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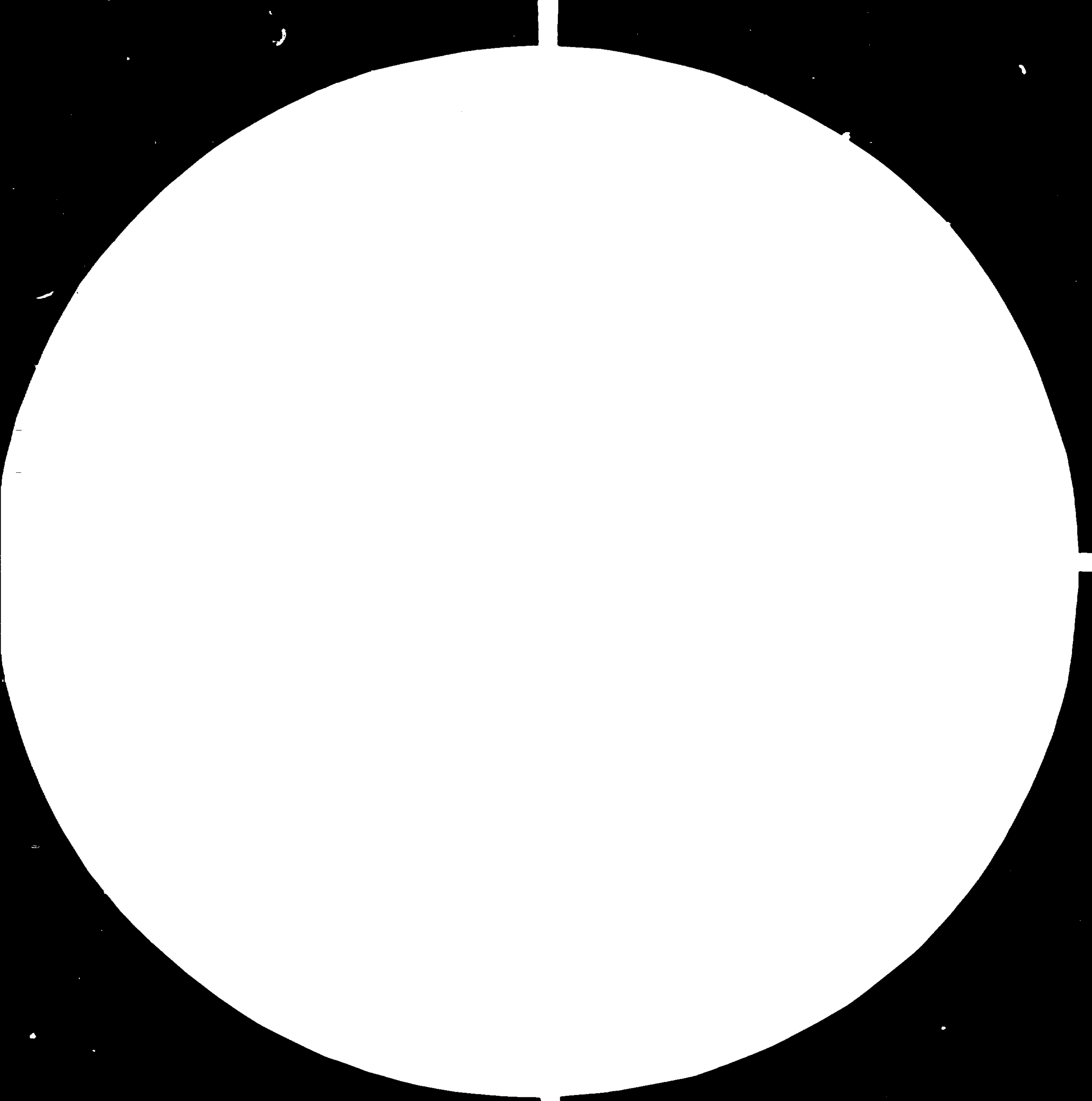

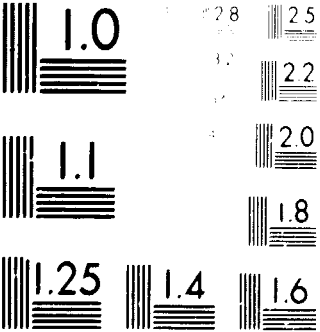
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ASSISTANCE TO ELECTRONICS INDUSTRY, TURKEY.
(8Mbit/s PCM Transmission Over Pair Type Cables).

