1) Introduction.

Having completed extensive hearing aid immunity testing [Ref. 5, 8] with simulated GSM transmission, it was necessary to assess the likely impact of the laboratory results on hearing aid users.

The key results taken from these laboratory investigations were that the hearing aids tested gave rise to 'perceptible' interference when subject to a field strength of 4V/m in some directions.

A typical urban cell is characterized using an RF link budget and a number of necessary assumptions. The salient assumptions used in this paper are listed in section 2 with local assumptions contained in individual scenario's.

Having characterized the cell, individual scenario's within the cell where hearing aid users may come in contact with GSM transmitters were chosen. A conclusion is drawn from the individual scenario's which highlights those likely to have the highest incidence of interference.

Having arrived at a model covering separate scenario's, it was necessary to combine these to build a 'day in the life of' a hearing aid user. Four typical 'days' were chosen and illustrate the incidence of interference with respect to the hearing aid user.

Subsequent discussion covers GSM subscribers who use hearing aids, possible solutions and other interferences to hearing aids.

It will be noted that this document has been compiled from Refs. 10,11 and 12 with modifications agreed at the coordination meetings of 4/12/89 and 15/1/90 held at the DTI.

2) Assumptions.

i) A central London base site has a 2km radius and a base station in power class 4 (40W).

ii) All cells are operating at 50% capacity.

iii) Vehicle mounted transceivers have power control to sustain at least 10^{-3} uplink BER.

iv) Transportables are in power class 2 (8W) and portables in power class 4 (2W) with antennas having 0dBi gain.

v) Subscribers will be evenly distributed between vehicle mounted transceivers and portables/ transportables.

vi) People are evenly distributed in the cell.

vii) Vehicle mounted transceivers are located on three concentric rings within the cell and are distributed in the ratio of their distance from the BS.

viii) The number of hearing aids in the UK is 1.5 million (DHSS estimate 1 to 2 million) i.e 2.5% of the UK population.

ix) The mean duration of a call is 3 minutes.

3) Cell characterization.

3.1) RF link budget.

This budget is based on GSM Recommendation 03.30.

Rx RF input sensitivity = NF (dB) + Ec/No (dB) + W - kT @ BS for 10^{-3} BER (dBm)

Where thermal noise, kT = -174 dBm/Hz @ 290K
W (bit rate) = 10 log 270.833kbit/s
NF (noise figure) = 8dB
Ec/No = 8dB

Therefore, Rx RF input sensitivity @ BS = -104dBm.

Isotropic power = Rx sensitivity + Interference margin + Cable loss - Antenna Gain

Where interference margin = 3dB
cable loss = 4dB
antenna gain = 12dBi

Therefore, Isotropic power = -109dBm

Allowing for lognormal (5dB) and Rayleigh fading (10dB) margins gives

Minimum signal level for 10^{-3} BER = -94dBm.

3.2) Minimum MS transmit powers.

The required power to be radiated from a mobile station to maintain a 10^{-3} uplink BER may be found after characterization of the propagation path loss.

A typical central London cell is 2km in radius and has a BS located 2m above the roof of a tall building. This building will be located in a dense urban environment and of similar height to its surroundings (60m). Assuming a receive antenna height of 2m and a frequency of 900MHz, the path loss may be found from equation 3.25 in Ref.7

$$L_{path} = 69.55+26.16\log f - 13.82\log h_t - A(h_r) + (44.9-6.55\log h_t)\log d_{path} \quad \text{(dB)}$$

where f - frequency in MHz (900)
h_t - transmit antenna height (62m)
d_{path} - distance from BS in km

and from equation 3.27 in Ref.7

$$A(h_r) = 3.2(\log(11.75\ h_r))^2 - 4.97 \quad \text{(dB)}$$

h_r - receive antenna height (2m)

These equations thus simplify to

$$L_{path} = 121 + 33\log d_{path} \quad \text{(dB)}$$

Such a cell may thus be characterized by a 1km intercept of 121dB and a path loss of slope γ=3.3. Hence the minimum transmit power needed from the MS to maintain a 10^{-3} BER will be

121-94 = 27dBm @ 1km (500mW)
27+33log1.5 = 32.8dBm @ 1.5km (1.9W)
27+33log2 = 36.9dBm @ 2km (4.9W)

all powers quoted being ERP at MS.

3.3) **Affected area.**

Equation for interfering distance, d_{int}

$S = \frac{E^2}{120\pi}$ and $S = \frac{G P_t}{4\pi d_{int}^2}$ where S = power density
G = antenna gain
E = field strength

Therefore, $d_{int}^2 = G \frac{30 P_t}{E^2}$

However, since path loss calculation leads to ERP from the mobile station then the antenna gain term, G, is redundant. i.e G = 1.

It was found, during interference tests [Ref.5], that a realistic hearing aid susceptibility was 4 V/m for a 90 degree arc and 10 V/m for the remaining 270 degrees as shown in Fig.1.

