Part I: Combinational Circuit Study Report

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ABSTRACT
The main goal of the experiment is to create a more efficient TV population algorithm, that provides better fault coverage results. Once new TVs are created, compare coverage to results from ece464 project 2, and analyze improvements (if any).

1 INTRODUCTION

Several different PRNGs were considered to come up with better ways to generate new TVs. For example, John von Neumann's "Middle Square" method. Biggest flow of it is that it cannot constantly generate new number 256 times in a row without repeating itself (for any seed). The thought of designing an experiment that was initially destined to failure was not very appealing. After some research, it became clear that it might be challenging to beat performance of 5 TVs described in Project 2 for that same reason. Therefore, it was decided to attempt to modify TVs from Project 2 to get better results with same or less efforts in testing.

Hypothesis:
Better fault coverage could be achieved by flipping test vector bit-wise values

- for every TV in a certain sequence of TVs - "Flip Everything"
- for every odd TV in a certain sequence of TVs - "Alt-Flip"

Within this experiment both ways are examined.

2 METHODS AND PROCEDURES

Experiment Design:
The values of lines in the circuit should be changed to discover new faults. The more values are changed with application of new TV – the more fault coverage can be obtained. At the same time if one part of the circuit never changes values from TV to TV, it will provide similar coverage, wasting time and resources. It makes sense to attempt to improve on techniques of populating randomized TVs used in project 2.

2.1 *Flipping every TV's bit - "Flip Everything".*

Most of gates in provided circuits are either AND or NAND gates. For example circuits below:

- c880.bench : 143 ANDs + 150 NANDs + 29 ORs + 61 NORs + 26 buffers
- c499.bench: 56 ANDs + 40 NANDs + 2 ORs + 104 XORs
- c432.bench: 4 ANDs + 119 NANDs + 19 NORs + 18 XORs

AND gates change values only if all inputs are 1s. Part of randomization is to try introduce more 1s in TV. For the first part of the experiment, every bit of populated TVs was flipped in the following matter:

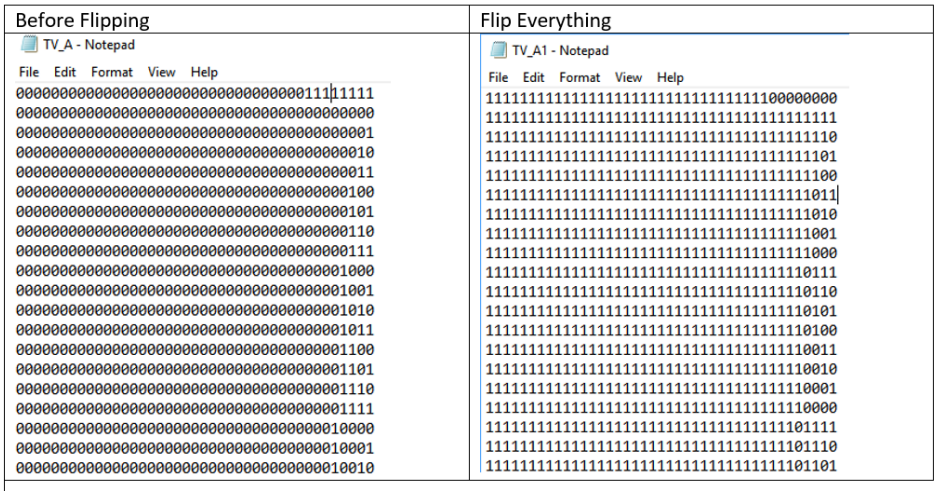

Figure 1. Modify TVs with Flip Everything method

Amount of 1s within test vector heavily depends on the seed for all of the TVs used in Project 2, except for TV A, where seed only affects first 8 bits from right. So it makes sense to flip remaining bits to have more 1's total. For TVs B-E it is not proper to judge whether Hypothesis is correct or not,because the seed affects the whole length of the TV (not just last 8 bits), which means that initial input could be selected to include more 1's without "flipping" technique at all. So in this case we are mostly interested in TV A, even though results for this particular test were better for every TV. Seed = 255, Batch = 10 Circuit c432. **Figure 3** .

