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TELEPHONE HANDSET DESIGN

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1. INTRODUCTION

This paper gives a technical perspective to handset design in the United Kingdom. The modern handset conceals many design parameters which are subtle and hidden from view. A model of the interactions between handset and the human I/O are described. Thoughts are given to the deviation from preferred performance standards as have been introduced by mobile handsets. Grateful acknowledgement is given to Alan Coleman, whose document, "General Design Considerations for Telephone Band (300 - 3400 Hz) Handset Telephones", an unpublished International Telecommunications Union Study Group XII contribution [1] has contributed to this paper.

2. IN THE BEGINNING

The telephone as we all know was invented by Alexander Graham Bell. Bell tells that the idea for the telephone came to him from his "thorough understanding of the workings of the human mouth and ear" Thorough is of course a relative term since the local mortuary used to supply Bell with ears and vocal tracts from cadavers so that he may "more fully understand" their operation. Thus the notion that understanding the telephones' interaction with the Human Acoustic Interface is a key element of its performance was born.

2.1 The Separate Receiver and Microphone

The first telephones did not contain amplification. The carbon Granule "Transmitter" or Carbon microphone were essentially current modulators and in order to obtain sufficient sensitivity to overcome the long American lines and the receivers sensitivity, the microphones were large. Firstly they had to have a large charge of carbon to keep the current density down, secondly they had to have a large diaphragm to exercise the carbon charge. One convenient way of doing this was to use a horn as the impedance convertor.

This is a long winded way of saying that the body of the early telephones, including the microphone had to be bolted to the wall at average head height. The receiver was a separate unit, but still used to enable the telephone by going "off hook".

The great unspoken benefit of this necessary arrangement was to disengage the fixed dimension between microphone and receiver and allow comfortable use by people of all sizes. The vertical discrepancies were solved by a selection of stools or a sliding arrangement.

2.2 Early Microphones

Early microphones were always of the carbon granule type. They were used as current modulators and frequently carried direct currents of 200 mA, which used to gently "fry" the granules. The inherent physics of the device generated a lot of second harmonic distortion giving rise to a uniquely identifiable sound quality. Interestingly the long time constant equivalent of this effect was the reduction in sensitivity at low speech levels, rather as an expander would operate. This had the effect of reducing room noise by some 10 to 15 dB - a neat trick.

2.3 Early Receivers

Most early receivers were diaphragm types whereby an electromagnet would attract or repel a flat magnetic disc mounted close to the poles. These had the advantage of high sensitivity, but the disadvantage of an extremely resonant, harmonically related frequency response, linked to poorly controlled transient performance.
Some receivers used the piezo principle for their operation. These were inherently cheaper but had an even worse performance. This was coupled to the fact that the Rochelle Salt crystals used were hygroscopic and would "melt" after a few years of operation.

3. MODERN "CONVENTIONAL" HANDSETS

3.1 The Microphone

In a modern handset, the microphone is invariably an electret type, i.e. A self polarising capacitor microphone. It has the advantages of being cheap, having an intrinsically smooth frequency response, low susceptibility to magnetic fields (important these days with the proliferation of desktop computers) and being physically small.
The main disadvantage in the authors opinion is that as a high acoustic impedance device it can only ever sample the sound pressure and will therefore not discriminate between near and far fields. This topic will be revisited in section 4.7.
The microphone entry port in modern handsets can be (and usually is) small, perhaps only 4 to 5 square millimetres. This generally causes problems with breath noise across the sharp edges and because the microphone diaphragm undergoes large variations in static pressure due to pitot effects, there can sometimes be dynamic sensitivity changes. These effects are never identified by objective measurements.
The opportunity is often taken to mount the microphone in a rubber protective "boot" which serves the twin functions of a degree of vibrational isolation and 4 kHz low pass filter by means of a Helmholz resonator. The filter supports the rejection of out-of-band speech reaching the Codec.

3.2 The Receiver

Modern receivers are nearly always of the moving coil type. Although being relatively expensive, the cost is all directed towards measurably improved performance. The advantages of the moving coil receiver are that they possess a medium acoustic output impedance, a smooth frequency response, good transient performance (we're mainly receiving speech after all) and can be made to be magnetically "leaky". This enables them to interface directly with hearing aid pick ups. An interesting but hidden fact is that they work very well in conjunction with electret microphones. This is because the fundamental transconductance mechanism of the two microphones is different. This has great benefit in decoupling the two transducers.

