Cover Sheet for Presentation to IEEE 802.16 Broadband Wireless Access Working Group (Rev. 0)

Document Number:
802.16pp-99/19

Title:
Out-of-Block Pilot-Assisted Frequency Domain Reciprocal Modulation (FDRM)

Date Submitted:1999-11-14

Source:

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Venue:
Session #4 of Physical Layer Task Group (PHY) in Hawaii, Nov, 1999

Base Document:
http://grouper.ieee.org/groups/802/16/phy/contrib/80216pc-99_19.pdf

Purpose:
For consideration for inclusion into the standard

Out-of-Block Pilot-Assisted Frequency Domain Reciprocal Modulation (FDRM)

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Microwave Transmission

- Line of site is primary method for 10-66 GHz
- Wide-beam antenna at base station site
- Narrow-beam antenna at subscriber site
- LOS may have some obstructions
  - like to use repeaters for better coverage
- Impairments
  - Rain fade > random noise
  - multipath, some dynamic
  - co-channel interference possible
  - intermod products from linear amplifier

Introducing FDRM

- Designed to deal with dynamic multipath distortion
- Uses two blocks that were encoded differently from the same information
- A multicarrier system that is related to OFDM
- Assumes that the same echoes distort each data block
- The two data blocks are processed together to find the unimpaired symbols -- with a 3 dB better S/N!
- Optionally the frequency response of the path can be measured and used for correcting future blocks or averaging -- with a 3 dB better S/N!
- Works well with antenna diversity

Characteristics of FDRM

- First block is like OFDM, second is a frequency domain reciprocal to the first block, HC by HC
- Tolerant to dynamic multipath & dispersed echoes
- Operates in 0 dB echo environment
- Tolerant to rapid fades
- Ideal for burst-mode > easy to demodulate
- Out-of-block pilot assistance solves problem of intolerance to phase-noise at microwave frequencies
- Allows use of repeaters & reflectors

Multipath Distortion

- Also known as echoes or ghosts
- A linear distortion
- Copies of the same signal with different delays and attenuations -- diffuse echoes are from many paths
- A weak uncorrected echo increases BER with noise. A strong uncorrected echo makes the data useless.
- A traditional solution is an adaptive equalizer, but adaptive equalizer's coefficients must be programmed to match the echoes
- Adaptive equalizer may use a training signal or blind equalization

Dynamic Multipath Distortion

- Caused by echoes or ghosts that change e.g. wind-blown foliage, tower sway, pedestrian traffic, birds
- Transmitter, receiver, or reflector may move
- The programming of the adaptive equalizer must change to match the moving echo
- At microwave frequencies change is very quick
- Rapid accurate reprogramming is difficult
- Noise increases the programming time
- Rapid signal fades also occur
- Sometimes no direct signal path is available

FDRM - Theory of Operation

Let S(f)= normal transmitted signal in frequency domain and H(f)= channel's frequency response. Therefore a normal received signal is:

$$X(f) = S(f) \cdot H(f)$$

If a reciprocal signal block is created:

$$R(f) = \frac{1}{S(f)}$$

A received reciprocal signal will be:

$$Y(f) = R(f) \cdot H(f) = \frac{H(f)}{S(f)}$$

Theory of Operation cont.

So the originally sent unimpaired signal can be found:

$$S(f) = \sqrt{\frac{X(f)}{Y(f)}} = \sqrt{\frac{S(f)\cdot H(f)}{\frac{H(f)}{S(f)}}} = \sqrt{S(f)^2}$$

Likewise, the channel's frequency response can be found by multiplying X(f) by Y(f):

$$X(f)\cdot Y(f) = S(f)\cdot H(f)\cdot \frac{H(f)}{S(f)} = H(f)^2$$

so the channel's frequency response is:

$$H(f) = \sqrt{H(f)^2}$$

Theory of Operation - cont.

- Approximately the same linear distortion must be applied to both blocks
- If any frequencies have low magnitude components computing the frequency domain reciprocal results in large (impractical) values
- OFDM fits the bill as a modulation with controlled energy at all frequencies (no low energy frequencies)
- Another method is single block FDRM. Normal carriers and reciprocal carriers are interleaved in the same block
- 3 dB improvement in S/N for signal, 3 dB for H(f) too!

