FM DEVIATION MULTIPLICATION

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ACHIEVEMENTS: introduction to the frequency multiplier; wide-band FM spectrum from Armstrong’s modulator; wide-band spectrum measurement.

PREREQUISITES: familiarity with the theory outlined in the Chapter entitled Analysis of the FM spectrum and completion of the experiment entitled Armstrong’s phase modulator, both in this Volume. For Tables of Bessel Coefficients see the Appendix to this Volume.

EXTRA MODULES: 100 kHz CHANNEL FILTERS (V.2); FM UTILITIES; SPECTRUM UTILITIES.

PREPARATION

**the angle modulated signal**

This experiment is about generating a wideband angle modulated signal, based on an Armstrong modulator, and examining its spectrum.

An angle modulated signal is one defined as:

\[ y(t) = E \cos(\omega t + \beta \cos \mu t) \] ........ 1

where the parameter \( \beta \) is the one which varies with the message in accordance with the definition given in the Chapter entitled Analysis of the FM spectrum.

Two examples of an angle modulated signal are those of phase modulation (PM) and frequency modulation (FM).

You will need an understanding of the theory if you are going to relate your measurements to expectations. This is especially so if the measurements are not in complete agreement, since you should be able to explain the discrepancy!

In a following experiment, entitled FM and Bessel zeros, some more insights into the behaviour of the spectrum with changing depths of modulation - deviation - will be examined.
**FM or PM?**

If either a PM or an FM transmitter is modulated by a single tone message, of fixed amplitude and frequency, there is no way an observer, by examining the spectrum, can distinguish which transmitter is being used.

They are both described by eqn.(1) above.

The degree of modulation (the ‘deviation’) is determined by the magnitude of $\beta$.

An expansion of eqn. (1) shows that the number of sidebands, and their amplitudes, are governed completely by the magnitude of $\beta$. Their frequency spacing is determined by the message frequency of $\mu$ rad/s.

- the magnitude of $\beta$ is directly proportional to the message amplitude.
- for a PM signal $\beta$ is equal to the peak phase deviation $\Delta \phi$.
- for an FM signal $\beta$ is equal to $\Delta \phi / \mu$

The difference between the two signals shows itself when the message frequency is changed. Suppose there is an increase of message frequency:

- for a PM transmitter $\beta$ remains fixed. The amplitude of each spectral component remains the same, but their spacing increases. The bandwidth therefor increases in proportion to the message frequency change.
- for an FM transmitter the magnitude of $\beta$ reduces, since it is inversely proportional to the message frequency. The spacing of spectral components increases. Some spectral component amplitudes will increase, some reduce, but the sum of the squares of their amplitudes remains fixed. The bandwidth will *not* increase in proportion to the message frequency change, since a smaller $\beta$ requires less components. To a rough approximation, the bandwidth remains much the same.

In the experiment to follow you will be using a fixed message frequency, so it is immaterial whether it is called an FM or a PM signal. In principle it is going to be a PM transmitter, since there will not be an integrator ($1 / \mu$ characteristic) associated with the message source.

**The need for frequency multipliers**

To achieve the signal-to-noise ratio advantages of which FM is capable it is necessary to use a deviation large enough to ensure that the signal has at least two or more pairs of ‘significant sidebands’.

A frequency multiplier is a device for increasing the deviation. It would have been better to have called it a deviation multiplier. It does indeed multiply the frequency, but this is of secondary importance in this application.

Frequency multipliers are used following PM and FM modulators which are themselves unable, usually because of linearity considerations, to provide sufficient deviation.

They are essential for most applications of Armstrong’s modulator, which was examined in the experiment entitled *Armstrong’s phase modulator* (this Volume). This modulator is restricted to phase deviations of less than one radian before the generated distortion becomes unacceptable.
Frequency multipliers consist of an \textit{amplitude limiter} followed by a \textit{bandpass filter}. They are discussed in the Chapter entitled \textit{Analysis of the FM spectrum}. These devices are also called \textit{harmonic multipliers}.

\textbf{wideband FM with Armstrong`s modulator}

The experiment will examine the operation of a FREQUENCY MULTIPLIER (in fact, two such operations in cascade) on the output of an ARMSTRONG MODULATOR. The spectral components will be identified with a WAVE ANALYSER. This instrumentation was introduced in the experiment entitled \textit{Spectrum analysis - the WAVE ANALYSER} in this Volume.

The aim of this experiment is to generate a signal at 100 kHz with sufficient frequency deviation to enable several significant sidebands to be found in the spectrum. This requires a phase deviation of a radian or more. Since the Armstrong modulator is only capable of a deviation of a fraction of a radian, if distortion at the demodulator is to be kept low, then a FREQUENCY MULTIPLIER is required.

