Performance of an Experimental 384 kb/s 1900 MHz OFDM Radio Link In a Wide-Area High-Mobility Environment

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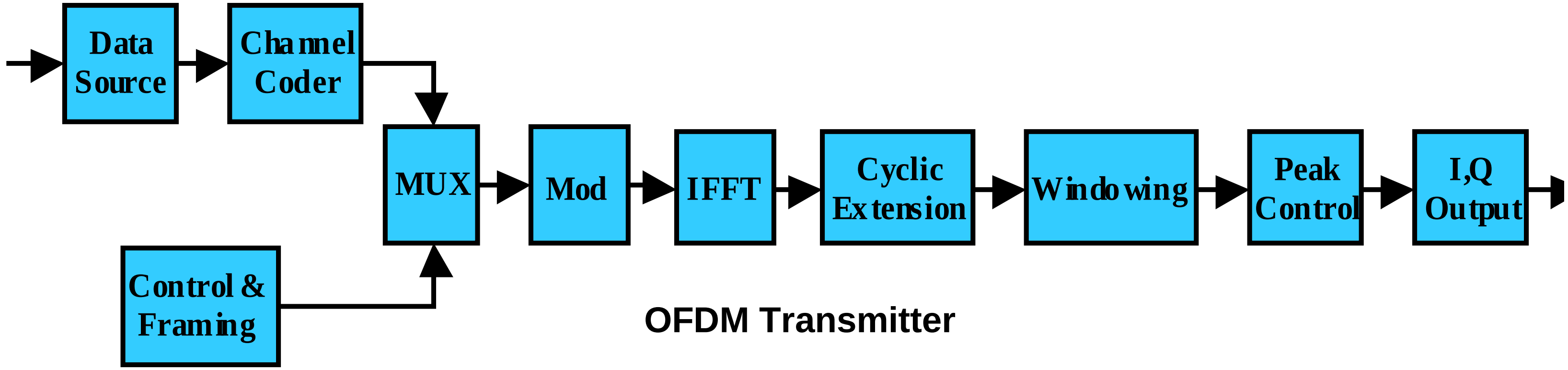
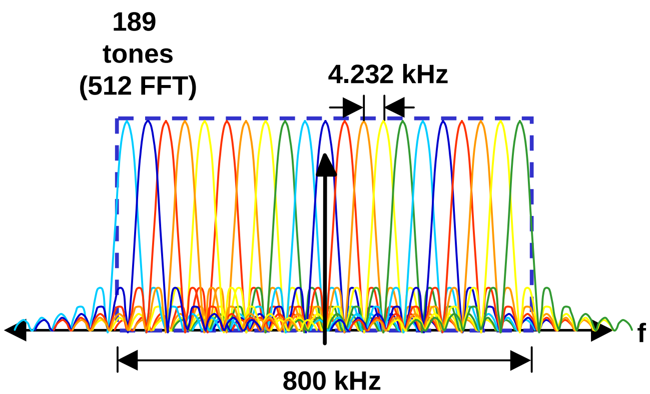
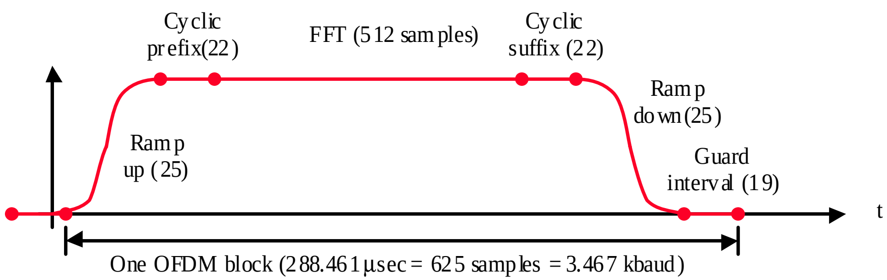
Red Bank, NJ

OFDM for High Speed Wireless Data Networking



OFDM Transmitter





- Low symbol rate (~3.5 kbaud) protects against changing mobile channel
- Sparse constellation on each carrier (QPSK) provides resistance against noise
- Coding across tones provides frequency diversity
- Large number of carriers provides high capacity (189 user bits/288 μsec ~544 kb/s)

