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Design of Radiated Comb Generator Using Single-Ended Positive Emitter Coupled Logic (PECL) D Flip-Flop

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Abstract—Comb generator has been an indispensable tool in the electromagnetic compatibility (EMC) testing field. It is used for calibration and self checking of the test systems. This paper presents a rarely explored yet promising radiated comb generator that makes use of a single-ended PECL D Flip-Flop as the pulse forming component. Measurements show that the generated pulses typically possess fall time and rise time of 330 ps and 410 ps, respectively. Its frequency accuracy is offset by +24 ppm, which is common for crystal oscillators. When being connected to a monopole rod antenna, the comb generator is able to generate radiated emissions that have smooth envelope profile up to 1000 MHz frequency range.

1. INTRODUCTION

A comb generator is basically a periodic pulse generator. In general, smaller duty cycle, which is characterized by shorter pulse width and also faster rising and falling times, generates higher frequency spectrum profiles. When being viewed in frequency domain, such a pulse train is transformed into frequency peaks at the fundamental frequency and its multiple harmonics.

Radiated comb generator, also known as radiation source, has been an important tool for electromagnetic compatibility (EMC) laboratories to ensure the quality of measurement results. Calibration is usually performed in the interval of one or two years. However, in between calibration periods, regular intermediate checks should be carried out to identify if there are any irregularities in measurement results. Self-check is also necessary when there is replacement of connectors, cables, or equipments. For practical reasons, comb generator is an essential tool in performing intermediate checks because it is usually portable, battery operated, and able to generate multiple frequencies simultaneously in the whole measurement frequency range.

Radiated comb generator essentially consists of periodic pulse generator and radiating elements. For EMC applications, the frequency range covers from 30 MHz up to 1, 2, 5 or 6 GHz, depending on the highest internal frequency of the unit under test [1]. There are several ways to produce periodic pulses, for example using discrete silicon RF transistor, step recovery diode (SRD), tunnel diode, nonlinear transmission line (NLTL), and custom monolithic microwave integrated circuit (MMIC) [2]. Pulse generators based on SRD and Schottky diode techniques are able to generate a pulse width of a few hundred picoseconds [3–5]. Another method employing differential AND gates of emitter coupled logic (ECL) devices shows that a pulse width of approximately 1 ns can be produced [6].

In low cost designs, a radiated comb generator producing periodic square waves has been constructed using inverter gates of TTL device [7]. It is shown that the frequency peaks have fluctuant spectrum envelope profiles. This can be explained by the fact that the comb generator makes use of

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square waves instead of short pulses, and also TTL devices have relatively slow rising/falling edges (2–10 ns) [8]. Another design of a comb generator using NAND gates also exhibits similar jagged spectrum envelope profiles [9]. However, for ease of use it is highly desirable that all the frequency peaks form a smooth envelope profile. As such, any irregularities that may show up during self calibration could be easily recognized.

Another simple and cost effective design of pulse generator employing CMOS D Flip-Flop 74AC74 is described in [10]. Although the generated pulse width is limited to about 6 ns, the ingenious design can be adapted to produce narrower pulses by using faster logic devices. In this paper, a comb generator using single-ended positive ECL D Flip-Flop is proposed. To our knowledge, this is the first paper that demonstrates the use of ECL D Flip-Flop as a comb generator. Among logic families, ECL technology is one of the fastest devices whose switching edges go below a nanosecond [8]. Unlike differential ECL method used in [6], single-ended PECL is simpler to implement and uses fewer components. The realized comb generator comprises a pulse generator board and a monopole rod antenna. Measurements and evaluation in time domain and frequency domain are presented.

2. IMPLEMENTATION

This paper aims to design a simple and low cost radiated comb generator usable up to 1 GHz range. The employed components such as CMOS oscillator, a single-ended ECL D Flip-Flop, SMD resistors and capacitors are common parts, widely available, and simpler than solutions that use NLTL, custom MMIC [2], and multiple differential ECL AND gates [6]. However it is worth to mention that each solution finds its own suitable applications. More complex solutions such as NLTL and custom MMIC provide much superior performance of transition edge, i.e., less than 10 ps. They are perfect solutions for extremely high frequency (EHF) applications, but are deemed over specification for lower frequency ones.

The comb generator consists of two main parts, i.e., a periodic pulse generator and a radiating element. The pulse generator implementation is based on a single-ended positive emitter coupled logic D Flip-Flop (PECL DFF). Due to its simplicity, monopole rod antenna is employed as the radiating element.

