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CIRCUIT TECHNOLOGY

APPLICATION NOTE #117

CT1553-1 Error Rate Analysis

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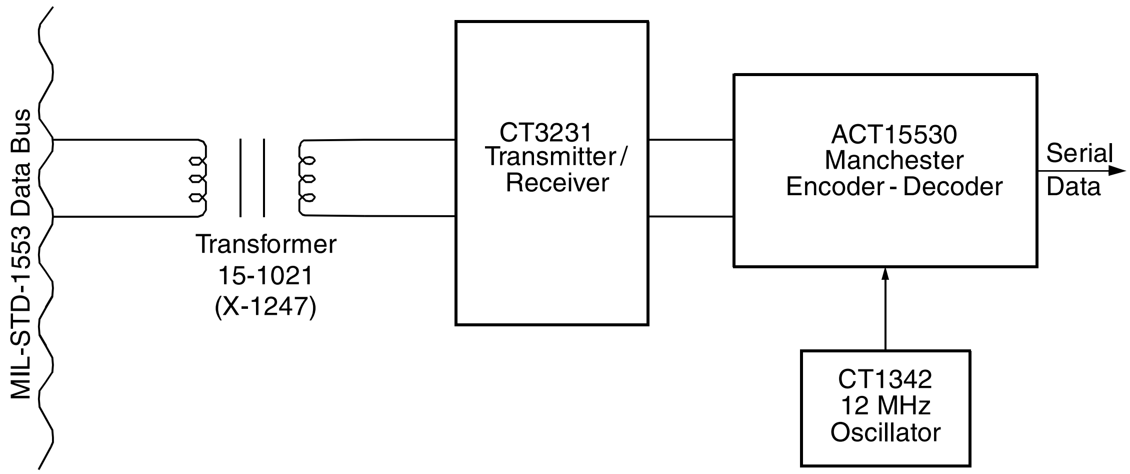

Figure 1
System Configuration of Analysis

This is a synopsis of the theory and summary of the calculations based on an ACT CT1553-1 Remote Terminal Unit.

The unit contains:

- **Interface transformer**
- **CT3231 Driver/Receiver Hybrid Microcircuit**
- **ACT15530 Encoder/Decoder**
- **12MHz Crystal Controlled Hybrid Oscillator**
- **Additional logic to present parallel Receive, Transmit Data and Subsystem Handshaking signals**

The object of the analysis is to calculate error rates that can be expected from this module design.

The analysis takes into consideration the actual filter in the CT3231, the various possible threshold settings that could be used as well as the algorithm of the ACT15530. It assumes that the transformer has the bandwidth, and proper inductance not to introduce any major errors.

EFFECT OF CT3231 FILTER:

Type — 3-Pole Butterworth
Cutoff Frequency (3db point) — 2MHz
Equivalent Noise Bandwidth —for a 3-Pole Butterworth, the noise bandwidth is 1.043 x fc. For the CT3231, NBW = 1.043 x 2 MHz = 2.086

EQUIVALENT NOISE GAIN:

Input Noise BW = 1 kHz to 4 MHz (per MIL-STD-1553B)
Filter Noise BW = 2.086 MHz
Noise Gain = Noise Density x Noise Bandwidth

$$= \frac{1}{\sqrt{4MHz}} \times \sqrt{2.086MHz} = \frac{1.442}{2} =$$

.721 Gain in RMS Value of Noise Voltage through the filter.

1553B RECEIVER PERFORMANCE SPECS

Stub Coupled. . . . . 140mVRMS Gaussian Noise,
1.05 VPK Signal;
No Response < 0. 1V;
Response > 0.43V;

$$\frac{S}{N} = \frac{\text{Signal}}{\text{Noise}} = \frac{1.05}{.140} = 7.5:1$$

Direct Coupled. . . . . 200mVrms Gaussian Noise,
1.5 Vpk Signal;
No Response < 0.14V;
Response > 0.60V;

$$\frac{S}{N} = \frac{\text{Signal}}{\text{Noise}} = \frac{1.5}{.2} = 7.5:1$$

Spec (MIL STD 1553B) requires WER = 10^{-7}

ACT15530 SAMPLING – GENERAL

The ACT15530 samples the signals that have been quantized by the two threshold comparators in the CT3231 hybrid receiver section.

