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Simulation of Waveform Generator

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M. S. Islam*, P. C. Baidya, S. B. Faruque

Department of Physics, Shahjalal University of Science and Technology, Sylhet, Bangladesh
*Corresponding Author's Email: shafayet_rahat@student.sust.edu

Abstract

Dirac's equation deals with the electromagnetic interactions in quantum mechanics. This equation can be modified for the classical modulated waveform. This paper presents a simulation approach for generating electromagnetic wave packets from the modified Dirac's electromagnetic equation solution. From this solution, an equivalent numerical circuit using SIMULINK is designed. This numerical circuit generates an exact amplitude modulated waveform of the solution. An analog circuit of the equation using op-amp is also designed with SIMULINK. The circuit generates an amplitude modulated waveform. The carrier frequency generated from this simulation is 9 KHz. Finally, a comparative analysis of the numerical and simulated waveform is also discussed briefly in this paper. The simulated result supports the theoretical assumption about the wave generation from modified Dirac's equation.

Keywords: circuit simulation, waveform generator, op-amp, modulation circuit, electromagnetic equation.

1. Introduction

Dirac's equation has been of great interest to the scientific community for a long time. It has many applications in particle physics, spectrum analysis, relativity, etc. [27, 28]. Though it is one of the fundamental equations of quantum mechanics, the interpretation of its solutions is abstract. Thus, the practical understanding of this equation can lead to a new application. In this paper, an approach to interpret the modified Dirac's equation to describe electromagnetic wave packets is discussed [1-3]. Thus, this equation can be used to describe AM wave packet. Amplitude modulation (AM) waveform generators are widely used for experimentation.

Furthermore, it can be used in communication technology such as AM and Frequency modulation (FM) transmitters, Wi-Fi technologies, satellite technologies, etc. [29]. Previous work has been done on the simulation of AM waveform generation [8-9]. Gao et al. has presented a simulation of AM modulation with MATLAB DSP module [8]. It has been done with the direct digital synthesis method. In this method, the signal is generated by a fully digital coded system.

Though in modern-day, AM waveform is generated with the digitally coded system, an analog system is also used for gaining some advantages. One of them is to build an analog wave generator that costs lesser than a digital system. Besides, the analog system gives a proper insight into the function generated in the wave generator [14-16]. In this work, comparative data of numerical and simulation of that equivalent circuit is presented. Thus, this work gives a way of using modified Dirac's equation in a wave generator. This circuit described in this paper can be used in designing any wave generator, analog transmitter, ADC (Analog to Digital Converter), DAC (Digital to Analog Transmitter), etc. [10-13].

In this paper, a comparative analysis of the numerical solution of modified Dirac's equation and function generator circuit is presented. First, the solution of modified Dirac's equation and its numerical circuit is described in section 2. Then, in section 3, circuit design using op-amp is described to support the numerical circuit. And finally, the resultant waveforms have been analyzed, and their performance and characteristics are discussed briefly in sections 3, 4, and 5. All simulation in this paper is done by using the MATLAB/ SIMULINK application [5].

2. Methodology

Previous work has been done on the space-time evolution of Dirac's equation [1-3]. This equation can be rewritten for generating waveform as,

$$\left(\frac{d^2}{dt^2} + 2t\frac{d}{dt} + t^2 + k\right)v(t) = 0 \quad (1)$$

The solution for this equation can be written as,

$$\left.\begin{aligned} v(t) &= e^{i\alpha t}.\, e^{-0.5\beta t^2} \\ v(t) &= \{\cos(\alpha t) + i\sin(\alpha t)\}.\, e^{-0.5\beta t^2} \end{aligned}\right\} \quad (2)$$

Which is the solution of a wave packet. Note that α and β are arbitrary constants. The exact shape of the waveform can be found by using SIMULINK [5]. Eqn. 2 can be rewritten as,

