Frequency Multiplier (using PLL 565)

In electronics, a frequency multiplier is an electronic circuit that generates an output signal whose output frequency is a harmonic (multiple) of its input frequency.

Frequency multipliers consist of a nonlinear circuit that distorts the input signal and consequently generates harmonics of the input signal.

• The output from a PLL system can be obtained either as the voltage signal $v_c(t)$ corresponding to the error voltage in the feedback loop, or as a frequency signal at VCO output terminal.

• The voltage output is used in frequency discriminator applications whereas the frequency output is used in signal conditioning, frequency synthesis or clock recovery applications.
Figure 1-1 Frequency multiplier using the 565
For the working of Frequency multiplier circuit the frequency divider is inserted between the VCO and phase comparator of PLL (Between pin 4 and 5 of 565).

Since the output of the divider is locked into the input frequency \( f_{\text{IN}} \), the VCO is actually running at a multiple of the input frequency.

The desired amount of multiplication can be obtained by selecting a proper divide-by-\( N \) network, where \( N \) is an integer.

For example, to obtain the output frequency \( f_{\text{OUT}} = 5f_{\text{IN}} \), a divide-by-\( N = 5 \) network is needed. Figure shows the function performed by a 7490 (4-bit binary counter) configured as a divide-by-5 circuit. In this figure, transistor \( Q_1 \) is used as a driver stage to increase the driving capability of the NE565.
Circuit Description of frequency multiplier

To verify the operation of the circuit frequency multiplier, one must determine the input frequency range and then adjust the free-running frequency $f_{\text{OUT}}$ of the VCO by mean of $R_1$ and $C_1$ so that the output frequency of the 7490 divider is midway within the predetermined input frequency range.

The output of the VCO now should be $5f_{\text{IN}}$. The output frequency $f_{\text{OUT}}$ can be adjusted from 1.5 KHz to 15 KHz by varying potentiometer $R_1$ ($f_{\text{OUT}} = 1.2/4R_1C_1$).

This means that the input frequency $f_{\text{IN}}$ range has to be within 300 Hz to 3 KHz. In addition, the input waveform can either be sine or square wave and may be applied to input pin 2 or 3.

Even though supply voltages of ±10 V are used in figure 1-1, the NE565 can be operated on ±5 supply voltage instead. A small capacitor $C_3$ typically 1000pF, is connected between pins 7 and 8 to eliminate possible oscillations. Also, capacitor $C_2$ should be large enough to stabilize the VCO frequency.
FSK

In computer peripheral & radio (wireless) communication the binary data or code is transmitted by means of a carrier frequency that is shifted between two preset frequencies.

Since a carrier frequency is shifted between two preset frequencies, the data transmission is said to use a FSK.

The frequency corresponding to logic 1 & logic 0 states are commonly called the mark & space frequency.

For example, When transmitting teletype writer information using a modulator-demodulator (modem) a 1070-1270Hz [mark-space] pair represents the originate signal, while a 2025-2225 Hz (mark-space) pair represents the answer signal.
FSK Generator: · The FSK generator is formed by using a 555 as an astable multivibrator

Slide 52 555FSK

By proper selection of resistance Rc, this frequency is adjusted to equal the space frequency of 1270 Hz. The difference between the FSK signals of 1070 Hz & 1270 Hz is 200 Hz, this difference is called “frequency shift”. · The output 150 Hz can be made by connecting a voltage comparator between the output of the ladder filter and pin 6 of PLL. · The VCO frequency is adjusted with R1 so that at $f_{IN} = 1070$ Hz.
FSK Demodulator: · The output of 555 FSK generator is applied to the 565 FSK demodulator. · Capacitive coupling is used at the input to remove dc line.

· R1 & C1 determine the free running frequency of the VCO,

As the signal appears at the input, the loop locks to the input frequency and tracks it between the two frequencies with a corresponding dc shift at the output.

