The AMAC ASIC for the ATLAS ITk silicon strip detector Results of prototype wafer testing

Division of Particles & Fields 2021

Luis Felipe Gutierrez







Outline

Jul 14, 2021

ASICs Design and Fabrication Overview

•Wafer Testing Setup at Penn

 AMAC Functionality and Performance Characterization

• AMAC Prototype Wafer Testing Results







ASICs Design and Fabrication Overview

Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results



ASIC Cycle Overview

Jul 14, 2021





ASIC Fabrication Overview



Wafer Testing

Jul 14, 2021





Wafer with dies

Dicing

DPF 2021 - AMAC Prototype Wafer Testing Results



Wafer Testing Setup at Penn

Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results



Probe Station, Probe Card and Test Board



Probe Station



DPF 2021 - AMAC Prototype Wafer Testing Results



Probe Card Needles







Wafer Die



DPF 2021 - AMAC Prototype Wafer Testing Results

Jul 14, 2021

Wafer Dies





Contact and Software



Probe Card - Die Contact

Jul 14, 2021

Probe Station Controller Software

Current setup takes a bit less than 4 minutes per AMAC





Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results

AMAC Functionality





AMAC Functions

AMAC desired functionality are translated to ASIC functions:

Power Status:

• i.e. DC-DC Converter

Parameter Calibration:

• i.e. VDD/AM Bandgap (Adjustable reference voltage)

Logic Control:

• i.e. Hybrid reset

Analog/Digital Conversions:

• i.e. External Voltages/Currents Measurements

Jul 14, 2021

Design tests to check ASIC functions. Types of tests:

- AMAC can be configured
- Resets
- Autonomous feature
- Range of measurements
- Measurements accuracy

DPF 2021 - AMAC Prototype Wafer Testing Results



AMAC Performance Characterization

Jul 14, 2021





Vital and Performance Functions

To know how well an AMAC is performing, we classify the AMAC functions in two:

- 1. Vital Functions (Absolutely needed for AMAC to work):
 - AMAC needs to power ON
 - AMAC needs to communicate
 - AMAC needs to recover
 - AMAC needs to turn things off, etc.
- 2. Performance Functions:
 - Measuring external currents accurately
 - Setting desired voltages, etc.

Jul 14, 2021

Functions tests output parameters used to characterize AMAC performance

• More than 1000 parameters per die

Die Grade	Vital Functions Tests	Performance Functions Tests
A		
B		
С		
F		-





Prototype Wafer AMAC Testing Results

Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results



Green: Die passed all tests (Grade A)

Red: Die failed at least one test (Grade B, C or F)

		Pas	s: 9	91 (94.8	8%)	Α	TLA	Progress VICVPYI				
	0	Fai	l: 5	(5.	2%)	1	2	3	4	5			
					13	12	11	10	9	8	7	6	
				14	15	16	17	18	19	20	21	22	
_5000	00		33	32	31	30	29	28	27	26	25	24	23
ו מאוז			34	35	36	37	38	39	40	41	42	43	44
one			55	54	53	52	51	50	49	48	47	46	45
-10000	00-		56	57	58	59	60	61	62	63	64	65	66
2			77	76	75	74	73	72	71	70	69	68	67
-15000				78	79	80	81	82	83	84	85	86	
-15000					93	92	91	90	89	88	87		•
							94	95	96			•	
		-50000 -25000 0 25000 50000 750										00'000) 1250

Jul 14, 2021



AMAC from 12 prototype wafers probed at Penn

- Dies tested: 1152
- Average yield: 96%



Main Failure (15): Highest Internal Voltage Reference

Below desired voltage range Visual Examination: AMbg ramp function Maximum Deviation (full range): 2.47m Fit param 0: -0.01 ± 0.00 580.00 m Fit param 1: 0.58 ± 0.00 — AMbg ramp function data (within range) Standard Deviation (target range): 1.28m 850.00 m data (outside range) Maximum Deviation (target range): 2.47m Standard Deviation (full range): 1.28m 560.00 m **ATLAS Work-In-Progress** 800.00 m Wafer Name: V0CVRFH (A) 98009 900 750.00 m 540.00 m 500BG(V) **Die: 83** 520.00 m ADC Q 500.00 m Failed 700.00 m 480.00 m Fit param 0: -0.02 ± 0.00 Fit param 1: 0.87 ± 0.00 650.00 m Standard Deviation (target range): 1.04m 460.00 m Maximum Deviation (target range): 3.51m Standard Deviation (full range): 1.04m 10 12 14 4.00 m 5.00 m Residue (V) 0.00 -5.00 m -4.00 m 10 12 14 END AMBG(bit)

Desired internal voltage reference: 0.65V-0.59V (Best is closest to 0.625V).

