Module 5 Theory

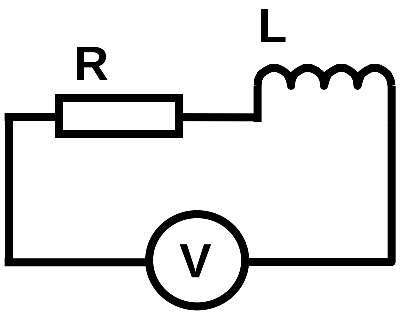
- Combination of components
- Filters
- Oscillators
- Phase Lock Loops
- Direct Digital Synthesis
- Multipliers

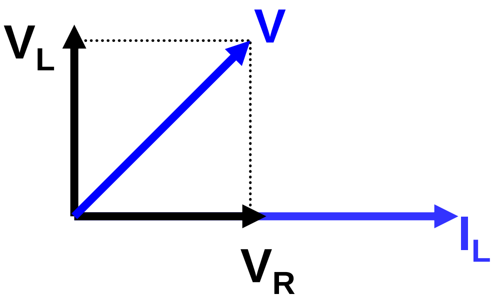
Components at HF

- Wire-wound and metal-film resistors are inductive
- Plastic film and ‘hi-K’ ceramic capacitors exhibit significant leakage resistance and losses at HF, as do electrolytic types
- At VHF the inductance of component leads can be significant
- At HF current tends to flow only on the outer surface of a wire (**skin effect**). This leads to losses in inductors as does the type of core material which is often frequency sensitive leading to losses outside the frequency band of intended use
- Inductors exhibit distributed capacitance between turns which may be significant

Resistance & Inductance in Series

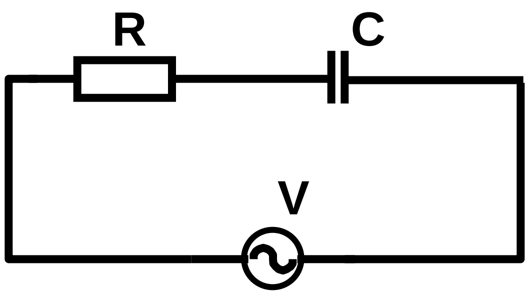
- **Impedance** is the vector sum of the resistance and reactance.
- A definition is the ratio of the RMS EMF in a circuit, to the RMS current

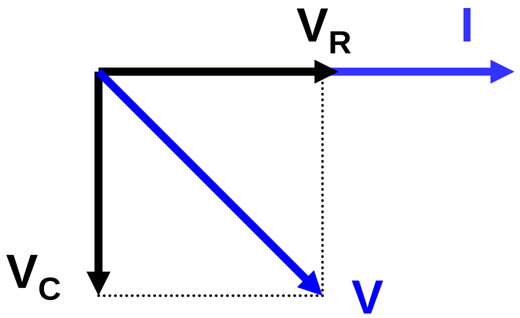




- R represents the 'total' circuit resistance.
- The Voltage is made up of two parts; a PD across the resistance V_R with the voltage and current in phase, and a PD across the inductance V_L leading the current by 90 .
- The resultant is the applied voltage V, which is the vector sum given by:-
- **Impedance, $Z = \sqrt{(R^2 + X_L^2)}$** The current in the circuit is **$I = V / Z$**

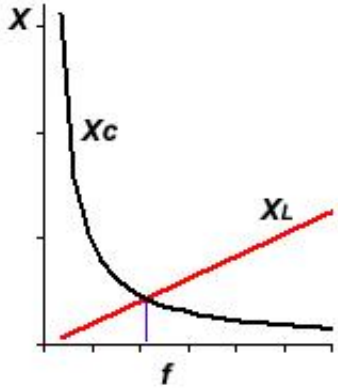
Resistance & Capacitance in Series

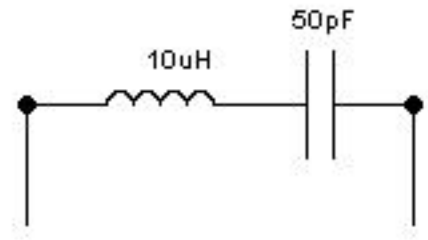




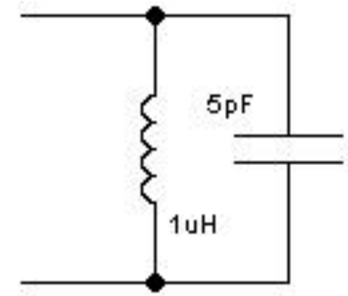
- To maintain a current of I the applied voltage provides two components;
  a) A voltage V_R = I.R across the resistance, in phase with the current, and
  b) A voltage V_C = I.C = I.1/(2πFC) which lags the current by 90 .
- The resultant is V which is the vector sum of these two components.
- The impedance of the circuit is **$Z = \sqrt{(R^2 + X_C^2)}$**

Tuned Circuits & Filters





f= 7.1MHz



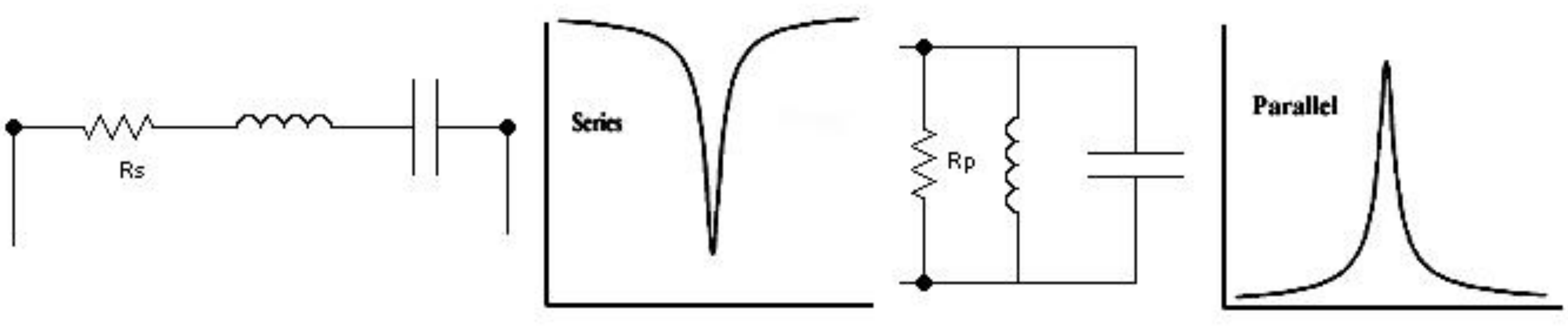
f= 71.1MHz

- Inductive reactance (**$X_L = 2\pi f L$**) increases with frequency
- Capacitive (**$X_C = 1/2\ \pi f C$**) decreases with frequency
- They are 180° apart; they are equal at a particular frequency, cancelling out each other
- Frequency at which this happens is called the **resonant frequency (f_R)**

