

Comments on the Caen TDC 1290 INL Correction

Ed Jastrzembski - 6/9/17

A previous document (“Notes on the Caen TDC 1290 Resolution” – 5/12/17) reported measurements of the Integrated Nonlinearity (INL) of the HPTDC chip in very high resolution mode and demonstrated the improvement in resolution obtained by correcting for it. The effects of such a correction on TDC bin distributions is discussed here.

The INL correction is summarized below. A code density test is used to measure the timing non-linearity of a single channel of an HPTDC chip. A large number of hits that are random in time are generated. If the generated hits are asynchronous with the clock of the HPTDC and all time bins are equally wide, then each bin of a histogram of the number of hits per timing bin will have the same number of entries. However, if the time bins vary in width, the histogram bins for wider time bins will collect relatively more hits than the histogram bins for narrow time bins. In very high resolution mode there are 1024 bins per clock cycle so only the lowest 10 bits of the reported TDC time (21 bits) are utilized in binning the data for the code density test.

Define the following:

$$n(i) = \text{number of hits in bin } i \text{ (} i = 0 - 1023 \text{)}$$

$$N(k) = \sum_{i=0}^{k-1} n(i) \quad (k = 1 - 1023), \quad N(0) = 0$$

$$N_{Total} = \text{total number of hits}$$

For perfect bins of uniform width, each bin would have a count close to $N_{Total}/1024$. Set the sum $N(k)$ of k actual bins equal to the sum of kp uniform bins (where kp is permitted to have a fractional part):

$$N(k) = kp N_{Total}/1024$$

$$kp = 1024 N(k) / N_{Total}$$

Define the integral nonlinearity as:

$$INL(k) = k - kp$$

The INL data ($INL(k)$, $k = 0-1023$) is written to a file and can be used to compensate for INL in *subsequent* data runs. Let *time* be a reported TDC hit (21 bits). Explicitly:

$$k = \text{time} \& (0x3FF) \quad (\text{bin within clock cycle})$$

$$kp = k - \text{round}(INL(k)) \quad (\text{corrected bin - round to nearest integer})$$

The consequences of applying this correction are explored. Consider hits in 3 bins ($k1, k2, k3$) where

$$k1 < k2 < k3.$$

Since $N(k)$ is a non-decreasing function of k , the above relation implies that

$$N(k1) \leq N(k2) \leq N(k3).$$

Since $kp = 1024 N(k) / N_{Total}$, the mapped bins satisfy

$$kp1 \leq kp2 \leq kp3.$$

That is, the bin mapping of the INL correction preserves bin ordering, with the exception that multiple bins may be mapped to the same corrected bin. In essence, the correction locally expands or contracts the bins across the fixed width 1024 bin interval. The statement (p.23) in the TDC 1290 User Manual [1] that the bins are “scrambled” by the correction is somewhat of an exaggeration.

It is also clear from the above that the only possible *1 to 1* mapping of k to kp is the trivial one, $kp = k$ (i.e. no correction).

Since the bin count is fixed at 1024, each kp bin that has 2 bins mapped into it will result in 1 bin ($kp1$) that has *no* bins mapped into it (so $n(kp1) = 0$, always). And each kp bin that has 3 bins mapped into it will result in 2 bins ($kp1, kp2$) that have *no* bins mapped into them (so $n(kp1) = n(kp2) = 0$, always).

Thus, an expected consequence of the INL correction is the appearance of bins with exactly 0 counts.

This is demonstrated with data obtained in the previous study. **Figure 1** shows the measured INL of a single TDC channel clocked at 41.666 MHz. Compensation from the table stored on the TDC 1290 module is turned OFF. In the raw data, there are *no* bins with zero counts.

