

QPLL - Irradiation tests & Status

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Outline

- Irradiation tests
 - Crystal
 - QPLL2
- QPLL status:
 - Production
 - Production testing

Thanks to Karl GILL for setting up the irradiation campaign

Irradiation conditions

□ Devices:

- 6 × QPLL2
- 6 × Xtal (tuned to 4.6 pF)

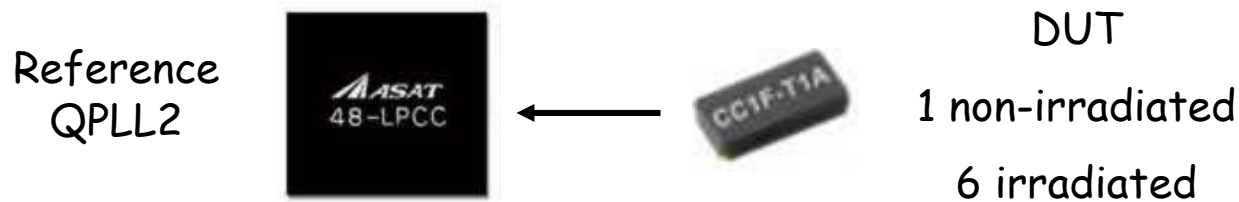
□ Irradiation dose:

- Group 1: 10 Mrad (Co-60 γ) + 3 E15 n/cm²
 - QPLL2: 3 and 4, Xtal: 2 and 3
- Group 2: 10 Mrad (Co-60 γ) + 9 E14 n/cm²
 - QPLL2: 5 and 6, Xtal: 5 and 6
- Group 3: 10 Mrad (Co-60 γ) + 6 E14 n/cm²
 - QPLL2: 1 and 2, Xtal: 1 and 4

Xtal - irradiation test

□ Test conditions:

- Pre-irradiation characterisation: 7 crystals
- Irradiation: 6 crystals
- Reference crystal: 1 non-irradiated
- Reference QPLL2: 1 non-irradiated
- Post-irradiation characterisation: 7 crystals
- (All crystals tuned to 4.6 pF, not exactly the final device)
- Measurement:
 1. externalControl = 1
 2. foSelect<5:0> = 100000 and Vdd = 2.5V
 3. clockIn = 0 → f(low) and clockIn = 1 → f(high)



Xtal - irradiation test

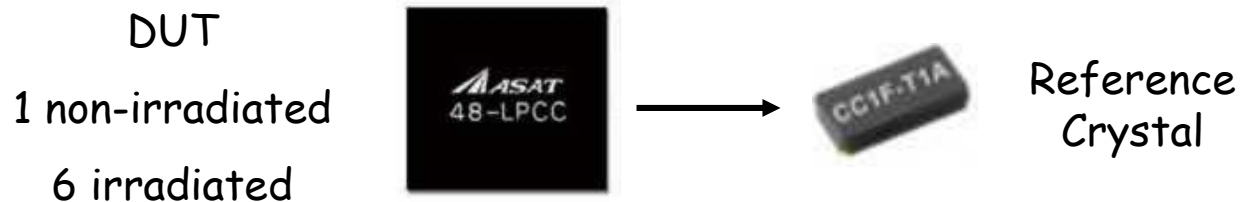
- Neutron irradiation:
 - Positive frequency shift
 - Worst case observed: 9 ppm for 3 E15 n/cm²

Post irradiation frequency shift					
XTAL	Dose [n/cm ²]	$\Delta f(\text{low})$ [Hz]	$\Delta f(\text{low})$ [ppm]	$\Delta f(\text{high})$ [Hz]	$\Delta f(\text{high})$ [ppm]
R	0	-10	0	-75	-2
1	6 E14	68	2	58	1
2	3 E15	308	8	137	3
3	3 E15	330	8	351	9
4	6 E14	229	6	188	5
5	9 E14	141	4	115	3
6	9 E14	96	2	66	2
< Δf >		195	5	152	4
σ		111	3	108	3
MAX		330	8	351	9

QPLL2 - irradiation test (1)

□ Test conditions:

- Pre-irradiation characterisation: 7 QPLL2
- Irradiation: 6 QPLL2
- Reference QPLL2: 1 non-irradiated
- Reference crystal: 1 non-irradiated
- Post-irradiation characterisation: 7 QPLL
- Measurement:
 1. `externalControl = 1`
 2. `foSelect<5:0> = 100000` and `Vdd = 2.5V`
 3. `clockIn = "0"` → `f(low)` and `clockIn = "1"` → `f(high)`



QPLL2 - irradiation test (1)

Post irradiation frequency shift				
QPLL2	$\Delta F(\text{low})$ [Hz]	$\Delta F(\text{low})$ [ppm]	$\Delta F(\text{high})$ [Hz]	$\Delta F(\text{high})$ [ppm]
R2	39	1	-41	-1
1	-486	-12	-914	-23
2	-399	-10	-820	-20
3	-314	-8	-672	-17
4	-444	-11	-847	-21
5	-501	-12	-943	-24
6	-418	-10	-813	-20
< Δf >	-427	-10	-835	-21
std	67	2	95	2
"MAX"	-501	-12	-943	-24

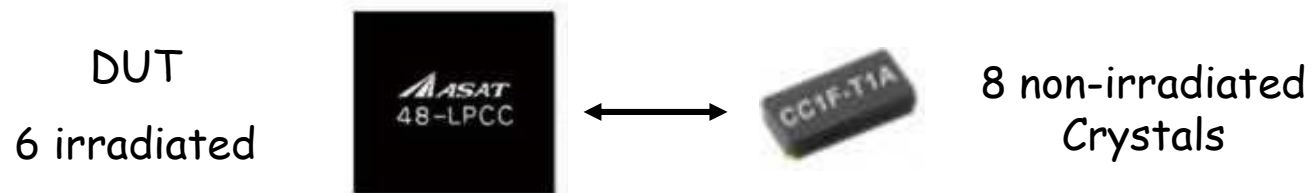
Bandgap voltage shift	
QPLL2	ΔV_{gap} [mV]
R2	0
1	267
2	224
3	200
4	260
5	273
6	230
< ΔV >	242
std	29
MAX	273

QPLL2 - irradiation test (1)

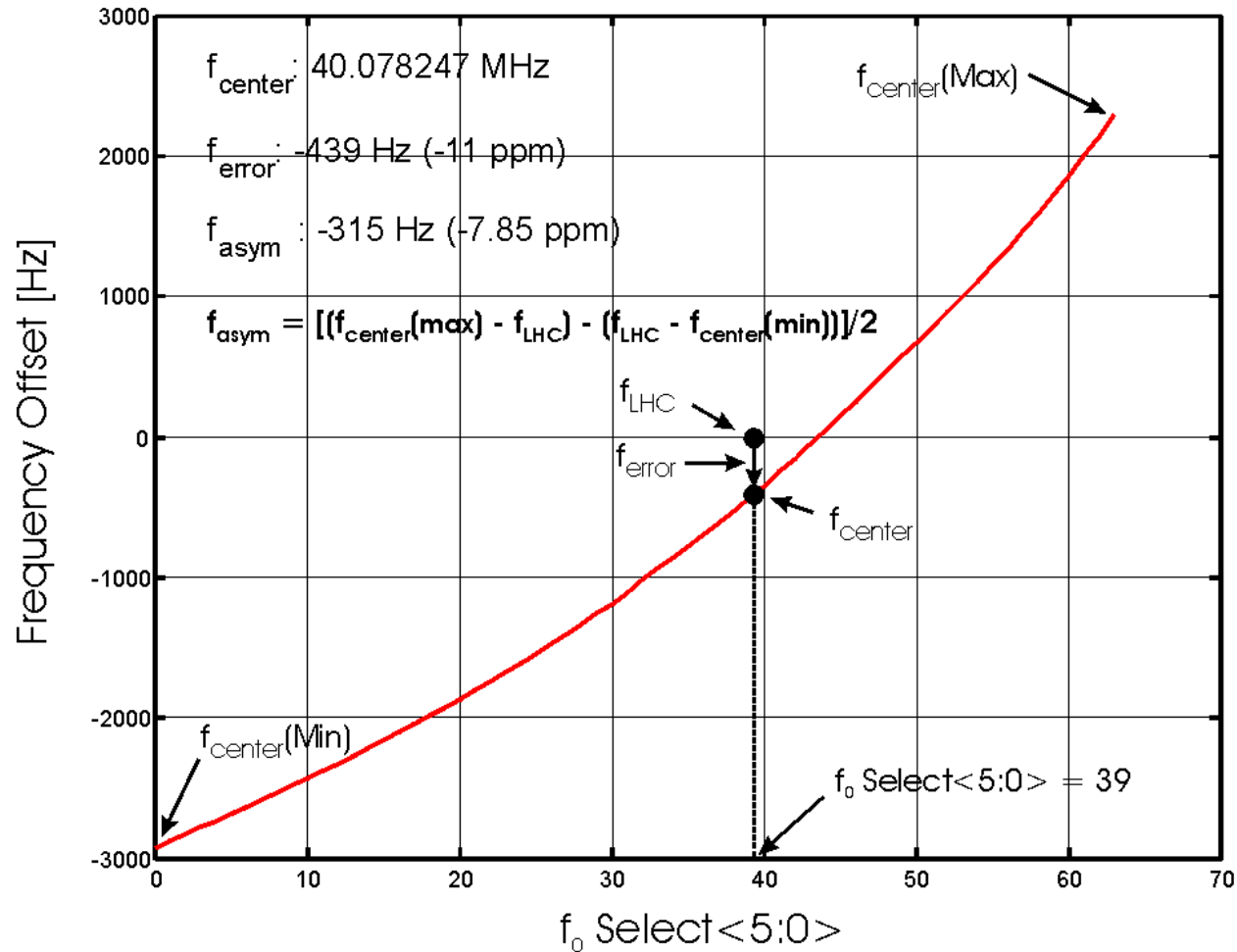
- Ionizing irradiation:
 - 10 Mrad (Co-60 γ) all chips
 - Negative frequency shift
 - Worst case observed: -24 ppm
 - The frequency shift is correlated with the bandgap voltage shift
 - Bias circuit
 - On chip voltage regulator
 - The mechanism responsible for the bandgap voltage shift is identified
 - "bandgaps" manufactured in ALTIS much less sensitive (see: <http://www.cern.ch/proj-qpll/images/bandgapRadEffects.pdf>)
 - QPLL tape out to ALTIS foundry done in March