11488

TURKEY

(SI/TUR/78/801)

Project findings and recommendations

Technical report prepared for the

Government of Turkey

by

Dr. Peter Cochrane (Telecommunications Engineer)
Expert of the United Nations Industrial Development.

S U M M A R Y

Details of a six week mission to the Marmara Research Institute at Gebze are given. The mission was concerned with limiting effects of cable cross-talk on the performance of 8 Mbit/s transmission systems. A computer model was developed that gave predictions in broad agreement with various published papers on the topic. From the early results it is clear that the PTT's system requirements may be attained in a variety of ways.

It is provisionally recommended that on the basis of 1 or 2km repeater spacing that AMI or HDB3 line codes would be quite adequate. There would be little advantage to be gained by going to the more complex 4B3T or Duo-Binary type of codes, unless repeater spacing and/or cable fill are to be maximised. It is also recommended that this possibility be fully explored on the computer model in order that the PTT are aware of all the options available.

The choice of equaliser shape is also quite straightforward for the PTT requirement and it is thought that an "α" in the range 0·35-0·5 would be adequate. Furthermore, it would not make the circuit realisation unduly difficult.

More comprehensive computer analysis is recommended to validate the above assertions which have been made on the evidence of trends in the initial results. It is also suggested that a further two computer models, initiated during the mission, are completed for further comparisons and for future digital radio system work.

CONTENTS

* These appendices are available as separate documents as they have been issued as MRI Research Reports.

+ This is also available as a separate document.

GLOSSERY OF TECHNICAL TERMS

Duobinary

A 3-level code in which binary spaces are transmitted as the centre "0" code and binary marks are transmitted as one of the extreme levels. Successive marks are of opposite polarity if the number of intervening spaces is odd, and of the same polarity if the number of intervening spaces is even.

High Density Bipolar (HDB3)

A modified bipolar code, again with long runs of zeros replaced by codes with some timing content, identified by "bipolar violations" in the marks in the inserted codes. This is an earlier form of Compatible High Density Bipolar.

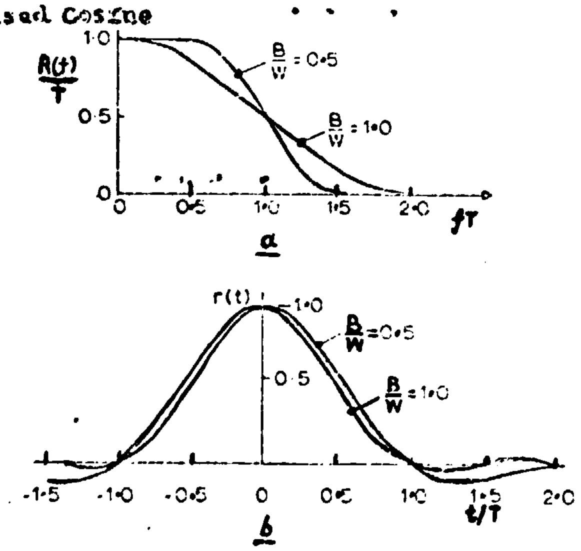
4B-3T

A 3-level code in which four binary symbols are represented by three ternary symbols, using mode alternation, controlled by the output disparity, to reduce the disparity of the transmitted signal.

Alternate Mark Inversion (A.M.I.)