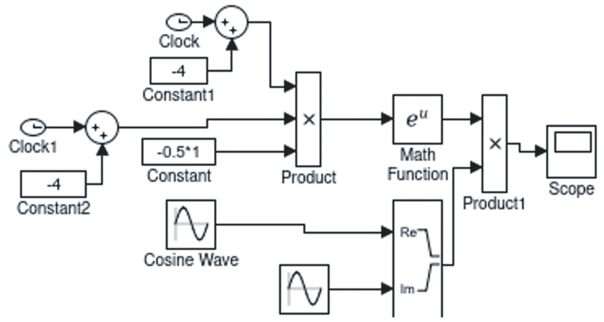


Figure 1: Simulink Circuit diagram for numerical solution of Equation 1, (a) Block circuit for Eqn. 2, (b) Real part of un - normalized waveform shape.

$$v(t) = \{\cos(\omega t) + i\sin(\omega t)\}.\, e^{-0.5(t-4)^2} \quad (3)$$

Here, $\beta t^2 = (t-4)^2$ and $\alpha = \omega$

The same block circuit and the waveform shape for Eqn. 2 is shown in figure 1(a) and 1(b).
An electric circuit that generates waveform V(t) can be formulated. If the imaginary part is ignored, Eqn. 3 can be rewritten as,

$$v(t) = \cos(\alpha t)\, e^{-0.5(t-4)^2} \quad (4)$$

This solution implies that the first part of the solution, "cos (ω *t*)" is the carrier signal, and the second part is an arbitrary message signal. Equation (2) can be modified for time-dependent waveform as,

$$v(t) = \cos(\omega t)\, e^{-0.5(t-4)^2} e^{-0.5[\sin\left(\frac{2\pi}{t-4}\right)^2]} \quad (5)$$

Now, from the theory of Double Sideband-Suppressed Carrier Signals, the received DSB-SC AM signal can be expressed as [17],

$$s(t) = f(t).\, A\cos(\omega_c t) + n(t) \quad (6)$$

Where f (t) is the information signal, A cos(ω_c t) is the carrier wave, and n (t) is the background noise. Ignoring this noise signal, Eqn. 6 can be rewritten as,

$$s(t) = f(t).\, A\cos(\omega t) \quad (7)$$

Note that Eqn.5 and Eqn.7 have a very similar form.

Now if $\beta = \frac{\sin\left(\frac{2\pi}{t-4}\right)^2}{4}$ is taken, then an equivalent SIMULINK circuit for this solution can be developed [5]. $\beta = \frac{\sin\left(\frac{2\pi}{t-4}\right)^2}{4}$ is taken so that it will give a

