Sources and Characteristics of Low Frequency Radio Noise

by

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30 September 2008

Introduction

Radio noise affects all manner of radio communications and has been a subject of intensive study since radio first came into wide usage in the early 20th century. The amount of literature that has been written on the subject would easily fill a library of moderate size. The purpose of this monograph is to highlight the principle sources of noise and the means by which they propagate as it is understood and accepted by the technical community. The content herein is intended to be informative only and not intended to form any opinions nor draw any conclusions.

Sources of Low-Frequency Noise

The ambient noise environment external to a radio receiving system is composed of emissions from natural and man-made sources, which include (1):

1. Radiation from lightning discharges;

2. Unintended man-made radiation from electrical machinery, electrical and electronic equipment, power transmission lines, or from internal combustion engines;

3. Emission from atmospheric gases and hydrometeors;

4. The ground or other obstructions within the antenna beam; and

5. Radiation from celestial radio sources.

The relative proportion of the emissions from these sources varies with receiver location, antenna beam direction, time, and frequency. A primary factor affecting receiver ambient noise is the location relative to a metropolitan area or to an intense man-made noise source. Man-made incidental noise sources such as deteriorated power lines and heavy automobile traffic can overpower any natural noise source if the receiver separation is small (Skomal 1969).

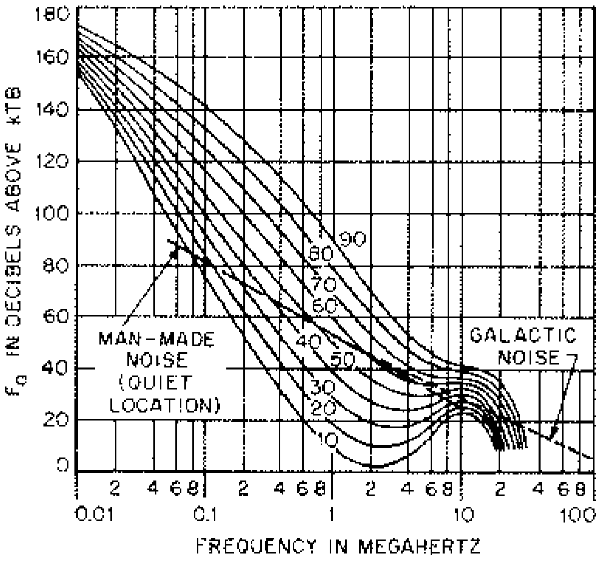

Figure 1 – Terrestrial Noise Distribution
as a Function of Frequency
and Latitude (from ref. 1)

There are occasions where more than one source of noise needs to be considered bacause two or more sources are of comparable magnitude. In general, this can be true at any frequency but it occurs most often at HF frequencies where atmospheric, man-made, and galactic noise can be of comparable magnitude. Fig. 1 depicts the distribution of terrestrial noise as a function of frequency and latitude. These distributions are not constant, but also vary by both the time of the year as well as the time of day (1).

Methods of Propagation

Energy radiated by very low frequency (VLF) or low frequency (LF) electromagnetic sources propagates via transverse electric (TE) or transverse magnetic (TM) modes in the earth-ionosphere waveguide, which is bounded by the earth's surface and the lowest regions of the ionosphere. To the extent that the waveguide can be considered to be flat for VLF/LF waves, the distribution of field intensity with altitude may be thought of as resulting from the interference of elementary up-going and down-going plane waves reflecting from the boundaries at certain oblique incidence angles (3, 4).

The TM modes are best excited by vertically polarized sources such as cloud-to-ground lightning and can be radiated or received at virtually any altitude. The TE modes, on the other hand, are best excited by horizontally polarized sources such as cloud-to-cloud lightning, and are weak unless they are both transmitted and received at least a few kilometers above the ground. The TE and TM modes are not strictly independent of one another because geomagnetic cross-coupling in the ionosphere causes partial conversion between the two polarizations, causing the TM mode to have a small horizontal component and likewise the TE mode to have a small vertical component, and these conversions are strongest during the night (3, 5).

Low-altitude sources radiate TE modes much less efficiently than TM modes, and low-altitude receivers are much less capable of receiving them. The attenuation of TE mode signals is virtually independent of ground conductivity, whereas TM mode attenuation is dependent on ground conductivity and exhibits a broad maximum for conductivities between 10^{-5} and 10^{-4} S/m under certain conditions (3, 6).