A 3-level code in which one binary level is always represented by the centre level of the 3-level code and the other is represented alternately by the two extreme levels.[4-9, 62]

Raised Cosine



Frequency Domain

$\frac{B}{W} = \alpha$

Time Domain

$R(f) = 1. \quad B - W < f < W - B$

and

$R(f) = 1 + \cos\pi\left(\frac{|f| - W + B}{2B}\right) \quad W - B < |f| < W + B$

$R(f) = 0$ elsewhere

1. INTRODUCTION

The technical mission described in this report was initiated by the Turkish Government who requested assistance for a Pulse Code Modulation (PCM) research programme being conducted at the Marmara Research Institute (MRI). This programme had initially been prompted by the requirements of the Turkish PTT who wished to develop and install 8 Mbit/s PCM systems in the existing cable network.

The principal objective of the MRI research programme was thus to produce a pre-production prototype 8 Mbit/s telephone transmission system. This was to be compatible with the CCITT* PCM+ hierachy as well as the Turkish PTT network requirements.

An important aspect of the total programme was the intention to manufacture and install complete 8Mbit/s systems using only the Turkish PTT resources. This had previously been achieved for some of the lower bit rate 2 Mbit/s systems already operating in the Turkish network - and again MRI had assisted in the programme. However, the transition from 2 to 8 Mbit/s, whilst superficially straightforward, does entail significant technical problems. This is especially true when the transmission media consists of pair type cables. The most significant of all the problems posed by the increase in speed is that of cross-talk.++ This phenomenon provides the principal performance degrading effect on such systems and ultimately dictates the maximum traffic capacity. Unfortunately this problem also impinges on many other aspects of system design and thus greatly influences the final transmission system realisation.

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* CCITT: The International Telegraph and Telephone Consultative Committee.

\+ PCM: Pulse Code Modulation

++ Cross-talk is a euphenism that dates back to the early days of telephony when interference between telephone circuits was common. In such cases the talkers on one line would be able to hear the conversation - albeit at a much lower audio level - on some adjacent line. In the context of multiplexed signals (i.e. more than one conversation on one pair of wires) it is not normal for any intelligent signal to be discernable. However, the interference between circuits or multiplexed channels is still termed cross-talk.

The present technical mission was thus specifically aimed at providing technical assistance in solving the problem of how to account for cable cross-talk in system design. It was also intended to investigate the ways in which this phenomenon influenced the many other parameters fundamental to the system realisation for application in the Turkish network.

2. ORGANISATION OF MISSION

In order to put this short duration (6 weeks) technical mission into perspective we quote a number of past, present, and projected future milestones in the total programme:

a) Initial investigation bh Turkish PTT	1977
b) Involvement of MRI by PTT	1978
c) Request by MRI to UNIDO for assistance	1978
d) Search for suitable expert initiated	78-79
e) Expert assigned to project	1979
f) Mission commenced	14/1/80
g) Mission terminated	22/1/80
h) Projected completion date for MRI involvement	1981
i) Projected date for commencement of system production by PTT	?

It should be noted that whilst the total mission occupied a period of six weeks, the effective time after briefing, debriefing and travelling was reduced to only 5 weeks. More specifically the working time at MRI was:

First effective day = January 17th
Last effective day = February 19th
Total working days = 24

3. FINDINGS

Upon commencement of the mission it was evident that the MRI team had completed a substantial amount of work for the 8 Mbit/s system realisation. Specifically:

a) A terminal equipment had been partially constructed to multiplex 4 x 2 Mbit/s plesiochronous data streams into a single 8 Mbit/s signal.

b) A basic prototype regenerator had been constructed for 8 Mbit/s operation and included a sharp cut-off raised cosine filter (α = 0.3) suitable for up to 1 km of 0.9mm pair taype cable.

c) Both HDB3 and Duobinary line codes had been investigated and encoders constructed.

d) A 400m sample of 0.9mm 400 pair type cable had been characterised for attenuation; phase response; impedance; and near and cross-talk.

In addition some background work had also been completed on the cross-talk problem. Principally, system performance estimates had been made on the basis of local cable data combined with published results from other PTT's and operating organisations throughout the world. Some additional estimates had also been provided by commercial manufactures - noteably the Japanese - for similar cable and system types.

