Design of a Klopfenstein Taper for Impedance Matching of a High-Speed Photodetector

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This paper focuses on the design of a specially shaped metal taper in order to solve the impedance matching problem between an integrated photodetector and its RF probing pad. Using a full-wave simulation approach, the effectiveness of the proposed taper is demonstrated.

Introduction

We deal with Photonic Integrated Circuits which have transmission lines operating at high frequencies (around 20 GHz). We are designing a ground-signal-ground (GSG) probing pad which is connected to coaxial cable through RF probes placed on the photonic integrated chip. The GSG pad should be matched to the RF probe impedance of 50 Ohm. Next, we are looking for an impedance matching circuit between the photodetector and the GSG pad.

Impedance Simulation

The GSG pad has a coplanar waveguide structure and must work in the even mode to have proper transmission on the chip [1]. In order to change the characteristic impedance of the GSG pad to match it with that of the RF probe, and therefore reduce reflections, we can change the metal width of the signal pad or vary the width between the signal and the ground pads. Figure 1a and 1b show the layout of the GSG pad and the schematic of the device.

Fig 1a: Layer stack of Pad

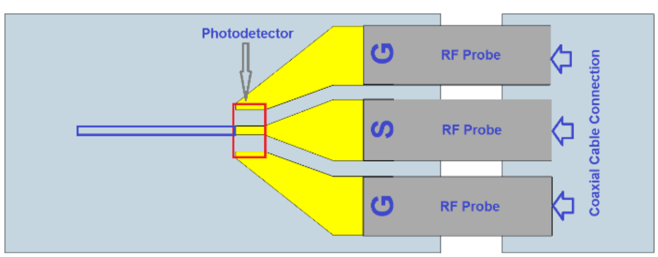

Fig 1b: Schematic of detector and probing pad

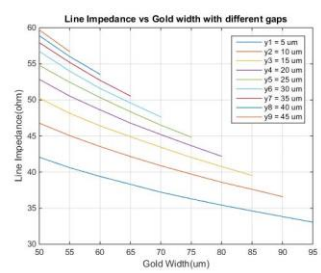

Fig 1c: Impedance vs signal metal width with "y1 to y9: different gaps between "G" and "S" "

An impedance match between the GSG pad and the RF probe can therefore be optimized based on these simulation results. The optimized structure consists of 65 um wide metal pads and 30 um wide gaps in between. In Figure 1c, simulations obtained from CST Microwave Studio, shows the relation between the metal width of GSG pad with line impedance at various gap values between Ground and Signal pad.

Klopfenstein Taper

The coplanar interface connected to the photodetector has the layer stack shown in Figure 1a and its impedance has been found from simulations to be 120 Ohm. We find out that the Klopfenstein taper is the best choice that we can use for impedance matching 120 Ohm to the 50 Ohm probing pad in this application. The reason is that the "Klopfenstein taper has been shown to be optimum in the sense that the reflection coefficient is minimum over the passband" [2]. The impedance profile $Z(z)$ of the Klopfenstein taper along the RF propagation direction can be defined as;

$$lnZ(z)= \frac{1}{2}ln(z_0 z_L)+\frac{\Gamma_0}{cosh\ A}A^2\Phi(\frac{2z}{L}-1,A), \qquad \text{for } 0\leq z\leq L, \quad (1)$$

where z_o is the impedance value of the initial point, z_L the impedance value of the end point, L the distance between matching points, ϕ a function containing the modified Bessel function as defined in [2], A the maximum allowed reflection magnitude in the passband and Γ_0 the reflection coefficient at zero frequency. The reflection coefficient of the Klopfenstein taper is;

$$|\Gamma(\theta)| = \Gamma_0 \frac{\sqrt{(\beta L)^2-(A)^2}}{\cosh A}, \qquad (2)$$

with β as the propagation constant of the tapered line.

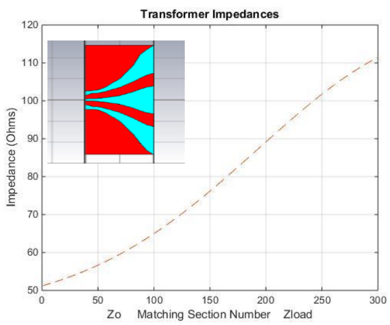

Fig.2a Klopfenstein Taper impedance profile and designed taper geometry from CST with layout of the taper

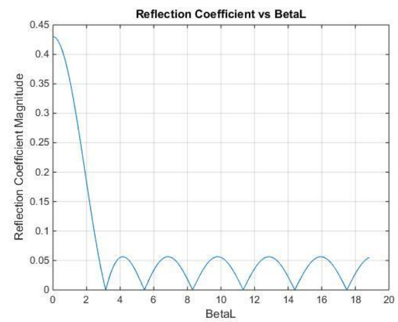

Fig.2b Reflection Coefficient Profile of Klopfenstein Taper

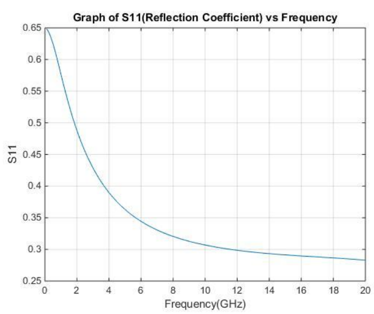

Fig.3a Reflection Coefficient (S11) between 0.1 to 20 GHz

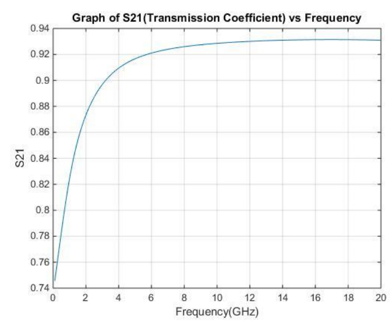

Fig.3b Transmission Coefficient (S21) between 0.1 to 20 GHz

Figure 2a and 2b show the numerically calculated impedance profile of the Klopfenstein taper and its resulting reflection coefficient. To construct the taper geometry, the impedance profile has been sampled at 11 points and the corresponding coplanar geometry on the layer stack shown in Figure 1a has been found from CST simulations. The complete taper structure can then be simulated in CST by linearly connecting the 11 geometries and the simulated reflection and transmission coefficients are shown in Figure 3a and 3b. Comparing Figure 2b and Figure 3a, one notices some differences between the reflection coefficients. The reason is because the graph in Figure 2b is calculated from the theoretical impedance profile but for the simulations, we only used 11 steps, which means the result is an approximation of the ideal Klopfenstein taper.

Conclusion

In this paper, we first found a suitable coplanar pad dimension with 50 Ohm impedance on the photonic layer stack. Furthermore, we have designed a Klopfenstein taper between the photodetector and its RF pad and proven its effectiveness using full-wave simulations.

References

[1] Ingo Wolff "Coplanar Microwave Integrated Circuits" A. John Wiley & Sons Publication pp.23
[2] David M. Pozar, "Microwave Engineering", John Wiley & Sons Inc., Second Edition, pp. 251-299