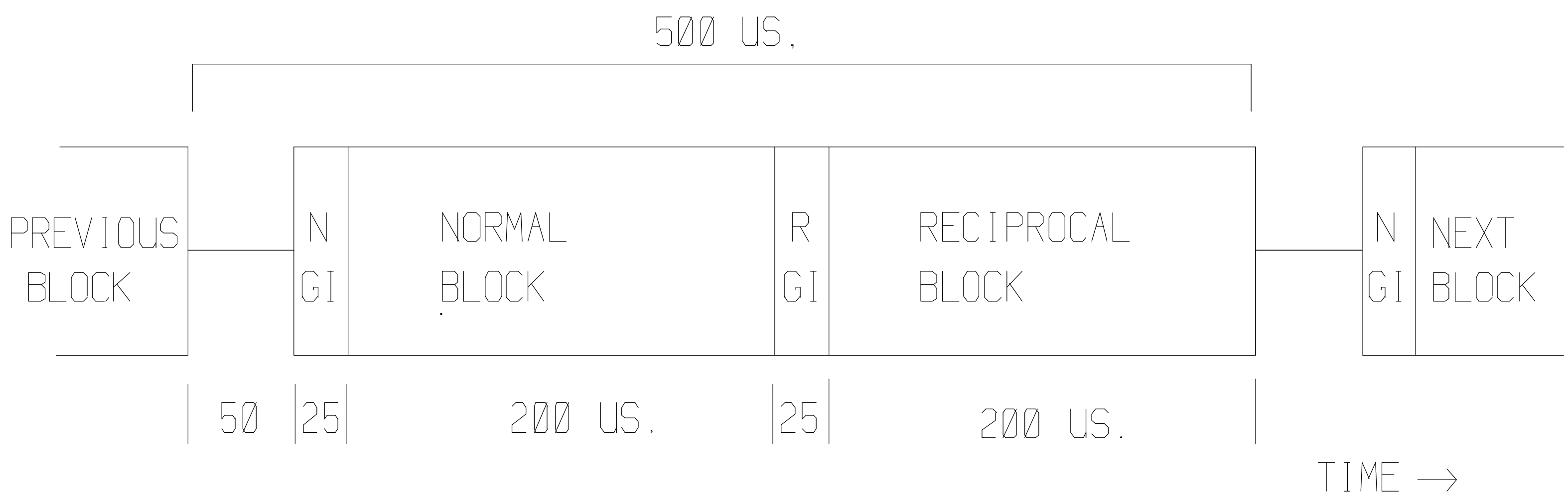
Holtzman's Proposal

- FDM downstream, FDM/TDMA upstream
- Out-of Band Pilot assisted demodulation upstream and downstream
- Full-Time FDRM in on upstream
- FDRM as-needed on downstream
- Single-cast downstream data to be custom tailored for user
  - Set order of modulation N
  - FEC strength
  - Number of harmonic carriers