The specific difficulties stalling the project at the commencement of the present mission may be listed in the form of the following fundamental questions:

a) How do you account for cross-talk in system error-probability calculations?

b) How does cross-talk influence the choice of equalisation shape?

c) How does cross-talk influence the choice of line code?

d) What other transmission impairments are important? How do they relate to cross-talk? How do you account for them?

A few additional problems, somewhat peripheral to the main theme of the mission were also evident; these concerned the realisation of fixed and adjustable aqualisers as well as problems associated with the positive negative justification scheme adopted.

4. MISSION WORK PROGRAMME

4.1 Introduction

Not all of the problems outlined in the previous section were included in the original job specification and some partial solutions (or "soft decisions") had been made locally before the mission commenced. However, the principal difficulties were focussed around the cable cross-talk problem which influences the choice of many other system parameters. The investigation of this phenomenon and the formulation of suitable technical solutions - specifically taylored to meet the local situation - was thus identified as the principal objective. A successful outcome to this part of the work would automatically provide solutions - or at the very least good technical indicators - as to the solution of many of the other outstanding problems.

The work undertaken was thus divided into technical lectures and seminars; production of theoretical models; computer implementation of models; interpretation of computed results. Each of these was completed as far as possible - on a group basis.

4.2 Lectures and Seminars

A total of 10 hours formal lectures were delivered covering most of the problem areas described in Section 3. An outline of the lecture programme is given in Appendix 1 at the end of this report.

The presentations were augmented by pre-prepared notes (which are available as a separate Appendix to this report) and/or hand written notes prepared for topics falling outside the original mission specification. Other background material in the form of published papers and memoranda was also provided.

4.3 Theoretical Models

It was necessary to produce theoretical models that would not only meet the local project requirements, but also utilise to the full, the limited cable and other data available.

The principal model developed has been entitled "A PCM System Model Based Upon Power Addition of Cross-Talk Interferers". An MRI Research Report describing the model and its computer implementation is currently being prepared and will be available in the near future – again as a separate Appendix.

In effect the power . takes a "Central Limit" view * of the problem and assumes that the addition of cross-talk, thermal noise and intersymbol interference is on a power basis. It thus automatically gives results that account for equalisation, line code, repeater spacing and signal levels. At best the approach is a fair approximation to the truth, and at worst it gives a somewhat pessimistic view (by about 1 - 3 dB).

A second model was also implemented that involved the use of a time domain description of the cross-talk interference (see papers by Bates and Cochrane in separate Appendix). However, this work requires further extension in that all the local cable data has been produced by frequency domain measurements. Brief discussions on how this could be done were held and the work is left for future investigation. If implemented it would give a more precise prediction of system performance than the power model. It also provides greater accuracy in accounting for other phenomena as well.

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* Central Limit – This pertains to a mathematical theorem that states that the addition of a large number of random variables results in a final distribution that tends to be Gaussien.

Finally a third model was discussed that involved the extension of some work previously undertaken by one of the MRI staff at Philips in the Netherlands. This involved a "Monte-Carlo" system simulation with the generation of a "Pseudo Random" bit stream, a software encoder and line model, and eventually the statistical analysis of a system "eye diagram". Again, only brief discussions were possible and actual development was left for future implementation.

4.4 Computer Implementation

All three models outlined were (or in the case of the third one, had previously been) implemented on a computer, but only the principal model was fully debugged and deemed operational during the period of the mission. Predictions produced by this model showed good agreement with the published results of other authors who utilised different theoretical techniques, or alternatively, based there estimates on actual operating experience with installed systems.

Full details of this program and example results are contained in Appendix 2.