Since TV A method, generally speaking, is not the most effective algorithm, it was decided to not continue testing circuits using "flip everything" method.

2.2 *Flipping every second TV's bit - "Alt-Flip".*

Flipping every second TV in a set is attempted. It provides significant change of TV and also would still provide unrepeated list of TVs in a set.* Every set is modified in the following manner:

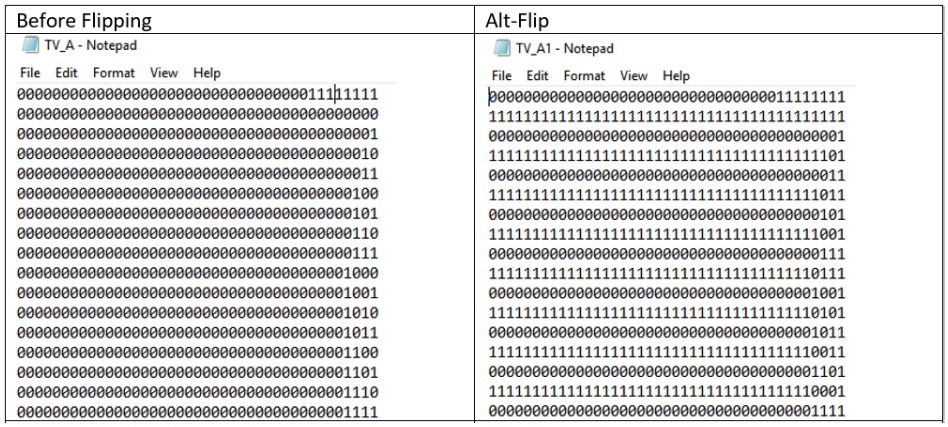

Figure 2. Flip Everything method results for c432 circuit. Green color shows better coverage.

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Three different circuits were tested using Alt-Flip method: c432, c499 and c880. See Results section for testing results (**Figures 4 - 9**)

[1]* TV B and TV C in fact are exceptions, since flipping bits actually produces repetition of TVs. But it is unrepeated for TV A, E and D, including TV E - test vector with best coverage.

3 RESULTS

3.1 *Results of "Flip Everything".*

This section shows testing results for Flip Everything method. It was tested with c432 circuit.

Circuit: c432
Seed = 255
Batch size = 10
NO FLIPPING

batch #	A	B	C	D	E
1	35.24436	38.25188	30.73308	43.1391	49.06015
2	35.33835	44.3609	36.74812	55.54511	63.43985
3	35.33835	44.73684	38.53383	55.6391	75.93985
4	39.84962	46.42857	53.66541	59.49248	83.08271
5	40.50752	49.81203	58.45865	59.49248	84.49248
6	40.50752	50.93985	62.21805	59.49248	85.52632
7	40.6015	51.31579	62.59398	59.49248	86.09023
8	40.6015	51.31579	62.59398	59.49248	87.68797
9	40.6015	51.31579	62.59398	59.49248	89.84962
10	40.97744	51.69173	64.84962	59.49248	90.31955
11	41.2594	51.69173	66.16541	59.49248	90.31955
12	41.44737	52.81955	67.19925	60.6203	90.31955
13	41.44737	52.81955	71.42857	61.74812	90.50752
14	41.44737	57.33083	77.63158	61.74812	90.50752
15	41.44737	57.70677	78.57143	62.12406	90.50752
16	41.44737	57.80075	80.26316	62.12406	90.6015
17	41.44737	58.83459	83.36466	62.31203	90.6015
18	41.44737	60.15038	83.92857	62.5	90.78947
19	41.44737	60.15038	83.92857	62.5	90.88346
20	41.44737	60.15038	83.92857	62.5	91.91729
21	41.44737	60.15038	83.92857	62.5	91.91729
22	41.44737	60.15038	83.92857	62.5	91.91729
23	41.44737	60.99624	85.6203	62.5	91.91729
24	41.44737	60.99624	85.90226	62.5	91.91729
25	41.44737	62.5	85.99624	62.5	91.91729