$f_R = 1/(2\pi\sqrt{LC})$ f, Hz   L, Henries   C, Farads

- Theoretical impedance of series circuit is zero - **acceptor**; parallel circuit is infinity - **rejector**

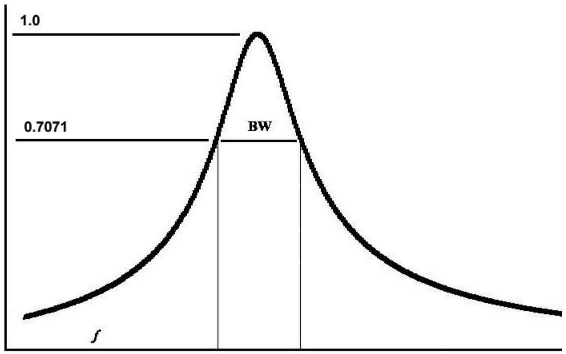
Tuned Circuits & Filters



- In practice there are always losses in inductors and capacitors, as discussed, and this is represented by a loss resistance; circuit impedance is limited by loss resistance
- The quality factor (Q) of a tuned circuit is the ratio of reactance to loss resistance at resonance

$Q = 2\pi f L/R_s$ $Q = R_p/ 2\pi f L$

Tuned Circuit & Filter Bandwidth



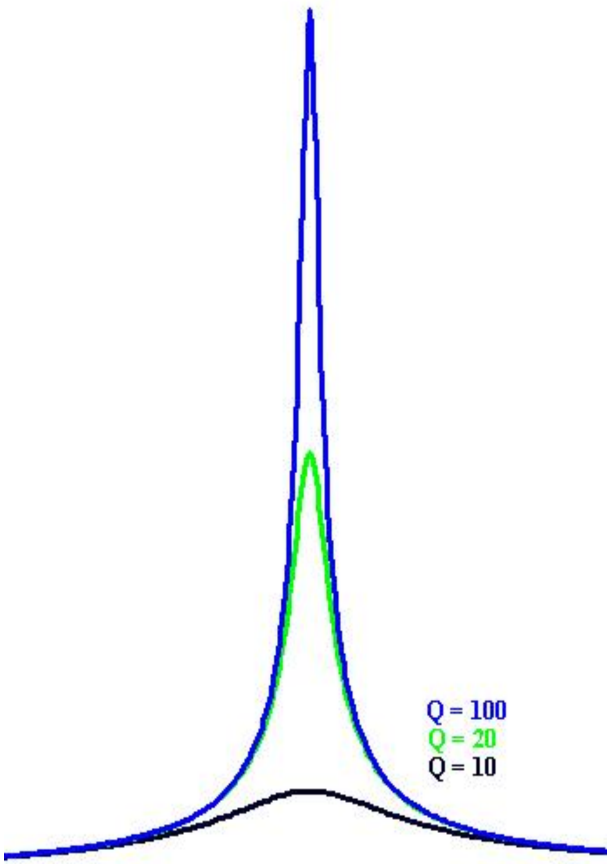
- Either side of resonance the response falls off. When the response in voltage terms reaches 0.707 (√ 1/2) of the value at resonance, this range of frequencies is known as the **(half power) bandwidth** or –3dB bandwidth
- For filters another important parameter can be **shape factor** which is the ratio of (–)6/60dB bandwidth; less than 2:1 is acceptable

Q & Bandwidth

- The **quality factor (Q)** of a tuned circuit may also be expressed in terms of the ratio of **resonant frequency** to (half power [–3dB]) bandwidth, B

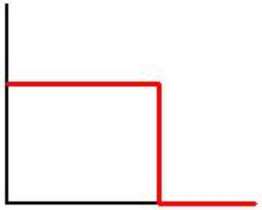
$$\mathbf{Q = \mathit{f}_{res} / B}$$

- Note that Q only tends to affect the response curve near resonance



Filters

- **Low pass filter** passes low frequencies, stops high

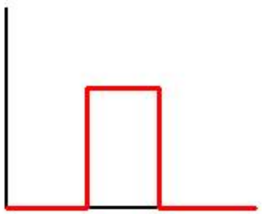


(a)

- **High pass filter** passes high, stops low

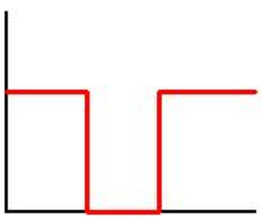
(b)

- **Band Pass** passes a range of frequencies and stops (rejects) frequencies outside the passband



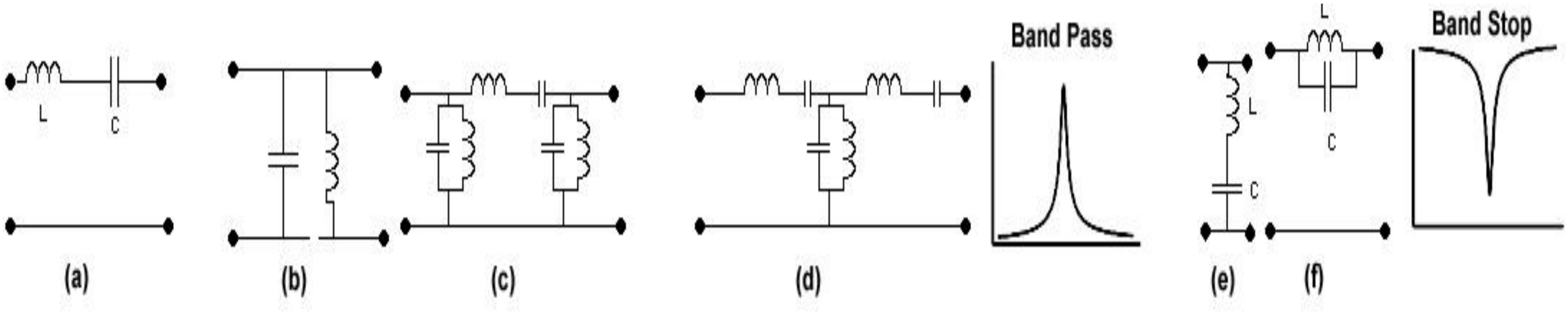
(c)

