CMOS SEVEN RING VOLTAGE CONTROL OSCILLATOR DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT:

Voltage controlled ring oscillators are commonly used in clock generation circuits which provides a more stable frequency. A seven ring and nine ring voltage control oscillator was constructed using CMOS inverters in Pspice. The oscillation frequency changes as the number of inverters increases; However, it was also controlled by changing the supply voltage.

KEYWORDS:

CMOS inverter, Ring oscillator, propagation delay, oscillation period, VCO, PSpice

8.1 INTRODUCTION

The purpose of this lab is to use the design of CMOS inverters to create a voltage controlled 7 ring oscillator. The ring oscillator consists of an odd number of inverters cascaded in a loop. Looking closely at figure 8.1, a ring of 3 inverters is shown. Every inverter has a propagation delay in which their respective outputs will show the complement of their input.

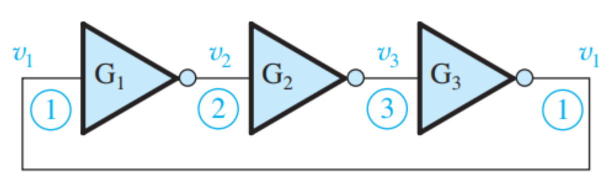


Fig. 8.1. A three-ring inverter

Looking closely at figure 8.2, the input V_1 has an output V_2 after a delay of t_p where V_2 is the complement of V_1. The inversion occurs again two more times forcing the initial input to invert. This forces the circuit to oscillate between logic 0 and 1 for a total delay of 3 t_p.

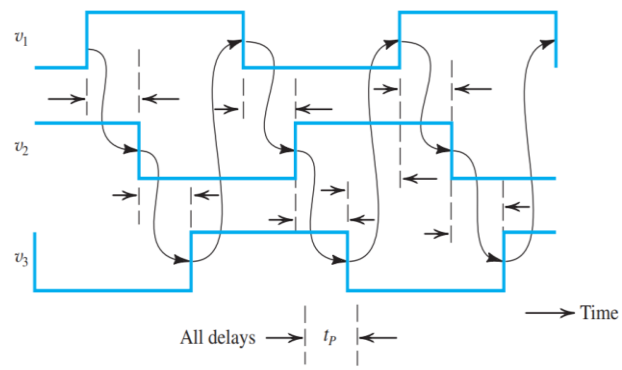


Fig. 8.2 Voltage levels of the Ring Inverter

As we have seen before, the oscillation frequency decreases, and the period increases as the number of inverters increases. However, by increasing the supply voltage the propagation delay will be decreased. This means the oscillation frequency can be controlled by changing the supply voltage.

