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DARK SOLITON GENERATION USING CMOS RING OSCILLATOR

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ABSTRACT

Electrical soliton find wide uses in ultra-sharp pulse generation, nonlinear communication schemes in electronics, sharp pulse formation and edge sharpening for high speed metrology in addition to high frequency generation through Nonlinear Transmission Line (NLTL). In this paper a novel method of electrical soliton pulse generation using CMOS ring oscillator is explored. The key elements of the ring Oscillators are CMOS inverters, in which feedback is provided by a voltage divider biasing circuit. Further, by varying the feedback voltage, soliton frequency and shape analysis is done.

Keywords: CMOS - ring oscillator, voltage divider bias, dark, bright electrical soliton.

1. INTRODUCTION

An electrical soliton pulse is characterized by its ability of maintaining its shape and size unaltered during the propagation through a given medium [1] [2] [3]. The electrical solitons can be generated by counterbalancing the linear propagation effects with the nonlinear effects. Extensive research has been carried out in the generation of electrical soliton pulses as they help in the understanding of the concept and the nature of complex nonlinear electrical systems [4][5][6]. Soliton based communication systems are more efficient than other communication systems that are implemented using various waveforms. For example, soliton based carriers support low distortion than square pulses [4][5]. There are two types of solitons that are categorized by their polarity of peaking: while the amplitude of bright solitons peak in the positive direction, dark solitons peak in the negative direction. Dark soliton electrical pulses find major application in novel linear/nonlinear communication in electronics and other areas like meteorology. Hence, the production of dark soliton electrical pulses in a more simple and robust way is a need for present day scenario.

Studies on the generation of bright solitons have been carried out in different contexts. For example, it is found that solitons can be generated in a simple way by using a CMOS amplifier circuit with adaptive bias control and nonlinear electrical transmission lines (NLTL) [7] [8] [9]. NLTLs are made up of a periodic arrangement of inductors and varactors. While the periodic arrangement of inductors in NLTL is responsible for the dispersive effects, the varactor diodes lead to nonlinear effects [10] [11]. Bright soliton pulses arise when there is exact matching between the linear effect and nonlinear effects [8] [12] [13].

In this paper, we intend to investigate the possibilities of generation of electrical soliton pulses using CMOS 4069 transistor. The structure of MOSFET is well understood. According to the small signal model, N-channel or P-channel MOSFET has a different junction capacitance. By varying the gate source voltage, the channel has developed. The RC equivalent channel structure is shown in Figure-1.

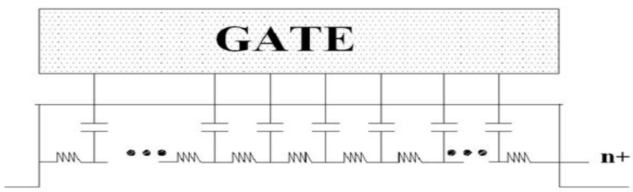

Figure-1. Shows RC equivalent structure of N channel MOSFET.

It is made up of an infinite number of parallel combinations of resistors and capacitors [14]. The structure of N-channel MOSFET is shown in Figure-2.

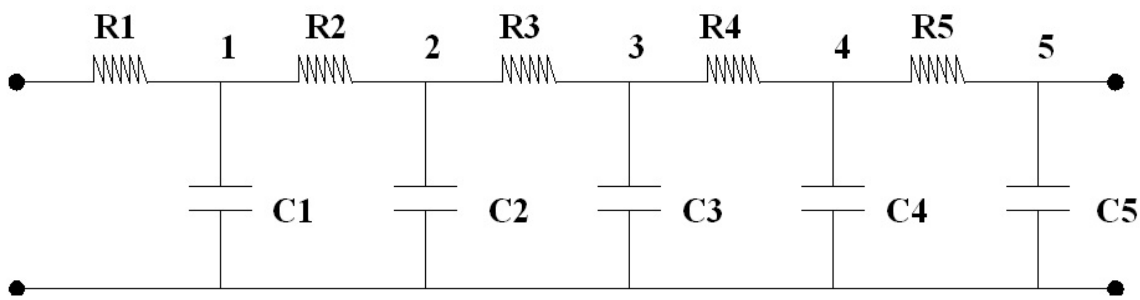

Figure-2. Periodic arrangement of resistors and capacitors.