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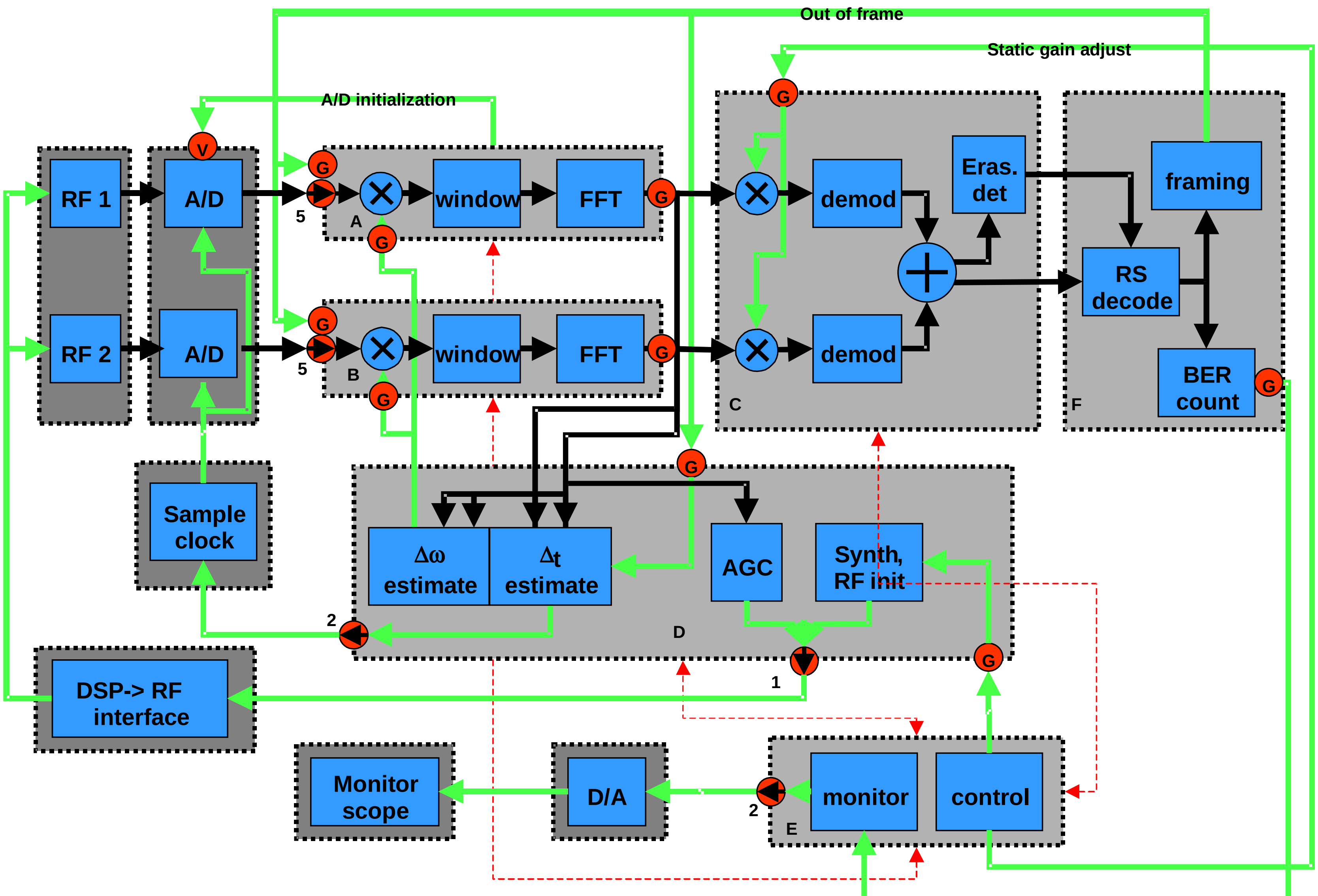
OFDM Receiver - DSP Hardware Architecture



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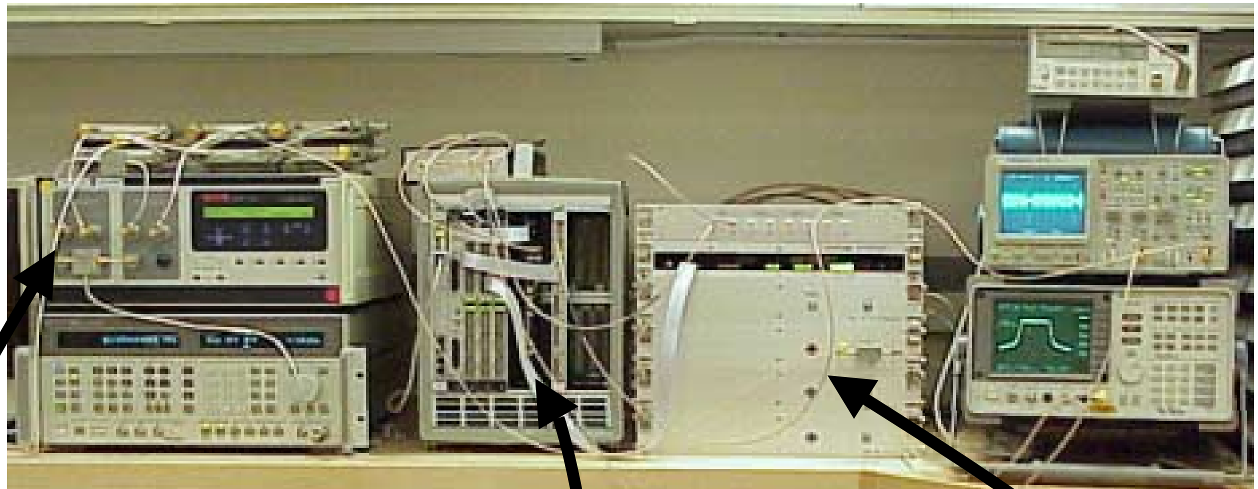
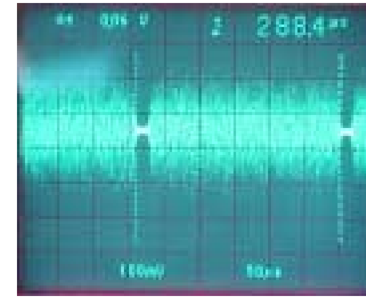
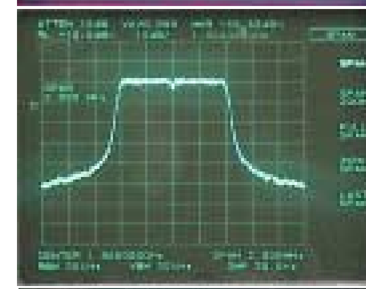
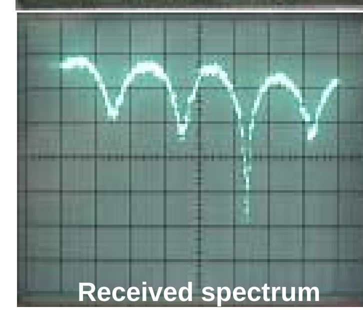
OFDM Experimental Hardware