\textbf{FM UTILITIES}

The FM UTILITIES module contains two amplitude LIMITER sub-systems, a 33.333 kHz BPF, and a source of sinusoidal carrier at 11.111 kHz. These sub-systems will be combined as shown in Figure 1 below.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{deviation multiplication times-9}
\end{figure}

The Armstrong modulator (not shown) uses the 11.111 kHz sinusoidal carrier.

The 100 kHz BPF is available in the 100 kHz CHANNEL FILTERS module.
The modelling arrangement of the block diagram of Figure 1 is illustrated in Figure 2. This has been sub-divided into three distinct parts, as in Figure 1, and each is described below.

**Figure 2: the models**

**the Armstrong modulator**

For an FM signal at 100 kHz the Armstrong modulator must operate at a frequency several multiples below this. The frequency of 11.111 kHz has been chosen, providing a deviation multiplication, and an inevitable frequency multiplication, of times-9.

The 11.111 kHz sinusoidal carrier is obtained from the FM UTILITIES module. This contains a sub-system which produces a sinusoidal carrier at 11.111 kHz from a sinusoidal input at 100 kHz.

**the frequency multiplier times-9**

The FM UTILITIES module can model the two triplers of Figure 1. It has two LIMITER sub-systems, and a 33.3 kHz BPF. The 100 kHz BPF is obtained from a 100 kHz CHANNEL FILTERS module (channel #3). The patching is shown in Figure 2.

**the WAVE ANALYSER**

The spectrum of the FM signal is examined with a WAVE ANALYSER, modelled as shown in Figure 2. Of particular importance is the method of fine tuning the VCO, using a combination of the controls of the VARIABLE DC and the GAIN of the VCO.

The fine tuning technique was described in the experiment entitled *Spectrum analysis - the WAVE ANALYSER.*
choosing the message frequency

The design of the BPF in a frequency multiplier chain is a compromise between allowing sufficient bandwidth for the desired sidebands, while still attenuating the adjacent harmonics of the non-linear action of the preceding LIMITER.

This is generally not a problem in a commercial system for speech, since the frequency ratios (speech bandwidth, and so the modulated bandwidth, to the carrier frequency) are significantly lower. But in the modelling environment of TIMS, where carrier frequencies are relatively low, some design difficulties do arise.

You have been presented with existing 33.333 kHz and 100 kHz bandpass filters, so have no control over their bandwidths. They will set an upper limit to your message frequency. This you will need to determine.

First see Tutorial Questions Q2 and Q3.

Bandwidth measurement is best performed before patching up the complete system, since, using the suggested method for the 33 kHz BPF, it is necessary to have easy access to the VCO board for tuning purposes (see below).

Alternatively you might prefer to devise your own method of providing a 33 kHz variable frequency sinewave, without the need to use the VCO in FSK mode. See Tutorial Question Q4.

BPF bandwidth measurement

33 kHz BPF

T1 set the on-board switch SW2 of the VCO to ‘FSK’. Plug in the FM UTILITIES module and the VCO, leaving plenty of room for hand-access to the on-board control RV8 (FSK2) of the VCO. Connect a TTL HI to the DATA input of the VCO (this switches the output of the VCO to the FSK2 frequency). Select the HI frequency mode of the VCO with the front panel toggle switch.

T2 connect the VCO output to the input of the 33 kHz BPF of the FM UTILITIES module, and the output to the oscilloscope. Sweep the VCO frequency through the filter, and measure the frequency response.

100 kHz BPF

T3 using the VCO in ‘VCO’ mode make a sweep of the 100 kHz BPF of the 100 kHz CHANNEL FILTERS module, and measure its bandwidth.

message frequency

T4 from the two bandwidth measurements determine an upper limit for the message frequency. See Tutorial Question Q3.

You will now realize that extending the message frequency to 3 kHz is not possible, considering the bandwidths involved. Something below 1 kHz would be preferable.
assembling the models

The system to be patched up is illustrated in Figure 2.

preparation

T5 before plugging in the PHASE SHIFTER (of the Armstrong modulator) set the on-board switch to ‘HI’. Set the on-board switch of the VCO (of the WAVE ANALYSER) to ‘VCO’, and the front toggle switch to ‘HI’.

T6 plug in the modules. Put the ARMSTRONG MODULATOR to the left, the FREQUENCY MULTIPLIER in the centre, and the WAVE ANALYSER to the right. Do not yet do any patching. This will be done in easy stages, detailed below.

Armstrong`s carrier

To test the frequency multiplier, first use only the 11.111 kHz unmodulated carrier from the Armstrong modulator.

The 11.111 kHz sinusoidal carrier is provided by the FM UTILITIES module, derived from a 100 kHz sinusoidal input. This carrier is 1/9 of the final output carrier frequency of 100 kHz.

T7 patch the 11.111 kHz sine wave from the FM UTILITIES module via the phase shifter to the ‘G’ input of the ADDER. Adjust the ADDER output to the TIMS ANALOG REFERENCE LEVEL. Leave the ‘g’ input of the ADDER empty.

