EEE6224 2015 SOLUTIONS

Q1) (a) Consider Fig.1. Assume we have 5 subcarriers with frequencies f_0 to f_4 separated by Δf with corresponding amplitudes F_0 to F_4 (Fig.1(a) to (e)). If the amplitude of each sub-carrier is either $F_m = 0 \; or \; 1$, then each carries one bit of information. Assume we transmit a word comprising 5 bits all set to '1' in this case ('11111'), so $F_0 = F_1 = F_2 = F_3 = F_4 = 1$. The OFDM symbol in (f) is obtained by multiplying signals (a), (b), (c), (d) and (e) by an incremental phase term and then summing, and this resultant signal is then transmitted. The OFDM symbol length is T_s, so the *symbol rate* = $1/T_s$ but the bit rate is $5/T_s$. At the receiver, a Fourier transform is then performed on this signal to recover the spectral components F_0 to F_4 and their amplitudes will then spell out the word '11111'. To transmit '11011' instead, we would set $F_2 = 0$ etc. For transmission in Fig.2(a), the sub-carrier amplitudes F_0 to F_{M-1} representing one OFDM symbol of duration T_s are mapped to the input of the IFFT chip. Guard subcarriers are added either side of the spectrum, and no information is transmitted on these. The IFFT output is then converted to a time sequence through parallel to serial conversion (P/S) and then a Cyclic Prefix (CP) is added to avoid interference between OFDM symbols. The resulting time sequence is then up-converted from baseband to the RF channel frequency, amplified and transmitted. At the receiver in Fig.2(b), the received signal is filtered, amplified and down-converted from RF to baseband. The CP sequence is discarded and the symbol time sequence of duration T_s converted to parallel format and FFT'd to reproduce the complex spectrum amplitudes F_0 to F_{M-1} representing the bits. Frequency Domain Equalisation (FDE) is performed using channel estimates from received pilot signals. 1 1 1 1

(b) The transmitted signal $s(t)$ is Fourier transformed at the receiver thus

$$F_n = \frac{1}{T_s}\int_0^{T_s} s(t)e^{-j2\pi n\Delta f t}dt \qquad (1)$$ 1

so from $s(t)$ in the question

$$F_n = \sum_{m=0}^{M-1} F_m \frac{1}{T_s}\int_0^{T_s} e^{j2\pi\Delta f(m-n)t}dt \qquad (2)$$ 1

and since

$$\frac{1}{T_s}\int_0^{T_s} e^{j2\pi\Delta f(m-n)t}dt = \begin{Bmatrix} 1, & n = m \\ 0, & n \neq m \end{Bmatrix} \qquad (3)$$ 1

because of orthogonality, then $F_n = F_m$ and the subcarrier is recovered. 1

(c) (i) Speed of light= $300m/\mu s$, so maximum path difference = $6.67 \times 300 \approx 2km$ 2

(ii) 64QAM $\equiv 6bits/symbol$, so bit rate is $6 \times$ baud rate $\times$ no. of carriers= $9Mbits/s$ 2

(iii) The CP reduces the overall capacity as a fraction of the symbol period, so here there is a 10% reduction in capacity. 2