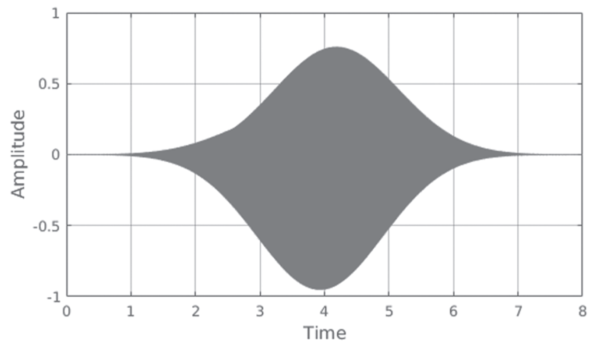


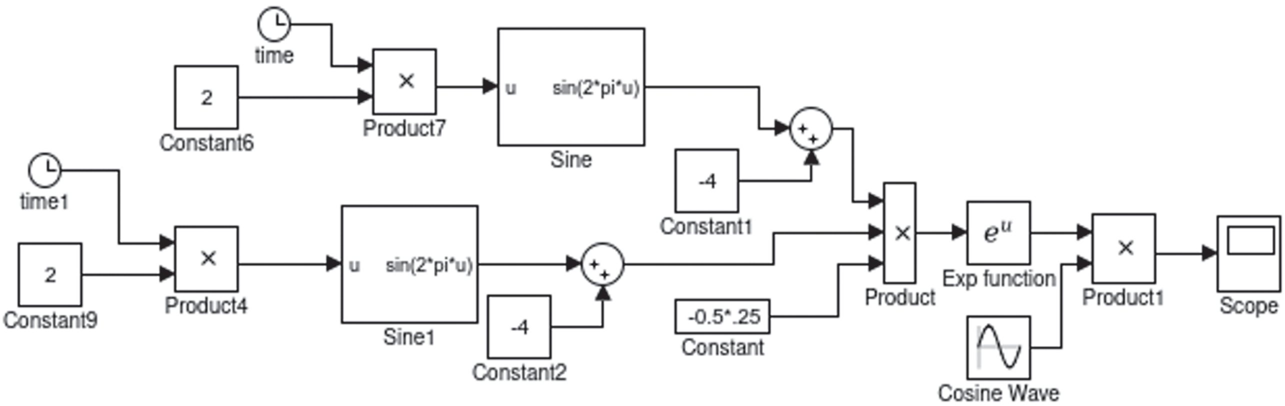
Figure 2: Block circuit for SIMULINK for $v(t) = cos(\omega t).\, e^{-0.5\beta t^2}$. Here $\alpha = \omega$ and $\beta = sin(2\pi/t-4)^2/4$.

periodic waveform pattern. This implies that the message signal can be shaped and changed by varying the value of β. The circuit diagram is shown in figure 2. The resultant waveform pattern of this circuit is shown later in figure 5(a)

3. Circuit Description

3.1 Waveform Generator Circuit

Operational Amplifiers can be used as functional signal generators [4]. There are many combinations of operational amplifiers such as summator, differentiator, integrator which can give expected



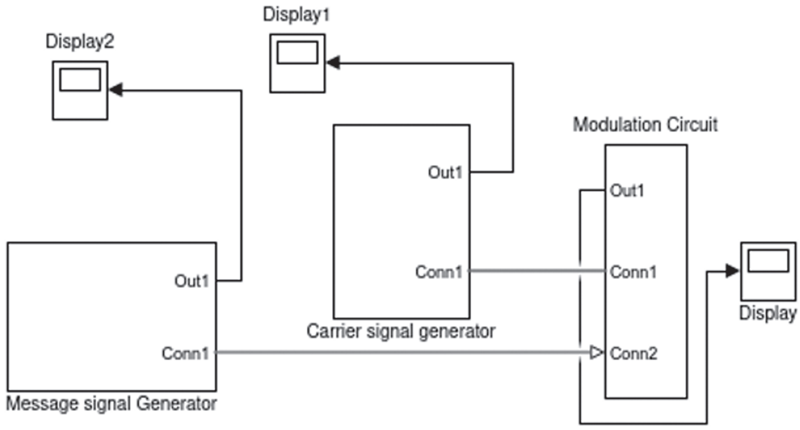


Figure 3: Block circuit for wave generator. Here three components are three subsystems in SIMULINK. In the later sections, these subsystems are described

waveform [25-26]. A combination of differentiators is used for the generation of pseudo Gaussian signals, as real Gaussian signals are very difficult to generate. The wave generator circuit is combined with three components-

1. Carrier signal generator component
2. Message signal generator component
3. Modulation circuit component.

These components are built-in SIMULINK as subsystems [5]. The total block circuit for waveform generation is as follows.

3.1.1 Carrier Signal Generator

In this simulation, the bubba Oscillator circuit is used as a carrier signal generator, as this oscillator produces a stable sine-cosine output signal [6, 18]. The oscillator frequency can be adjusted with $R = \frac{1}{2\pi f c}$. Here, 3V voltage is used as a source. $C_1 = C_2 = C_3 = C_4 = 40\text{nF}$; $R_1 = R_2 = 10\text{K}\Omega, R_3 = 150\text{k}\Omega, R_4 = 1.4\text{ M}\Omega, R_5 = R_9 = R_{10} = 300\Omega, R_6 = R_8 = 1\Omega, R_7 = 2\text{K}\Omega, R_1 = 400\Omega$. The output is going out through Conn1. This circuit results in a cosine signal of band ~ 9 KHz. The signal shape is described in figure 5(b)

The circuit diagram for this subsystem is illustrated in figure 4(a),

3.1.2 Message Signal Generator

Perfectly Gaussian-shaped signal generation with analog circuits is tough to generate. So, a pseudo-gaussian-shaped waveform is generated. A combination of bubba oscillator and clipper circuit is used to clip the negative voltage pattern. Thus, it generates a semi-Gaussian-shaped signal. The circuit diagram of the subsystem is described in figure 4(b).