The carrier is now ready for testing the FREQUENCY MULTIPLIER.

modelling the frequency multiplier

the first tripler

The first tripler is modelled with a LIMITER and 33.333 kHz BPF in the FM UTILITIES module.

T8 patch the output of the Armstrong modulator (the unmodulated 11.111 kHz carrier) to the first tripler. Confirm that the output is a 33.333 kHz sinusoid at or about the TIMS ANALOG REFERENCE LEVEL. Its amplitude may be adjusted with an on-board trimmer. Precise level adjustment is not necessary.
The second tripler is modelled with a LIMITER from the FM UTILITIES module, and a 100 kHz BPF from the 100 kHz CHANNEL FILTERS module.

**T9** patch the output of the 33.333 kHz BPF to the unused LIMITER of the FM UTILITIES module. Connect its output to the 100 kHz CHANNEL FILTERS module, switched to the 100 kHz BPF.

**T10** confirm that the output of the second tripler is a 100 kHz sinewave. It should be at or about the TIMS ANALOG REFERENCE LEVEL. Its amplitude may be adjusted with an on-board trimmer. Precise level adjustment is not necessary.

You have now modelled the FREQUENCY MULTIPLIER, although with an unmodulated carrier.

**Armstrong`s modulator**

It is now time to complete the model of Armstrong’s modulator by adding the DSBSC to the carrier in the ADDER.

We want the Armstrong modulator to have as large a deviation as possible, so as to have several significant sidebands on the 100 kHz carrier, yet not so large as to generate too much distortion (which would upset the predictable amplitude ratios of the sidebands).

After adjusting the quadrature phase of the DSBSC and carrier, a suggestion is to set the DSBSC to carrier amplitude ratio to a about 1:3.

**T11** complete the modelling of the ARMSTRONG MODULATOR. Set the AUDIO OSCILLATOR to, say, 500 Hz \(^1\). There is no DC involved, so switch the MULTIPLIER to AC coupling. Remember it is easier to set the phase \(^2\), while watching the envelope, with the ratio of DSBSC to CARRIER approximately unity. The detailed procedure was described in the experiment entitled *Armstrong`s phase modulator*.

**T12** having adjusted the phase, reduce the phase deviation to 0.33 radians, in preparation for the next part of the experiment. Remember to keep signal levels, where possible, at or near the TIMS ANALOG REFERENCE LEVEL.

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\(^1\) do you agree that this is acceptable? If not, or in any case, you are free to choose your own frequency.

\(^2\) the on-board switch SW1 is probably best set to ‘HI’. 

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FM deviation multiplication
measuring the FM spectrum

The ARMSTRONG MODULATOR now has a phase deviation of 0.33 radians. The FREQUENCY MULTIPLIER output will be a phase modulated signal with a peak phase deviation of nine times this, or 3.0 radians.

T13 examine the output of the FREQUENCY MULTIPLIER with the oscilloscope. As seen in the time domain (the oscilloscope being triggered by the signal itself) it will have the appearance of a compressed and expanded spring. It should be at about the TIMS ANALOG REFERENCE LEVEL. Notice that the envelope is flat.

Now use the WAVE ANALYSER to check the 100 kHz spectrum.

\[
\text{it is essential that you are familiar with the method of fine tuning the VCO}
\]

T14 patch up the WAVE ANALYSER. Set the VCO to the ‘HI’ frequency range with the front panel switch.

T15 examine the output of the FREQUENCY MULTIPLIER with the WAVE ANALYSER. Record the frequency and amplitude of each spectral component of significance 3.

T16 use the Tables of Bessel Coefficients in Appendix C to this text to draw the amplitude spectrum of an angle modulated signal with \( \beta = 3.0 \). Compare with your measurements.

special cases

It is always interesting to investigate special cases. The obvious cases are those of the Bessel zeros. With these special values of \( \beta \) the amplitude of particular components falls to zero. These and other cases are examined in the experiment entitled \textit{FM and Bessel zeros}.
TUTORIAL QUESTIONS

Q1 see first the tutorial questions in the Chapter entitled Analysis of the FM spectrum.

Q2 suppose a message frequency range of 300 to 3000 Hz was desired. Knowing the maximum phase deviation allowed by the limitations of the Armstrong modulator, specify the characteristics of the two BPF of the system. Remember they must pass the wanted sidebands, but stop the unwanted components from the preceding LIMITER.

Q3 from your measurements of the bandpass filter bandwidths, and knowing the limits upon the phase deviation set by the Armstrong modulator, how would you specify the upper message frequency?

Q4 you may have found it inconvenient to use the suggested method of tuning the VCO around 33 kHz for the BPF measurement. Devise another method, which does not involve adjustment of the on-board control of the VCO; that is, all frequency changes are made using front panel controls of existing TIMS modules. hint: there is a 130 kHz sinusoid at TRUNKS.