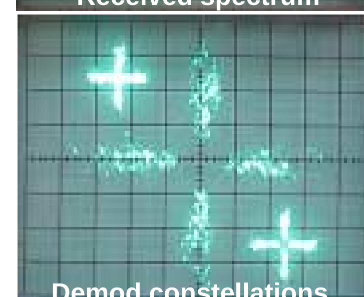








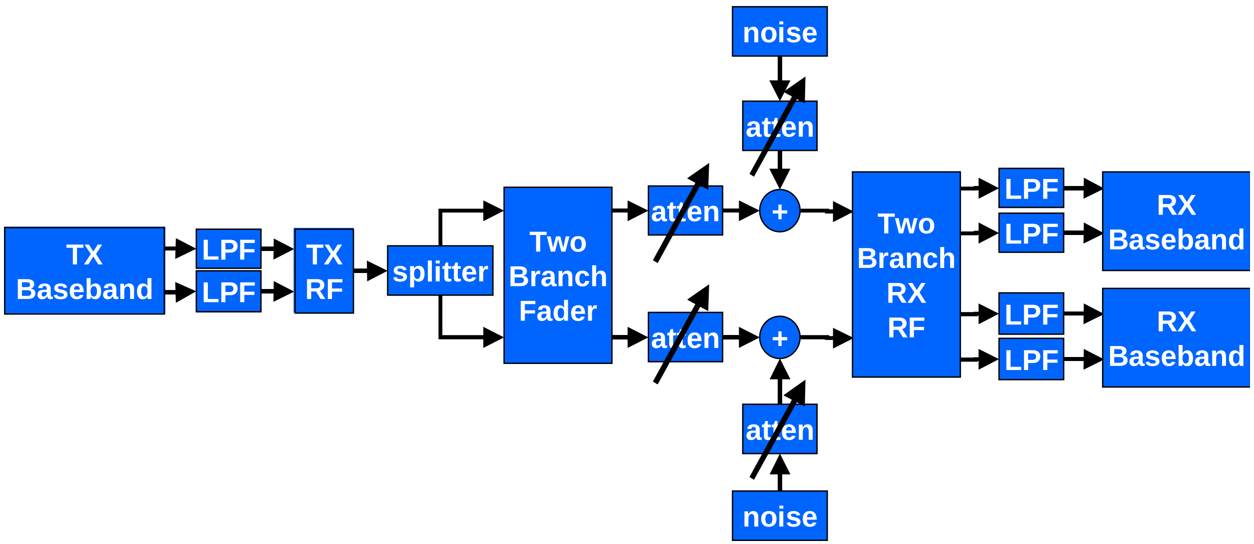
Received spectrum



Demod constellations

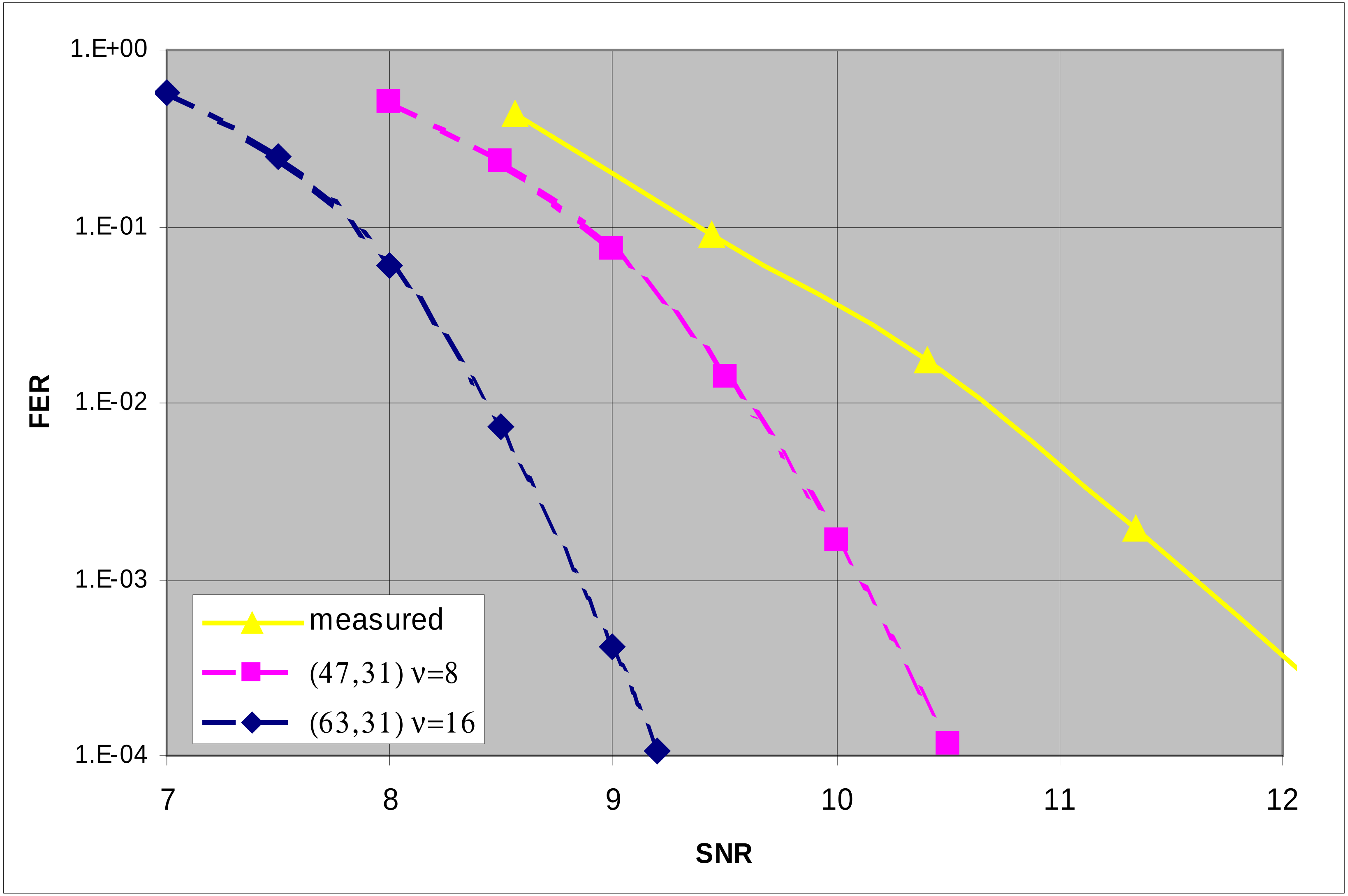
- Baseband signal processing based on commercial off-the-shelf DSP hardware with some custom designed components
- 1900 MHz transceiver
- Real-time performance measured through RF fading simulator
- System parameters:
  - >384 kb/s end user data rate
  - 800 kHz downlink bandwidth
  - GSM-derived clock rates

