UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems.	Section A Page 1
Question 1		Mark Allocation

(a) A general expression for a time varying radio signal can be of the form :-

$$f(t) = A \cdot \cos(\omega_0 t + \phi_0) \text{ where}$$

A = Amplitude - $\omega_0 = 2\pi f_0$ where f_0 represents the frequency.

ϕ_0 - Initial phase.

For amplitude modulation, A may be varied by an expression of the form :- $(1 + m\cos\omega_m t)$ where m is the modulation depth $(0 \le m \le 1)$ and $\omega_m = 2\pi f_m$, where f_m is the modulating frequency. Thus the expression becomes :-

$$f(t) = A(1 + m\cos\omega_m t) \cdot \cos(\omega_0 t + \phi)$$

or, more typically : $f(t) = A(1 + m\cos\omega_m t) \cdot \cos\omega_0 t$

where $\omega_0 = \omega$ = carrier frequency.

For frequency modulation, the term ω may be replaced by : $\omega \to (\omega_0 + \omega(t))$ or similar where ω_0 is the carrier frequency and $\omega(t)$ is a time-varying frequency related to the modulation ~~frequency~~ function of the form :-

$\omega(t) = K_f f_m(t)$ so the full expression can (K_f is a constant). be of the form : $f(t) = A\cos([\omega_0 + K_f \cdot f_m(t)]t + \phi)$

or $f(t) = A \cdot \cos([\omega_0 + K_f \cdot f_m(t)]t)$.

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems.	Section A Page 2
Question 1		Mark Allocation

for phase modulation, the term ϕ is modified by a term involving the modulating frequency :-

$$f(t) = A\cos(\omega t + \phi(t))$$

If $\phi(t) = K_\phi f_m(t) + \phi_0$ (K_ϕ is a constant) ($f_m(t)$ is modulating function).

$$\Rightarrow f(t) = A\cos(\omega t + K_\phi f_m(t) + \phi_0)$$

Usually $f(t) = A.\cos(\omega t + K_\phi \cdot f_m(t))$. (5/25)

(b) Audio signal is in a range 250Hz $\rightarrow$ 4KHz.

Carrier is 170MHz. Audio is ± 2 volts. Carrier is 5 volts, peak-to-peak.

Hence, if $f(t) = A(1 + m\cos\omega_m t).\cos\omega_0 t.$

$A = 2.5$ volts. $m = (4/5) = \left(\frac{A_m}{A}\right)$ where

A_m is the modulating signal amplitude.

$$\Rightarrow f(t) = 2.5(1 + 0.8.\cos\omega_m t).\cos\omega_0 t.$$

where $\omega_m = 2\pi f_m$

$250 \le f_m \le 4KHz$

and $\omega_0 = 2\pi f_0$; $f_0 = 170MHz$

To find the various powers, the original expression for $f(t)$ must be examined :-

$$f(t) = A(1 + m\cos\omega_m t)\cos\omega_0 t.$$

Expanding this gives :-

$$f(t) = A\cdot\cos\omega_0 t + A.m.\cos\omega_m t.\cos\omega_0 t.$$

Using an identity : $\cos\theta_1 . \cos\theta_2 = \frac{1}{2}\left(\cos(\theta_1+\theta_2) + \cos(\theta_1-\theta_2)\right)$

gives : $f(t) = A\cos\omega_0 t. + \left(\frac{Am}{2}\right)\left(\cos(\omega_m+\omega_0)t + \cos(\omega_0-\omega_m)t\right).$

Where $(\omega_m+\omega_0)$ represents the upper sideband and
$(\omega_0-\omega_m)$ " " lower " .

