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Safety analysis of 2-pin capacitor as 4-pin capacitor with frequency response

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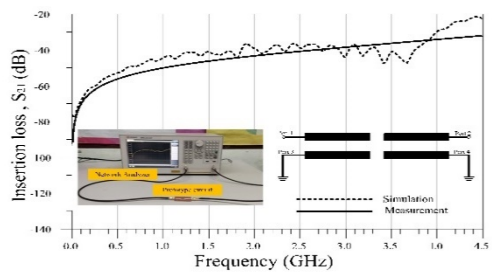
Abstract

This paper presents an experiment to verify the safety effect of resolving an open capacitor failure by 4-pin capacitor structures or 2-pin capacitor structures by cut the copper pattern of the printed circuit board (PCB). Both solutions to the problem of open capacitor failure do not affect the next part of the circuit or devices in the operating frequency range of 100 kHz to 500 kHz. This research analyses the effect of using a 2-pin capacitor by cutoff the printed circuit board. The results of parallel patterns of copper stripes were analyzed at different stages and frequency responses analysis in the range of 100 kHz to 4.50 GHz based on a frequency response analysis (FRA), which are experimental results of insertion loss (S_{21}) and return loss (S_{11}). Using a conventional capacitor instead of a 4-pin capacitor of RT2010 type did not show any harmful effects from self-oscillation within the circuit or from the external circuit. The accuracy was verified by simulating the computer program and measuring the test circuit.



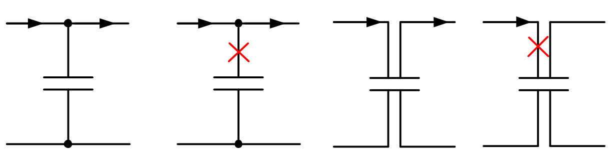
Keywords: Fail-safe; 4-pin capacitor; Open fault; Parallel coupled lines

1. Introduction

A capacitor input open fault in the complementary metal oxide semiconductor (CMOS) inverter relaxation oscillator circuit causes high frequency self-oscillation as result of latent capacitance value within the CMOS inverter [1 – 4]. Parasite capacitors rated at 5 pF produce a self-oscillation frequency of about 2 MHz to 1 GHz. The circuit can be solved by 4-pin capacitors or 2-pin capacitors by cut the copper pattern of the printed circuit board. The circuits can be protected against self-oscillation and capacitor input open faults [2 – 3] by adding a capacitor and metal shield to the CMOS inverter as an input buffer and band pass filter circuit. These countermeasures ensure that no self-oscillation occurs. The 4-pin capacitor in the oscillator circuit [4], feedback resistor and capacitor are not connected to the input and do not add resistance and capacitance to the circuit.

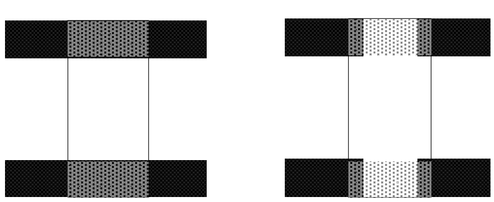
Countermeasures against open-circuit self-oscillation for a general capacitor are shown in Fig. 1(a). The junction does not separate from other parts of the circuit. When an open fault at a pole and the current can flow because the pole is connection. This might the system to a faildangerous consequence. The fail-safe capacitor is shown in Fig. 1(b), the current cannot flow through to other parts of the circuit when an input open fault at a pole and cuts off the capacitor from the other part of circuit. This method is a fail-safe. The method that uses four pin special capacitors, which are rare or special order. The conventional capacitors are unavailable, the design for the printed circuit board (PCB) can be adapted to use normal capacitors. This method cut the copper on the PCB and uses the terminal of the capacitor instead the pins [4].

Diagnosis of analogue electronic circuits is very important in fail-safe systems. Reducing tolerances increases diagnostic efficiency. Access to nodes within the circuit limits the source of information about the state and potential faults [5]. Circuit reliability can be performed by FMEA (Failure Mode and Effect Analysis) [1 – 4] including multiple failure modes. FMEA was designed as a component to be used to test whether the hardware is inherently fail-safe.



(a) General capacitor (b) Fail-safe capacitor

Fig. 1 Comparisons of capacitors [1 – 4].



(a) Capacitor in general (b) Capacitor in fail-safe

Fig. 2 Comparison of capacitors in general and fail-safe circuits [4].

The scope of this paper concerns the analysis of a 4-pin capacitor by cut the copper pattern of the printed circuit board with high frequency from other parts of the circuit to input open fault in the range of 100 kHz to 4.50 GHz and analyzed by a microstrip parallel coupled lies method. Ports 3 and 4 were assigned to virtual ground against the input capacitors in the Schmitt trigger inverter relaxation oscillator circuit, calculated by two-ports network analysis. The accuracy was verified by simulating the computer program and measuring the test circuit.

