# A Method to Solve the Probe Load Effection in the High Speed Digital Circuit

Yi Xie, Jianhong Zhou, and Changle Lu

***Abstract*—**The measuring result has much business with the performance of the oscilloscope probe. First we analyze the probe load effection, and then present a method to solve the problem by using the probe attenuator. After that in order to identify the accuracy of the theory, we do a careful detailed consequence process. Finally we bring up the factual circuit of the whole method.

***Keywords*—**Probe Load Effection; Attenuator; Oscilloscope; Bandwidth

## I. Introduction

DURING measuring, it is often considered that the voltage in circuit remains steady with or without oscilloscope. However, every probe has its import resistance that includes electrical resistance, capacitance and inductance heft. Because of the extra load inducted by the probe, therefore we should consider the affections produced by probe when we analyse the testing results and examine the resistance of the circuit. This paper processes a research in this problem and put forward a solution.

## II. Equivalent Circuit of Probe

### *A. Probe Load Effection*

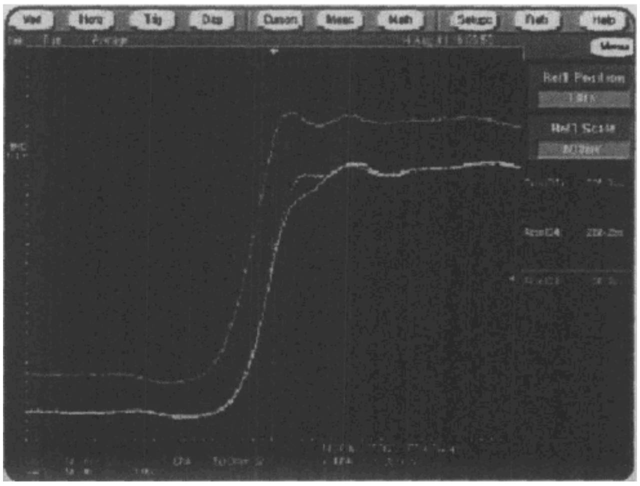

Fig. 1 Probe Load Effection

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In Fig. 1 there is a typical high speed signal which effected by probe load effection. We can see three signals in the screen of the 4GHz oscilloscope. The first one which is highest is the wave shape when there is no load; the second one which is lower is the wave shape when there is load; the last one is affected by probe load effection, so its raising speed is depressed. The phenomena will get worse if the inductance and capacity of the probe increase which cause bigger probe load effection.

### *B. Equivalent Circuit of Probe*

Probe is an import component outside the oscilloscope, which could extract the signal from the circuit and enhance the import resistance of oscilloscope. The efficiency of probe could greatly affect the test results (especially in frequency idiosyncrasy). So using the probe properly is crucial for the test of signals (especially high frequency signals). There are no series-wound resistances in normal oscilloscope. One testing header and one section of cable constitute the probe of this kind of oscilloscope. So there is no attenuation on signal when the probe (1:1 probe or X1 probe) is in working frequency range or effective bandwidth. Because the probe connects the import resistance of oscilloscope with the capacitance of itself at the testing point, so the probe has load effect. When the frequency is high, the load effect is more obvious. The equivalent circuit is illustrated as Fig. 2:

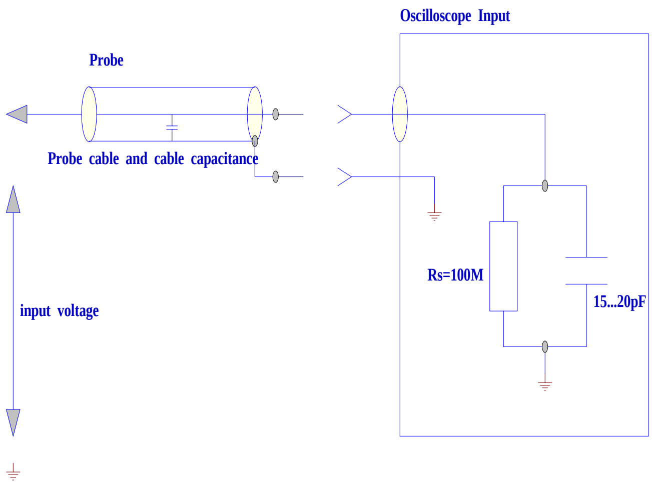


Fig. 2 Equivalent Circuit of Probe

## III. Analysis of the Probe Load Effection

For the convenience of discussion, we could equal the probe in Fig. 2 to the following Fig. 3:

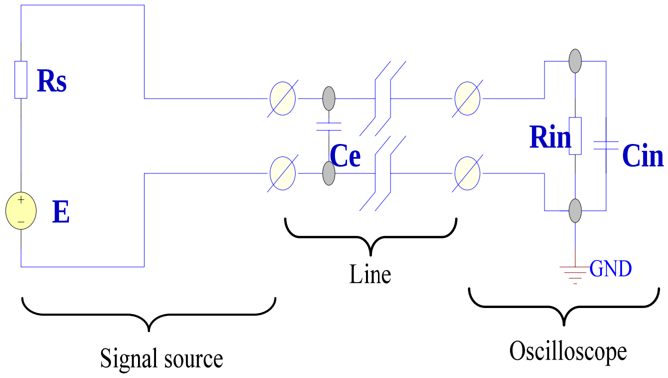


Fig. 3 Equipollence Form of the Probe Equivalent Circuit

On measuring, as volts D.C., if $R_{in} \geq R_s$, the results are: $V_{osc} = \frac{R_{in}}{R_{in} + R_s}$. But if there are AC signal (in most cases), effection of autoeciousness capacitance could not be ignored. The load of signal source in Fig. 2 is $R_{in}$ and $C$ ($C$ and $C_c$ parallel connected, $C_c$, $C_{in}$ are capacitance of probe and oscilloscope respectively). Because of $X_c = \frac{1}{2\pi fc}$, $X_c$ declines as the frequency of tested signal increase, which means circuit is under heavier load. This heavy load could affect the work efficiency of the tested circuit, which is not expected. The load effect of probe should be avoided and improved in real testing environment.