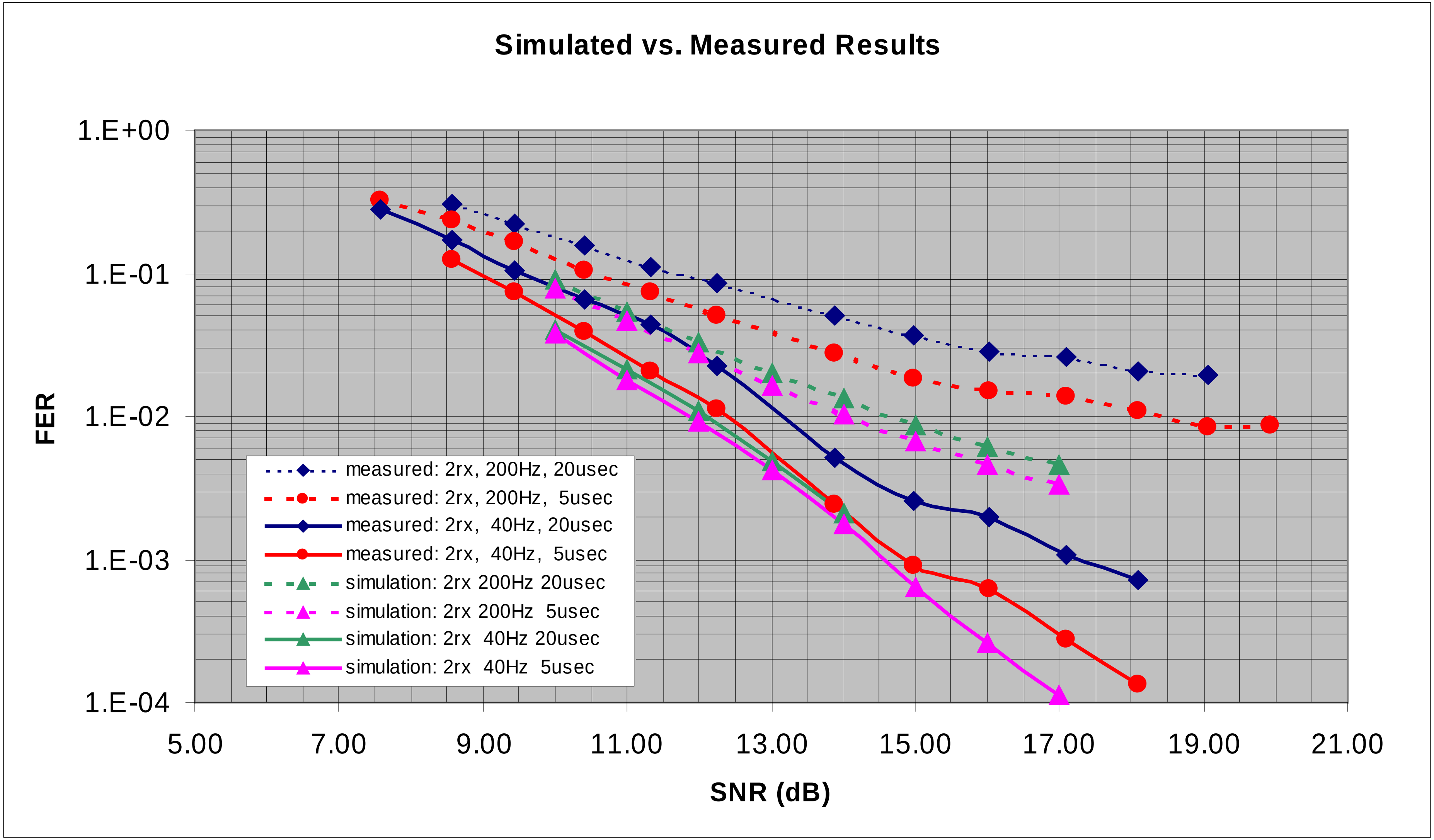
Experimental setup for OFDM receiver performance measurements



