

DEVELOPMENT OF WIRELESS CHANNEL SIMULATOR USING LABVIEW

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ABSTRACT

In the design of a digital communication link an assessment of its performance and reliability in the desired operational environments is required. Thus for clear understanding of wireless channels, their multipath and time variations should be characterized properly and suitable channel model should be developed. A class of aeronautical channel models is proposed for en-route, taxi, arrival and take-off situations. In this paper the different airborne channel and airborne scenario during different stages of a flight of an aircraft are presented and implemented by using MATLAB. A channel simulator is developed on Wideband Digital Scanning Transceiver using LabVIEW. Wideband Digital Scanning Transceiver is capable of recording and playing back faded signals which are practical solutions for testing receivers under signal fading and multipath conditions.

Keywords: Airborne scenarios, Channel simulator, Multipath propagation, VSA and VSG.

INTRODUCTION

The development of channel model for wireless communication system is currently becoming important to fulfill the entire user's requirements and increasing demand where to provide a good communication link between the users at everywhere and anytime. In wireless environment, transmitted signals are received through multiple paths due to reflection, scattering, and diffraction which results in fading of the received signal. The different paths have different propagation delays, attenuation and phase. Reflection, scattering and diffraction with direct line of sight path are shown in Fig. 1. They are known as multipath propagation and result in fading of the signal due to constructive and destructive superposition.

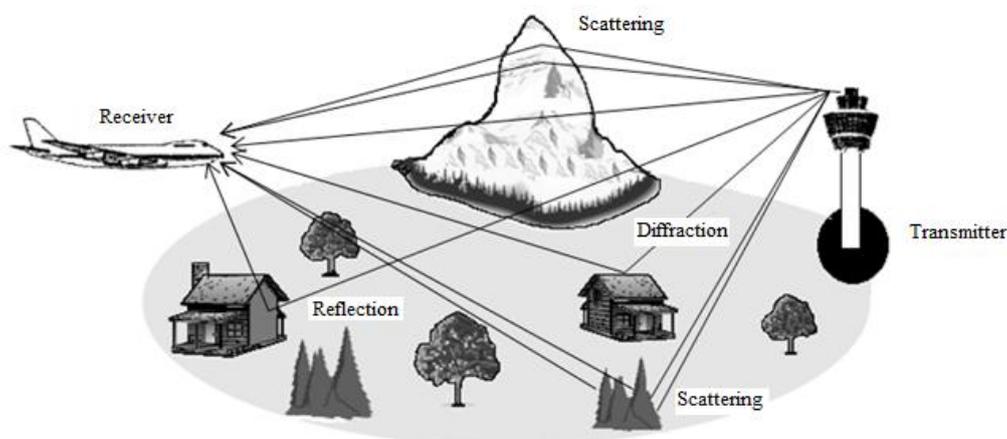


Fig. 1 Multipath propagation in aeronautical communication



II. AERONAUTICAL CHANNEL MODELS

The different channel scenarios are occurred due to the different conditions during the flight of an aircraft. These scenarios are characterized by the type of fading (Rayleigh or Rician fading), the Doppler (Fast or Slow fading), and the delays in the system, where the Doppler and the delay power spectra represent the diffuse scattered multipath components. Rice factor is the power ratio between the LOS and the diffuse components and is given by

$$K_{Rice} = \frac{a^2}{c^2} \text{ or } K_{Rice} = 10 \log \frac{a^2}{c^2} \text{ dB} \tag{1}$$

where $a \in R$ is the amplitude of the LOS path and $c^2 \in R$ is the variance of the diffuse component with zero-mean quadrature components. For a simple implementation of the multipath fading channel models, it is required that the mean throughput power remain unchanged, i.e., $E[|h(\tau, t)|^2] = a^2 + c^2 = 1$. Then the following normalization as a function of the Rice factor is obtained.

$$a = \sqrt{\frac{K_{Rice}}{K_{Rice}+1}} \text{ and } c = \sqrt{\frac{1}{K_{Rice}+1}} \tag{2}$$

If $a = 0$ and $c = 1$, then $K_{Rice} \rightarrow 0$ (Rayleigh fading), whereas $a = 1$ and $c = 0$, then $K_{Rice} \rightarrow \infty$ (additive white Gaussian noise).