8.2 PROCEDURES, SIMULATION AND EXPERIMENTAL SET-UP

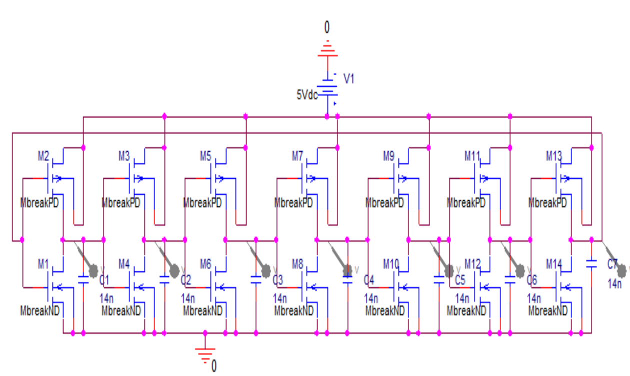


Fig. 8.3. Seven Ring Oscillator at 5v and C = 14nF

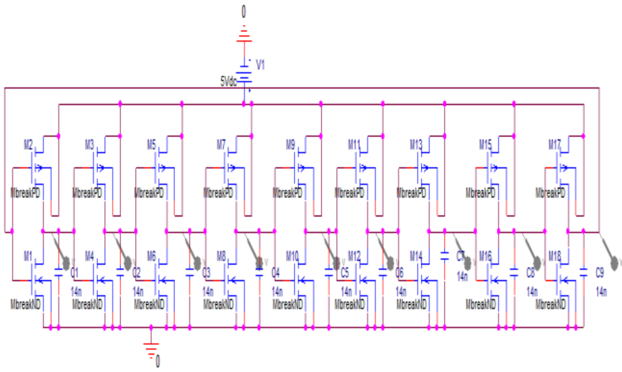
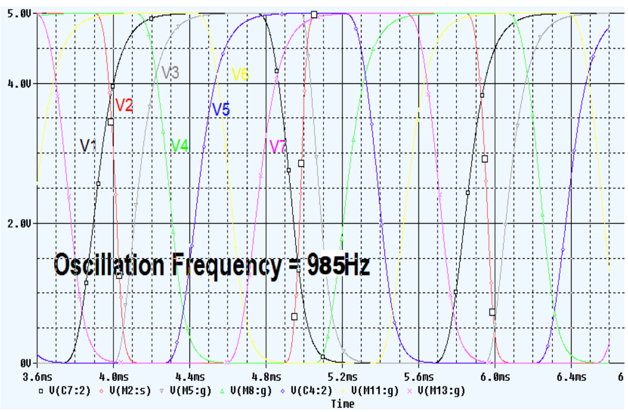


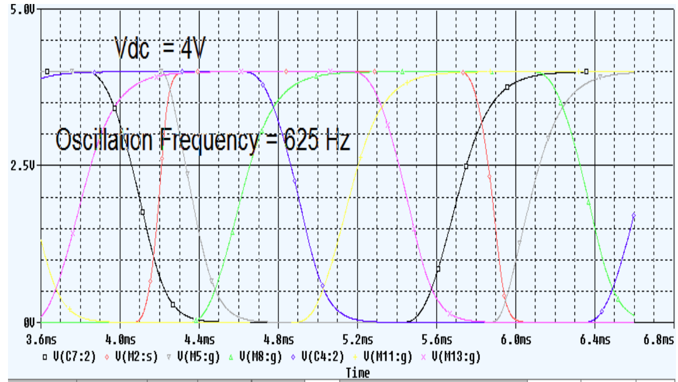
Fig. 8.4. Nine Ring Oscillator at 5v and C = 14nF

8.3 SIMULATION AND EXPERIMENTAL RESULTS



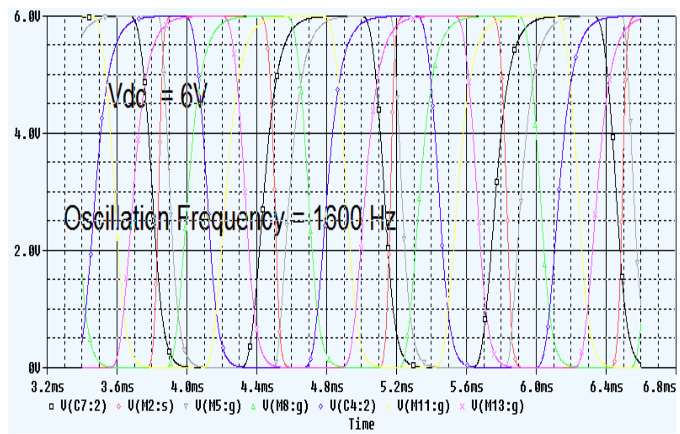
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		3.0542m		
	X Values	3.9140m	4.9292m	-1.0152m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	A
	V(C7:2)	2.4557	2.4526	3.0542m		0.000	0.000	2.4557	2.4526	2
	V(M2:s)	4.9847	172.834m	4.8119		2.5290	-2.2798	4.9847	172.834m	2
	V(M5:g)	-39.290n	4.9999	-4.9999		-2.4557	2.5473	4.9999	-39.290n	2
	V(M8:g)	4.9994	1.5049u	4.9994		2.5437	-2.4526	4.9994	1.5049u	2
	V(C4:2)	74.319u	4.9953	-4.9952		-2.4556	2.5427	4.9953	74.319u	2
	V(M11:g)	4.9541	2.7223m	4.9514		2.4984	-2.4499	4.9541	2.7223m	2
	V(M13:g)	135.269m	4.6424	-4.5071		-2.3204	2.1897	4.6424	135.269m	2

