Bit error distribution on a DC-coupled Backplane channel

Andre Szczepanek

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Introduction

- **In order to understand the applicability of FEC to backplane systems we need to know how errors are distributed.**
- **This presentation provides error distribution data for one example backplane channel.**
- **Equipment and silicon availability limited the test set-up to a 3.6Gbps DC coupled channel, but it is assumed that the results can be extended to 10Gbps operation.**

Test Set-up, #1 :Silicon

- **TI 4Gbps SERDES testchip with 2 independent quad bidirectional SERDES macros interconnected back-to-back by FIFOs.**
  - Macro A, Chn 0 Tx feeds Macro B Chn 0 Tx via a FIFO
    - And vice-versa for this and the other 3 bi-di SERDES
  - Each SERDES macro has its own PLL, but is fed from the same frequency reference
    - The Macros are Frequency locked, but not phase locked

- **This arrangement allows a BERT to analyse a channel independent of its own connections to the test-chip**
  - Macro A connects to the test channel, Macro B handles BERT connections
  - BERT->B8b R2->B8a T2->Test channel->B8a R2->B8b T2->BERT

- **Spare SERDES Transmitters on the "B" macro can be used as crosstalk aggressors on the channel connected to the "A" macro.**
  - The aggressor is frequency locked but not phase locked
  - Internal self-test PRBS generators can be used as aggressor data

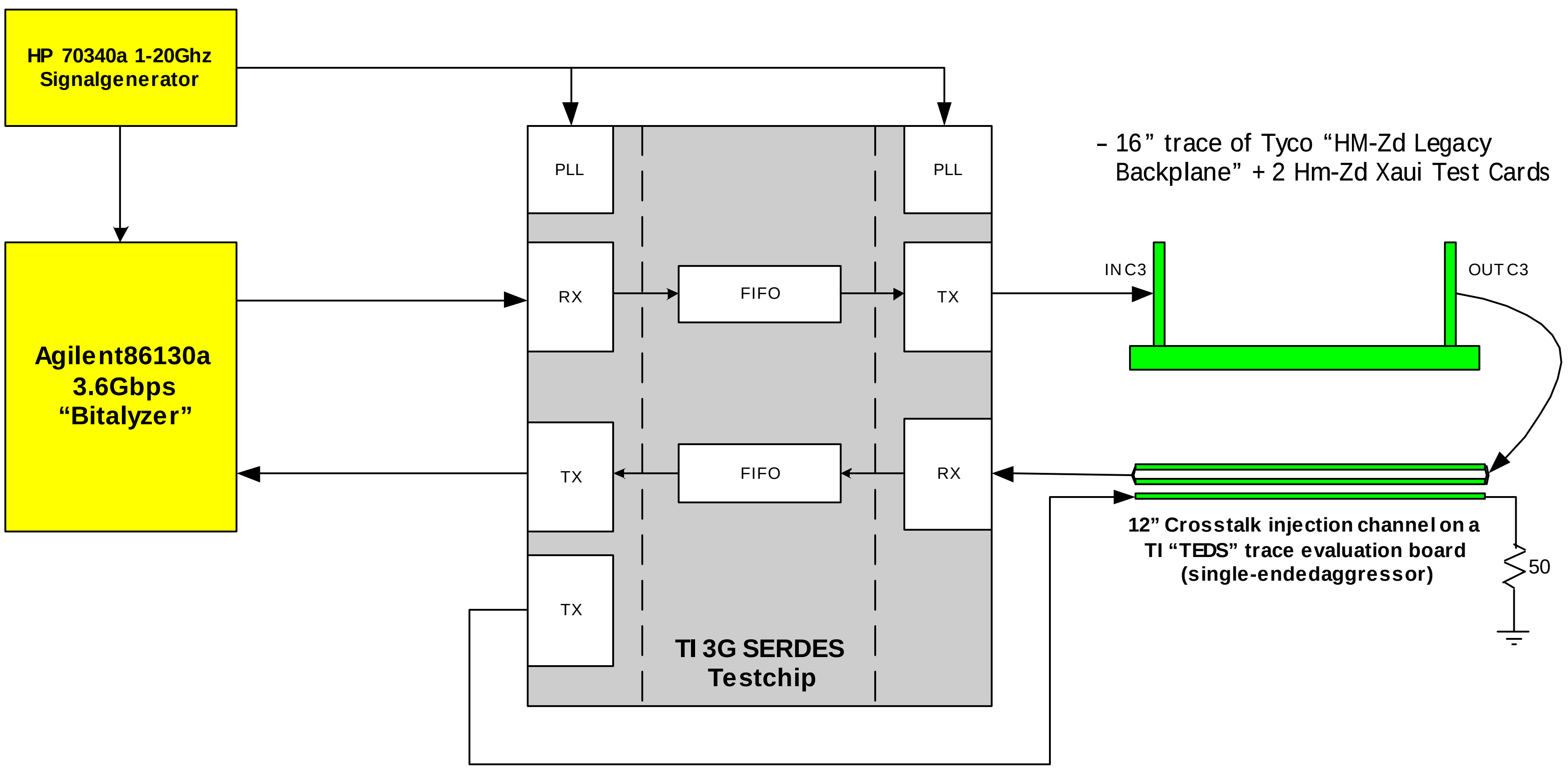
Test Set-up, #2 :Test Channel

- **Composite channel – to allow crosstalk injection**
  - 16” trace of Tyco “HM-Zd Legacy Backplane” + 2 Hm-Zd Xaui Test Cards
  - 12” Crosstalk injection channel on the TI “TEDS” trace evaluation board
    - Injection point is at Rx’er end - FEXT

Test Set-up, #3 :BERT

- **Agilent 86130a 3.6Gbps "Bitalyzer"**
  - Provides extensive bit error distribution analysis tools
    - Burst length
    - Pattern sensitivity
- **HP 70340a 1-20Ghz Signal generator**
  - Clock reference for BERT & testchip

Test Set-up, #3 :Diagram



Test Set-up, #4 :Details

- **BERT->B8b R2->B8a T2->Tyco 16”->TEDS 12”->B8a R2->B8b T2->BERT**
- **B8b T1 (2^{23}-1 PRBS aggressor) ----------^ (FEXT)**

- **BERT PRBS pattern length varied (2^7 , 2^{10} , 2^{15} , 2^{23})**
- **Crosstalk aggressor (B8b T1) transmit amplitude varied**
  - Crosstalk agressor uses 2^{23}-1 PRBS (can never be in sync with channel PRBS)
  - Crosstalk agressor uses 0% Tx pre-emphasis

- **B8a Chn2 parameters**
  - DC coupled
  - 500mV Tx amplitude
  - 61.9% Pre-emphasis
  - 3.61Gbps
- **BERT burst analysis parameters**
  - Minimum burst size : 2 bits
  - Burst error free threshold : 1584
    - Distance between 2 errors for them NOT to be regarded as a burst

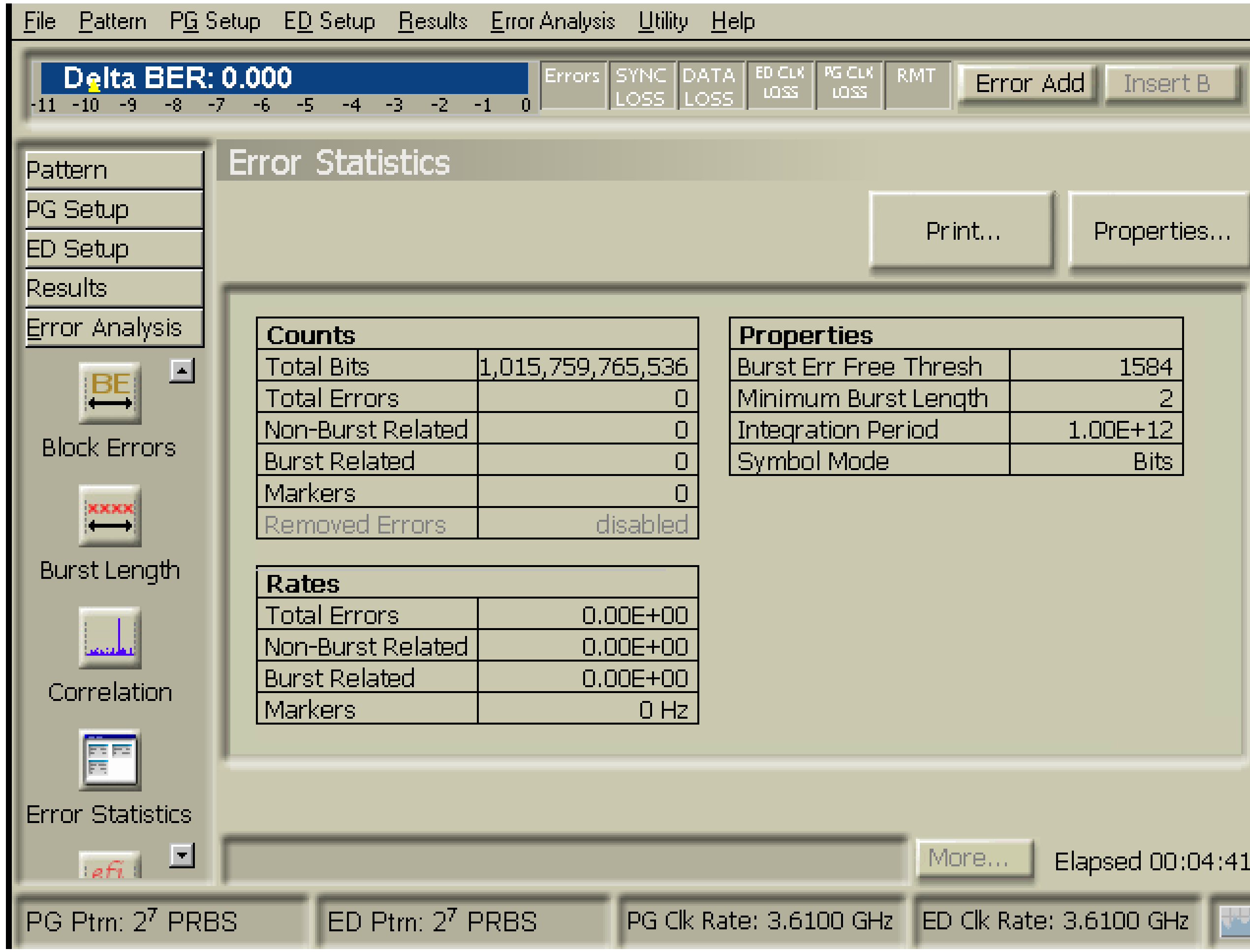
Raw Results

- BERT Screen-shots, with my comments to the left
- Increasing PRBS lengths are evaluated for a range of crosstalk amplitudes

PRBS7/1375 error statistics

- 2^7 PRBS
- 1375mV Xt

- No errors seen in this limited time period



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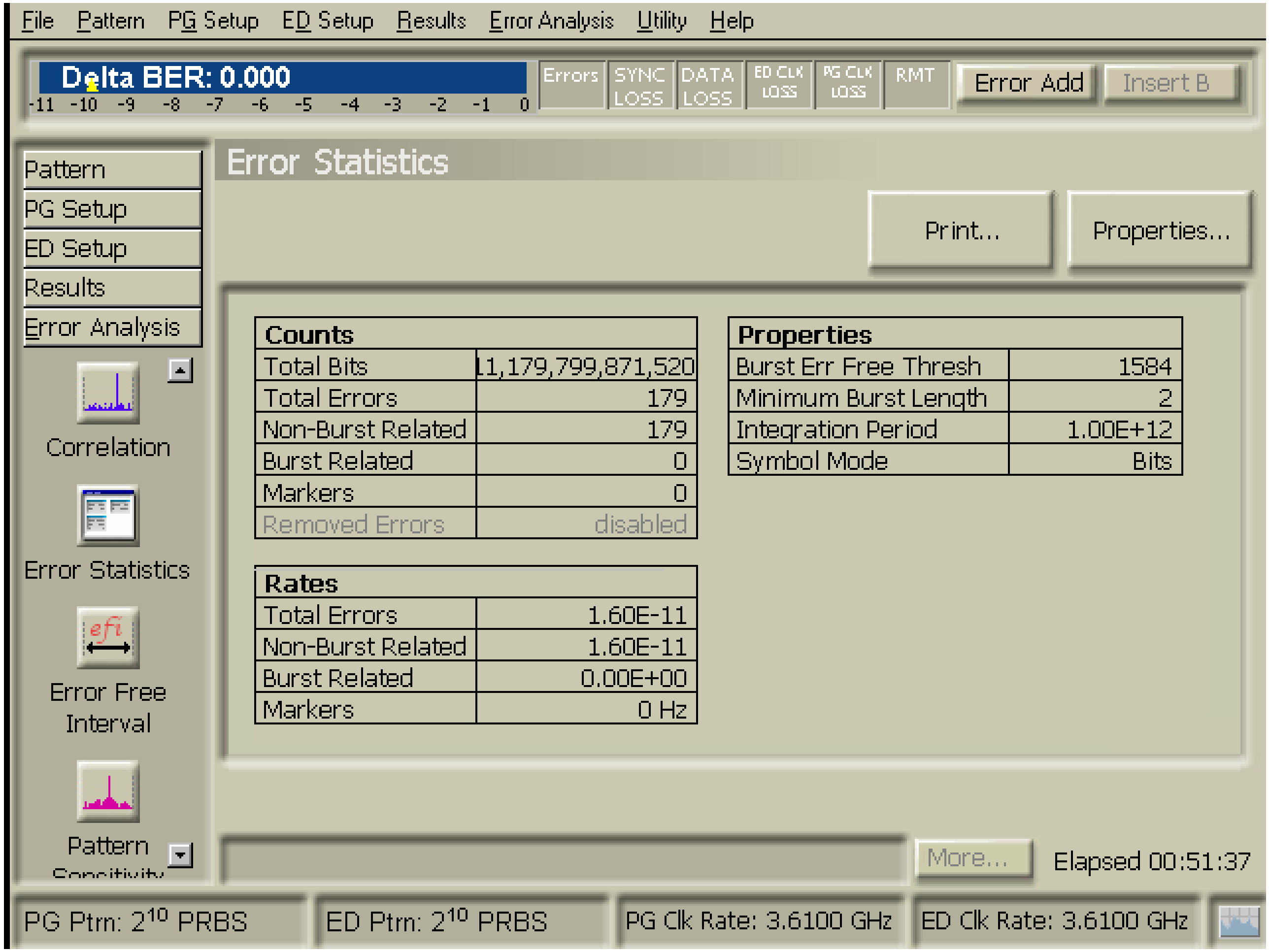
PRBS10/750 error statistics

- **2^{10} PRBS**
- **750mV Xt**

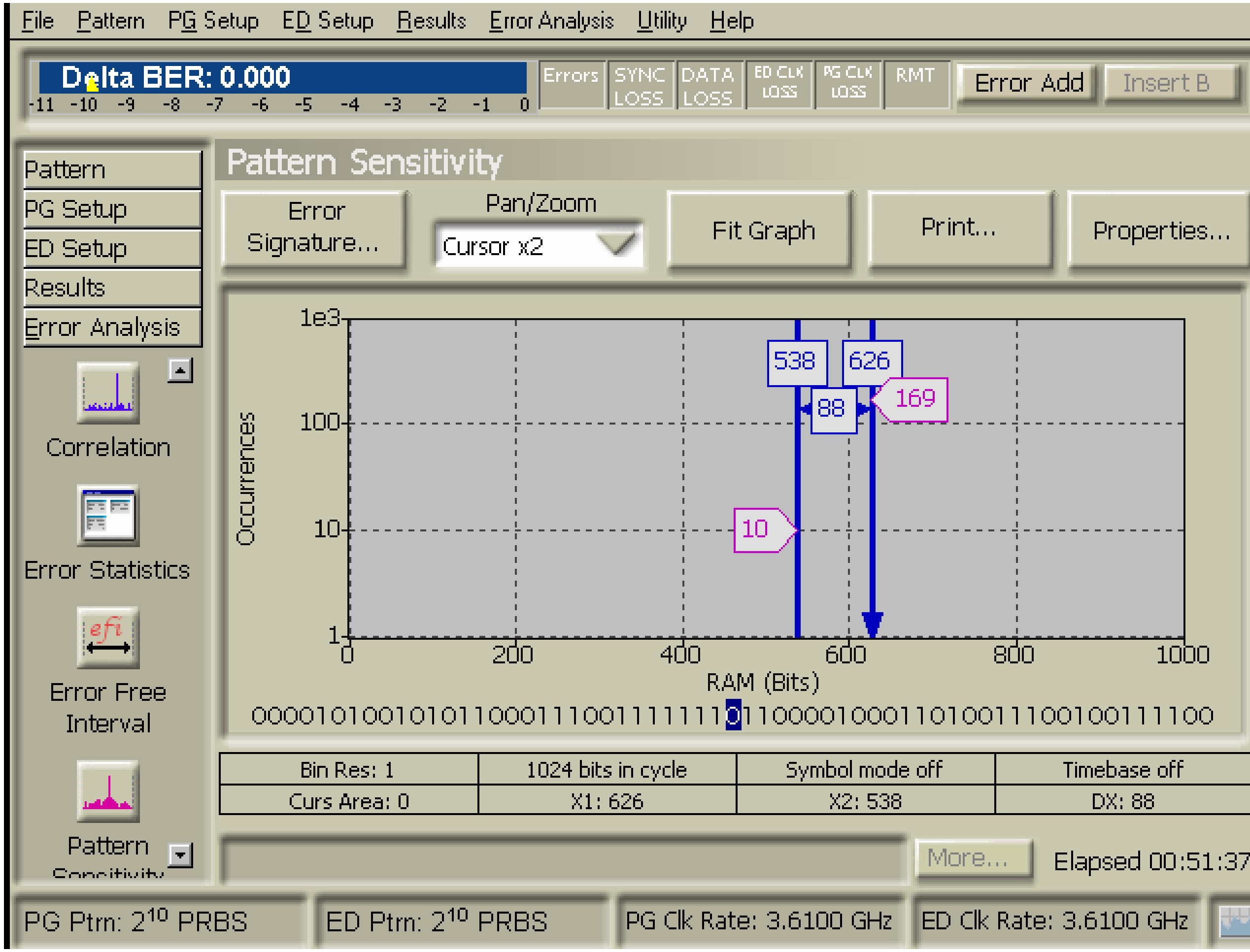
- 179 single bit errors
- No multi-bit errors seen