4.5 Interpretation of Computed Results

Because the raw cable data has a statistical base, it is necessary to adopt a probabalistic view of the system predictions produced by the computer model. This was achieved by selecting cable data at a 99% confidence level for any given combination of pairs. The effect of adding many random samples from the "Log-normal" distribution of the cross-talk interferers was also accounted for by computing a mean adjustment figure. Thus all the data fed into the model automatically takes into account any uncertainties due to measurements and cable pair selection.

To back up the work a survey of all available cable data was undertaken and used to ratify the results obtained on the 400m sample at MRI. This was also necessary to derive relationships between the Near End and Far End Cross-Talk (NEXT and FEXT) .he MRI results only provided the former and not the latter. Unfortunately this process leads to an uncertainty of about 2 dB in prediction of FEXT from NEXT. However the computed results are mainly NEXT dominated and assuming the worst case FEXT prediction does not entail a severe penalty.

5. RECOMMENDATIONS

5.1 System Realisation: General

Full computer analysis of all the possible combinations had not been completed at the termination of the mission. It is thus impossible to make solid recommendations on the final system definition. However, some trends were becoming apparent and so we make tentative suggestions based upon these early predictions.

In making these suggestions we assume the PTT's requirements to be definite. These are quite relaxed in terms of system design in that repeater spacings of 1 km for bi-directional and 2 km for uni-directional operation have been deemed satisfactory. Moreover, it is not envisaged that more than about 16 x 8 Mbit/s systems will be required on any one cable. It is, however, expected that a mixture of 2 and 8Mbit/s systems will have to work on the same cable.
If at a later date the PTT decide to go for maximum cable fill and/or maximum repeater spacing, then the problem falls in a different "ball park" and our approach would have to be revised.

5.2 System Realisation: Equalisation Shape.

From the early results it is clear that a fast rate of cut off affords some advantage in terms of cross-talk, and as might be expected introduced the penalty of increased ISI. When a raised cosine response is used, then an $\alpha \sim 0.35 - 0.5$ seems to produce a reasonable compromise between the two penalties.
The advantage (in terms of cross-talk) of going to an even smaller α value is rapidly "off-set" by the increased circuit complexity necessary and build up of ISI.

5.3 System Realisation: Line Code.

From the results produced, at the time of writing, it would appear that even AMI would melt the PTT requirements. HDB3 or 4B3T would also meet the requirements with ease. There seems little point therefore in considering the use of Duobinary as the reduced handwidth capability would not be exploited to the full. In addition it poses a number of problems - not least of which is how to provide timing recovery. Other complications also present themselves and include an increased sensitivity to ISI and thus a need for accurate and stable equalisation. In short - it is an expensive solution when there are other viable alternatives.

It is thus suggested that either HDB3 or AMI are used. At present it is not clear which of these gives a definite advantage in terms of circuit complexity or immunity to cross-talk from either 8 or 2 Mbit/s systems. Further investigation is thus recommended - especially with respect to the interference from and to 2 Mbit/s systems.

5.4 System Realisation: Equaliser Circuit Design.

Unless repeater spacings in excess of 2 km are adopted, then thermal noise limitations are insignificant compared with cross-talk and ISI. The circuit realisation of the equaliser is thus open to exploitation. A noise figure of 10-15 dB is likely to be sufficient, and it may even be possible to extend this to 20 dB or above. There is little point therefore in adopting a more complex realisation that is really necessary.

5.5 System Realisation: Cable Pair Selection

Fundamentally there are three options when cable pairs are to be selected for a given system. These are: random selection; intelligent selection; and select-on-test. From the early results it is clear that the select-on-test option is far too stringent - as well as being expensive - and is not warranted unless maximum cable fill is desired. Completely random selection appears to give an adequate operating margin and gives the simplest option. However, if intelligent selection is used (i.e. selecting pairs from well isolated parts of the cable for the GO and Return Paths) a further margin of safety is provided. Typically it would appear that this is likely to be of the order 8-10 dB. It is thus recommended that intelligent selection of cable pairs is adopted as part of the installation procedure.