Circuit: c432
Seed = 255
Batch size = 10
Flip Everything

batch #	A	B	C	D	E
1	40.13158	45.0188	49.53008	40.13158	54.41729
2	45.30075	52.16165	57.14286	44.26692	69.73684
3	45.77068	52.81955	58.83459	56.95489	76.12782
4	45.95865	52.81955	62.31203	57.33083	80.26316
5	46.05263	57.98872	64.75564	57.98872	83.7406
6	46.05263	57.98872	64.75564	58.17669	93.1391
7	48.1203	58.92857	67.4812	58.36466	93.1391
8	48.21429	58.92857	75.93985	59.68045	93.32707
9	48.40226	60.24436	76.12782	59.68045	94.54887
10	48.68421	60.24436	76.12782	59.68045	94.73684
11	48.68421	60.24436	76.50376	59.68045	94.83083
12	48.68421	60.24436	76.50376	59.68045	94.83083
13	48.68421	60.43233	80.73308	59.68045	94.92481
14	48.68421	62.31203	83.83459	59.86842	94.92481
15	48.68421	62.31203	87.96992	59.86842	94.92481
16	48.68421	62.31203	88.06391	59.86842	94.92481
17	48.68421	62.31203	88.06391	59.86842	95.67669
18	48.68421	62.31203	88.06391	59.86842	95.67669
19	48.68421	62.31203	88.06391	62.5	95.67669
20	48.68421	62.31203	88.06391	62.5	95.77068
21	48.68421	62.5	88.43985	62.5	95.77068
22	48.68421	62.5	88.90977	62.5	95.77068
23	48.68421	62.5	88.90977	62.5	95.77068
24	48.68421	62.5	88.90977	62.5	95.77068
25	48.68421	62.5	88.90977	62.5	95.77068

Figure 3. Flip Everything method results for c432 circuit. Green color shows better coverage.

3.2 *Results of "Alt-Flip".*

This section shows testing results for Alt-Flip method. It was tested with c432, c499 and c880 circuits.

Circuit: c432
Seed = 255
Batch size = 10
NO FLIPPING

batch #	A	B	C	D	E
1	35.24436	38.25188	30.73308	43.1391	49.06015
2	35.33835	44.3609	36.74812	55.54511	63.43985
3	35.33835	44.73684	38.53383	55.6391	75.93985
4	39.84962	46.42857	53.66541	59.49248	83.08271
5	40.50752	49.81203	58.45865	59.49248	84.49248
6	40.50752	50.93985	62.21805	59.49248	85.52632
7	40.6015	51.31579	62.59398	59.49248	86.09023
8	40.6015	51.31579	62.59398	59.49248	87.68797
9	40.6015	51.31579	62.59398	59.49248	89.84962
10	40.97744	51.69173	64.84962	59.49248	90.31955
11	41.2594	51.69173	66.16541	59.49248	90.31955
12	41.44737	52.81955	67.19925	60.6203	90.31955
13	41.44737	52.81955	71.42857	61.74812	90.50752
14	41.44737	57.33083	77.63158	61.74812	90.50752
15	41.44737	57.70677	78.57143	62.12406	90.50752
16	41.44737	57.80075	80.26316	62.12406	90.6015
17	41.44737	58.83459	83.36466	62.31203	90.6015
18	41.44737	60.15038	83.92857	62.5	90.78947
19	41.44737	60.15038	83.92857	62.5	90.88346
20	41.44737	60.15038	83.92857	62.5	91.91729
21	41.44737	60.15038	83.92857	62.5	91.91729
22	41.44737	60.15038	83.92857	62.5	91.91729
23	41.44737	60.99624	85.6203	62.5	91.91729
24	41.44737	60.99624	85.90226	62.5	91.91729
25	41.44737	62.5	85.99624	62.5	91.91729

