Fixing Delay Variations in IBOC Audio

And IBOC Measurement Methods

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Topics for Discussion

- Network Problems
- Audio delay stability
- Digital audio dropouts
- IBOC sampling rate stability
- RF carrier frequency stability
- Computer quality clocks vs. radio quality clocks

How the Problem Shows Up

- You set your audio delay accurately
- The network glitches
- Your audio delay changes
- Go to step 1 and repeat

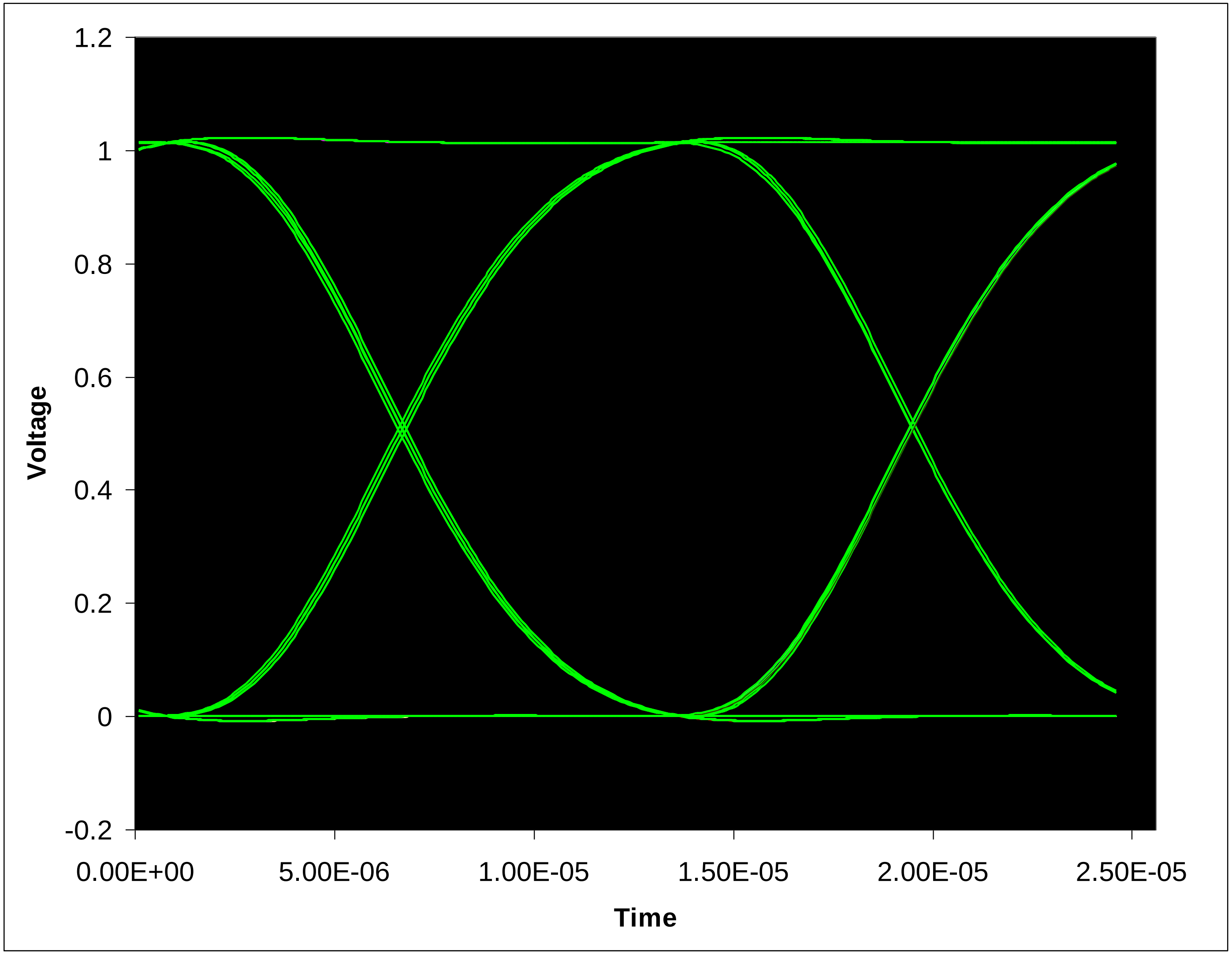
Effects of Network Problems

- **Slight Latency Variation of Network or STL**
  - Causes delay to move around and recover
  - Creates wobble in IBOC clock
  - Stream locking creates wobble in 10 MHz clock
- **Large Latency Variation of Network or STL**
  - Causes underflow/overflow of Exgine
  - Receiver dropouts
  - Delay changes and may not recover
  - Causes wobble in IBOC clock
  - Stream locking creates wobble in 10 MHz clock
- **Dropped, Corrupted, or Missed Packets**
  - Receiver dropouts
  - Delay changes and may not recover

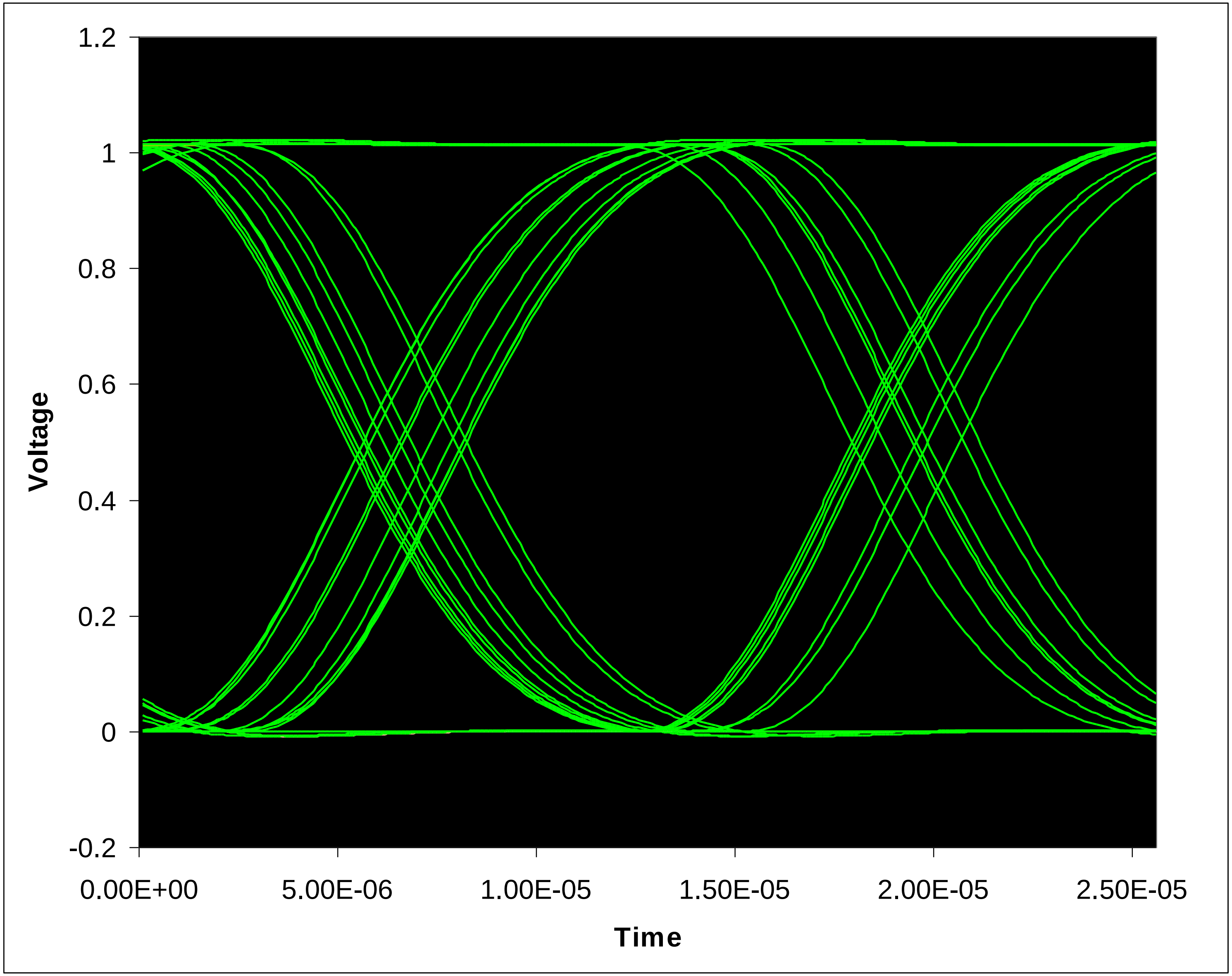
How to Mitigate Network Problems

- **GPS Locking**
  - Most bulletproof but requires GPS at studio and transmitter
- **Better Stream Locking**
  - PLL/FIFO system to buffer exgine input
- **Asynchronous Resampling Technology**
  - Gets rid of “computer quality” clocks in RF systems