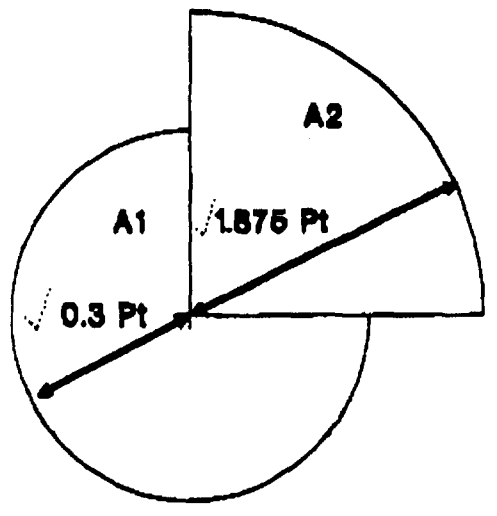

Fig.1

Let interference radius at 4 V/m be d_4 and at 10 V/m d_{10} then

$d_4^2 = \frac{30 P_t}{16} = 1.875 P_t$ and

$$d_{10}^2 = \frac{30\ P_t}{100} = 0.3\ P_t \qquad \text{as shown in Fig.1}$$

Therefore, $$A_1 = \frac{\pi\, d_1^2}{4} = 1.47\ P_t$$

and $$A_2 = \frac{3\pi\, d_{10}^2}{4} = 0.71\ P_t \qquad \text{as shown in Fig.1}$$

Therefore, $$A_{tot} = A_1 + A_2 = 2.18\ P_t \quad \text{Eq. 1}$$

3.4) Spectrum allocation.

The GSM system will probably operate with 3 base sites per cluster and therefore, even if sectorization is employed, the entire spectrum allocation will be used repeatedly by groups of these base sites. It has been assumed that each base site (BS) covers a circular area of radius 2km.

The GSM system will begin in 1991 with an initial duplex spectrum allocation of 5MHz per operator above the current TACS bands. This allows 25 200kHz carriers and thus 25/3=8 carriers per BS and 8 x 8 time slots = 64 physical channels per BS per operator.

Assuming that there will be no more than 8 of these time slots unavailable for traffic, then 56 physical channels remain giving a maximum of 112 subscribers.

As the GSM system matures, the current TACS allocation will be gradually handed over until GSM occupies the entire 25MHz cellular allocation. Each operator will therefore have 12.5MHz or 62 200kHz carriers and thus 62/3=21 carriers per base site. This number of carriers allows 21x8=168 physical channels and thus 160 available for traffic per operator and 320 in total.

3.5) Overall probability.

It was found that a good approximation to even distribution of MS's could be attained by assuming the transmitters were located on three concentric rings and distributed in the ratio of their distance from the BS. Two rings proved to be inaccurate with four giving little change in the result obtained with three.

Using a 10MHz allocation and full cell capacity gives the following result :

$$112 \times \frac{1}{4.5} = 25 \text{ MS @ 1km}$$

$$112 \times \frac{1.5}{4.5} = 37 \text{ MS @ 1.5km}$$

$$112 \times \frac{2}{4.5} = 50 \text{ MS @ 2km}$$

The affected area around each transmitter from equation 1 is :

$2.18 \times 0.5 = 1.1m^2$
$2.18 \times 1.9 = 4.1m^2$
$2.18 \times 4.9 = 10.7m^2$

Giving a total affected area from MS's of $25x1.1 + 37x4.1 + 50x10.7 = 714.2m^2$. Assuming the BS is power class 4 (40W) then, from equation 1 there will be a further affected area of $87.2m^2$ around the BS giving a total of $801.4m^2$.

Since the area of the 2km cell is $\pi(2000)^2 = 1.26x10^7m^2$ then the percentage affected area is

$$\frac{801.4}{1.26x10^7} = 0.0064\%$$

Substituting figures for a fully loaded 25MHz system yields a total affected area of $2128.4m^2$ or 0.017%.

As yet, however, we have no information concerning the frequency and duration of this interference.

4 Scenarios.

4.1) Vehicle mounted MS.

4.1.1) Vehicles and pedestrians.

A mobile on the edge of the 2km cell has been shown to be transmitting 4.9W giving rise to an affected area of $10.7\ m^2$ and hence a mean interference radius of 1.8m.

Assuming the separation between pedestrians on the pavement and vehicles on the road is 4m, the hearing aid user will not experience interference from the transmitter. Even if the aid is orientated with maximum susceptibility towards the road, the car would still have to be closer than 3m to cause interference.

It is unlikely that interference will be perceived from vehicles on the road whilst walking on the pavement.

4.1.2 Trains.

If it is assumed that there is a 10dB attenuation into a carriage from a roof mounted antenna,then a GSM pay phone on the train in power class 1 (20W) will have an affected radius in the train equivalent to that from a 2W transmitter.

Assuming the transmitter is located in the centre of the train, it is found that 1.2m or 1.2% of the train will be affected from equation 1. Assuming people are evenly distributed on the train then the probability of perceiving interference is 0.012.

It should be noted that investigation has shown that personal tape players are equally as susceptible to AM transmission and there is likely to be a high density of such equipment on commuter trains.

The probability of interference from a pay phone on a train is 0.012.

4.2) Bases.

4.2.1) Low sites.

If it is assumed that the BS is power class 4 (40W), then the affected area will be $942m^2$ from equation 1.

Assuming people are evenly distributed within the cell, then the probability of a hearing aid user experiencing interference will be

$$\frac{942}{1.26 \times 10^7} = 7.5 \times 10^{-5}$$

since the area of a 2km radius cell is $12.6km^2$.

The probability of interference from a base site whilst walking on the pavement is negligible. This is further reduced since BS's will be sited on top of buildings and not at ground level.

4.2.2) High Sites.

Many GSM BS will be located on top of tall buildings which may be office blocks containing a high density of people.

Assuming the dimensions of a typical office block are 60 x 15 x 15 m with a BS antenna mounted 10m above the top floor then radiation at angles greater than 60 degrees from the main lobe will penetrate the building assuming the antenna has not been tilted to modify coverage.

