ENGINEERING APPROACHES AND COMPROMISES IN THE DESIGN OF SMALL ION MOBILITY SPECTROMETERS.

R.F.D.Bradshaw, Bulstrode Technology, 17 Avebury Court, Mark Road, HEMEL HEMPSTEAD , HP2 7TA UK

ABSTRACT

The engineering approaches in the design phase of small portable I.M.S.-based instruments are discussed. The choices available are described, and their effect on instrument dimensions analysed. Possible future developments are outlined.

INTRODUCTION

The motive for miniaturisation of IMS devices is primarily to address the perceived market for small, portable detection devices, and secondarily to take advantage of the fact that smaller devices tend in general to cost less and to be more robust.

TARGET DIMENSIONS

There is little point in miniaturisation for its own sake. There comes a point beyond which further size reduction is counter-productive. The target has to be a device of which the user will not be constantly aware if he has it about his person, which has sufficient surface area to carry the necessary user interfaces, and which can be held comfortably in the hand.

The first target, comfort in carrying, is met by pocketbooks and diaries. These can be relatively large in two dimensions as long as they are thin and flexible. Complex user interfaces are used on Calculators and Mobile Phones, which tend to have their plan area defined by these interfaces.

The need to hold an instrument comfortably in the hand requires that its girth does not much exceed nine inches; however a three inch diameter cylinder would be unacceptable. It becomes clear that, within the girth restriction, plan area is not of prime importance; the critical dimension is thickness. Length should not exceed the depth of a pocket. All these considerations taken together lead to the conclusion that an instrument having a rectangular plan form of about seven inches by two point five inches would be acceptable; the thickness should be no more than one inch, and preferably much less.

CRITICAL COMPONENTS

In any device there is likely to be one component that will set a minimum value on the critical outside dimension. In an IMS-based device a natural assumption is that this critical component is the Drift Cell. This assumption should not go unquestioned; the other candidate is the Battery. System studies must be done to check that adequate battery life is available considering the mode of operation of the instrument and the volume available.

Cell Dimensions

Assuming the cell to be the critical component, it is clear that typical cell lengths can easily be accommodated within the plan areas being considered. The drift length of a CAM cell is just over an inch.

More difficult is the cell diameter. This may be the primary constraint on thickness reduction. The Graseby Ionics 'Mini' embodies a standard CAM electrode structure; its thickness represents the best that can be achieved without cell re-design.

Cell diameter, or rather thickness if non-circular geometries are considered, is governed primarily by the aperture of the central drift region. Reduction of this aperture results, with a given maximum ion concentration, in reduction of the collected current and consequent degradation in signal-to-noise ratio. With a circular cross-section this degradation goes as the square of diameter. Some reduction of the outside diameter, which is what matters, can be achieved by careful electrode design.

Increase of Ion concentration, even if allowed by the nature of the ionisation source, is of limited use, as space-charge effects begin to give trouble at charge densities much above those currently employed. The problem is not so much one of lateral expansion of the ion pulse, leading to a requirement of increased drift region diameter, as of axial expansion, leading to loss of resolution in the output spectrum.

There is thus a rather fundamental limitation placed by minimum drift-space cross-section. Some relief might be found in high-aspect-ratio rectangular cross-sections, but these bring problems in ionisation source design.

A typical thickness contribution for a circular cross-section may be 0.4 inches. By itself, this would allow a satisfactorily thin device. However, to this figure must be added allowances for the field-defining electrode structure, clearances for electrical insulation, and the space required for the gas-tight containment of the cell. Depending on the design choices made, there may also need to be room for lead-throughs and resistor chains.

OTHER COMPONENTS

Having established a feasible cell thickness (which may in fact be increased somewhat if that allows the adoption of a low-cost assembly method - a trade-off of cost against size) other components of the system can be considered. These will fall into three classes: ancillaries of the cell, electronic components, and batteries.

Cell Ancillaries

Cell ancillaries will include Drying agent and its containment, pumps (if used), sample inlet means and dopant sources. In most cases these will be specifically designed for the equipment and the need to be no higher than the cell will be a primary design requirement.

Electronics

Electronic components similarly will be chosen with thickness in mind.

Two points need to be made here. The first is that in concentrating on thickness, plan area must not be forgotten; the second is that due note should always be taken of the *next* highest component, which may be an electronic component, when considering schemes for reduction in the height of the cell.

Batteries.

A miniature instrument will not have much room for batteries. Since an IMS cell operates in principle on nanoamperes of current, the cell power used is almost all wasted and will be substantially independent of cell size. The principle of demand sampling, exemplified by the Graseby Ionics Mini and made possible by the use of passive pumping, allows substantial scope for power economy in that the instrument is only turned on when a sample is to be taken. Also, due to the sequential nature of operation, savings can be effected by careful scheduling of supplies to power-hungry areas.

Demand sampling allows good battery life with battery volume comparable to that of the cell module. The effect of other types of operation on power demand should be considered very carefully. System studies may show that battery size and weight may become dominant, negating the value of miniaturisation in other areas, unless very stringent power-management techniques are adopted.

CASE AND USER INTERFACE

Having generated a design and layout of suitably small dimensions, two other related matters remain; the outer case, and the operator interface.