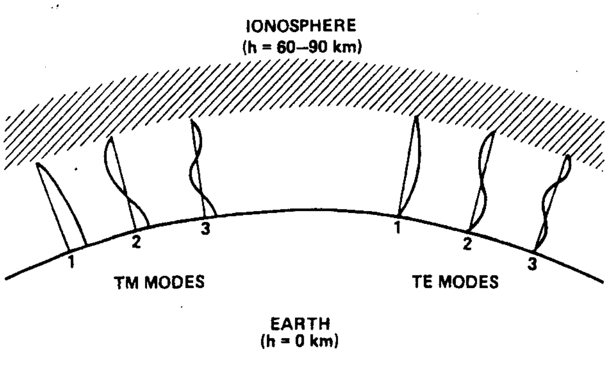

Figure 2 – Idealized Height-Gain Functions in Earth-Ionosphere Waveguide (from ref. 3)

Fig. 2 illustrates the concept of height-gain function for the first three modes of TE and TM excitation. Although grossly oversimplified for the purpose of discussion, these profiles illustrate the qualitative structure of the individual modes, especially the weakness of the TE mode at low altitude. They also illustrate that at altitude the TE mode function becomes large enough to overcome the limitations of low-altitude excitation and these modes can be excited nearly as well as the TM modes (4).

It is common knowledge that the vertical electric field excited by a horizontal dipole at the ground varies as N_g^{-1}, where N_g is the complex index of refraction of the ground, defined as:

$$N_g = \sqrt{\frac{\varepsilon}{\varepsilon_0} - j\frac{\sigma}{\omega\,\varepsilon_0}} \qquad (1)$$

where σ is the ground conductivity in S/m (6, 7).

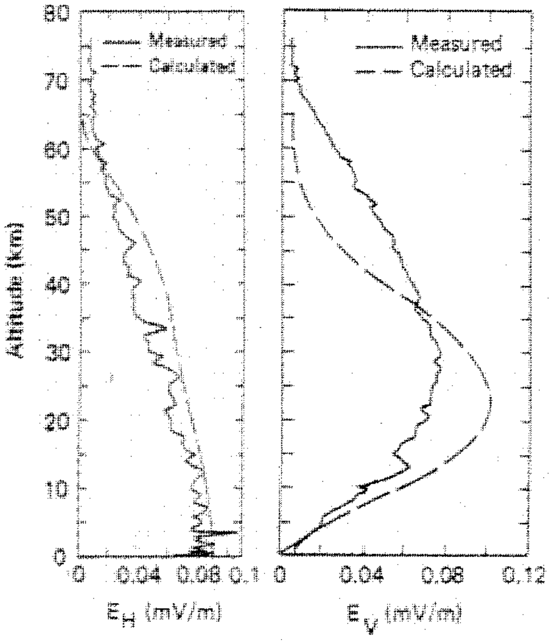

Figure 3 – TM_1 and TE_1 Signal Height Profiles, f = 23kHz (from ref. 8)

A good portion of low-frequency noise propagates in the form of surface waves, which are defined as (9):

> *A surface wave is one that propagates along an interface between two different media without radiation; such radiation being construed to mean energy converted from the surface-wave field to some other form.*

The concept of surface waves was first presented by Sommerfield in 1899 109), but it wasn't until 1907 that Zennick, one of Sommefield's students, gave the appropriate solution of Maxwell's equations for the inhomogeneous plane wave over a flat surface with finite losses (11). This is the simplest and most common case of surface waves, where the propagating wave is E-mode, having a component of the electric field in the direction of propagation and a transverse magnetic field. In their simplest form, the three field equations that describe such a surface wave are (9) :

$$H_z = \frac{A\,\varepsilon^{j\omega t}}{\varepsilon^{u y}\,\varepsilon^{\gamma x}} \tag{2}$$

$$E_x = -\left(\frac{u}{\sigma + j\,\omega\,\varepsilon}\right)\frac{A\,\varepsilon^{j\omega t}}{\varepsilon^{u y}\,\varepsilon^{\gamma x}} \tag{3}$$

$$E_y = \left(\frac{\gamma}{\sigma + j\,\omega\,\varepsilon}\right)\frac{A\,\varepsilon^{j\omega t}}{\varepsilon^{u y}\,\varepsilon^{\gamma x}} \tag{4}$$

$$u = j\sqrt{k^2 + \gamma^2} \tag{5}$$

where γ is the complex propagation constant of Eq. 1 and *k* is the intrinsic propagation coefficient for the ground, defined as:

$$k^2 = j\,\omega\,\mu\,(\sigma + j\,\omega\,\varepsilon) \tag{6}$$

These equations describe the surface wave on both sides of the boundary, and for the portion of the wave above ground (Y>0), they reduce to a more convenient form of:

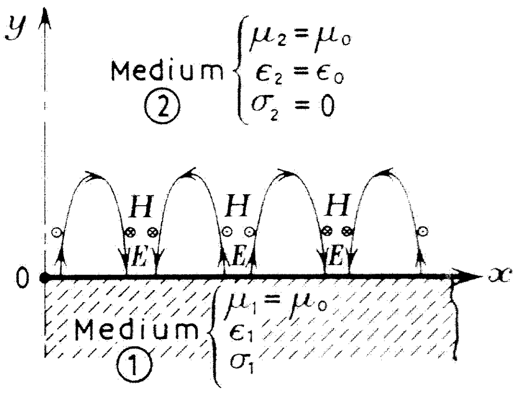

Figure 4 – Inhomogeneous Plane Wave (Zenneck Wave) (from ref. 6)

$$H_z = \frac{A\,\varepsilon^{j\omega t}}{\varepsilon^{u_2 y}\,\varepsilon^{\gamma x}} \tag{7}$$

$$E_x = -\left(\frac{u_2}{j\,\omega\,\varepsilon_0}\right)\frac{A\,\varepsilon^{j\omega t}}{\varepsilon^{u_2 y}\,\varepsilon^{\gamma x}} \tag{8}$$

$$E_y = \left(\frac{\gamma}{j\,\omega\,\varepsilon_0}\right)\frac{A\,\varepsilon^{j\omega t}}{\varepsilon^{u_2 y}\,\varepsilon^{\gamma x}} \tag{9}$$

$$u_2 = j\sqrt{\omega^2\,\mu_0\,\varepsilon_0 + \gamma^2} \tag{10}$$

which is the basis for more sophisticated derivations (12)

Lightning Noise

The dominant naturally occuring radio noise source in and below the HF band is atmospheric noise produced by electrical discharges occuring during thunderstorms, which has a moderate broad emission spectra with the largest amplitude components occurring between 2kHz and 30kHz. For frequencies below ionospheric cutoff, the preponderence of atmospheric noise detected at a temperate location is produced by local thunderstorms during the summer and by tropical region thunderstorms during the winter, the latter of which are propagated by an ionospheric sky wave over distances of several thousand kilometers (13).

For frequencies above the ionospheric cutoff, local lightning discharges are the dominant atmospheric noise sources. The resulting isolation from tropical thunderstorm centres and the decreasing spectral density of the discharges causes atmospheric noise to become an insignificant noise source above HF frequencies in temperate and polar regions (13).

Horizontal lightning strokes are weak TE noise radiators unless their altitude exceeds a few kilometers, above which horizontal strokes can radiate TE noise almost as efficiently as vertical strokes radiate TM noise. Because TE noise does not propagate as well as TM noise, the TE/TM noise ratio tends to diminish with distance, particularly under disturbed ionospheric conditions (3).

Most horizontal (cloud-to-cloud) lightning occurs above 3 km and is more frequent than vertical (cloud-to-ground) lightning, and the horizontal structure of lightning is typically 2 to 3 times greater in extent than the vertical structure, even for cloud-to-ground strokes. Horizontal lightning is high enough, occurs often enough, and has enough channel length to radiate substantial TE mode noise (3).

