

# SOFTWARE BASED MIMO CHANNEL EMULATOR

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## ABSTRACT

Fox is a software based channel emulator that models a wireless channel with up to 4x4 MIMO paths. While currently supporting 802.11n channel models, Fox can be extended to incorporate other channel models, including LTE and a variety of military or proprietary models. Fox works on MIMO streams of IQ samples and operates in the National Instruments LabVIEW application development and graphical programming environment. Fox takes as input a sampled 802.11n baseband signal stored in a file, mathematically applies 802.11n channel models and other distortion to this signal and outputs the resulting signal to a file.

## 1. INTRODUCTION

The 802.11n multipath and fading channel models consist of 6 models, A through F, each representing a successively larger physical space (small room, large office, etc.) [2]. Butler matrix and identity matrix are also sometimes used as simple static channel models.

In addition to multipath and fading (figure 1, 802.11n 4x4 channel emulator block), Fox can add common distortion such as AWGN, spurious, phase noise, IQ imbalance and frequency shift to the signal (figure 1, Distortion block). The identity matrix channel model can be selected in order to bypass channel modeling, but still add distortion. This enables the user to test the radio in a controlled way – by adding one impairment at a time.

The channel emulator and distortion subsystems both expect 100 Mps IQ streams because path delays for the 802.11n channel models are specified in 10 ns increments [2]. Therefore, re-sampling of the input and output IQ streams may be necessary (figure 1, sample rate conversion blocks).

The implementation of the channel emulator can be verified by comparing the statistics of the generated tap coefficients with those predicted by theory (figure 1, channel model statistics viewer block).

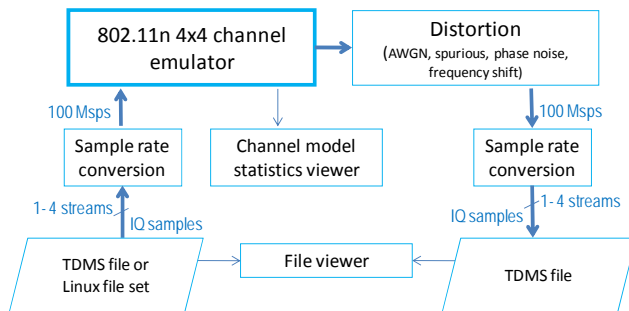


Figure 1: System block diagram

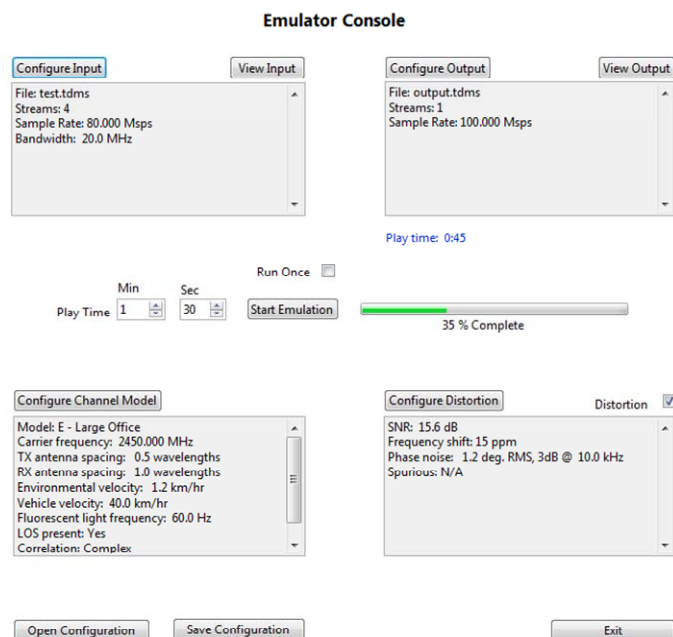


Figure 2: LabVIEW console screen showing the configuration of the input, output, channel models and distortion. The input file, representing the transmitter, contains 4 MIMO streams. The output file, representing the receiver, contains one stream. This represents a 4x1 MIMO configuration. The 802.11n channel parameters are shown on the lower left and distortion settings are shown on the lower right. If the input file is short, its contents can be repeated to create the output of a desired length (play time).

