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The Simulation of the Electromagnetic Disturbances against One Electronic Circuit and Their Effects

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Abstract. This paper presents a SPICE-based simulation study of electromagnetic disturbances acting on ground circuits in naval electronic equipment. The analyzed system is an analog-digital oscillator powered at 5 V, composed of a TTL analog section with two npn transistors and a digital JK logic section, separated by an inverter with an anti-interference role. First, the useful signal is examined under normal operating conditions by waveform observation, logic-state evolution, and Fourier analysis up to the ninth harmonic. From these results, a disturbance factor of $k_{du} = 0.42$ is obtained. Next, fictitious voltage sources are inserted on different ground nodes to simulate electromagnetic interference. For a sinusoidal disturbance of 100 kHz and 1 V applied to ground node 2, the disturbance factor rises to $k_{du1} = 0.57$, showing significant signal degradation. Additional simulations at 10 MHz, 10 kHz, and DC confirm the harmful influence of disturbances and the need for electromagnetic protection.

Keywords: Electromagnetic compatibility; SPICE simulation; electromagnetic disturbances; Fourier analysis; analog-digital oscillator.

1. Introduction

Electromagnetic compatibility (EMC) is the ability of electronic equipment to operate correctly in its electromagnetic environment without introducing intolerable disturbances into that environment (Ianoz, 1992; Schwab, 1996; Sotir & Mosoiu, 1997). In modern electronic equipment, switching power converters are major sources of conducted emissions, which can be reduced by spread-spectrum modulation of the switching frequency (Stepins et al., 2023) and by properly designed and shielded EMI filters (Stepins et al., 2018).

Software simulation, alongside measurements and tests, has become necessary due to the increasing complexity of electronic systems and the need to shorten research and design cycles.

The SPICE software package (Serban, 1994) enables the simulation of analog and digital electronic circuits and includes modules for Fourier analysis, internal noise analysis, analysis under disturbing conditions, and Monte Carlo analysis.

2. The oscillator subjected to disturbing signals

In this paper, the disturbing phenomena affecting the ground circuits of naval equipment are analyzed using the SPICE software package.

The occurrence of electromagnetic disturbances on the electronic ground circuits is simulated by inserting fictitious sources and analyzing the analog and digital signals at different nodes of the circuit.

For this study, an analog-digital oscillator was chosen. Its analog part is a TTL logic circuit containing two npn transistors, and it is separated from the digital part by an inverter, which here plays

an anti-interference role by providing capacitive separation, since both parts share a common voltage source. The digital part is a JK logic circuit. The analyzed circuit is supplied by a 5 V DC source (Figure 1).

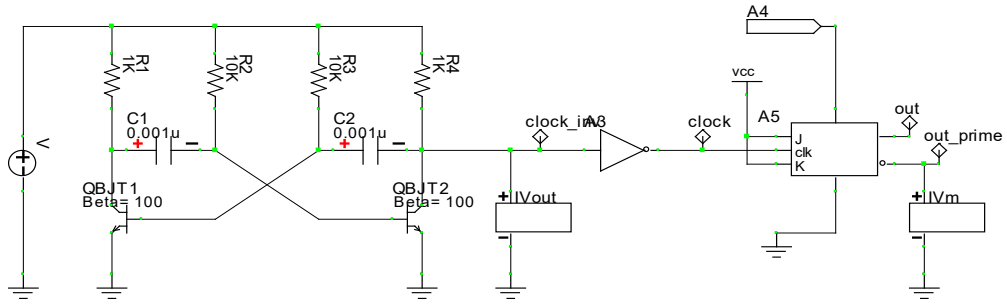


Figure 1. Analog-digital oscillator

The output signal before the inverter is observed on the software oscilloscope "IVout" in the analog part (blue), and the input signal on the software oscilloscope "IVm" in the digital part (red), as shown in Figure 2.

The axes represent voltage (0–6 V) and time (0–50 μs).

SPICE also provides the time evolution of the logic states (0/1) of the digital part, shown in Figure 3.