- **Band stop** rejects a range of frequencies and passes all others; if sharp called a **notch filter**



(d)

Filters

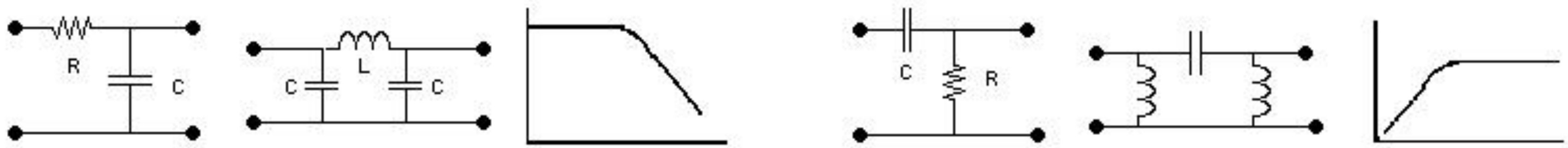


- **Band Pass** (a,b,c,d); shape is not ideal as circuit is only an approximation; in (c,d) filters are cascaded to give better response

- **Band stop** (e,f)

- The LC tuned circuits discussed earlier can be used for either

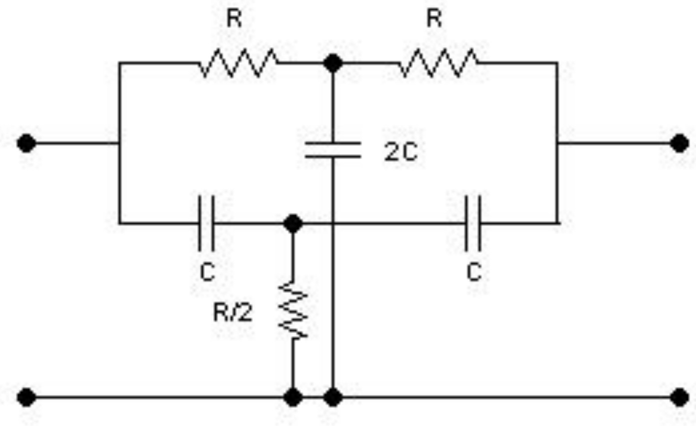
Filters

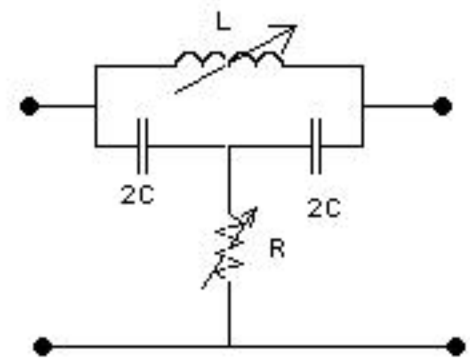


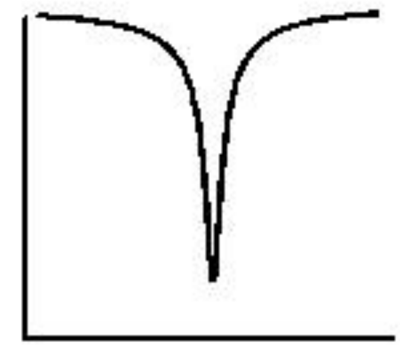
(a) (b) LPF (c) (d) HPF

- **Low pass** (a,b)
- **High pass** (c,d)
- RC at audio frequencies. LC at RF
- (b) and (d) are known as **Pi filters** due to similarity of configuration to Greek letter π

Filters



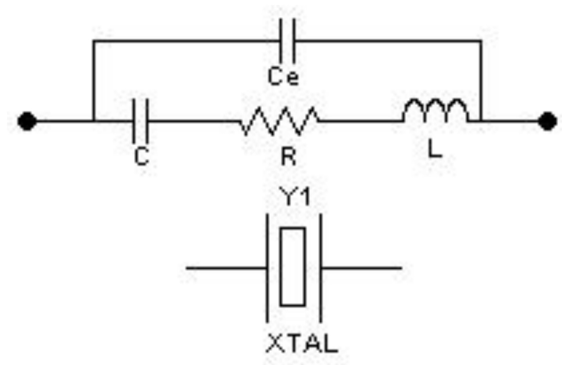




- RC **Twin T-notch filter** can provide a sharp notch at audio frequencies

- LCR **T-notch filter** (bridged-T) can provide notch at higher frequencies. L adjusts frequency, R depth of notch

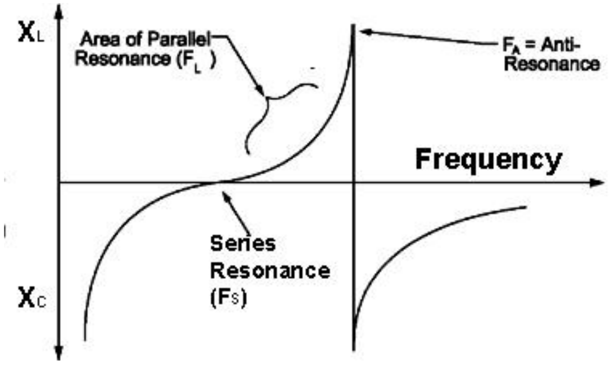
Quartz Crystals



- A quartz crystal is held between two electrodes. The piezo-electric effect which converts a mechanical stress into a voltage and vice versa results in a high-Q tuned circuit. Equivalent circuit will have a series resonant frequency and a slightly higher (+0.1%) parallel resonant frequency as a result of C_E the electrode and load capacitance

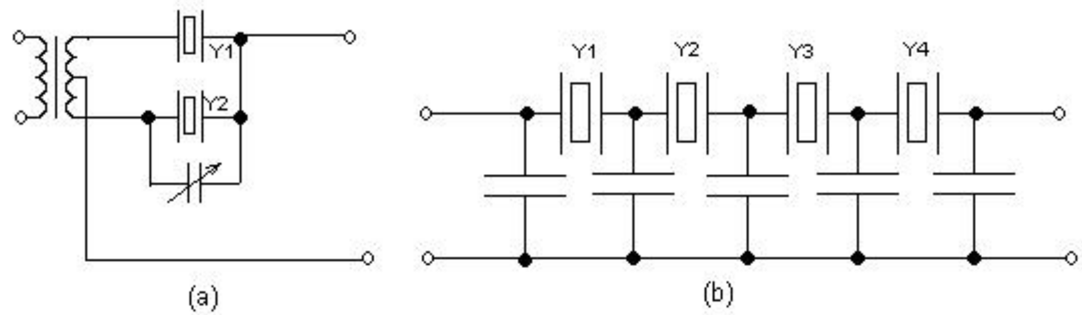
- In addition the crystal can vibrate and exhibit resonance on **overtones (odd harmonics)**