<u>To determine powers</u> :-

Power in carrier component (referred to 1Ω)

$= (V_{RMS})^2$ where V_{RMS} is the RMS value of the carrier component voltage ;

$$= \left(\frac{A^2}{2}\right) = \left(\frac{2.5^2}{2}\right) = \left(\frac{6.25}{2}\right) = \underline{3.125}$$

In a $50\,\Omega$ load $\rightarrow$ power $= \frac{(V_{RMS})^2}{50} = \frac{3.125}{50}$

$$= \underline{62.5\,mW}.$$

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems.	Section A Page 4
Question 1		Mark Allocation

Power in each sideband in 1Ω is :-

$$(V_{RMS})^2 \text{ where } V_{RMS} = \left(\frac{\text{Peak amplitude}}{\sqrt{2}}\right),$$

as before for calculation of the carrier component.

As the audio is ± 2 volts, peak = 2 volts so

$$V_{RMS} = \left(\frac{2}{\sqrt{2}}\right) = \sqrt{2} \text{ volts}.$$

$$\Rightarrow (V_{RMS})^2 = 2$$

$$\Rightarrow \text{power in } 50\Omega \text{ is } \left(\frac{2}{50}\right) \equiv \underline{\underline{40\,mW}}$$

Both sidebands are equal as well.

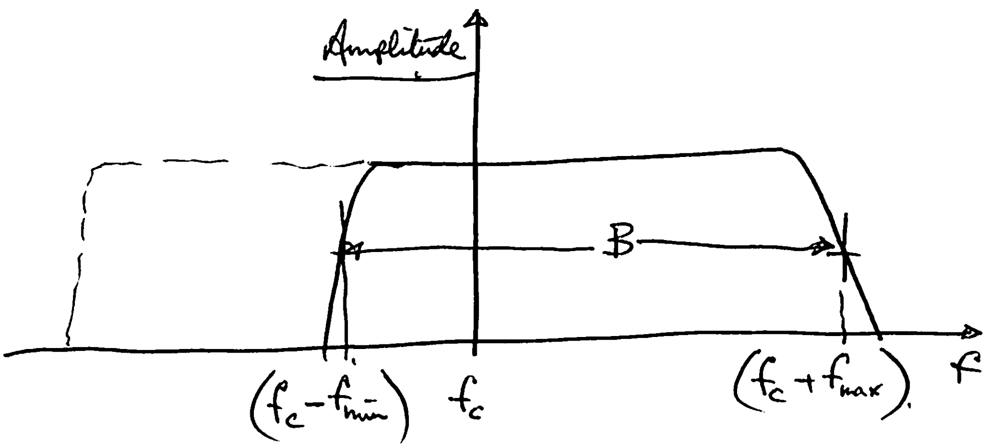
Wasted power is that transmitted in the carrier as it is not related to the modulating function ie 62.5 mW. The whole power ~~transmitted~~ is the sum of (carrier power + power in both sidebands)

$$\therefore \text{Ratio is } \frac{62.5\,mW}{(62.5+40+40)\,mW} = \underline{\underline{0.439}}$$ $\left(\frac{10}{25}\right)$

(c) VSB means "Vestigial Sideband" and refers to the technique of filtering a double sideband signal

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES3350	Title of Examination:– Communication Systems.	Section A Page 5.
Question 1		Mark Allocation

— to give only a vestige of one of the sidebands, to reduce the bandwidth used :—



f_c = Carrier frequency

$f_{min} < f_{max}$

If $f_{min} \le f_{max}$ but not zero, some carrier is still transmitted but the overall bandwidth ($f_{max} + f_{min}$) is still less than the full AM bandwidth $2f_{max}$. The other advantage of the method is that the signal can still be detected using an AM detector, which is quite simple to implement. This is why it has been used in a popular consumer application, analogue T.V. because it makes the receiver cheaper (or it used to in the days of valve technology — not so much nowadays). In comparison, SSB requires a balanced mixer, phase locked local oscillator (ideally) in order to be detected properly. However, SSB requires even less bandwidth & is more power efficient. (10/25)

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UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems	Section A Page 6
Question 2		Mark Allocation

(a) Shot noise is caused by random processes of conduction in an active device, or random processes of generation of electronic signals due to active devices.

