Frequency Domain Reciprocal Modulation for Channels with Dynamic Multipath Proposal

IEEE 802.16 Presentation Submission Template (Rev. 8.2)

Document Number:
IEEE 802.16.4p-01/09
Date Submitted:
2001-01-21
Source:
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Venue:
Session #11
Base Document:
IEEE 802.16.4c-01/09
Purpose:
Explain contribution.

Frequency Domain Reciprocal Modulation for Channels with Dynamic Multipath
Proposal #9

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Frequency Domain Division Modulation

- General idea is to divide a set of numerator harmonic coefficients (HCs) by a set of denominator HCs. If both coefficients have a same echo multiplier, H(f), the echo cancels.
- A(f)*H(f) / B(f)*H(f) = A(f)/B(f)
- Works for single frequency carriers (SFC) and multi-frequency carriers (MFC)

Single Frequency Carrier (SFC) Case

- A single frequency carrier, such as QPSK, is transmitted as a block with a guard interval (cyclic extension) along with a reference signal that acquires the same echo. H(f)=1.0 for all HCs.
- Guard interval may be symbols copied from the end and pasted on the the front, or it may be dead-air time copied and pasted on front and back
- Convert both blocks to freq. domain, process using division, and convert quotient back into time domain.
- Can be dubbed "Irrational Modulation" because the quotient is an irrational complex number

Single Frequency Carrier (SFC) Case

- Advantages
  - Lower peak to average power ratio (e.g. QPSK case vs. OFDM case)
  - Symbol timing is automatically correct
  - All linear distortion is removed
  - One reference signal may be used to deghost several SFC blocks
  - Works with multiple antennas
- Disadvantages
  - Double noise hit: reference signal noise + SFC
  - Phase noise must be low
  - Noise enhancement on deep fades

Multi-Frequency Carriers (MFC) Cases

- Two multi-frequency carrier blocks are transmitted. At the receiver, the blocks' HC coefficients are divided in frequency domain such that H(f)'s cancel, and information is derived from the quotient symbols.
- Two blocks can be statistically independent, one block can be static (a reference signal), or blocks can be in a reciprocal relationship.
- Two blocks can be interleaved in frequency domain, resulting in a single block.
- Can be dubbed "Rational Modulation" because quotient is a rational complex number

Multi-Frequency Carriers (MFC) Cases

- Three variants
  - Numerator is an OFDM harmonic carrier, denominator HC is a reference signal (Normal OFDM)
  - Numerator and denominators HCs are independent symbols (technique not named yet)
  - Denominator HC is a reciprocal of numerator HC, making Frequency Domain Reciprocal Modulation (FDRM)

Frequency Domain Reciprocal Modulation

- 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
- The frequency response of the path is measured and used for correcting future blocks or OFDM HCs

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
- Operates in 0 dB echo environment
- Operates with dispersed echoes
- Tolerant to rapid fades
- Ideal for burst-mode transmissions

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:

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

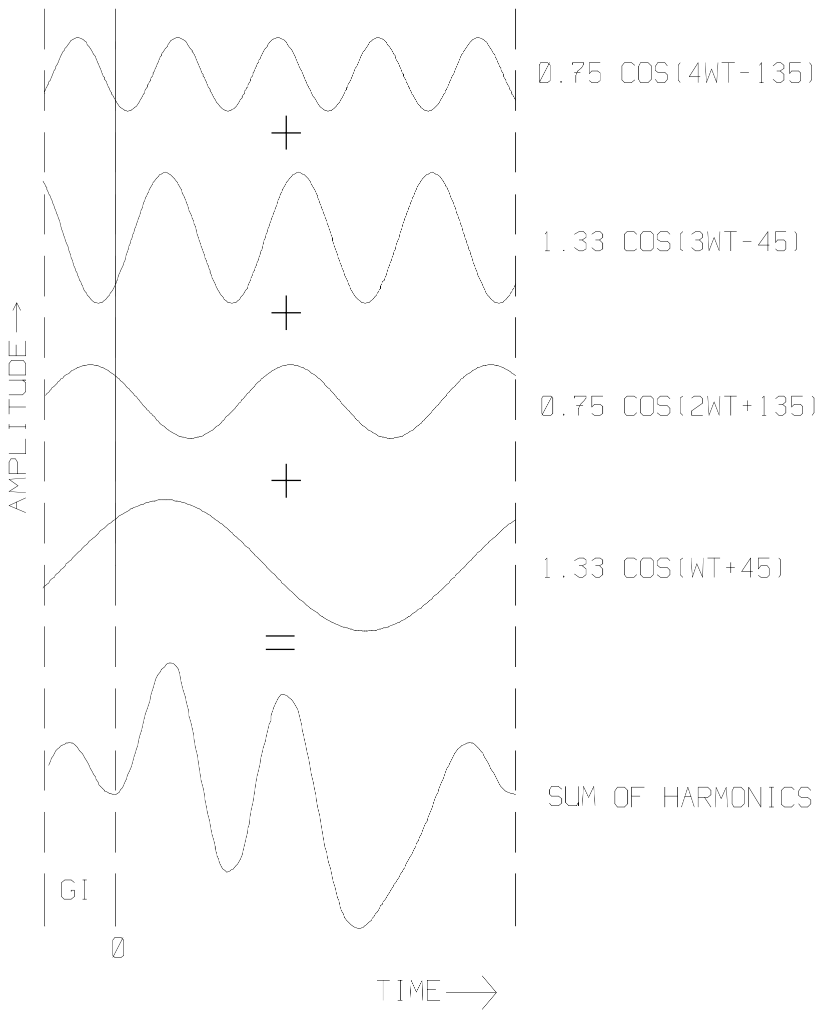
Ways to Implement FDRM

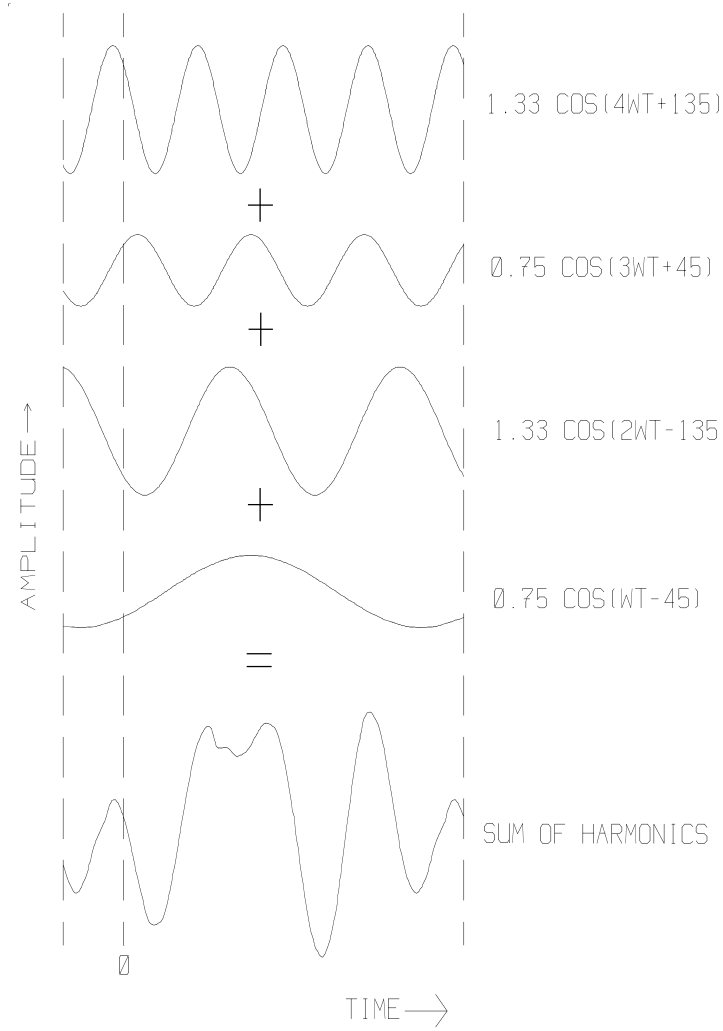
- Block formation
  - Two blocks sequential: normal block followed by a reciprocal block
  - One block interleaved: normal HCs at odd frequencies, reciprocal HCs at even frequencies
- Square Root taken at transmitter or receiver
  - Square root at receiver has a noise advantage, but correct root must be chosen

Theory of Operation - cont.

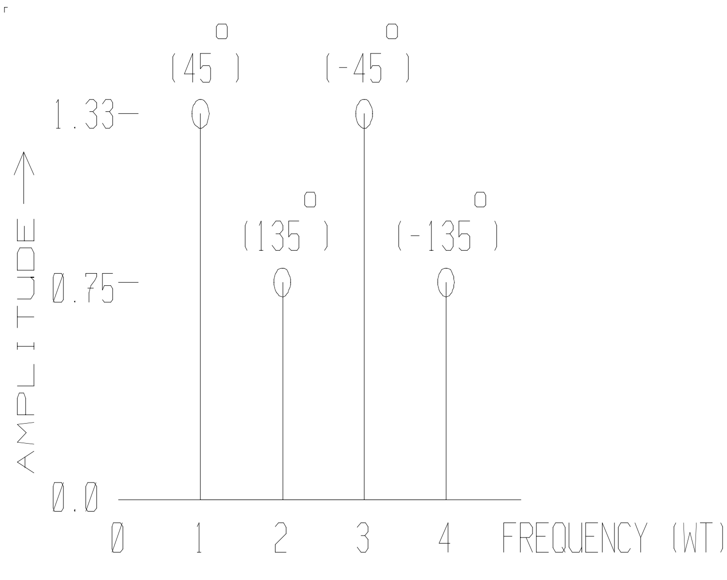
- Approximately the same linear distortion must be applied to both blocks
- If any frequencies have low magnitude components computing the frequency domain reciprocal results in large (impractical) values
- A square root has two two solutions
- Another way to implement FDRM is single block FDRM. Normal carriers and reciprocal carriers are interleaved in the same block
- Assumption for single block FDRM is that approximately the same echo afflicts adjacent carriers