Here, 3V voltage is used as a source. $C_1 = C_2 = C_3 = C_4 = 20\mu\text{F}; R_1 = 10\text{K}\Omega, R_2 = 10\text{K}\Omega. R_3 = 150\text{km}, R_4 = 1.4\text{M}\Omega, R_5 = R_{12} = R_{10} = 300\Omega, R_6 = R_9 = R_{11} = 1\Omega, R_7 = 2\text{k}\Omega$ and $R_8 = 100\Omega$

The output is going out through Conn1. The signal shape is described in Figure 5(b)

3.1.3 Modulation Circuit

A low-level modulation circuit is used as the signal power is suitable for this kind of modulation [7]. In this circuit, an n-p-n bipolar transistor with a 5V source is used for modulation. After that, the output signal can be used for transmission. The modulation circuit described in the figure below tank circuit is designed with

$C = 10\text{nF}, R3 = 6.8\text{K}\Omega, R4 = 10\text{K}\Omega$

L=130MH, and R2=1KΩ.

Here, Input Conn1 is the carrier signal, and Conn2 is the message signal. Capacitor C and inductor L combines into a tank circuit which collects the modulated signals. Voltage is added for clamping the signals. The output signal shows a modulated pattern which is shown in Figure 5(d)

4. Simulation Results

Two simulations is run in SIMULINK. The first one is the numerical circuit from modified Dirac's equation. The second one is the modulated waveform generated by the circuit built with an op-amp function generator.
This simulation is run for about 2 seconds. Observing the wave packet pattern, it can be said that the waveform is not modulated. Carrier frequency is ~80Hz. Waveform shape is controlled by $\beta = \frac{\sin\left(\frac{2\pi}{t-4}\right)^2}{4}$. The second simulation is designed with

electrical components from the SIMSCAPE module of Simulink. This circuit gives an AM modulated waveform. The carrier and message signal generated from the carrier signal generator and message signal generator are described in Figure 5(b) 5(c). An AM modulated waveform is caused by the modulation circuit [20]. The modulated signal is generated taking input from the carrier and message signal described in subsections 3.1., 3.1.2, and 3.1.3. Figure 5(d) presents the output results of the modulated waveform.