Circuit: c432
Seed = 255
Batch size = 10
Alt-Flip

batch #	A	B	C	D	E
1	45.48872	39.09774	47.93233	38.90977	52.63158
2	48.59023	41.44737	55.54511	44.45489	66.82331
3	48.68421	47.55639	57.89474	46.99248	74.53008
4	51.2218	47.74436	65.88346	58.08271	78.28947
5	51.78571	51.12782	68.42105	59.30451	80.16917
6	51.78571	52.25564	69.07895	59.49248	87.5
7	51.78571	53.00752	70.58271	59.68045	90.03759
8	51.78571	53.00752	70.58271	59.68045	90.03759
9	51.97368	53.38346	70.58271	59.68045	92.10526
10	51.97368	53.38346	70.77068	59.68045	92.66917
11	51.97368	53.38346	71.52256	59.68045	93.98496
12	51.97368	53.38346	71.52256	59.68045	93.98496
13	53.47744	53.38346	71.80451	60.05639	94.64286
14	53.47744	53.38346	76.97368	60.05639	94.64286
15	53.47744	53.38346	78.28947	60.05639	94.73684
16	53.47744	53.38346	78.47744	60.05639	95.0188
17	53.47744	53.38346	78.66541	60.05639	95.58271
18	53.47744	53.38346	78.66541	60.05639	95.58271
19	53.47744	53.38346	78.66541	61.18421	95.67669
20	53.66541	53.38346	79.04135	61.18421	95.86466
21	53.66541	53.38346	79.04135	61.18421	95.86466
22	53.66541	53.38346	79.04135	61.18421	95.86466
23	53.66541	53.38346	79.51128	61.18421	95.86466
24	53.66541	53.38346	79.69925	61.18421	95.86466
25	53.66541	53.38346	79.69925	61.18421	95.95865

Figure 4. Alt-Flip method results for c432 circuit. Green color shows better coverage.

