THE ANALYSIS OF PHOTOPARAMETRIC AMPLIFYING DEVICES AND CHARACTERISTICS

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ABSTRACT

The photoparametric mode of operation involves optical detection and pre-amplification/frequency conversion within a single device (a photodetector). In this paper, we discuss the potential applications, the required device structure and characteristics and amplifier simulation techniques. Experimental results from implementation of a prototype receiver are presented and measured results are discussed.

1-INTRODUCTION

Fibre optic communication links are widely used in most of todays telecommunication networks as well as other applications, such as phased array control, remote sensing etc. Free space optical links have not attracted much attention so far but are potentially a secure way of providing terrestrial links including local area networks and inter satellite links [1]. Non the less there are certain technical obstacles yet to be removed to enable system engineers to take advantage of the optical network full potential. As an example, in free space terrestrial links, fibre amplifiers are not applicable and the maximum power of the transmitting laser is limited for safety reasons. Such links suffer from defocusing and atmospheric turbulences and hence very sensitive receivers are desirable. There are also an increasing interest in WDM (Wavelength Division Multiplexed) and SCM (Sub-carrier Multiplexed Systems) in which many forms of signal are transmitted. In SCM, the bandwidth can be few giga-Hertz wide and since sub-carriers are independent of each other, there is a great flexibility to deliver a variety of services to the subscribers [2]. In the practical systems, a number of microwave carriers are combined by the conventional multiplexing techniques and these signals are used to intensity-modulate a laser diode at the transmitting end. In the receiver, a photodiode is followed by an appropriate low noise amplifier to detect the multiplexed signal. Then, this signal is demultiplexed to recover each sub-carrier. The use of a photodiode as a parametric amplifier can increase the sensitivity of the receiver and reduce the complexity of the circuit, as the photodiode can be used as a downconverter to demultiplex the wanted sub-carrier [3]. In photoparametric amplifiers, the amplification depends on the nonlinear capacitance of the photodiode, and therefore, the mechanism constituting gain is highly non-linear and different to that in a conventional amplifier/mixer chain. There are also some implications on the gain-bandwidth products as well, which should be balanced against the simplicity of the detection- and demultiplexing hardware.

The amplifier non-linearity analysis is of prime concern in an SCM system and therefore, the amplifier performance has been studied by using harmonic balance technique and is presented. This should enable system designers in frequency planning. Different modes of operation and the optimum characteristics for a photodiode are studied. An outline device structure is presented, based on III-V implementation, although the device operation is independent of fabrication technology. Thus, it lends itself equally to the advancing Silicon approach, in which operation well into X-band is now realistic [4].

2- THEORY OF OPERATION

In a conventional parametric amplifier [6], the pump and the signal are both at microwave (or RF) frequencies and the main advantage of this amplifier is its ultra low noise performance. Parametric amplifiers have the capability of frequency conversion, but they are mainly designed for the same input/output frequencies. In our proposed system, the diode is pumped at microwave frequencies and the up or down converted photo-detected signal can be delivered at microwave frequencies. In a sub-carrier multiplex system, therefore, sub-carriers can be individually selected and amplified.

Figure 1 shows the arrangements for an experimental photoparametric amplifier. The generated photo-current can be amplified, up or down converted, and the idler circuits define the mode of operation. If the photoparametric amplifier is used in down conversion mode, the signal can be recovered form each of the sub-carrier. In the up conversion mode, the signal is translated to a higher frequency and the up converted output signal can then be down converted to the desired frequency by the conventional means.

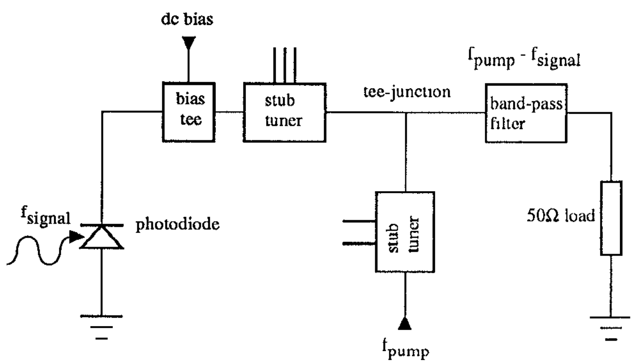

Figure (1), Experimental amplifier setup

In up or down conversion mode of operation, the gain and bandwidth of photoparametric amplifiers are functions of the pump to signal frequency ratio [5]. Amplification in the down conversion mode is only possible for inverting case and at the expense of the bandwidth and the stability of the amplifier has to be ensured.