A three stage filter removes the carrier component and the output signal is made logic compatible by a voltage comparator.
565 As An FSK Demodulator
UNIT V
Sensors and Transducers

A device capable of detecting and responding to physical stimuli such as movement, light, heat, pressure, humidity, gas concentration, etc., is known as a sensor.

Physical quantities that can be measured electrically are primarily displacement, velocity, force, torque, strain, pressure, sound, acceleration, acoustic emission, humidity, gas concentration, etc.

A number of physical effects can serve for converting a physical quantity into an electrical output signal. The most important ones are:

- a change in resistance (strain gauge, piezoresistive, potentiometric sensors),
- a change in capacitance or in inductance and
- a change in polarization (piezoelectric)
• According to American National Standards Institute

  A device which provides a usable output in response to a specified measurand

• A sensor acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

• Nowadays common sensors convert measurement of physical phenomena into an electrical signal
Types of Sensors

Basically there are two types of sensors: **Active and Passive sensors**.

**Active Sensor**

A sensor is called active if no external source of power is required for measuring. An Active Sensor is known as a Transducer.

**Passive Sensor**

Most other sensors are of the passive type. (i.e.,) they do not directly yield any output, rather they passively change their electric properties (change in resistance, capacitance, etc) as a function of the measurand.

Such change can only be detected by applying an external source of power which will reveal the output signal in the form of a change in electric current or voltage.
Classification of Transducers

- Transducers may be classified according to their application, method of energy conversion, nature of the output signal, and so on.
SENSORS

Physical Parameter

Electrical signal

ACTUATOR

Electrical Inputs

Physical outputs
Sensors in Use – Example 2
Measurement and Control

• The aim of any measuring system is to obtain information about a physical process and to find appropriate ways of presenting that information to an observer or to other technical systems.

• With electronic measuring systems the various instrument functions are realized by means of electronic components. A measuring system may be viewed as a transport channel for the exchanging of information between measurement objects and target objects.
Three main functions may be distinguished: data acquisition, data processing and data distribution.

Data acquisition: this involves acquiring information about the measurement object and converting it into electrical measurement data.

Data processing: this involves the processing, selecting or manipulating – in some other way – of measurement data according to a prescribed program.

Data distribution: the supplying of measurement data to the target object.
• Since most physical measurement quantities are non-electric, they should first be converted into an electrical form in order to facilitate electronic processing. Such conversion is called transduction and it is effected by a transducer or sensor.
Signals

Physical quantities that contain detectable messages are known as signals. The information carrier in any electrical signal is a voltage, a current, a charge or some other kind of electric parameter.

The message contained in such a signal may constitute the result of a measurement.

The nature of the message cannot be deduced from its appearance. Processing techniques are necessary to derive the message content.
Types of signals

• **Static or DC signals**: the signal value remains constant during the measuring time interval.

• **Quasi-static signals**: the signal value varies just a little, according to a given physical quantity. An example of a quasi-static signal is drift.

• **Dynamic signals**: the signal value varies significantly during the observation period. Such signals are also termed AC signals (AC = alternating current or alternating voltages).
Another way to distinguish signals is on the basis of the difference between deterministic and Stochastic.

**Stochastic signal** has the fact that its exact value is impossible to predict. Most measurement signals and interference signals, such as noise, belong to this category.

**Deterministic**

Periodic signals, characterized as $x(t) = x(t + nT)$, in which $T$ is the time of a signal period and $n$ the integer.

Transients, like the response of a system to a pulse-shaped input: the signal can be repeated (in other words predicted) by repeating the experiment under the same conditions.
Signal Conditioning

The output signal from the sensor of a measurement system has generally to be processed in some way to make it suitable for the next stage of the operation.

- the signal may be too small and have to be amplified,
- contain interference which has to be removed,
- be analogue and have to be made digital (vice versa),
- be a resistance change and have to be made into a current change,
- be a voltage change and have to be made into a suitable size of current change, etc.