1.1 En-Route Scenario

The en-route scenario is applied in the case where the aircraft is airborne and engaged in ground-air or air-air communication, as shown in Fig. 2. Ground-air communication is the link between a base station on the ground and an aircraft. Air-air communication is the link between two air-borne aircrafts.

- 1) Type of Fading: The multipath channel consists of an LOS path as well as a cluster of reflected, delayed paths. Therefore, the en-route scenario is characterized by a two-ray model which is show in the Fig. 4. The direct path which is LOS is modeled as a constant process and the cluster of reflected components i.e. diffuse channel component as a Rayleigh process. Therefore channel is Rician with typical Rice factor of about $K_{Rice} = 18 \text{ dB}$.

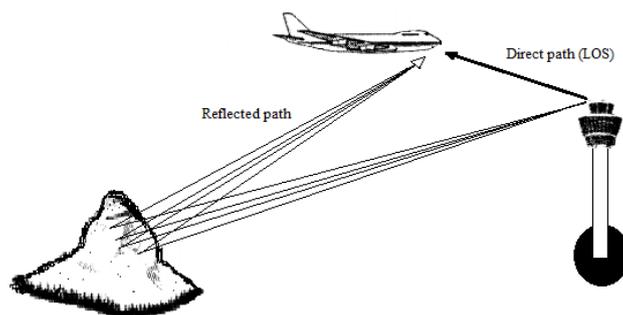


Fig. 2 Multipath propagation for en-route scenario

- 2) Doppler: In this scenario the velocity of aircraft are $v_{max} = 440 \text{ m/s}$ for ground-air links and $v_{max} = 620 \text{ m/s}$ for air-air links. The maximum Doppler shift of 7333.3 Hz is obtained. Thus the Doppler spread is very high and en-route scenario is characterized by fast fading.

The scattered components are typically not isotropically distributed, i.e., the beamwidth of the scattered components is less than 360° . A beamwidth of scattered component about $\beta = 3.5^\circ$ is considered and a



corresponding Doppler spectrum was derived, assuming that the scatters are uniformly distributed within the beamwidth [1]. This non-isotropical distribution results in a Doppler probability density function and given by [2], [3]

$$p_{f_d}(f_D) = \begin{cases} \frac{1}{\pi f_{D_{max}} \sqrt{1 - (f_D/f_{D_{max}})^2}}, & \text{if } |f_D| < f_{D_{max}} \\ 0, & \text{else} \end{cases} \quad (3)$$

Also, the beamwidth depends on the distance between the transmitter and receiver and the beamwidth is likely to decrease with increasing distance. In this case the distance between transmitter and receiver is more and beamwidth is less compared to taxi, arrival and takeoff scenarios. As a worst case, the direction of the LOS path coincides with the heading of the aircraft resulting in a carrier shift of the LOS path of $f_{D_{LOS}} = f_{D_{max}}$, whereas the scattered components come from behind which is shown in the Fig. 3.

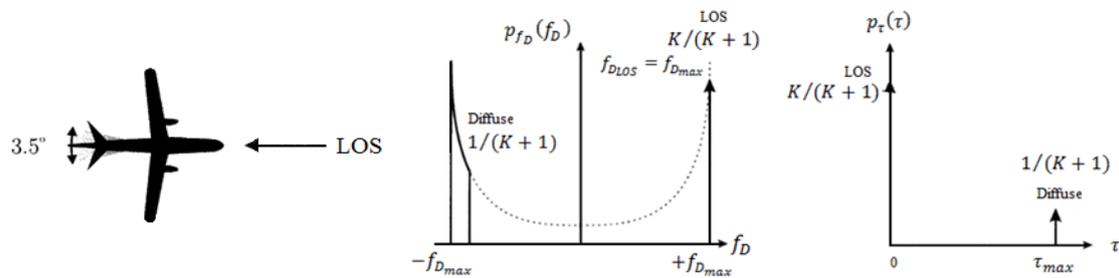


Fig. 3 Doppler power spectrum and delay power spectrum for en-route scenario

3)Delay: According to simple geometrical analysis during the flight, the aircraft distance to the base station is large compared to its altitude, so that the projected distance on the ground is about the same as the real distance. If now reflection, scattering, or diffraction occurs on objects on the ground, the maximum detour distance can be estimated to be the aircraft altitude for ground–air communication and twice the altitude for air–air communication i.e. $\Delta d \approx h$ for ground–air links and $\Delta d = 2h$ for air–air links, if one dominant reflector is present, where h is the altitude of the aircraft. Assuming a typical maximum altitude of 10 km, maximum delay of $33 \mu s$ for ground–air links and $66 \mu s$ for air–air links is obtained. Doppler and delay power spectra are shown in Fig. 3.

