AN ESTIMATION OF DOPPLER FREQUENCY DUE TO MOVING OBJECT LIKE RAIN AND OTHERS TO FIND ITS REMEDIAL MEASURES FROM A MICROWAVE COMMUNICATION SYSTEM

Kausik Mal [1], Rabindranath Bera [1] & Sanjib Sil [2]

[1]Sikkim Manipal Institute of Technology, Sikkim Manipal University, Majitar, Rangpo, East Sikkim-737132, INDIA, E-mail: kausik_mal@yahoo.com; r_bera@hotmail.com

[2]Institute of radiophysics & electronics, University of Calcutta 92 Acharya Prafulla Chandra Road, Kolkata-700 009, INDIA E-mail: sanjib_sil1@rediffmail.com

ABSTRACT

This paper aims at the measurement of Doppler information generated by moving objects like rain in wireless transmission medium in terms of major Doppler frequency component from a microwave setup. It consists of Gunn diode, isolator, X-band detector, preamplifier and a computer terminal with software program written in Matlab. The other sources of noise make it difficult to measure Doppler information and lead to a wrong measurement. The peak detection, threshold detection techniques and proper gain adjustment of preamplifier as explained in this paper improve the efficiency of measurement. Interestingly, the increasing values of Doppler frequency with high intensity of rain severely affect the constellation points and bit error rate. A simulation model is developed using DSP based Doppler filtering for its remedy.

INTRODUCTION

Rain effects in DTH (Direct-To-Home) and other microwave communication applications are severe in tropical countries like India. Rain Doppler effect is again a serious deterioration in such systems due to the carrier frequency shifting and introduction of additional phase noise. The rain induced Doppler shift of the carrier wave will be more pronounced in the forthcoming days, as the satellite communication is shifting gradually towards Ku and Ka band. In many cases of propagation of a signal from transmitter to a receiver, the signal suffers one or more reflections so that the path becomes indirect. In the case of sky-wave propagation that provides long distance transmission possible compared to ground wave propagation, is more affected by such multiple reflection. However in many cases of such propagation the reflections can be from different layers of the ionosphere or there can be multiple reflections providing multi-hop transmission with much extended propagation distances.

In all the cases involving multiple reflection of the transmitted wave, we can expect that the distances traveled by the arriving signals will be different. This means that the same transmitted signal may arrive at the receiver at different time instance or the receiver will receive multiple copy of the same signal at different time instances. The difference in time between the earliest and the latest reflections to arrive at the receiver is defined as the delay spread. Now dynamically change of the propagation medium causes change in transmission time that implies dynamically change in propagation distance. If the path distance changes dynamically this is similar to the effect of the receiver or transmitter moving relative to each other keeping the propagation medium unchanged and this phenomena can well be characterized by Doppler spread.

The concept of Doppler effect is not limited to the sky wave propagation due to ionospheric scattering of the signal, but is also applicable to the land mobile radio, including PCS and digital cellular transmission link. Here the cause of Doppler effect is due to the movement of mobile unit, natural and constructed obstacles. Natural calamities like rain, storm and snowfalls also causes significant Doppler effect in wireless communication.

The Doppler spread f_d, which is related to the signal wavelength λ, and the speed v of the mobile unit as $f_d = v/\lambda$ [1], determines how fast the signal varies or fades. Since the performance of many receiver techniques depends on the fading rate of the received signal. Hence to increase the performance of the receiver in presence of Doppler spread, we need to employ some adaptive technique at the receiver side which provides Doppler information to control receiver parameters, such as pilot filter band-width, automatic gain control loop band-width, phase tracker band-width and interleaver size [2]. The Doppler information is also used to aid hand-off process in cellular communication systems [3], [4].

Numerous techniques have been proposed and used to estimate the Doppler spread and velocity. Most of the prior techniques can be categorized into two classes: the techniques based on the level crossing rate (LCR) [1], [5] and the ones based on the covariance of the channel estimates [5], [6]. The performance of these techniques has been extensively studied and shown in [4]. All these prior techniques have been proven to be efficient and robust to the variation of propagation medium provided that the signal-to-ratio (SNR) should be high enough. In this propose, we propose a much simpler and efficient Doppler spread estimator that works as well under low SNR regardless of the variation on propagation medium.