Table 1 presents the Fourier analysis of the non-sinusoidal periodic signal up to the ninth harmonic, as follows:

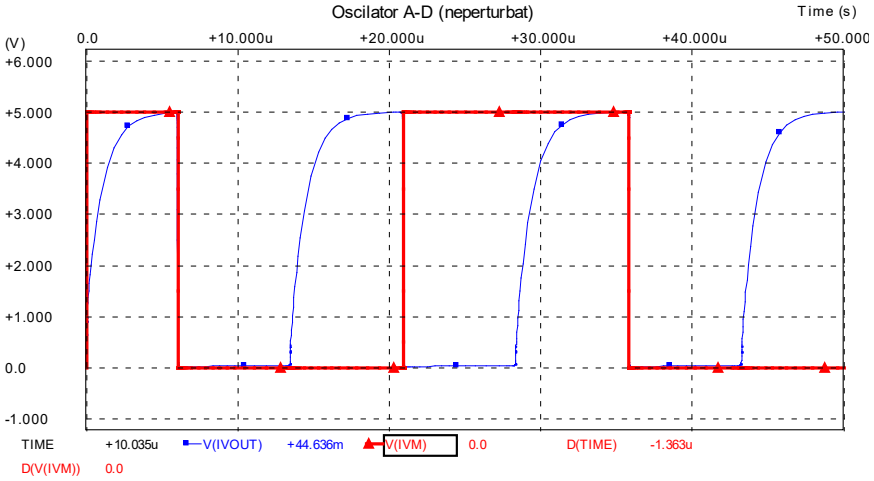


Figure 2. Signal evolution on the "IVout" and "IVm" software oscilloscopes

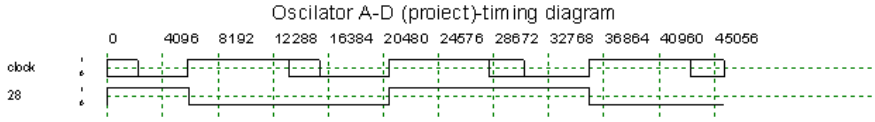


Figure 3. Evolution of the logic states of the circuit

- the first column contains the fundamental frequency of the circuit signal and its harmonics, up to the ninth;
- the second column contains the signal amplitude (in V); note that the suffix "m" denotes millivolts in SPICE notation;

- the third column contains the signal phase; the last two columns contain the amplitude and phase normalized to the fundamental component.

Table 1. Fourier analysis of the IVout signal (analog-digital oscillator).

FREQ (Hz)	mag_vclock_inv	phase_vclock_inv	norm_mag_vclock_inv	norm_phase_vclock_inv
0.0	+2.893	0.0	0.0	0.0
+100.000k	+2.785	-165.007	+1.000	0.0
+200.000k	+817.961m	+147.512	+293.689m	+312.519
+300.000k	+411.636m	-151.769	+147.798m	+13.238
+400.000k	+531.189m	-173.771	+190.724m	-8.765
+500.000k	+299.378m	+167.517	+107.492m	+332.524
+600.000k	+222.359m	-162.212	+79.838m	+2.794
+700.000k	+273.840m	-170.839	+98.322m	-5.832
+800.000k	+193.454m	+175.772	+69.460m	+340.779
+900.000k	+152.730m	-164.562	+54.838m	+444.814m

The disturbance factor was calculated using Eq. (1):

$$k_{du} = \frac{\sqrt{\sum_{i=2}^{9} U_i}}{\sqrt{\sum_{i=1}^{9} U_i}} \tag{1}$$

For the given signal, the value of this factor is $k_{du} = 0.42$.

3. Simulation of disturbing signals using voltage sources on the ground circuits and their effects

Next, disturbing signals were *injected* (as voltage signal sources) at different nodes of the ground circuits in order to observe their effects on the useful signal.

For this purpose, voltage sources acting as disturbing sources were inserted at the ground nodes of the schematic, to obtain different disturbance cases.

The configuration of the resulting schematic, containing six sources, is shown in Figure 4. The same type of analysis presented above was performed for this *new circuit*.

As an example, the case of a sinusoidal disturbing voltage source with f = 100 kHz and U_{max} = 1 V, inserted at ground node 2, is presented and analyzed below.

The effects of this type of disturbance on the useful analog and digital signals are presented in Figure 5 and Figure 6.

The spectral (Fourier) analysis of the signal subjected to the noise source *Vpert2* is shown in Table 2.

The disturbance factor obtained from these data is $k_{du1} = 0.57$ in this case. The difference between the two factors is 34.9%, which shows that the useful signal is strongly disturbed.

