EFFECTS OF ETCHING PROCESS INACCURACY IN THE MALFUNCTIONING LEVEL OF PCB CIRCUITS - A SIMULATION BASED ANALYSIS

Hgigat Aregawi [1], Mohammed Abdo [2]
[1]Department of Computer Science and Engineering, Mekelle Institute of Technology, Mekelle University, Mekelle, Ethiopia. Email: hgigat.aregawi@mu.edu.et
[2]School of Electrical and Computer Engineering, Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia, Email: mohammed.abdo@aait.edu.et

ABSTRACT

The PCB is a mechanical base used for interconnection of electronic components. In PCB manufacturing industry, the quality and reliability of circuits is highly dependent upon the accuracy of the manufacturing processes. Among the manufacturing processes, etching is the most sensitive process and needs more accuracy. The etching inaccuracies cause severe problems that may result in degradation of circuit performance and malfunctioning of circuits.

In this research the levels of effects of etching manufacturing process inaccuracies on the malfunctioning of PCB circuits is investigated and analysed. The effects of the process inaccuracies on circuits as well as how the process is related with the affecting parameters are addressed. Afour-layer multilayer board is considered for the study and the software selected to study the effects of manufacturing inaccuracies is OrCAD PCB designer. Schematic development, PSpice simulation and layout design are made for selected circuits to study the effects of the etching inaccuracies.According to the results obtained; inaccurate etching results in either larger or smaller width of traces, leaves unwanted conductive materials, and creates unnecessary holes or open circuits and short circuits.

In the over etching scenario, when the over etching effect is increased and results in 14.36-ohm resistance, output voltage drops from 48mV to 22mV. For the open circuit scenario, it results in zero output voltage. Similarly, for the short circuit case which is the case of under etching, the output result shows 1.8nV which is very small and it can be considered as zero output voltage. For capacitive effects, the output becomes very small (140uV), unstable and oscillating. For the combined resistive and capacitive effects, the output is nearest to zero (65uV) and oscillating.

Keywords: *etching, inaccuracies, OrCAD, over etching, PCB, under etching,*

INTRODUCTION

Printed circuit board (PCB) is a device used for mounting electronic components and providing electrical interconnections to the circuits that are found in electronic or electrical devices and systems [1,2].

PCB is constructed from an insulating material placed as the core and conducting material i.e. copper coated on the surfaces. This copper plating is etched away to form the actual copper pads and connection traces on the board surfaces as part of the board manufacturing process [3, 4, 5]. There are three major types of printed circuit board constructions namely, single-sided, double-sided and multi-layered. Single-sided boards are with copper pads and traces on one side of the board and the components are on one side of the substrate.

When the number of components becomes too many for a single-sided board, a double-sided board may be used in which there are copper pads and traces on the top and bottom sides of the board. Electrical connections between the circuits on each side are made by drilling holes through the substrate in appropriate locations and plating the inside of the holes with a conducting material. The third type, a multi-layered board, has a substrate made up of layers of printed circuits separated by layers of insulation. It is designed with copper pads and traces on top and bottom of board with a variable number of internal copper layers with traces and connections. The components on the surface connect through plated holes are drilled down to the appropriate circuit layer [6].

A multilayer board consists of a number of layers of dielectric material that has been impregnated with adhesives, and these layers are used to separate the layers of copper plating. All of these layers are aligned and then bonded into a single board structure under heat and pressure. Multilayer boards with 48 or more layers can be produced with today's technologies [7].

The exposed inner layers are developed in a 1% sodium carbonate solution, which removes resist from areas that were not hardened (polymerized) by the light. In Inner Layer Etching copper is chemically removed from the areas where the dry film is removed. This creates the copper pattern that matches the film pattern.

The traditional process of exposing the copper and other areas unprotected by the etch resist film to a chemical that removes the unprotected copper, leaving the protected copper pads and traces in place; newer processes use plasma/laser etching instead of chemicals to remove the copper material, permitting finer line definitions. In Resist Stripping, developed dry-film resist is chemically removed from the panel leaving the copper on the panel.

In this traces, pads, ground plane and other design features are exposed. Finally, Automated Optical Inspection (AOI) is done after resist stripping. Inner layers are then inspected against design rules using data from the Gerber files. After inspection, the panels are chemically coated with oxide to improve adhesion of the copper surface [8, 9, 10].

In this paper, the focus of our study is with multilayer PCB manufacturing processes, and we chose a four layer which is the simplest multilayer board for our study. However, we have used simpler circuits with components consisting of less than 22 which can be even implemented with a single sided board if the design is to be done merely based on complexity. Therefore, our interest is to study on multilayer board, and we chose four layer to illustrate etching inaccuracy effects in multilayer boards.