PRBS10/750 Pattern Sensitivity

- 2^{10} PRBS
- 750mV Xt

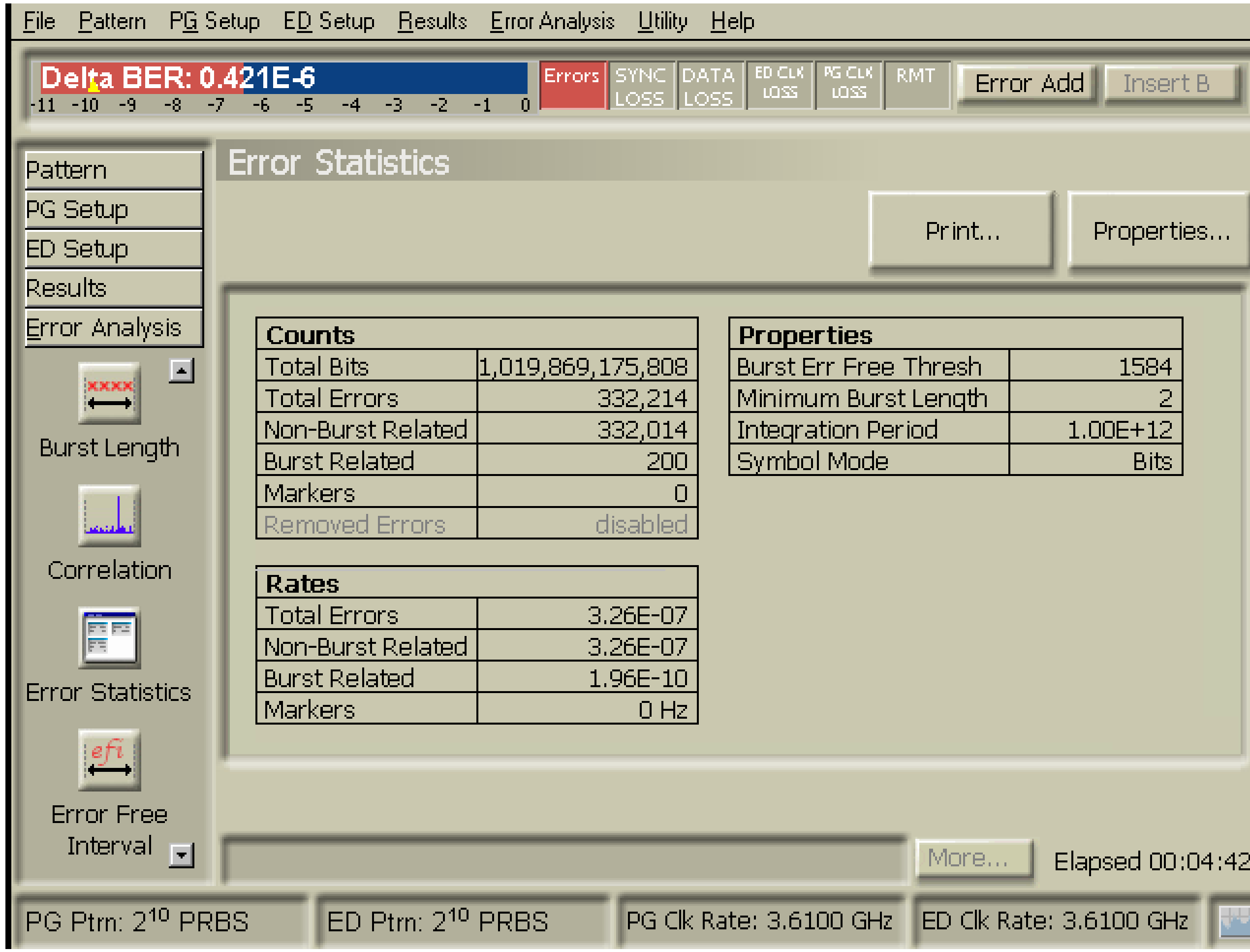
- All 179 bit errors captured are associated with just two pattern locations
  - **169 (94%) at the point shown**



PRBS10/1375 error statistics

- **2^{10} PRBS**
- **1375mV Xt**

- As overall BER goes up, Burst errors start to be reported



Counts	
Total Bits	1,019,869,175,808
Total Errors	332,214
Non-Burst Related	332,014
Burst Related	200
Markers	0
Removed Errors	disabled

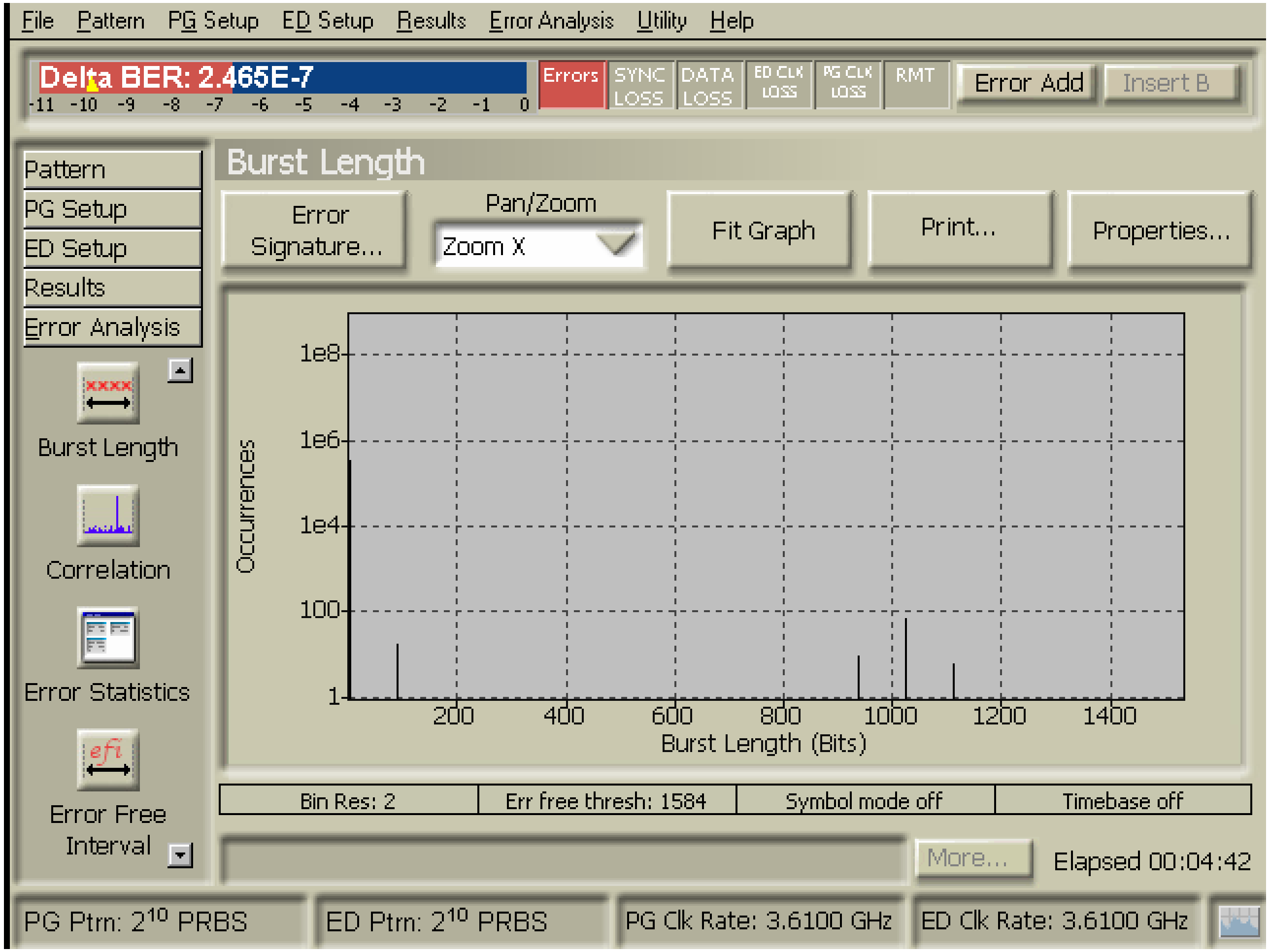
Rates	
Total Errors	3.26E-07
Non-Burst Related	3.26E-07
Burst Related	1.96E-10
Markers	0 Hz

Properties	
Burst Err Free Thresh	1584
Minimum Burst Length	2
Integration Period	1.00E+12
Symbol Mode	Bits

PRBS10/1375 burst length distribution

- **2^{10} PRBS**
- **1375mV Xt**

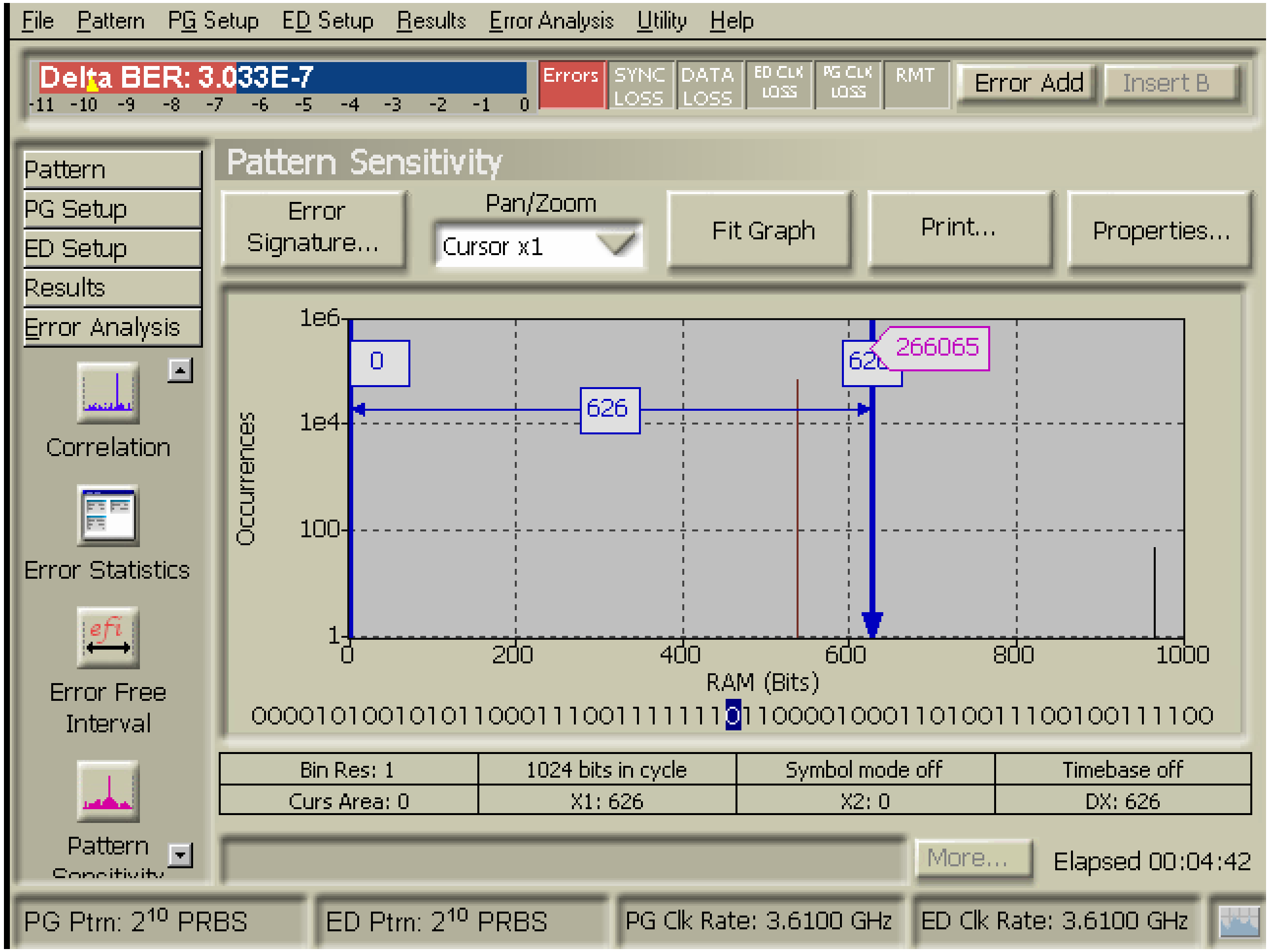
- Burst errors have 4 specific lengths



PRBS10/1375 Pattern Sensitivity

- 2^{10} PRBS
- 1375mV Xt

- 80% of errors are located at the same point in the pattern
  - **This point was responsible for 94% with 750mV of Xtalk**
- There are now 3 failing pattern points
  - **The burst lengths seen correspond to pairs of errors at these points**



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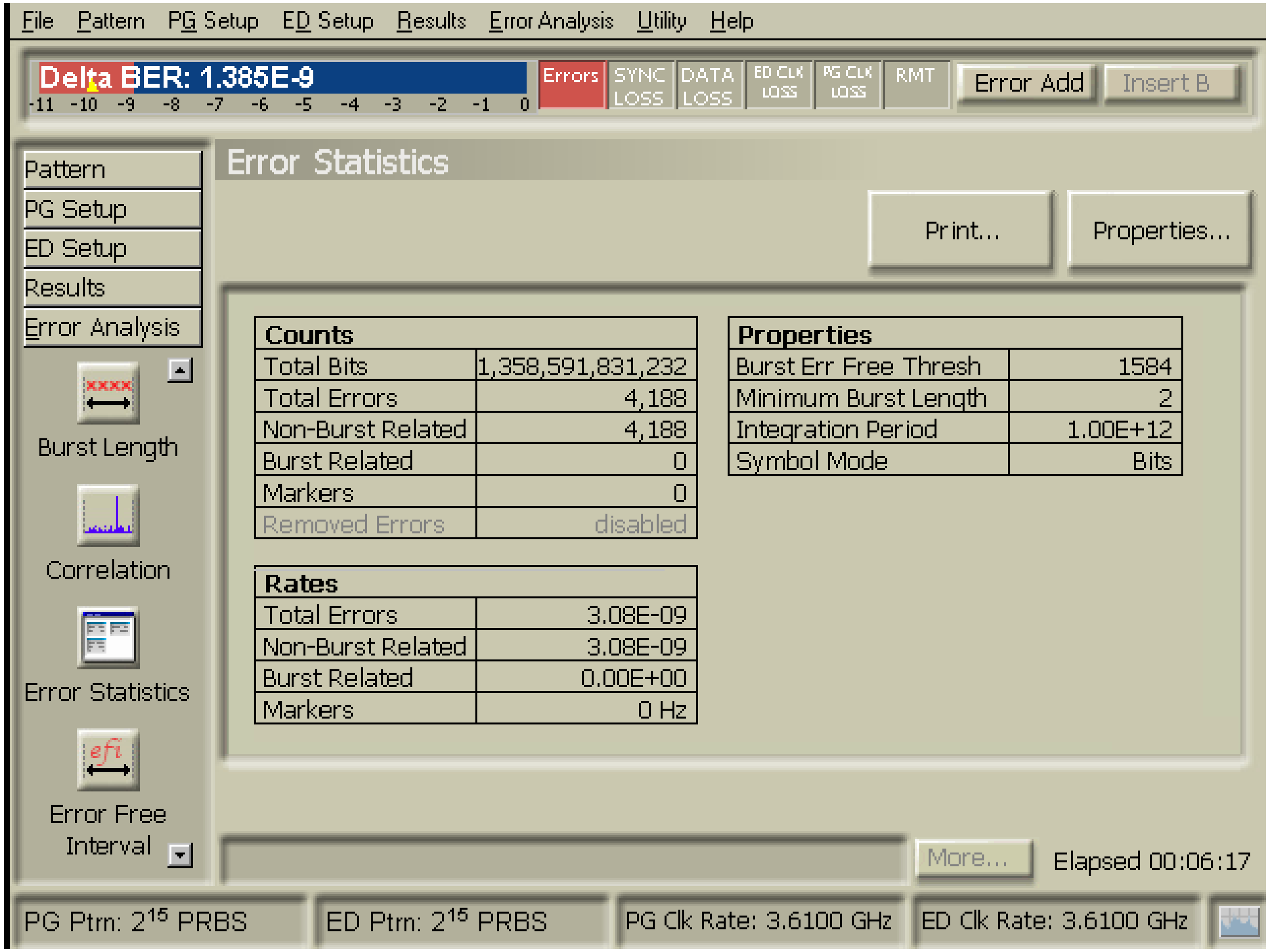
PRBS15/250 error statistics