The theory of electrical pulse propagation in the N-channel MOSFET is as follows: the delayed periodical arrangement of resistors provides an effect of inductance. Now the channel structure becomes infinite number of parallel combination of inductors and capacitors [14] as shown in Figure-3.

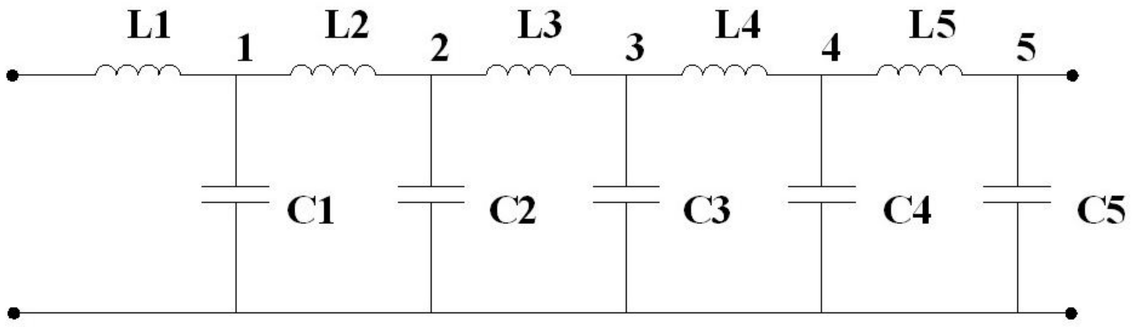

Figure-3. Parallel combination of inductors and capacitors.

From the data sheet of 4069 CMOS transistor which is shown in Figure-4, it is found that the input and output characteristics curve has nonlinear region [15]. A signal operated on the non-linear region of the circuit, new frequency components are generated. The position of Q point can be tuned by varying the DC feedback voltage, CMOS operating region can be varied anywhere in the characteristic curve.

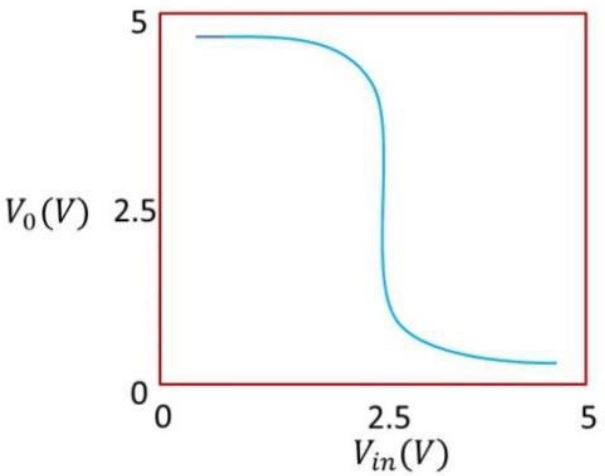

Figure-4. CMOS input and output characteristics.

Hence, it is highly possible for generation of electrical soliton pulses in a CMOS transistor. In this paper, we study the generation of dark solitons pulses using CMOS (4069) inverter. We consider three stage and five stage inverters as the frequency of generated pulses depends on the level of stages as follows: frequency = $\frac{1}{2n\tau_p}$, where τ_p is stage delay, n = number of stages. As the number of stages increases, obtained frequency values decreases.

2. METHODOLOGY

In the present work we have proposed an alternative experimental approach to the generation of dark soliton pulses by providing exact feedback voltage (operated in the nonlinear region) to the input of the circuit from the voltage divider bias circuit.