Typical devices which generate shot noise include :-

(1) Bipolar transistors.
(2) Diodes.
(3) Field Effect Transistors.
(4) Vacuum tube devices.
(5) Photodiodes.
(6) Phototransistors (etc).

The formula relating the noise current in a device and the shot noise associated with it is given by:-

$$\overline{i_s^2} = 2q\, I_s\, \Delta f$$

where q = charge on electron.
I_s = signal current
Δf = Bandwidth of channel/measurement.

(6/25)

(b) For thermal noise : $\overline{i^2} = 4KTG\,\Delta f = \frac{4KT}{R}.\Delta f$

Alternatively, this can be regarded as a voltage given by

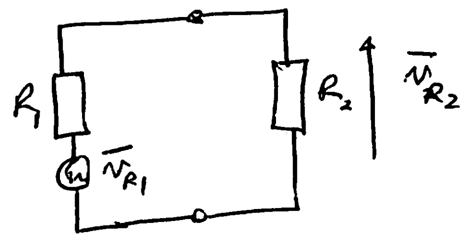
$$\overline{v^2} = \overline{i^2}.R^2 = \left(\frac{4KT.\Delta f}{\cancel{R}}\right)R^{\cancel{2}} = \underline{4KTR.\Delta f}$$

or $\overline{v} = \sqrt{4KTR\Delta f}$

K = Boltzmann's constant.
T = Absolute temperature
Δf = Bandwidth

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems.	Section A Page ~~3~~ 7
Question 2		Mark Allocation

The available noise power from a resistance R is ~~that~~ which it would deliver to another resistance R according to the maximum power transfer theorem:–



Resistances R_1 and R_2 deliver equal thermal noise to each other – if $R_1 = R_2$. In terms of voltage $\bar{v}_{R_2}$ due to noise source $\bar{v}_{R_1}$:–

$$\bar{v}_{R_2} = \left(\frac{R_2}{R_1+R_2}\right)\bar{v}_{R_1} = \frac{\bar{v}_{R_1}}{2}.$$

$$\therefore \quad \bar{v}_{R_2} = \frac{\sqrt{4KTR_1\Delta f}}{2} \quad \text{or} \quad \bar{v}_{R_2}^{\,2} = \left(\frac{4KTR\Delta f}{4}\right)$$

$$\Rightarrow \bar{v}_{R_2} = KT.R_1\Delta f.$$

$\therefore$ Noise power delivered to R_2 due to R_1

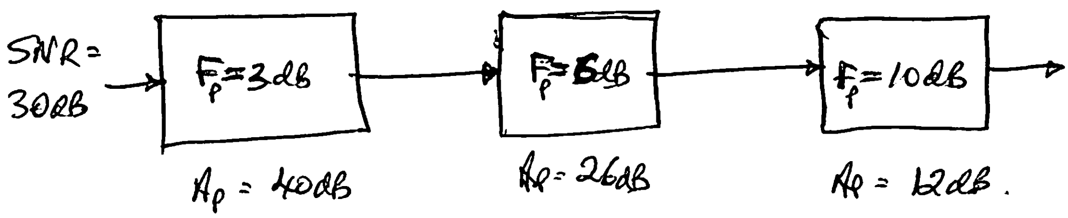
$$= \left(\frac{\bar{v}_{R_2}^{\,2}}{R_2}\right) = \frac{\cancel{4}KTR_1\Delta f}{R_2} = \underline{\underline{\cancel{4}KT\Delta f}}$$

$\left(\frac{7}{25}\right)$

<u>$KT\Delta f$ is the available noise power.</u>

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems.	Section A Page 8
Question 2		Mark Allocation

(c)



To determine the overall noise figure, the noise figure of each stage must be calculated from :-

$$F_p(\text{as a ratio}) = 10^{(F_p/10)} \quad \text{where } F_p \text{ is in dB.}$$

∴ For the first stage → $3\text{dB} \equiv 10^{3/10} = \times 2$.

— — second " → $6\text{dB} \equiv 10^{6/10} = \times 4$

third " → $10\text{dB} \equiv 10^{10/10} = \times 10$.