PROBLEM DESCRIPTION

PCB manufacturing processes must be accurate to minimize the failure of circuits after final production. To avoid the possible failures in PCB circuits, analysis of effects of individual process inaccuracies on the level of malfunctioning of circuits is important. It helps give awareness in making processes accurate and avoid the possible causes of PCB process inaccuracy.

The study of manufacturing inaccuracies and their effects in circuits is very important as it paves way for making processes more accurate and building robust PCB circuits and then meets customer satisfaction.

As it is very well known, the inaccuracies of the processes followed by the manufacturing technology are the main reasons for circuit malfunctioning.Therefore, in this paper the etching process inaccuracies along with the factors affecting it and the corresponding effects on the level of malfunctioning of circuits are identified and discussed.

ETCHING RPCESS INACCURACIES AND AFFECTING PARAMETERS

PCB circuits can malfunction due to the inaccurate etching of traces in the etching manufacturing process. The inaccurate etching results in either more width of cupper (more width of traces than normal) or small width of traces (small cupper). In addition, the inaccurate etching process leaves unwanted conductive materials, creates unnecessary holes or open circuits. This inaccuracy of PCB etching which results in thicker width of traces and unwanted copper on the board may result in short circuits.

On the other hand, the excessive etching which happens in thinner traces and gaps may result in open circuits. Those defects are called fatal defects. There are also other forms of defects due to the inaccurate etching process which doesn't directly cause malfunctioning of PCB circuits. Those types of irregularities form neither short circuits nor open circuits immediately. Due to the inaccurate size of traces and holes on PCB circuits, the performance of the circuit is compromised. Such defects are called potential defects.

Since copper is not a perfect conductor, the inaccurate etching or inexact sizes of traces and holes (smaller sizes) presents a certain additional amount of impedance to current flowing through it, this additional impedance results in extra energy lost in the form of heat [11,12]. Moreover, when signal traces are smaller in width than normal, signal loss in the circuit occurs. There is a need to study the combined effects of all other parameters on etching. The parameters that influence the accuracy of etching process are material removal rate, etch factor, undercut, and concentration of etchant, etching time and etchant temperature.

An optimal parameter combination for maximum material removal rate and undercut within the range selected control parameters are obtained by using analysis of variance [13]. In order to obtain the effect of the etching parameter on etching performance for each different level, the average response of each fixed parameter and level for each etching performance are summed up. The undercut increases with increase concentration.

The affecting parameters for undercut are temperature, concentration and time. Out of these temperature and time are the most significant parameters on undercut.

When copper is etched, the edge of the copper trace is neither a completely smooth nor a vertical wall. The roughness called the edge definition occurs because of mask resolution limitations, non-uniformity of the acid circulation, gas bubbling during etching and etc. The wall will have a slight angle to it because as the acid begins to work its way into the exposed copper a sidewall begins to form, which also is attacked by the acid, and the copper near the etch resist begins to be removed under the mask. This effect is called etch back or undercutting.

Parasitic impedance in high-speed PCBs destroys circuit performance [14]. PCB parasites are in the form of undesired capacitors, inductors and resistors embedded within the PCB.

The standards considered in PCB design, the size of trace-to- trace width is a minimum of 3.5MIL, width of trace to hole is a minimum of 5MIL, and perpendicular traces are not allowed. If the sizes are below the minimum levels, short circuits and cross talks may happen in the given circuits.

METHODOLOGY

In this section the method of analysing the effects of inaccuracies of PCB manufacturing processes on the level of malfunctioning of circuits are discussed. Because of the unavailability of the PCB manufacturing laboratory as the laboratory set-up is not yet established, a simulation based analysis is considered in this paper. The type of application software used for simulation as well as the procedures followed to study the effects are described.

Software Requirement

The Software selected to study the effects of manufacturing inaccuracies is OrCAD PCB designer. Among other software's, OrCAD is the appropriate one for this purpose because of the features it has starting from schematic capture to layout design. Schematic development, PSpice simulation and layout design are the main task of the OrCAD software in this research.

OrCAD capture is a PCB schematic designer tool. OrCAD Capture is applied for designing the schematic circuit selected for studying the effects, and OrCAD PSpice is an analog and digital simulator. It simulates a captured circuit so that its performance can be investigated.

OrCAD PSpice technology is seamlessly integrated with OrCAD Capture which is one of the most widely used schematic design solutions allowing to easily cross-probe between the schematic design and simulation plot results and measurements. This integration also allows to use the same schematic for both simulation exploration and PCB layout, reducing rework and errors.

Implementation Procedures

The major PCB etching manufacturing process inaccuracies are considered for analysing and discussing the effects of manufacturing inaccuracies. The procedures followed to study the circuit effects of different scenario is given as follows.