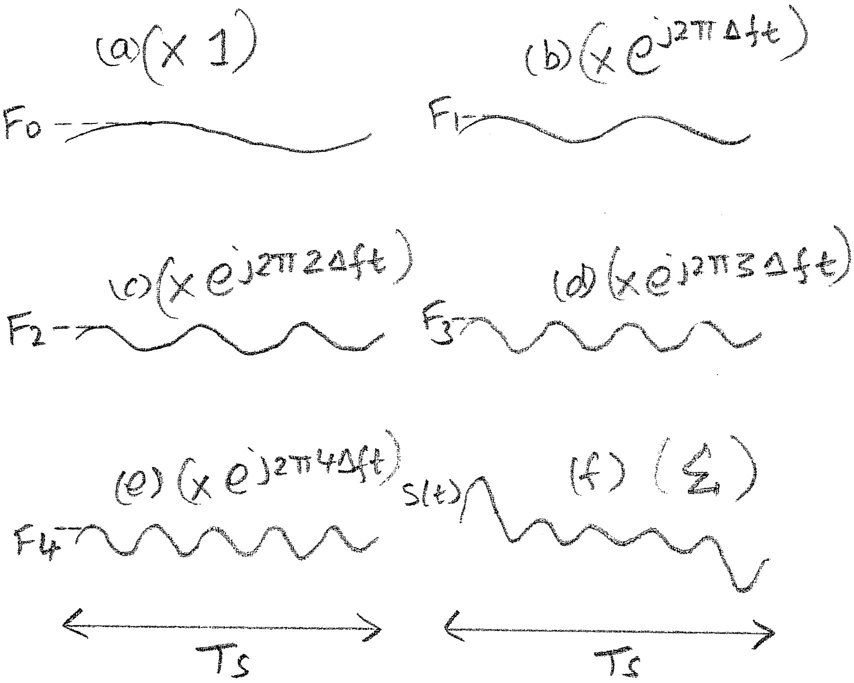

Fig 1

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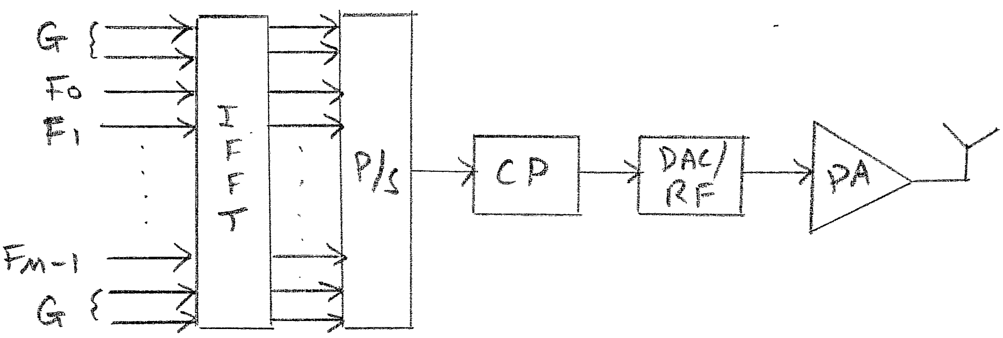
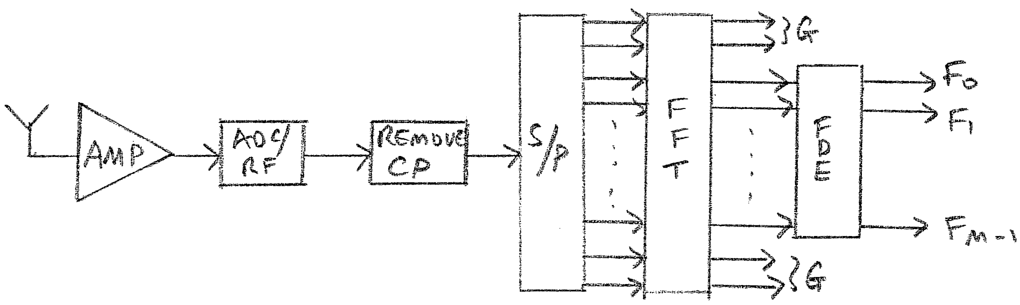


2

(a)

Fig 2



2

(b)

Q2)

