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Design of electronic equipment for broadcasting

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Abstract: The paper considers the design of electronic equipments for use in the BBC's broadcast operation and deals with the various aspects which must be considered in the design if the result is to be successful. The requirements of the user are considered, and the paper stresses the need to prepare a comprehensive functional and technical specification at the start of the design. Attention is drawn to the man-machine interface, and the paper goes on to highlight the necessity of the designer ensuring that the balance he chooses between performance and cost results in a design which is value for money. In broadcasting, reliability and ease of maintenance are important considerations, and these are dealt with, as is the necessity to ensure that the equipment can be easily made. The paper also considers the use of new technology in broadcasting equipment and the reaction its use produces. In conclusion, the application of the principles outlined to the design of a UHF transposer is described.

1 Introduction

The design process in electronic engineering is one which is not always appreciated, sandwiched as it is between research on the one hand and manufacture on the other. Generally design work does not attract the glamour associated with research work, a fact which many graduates are quick to notice. Whereas research shows that it is possible, with the latest technology and using the highest-calibre staff, to achieve a specific result, the design process is converting this achievement into a physical realisation in such a way that the result can be repeated by any practitioner in the field if he follows the specification drawn up by the designer. This requires the designer to concentrate on more mundane matters such as the choice of components, mechanical tolerances, heat distribution and heat flow, together with other seemingly boring, but vital, items. The result of the designer's work must be a piece of equipment which the customer can afford and that the operator can use without very much specialised knowledge or training.

In the BBC, the Engineering Designs Department can get confused with the scenic and graphic design groups, but this does highlight a very important aspect: namely, that design is a creative function. The purpose of electronic design in the BBC is to translate an idea into a piece of equipment so that a facility can be used in the broadcasting operation.

2 Design functions

In the design of electronic equipment for use in the BBC's broadcasting operation a number of aspects must be considered if the result is to be successful. The most important aspects of any design are as follows:

(*a*) user requirements
(*b*) man-machine interface
(*c*) performance versus value for money
(*d*) reliability
(*e*) ease of manufacture
(*f*) ease of maintenance
(*g*) use of new technology.

2.1 User requirements

Before any design can be started it is essential that there is a clear user specification outlining the functions which are to be performed by the equipment, as well as the technical performance figures the equipment must meet.

In the BBC this is done by having initial discussions with those in the operational areas who will use the equipment to carry out the function required. In these discussions the functions of the equipment are discussed and a functional specification is agreed, bearing in mind the various options which can arise.

The technical performance of the equipment is also discussed and a realistic specification is decided. At the same time an estimate of the total number of equipments which it is thought will be used is provided, as well as a timetable for when the equipment will be required. The number of equipments required has a significant bearing on the design in that, if this number is large, it may then be economical to use specialist pieces such as extrusions or mouldings, whereas if the number is small such items may be ruled out.

The man-machine interface is also raised in these discussions since the user reaction to a piece of equipment is very dependent on how the operator finds this particular aspect. For instance, the layout of controls on the panels and the type of keys or switches chosen can either break or make a design. The designer's role in this early part of the process is to weigh up and bring to the attention of the user the cost of the various functions which are being demanded of the equipment. If the user finds that a particular function is paramount, then it is important at this early stage that he realises the cost which will be involved. By this means it is possible to produce a piece of equipment which, when finally made, will be at a price that the customer finds acceptable. At the same time the designer must translate into design effort the process of converting the requirements into a piece of hardware so that the development cost can be assessed as well as the time that the development will take. Having obtained from the user the date when the equipment is required, then the designer can decide the number of people that he willl put on to the particular development. The designer can also bring to the attention of the user any new techniques which will be employed in the particular piece of equipment which could give rise to union dispute when it goes into service.

Although the discussions consume a considerable amount of time, they are a very important part of the design process. If they are not undertaken, then the resulting equipment and the facility it provides will generally not be what the user expects and consequently he could be dissatisfied. On the other hand, the designer must be very careful that these discussions do not drag on so that the equipment facilities and parameters are never fully decided and that the time when the equipment becomes available recedes further into the distance. In this aspect of the design the designer must be able to judge the optimum point at which to call a halt and get the design process really moving. It could be said that the saying 'a camel is a horse designed by committee' is a typical outcome of user requirement discussions which have carried on too long.

