare your measurement with that recorded for the previous experiments - this will confirm that the PHASE-LOCKED LOOP DETECTOR is superior to most of the demodulators used previously, when it comes to noise rejection.

19. If you wish, you can try to reduce the effect of amplitude variations even further, by connecting an AMPLITUDE LIMITER block between the FM OUTPUT and the input to the PHASE-LOCKED LOOP DETECTOR.

    The AMPLITUDE LIMITER removes amplitude variations from the FM output signal, so that the input signal to the PHASE-LOCKED LOOP DETECTOR has constant amplitude.

    To use the AMPLITUDE LIMITER, reconnect the AMPLITUDE LIMITER block between the MIXER/AMPLIFIER block and the PHASE-LOCKED LOOP DETECTOR block, as shown in Figure 41 at the end of this chapter.

    Once again monitor the LOW PASS FILTER / AMPLIFIER's output at t.p.73, triggering the oscilloscope from t.p.5, the 'noise' input from the signal generator.

    Has the use of the AMPLITUDE LIMITER block improved the rejection of noise?

20. Return the AUDIO OSCILLATOR block's AMPLITUDE preset to its MAX position, and monitor t.p.73, triggering the oscilloscope on the audio modulating input at t.p.14.

    The final audio output should no longer be affected by amplitude variations.

Nevertheless, the PHASE-LOCKED LOOP DETECTOR is very good at ignoring amplitude variations in the FM signal, which is why the effect of the 'noise' input is much less than for most of the other FM demodulators we have examined. In fact, for many applications the noise rejection offered by the PHASE-LOCKED LOOP DETECTOR is quite acceptable.

18. Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its MIN position, so that no frequency modulation takes place. Then monitor the 'noise' input (at t.p.5), and the output from the LOW PASS FILTER/AMPLIFIER block (at t.p.73), triggering the oscilloscope from t.p.5.

    The signal at t.p.73 is now purely composed of the 'noise' output resulting from amplitude variations occuring at the input to the PHASE-LOCKED LOOP DETECTOR.

    Measure and record the peak-to-peak amplitude of the 'noise' output at t.p.73; this measurement will allow you to compare the PHASE-LOCKED LOOP DETECTOR with other types of FM detector, as far as susceptibility to amplitude variations is concerned.

    Compare your measurement with that recorded for the previous experiments - this will confirm that the PHASE-LOCKED LOOP DETECTOR is superior to most of the demodulators used previously, when it comes to noise rejection.

19. If you wish, you can try to reduce the effect of amplitude variations even further, by connecting an AMPLITUDE LIMITER block between the FM OUTPUT and the input to the PHASE-LOCKED LOOP DETECTOR.

    The AMPLITUDE LIMITER removes amplitude variations from the FM output signal, so that the input signal to the PHASE-LOCKED LOOP DETECTOR has constant amplitude.

    To use the AMPLITUDE LIMITER, reconnect the AMPLITUDE LIMITER block between the MIXER/AMPLIFIER block and the PHASE-LOCKED LOOP DETECTOR block, as shown in Figure 41 at the end of this chapter.

    Once again monitor the LOW PASS FILTER / AMPLIFIER's output at t.p.73, triggering the oscilloscope from t.p.5, the 'noise' input from the signal generator.

    Has the use of the AMPLITUDE LIMITER block improved the rejection of noise?

20. Return the AUDIO OSCILLATOR block's AMPLITUDE preset to its MAX position, and monitor t.p.73, triggering the oscilloscope on the audio modulating input at t.p.14.

    The final audio output should no longer be affected by amplitude variations.

This shows how an amplitude limiter can help to minimize the effect of amplitude variations caused by noise, in a practical FM receiver. However, since the PHASE-LOCKED LOOP DETECTOR is so good at rejecting amplitude variations anyway, an amplitude limiter may well prove unnecessary in many receiver applications.

21. By using the optional AUDIO INPUT MODULE (L.J. Order Code CT7) and AUDIO OUTPUT MODULE (L.J. Order Code CT8), the human voice can be used as the audio modulating signal, instead of using ANACOM 2's AUDIO OSCILLATOR block.

    If you have these modules, make the following connections:

    - Output of AUDIO INPUT MODULE to AUDIO INPUT socket in ANACOM 2's MODULATOR CIRCUITS block;

    - Output of ANACOM 2's LOW PASS FILTER / AMPLIFIER block to INPUT socket of AUDIO OUTPUT MODULE.