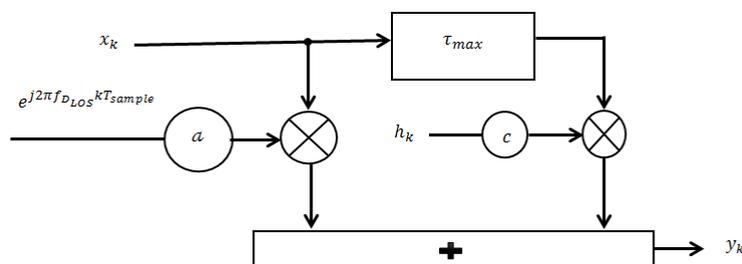


Fig. 4 Two ray model

1.2 Arrival and Takeoff Scenario

The arrival is applied when the aircraft is engaged in ground–air communication, already has left its cruising speed and altitude, and is about to land, and it’s vice versa is takeoff scenario; compare Fig. 5. This scenario is a



combination of the en-route scenario and the taxi scenario. It is un-likely to be the worst case, but since the aeronautical data link is particularly used during the arrival of an aircraft at the air-port, a special arrival scenario is proposed here for this case. A takeoff scenario would be similar with the difference of inverted Doppler frequencies.

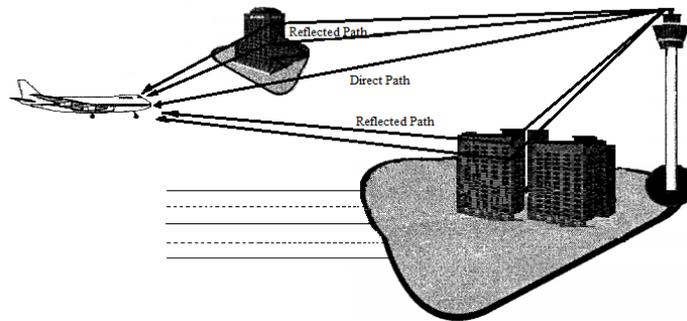


Fig. 5 Multipath propagation for arrival scenario

- 1) Type of Fading: The LOS path is present during the arrival while the aircraft is still airborne and the LOS component is modeled as constant process. On the other hand, there will also be scattered path components, mainly from buildings at the airport itself that can be modeled by a Rayleigh process. Thus the channel is Rician channel with the Rice factor of $K_{Ri\ ce} = 15\ dB$.
- 2) Doppler: The velocity of an aircraft is in the range of $v = 25 \dots 150\ m/s$ during the arrival of the aircraft. The scenario is characterized by fast fading and the Doppler spread is more but it is less compared to en-route scenario. The maximum Doppler shift of 2500 Hz is obtained which is less than en-route scenario. The scattered components are not isotropically distributed but are assumed to arrive at the front of the aircraft. Generally the base station will be located at the airport itself, so that the scattered components will result from reflections on buildings, aircrafts, or other obstacles in the airport area. Therefore beamwidth of the scattered components is $\beta = 180^\circ$ which is broader than in the en-route environment but typically will be narrower than in the taxi environment. The LOS path is assumed to arrive directly in front of the aircraft, resulting in a carrier shift of the LOS path of $f_{D_{LOS}} = f_{D_{max}}$.
- 3) Delay: Since the aircraft is still some distance away from the airport, excess delay is $7\ \mu s$ is obtained. This is equal to $\Delta d = 2100\ m$. The limit stays below the value for en-route scenarios. The delay power spectrum is likely to switch from a two-ray scenario toward exponentially decreasing as shown in Fig. 6. The pdf of such a one-sided delay power spectrum is expressed by

$$p_{\tau}(\tau) = \begin{cases} \frac{1}{\tau_{slope} (1 - e^{-\tau_{max}/\tau_{slope}})} e^{-\tau/\tau_{slope}}, & \text{if } 0 < \tau < \tau_{max} \\ 0, & \text{else} \end{cases} \quad (4)$$

Where $1/\tau_{slope}$ is the slope and is expected to be $1\ \mu s$ here.