3.3 The Handset Body

Early (60's, 70's) handsets were usually fitted with screw caps to contain the transducers. This was a necessary part of the design as this was the pre-liberalisation era and telephones were repaired as "instruments" as opposed to being consumer objects which could be replaced, discarded or upgraded. An incidental feature of these screw cap ends was that they were necessarily round, and in the case of the receiver made it particularly easy to seal to an ear simulator for objective measurement. The body was a one piece moulding and could therefore be specifically designed to be comfortable to hold. Another hidden advantage was the fact that they didn't impart any "creaks" to the microphone.

4. HANDSET OBJECTIVE MEASURES AND INTERACTIONS

Over a period of many years the International Telecommunication Union (ITU-T) has developed, through its Study Group XII a range of objective measurements which can be used to characterise the performance of handset telephones. Furthermore, these objective measures can be directly input into a subjective model of a double ended telephone conversation. This has been an invaluable tool in developing International Standards in this area.

It is not the remit or intention of this paper to detail this body of work, the handbook alone takes up 360 pages of A4. However, the following handset parameters should give the reader a flavour of the detail required to build a software descriptor of the handset / human acoustic interface. The opportunity is taken here to add comments on preferred targets to avoid these same headings later.

4.1 Sending Sensitivity

A smooth frequency response is required, preferably following the guidelines of figure 1 below:

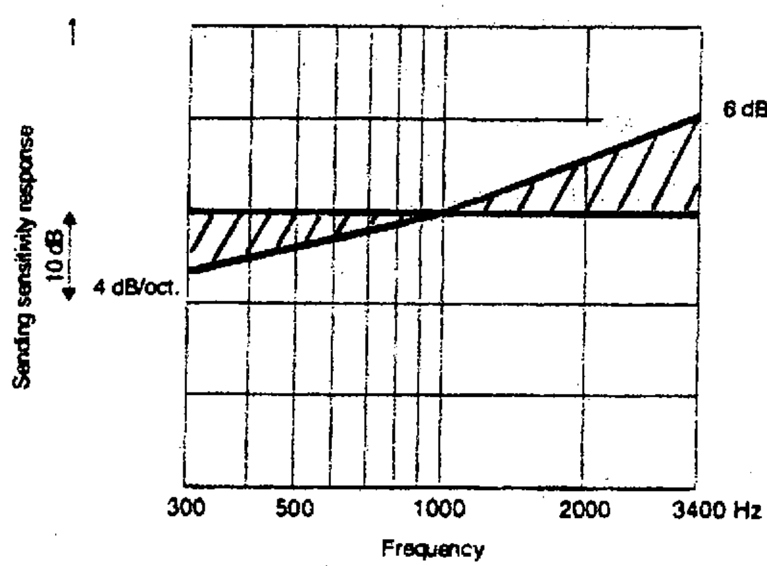

Figure 1

The pre-emphasis serves to enhance the intelligibility of the speech together with compensation for traditional local line loss.

4.2 Receiving Sensitivity

The receiving sensitivity is essentially flat. For the purposes of Sidetone stability or Terminal Coupling Loss, it is much easier to tolerate dips in the response than peaks.

4.3 Talker Sidetone

Over a number of years, Sidetone has been studied and some important conclusions have been reached from the point of view of the user in his / her role as both talker and listener. These conclusions relate to the effect of Sidetone on a user as he hears his own voice, the way his talking level changes as a result and some effects of Sidetone when the customer is listening in conditions of moderate to high-level room noise. These effects are summarised in figure 2 below.

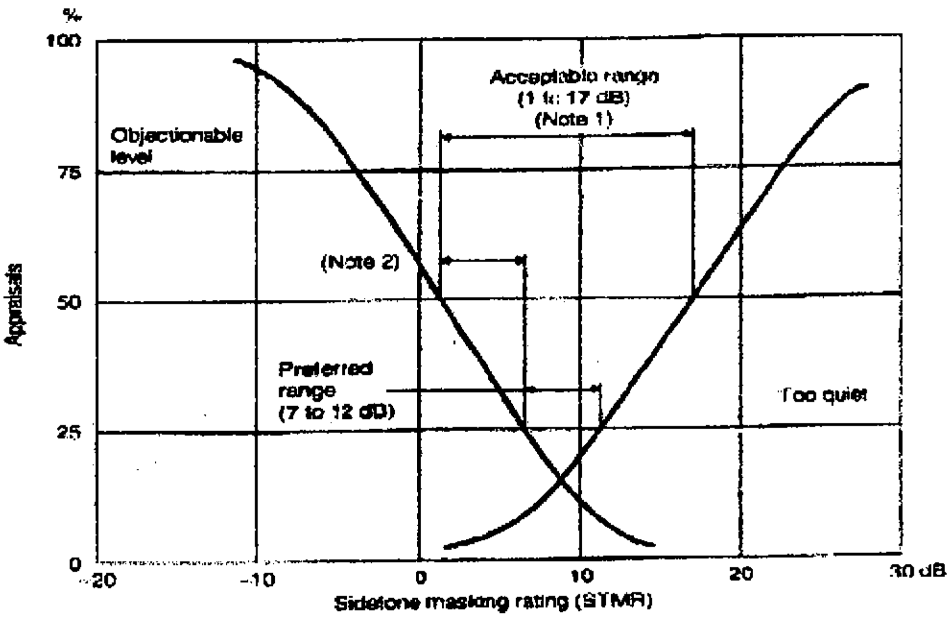

Figure 2

Graph showing Sidetone levels that are objectionable and too quiet, together with the preferred range for the user as a talker.