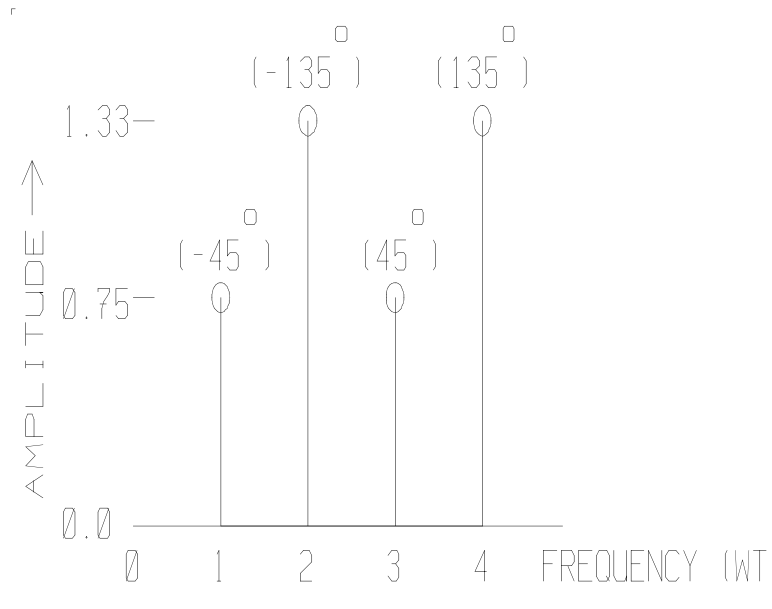
Normal Blk. Reciprocal Blk.





Normal Blk. Reciprocal Blk.





Microwave Transmission

- Impairments
  - Foliage fade
  - dynamic multipath
  - static multipath
  - co-channel interference
  - intermod products
  - random noise

Characteristics of Echoes in 2-11 GHz. Band

- Longer distances and longer delay dispersion relative to the paths assumed for Hyperlan 2
- Foliage causes high attenuation
- Foliage will get wet causing higher attenuation
- Wind will blow foliage causing rapid changes in multipath and fast attenuation changes
- Other multipath problems: tower sway, pedestrian traffic, birds, vehicle traffic, elevators moving etc.

Dynamic Multipath Distortion

- Transmitter, receiver, or reflector may move
- The characterization of the echoes H(f) must change to match the moving echo
- At microwave frequencies change is very quick
- Rapid signal fades also occur
- Sometimes no direct signal path is available (Rayleigh fading), so received signal is all echoes
- Sometimes direct signal path is available but is contaminated with echoes (Ricean fading)