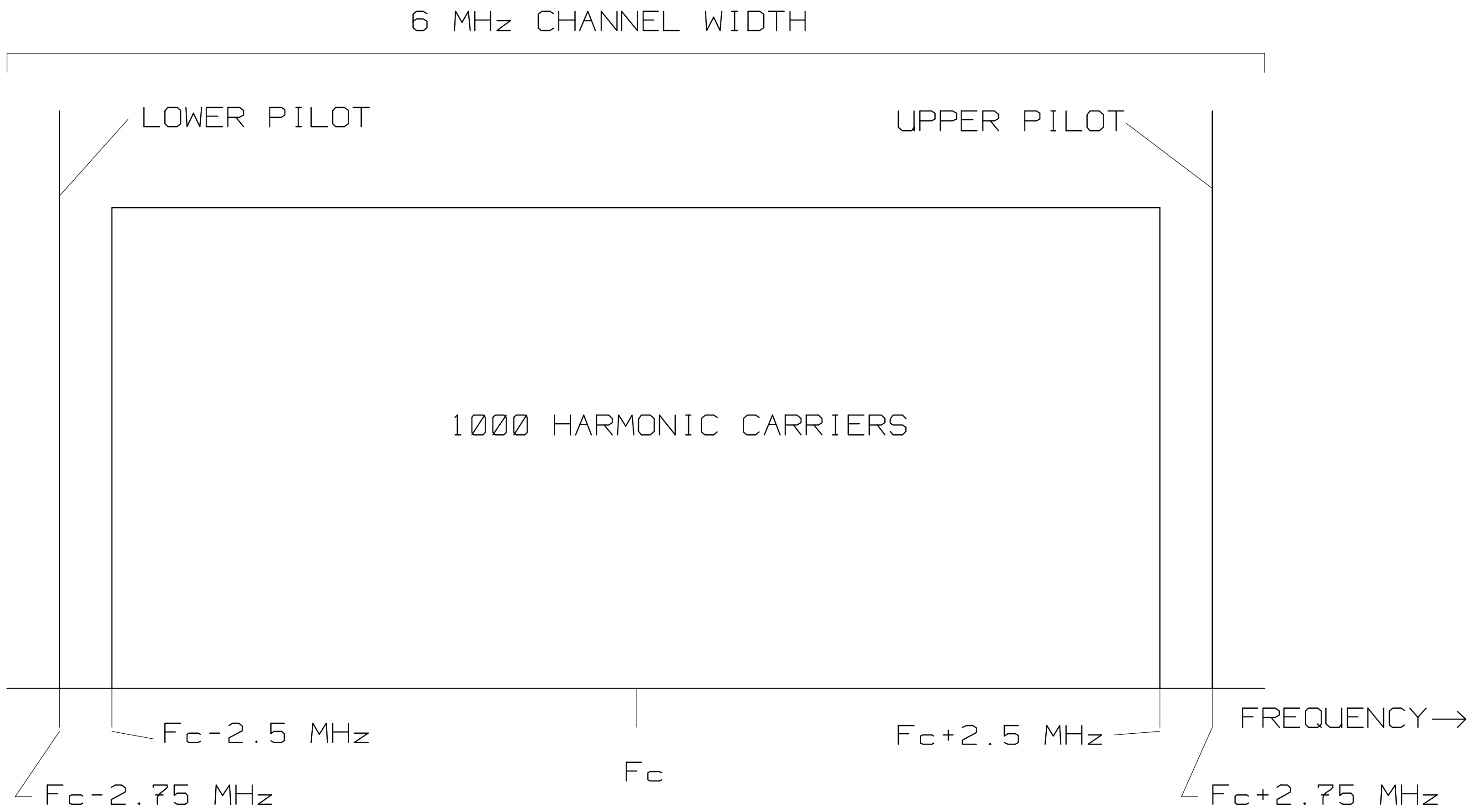
Continued

- Conventional COFDM style in-band pilots are sub-optimal
  - at the minimum they should be made into reciprocals of their neighbors. This will improve their channel characterization accuracy by 3dB
  - plus the neighbor harmonic carrier has an improved C/N!