As shown in Figure 1, the pulse generator is powered at VCC 5 volts and consists of three main parts, i.e., square wave oscillator, TTL to PECL level shifter, and PECL DFF pulse former. The square wave oscillator is constructed from 74HCT04 TTL-compatible CMOS inverter and a 10 MHz crystal. R9, R10, C6, and C18 function as ringing filters at the inverter's output. Unless damped, the ringing could disrupt power supply lines and eventually propagates to next stages in the circuit. As a result, the final pulse output may become deteriorated. The square wave has a TTL voltage level where a LOW is at 0 volts and HIGH is 5 volts. However positive ECL (PECL) has different voltage level definitions where 3.2 volts is a LOW and 4.0 volts is a HIGH. Therefore, TTL square waves need to be converted to ECL level before being fed to the MC100EP DFF. MC100EP has a truth table as shown in Table 1 [11]. Resistors and capacitors used in Figure 1 are of SMD 0805 ceramic type.

Table 1. Truth table of MC100EP DFF.

D	**SET**	**RESET**	**CLK**	**Q**
L	L	L	↑	L
H	L	L	↑	H
X	H	L	X	H
X	L	H	X	L
X	H	H	X	UNDEF

Referring to Figure 1, D and RESET of MC100EP are always held LOW. Incoming rising edge at CLK input causes Q become LOW and $\bar{Q}$ transit HIGH. Because $\bar{Q}$ output is tied to SET input, when $\bar{Q}$ is going HIGH, then Q is forced to HIGH immediately irrespective of the CLK input. Q then stays at HIGH state until the next rising edge of the CLK input. Because of such an abrupt SET action, a very

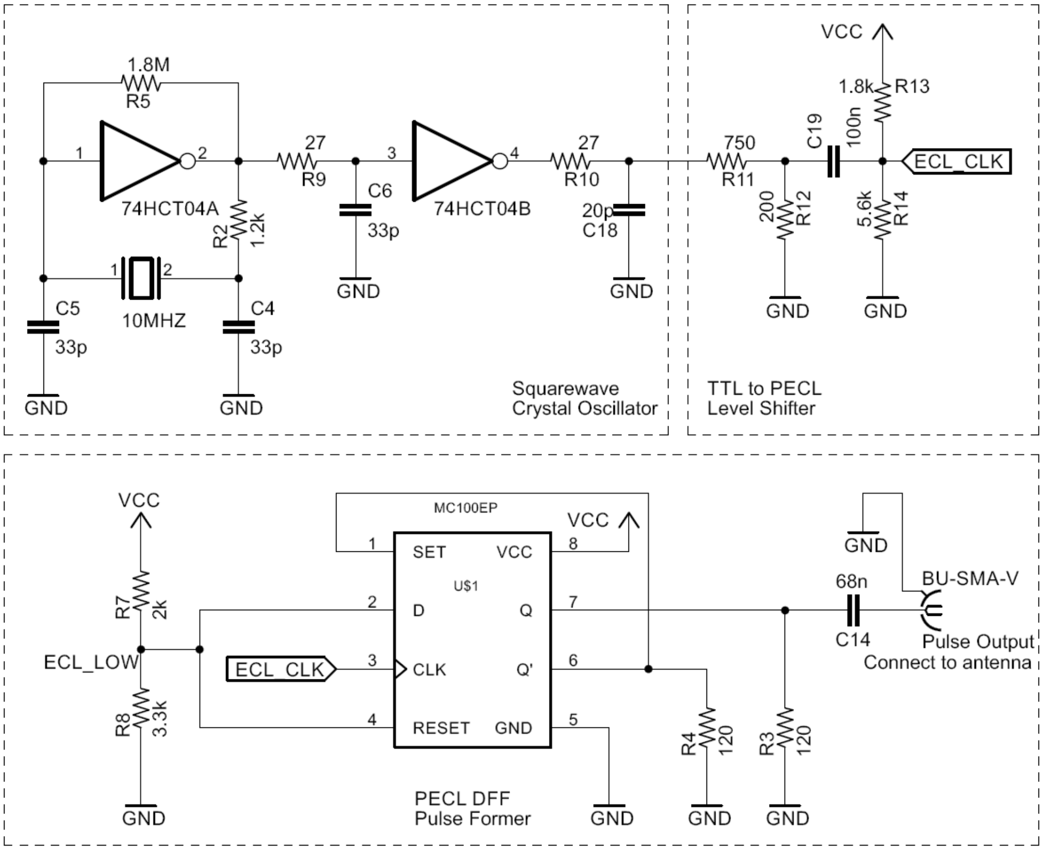

Figure 1. Schematic of PECL DFF based pulse generator.