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3- SIMULATION TECHNIQUES

The time domain analysis was used in earlier attempts to evaluate the amplifier performance and is presented [3] and [5]. This method although is versatile, proved to be inefficient computationally and it will not be appropriate for circuit optimization. Later simulations are based on the harmonic balance method which is better in terms of its efficiency. The method allows simulation of the intermodulation performances (IMD) in the different modes of operation.

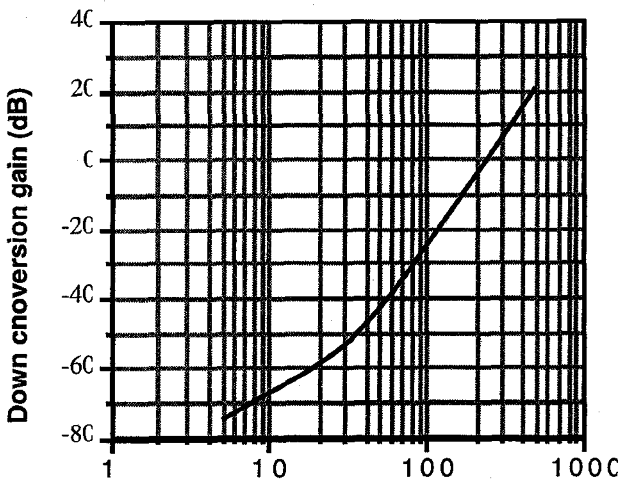

Figure (2)

Figure 2 shows the simulated frequency response of a photoparametric amplifier working in down conversion mode. The pump frequency is at 1 GHz and the circuit is tuned to each frequency. The simulation results agree with the analytical theory. This method allows the simulation and study of the dynamic range and (IMD) in the different modes of operation.

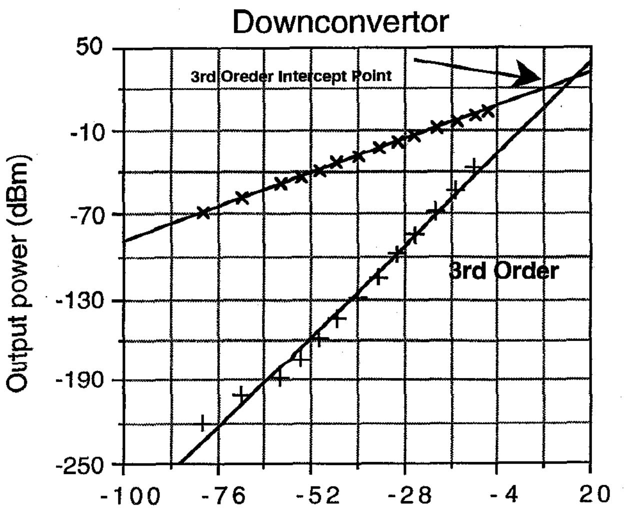

Figure (3)

In Figure 3, the variation of gain against input level and the 3rd order intercept point in down conversion mode are shown. The pump frequency is at 1 GHz and the circuit is automatically tuned to each frequency.

4- DEVICE STRUCTURE

The device structure is shown in Fig. 4a and 4b. It consist of a semi-insulating GaAs substrate, on which there was a series of layers to implement a PIN configuration. The thickness of the heavily doped n-layer was around $3x10^{-4}$cm with a doping density, ND, of about $2x10^{18}$. In consideration of a breakdown voltage of around 20 volt, good absorption volume (high quantum coefficient), and 1-3 GHz operation frequency (short carrier transit time), the intrinsic layer was optimised around $7x10^{-5}$ Cm. In order to allow maximum light absorption the top layer was heavily doped with minimised width of around $3x10^{-5}$ cm. Two techniques were used to secure contact to the device. One of these used air bridge technology to isolate the bond pad capacitance from the device, and the other one, used silicon nitride to prevent the bond pad which sat on the substrate in this case, from shorting across the mesa edge. These structures were implemented in 10, 20, and 50 10^{-4} cm diameter variety.

