The Noise Performance of 20 GHz Optical Receivers Using a Distributed Amplifier and P-I-N Photodiode Combination with Matched and Unmatched Input Terminations

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Abstract

High speed optical receivers have been fabricated by using p-i-n diode and distributed amplifier combinations. The preliminary experimental results show that the +/-3dB bandwidth from 1 GHz to 20 GHz was achieved for both input matched and unmatched configurations, while the later reduced the average equivalent input noise to nearly half the value of the former.

Introduction

As the requirement for optical communication systems extends into the tens of GHz range, the conventional optical demodulation circuits, e.g. grounded source amplifiers, are not suitable, because of their poor signal to noise ratio performance[1]. The alternative approach using distributed amplifiers become attractive because of its superior signal to noise performance. The distributed amplifier has a number of advantages over the grounded source[1],[2],[3] and a previous publication has already given some experimental support to the theoretical analysis[4],[5],[6].

1) The distributed amplifier will reduce the noise contribution by absorbing the p-i-n diode capacitance into the artificial transmission line of the distributed amplifier.

2) The distributed amplifier has a purely resistive input impedance of 50Ω, thus no equalising circuit with its high frequency equalisation noise penalty is required after the amplifier. Additionally, the cross correlation noise contribution from the MESFETs is removed.

3) Distributed amplifiers are readily constructed with flat gain up to 40 GHz and beyond. Moreover, the theoretical simulation has shown that up to 10dB improvement on signal to noise ratio performance for a distributed amplifier over a grounded source amplifier should be achievable[2],[3].

Modelling of the p-i-n photodiode

A p-i-n photodiode plays an essential role in a high speed optical receiver, which converts the input optical intensity into electrical current. Without accurate modelling of the p-i-n photodiode, it is impossible to achieve the predicted performance for a high-speed, broadband optical receiver, as the p-i-n photodiode must be treated as an optical controlled current source. The modelling of the p-i-n photodiode can be divided into two parts: one is the electrical modelling which determines the parameters of the diode, such as junction capacitance, series resistance, bonding inductance and package capacitance, and the other is the optical modelling which gives the transit time of the electrons and holes experienced in the depletion layer, i.e. the intrinsic optical limit of the photodiode.

A 25 μm p-i-n photodiode with a depletion layer of about 1.8 μm has been bonded on a SMA connector for modelling. The electrical equivalent circuit of a p-

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i-n photodiode is shown in Fig.1. The electrical modelling was carried out by measuring the one-port reflection coefficient, S11, of which the reference plane was calibrated at the end of the SMA connector, then the electrical parameters were optimised by EEsof Touchstone. The modelling shows that the photodiode has a junction capacitance of 0.142 pF, a series resistance of 17 Ω, a bonding inductance of 0.9 nH and a package capacitance of 0.06 pF. The optical modelling was carried out by measuring the frequency response of the photodiode so that the intrinsic optical response of the photodiode limited by the transit time could be extracted. Fig. 2 gives the simulated and measured frequency response of the photodiode, which includes both the electrical and optical effects. The measured results are a reasonable fit to the simulated one, while the ripple in the measured frequency response is believed to be caused by the mismatch between the photodiode and the network analyser. The extracted intrinsic frequency response for the p-i-n photodiode indicates a 3-dB bandwidth of 25 GHz. This gives an equivalent transit time 14 pico-second, which is slightly different from the calculated transit time of 12 pico-second.

Fabrication of the optical receivers

The optical receivers have been fabricated using TI distributed amplifiers (TGA8310) and the modelled 25 μm diameter p-i-n photodiodes for both matched and unmatched configurations.

For the match-terminated configuration, the photodiode was embedded into a 50 Ω terminated T-network using unencapsulated components together with a bias arrangement, which is then connected to the input of the distributed amplifier and terminated by a matched 50Ω load. The photodiode T-network behaves as an extended section of the gate artificial transmission line of the amplifier. This T-network was evaluated using a Network Analyser HP8510B, which gave the return loss less than -18dB over a band of 50 MHz to 20 GHz and its insertion loss varied from 0dB at 50 MHz to 1dB at 20 GHz. Both results are considered to be satisfactory. The photodiode T-network can be connected to the distributed amplifier either internally or externally.

