

# SOLUTION to ELE22EMI 2004 NOVEMBER Exam

## Question 1.

(a) What are the name and symbol for the fundamental SI unit of luminous intensity?

**Candela (Cd).**

(b) Given one example each of a direct, an indirect, and a null measurement.

**Direct measurement: measuring the dimensions of A4 paper by placing a ruler beside each edge of the paper.**

**Indirect measurement: measuring temperature using a mercury thermometer.**

**Null measurement: measuring resistance using a Wheatstone bridge.**

(c) What kind of AC bridge is suitable for measuring:

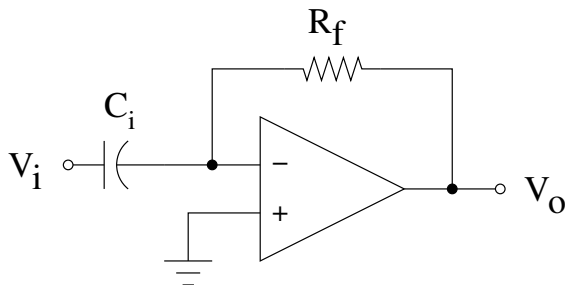
- (1) High-Q inductors? **Hay (or Owens).**
- (2) Capacitance? **Schering.**
- (3) Low-Q inductors? **Maxwell (or Owens).**

## Question 2.

(a) Give five properties of an ideal operational amplifier.

**Infinite gain, bandwidth, input impedance, power supply rails. Zero output impedance, noise generation, phase shift.**

(b) Draw the circuit for an op-amp differentiator.



(c) In a differential op-amp:

- (1) Define the input offset voltage. **The potential difference between the negative and the positive inputs ( $v_a = v_- - v_+$ ). [NB: The value of the offset voltage when the output voltage is zero ( $v_o = 0$ ) is called the zero offset.]**

- (2) Why does a real op-amp have a nonzero input offset voltage? **Because its differential gain is not infinite and its common-mode gain is nonzero.**
- (3) Why do its inputs have nonzero currents? **Because its input impedance is finite.**

### Question 3.

(a) Name two applications of isolation amplifiers.

- (1) **In surgery, separating the currents of the (ungrounded) very low-current sensor attached to the patient from the biologically dangerous currents of the (grounded) electrical equipment that processes and displays the sensor's signals.**
- (2) **Signal acquisition in high voltage circuits. The isolation amplifier protects the low voltage electronics from the high voltage signal sources.**

(b) What is the unit for:

- (1) noise specification?  $\text{V}/\sqrt{\text{Hz}}$ .
- (2) voltage drift?  $\text{V}/\text{K}$  or, equivalently,  $\text{V}/^\circ\text{C}$ .

(c) Describe two (2) situations in which the effect of noise can be reduced. In each case, explain the noise reduction technique that you would use, and why it works.

- (1) **Still images with salt-and-pepper noise can be improved by taking successive photographs and averaging. The S&P noise is random, so it diminishes when averaged.**
- (2) **Mains power noise can be eliminated by a 50 Hz notch filter. This works if the desired signals do not include any frequencies near 50 Hz because the notch filter rejects frequencies immediately near 50 Hz and passes all other frequencies.**

### Question 4.

(a) Strain gauges:

- (1) What is another name for the sensitivity  $S$  of a strain gauge?  
**Gauge factor.**
- (2) Write the formula for  $S$  in terms of the resistance  $R$  and the length  $L$  of a conductive bar under longitudinal compression.

$$S = \frac{\Delta R/R}{\Delta L/L}$$

(b) Thermistors:

- (1) Write the formula for the resistance  $R$  of a thermistor as a function of *absolute* temperature  $T$ , coefficient  $\beta$ , reference temperature  $T_0$  and reference resistance  $R_0$ .

$$\frac{R}{R_0} = \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

- (2) If a thermistor has a resistance of  $300 \text{ k}\Omega$  at  $20$  degrees *Celsius*, and a coefficient  $\beta = 4000 \text{ K}$ , then at what temperature is its resistance equal to  $280 \text{ k}\Omega$ ?

$$\frac{280 \text{ k}\Omega}{300 \text{ k}\Omega} = \exp\left[4000 \text{ K}\left(\frac{1}{T} - \frac{1}{20 + 273.15 \text{ K}}\right)\right]$$

$$\Rightarrow T = \frac{1 \text{ K}}{\frac{1}{4000} \ln\left(\frac{280}{300}\right) + \frac{1}{293.15}}$$

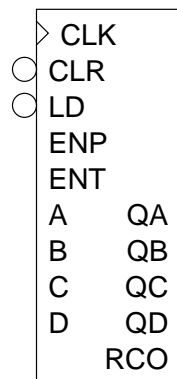
$$\Rightarrow T = 294.64 \text{ K} = 21.49^\circ\text{C}$$

- (c) For a thermocouple, what is the name of the effect whereby a potential applied between the junctions generates a temperature gradient?