- In the first step, appropriate circuit which is a two stage BJT amplifier is selected.
- The normal schematic circuit is captured on OrCAD PCB Capture.
- Simulation of the given circuits is done on OrCAD PS pice.
- A four-layer PCB layout is routed for the given schematic and the possible manufacturing inaccuracy scenarios are indicated on the circuit layout.
- Equivalent circuit model for the given increased scenario is developed
- Schematic capture incorporating circuit model for the inaccuracy scenario is done for the selected circuits.
- Difference in circuit performance and any circuit malfunctioning is observed

EFFECTS OF ETCHING INACURACY

During etching process, the anomalies occurring on bare PCB could be largely classified in to two categories: one is excessive copper and missing copper. The incomplete etching process leaves unwanted conductive materials and forms defects like short-circuit, extra hole, protrusion, island and small space. Excessive etching leads to open circuit and thin pattern on PCB. In addition, some other defects such as missing holes, scratch, and cracks may exist on bare PCB.

For perfect etching case, the resistance of the tracks is assumed to be negligible. However, it has a considerable resistance value for the over etching scenario above. A formula for calculating the sheet resistance R of a copper trace, given the length Z, the width X, and the thickness Y is given by:

$$\boldsymbol{R} = \frac{\rho Z}{XY} \qquad (1)$$

Where $\rho = 1.724\text{x}10^{-6}\Omega\text{cm}$ is the resistivity of the copper.

Inaccurate etching can cause undesired signal output which is a decreasing effect. But the idea is that the effect of inaccuracy is an obstacle to getting the desired signal output. It makes the circuit fluctuate and deviate from the functionality it is designed for.

Capacitive Effects

When the gap between two parallel traces is smaller than the standard spacing that should be between traces, capacitive impedance will be introduced across the traces and results in cross talk and unstable output.

The capacitance between two parallel traces can be calculated using equation (2).

$$C = \frac{KA}{11.3d} \quad (2)$$

Where A is area of a trace in cm^2, d is distance between traces and K is relative dielectric constant. If the normal spacing between traces, d1=250MIL is changed to d2=125MIL, then one can calculate the effective capacitance using equation (2).

SIMULATION SETUP

Selection of circuits

In this section, the simulations of selected circuit considering the different manufacturing inaccuracies are done. The effects of etching inaccuracies are discussed. The effects considered are open circuit, short circuit, under etch, and over etching. For the purpose of simulating and analysing the effects of PCB manufacturing inaccuracies on circuits, we already considered different analog and digital circuits for studying the effects, among the circuits a two stage BJT amplifier and ADC circuits are discussed in this paper.

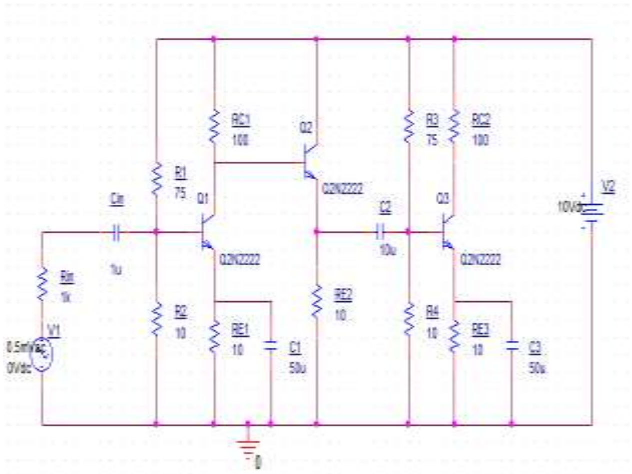

Figure 1:Two stage BJT amplifier

Four-layer PCB Routing

The electrical connections depicted by the ratsnest must now be replaced by copper tracks on the PCB. This procedure is called routing the board. Tracks should be drawn on the bottom of the board with the components placed on the top.

The wires from the components pass through the holes in the pads and are soldered to the tracks on the bottom of the board. The ground and power planes are placed on the second and third layers. The layout is shown in Fig. 2.

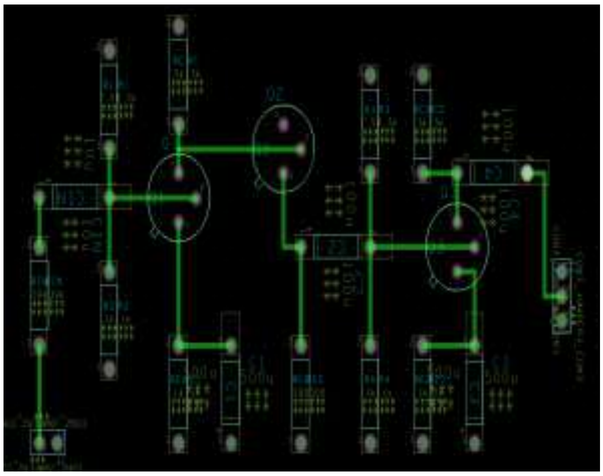

Figure 2:Layout for the two stage BJT amplifier

Effect Levels of Etching Inaccuracies

Fig. 3 shows some of the common etching inaccuracy scenarios. By taking one scenario at a time, the corresponding possible effects are simulated and discussed. In the first step the simple etching problems are considered and their effects observed. In the next stage, more serious problems and some critical scenarios are considered and discussed.