All these changes can be referred to as signal conditioning.
• For example, the output from a thermocouple is a small voltage (a few mv). A signal conditioning circuit or module is necessary to convert this millivolts into suitable size current signals and to provide noise rejection, linearization.
Signal Conditioning Processes

1. **Protection** to prevent damage to the next element (There can be series current limiting resistors, fuse breaks, polarity protection etc.,)

2. **Getting the Signal into the right type of signals** (Making the signal into DC voltage or current). Thus for example, the resistance change of the strain gauge has to be converted into a voltage change. This can be done by the use of Wheatstone bridge.

3. **Getting the level of the signal right.** (Thermo couple to \( \rightarrow \) microprocessor : mv \( \rightarrow \) Volts), Op-Amps widely used for this amplification.

4. **Eliminating or reducing Noise**: Filters may be used to eliminate main noise (50 Hz) from the signal for example.

5. **Signal Manipulation**: Making it a linear function of some variable. (ie) a nonlinear signal is conditioned to a linear one.
Noise

- *With reference to an electrical system, noise may be defined as any unwanted form of energy which tends to interfere with proper reception and reproduction of wanted signal.*

  OR

- The **noise** is a summation of unwanted or disturbing energy from natural and sometimes man-made **sources**.

  OR

- Noise is an unwanted disturbances superposed upon a useful signal that tend to be obscure its information content.
Noise in an electronic devices varies greatly, as it can be produced by several different effects.

Noise is a fundamental parameter to be considered in an electronic design as it typically limits the overall performance of the system.
Impulses are unwanted spikes in analog or in digital signals.
Classification of Noise

Noise may be put into following two categories.

1. **Intrinsic noises or Instrumental Noise and**
2. **Extrinsic or External Noises** i.e. noise whose sources are external.

**Intrinsic Noise**

- The noise generated inside an investigated device or circuit. In linear systems the physical origin of noise is the discrete nature of charge carriers. This noise is associated with each component of an instrument – i.e., with the source, the input transducer, signal processing elements and output transducer. Noise is a complex composite that usually cannot be fully characterized. Certain kinds of instrumental noise are recognizable, such as:

**Characteristics**

- Intrinsic noise is random in nature. This means that it is not possible to predict the amplitude of fluctuating voltage or current.
- The amplitude of intrinsic noise is very low usually 1uv. As for the frequency spectrum many noise mechanisms yields white noise i.e., the noise power is equally distributed over all frequencies.
Internal noise may be put into the following four categories.

1. *Thermal noise* or *white noise* or *Johnson noise*
2. *Shot noise.*
3. Flicker Noise
4. *Miscellaneous internal noise.*
Thermal Noise or Johnson Noise or white Noise:
Thermal noise is caused by the thermal agitation of electrons or other charge carriers in resistors, capacitors, radiation transducers, electrochemical cells and other resistive elements in an instrument.

The magnitude of thermal noise is given by

\[ \nu_{\text{rms}} = \sqrt{4kTR\Delta f} \]

where, \( \nu_{\text{rms}} \) = root mean square noise, \( \Delta f \) = frequency band width (Hz), \( k = \) Boltzmann constant (1.38 x 10^{-23} \text{ J/K}), \( T = \) temperature in Kelvin, \( R = \) resistance in ohms of the resistive element.

Thermal noise can be decreased by narrowing the bandwidth, by lowering the electrical resistance and by lowering the temperature of instrument components.
Figure 8-3  Thermal noise affecting analog and digital signals
2. Shot Noise:
The most common type of noise is referred to as shot noise which is produced by the random arrival of electrons or holes at the output element, at the plate in a tube, or at the collector or drain in a transistor. Shot noise is encountered wherever electrons or other charged particles cross a junction.

\[ i_{rms} = \sqrt{2Ie\Delta f} \]

Where, \( i_{rms} \) = root-mean-square current fluctuation, 
\( I \) = average direct current, 
\( e \) = charge on the electron \((1.60 \times 10^{-19} \text{ C})\),  
\( \Delta f \) = band width of frequencies.