The CMOS is the combination of N-MOS and P-MOS transistor. By considering N Channel MOSFET, the channel is formed at $V_{GS(th)}$ and it grows by slightly increasing the $V_{GS.}$ The nonlinear region in the characteristics of MOSFET occurs at $V_{GS(th)}$ and slightly greater than $V_{GS(th).}$ The structure of the channel is a parallel combination of periodical arrangement of resistor and capacitor. The delayed periodical arrangement of resistor provides the effect of inductance and it will provide linear effect i.e. dispersion. The capacitor provides non - linear effect. Q=C (V). The capacitance is a nonlinear function of applied or feedback voltage. For a particular value of applied or feedback voltage the capacitance effect (nonlinear) and inductance effect (linear) balances each other, and hence the soliton pulses are generated. The device CMOS, P-MOS or N-MOS when operated in the non-linear region we may get the pulse, but at the same time the linearity and non-linearity balances each other soliton pulses are formed.

We did experiment Figure-5 with various combination of resistance and feedback voltage. By changing the value of feedback voltage to the circuit the operating point may be varied anywhere in the non-linear region, each position in the non-linear region the wave shape, frequency and amplitude (peak to peak) are changed Figure-6.

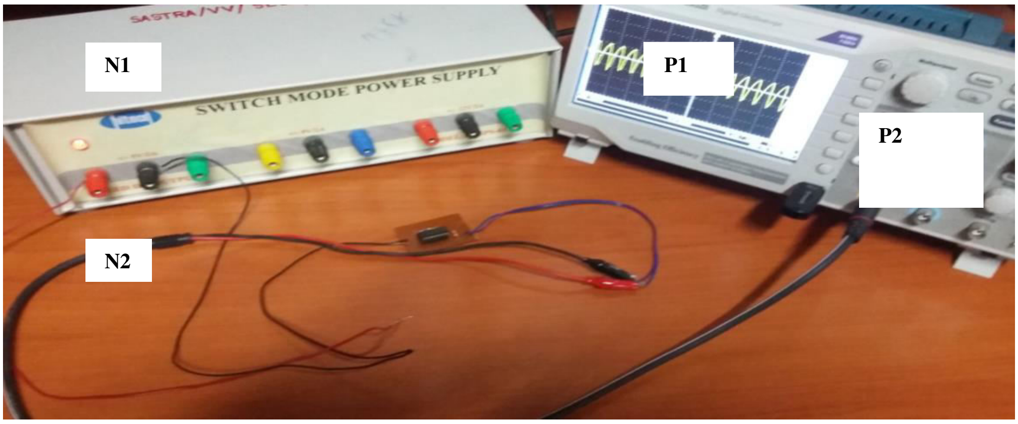

Figure-5. Circuit diagram of ring oscillator.

3. RESULTS AND DISCUSSIONS

3.1 Three stage ring oscillator

By varying the feedback voltage, the output voltage waveform amplitude and frequency, wave shape varies accordingly. As soon as the capacitance effect (non-linear) is exactly matching the inductance (linear) effect the dark soliton pulses are generated. This is the modest way to generate a soliton pulse using the intrinsic parameters of the device.

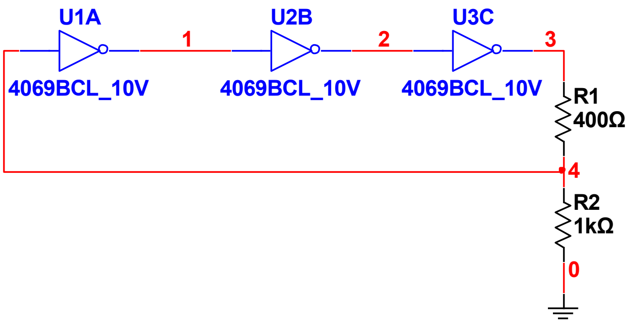

Figure-6. Tuning the Q-point by varying the feedback voltage.