## 2. IEEE 802.11N CHANNEL MODELS

A wireless channel is modeled by its impulse response. A simple SISO channel with a single path between transmitter and receiver is represented by a Tapped Delay Line (TDL) structure (figure 3). The taps in the TDL model reflections, which propagate in clusters [2]. Contributions from multiple clusters, which overlap in time, are modeled at each tap. As delay through the TDL increases, the tap coefficients model higher statistical loss distributions to represent reflections traveling longer distances.

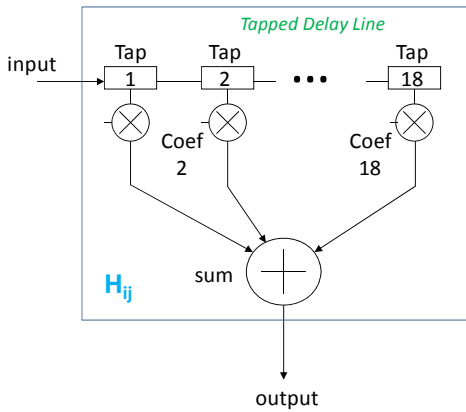


Figure 3: A wireless fading channel,  $H$ , is modeled by a Tapped Delay Line (TDL) structure. Delay taps and multipliers model reflections. The multiplier coefficients at each tap are time-variable, modeling motion and other dynamics of the wireless channel. The number of taps varies with the model (A-F) per table 1 – more taps to model bigger spaces.

A MIMO channel model incorporates signal paths from each transmitter to each receiver, resulting in  $N$  times  $M$  paths, where  $N$  is the number of transmitters and  $M$  is the number of receivers.  $N$  and  $M$  can each range from 1 to 4. A system with 2 transmitters and 2 receivers (2x2 MIMO) has 4 paths (figure 4). Each path is modeled as a fading channel,  $H_{ij}$ . The maximum order of MIMO defined in the 802.11n standard is 4x4, a system with 16 paths.

Tap coefficients are time-variable. The rate of change of the coefficients is a function of Doppler effects that model motion in the channel. The coefficient values are also impacted by noise from fluorescent lights. The coefficients for all the paths in the MIMO channel are correlated with correlation being a function of the antenna element spacing and of the angle of arrival (AoA) and angle of departure (AoD) of the signal. The math to derive the coefficients is explained in [2].

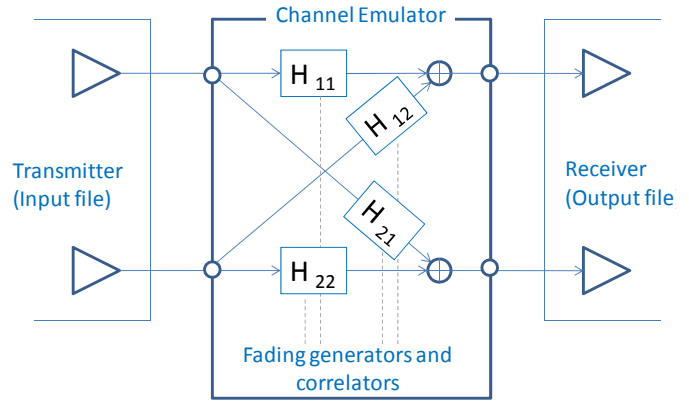


Figure 4: An example of a 2x2 MIMO configuration (2 transmitters, 2 receivers) with 4 paths. Each path is a fading channel,  $H_{ij}$ . Each fading channel is modeled by a TDL (figure 3). Fox supports channel modeling for MIMO links with up to 4 transmitters and 4 receivers (4x4 MIMO) with up to 16 paths (not shown).

Table 1 summarizes the parameters of the six 802.11n channel models, A through F.

Table 1: 802.11n models A through F – parameters

Model	Distance to 1 <sup>st</sup> wall (avg)	# taps	Delay spread (rms)	Max delay	# clusters	
A*	test model	1	0 ns	0 ns		
B	Residential	5 m	9	15 ns	80 ns	2
C	small office	5 m	14	30 ns	200 ns	2
D	typical office	10 m	18	50 ns	390 ns	3
E	large office	20 m	18	100 ns	730 ns	4
F	large space (indoor or outdoor)	30 m	18	150 ns	1050 ns	6

\* Model A is a flat fading model; no delay spread and no multipath

In addition to models A through F, Fox also supports Butler matrix, which exhibits evenly distributed phase offsets for the MIMO paths among transmitters and receivers (table 2). A Butler matrix is static in time and is used as a simple predictable reference channel.