- 2^{15} PRBS
- 250mV Xt

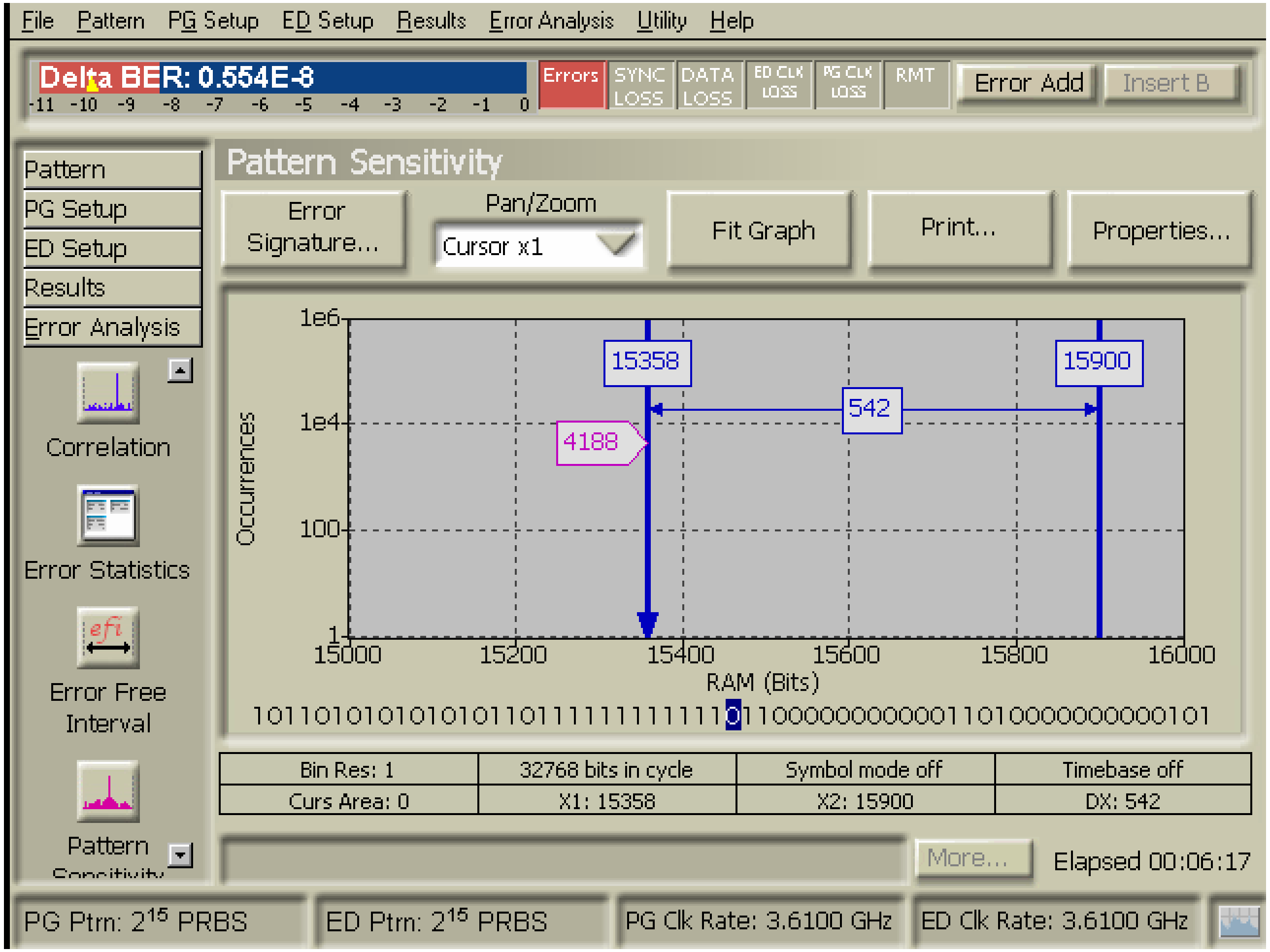
- No burst errors seen in this limited time period



PRBS15/250 Pattern Sensitivity

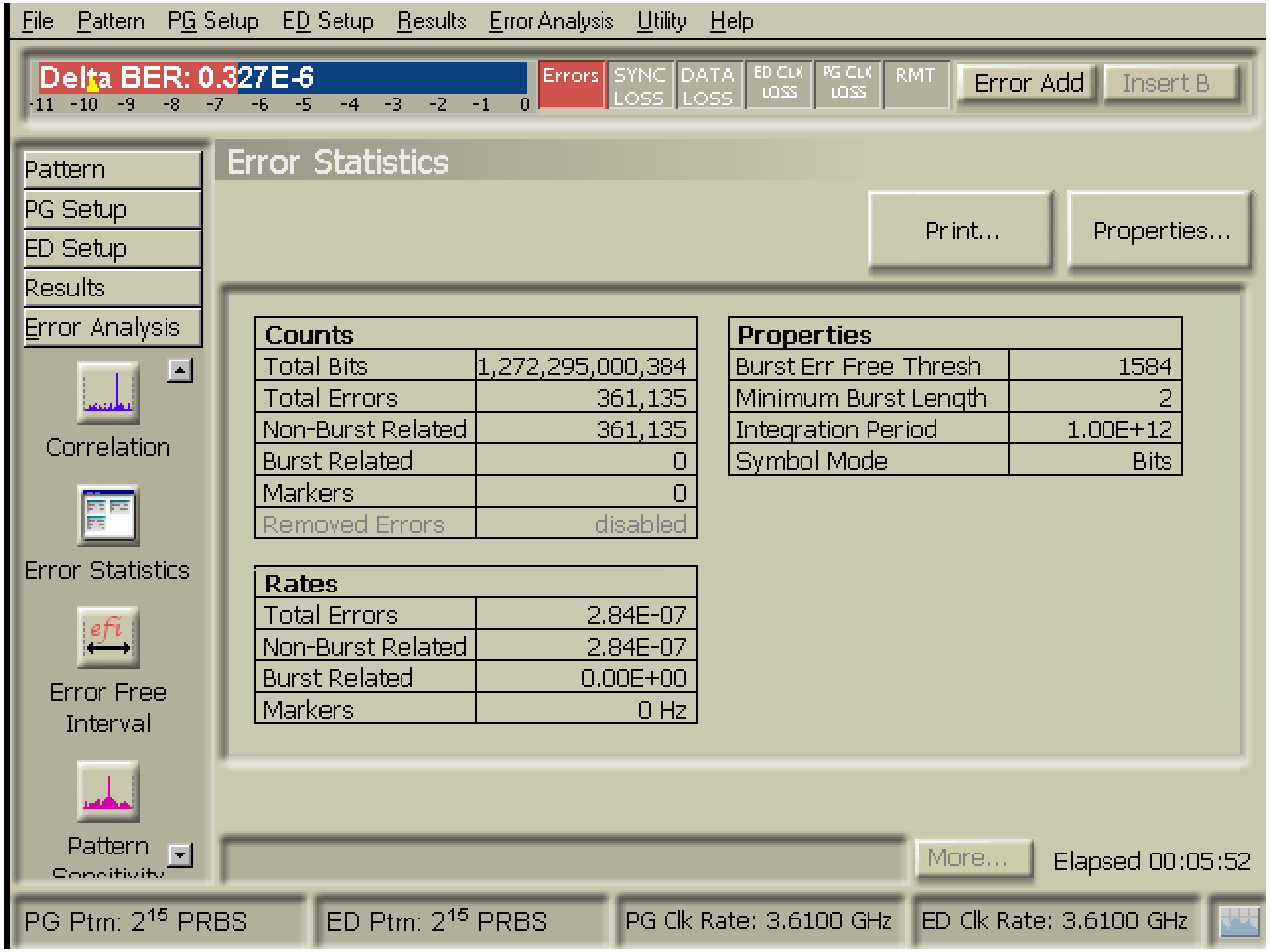
- 2^{15} PRBS
- 250mV Xt

- All errors stem from one point in the pattern



PRBS15/500 error statistics

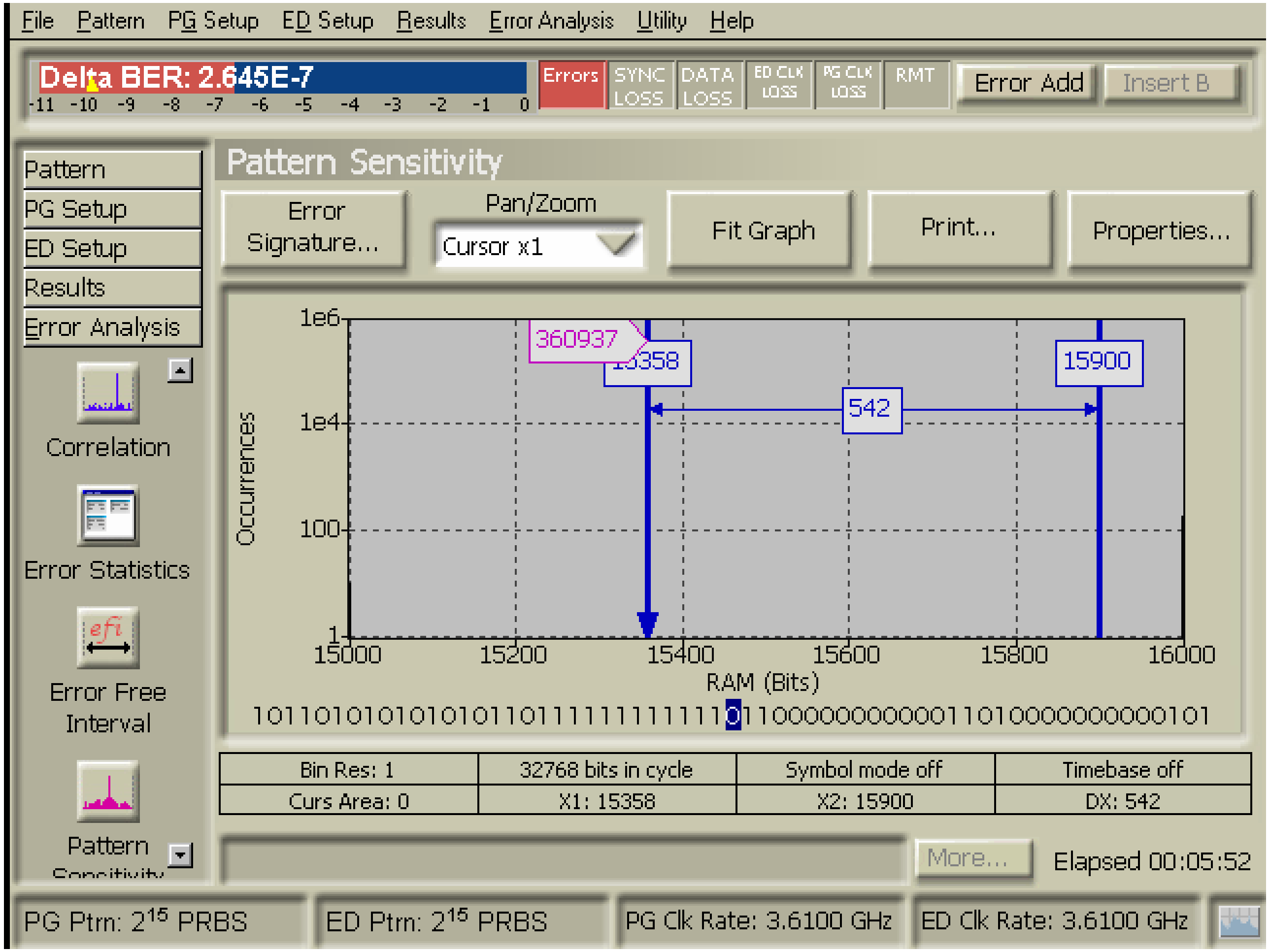
- 2^{15} PRBS
- 500mV Xt



PRBS15/500 Pattern Sensitivity

- **2^{15} PRBS**
- **500mV Xt**

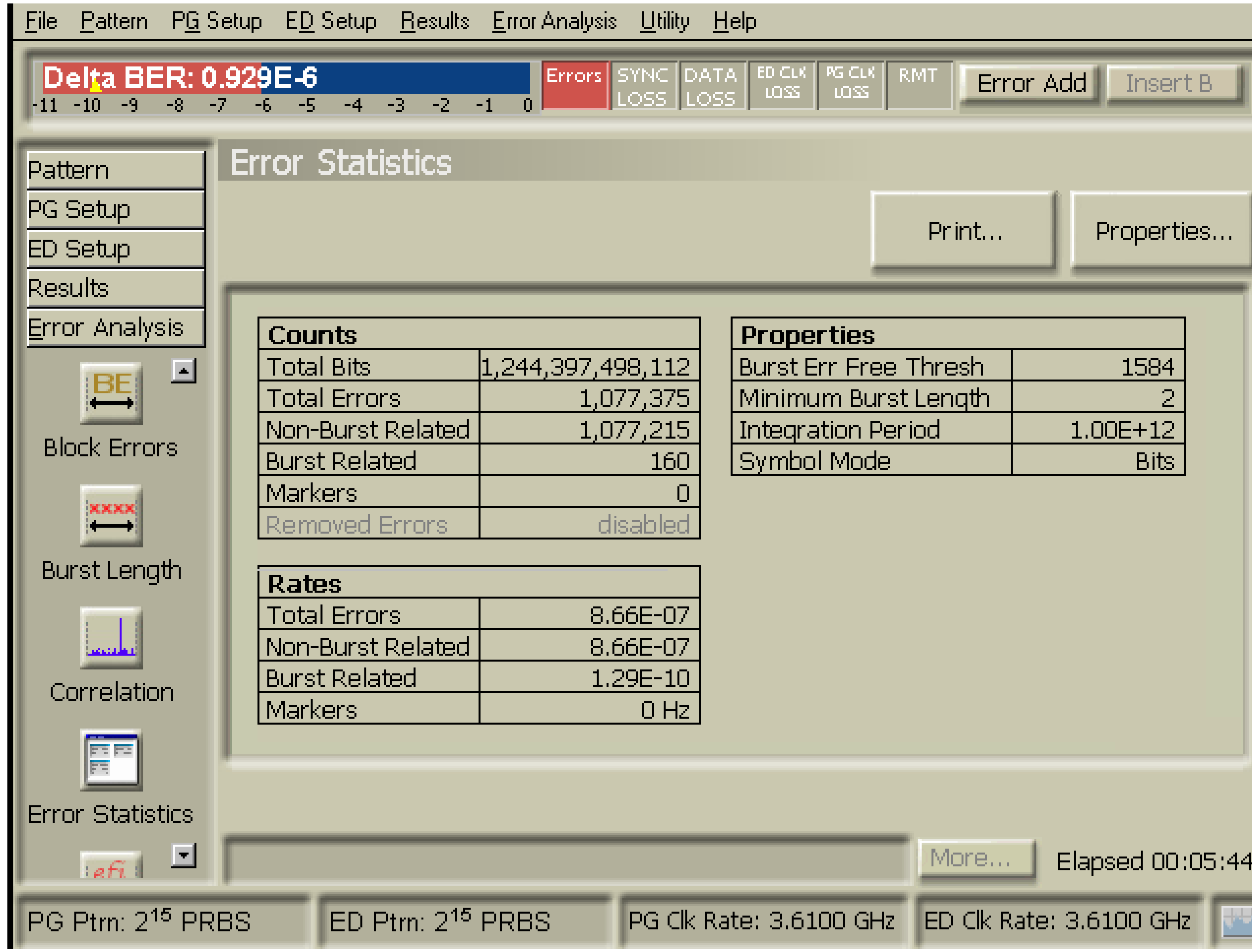
- As the error rate increases additional pattern positions fail.
- The dominant failure point still accounts for 99.9% of errors
- Pattern failure points are too far apart to cause burst errors