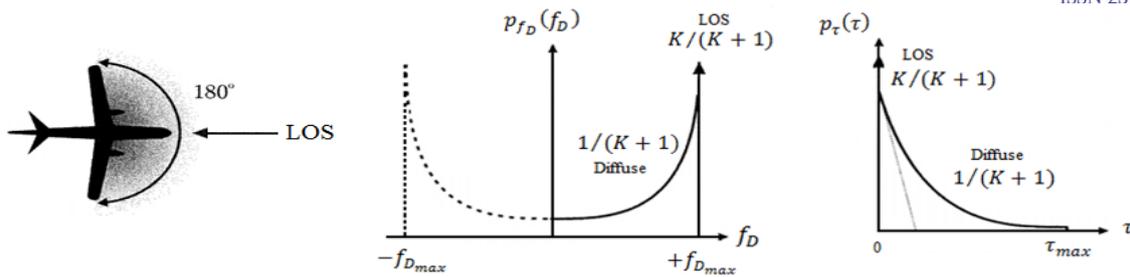


Fig. 6 Doppler power spectrum and delay power spectrum for arrival scenario

1.3 Taxi Scenario

The taxi scenario is applied when the aircraft is on the ground and travelling toward or from the terminal, as shown in Fig. 7.

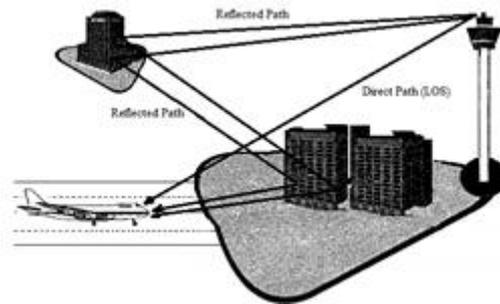


Fig. 7 Multipath propagation for taxi scenario

- 1) Type of Fading: In taxi scenario both LOS and diffuse components are present hence it is modeled as Rician channel.
- 2) Doppler: The velocity of aircraft is in the range of $v = 0 \dots 15 \text{ m/s}$. Thus this scenario is characterized by slow fading and Doppler spread is less. The Doppler shift of 250 Hz is obtained. As a worst case, 2-D isotropic scattering can be assumed, i.e., the echoes are assumed to arrive equally distributed from all directions within a plane i.e. the beamwidth of the scattered components is $\beta=360$. The LOS path is assumed to come slantwise from the front, resulting in a carrier shift of the LOS path of $f_{D_{LOS}} = 0.7 f_{D_{max}}$.
- 3) Delay: A maximum delay of $\tau_{max} = 0.7 \mu\text{s}$ corresponding to $\Delta d = 210 \text{ m}$ is obtained. The delay is exponentially decreasing with a slope time of $\tau_{slope} = \frac{1}{9.2} \mu\text{s}$ [1].

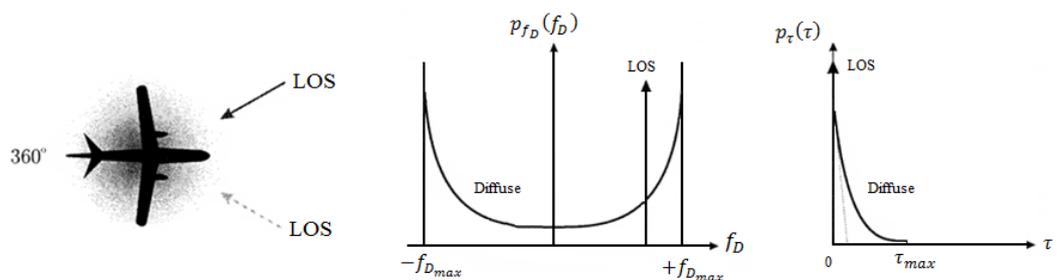


Fig. 8 Doppler power spectrum and delay power spectrum for taxi scenario



1.4 DEVELOPMENT OF CHANNEL MODEL

The aeronautical channel model is developed based on WSSUS (Wide Sense Stationary Uncorrelated Scattering).

Then time-varying impulse response of a WSSUS process can be written as [4]

$$h(\tau, t) = \lim_{N \rightarrow \infty} \frac{1}{\sqrt{N}} \sum_{n=1}^N e^{j\theta_n} e^{j2\pi f_{D_n} \tau} \delta(\tau - \tau_n) \tag{5}$$

First the random numbers phase $\theta_n (0 \leq \theta_n < \pi)$, Doppler frequencies $f_{D_n} (-f_{D_{max}} < f_{D_n} < f_{D_{max}})$ and delays $\tau_n (0 \leq \tau_n \leq \tau_{max})$ are generated.