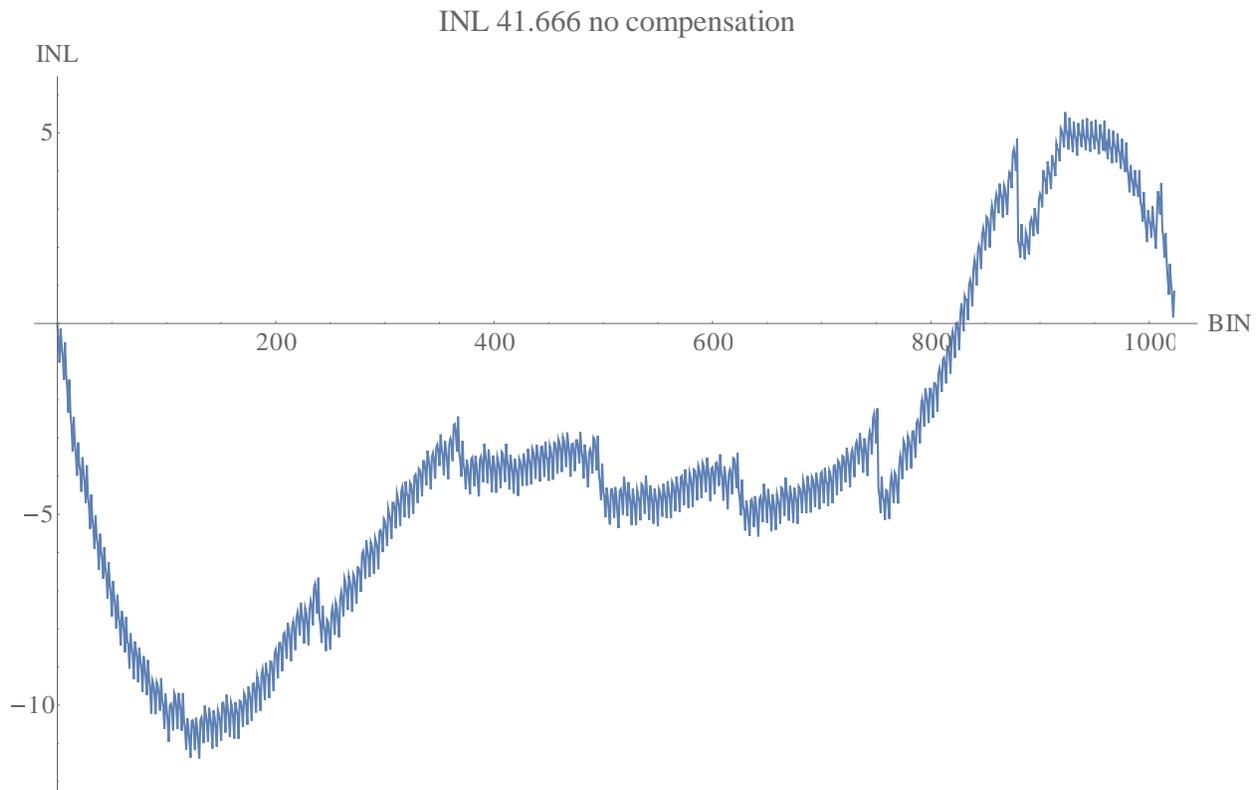


Figure 1. INL at 41.666 MHz.

Figure 2 shows the bin mapping of the INL correction. **Figure 3** shows the mapping over a restricted range. The red dashed line in each figure is the mapping $kp = k$ (no correction).