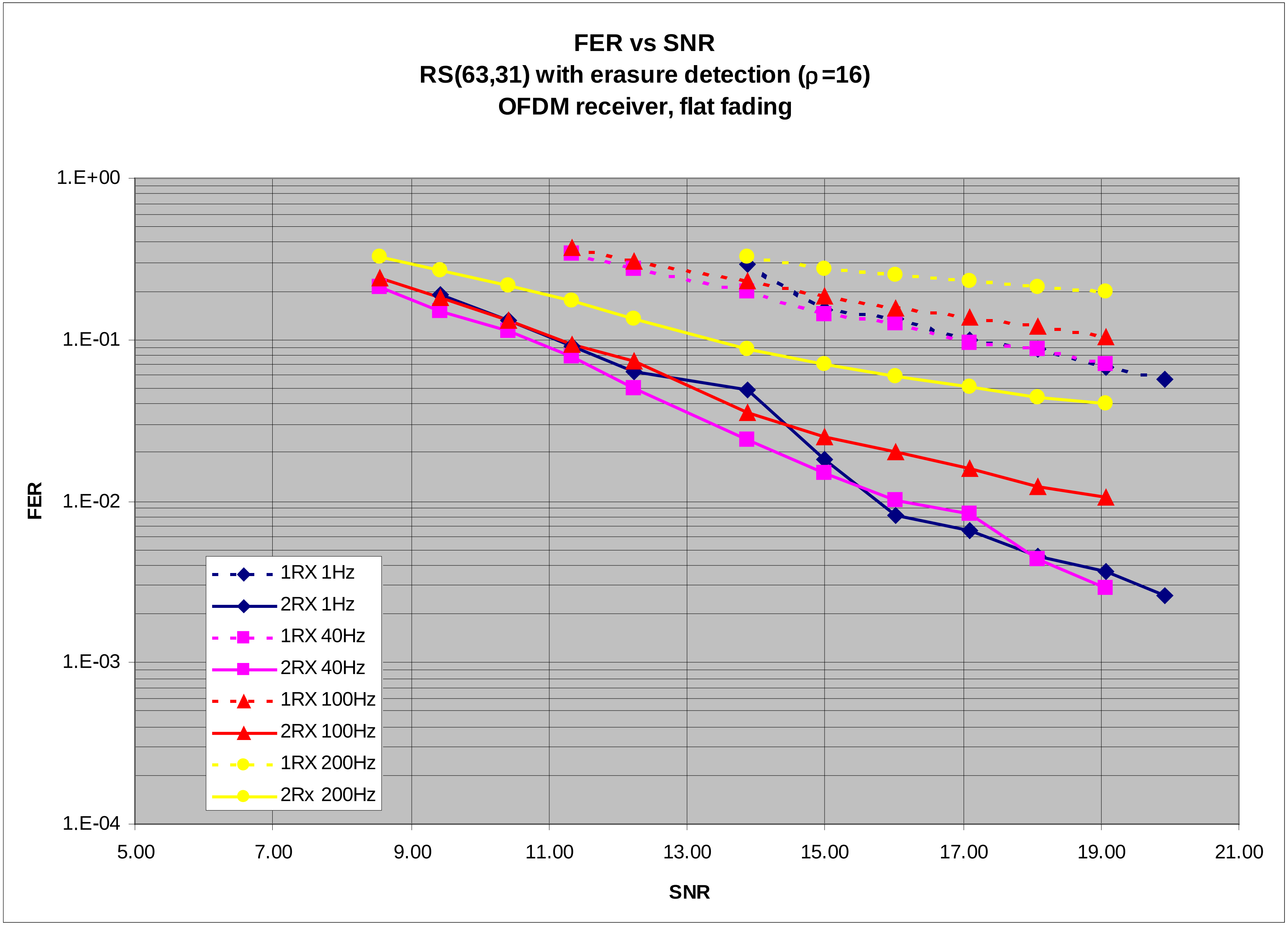
- Simulated channels: AWGN, flat fading, two-ray, GSM models
- Tested one- and two-branch receiver
- Excellent repeatability and agreement with simulation and theory

Theoretical versus measured performance: one-branch receiver in AWGN





Simulated vs. Measured Results
FER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
5.00
7.00
9.00
11.00
13.00
15.00
17.00
19.00
21.00
SNR (dB)
measured: 2rx, 200Hz, 20usec
measured: 2rx, 200Hz, 5usec
measured: 2rx, 40Hz, 20usec
measured: 2rx, 40Hz, 5usec
simulation: 2rx 200Hz 20usec
simulation: 2rx 200Hz 5usec
simulation: 2rx 40Hz 20usec
simulation: 2rx 40Hz 5usec



