University of Sri Jayewardenepura
Faculty of Graduate Studies

Department of Mathematics

A FINITE ELEMENT BASED TOPOGRAPHIC PROFILE MODELLING TECHNIQUE FOR PROPAGATION-PATH-LOSS CALCULATIONS IN VHF ELECTRIC FIELD STRENGTH PREDICTION

A thesis
By

P.S.Panawennage

Submitted in partial fulfillment of the requirements of the
Master of Science Degree in Industrial Mathematics,

December, 2000

Signature: ....

Name : P.S.Panawennage

We approve this thesis titled **"A Finite Element Based Topographic Profiling Technique for Propagation-Path-Loss Calculations in VHF Electric Field Strength Prediction"** of Mr. **Preethi Sanath Panawennage**.

Prof. G.T.F.De Silva Professor of Mathematics, Department of Mathematics, University of Moratuwa	23/2/2001 Date:
Prof. (Mrs.) Sunethra Weerakoon Course Co-ordinator of PG Diploma / M.Sc. programme in Industrial Mathematics, University of Sri Jayewardenepura.	2001.02.23 Date:
Mr. **W.P.A.M. Wijesinghe** Engineering Manager, Independent Television Network.	23.02.01 Date:

DECLARATION

I hereby declare that this thesis titled "A Finite Element Based Topographic Profiling Technique for Propagation-Path-Loss Calculations in VHF Field Strength Prediction" contains my own work and no part of this thesis has been previously submitted to this or any other university or institution in application for admission to a degree, diploma or any other qualification.

P.S. Panawennage

December, 2000

CONTENTS

ACKNOWLEDGEMENTS

I wish to express my deep gratitude to:

- Professor (Mrs) Sunethra Weerakoon, course co-ordinator of the Master of Science degree programme in industrial mathematics, university of Sri Jayewardenepura, for her valuable advice and guidance.
- Professor G.T.F. De Silva, professor of mathematics and former Vice Chancellor university of Moratuwa, who devoted a great deal of his valuable time advising, guiding and continually encouraging me throughout this research.
- Mr. W.P.A.M.Wijesinghe, Engineering Manager, Independent Television Network, for his valuable advice, particularly in matters relating to broadcast engineering.
- Mr. Janadasa Peiris, Secretary to the Ministry of Media and Information and Chairman of the Sri Lanka Broadcasting Corporation, and Mr. Eric Fernando, Director General of the Sri Lanka Broadcasting Corporation, for granting me study leave for completing the research work and the thesis.
- Mr. Mahesh Fernando, Deputy Surveyor General (mapping), Mr. S.D.P.J.Dahampegama Superintendent of Surveys, and Mr. K.D. Perakum Shantha Superintendent of Surveys, of Sri Lanka Survey Department, for providing the topographic maps and some useful information on the subject.
- Miss K.S.M.Vishaka and Mr. Nihal Ratnapala, Assistant Directors, and Mr. RG.H.K.Ranatunge, Deputy Director, of the Sri Lanka Telecommunications Regulatory Commission, for providing access to relevant recommendations and reports of the International Telecommunication Union.
- Mr. Amal Punchihewa, Deputy Director General (.Engineering), Mr. Sanath Nirosha and Mr. Abeysinghe of Sri Lanka Rupavahini Corporation, for providing some relevant data from the results of the field strength measurement campaign conducted by the Asia-Pacific Broadcasting Union.
- Messrs Priyantha Perera and Lalith Priyantha of Asia Broadcasting Corporation, and Mr. Kolonne, Engineering Manager, MBC networks Ltd., for providing relevant data of their respective transmissions.
- Ms. Sudharma, Neetha and Kanthi of the Disc Dubbing section of the Sri Lanka Broadcasting Corporation, for their assistance in recording the topographic height data.
- Mr. Indika De Silva and Mr. Sudesh Peter for the technical support in the preparation and printing of the draft
- My friends I.D.Wimal and Sanath Dissanayake for providing me two computers for the whole duration of the research.
- My brother Upul, brother-in-law Shanku, sister Deepika, and wife Chandima who assisted me in many a labourious and time-consuming activity involved in this effort

ABSTRACT

The main objective of this research was to explore the possibility of using a Finite Element based technique for modelling the Topographic Height Profile, between the transmitting and the receiving locations, of any desired tropospheric radio wave propagation path that is lying over a known contiguous geographical area. The topographic profile thus generated is used in order to estimate the path-loss involved in the propagation of radio waves over the path. This path-loss is then used in predicting the Electric Field Strength received at the receiving location due to some known radio frequency (RF) power radiated (with known transmission parameters) from the transmitting site.