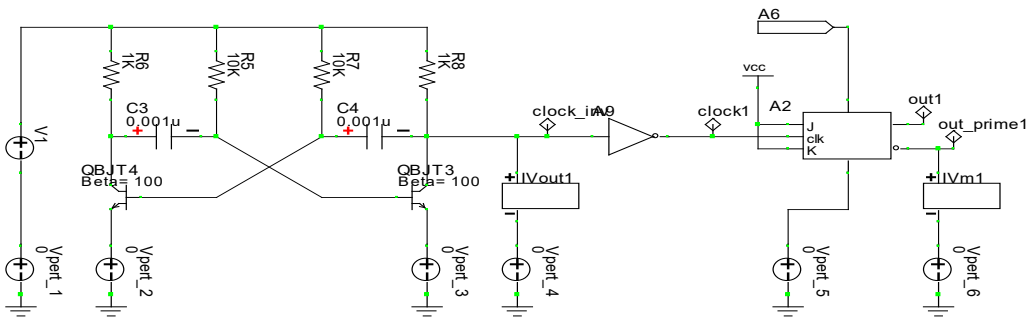


Figure 4. Oscillator with disturbing voltage sources on the ground nodes

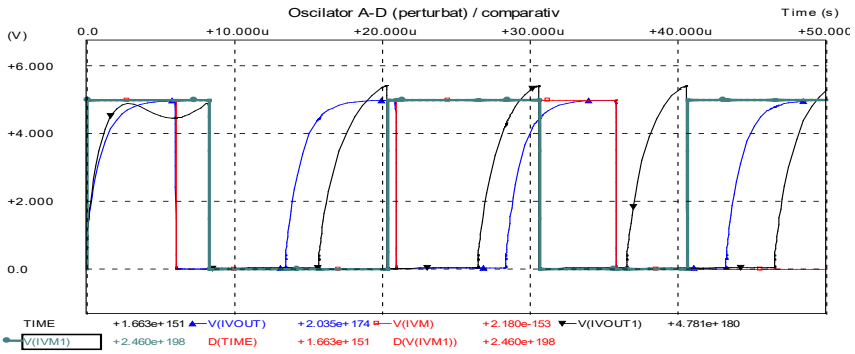


Figure 5. Disturbed analog signal

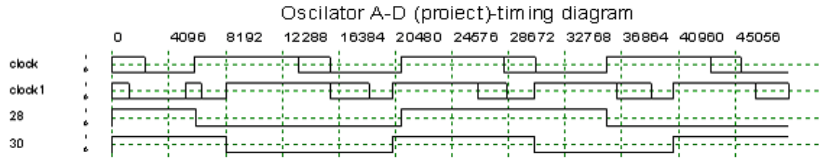


Figure 6. Disturbed digital signal

4. Interference at other frequencies

To observe the effects of electromagnetic interference on the useful signal at frequencies higher or lower than the operating frequency, three cases are presented in Figure 7, Figure 8, and Figure 9.

Figure 7 shows interference with a 10 MHz signal and Figure 8 with a 10 kHz signal, while Figure 9 shows interference with a DC signal. In all cases, the disturbances result from interference on the ground circuits.