Fig. 8.5. Seven ring oscillator at 5v with oscillation frequency of 985Hz



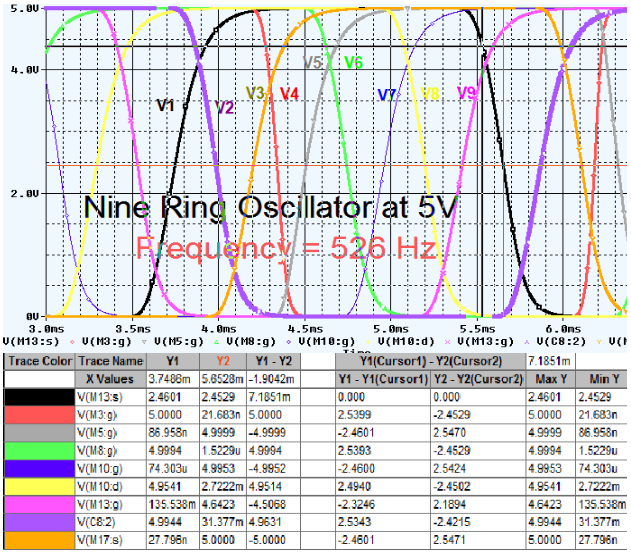
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-14.567m		
	X Values	4.0593m	5.7503m	-1.6910m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	V(C7:2)	2.4934	2.5080	-14.567m		0.000	0.000	2.5080	2.4934	2.5007
	V(M2:s)	214.463n	3.9490	-3.9490		-2.4934	1.4411	3.9490	214.463n	1.9745
	V(M5:g)	4.0000	-387.555n	4.0000		1.5066	-2.5080	4.0000	-387.555n	2.0000
	V(M8:g)	367.839n	4.0000	-4.0000		-2.4934	1.4920	4.0000	367.839n	2.0000
	V(C4:2)	3.9988	7.0178u	3.9988		1.5054	-2.5080	3.9988	7.0178u	1.9994
	V(M11:g)	1.4914m	3.9907	-3.9892		-2.4919	1.4828	3.9907	1.4914m	1.9961
	V(M13:g)	3.7484	38.949m	3.7095		1.2550	-2.4690	3.7484	38.949m	1.8937

Fig. 8.6. Seven ring oscillator at 4v with oscillation frequency of 625 Hz



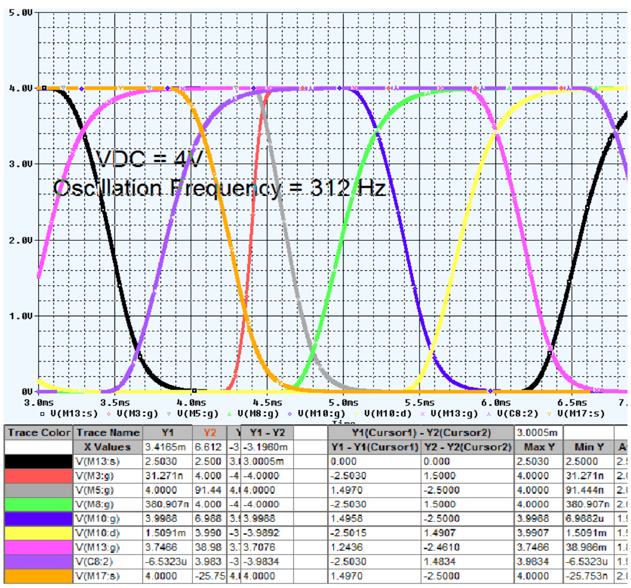
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		39.992m		
	X Values	3.8123m	4.4286m	-616.322u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	V(C7:2)	2.5432	2.5032	39.992m		0.000	0.000	2.5432	2.5032	2.5232
	V(M2:s)	641.975m	5.9881	-5.3461		-1.9012	3.4849	5.9881	641.975m	3.3150
	V(M5:g)	5.9998	218.317n	5.9998		3.4566	-2.5032	5.9998	218.317n	2.9999
	V(M8:g)	5.0041u	5.9977	-5.9977		-2.5432	3.4944	5.9977	5.0041u	2.9988
	V(C4:2)	5.9893	310.180u	5.9889		3.4460	-2.5029	5.9893	310.180u	2.9948
	V(M11:g)	4.7419m	5.8915	-5.8868		-2.5385	3.3883	5.8915	4.7419m	2.9481
	V(M13:g)	5.5161	281.211m	5.2349		2.9729	-2.2220	5.5161	281.211m	2.8986