TEXAS INSTRUMENTS

PRBS15/625 error statistics

- 2^{15} PRBS
- 625mV Xt

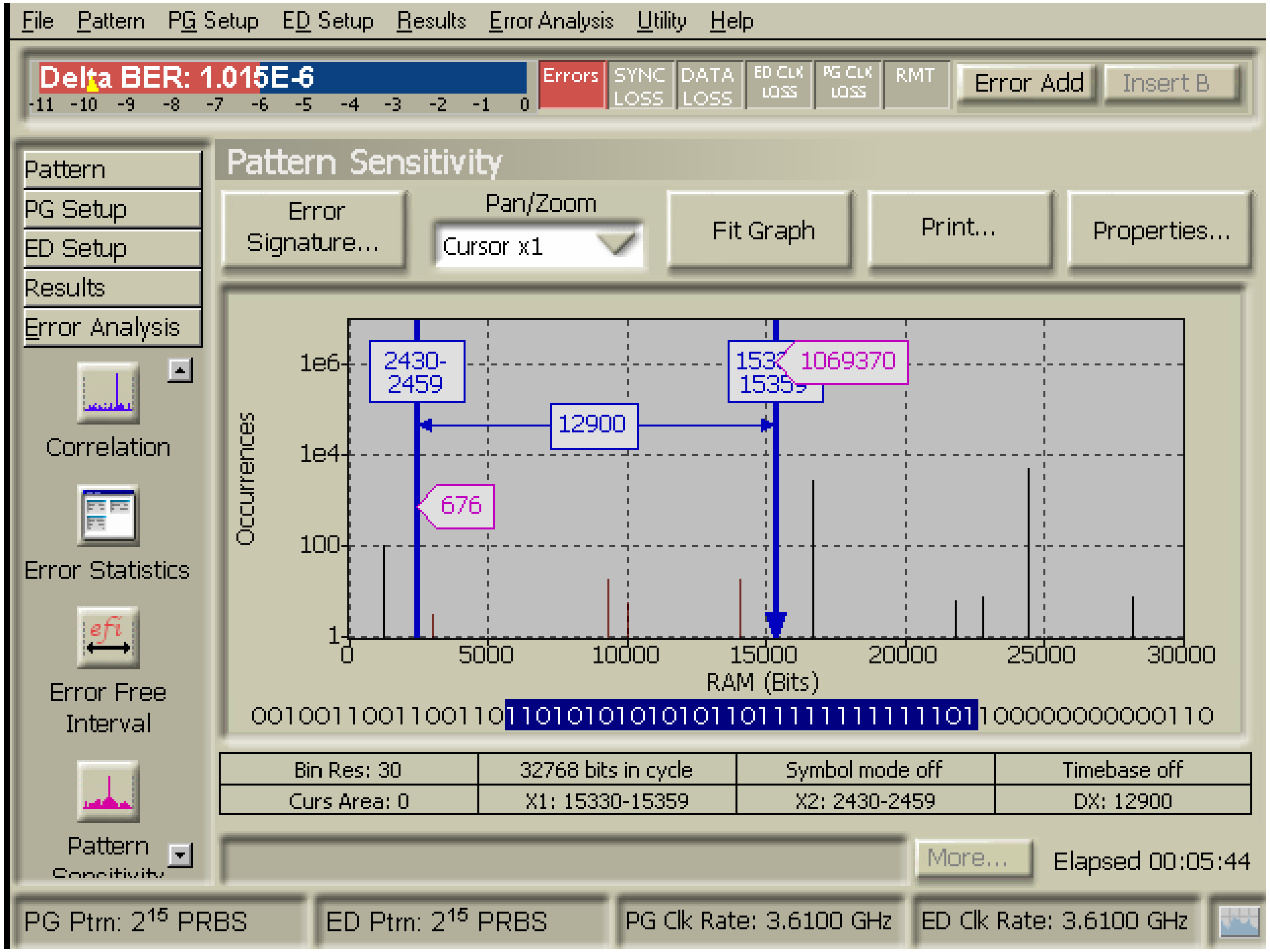


TEXAS INSTRUMENTS

PRBS15/625 Pattern Sensitivity

- 2^{15} PRBS
- 625mV Xt

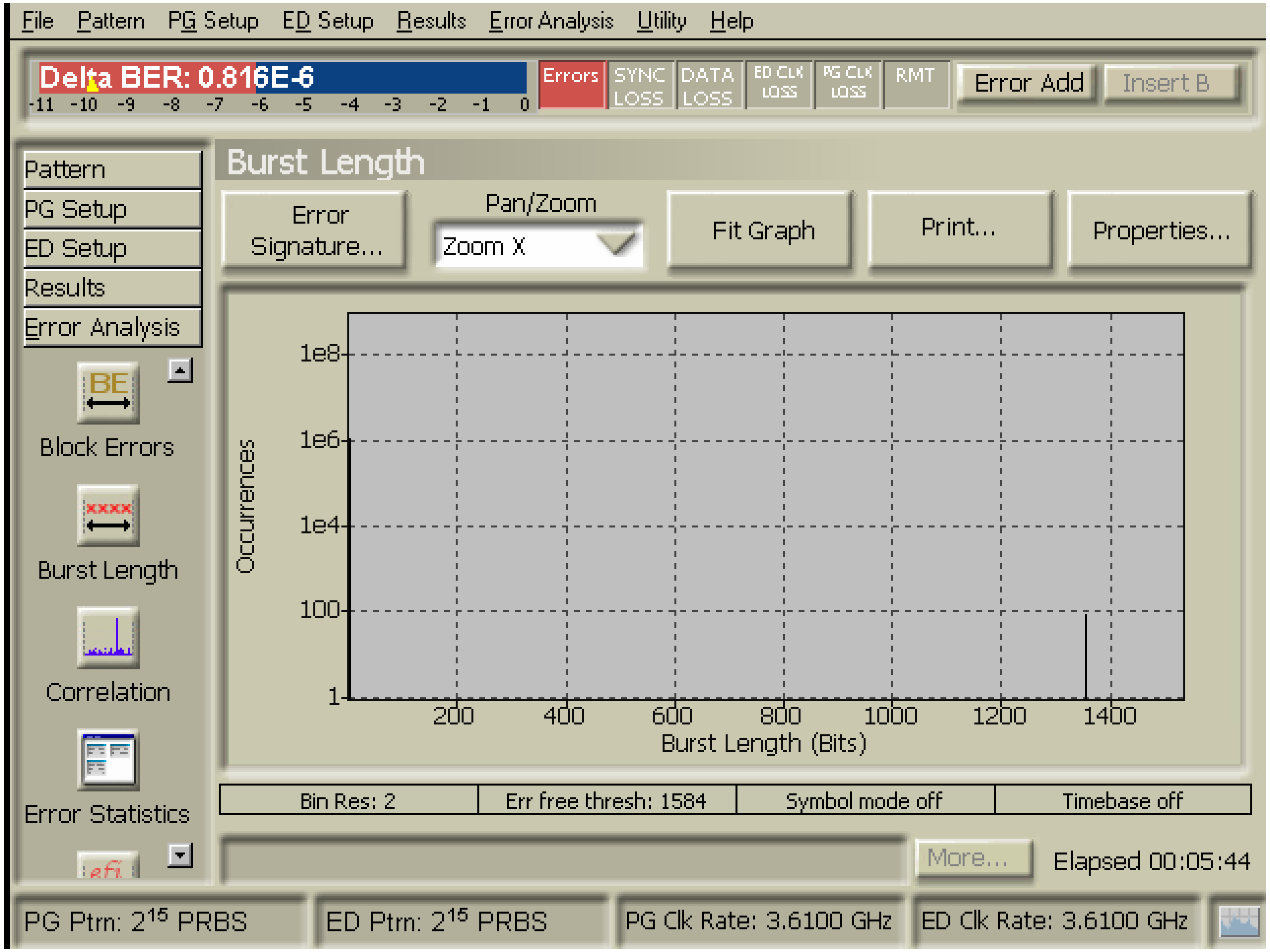
- Additional failing pattern positions have now appeared
  - **Some are within 1584 bits of each other, So burst errors can occur.**
- The dominant failure point still accounts for 99.2% of errors



PRBS15/625 burst length distribution

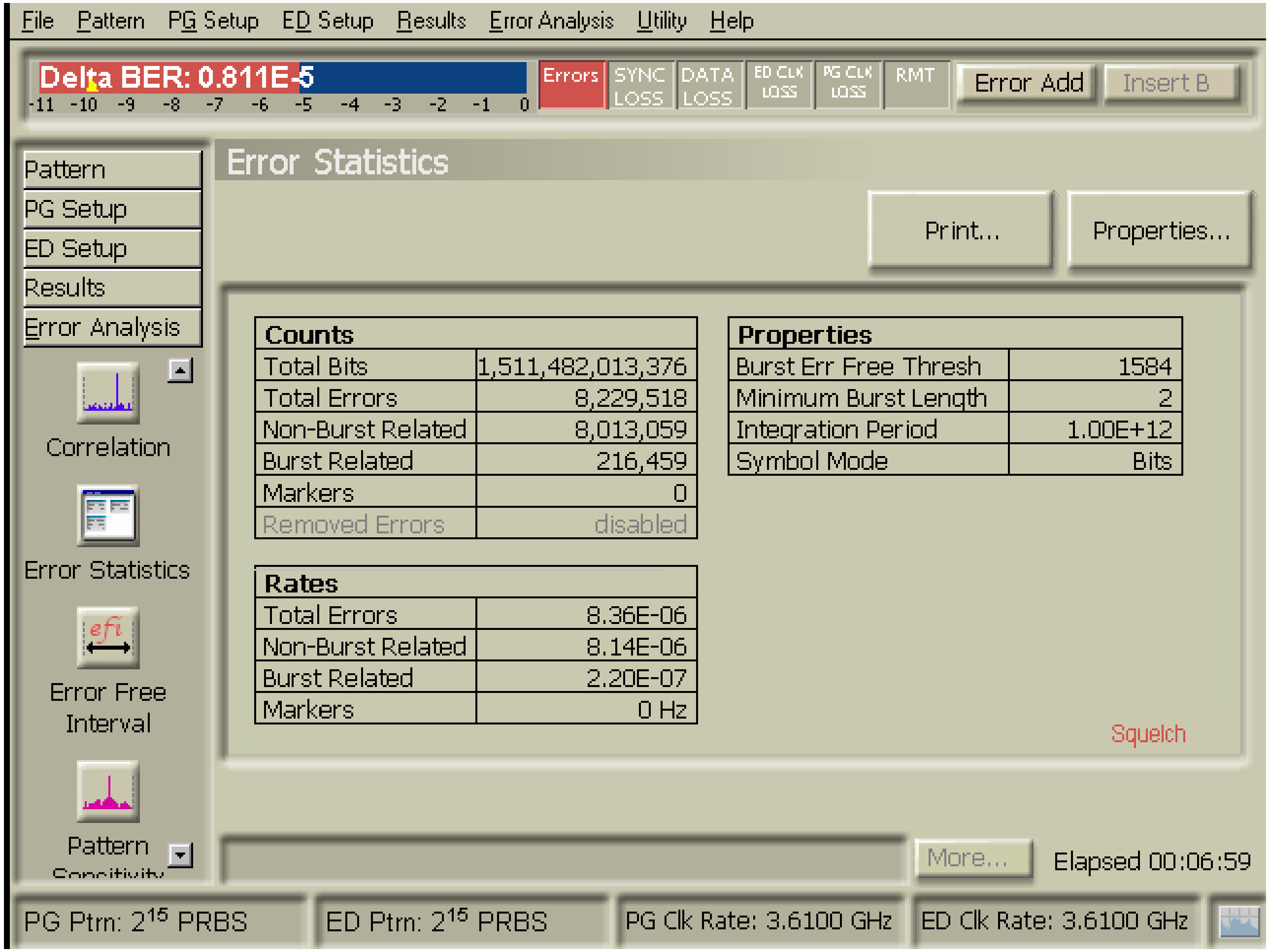
- **2^{15} PRBS**
- **625mV Xt**

- All 160 burst errors are exactly the same length
  ~1350 bits long



PRBS15/1375 error statistics

- 2^{15} PRBS
- 1375mV Xt



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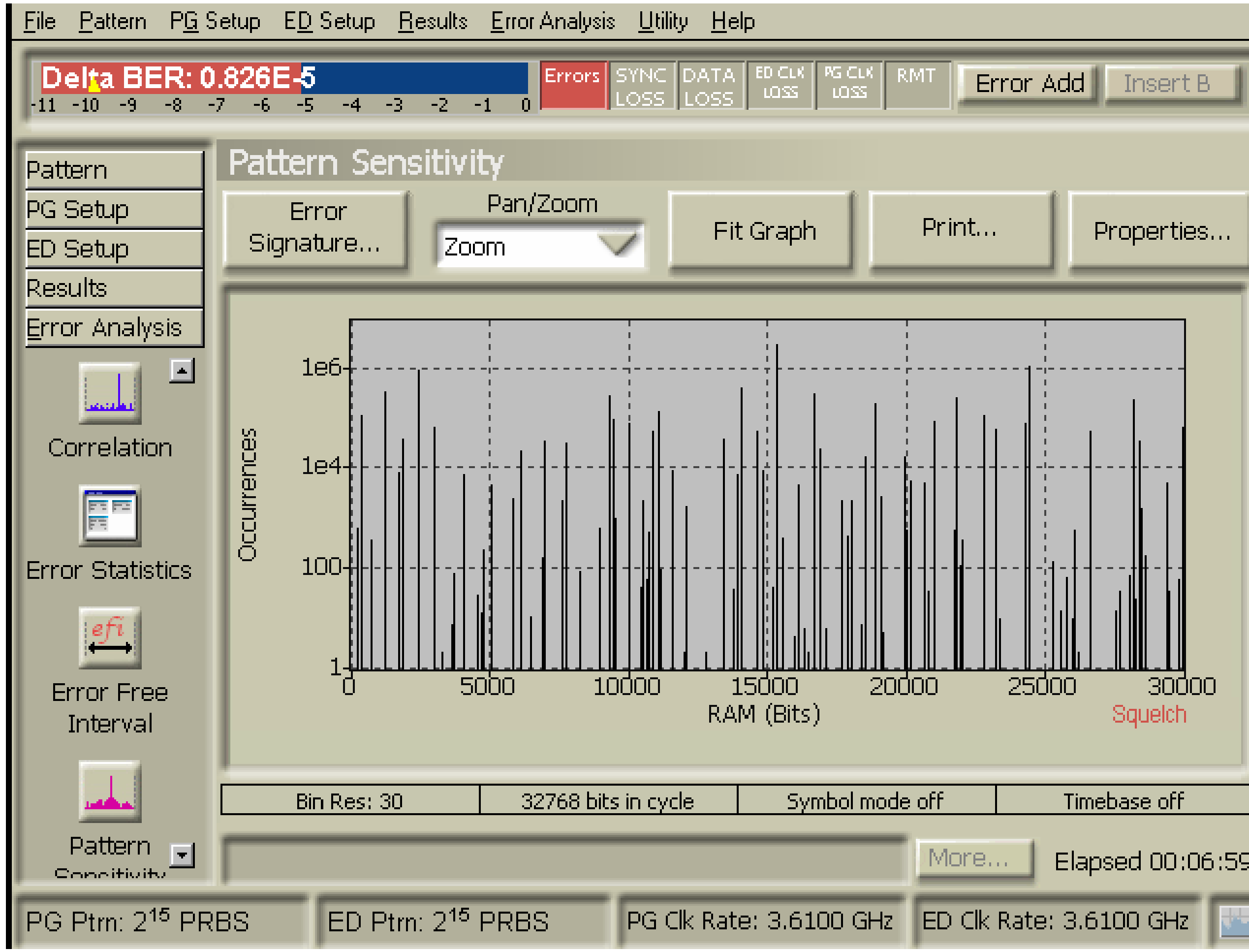
PRBS15/1375 Pattern Sensitivity

- **2^{15} PRBS**
- **1375mV Xt**

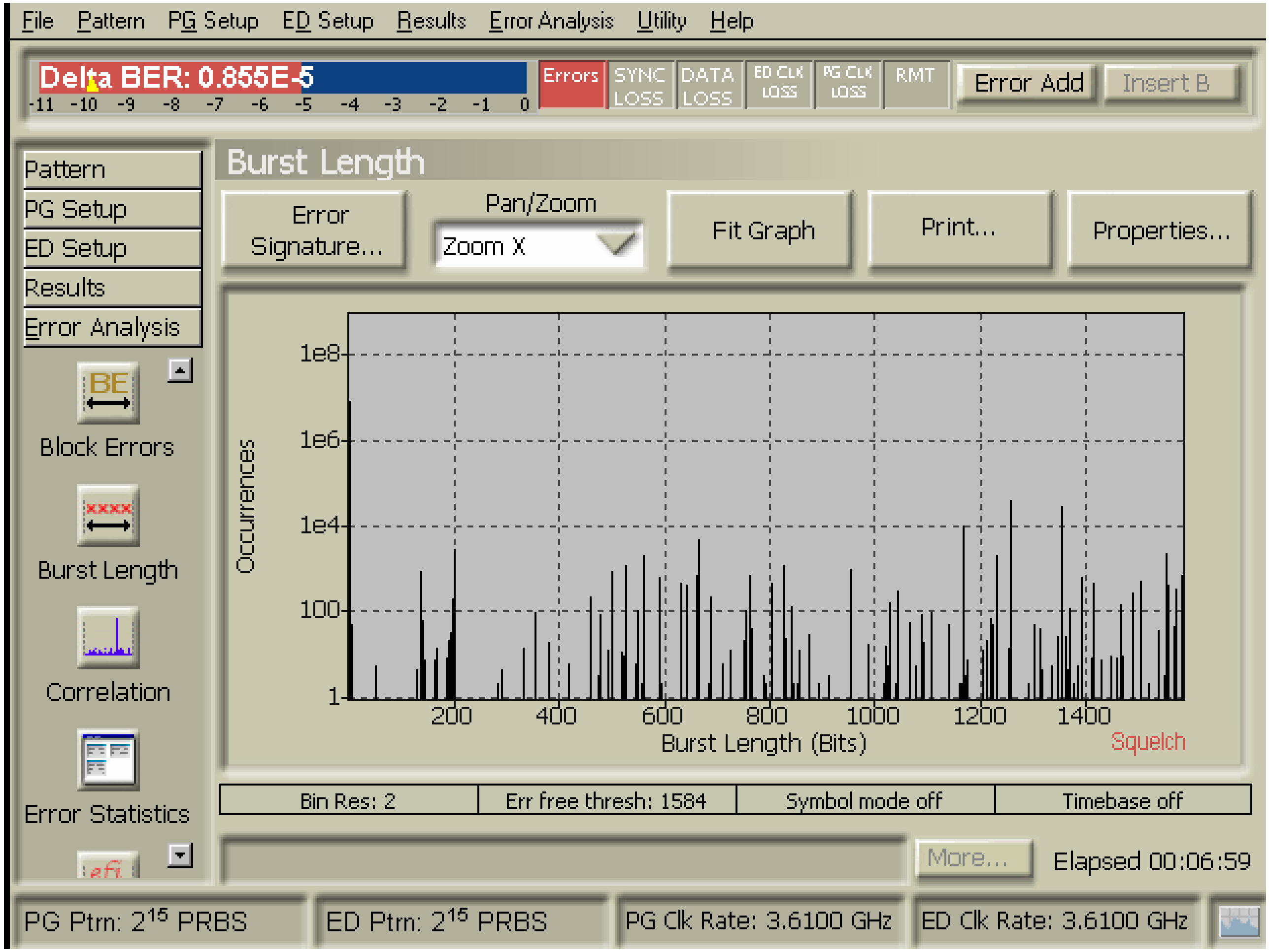
- At this highest level of crosstalk there many failing pattern positions.