Shot noise in a current measurement can be minimized only by reducing bandwidth.
3. **Flicker Noise:**

Flicker noise is characterized as having a magnitude that is inversely proportional to the frequency of the signal being observed.

$$FN = \frac{1}{f}$$  it is also called as Pink Noise.

Flicker noise becomes significant at frequency lower than about 100 Hz.

Flicker noise can be reduced significantly by using wire-wound or metallic film resistors rather than the more common carbon composition type.
Impulses are unwanted spikes in analog or in digital signals.
Extrinsic noise

The sources of extrinsic noise are situated outside the investigated circuit.

External noise may be classified into the following three types:

1. *Atmospheric noises* 
2. *Extraterrestrial noises* 
3. *Manmade noises or industrial noises*.

This kind of noise is also called extraneous signals or spurious signals or perturbations.
Signal to Noise Ratio (SNR)

Noise is important whenever we are dealing with weak signals.

A more appropriate statement would be that noise is important whenever the amplitudes of the processed signals are similar to those of the exiting noise.

Therefore what really matters is not the signal level, but the signal to noise (S/N) ratio. Low S/N ratios indicated vulnerability to noise, while high S/N ratios indicate immunity to noise.
Two main reasons to calculate Noise Ratio

To compare signal and the noise at the same point to ensure the noise is not excessive

To compare two devices in order to evaluate their performance.

The measure for this calculation is Signal To Noise Ratio.

Signal-to-noise (SNR) is much more useful figure of merit than noise alone for describing the quality of an analytical method.

$\text{SNR} < 2 \text{ or } 3 \rightarrow \text{impossible to detect a signal.}$

\[
\text{SNR} = \frac{P_s}{P_n}
\]

Expressed as logarithmic function,

$\text{SNR} = 10 \log \frac{P_s}{P_n} \text{ dB}$
Noise Factor (F) and Noise Figure (NF)

Noise factor is simply a ratio of input SNR to output SNR

\[ F = \frac{\text{Input SNR}}{\text{Output SNR}} \]

Figure of Merit or Noise figure is used to indicate how much the SNR damage or deteriorates as a signal passes through a circuit.

\[ \text{NF} = 10 \log F \quad \text{dB} \]

For a perfect noise less circuit or component, \( F=1 \) and \( \text{NF} = 0 \text{ dB} \)
Signal power in \( \frac{S_i}{N_i} \) = Signal power out \( \frac{A_p S_i}{A_p N_i + N_d} \) = \( \frac{S_i}{N_i + \frac{N_d}{A_p}} \)

Ideal Noiseless Amplifier

Ap = power gain

Nonideal amplifier

Ap = power gain
Nd = internally generated noise
Lock In Amplifier

Filters are frequency selective and therefore they can be utilized to reject noise or unwanted signals if the desired and spurious signals are located in different positions in the frequency spectrum. Such filters are of little use or no use if the signal and noise having nearly equal frequencies.

Even in such situation the signal can be recovered if the noise is random and the desired signal is periodic or can be made periodic.

Lock in Amplifier circuits provide a technique for the recovery of a coherent signal in the presence of noise. They can provide a very high degree of signal to noise ratio improvement without the drift associated with the production of high Q band bass filters.
Fig. Lock-in amplifier—circuit scheme.
Lock In Amplifier – Block Diagram
A lock-in amplifier provides a DC output proportional to the AC signal under investigation (common with most AC measuring instruments).

It is a combination of Phase Sensitive Detector (PSD) and a low pass filter (LPF).

The special rectifier, called a phase-sensitive detector (PSD), which performs this AC to DC conversion forms the heart of the instrument/circuit.

It is special in that it rectifies only the signal of interest while suppressing the effect of noise or interfering components which may accompany that signal.

The traditional rectifier makes no distinction between signal and noise and produces errors due to rectified noise components.

The noise at the input to a lock-in amplifier, however, is not rectified but appears at the output as an AC fluctuation.