Sampling of 1MHz bi-phase data with a higher frequency clock (12MHz) results in two cases to be analyzed for Bit-error contribution.

CASE A. The receiver can miss a half bit if the amplitude of the noise during sample times reduces the resultant signal to a value below the threshold settings.

CASE B. Noise occurring near the signal zero crossover intervals can result in an effective widening of the signal half bit giving rise to a condition termed as "extra half bit." If the widening can add enough pulse width, the sampling circuits will interpret the quantized signal as two half bits instead of one.

Both conditions must be considered to arrive at an optimum setting of the threshold comparators.

Example: If the threshold settings are low, missed bits become unlikely, but the probability of extra half bits increases. Higher threshold settings decrease the probability of extra half bits but increases the probability of missing a half bit.

Curves of the two functions have been generated and the threshold set at the point which produces the best combined performances.

ACT15530 Sampling Algorithm

(Half Bit Detection)

Requires a sample positive (>pos. thresh.) and the next two samples non-negative (not below negative threshold) for a positive half bit success. If either the second or third sample is negative (<neg. thresh.) then the positive sample is erased and logic searches for another positive sample set or a negative half bit by looking for the next 2 consecutive samples.

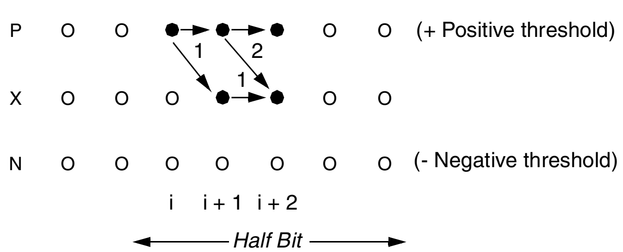

Figure 2

Sample Points for a Successful Positive Half Bit

Probability of a good half bit

$$P_{S_{Bit/2}} \equiv \sum_{i=1}^{7} P_{S_i}$$

$$P_{S_i} = (Pi \bullet Pi+1 \bullet Pi+2)_3 + (Pi \bullet Xi+1 \bullet Xi+2)_1 + (Pi \bullet Pi+1 \bullet Xi+2)_2 =$$

Prob. of Sucess.

Probability then must be calculated for all sample points for a half bit and then take the set of sample points over all phases of the sampling clocks with respect to the signal waveform. Since the probability of a good bit requires two half bit detections a second half bit calculation is performed. Some subtleties on this point are introduced later which considers data patterns.

True error is then the average over all phase relationships of the two clocks since the BER is measured over time periods far in excess of any single phase relationship. True error rate is the average of all pattern sequences since the data patterns are generated in a random matter.

For narrow band filter systems-noise is bandlimited to the filter bandwidth-there is a relationship between successive samples as they are not independent (correlation)-noise signal moves from sample to sample with less freedom than in pure independent statistical sense, relationship is defined by correlation coefficient derived from impulse response of the filter. Correlation analysis results in a slightly more pessimistic prediction of BER.

Detailed BER / WER Computations

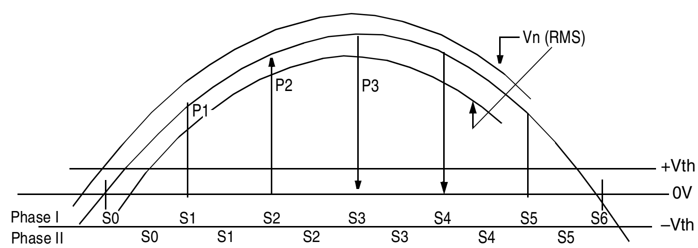

Figure 3

(Specific Sampling Points)

P1, P2, P3 are sample points
S1, S2, S3 are sample times
Vn = RMS value of noise

S/N ratio must be computed for each sample point

$S/N = \frac{P1 - (+Vth)}{Vn}$ or it is the value of noise required to drive the signal below the Positive Threshold. (For a 1st positive sample)

$\frac{P1 - (-Vth)}{Vn}$ is the value of noise required to drive a positive signal below the negative threshold.