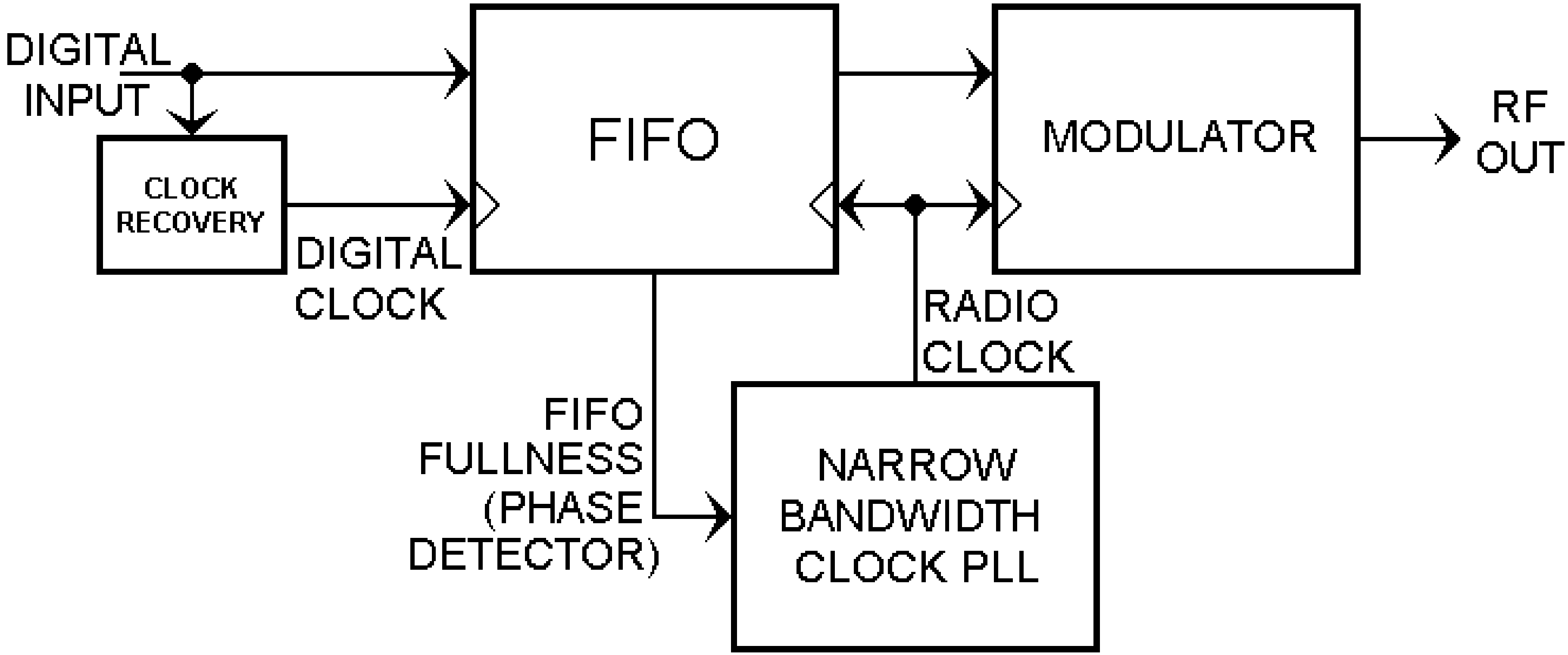
RADIO QUALITY DATA SIGNAL



COMPUTER QUALITY DATA SIGNAL



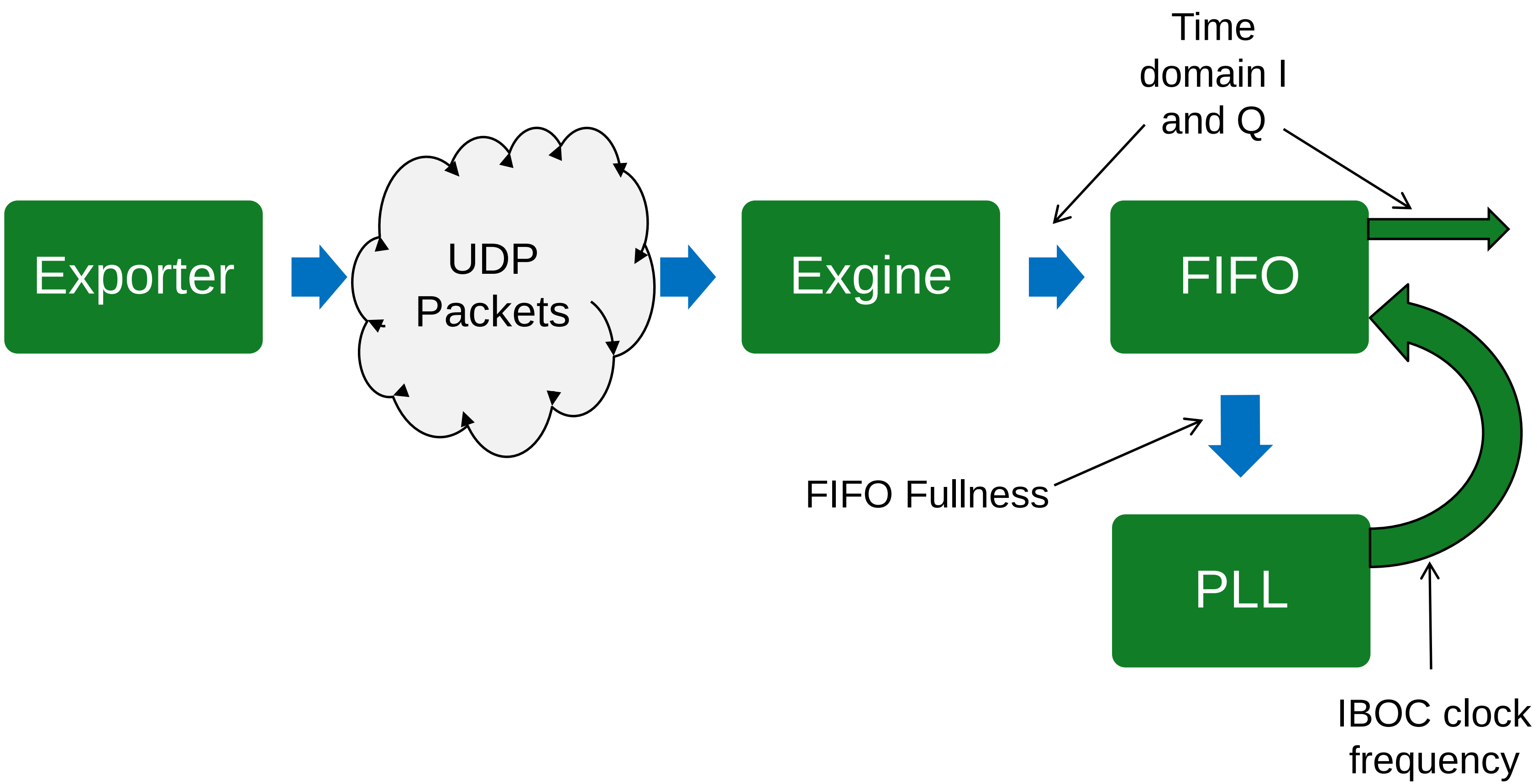
RADIO QUALITY (ALMOST?) CLOCK RECOVERY FROM DATA QUALITY SIGNAL



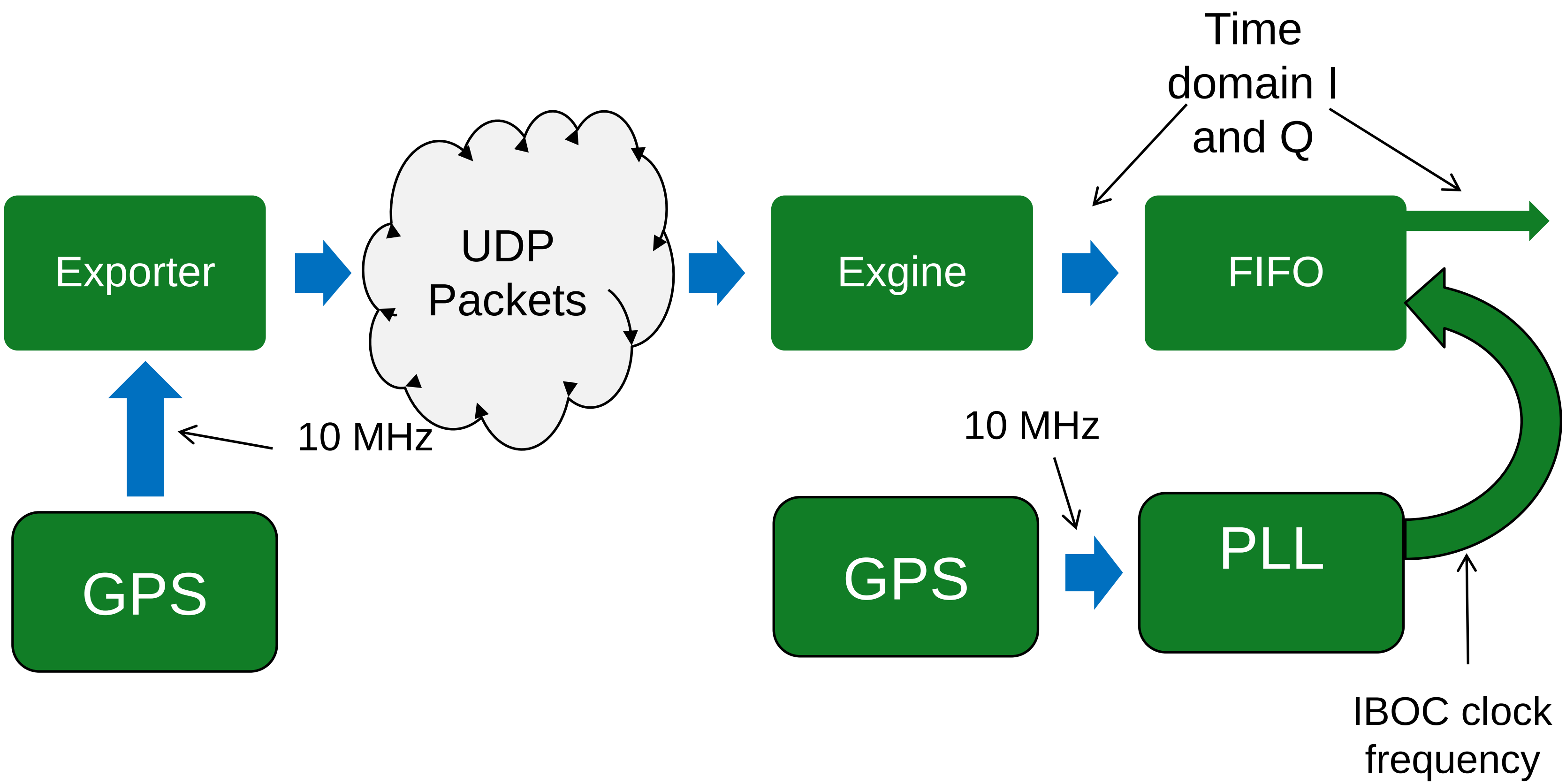
VARIABLE STL or NETWORK LATENCY

If your STL or network acts like a rubber band, there may be audio delay timing problems!

Stream Locking of IBOC Clock



GPS Locking of IBOC Clock



16 X (2160/2048) X 44.1 kHz = 744187.5 Hz = 10 MHz X 11907/160000

Stream Locking and GPS Locking

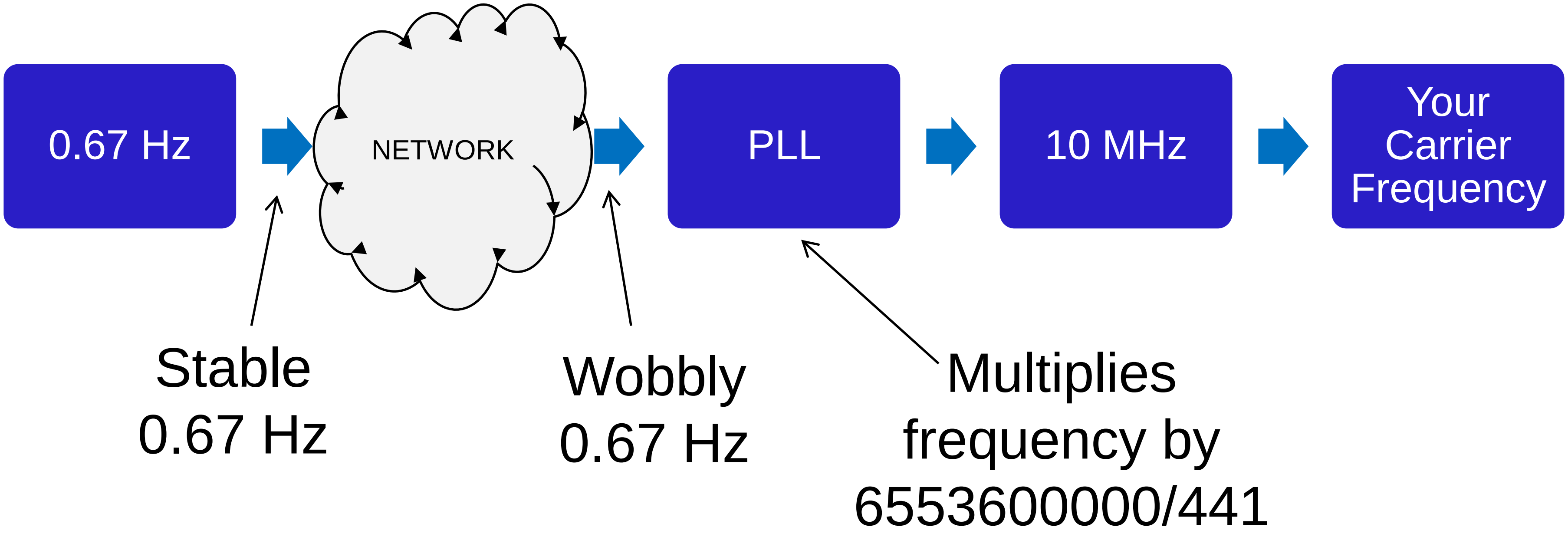
- **Concepts from ATSC Distributed Transmission**
  - Same issues, problems, and solutions exist in IBOC
- **Stream Locking**
  - Clocks are derived from incoming data stream
  - Data stream may have hiccups, dropouts, variable latency
  - Stream locked clock may have low frequency phase noise
- **GPS Locking**
  - IBOC clocks at both studio and transmitter site are GPS locked
  - Data stream latency problems may be ***ignored!***

Stream Locking PLL Speed

- **Should the Stream Locked PLL be fast or slow?**
- **Slow PLL**
  - Lower phase noise
- **Fast PLL**
  - Keeps up with latency variations
  - FIFO fullness is better controlled