**Peltier effect.**

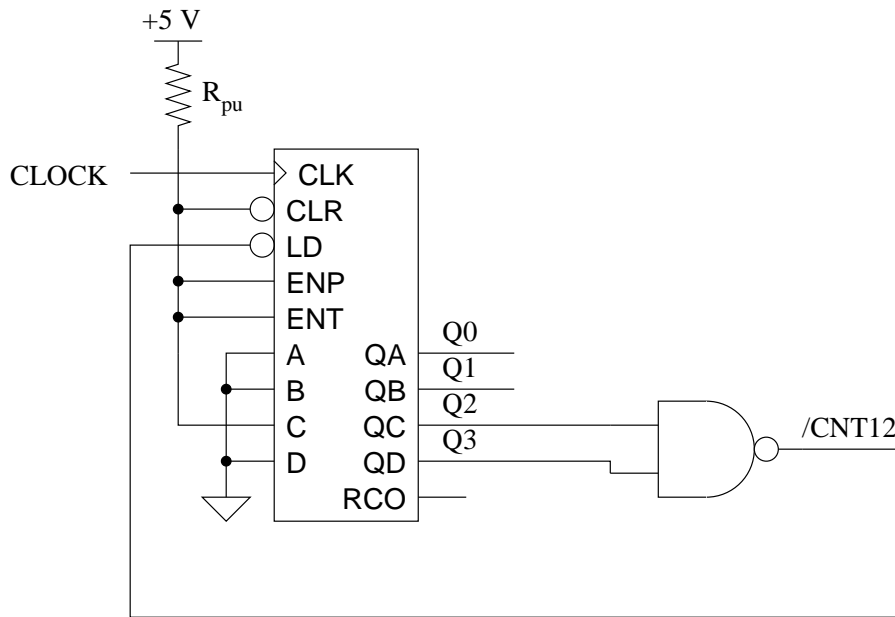
### Question 5.

- (a) In the 74LS163 (see following diagram), what is the function of the control inputs labelled CLK, CLR, LD, ENP and ENT, and what does it mean if the output RCO is high?

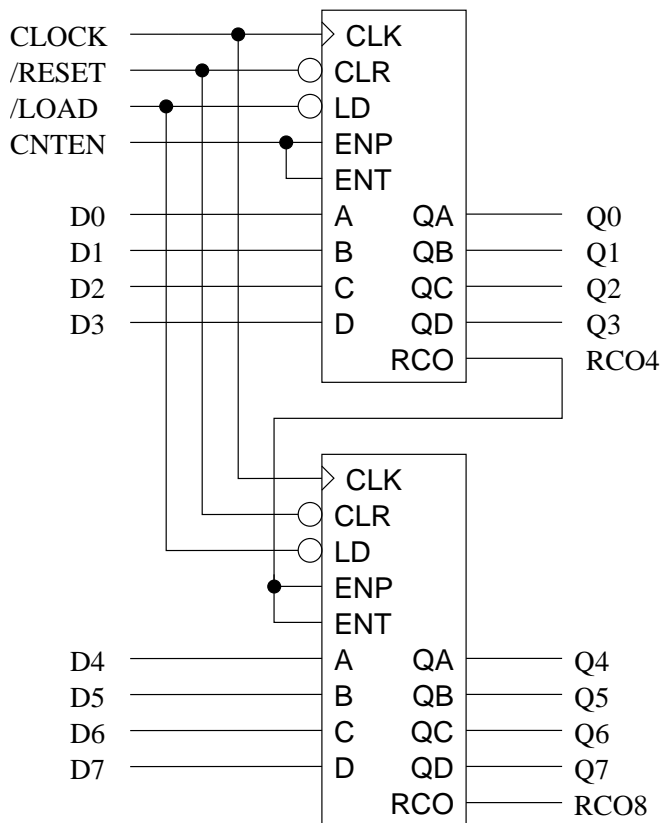


- **CLK = CLoCK**, which paces the counter (controls the rate at which it counts up).
- **CLR = CLeaR**, which when **0** sets all **Q** bits to **0**.
- **LD = LoaD**, which copies (**A B C D**) to (**QA QB QC QD**).
- **ENP = ENable Pulse**, which when **0** halts the counter by preventing the **Q** outputs from changing, thus making the **CLK** input ineffective.
- **ENT = ENable Transition**, which when **0** compels the **RCO** output to remain **0**.
- **RCO = 1** means that **ENT** is **1** and the **Q** bits are all **1** so they represent the hex number **F** (decimal **15**), and the next number will be all **0**. **RCO** acts as a carry-out from the 4-bit counter and is intended as a carry-in to the next higher stage.