The factor $\sqrt{1/N}$ ensures that the average power is one; this factor is the same for all echoes and for all spectra.

The parameters θ_n, f_{D_n} and τ_n are generated by a functional transformation

$$v_n = g_v(u_n) = P_v^{-1}(u_n), \quad 1 \leq n \leq N \tag{6}$$

Where v_n a substitute for is θ_n, f_{D_n} and τ_n , respectively, $u_n \in (0,1)$ is a random, uniformly distributed input variable produced by a random number generator, and $g_v(u_n)$ is a memory-less nonlinearity, which is the inverse of the desired cumulative distribution function $P_v^{-1}(\cdot)$.

The classical Doppler spectrum (3) with application of (6) results in the nonlinearity

$$f_{D_n} = g_{f_D}(u_n) = f_{D_{max}} \cdot \cos(\pi u_n) \tag{7}$$

If the scattering is 2-D uniform non-isotropic

$$f_{D_n} = f_{D_{max}} \cos(\varphi_{\alpha_l} + (\varphi_{\alpha_h} - \varphi_{\alpha_l})u_n) \tag{8}$$

The nonlinearity for the one-sided exponentially decreasing delay power spectrum of (4) is

$$\tau_n = -\tau_{slope} \log(1 - u_n(1 - e^{-\tau_{max}/\tau_{slope}})) \tag{9}$$

The parameters τ_n and f_{D_n} (representing the excess delays, Doppler frequencies of discrete N paths) are easily generated by feeding a uniformly distributed random variable $u_n \in (0,1)$ into a simple nonlinearity (which may be implemented as a table lookup).

From equation (5) we generate the Aeronautical Rayleigh channel as,

$$h_k(i) = c \frac{1}{N} \sum_{n=1}^N e^{j\theta_n} e^{j2\pi f_{D_n} k T_{sample}} \delta(i T_{sample} - \tau_n) \tag{10}$$

Where N is the Number of paths, θ_n is Phase, f_{D_n} is Doppler shift, k is the Time index ($t = k T_{sample}$), T_{sample} is Sampling time, and $f_{D_{LOS}}$ is the Doppler shift of LOS component. A Rician channel can be modeled by adding a constant to the Rayleigh process. Let us denote the complex-valued direct (LOS) component is given by

$$h_{LOS_k} = a e^{j2\pi f_{D_{LOS}} k T_{sample}} \tag{11}$$

Where $a \in R$ is the amplitude of the LOS path and $f_{D_{LOS}}$ is the Doppler shift of the LOS path; and the complex-valued multipath component is denoted by $c \cdot h_k$, where $c \in R$ is a constant weighting factor and



$E[|h_k|^2] = 1$ (due to the factor $\sqrt{1/N}$). The resulting transmission model for arrival and taxi channel (Rician

channel) is given by

$$h_k = h_k(i) + h_{LOS_k} \tag{12}$$

For en-route channel (Two ray model) the reflected component is given as

$$h_k = \frac{1}{N} \sum_{n=1}^N e^{j\theta_n} e^{j2\pi f_{D_n} k T_{sample}} \tag{13}$$

These aeronautical channel models are simulated in MATLAB by considering DPSK modulation of M=2 and BER performance for en-route, arrival and taxi scenarios is shown in Fig.9.