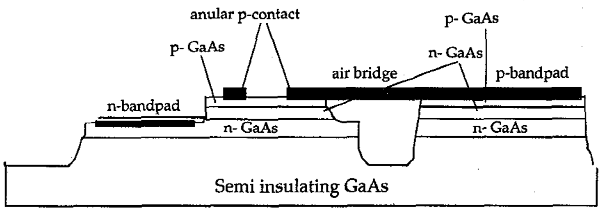

Figure (4.a) Device cross section, air bridge.

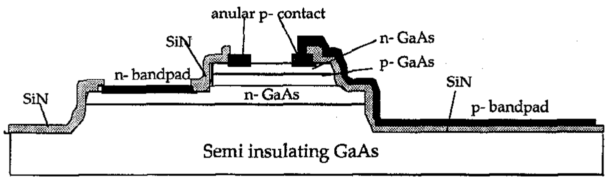

Figure (4.b) Device cross section, Nitride

In order to reduce parasitics at operating frequency and to facilitate performing the measurements, the wafer was sliced, mounted, and bonded directly on SMA connectors. The C-V data (Figure 5) were extracted from the S-parameters measurements at different operating frequency. Device bulk resistance was minimised to around 50 ohm.

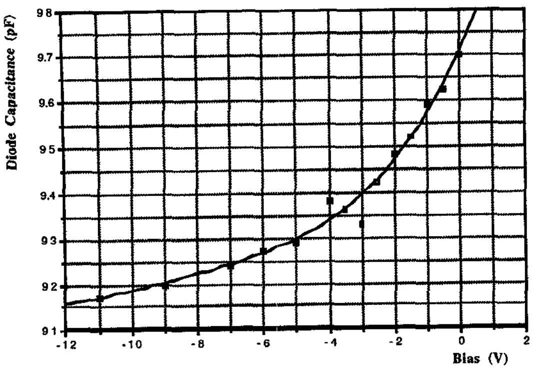

Figure (5)

5- MEASURED RESULTS

Figure 6.a and 6.b are the measured results using the fabricated diodes in direct detection and upconversion mode (when the diode is pumped), indicating gain.

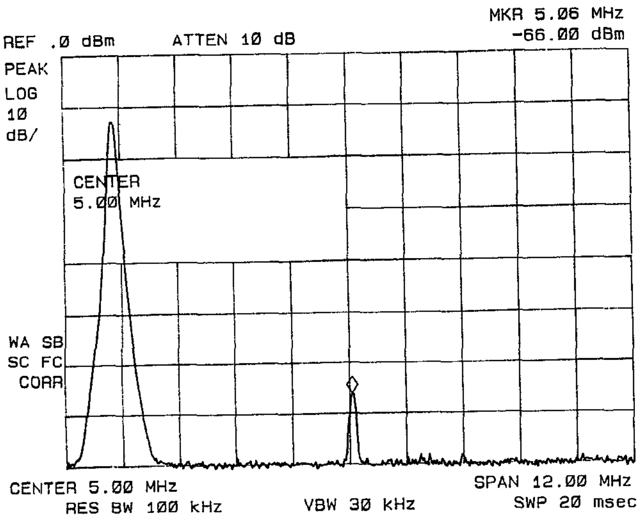

Figure (6.a)