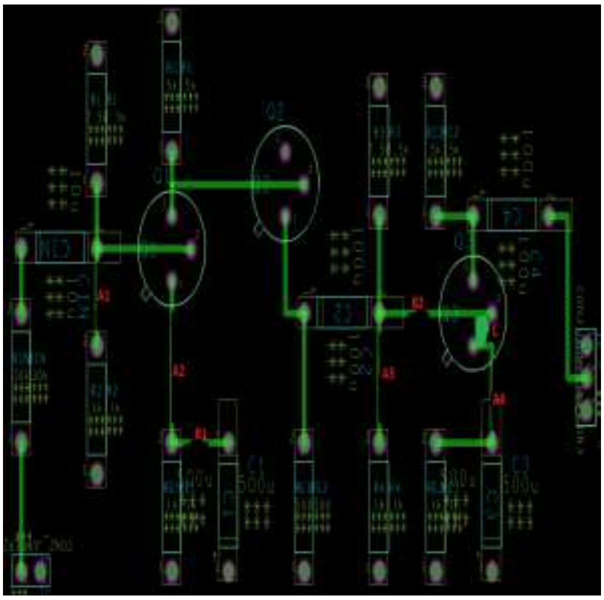

Figure 3: different etching inaccuracy scenarios

From Fig. 3, the general name for inaccuracy denoted by A1 is an over etching. This over etching scenario is modelled into a circuit to see the effect on circuit performance and malfunctioning as it is depicted in Fig. 4.

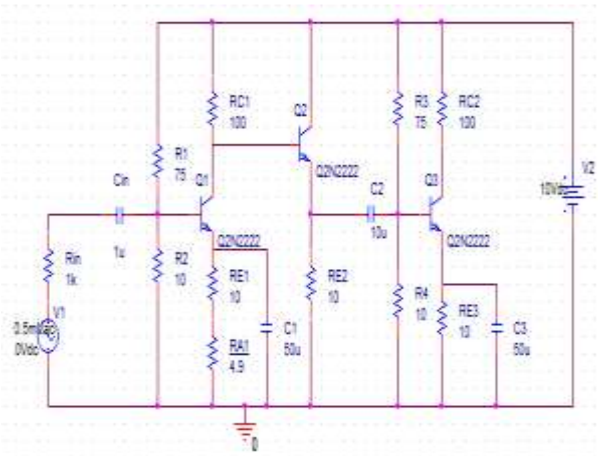

Figure 4: Equivalent circuit for over etching scenario

Fig. 5 depicts the frequency response of the circuit for different levels of over etching scenarios represented by A1 with the effect indicated by resistance R_{A1}. It shows that the gain is decreasing as R_{A1} keep increasing.

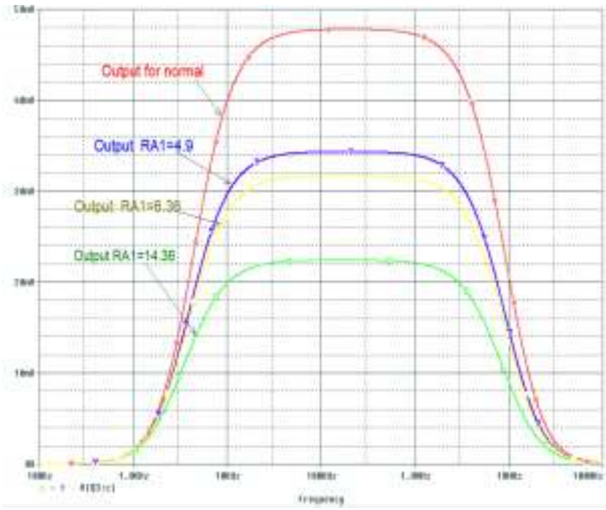

Figure 5: Frequency response for over etching scenario for different levels of RA1

Open Circuit and Short Circuit Scenario

The equivalent circuit for the open circuit scenario is shown in Fig. 6. As can be seen in the circuit, the input to transistor Q3 is floating (open) due to over etching.