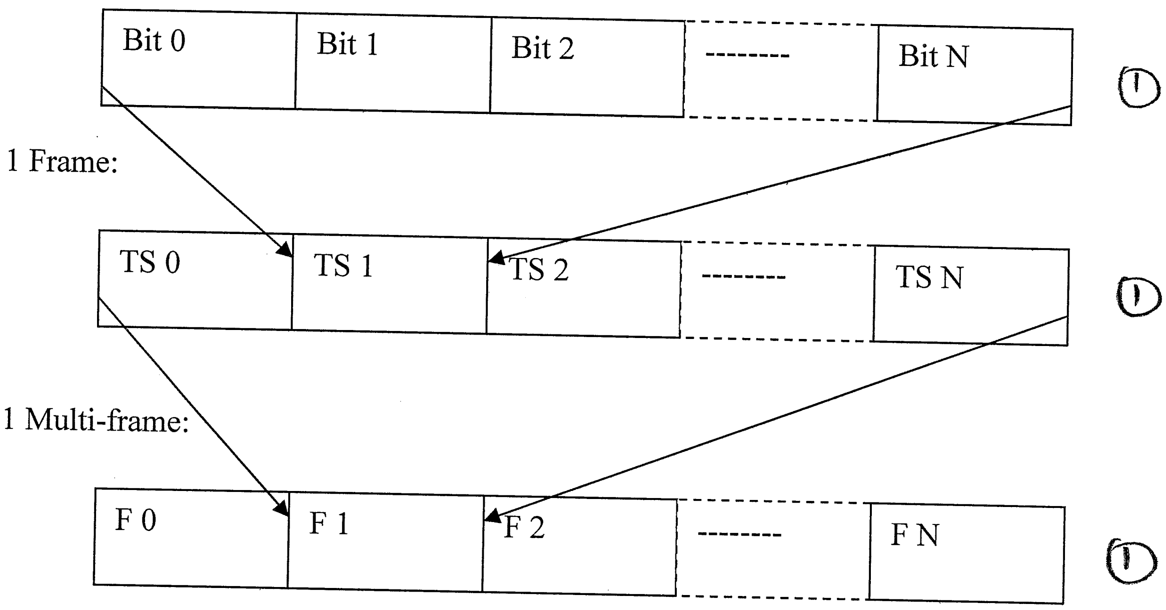
(a)

Terrestrially Enhanced Trunk RAdio is a dedicated network for the emergency services, providing both a mobile phone service and also allowing handsets to communicate directly with one another in 'walkie-talkie' mode.

2

(b)

1 Burst:



GSM	TETRA	
Bit: N = 155.25	Bit: N = 509	1
Normal burst duration = 576.56us	Burst duration = 14.17ms	1
TS: N = 7	TS: N = 3	1
Frame length = 4.61ms	Frame length = 56.67ms	1
F: N = 25 (Traffic), N = 50 (Control)	F: N = 16 (Traffic), F 17 = Control	
GMSK @ 271kbps	QPSK @ 36kbps	1
Channel B/W = 200kHz	Channel B/W = 25kHz	

(c) Since all bits are set equal in the burst, the spectrum is given by

$$\left[F(f)\times\delta_f\left(\frac{1}{T}\right)\right]*\delta(f-f_c) \qquad (1) \qquad 1$$

where

$$F(f)=A\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} e^{-j2\pi ft}\,dt = A\tau Sinc(\pi f\tau) \qquad (2), \qquad 1$$

τ is the burst duration, f_c the carrier frequency and $\delta_f(\frac{1}{T})$ is a series of delta functions in frequency separated by the reciprocal of the burst repetition period.

(i) The separation between spectral harmonics is given by the frame repetition period, $T = 56.67ms$, so

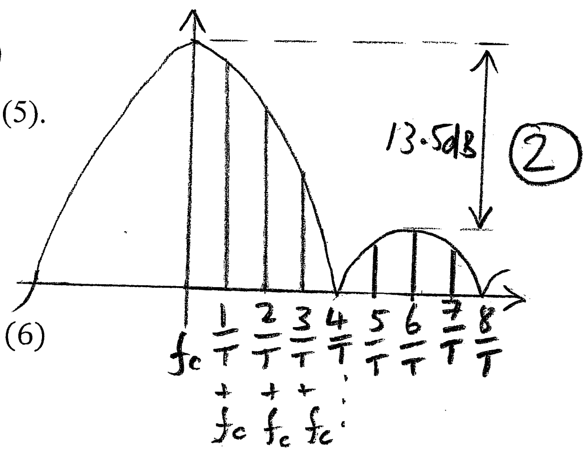
$$\frac{1}{T} = 17.65Hz \qquad (3) \qquad 1$$