MATHEMATICAL MODEL OF DOPPLER SPREAD

To have a theoretical model of Doppler spread we assume that transmitted signal $S_T(t)$ is a constant envelop phase-modulated signal given by

$$S_T(t) = A.\exp[j(\omega t + \psi_s(t))] \quad (1)$$

Where A is a constant, ω is the angular radio frequency, $\psi_s(t)$ is the information-bearing baseband signal. We can also model the time varying random propagation medium having the transfer function p(t) given by

$$p(t) = r(t)\exp[j\psi_r(t)] \quad (2)$$

where r(t) is the time-variable envelope of p(t) and $\psi_s(t)$ the time-variable random phase of the propagation medium. The envelop of the random propagation medium r(t) can be separated into long-term or average fading m(t) and short-term or fast multipath fading $r_o(t)$ parts defined by

$$r(t) = m(t).r_o(t) \quad (3)$$

Considering the model of propagation medium to be multiplicative fading channel, the received signal $S_R(t)$ at the receiving end is the product of $S_T(t)$ and p(t) and can be expressed as

$$S_R(t) = S_T(t).p(t) = A.\exp[j(\omega t + \psi_s(t))] \,.\, r(t)\exp[j\psi_s(t)] = A.\exp[j(\omega t + \psi_s(t))].m(t).r_o(t).\exp[j\psi_r(t)]$$

$$S_R(t) = A.m(t).r_o(t).\exp[j(\omega t + \psi_s(t) + \psi_r(t))] \quad (4)$$

Here random-phase varying term $\psi_r(t)$ in the expression of $S_R(t)$ given by (4) is the cause of Doppler spread. This random phase variation induces random frequency modulated (FM) noise at the receiver.

SIMULATION OF DOPPLER SHIFT

A Matlab based simulation program is developed to study the performance degradation of a RF LOS link where 16 QAM modulation technique is used to modulate a RF carrier of 11 GHz. The simulation will allow varying the Doppler shift to be introduced on the radio carrier and Constellation diagram and Bit error rate can be monitored. Both the parameters are degrading with higher values of f_d and f. A Doppler compensation is also introduced in the program by using a Doppler based rejection filter whose center frequency should match with the exact values of f_d. One interesting point is to be noted that for the successful compensation, the f_d values should be exact within a tolerance of 1%. This simulation result particularly the compensation scheme guides us to evolve a method for the exact measurement of f_d values and accordingly a simple and novel method is evolved, the detailed of which is described in the experimental setup below.

LABORATORY EXPERIMENTAL SETUP

For the Indoor experimentation an experiment has been set up using a Gunn oscillator as a transmitting source fitted with a horn antenna as shown in Fig.1. The radiation at Ku band frequency is detected using a LNB fitted with another horn antenna placed a small distance of 2meters apart. The detected output is then fed to an audio preamplifier followed by the sound port of a Personnel Computer. Using the above experimental setup we are able to detect the velocity of any moving object. At the receive end, we have written software program in Matlab (version 6.1) to visualize the incoming Doppler signal as well as to compute f_d having maximum peak. After getting this analog time domain signal we perform Fast Fourier Transform (FFT) by using Matlab's inbuilt function. It generates a matrix where each element of it gives the amplitude at a particular frequency for a range of frequencies. This matrix is used to plot amplitude vs. frequency curve, which shows the Doppler effect of a moving object on radio waves. The range of frequency used to perform FFT operation determines the range of Doppler frequencies we can detect. Our software technique is based on peak detection of the spectrum for input signal. Our software program can detect the velocity of any moving object in between the antennas by comparing these matrix elements and the frequency corresponding to the largest peak value is the fundamental Doppler frequency created by this moving object. We have used Matlab's Graphics User Interface (GUI) tool to make our software program more user-friendly and interactive.