The vertical radiation pattern from a typical sectorized BS antenna shows that radiation at 60 degrees or greater from the main lobe is suppressed by 20dB to 50dB and thus, assuming an attenuation of 10dB [Ref.6] into the building and a further 5dB from the roof (no windows) gives a minimum attenuation of 35dB.

Assuming the transmitter is in power class 1 (320W) 55dBm, then the analogous scenario is a 55-35 = 20dBm (100mW) transmission into free space. This equates to an interference radius of 0.26m at 60 degrees from the main lobe and 0.8cm (65dB attenuation) vertically downwards from equation 1.

It is therefore unlikely that hearing aid users in an office block directly underneath a GSM BS will experience any interference even if they are at the top of the building and the BS is in power class 1.

4.2.3) Building coverage.

A typical attenuation into a building is 10dB [Ref.6] and thus the interference radius from a class 4 BS (40W) into a building will be equivalent to that from a 4W transmitter into an open site. It follows that any building within a 1.7m radius from the BS will have sufficient field strength inside the building to give rise to interference to hearing aid users.

As this distance is not practically realisable, it is most unlikely that a BS will give rise to interference in adjacent buildings.

4.3) Portables and Transportables.

4.3.1) Railway Station.

Portable GSM transmitters may be in power class 4 and will hence have a

maximum power of 2W. This gives rise to an affected area of $4.4m^2$ per transmitter, assuming no antenna gain at the portable, from equation 1.

Taking the area of a platform as 100m x 10m = $1000m^2$ and the number of platforms as 10 then the total station area is $10,000m^2$. If each train has 10 carriages carrying 100 people, and a train arrives at each platform during the rush hour simultaneously then 1000 x 10 = 10,000 people will be in the station at any one time leading to 1 person per m^2.

The population of greater London is roughly 7 million in an area of $1580km^2$ which is assumed to rise to roughly 10 million, from traffic flow analysis, during working hours.

Assuming the station is located in a 2km radius cell of area $12.6km^2$ and that the population of London is evenly distributed in the $1580km^2$ within Greater London, then

$$10 \times 10^6 \times \frac{12.6}{1580} = 80,000$$

people will be in the cell.

Since there are 10,000 people in the station during rush hour (1/8th of the total), assuming the cell is 50% loaded and that 50% of calls will be from hand portables then 28 x 1/8 = 3.5 calls will be active in the station at any one time during rush hour with a 10MHz allocation.

Since each transmitter has an affected area of $4.4m^2$ around it then a total area of 3.5 x 4.4 = $15.4m^2$ (0.154%) of the station area will be affected. There is thus a probability of 0.00154 that a hearing aid user will be in an affected area assuming class 4 portable transceivers.

When the system finally occupies 25MHz, the number of calls originating in the station from hand portables rises to 80 x 1/8 = 10, the affected area to 10 x 4.4 = $44m^2$ and thus the probability rises to 0.0044.

The probability of interference from a hand portable transceiver in a railway station is 0.00154 with a 10MHz allocation and 0.0044 with 25MHz.

4.3.2) Office.

It has been found that there are 80,000 people in a 2km radius cell thus with a 50% loaded cell and a 10MHz allocation, 28 of these (1 in 2800) will be using a GSM hand portable. A typical office has 1 person in $10m^2$ and hence with a 10 storey building with 100 people per floor there will be 1000 people in $10,000m^2$.

Since 1 in 2800 people will be using a GSM transmitter, 0.36 people in the building will be radiating 2W (class 4) giving a total affected area of $1.6m^2$ from equation 1. This equates to 0.016% of the office area and hence a probability of interference of 0.00016 assuming even distribution of workers.

With a 25MHz allocation, 1 in 1000 people will be using a GSM hand portable and thus the total affected area will be $4.4m^2$ from equation 1 and the interference probability rises to 0.00044.

The probability of interference from hand portable transceivers in an office block is 0.00016 with 10MHz allocated and 0.00044 with 25MHz.

4.3.3) Street.

Assuming the pavements of central London are 3m in width and are located on both sides of the road then, knowing there are 17.5 km of road per km^2, we have a pavement area of $17.5 \times 10^3 \times 2 \times 3 = 100,000m^2$ in $1km^2$. Assuming there is 1 person per $5m^2$ then there will be 20,000 people on the pavements in $1km^2$.

Assuming this represents a 50% loaded cell and the allocation is 10MHz then there

will be 28 actively transmitting hand portables distributed between 20,000 people (1 in 714).

Since the pavement is 3m in width then there will be 1 person every 1.6m and hence 1 hand portable every 1.6 x 714 = 1143m. Assuming the transmitter is stationary and the hearing aid user is walking at 3km/h (0.83m/s), then it will take 23 minutes to walk between transmitters.

When the system occupies 25MHz, there will be 1 in 250 people with an actively transmitting hand portable and thus one transmitter every 400m. At 3km/h it will take 8 minutes to walk between transmitters.

If the transmitter is in power class 4 (2W) then the interference radius will be 1.2m from equation 1, and thus the subject will have to walk for 2.4m whilst experiencing interference. At 3km/h this will take 2.9 seconds.

Therefore, a hearing aid user walking along a London street during peak time will experience 2.9 seconds of interference from hand portable transceivers every 23 minutes with 10MHz allocated and every 8 minutes with 25MHz.

4.3.4) Train.

Since it has been shown that there are 80,000 people in a 2km radius cell and assuming 50% of the 112 channel capacity will be taken up by hand portables then 1 in 2800 people will carry portable transceivers.