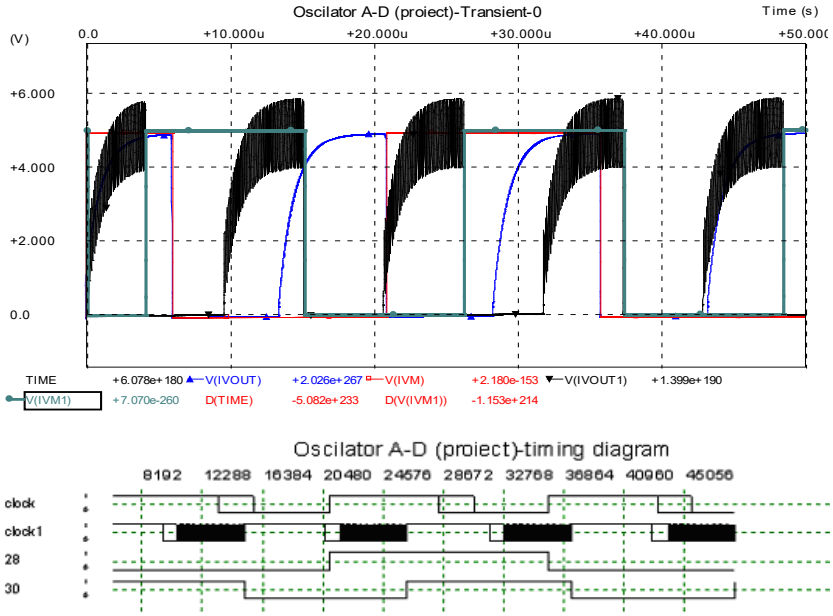


Figure 7. Interference with a 10 MHz signal

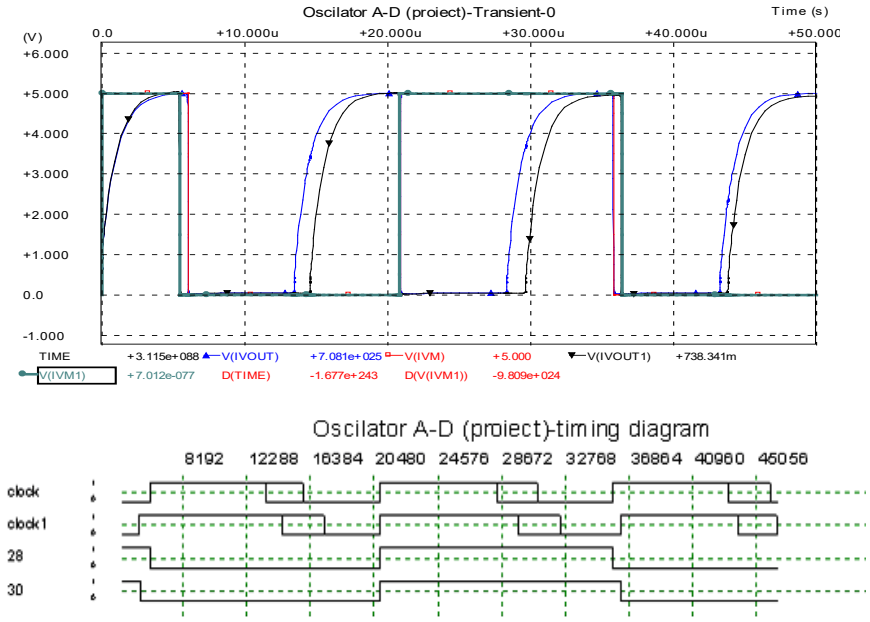


Figure 8. Interference with a 10 kHz signal

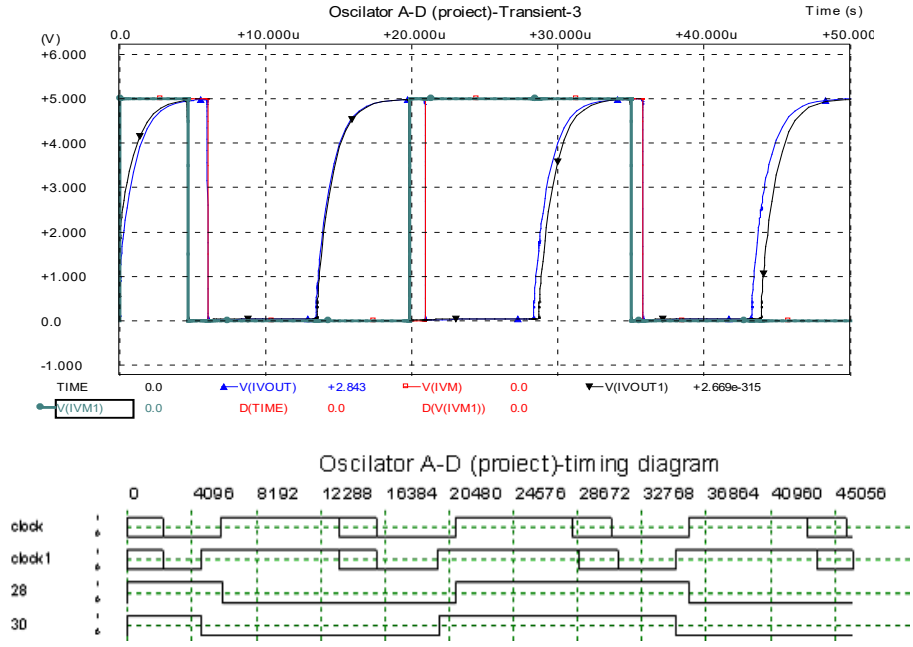


Figure 9. Interference with a DC signal

5. Conclusions

This work identifies, by software simulation, the undesired effects of electromagnetic disturbances on the ground circuits of naval electronic equipment. Understanding these phenomena is essential to protect such equipment against electromagnetic interference.

Author contributions:

- Conceptualization and supervision: V.D.
- Methodology, writing – review and editing: V.M.
- Software and simulation: L.P.
- Writing – original draft and simulation: E.D.

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Conflict of interest: The authors declare no conflict of interest.

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