Quartz Crystals



- Crystals have high temperature stability and are used as tuned circuits in oscillators (mostly **parallel mode**) and in filters (mostly **serial mode**)
- Specification of crystals requires information on frequency, mode and load impedance
- In parallel mode the frequency of a crystal may be varied (**pulled**) by changing the load impedance
- The current through the crystal needs to be limited to avoid mechanical failure

Crystal Filters



- The high-Q of crystals means that they can be used in effective filters in radio receivers and transmitters
- (a) **half-lattice** filter – usually parallel resonant frequency of Y_2 matches series resonant frequency of Y_1. C trims the circuit
- (b) **ladder** filter – crystals have same series resonant frequencies
- Multiple electrodes can be deposited on a single crystal to form **monolithic crystal filters**

Feedback in Amplifiers

- **Feedback** is where a portion of the output signal of an amplifier unintentionally appears or is deliberately fed back to the input circuit
- If the feedback is 180° out of phase with the input this is termed **negative feedback**
- Negative feedback has the **benefits** of reducing distortion, improving stability, making frequency response flatter and increasing input impedance, though at the expense of gain

Feedback in Amplifiers

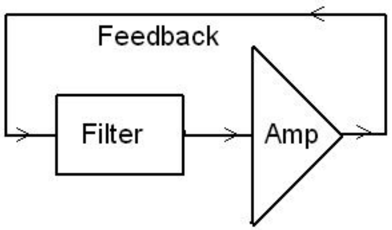
- If the feedback signal is in phase with the input at a ceratin frequency, i.e., **positive feedback**, amplifier gain and distortion inceases and oscillation occurs

- This is ruinous to amplifier performance

- Oscillation may occur at frequencies well away from the design frequency of the amplifier due to stray capacitance /inductance in devices and circuits – parasitic oscillation

- Circuit design and layout, use of neutralising circuitry, and correct operating conditions minimise **parasitic** oscillations

Oscillators



- An oscillator is an amplifier with positive feedback provided by a resonant circuit acting as a filter; the resonant circuit determines frequency; harmonics **(overtones)** can be extracted

- For oscillation to occur the phase shift around the loop has to be zero and the gain at least unity

- The stability of the resonant circuit and stray reactances affect frequency stability, which may vary with temperature or loading

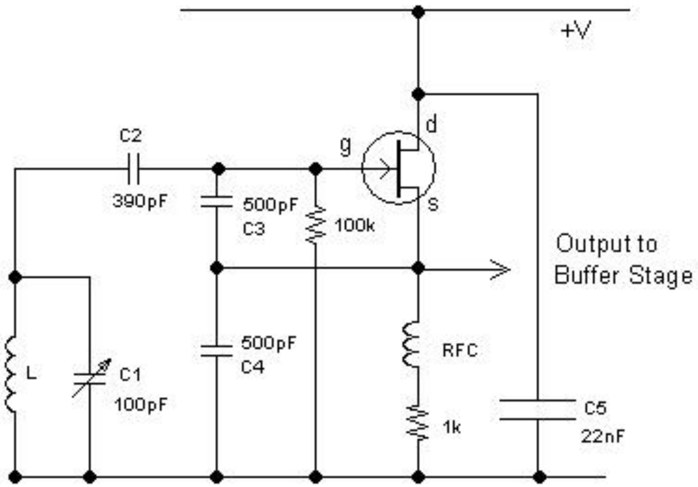
Oscillators

- Recall Intermediate Course: Oscillators can be
  - Colpitts oscillator based on simple LC resonator
  - Varactor controlled LC
  - Quartz crystal based - perhaps a switched bank

- Important to use stable components/PSUs, sound construction, and temperature compensation
- LC VFOs need a method to check their frequency
- A buffer amplifier is often on used at a VFO oscillator output to to prevent unwanted changes to its output frequency or purity

LC Oscillator

- **Colpitts** LC oscillator
- Feedback from source of FET via C3, C4
- C3 = C4
- Frequency determined by L, C1,2,3,4
- L,C1,C2 can be replaced by a series tuned circuit, called **Clapp** oscillator
- Temperature compensating capacitors and good mechanical construction in a practical circuit!

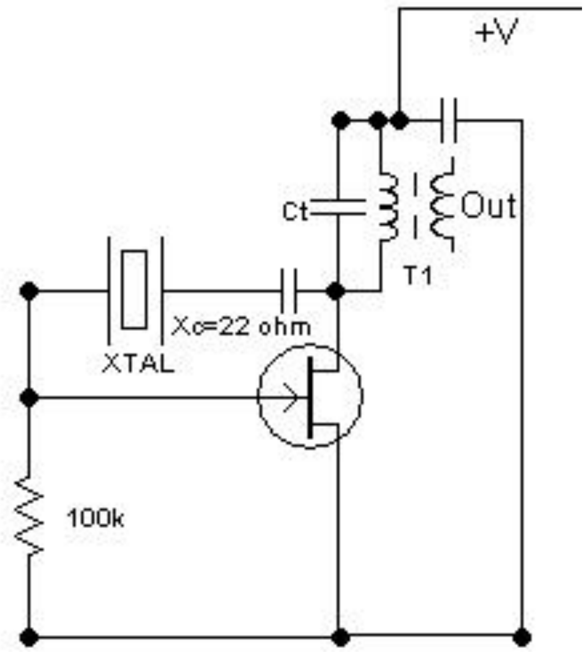


Crystal Oscillator

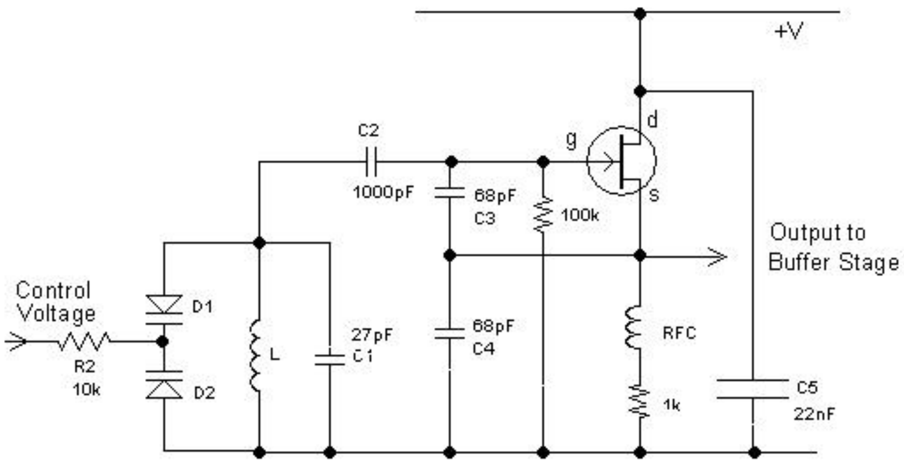
- The tuned circuit in the previous slide can be replaced with a **quartz crystal** to make a highly stable oscillator