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In arriving at a comprehensive specification for both the facility required and the technical performance of the system, the designer is then in a position to specify each individual unit of the system, which helps substantially in both the testing and setting to work of the final equipment.

2.2 Man-machine interface

Since many of the pieces of equipment found in the broadcast chain have an interface with an operator, it is essential that the type of control panel provided is acceptable to the person using it. Consequently, in the design stage it is essential to produce mock-up panels using the types of switches, keys and lamps in the positions in which they will eventually appear on the final equipment so that operators can get the feel of the equipment on a simulated system before the final design is completed. The design of units which go into bays in apparatus rooms is much more routine, and providing the units are easily accessible then the man-machine interface on these is not so important. On equipment such as editing suites, vision mixers, electronic graphics etc., the operator plays a very significant part, and consequently the type of control and its placing is of paramount importance. If a designer chooses to ignore this, then, no matter how excellent his design, it may not be favourably accepted by the operator since a dislike may have been taken to the panel layout or the type of switch involved.

With the greater use of microcomputers in electronic equipment, there is an ever increasing use of keyboards. Consequently the designer must on many of these equipments decide whether he will use a conventional typewriter-like keyboard or whether he will use a custom-designed keyboard for the particular application. All these are features which must be agreed with the user of the equipment. Consequently the designer may feel he has little freedom to devise layouts radically different from those to which the operator has become accustomed. However, from time to time the designer can identify big advantages in changes, and so he must then exercise his powers of persuasion so that these advantages can be attained and the co-operation of the operator still retained.

In the design of control panels, although components over the years have been greatly miniaturised, the designer must always remember that the size of human fingers has remained the same. Consequently the spacing between keys and the size of keys or push buttons, as well as their shape, need to be considered in relation to the features of the human fingers. Ergonomic considerations must also be applied when deciding the height at which to place a control panel, bearing in mind the variable reach of both male and female operators. In the case of equipment which is to be portable, the weight of a module needs to be considered, as well as its weather protection. The placing of certain items of equipment, such as power packs within a rack, needs to be carefully considered in view of the weight problems. Although these features may appear to be mundane considerations, particularly to young engineers straight from university well versed in the latest programming techniques, to ignore these features would ensure that a design was not accepted by the operators and consequently would fall into disuse.

The increasing use of microprocessor-controlled equipment using video display units has given rise to another form of man-machine interface, generally known as user friendliness. This is a vital requirement of such systems if they are to be accepted by the users. This requirement can be built-in when the program is being written. In the case of transmitter control equipment where microprocessors are used, the program is designed to draw the operator's attention to any errors on the data he inputs to the system.

2.3 Performance versus value for money

One of the hazards facing all designers is 'specmanship', which can be defined as the business of producing a specification which appears more inviting to the user than that of competitors. A specification can be written just to attract a customer or it can be written with a view to the equipment actually meeting it; in the BBC the latter is the case. Consequently, if we are able to get value for money, it is essential that the specification only calls for that which is necessary and sufficient to perform the task in hand. In some cases, for instance on our UHF transposers, which are small transmitters, the question of crossmodulation between the sound and vision parts of the signal is very important, and certain specification figures have been agreed. Although it is imperative that these are met, it is not good practice to strive to make them significantly better if, in so doing, the price of the final item is greatly increased.

In a broadcasting chain every designer aims to obtain the highest performance he can from his particular piece of equipment. However, he quickly realises when he is well along the exponential curve of improvement in performance against the amount of effort expended. Consequently he must at an early stage make a value-for-money judgment concerning the performance specification that will be given to his piece of equipment. The higher the specification required, the longer is the development time and generally the longer is the setting up time required during the manufacturing process. Consequently, in view of the cost of all these particular operations, there must inevitably be a point beyond which it is not worth while proceeding, particularly in a competitive situation. In addition to deciding the performance of the equipment, the designer should take into consideration whether the improvement in the performance of his particular item would make a noticeable difference to the result as shown on the viewer's screen or via his loudspeaker.