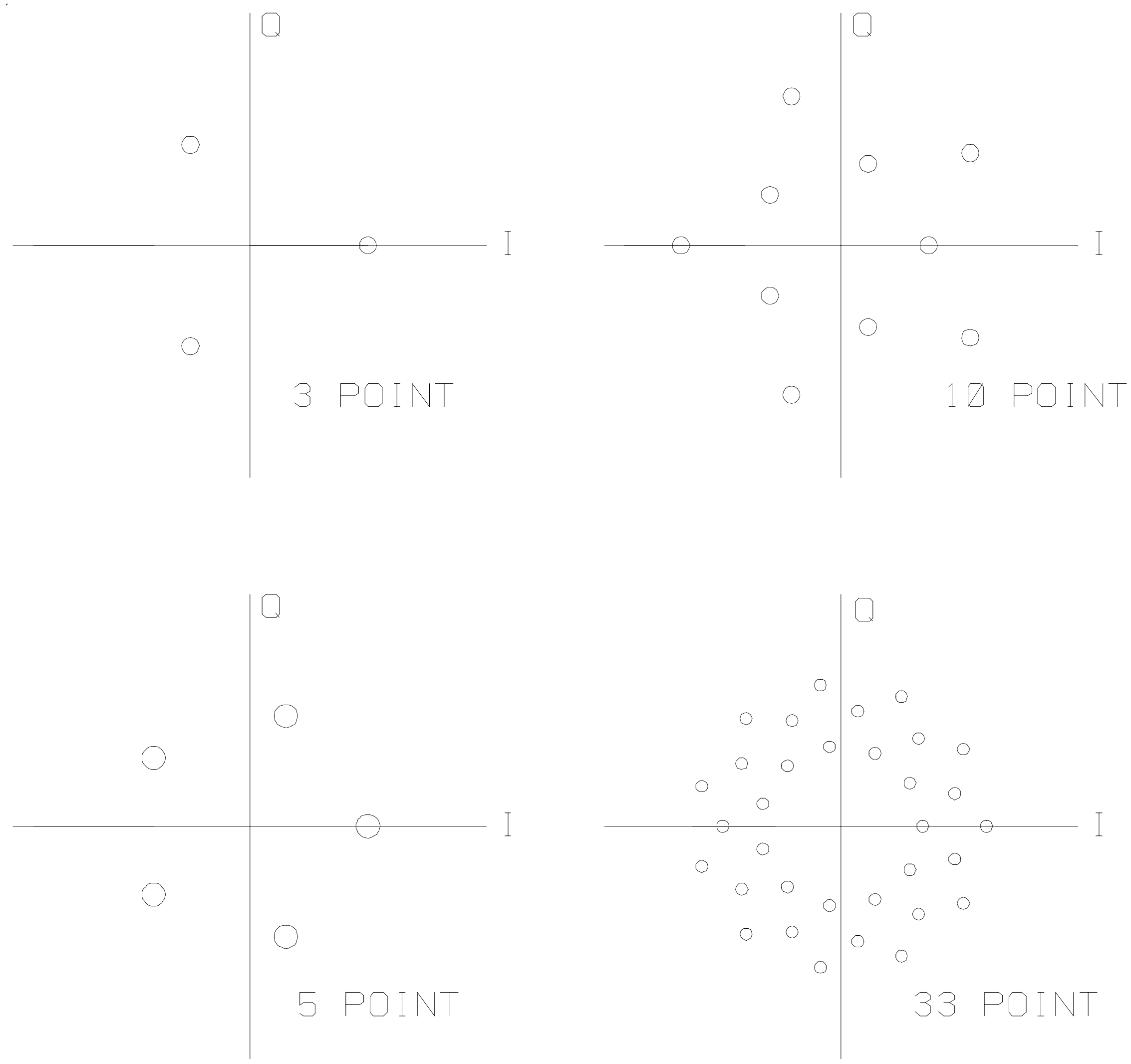
Holtzman's Proposal

- Basically Hyperlan 2 modified for:
  - Longer guard intervals
  - Longer blocks to reduce overhead of longer guard intervals
  - Pilots replaced by normal-reciprocal HC pairs
  - Adapt number of normal-reciprocal HC pairs to the path conditions
  - Use H(f) from normal-reciprocal pairs to deghost neighboring OFDM carriers
  - Other parameters also adapted to signal path

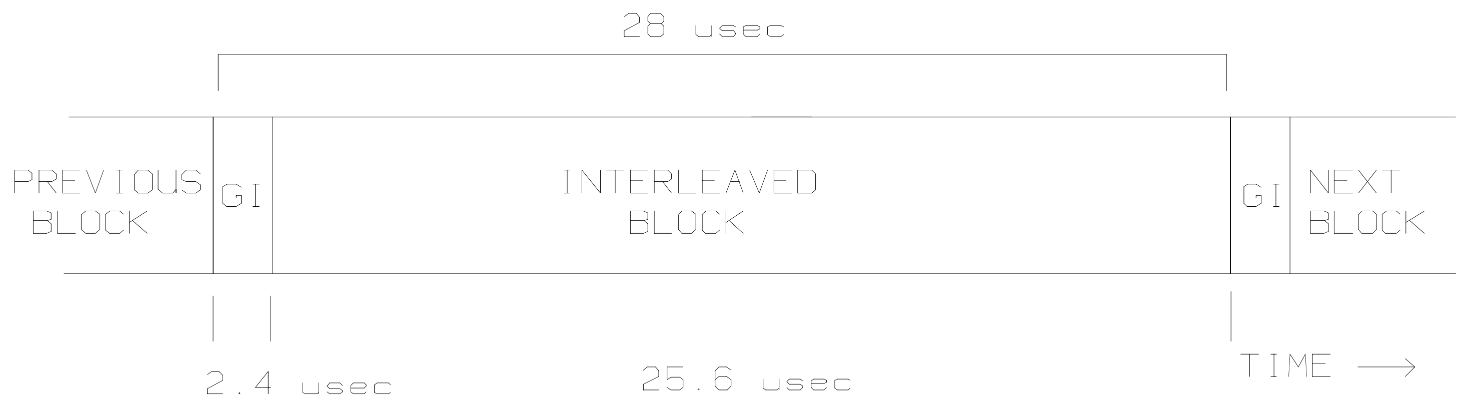
Details of Holtzman Inc. Proposal

• Sample Rate	20.0 M Samples/sec.
• Useful Block Duration	25.6 microsec. + GI
• Guard Interval (GI)	2.4 microsec.
• Total Block Duration	28 microsec.
• HC Spacing	39.0625 kHz
• Freq. Bet. Two Outside HCs	16.25 MHz
• Size of Fourier Transform	512 points
• Number of HCs	208 USB + 208 LSB