    Consult the user manuals for the AUDIO INPUT MODULE and AUDIO OUTPUT MODULE, for further details of how to use them.

22. Throughout this experiment, frequency modulation has been performed by ANACOM 2's VARACTOR MODULATOR block.

    Equally, frequency modulation may be performed by using the REACTANCE MODULATOR block. If you wish to repeat any of the above experimentation with the REACTANCE MODULATOR, simply put the REACTANCE / VARACTOR switch in the REACTANCE position.

    Note, however, that the linearity of the Reactance Modulator is not as good as that of the Varactor Modulator. This means that, when the Reactance Modulator is used, some distortion of the demodulated audio signal may be noticeable at the detector's output, if the amplitude of the audio modulating signal is too large.

23. Finally, make sure that you fully understand the working of the PHASE-LOCKED LOOP DETECTOR, by examining the circuit diagram for the detector at the end of this manual, and monitoring test points within the circuit.

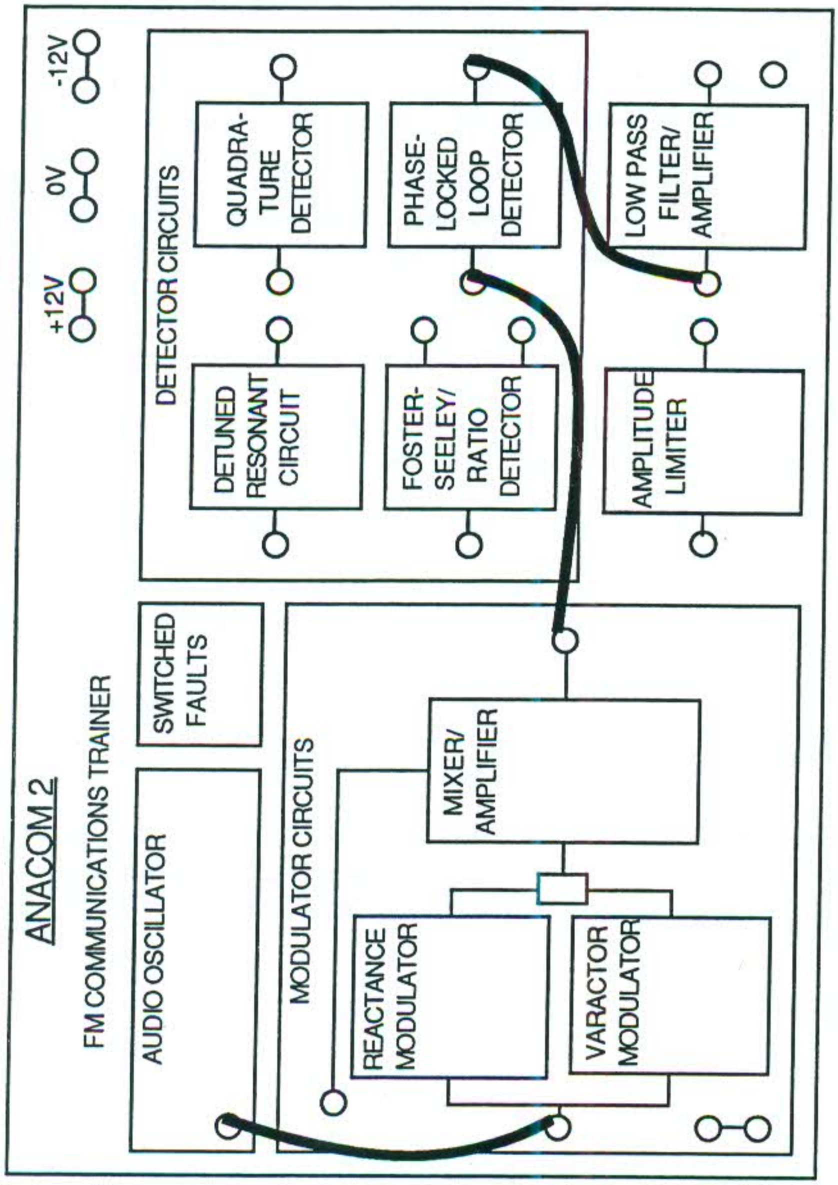

+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
ANACOM 2
FM COMMUNICATIONS TRAINER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 40