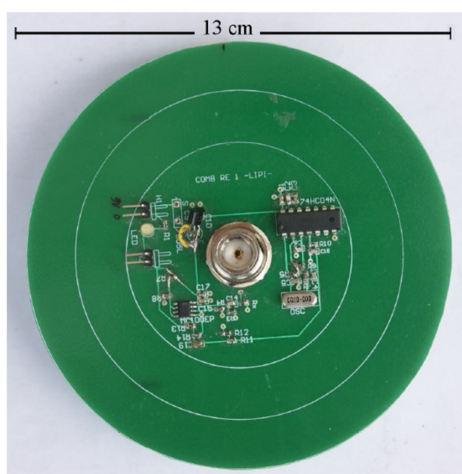

Figure 2. Printed circuit board of pulse generator.

short downwards pulse is generated at Q output. Therefore periodic downwards pulses are produced at each rising edge of the clock. C14 is used to filtered out the DC component so that the net result is a negative pulse on the RF connector output.

Figure 2 depicts the pulse generator printed circuit board. It has a diameter of 13 cm and a solid copper on the bottom layer functioning as a ground plane. The female N connector located in the center of the board serves as the antenna holder. For simplicity purposes, the antenna is made of a copper rod. It has a diameter of 1.7 mm and length of 30 cm, and it fits in the signal pin of the N connector. It behaves effectively as a simple monopole antenna.

3. EVALUATIONS

3.1. Time Domain

Frequency spectrum produced by comb generator is directly related to the generated pulse repetition as well as pulse shape in the time domain. It is known that the pulse repetition rate translates to the frequency spacing in the frequency spectrum. Whereas pulse shape determines the spectrum envelope profile. To obtain flat and smooth envelope across wide frequency range, the pulse width should be as short as possible. Pulse width measurement is done using Agilent 3 GHz DSO80304B oscilloscope, which has capability of measuring rise time and fall time as fast as 140 ps [12]. The generated pulse has a period of 100 ns. Figure 3 shows the typical pulse shape measured at the comb generator RF output. It has a fall time and and rise time equal to 330 ps and 410 ps respectively.

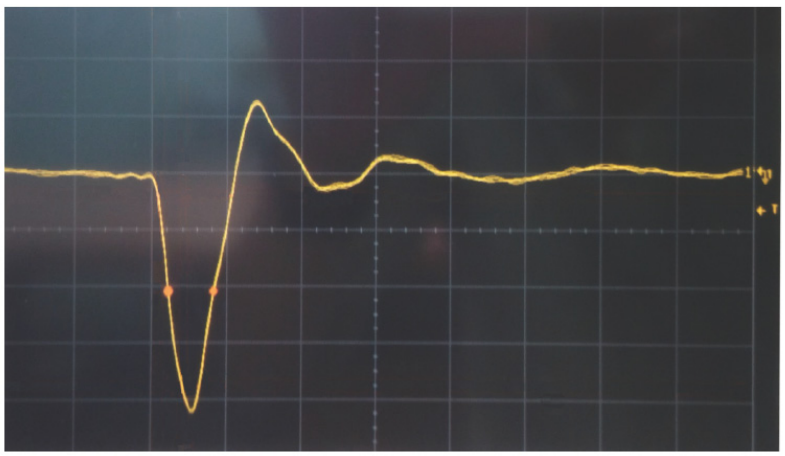

Figure 3. Typical pulse shape measured at the board RF output (1 ns/div, 200 mV/div)

Table 2 shows the comparison of the proposed pulse generator among other techniques. Although our proposed solution is not the sharpest pulse generator, it does demonstrate a promising result of generating sub nanosecond pulses. As in any engineering field, usually there is no single solution that fits for all applications. For example, although NLTL and step recovery diode have excellent performance of sharp transition edges, the voltage amplitude level is considered too high for highly sensitive measuring

Table 2. Comparison of pulse generators.