The research methodology constituted of comparison of the field strength values theoretically predicted using the technique proposed above, for a total of 106 different propagation paths of 03 different VHF/ FM broadcast transmissions, with the corresponding field strength values experimentally measured at those respective receiving locations.

The above 106 propagation paths considered in the research are encompassed in a contiguous geographical area of $3250km^2$ located west of the central hills of Sri Lanka, partly covering Western and Sabaragamuwa provinces. The variation of the topographic height over this area is modelled using 13,000 triangular finite elements. Heights of the 6616 geographic locations, which constitute the vertices of those triangular elements, were manually extracted from 1:50,000 topographic maps, and these data comprise the topographic data file.

The overall software programme developed in this research for received field strength prediction basically comprises of two components, serving two broad functions: One is the software module for modelling the topographic height profile of any desired propagation-path, using finite element approach. The other is the software implementation of the combination of mathematical models and other recommendations, by the radio sector of the international telecommunication union (ITU-R) and the European broadcasting union (EBU), which were used for estimating different elements of path-loss. The software implementation was carried out exclusively on MATLAB platform.

The comparison of the predicted and the observed results stand in strong evidence for the aptness of this topographic profile modelling technique for path-loss calculations involved in field strength prediction. The technique is particularly strong in FS prediction over obstructed diffraction-dominant propagation paths. Though the validation of the technique was confined, in this work, to the very high frequency (VHF) band, the technique should be extendable to tropospheric propagation in the ultra high frequency (UHF) band too, the underlying principles and assumptions being the same.

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Background of the Research

The primary objective of the radio wave propagation analysis, be it in a broadcast transmission or a point- to- point transmission situation, is to predict the Electric Field Strength of the signal received at a given receiving location, due to the radio frequency (RF) power radiated from a given transmitting site. In any radio transmission planning exercise, estimating the received field strength is important for two reasons: firstly in order to assess whether the signal meets the minimum desired signal level in the desired receiving point or area, and secondly, to assess whether the signal exceeds the maximum permissible signal levels outside the desired receiving point or area, where it may become a potential source of interference to some other signal.

Generally there are two approaches to estimate the received field strength at a given receiving point of a terrestrial broadcast transmission:

(i) Field strength prediction curves, and

(ii) Terrain-profile methods

1.1.1. Field Strength Prediction Curves

The radio sector of the international telecommunication union, ITU-R (formerly known as the international consultative committee for radio, CCIR), has published a set of curves, for the broadcast frequency bands, giving the median received electric field strength of a transmission with given effective radiated power and transmitting antenna height, versus the distance from the transmitting site. Those curves which can produce rough approximations of field strength, are based on field strength measurements carried out over a vast number of radio paths over European and African Broadcasting regions. Predictions using these curves involve application of several simple correction factors to the values obtained from the curve. These correction factors are mainly of statistical nature and do not take into account the actual form of the terrain.

In addition to the inherent errors consequent to being not terrain -specific, the method, when applied to the Sri Lankan situation, also has the disadvantage of not having being validated for the region.

1.1.2. Terrain-Profile Methods

This approach involves construction of a topographic terrain-profile diagram for the path from the transmitting site to the receiving site, representing the variation of terrain height versus distance. In fact, the actual heights are modified to account for effects of earth- curvature and the tropospheric refraction. Then the mathematical models based on the physical laws of electromagnetic wave propagation are applied to compute the received field strength. There are a number of different models, for computing various aspects involved in field strength prediction, due to ITU-R, EBU, and due to several other authors. Each model differs slightly from the others.

The ability to predict field strength assumes greater importance in broadcast transmission as opposed to point-to-point transmission: the former involves a larger contiguous geographical extent as its desired receiving area while the latter involves just one desired receiving point. Obviously, the same situation exists in the two respective cases with regard to the radio frequency interference prediction too.

1.2. Present Status of the Problem

Application of the techniques of field strength prediction has not found widespread use in Sri Lanka's broadcast industry. Obviously, application of those complex mathematical models based on physical laws of propagation needs specialized software implementations on one hand, and a detailed computer-based topographic database for constructing terrain-profile diagrams on the other. Apparently, absence of the latter has discouraged development of the former (software implementations).

For effective use of terrain-profile based methods of field strength prediction, the terrain profile diagram of the desired propagation path must constitute of topographic height samples obtained at intervals of around 250 meters on the propagation path. Extracting this information, manually, from 1: 50,000 topographic maps is obviously an extremely laborious exercise, particularly in a broadcast transmission coverage planning situation which may typically require around 50 to 60 such path profiles, most of them involving 50 to 150 profile samples. In the absence of computer based methods of analysis, the effort expended at generating such a detailed terrain profile diagram is hardly justifiable.