For the unmatch-terminated configuration, the unencapsulated photodiode was embedded in a half-L section, which also behaves like an extension of the gate artificial transmission line. However, there is no matched termination at the input, and the input impedance to the gate line of the amplifier is totally unmatched. The advantage of this arrangement is not only to increase the signal output by 6 dB, but also to increase the output signal-to-noise ratio, as the distributed amplifier is driven by the total current from the photodiode, unlike the matched case in which half of the current was dissipated in the input termination. Moreover, bond-wire inductance can be used to optimise the frequency and noise performance of the optical receiver.

Performance of the matched configuration

In this arrangement for the sake of circuit construction and measurement, the photodiode and distributed amplifier were externally. The optical input power was launched to the top-entry p-i-n photodiode by using a 40 μm lensed optical fibre, which was manipulated by a micro-positioner under a microscope. The optical coupling was optimised by monitoring the photo-voltage and photo-current of the photodiode. The frequency response of the photodetector was measured by a HP 8703A Lightwave Component Analyser, and its frequency response is shown in Fig. 3, which gave a +/-3 dB bandwidth from 1 to 20 GHz. The low frequency rolling-off is due to the input DC-blocking capacitor of the amplifier. The equivalent input noise current measurement was carried out by placing a high gain post-amplifier after the photodetector, which amplifies the noise power from the photodetector above the noise floor of a calibrated spectrum analyser. Afterwards, the measured noise power was referred back to the input end to calculate the equivalent input noise current by taking the amplification into account. The measured equivalent input noise current for the match-terminated configuration is illustrated in Fig. 5, which gives an average equivalent input noise current about 22 $pA/Hz^{1/2}$.

Performance of the un-matched configuration

For the unmatch-terminated configuration, the photodiode has to be directly bonded to the input pad of the monolithic distributed amplifier as any additional parasitic component will degrade the performance. The length of the gold bond wire was simulated by EEsof LIBRA to optimise the frequency response and noise performance of the photodetector. Fig. 4 shows its frequency response which is similar to the matched configuration, except that it resonates around 5.7 GHz. This is caused by a photodiode bias network resonation, which is currently being removed. The peaking response at low frequency of the circuit is due to the high input impedance associated with idle gate DC-blocking capacitor, which can be used to compensate the low frequency rolling-off at the post amplifiers. The transimpedance gain has been increased by 6 dB in comparison with the matched circuit. The equivalent input noise current for the unmatched configuration is also given in Fig. 5. It can be seen that the equivalent input noise currents at the low and middle sections of band are less than 12 $pA/Hz^{1/2}$, which is nearly half the value in the matched configuration. This noise reduction effect was predicted by theoretical analysis and simulation. The high equivalent input noise current around 5.7 GHz is due to the resonant loss, and the noise increase at high frequency range is caused by the gain rolling-off.

Conclusion

The high speed photodetector configurations have been fabricated by using a distributed amplifier and p-i-n photodiode combinations. A 25 μm p-i-n photodiode has been electrically and optically modelled. Both input matched and unmatched configurations have been investigated. The matched termination circuit gives a +/- 3dB bandwidth from 1 GHz to 20 GHz with an average equivalent input noise current about 22 $pA/Hz^{1/2}$. The unmatched termination circuit also gives a similar frequency response, but with 6 dB more gain than the matched case and the average equivalent input noise current has been reduced to less than 12 $pA/Hz^{1/2}$, which is about half of the value in the matched circuit over some of the frequency range.