2.4 Reliability

For equipment intended for use in a broadcasting chain, reliability is a paramount requirement and an attribute of the equipment which can only be attained by a total integration into the design as it progresses. Reliability is not a readily available component which one plugs into a design, but is a resulting attribute following upon careful attention to a large number of individual parts of that design. Reliability is something which becomes apparent at an early stage in the use of a new design, and if a piece of equipment is unreliable then this can usually be traced to a particular item which may be relatively insignificant in relation to the total equipment. For example, a common form of unreliability is attributable to plugs and sockets. This often results from either poor siting of these or poor tolerancing of the mechanical parts on which they are mounted. Occasionally a designer may be tempted to use a cheap component, the cheapness having been achieved by some particular process such as the plating having been skimped. In such instances he is endangering the reliability of his equipment. Broadcasting is a 24 hour a day 365 days a year business and breakdowns are both inconvenient and expensive. In particular, in the transmitter field this is even more true, and in the case of the small transmitters, called transposers, the failure of one of these would deprive an isolated community of a source of entertainment. Consequently, in the design of equipment for broadcasting the reliability must be such that, for the whole equipment such as a transposer, a mean time between failure of some one and a half years, i.e. 15 000 h, is a design requirement. Reliability in equipment is very quickly reduced when it is allowed to develop heat spots; consequently to design reliable equipment requires that the designer pays particular attention to the distribution of the heat dissipated within the system.

One very important item in any piece of electronic equipment is the printed circuit board, and the layout of this board as regards track widths and track spacings can have a significant effect on the reliability of the equipment, particularly in adverse environments. In the case of plated-through-hole boards, it is essential that the design is such as to allow the manufacture of the board to be carried out effectively. When a piece of equipment has been in service for some time, reliability can often be affected by the difficulty in carrying out any repairs that are necessary; consequently the designer should ensure that when maintenance is carried out there is adequate room on the board for the soldering, if required, to be carried out. The choice of components used in a piece of equipment has a significant bearing on the reliability of that equipment, and it is true to say that the higher the quality of a component, the higher its cost. Consequently reliability can reflect in the cost of a piece of equipment. The designer must try and weigh the cost of building in reliability against the final cost of the equipment as to whether it will be acceptable to the person who is acquiring it.

In general, reliability is attained by maintaining quality control throughout the whole of the design and manufacturing process.

2.5 *Ease of manufacture*

Having worked out the electrical circuit for a design, it is essential that the designer then plans how this should be turned into a final piece of equipment, which must be capable of being made as cheaply as possible with as little specialist effort and equipment as possible. Very often equipment is held up in manufacture owing to the poor choice of a component or owing to some other mundane aspect being overlooked. In order to ensure a piece of equipment shall be easily manufactured, it is important to choose components which are, if possible, at least dual sourced, so that any failure of supply from one manufacturer can be overcome by ordering from another. This policy is adopted in the BBC for both active and passive components. The printed circuit board should be laid out so that the track widths are as wide as possible and so that the spacing is adequate. Very close packing of components leads to close track spacing, which can give a large amount of trouble in the board manufacturing process, resulting in the printed board being difficult and expensive to manufacture.

In the case of mechanical parts having complex shapes, wherever possible these should be achieved through the use of extrusions. If from the initial discussions with the user the designer feels that a large number of equipments will be made, then he should certainly consider the use of extrusions for these complicated mechanical parts. In the choice of all mechanical parts great care should be paid to the tolerancing so that in the manufacturing process the final equipment can be assembled without much difficulty. In the BBC a standard chassis system has been adopted which eases both the supply and the manufacture of equipment since it can be obtained readily in large quantities and to a close tolerance.

2.6 *Ease of maintenance*

No matter how good a design is, or how well it is made, there will inevitably come a time when it will break down. Once this happens it is essential that it should be easy to maintain. Maintenance can be split into two parts. The first part is the restoration of the service which has been interrupted, and this is generally achieved by replacing a unit or a module in the complete equipment. The second part of the maintenance is to repair the unit removed. This would normally be done at a base with specialised equipment and staff. The service having been restored, the faulty module must be repaired, which is something the maintenance man must be capable of doing fairly easily. The ease with which it can be repaired is affected significantly by the thought put into the design. Nothing can be more frustrating when repairing a faulty unit than to be unable to readily see how to gain access to the unit. The fixing of covers by screws is preferred to using nuts and bolts. The number of screws should be kept to a minimum so that there is no unnecessary work needed to gain access. The designer in laying out the unit should bear in mind that the maintenance man's attitude to the particular design will be significantly affected by his reaction to the general state of the unit. If a unit looks as though it is well laid out, then the maintenance man may be somewhat sympathetic towards the fault having occurred. If, however, it is poorly laid out, then the maintenance man's opinion of the unit will quickly drop.