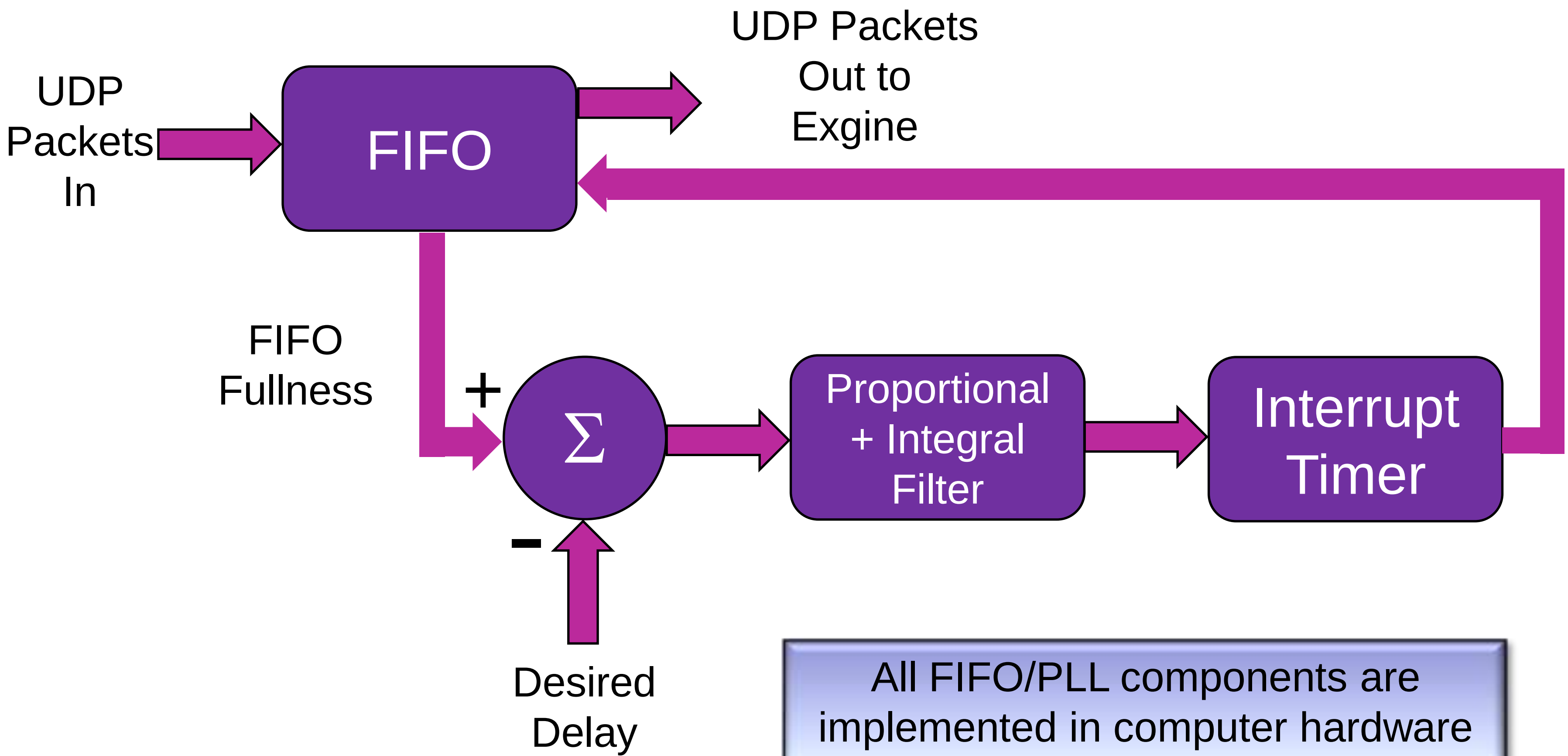
What is Wrong with this Picture?

Block rate = 744187.5 Hz/(512 × 2160)
= 44.1 kHz/65536 = 0.67291259765625 Hz
Clock packet rate is 16 times the block rate or 10.7666015625 Hz



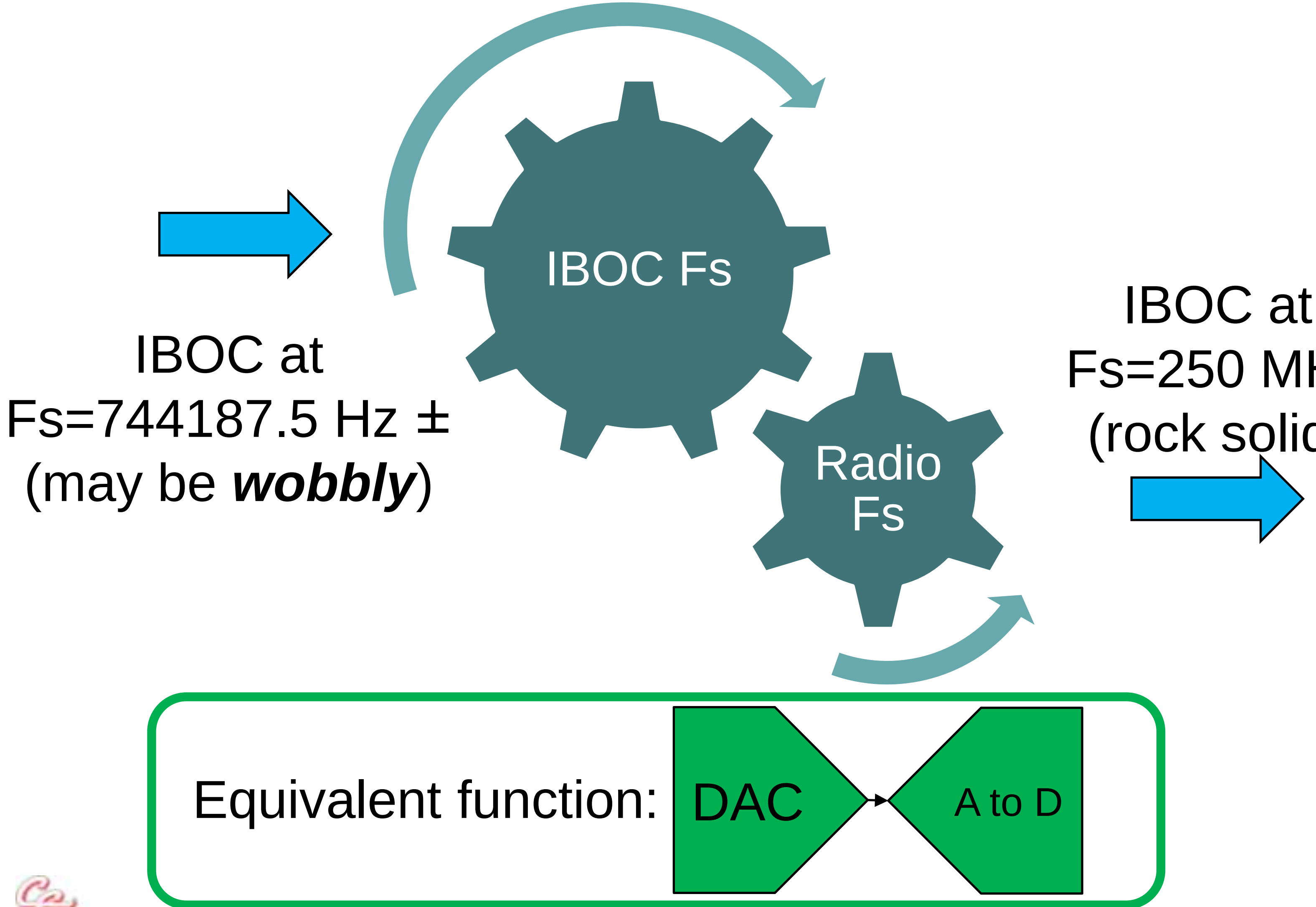
Capacitors Large Enough for PLL

Packet Buffering FIFO/PLL System



All FIFO/PLL components are implemented in computer hardware and software except for the interrupt timer, which is hardware.