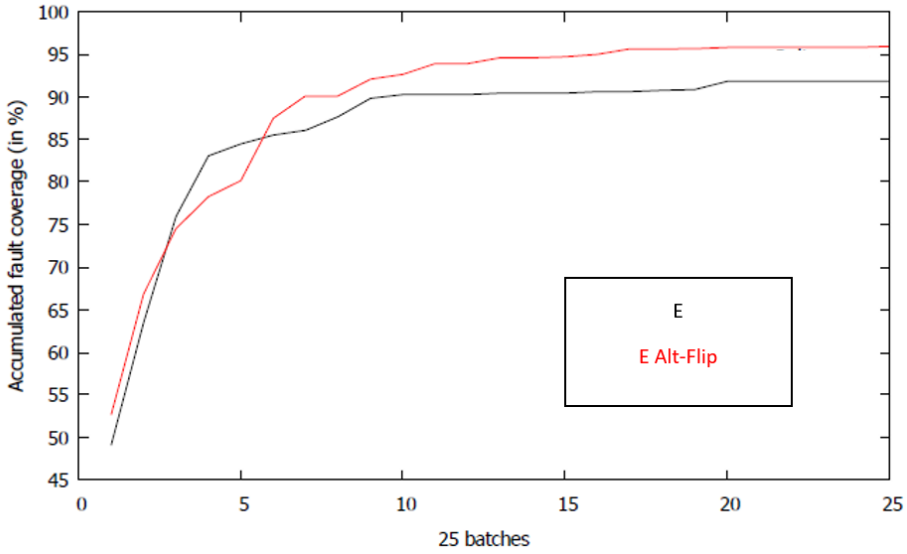

Figure 5. Comparison of TVs for c499

Circuit: c499
Seed = 255
Batch size = 10
NO FLIPPING
TV_E vs TV

batch #	A	B	C	D	E
1	43.54839	32.8725	47.23502	53.45622	54.60829
2	46.39017	37.78802	62.90323	67.28111	66.97389
3	48.92473	55.76037	65.89862	67.74194	70.96774
4	49.15515	59.83103	68.89401	73.19508	75.49923
5	49.15515	60.21505	69.81567	74.57757	76.42089
6	49.15515	61.52074	72.11982	74.57757	79.26267
7	49.53917	61.98157	76.26728	74.57757	79.26267
8	49.53917	62.13518	78.03379	75.11521	81.87404
9	49.53917	70.58372	78.1874	75.11521	84.79263
10	49.53917	73.65591	78.87865	75.11521	87.01997
11	49.53917	74.80799	80.10753	76.88172	87.4808
12	49.53917	76.80492	80.56836	78.64823	87.4808
13	49.69278	77.11214	81.2596	79.87711	87.94163
14	49.76959	77.57296	82.71889	80.41475	88.40246
15	49.76959	79.87711	83.25653	82.33487	91.01382
16	49.76959	81.10599	83.25653	82.33487	91.01382
17	49.76959	83.25653	83.71736	83.64055	91.01382
18	49.76959	84.02458	83.71736	84.4086	92.62673
19	49.76959	85.56068	83.71736	84.56221	92.62673
20	49.76959	86.02151	86.55914	85.02304	93.54839
21	49.76959	86.02151	88.32565	85.40707	93.54839
22	49.76959	86.48233	89.0169	85.56068	94.00922
23	49.76959	86.94316	89.40092	86.17512	94.77727
24	49.76959	86.94316	90.16897	86.17512	95.08449
25	49.76959	86.94316	90.6298	86.94316	95.39171

Circuit: c499
Seed = 255
Batch size = 10
Alt-Flip
TV_E_alt

batch #	A	B	C	D	E
1	45.92934	33.48694	49.84639	38.47926	37.4808
2	55.83717	38.32565	57.29647	66.89708	60.36866
3	65.36098	56.2212	58.75576	67.35791	65.51459
4	65.74501	62.21198	59.06298	69.58525	73.19508
5	66.05223	63.05684	59.21659	74.03994	73.96313
6	67.43472	63.97849	59.21659	74.11674	74.27035
7	68.04916	65.20737	63.74808	74.11674	75.96006
8	68.20276	67.66513	63.74808	75.19201	78.72504
9	68.20276	78.26421	63.74808	75.65284	80.95238
10	68.20276	80.26114	63.74808	77.88018	83.25653
11	68.20276	83.56375	63.74808	77.88018	83.25653
12	68.20276	85.56068	63.74808	80.41475	84.56221
13	68.20276	86.02151	63.74808	80.41475	85.8675
14	68.20276	86.02151	64.36252	80.41475	85.8675
15	68.20276	86.02151	64.36252	81.64363	88.40246
16	68.20276	86.02151	64.36252	82.10445	90.553
17	68.20276	86.02151	64.36252	83.17972	90.553
18	68.20276	86.02151	64.36252	83.79416	92.39631
19	68.20276	86.02151	64.36252	84.25499	92.39631
20	68.20276	86.02151	67.2043	84.4086	93.702
21	68.20276	86.02151	67.2043	84.4086	93.702
22	68.20276	86.02151	67.2043	84.56221	94.16283
23	68.20276	86.02151	67.2043	84.94624	94.77727
24	68.20276	86.02151	67.2043	85.40707	95.39171
25	68.20276	86.02151	67.2043	85.40707	95.39171

Figure 6. Flip Everything method results for c499 circuit. Green color shows better coverage.