PRBS15/1375 burst length distribution

- **2^{15} PRBS**
- **1375mV Xt**

- There is now a distribution of burst error lengths
  - **Due to many failing pattern positions and their spacings**



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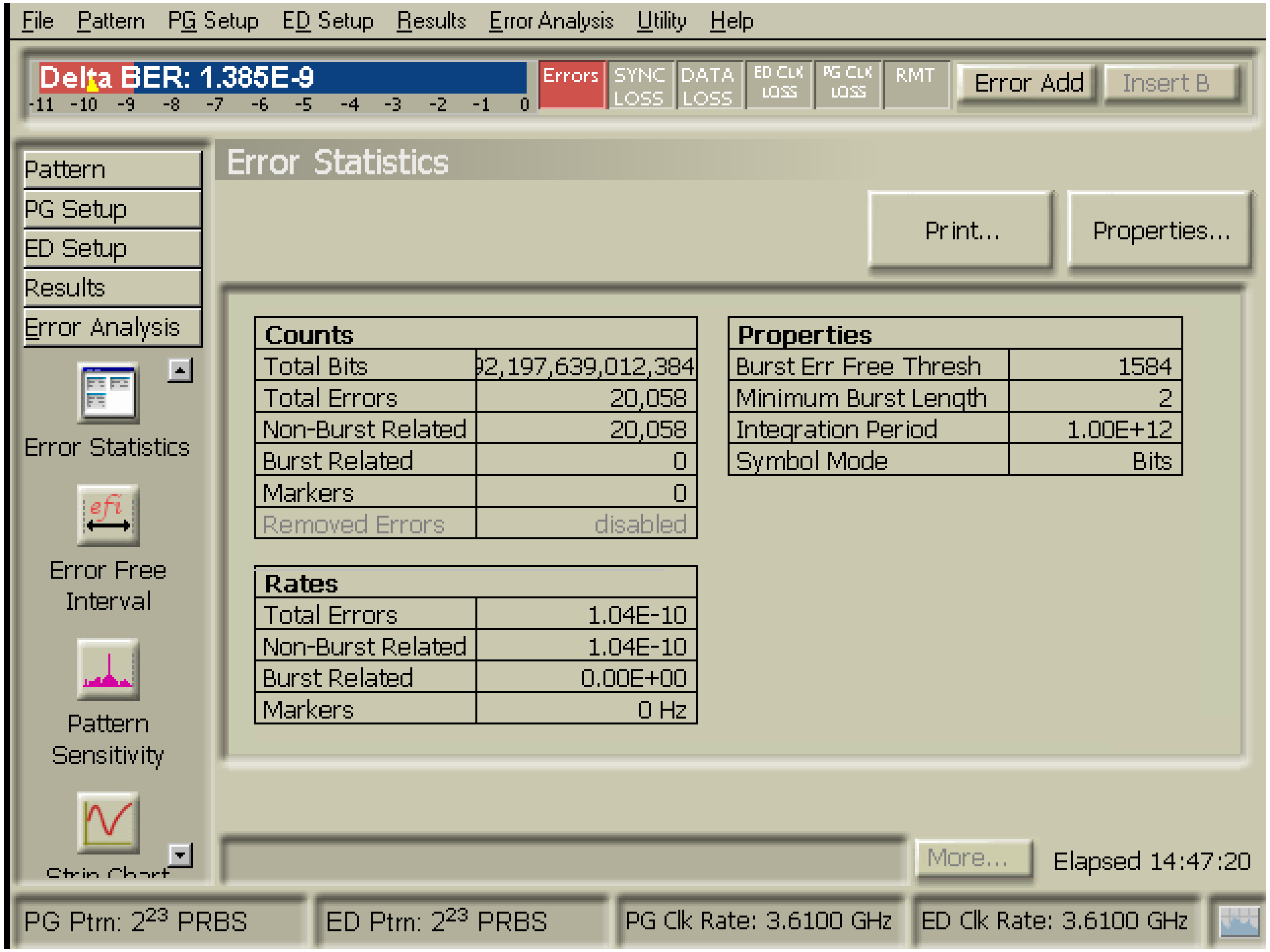
PRBS23/0 error statistics

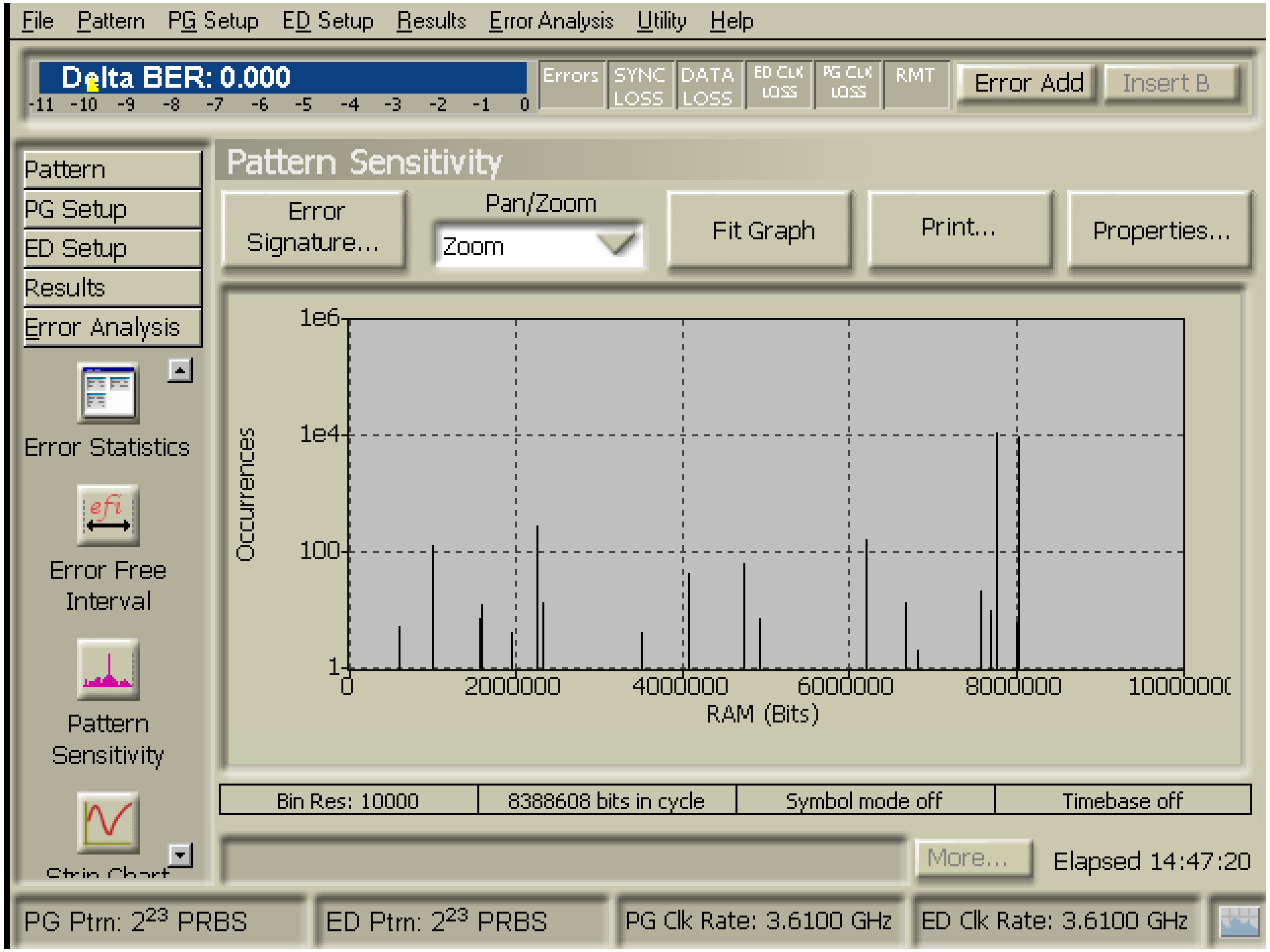
- 2^{23} PRBS
- 0mV Xt



PRBS23/0 Pattern Sensitivity

- **2^{23} PRBS**
- **0mV Xt**

- The 2^{23} PRBS has many failing points but with such a long pattern they are sufficiently far apart not to produce burst errors
- There are two main failure points
  - **Responsible for 96% of all errors**
  - **Shown on next two slides**



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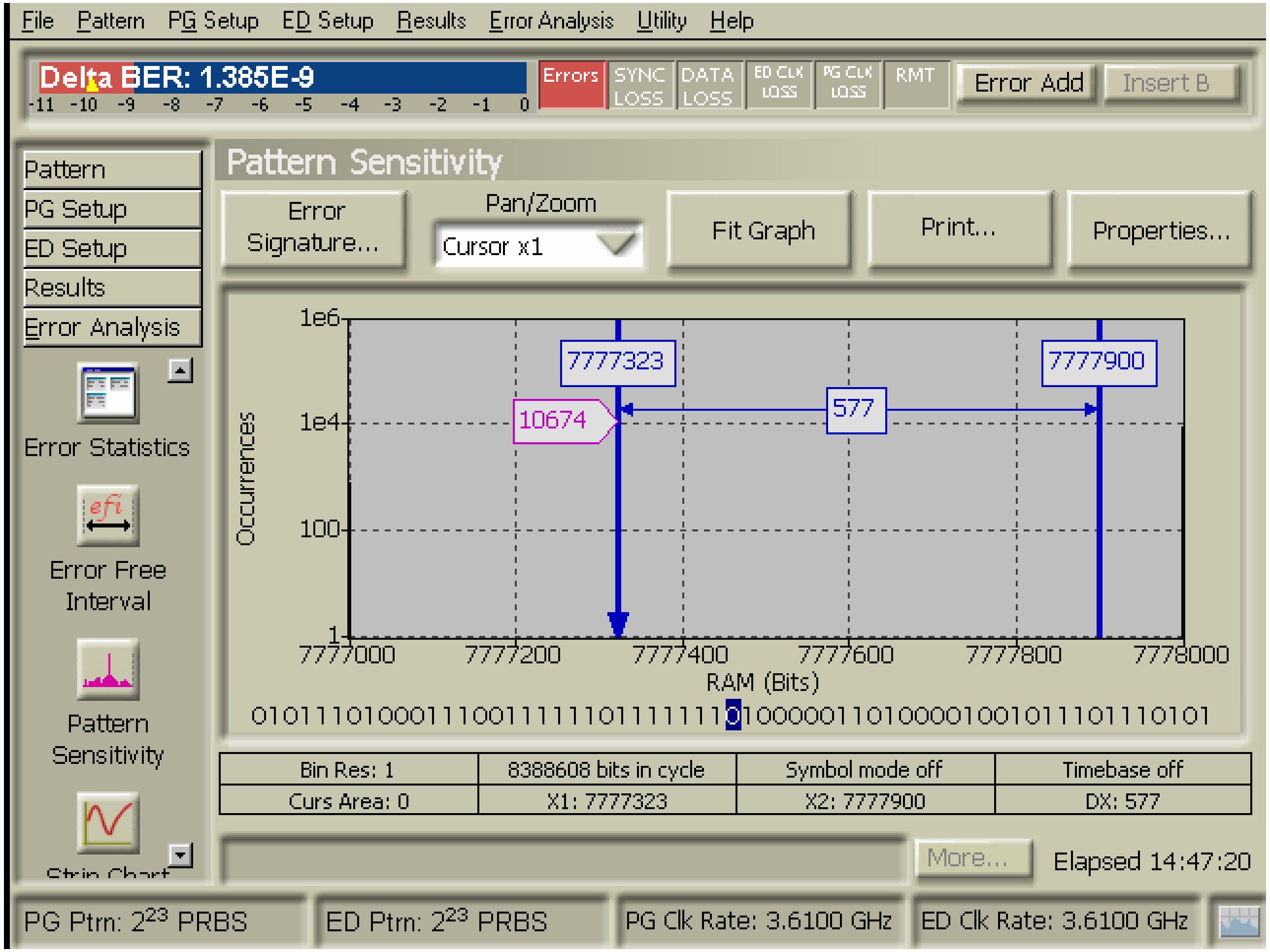
PRBS23/0 Pattern Sensitivity