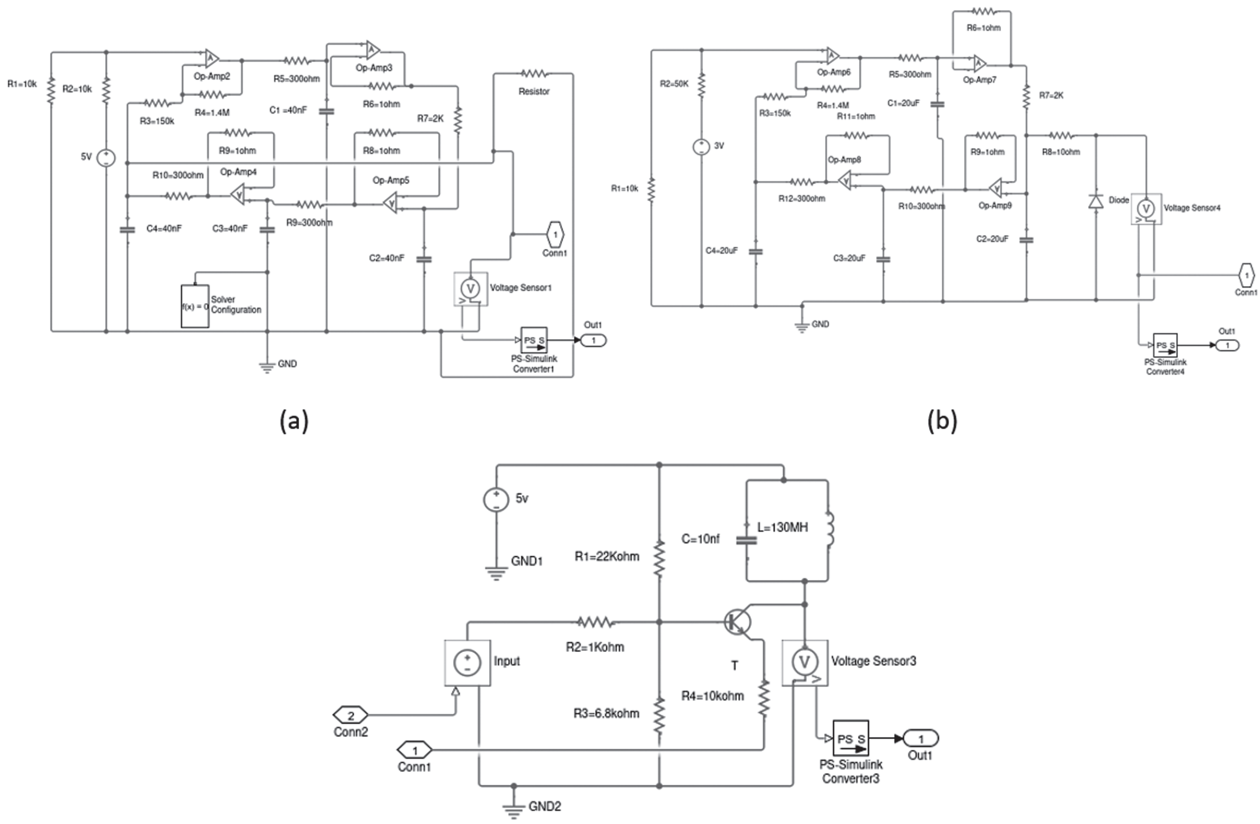


Figure 4: (a) Carrier signal generator circuit (b) Message signal Generator (c) Modulation circuit

From figure 5, it is observed that the carrier signal is ~2V, and the message signal is ~1V. From these values, the modulation index μ [19] can be calculated. The modulation index found $\mu = \frac{M}{A} \approx \frac{1}{2} \approx 0.5$ from this simulation.

Here, M = Amplitude of the message signal and A = Amplitude of carrier signal. This modulation index indicates that the simulated carrier amplitude varies 50% above its unmodulated level. This waveform can be transmitted after necessary power amplification. The transmission band is ~9 KHz.

5. Results and discussion

After comparing figure 5(a) and figure 5(d), it is clear that there is some noise in the generated waveform from the wave generator circuit [21-22].

The circuit needs 0.5 sec to stabilize. Thus, the waveform becomes distorted at the beginning. Moreover, the message signal is hard clipped [23, 24]. Because of that, there is a break of periodicity in the modulated waveform. As a result, low noise is created in the carrier signal. As the modulated signal is generated with analog signals, there are many drawbacks and less control over the modulation and waveform generation. But, from the result described in figure 5, it can be said that waveform modulation can be explained from modified Dirac's equation. The simulated circuit can further be developed with SPICE simulation or can be converted into VHDL code. That way, it will give more control over the circuit and can generate more precise waveforms. The generated waveform can be transmitted through an efficiently designed antenna.