Assuming the train is carrying workers to London, then roughly 0.36 people will be using a GSM hand portable. If this is a class 4 (2W) transmitter then the interfering radius will be 1.2m and hence, assuming the transmitter is not at the end of the train, a 0.36 x 2.4 = 0.9m length of the train (0.9%) will be affected. Assuming an even distribution of people, the probability of interference is 0.009.

With a 25MHz allocation, the penetration rises to 1 transmitter in 1000 people and thus 2.4% of the train will be affected and the probability rises to 0.024.

Again there are likely to be a large number of personal tape players on such a train which have been found to be equally as susceptible to interference.

The probability of interference from a hand portable transceiver on a train is 0.009 with 10MHz allocated and 0.024 with 25MHz.

5) 'A Day in the life of' scenarios.

5.1) Daily commuter from outside London.

This day in the life of a hearing aid user is made up of the following scenarios

Travel from home (rural) to railway station and return	2 x 15mins = 30mins
Return train journey to London	2 x 1hr = 2hrs
Time spent leaving and waiting for train	2 x 15mins = 30mins
Tube journey	2 x 15mins = 30mins
Walking to and from office	2 x 15 mins= 30mins
Time spent in office	8hrs

The travel conducted in the rural area and on the tube may be ignored since there will be no interference.

When travelling on the train, interference may be caused by a pay phone on the train or from a hand portable. The probability of perceiving interference from either of these

sources is

$$P_{total} = P_{payphone} + P_{portable} + P_{payphone}P_{portable}$$
$$= 0.012 + 0.009 + 1.08\times10^{-4}$$
$$= 0.021 \text{ for } 10\text{MHz}$$

$$P_{total} = 0.012 + 0.024 + 2.88\times10^{-4}$$
$$= 0.036 \text{ for } 25 \text{ MHz}$$

Assuming the average duration of a call is 2mins and since the time spent on the train is 2 hours, then

Total interference duration = 120 x 0.021 = 2.5 mins

Number of calls $= \frac{2.5}{2} = 1.26$ calls

Time between calls $= \frac{120}{1.26} = 95$ mins

Substituting $P_{total} = 0.036$ gives a corresponding time between calls for a 25MHz system of 56 minutes.

It will be noted that if the probability of interference from the pay phone and the hand portable transceiver are separated, the time between exposure to interference for the duration of a call is 167 minutes due to the pay phone, 222 minutes due to the hand portable with 10MHz allocated and 83 minutes due to the hand portable with 25MHz. *Whilst on the train interference will be experienced for 2mins every 95mins for a 10MHz system and every 56 mins for a 25MHz system.*

Whilst in the railway station, the probability of incidence of interference is 0.00154 (10MHz) or 0.0044 (25MHz). Assuming 30 minutes (1800s) are spent in the railway station and a call lasts for 2mins, then

Total interference duration = 1800 x 0.00154 = 2.8seconds

Number of calls $= \frac{2.8}{120} = 0.02$ calls

Time between calls $= \frac{30}{0.02} = 22$ hours

Substituting a probability of 0.0044 gives a corresponding time between calls for a 25MHz system of 7.6 hours.

Whilst in a railway station, interference will be experienced for 2 mins every 22 hours for 10MHz and every 7.6hours for 25MHz.

It has been shown in section 4.3.3 that a 2.9 second burst of interference will be heard every 23 minutes for 10MHz and every 8 minutes for 25MHz.

During the 8 hours in the office, the probability of interference is 0.00016 with 10MHz and 0.00044 with 25MHz. Assuming 2 minute call duration then

Total interference duration = 8 x 60 x 60 x 0.00016 = 4.6seconds

Number of calls $= \frac{4.6}{}$ = 0.038 calls

$$\text{Time between calls} = \frac{\frac{120}{8}}{0.038} = 208 \text{ hours}$$

Substituting a probability of 0.00044 gives a corresponding time between calls for a 25MHz system of 75 hours.

Whilst in the office, interference will be heard for 2 minutes every 208 hours for a 10 MHz system and every 75 hours for a 25MHz system.

Overall conclusion of scenario 5.1.

The incidence's of interference will be as *follows* :

10MHz.

1 x 2 minutes every day on the train
1 x 2 minutes at the station every 1.5 months
1 x 3 second burst every day whilst walking on the street
1 x 2 minutes every month in the office

25MHz.

2 x 2 minutes every day on the train
1 x 2 minutes at the station every 2 weeks
4 x 3 second burst every day whilst walking on the street
1 x 2 minutes every 9 days in the office

5.2) Person working and dwelling in London.

This day in the life of a hearing aid user may be characterized bt the following scenarios :

Walk from home to tube station	2 x 15 mins = 30mins
Tube journey	No interference
Walk from tube station to office	2 x 15 mins = 30mins
	Total time on street = 60 mins
Time spent in office	8 hours

Overall conclusion of scenario 5.2.

Using the reasoning in 5.1, the incidence of interference will be as follows.

10MHz.

3 x 3 second burst every day whilst walking on the street
1 x 2 minutes every month in the office

25MHz.

7 x 3 second burst every day whilst walking on the street

1 x 2 minutes every 9 days in the office

5.3) Retired person.

Whilst the retired person is dwelling in a rural area, the incidence of interference will be negligible. However, if that person spends a day shopping in London, the day may be characterized as follows.

Travel from home (rural) to railway station and return	No interference
Return train journey to London	2 x 1hr = 2hrs
Time spent leaving and waiting for train	2 x 15mins = 30mins
Tube journey	No interference
3 hours shopping of which 1 hour is spent in the street	1 hour

Overall conclusion of scenario 5.3.