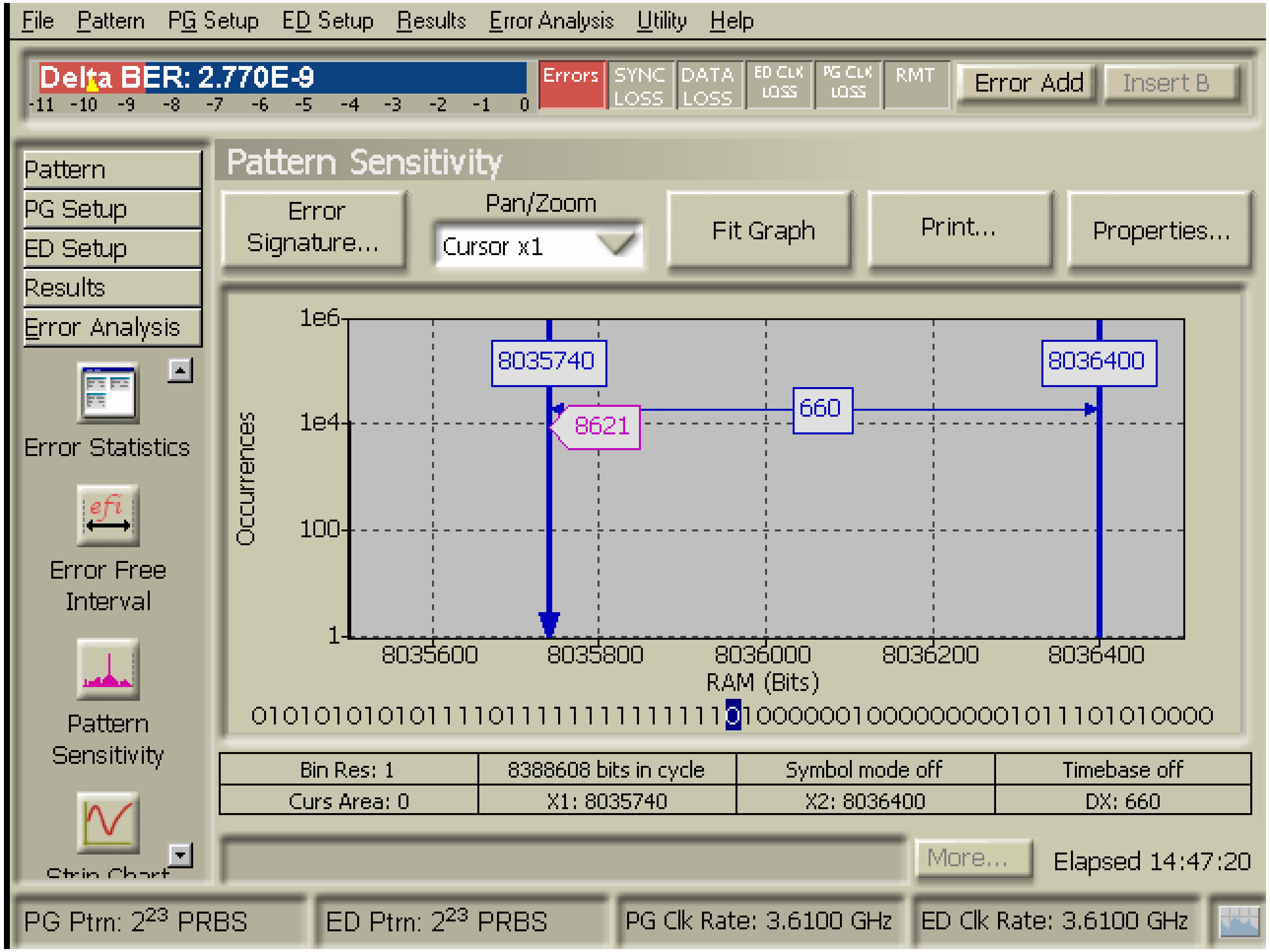
- **2^{23} PRBS**
- **0mV Xt**

- This point is responsible for 53% of all errors



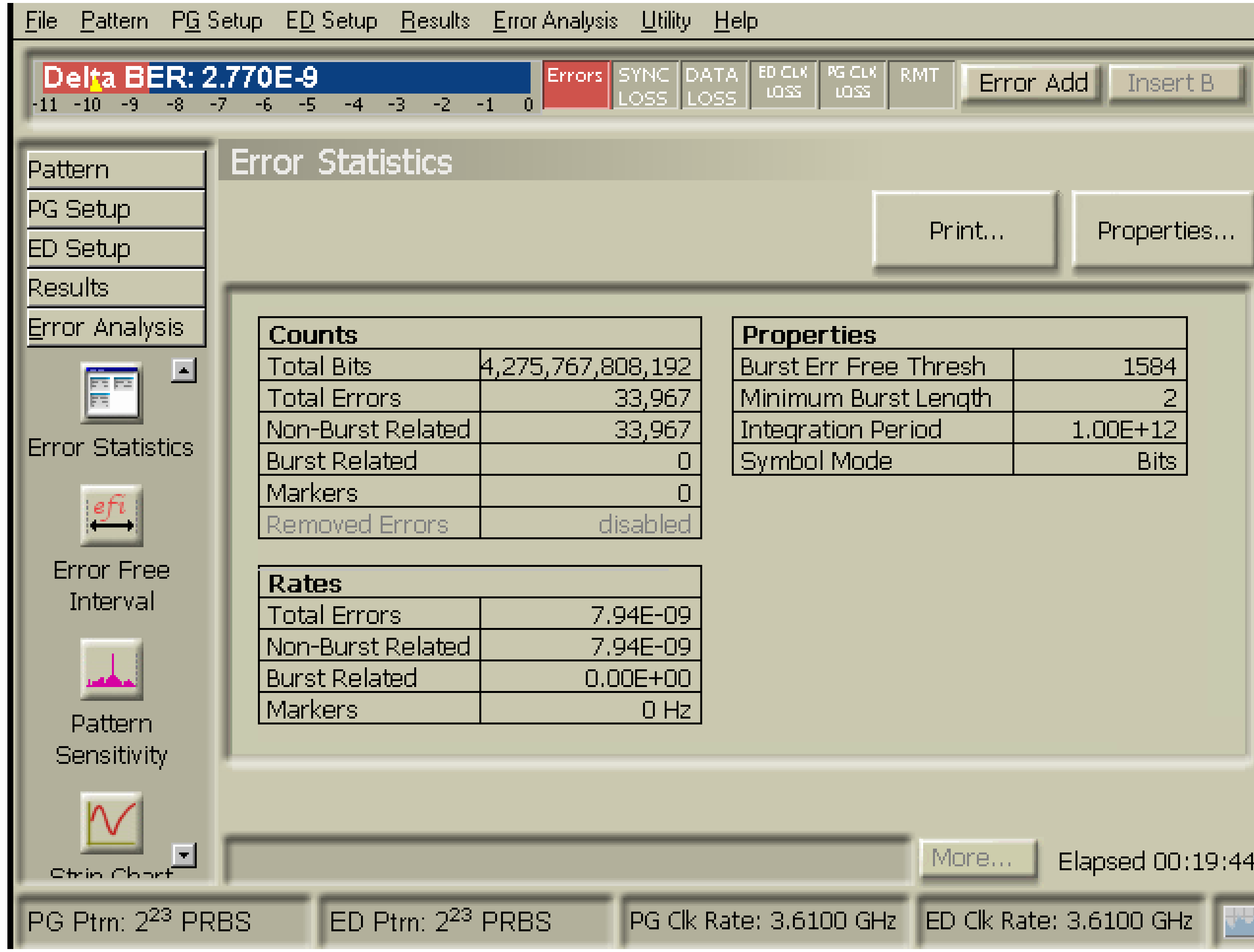
PRBS23/0 Pattern Sensitivity

- 2^{23} PRBS
- 0mV Xt



PRBS23/250 error statistics

- 2^{23} PRBS
- 250mV Xt



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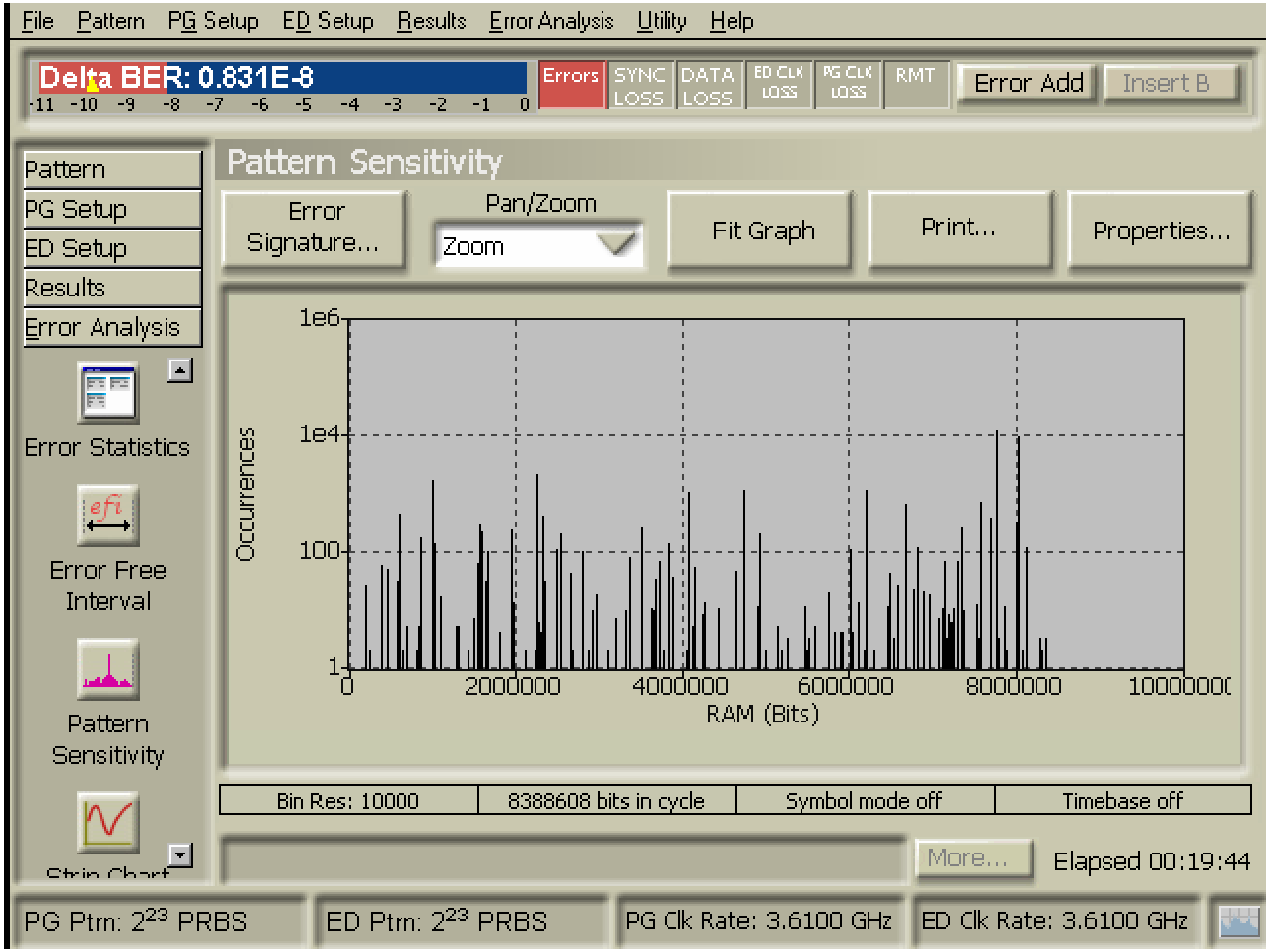
PRBS23/250 Pattern Sensitivity

- **2^{23} PRBS**
- **250mV Xt**

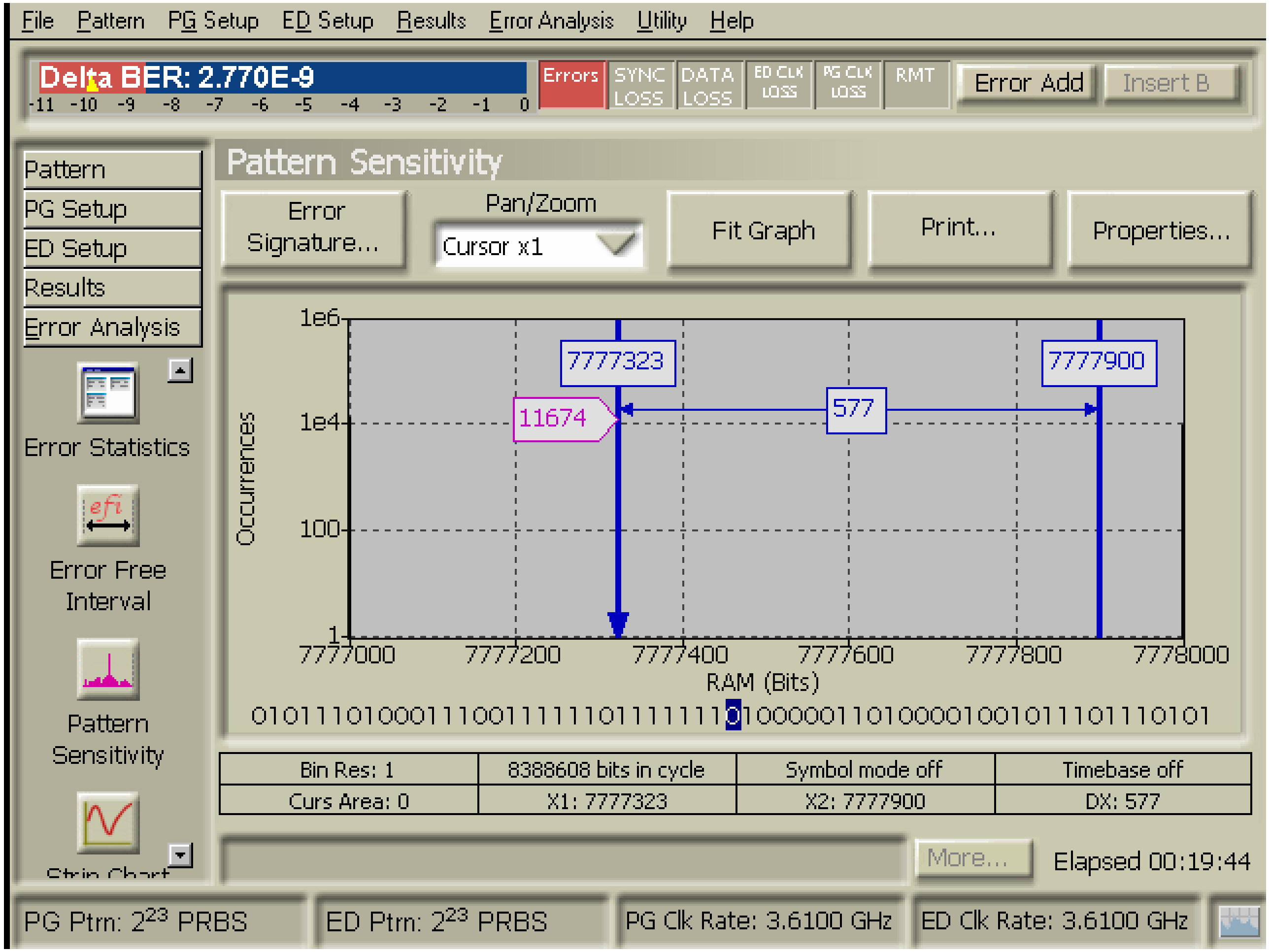
- As crosstalk increases new failure points are stimulated and the influence of the dominant points fade



PRBS23/250 Pattern Sensitivity

- 2^{23} PRBS
- 250mV Xt

- This point is still responsible for only 34% of all errors
  - **Down from 53%**



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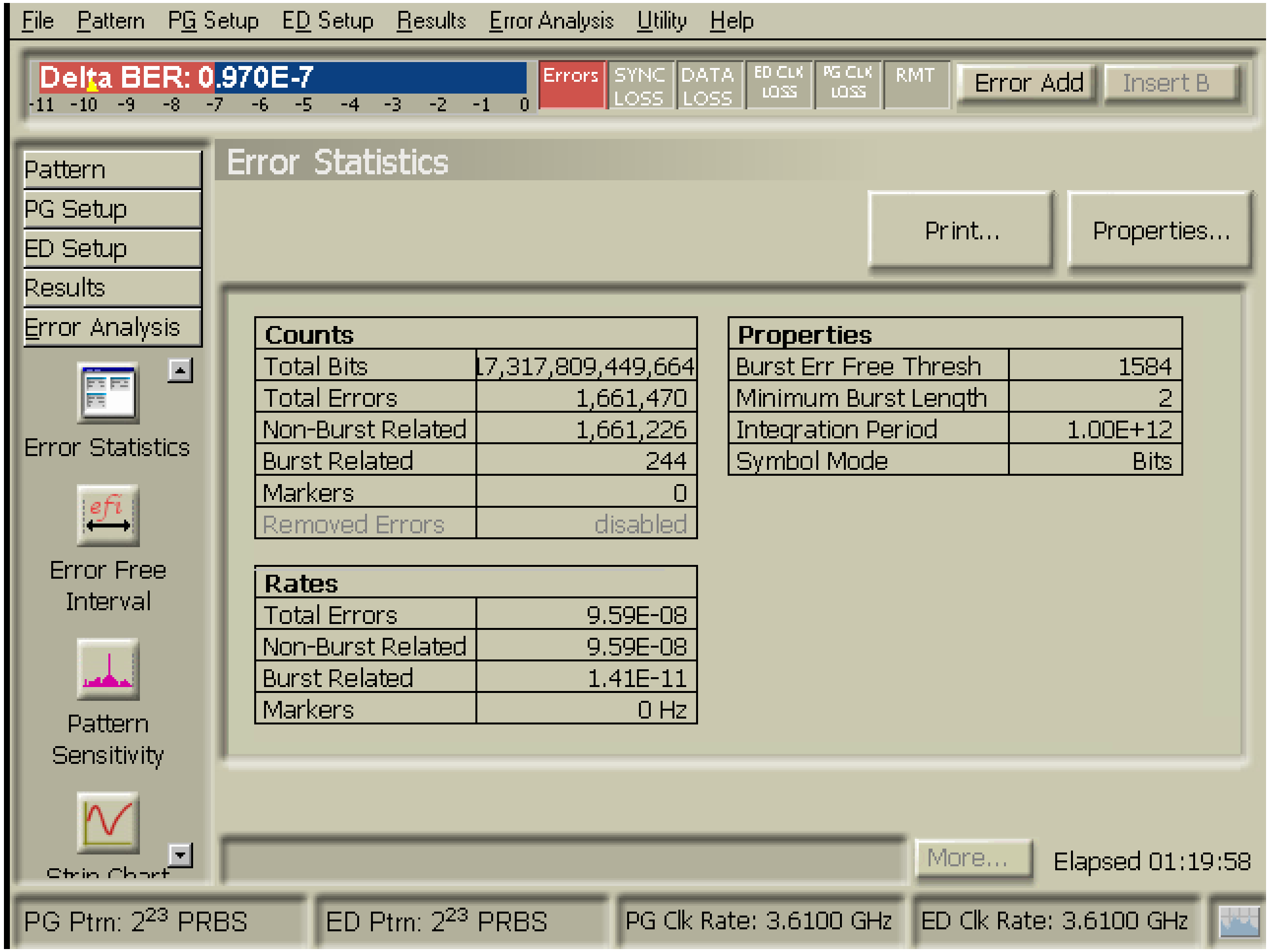
PRBS23/500 Error Statistics

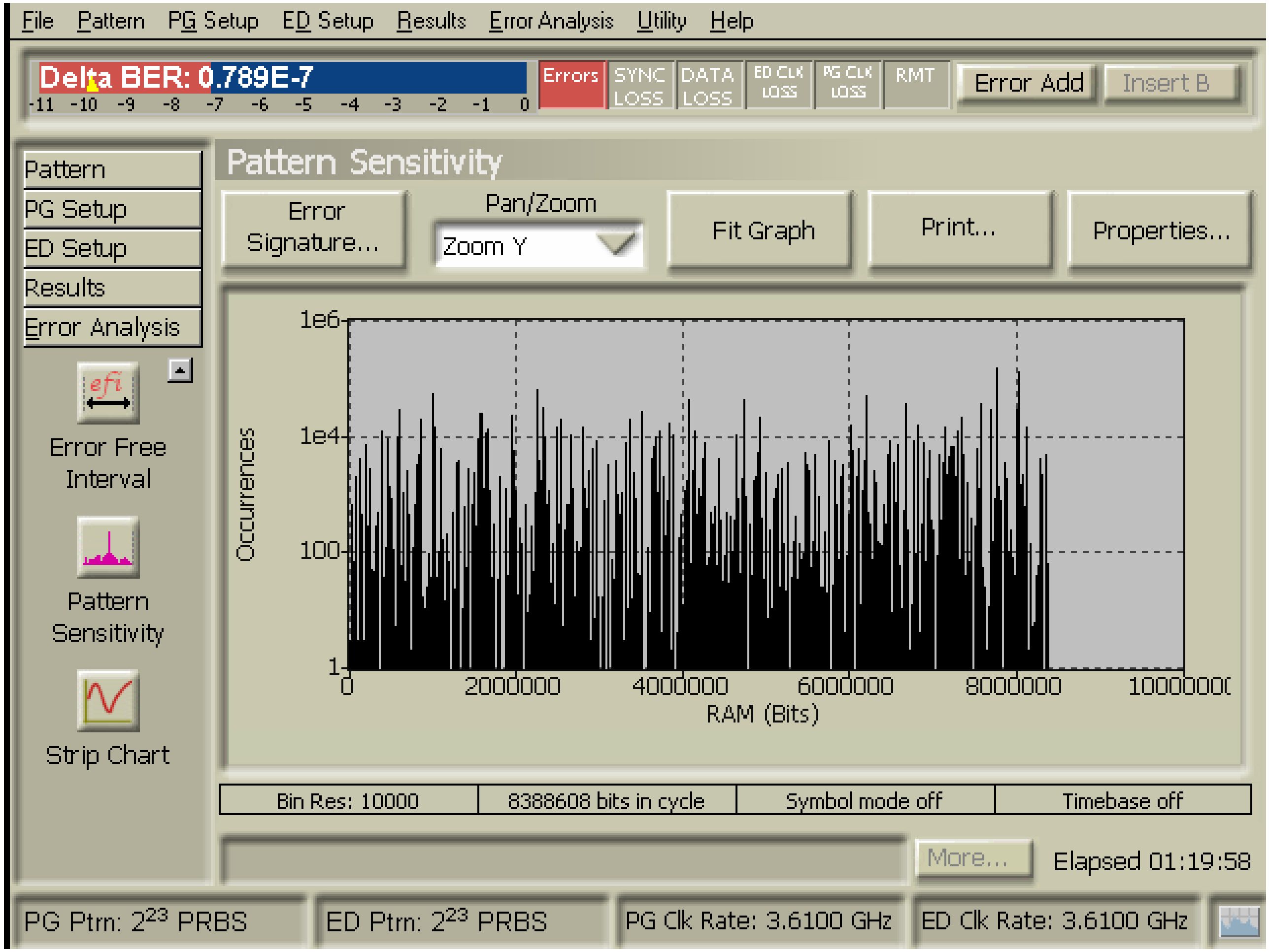
- 2^{23} PRBS
- 500mV Xt



PRBS23/500 Pattern Sensitivity

- 2^{23} PRBS
- 500mV Xt

- A mass of failure points.
  - **Original 2 points still visible and more likely than the rest**
- Despite the number of failure points they are still too widely spaced to create many burst errors

