Studying the parameters of frequency dispersion for radio links of different length using SDR based sounding system.

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Abstract

Methods and software were developed for studying parameters of frequency dispersion for radio links of different length. We used SDR based sounding system for studying a HF radio channel and determining parameters of frequency dispersion. The software component was implemented using licensed software LabVIEW. The hardware component was implemented using a programmable transceiver USRP N210. We studied the parameters of broadband radio channels (up to 1 MHz) for near-vertical incidence skywave (NVIS) radio path (up to 500 km), as well as the parameters of the regular component of the third order phase dispersion for long-distance radio path (1000 - 3500 km). We studied parameters of frequency dispersion depending on the time of day, path length as well as the central channel frequency.

1. Introduction

Since past decades, high frequency (HF) Communication systems have attracted a lot of interest from the researchers to develop and evaluate the performance of such systems. This attraction is due to the advantages of HF communication systems. Beside this such systems are an alternative of the more expensive satellite communication systems because HF communication systems have the ability to access remote or rural areas which is difficult to access using wire communication system. This long-distance communication can be achieved with employing ionosphere as a transmission medium [1].

The performance of HF Communication systems which operate in the frequency range of 3-30 MHz, is heavily influenced by the dynamic nature of the ionosphere. It is known [1], that that a HF radio channel is exposed to both deterministic and stochastic influences. The amplitude and phase of broadband radio signals which propagate in the ionosphere is significantly distorted due to number of “negative” effects. The most significant of these are the effects of multipath propagation, double refraction in a magnetoeactive plasma, scattering on random inhomogeneties, frequency dispersion due to the dependence of the wave phase velocity on frequency [1, 2].

In this regard, it is crucial to research the influence of frequency dispersion and compensate it for effective using radio channel frequency resources, increasing noise immunity as well as a security of a communication system under conditions of channel unsteadiness.

This paper presents a hardware-software system for sounding the ionosphere based on software-defined radio (SDR) technology as well as the results of investigation of frequency dispersion parameters depending on time of day, path length, channel central frequency as well as their influence on a channel impulse characteristic. We used licensed software packages LabVIEW for developing software for processing ionograms and obtaining parameters of frequency dispersion.

2. Measurement system

SDR based system is a system where components that have been typically implemented in hardware, e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc., are instead implemented by means of software on a personal computer. The software component of our hardware-software system was implemented using LabVIEW, while the hardware component was implemented using a programmable transceiver USRP N210.

Figure 1 shows a block diagram of the receiving terminal of the linear frequency modulation (LFM) ionosonde which we used in the research [3].

Figure 1. Block diagram of the receiving terminal of LFM ionosonde.

Figure 2 shows an example of ionogram derived from the radio path Cyprus-Yoshkar-Ola.
3. Method for obtaining parameters of frequency dispersion

The experimental discrete dispersive characteristic (DC) is defined as a set of points with coordinates \((f, \tau)\). For obtaining frequency dispersion parameters of HF radio channel we had to get a continuous model DC. The experimental discrete samples are contaminated with various noise (interference at receiving, primary data processing errors, etc.). Smoothed frequency dependencies contain both regular and residual components. In terms of radio physics residual component is a high frequency, regular – a low-frequency (LF) process. LF component could be extracted using a low-pass filter or polynomial approximation of experimental samples DC [1].

According to paper [4] a channel DC \(\tau(f)\) has several components - regular \(\bar{\tau}_r(f)\), nonregular \(\bar{\tau}_{nr}(f)\), and stochastic \(\bar{\tau}(f)\). Tracks on an ionogram are various wave propagation mechanisms and correspond to receiving rays. Their processing gives a DC in the form of an ordered set of samples. We developed methods and appropriate software using LabVIEW for extracting regular component from the experimental discrete DC. The method is based on the polynomial approximation [2, 3]. Thus, the regular component of DC could be presented as follow:

\[
\bar{\tau}_r(f) = P_n(f) \tag{1}
\]

In case of an expansion in powers of \(f\), the polynomial has the form:

\[
P_n(f) = \sum_{j=0}^{n} a_j f^j \tag{2}
\]

Thus the polynomial approximant is a regular component \(\bar{\tau}_r(f)\) of DC.