Table 2: Butler matrix. N1-N4 are transmitters and M1-M4 are receivers. The phase offset values are in degrees.

	M1	M2	M3	M4
N1	-45	180	45	-90
N2	0	-45	-90	-135
N3	-135	-90	-45	0
N4	-90	45	180	-45

You can select models A through F, Butler matrix or identity matrix via the API or GUI. Identity matrix routes input 1 to output 1, input 2 to output 2, etc. and should be used to bypass channel modeling while applying other distortion to the input signal.

The block diagram depicting how tap multiplier coefficients are computed and fed into the TDL structures is shown in figure 6. This figure provides an example of a 2x2 MIMO system with 2 inputs, 2 outputs and 4 paths. The number of taps in figure 6 is shown as 18, but this number can vary depending on the model (table 1). All fading channels,  $H_{ij}$ , in a channel emulator have the same number of taps.

Each AWGN source in figure 6 is connected to a Doppler filter, which can be implemented as an FIR or an IIR filter. The filter provides the desired spectral shape of the fading. The Doppler filter models the bell shaped curve for models A through F and a bell plus spike curve for model F [2].

The bell spectrum models fading due to walking-speed motion in the environment at an average speed of 1.2 km/hr. The spike in the bell plus spike spectrum adds the effect of a vehicle moving at an average speed of 40 km/hr.

The parameter K (Rician K-factor) in figure 6 determines the relative strength of the LOS and NLOS components and is based on the chosen model. The  $\sqrt{K/(1+K)}$  term models the LOS component. The  $\sqrt{1/(1+K)}$  models the NLOS component. K-factor for LOS conditions applies only to the 1<sup>st</sup> tap and ranges from 1 to 4. The value of K=0 corresponds to NLOS conditions for the 1<sup>st</sup> tap and is used on all taps beyond the 1<sup>st</sup> tap in both LOS and NLOS conditions.

The 1<sup>st</sup> tap LOS component is only present if the distance between the transmitter and receiver is less than the distance to 1<sup>st</sup> wall (table 1).

Since the 1<sup>st</sup> tap's LOS component is not Doppler filtered, the spectrum for the 1<sup>st</sup> tap deviates from the bell spectrum. The CDF of the 1<sup>st</sup> tap's coefficients is Rician in LOS conditions and Rayleigh in NLOS conditions. On taps beyond tap 1 the power is based only on the NLOS component and the CDF is Rayleigh.

$\text{Sqrt}(P_k)$  represents the Power Delay Profile (PDP) weighting, summed over all the clusters that contribute power for the k<sup>th</sup> tap. It reflects how strong the total power is at tap k.

The spatial correlation matrix in figure 6 models the angular spread of the clusters, which is a function of angle of arrival (AoA) and angle of departure (AoD) depicted in figure 5.

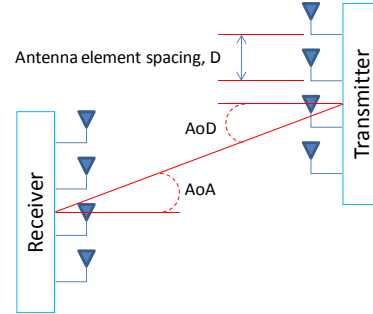


Figure 5: Angle of arrival (AoA), angle of departure (AoD) and antenna spacing

802.11n models assume that RX and TX antenna systems are uniform linear arrays with equally spaced antenna elements [2].

Spatial correlation is implemented using the Kronecker product of the transmit and receive correlation matrices,  $R_{tx}$  and  $R_{rx}$ , respectively [2]. These matrices are comprised of correlation coefficient terms,  $\rho$ , that depend on the power angular spectrum (PAS), AoA, AoD, tap powers and distance D between antenna elements. Fox computes the real and imaginary parts,  $R_{XX}(D)$  and  $R_{XY}(D)$ , respectively, for each  $\rho$ . This allows spatial correlation based on the complex field (i.e., using  $\rho=R_{XX}(D)+jR_{XY}(D)$ ) or real power (i.e., using  $\rho=R_{XX}^2(D)+R_{XY}^2(D)$ ).