Having found the faulty component and replaced it, the maintenance man will then need to set the unit to work again correctly according to the specification. It is essential in the design process to ensure that the unit can be lined up in the field without requiring very complex equipment or needing expertise of the calibre required in the design stage. The designer should arrange in the layout of his circuit and in the breakdown of his completed equipment into modules that it is possible for the maintenance man to isolate various parts of the equipment or circuit in a logical manner in order to trace faults. Monitor points should be built in to enable test signals to be fed in and, where possible, in-built diagnostics. In the case of test signals the designer should remember that in the field the maintenance man has only a limited number of these, and consequently the designer should arrange that the standard signals will give a result which is meaningful. One important aspect of the ease of maintenance is the handbook which the designer should so organise to cover his equipment. This should outline the necessary procedure to set the equipment to work again after a fault and should be written around the type of test equipment found in the field.

2.7 *Use of new technology*

All designers like to keep up with the fashion in electronic components and techniques, and the term 'new technology' is one which has become very popular in the last few years in order to demonstrate the prowess of those engaged particularly in electronics. All designers feel that if they do not employ the latest technology in their design then they have failed. However, designers must always be conscious of the fact that the latest technology may not be the best for their particular application. For instance, the use of microprocessors in equipment has increased enormously. In many cases this is justified, but in many others it is only to satisfy the fashion, and the job which they are undertaking could be done as effectively by using a few logic gates or possibly a few relays. When a microprocessor is used it allows the designer to utilise a set of standard hardware for many applications simply by changing the program, thereby reducing the time to produce working equipment. The use of new technology in equipment has also brought with it other implications which the designer should bear in mind. These are the union implications concerning the use of equipment employing new technology. Naturally the designer, having announced the marvels of his new equipment, will have ensured that the user is aware of what is to come, and consequently union pressure may be brought to bear in order to obtain for the operators some financial benefit from using the new equipment. The result of this could be that the latest piece of equipment may be the most technologically advanced, but may never be used. An example of this occurred when new equipment using digital techniques was introduced for distributing the radio services to the transmitters broadcasting them in stereo on VHF. When the equipment arrived on site the union instructed its members not to operate it unless there was a financial reward, as it was claimed that the new technology used required greater skills and these should be paid for. After a series of negotiations a formula was agreed, and the equipment was then allowed into service. Consequently, if new technology can give significant advantages in a piece of equipment, it should be used and the equipment should then be forced into use. If that proviso cannot be met, the use of new technology for new technology's sake should be carefully watched.

3 Design of the 'Silver Streak' UHF transposer

The design of the 'Silver Streak' UHF transposer, shown in Fig. 1, is a good example of the application of the design principles outlined in producing an important piece of equipment which receives signals on one UHF channel and retransmits them on another. Each transposer serves a population of around 200 to 1000 people living in a remote area, and so failure of the equipment means that these people would lose their source of information and entertainment.

Before the design was started discussions were held with the Transmitter Department and Installation Department to agree the function of the transposer, its performance and cost. On the basis of previous experience with the use of transposers, it was decided that it should have a power output of 2 W, as this was the optimum that could be easily obtained entirely by solid state. As many of the sites at which the transposers were to be installed would receive relatively weak input signals, good sensitivity and a low noise figure were required. In view of the remoteness of many of the sites and their distance from the maintenance team base, the user insisted on high reliability, and a target of an MTBF of 18 months was agreed as a minimum requirement. Since the transposer was intended to serve populations down to 200, the cost of the equipment, as well as