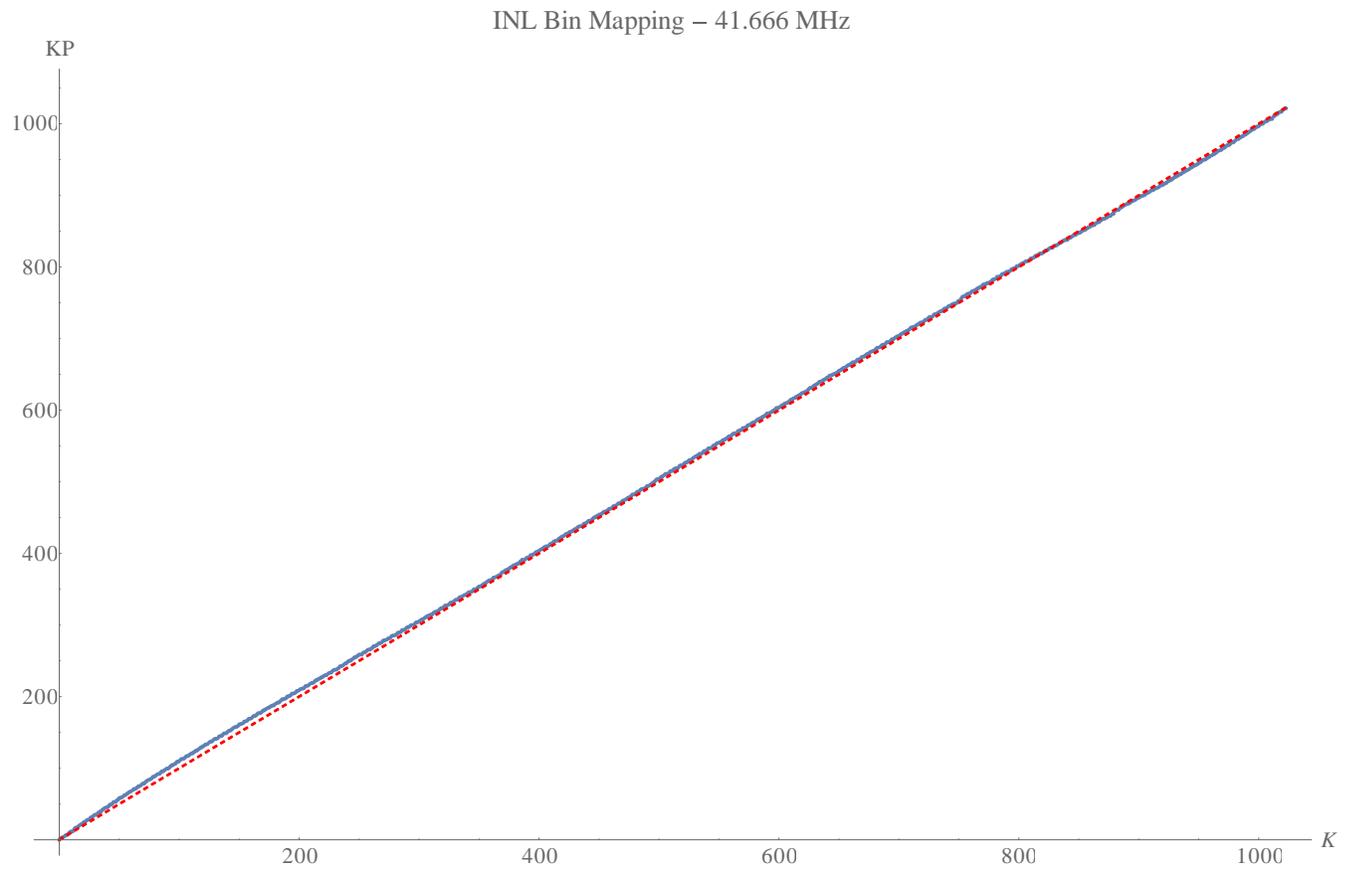


Figure 2. INL bin mapping.