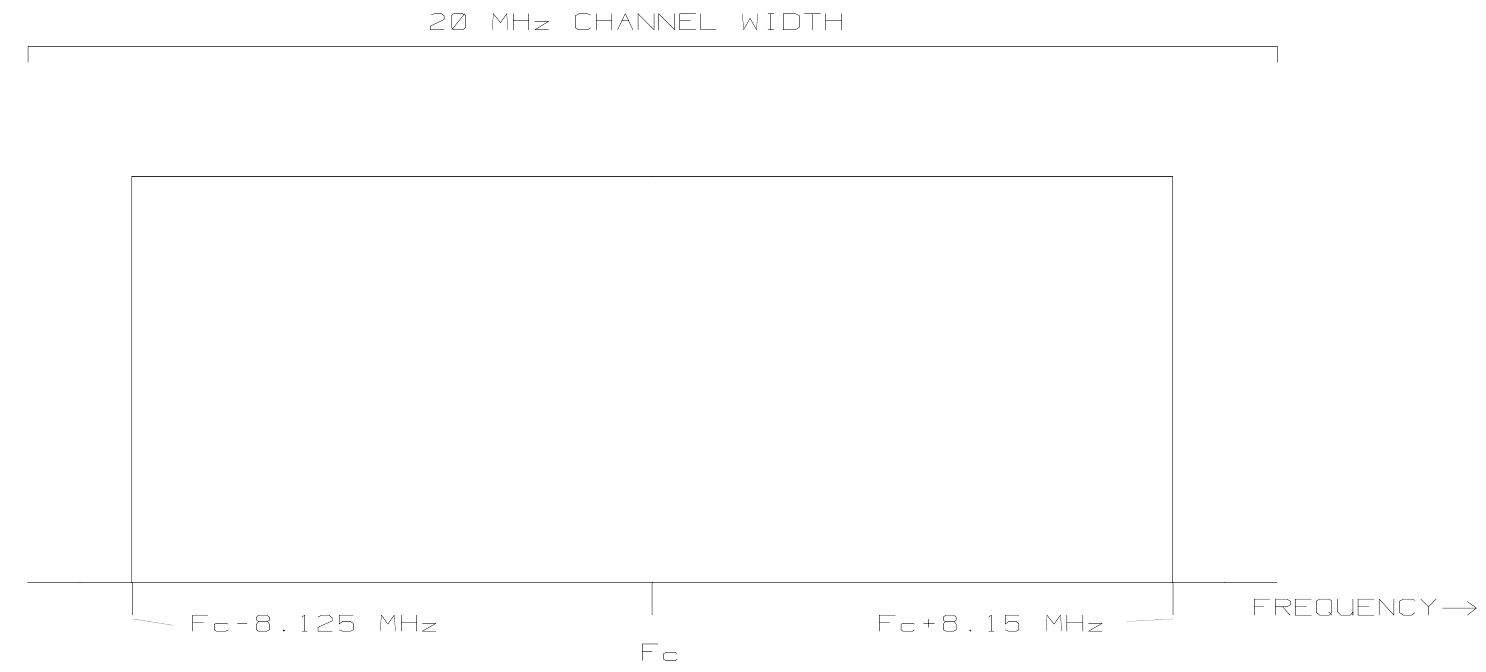
Proposed Constellations



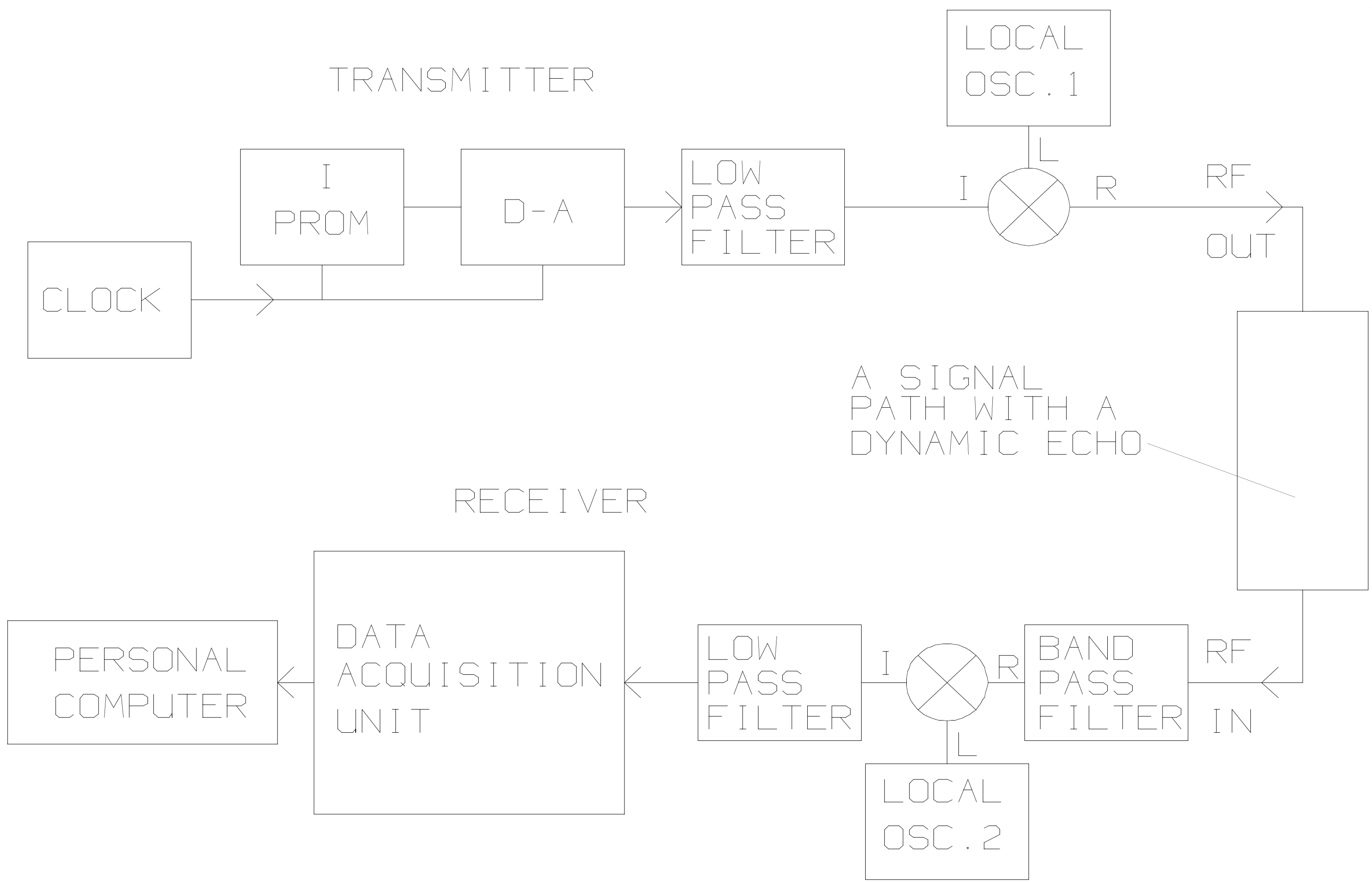
Proposed Time Plot of an Interleaved Burst