5.6 Future Work

A comprehensive series of computer prediction are required for different line codes, equaliser shapes, and combinations of 2 and 8 Mbit/s systems on one cable. It is also suggested that these predictions be made on the basis of 1 and 2 km repeater spacings, i.e. bi-directional and uni-directional working.

In order to give the PTT the full picture, it is further suggested that alternative solutions are sought that maximise the repeater spacing and/or cable fill. The final choice of system can then be made with a high degree of confidence.

It is also suggested that the work started on the other two computer models be completed if at all possible. This would give even more surety - over and above that gained by comparison with other published work - that the system predictions and choices were correct. Furthermore, these particular models are likely to be more adaptable than the power model, and could probably be extended to cope with radio systems as well.

5.7 Back-up Mission

It is not thought likely that any form of back-up mission will be necessary for the successful completion of the project. It is the opinion of the author that the MRI staff are quite capable of completing the present project unaided. However, it has been agreed that the dialogue on the uncompleted aspects of the work will continue, and the author has agreed to assist whereever and whenever possible.

5.8 Further Education/Training

The MRI staff are well qualified and technically quite capable, but they have expressed some concern about several areas where they see themselves lacking in practical experience. For example, they seem a little uncertain about the practical realisation of particular equaliser designs. Thus, it is recommended that at an appropriate time assistance be given for a member of the team to attend a suitable university course, or alternatively to make a working visit to an overseas manufacturer or PTT. To this end the author has agreed to provide details of UK university/polytechnic/IEE short courses and summer schools on the topic.

6. PROBLEMS

6.1 Project organisation

Within a few hours of arriving at MRI it was evident that a good deal of material prepared for the project was no longer applicable and — even worse - material that was applicable had been left back in the UK. The prime reason for this was that the project specification had been overtaken by events, and no contact between the author and the staff of MRI involved had been made prior to the commencement of the mission. Thus it is recommended that for future missions contact between the expert and MRI staff be implemented at the very earliest opportunity. The need for this early contact is in the interest of greater efficiency, and its importance is considered to be inversely proportional to the mission duration.

6.2 Supply of Hardware

During the mission it was evident that delays in the supply of electronic components (via UNIDO) was causing some difficultice. If this delay could be reduced then it would greatly assist the project in coming to successful conclusion.

6.3 Timing of Mission

Throughout the present mission local conditions were not at all conducive to any rapid progress. The winter of 1979-80 was proving particularly severe, and coupled with an oil crisis, was making life difficult. For example, there was little heating oil - and so it was not unusual to have to work in the cold, power cuts were frequent and so were cuts in the water supply. Under such conditions it is extremely difficult to solve technical problems.

It is suggested that future missions are arranged for the autumn or spring, but not for the winter or mid-summer, when conditions can be extreme.

7. CONCLUDING REMARKS

Overall the mission was a success despite the very severe problems caused by the harsh winter coupled with a dire oil shortage. A high proportion of the original objectives were achieved, but inevitably time was short and some issued had to be left unconsidered or unanswered. But it is considered that the MRI staff are now in a position of being able to complete the project unaided.

8. APPENDIX 1: LECTURE PROGRAMME

TOPIC/S	DATE AND DURATION
1. Introduction of author to MRI staff. Background and purpose of mission. Outline of BPO and research activities. Introduction to lecture series and outline programme of work.	21/1/80 2 hours
2. Central Limit Theorem and its implications and application. Error Probability calculations. Accounting for single discrete Echoes.	22/1/80 2 hours
3. Generalised model for Echoes, isi and cross-talk. Practical implications of each phenomenon.	23/1/80 2 hours
4. A simplified cross-talk model based upon power addition of components.	28/1/80 2 hours
5. Introduction to equalisation and problems of ripple, phase distortion. Implications of jitter, Lf cut off, over-and-under equalisation. Classes of functions available for equaliser definition.	30/1/80

APPENDIX 2 - 4

These appendices are available as separate documents as they have been issued as MRI Research Reports. See list of contents for further details.

APPENDIX 5

This is available as a separate document.
See list of contents for further details.