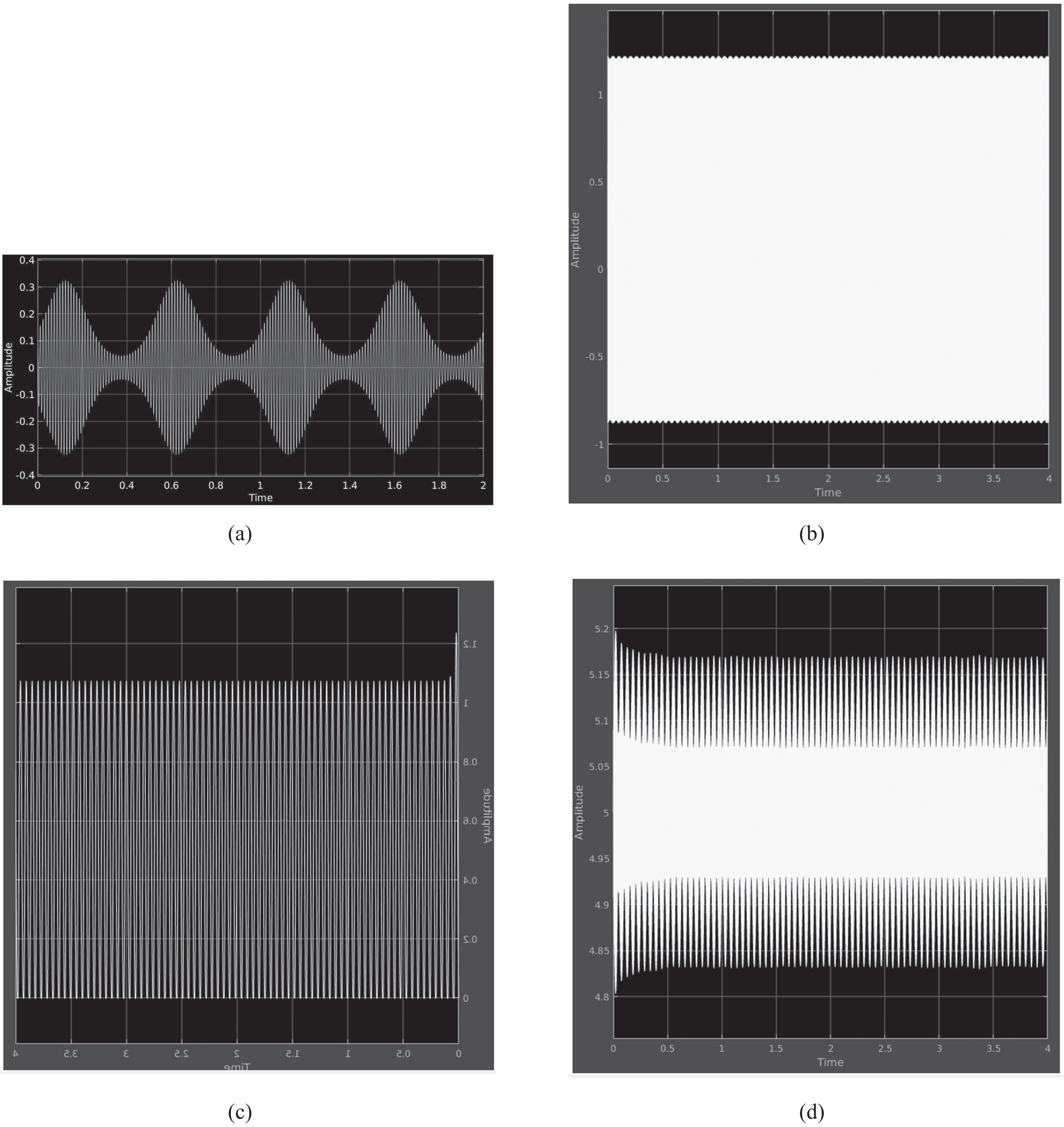


Figure 5: (a) Modulated waveform pattern solved numerically from equation (4). (b) Carrier signal generated for 4 sec. (c) Message signal (d) Modulated waveform Generated by Modulation circuit described in section 2.2.3

6. Conclusion

In this paper, the proposed idea is to connect modified Dirac's equation and AM modulated waveform. From the resultant waveform of AM modulator and the numerical circuit, it is clear that the simulated data supports the numerical data. Still, a lot of work can be done to improve the simulation result. Since this paper aims to describe an analogical system from the modified Dirac's equation, we work only on the waveform generator. In the future, we would like to develop a demodulation circuit in our simulation and build the whole waveform generator.

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