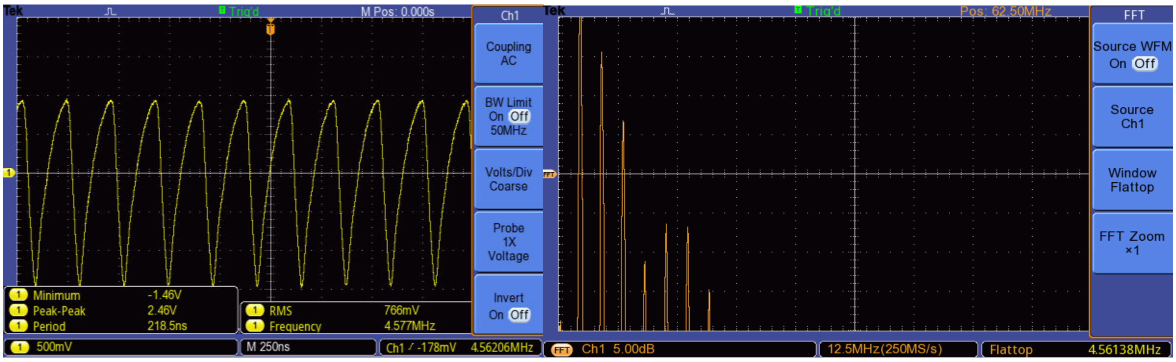

Figure-7. Waveform and its spectrum of the output voltage with R1=100Ω, R2=1KΩ.

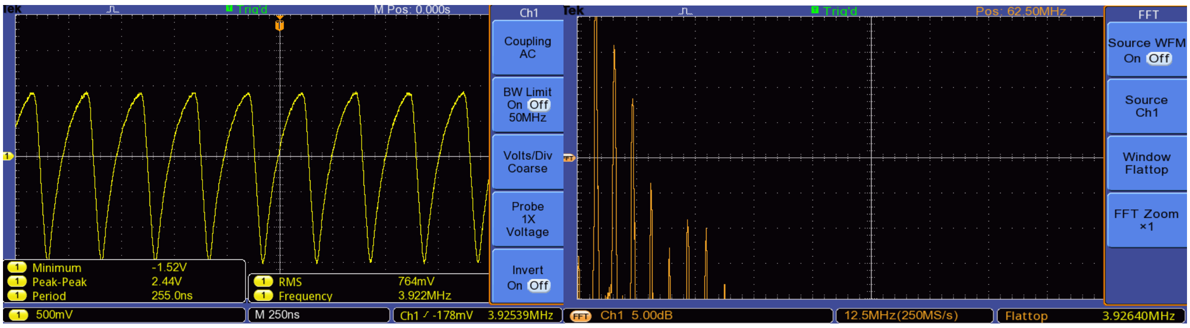

Figure-8. Waveform and its spectrum of the output voltage with R1=200Ω, R2=1KΩ.

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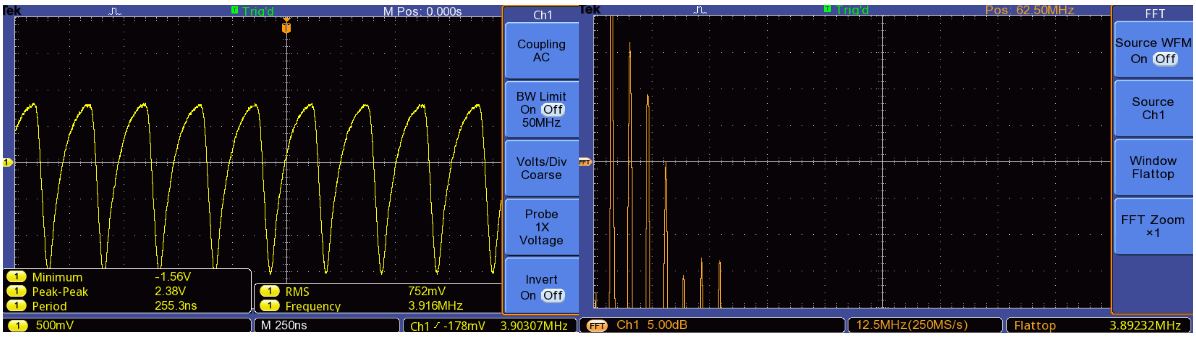

Figure-9. Waveform and its spectrum of the output voltage with R1=300Ω, R2=1KΩ.