The up-arrow symbol in figure 6 represents the interpolation of the Doppler coefficients samples up to 100 Msps, the update rate for the tap multiplier coefficients.

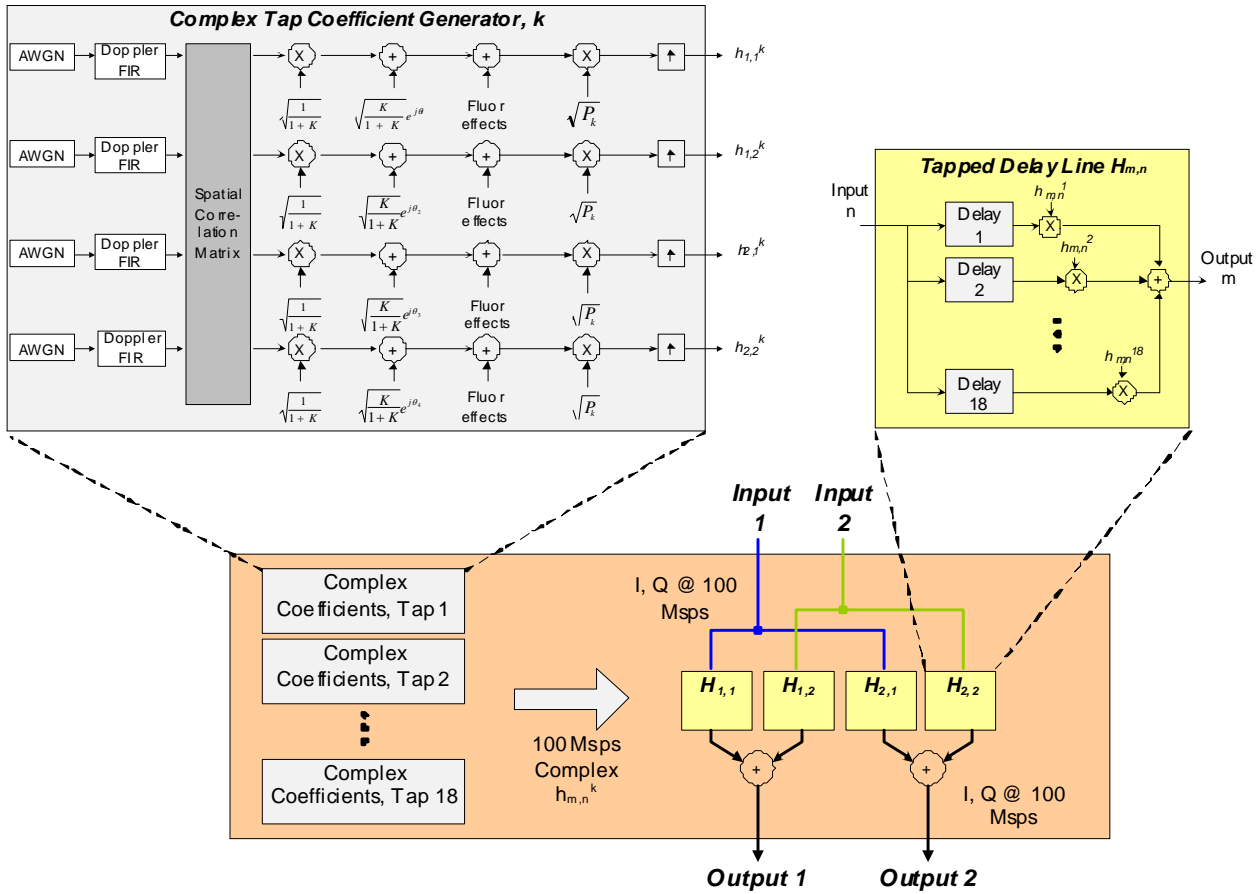


Figure 6: Block diagram showing computation of time-variable coefficients for tap  $k$ , where  $K$  is the Rician  $K$ -factor and  $P$  is the power of each tap. This is an example of a  $2 \times 2$  MIMO system. A  $4 \times 4$  MIMO system has 4 inputs and 4 outputs; 16 paths – with 16 AGWN sources, 16 Doppler filters, and so forth.