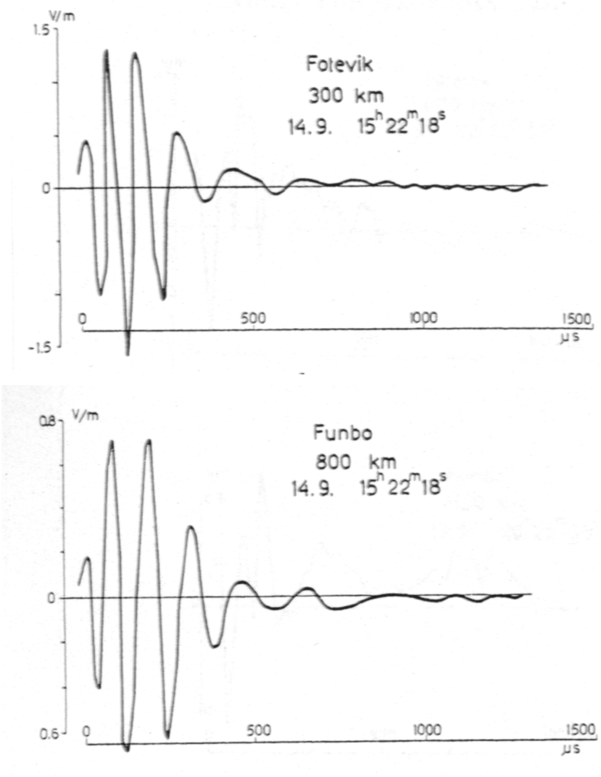

Figure 5 – Waveform of Atmospheric from a Thunderstorm in Germany as Measured at Two Monitoring Stations in Sweden (from ref. 15)

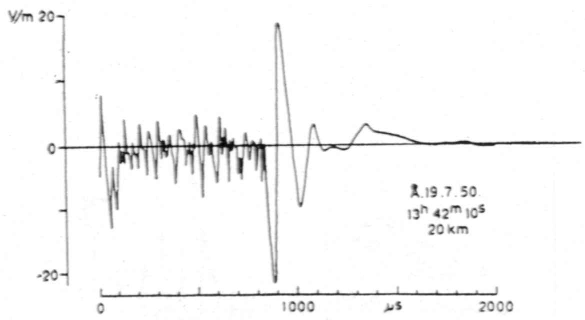

Figure 6 – Waveform of Lightning Showing Typical Pronounced Predischarges (from ref. 15)

When measured across sea water, the frequency spectra for lightning return strokes has an f^{-1} frequency dependence from 100 kHz to 2 MHz, an f^{-2} dependence between 2 and 10 MHz, and an f^{-5} dependence above 10 MHz (14). The waveforms vary greatly, even for sources at large distances, some typical waveforms being shown in Fig. 5 and Fig. 6 (15)

Man-Made Noise

The principle sources of man-made radio noise to be found in residential areas are power lines, rotating electrical machines (especially those with commutators), arcing electrical contacts, gaseous discharge lighting, and vehicular ignition. In industrial areas, additional contributions are found from such apparatus as electric arc welders and smoke precipitators. The noise generated from many of these devices is impulsive in nature and, although the repetition rate or the fundamental frequency of the pulse envelope may be low, the very steep wave shapes or the shock excitation of electrical circuits may produce strong components which extend far into the radio frequency spec-