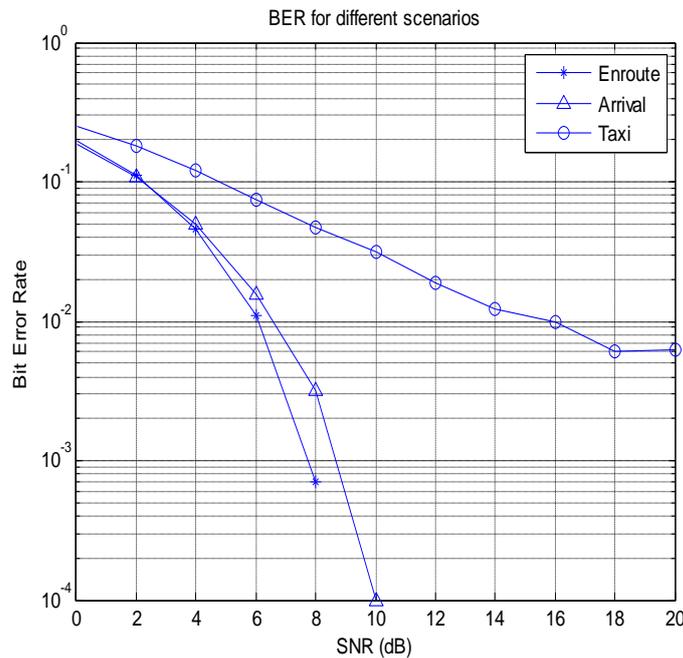


Fig. 9 BER performance for different scenarios

III. DEVELOPMENT OF CHANNEL SIMULATOR ON WIDEBAND DIGITAL SCANNING TRANSCEIVER

Real time simulation is not possible in MATLAB. Hence a channel simulator is developed on Wideband Digital Scanning Transceiver. The development and measurement of channel simulator is done by using LabVIEW. The LabVIEW can be used as basic software and can be turned into hardware part by connecting to other devices for real-time channel simulation.

To presence the real time measurement for the reliable wireless communication system designs, the basic-design software which suitable to the generic channel modeling is used. Wideband Digital Scanning Transceiver is basically RF record and playback system which are practical solutions for testing receivers under signal fading and multipath conditions. Once a large amount of data is captured (hours or more of signal data), the recorded signal can be regenerated in a controlled laboratory environment and directly connected to the receiver for evaluation [5]. Wideband Digital Scanning Transceiver is shown in Fig.10 and consists of

- PXIe-1065,18-Slot 3U PXIe/PXI Chassis [6]
- NI PXIe-8840 core i5-4400E 2.7GHz, Dual core, Win7 (64 bit) [7]

- NI 8260, 4-Drive , 3TB HDD High Speed Storage Module, Win7 [8]
- NI PXIe-5663E 6.6 GHz RF Vector Signal Analyzer w/64MB RAM [9]
- NI PXIe-5672 2.7GHz RF Vector Signal Generator (32 MB)[10]



Fig. 10 Wideband Digital Scanning Transceiver

The block diagram for entire setup is shown in Fig. 11.

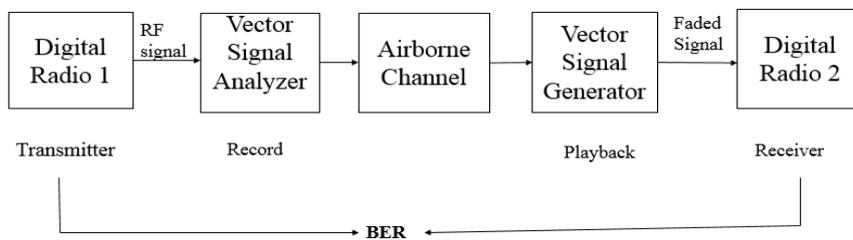


Fig. 11 Block diagram

The RF signal from digital radio 1 is fed to wide band digital scanning transceiver. Which consist of Vector Signal Analyzer (VSA) and Vector Signal Generator (VSG). The function of vector signal analyzer is to record the RF signal as IQ data, channel impairments which are nothing but the real world environments are added to this signal. Original signal with channel impairments is play-backed using the vector signal generator. Thus faded signal is generated by the vector signal generator and given to the digital radio 2.

Both the transmitter and receiver signals are compared by BER (bit error rate).A Virtual Instrument (VI) in LabVIEW for VSA Configure and Record data for test panel is shown in Fig. 12 [11], [12].