- Shown is a xtal oscillator where the mode (**fundamental or overtone**) is determined by the tuned transformer T1

- The xtal acts in series resonant mode; **3rd and 5th overtones** can normally be extracted

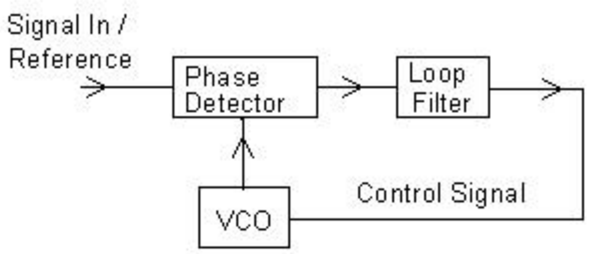


Voltage-Controlled Oscillator (VCO)



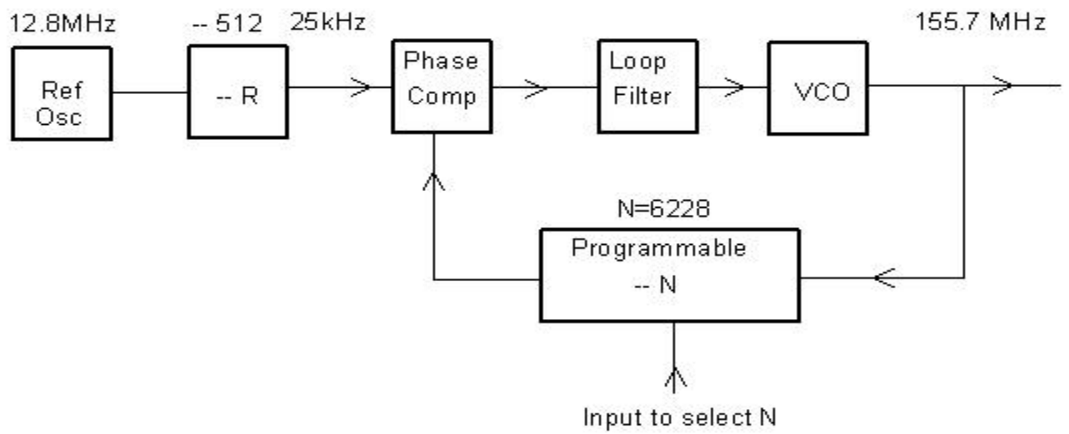
- Typical **VCO** operating at about 30Mhz
- D1 and D2 are variable capacitance diodes (varactors or varicap diodes), capacitance about 40pF at 3v reverse bias; capacitance decreases as reverse bias increases
- Back to back diodes have been used to prevent the RF on the tuned circuit driving the diode into conduction

Phase Locked Loop (PLL)



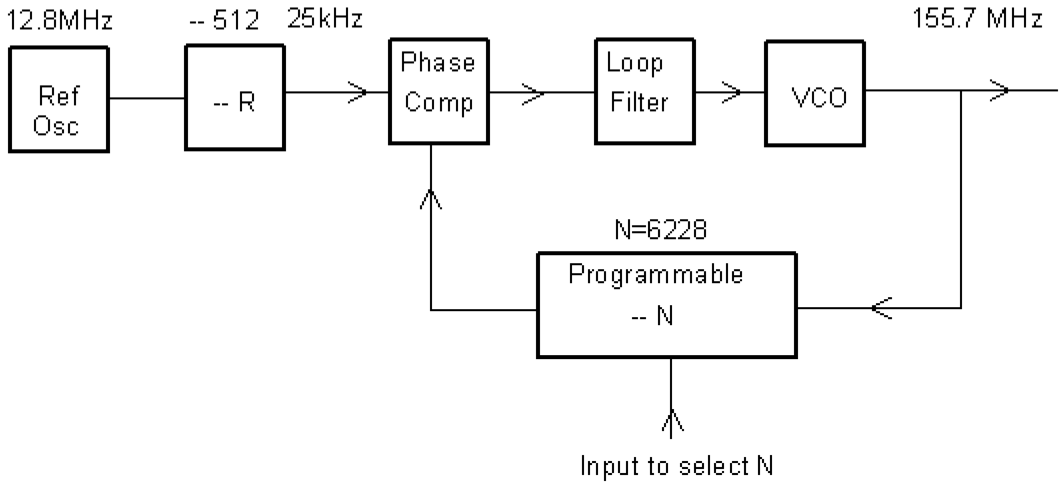
- The **VCO** is locked to a reference or input signal using a control loop
- The **phase detector** (**or comparator**) produces a voltage proportional to the phase difference between the VCO and Reference
- This control voltage is fed back to adjust the VCO and keep it locked to the reference
- The loop filter adjusts the loop response, determining lock-in range

PLL Frequency Synthesis



- A **PLL** keeps its **VCO locked** to a **reference signal**
- If a **programmable divider** (÷N) is placed at the output of the VCO, the VCO can lock at N times the reference frequency
- Therefore, frequency of the VCO can be changed in steps determined by the reference frequency
- The reference frequency is normally generated by stepping down a stable crystal oscillator