(b) Using a 74LS163, draw the circuit for a counter with counting sequence 4, 5, ..., 12.

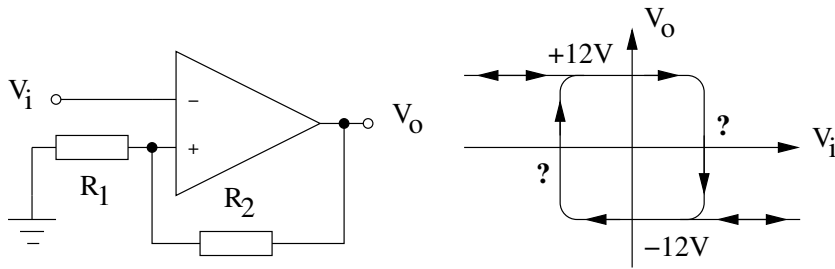


(c) Using as many 74LS163 ICs as necessary, draw the circuit diagram for an eight-bit counter.



### Question 6.

(a) For the simple Schmitt trigger in the next diagram, assume that the maximum and minimum output voltages are +12V and -12V, and that  $R_1 = 3 \text{ k}\Omega$  and  $R_2 = 6 \text{ k}\Omega$ . Calculate the input voltages at which the transitions occur.



$$\frac{v_+}{v_o} = \frac{R_1}{R_1 + R_2}$$

so the upper and lower thresholds for  $v_+$  can be found:

$$v_o = +12V \Rightarrow v_+ = +4V$$

$$v_o = -12V \Rightarrow v_+ = -4V$$

Therefore if  $v_o = +12V$  and  $v_i$  exceeds  $+4V$ , then  $v_o$  will swing to  $-12V$ ; conversely, if  $v_o = -12V$  and  $v_i$  drops below  $-4V$ , then  $v_o$  will swing to  $+12V$ .

(b) State the sampling theorem.

**A bandlimited signal may be reconstructed exactly from a sample if the sampling rate is at least twice the signal's bandwidth.**

(c) An eight-bit DAC has a minimum voltage of zero volts (for the binary input zero) and a maximum voltage of 5.10 V. What binary number produces the output voltage 3.20 V?

**Eight bits implies a digital range of 0 to  $2^8 - 1 = 255$ . Thus each increment corresponds to a voltage step of  $\frac{5.10 - 0.00}{255 - 0} \text{ V} = 0.02 \text{ V} = 20 \text{ mV}$ . Each digital number  $n$  corresponds to a voltage of  $0.00 \text{ V} + n \times 20 \text{ mV} = 20n \text{ mV}$ . Conversely, a voltage  $v$  corresponds to a number  $n = \frac{v}{20\text{mV}}$ . Thus 3.20 V which equals 3200 mV corresponds to  $n = \frac{3200}{20} = 160$ .**

## Question 7.

(a) Describe amplitude modulation (AM).

**In AM, the modulated carrier's voltage *amplitude* is a linear function of the signal amplitude:**

$$c_m(t) = C_0[1 + s(t)] \cos(\omega_c t)$$

**If the signal  $s(t)$  is a sinusoid, then:**

$$c_m(t) = C_0[1 + m \cos(\omega_s t)] \cos(\omega_c t)$$

(b) Describe frequency modulation (FM).

**In FM, the modulated carrier's frequency is a linear function of the signal amplitude:**

$$c_m(t) = C_0 \cos\left\{\left[\omega_c t + \Delta\omega \int_0^t s(t_1) dt_1\right]\right\}$$

**In the simple case of a sinusoidal signal,  $s(t) = \cos(\omega_s t)$ , the formula for the modulated carrier voltage evaluates to:**

$$c_m(t) = C_0 \cos\left\{\left[\omega_c + \frac{\Delta\omega}{\omega_s} \sin(\omega_s t)\right]t\right\}$$

(c) Quote the formula for the modulation index  $m$  of an FM system, and name all the variables in the formula.