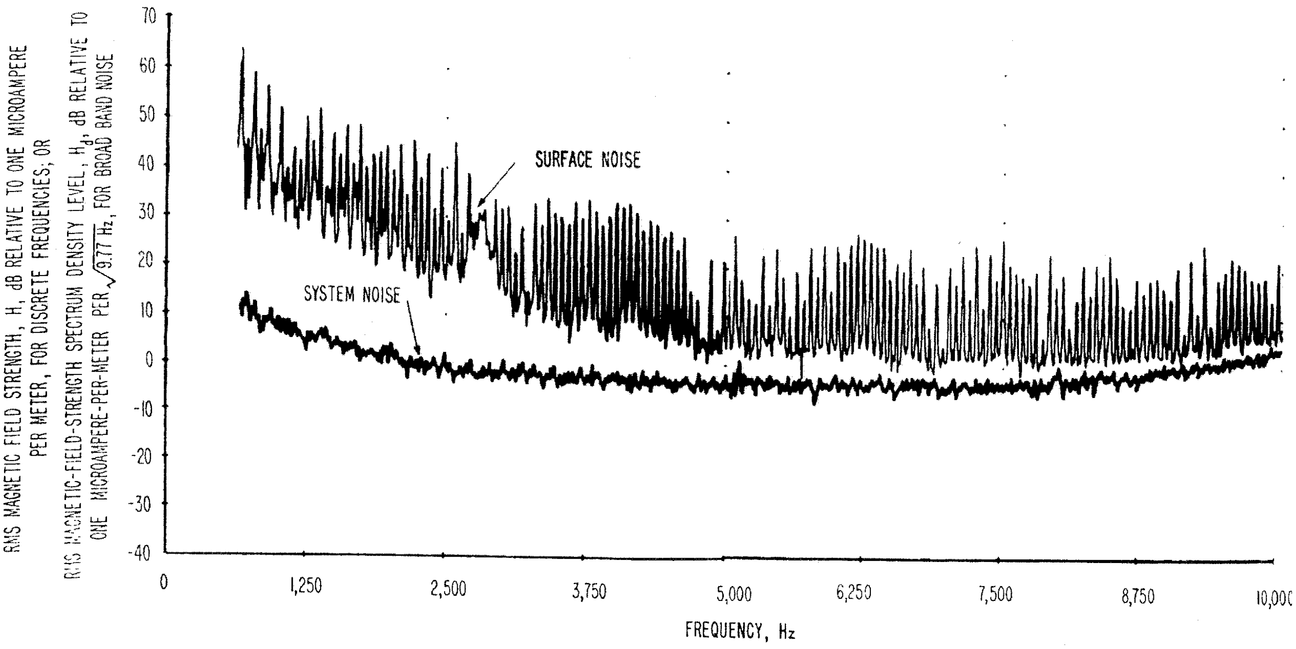

Figure 7 - Spectrum of Vertical Magnetic Field from Commercial Neon Lights at a Distance of 10m (from ref. 17)

trum (15).

Unintentionally generated noise of a metropolitan area may arise within any portion of the radio spectrum between 30 Hz and 7 GHz. The characteristics of the noise waveforms show distinctive variations with spectral interval as the relative intensities of the sources that create the noise environment shift (2). Commercial neon lighting can yield a strong source of broad spectrum magnetic as well as electric field noise, as is shown in the accompanying Fig. 7 and Fig. 8. Note that these figures have been edited in order that the vertical scales be consistent so as to aid in the visual clarity of the three measurements.

With increasing radio frequency, unintentionally generated radio noise displays a decrease in peak electric field strength and average power. The spectrum level variation is not uniform, and it varies from dissimilar alterations in the emissions generated by the types of noise sources coexisting in an area. In the lower portion of the spectrum, the dominant noise sources are electric transmission facilities (power lines) and ISM equipment. At higher frequencies, automotive ignition noise dominates in urban areas but is occasionally superseded in rural areas by power-distribution lines. Ignition systems and gas-discharge noise sources found in power lines emit impulsive patterns accompanied by broad spectrum radiation (2).

Corona discharges occurring in electric power facilities likewise yield broad spectrum radiation, a series of typical measurement in proximity to high tension lines being shown in Fig. 9. Radio noise on power lines is caused by partial electrical discharges, such as corona, by electrical discharges or small gaps in insulators, between hardware parts due to excessive electrical stress, across wood, or due to corrosion between metal parts, at small gaps between neutrals and hardware, ground wires and hardware, and by many types of corona or gap sources in electrical apparatus if defective or damaged, or if improperly designed, mounted, or applied (18).