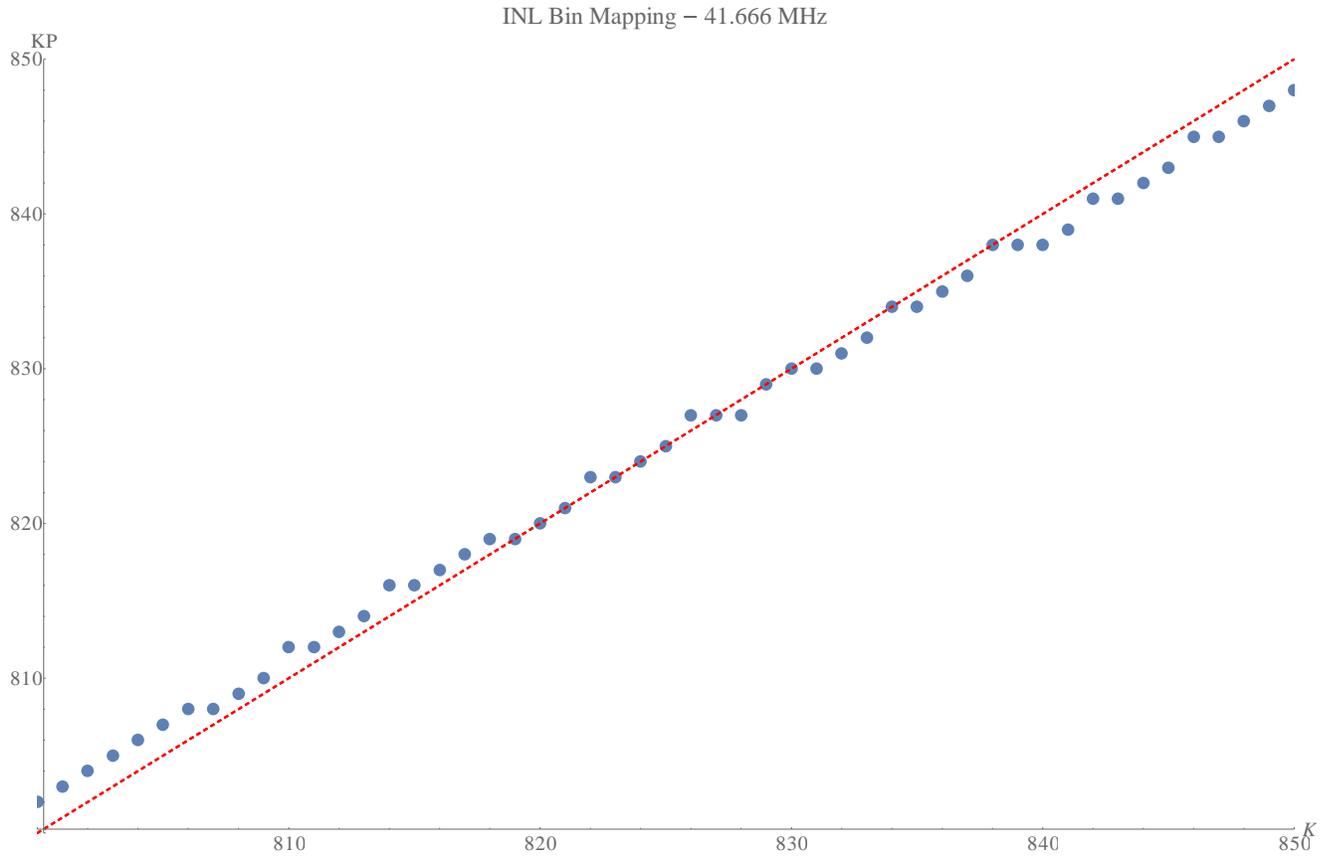


Figure 3. INL bin mapping.

The mapping of multiple bins into single bins and the voids that are created in kp are visible in **Figure 3**.

We define the mapped bin density as the number of bins mapped into a corrected bin kp . **Figure 4** shows the mapped bin density of the INL correction. **Figure 5** shows the density over a restricted range.