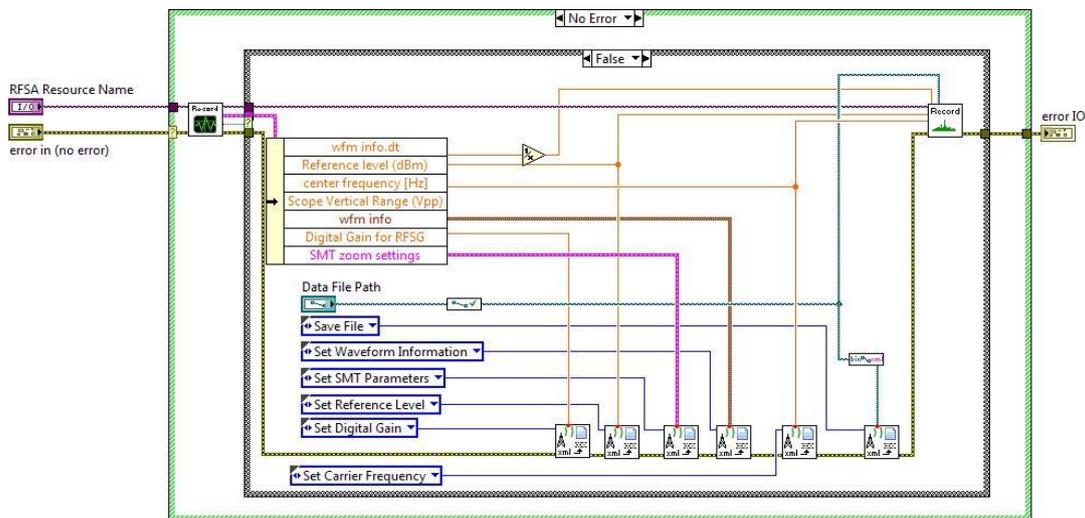


Fig. 12 Configure and Record data for test panel

A VI for rician channel is shown in Fig. 13.

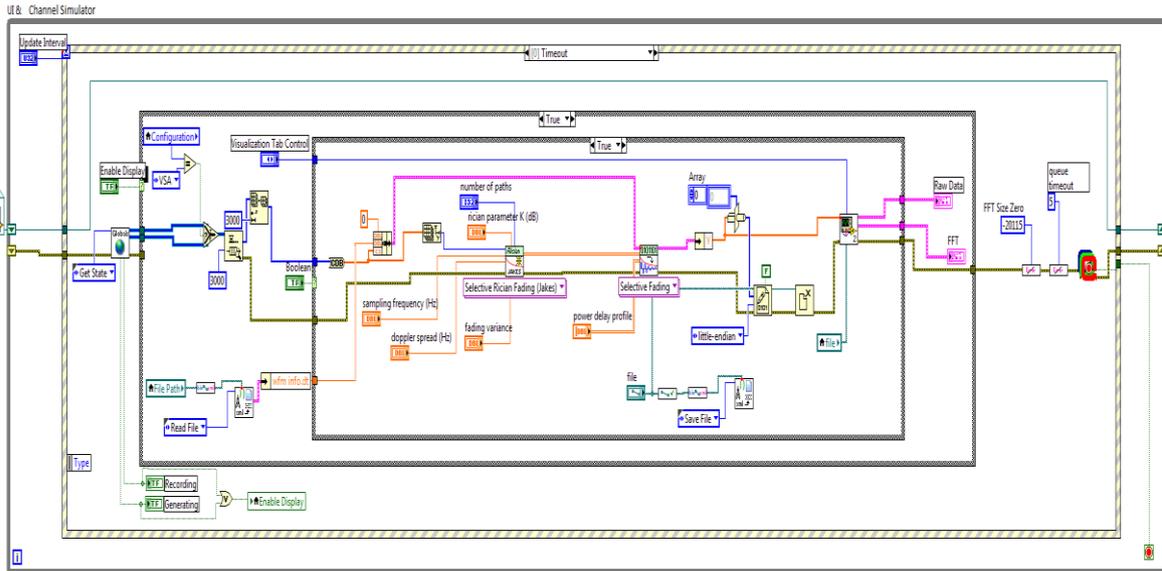


Fig. 13 Rician Channel

A VI for VSG Playback data for test panel is shown in Fig. 14.