Ideally, we should be able to measure velocity of a slowly moving object as well as of a high-speed moving object. But the interference level introduced through the cable, feeding the audio amplifier of our experimental setup limits us to use our program only to detect the velocity of high-speed moving object. Random environmental noise also creates the same problem. That is because the low frequency noise amplitude may be greater than the amplitude of Doppler frequency component and it leads us to use FFT operation over a range of frequency with lower frequency greater than noise frequency instead of zero.

Another problem is there, when the object is not moving at all and in this case the program shows a Doppler frequency value corresponding to the noise frequency having maximum amplitude. We overcome this problem by using peak detection as well as threshold detection strategy such that the program shows the Doppler frequency to be zero if the highest peak is below some threshold value. But in this case we need to adjust the gain of the audio amplifier such that when the object is not moving, the maximum noise amplitude should be lower than the threshold value.

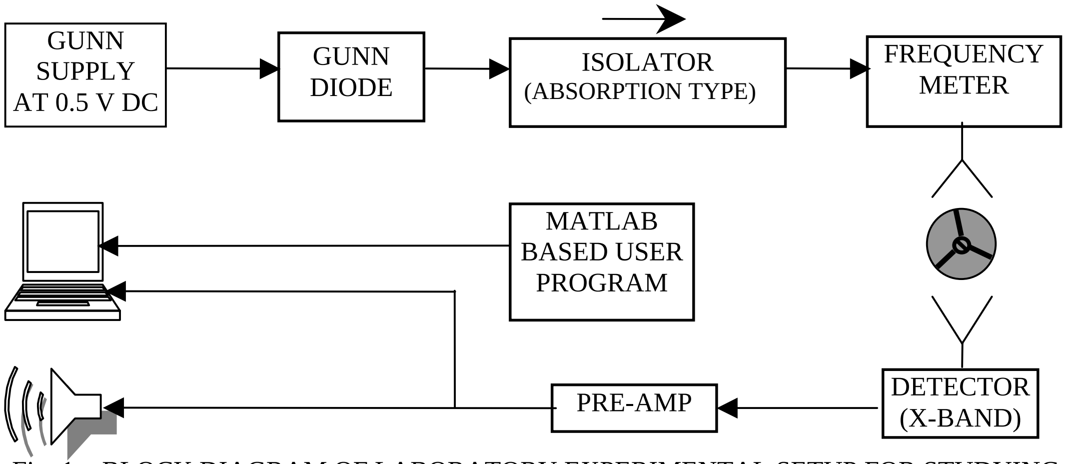

Fig. 1.: BLOCK DIAGRAM OF LABORATORY EXPERIMENTAL SETUP FOR STUDYING THE DOPPLER SHIFT.

OUTDOOR EXPERIMENTAL SETUP

For the outdoor set up, the same type of set up is utilized only the low sensitive detector is replaced by a high sensitive satellite Direct To Home receiver. The same method is repeated and successful results are obtained.

EXPERIMENTAL RESULTS

In our laboratory setup, we have used a table fan as a Doppler source in between the transmitting and receiving antennas. We have varied the speed of table fan by using voltage regulator and recorded the speed of the fan in r.p.m using a tachometer. Our software program shows the Doppler spread spectrum as shown in fig.2 and calculates the speed of table fan ω in rpm corresponds to Doppler frequency having maximum peak.