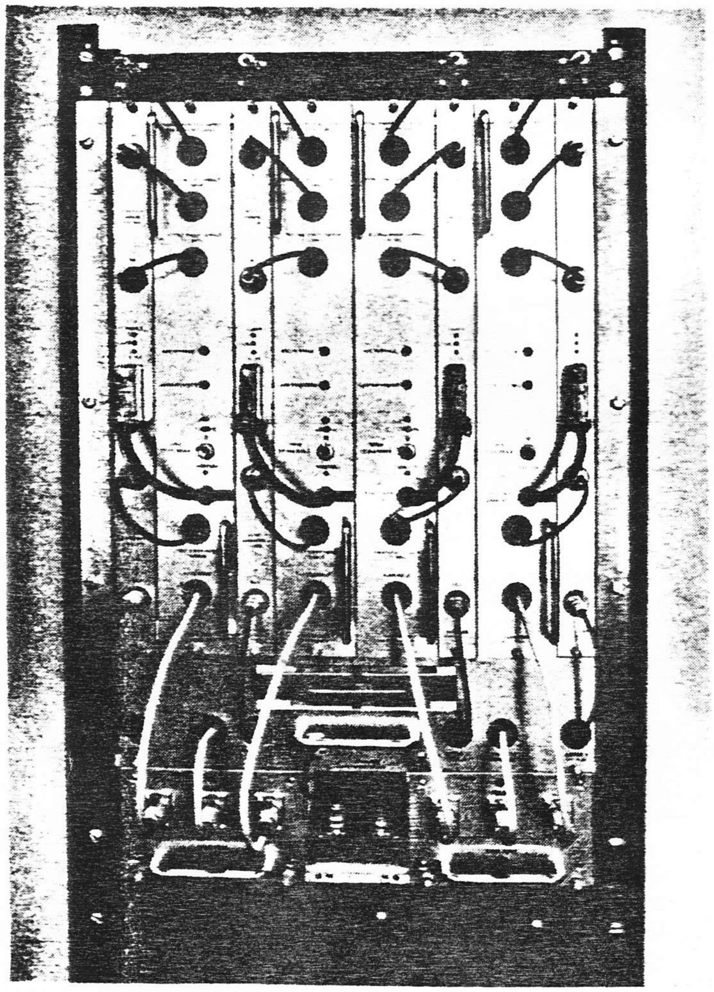

Fig. 1 *'Silver Streak' UHF transposer*

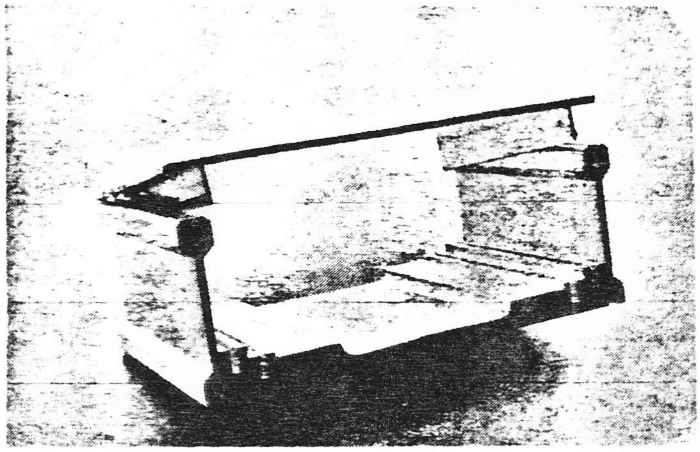

Fig. 2 *Special extrusion*

the installation costs, became a significant factor, and the user asked that the cost of the transposer should be half that of previous transposers and consequently a figure of £2000 per channel was agreed. Since four services could be handled from a particular site, the user requested that the design should be packaged so that four transposers could be powered and worked successfully as a complete entity with the ability to use any number between one and four. Since many of the sites are not accessible by normal roads, and in some instances only on foot, the size and weight of the transposer was important, and so the designer was asked to ensure that both were kept to a practical minimum, bearing in mind that the design needed to be rugged if it was to be capable of standing up to the treatment expected. The user also asked that the transposers should be capable of fitting into a small cubicle about 1 m square or a cabinet so that it could be installed cheaply in a variety of places, from exposed hillsides to landing space in a block of flats.

After the discussions with the user, the amount of design effort was assessed at 1300 man-days to cover the design as far as the production of a prototype in final form, and the time scale required that this effort would be expended over a period of 18 months. This required a design team of about eight people. It was further expected that at the end of the development phase additional effort would be needed to see the equipment through the first phase of production to iron out any difficulties arising and to deal with further development which could not be precisely foreseen at the outset of the design.

Early in the design it was decided that, in order to meet the requirements of weight, ruggedness and cost, a special-purpose aluminium extrusion should be designed for use on all active units. By careful design the extrusion was made to reduce very substantially the amount of mechanical work normally needed to produce a working module requiring extensive marking out, machining, drilling and tapping. The extrusion (see Fig. 2) was made with threaded grooves to accommodate fixing screws. By this and other means the amount of effort needed to make each module was reduced to an absolute minimum. The decision to use a special extrusion was taken because it was known that several hundred units would be built and the cost of the extrusion tooling could then be amortised over a large number of equipments. From the technical point of view the use of the extrusions enabled the screening of the various active units to be maintained at a high level cheaply.