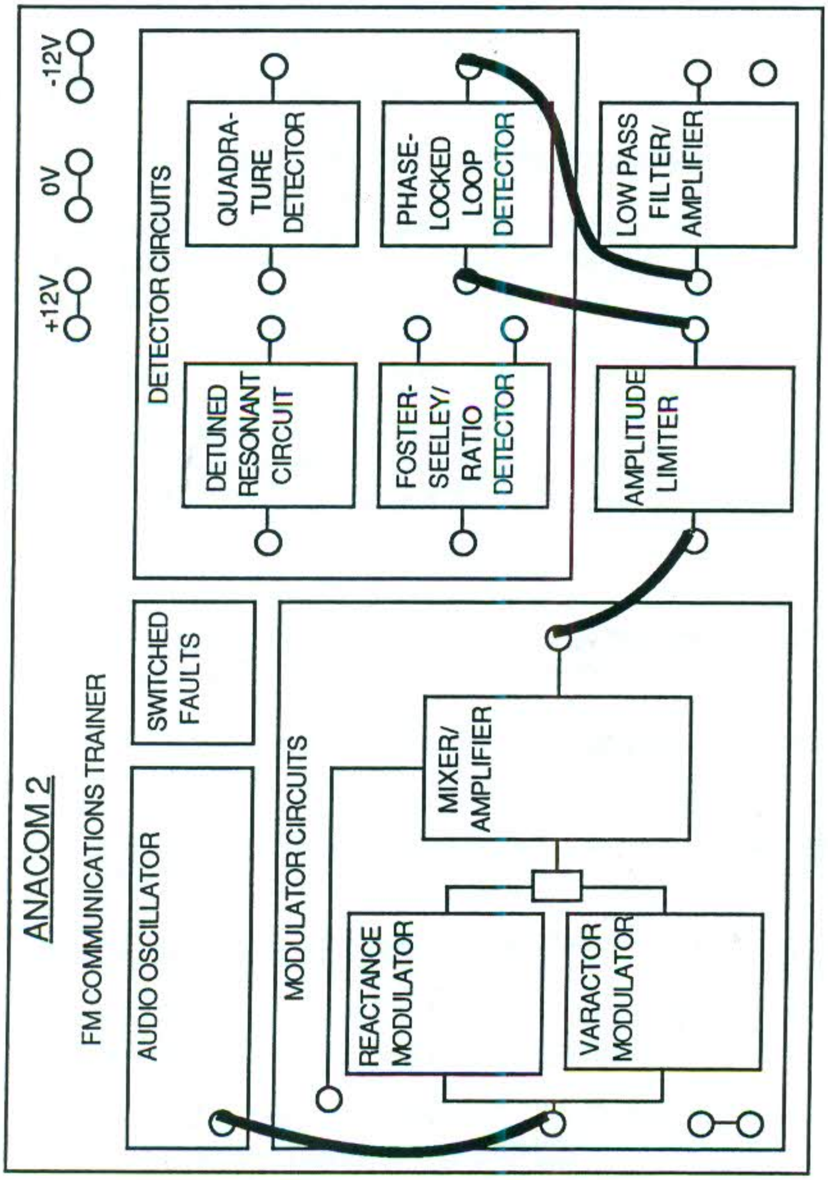

ANACOM 2
FM COMMUNICATIONS TRAINER
+12V
0V
-12V
DETECTOR CIRCUITS
QUADRA-
TURE
DETECTOR
PHASE-
LOCKED
LOOP
DETECTOR
LOW PASS
FILTER/
AMPLIFIER
DETUNED
RESONANT
CIRCUIT
FOSTER-
SEELEY/
RATIO
DETECTOR
AMPLITUDE
LIMITER
SWITCHED
FAULTS
AUDIO OSCILLATOR
MODULATOR CIRCUITS
MIXER/
AMPLIFIER
REACTANCE
MODULATOR
VARACTOR
MODULATOR

Figure 41

Adjustment of ANACOM 2's Tuned Circuits

This chapter describes how to adjust ANACOM 2's tuned circuits for correct operation.

Where signals are to be monitored with an oscilloscope, the 'scope's input channels should be a.c.-coupled, unless otherwise indicated. Ensure that X10 oscilloscope probes are used throughout.

A frequency counter should be used for all frequency measurements.