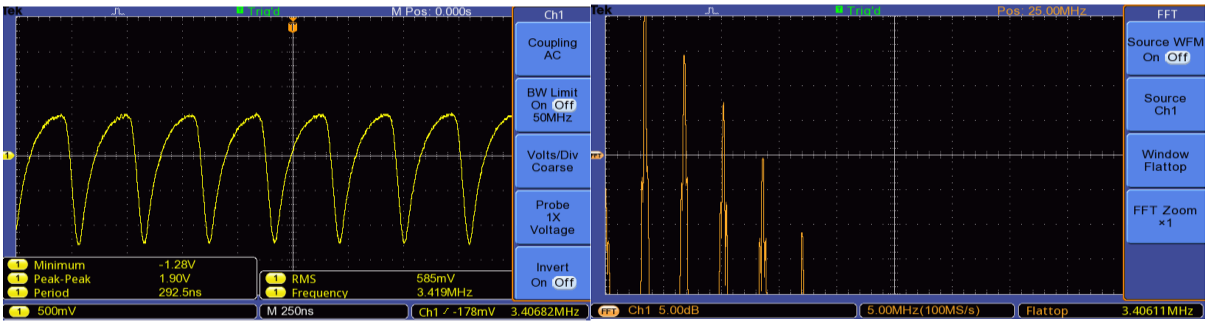

Figure-10. Waveform and its spectrum of the output voltage with R1=400Ω, R2=1KΩ.

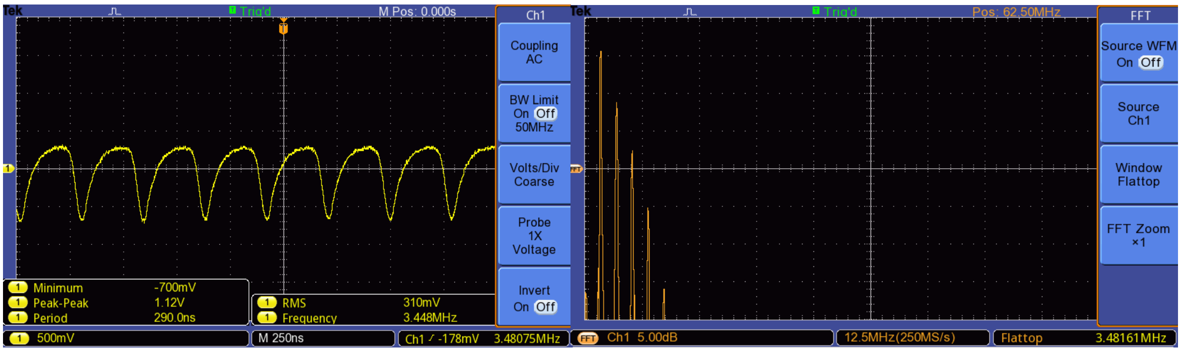

Figure-11. Waveform and its spectrum of the output voltage with R1=500Ω, R2=1KΩ.

Table-1. Parameters of the three stage ring oscillator.

Case no.	**R1** (Ω)	**R2** (Ω)	**Feedback voltage** (V)	**Output voltage (peak to peak)**	**Frequency** (MHZ)	**Shape of the output**
1	0	0	0	0	0	----
2	100	1000	4.2	4.7	4.56	Pulse
3	200	1000	4.7	5.2	3.93	Pulse
4	300	1000	4.9	5.8	3.8	Pulse
5	400	1000	5.2	6.7	3.4	Soliton
6	500	1000	5.4	7.6	3.4	Soliton

From the above table it is imperative only up on the suitable combination of R1, R2 and feedback voltage, we have obtained soliton pulses when exact balancing occurs between linear and nonlinear effects.