This means that the desired signal response, now a DC level, can be separated from the noise accompanying it in the output by means of a simple low-pass filter. Hence in a lock-in amplifier the final output is not affected by the presence of noise in the applied signal.
• The periodic signal (mixed with noise) is fed to the two throws of an electronic SPDT in two ways one directly and another through an inverting voltage follower. The SPDT in turn is actuated by a square wave reference signal.
• If the reference signal has the same frequency and the phase as those of the desired signal, then the switch will be in position 1 to sample the direct signal for the first half (ie). For phase angle 0° to 180° of the wave, and at position 2 to sample the inverted signal for the next half.
• As a result the PSD output will resemble that of a full wave rectifier and the LPF acting as averaging circuit and the circuit will give a steady DC output.
• If however, the input signal is of different frequency or of the same frequency but different phase from the reference signal, the LPF output will be zero or negligibly small if averaging is done over a sufficient time.
Fig. 16.57 Lock-in amplifier—signals at different stages.

Fig. 16.58 Lock-in amplifier operation: (a) For an input signal of different frequency, and (b) for an input signal of different phase.
• LIA are capable of reducing the noise and retrieving signals that are otherwise buried below the noise level. Improvements up to 85 dB are relatively easy to obtain and up to 100 dB reduction is possible.

• Their extensive range of applications includes signal processing from capacitate and inductive displacement transducers, radiometry, nuclear magnetic resonance and fringe position monitors. The central element of the LIA is the PSD
Mathematical Explanation for Lock in Amp

Consider the case where a noise-free sinusoidal signal voltage $V_{in}$ is being detected, where

$$V_{in} = A \cos(\omega t)$$

$\omega$ is the angular frequency of the signal ($\omega = 2\pi F$)

The lock-in amplifier is supplied with a reference signal at frequency $F$ derived from the same source as the signal, and uses this to generate an internal reference signal of:-

$$V_{ref} = B \cos(\omega t + \theta)$$

where $\theta$ is a user-adjustable phase-shift introduced within the lock-in amplifier.
The detection process consists of multiplying these two components together so that the PSD output voltage is given by:

\[ V_{psd} = A \cos(\omega t) \cdot B \cos(\omega t + \theta) \]

\[ = AB \cos \omega t (\cos \omega t \cos \theta - \sin \omega t \sin \theta) \]

\[ = AB(\cos 2\omega t \cos \theta - \cos \omega t \sin \omega t \sin \theta) \]

\[ = AB((\frac{1}{2} + \frac{1}{2}\cos 2\omega t)\cos \theta - \frac{1}{2}\sin 2\omega t \sin \theta) \]

\[ = \frac{1}{2}AB((1+ \cos 2\omega t)\cos \theta - \sin 2\omega t \sin \theta) \]

\[ = \frac{1}{2}AB(\cos \theta + \cos 2\omega t \cos \theta - \sin 2\omega t \sin \theta) \]

\[ = \frac{1}{2}ABcos \theta + \frac{1}{2}AB(\cos 2\omega t \cos \theta - \sin 2\omega t \sin \theta) \]

\[ = \frac{1}{2}AB \cos \theta + \frac{1}{2}AB \cos(2\omega t + \theta) \]
• If the magnitude, B, of the reference frequency is kept constant, then the output from the phase-sensitive detector is a DC signal which is:

  • proportional to the magnitude of the input signal A
  • proportional to the cosine of the angle, θ, between it and the reference signal modulated at 2ωt, i.e. it contains components at twice the reference frequency.
The output from the PSD then passes to a low-pass filter which removes the 2wt component, leaving the output of the lock-in amplifier as the required DC signal.

In a practical situation the signal will usually be accompanied by noise, but it can be shown that as long as there is no consistent phase (and therefore by implication frequency) relationship between the noise and the signal, the output of the multiplier due to the noise voltages will not be steady and can therefore be removed by the output filter.
LIA usage
Box-Car Integrator or Averager
Box-Car integrators or averager provides a method of averaging out the noise signals and of thus improving signal to noise ratio.