Notes: (1) Conversational conditions will determine what part of this range is acceptable for a given connection.

(2) This part of the acceptable range (1 to 7 dB) should only be entered with caution e.g. On low loss connections or where there is a receive volume control.

The local Sidetone is usually considered as a masked rating value as there is always a fixed acoustic path from mouth to the "telephone" ear regardless of whether or not a handset is in use.

4.4 Listener Sidetone

High room noise in the users' environment disturbs the received speech in two ways: (1) Noise picked up by the handset microphone and transmitted to the handset receiver via the electrical path. (2) Noise leaking past the earcap at the handset earphone.
The relationship between talker and listener Sidetone for a given telephone depends primarily on two factors: a) The geometry of the handset, b) Whether or not there are any non-linear gain or loss characteristics in the Sidetone path.

4.5 Loss - Room Noise to Ear

Yet another factor to be measured and input to the model is the acoustic loss from the room noise to the "telephone" ear. For example quiet incoming speech will cause the handset to be held close to the ear such that the earcap seal is low. This has the effect of reducing the room noise in that ear. Similarly high room noise levels coupled with high incoming speech levels cause great difficulty as the user defined optimum earcap position will not exist. This is yet another complex interaction.

4.6 Terminal Coupling Loss

In order to cope with the advent of 4 wire telephony e.g. GSM networks, the concept of Terminal Coupling Loss is essential and describes the digital loss likely to be encountered for the purposes of echo canceller control. Because GSM networks have a large and inherent delay path there is a need to control the amount of energy returned by the far end user, otherwise a discreet version of your own conversation is received and is usually a barrier to good communications. The advent of the smaller and physically shorter phones has made the specified TCL limit particularly difficult to meet.

4.7 Two Microphone Sensitivities

Because handset microphones are close to the speech source, if the microphone has anything other than a high acoustic impedance then it will respond differently to the speech source, modelled as a 30 to 40 mm diameter source i.e. highly reactive. The effect is also a function of wavelength. The net result is a microphone which can have one sensitivity to room noise and another to speech. It is an advantage to design this feature into handset microphones to enable partial discrimination against room or environmental noise.

5. PREFERRED HANDSET DIMENSIONS

5.1 The Lip Ellipse

Much work has been done in the past to determine the optimum placement of handset microphones relative to the receiver earcap. Figure 3 below shows the positions for 80% and 90% of the subjects lip centres. This is combined with the handset geometry to exploit this information and provide the best possible speech to room noise ratio. Naturally figure 3 is a 2D representation of a 3D reality. The actual solid object formed is an ellipsoid or rugby ball shaped solid volume.