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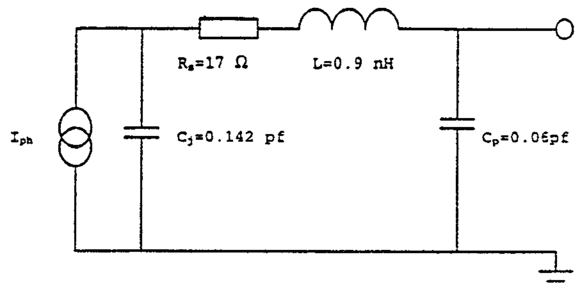

Fig. 1 The electrical equivalent circuit of the modelled 25 μm p-i-n photodiode

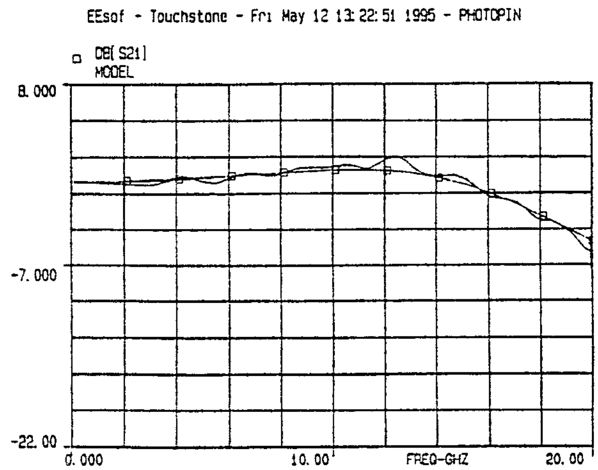

Fig. 2 The measured and simulated (with square points) frequency response of the p-i-n photodiode, including both electrical and optical effects.

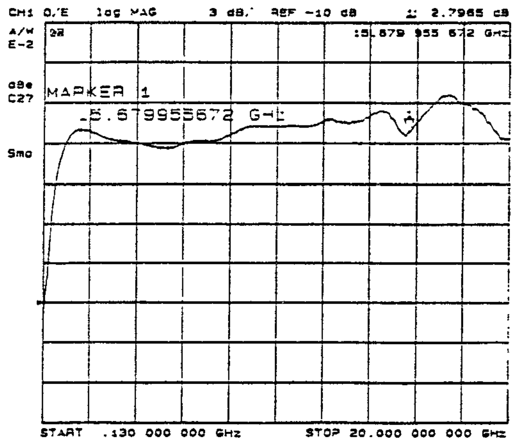

Fig. 3 The measured frequency response of the p-i-n diode distributed amplifier combination with a matched input termination.

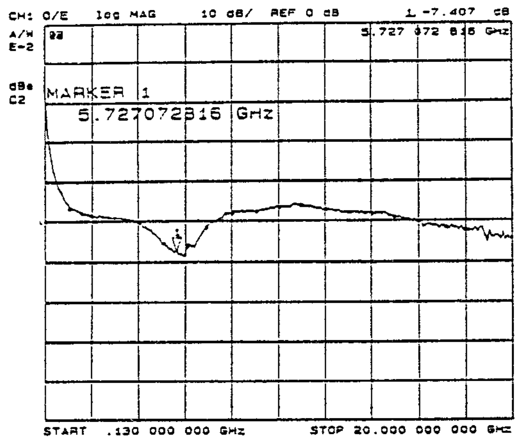

Fig. 4 The measured frequency response of p-i-n diode distributed amplifier combination with an unmatched input termination

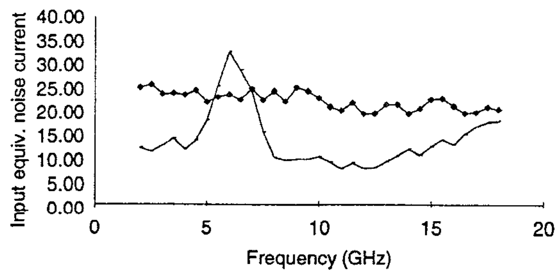

Fig. 5 The measured equivalent input noise current ($pA/Hz^{1/2}$) for the p-i-n diode and distributed amplifier combination with matched termination (above) and unmatched termination (below).