**operation**

- The system employs a triggering signal which is time referenced to the signal being averaged. This variable delay allows a particular section of the response signal to be selected.

- The sample and hold circuit is opened for a short aperture period and the signal within the gate width of the sample and hold circuit is stored. Repetition of the signal allows the portion of the signal at exactly the same time relative to the trigger to be selected.

- The system then averages the signal in this portion of the waveform. As the number of repetitions increases, the signal to noise ratio of the averaged signal improves.

- The improvement is proportional to the root of the number of repetitions. Automatic systems are available which scan the whole of the waveform, with an internally selected gage width to ensure that over a series of repetitions of the signal each section is averaged several times.
5. Examples of Signal Extraction from Noise

5.1. BOX-CAR INTEGRATOR

The *Box-Car Integrator* (BCI) improves the S/N ratio by
- gating the detection (time window $\Delta t$),
- averaging over multiple pulses, $S/N \sim \sqrt{N}$,
  e.g. $N = 10^4$ improves $S/N$ by 20dB.

Beginning with $t_0 = 0$, the "box-car" is shifted gradually to higher values so that the full signal dependence of the signal is covered, see Fig. 14. Today, BCI's are a standard tool in most physics laboratories.

Typical properties of commercially available instruments are
- integration time: $\Delta t = 2 \ldots 15\mu s$,
- number of samplings: $N = 1 \ldots 10000$,
- trigger rate: dc$\ldots 20$kHz.
Therefore, box-car systems are particularly well suited to average a single point in time repetitively. As an example, the amplitude of one peak of a spectrum, derived from a repetitively swept monochromator, could be averaged easily and recorded as a function of time using a box-car system. This technology can also give a good time resolution, lower than 1 ns. Signal averagers can provide maximum time resolutions of a similar level, but are better suited to waveform recovery and to monitoring short lived phenomena due to their better time efficiency.
Sample and Hold Circuit

• A typical data acquisition system receives signal from a number of different sources and transmits these signals in suitable form to a processing unit or a communication channel.

• A multiplexer selects each channel in sequence, and then the analog information is converted into a constant voltage over the gating-time interval by means of a Sample and Hold Circuit.

• A simple S/H circuit is based on a high speed switch and a Capacitor.
When the switch is closed, the capacitor quickly charges or discharges so that its voltage, and hence the output voltage equals the input voltage.

If the switch is not opened the capacitor simply holds its charge and its voltage remains constant.

The circuit is used to take a sample of varying voltage by closing the switch, and then to hold that value by opening the switch.
The simple S/H has the following drawbacks

• When the Switch is closed, the capacitor represents very low impedance to the source and hence loads it heavily – the result is distortion in the input signal.

• If the source has high output resistance, the time taken by the capacitor to charge increases – the result is reduction in speed.

To overcome these problems, MOSFET switches, and buffer amplifiers (voltage followers) are used.
• In practice the switch may be a relay (For very low frequency), a sampling diode bridge gate, a bipolar transistor switch or a MOSFET controlled by a gating signal.

• The MOSFET makes an excellent chopper because its offset voltage when ON (~5 micro volt) is much smaller than that of a BJT.
• A negative pulse at the gate of the P-Channel MosFET will turn the switch ON, and the holding capacitor C will charge with a time constant $R_{on}C$ to the instantaneous value of the input voltage.

• In the absence of a negative pulse, the Switch is in the OFF state and the capacitor is isolated from any load through the Op-Amp. Thus it will hold the voltage impressed upon in it. For effective S/H polycarbonate, polyethylene or Teflon dielectric capacitors are used.

• **Aperture time:** The delay between the time that the pulse is applied to the switch and the actual time the switch closes.

• **Acquisition Time:** Time taken by the capacitor to change from one level of holding value to the new value of input voltage after the switch is closed.
LF398 single-chip S/H