Thus by varying the elements of the feedback network in the 3 stage ring oscillator can be made to operate in the region where linearity and non-linearity balances each other. The output waveform appearances like a bell shape in time domain and its Fast Fourier Transform contains harmonic frequencies and its amplitude decreasing exponentially. Figure-7 to Figure-11 shows different output voltage waveforms with corresponding FFT by varying the feedback voltage. We

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have obtained dark soliton when the feedback voltage is in between 71 percent of Vo and 75 percent of Vo.

3.2 Five stage ring oscillator

By varying the feedback input voltage, the output voltage waveform varies accordingly. When ever the capacitance effect (non-linear) is exactly balancing the inductance (linear) effect the dark soliton pulses are generated. This is the simplest way to generate a soliton pulse using the inherent parameters of the device.

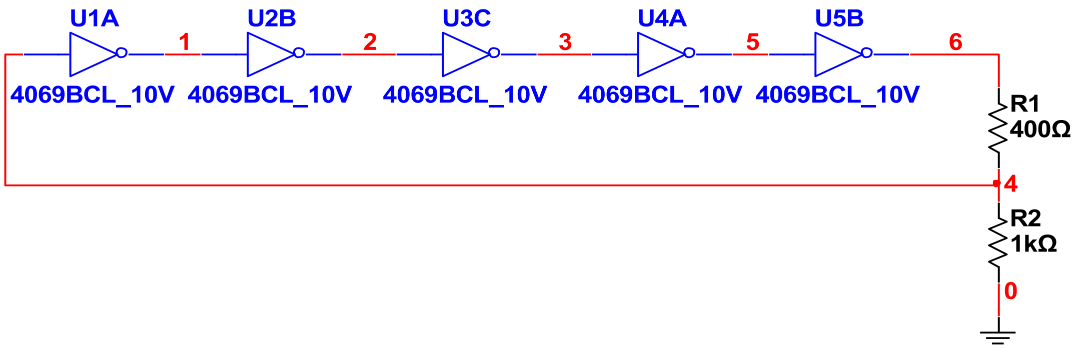

Figure-12. Schematic diagram of five stage ring oscillator.

Table-2. Observed frequency and shape of the wave form for various combinations of resistance and feedback voltage.

Case no.	**R1** (Ω)	**R2** (Ω)	**Feedback voltage** (V)	**Output voltage (peak to peak)**	**Frequency** (MHZ)	**Shape of the output**
1	0	0	0	0	0	----
2	300	1000	0.64	3.08	2.513	Pulse
3	400	1000	0.88	3	2.47	Pulse
4	500	1000	1.13	2.8	2.05	Pulse
5	600	1000	1.45	2.4	1.34	Soliton

Case (i) R1=R2 =0 No feedback voltage, no output waveform

Case (ii) R1=300Ω R2=1KΩ, the feedback voltage is 0.64V, Vo=3.08V (PP) and frequency is 2.513MHZ (Pulse)

Case (iii) R1=400Ω R2=1KΩ the feedback voltage is 0.88V, VO=3V (PP) and frequency is 2.47 MHZ (Pulse)

Case (iv) R1=500Ω R2=1KΩ the feedback voltage is 1.13V, Vo=2.8V (PP) and frequency is 2.05 MHZ (Pulse)

Case (v) R1=600Ω R2=1KΩ the feedback voltage is 1.45V, Vo=2.4V (PP) and frequency is 1.34 MHZ (Soliton Pulse)

Thus by increasing the dc bias voltage i.e. feedback voltage, the linearity and non-linearity balances each other. We have obtained dark soliton when the feedback voltage is 60 percent of V_0. The output waveform looks like a bell shape and its FFT shows the harmonics decreasing exponentially. Figures-13 to Figure-16 shows different values of feedback voltage and different wave shape and its corresponding FFT.