2. Materials and Methods

Design Concept

The electrical and magnetic phenomena are described by Maxwell's equations based on a plethora of empirical and theoretical knowledge developed by Gauss, Ampere, Faraday, and others [6]. Parallel microstrip coupled lines are used in circuit design and construction. They are light in weight with small size and can be used in a wide frequency range. They are also easy to connect to electronic devices and recognize different types of diodes or transistors [6 – 8]. However, parallel copper patterns result in energy transmission at different frequency levels, especially in the high frequency band. Electrical interactions form on microstrip transmission lines connected in parallel.

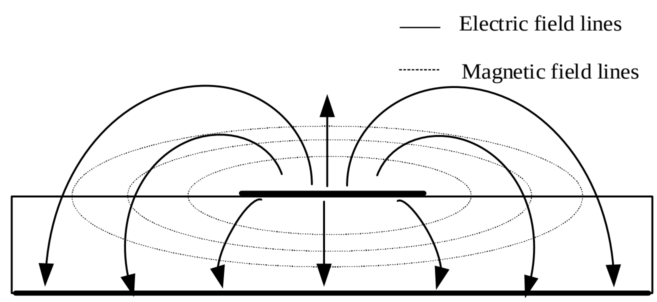


Fig. 3 Electrical and magnetic fields of microstrip transmission lines [6].

A transmission line has three important structural components as 1) the width (w), 2) copper thickness(t) and 3) the thickness of the substrate (h), as shown in Fig 3. These components can be used to find the impedance characteristic, as shown by Eq. 1 and the effective dielectric constant as shown by Eq. 2.

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{w}{h} + 1.39 + 0.66\ln\left(\frac{w}{h} + 1.44\right)\right]} \quad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\left(\frac{1}{2}\right)} \quad (2)$$

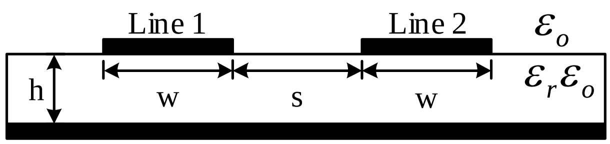


Fig. 4 A transmission line [9 – 10].

Crosstalk occurs between parallel transmission lines with a distance between them of less than the wavelength, proportional to the power from one transmission line [10 – 11]. A power leak affects other microstrip transmission lines. This is an unpleasant phenomenon and creates obstacles in the design of communication systems that require microstrip transmission lines. For two or more microstrips, a distance between them at less than the wavelength will affect the impedance, characteristics and transmissive signal that occurs, as shown in Fig. 4 and Eq. 3 and 4.

$$Z_0 = \frac{\eta_0}{\sqrt{\varepsilon_{eff}}}\frac{K(k)}{K(k')} \quad (3)$$

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2}\frac{K(k')K(k_1)}{K(k)K(k_1')} \quad (4)$$

$$k = \frac{s}{2w + s} \quad (5)$$

$$k' = \sqrt{1 - k^2} \quad (6)$$

$$k_1' = \sqrt{1 - k_1^2} \quad (7)$$

A problem occurs in microstrip transmission as crosstalk as Fig. 5 and compensation of coupled lines [9 – 12] in a parallel connection with a distance apart at less than the wavelength. The proportion of power leakage affects the transmission.

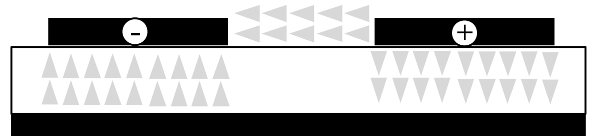


Fig. 5 Characteristics of the crosstalk [8 – 9].

This can cause consequences in various cases. Fig. 2(b) shows the normal condition. A failure from another part of the circuit that causes high frequencies results in the equivalent circuit, as shown in Fig. 6.

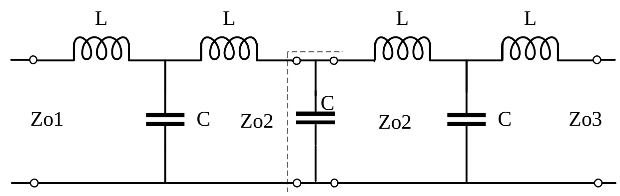


Fig. 6 The equivalent circuit in normal condition.

The equivalent circuit can be viewed as a two ports network in terms of impedance parameters for easy computation, as shown in Fig. 7 and Eq. 8.