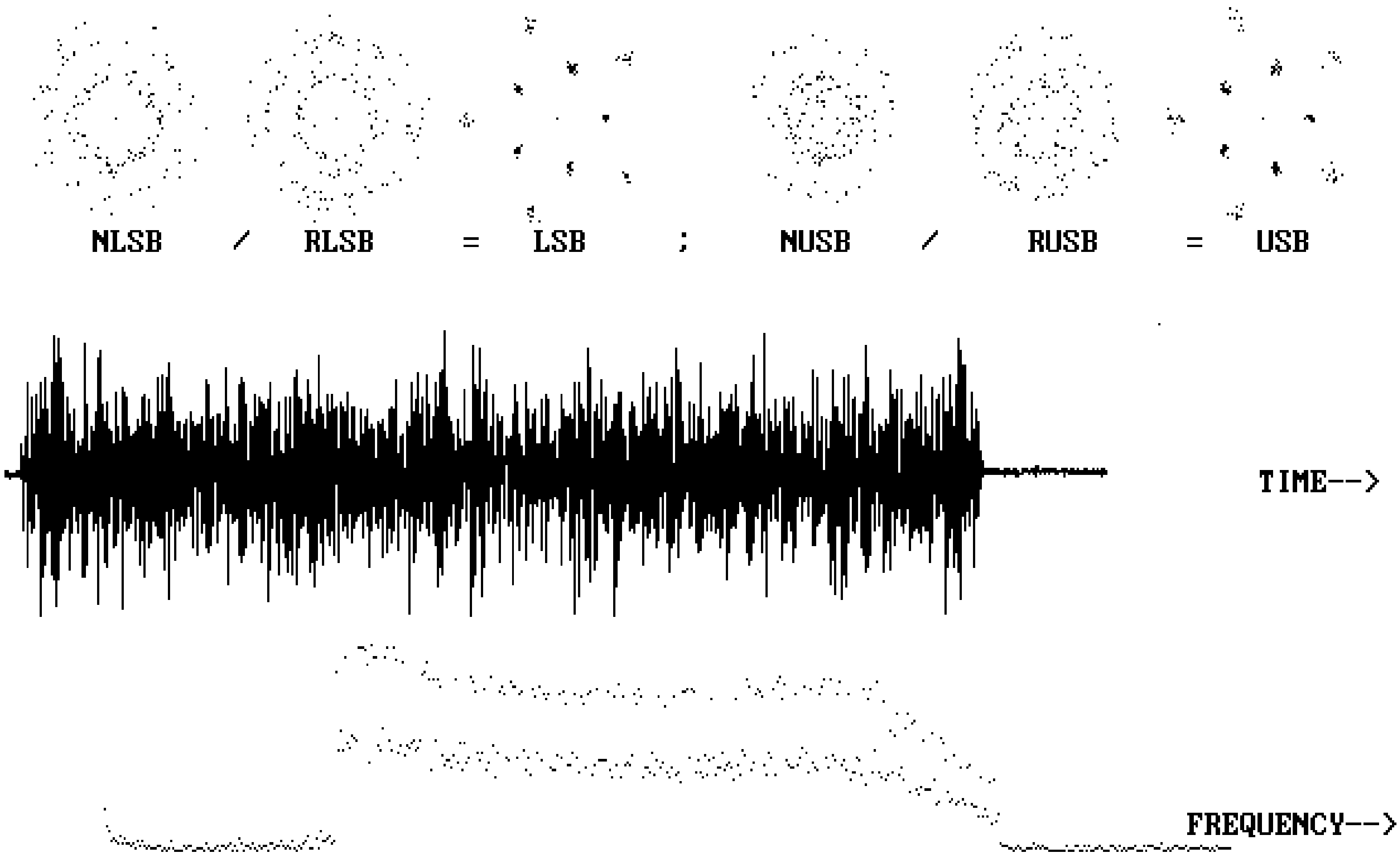
Proposed Spectral Plot



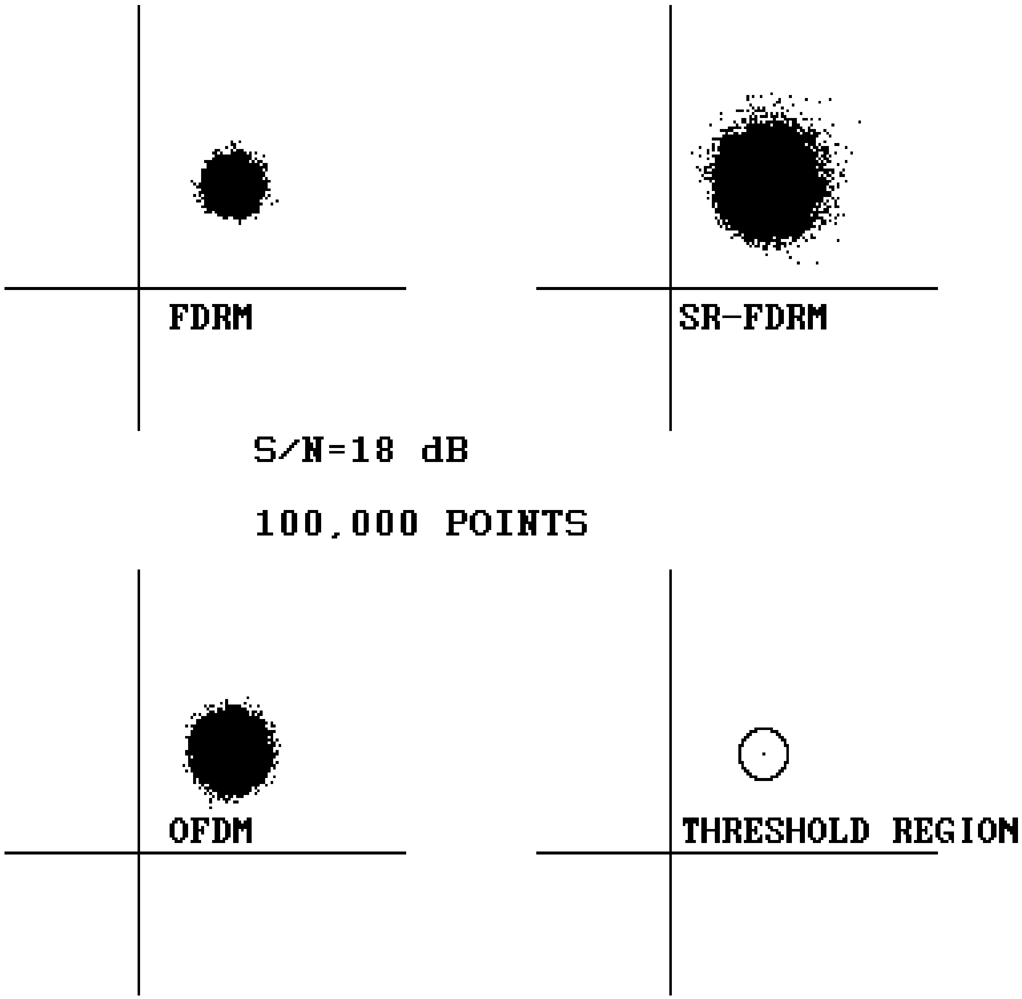
Block Diagram of Test Hardware



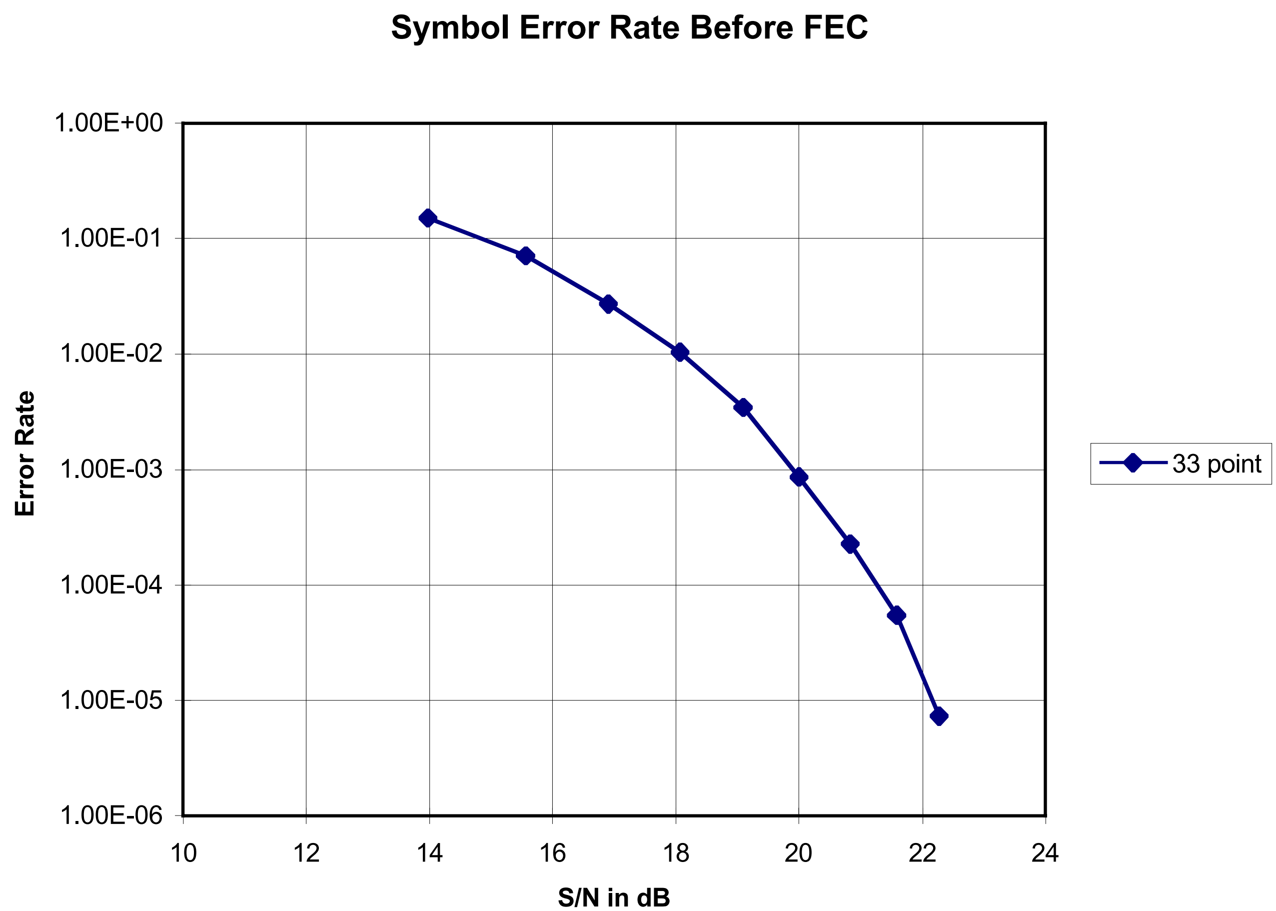
Test Results from Processing a Single Burst



Constellation Spread from Random Noise



Symbol Error Rate vs. Carrier to Noise



Antenna Diversity

- A second receive antenna is located a half wavelength further from the transmitter
- Deep fades are very unlikely to occur at the same frequencies on both antennas
- With OFDM or FDRM receiver can pick best antenna to use on a harmonic carrier by harmonic carrier basis
- With FDRM channel information, H(f), makes antenna choice easy
- Signals from 2 antennas can be vector added, using H(f), to align phases and allow optimal combining
- Coding gain on OFDM or FDRM block can be lower

Observations from Test Data

- Technique works well; easier to implement than OFDM
- Impairments from test setup corrected along with any echoes
- Forward error correction 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.
- Channel characterization, H(f), also has a 3 dB better S/N ratio
- 6 dB better than OFDM with noise on pilots
- 3 dB better than OFDM without noise on pilots

Conclusions

- FDRM = frequency domain reciprocal modulation
- Two harmonic carriers that are reciprocal to each other in the frequency domain are sent at adjacent frequencies in a single block
- The same echoes contaminate both HCs. The HCs are processed together at the receiver
- Linear distortion is automatically canceled as an intrinsic property of the modulation

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Patents Pending