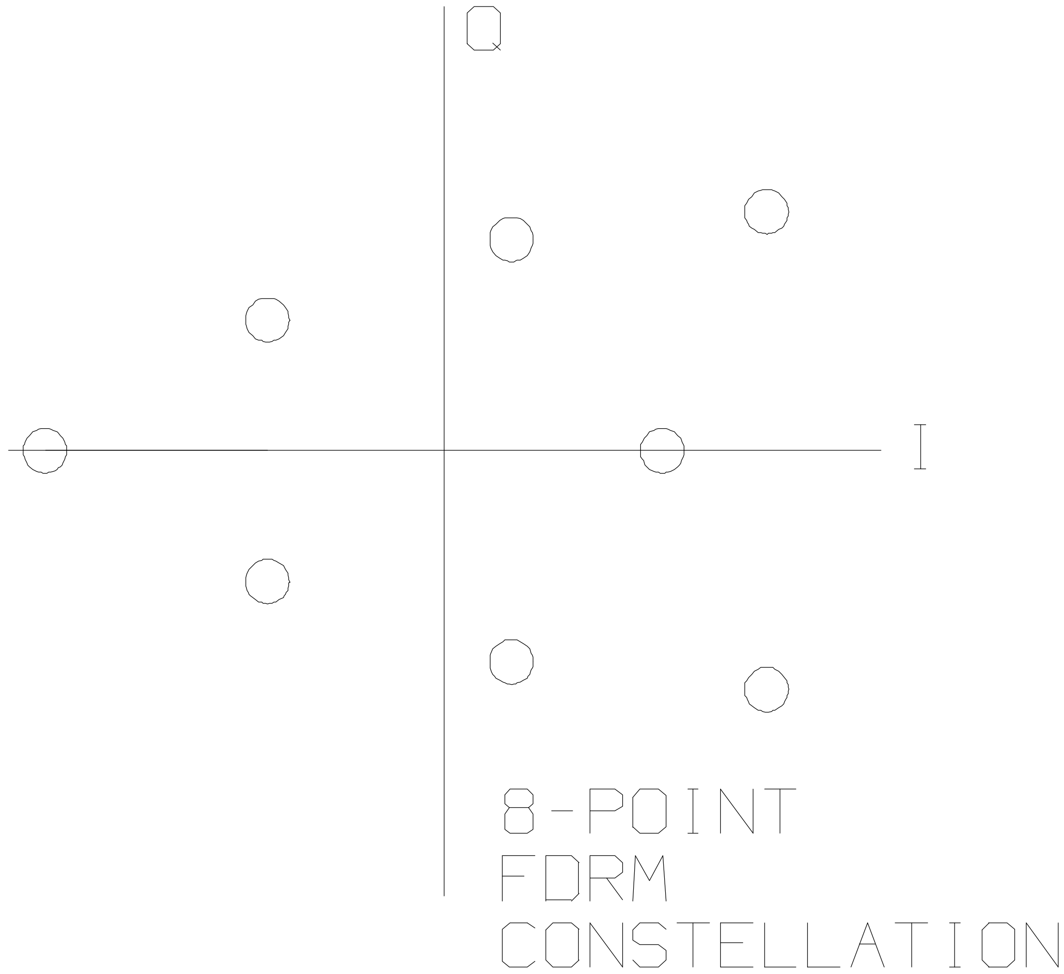
Proposed Time Plot of a Burst



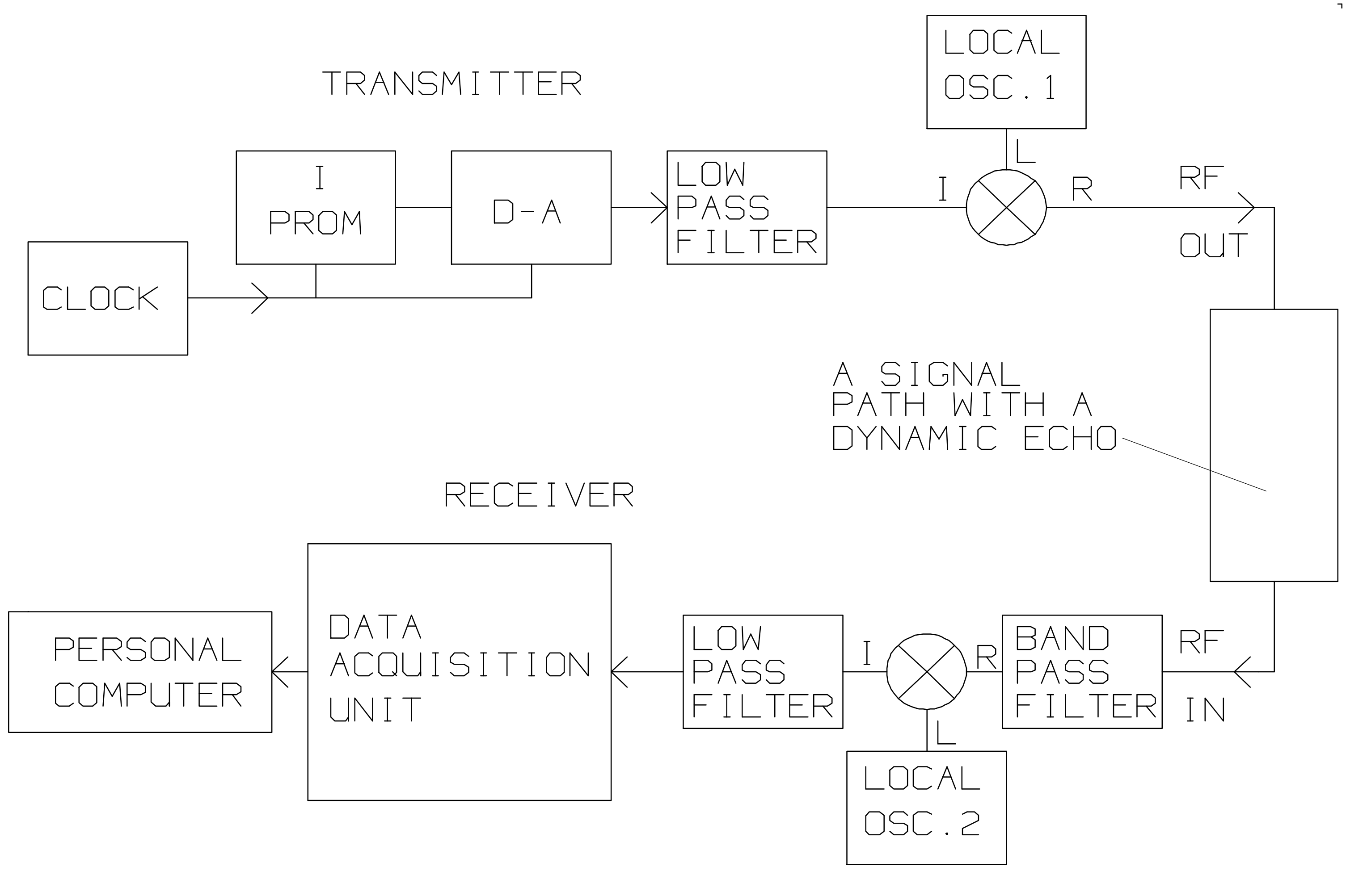
Proposed Spectral Plot



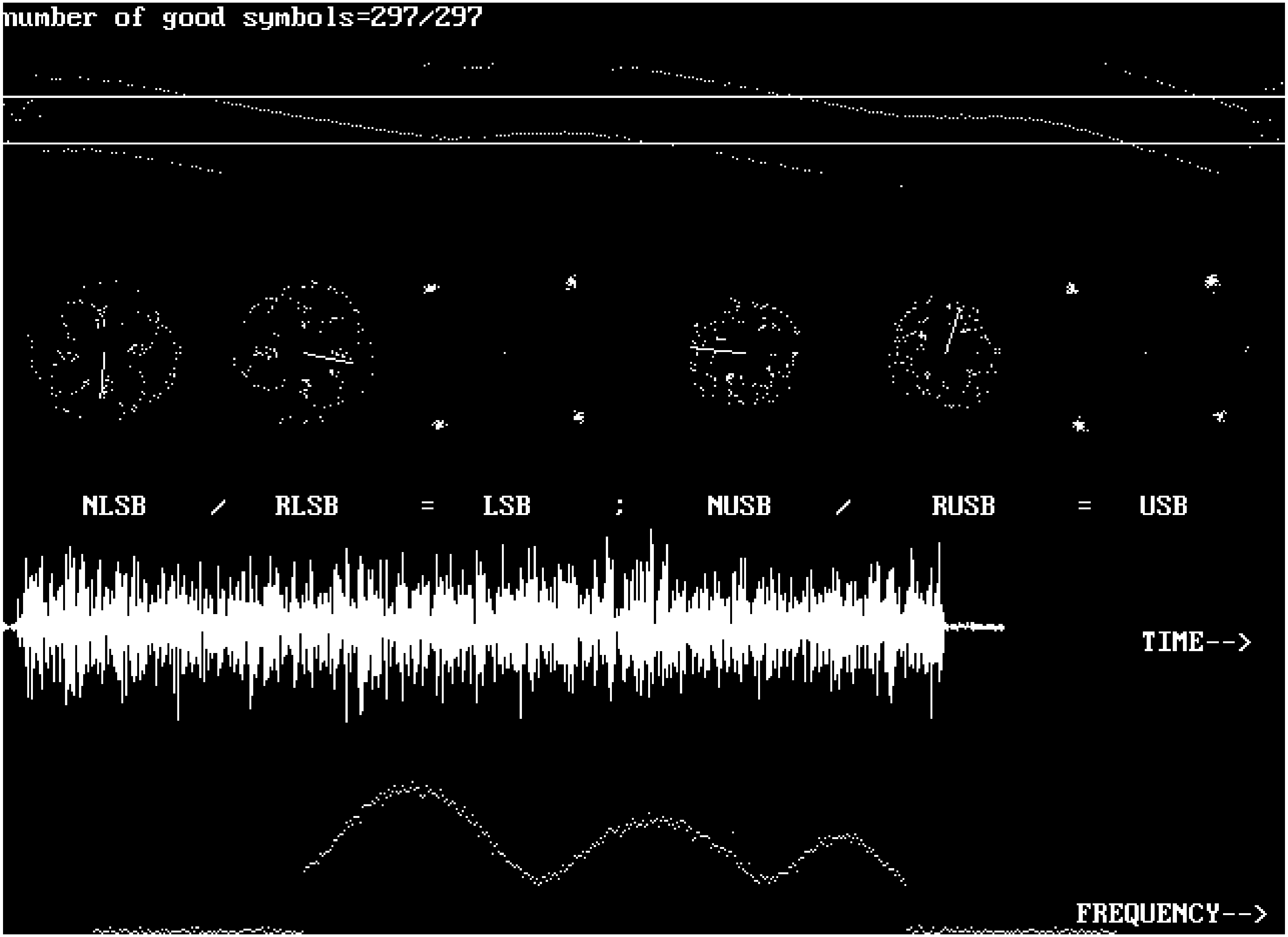
Constellation with Good Properties



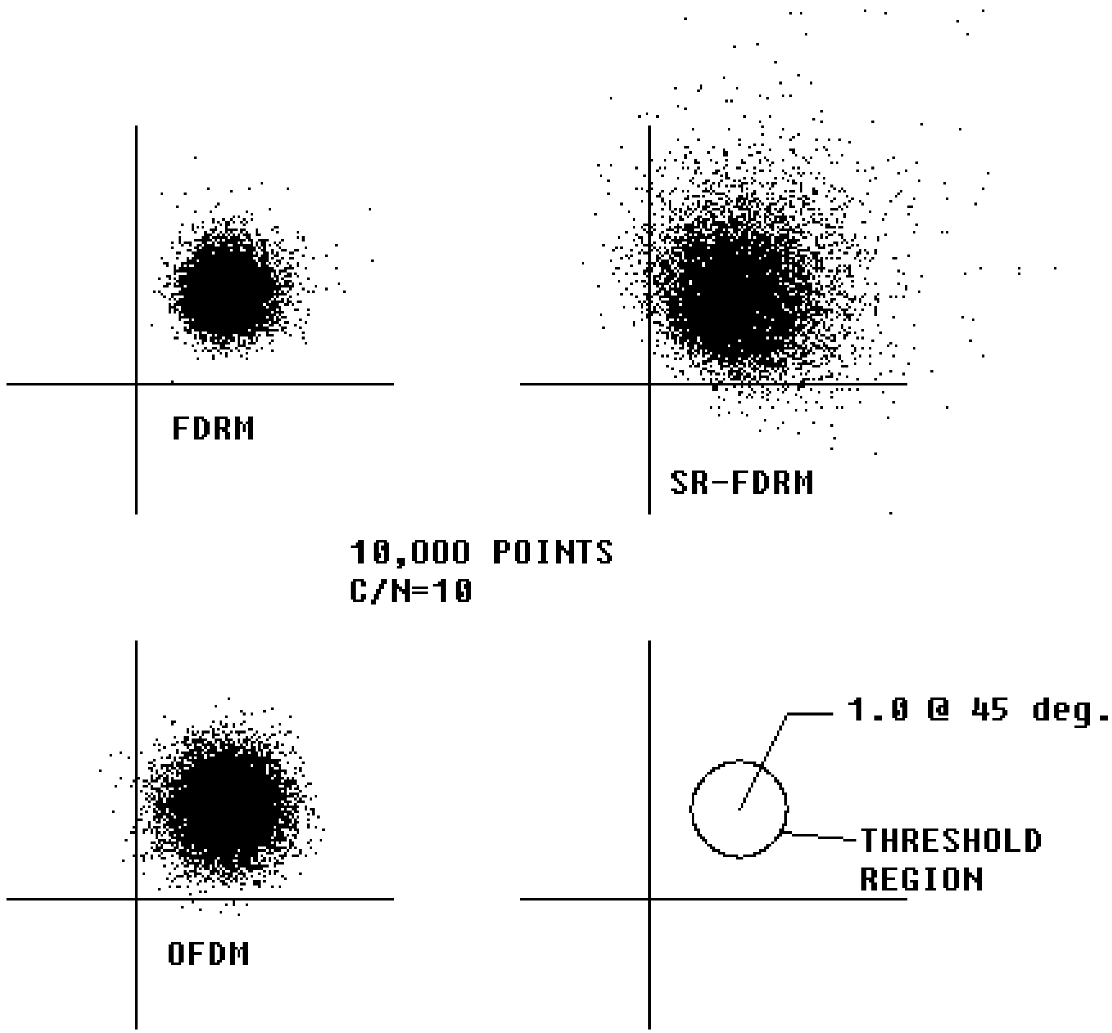
Block Diagram of Test Hardware