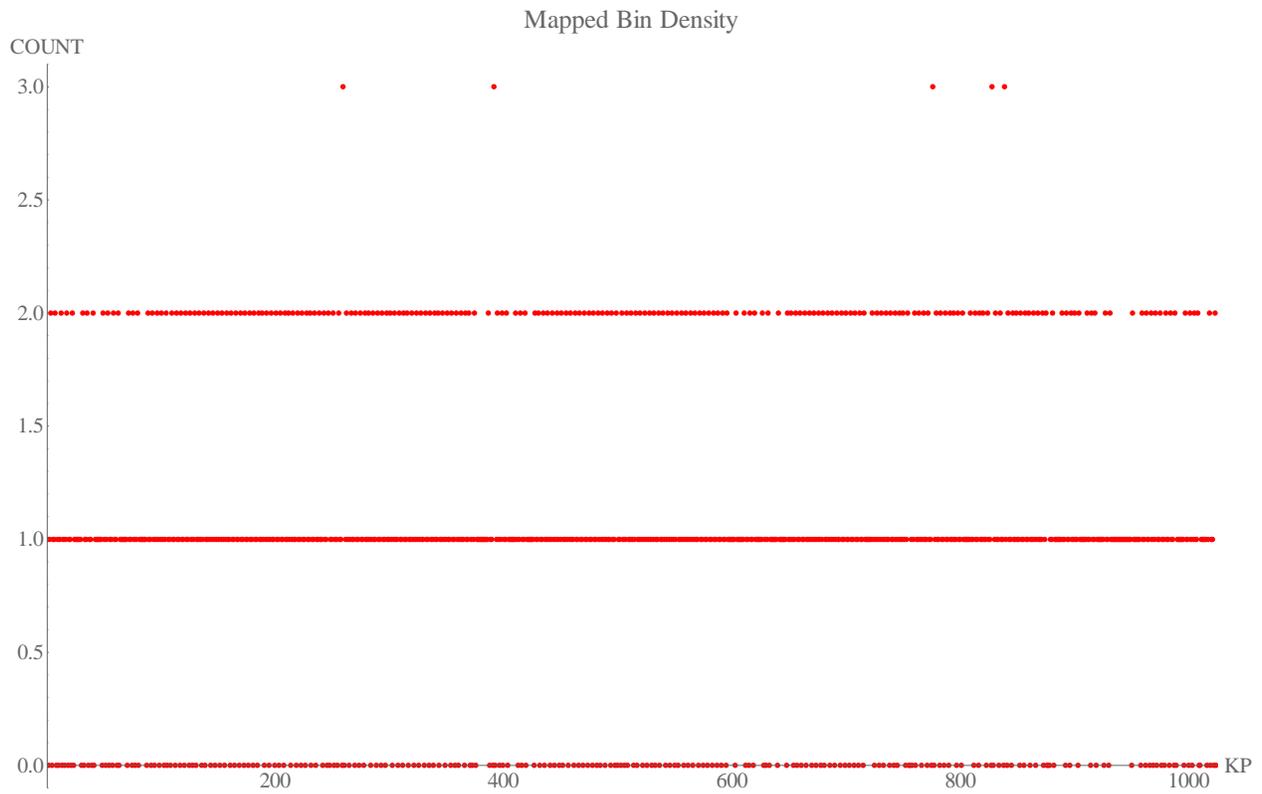


Figure 4. Mapped bin density.

Bins with 0 mappings = 236 (23.0%)

Bins with 1 mappings = 557 (54.4%)

Bins with 2 mappings = 226 (22.1%)

Bins with 3 mappings = 5 (0.5%)

Bins with 0 mappings = (Bins with 2 mappings * 1) + (Bins with 3 mappings * 2)