Fig. 8.7. Seven ring oscillator at 6v with oscillation frequency of 1600 Hz



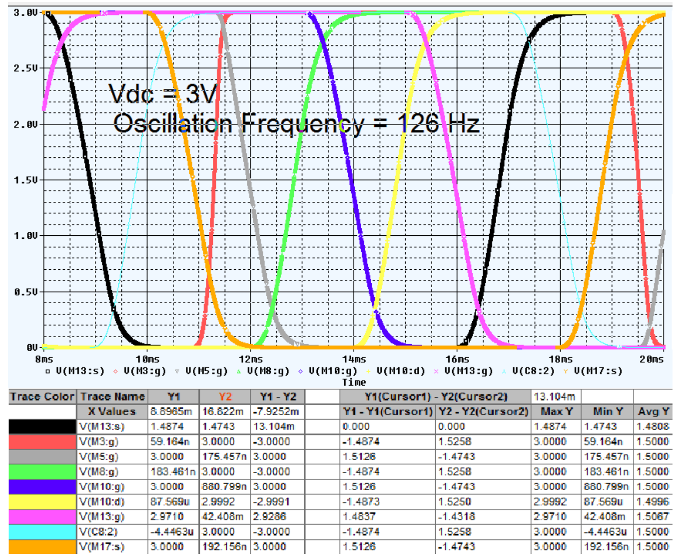
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		7.1851m	
	X Values	3.7486m	5.6528m	-1.9042m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y
	V(M13:s)	2.4601	2.4529	7.1851m		0.000	0.000	2.4601	2.4529
	V(M3:g)	5.0000	21.683n	5.0000		2.5399	-2.4529	5.0000	21.683n
	V(M5:g)	86.958n	4.9999	-4.9999		-2.4601	2.5470	4.9999	86.958n
	V(M8:g)	4.9994	1.5229u	4.9994		2.5393	-2.4529	4.9994	1.5229u
	V(M10:g)	74.303u	4.9953	-4.9952		-2.4600	2.5424	4.9953	74.303u
	V(M10:d)	4.9541	2.7222m	4.9514		2.4940	-2.4502	4.9541	2.7222m
	V(M13:g)	135.538m	4.6423	-4.5068		-2.3246	2.1894	4.6423	135.538m
	V(C8:2)	4.9944	31.377m	4.9631		2.5343	-2.4215	4.9944	31.377m
	V(M17:s)	27.796n	5.0000	-5.0000		-2.4601	2.5471	5.0000	27.796n

Fig. 8.8. Nine ring oscillator at 5v with oscillation frequency of 526v.