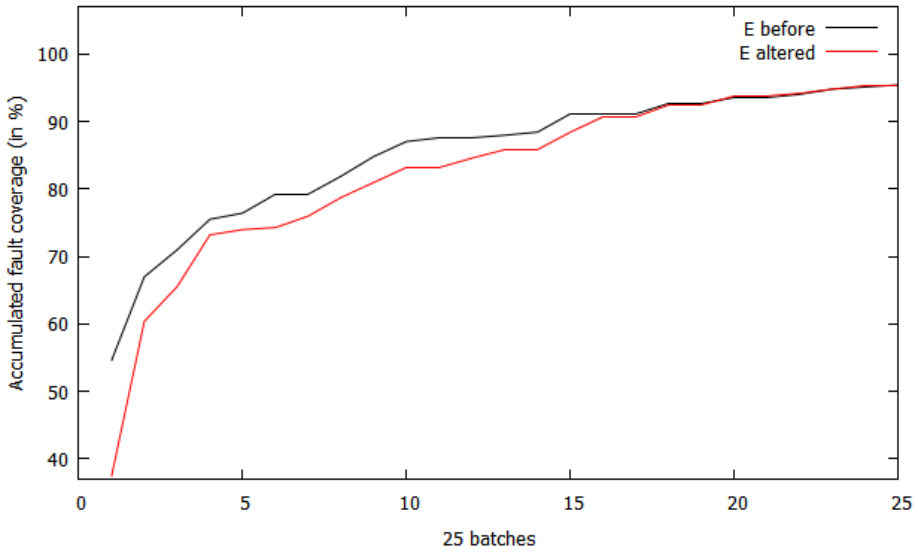

Figure 7. Flip Compare TVEs for c499 circuit

Circuit: c880
Seed = 255
Batch size = 10
NO FLIPPING
TV_E vs TV

A	B	C	D	E
19.06997	58.36177	56.65529	71.67235	70.69113
19.41126	65.69966	63.3959	78.66894	81.10068
19.53925	69.96587	66.04096	82.72184	84.343
19.92321	73.33618	70.43515	83.31911	85.79352
19.92321	76.10922	71.41638	84.51365	87.54266
19.92321	77.09044	72.09898	86.2628	89.0785
19.92321	78.88225	74.78669	86.73208	89.29181
19.92321	81.48464	76.19454	87.41468	89.29181
19.92321	82.33788	76.53584	87.41468	89.29181
20.00853	82.59386	77.17577	87.8413	89.33447
20.00853	82.76451	77.17577	88.35324	89.4198
20.00853	82.84983	77.34642	88.7372	89.71843
20.05119	83.40444	79.65017	88.7372	90.44369
20.05119	84.42833	80.11945	88.7372	90.87031
20.05119	84.59898	80.11945	88.77986	90.87031
20.05119	86.68942	80.11945	88.77986	90.87031
20.13652	86.77474	80.46075	88.90785	91.12628
20.13652	86.86007	80.50341	88.90785	91.12628
20.13652	88.09727	80.93003	88.99317	91.16894
20.26451	88.90785	82.12457	88.99317	91.2116
20.26451	89.33447	82.29522	89.24915	91.25427
20.26451	89.63311	82.29522	89.24915	91.25427
20.34983	89.9744	82.38055	89.24915	91.25427
20.34983	89.9744	82.38055	89.80375	91.25427
20.34983	89.9744	82.38055	89.80375	91.25427

Circuit: c880
Seed = 255
Batch size = 10
Alt-Flip
TV_E_alt

A	B	C	D	E
30.84471	56.39932	64.50512	72.31229	68.00341
30.9727	66.16894	69.15529	75.93857	77.09044
30.9727	71.11775	69.83788	80.11945	81.39932
31.69795	74.36007	72.78157	82.16724	82.67918
31.69795	76.70648	73.12287	82.80717	85.79352
31.69795	77.34642	73.59215	86.09215	87.58532
31.95392	78.157	74.36007	86.2628	87.96928
31.95392	79.09556	74.70137	87.37201	88.22526
31.95392	80.16212	74.78669	87.58532	89.16382
32.03925	80.46075	75.04266	87.8413	89.24915
32.03925	81.39932	75.08532	87.88396	90.35836
32.03925	81.39932	75.08532	88.65188	90.52901
32.16724	81.44198	75.17065	88.90785	90.99829
32.16724	81.44198	75.17065	88.90785	91.68089
32.16724	81.44198	75.17065	88.95051	91.68089
32.16724	81.44198	75.17065	88.99317	91.68089
32.16724	81.44198	75.17065	88.99317	91.72355
32.16724	81.44198	75.17065	88.99317	91.72355
32.16724	81.44198	75.17065	88.99317	91.72355
32.16724	81.44198	75.17065	88.99317	91.72355
32.16724	81.44198	75.17065	88.99317	91.72355
32.16724	81.44198	75.17065	89.03584	91.76621
32.16724	81.44198	75.17065	89.03584	91.76621
32.16724	81.44198	75.21331	89.03584	91.76621
32.16724	81.44198	75.21331	89.0785	91.76621

Figure 8. Flip Everything method results for c880 circuit. Green color shows better coverage.