The task of building and analyzing continuous model \(P_n(f)\) of ionogram was viewed from the standpoint of minimizing the functional \(\min f(t)\):

\[
j(t) = \frac{1}{N} \sum_{i=1}^{N-1} p_i |P_n(f_i) - \tau(f_k)|^2 \tag{3}
\]

Where \(\tau(f_k)\) – frequency dependence of the group delay time (ionogram); \(P_n(f)\) – the required continuous function; \(p_i\) – weighting coefficient, which was chosen equal to 1; \(N\) – the number of points in a discrete model ionogram.

The following algorithm was developed to obtain analytical DC:

1) the desired area of ionogram is selected with a given frequency band \(df\) and overlap in the band \(0,5MUF \div 0,85MUF\) (where MUF is a maximum usable frequency) (figure 3);
2) algorithm chooses the coordinates of the points of the selected area, which match to a signal with the largest signal-to-noise ratio;
3) the resulting values are approximated by a polynomial of the second order.

Thus analytical dispersion characteristics allows us to determine the dispersion parameters of second and third orders (the slope \(s(f)\) and nonlinear parameter \(n(f)\) respectively). These parameters are used to constructing the spectra (impulse responses) of the difference frequency signal components for a variety central frequencies of sounding signal, taking into account phase dispersion distortions [5].

4. Results

The method for obtaining parameters of frequency dispersion, allowed us to study the parameters of broadband radio channels (up to 1 MHz) for NVIS radio path (up to 500 km), as well as the parameters of the regular component of the third order phase dispersion for long-distance radio path (1000 - 3500 km). As an example, table 1 shows the average values of the third order dispersion parameter \(\tau(f)\) obtained for the radio channels with a frequency band 1 MHz depending on the time of day, path length and channel central frequency. The average frequency of radio channels were normalized to the MUF \((\bar{f} = f_j / MUF)\).
Table 1. Experimental data of the average values of the third order dispersion parameters for radio channels with frequency band $B_{ch} = 1 \text{ MHz}$

<table>
<thead>
<tr>
<th>Channel central frequency</th>
<th>Path length 2620 km</th>
<th>Path length 3500 km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day</td>
<td>Night</td>
</tr>
<tr>
<td>0.5MUF</td>
<td>0.3</td>
<td>0.8</td>
</tr>
<tr>
<td>0.7MUF</td>
<td>1.1</td>
<td>2.3</td>
</tr>
<tr>
<td>0.8MUF</td>
<td>3.4</td>
<td>19.3</td>
</tr>
</tbody>
</table>

The nonlinear part of phase-frequency characteristic leads to signal dispersion distortions [5]. We conducted numerical study of the effect of the nonlinear parameter $v(\bar{f})$ on the distortions of the impulse characteristic (IC) of the HF ionospheric radio channel with frequency band $B_{ch} = 1 \text{ MHz}$ . Figure 4 shows examples of impulse characteristics, depending on the nonlinear parameters with a constant slope $50 \mu s/\text{MHz}$.

![Examples of IC depending on the nonlinear parameters with a constant slope $50 \mu s/\text{MHz}$](image)

When $v(\bar{f}) < 25 \mu s/\text{MHz}^2$, the form of IC is symmetric about the vertical axis (case of linear frequency dispersion). When $v(\bar{f}) > 25 \mu s/\text{MHz}^2$, the symmetry is broken, due to the influence of a nonlinear frequency dispersion. IC leading edge increases with the increasing dispersion nonlinear parameter $v(\bar{f})$ that leads to the case without the frequency dispersion, while the trailing edge moving away from the peak, which leads to the case of linear frequency dispersion. It was found that nonlinear parameter increases with increasing the channel central frequency, moreover parameter values is higher when the channel frequency closer to the MUF. Nonlinear parameters decrease with increasing path length as well as increase from day to night.

5. Conclusions

The methods and software were developed for analytical approximation experimental DC for obtaining parameters of frequency dispersion of a HF radio channel. We studied parameters of frequency dispersion depending on the time of day, path length and the channel central frequency. It was found that nonlinear parameter increases with increasing the channel central frequency as well as from day to night. The parameter values is higher when the channel frequency closer to the MUF. Nonlinear parameter $v(\bar{f})$ decreases with increasing path length..

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7. References