Trace Color	Trace Name	Y1	Y2	Y	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		3.0005m		
	X Values	3.4165m	6.612	-3	-3.1960m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	A
	V(M13:s)	2.5030	2.500	3.	3.0005m		0.000	0.000	2.5030	2.5000	2.
	V(M3:g)	31.271n	4.000	-4	-4.0000		-2.5030	1.5000	4.0000	31.271n	2.
	V(M5:g)	4.0000	91.44	4.	4.0000		1.4970	-2.5000	4.0000	91.444n	2.
	V(M8:g)	380.907n	4.000	-4	-4.0000		-2.5030	1.5000	4.0000	380.907n	2.
	V(M10:g)	3.9988	6.988	3.	3.9988		1.4958	-2.5000	3.9988	6.9882u	1.
	V(M10:d)	1.5091m	3.990	-3	-3.9892		-2.5015	1.4907	3.9907	1.5091m	1.
	V(M13:g)	3.7466	38.98	3.	3.7076		1.2436	-2.4610	3.7466	38.986m	1.
	V(C8:2)	-6.5323u	3.983	-3	-3.9834		-2.5030	1.4834	3.9834	-6.5323u	1.
	V(M17:s)	4.0000	-25.75	4.	4.0000		1.4970	-2.5000	4.0000	-25.753n	2.

Fig 8.9. Nine ring oscillator at 4 v with oscillation frequency of 312 Hz



Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		13.104m		
	X Values	8.8965m	16.822m	-7.9252m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	V(M13:s)	1.4874	1.4743	13.104m		0.000	0.000	1.4874	1.4743	1.4808
	V(M3:g)	59.164n	3.0000	-3.0000		-1.4874	1.5258	3.0000	59.164n	1.5000
	V(M5:g)	3.0000	175.457n	3.0000		1.5126	-1.4743	3.0000	175.457n	1.5000
	V(M8:g)	183.461n	3.0000	-3.0000		-1.4874	1.5258	3.0000	183.461n	1.5000
	V(M10:g)	3.0000	880.799n	3.0000		1.5126	-1.4743	3.0000	880.799n	1.5000
	V(M10:d)	87.569u	2.9992	-2.9991		-1.4873	1.5250	2.9992	87.569u	1.4996
	V(M13:g)	2.9710	42.408m	2.9286		1.4837	-1.4318	2.9710	42.408m	1.5067
	V(C8:2)	-4.4463u	3.0000	-3.0000		-1.4874	1.5258	3.0000	-4.4463u	1.5000
	V(M17:s)	3.0000	192.156n	3.0000		1.5126	-1.4743	3.0000	192.156n	1.5000

Fig. 8.10. Nine ring oscillator at 3 v with oscillation frequency of 126 Hz

8.4. DISCUSSION AND CONCLUSION:

The setup of the 7-ring oscillator is shown in figure 8.3. First the supply voltage was set to 5v and the voltage at each inversion was measured. The results for the 5v was shown in figure 8.5. The delay of each inverter was reduced by varying the capacitance between each inverter. At a capacitance of 14nF, each inverter had a propagation delay of 77.5 us compared to the expected value of about 74 us. The calculated error of our simulation and our CD4007UBE chip was about 4.7%. The oscillation frequency was measured by determining the time the voltage shifted from logic low to logic high or the other way around. The oscillation frequency for the seven ring at 5 v was found to be 985 Hz as shown in figure 8.5.

The seven-ring oscillator was changed by decreasing the supply voltage to 4v. The oscillation frequency of the 4v seven ring oscillator was found to be 625 Hz in figure 8.6. The supply voltage was then increased to 6v because lowering past 4v created accuracy errors in simulation. At 6v, the oscillation frequency was found to be 1600 Hz as shown in figure 8.7. These results agree with the expected result which is that increasing the supply voltage also increases the oscillation frequency of the ring oscillator.

As an addition to the lab, a nine-ring oscillator was simulated and shown to increase in oscillating frequency by increasing the supply voltage. Figure 8.4 shows the setup for the nine-ring oscillator. Figures 8.8, 8.9, and 8.10 show the frequencies for 5v, 4v, and 3v respectively. By decreasing the supply voltage, the oscillation frequency also decreased which agrees with our previous results.

REFERENCES

[1] A. S. Sedra and K. C. Smith, Microelectronic circuits. New York: Oxford University Press, 2015.

[2] ECE lab manual

[3]