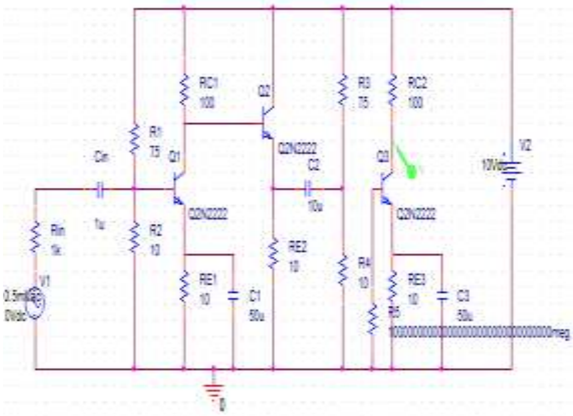

Figure 6: Equivalent circuit for open circuit scenario

The output of the circuit given in Figure 6 is depicted in Fig. 7. It shows that the effect of the open circuit scenario is fatal and it results in zero output.

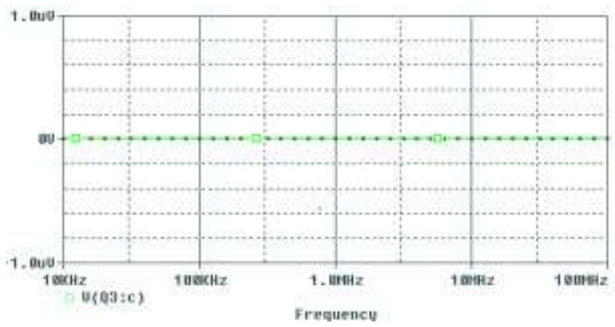

Figure 7: Frequency response for open circuit scenario

Fig. 8 shows the equivalent schematic for the short circuit scenario. It shows that the base and emitter of transistor Q3 are shorted together.

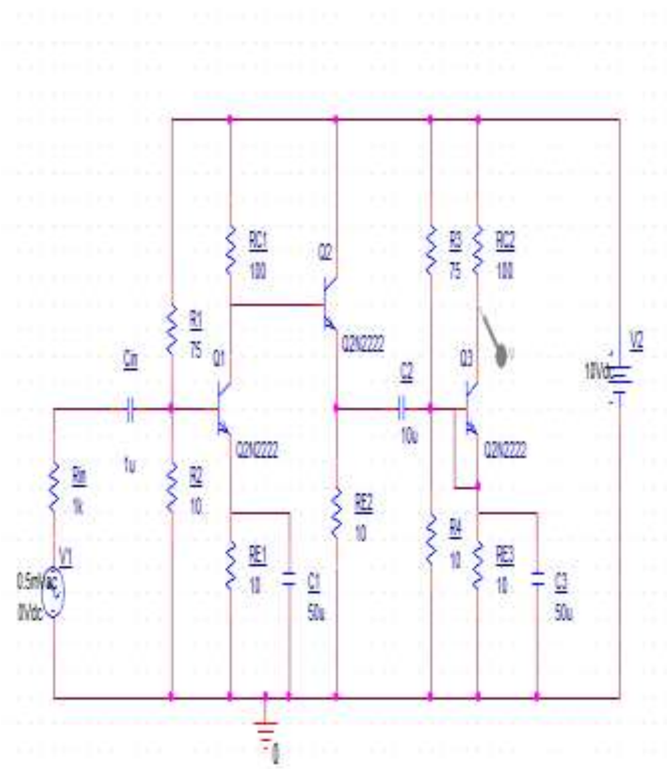

Figure 8: Equivalent schematic for short circuit scenario

Fig. 9 shows the simulation output for the short circuit scenario depicted in Figure 8. As can be seen from the figure, the output is diminished and very small as compared to the output of the normal circuit.

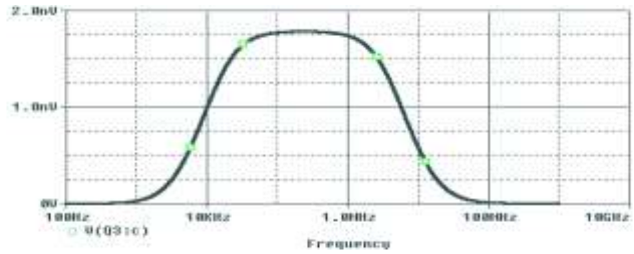

Figure 9: Frequency response for short circuit scenario

Capacitive Effects

Fig. 10 shows the equivalent circuit under the consideration of capacitive effects.