(ii) For the TETRA burst $\tau = 14.17\times 10^{-3} = T/4$, and the frequency of the 6^{th} harmonic is $f = 6/T$ so in (2)

$$\pi f\tau = \pi\frac{6\,T}{T\,4} = \frac{3\pi}{2} \qquad (4) \qquad 1$$

so the magnitude of the spectral envelope and hence the 6^{th} harmonic with respect to the carrier at this frequency is given by

$$\frac{\left|sin(\frac{3\pi}{2})\right|}{\frac{3\pi}{2}} = \frac{2}{3\pi} = -13.46dB \quad (5). \qquad 1$$



(iii) The first two spectral envelope zeros occur at

$$\pi f\tau = \pi f\frac{T}{4} = \pi \text{ and } 2\pi \qquad (6)$$

1

so

$$f = \frac{4}{T} \text{ and } \frac{8}{T} \equiv f_c \pm 70.6Hz \text{ and } f_c \pm 141.2Hz \qquad (7)$$

$f_c = 400MHz$

(the 4^{th} and 8^{th} harmonics have zero magnitude). 2

Q3)

(a)

During *softer handover*, a 3G mobile station is in the overlapping cell coverage of two adjacent sectors of a single base station. The communications between the mobile station and 1 base station take place concurrently via two air interface channels, one for each sector separately. This requires the use of two separate (channelisation) codes in the downlink direction, so that the mobile station can distinguish the signals. The two signals are received in the mobile handset using Rake processing. In the uplink direction the (scrambling) code 1 channel of the mobile is received in each sector, then routed to the same baseband Rake receiver and the maximal ratio combined there in the usual way. Only one power control loop per connection is active.

During *soft handover*, a 3G mobile station is in the overlapping cell coverage area of two sectors belonging to two different base stations. Communication takes place concurrently 1 between the mobile and both base stations, and from the mobile's perspective there is little difference between *soft* and *softer* handover (except perhaps for the different scrambling codes differentiating the base stations). However in the uplink direction the received data 1 from each base station is routed to the **R**adio **N**etwork **C**ontroller (**RNC**) for combining. Two power control loops per connection are active, one for each base station.

A *hard handover* can be used to change the physical channel frequency of the connection between the mobile and base station, and is used to switch between one cell and another in a 1 point to point link in the GSM protocol. It can also be used to change between 3G and 2G networks, in cases where a mobile moves out of a 3G coverage area for instance, and relies upon the better coverage provided by the longer established GSM network.

(b)

Fast power control is required in WCDMA systems, since without it a single overpowered 1 mobile could block an entire cell, or a mobile close to the base station could block those further away. The optimum strategy for maximising capacity therefore is to equalize the received power per bit from all mobile stations. Whereas *open loop* power control can be used to provide a coarse initial power setting for a mobile, the only effective solution is fast *closed loop* power control. Here the base station performs frequent estimates of the **S**ignal to 3 **I**nterference **R**atio (**SIR**) on the *uplink* pilot bits on every slot of the DPCCH, and instructs the mobile to adjust its power to achieve a target SIR on the *downlink* TPC bits. This measure-command-react cycle is executed at a rate of 1500Hz for each mobile station and 1 thus operates faster than any path loss change. The basic step size is 1dB. The *near-far* problem of one strong signal blocking weaker ones is not so important in the *downlink* direction since there is usually only one base station transmitting to a mobile. However *closed loop* power control is still used to provide additional signal power to mobiles on the edge of cells.

(c)

Mobile transmit power is

$$P_t = 21dBm \quad (1)$$ 1

Mobile antenna directivity is

$$D_m = 2dBi \quad (2)$$ 1

Body loss is

$$\eta_b = 3dB \quad (3)$$

Equivalent **I**sotropic **R**adiated **P**ower is

$$EIRP = P_t + D_m - \eta_b = 20dBm \quad (4)$$ 2

Receiver sensitivity

$$S = -120dBm \; (5)$$

Base station antenna directivity is

$$D_{BTS} = 14dBi \quad (6)$$

Feeder loss

$$\eta_f = 3dB \quad (7)$$

The maximum allowed propagation loss L which must therefore define the cell boundary is when the received power reduces to *–120dBm* from an initial effective power of $EIRP + D_{BTS} - \eta_f$, so

$$L = EIRP + D_{BTS} - \eta_f - S = 151dB \; (8)$$ 2

From the given formula therefore, the range R of the cell is

$$R = 10^{\frac{151-137.4}{35.2}} = 2.43km \quad (9)$$ 2

(d)