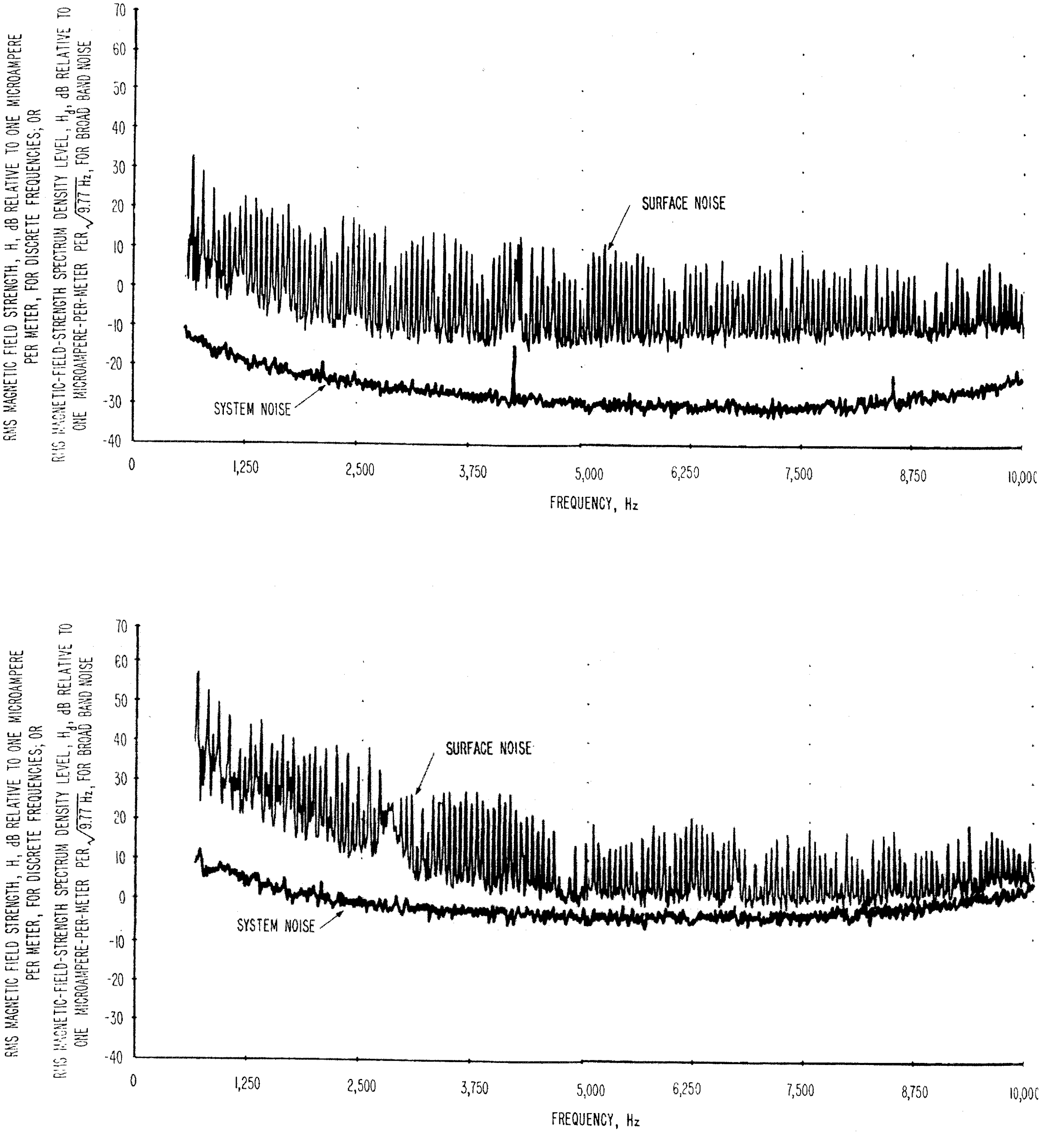

Figure 8 - Spectrum of Horizontal Magnetic Field from Commercial Neon Lights at a Distance of 10m with Antenna Oriented East-West (upper plot) and North-South (lower plot) (from ref. 17)