Asynchronous Resampling ("gearbox")



Gearbox Summary

- **Unlinks radio quality clocks from computer clocks**
  - RF carrier stability independent of computer clock
  - No computer clock phase noise gets on the air
  - Digital waveform jitter may end up on the air, but only very low frequency jitter within PLL bandwidths. Only the digital signal is affected.
- **Does not correct for audio delay variations**

FAULT BEHAVIOR	Small Latency Δ	Large Latency Δ	Dropped Packet
Standard System	1. Timing wanders, recovers 2. IBOC clock wanders, recovers 3. RF clock wanders, recovers	1. Receivers unlock 2. Timing jumps, does not recover 3. IBOC clock wanders 4. RF clock wanders	1. Receivers unlock 2. Timing jumps, does not recover 3. IBOC clock wanders 4. RF clock wanders
With PLL/FIFO Buffer	Same as above but greatly reduced wander	1. Frequencies wander slightly 2. No receiver unlock, no timing jumps	1. Receivers unlock 2. Reduced frequency wander 3. Timing recovers to correct value
With Gearbox	Same as above but RF clock does not move at all	Same as above but RF clock does not move at all	Same as above but RF clock does not move at all

CONCLUSIONS

- **IBOC PACKET PLL/FIFO SYSTEM PROVIDES BUFFERING FOR EXGINE. DELAY REMAINS CONSTANT AND SELF CORRECTS AFTER INTERRUPTIONS.**
  - Works with any source – no special coding required
  - Typically about one second of buffering is adequate
- **ASYNCHRONOUS RESAMPLING SYSTEM KEEPS RADIO CLOCKS PURE. NO COMPUTER CLOCK JITTER GETS ON THE AIR.**
- **GPS LOCKING IMPROVES PERFORMANCE**

Bonus Topic: NRSC MER Measurement

- **NRSC is writing NRSC-G201 guideline, will include reference to MER measurement techniques**
- Ibiquity Document: **SY_TN_2646s - Transmission Signal Quality Metrics for FM IBOC Signals**
- **MER is Modulation Error Ratio**
  - Measures noise and distortion in demodulated OFDM carriers
  - A measurement of signal quality from the receiver's perspective
- **Requires demodulation of OFDM carriers**
- **MER may produce constellation displays as a byproduct**
  - Constellation displays can be more meaningful than a number or a vector

Demodulating OFDM

1. Demodulate to I and Q
2. Filter out analog FM
3. Autocorrelate to find framing
4. Find and correct frequency error
5. Correct for Pulse Shaping Function