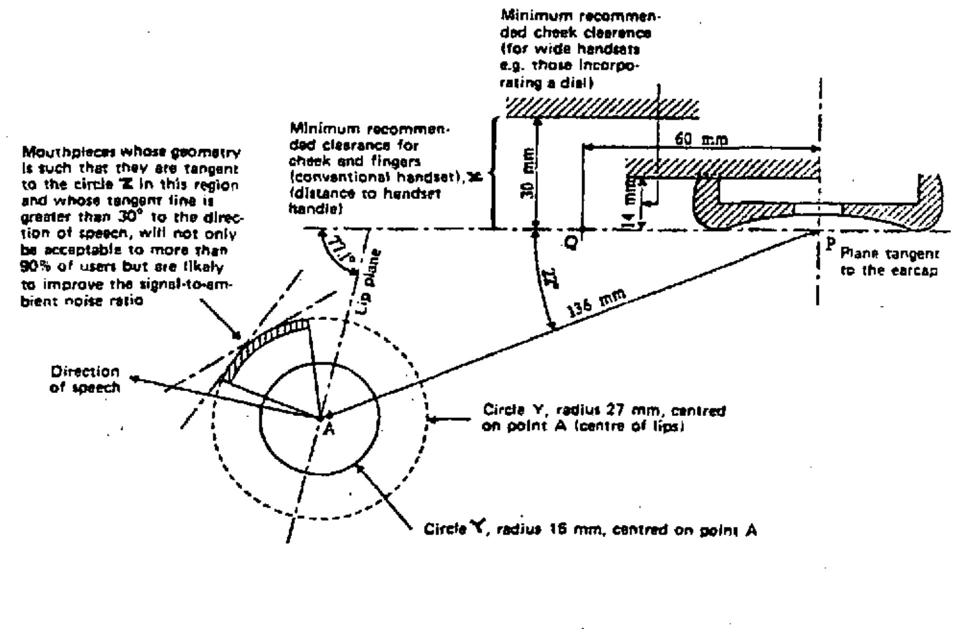

Figure 3

Note 1 Point A is located at the centre of a circle Y which encloses 80% of lip positions of the subjects tested.

5.2 Earcap Design

A concave region around the receiver of at least 26 mm based on a sphere of 50 to 100 mm radius is optimum as it allows all known types of ear simulators to be fitted for testing. This will also provide a comfortable fit to the user.

6. GOOD HANDSET DESIGN

This section is intended to be a distillation of experience, but not a full technical description, of the visible and invisible parameters which make up good handset design.

6.1 Microphone

The microphone should be an electret noise cancelling type, preferably large diaphragm. The microphone should be mounted at a glancing angle to the direction of speech to avoid breath puff blasts. All surfaces in front of the microphone should have large (as possible) diameter corners to avoid noise generated from airflow diffraction. The frequency response should be smooth and in accordance with the curve in figure 1.

6.2 Receiver

The receiver should be a moving coil type with a medium acoustic output impedance. This allows it to work into an ear with a leak without altering the frequency response significantly. The external profile should follow the guidelines outlined in 5.2 above. The response should be substantially flat (+/- 2 dB) from 400 Hz to 3 kHz. Good transient performance will come inherently from the moving coil motor and help maintain intelligibility.
It is worth noting that some receivers have an external DC magnetic field which is strong enough to pick up and retain pins and drawing pins. This is not a good idea since the pins may be inserted directly into the ear canal !

6.3 Overall Dimensions

Figure 3 above gives ideal dimensions for the positioning of the two transducers. The case used to be used for this purpose only. The advent of GSM and associated portability has compromised these paradigms with appropriately poor performance.. Novel designs such as the extendable microphone or the flip design can be used to gain the best of both worlds.

6.4 Case Creak

Handset cases which creak due to poorly fitting parts or poor assembly are not usually heard by the user, but by the person at the other end and can be a barrier to good communications. The poorly fitting parts impart a high level mechanical impulse to the microphone at a level much higher than can be dealt with by the electronics. Good design usually includes multipoint fixing, suitable materials or ultrasonic welding of the case parts.

6.5 Weight

Handsets need to have a quality feel. Part of this difficult to define area is the weight of the handset. This is achieved by metal weights or more usually hermetically sealed clay material. GSM phones don't usually have this problem as the battery has a considerable mass.

6.6 Acoustic shock

In the UK Handsets are not allowed to deliver sound pressure levels greater than 118 dB spl unweighted. This is normally achieved by limiting the supply to the receiver amplifier. There is a possibility that the supply could be faulty and this level may be exceeded, although this is rare. The problem is even worse with headsets as they take a longer time to remove from the ear.

7. POOR HANDSET DESIGN

7.1 Similar Transducers

Many cases have been found where the handset manufacturer has decided to use the same transducer as microphone and receiver to save money by increasing the bulk purchase discount. Unfortunately, this usually means that the resonant peaks associated with the transducer appear at both ends and drastically reduces the Terminal Coupling Loss.

7.2 Receiver as Calling Device

Some designs of cordless and GSM phones use the receiver as the calling device, although this is falling out of favour. The reason for this is that many people (especially children) have put the receiver to their ear while an incoming call alert has arrived, resulting in an acoustic shock. This design feature should be discouraged.

8. CONCLUSIONS

This paper is a meander through the world of handset design. The author has long considered that the telephone handset is such a ubiquitous object, that perhaps people have wondered why it is what it is. The paper has described how we've arrived at where we are today. For the future, GSM handsets seem to have stabilised in size, but are still generally too short for good speech / room noise performance. This, coupled with the removal of locally generated Sidetone through the use of separate send and receive radio paths has resulted in increased vocal effort...... Or shouting ! As we call it.

8.1 The Future

The next generation of high speed WAP (Words and Pictures) phones will concentrate on supporting internet and e-mail access. Delivery of good speech intelligibility may once again take a necessary commercial back seat. However, good performance through an understanding of the visible and invisible properties of handset communications will always be a goal worth striving for.

REFERENCES

[1] ITU - T Draft Recommendation P.350