Other factors influencing the range could include

(i) Unpredicted terrain / buildings which could attenuate or scatter the mobile signal

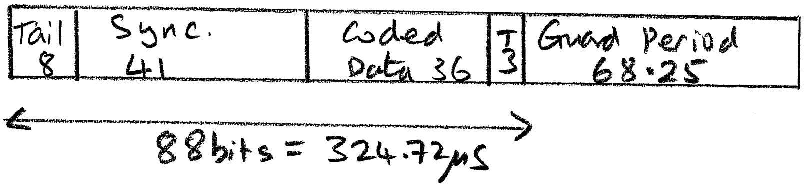
(ii) Unpredicted mobile enclosure such as building walls etc.

(iii) Interference from users of adjacent cells, 2

(iv) Too many users of serving cell

Q4)

(a)



2

The *random access burst* is so called because the MS transmits this type of burst at random times, and only when a mobile is trying to gain initial access to the system. The long *guard period* allows for propagation delay between the MS and BTS. The MS will be synchronised to the data stream from the BTS when it is idling on standby. It will know the timing of the random access time slot, and when required the MS will start transmitting when it thinks this time slot starts. However, in reality the time slot has already started (i.e. the BTS has started listening for random access bursts) *d/c* seconds ago, where *d* is the distance between the BTS and MS, and *c* is the propagation velocity of radio waves ($c = 3\times10^{8}\,ms^{-1}$). It will also take *d/c* seconds for the MS transmission to reach the BTS, meaning that the access request will be received at the BTS *2d/c* seconds after the listening period starts. For a successful access attempt, all the *88* bits of the RA burst data must be received at the BTS, and to compensate for the propagation delay the BTS actually listens for a time longer than is required to receive these, i.e. for an extra *guard period* corresponding to *68.25* bits. This therefore defines a maximum distance from which an MS can successfully access a BTS 1 1

Once a successful access attempt has been made, the BTS then instructs the phone to *time advance* its transmissions by 1

$$n\tau \approx \frac{2d}{c} \qquad (1)$$ 1

($where\ bit\ period\ \tau = 3.69\times10^{-6}\,s,\ n = 0\ to\ 63$) so that the BTS actually receives data at the beginning of the time slot allocated to the MS.

(b)

From (1)

$$d = \frac{cn\tau}{2} = \frac{300 \times 41 \times 3.69}{2} = 22.7km \quad (2)$$

2

Since the TA is implemented in integer multiples of the bit period τ, then the accuracy is to half a bit period, or more precisely to the distance radio waves propagate in that time, i.e.

$$\pm \frac{1}{2} c\tau = \pm 553.5m \qquad (3)$$

2

(c)

The maximum distance from which a mobile can access a GSM BTS is therefore

$$\frac{2d_{max}}{c} = 68.25\tau \text{ so } d_{max} = 37.8km \qquad (4)$$

2

which therefore limits the size of the GSM cell. Hence, although the mobile in the question receives a strong signal from the BTS, it is too far away to get it's RA burst back in time. 1

(d)

Since the approximate distance of a GSM handset from the BTS is known from the TA value, 1 network protocol could be implemented to allow the mobile to obtain TA's from 3 BTS's in range, and hence 3 distance estimates could be obtained from which the network could 1 triangulate the mobile's position using the known locations of the BTS's. This position 1 information could then be sent to the mobile using SMS.

Advantage over GPS: Would work in forests with dense vegetation and in short tunnels 1

Disadvantage: Aforementioned distance accuracy (3) (although would be improved by triangulation). GPS accuracy to ~10m or so.

1

(e)

The approximate location of a mobile could be obtained using a knowledge of the serving 1 cell ID, and previous serving cells, plus relative signal strengths. This information could be sent on the uplink over a data connection to a Google server for instance which has a 1 database of BTS locations and cell ID's. The location estimate could then be sent back on the downlink and plotted on the phone's Google map application.