QPLL2 - irradiation test (2)

- Test conditions:
 - No pre-irradiation characterisation
 - Irradiation: 6 QPLL2
 - Crystals: 8 non-irradiated, tuned to 5.5 pF (the final devices)
 - Post-irradiation characterisation:
 - 6 QPLL2 each one tested with 8 non-irradiated crystals
 - Measurement:
 1. externalControl = 1
 2. foSelect<5:0> = All values and Vdd = 2.5V
 3. clockIn = "0" → f(low) and clockIn = "1" → f(high)



QPLL2 - irradiation test (2)

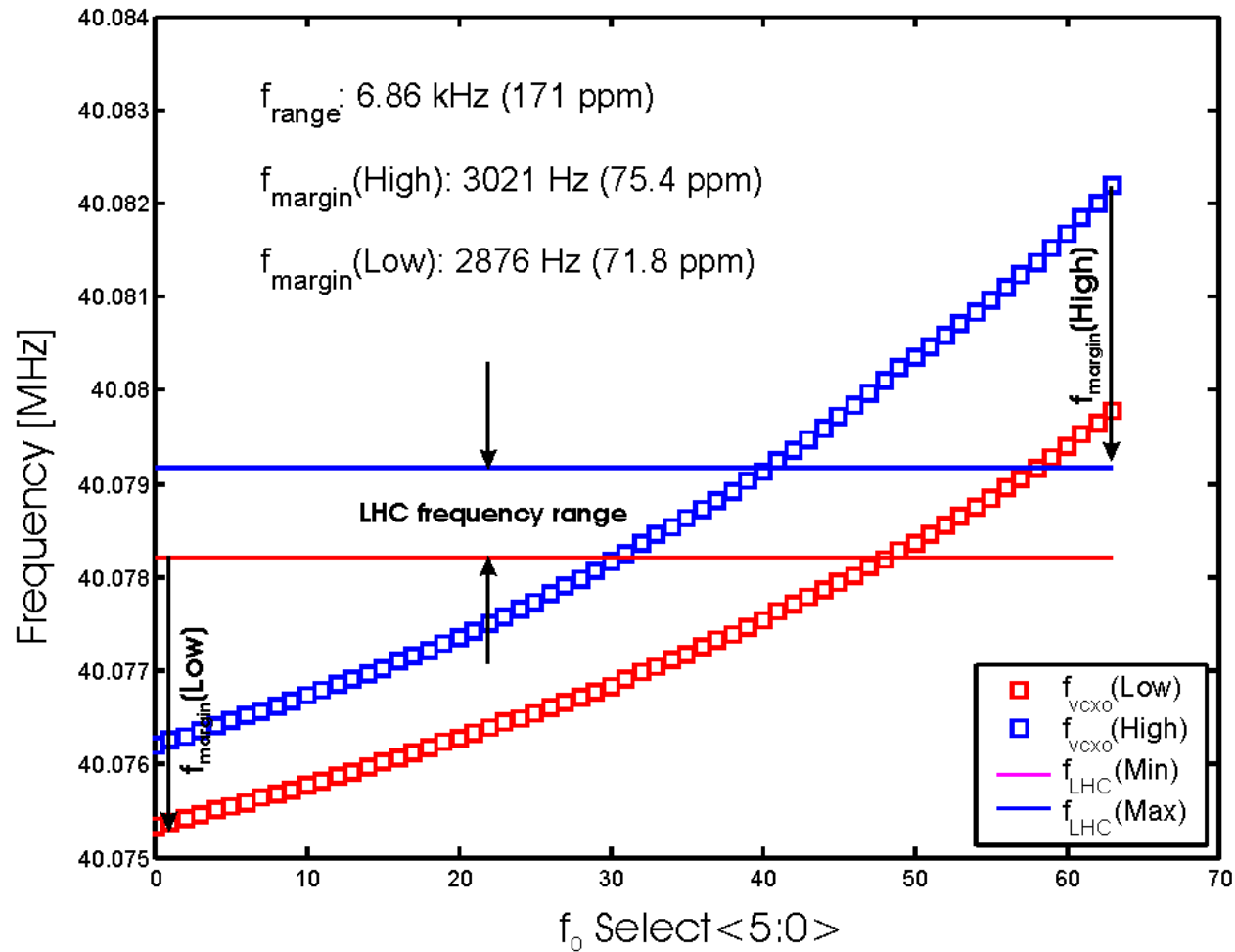


QPLL2 - irradiation test (2)

- "All QPLL - All Xtal" measurements collected together
- See picture on previous page for "definitions"
- Full irradiation data can be retrieved from the QPLL web site:
 - <http://www.cern.ch/proj-qpll>
 - Radiation Effects
 - <http://www.cern.ch/proj-qpll/images/qpll2IrradData.pdf>

	f_{centre} [MHz]	f_{error} [Hz]	f_{error} [ppm]	$f_{\text{asymmetry}}$ [Hz]	$f_{\text{asymmetry}}$ [ppm]
< >	40.077808	-913	-23	-833	-21
σ	0.000538	577	14	599	15
Min	40.076397	-2290	-57	-2190	-55
Max	40.078716	-30	-1	-15	0

QPLL2 - irradiation test (2)



QPLL2 - irradiation test (2)

- See picture on previous page for “definitions”
- Full irradiation data:
 - <http://www.cern.ch/proj-qpll/images/qpll2IrradData.pdf>

	f_{range} [kHz]	f_{range} [ppm]	$f_{\text{marg}}(\text{low})$ [Hz]	$f_{\text{marg}}(\text{low})$ [ppm]	$f_{\text{marg}}(\text{high})$ [Hz]	$f_{\text{marg}}(\text{high})$ [ppm]
< >	8.00	200	3830	96	3261	81
σ	0.74	18	707	18	774	19
Min	6.83	170	2524	63	1861	46
Max	9.50	237	5241	131	5029	125

QPLL - Status

□ Production:

- 18,500 chips in "MPW11": Burlington Foundry

1. Tape out done
2. Wafers in 4 weeks
3. + 6 weeks for packaging

- 10,000 chips in "CRTALL": ALTIS Foundry

(improved radiation tolerance)

1. Tape out done
2. Wafers in 10 weeks
3. + 6 weeks for packaging

□ Production testing test setup:

- Hardware developed
- Software close to completion