Case

Sophisticated designs in other fields tend to combine the case and the main structure, often in the form of elaborate plastic mouldings. In the current stage of IMS-based instrument development it is more likely that a scheme in which self-supporting internals are housed within a separate hard protective case will be chosen, the advantage being low tooling cost and easier and more flexible design. It is galling to find that this latter approach, if plastics are used, can add 0.25" to the thickness of an instrument.

A major consideration in case design is accommodating the User Interface. In terms of input this may be simple, being one or two push-buttons; the output is likely to be the ubiquitous LCD Display. This in itself requires little more than a viewing aperture in the case, but space conflicts can arise when considering its location. In an instrument in which the sampling probe is at one end, the natural position for both cell and display is close to that end. If the display is located on a major face of the instrument it will add its thickness, which may be a quarter of an inch, to that of the cell, causing a corresponding local increase in instrument thickness.

Sample Interface

The sample interface itself should not present a space problem, except in that if a pump or flow inducer is required it can have a secondary effect on battery volume, depending on its mode of use, continuous or intermittent.

Any requirement for continuous heating is bound to have a serious effect on battery volume.

THE DESIGN PROCESS

The smaller the target envelope, the more complex the design process. It becomes increasingly difficult to segregate the design into independent areas to be worked on by specialists; design must proceed in an iterative manner, with the effect of each choice on all other areas being considered. It calls for strong overall project management with detail involvement.

System engineering nevertheless remains vital; the operating regime of the detector will determine the battery size/battery life trade-off.

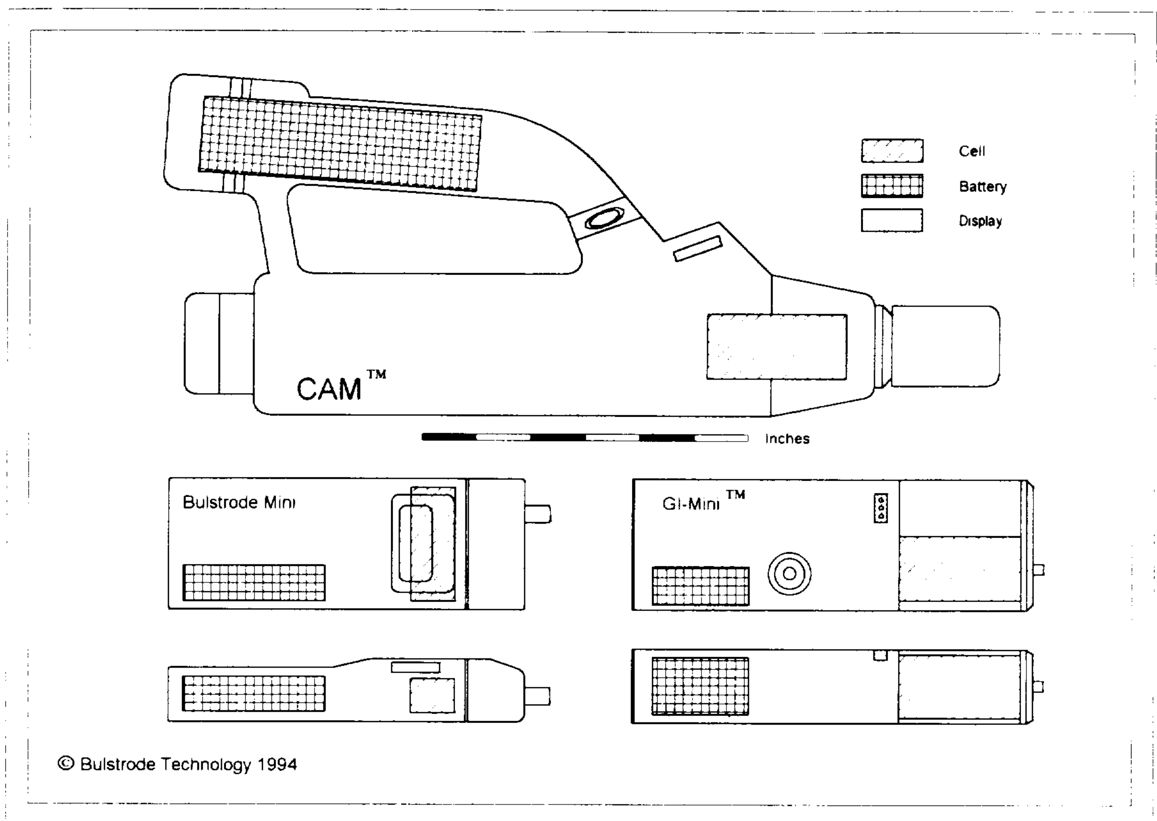
EXAMPLES

Three examples of miniaturisation are shown (*Fig.1*). The CAM instrument was in fact a remarkable achievement for its day and set a standard for emulation. The Graseby Ionics 'Mini' is an interim design, using standard CAM cell components, and is being used to explore the concepts of passive pumping and demand sampling. Its design evades the issues of display location. The current Bulstrode Mini is a more integrated design in which a revised cell structure allows a character display to be used, but in which concessions have been made for ease of manufacture and lower cost.

FUTURE DEVELOPMENTS

The experience gained in these designs allows reasonable estimates to be made of achievable sizes of future products. An informed guess would be that an overall thickness of about 0.7" should be attainable. Whether or not the necessary investment in development and tooling will be justified will become apparent from the market reaction to the present generation of instruments.

Fig. 1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