∴ Using the standard Friis formula :-

$$F = F_1 + \left(\frac{F_2 - 1}{G_1}\right) + \frac{(F_3 - 1)}{G_1 G_2}$$

gives the noise figure, as a ratio, for the whole chain.

The gains need to be calculated as numerical ratios also :-

$$G_1 = 40\text{dB} \equiv 10^{(40/10)} = 10^4$$
$$G_2 = 26\text{dB} \equiv 10^{(26/10)} = 4 \times 10^2 = 400$$
$$G_3 = 12\text{dB} \equiv 10^{(12/10)} = 16$$

UNIVERSITY OF WARWICK Department of Engineering	Year 2011
ES 3350 | Title of Examination:– Communication Systems.	Section A Page 9
Question 2	Mark Allocation

Thus the overall noise figure is:–

$$F = 2 + \left(\frac{4-1}{10^4}\right) + \left(\frac{10-1}{10^4 . 400}\right)$$

2 . 000 000 000 000
. 0003
. 00000225

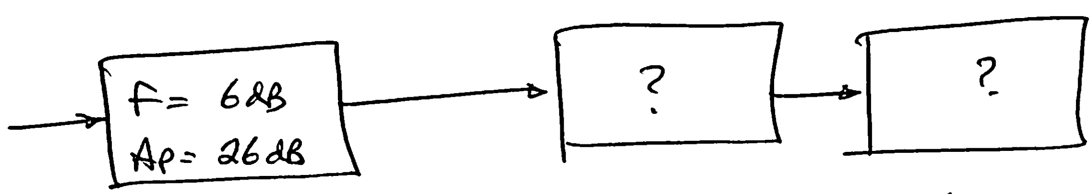
$$= 2 + \left(3\times10^{-4}\right) + \left(\tfrac{9}{4}\times 10^{-6}\right)$$

$$= \underline{\underline{2.00030225}} \equiv \underline{\underline{3\,dB (approx)}}$$

∴ The SNR at the ~~output~~ is given by:–

$$SNR_o(dB) = SNR_i - F(dB) = \underline{\underline{27\,dB}}$$

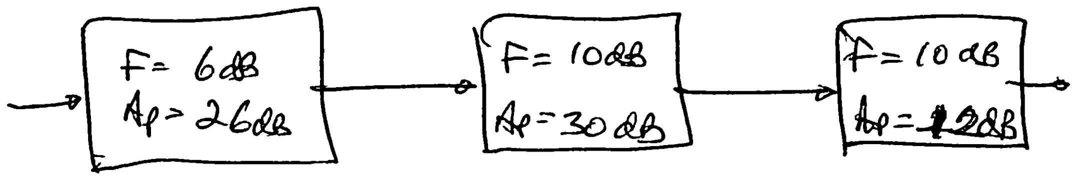
If the first stage became:– F = 10 dB & G = 30 dB, then the order may have to be different. In general, the stages with the lowest noise figures should go first, with account taken of gain in borderline situations. The current second stage has a noise figure of 6 dB, so this should go first:–



The question is: which should be next – the stage with a gain of 30 dB and noise figure 10 dB, or

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES3350	Title of Examination:– Communication Systems.	Section A Page 10
Question 2		Mark Allocation

one with a gain of 12 dB and noise figure 10 dB ?
As they both have the same noise figure, then the one with the higher gain should go first :–



The overall noise figure is thus :–

$$F = F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2}$$

$$= 4 + \frac{(10-1)}{400} + \frac{(10-1)}{400 \times 1000}$$

Due to 2nd stage

$$= 4 + 0.0225 + 0.0000225$$

$$= \underline{4.023}$$

If the second and third stages were exchanged, the denominator of the third term would be ~~larger~~ smaller so that the third term would be larger. (12/25)