Demodulating OFDM - Continued

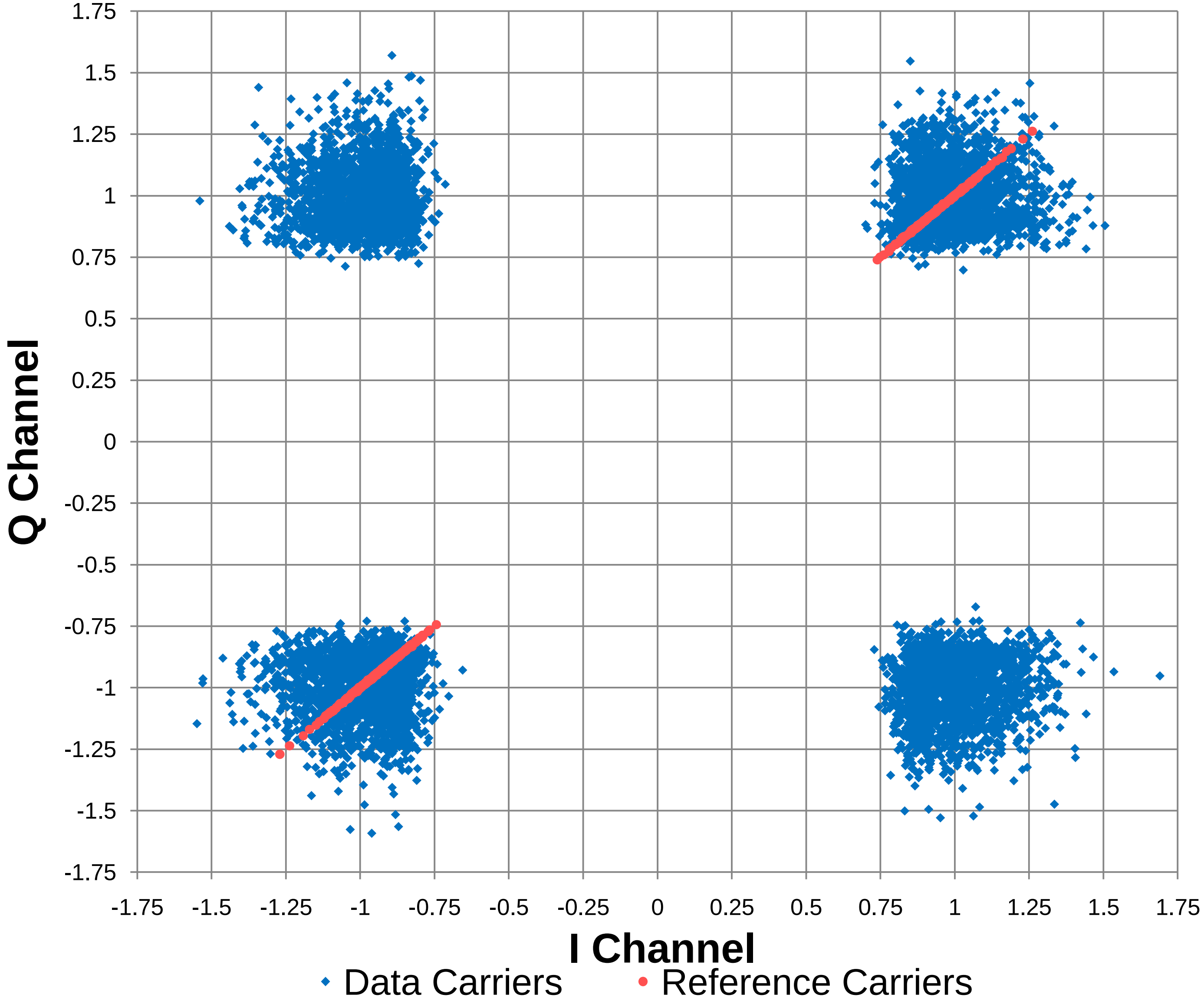
Perform FFT

Use reference carriers to find phase slope and align phases

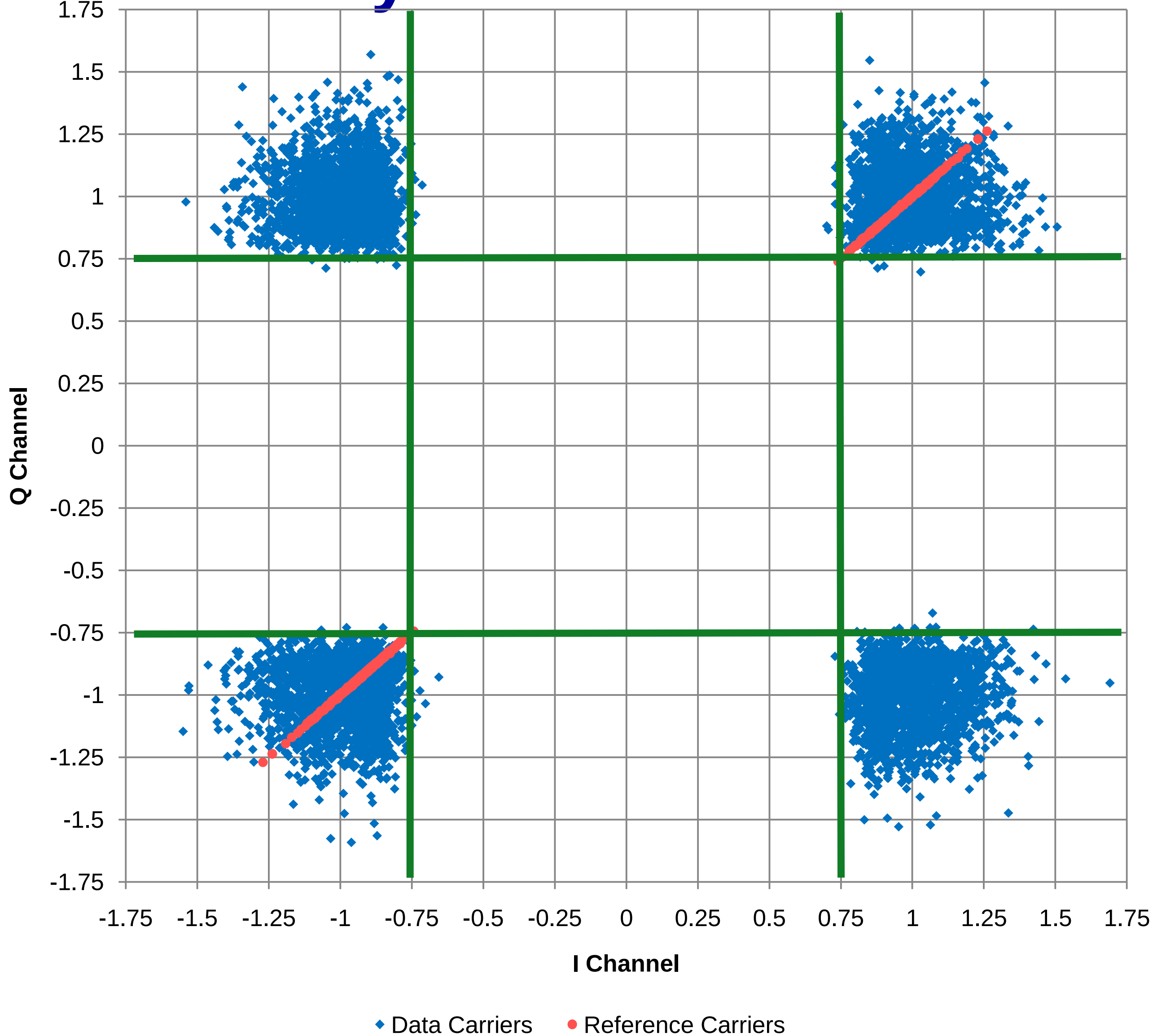
Apply linear equalization from reference carriers to data carriers