$$236 = 226 + 10$$

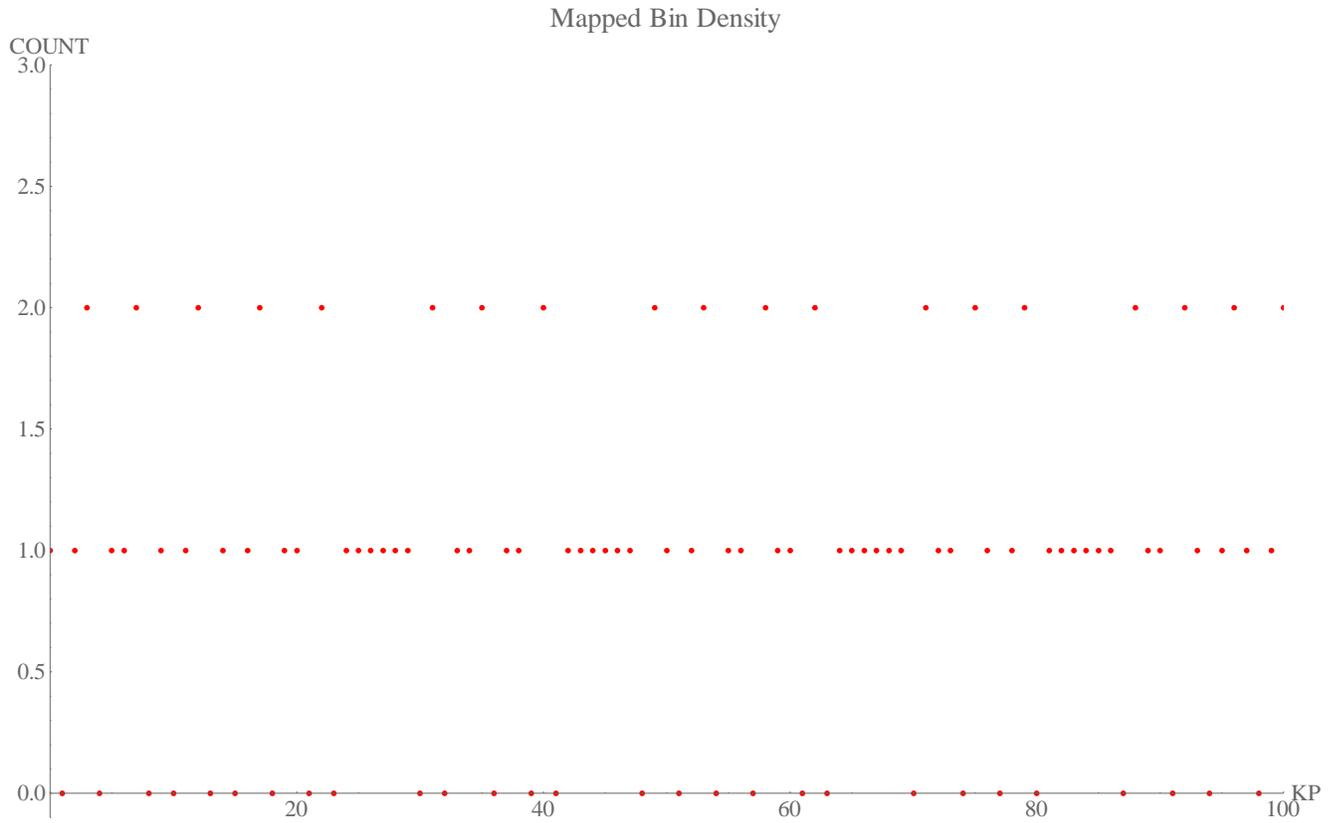


Figure 5. Mapped bin density.

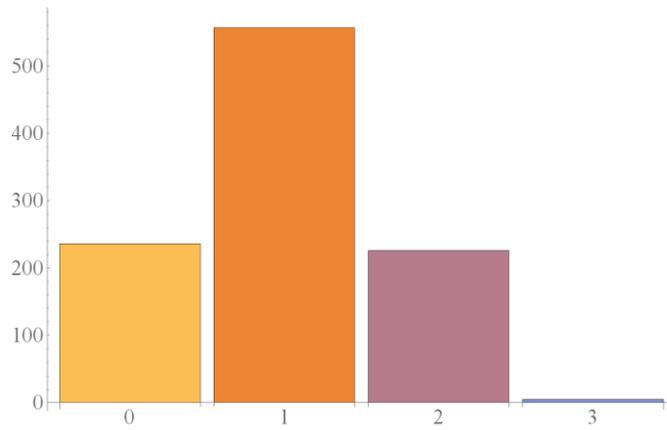


Figure 5. Bin mapping count.

References

1. Caen V1290 User Manual

<http://www.caen.it/servlet/checkCaenManualFile?Id=8653>