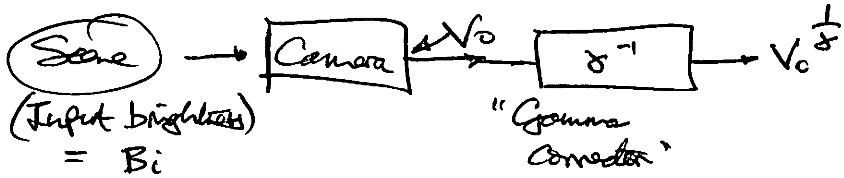
(25)

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems.	Section A Page 11
Question 3		Mark Allocation

(a) A standard analogue T.V. system employs gamma correction because originally it was designed to deliver pictures to cathode ray tube displays. These displays have a relationship between control voltage and displayed brightness of the form:–

$$\underset{\substack{(\text{Output brightness}) \\ B_o}}{(\text{Brightness})} = kV^{\gamma}$$ where γ lies between 2 and 3 typically.

Therefore, to obtain overall linearity from camera input to display output requires predistortion of the signal from the camera before it is sent over the TV channel:–



If the signal is then applied to the T.V. display:–

$$B_o = kV^{\gamma} = k\left(V_o^{\frac{1}{\gamma}}\right)^{\gamma} = \underline{\underline{kV_o}}$$

$$\therefore B_o = kV_o \text{ (from camera)}$$

If V_o (from camera) $= KB_i \rightarrow B_i =$ Input brightness

UNIVERSITY OF WARWICK Department of Engineering	Year 2011
ES 3350 — Title of Examination:– Communication System	Section A Page 12
Question 3	Mark Allocation

Then $B_o = kV_o = k(KB_i) = (kK)B_i$

k, K are constants, so if $(kK) = C$ then

$\underline{B_o = C.B_i}$ (Overall linearity)

This affects monochrome compatibility because a colour image is sent :-

$Y' = (l_1 R' + l_2 G' + l_3 B')$ where R' etc are the gamma corrected primary signals, and l_1 etc are the luminosity coefficients, and Y' the gamma corrected luminance.

In general $(Y')^{\gamma} \neq Y$ ~~→ the~~ true luminance $= (l_1 R + l_2 G + l_3 B)$

except for greys. Therefore monochrome compatibility is lost when a gamma corrected luminance signal is generated