Calculate MER

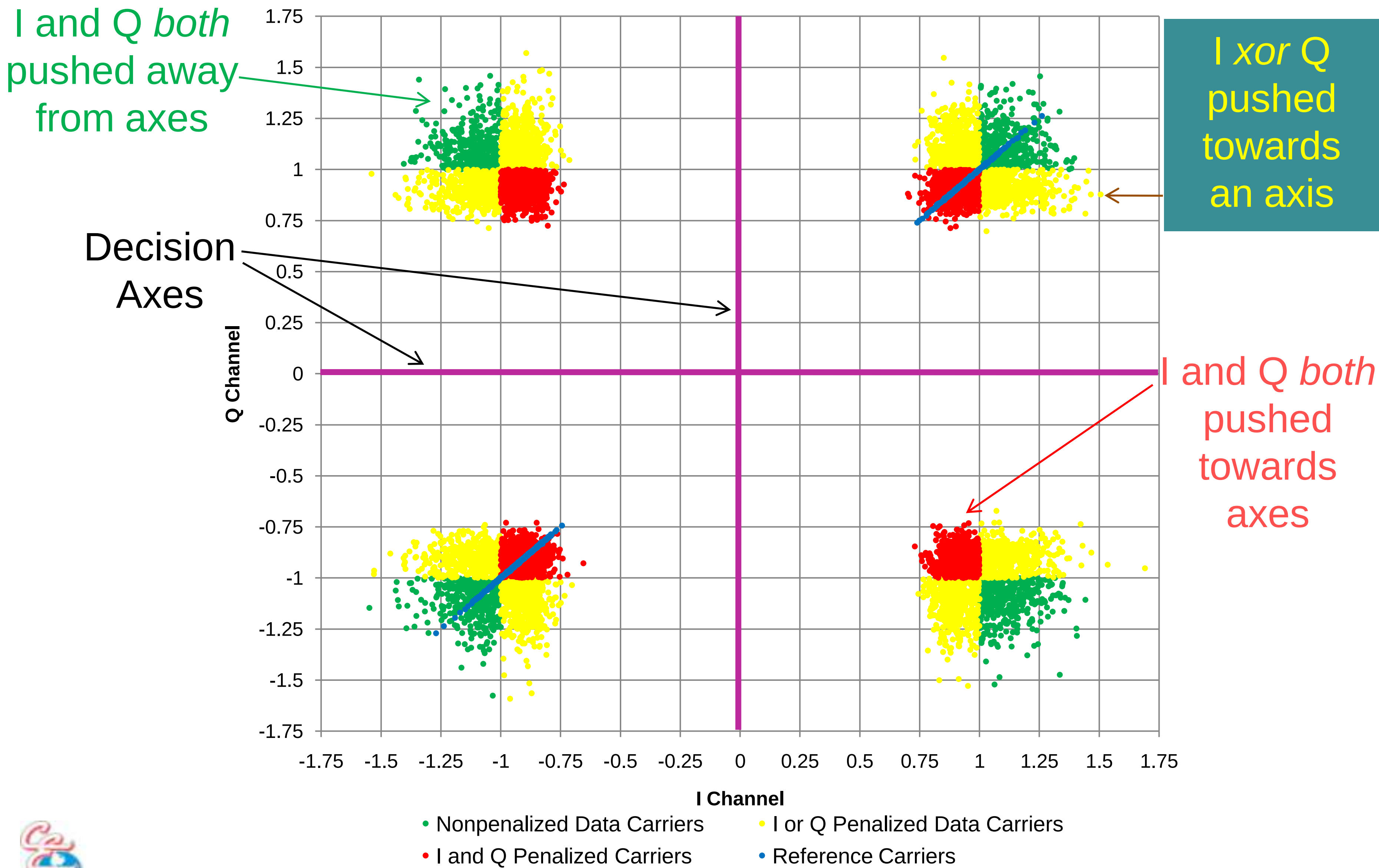
Ideal Constellation Plot



PAR reduction pushes constellation points mostly outward



Modified MER Calculation



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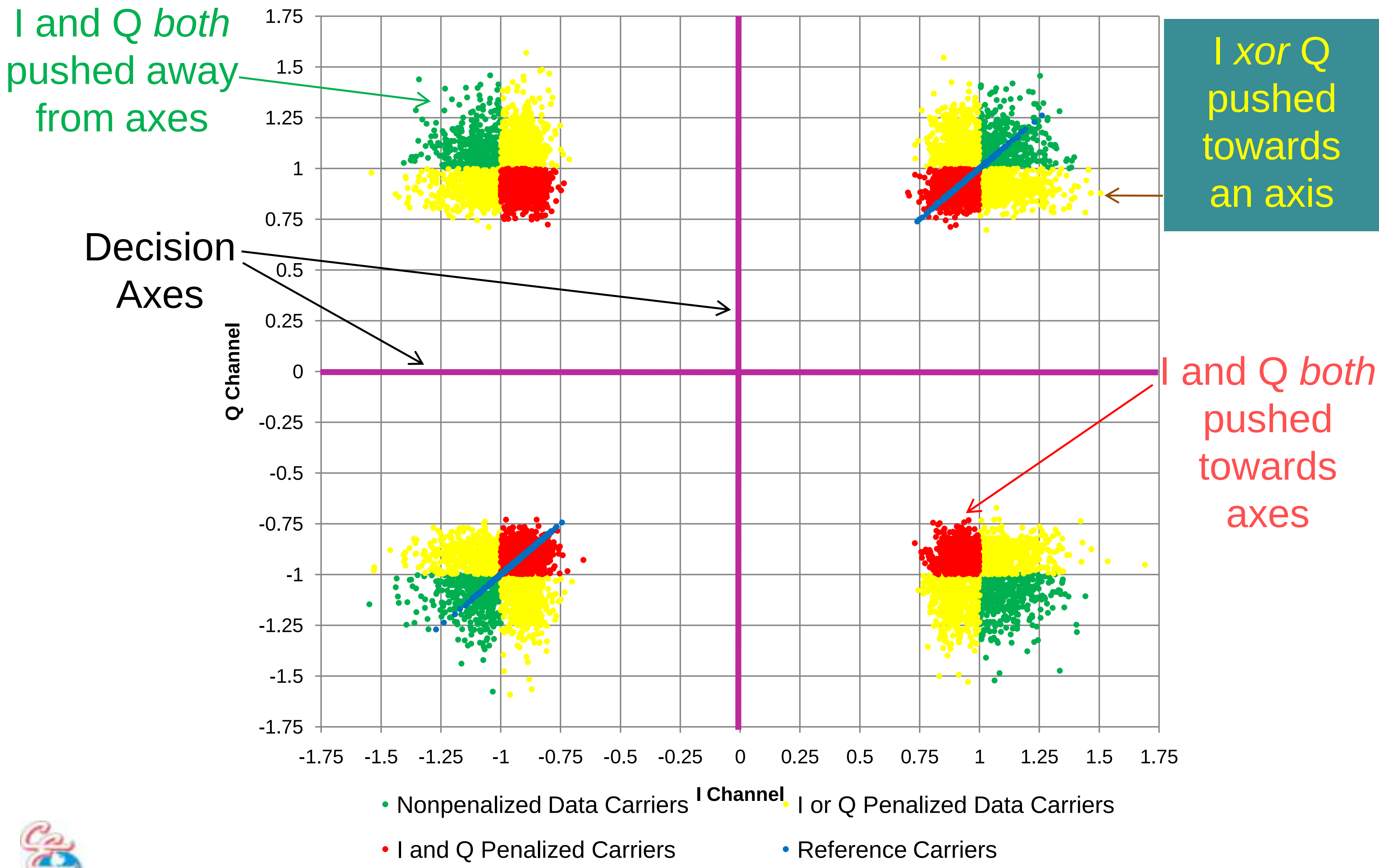
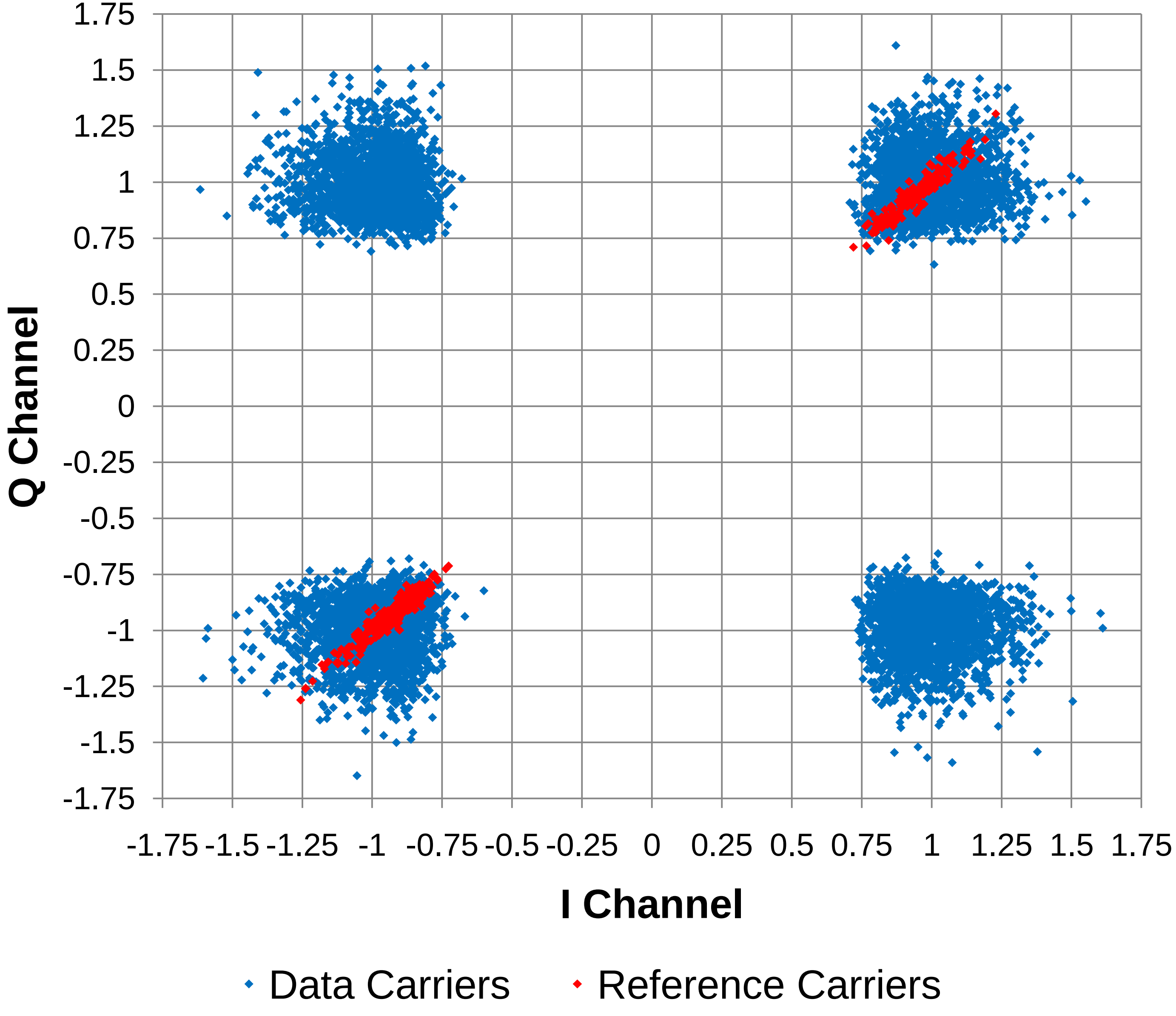
MER Measurement & PAR Noise

- **General MER measurement is the dB expression of the ratio of the signal power divided by the vector error power**
- **PAR reduction noise would dominate any transmitter induced noise**
- **PAR reduction noise may be reduced by:**
  - Measuring the MER of just the reference carriers
  - Considering only the noise vectors which move constellation points inward, towards the decision axes