## IV. Analyses and Improvement of the Probe Load Effection

### A. *Principle of the Attenuator*

When testing high frequency signals, probes with attenuators are often used in order to get rid of the effects inducted by the connecting oscilloscope. The following figure shows the principle:

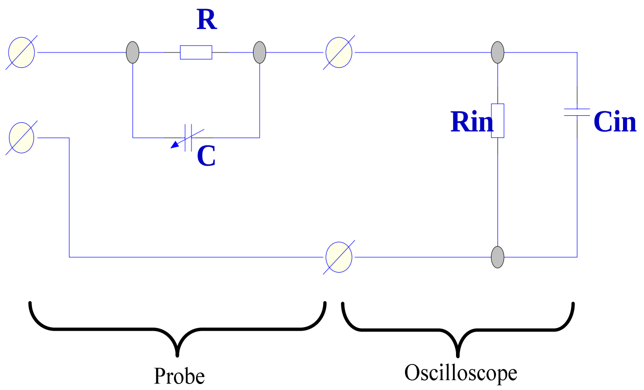


Fig. 4 Principle of the Attenuator

When the working frequency is changing followed by the frequency change of parallel connection impedance $Z$ of $R$ and $C$, parallel connection impedance $Z_{in}$ of $R_{in}$ and $C_{in}$. Choosing right parameters of resistance and capacitance probably, it is possible to keep the attenuator voltage stable in a wider frequency domain, namely prevent the working state not to change with the go up and down of the frequency by using the voltage divider. From the analyses below, we can easily find the change rules between the divide voltage of attenuator and the frequency. From Fig. 3 we can get:

$$Z = \frac{\frac{1}{jwc} \times R}{\frac{1}{jwc} + R} = \frac{R}{1 + jwcR}$$

$$Z_{in} = \frac{\frac{1}{jwc} \times R_{in}}{\frac{1}{jwc} + R_{in}} = \frac{R_{in}}{1 + jwcR_{in}}$$

The divide voltage ratio of the probe attenuator:

$$k = \frac{U_{in}}{U} = \frac{Z_{in}}{Z + Z_{in}} = \frac{R(1 + jwc_{in}R_{in})}{R(1 + jwc_{in}R_{in}) + R_{in}(1 + jwcR)}$$

Usually there is little capacitance in the circuit. So when the frequency is low, and makes $X_c \gg R$, $X_{c_{in}} \gg R_{in}$, the divide voltage ratio of the attenuator is only depends on the resistance. That is:

$$k_o \approx \frac{R}{R + R_{in}}.$$

After analyzing we can be easily find that: if the divide voltage ratio equals $k_o$ (a constant) at any frequency, in other words divided voltage ratio have no relationship with frequency, then the oscilloscope do no harm to the circuit measured. But the above all must abide that:

$$\frac{k_o}{k} = \frac{R}{R + R_{in}} \times \frac{R(1 + jwc_{in}R_{in}) + R_{in}(1 + jwcR)}{R(1 + jwc_{in}R_{in})}$$

$$= \frac{1}{R_{in} + R} \times (R + R_{in} \times \frac{1 + jwcR}{1 + 1 + jwc_{in}R_{in}})$$

$$= 1$$

As long as $1 + \mathrm{jwc}_{in}R_{in} = 1 + jwcR,$ namely:

$$c_{in}R_{in} = cR$$

Then

$$k = k_o = \frac{R}{R + R_{in}}$$

We can make $k = k_o = \frac{1}{10}(or\frac{1}{100})$ by Choosing probable $R$, $R_{in}$, namely attenuator attenuate the signal by 10:1 (100:1). From analyses above we can also know that the frequency characteristic is largely improved, although the signal power is reduced by attenuator when passing the probe. So we can enhance the bandwidth of the oscilloscope from several MHz to dozens MHz. Once more we can increase the bandwidth by adding a extra RLC impedance matching network.

### *B. Factual Circuit of the Probe Attenuator*

Actually the compensate networks are not so easy as showed in Fig. 4. The more factual circuit of the probe attenuator is showed as Fig. 5:

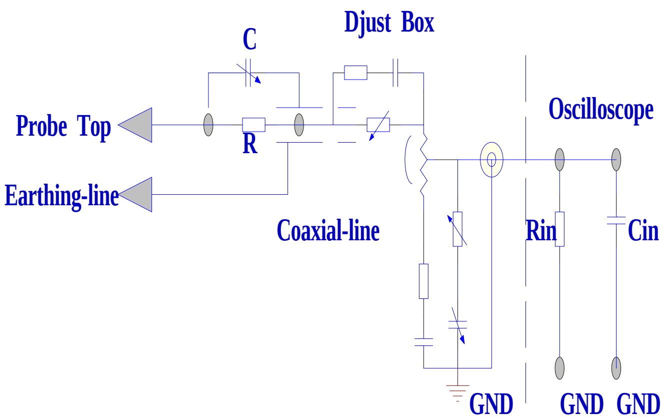


Fig. 5 Actual Circuit of the Probe Attenuator

## V. Conclusion

Focusing on the probe load effection, we analyze its influence to the oscilloscope carefully. And then we present a method to solve the problem by using attenuator. Followed by we give the detailed consequence process of the theory to prove the accuracy of it.

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