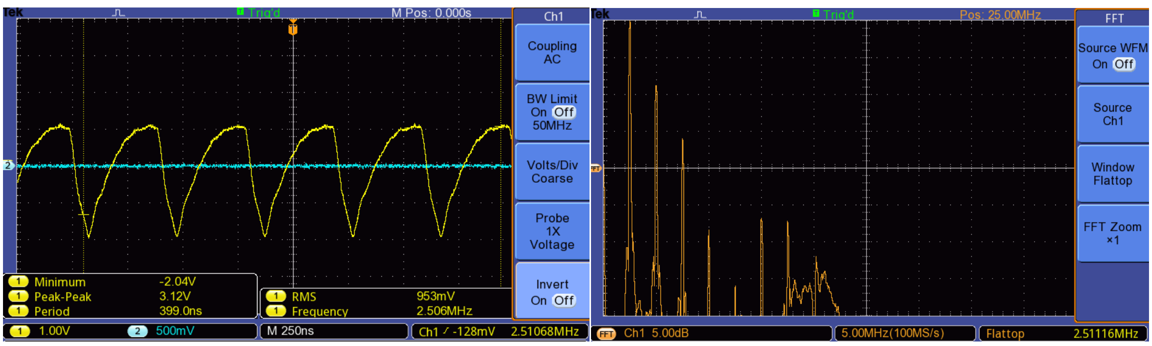

Figure-13. Waveform and its spectrum of the output with feedback=20% of output voltage.

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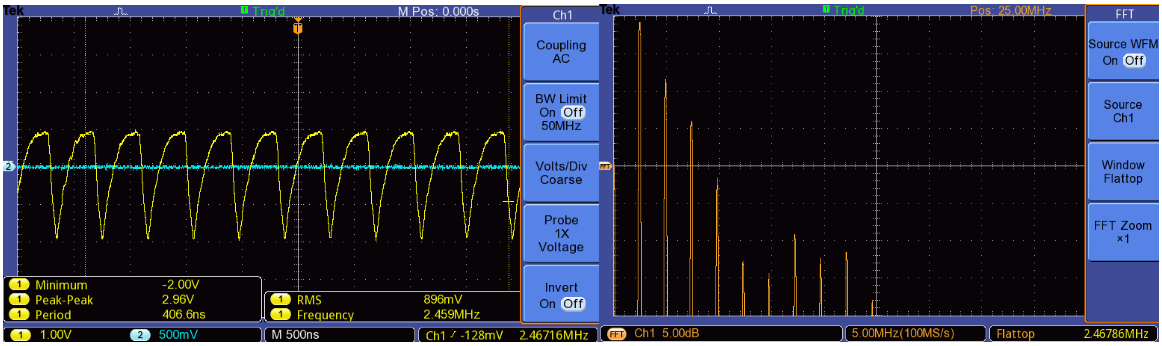

Figure-14. Waveform and its spectrum of the output with feedback =30% of output voltage.

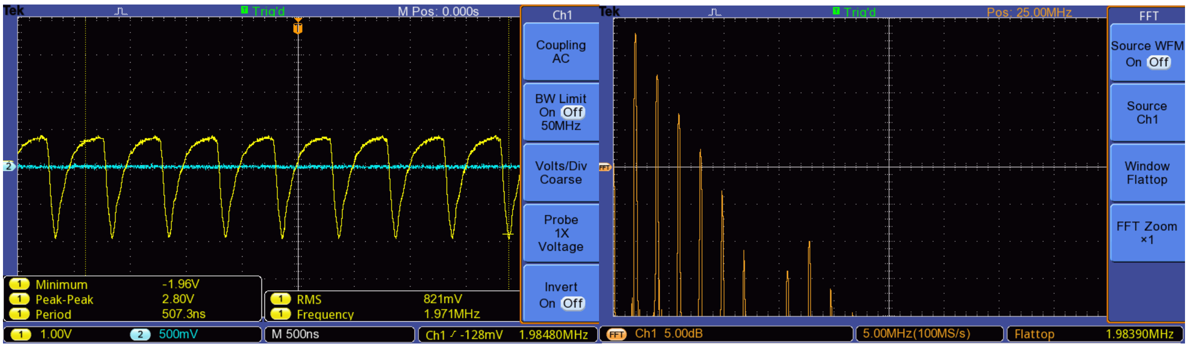

Figure-15. Waveform and its spectrum of the output with feedback =40% of the output voltage.