PLL Synthesis Example

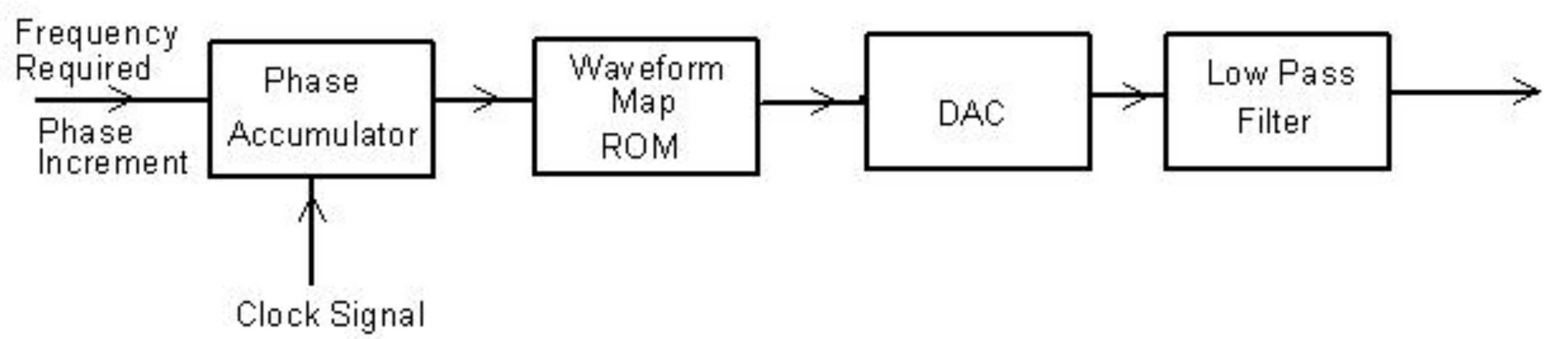


- Ìn the example above the VCO is tuned to 155.7 MHz (145.00 +10.7) to be used in a 2m receiver with 25kHz channel steps
- The VCO is divided by 6228, locked to the reference; 6229 would give 155.725, etc.
- This simple model is limited to wide step spacing

Phase Noise

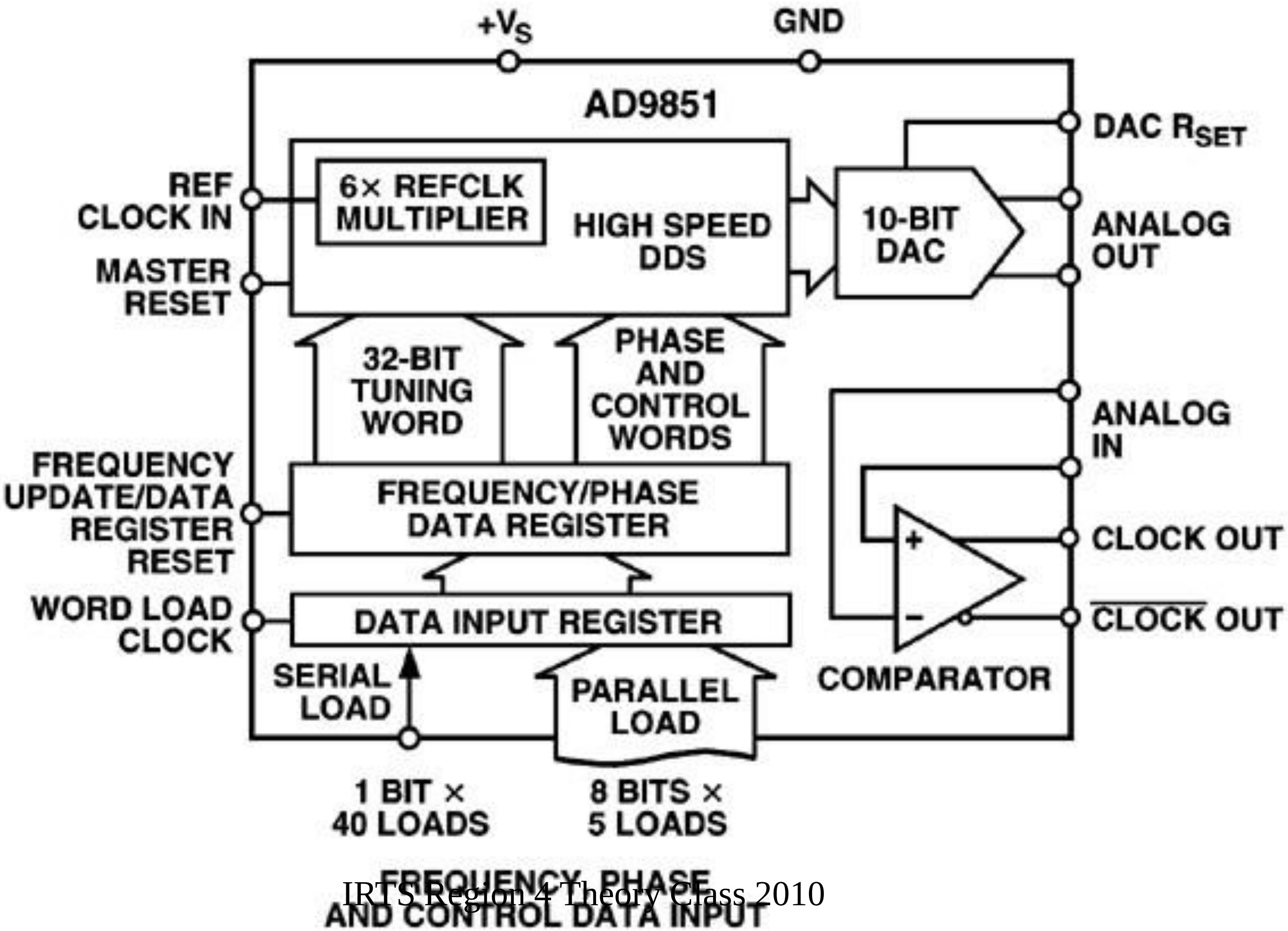
- All analogue oscillators have some noise, phase noise, as a result of noise voltages in the circuit causing phase variations, frequency jitter
- This noise is a lack of purity of the oscillator signal and manifest itself as noise sidebands, (mainly) adjacent to the oscillator frequency
- This will affect transmission causing unnecessary band noise or lead to reciprocal mixing in receivers, reducing performance
- It is least in crystal oscillators; PLL synthesiser circuits tend to be plagued with it

Direct Digital Synthesis (DDS)