Using the reasoning in 5.1, the incidence of interference will be as follows.

<u>10MHz.</u>

1 x 2 minutes on the train
Unlikely incidence of interference at station
3 x 3 second burst whilst walking on the street

<u>25MHz.</u>

2 x 2 minutes on the train
Unlikely incidence of interference at station
7 x 3 second burst whilst walking on the street

5.4) Motorway traffic jam.

It has been shown [Ref.10] that a hearing aid user driving a vehicle on a motorway, with the aid orientated such that maximum susceptibility is towards the traffic, will experience interference if the adjacent vehicle is radiating a GSM transmit power of more than 2W.

It was found that the probability of the adjacent vehicle having a GSM transceiver was 0.05 and that if the traffic had a relative speed of 5 mph interference would be heard for 2 seconds every 4 minutes.

<u>6) Discussion.</u>

6.1) GSM customers with hearing aids.

<u>6.1.1) Hand-Portables.</u>

Equation 1 states that $A_{tot} = 2.18\ P_t$ and hence $d^2_{max} = \frac{2.18}{\pi} P_t$

The distance between the ears is less than 0.25m and hence

$$P_t = \frac{0.25^2}{0.7} = 90mW$$

or, the maximum transmit power from a hand-portable transmitter held to the unaided ear is less than 90mW to prevent interference to the hearing aid on the other ear.

If it is assumed that minimum susceptibility is in the direction of the transmitter (i.e through the head) than this power may rise to 210mW. Since GSM hand portable's in power class 5 will be radiating 800mW, a hearing aid user will be unable to use such a transceiver when not under power control.

6.1.2) Transportables.

Transportable transceivers will be in power class 2 and will hence radiate a maximum power of 8W with an interference radius of 2.4m from equation 1. The operator of such a transceiver will obviously be within this radius and hence interference will be perceived by a hearing aid user whilst a call is being made. It is possible that the subject could orientate himself with respect to the antenna to eliminate the interference and make a call possible.

6.1.3) Mobiles.

An investigation [Ref.9] has shown that a hearing aided driver of a vehicle is likely to be able to use a GSM mobile transmitter provided the antenna is mounted in the centre of a continuous metallic roof. Other antenna positions or a non-metallic sun-roof may lead to unacceptably high field strength inside the vehicle.

6.2) Solutions.

It was noted during interference testing, that the 100% AM introduced by the TDMA structure of GSM was the cause of the interference and that continuous GMSK had no effect. The interference from the base site could therefore be eliminated by full loading at all times i.e all time slots active all the time and constant amplitude transmission. However this dramatically increases C/I for the following reasons :

i) Continuous transmission requires unused time slots to be active

ii) Discontinuous transmission (DTX) at the BS would be impossible leading to a two fold degradation in spectral efficiency since one way speech is interspersed with roughly 50% of silence.

iii) Adaptive power control at the BS would be impossible since this would be required on individual time slots leading to amplitude modulation of the carrier.

It should be noted that anything less than 100% loading will result in a similar audio spectrum perceived by the subject as having only one time slot active. This is to say that the audio spectrum demodulated from a one time slot active BS will be the same as that from one with one time slot inactive.

The base site scenarios presented in this document are based on the results of the interference studies at BTRL i.e one carrier active. However, a GSM base site will have 8 carriers per cell when occupying 5MHz per operator and utilizing a three cell repeat pattern. Since TDMA frames on separate carriers will be synchronised at the BS, the broadband AM demodulation process may give rise to 8 times (9dB) increase in

interference level when corresponding time slots are active.

6.3) Other interferences.

The two hearing aid users who took part in the original susceptibility testing were given a questionnaire concerning current levels of interference.

It was determined that one subject used his hearing aid only once or twice a month where the other used his for the majority of the working day. The times when the aids would definitely be used were in the office, at meetings and during lectures.

Both subjects very rarely perceived any interference to their aids with one recalling only ever hearing a single burst lasting for several minutes. The second subject recalled hearing bursts lasting a second or so very infrequently and identified the source as fluorescent lights.

6.4) Possible variables.

The scope of this model is seen to be small and dominated by assumptions. There follows a list of variables that may significantly affect the conclusions drawn from the model.

i) The hearing aid user may switch the aid off for periods of the day when verbal communication is not essential.

ii) Hearing aid users may identify the source of the interference and learn to position themselves away from this source.

iii) The scenarios only apply to Greater London.

iv) There tends to be a natural exclusion zone around a person using a hand portable transceiver which will reduce the area in which a hearing aided pedestrian may be and hence reduce the probability of interference.

v) Discontinuous transmission at the MS will produce breaks in transmission will change the way in which interference is perceived.

vi) Not all trains will have a public pay phone and those that do will have the phone located between carriages i.e where there are no passengers.

vii) The hearing aided population will be biased towards retired people who do not commute into the city.

viii) Due to the nature of the calculation, the number of exposures to interference are average figures. The standard deviation away from this mean is likely to be large.

ix) The 'hand portable on a train' figures may be significantly reduced if the hearing aid is not located in the centre of the train and if a significant attenuation of the transmitted signal is created by the crowded environment.