Technique	**Transition edge**	**Amplitude**
Discrete silicon RF transistor	2.5 ns	20 V
Avalanche transistor	250 ps	50 V
Custom MMIC	8–100 ps	2.5 V
Step recovery diode	45–100 ps	10–35 V
Tunnel diode	20 ps	250 mV
NLTL	< 5 ps	5 V
Differential ECL AND gates	250–400 ps	620 mV
Single-ended PECL DFF	*330–410 ps*	*830 mV*

instruments in EMC radiated emission applications. Therefore, the proposed solution employing single-ended PECL DFF is a new alternative of pulse generator designs that is simple to implement using widely available components.

3.2. Frequency Domain

Measurements in the frequency domain are done in two methods, i.e., direct measurement and radiated emission measurement in a 3 meter semi anechoic chamber (SAC). In the former, the comb generator is directly connected to a spectrum analyzer, whose measurement results depicted in Figure 4. It does not show a straight flat profile in the whole frequency range, which might be explainable by the fact that the pulse shape in Figure 3 shows some amount of overshoot and ringing. However, in general it still exhibits a smooth profile and stands out from the noise floor. It can be reported that the frequency accuracy is offset by +24 ppm. This is a typical figure obtainable from crystal oscillators. In order to achieve higher accuracy, temperature compensated crystal oscillator (TCXO) or oven-controlled crystal oscillator (OCXO) can be used instead.

Meanwhile, measurements in SAC follow a standard radiated emission test procedure. The comb

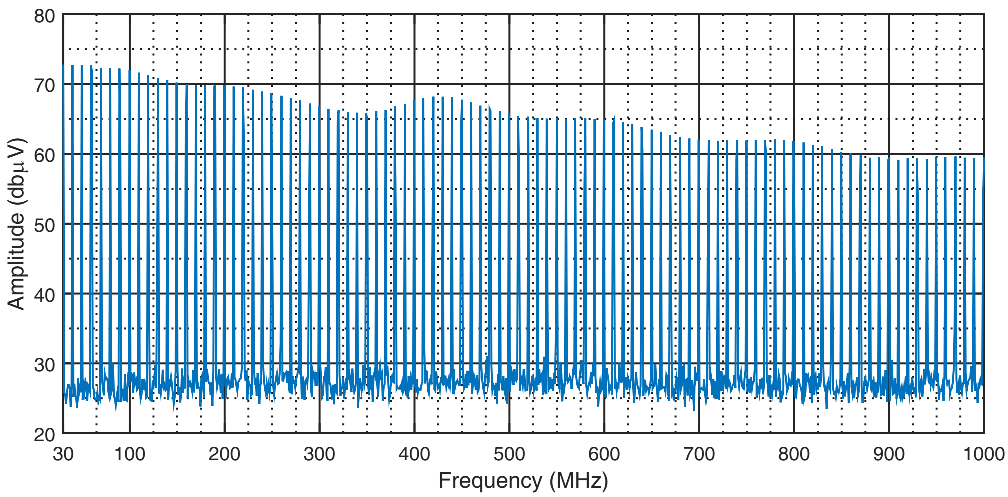

Figure 4. Frequency spectrum measured directly at the board RF output.

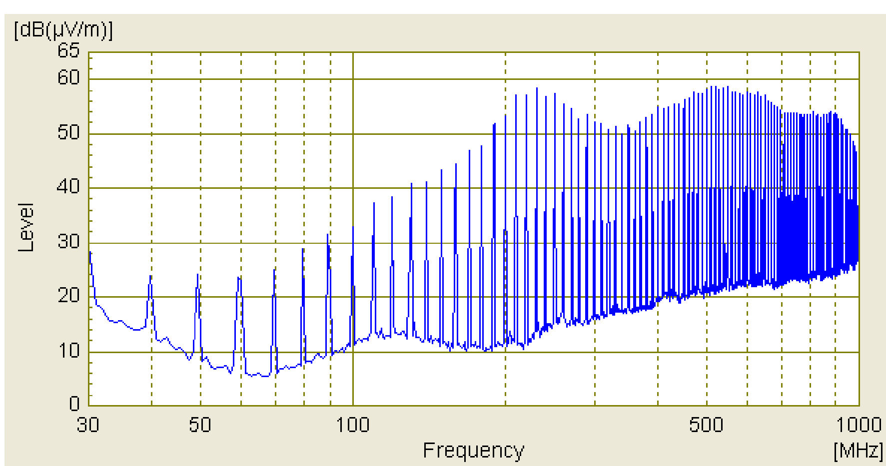

Figure 5. Field strength measured in 3 m semi anechoic chamber.