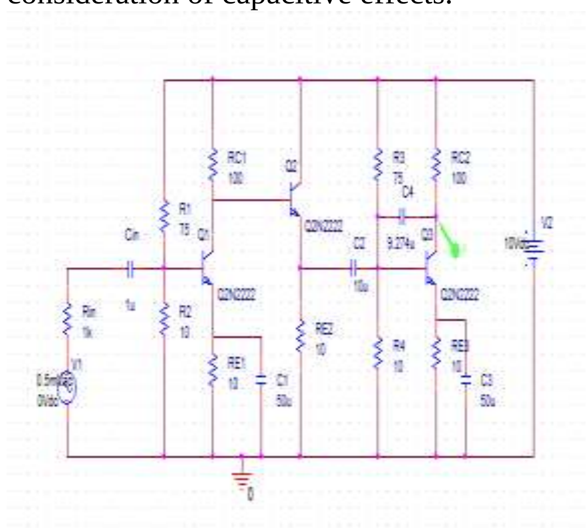

Figure 10: Equivalent circuit with capacitive effect

Fig. 11 shows the simulation output of the circuit depicted in Fig. 10 by considering different capacitive effects. As can be seen from the simulation output, cross talk or unstable output occurs over the frequency on which the expected output should be stable.

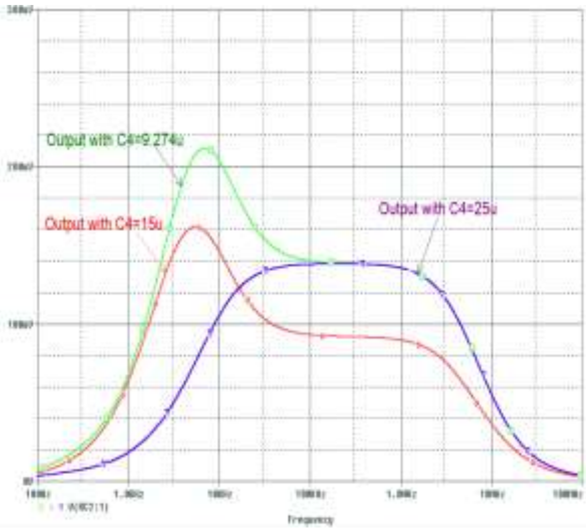

Figure 11: Frequency response for different capacitance values

When the capacitive impedance effect is 25uF, the output drops from around 50mV to 140uV and the output waveform looks like the waveform of the normal circuit. On the other hand, at lower capacitance values the output becomes unstable and gives a waveform with a different nature.

Capacitive and Resistive Effects

In this section, the capacitive effects due to wrong spacing between traces as well as resistive effects due to over etching are considered and the corresponding equivalent circuit is depicted in Fig. 12.

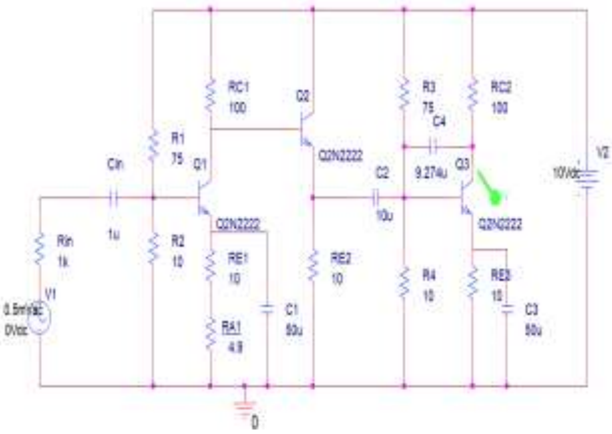

Figure 12: Equivalent circuit for capacitive and resistive effects

Fig. 13 shows the simulation result for the combined resitive and capacitive effects. As can be seen in the figure, the output waveform results in instability and oscillations.