7) Conclusions.

i) The scenarios presented in this document suggest that the maximum incidence of GSM interference will be from hand portable and transportable transceivers since this apparatus is carried by the public into areas of high population concentration.

ii) There is also a significant probability of interference from a public pay phone on a commuter train.

iii) It appears that a hearing aid user will be unable to use a GSM portable or transportable transceiver in any power class.

iv) It is likely that a hearing aid user will be able to use a vehicle mounted transceiver provided the antenna is mounted in the centre of the roof.

v) Since it has been found that interference may be perceived infrequently from other sources, then it is GSM interference perceived daily that gives rise to the most concern.

vi) Of the four 'day in the life of' scenarios chosen the daily commuter to London from a rural area is most likely to experience regular interference with a daily exposure for the duration of a call (2mins) whilst on the train and a 3 second daily burst whilst walking on the street even with the initial 10MHz allocation.
This rises to two daily exposures for a call duration and four 3 second daily bursts when the allocation reaches 25MHz.

vii) The scenario of the London worker dwelling in the city highlights a smaller exposure to interference. Whilst operating with a 10MHz allocation, three 3 second bursts will be experienced on the street every day rising to seven daily bursts with system maturity.

viii) The retired person is far more likely to be wearing a hearing aid but less likely to be in the city. If spending a day shopping in the city, the exposure to interference will be high during that day with a burst for a call duration during the train journey and three 3 second bursts whilst walking between shops. This rises to two exposures for a call duration and seven 3 second bursts with system maturity.

ix) Whilst in a vehicle in a motorway traffic jam moving at 5mph, a hearing aid user will experience bursts of interference lasting 2 seconds every 4 minutes.

x) It can be seen that given the current immunity of NHS hearing aids to 900MHz GSM EMI, a person wearing such an aid and requiring to use it during the working / travelling day will experience regular daily interference as the GSM system matures.

xi) If the incidence of interference is deemed unacceptable, a greater hearing aid immunity at 900MHz will be required to reduce the incidence of GSM interference, since there appears to be no practical modification to the GSM structure that will achieve this.

8) References.

1) Central Statistical Office - 'Annual abstract of statistics 1987' HMSO No. 123

2) Central Statistical Office - 'Regional trends 1985' HMSO

3) CCIR - 'VHF and UHF propagation curves for land mobile services' CCIR Rec.529 Rep.567-3

4) GSM recommendations 03.30 and 05.05

5) Short J M - 'An investigation into the effects of RF interference on hearing aid users' 23/8/89

6) IEE Group E11 - 'Propagation factors and interference modelling for mobile radio systems' IEE Colloquium, Digest No. 1988/123

7) Holbeche R J - 'Land mobile radio systems' IEE Telecomms series 14 Peter Peregrinus 1985

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9) Short J M - 'An investigation to determine the penetration of 900MHz RF into vehicles' 23/10/89

10) Munday P J - 'GSM EMC scenario model - Motorway traffic jam' 9/1/90

11) Short J M - 'GSM Interference Scenarios' 30/11/89

12) Short J M - 'A day in the life of a hearing aid user' 9/1/90

13) Munday P J - Correspondence of 31/1/90 and 12/12/89

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Annex B: GSM - Hearing aid interference modelling parameters

GSM - HEARING AID INTERFERENCE

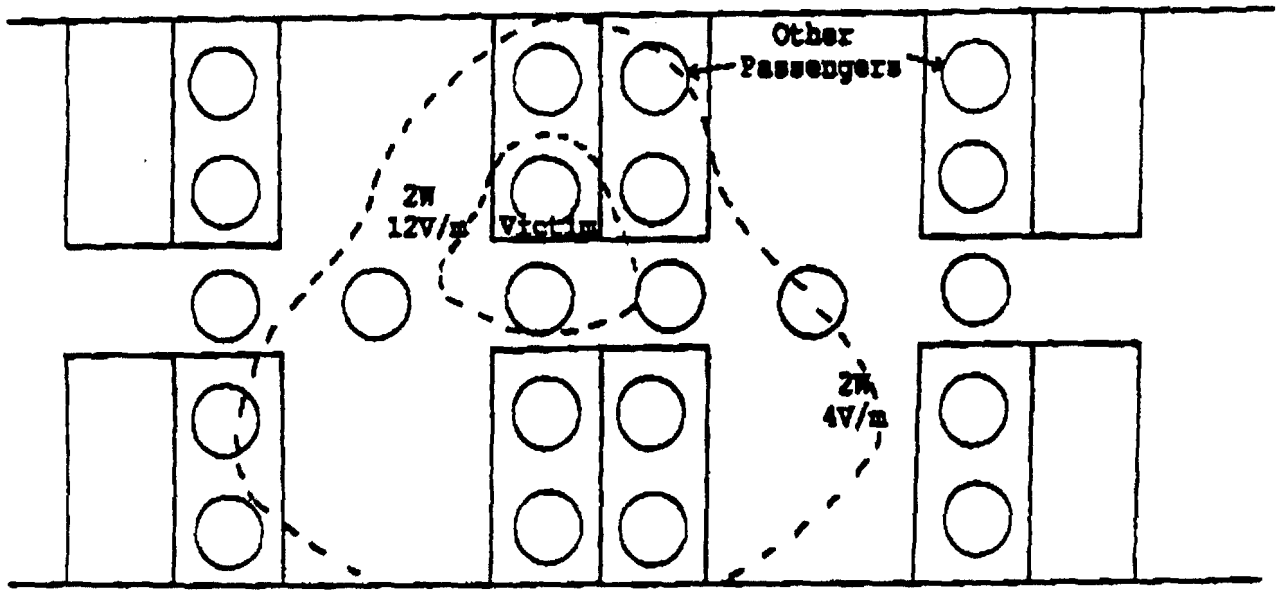
MODELLING PARAMETERS

Interference levels causing "audible slightly annoying" interference. } 4V/m in model (5 to 8.5 V/m measured)