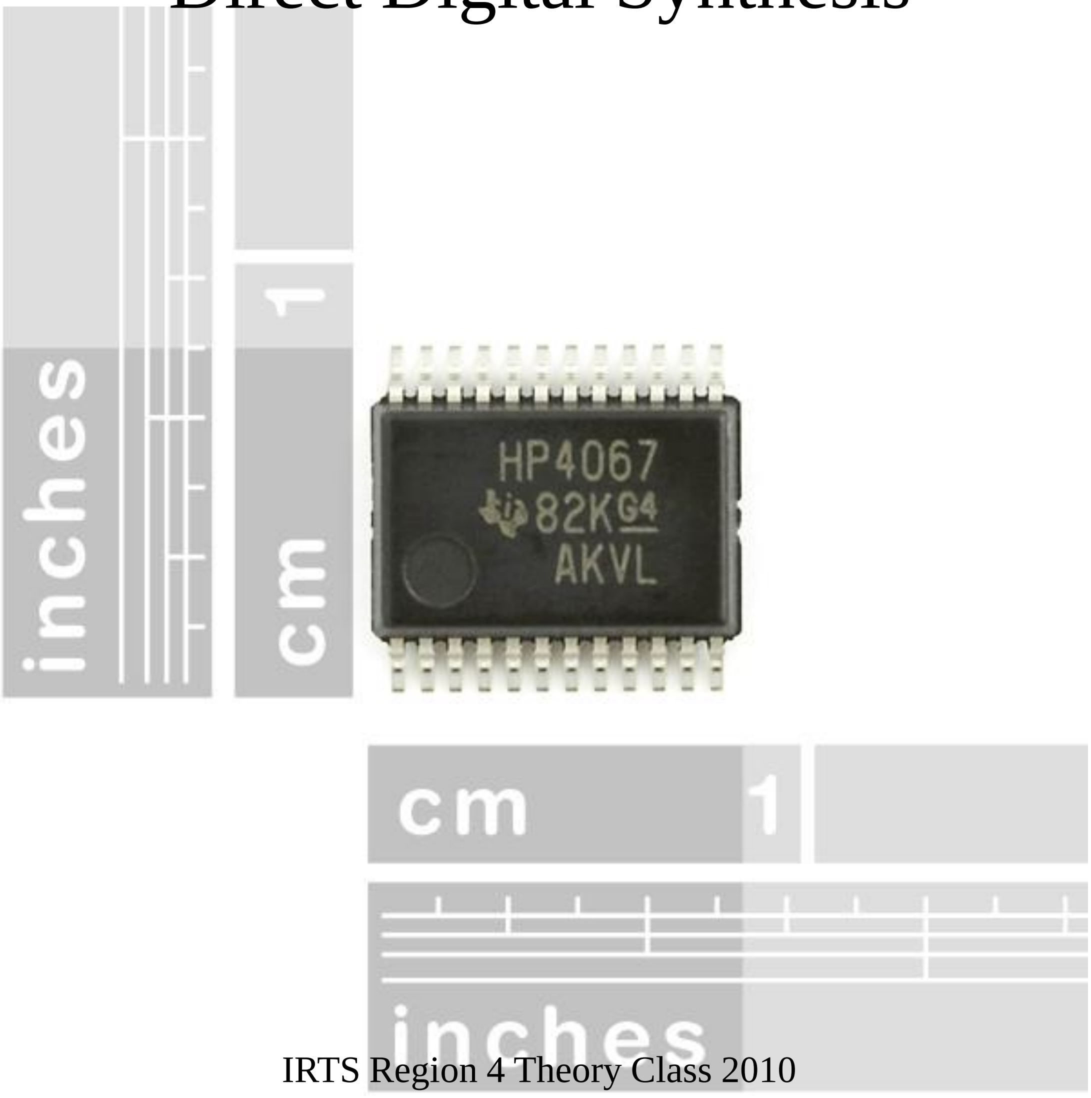


- DDS is a method of generating a waveform which is all digital; the only analogue part is a Digital to Analogue Converter (DAC) at the output
- The points (map) of a waveform for different values of its phase are stored in ROM; they are recalled to generate the waveform; the rate at which this is done determines the frequency;
- The phase increment value determines how much the phase accumulator increments by a for each clock cycle and thus the rate of phase change