Highest internal voltage reference limits: 0.85V-0.78V

Jul 14, 2021

Performance function parameter









- Average yield over 12 wafers is 96% (Grade A dies).
 - More work will be done towards defining grade B and C dies.
- Main failure is a performance test parameter: Highest Internal Voltage Reference.
- Coming soon: Improved AMAC testing and probe station controlling softwares.







Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results





Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results

Backup



Prototype Wafer Reticle

ATI AS Work-In-Progress

							AC AD	AB AB	AC AD	AB AA	AC AD	AB aA	AC AD	AB AB	AC AD	AB	AC	AB AA	AC AD	A GA					
							AA	AA	AA	AA	₩	AA	AA	AA	A A-	AA	AA	AA	AA	AA					
							AA	₩	¥¥	AA	AA	AA	AA	AA	AA	AA	AA /	¥¥.	AA	AA					
					AC AD	AB		B I	AC	AB ₽	a∧ S	AB dA	AC AD	AB GA	a∧ S	AB AB	AC AD	AB	R Sa	AB ⊿A	AC AD	AB AA			
					AA	¥X	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	¥¥	AA			
					¥¥	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA			
			AC AD	AB	AC A	AB a∧	AC ∧⊔	BA ⊡∧	a∧ Ac	AB ⊿A	a∧ S	AB dA	AC AD	AB aA	a∧ S	AB dA	AC	AB aA	AC AD	AB dA	AC	₹. ₹ ₹	A C AD	AB AA	
			AA	ЖX	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	¥∀	AA	
			¥¥	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	
	AC	AB	f /a	AB GA	AC AD	AB AB	AC	AB dA	AC AD	AB	AC AD	AB dA	AC AD	AB dA	AC AD	AB dA	AC	AD dA	AC AD	AB dA	AC AD	AB AA	an S	A ∎	a۸
	AA	∀∀	∕∀∀	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	<i>₩₩</i>	۲
	AA	¥∀	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	Y
	ACA₽	B	a∧ Ao	AD AB	AC AD	AD AB	AC A⊡	AD AB	AC №	AB	a∧ S	AB dA	¥ V	AB GA	a∧ S	AB	ACA₽	AD AB	AC AD	AB dA	AC AD	AB	av S	AB dA	é4
	∀∀/	¥∀	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	ł
	∀∳	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	۲
	av S	AB a∧	AC AD	AD AB	AC AD	AB dA	AC AD	AD AB	AC AD	AB ₫A	a∧ AD	AB dA	AC AD	AD AB	AC AD	AB dA	A AD	AD AB	A AD	AB dA	AC AD	AB	AC AD	AB dA	_
	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	
2	ΑA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	
5	a∧ AC	AB ^{GA}	AC AD	AB dA	AC AD	AB dA	AC AD	AB dA	AC AD	AB dA	a∧ AD	AB dA	AC AD	AD AB	AC AD	AB dA	A AD	AB ₫A	A AD	AB dA	AC AD	AB	AC AD	AB dA	
	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	
	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	
		AB dA	AC AD	AD AB	AC AD	AD dA	AC A⊡	AD AB	AC A⊡	AD GA	a∧ S	AD dA	¶ A⊓	AD AB	a∧ S	AD GA	AC AD	AD dA	AC AD	AD dA	AC A⊡	AB	a A	AB dA	α¥
	AA	ÁΑ	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	Y
	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	/y
	a∧ AD		GA AD	AD AB	GA AD	AD dA	AC A⊡	AD AB	AC A⊡	AB	a∧ S	AD AB	AC AD	AD AB	a∧ S	AB	AC	AD AB	AC AD	AD AB	¥ ¥0	AB	a∧ A	AB ▲	Þ
	AA	₩¥	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	ΑA	AA	¥∀∕	£
	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	₩	₩ע	۲
			u ¥	AB GA	AC AD	AB AA	AC	AD AB	AC AD	AB	AC AD	AB AB	AC AD	AD AB	AC AD	AB AB	AC	AB AB	AC AD	AB dA	AC	AB	∎ ∕S	AB dA	
			AA	ÁΑ	AΑ	AΑ	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	¥₹	AA	
			AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	XX	AA	AA	
						AB	AC	AD AB	AC AC	AB AB	AC AD	AB AB	AC AD	AB	AC AD	AB AB	AC	AB AB	AC	AB	₽	AB			
					AA	ЖŔ	$\forall \forall$	ΑA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AΑ	AA	AA	×₩∀	AA			
					AA	$\forall A$	₩¥	AA	AA	$\forall A$	AA	AA	AA	AA	AA	AA	AA	AA	¥¥	AA	$\forall \forall$	$\forall A$			
							ACAD	AB		AB V≅	AC AD	AB	ACAD	AB	AC	AB	A A	B							
							AA	AA	AA	AA	AA-	AA	AA	AΑ	¥¥-	-44	AA	AA					*	кЛ	~
							$\forall \forall$	AA	$\forall \forall$	$\forall A$	AA	$\forall A$	$\forall A$	$\forall A$	AA	$\forall \forall$	$\forall A$	$\forall \forall$						IVI	d