**This applies to a sinusoidal signal  $s(t)$  :**

$$m = \frac{\Delta f}{f_m} = \frac{\Delta\omega}{\omega_s}$$

**where  $f_m$  is the modulating frequency which is the instantaneous frequency  $f_s = \omega_s/2\pi$  of the signal  $s(t)$ , and  $\Delta f$  is the maximum frequency deviation which is the difference between the instantaneous frequencies of the modulated and unmodulated carriers.**

(d) Define the following terms:

(1) rise time;

**Rise time is the interval during which a pulse's rising edge increases from 10% to 90% of its amplitude.**

(2) ringing.

**Ringing is the (unwanted) oscillation of a circuit under test (CUT) that can superimpose on its normal frequency response when the input of the CUT is frequency-swept too quickly.**

## Question 8.

(a) Name the three (3) functional parts of a cathode-ray tube (CRT).

(1) **Electron gun.**

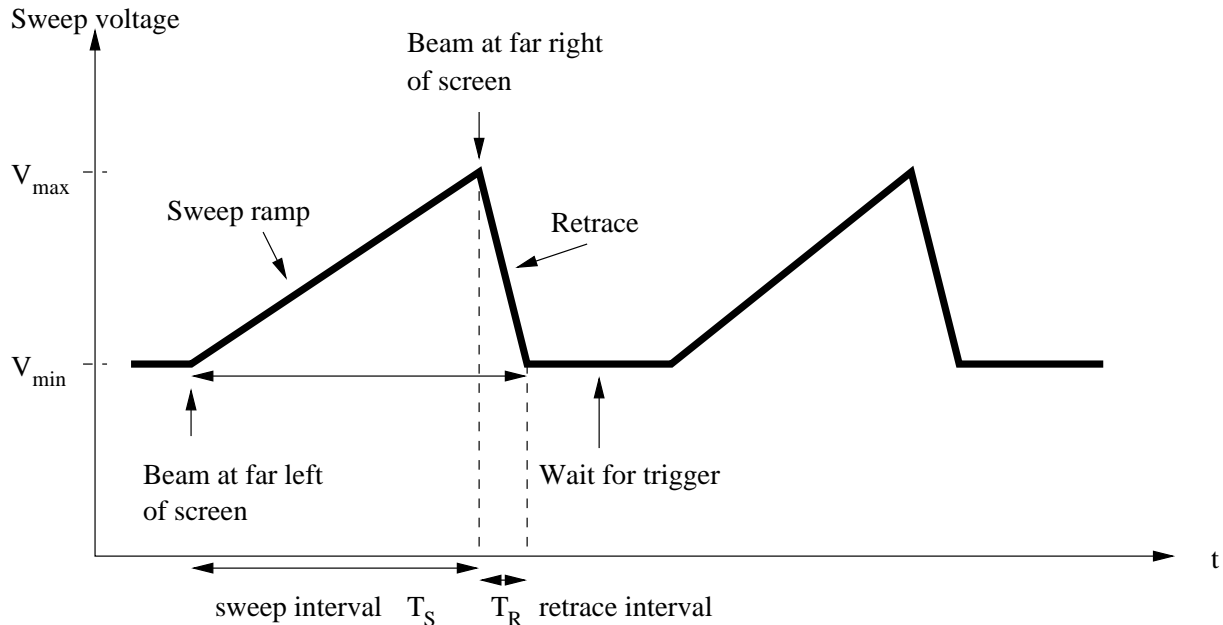
(2) **Deflection plates.**

(3) **Phosphor screen.**

(b) Give the formula relating the oscilloscope bandwidth BW to the rise time  $t_r$ .

$$BW = \frac{0.35}{t_r}$$

(c) Draw the waveform produced by a sweep generator. Label each of the sections and significant points of the waveform.



(d) Name two (2) advantages of sampling oscilloscopes over standard oscilloscopes.

- (1) **Much greater bandwidth.**
- (2) **Digital storage of waveforms.**

### Question 9.

(a) What is the approximate capacitance of a one metre (1 m) length of small-diameter coaxial cable?

**100 pF.**

(b) If a CRO has an input impedance of  $1 \text{ M}\Omega$  in parallel with  $30 \text{ pF}$ , and is connected to  $90 \text{ cm}$  of coaxial cable to a signal generator producing a  $1 \text{ MHz}$  sine wave, then what is the capacitive impedance of the combination of CRO and cable?