Use the trimming tool, supplied with the ANACOM 2 module, for trimming inductors. **Never** use a screwdriver, as this may damage the inductor's core. Also, take care not to turn any inductor's core past its end stop, as this may also result in damage.

REACTANCE MODULATOR Tuned Circuit (Transformer T1)

Put the REACTANCE/VARACTOR switch in the REACTANCE position, then turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position.

Turn the REACTANCE MODULATOR block's CARRIER FREQUENCY preset to its **midway** position (arrowhead pointing towards top of PCB).

Monitor t.p.34 in the MODULATOR CIRCUITS block, and adjust Transformer T1 until the frequency of the monitored sinewave is 455kHz (±0.5kHz).

VARACTOR MODULATOR Tuned Circuit (Transformer T2)

Put the REACTANCE/VARACTOR switch in the VARACTOR position, then turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position.

Turn the VARACTOR MODULATOR block's CARRIER FREQUENCY preset to its **midway** position (arrowhead pointing towards top of PCB).

Monitor t.p.34 in the MODULATOR CIRCUITS block, and adjust Transformer T2 until the frequency of the monitored sinewave is 455kHz (±0.5kHz).

MIXER / AMPLIFIER Tuned Circuit (Transformer T3)

Turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position, and monitor the FM OUTPUT signal at t.p.34.

Note the position of the REACTANCE/VARACTOR switch, and adjust the selected modulator's CARRIER FREQUENCY preset until the monitored sinewave's frequency is 455kHz (±0.5kHz).

Finally, adjust transformer T3 until the amplitude of the monitored sinewave is a maximum.

AMPLITUDE LIMITER Tuned Circuit (Transformer T7)

Turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position, and monitor the FM OUTPUT signal at t.p.34.

Note the position of the REACTANCE/VARACTOR switch, and adjust the selected modulator's CARRIER FREQUENCY preset until the monitored sinewave's frequency is 455kHz (±0.5kHz).

Link the FM OUTPUT from the MIXER/AMPLIFIER block to the INPUT socket of the AMPLITUDE LIMITER block.

Monitor the output from the AMPLITUDE LIMITER block (at t.p.68), and adjust Transformer T7 until the monitored sinewave has maximum amplitude.

Finally, remove the MIXER/AMPLIFIER-to-AMPLITUDE LIMITER connection.

DETUNED RESONANT CIRCUIT Tuned Circuit (Transformer T4)

Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its fully **clockwise** position.

Turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position, and monitor the FM OUTPUT signal at t.p.34.

Note the position of the REACTANCE/VARACTOR switch, and adjust the selected modulator's CARRIER FREQUENCY preset until the monitored sinewave's frequency is 455kHz (±0.5kHz).

Make the following connections:

- OUTPUT of AUDIO OSCILLATOR block to AUDIO INPUT of MODULATOR CIRCUITS block;
- FM OUTPUT of MIXER/AMPLIFIER block to INPUT of DETUNED RESONANT CIRCUIT block.

Monitor the output of the DETUNED RESONANT CIRCUIT block (at t.p.40), together with the audio signal at t.p.1, triggering the 'scope from t.p.1.

Trim Transformer T4 until the d.c. level at t.p.40 is at its most positive, and the amplitude of the audio-frequency component is minimized.

Then turn transformer T4 slowly **counter-clockwise** from its present core position, until a position is found where the a.c. signal at t.p.40 is an audio-frequency sinewave, and has **maximum amplitude**.

Finally, remove both connections.

QUADRATURE DETECTOR Tuned Circuit (Transformer T5)

Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its fully **clockwise** position.

Turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position, and monitor the FM OUTPUT signal at t.p.34.

Note the position of the REACTANCE/VARACTOR switch, and adjust the selected modulator's CARRIER FREQUENCY preset until the monitored sinewave's frequency is 455kHz (±0.5kHz).

Make the following connections:

- OUTPUT of AUDIO OSCILLATOR block to AUDIO INPUT of MODULATOR CIRCUITS block;
- FM OUTPUT of MIXER/AMPLIFIER block to INPUT of QUADRATURE DETECTOR block.

Monitor the output of the QUADRATURE DETECTOR block (at t.p.46), together with the signal at t.p.1, triggering on t.p.1.

Trim transformer T5 so that the audio-frequency sinewave at t.p.46 has maximum amplitude.

Finally, remove both connections.