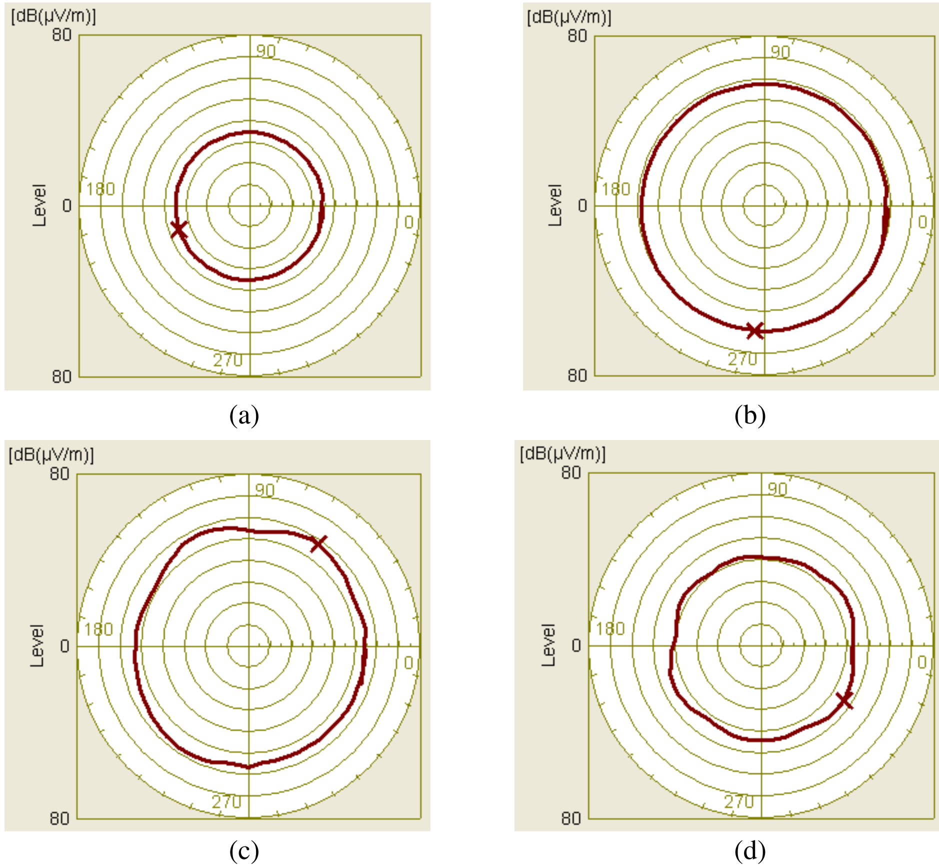

Figure 6. Radiation patterns at various frequencies. (a) Radiation pattern at 100 MHz. (b) Radiation pattern at 230 MHz. (c) Radiation pattern at 800 MHz. (d) Radiation pattern at 970 MHz.

generator (pulse generator with monopole antenna) is placed on a 80 cm high non-metallic rotating table. A measuring BiLog antenna is located 3 m away from the rotating table, and is movable from 1 m to 2 m above the ground. Since the comb generator's antenna is vertically oriented, so is the measuring antenna's orientation in order to obtain a matched polarization. The table is turning 360° while the spectrum analyzer is acquiring *maxhold* measurements. This is done for at antenna's heights of 1 m and 2 m. Figure 5 demonstrates the measurement results. It can be seen that in general smooth spectrum envelope profile is obtained.

Figure 6 depicts the comb generator radiation patterns at various frequencies. At low frequencies, it exhibits the expected omnidirectional radiation pattern of a monopole antenna. Meanwhile at high frequencies some irregularities are observable. This is probably because at high frequencies the component placement on the board is becoming significant compared to the wavelength. Therefore any asymmetry around the board center is then manifested in the radiation patterns.

4. CONCLUSIONS

A simple radiated comb generator has been designed and implemented. It comprises a circular-shaped pulse generator board and a monopole copper rod antenna. It has a unique design in which the pulse former is implemented using PECL DFF. The working principle is exploiting on the asynchronous reset mechanisms of the D Flip-Flop. Although this method is much less explored compared to other methods, such as SRD, Schottky diodes, NLTL, etc., it however shows good performance up to 1000 MHz frequency range. Using crystal oscillator, its frequency accuracy was measured +24 ppm. This can be improved by using more accurate oscillators, such as TCXO and OCXO.

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