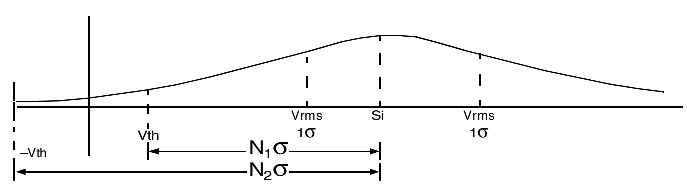

Figure 4

Displayed against the normal curve, it takes $N_1\sigma$ or N_1. Vrms noise voltage to cause a nonpositive sample or 1st sample miss. (Used in 1st sample point calculation). $N_2\sigma$ is the value of noise required to drive the positive signal below the negative threshold. (Used for 2nd and 3rd sample point calculations).

For Missed Bit Computations

Since the samples close to the zero crossing have low probability of being good, it is sufficient to analyze only the samples occurring near the high amplitude section of the signal.

Since the sampling times are transitions of the local oscillator they are asynchronous times with respect to the incoming signal. Therefore, the sampling must be averaged over all possible phases of the two frequencies (incoming signal and local oscillator).

A reasonable estimate can be achieved by investigating several phases and selecting the most significant phases of maximum distance and averaging the two.

Two computations are performed-missed bit and extra half bit. Calculations are performed for various values of threshold voltages and for a receiver with no filter and filter (discussed previously).

Examination of three sample points S2, S3 and S4 for being positive, non-negative (Refer to Figure 3).

	S2	S3	S4	Sample Points
	$\overline{P}_2$	$\overline{N}_3$	$\overline{N}_4$	All sample cases that result in misses, can be expressed as
	$\overline{P}_2$	N_3	$\overline{N}_4$	$Pmiss_1 = \overline{P}_2(\overline{N}_3\overline{N}_4 + N_3\overline{N}_4$
	$\overline{P}_2$	$\overline{N}_3$	N_4	$+ N_3N_4 + \overline{N}_3N_4) = \overline{P}_2(1)$
	$\overline{P}_2$	N_3	N_4	
PSUCCESS →	P_2	$\overline{N}_3$	$\overline{N}_4$	
	P_2	N_3	$\overline{N}_4$	$Pmiss_2 = P_2(N_3\overline{N}_4 + N_3N_4$
	P_2	$\overline{N}_3$	N_4	$+ \overline{N}_3N_4) \approx \; = N_3 + N_4$
	P_2	N_3	N_4	

$\therefore \; Pmiss = \overline{P}_2 + N_3 + N_4$

This says that the probability of a miss is controlled by $S_2 = \overline{P}_2$ which means the 1st sample below the positive threshold, or one of the next two samples being negative (below negative threshold).

$\overline{P}$ = Probability of S below positive threshold

$\overline{N}$ = Probability of S above negative threshold

It can be readily seen by examination of Figure 3, those sample points that limit error rate performance. A similar type analysis is performed for extra half bit conditions and is just stated here with the results presented in tabular form along with missed bit calculations.

Calculations (Based on Sinusoidal Waveform)

Sample	*Voltage (Phase I)	*Voltage (Phase II)
S0	0	0.271
S1	0.551	0.742
S2	0.909	1.014
S3	1.05	1.014
S4	0.909	0.742
S5	0.551	0.271
S6	0	

$$\frac{V_S \pm V_{th}}{V_N} = S/N \text{ (effective)}$$

$$\frac{V_S}{V_N} \pm \frac{V_{TH}}{V_N} = S/N_1 \pm S/N_2$$

Useful Tables

Phase I	Without Filter S/N$_1$ (140mV)	With Filter S/N$_1$ (100mV)
S0	-	-
S1	3.94	5.51
S2	6.49	9.09
S3	7.50	10.05
S4	6.49	9.09
S5	3.94	5.51
S6	-	-
Vth	**S/N$_2$ (140mV)**	**S/N$_2$ (100mV)**
100	0.714	1
130	0.928	1.3
160	1.143	1.6
190	1.36	1.9
Phase II	**S/N$_1$ (140mV)**	**S/N$_1$ (100mV)**
S0	1.94	2.71
S1	5.30	7.42
S2	7.24	10.14
S3	7.24	10.14
S4	5.3	7.42
S5	1.94	2.71
S6	-	-