Attenuation produced by wearer's head: Up to 8 dB

GSM Power Level	Distance from GSM Transmitter
2W	0.8m to 1.9m
5W	1.3m to 3.0m
8W	1.6m to 3.8m
20W	2.4m to 6.0m
	↑ Best side of head — ↑ Worst side of head

Note - Metallising hearing aid case gave about 10dB reduction in susceptibility



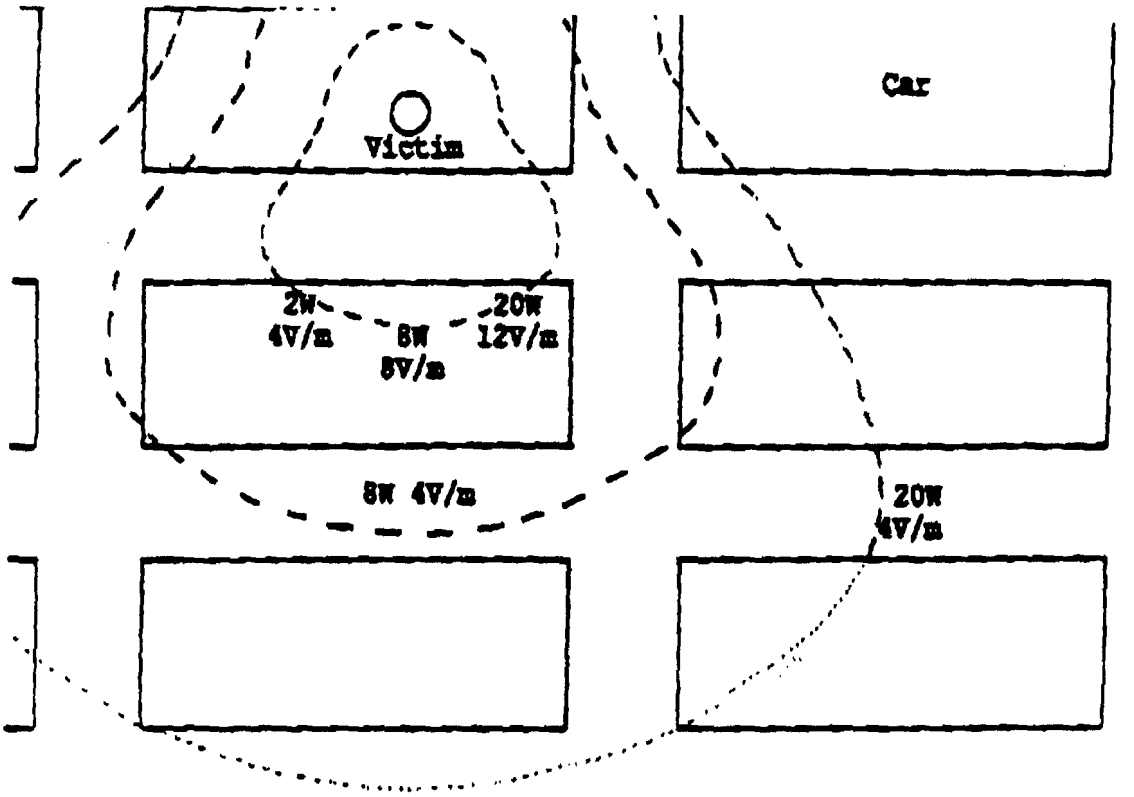
1 other passenger in 2W,12V/m area
10 other passengers in 2W, 4V/m area

Crowded Train Scenario

Crowded Train Scenario

Assume: Half GSM HPU's used on a given journey
Average call lasts 2 min

Passengers with 2W GSM HPU	Probability of 2 min interference on a given journey	
	4V/m	12V/m
1%	5%	0.5%
3%	14%	1.5%
10%	40%	5%



Motorway Traffic Jam Scenario

Motorway Traffic Jam Scenario

Assume: 5% of vehicles have GSM phone
20% of GSM phones active at a time
Average calls last 2 minutes

Traffic	Interference	2W 4V/m	8W 8V/m	20W 12V/m	8W 4V/m	20W 4V/m
Stationary	2 min interference bursts with Prob →	2%			5%	10%
Lanes passing at 10km/hr	Interference bursts → (on average)	0.7s every 3 min			2s every 3 min	3s every 2.5 m

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Annex C: New digital transmission technologies - the EMC conundrum

NEW DIGITAL TRANSMISSION TECHNOLOGIES - THE EMC CONUNDRUM

1 INTRODUCTION

The growth of our 'cordless' society has placed a premium on personal mobility. In the telecommunications sector the growth in the use of cordless telephones and cellular radios has been spectacular. To provide for this growth, in an age where frequency spectrum is similarly in demand, has required the development of new technologies.

2 RADIO TECHNOLOGIES

Recent developments in radio in Europe and worldwide have selected 'time division multiple access' (TDMA) technologies for assigning channels to individual radio users. The traditional frequency division multiple access (FDMA), mainly analogue, techniques are still used extensively but are slowly being replaced by digital TDMA systems, which offer both improved performance and spectral efficiency, particularly in large 'public systems'.

3 WANTED RF EMISSION

In a TDMA system the 'channel' used by an individual represents one time slot from say 10, allocated to that user normally at a sub-audio rate, for example, 200Hz.

The resultant effect is that a burst of RF is transmitted at that sub-audio rate, in the example above the RF burst would last for 5 msec and be repeated every 50 msec. The 5msec RF burst would contain the transmitted information at a rate 10 times faster than the basic rate to provide a continuous transmission for the user.