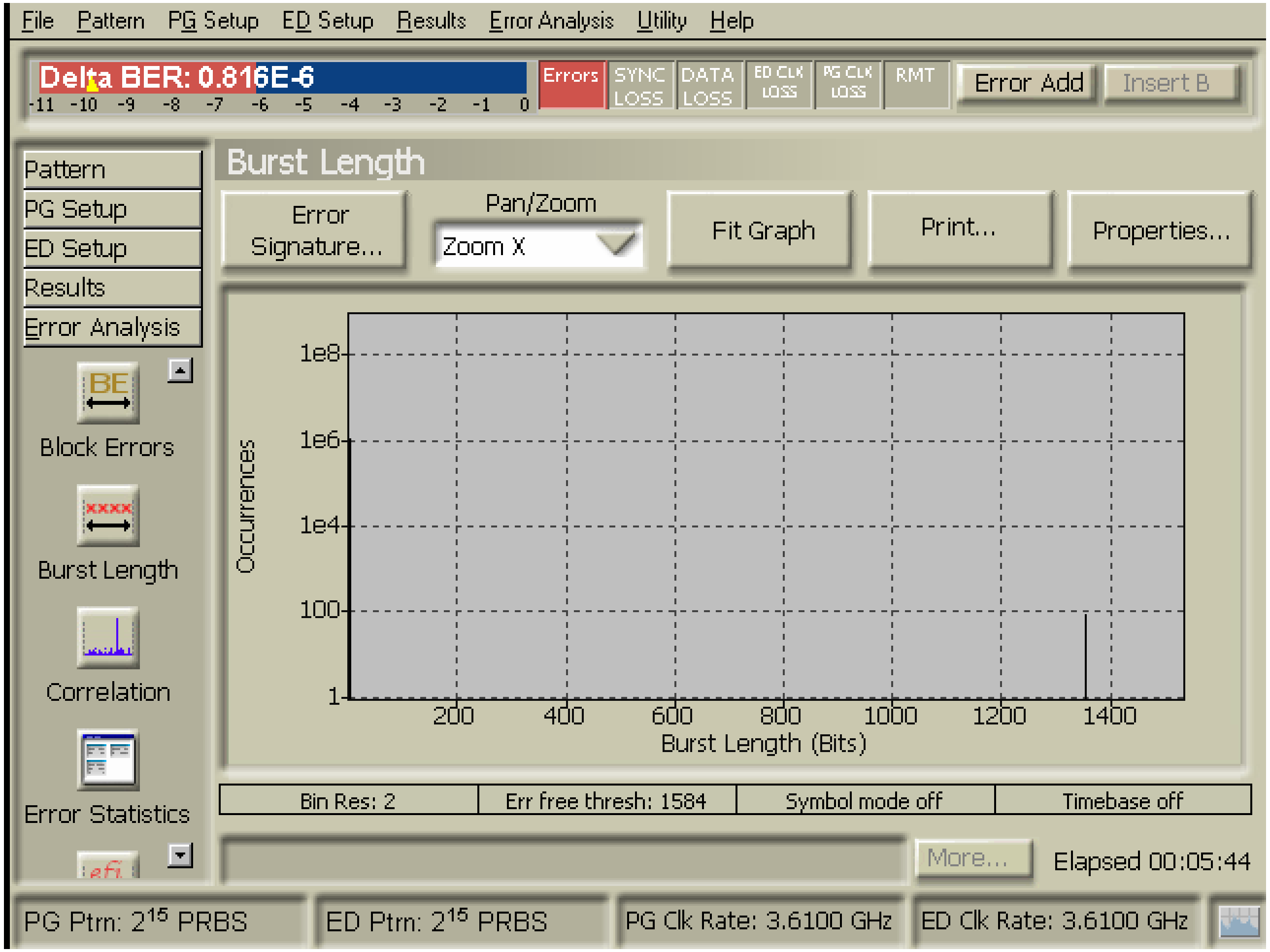


TEXAS INSTRUMENTS

PRBS23/500 burst length distribution

- 2^{23} PRBS
- 500mV Xt

- All burst errors are of exactly the same length
  - **Presumably the pattern distance between two failure points**



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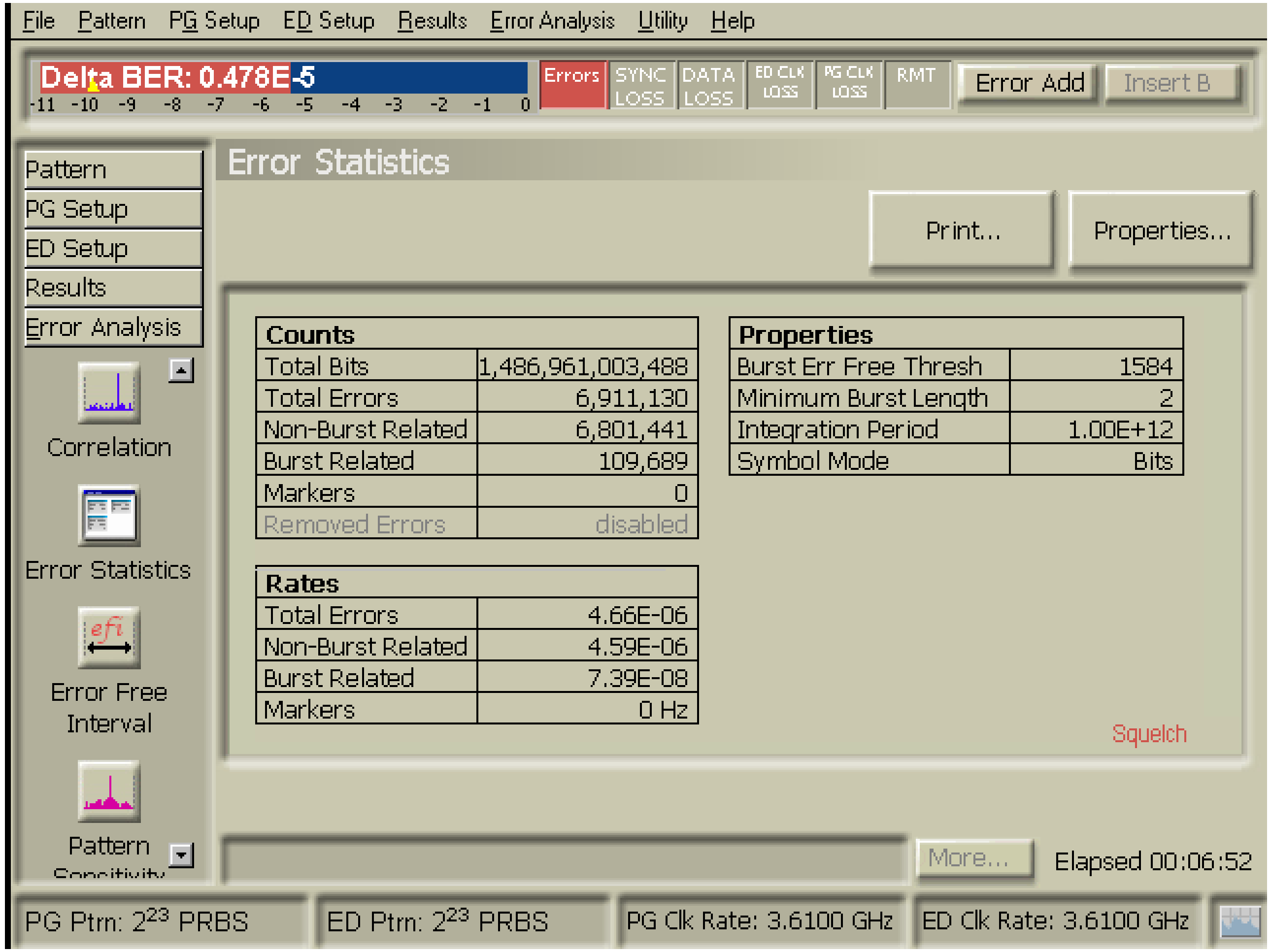
PRBS23/1000 Error Statistics

- 2^{23} PRBS
- 1000mV Xt

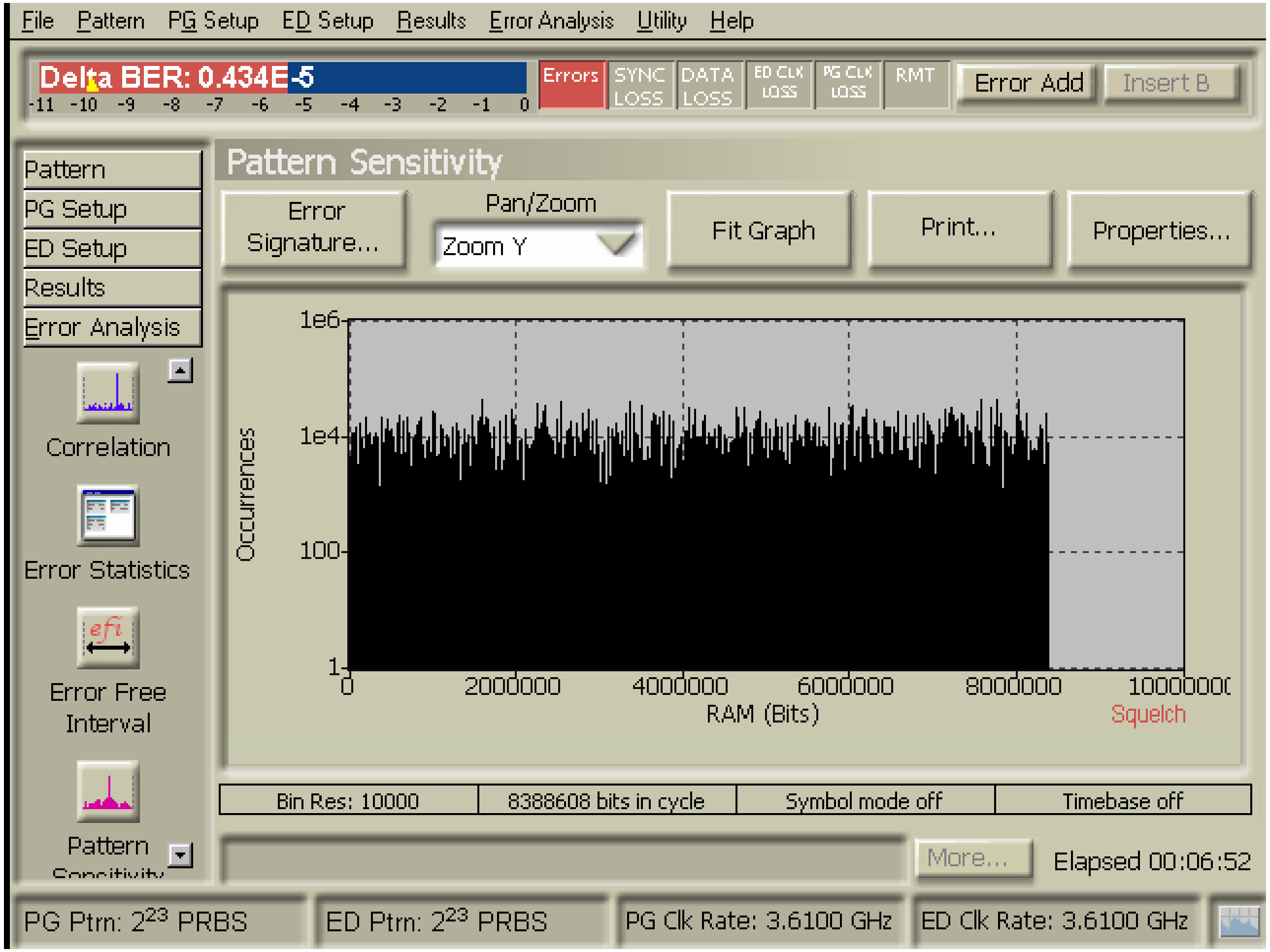
- Note the BERT has squelched due to the high error rate and some errors have been dropped



PRBS23/1000 Pattern Sensitivity

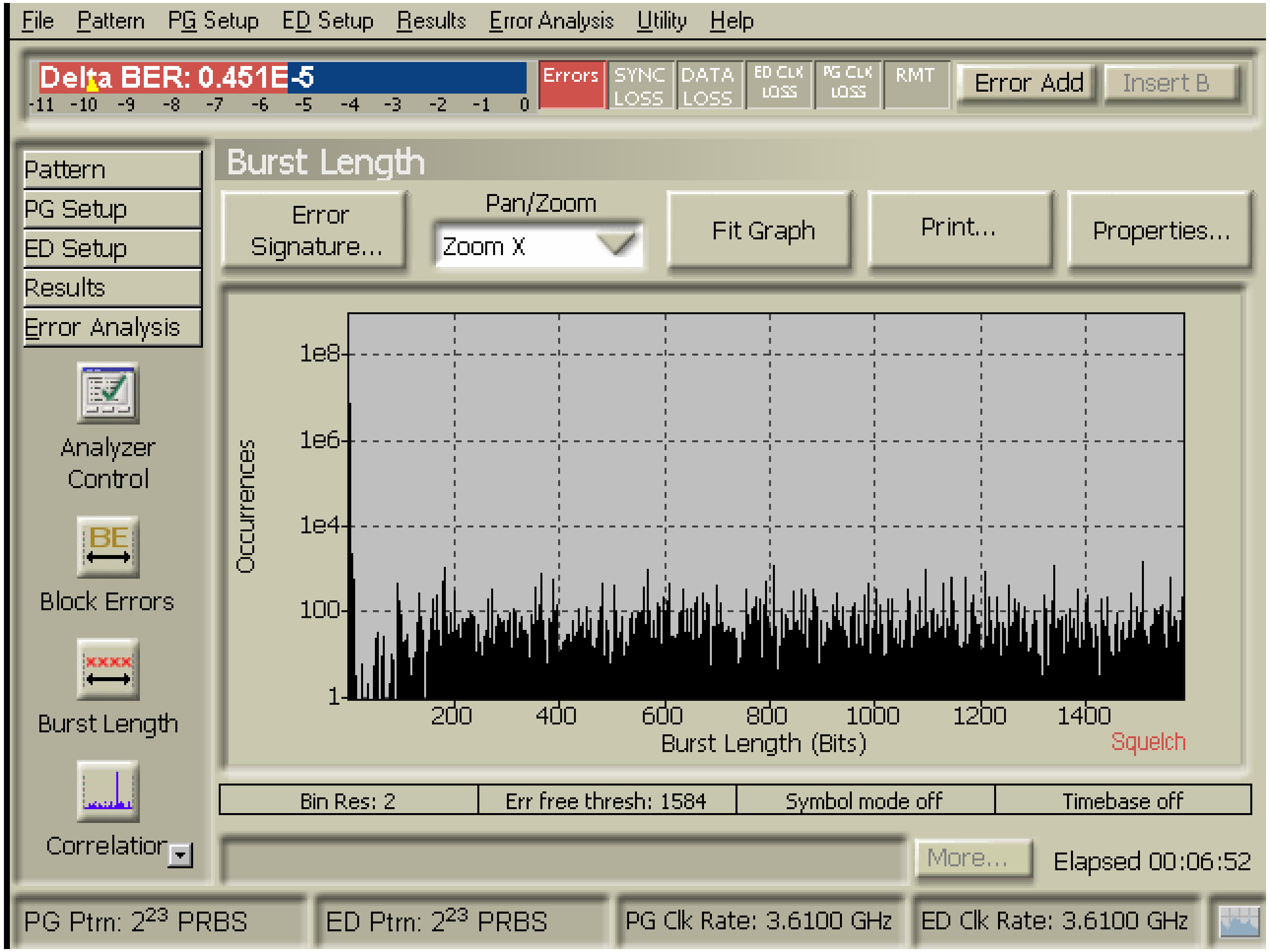
- **2^{23} PRBS**
- **1000mV Xt**

- At this scale a continuous spectrum of error locations
- The two original failure modes are now indistinguishable from the pack