Notch

Jul 14, 2021

DPF 2021 - AMAC Prototype Wafer Testing Results

ATLAS Work-In-Progress

Die ID	Design Name	Estimated Max Die Size X	Estimated Max Die Size Y	Estimated Quantity on Wafer
AA	ABCSTAR	8057	7090	371
AB	HCCSTAR	3650	5450	98
AC	AMAC	3650	5450	96
AD	PATT	2577	3650	199
			Total on Wafer:	764

ap rotated on purpose to have notch on the left (testing orientation)





Green: Die passed all tests (Grade A) **Red:** Die failed at least one test (Grade B, C or F)



DPF 2021 - AMAC Prototype Wafer Testing Results



Green: Die passed all tests (Grade A) **Red:** Die failed at least one test (Grade B, C or F)



DPF 2021 - AMAC Prototype Wafer Testing Results



Green: Die passed all tests (Grade A) **Red:** Die failed at least one test (Grade B, C or F)



DPF 2021 - AMAC Prototype Wafer Testing Results



Green: Die passed all tests (Grade A) **Red:** Die failed at least one test (Grade B, C or F)



DPF 2021 - AMAC Prototype Wafer Testing Results



Prototype AMAC Wafer Testing Failures

ATLAS Work-In-Progress

Parameter name	Failures	Parameter name	Failures	Parameter name	Fail
AMbg ramp intercept	15	Hx Flag Logic 100	2	DCDC Flag Logic 011	
ADC AM VDDLR A	10	Hx Flag Logic 010	2	DCDC Flag Logic 010	
No communication	8	Hx Flag Logic 000	2	DCDC Flag Logic 001	
Best slope	7	Hx Flag Latching	2	DCDC Flag Logic 000	
Best AM600BG	5	HV2 Flag Logic 110	2	CH9 Zero Calib	
VDDbg ramp ADC VDD range max	4	HV2 Flag Logic 100	2	CH8 Zero Calib	
DCDC Flag Latching	4	HV2 Flag Logic 010	2	CH2 Zero Calib	
CH14 Zero Calib	3	HV2 Flag Logic 000	2	CH15 Zero Calib	
VDDbg ramp ADC VDD range min	2	HV2 Flag Latching	2	CH13 Zero Calib	
Hy Flag Validation Val3	2	HV0 Flag Logic 110	2	CH11 Zero Calib	
Hy Flag Validation Val2	2	HV0 Flag Logic 100	2	CH10 Zero Calib	
Hy Flag Validation Val1	2	HV0 Flag Logic 010	2	Best VDD	
Hy Flag Logic 110	2	HV0 Flag Logic 000	2	CH6 Zero Calib	
Hy Flag Logic 100	2	HV0 Flag Latching	2	CH3 Zero Calib	
Hy Flag Logic 010	2	DCDC Flag Logic 111	2	CH1 Zero Calib	
Hy Flag Logic 000	2	DCDC Flag Logic 110	2	CH12 Zero Calib	
Hy Flag Latching	2	DCDC Flag Logic 101	2	CH0 Zero Calib	
Hx Flag Logic 110	2	DCDC Flag Logic 100	2		

Jul 14, 2021

ures
2
2
2
2
2
2
2
2
2
2
2
2
1
1
1
1
1



Topological analysis

Edge dies: 29 per wafer (30.2%).