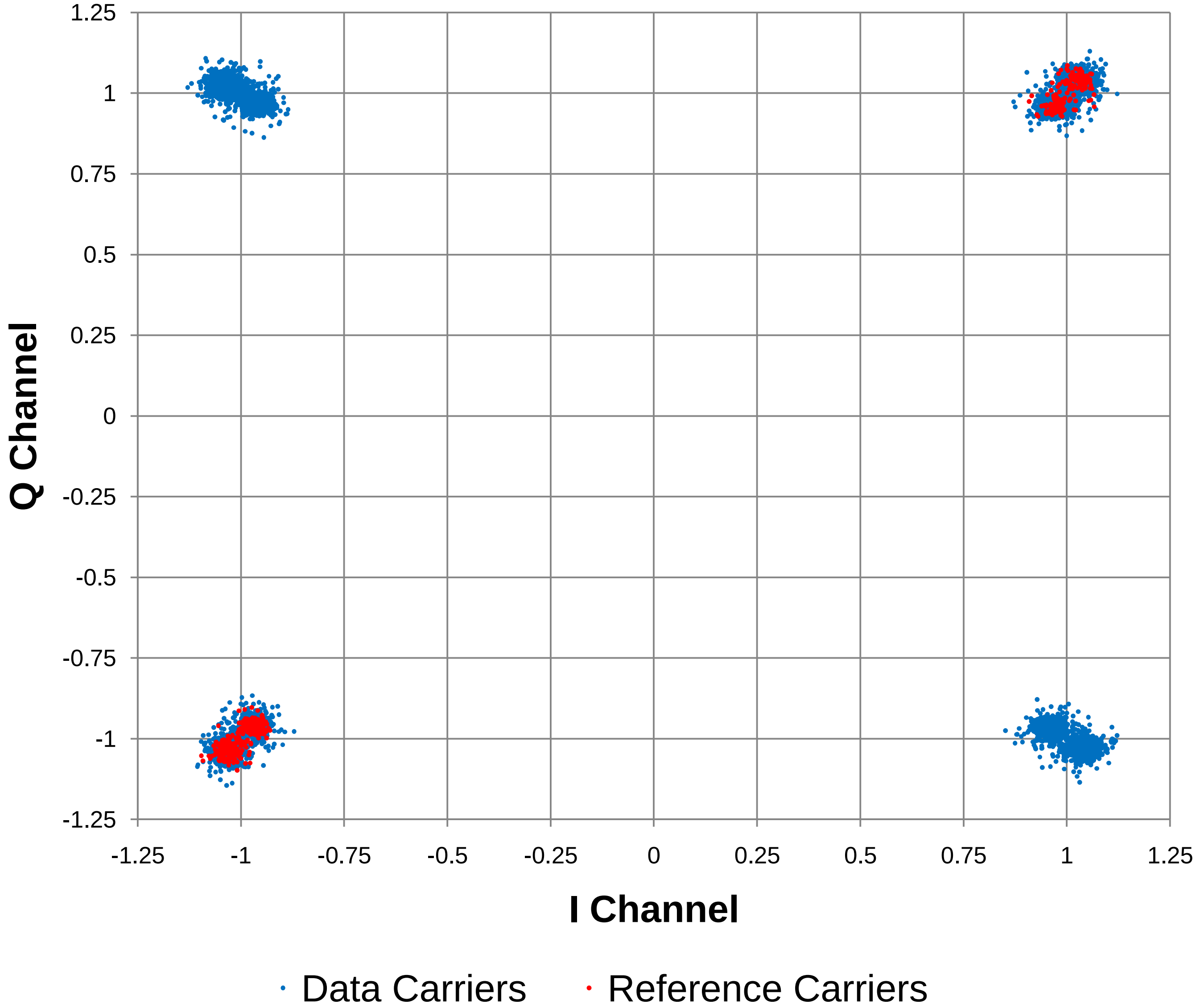
Modified MER Calculation



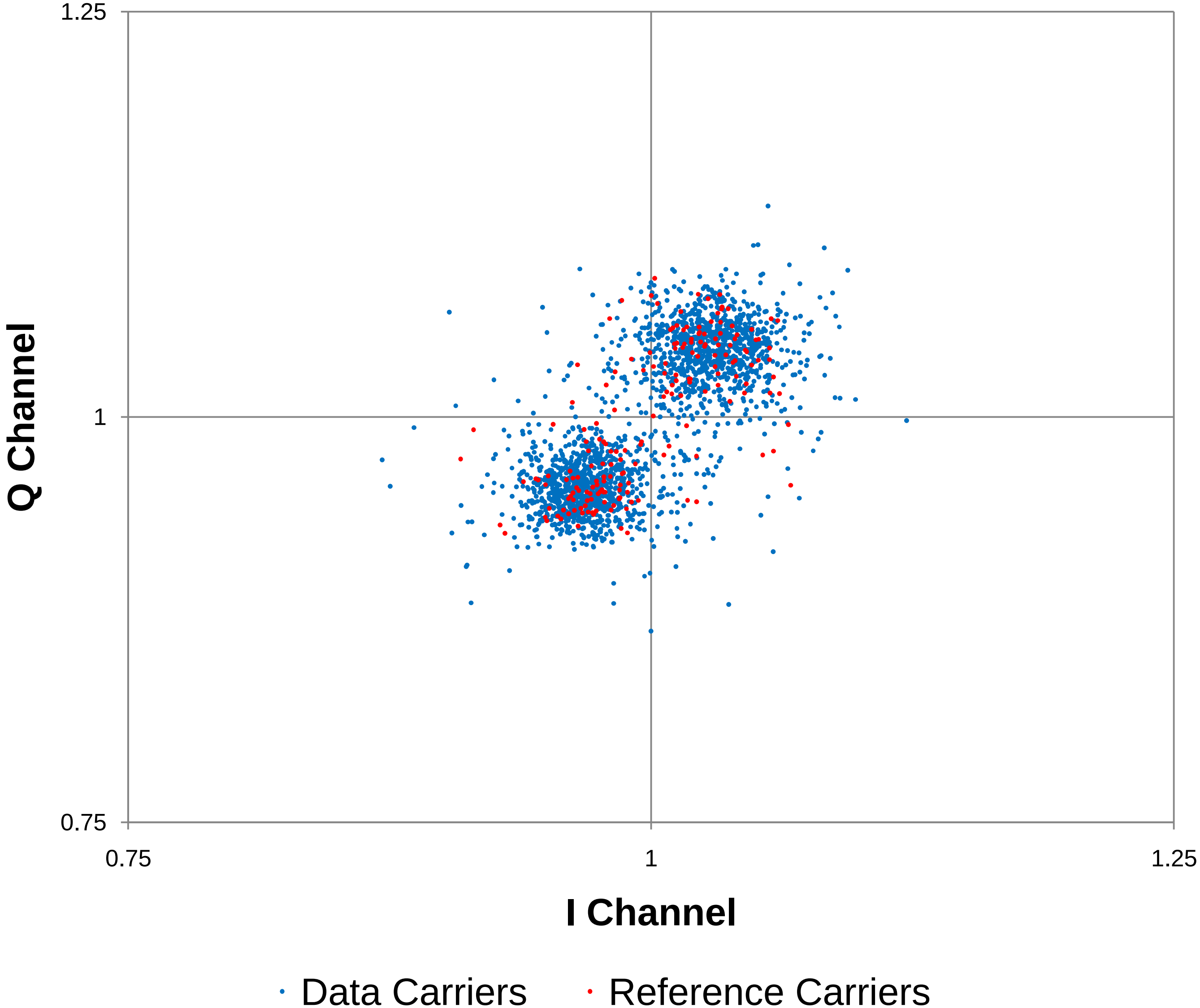
Demodulated Constellation Plot



Relative Constellation Plot



Relative Constellation Plot – Zoomed In



Textbook Definition of MER

$$MER(k) = 10\log \frac{\sum_{1}^{N}(I_j^{\,2} + Q_j^{\,2})}{\sum_{1}^{N}(\Delta I_j^{\,2} + \Delta Q_j^{\,2})} dB$$

N is the number of symbols

I_j and Q_j are the I and Q values for symbol j

ΔI_j and ΔQ_j are the I and Q vector errors for symbol j

k is the carrier number

MER Measurement Types

- **CARRIERS MEASURED**
  - All carriers
  - Reference carriers only
  - Data carriers only
- **VECTOR OR SCALAR**
  - A single number or MER as a function of frequency
- **ABSOLUTE OR RELATIVE**
  - With or without PAR reduction noise subtracted out
- **IDEAL OR TRANSMITTER OUTPUT**
  - The exgine signal or the transmitter output
- **EQUALIZED OR UNEQUALIZED**
  - With or without linear distortions
- **TEXTBOOK OR NRSC MODE**
  - All error vectors or just those that push constellation points towards decision axes

NRSC Recommended MER Measurements

- **REFERENCE CARRIERS ONLY**
  - Vector and scalar
  - Averaged over 512 symbols
  - Linear equalization applied
- **DATA CARRIERS ONLY**
  - Vector
  - Averaged over 512 symbols
  - Linear equalization applied
  - Modified measurement, outward displaced constellation points incur no penalty. Only constellation points that move toward decision axes contribute to noise power.

CONCLUSIONS

- **OFDM demodulation provides new analysis techniques**
  - Constellation displays
  - Modulation Error Ratio (MER) measurements
- **NRSC has developed recommendations for MER measurement methods**
  - Reference carriers only
  - Only penalize noise that moves constellation points inward
- **MER is an excellent way of looking at signal quality from the receiver’s point of view**

Thank You!

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