PRBS23/1000 burst length distribution

- 2^{23} PRBS
- 1000mV Xt

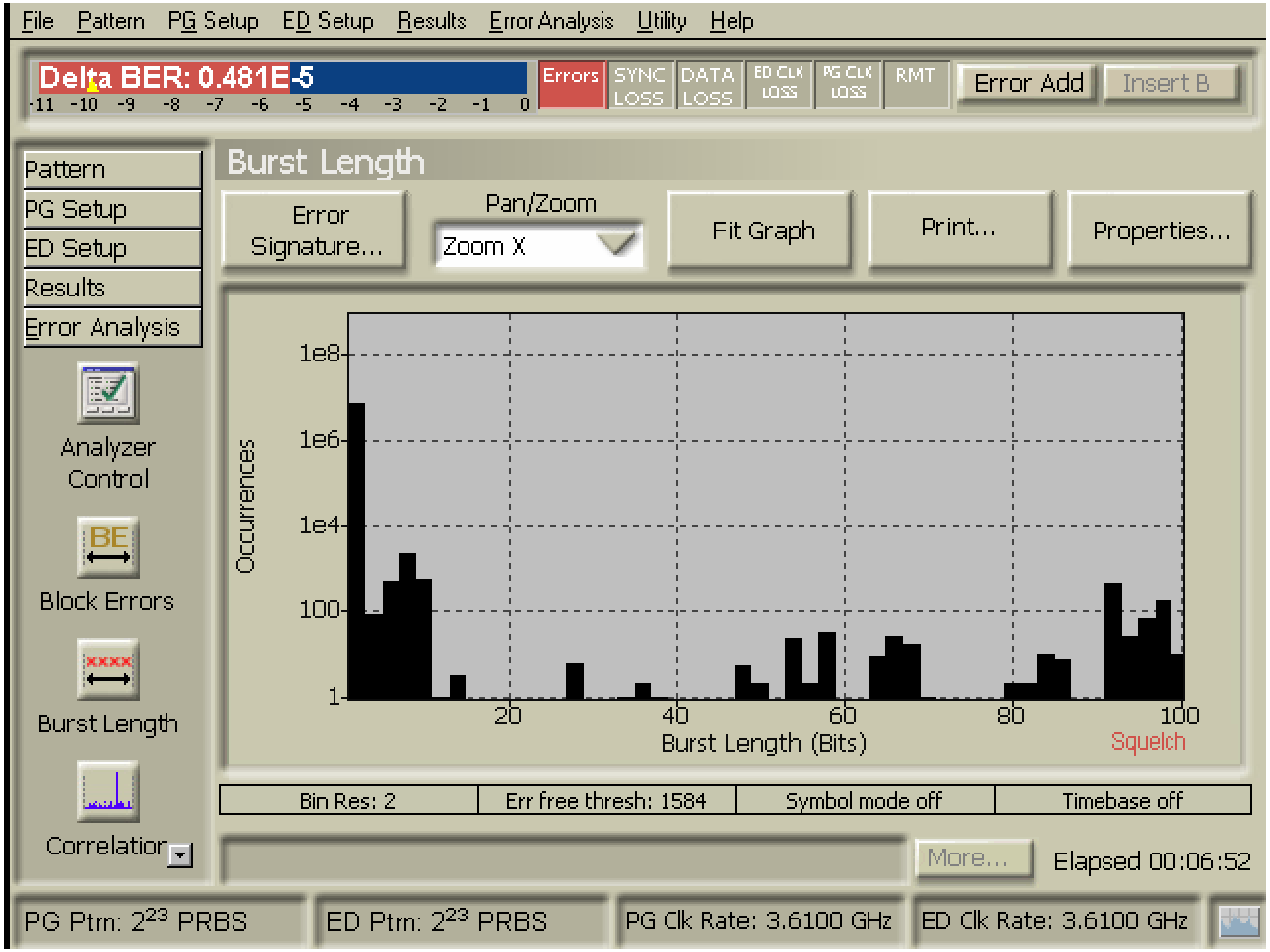


- A “random” distribution of error locations results in a “random” distribution of burst lengths

PRBS23/1000 burst length distribution

- **2^{23} PRBS**
- **1000mV Xt**

- A zoomed-in view of burst sizes <100
  - **Not so random at this scale**



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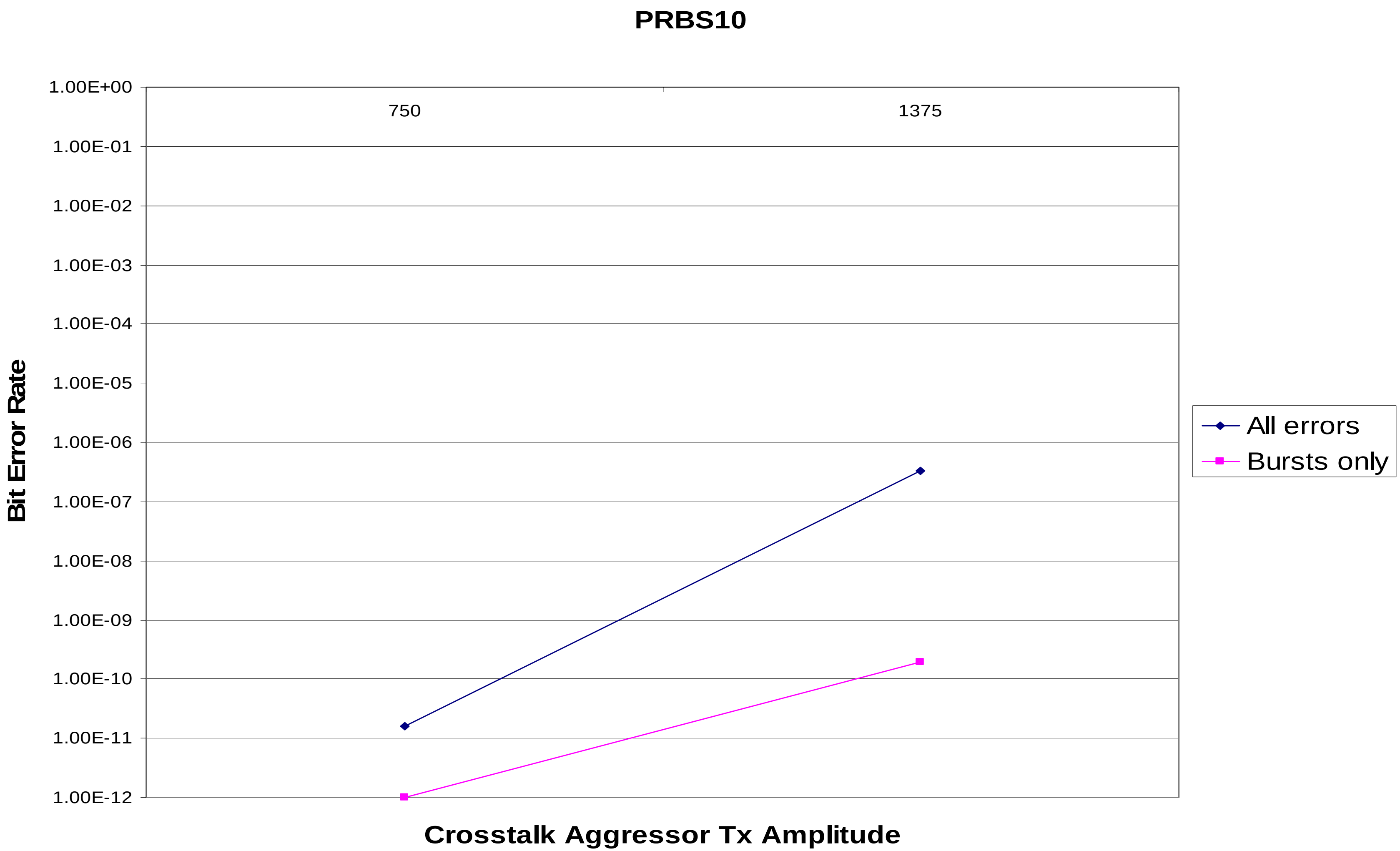
Interpreted Results

Burst error probabilities

- **The charts in the following slides show the relationship between overall BER and Burst error rate**
  - Any two error events less than 1584 bits apart are regarded as a burst
  - I did not acquire data for long enough to resolve burst error rates to levels better than $1e^{-12}$
    - Where 0 burst errors were detected, I have plotted rate as $1e^{-12}$

2^{10} PRBS Error rates



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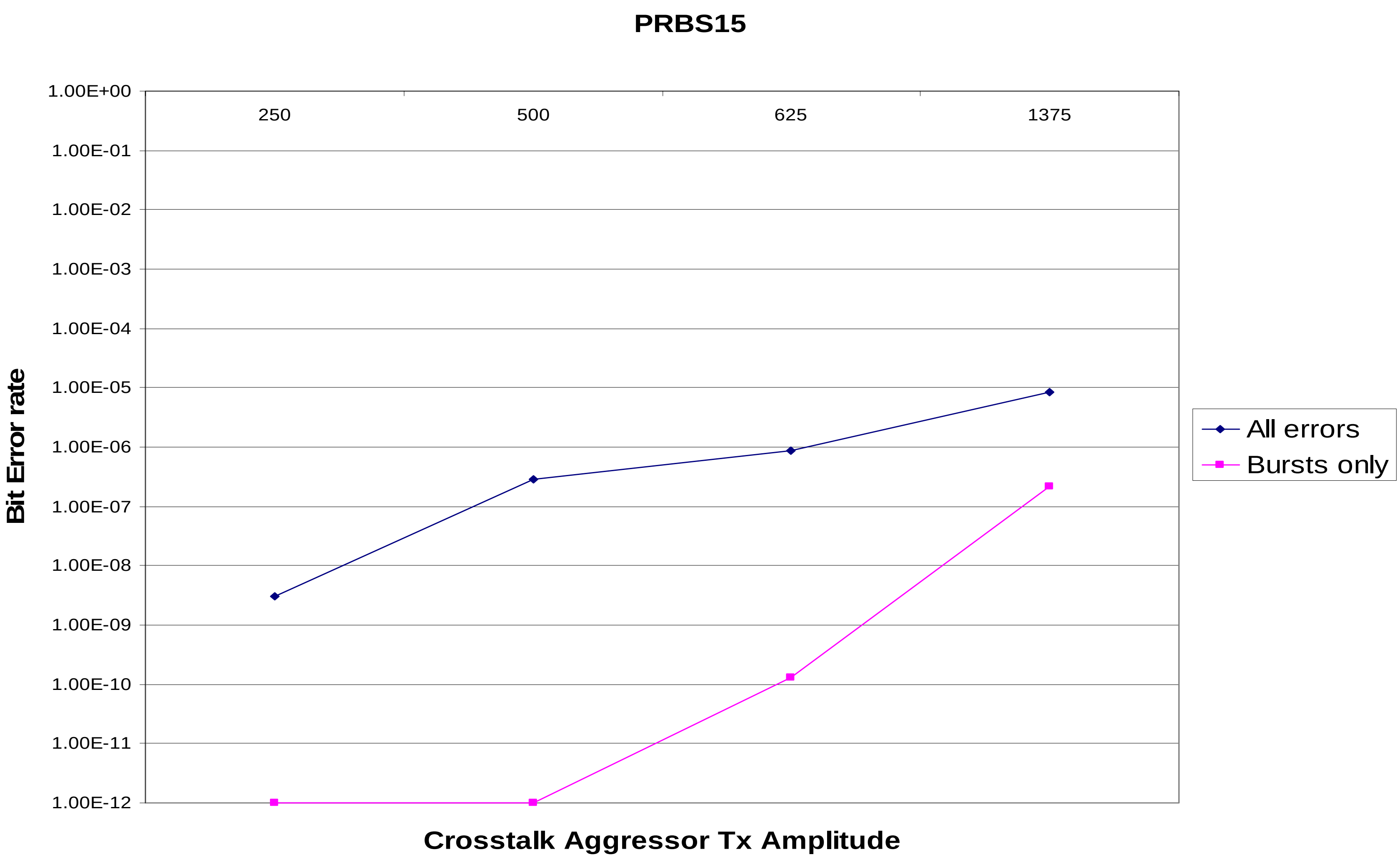
2^{15} PRBS Error rates



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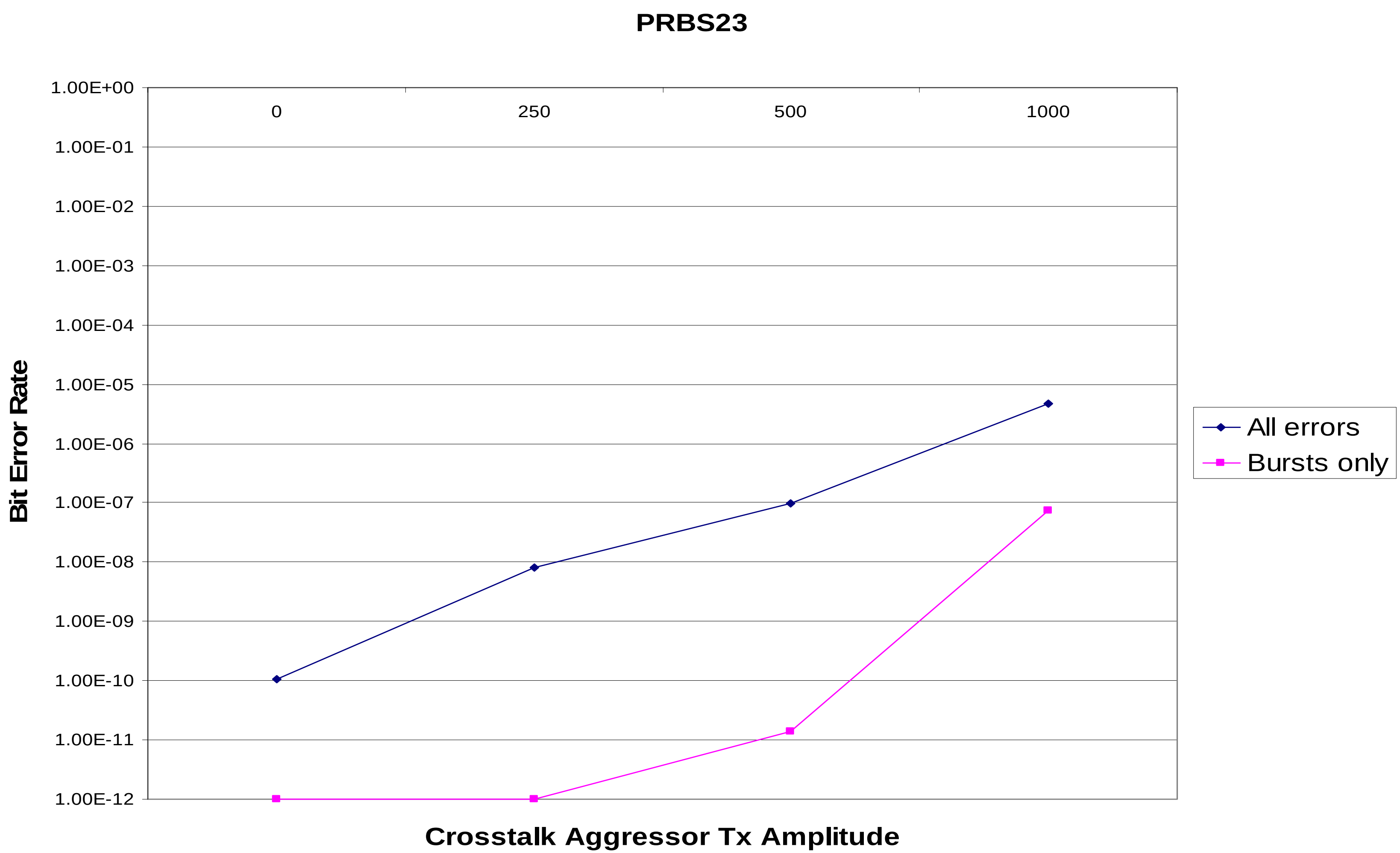
2^{23} PRBS Error rates



Conclusions (1)

1. **I see no evidence for any mechanism that causes multi-bit errors.**
    - The receiver used only has linear equalization
    - DFE is known to have error multiplication properties
2. **The rate of burst errors declines as the square of the decline in overall BER**
    - This is what we would expect if burst errors are made up solely of pairs of independent single bit errors
    - Due to this :
        a. For BERs below 1e-7 only single bit events were observed.
            - Within the (relatively) short acquisition time
        b. For BERs at or above 1e-7, burst errors within the 1584bit frame size of the CEI-P FEC start were observed.
            - However these "bursts" are pairs of single bit errors spaced less than 1584 bits apart.
            - No contiguous bit errors observed

Conclusions (2)

3. **The cause of bit errors is pattern sensitivity in the receiver.**
   - At lower BERs >80% of bit errors come from just 1 or 2 pattern positions in the shorter PRBS's.
   - Addition of crosstalk to the channel increases BER by increasing the number of errors that occur at sensitive points in the pattern.
     - For small and medium crosstalk amplitudes only a few major sensitive points seem to be stimulated
     - Large crosstalk amplitudes suddenly start stimulating many more sensitive points
       - If sensitive points are closely spaced they will produce burst errors

Conclusions (3)

4. **BER performance is strongly affected by length of PRBS used - longer PRBSs hit more sensitive spots.**
    - A Short PRBS (2^7) has low BER as it does not have the long strings of 1's & 0's needed in the sensitive patterns.
    - \- A Medium PRBS (2^{10},2^{15}) has worse BER as it hits more sensitive patterns, but doesn't generally cause burst errors unless the error points are <1584 bits apart.
    - \- A long PRBS (2^{23}) has worst BER. Sensitive points within the pattern have relatively random distribution leading to a semi-uniform distribution of error spacing (and hence burst length).

5. **If we presume scrambled data is random we will see similar BER results as that for long PRBSs.**
    - Ie error distribution will appear pretty uniform and random.
    - However if the underlying error mechanism is pattern dependant, it would certainly be possible to construct "killer patterns".
        - This is a far wider problem than the construction of FEC codes
            - there will be implications for CRC too.