- Total edge dies tested: 348
- Total edge dies failures: 28 ullet
- Edge dies yield: 92.0%

Core dies: 67 per wafer (69.8%)

- Total core dies tested: 804 lacksquare
- Total core dies failures: 18 lacksquare
- Core dies yield: 97.8%

DPF 2021 - AMAC Prototype Wafer Testing Results



Some reticles are cut because it is a multidie project wafer







Wafer Edge Exclusion Zone

Burkeen, Vedula, Meeks - "Transition from a planar surface to the wafer bevel creates a high-stress area"

- Film does not adhere properly
- Film delamination

Jul 14, 2021







AMAC Probe Cards Comparison

Probe Card 1



ATLAS Work-In-Progress

Jul 14, 2021

Probe Card 2





AMAC Probe Cards Comparison

Wafer Name: VHCVPZH **Die Number: 2**

Row 2: ADC_AM_VDCDC_V is supposed to be zero. 60% difference is pure noise.

Row 9:

VDDbg_ramp_function_ADC_VDD_range _max is mostly affected by contact. With the second probe card we had better contact on this die, that is why we see 9.2% difference

> **Overall: Wafer results from both** probe cards were consistent

ATLAS Work-In-Progress

diff parcent	kov.	wal card 1	val car
			vat_car
1 626120		0.027527	1.4/9
60 000105		0.03/33/	0.030
00.000105		0.000361	0.000
0.000000		0.000155	0.000
0.000000		0.000015	0.000
1.4/9922		0.004175	0.003
4.404230	AUC_VUU_HI_A_KU7_4HVU3	0.005000	0.004
0.243329	ADC_AM_LVDS_CMI	0.690013	0.691
1.100191	<pre>vbbbg_ramp_tunction_ADC_vbb_range_min</pre>	1.105200	1.1/8
9.185040	VDDbg_ramp_tunction_ADC_VDD_range_max	1.246810	1.361
0.2/3296	AMbg_ramp_tunction_intercept	0.820452	0.818
0.385548	Best_AM600BG	0.613413	0.611
0.236353	Best_slope	0.960850	0.958
0.806888	Best_VDD	1.219500	1.229
0.000000	CH0_Zero_Calib	36.000000	36.000
0.000000	CH1_Zero_Calib	34.000000	34.000
0.000000	CH2_Zero_Calib	25.000000	25.000
3.703704	CH3_Zero_Calib	27.000000	28.000
0.000000	CH4_Zero_Calib	30.000000	30.000
0.000000	CH5_Zero_Calib	26.000000	26.000
0.000000	CH6_Zero_Calib	30.000000	30.000
3.333333	CH7_Zero_Calib	30.000000	31.000
0.000000	CH8_Zero_Calib	28.000000	28.000
0.00000	CH9_Zero_Calib	27.000000	27.000
0.00000	CH10_Zero_Calib	35.000000	35.000
0.00000	CH11_Zero_Calib	35.000000	35.000
6.250000	CH12_Zero_Calib	16.000000	17.000
0.00000	CH13_Zero_Calib	31.000000	31.000
0.00000	CH15_Zero_Calib	35.000000	35.000
0.00000	CH14_Zero_Calib	127.000000	127.000





AMAC Power Consumption vs. RO Frequency

One of the ideas was to reduce current consumption by slowing down the AMAC ring oscillator frequency

ATLAS Work-In-Progress

Die 1 (ZeroCalib ON, AMen OFF)												
RO Frequency Setting	0	1	2	3	4	5	6	7				
RO Frequency (MHz)	29.3	29.9	31.2	31.9	34.1	34.7	36.7	37.5				
Current Consumption (mA)	36.8	36.8	37.5	37.7	38.3	38.9	40.7	39.8				

ATLAS Work-In-Progress

Die 2 (ZeroCalib ON, AMen OFF)												
RO Frequency Setting	0	1	2	3	4	5	6	7				
RO Frequency (MHz)	29.6	30.2	31.5	32.2	34.3	35.0	37.0	37.8				
Current Consumption (mA)	36.0	36.8	37.4	36.8	39.1	39.8	40.0	39.8				



ATLAS Work-In-Progress

Die 1 (ZeroCalib OFF, AMen OFF)												
RO Frequency Setting	0	1	2	3	4	5	6	7				
RO Frequency (MHz)	29.3	29.9	31.2	31.9	34.1	34.8	36.7	37.5				
Current Consumption (mA)	36.8	36.8	36.8	37.7	38.3	38.3	39.8	39.7				

ATLAS Work-In-Progress

Die 2 (ZeroCalib OFF, AMen OFF)												
RO Frequency Setting 0 1 2 3 4 5 6 7												
RO Frequency (MHz)	29.6	30.1	31.5	32.1	34.4	35.0	36.9	37.8				
Current Consumption (mA)	35.9	36.0	37.7	37.4	38.3	39.1	40.6	40.7				

Conclusion: Lower RO Frequency results in lower power consumption