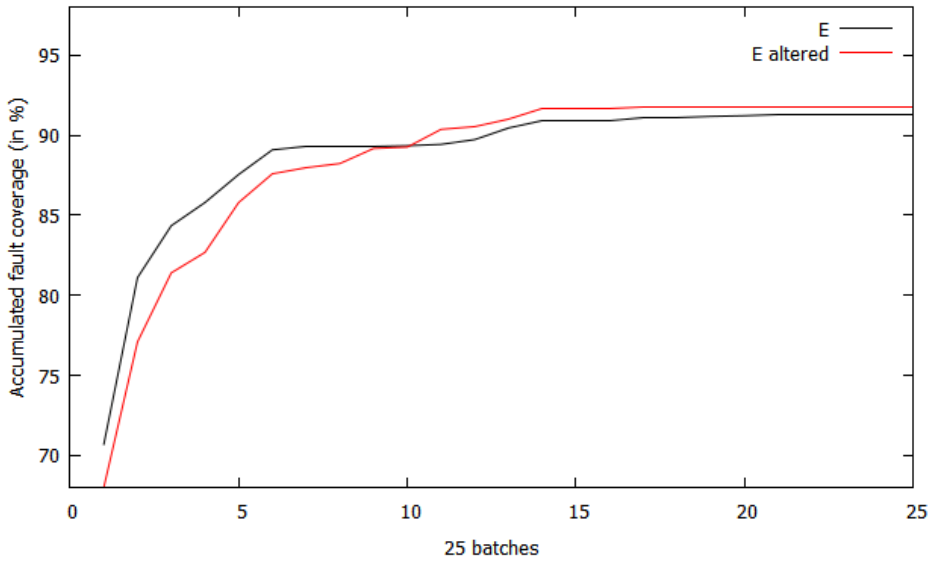

Figure 9. Flip Compare TVEs for c880.

4 DISCUSSION

4.1 *Analysis of "Flip Everything" method.*

The main point of testing of Flip Everything is to test TV A. Increase in coverage by 7.2 percent was achieved for c432 circuit. Other TVs also show improvements, but similar result could be achieved by selecting different seed (without flipping any bits). More research could be implemented in developing techniques of seed selection, but it is not part of this experiment.

4.2 *Analysis of "Alt-Flip" method.*

c432 showed best results in coverage improvement. TVE coverage grew by 4.04 percent.TVA showed better coverage for all three circuits. c499 has exact same results for TVE. Overall out of 3 circuits tested none of tests gave worse results for Alt-Flip TVs than for regular TVs.

CONCLUSIONS

Overall the experiment turned out to be a success. It was possible to improve on the existing counter and lfsr TV-generation methods. It became clear during the experiment that Flipping Everything method only improves coverage of TV A (see Analysis of "Flip Everything" method.), so primary focus of the experiment switched to Alt-Flip method. Depending on the circuit, were were able to achieve improvement in coverage between 0 and 4.04 percent for the TV E (multiple 8-bit lfsr). TV A coverage was improved for all three circuits, but it is a minor achievement since TV A is not the most efficient TV out of all considered within this experiment. There might be a relationship between the size of the circuit and the benefit of using Alt-Flip. Just from results of testing three circuits it is assumed that the bigger the circuit the less is the effect of using Alt-Flip. Of course, this theory requires much more testing data.

REFERENCES

1. Middle square Method, *https://en.wikipedia.org/wiki/Middle-square-method* (accessed Dec.2, 2019)