The RF signal described above is amplitude modulated (AM), in this case at 200Hz, this AM is in addition to the modulation contained within the RF burst itself. Tests to date have shown that many radio and non-radio (particularly audio products) are susceptible to an RF signal with these characteristics.

The growth of cordless telephones and personal communications equipment also means that the transmitter will be physically much closer to potentially susceptible equipment.

4 EMC DIRECTIVE AND LEGISLATIVE PROVISION

The Community's EMC Directive requires that all electrical/electronic equipment neither emit nor radiate unwanted RF signals, and not be susceptible to other (wanted) RF signals, ie legitimate radio transmissions.

Legitimate radio transmissions are licensed in the UK by the Radiocommunications Agency of DTI, under the 'Wireless Telegraphy' Acts. The licence provision includes the frequency, form of modulation, permitted power level and

controls spurious and other parameters by only licensing equipment approved to definitive standards of performance.

The EMC Directive will come into force on 1 January 1992; it offers the power to control, from that date, equipment 'placed on the market' and will require compliance with essential immunity' standards.

The pan-European digital cellular radio system - GSM - which is also supported by a Community Directive, should become operational at a similar date. The WT Act licence offers the potential to control the power levels of GSM equipment.

5 THE CONUNDRUM

The 'generic' immunity standard being set by CENELEC has been currently agreed to be set at '3 volts per metre'

The immunity standard necessary to avoid interference from a GSM equipment will need to be in the range '10 volts per metre' to '20 volts per metre' if the current power levels of GSM equipments are to be maintained. It is, of course, subject to the distance between the GSM transmitter and the target device being defined.

The obvious incompatibility and potential hazard to 'safety related' or 'pseudo-medical' applications eg hearing aids, provides the conundrum.

6 DISCUSSION

Scant regard, has in the past been paid to the design of equipment with realistic immunity standards - particularly in the domestic market. The EMC Directive provides the legislative framework to correct this deficiency. The 'generic' immunity standard of '3 volts per metre' has been pitched at a level that most equipment designs already meet and thus provides little or no real improvement. A more realistic figure would be '10 volts per metre'.

The adoption of TDMA technology, with its inherent advantages is more intrusive, in EMC terms, than previous FDMA technologies. This is particularly true of 'audio' equipments such as personal stereos, which have a high probability of being in close proximity to the new digital radio telephones.

It could be argued that the AM component of the TDMA transmission is also 'unwanted' and hence covered by the EMC Directive; this view is not shared by the spectrum managers, where it seen as a legitimate and efficient transmission.

The spectrum manager has the option of defining the maximum radiated power, to a level compatible with realistic immunity standards.

7 CONCLUSION

A compromise between 'immunity' standards for all radio and non-radio equipments, coupled with a limitation of radiated power from, particularly hand held TDMA transmitters, will be essential to avoid unwanted EMC problems. The attached Annex proposes a scenario for discussion purposes.

O J WHEATON 4.5.90

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ANNEX

EMC CONSIDERATIONS

1 **Assumptions:**

- the minimal distance between a radio transmitter and a target radio or non-radio equipment shall be 1 metre;

- safety conscious and pseudo medical systems shall have higher immunity standards than the 'generic' standard level.

2 **Proposes that:**

- generic immunity standards for all equipment be set at 10 volts per metre minimum;

- sectorial immunity standards for body worn audio equipments be set at 15 volts per metre minimum;

- sectorial immunity standards for any 'safety conscious' system be set at 25 volts per metre minimum.

3 **Transmitters using AM or TDMA technologies be limited in radiated power to:**

- hand held devices - 1 watt peak power;

- vehicle mounted equipment, where the antenna is at a minimum height of 1.5m, located at least 0.75m from the vehicle's outline - 5 watt peak power.

Annex D: Potential GSM hazards on cardiac pacemakers

Source: CSELT (Italy)

Potential GSM Hazards on Cardiac Pacemakers

1 - Pacemaker Operation

Cardiac pacemakers are pulse generators implanted in subjects suffering from heart disease in order to stimulate artificially the beat of the heart.

Demand types sense when the heart beat is abnormal and make necessary corrections. Most pacemakers in use are of the demand type.

A simplified block diagram of a demand type pacemaker is shown in fig. 1. The circuit and the power supply (a solid state battery) are sealed in a titanium package to reduce the rejection phenomena as well as to improve the electromagnetic shielding.

The circuit is implanted in the abdomen of the patient while the pacing lead carries the pulses directly to the heart.

The pacing lead is a catheter introduced through veins and has the double function of exciting the cardiac activity and detecting the spontaneous signals. In fact when the detector reveals the natural heart beat (which is an electric pulse with a peak to peak amplitude near to 5 mV) turns off the pulse generator (which give out a peak to peak pulse of approximately 5 V). So acting the pacemaker reduces the power consumptions and avoids unnecessary stimulations. There are two different kinds of pacing leads: unipolar and bipolar, bipolar leads are less sensitive to the external interferences but they are less sensitive to the cardiac signal too.

Single channel and multichannel devices (i.e. with a stimulation and detection in more than a single heart point) are available according to the patient needs. In a large part of the pacemakers the physician can program the parameters of the implanted generator (e.g. amplitude, frequency, sensitivity) using a radio interface controlled by a computer. Moreover the radio interface allows the physician to get the operating parameters of the stimulator using some telemetry measurement functions built in into the device.

2 - GSM Interference to Pacemakers

Since the pacing lead acts as an antenna, exposure to an electromagnetic field may:

a) Introduce currents from the leads into the heart causing fibrillation or local heating;