$C_{total} = C_{CRO} + C_{cable} = 30 \text{ pF} + 90 \text{ pF} = 120 \text{ pF}$ .  $Z_{cap} = 1/j\omega C_{total} = -j / (2\pi \times 1 \text{ MHz} \times 120 \text{ pF}) = -j 1326\Omega$ .

(c) If the signal generator in part (b) has a source impedance of  $600 \Omega$ , then what is the ratio of the voltage measured by the CRO to the nominal voltage produced by the signal generator? (The nominal voltage may be taken as being the same as the signal generator's Thevenin equivalent voltage.)

**Ignoring capacitive effects, the ratio is  $1\text{M}\Omega / 1.0006 \text{ M}\Omega = 0.9994$ .**

(d) What is the purpose of the variable capacitor in a times-ten probe?

**To adjust the probe's high-frequency compensation.**

(e) What is flashover?

**The arcing of electric current over the body of a probe when attempting to measure a very high voltage.**

### **Question 10.**

(a) In a spectrum analyser, what is the function of the voltage controlled oscillator (VCO)?

**The VCO produces the swept frequency that provides the frequency range represented by the horizontal scale of the spectrum analyser's display.**

(b) Wave analysers are used to measure what three (3) types of quantity?

- (1) **Amplitudes of frequency components.**
- (2) **Signal amplitudes in the presence of noise and interference.**
- (3) **Energy of a signal in a specified frequency band.**

(c) Define total harmonic distortion.

$$\text{THD} = \frac{E_h}{E_f} = \frac{V_{RMS}(\text{harmonics})}{V_{RMS}(\text{fundamental})}$$

**where  $E_h$  = the energy (RMS voltage) due to the harmonics produced in the distortion by the nonlinearity of the amplifier, and  $E_f$  = the energy (RMS voltage) of the fundamental.**

(d) Describe how a distortion analyser works.

**A sinusoid from an oscillator is fed into the Amplifier Under Test (A.U.T.) and the amplifier's output voltage is read on an RMS voltmeter. This measures the total output energy  $E$ . The output of the amplifier is switched to a notch filter centred on the oscillator's frequency, and the filter's output is read on the RMS voltmeter. This measures the energy of the harmonics  $E_h$ . The ratio of these two voltages gives the THD of the amplifier at the oscillator's frequency and amplitude.**

(e) Name five (5) instruments contained in an audio analyser.

- (1) **RMS voltmeter.**
- (2) **DC voltmeter.**
- (3) **Low-distortion audio oscillator.**
- (4) **Signal-to-noise (S/N) ratio meter.**
- (5) **Frequency counter.**

## Question 11.

(a) Define frequency response.

**Frequency response is the ratio of a circuit's output voltage to its sinusoidal input voltage plotted against the frequency of the input.**

(b) What is intermodulation distortion?

**Intermodulation distortion is the amplitude modulation of one signal by another due to nonlinearity of the system in which both signals simultaneously occur. This distortion is measured by  $IMD = \frac{b-a}{a}$  where  $a$  is the distance between the centres of the upper and lower envelope waveforms, and  $b$  is the peak-to-peak voltage of the full envelope.**

(c) Define slew rate.

**An amplifier's slew rate  $S_r$  is the maximum rate of change of the output voltage,  $(\frac{dE_{out}}{dt})_{max}$ , during the transition from the low voltage rail to the high voltage rail.**

(d) Define full-power bandwidth.

**Full-power bandwidth is (high) frequency at which an open-loop amplifier's gain falls to unity (1) while it is delivering its full rated output power.**

(e) Define input offset voltage.

**Input offset voltage is the voltage between the inverting and noninverting inputs of a differential amplifier when its output voltage is zero.**

## Question 12.

(a) State the formula for the total impedance of the RLC series resonant tank circuit.

$$Z_{RLC} = R + j\omega L + \frac{1}{j\omega C}$$

(b) Give the formula from the notes for the bandwidth of a tank circuit.

$$B = \frac{1}{2\pi} \frac{R}{L}$$

(c) In a tuned transformer, there is a magnetic coupling between the primary and secondary windings.

(1) If this coupling is large, what effect does it have on the Q of the circuit?

**The quality factor Q decreases.**

(2) What happens to the frequency response curve if the coupling is very large?

**The curve forms a trough between two broad peaks.**

(d) What is a notch filter?

**A filter that passes all frequencies except for a very narrow band about one frequency (the notch frequency).**

### Question 13.

(a) What company devised the ATE bus architecture on which the GPIB was based? What was their bus called?

