

LF/MF Antennas for Amateurs

Rudy Severns

N6LF

Preface

Vertical transmitting antennas have been used since the beginning of radio. With well over 100 years of experience, literally thousands of articles and hundreds of books you would think there would be very little left to discover. However, when I began researching the literature I found continuous repetition of the same basic information but not so much on fine details, especially over the last 40 years or so. Useful information current at earlier times has often been dropped or forgotten. In a few cases I felt some of the accepted "common knowledge", much of it derived from broadcast applications, was not correct or at least not appropriate for amateur applications. In particular HF ground system design and the significant differences between HF and LF-MF soil electrical characteristics has not been adequately aired. I admit to a passion for fine details bordering on obsession but in the case of vertical antennas at least some details can be of practical help.

Sixty plus years ago Tom Erdmann, W7DND (SK), gave me some advice on priorities for my first station: if I had a \$100 I should spend \$90 on the antenna, \$9 on the receiver and \$1 for the transmitter. Prices have gone up a bit in the past 65 years but I still keep Tom's priorities firmly in mind. I've always invested far more time, money and effort in my antennas than the rest of the station. Antennas are a lot fun and in retirement LF, MF and HF verticals have become an obsession. For the past 25 years I've been particularly interested in 160m operation, building a number of vertical and sloper arrays. For the last 10 years I've been part of the ARRL 600m experimental group (WD2XSH) transmitting at 465-510 kHz. At the 2012 WRC amateurs succeeded in obtaining worldwide allocations on 2200m and 630m and the FCC has now given U.S. amateurs access to these bands.

For many years amateurs have had only one MF band, 1.80-2.0 MHz (160m) but now 135.7-137.8 kHz (2200m) and 472-479 kHz (630m) has been added. Except for a few experimental licenses amateurs haven't been allowed on these frequencies for over 100 years. This lack of experience means there is a need for practical information on many subjects related to LF/MF operation including antennas. There are many "old" but potentially useful ideas which deserve renewed consideration.

Because of the vast literature on vertical antennas I've made no attempt to make this book a compendium, it is just "some notes", nothing more. I've

focused on subjects of interest to me and have direct experience with. Some of the material in this book is original but most is drawn from the work of others which I acknowledge whenever I can identify the source. The references have been placed at the end of each chapter.

It's my personal philosophy that one needs both theory and experiment to understand a phenomenon. In particular theory and experiment must give the same answer, if not then you don't understand what's going on and need to keep working to resolve the differences! I have spent many hours wondering "what the h... is going on?"

Because I'm speaking to a audience with a very wide range of experience, from the non-technical newcomer to the graduate engineer, the arrangement of this book has to be a little different. I've divided the material into two levels. The six chapters in the body of the book are limited to basic information which, combined with a little modeling or simple calculations, can be applied directly using graphs for special problems like inductor design. The math has been minimized. For those more mathematically proficient and wanting more detailed justification for the advice given in the main text, an extensive body of technical information has been placed in a series of appendices which are available on-line (tbd).

While this book is far from perfect or complete I hope it's useful.

GL and 73, Rudy Severns N6LF, WD2XSH/20

April 2017

Acknowledgements

In preparing these notes I've had a great deal of help from other hams reviewing my scribbling which has been crucial, resulting in rewriting of the entire text several times. in short they've kept me reasonably honest! I would like to thank Fritz Raab, W1FR, Pat Hamel, W5THT, and Jim Miller, AB3CV, for their time and efforts which really helped. In the process these notes were placed on my web page and a number of amateurs made helpful comments. Many of the pictures in chapter 6 were supplied by others who are identified in the captions.

Table of Contents

Preface

Acknowledgments

1. LF/MF Overview

1.0 Introduction

1.1 Long wavelengths

1.2 Soil characteristics

1.3 EIRP and radiated power

1.4 Some fundamental advice

1.5 Modeling and calculations

1.6 Loading inductors

1.7 Examples of early LF/MF antennas

2. Short Unloaded Verticals

2.0 Introduction

2.1 Equivalent circuit for a short vertical

2.2 Definition of R_r in a lossless antenna

2.3 Definitions for R_r , P_r , P_g and R_g over real ground

2.4 R_r from NEC modeling

2.5 Calculating R_r

2.6 Effective height h

2.7 X_i and X_c from modeling

2.8 Calculating X_c and X_a

2.9 X_L , R_L and efficiency

2.10 Voltages and currents

3. Capacitive Top-loading

3.0 Efficiency

3.1 Efficiency with top-loading

3.2 X_i with top-loading

3.3 R_r with top-loading

3.4 More realistic antennas

3.5 Using a Tower for support

3.6 More complicated top-loading

3.7 Umbrella top-loading

3.8 Horizontal or flat umbrellas

3.9 Sloping wire umbrellas

3.10 Combining sloping and flat umbrellas

3.11 R_c and Conductors

4. Inductive Loading

4.0 Introduction

4.1 Loading inductor location

4.2 Inductor location with top-loading

4.3 Grounded Tower Verticals

4.4 Multiple Tuning

4.5 Multiple tuning examples

4.6 Loop antennas

4.7 Grounded towers and multiple tuning

5. LF-MF Ground Systems

5.0 Why do we need a ground system?

5.1 Choices for ground systems

5.2 Ground system dimensions

5.3 Feedpoint equivalent circuit

5.4 Definitions for P_r , P_g , R_r and R_g

5.5 Efficiency with ground losses

5.6 Simple advice

5.7 Ground system for an unloaded vertical

5.8 Ground systems for urban lots

5.9 Larger ground systems

5.10 Elevated ground systems

6. Design and Fabrication of High Q tuning Inductors

6.0 Introduction

Part I

Basics

6.1 How much inductance?

6.2 Definitions

6.3 Inductor design using graphs

6.3.1 Design

6.3.2 475 kHz design graphs

6.3.4 137 kHz design graphs

6.4 Bucket inductors

6.5 Frame or cage coil forms

6.6 Variable inductors

6.7 Winding voltages, currents and power dissipation

6.8 Enclosures

6.9 Coupling, isolation and matching

Part II

Detailed Design and Q Optimization

6.10 Introduction

6.10.1 Circular single layer coils

6.10.2 Flat inductors

6.10.3 Toroidal inductors

6.10.4 Some practical concerns

6.11 Skin and proximity effects

6.11.1 Winding resistance

6.11.2 Skin effect factor K_s

6.11.3 Proximity factor K_p

6.11.5 Litz wire windings

6.12 Self resonance

6.13 Q

6.13.1 Equation verification

6.13.2 Maximizing Q

6.14 Symbols and abbreviations

References