FOSTER-SEELEY/RATIO DETECTOR Tuned Circuit (Transformer T6)

Turn the AUDIO OSCILLATOR block's AMPLITUDE preset to its fully **clockwise** position.

Turn the MIXER/AMPLIFIER block's AMPLITUDE preset to its fully **clockwise** position, and monitor the FM OUTPUT signal at t.p.34.

Note the position of the REACTANCE/VARACTOR switch, and adjust the selected modulator's CARRIER FREQUENCY preset until the monitored sinewave's frequency is 455kHz (±0.5kHz).

Make the following connections:

- OUTPUT of AUDIO OSCILLATOR block to AUDIO INPUT of MODULATOR CIRCUITS block;
- FM OUTPUT of MIXER/AMPLIFIER block to INPUT of FOSTER-SEELEY/RATIO DETECTOR block.

Put the FOSTER-SEELEY/RATIO switch in the FOSTER-SEELEY position.

Monitor the FOSTER-SEELEY OUTPUT (at t.p.52), together with the signal at t.p.1, triggering the oscilloscope on t.p.1.

Trim transformer T6 so that **average** level of the signal at t.p.52 is 0 volts.

Finally, remove both connections.

ANACOM 2 Switched Faults Chapter 10

ANACOM 2 Switched Faults

This chapter lists the switched faults on the ANACOM 2 module.

There are 8 fault switches on the module, and they are hidden behind a locked cover. To remove the cover, use the key provided. Insert it into the socket on the top of the cover, and turn it counter-clockwise.

To replace a fault cover, locate the cover's locking pin in the hole in the support pillar, and turn the key fully clockwise in the cover's socket. To remove the key, turn it counter-clockwise slightly.

The component references given below refer to the circuit diagrams at the end of this manual.

Open-Circuit Faults

1. Open-circuits the 68mH choke from t.p.19 (transistor TR4's collector) in the VARACTOR MODULATOR block, preventing any reverse bias from being applied across the BB221 varactor diode. This causes the VARACTOR MODULATOR's output (at t.p.24) to be an unmodulated sinewave, whose output frequency is fixed at approximately 450kHz, irrespective of the position of the block's CARRIER FREQUENCY preset.

2. Disables the output from the DETUNED RESONANT CIRCUIT (at t.p.39), by disconnecting the grounded end of T4's secondary winding from 0 volts.

3. Disconnects the QUADRATURE DETECTOR's INPUT socket (and t.p.41) from the 10n capacitor (C44) which drives the 'carrier+' input (pin 10) of IC4 (1496). This prevents the non phase-shifted FM signal from reaching the 1496, so that phase comparison with the phase-shifted signal (at t.p.43) cannot take place. The result is a vast reduction in the amplitude of the output signal at t.p.46.

4. Removes the base bias voltages of all three transistors (TR9, 10 & 11) in the AMPLITUDE LIMITER block, by open-circuiting the non-supply end of 56K bias resistor R38. Causes the block's output amplitude (at t.p.68) to drop to 0 volts peak-to-peak.

Short-Circuit Faults

5. Shorts out the 1K feedback resistor between the output (pin 1) and the inverting input (pin 2) of the REACTANCE MODULATOR block's driver op-amp (34084/a - I.C.1). This prevents the REACTANCE MODULATOR's output (at t.p.13) from being frequency-modulated by the signal applied to the AUDIO INPUT socket.

6. Shorts the base of the MIXER/AMPLIFIER's modulating transistor (TR7) to 0 volts. This causes the output amplitude from the MIXER/AMPLIFIER block (at t.p.34) to drop to 0 volts pk/pk, irrespective of the position of the block's AMPLITUDE preset.

7. Shorts t.p.48 in the FOSTER-SEELEY/RATIO DETECTOR block to 0 volts. This prevents any signal from appearing across T6's resonant circuit (between t.p.'s 49 & 51), and disables the outputs from the block for both Foster-Seeley and Ratio modes of operation.

8. Shorts out the PHASE-LOCKED LOOP DETECTOR block's FREQUENCY ADJUST preset (VR7). This increases the free-running frequency of the voltage-controlled oscillator (VCO) to approximately 500kHz, preventing the phase-locked loop from locking onto the incoming 455kHz FM carrier, irrespective of the setting of the FREQUENCY ADJUST preset. Consequently, the block's output (t.p.60) no longer contains a component at the orignal audio modulating signal frequency.