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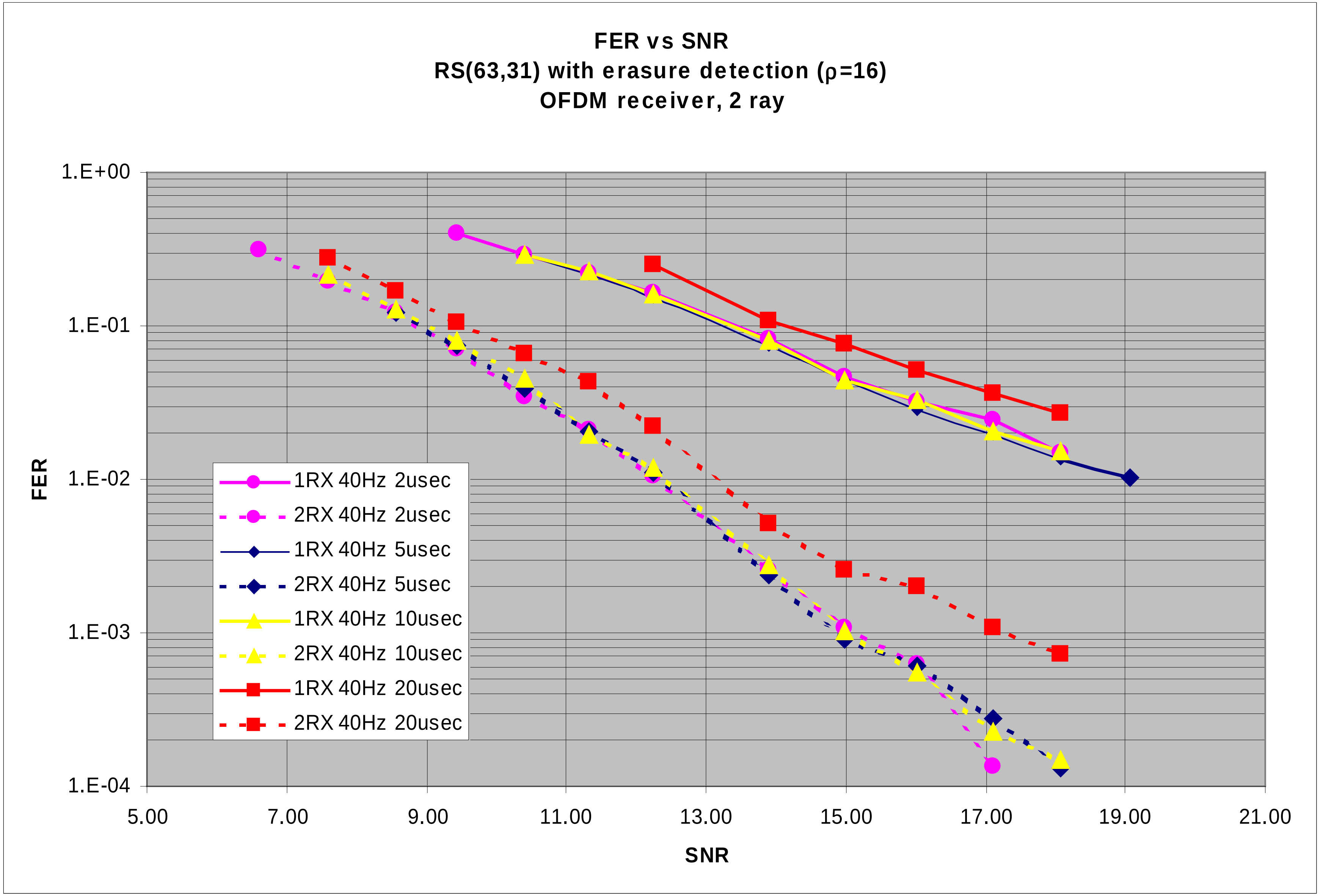