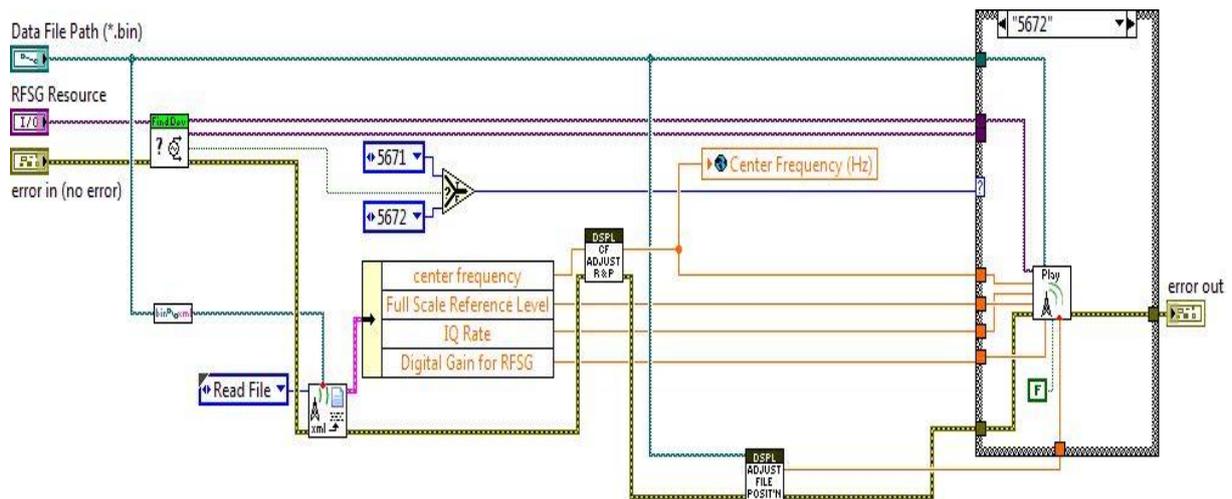


Fig. 14 Playback data for test panel

IV. RESULTS

The Offset quadrature phase-shift keying (OQPSK) signal of 200 KHz bandwidth and 64Kbps data rate from Digital Radio 1 is given to VSA. The VSA record the OQSK signal with and passed through the channel simulator and faded signal is generated by VSG and given to the Digital Radio2. The bit error rate (BER) values for different $\frac{E_b}{N_o}$ are obtained and by these values BER performance for the en-route, arrival and taxi scenarios is plotted in MATLAB which is shown in Fig. 15.

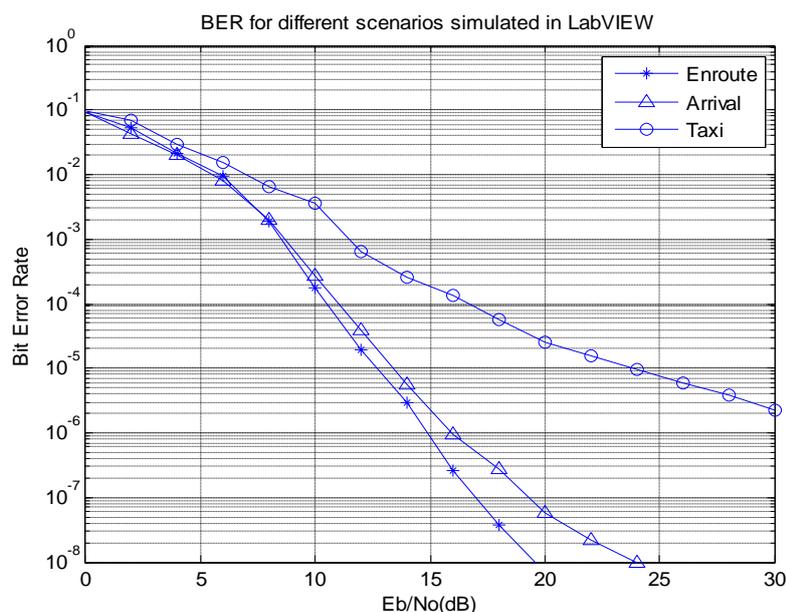


Fig. 15 BER performance for different scenarios by real time simulation

V. CONCLUSIO

Due to the high speed of the aircraft, the Doppler spread will be very serious. For en-route scenario the Doppler shift is 7333.3Hz and Delay is 33 μ s, for arrival scenario the Doppler shift is 2500Hz and Delay=7 μ s and for taxi scenario Doppler shift is 250Hz and Delay is 0.7 μ s. Even though the maximum Doppler and maximum delay are decreased, the decrease in Rice factor of taxi scenario compared to en-route and arrival will lead to severe fading of the signal. In MATLAB real time simulations cannot be performed. Real time measurement for the reliable wireless communication system designs cannot be done by MATLAB. Real time faders are present but which are very expensive. Hence a Channel simulator is developed on Wideband Digital Scanning Transceiver using LabVIEW. By this real time measurements can be done. Finally simulation results show the necessity to distinguish between the different scenarios due to the different effects they have on the transmitted signal. Taxi scenario has worst performance compared to en-route and arrival scenarios.

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