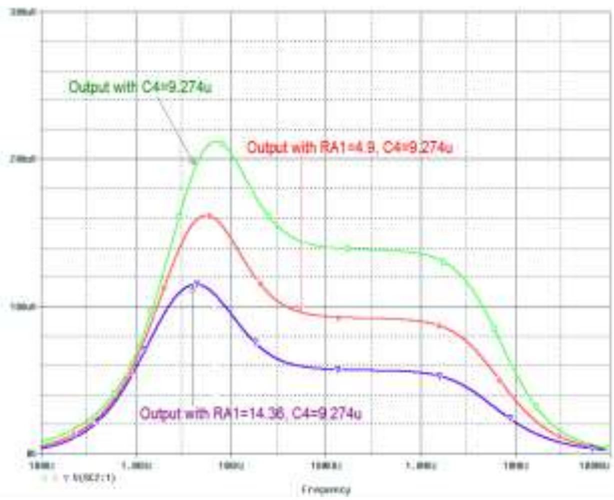

Figure 13: Frequency response for combined capacitive and resistive effects

Analysis of effects with 4-bit ADC circuit

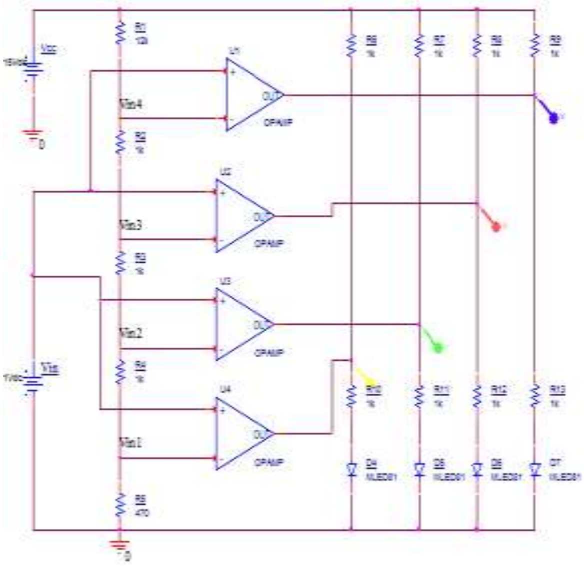

Figure 14: Implementation of 4-bit ADC

For the circuit depicted in Figure 14, we considered under etching scenario which results in short circuits, and the circuit with the effect produces no output which means the circuit totally mal functions. We also tried to analyse the over etching scenario for the circuit which finally results in open circuit. The equivalent circuit for the open circuit is depicted in Figure 15.

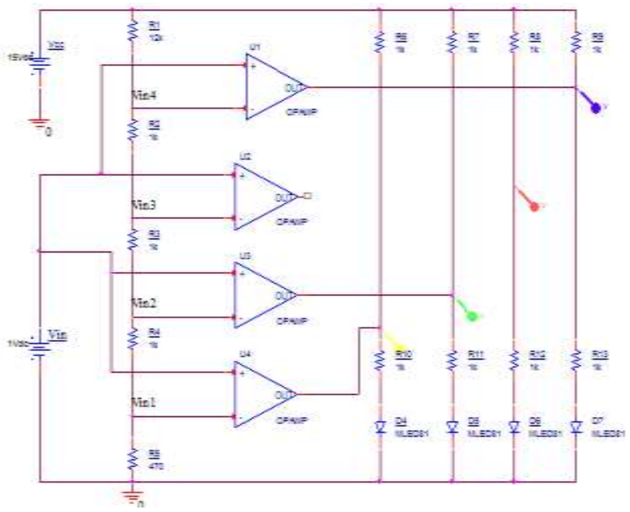

Figure 15: Equivalent circuit for open circuit scenario

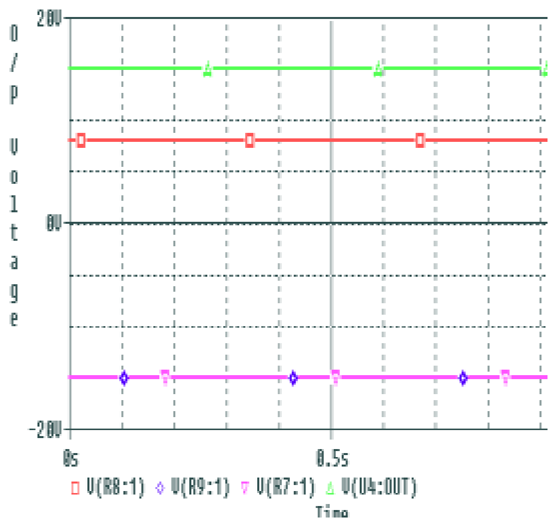

Figure 16: Output signal for open circuit scenario

As it is illustrated in Figure 16, the output for 1V input is 0101 instead of 0001which is a wrong output due to open circuit effect.

RESULTS

Table 1 summarizes the simulation results. The table shows the simulation output for the non-defective (normal) circuit and defective circuits by considering different inaccuracy scenarios and defect levels. The output is obtained by giving the same input to all types of circuits.

CONCLUSIONS

In this paper, simulations using OrCAD PSpice have been made to illustrate the possible effects on the different circuits caused by the possible manufacturing errors. Simulation results show that small reduction of widths of traces (over etching) results in small performance reduction of the given circuit. If the over etching rate is medium, then a medium performance reduction happens. For much larger over etching rate, there is a higher probability of totally malfunctioning of the circuit.