DDS
Direct Digital Synthesis



DDS
Direct Digital Synthesis

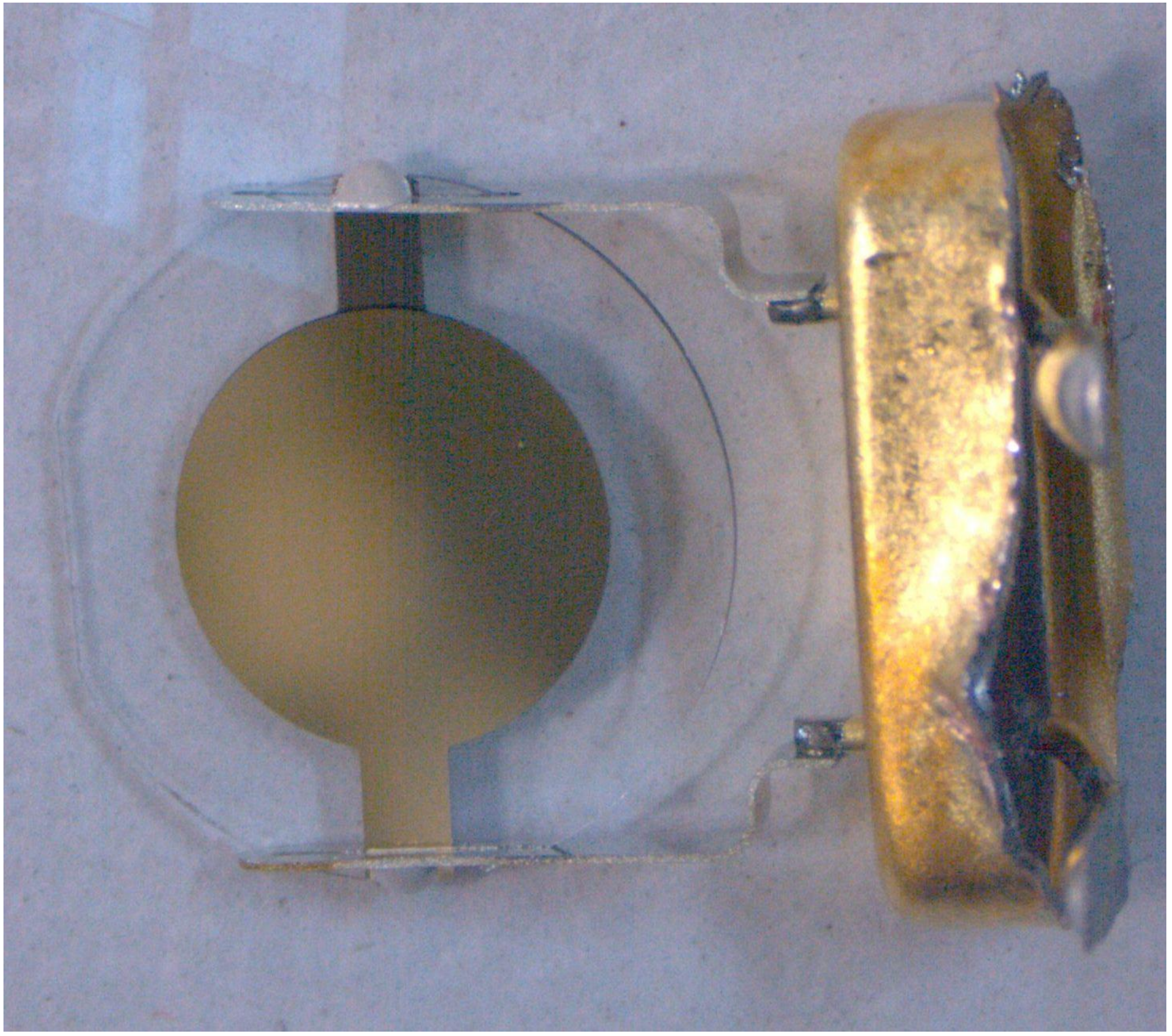


Synthesiser Spurii

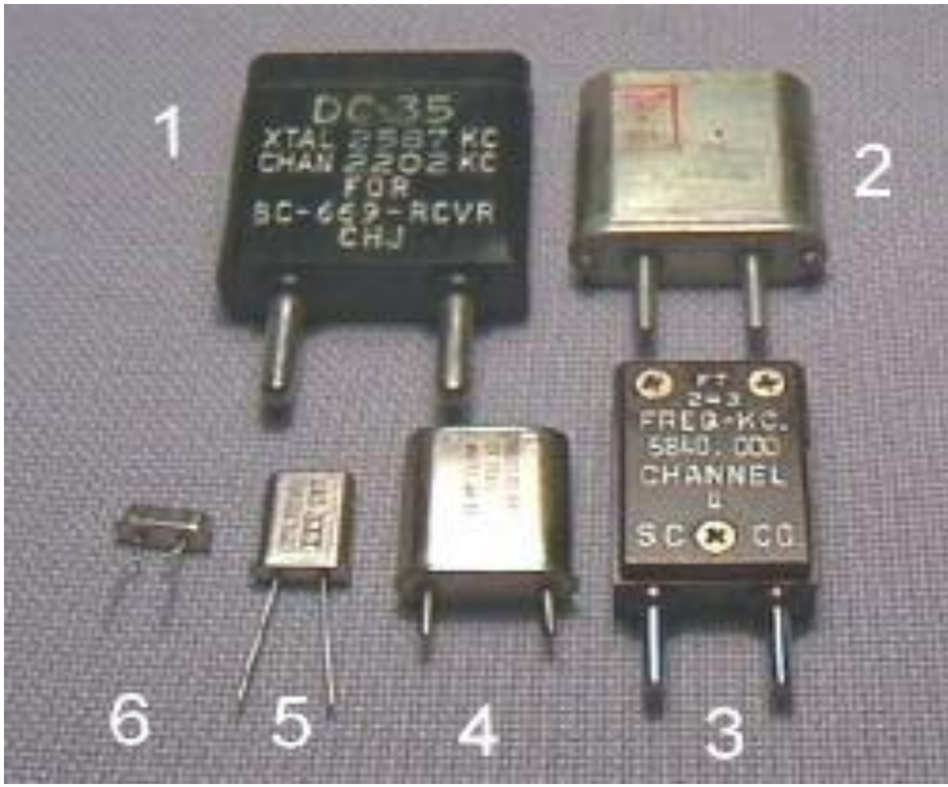
- Phase comparator time constant and frequency has a degree of uncertainty which manifests itself as phase noise
- Situation is not helped if small frequency step resolution, but rapid tuning are both desired
- Synthesisers must detect ‘out of lock’ and inhibit transmission
- Modern synthesisers use dual loops to get small step sizes
- DDS steps would also show up as sidebands/jitter unless filtered out

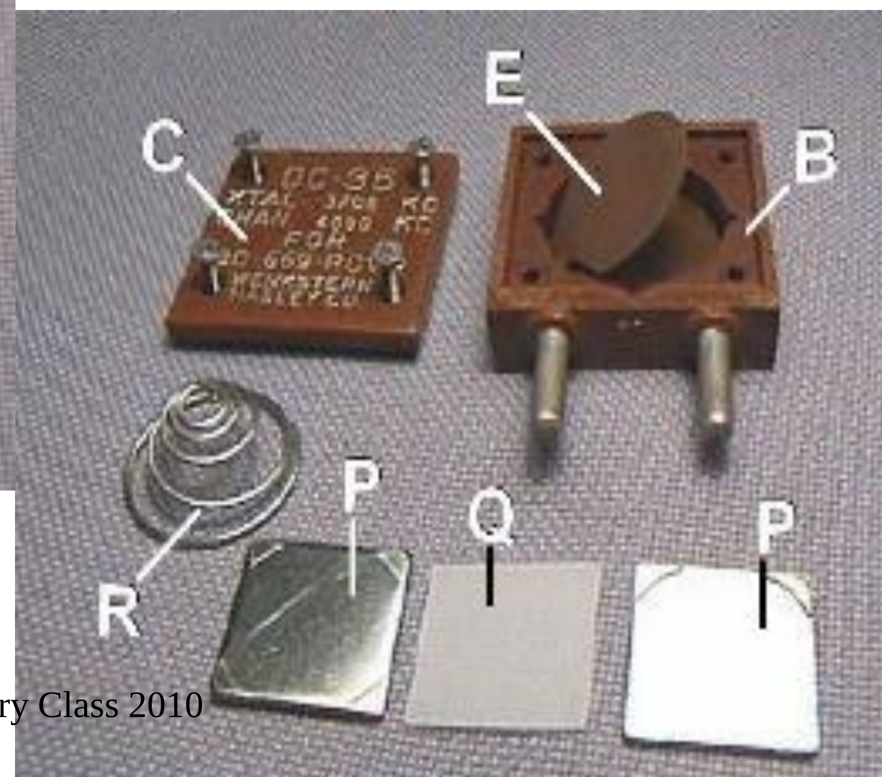
Multipliers

- Multipliers use a severely non-linear stage to deliberately generate harmonics - eg a Class-C amplifier or a diode
- The desired multiples of the input frequency can be selected by a bandpass filter.
- Multipliers are not very efficient, needing up to Watts of input power for milliwatt outputs
- Used in simple crystal based PMR VHF radios, before synths.
- Main role now is in microwave multiplier chains eg. for x2, x3, x5
  - 432MHz x 3 = 1296MHz (23cms)
  - 3.4GHz x 3=10GHz



Quartz Crystals





Crystal Filter