**All voltages and calculations are referred to the Stub coupled mode of operation. For direct coupled equivalents, multiply all voltages by 1.40.*

Sample Calculation

Phase I

	PS2	NS3	NS4
S/N$_1$	9.09	10.05	9.09
S/N$_2$ (190 mV)	-1.90	+1.90	+1.90
	7.19	11.95	10.99
Pmiss	↓ (0.3×10^{-12})	↓ (0)	↓ (0)

(From Table of Nσ Normal Distribution Curve)

	PS3	NS4	NS5
	10.05	9.09	5.51
	-1.90	+1.90	+1.90
	8.15	10.99	7.41
	↓ (0)	↓ (0)	↓ (0.68×10^{-13})

Phase II

	PS2	NS3	NS4
	10.14	10.14	7.42
	-1.90	+1.90	+1.90
	8.24	12.04	9.32
	↓ (0.12×10^{-15})	↓ (0)	↓ (0)

Avg 1/2 BER

3.0×10^{-13} } Most significant
$.68 \times 10^{-13}$ }
$.0012 \times 10^{-13}$

3.68×10^{-13}

1.84×10^{-13} = 1/2 BER

Average number of times this 1/2 Bit Waveform appears is once per Bit. Average number of times this 1/2 BIT Waveform appears per word = 17 times.

WER $= 17 \times 1.84 \times 10^{-13} = 3.128 \times 10^{-12} = 0.3 \times 10^{-11}$

Summary of Calculations (Missed Bit) WER vs Vth

100 mV Vn (Filtered)

Vth = 190mV BER/2 . . .	0.3×10^{-12}	0.12×10^{-15}	0.68×10^{-13}
Avg WER		0.3×10^{-11}	
Vth = 160mV	0.319×10^{-13}	0.95×10^{-7} 0.55×10^{-11}	0.62×10^{-12}
Vth = 130mV	0.3×10^{-14}	0.16×10^{-17} 0.44×10^{-11}	0.52×10^{-11}
Vth = 100mV	0.274×10^{-15}	0.22×10^{-16} 0.34×10^{-9}	0.4×10^{-10}

140 mV Vn (Unfiltered)

Vth = 190mV	0.169×10^{-6}	0.18×10^{-8} 0.5×10^{-6}	0.57×10^{-7}
Vth = 160mV	0.58×10^{-7}	0.53×10^{-9} 0.49×10^{-6}	0.17×10^{-6}
Vth = 130mV	0.189×10^{-7}	0.28×10^{-9} 0.16×10^{-6}	0.48×10^{-6}
Vth = 100mV	0.33×10^{-8}	0.53×10^{-9} 0.3×10^{-7}	0.21×10^{-5}

Summary (Missed Bit)

Vth	No Filter Vn = 140mV	2MHz Filter Vn = 100mV
190	0.5×10^{-6}	0.3×10^{-11}
160	0.49×10^{-6}	0.55×10^{-11}
130	0.16×10^{-6}	0.44×10^{-11}
100	0.3×10^{-7}	0.34×10^{-9}

Summary (Extra Half Bit)

190	0.2×10^{-6}	0.16×10^{-12}
160	0.8×10^{-7}	0.5×10^{-14}
130	0.4×10^{-7}	0.6×10^{-11}
100	0.4×10^{-7}	0.32×10^{-13}

Summary – Total WER
(Average of Missed Bit and extra Half Bit)

190	0.35×10^{-6}	0.15×10^{-11}
160	0.28×10^{-6}	0.27×10^{-11}
130	0.1×10^{-6}	0.5×10^{-11}
100	0.35×10^{-7}	0.17×10^{-9}

As the threshold level increases above 190mV the WER starts to decrease rapidly. Since the threshold voltage will drift a maximum of ±40mV over the temperature extremes of the CT3231, an initial setting point must be selected so that over temperature the unit will not go below 100mV* or go much above 190mV. Aeroflex sets the threshold at approximately 160mV nominal.

* *To meet no response below 0.1 Volt.*