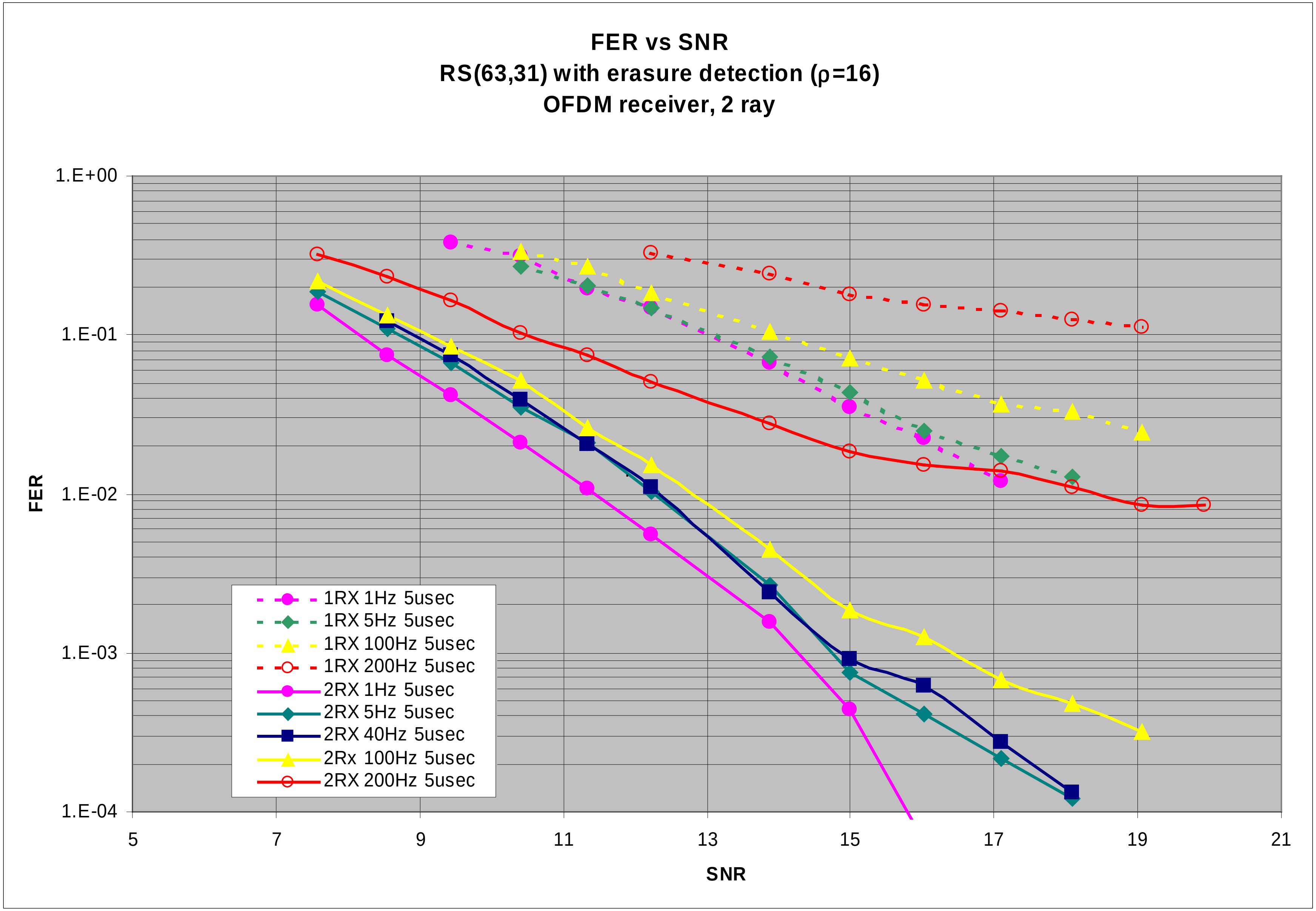
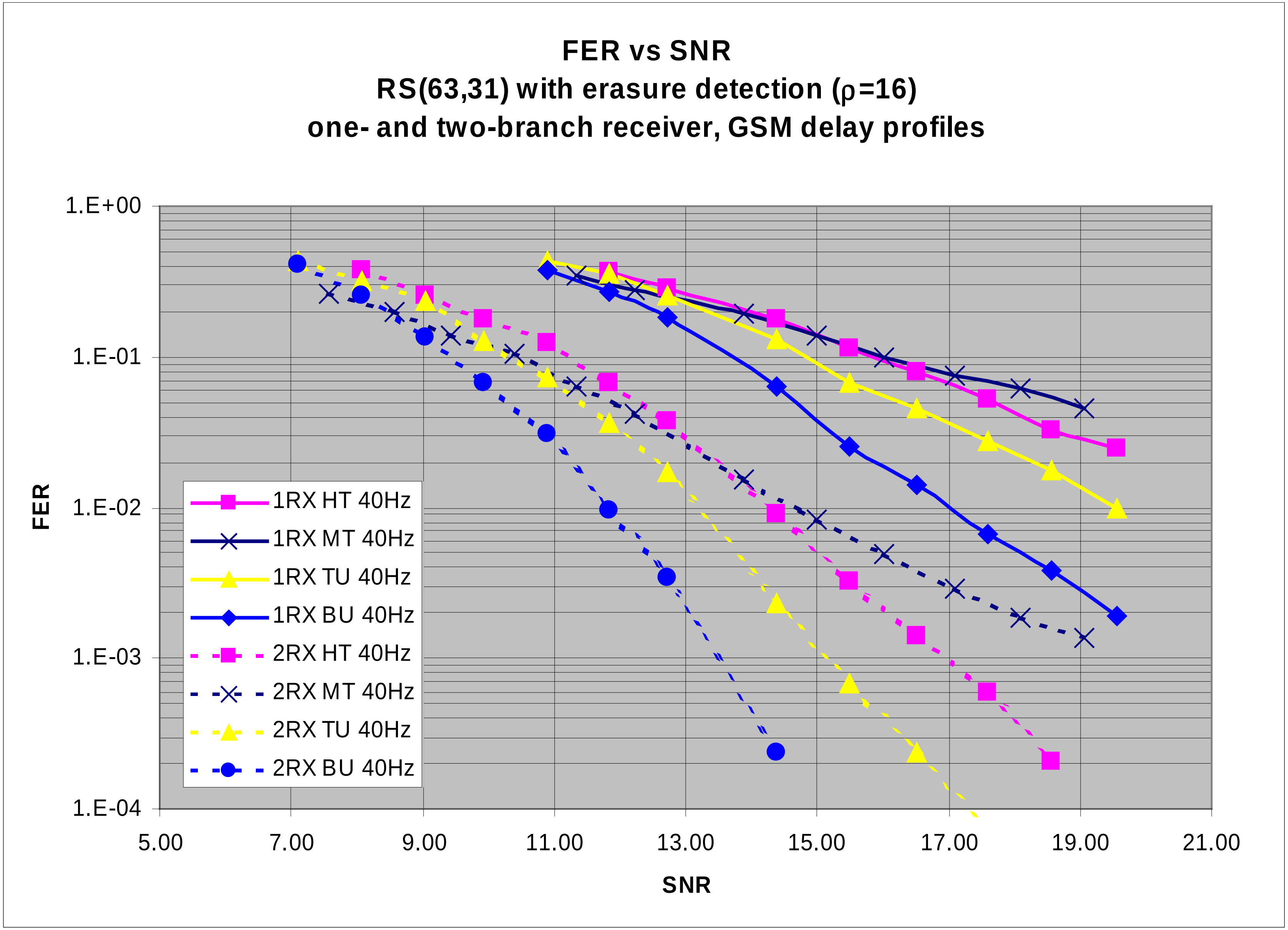
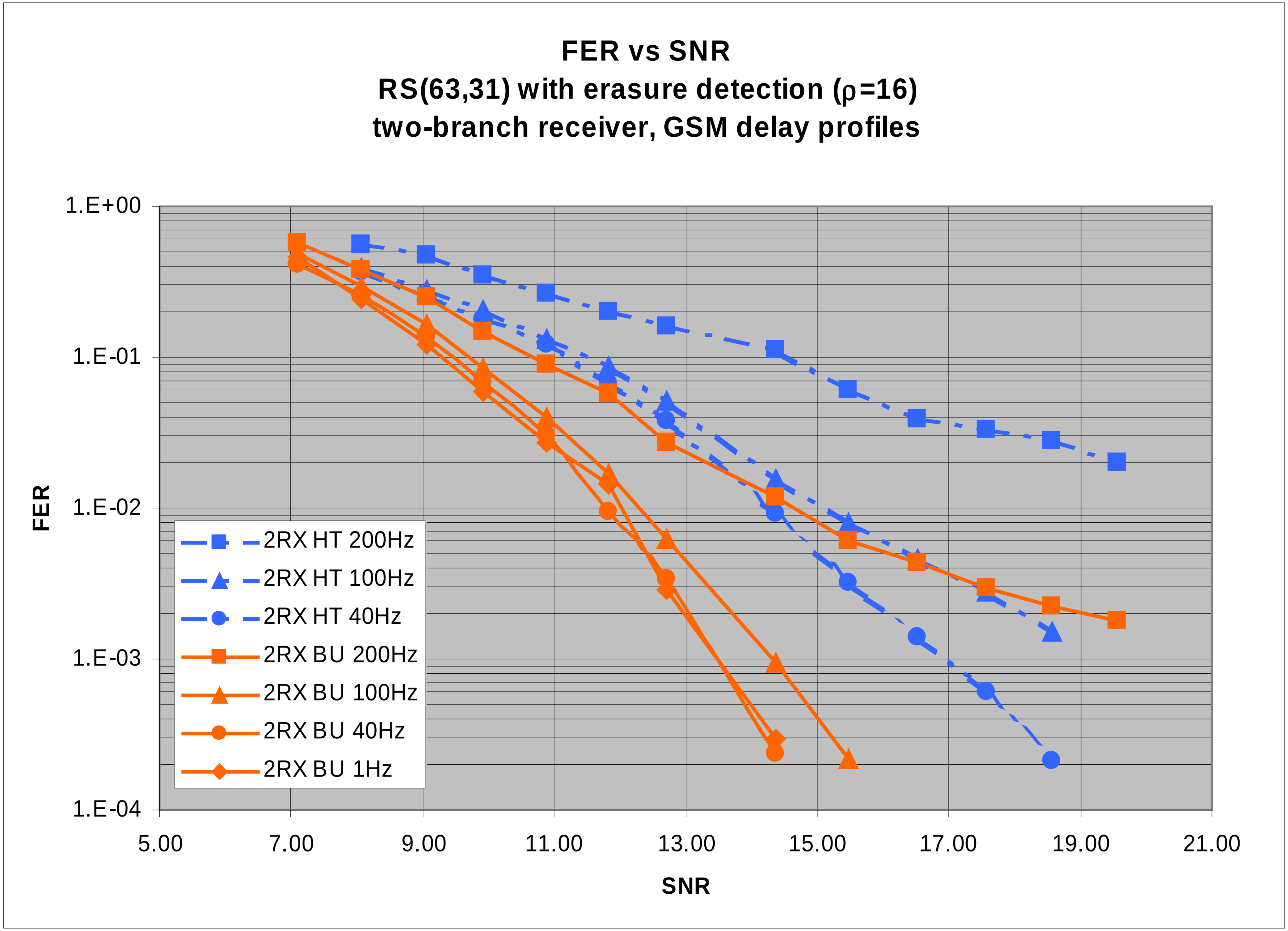