**Hewlett-Packard. The Hewlett-Packard Interface Bus (HPIB).**

(b) Name the two GPIB data rates, and state how many kilobytes per second (kB/s) each operates at.

**Unrestricted rate (up to 250 kB/s) and Restricted rate (over 250 kB/s).**

(c) Of what does a minimal GPIB system consist?

**One talker, one listener, no controller.**

(d) What are the three (3) functions of a controller in a GPIB system?

- (1) **Designate the talkers and the listeners.**
- (2) **Command actions within devices.**
- (3) **Is usually a computer (or possibly a programmable calculator).**

(e) Name four classes of commands or address codes used by the GPIB.

**Four (4) of:**

- (1) **Addressed Commands.**
- (2) **Universal Commands.**
- (3) **Listen Addresses.**
- (4) **Talk Addresses.**
- (5) **Secondary Addresses or Commands.**

### Question 14.

(a) Name the three (3) classes of noise source given in the notes.

- (1) **Transmitted.**
- (2) **Intrinsic.**
- (3) **Interference.**

(b) How does pink noise differ from white noise?

**White noise is wideband; pink noise is more intense at low frequencies.**

(c) What causes shot noise?

**Small local fluctuations in DC current.**

(d) Electrically coupled interference voltage increases with what four (4) quantities?

**Four (4) of:**

- (1) **Proximity.**
- (2) **Capacitance between source and pickup circuit.**
- (3) **Frequency of source.**
- (4) **Amplitude of source.**
- (5) **Input impedance of pickup circuit.**

(e) List four (4) everyday sources of electromagnetic interference.

**Four (4) of:**

- (1) **Radio and TV stations.**
- (2) **Radio and TV receivers.**
- (3) **Remote garage door openers.**
- (4) **Remote controls for TV receivers.**
- (5) **Unterminated, active power sockets.**
- (6) **Fluorescent lamps.**
- (7) **Car ignitions.**
- (8) **The sun, Jupiter, and the galaxy.**

### **Question 15.**

(a) State the international standard color for each of the three (3) lines in an AC power cord.

- (1) **Active = brown.**
- (2) **Neutral = blue.**
- (3) **Ground = green with yellow (diagonal) stripes.**

(b) Describe a situation that may give rise to a leakage current inside an instrument.

**If a break occurs in the insulation of the neutral wire inside an instrument with a grounded chassis, then the neutral and the chassis form a leakage capacitance through which AC may flow from the neutral to the chassis, and hence as a leakage current through the ground wire.**

(c) List four (4) possible causes of a ground loop.

- (1) **Potential differences between two connections to different points of a ground plane.**
- (2) **Inductive (magnetic) coupling.**

(3) **Capacitive (electric) coupling between an electrical system and ground.**

(4) **Common-mode noise.**

(d) Give a possible solution to the problem of crosstalk.

**Completely shield the circuits for the mutually interfering channels, and use separate power supplies. (However, this is costly, and not always feasible.)**

## Question 16.

(a) Name and describe two (2) properties of real amplifiers that give rise to distortion.

**Two (2) of:**

(1) **Finite bandwidth (gain depends on frequency).**

(2) **Nonlinearity (gain depends on amplitude).**

(3) **Frequency-dependent phase.**

(4) **Amplitude-dependent phase.**

(5) **Finite power supply.**

(b) What is hiss noise?

**Radio frequency (RF) noise that is evenly distributed over a wide frequency band. (In other words, it's RF white noise.)**

(c) If an electric shield has an opening in the shape of a cylinder with a diameter of 2 cm and a sleeve of length 8 cm, then what is the attenuation of an interference waveform of wavelength 60 cm that enters that opening? [Hint:  $54.5(\frac{L}{\lambda_c})\sqrt{1 - (\frac{\lambda_c}{\lambda})^2}$ , where  $\lambda_c = \pi r$ . ]

**Given data:**  $r = d/2 = 1 \text{ cm} = 0.01 \text{ m}$ ;  $L = 8 \text{ cm} = 0.08 \text{ m}$ ;  $\lambda = 60 \text{ cm} = 0.60 \text{ m}$ .

**Derived data:**  $\lambda_c = \pi \times 0.01 \text{ m}$ .

**Attenuation is:**

$$54.5\left(\frac{0.08}{0.01\pi}\right)\sqrt{1 - \left(\frac{0.01\pi}{0.60}\right)^2} = 138.6$$

(d) What might you use to eliminate the interference caused by the 50 Hz hum from the mains power?

**A notch filter centred at 50 Hz.**