Table 1: Summary of simulation results

S/N	Type of defect	Resulting effect	Defect level	Output of circuit in **(mV)**	Remark of output
1	No defect	-	-	48	Normal
2	Over etching	Resistive	RA1=4.9Ω	34	
3	Over etching	Resistive	RA1=6.36Ω	32	
4	Over etching	Resistive	RA1=14.36Ω	22	
5	Open circuit	Resistive	R5= ∞	0	Zero
6	Short circuit	Short circuit	fatal	0.0018	Negligible
7	Over etching	Capacitive	C4=9.27 μF	0.140	Diminished & oscillating
8	Over etching	Resistive and Capacitive	RA1=14.36Ω, C4=9.27 μF	0.065	Very Diminished & oscillating
9	Under etching in ADC		severe	null	malfunctions
10	Over-etching in ADC		severe	0101	Wrong output

In the over etching scenario, when the over etching effect is increased and results in 14.36-ohm resistance, output voltage drops from 48mV to 22mV. This is simply considering only one simple scenario. The situation even worsens when augmented with other effects. For the open circuit scenario, it results in zero output voltage. Similarly, for the short circuit case, the output result shows 1.8nV which is very small and it can be considered as zero output voltage.

For capacitive effects, the output becomes very small (140µV), unstable and oscillating. For the combined resistive and capacitive effects, the output is nearest to zero (65 µV) and oscillating.

It can be concluded that the output of the circuits is affected as the manufacturing processes become inaccurate. It results in signal loss, poor performance and malfunctioning of circuits.

REFERENCES

[1] Marina Y. Koledintseva, Praveen K. R. Anmula, James L. Drewniak "*Effect of Conductor Surface Roughness upon Measured Loss and Extracted Values of PCB Laminate Material Dissipation Factor" EMC Laboratory,* Missouri University of Science & Technology Rolla, MO 65401, 2011

[2] Marina Y. Koledintseva, James L. Drewniak, AmendraKoul, *Fan Zhou "Thermal Effects on PCB Laminate Material Dielectric Constant and*

[3] *Dissipation Factor"* EMC Laboratory, Missouri University of Science & Technology Rolla, MO 65401, 2011

[4] G.A. Schuerinka, M. Slompa, Wessel W. Witsa, R. Legtenbergb, E.A. Kappelb "*Modeling printed circuit board curvature in relation to manufacturing process step*s "2nd CIRP Global Web Conference, London, UK, 2012

[5] Andy Haas, TaranjitKukal "*Ensuring Reliable and Optimal Analog PCB Designs with Allegro AMS Simulator*" Cadence Design Systems, Silicon Valley 2007

[6] Toshiyuki Matsuki and Yoneta Tanaka "*High Overlay Accuracy Using Scaling Method in PWB Photolithography*" Ushio Inc, Aoba-Ku, Yokohama, Japan, 2013

[7] Ajay Pal Singh Chauhan, Sharat Chandra Bhardwaj, '*'Detection of Bare PCB Defects by Image Subtraction Method using Machine Vision''* Proceedings of the World Congress on Engineering 2011 Vol II WCE 2011, London, U.K, July 6 - 8, 2011

[8] Barry Olney "*Introduction to Board Level Simulation and the PCB Design Process" In circuit design* PTY LTD, Australia, March 2012

[9] Alexandru Topo, "*Optical Correlation Techniques for Alignment in Future Pattern Generator*" Master's Thesis at the Department of Production Engineering School of Industrial Engineering and Management, KTH, June 2013

[10] Peter W.Lehmann '*PCB manufacturing process improvement: drilling Machine Optimization*", University of Wisconsin-stout, December 2005

[11] Cheryl Tulkoff, Greg Caswell, Dr. Craig Hillman "*Best Practices for Improving the PCB Supply Chain: Performing the Process Audit*", DfR Solutions Beltsville, MD, USA, 2011

[12] L. J. Zheng, X.Zhang, C. Y. Wang, L. F. Wang1, S. Li1, Y. X. Song, L. Q. Zhang2, "*Experimental Study of Micro-holes Position Accuracy on Drilling Flexible Printed Circuit Board*", 11th Global Conference on Sustainable Manufacturing, Berlin, Germany, September 23-25, 2013

[13] Abdelghani Renbi, ArashRisseh, RikardQvarnstro¨m and Jerker Delsing "*Impact of etch factor on characteristic impedance, crosstalk and board density"* IMAPS, San Diego, California, USA, 45th International Symposium on Microelectronics, 2012

[14] N.D. Misal "*Optimization of process parameters in etching during photo chemical machining process* "Department of Mechanical Engineering, SVERI's College of Engineering (Poly), Pandharpur, 2013

[15] Christopher F. Wise "*Fabrication of Printed Circuit Boards Using a Table Top CNC Mill"* Departmental Engineer, New Mexico State University, Department of Engineering Technology and Surveying Engineering P.O.Box 30001, MSC 3566, Las Cruces, NM 88003-8001, chwise@nmsu.edu, 2010

[16] Kraig Mitzner" *Complete PCB Design Using OrCad Capture and Layout*" Elsevier, 2007