The design team had as its first task the preparation of the block schematic diagram of the complete equipment with the specification of gain, levels and impedance at various points in that schematic. In this process it is important to keep in mind the needs of ease of manufacture and, most important of

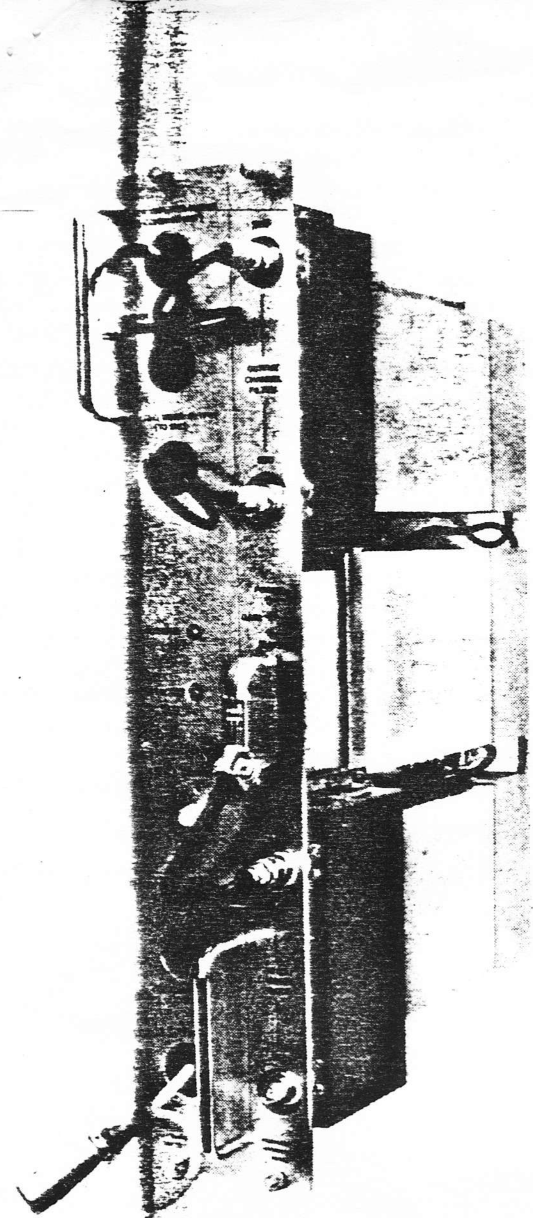

Fig. 3 *Two basic modules*

all, the ease of maintenance should the equipment fail at any time. With this in mind the concept of the separation of functions into active wideband and passive executive areas was at the forefront. Also it was decided that the active modules should be designed to be broadband, covering the whole of Band IV and Band V, thereby reducing the spares holding considerably. The design rapidly developed into two sections: one active and the other passive (see Fig. 3). The passive module was termed the personality module as it embodied the main features such as channel number etc. of the specific station. It was also decided that the transposer should be universal, i.e. one with no adjustments to be made on site, resulting in the use of identical active units at all sites. This made maintenance of the service easy and also reduced the number of types to be manufactured, but in doing so added considerably to the design difficulties. The passive unit, the personality module, contained the filters, frequency selection elements and gain controls particular to the station, and this unit was designed to last the lifetime of the installation without further adjustments once it had been installed and set up. The active units of the transposer were mounted as a single unit and comprised the broadband amplifiers and mixers necessary to change the frequency of the channel. The problem of getting the oscillator frequency correct for each station was solved by the provision of a synthesiser with external frequency setting determined by the personality module. The vexed question of dealing with offset and input signal frequency errors was solved by elegant circuit design.

Weight reduction was achieved by making extensive use of purpose-designed extrusions. Weight is an important consideration as the equipment could be used at some distance from the nearest point of vehicle access. Equipment reliability was maximised by judicial mixture of component duplication and circuit simplification. The overall equipment was designed so that it could be installed conveniently either as pairs or quads to suit as many different types of installation as possible. Very careful attention to manufacturing detail was given to ensure that the equipment was simple to make and test and correspondingly easy to maintain in service.