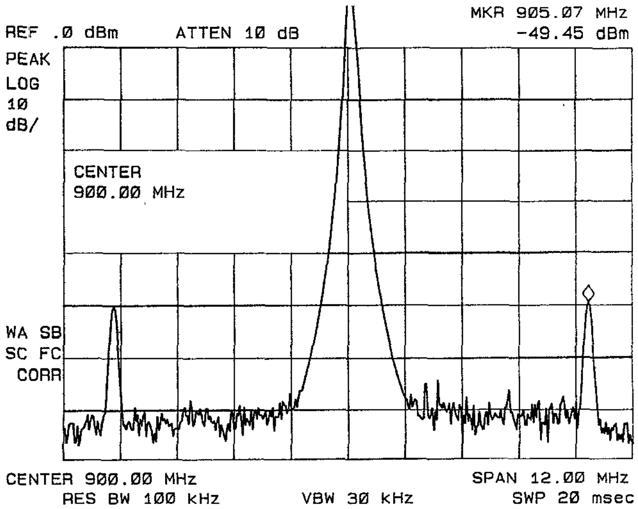

Figure (6.b), The pump power=15 dBm

Amplifier gain improvement were obseved in comparison with the results achieved earlier, where commercial diodes had been used [3]. This would be expected from the diode's C-V behaviour which showes a higher capacitance / voltage variations compared to the commercial diodes. However, the quantum efficiency appears to be some what lower than that of the commercial diodes that are optimised for optical conversion efficiency. Further work is underway to optimize the diode performance.

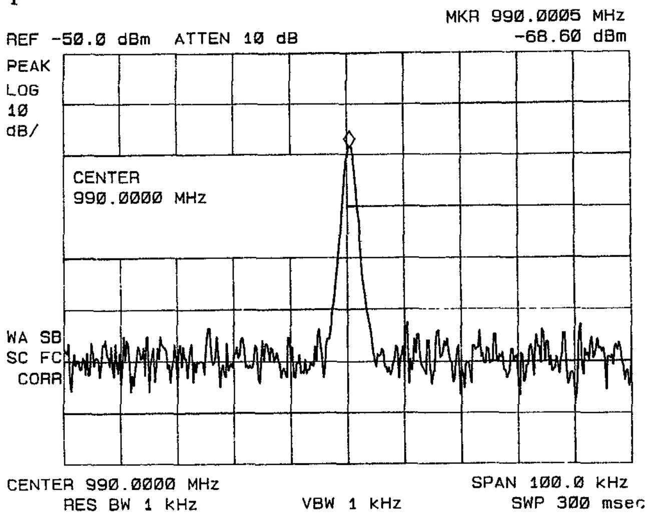

Figure (7.a), Photo-detected signal at 990 MHz.

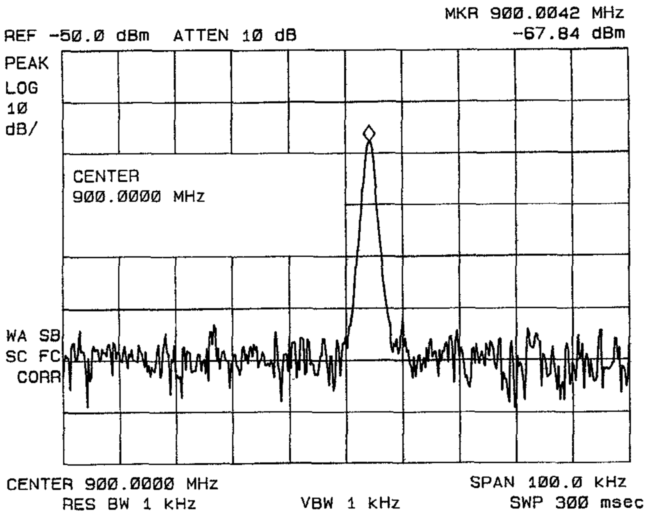

Figure (7.b), Amplifier output at 900 MHz, Pump Freuency' 1890MHz, Pump power 20dBm.

Figure 7.a and 7.b represents the diodes used in an amplifier in the down conversion mode. The conversion gain measured here are some what lower than predicted in theory. This was traced back into the Q-factor of the filters used in the experimental setup. As the gain of the amplifier is proportional to the Q of each filter as well as the diode figure of merit [6].

6- CONCLUSION

An efficient simulation technique for the design of a photoparametric amplifier/converter is reported. The simulation takes into account the interaction with idler circuits in order to optimize amplifier performance. More importantly in subcarrier system applications, the simulation can be used for frequency allocation. The IMD noise of the amplifier is an important parameters which can be evaluated by the proposed method of simulation. This technique is based on the harmonic balance method and provides the required accuracy and flexibility for simulatıng the photo-parametric amplifiers/converters. Practical results and comparison with simulations are presented. The device structures considered form an initial optimization attempt, successfully combining the required two functions. Further work will examine the possibility of modifying the intrinsic regions to give improved varactor action, as distinct from effective photo-detection requirements. This will be accompanied by mathematical models to simulate the performance of different device structures.

7- REFERENCES

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