### 3. Model statistics verification

Model implementation can be validated by comparing the statistical distribution of coefficients that Fox generates to the theoretical values of these coefficients.

The model statistics VI can generate the following plots:

- Emulated power delay profile (PDP) vs. theoretical (figure 7)
- Tap magnitude cumulative distribution function (CDF) vs. theoretical Rician or Rayleigh distribution (figure 8)
- The emulated Doppler spectra vs. the spectra predicted by theory (figure 9)
- Impulse response (figure 10)
- Spatial correlation coefficients vs. theoretical

Some examples of model statistics plots are shown below.

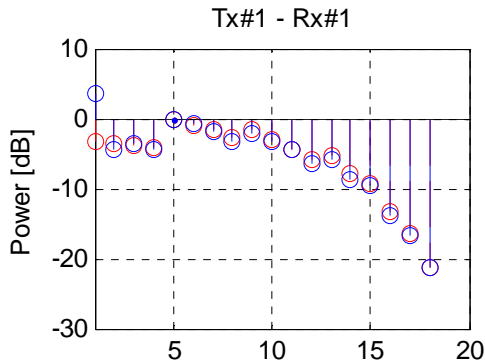


Figure 7: Example of PDP plot (model F)

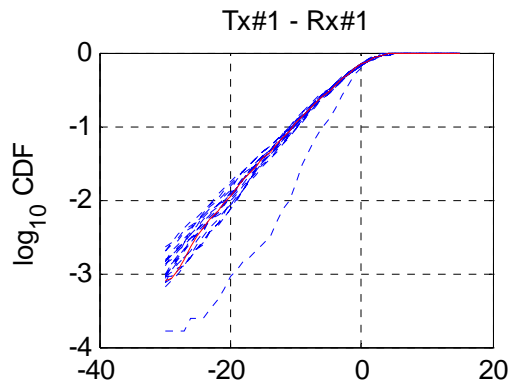


Figure 8: Example of CDF plot (model F); lower curve is the line of sight component on the first tap

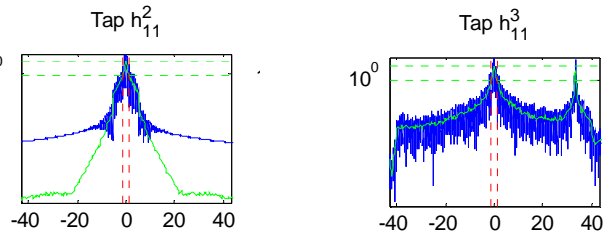
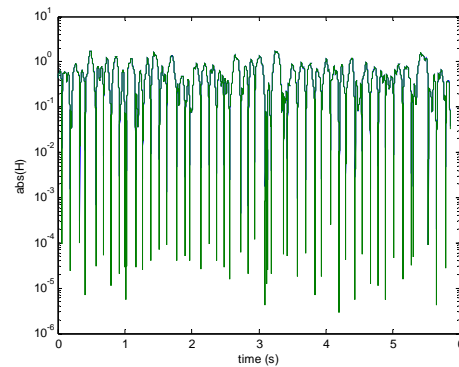


Figure 9: Example of Doppler spectra plots for model F; tap 3 exhibits automotive velocity spike



Model D 2x3, LOS conditions

Figure 10: Example of impulse response plot (model F)

## 7. ACRONYMS

AFD	Average Fade Duration
ANSI	American National Standards Institute
API	Application Programming Interface
CDF	Cumulative Distribution Function
CLI	Command Line Interface
CSV	Comma Separated Variables
FIR	Finite Impulse Response
IIR	Infinite Impulse Response
LCR	Level Crossing Rate
MIMO	Multiple Input Multiple Output
Msp	Mega samples per second
NLOS	Non Line Of Sight
PAS	Power Angular Spectrum
PDF	Probability Density Function
PDP	Power Delay Profile
POSIX	Portable Operating System Interface [for Unix]"
SISO	Single Input Single Output
TDL	Tapped Delay Line

## 10. REFERENCES

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- [6] Schumacher et al, "From antenna spacings to theoretical capacities - guidelines for simulating MIMO systems"

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