FER vs SNR
RS(63,31) with erasure detection (ρ=16)
OFDM receiver, 2 ray
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
FER
5.00
7.00
9.00
11.00
13.00
15.00
17.00
19.00
21.00
SNR
1RX 40Hz 2usec
2RX 40Hz 2usec
1RX 40Hz 5usec
2RX 40Hz 5usec
1RX 40Hz 10usec
2RX 40Hz 10usec
1RX 40Hz 20usec
2RX 40Hz 20usec


FER vs SNR
RS(63,31) with erasure detection (ρ=16)
OFDM receiver, 2 ray
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
FER
5
7
9
11
13
15
17
19
21
SNR
1RX 1Hz 5usec
1RX 5Hz 5usec
1RX 100Hz 5usec
1RX 200Hz 5usec
2RX 1Hz 5usec
2RX 5Hz 5usec
2RX 40Hz 5usec
2Rx 100Hz 5usec
2RX 200Hz 5usec



FER vs SNR
RS(63,31) with erasure detection (ρ=16)
one- and two-branch receiver, GSM delay profiles
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
FER
5.00
7.00
9.00
11.00
13.00
15.00
17.00
19.00
21.00
SNR
1RX HT 40Hz
1RX MT 40Hz
1RX TU 40Hz
1RX BU 40Hz
2RX HT 40Hz
2RX MT 40Hz
2RX TU 40Hz
2RX BU 40Hz


FER vs SNR
RS(63,31) with erasure detection (ρ=16)
two-branch receiver, GSM delay profiles
FER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
5.00
7.00
9.00
11.00
13.00
15.00
17.00
19.00
21.00
SNR
2RX HT 200Hz
2RX HT 100Hz
2RX HT 40Hz
2RX BU 200Hz
2RX BU 100Hz
2RX BU 40Hz
2RX BU 1Hz

Performance Summary

	Fading rate:	1 Hz	5 Hz	40 Hz	100 Hz	200 Hz
Channel:	AWGN	7.0 dB				
	Bad Urban	9.3 dB		9.4 dB	9.7 dB	10.8 dB
	2 μsec			8.9 dB		11.9 dB
	5 μsec	8.1 dB	8.6 dB	8.9 dB	9.2 dB	10.4 dB
	10μsec			9.1 dB		
	20μsec	9.0 dB		9.5 dB		11.6 dB
	Typical Urban	10.4 dB		10.5 dB	10.6 dB	12.0 dB
	Hilly Terrain			11.2 dB	11.6 dB	14.2 dB
	Mountainous Terrain			10.4 dB		13.1 dB
	Flat	11.2 dB		10.9 dB	11.2 dB	12.7 dB

SNR required for 10% FER, two-branch receiver

	Fading rate:	1 Hz	5 Hz	40 Hz	100 Hz	200 Hz
Channel:	AWGN	9.4 dB				
	Bad Urban	13.4 dB		13.5 dB	14.4 dB	18.3 dB
	2 μsec			13.5 dB		~21 dB
	5 μsec	13.1 dB	13.1 dB	13.1 dB	14.0 dB	~21 dB
	10 μsec			13.2 dB		
	20 μsec	14.5 dB		14.0 dB		>21 dB
	Typical Urban	14.4 dB		14.8 dB	15.5 dB	>21 dB
	Hilly Terrain			15.8 dB	17.3 dB	>>21 dB
	Mountainous Terrain			16.0 dB		>>21 dB
	Flat	17.1 dB		17.1 dB	19.1 dB	>21 dB

SNR required for 10% FER, one-branch receiver

Conclusions

- Real-time DSP prototype demonstrated:
  - performance within 1-2 dB of theory in AWGN
  - performance within .25 dB of idealized simulation for two-ray fading
  - robustness of OFDM against delay spread
  - robustness of blind differential-in-frequency timing estimation

- OFDM can offer good performance with straightforward receiver (e.g., simple combining, differential detection, (63,31) RS coder)

- Two-branch receiver diversity provides 4 - 8+ dB performance gain for variety of channel conditions

- Coding across OFDM tones provides effective frequency diversity

- Shorter (<288 μsec) OFDM blocks needed for high fading rates

- Wideband OFDM with improved modulation, coding, channel estimation promises excellent performance