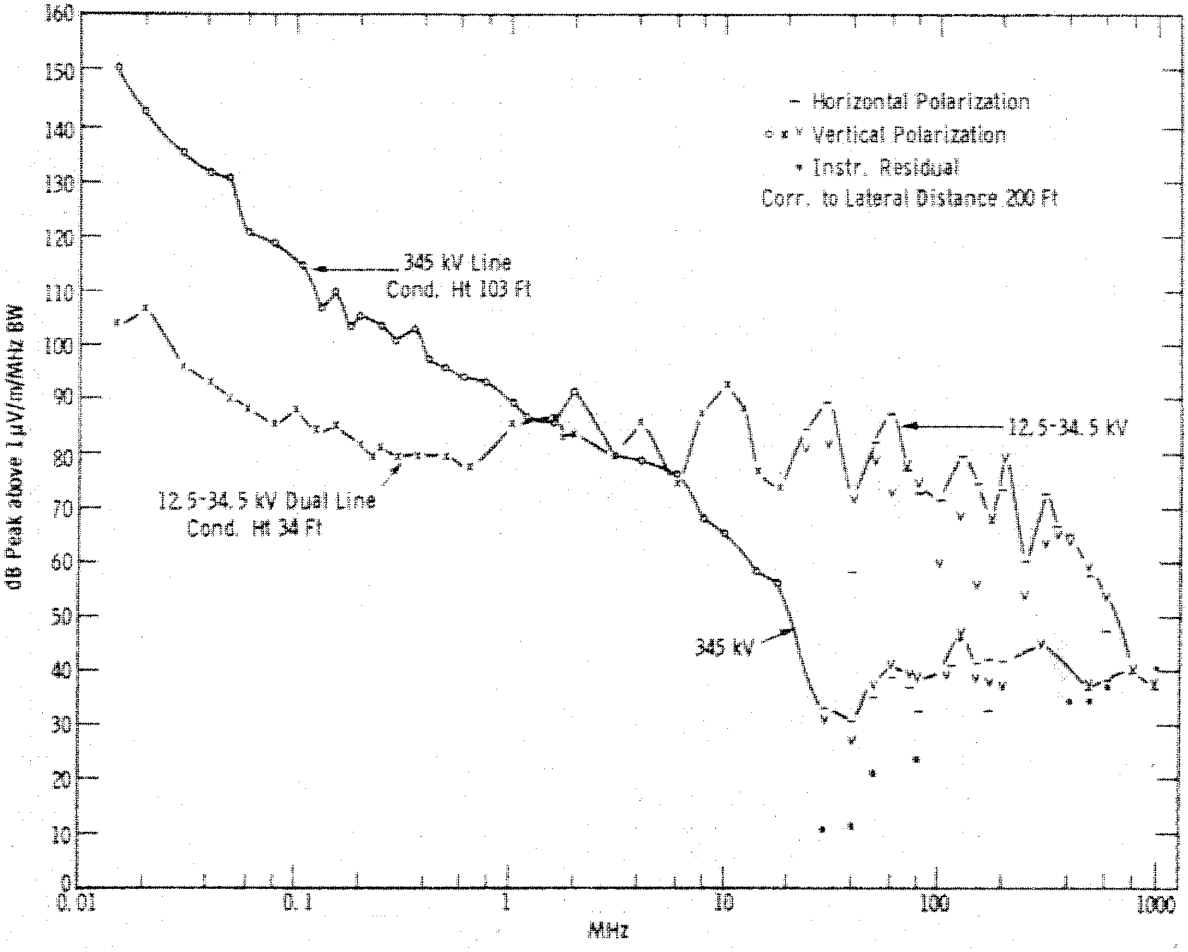

Figure 9 - Frequency Spectra of 12.5/34.5 kV and 345 kV Transmission Lines (from ref. 18)

Extraterrestrial Background Noise

Extraterrstrial noise is a significant topic within radio astronomy, and there is a formidable amount of literature related to the information content in the noise, the primary sources of which are (19):

1. The sun;
2. the galaxy;
3. the cosmic background;
4. discrete stellar sources; and
5. the moon and planets.

Quiet sun noise emisson is the minimum solar radiation condition which occurs during periods of low sunspot activity. A solar noise storm, representing a period of intermediate noise intensity, produces short duration bursts of narrow noise impulses. During periods of high solar activity, intense visible bursts of energy are emitted in the vicinity of the sun spots as frequently as 12 times a day. These intense visible flares are accompanied by a sharp rise in solar noise output, the spectral content, duration, and polarization of which depends on which of five types of flares predominates (13, 20).

Galactic noise is not thought to be thermal in nature as the frequency dependence is wrong (19). It is instead thought to be generated by a combination of unresolved discrete sources and which has a noticable concentration in the galactic plane. The continuously distributed noise arises from two mechanisms, one of which is ionized hydrogen displaying a blackbody spectrum, and other being electron synchroton radiation having a non-thermal spectra with a linearly polarized radiation field and which is not concentrated in the galactic plane (21). This composite galactic background noise produces significant radio emissions in and above the MF band throughout both hemispheres and undergoes a daily variation which is determined by the relative location of the closest approach of the receiving antenna beam to the galactic equator (13).

The moon and planets behave essentially as thermal noise sources with the exception of Jupiter (19), which is a sporadic, fluctuating, and intense source of radiation which has an equivalent blackbody temperature that is much too large to be considered as being of thermal origin, nor is it directly related to any of the Jovian surface features, such as the intense storm marked by the great red spot. The intensity of the radio noise source of Jupiter varies in the order of ten years and shows an inverse relationship with the 11-year period of mean solar activity (21).

The non-thermal linearily polarized HF/VHF band radiation from Jupiter is produced by accelerated electrons trapped by the Jovian magnetic field. At frequencies below the earth's ionospheric cutoff frequency, Jovian noise does not penetrate to the earth's surface. However, in the frequency interval of 20 to 40MHz when the planet is in the receiving antenna beam and the noise emission cycle is at its peak, Jovian noise is exceeded only by the distibuted sun and sky background noise (13).

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