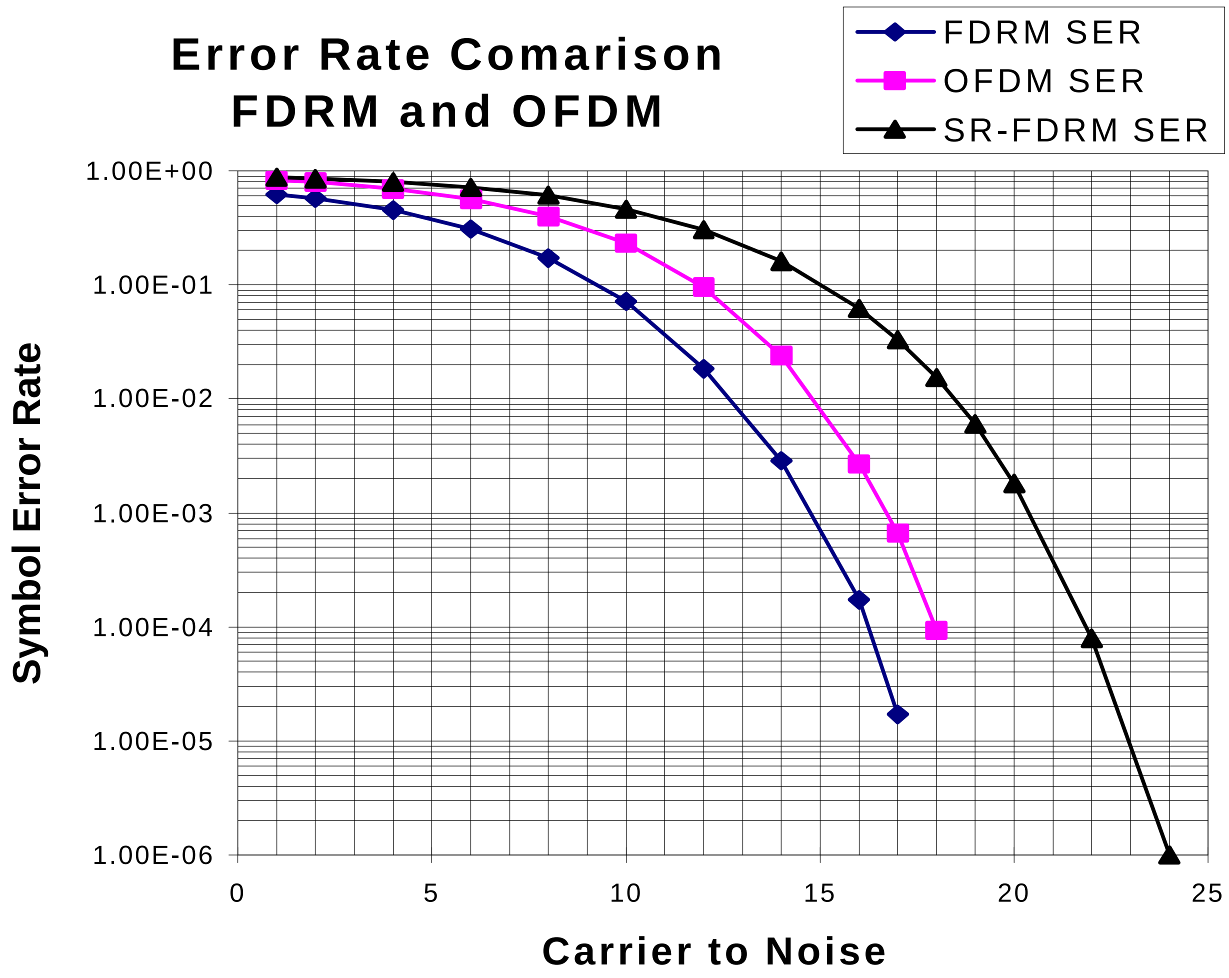
Test Results



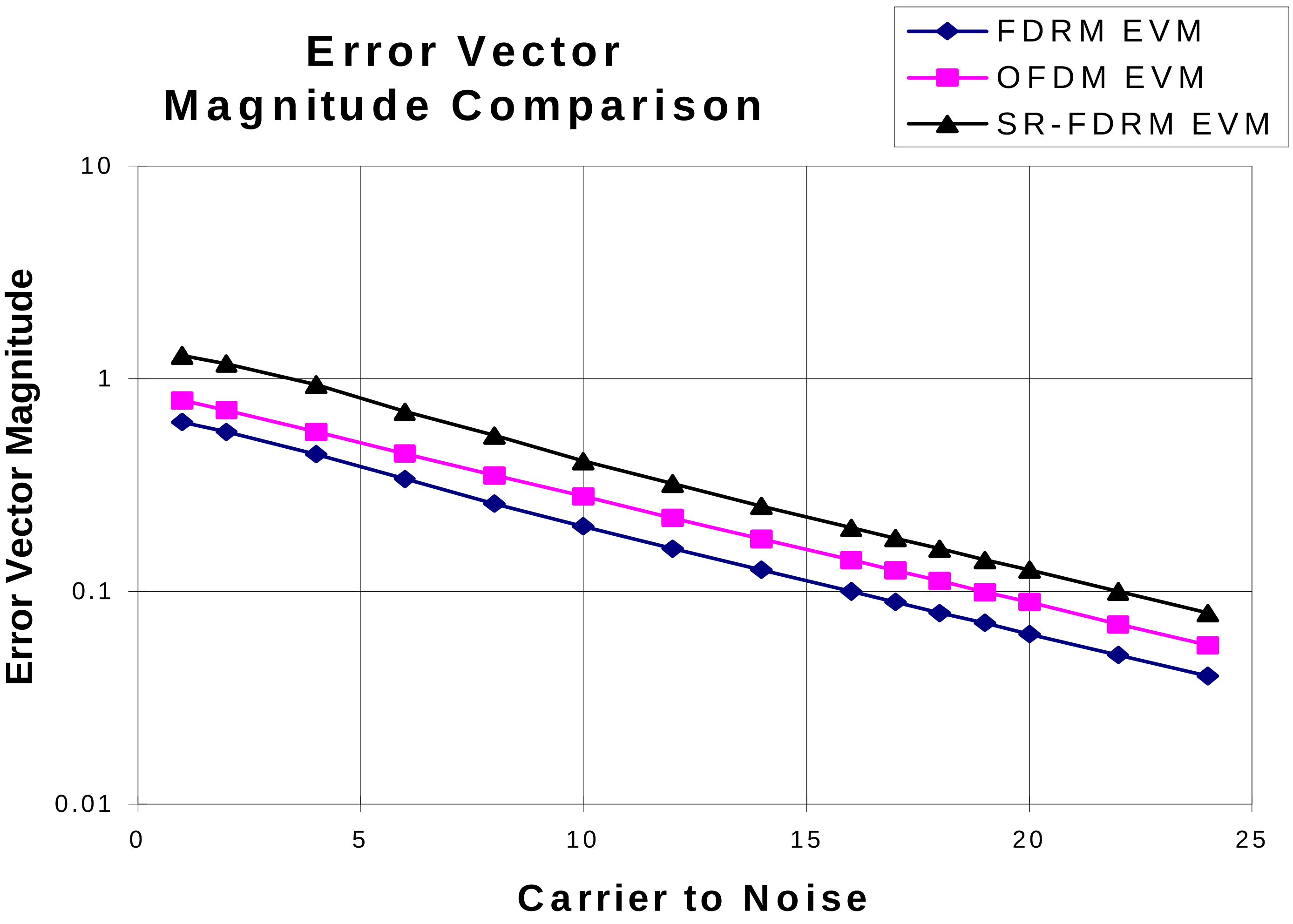
Constellation Spread from Random Noise



Symbol Error Rate vs. Carrier to Noise



EVM vs. Carrier to Noise



Observations from Test Data

- Technique works well
- Impairments from test setup corrected along with any echoes
- Easier to process than OFDM with in-band pilots
- Frequency differences between TX and RX carriers & phase noise fixed by out-of-block pilot
- Forward error correction will needed to recover symbols lost in deep fades.
- Signal adds on a 20 log basis while random noise adds on a 10 log basis. Result is a 3 dB better S/N ratio.

Conclusions

- FDRM = frequency domain reciprocal modulation
- Out-of-block pilot assistance for phase noise
- Two blocks of data that are reciprocal to each other in the frequency domain are sent in adjacent time slots
- The same echoes contaminate both blocks. The blocks are processed together at the receiver
- Linear distortion is automatically canceled as an intrinsic property of the modulation

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Patents Pending