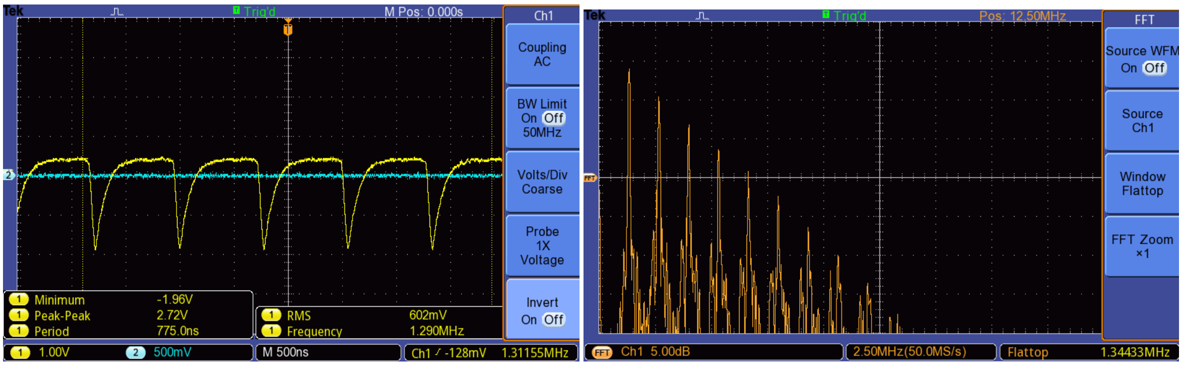

Figure-16. Waveform and its spectrum of the output with feedback =60% of the output voltage.

The output of the three stage oscillator is compared with the profile of $\tanh^2 x$ which replicate a soliton pulse [16] and is shown in Figure-17. In the figure, the yellow color curve represents the obtained waveform and the green color curve represents the simulated soliton pulse using$\tanh^2 x$. It is clearly seen that the shape of the generated pulses from the proposed three stage oscillator circuit resembles with the soliton pulse. The full width at half maximum of the obtained soliton pulse is 0.01 μ sec for the three stage ring oscillator. Similarly, the output waveform of the five stage oscillator can be compared with the simulated soliton pulse.

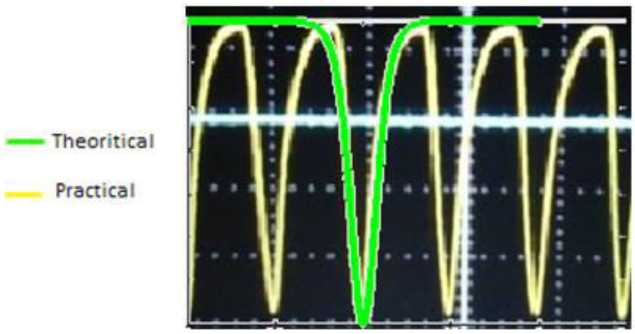

Figure-17. The comparison between the output of the three stage oscillator with the profile of $\tanh^2 x$.

4. CONCLUSIONS

In this paper we have generated electrical dark solitons using CMOS ring oscillator. It is found that, electrical pulses are generated, when the CMOS inverter is operated in the nonlinear regime. More importantly, by adjusting the feedback voltage, soliton pulses are generated when the linear and nonlinear effects balance each other. The linear effect which is induced by an inductor is balanced by the nonlinear effect which is induced by a capacitor. By varying the percentage of feedback voltage the shape of the output waveform, frequency is analyzed. The soliton pulses are analyzed with three-stage and five-stage CMOS ring oscillators. It is found that the three stage ring oscillator generates soliton pulses with a frequency of 3.4 MHz when the feedback voltage is between 71 to 75 percentage of V_0. Similarly, in a five stage ring oscillator, the frequency of generated soliton pulses is 1.34 MHz, when the feedback voltage is 60 percentage of the output voltage. The generated dark solitons find applications in the field of communication.

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