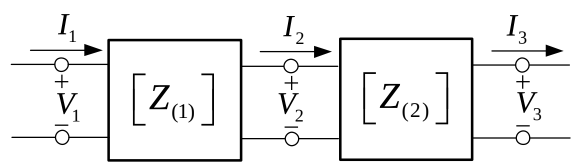


Fig. 7 The two ports network in normal condition.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} Z_{(1)11} & Z_{(1)12} \\ Z_{(1)21} & Z_{(1)22} \end{bmatrix}\begin{bmatrix} Z_{(2)11} & Z_{(2)12} \\ Z_{(2)21} & Z_{(2)22} \end{bmatrix}\begin{bmatrix} V_3 \\ I_3 \end{bmatrix} \quad (8)$$

In a capacitor open faults condition, assuming that the capacitors are detached from the printed circuit board on all four pins, there is a gap between the copper lines that causes an equivalent circuit, as shown in Fig. 8.

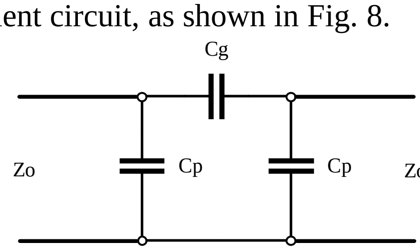


Fig. 8 The equivalent circuit in open fault condition.

The equivalent circuit can be viewed as a two ports network in terms of impedance parameters, as shown in Fig. 9 and Eq. 9.

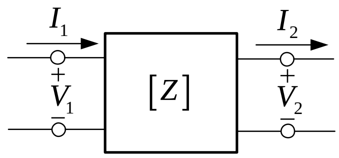
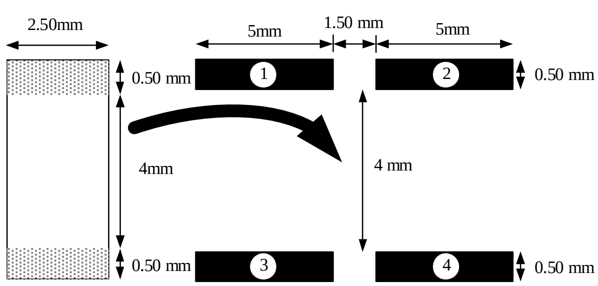


Fig. 9 The equivalent circuit in open fault condition.

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{9}$$

The scope of this paper is, firstly, to confirm that the methods presented had no effect because the distance of the gap was greater than the length of the resulting wave and secondly, to analyze the effect of a 2-pin capacitor by cutting the copper pattern of the printed circuit board with high frequency from other parts to input an open fault in the range of 100 kHz to 4.50 GHz. The experiment is designed by simulating the size of the capacitor type RT2010, as shown in Fig. 10.



$$S_{ij} = 20\log\left(\frac{V_i}{V_j}\right) \tag{12}$$

$$S_{21} = 20\log\left(\frac{V_2}{V_1}\right) \tag{13}$$

$$S_{11} = 20\log\left(\frac{V_1}{V_1'}\right) \tag{14}$$

Fig. 10 Design for capacitor type RT2010.

The oscillator or filter circuits on ports 3 and 4 are grounded, as shown in Fig. 11.

Fig. 11 Parallel coupled lines for capacitor type RT2010.

The equation is calculated only on ports 1 and 2.

$$V_1 = I_1 Z_{11} - I_2 Z_{12} \tag{10}$$

$$V_2 = I_1 Z_{21} - I_2 Z_{22} \tag{11}$$

For the printed circuit board design for testing the circuits, ports 1 and 2 are connected to the SMA connector.

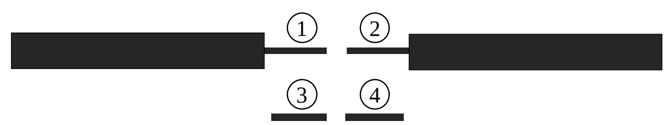


Fig. 12 Implementation of the PCB.

From the correlation equations 10 and 11, the relation between the diffusion variable (S-parameter) and the connection coefficient (coupling factor, S_{21}) is the capacity of power transmission from port 1 to port 2, as shown in Eq. 13, while the return loss from at port 1 is shown as Eq. 14.

3. Results and Discussion

The circuit is calculated by a closed equation to verify the accuracy by simulating the computer program and measuring the test PCB circuit, as shown in Fig. 13.

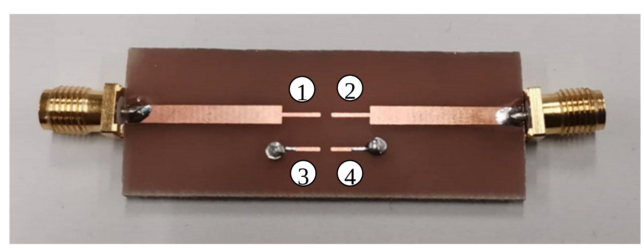


Fig. 13 The experiment PCB for capacitor type RT2010.