Therefore, the present practice of the industry in the country is to manually construct, whenever required, a terrain profile with height samples at 1km intervals along the desired path (1km profile sample spacing is clearly about 04 times the minimum spacing recommended by ITU-R for diffraction prediction!). As such, whenever constructed, the use of path profiles is often restricted at present to that of the straightforward test of determining whether or not line-of-sight clearance is present between the transmitting site and the receiving site, rather than prediction of field strength.

Further contributing to the ineffectiveness of even this primitive level application, is the fact that, the data obtained for a particular path-profile being applicable only for that particular path, there is no way of re-using this 'hard-to-generate' data.

In this context, it is inevitable that resort is always made towards carrying out a field strength survey on an actual test-transmission: in a broadcast transmission planning situation, for example, from each probable transmitting site before the final site is decided upon.

Such test-transmissions, in many cases require provision of temporary infrastructure facilities such as road access, buildings, electricity and water supply etc. which risk eventual abandonment should the test become unsuccessful. On the other hand, a prospective transmitting site capable of giving the optimum coverage, but located in relatively difficult terrain, may have to be overlooked even without a test-transmission, when the calculated risk of abandoning the site after spending on the test-transmission is apparently larger.

1.3. The Objective of the Research

The main objective of this research project was to explore the possibility of applying the finite element technique as a tool for topographic height profile modeling of the propagation path, in the prediction of field strength received at a given receiving location due to a very high frequency transmission, with given parameters, radiated from a given transmitting location.

1.4. The Scope of Work

The research methodology constituted of comparison between the received field strength values of 03 VHF/ FM broadcast transmissions, measured over 106 different propagation paths, and the corresponding field strength values theoretically predicted (by the prediction model implemented in this research work) for those respective locations. The predicted value for each receiving location is computed based on the topographic height profile of the particular propagation path, which is modelled using a triangular finite element scheme applied to the $3250km^2$ contiguous geographical area selected for the research.

The geographical area selected for the research, which encompasses the above-mentioned 106 propagation paths, is that covered by the four 1:50,000 topographic maps designated as **Colombo, Avissawella, Attanagalle, and Negombo**. The effective area excluding sea is around 3250 km^2.

Terrain heights of a total of 6616 points, which constitute the vertices of 13,000 nos. $0.25km^2$ uniform triangular finite elements chosen to represent this area, were manually extracted from the above maps. The height of any desired terrain profile point lying within a finite element is then computed using the "Height function" for the element, which is written in terms of the coordinates and heights of the 03 vertices.

The overall field strength prediction model is based on a combination of mathematical models and recommendations for estimating different elements of path loss, by the radio sector of the international telecommunication union (ITU-R) and the European broadcasting union (EBU). The terrain height profile model for a desired transmitter-to-receiver path, sampled at intervals of 250m, is generated by the Matlab programme ***Finite_Elements*** which was written for this purpose. This terrain height profile model is then used by the Matlab program for predicting the field strength.

1.5. Software Implementation

Software implementation of all models, including the triangular finite element model proposed in this research and, various mathematical models based on ITU-R and EBU recommendations, which constitute the final overall field strength prediction model, was carried out using Matlab

1.6. Results

Field strength predictions made using the prediction model implemented, were compared with actual measurements made in field-strength-surveys. The predictions were found to closely follow the field observations. The most important outcome was that the predictions for those propagation paths obstructed by the hilly terrain, where the accuracy of terrain profile modelling is critical, were much more closer to the field observations.

Given the present state of technology in Sri Lanka (and, probably, in most other developing countries as well), where no computer-based detailed topographic database sampled at smaller intervals is available, the technique could be clearly beneficial in VHF broadcast or point-to-point transmission planning.

2. THEORETICAL BACKGROUND

2.1. Introduction

This chapter discusses a few salient aspects of the theory of propagation of electromagnetic waves as applied in the analysis of tropospheric propagation. This involves discussion on some important concepts and phenomena in tropospheric propagation as well as on several different models for the prediction of Electric Field Strength. These models include those recommended by the ITU-R, the EBU and a few more due to several other authors.

2.2. Tropospheric Propagation

Troposphere is the layer of the atmosphere closest to the surface of the earth extending up to around 15 kilometres above the surface of the earth. This is the region through which the propagation of the VHF broadcast signals (the frequency band for which the results of this research were validated), as well as UHF and microwave terrestrial transmission links operate. A signal transmitted through the troposphere undergoes loss of energy *mainly* due to the following phenomena associated with tropospheric propagation:

01. Diffraction
02. Refraction
03. Reflection
04. Tropospheric scatter

2.2.1. Diffraction

Diffraction is the 'bending effect' undergone by the electromagnetic waves when travelling over obstacles having wavelengths comparable with that of the dimensions of the obstacle. It is mainly the attenuation caused by diffraction, due to topographical obstacles such as hills present in the propagation path, that was assessed, among