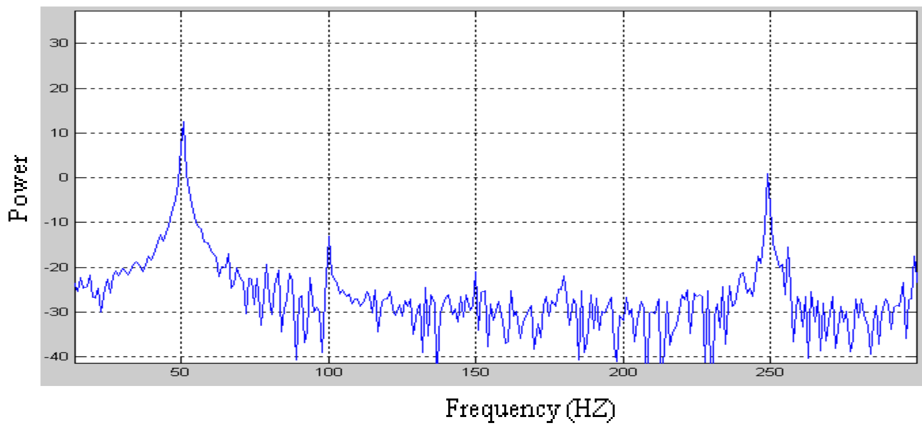

Fig. 2.: DOPPLER SPREAD SPECTRUM OF THE RECEIVED CARRIER

Fig.2 shows the maximum peak of Doppler frequency to be 50 Hz along with its harmonics. The maximum Doppler frequency is given by the expression:

$$f_d = v/\lambda = v.f / c \quad (5)$$

$$\omega = v/r = c.f_d / (r.f) \quad \text{rad/sec.}$$

$$= c.f_d / (120.\Pi.r.f) \quad \text{rpm.} \quad (6)$$

where f is the frequency of the transmitted carrier, c is the velocity of light and r is the radius of the table fan.

In the simulation model Fig.3 shows the constellation points at the receiver without Doppler spread. The same is shown to be highly affected by Doppler spread due to rain as in Fig.4.

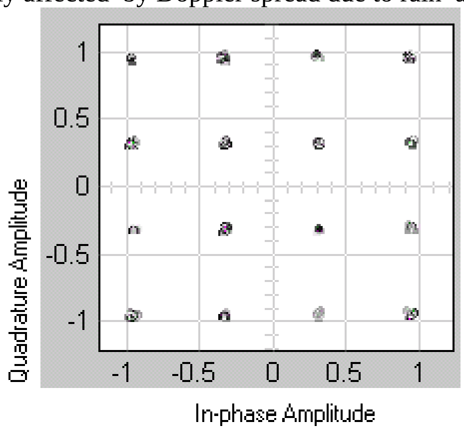

Fig. 3.: CONSTELLATION DIAGRAM WITHOUT DOPPLER SPREAD

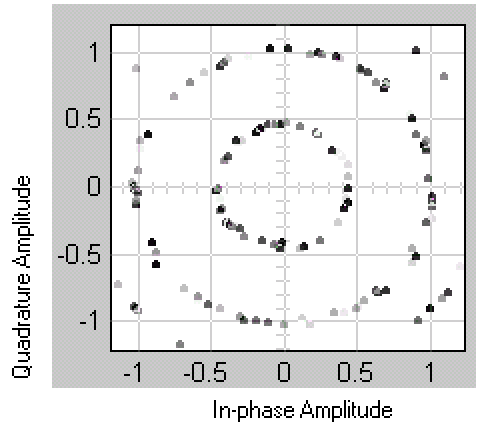

Fig. 4.: CONSTELLATION DIAGRAM WITH DOPPLER FREQUENCY OF 50 HZ.

SUMMARY AND CONCLUSION

Satellite and terrestrial wireless communication is trying to utilize the Ka band and higher carrier frequency to exploit their several advantages. The authors are interested in doing the research in this high technology area and accordingly a matlab based simulation program has been developed to study the performance of the RF LOS link. They have noticed the severe effect of rain Doppler and a compensation-based simulation is also performed. For the successful compensation, the fd values should be exact within a tolerance of 1%. If the error in measuring f_d is more than 1%, then the simulation model shows rotation of constellation points and an increase in bit-error-rate. This simulation result particularly the compensation scheme guides us to evolve a method for the exact measurement of f_d values and accordingly a simple and novel method is evolved. The experimental set up both indoor and outdoor successfully can measure the f_d values within the accuracy of 1%. In this way the authors have achieved their goals and they are now trying to implement the full system in the heavy rain zone of Sikkim, India.

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