$\left(\frac{8}{25}\right)$

(b) ∴ The true luminance is ∴ $Y = 0.3(0.3) + 0.6(0.6) + 0.1(0.4)$

$= 0.09 + 0.36 + 0.04 = \underline{0.29}$

The transmitted luminance is $Y' = l_1 R' + l_2 G' + l_3 B'$

$$Y' = 0.3R' + 0.6G' + 0.1B'$$

$$R' = (0.3)^{\frac{1}{2}} = 0.55. \quad G' = (0.6)^{\frac{1}{2}} = 0.77.$$

$$B' = (0.4)^{\frac{1}{2}} = 0.63.$$

$$\Rightarrow Y' = (0.3)(0.55) + (0.6)(0.77) + (0.1)(0.63)$$

$$= \underline{\underline{0.65}}$$

The colour difference signals are :–

$(B'-Y')$ and $(R'-Y')$

$$(B'-Y') = (0.63 - 0.65) = \underline{\underline{-0.02}}$$

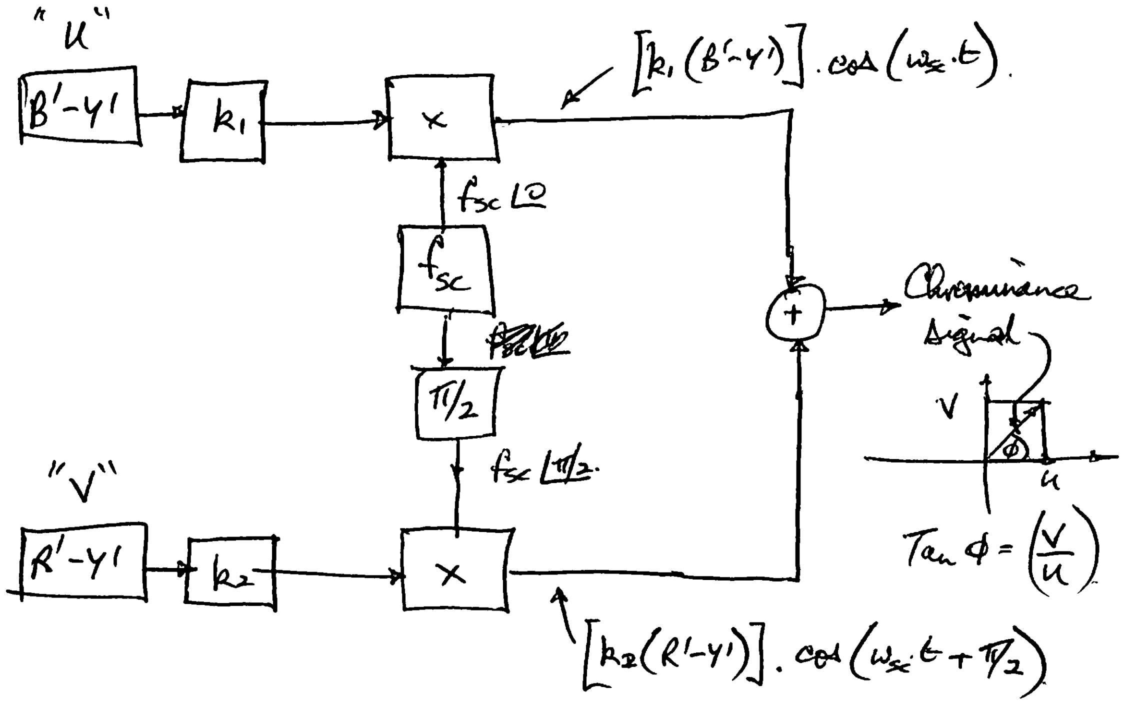
$$(R'-Y') = (0.55 - 0.65) = \underline{\underline{-0.10}}$$

The luminance on a monochrome display is :–

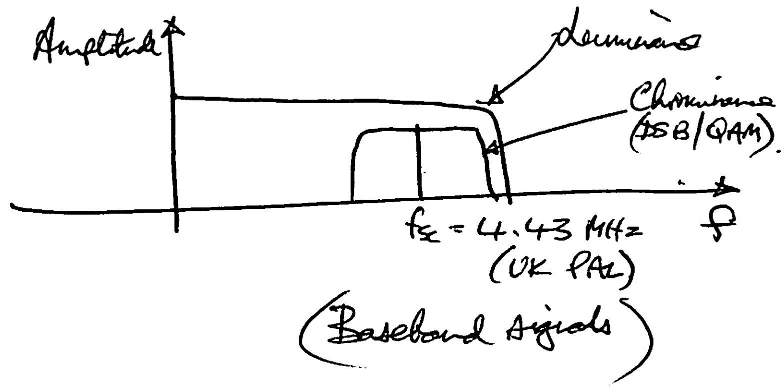
$$Y = (Y')^{\gamma} = (0.65)^2 = \underline{\underline{0.42}} \qquad \left(\frac{10}{25}\right)$$

(c). The chrominance signals are transmitted using quadrature amplitude modulation of a subcarrier. The frequency of the subcarrier is chosen to minimise interference with harmonics of line frequency. The QAM system involves two balanced modulators and each colour difference signal is weighted before it is used to modulate its own subcarrier as follows:

UNIVERSITY OF WARWICK Department of Engineering		Year 2011
ES 3350	Title of Examination:– Communication Systems	Section A Page 14
Question 3		Mark Allocation



The chrominance signals occupy spectrum as follows:



The chrominance signal is a suppressed carrier signal & so disappears when $(R'-Y') = (B'-Y') = 0 = (G'-Y')$, for greys, white & black.

They are ~~detected~~ using a colour subcarrier of the correct phase and two balanced demodulators, the subcarrier being sent as a reference on each line (UK PAL).

(7/25)

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