The active unit (see Fig. 4) was arranged as four modules; one of these, the low-noise head amplifier, had four different outputs serving all the transposers on the station. Another module was the IF unit, which incorporated mixers to convert the signal from UHF to IF and conversely. The third module was an oscillator unit providing two outputs to apply to the mixers; the fourth module was the output power amplifier. The distribution of gain was largely determined by the operating levels of the mixers. The design of the various modules was allocated among the members of the design team.

Each of the major active modules presented design problems. The output power amplifier was required to have a substantially constant gain of 55 dB over Bands IV and V, with a minimum output power of 2 W, and at the same time have acceptable linearity at any frequency within the total bandwidth range. To accomplish the design so that this specification could be met on the production units required the designer to measure the parameters of the transistors and the locus optimum load determined by a series of spot frequency measurements. The impedance was then synthesised using a desk-top com-

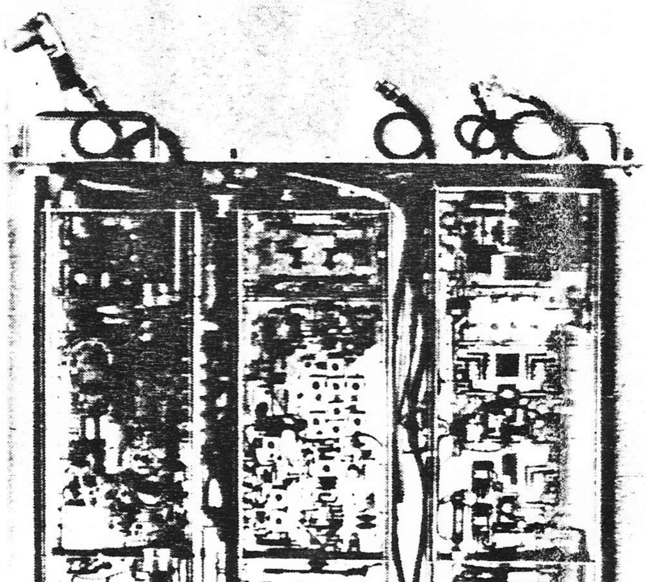

Fig. 4 *Active unit*

puter. In addition the intermediate stages had to be designed to cope with the transistors, which tended to give increasing gain with decreasing frequency, and it was imperative to avoid losing power handling capacity in offsetting this gain. The resulting unit design was such that the spread of gain over the required bandwidth was about 1 dB.

In order to make the transposer easy to manufacture and maintain, the oscillator unit had to be capable of being set to any of the UHF channels 21 to 68, and each channel could have one of three frequency offsets, which meant that each oscillator had to be capable of taking up any one of 144 frequencies.

The ability to meet the overall design specification was assured because the individual units of the transposer had been carefully specified at the outset. The correct specification to achieve this result was possible because the team of engineers had substantial previous experience in this sort of work.

At each stage of development the units were scrutinised to ensure that the production costs were minimised and adequate test facilities were provided to expedite production testing as well as to make for easy maintenance. In addition every effort was made to maximise reliability, and component duplication was employed judiciously to ensure the best compromise between overall reliability and cost of the equipment. Finally, careful thought was given to the production testing to ensure that test costs were kept to a minimum consistent with a high standard of production.

The design process was managed and controlled by a senior design engineer, who had overall responsibility for ensuring that work was completed in time and met both the cost and technical specifications. A team of engineers was allocated to the project. Each member of the team was given a specific task and was expected to keep to the estimates of effort, time and cost. As is normal with all design projects, bar charts were produced so that progress could be measured and assessed. The engineer in overall charge monitored progress on a regular basis to ensure that the timetable was being met and that costs were under control. The information on effort and costs was collected from each member of the team on a weekly basis and compared with the estimate so that corrective action could be taken if required. Regular contact was maintained with the user during the design period. Since the service requirements had been closely specified at the beginning of the design, the discussion during the design usually covered mechanical aspects such as layout of controls, packaging etc. These discussions were found to be very useful, ensuring that the equipment went into service smoothly.

The design took two months longer than forecast and encompassed the construction of two sets of transposers, each capable of handling four services. One of these sets was used for field trial and the other was for use in the laboratory for further tests and investigation. As a result of experience on the first production batch, a number of modifications were incorporated to ease production and assist with rapid testing to produce further cost savings.

4 Acknowledgment

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F.G. Parker, who is Head of the BBC's Engineering Designs Department, has been associated for many years with the design of the complete range of specialised electronic equipment used in the BBC's broadcasting operations.