The frequency response measurement of the prototype circuit is performed with a E5063A ENA vector network analyzer as shown in Fig. 14.

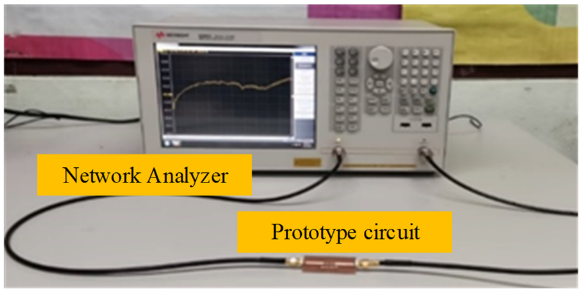


Fig. 14 Experiment with vector analyzer.

The instrument is calibrated from frequency 100 kHz to 4.50 GHz. Plot graph data are recorded and compared with the computer program simulation results. Results of the frequency response of transmission loss and return loss are shown in Fig. 15 and 16.

In Fig. 15, comparison of the results of the forward transmission loss frequency response is found to be less than –20 dB throughout the measurement range. The amount of power transmitted increased when the frequency is higher than 4 GHz.

The experimental simulation results and actual measurements are the same. The printed circuit board design using a conventional capacitor instead of a 4-pin capacitor [4] RT2010 type did not show any harmful effects arising from self-oscillation within the circuit or from the external circuit.

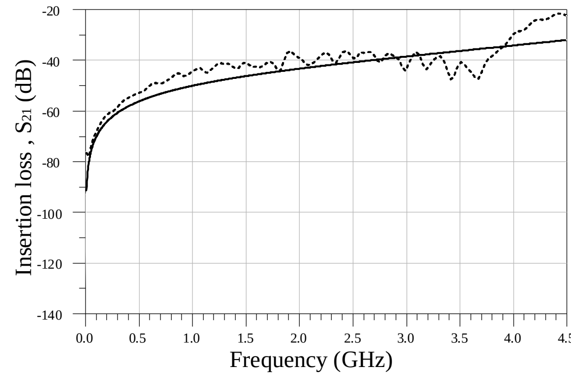


Fig. 15 Frequency response of insertion losses.

Fig. 16 compares the results of the return loss frequency response. The coefficient of the amount of power reflected from the secondary channel decreased for frequencies higher than 4 GHz. And Table 1 Comparison of safety analysis of 2-pin capacitor as 4-pin capacitor based on microstrip coupled lines.

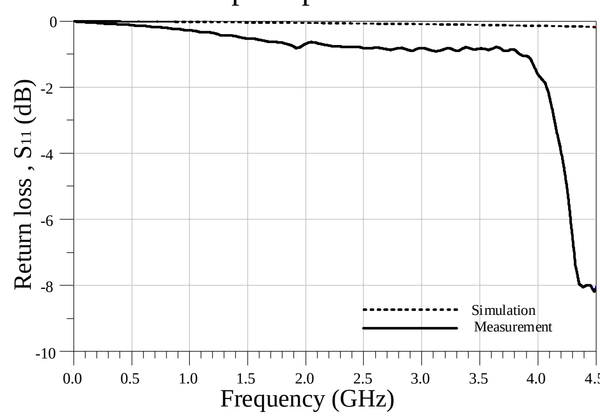


Fig. 16 Frequency response of return losses.

Table 1 Comparison of safety analysis of 2-pin capacitor as 4-pin capacitor

Ref.	Frequency	Techniques	Time domain	Frequency domain
[1, 2]	NA	FMEA	Yes	Not proposed
[3]	NA	FMEA	Yes	Not proposed
[4]	NA	Capacitor in fail-safe circuit	Yes	Not proposed
[5]	Max 6	Fault Diagnosis	Yes	Yes
This work	100 kHz – 4.50 GHz	4-pin capacitor	No	Yes

4. Conclusion

This paper presented a test to verify the safety effect of resolving open capacitor failure using a 2-pin capacitor by cut the copper pattern of the printed circuit board. The problem of open capacitor failure did not affect the next part of the circuit in the frequency range of 100 kHz to 500 kHz. The objective of this research was to analyze the effects of using a 2-pin capacitor by cut the print circuit board. The results of parallel patterns of copper stripes were analyzed at different stages and frequencies in the range of 100 kHz to 4.50 GHz by parallel coupled lines analysis method with a symmetrical capacitor center and calculated by a closed loop equation. The accuracy was verified by simulating the computer program and measuring the test circuit.

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