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# Gain flattening technique for optical wireless front-end receiver considering various large window photodetectors

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ABSTRACT

A novel gain flattening technique for an optical wireless front-end receiver structure involving a bootstrap transimpedance amplifier (BTA) integrated with a MEMS variable feedback capacitor has been demonstrated. The MEMS varicap replaces a fixed capacitance as the feedback element in the front end system to optimize the performance of the BTA in terms of its frequency response. The implementation of the MEMS device with a BTA optical front-end receiver was verified using CoventorWare ARCHITECT. The simulation results showed that the approach can significantly flatten the peaking gain by up to 14 dB, when considering a system with various photodetector capacitances, ranging in value from 100 pF to 1 nF.



## 1. Introduction

With the explosive growth in commercial wireless telecommunication systems, optical wireless has received considerable attention because of the opportunities it offers in terms of requirements for broadband communications. Optical wireless has evolved, and the IEEE 802.11 IR standard for wireless local area networks (LAN) is a result of realizing the importance of the approach [1]. When considering communication systems in general, the receiver has to be one of the crucial elements to be considered. In optical wireless, as with other systems, the link budget must be considered, and the receiver, especially at its front end, is significant in determining of the overall system performance. Unfortunately, in optical wireless (or FSO), the large detection area required for the photodetector, in order to increase the system's sensitivity, inevitably incurs high input capacitance. Generally, large area photodetectors have a typical capacitance from 30 pF to 3 nF, but a lower capacitance than this is essential to achieve a wide bandwidth. There has been considerable effort to obtain the required bandwidth for such large capacitance devices [2–5], but less consideration has been given to front end structures with a photodetector capacitance of up to 1 nF. Therefore, in this paper, we propose an optical front end structure that is able to adapt to a range of photodetector capacitances by integrating a BTA with a MEMS variable capacitor. The BTA concept was introduced by Green and McNeill [6], as a means of beneficially combining two already established techniques for firstly reducing of the effect of a capacitive source, and secondly interfacing a photodiode to a subsequent front end amplifier.

In this work, MEMS technology was chosen for the variable capacitor design because it has the potential of realizing variable capacitors with a performance that is superior to that of varactor diodes and MOS capacitors, in properties such as nonlinearity and loss. To date, MEMS variable capacitors have been actively researched for achieving high Q-factors, tuning ratios and self resonance frequency [7]. Amongst the possible MEMS variable capacitor structures, MEMS parallel plate capacitors have been commonly developed [8–10]. Such capacitors often consist of a suspended top plate that can be electrostatically actuated via an applied voltage to change the capacitance between the plates. In this work, a three, parallel-plate capacitor was utilized as a variable feedback element, as the requirement was for a wide tuning range for the BTA system.

In the next section, the operating principle and system architecture, including the BTA front-end receiver configuration and three parallel-plate MEMS variable capacitor, will all be described. The MEMS variable capacitor design, and its analysis, in order to achieve suitable tuning range for implementation with the BTA circuit, will be discussed in Section 3. Section 4 provides details of the simulation result and discussion.

## 2. Operation principle and system architecture

The basic architecture of the proposed optical wireless front-end receiver is implemented by combining the bootstrap

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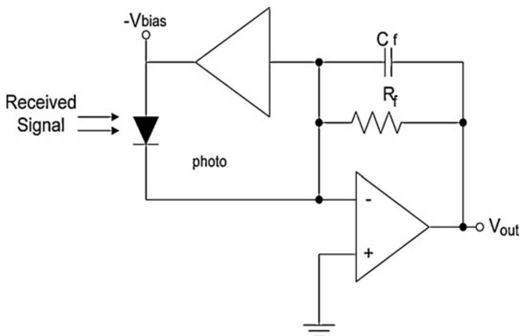


**Fig. 1.** Shunt and floating source BTA circuit arrangement.

transimpedance amplifier with a MEMS variable feedback capacitor. The BTA consists of a current-to-voltage converter applied to the photodiode current, and a feedback element to ensure the circuit's stability. The effect of the bootstrapping is to produce two almost complementary signals, $V_c$, at either side of the photodiode [11]. This has the effect of ensuring that the photodiode's internal capacitance does not absorb current significantly especially at higher frequencies, as the $\{dV_c/dt\}$ component must also be reduced across the photodiode by the bootstrap action, where $C$ is the photodiode capacitance.

Consequently, the effect of high photodiode capacitance seen by the signal is reduced according to the feedback gain of the configuration. The basic circuit of the BTA is illustrated in Fig. 1 in which it shows the shunt circuit arrangement.

An effect of the high photodetector capacitance associated with a large window photodetector required in an optical wireless system is that it will produce peaking gain that affects the stability of the circuit, and causes undesirable ringing in digital systems. With regard to the requirements of the system, the peak in the frequency response begins to appear and increase as the photodetector capacitance is increased. In this work, a variable feedback capacitor has been applied, together with a feedback resistor as the feedback element, instead of just a fixed feedback capacitor, as reported in [12]. MEMS varicap technology was utilized in which the designed variable capacitor used a widely-adopted polysilicon surface micromachining structure known as MUMPs. The MUMPS technology has the same general features as a standard surface micromachining process [9]. Polysilicon is used as the standard layer, deposited oxide is used as the sacrificial layer, and silicon nitride is used as the electrical isolation between the polysilicon and substrate.

The variable feedback capacitor needed in the BTA circuit must have a large tuning range. Therefore, the variable capacitor chosen was one which consists of three parallel plates and which exhibits a wider tuning range, as reported previously by Dec et al. [10]. The conceptual model of a three parallel plate MEMS varicap is illustrated in Fig. 2. The top and bottom plates are fixed mechanically, whilst the middle plate is suspended by two springs, each with a spring constant of $k/2$.

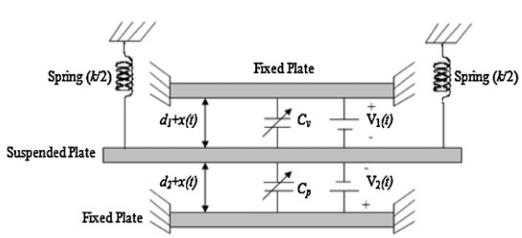


**Fig. 2.** The conceptual model of the three parallel-plate MEMS varicap.

The designed three parallel plate MEMS varicap consists of two capacitances; the variable capacitor, $C_v$ and parasitic capacitor, $C_p$. In this kind of structure, the two varicaps are in parallel, and only one was actually used in the application ($C_v$), and the other was considered as a parasitic (the one with smallest capacitance was designated as $C_p$). In general, the parallel plate capacitance is clearly given by:

$$C = \frac{\varepsilon A}{d + x} \tag{1}$$

where $\varepsilon$ is the dielectric constant, $A$ is the area of the capacitor plates, $d$ is the separation of the capacitor plates under zero-bias voltage, and $x$ is the displacement of the suspended plate from its original position when a bias voltage is applied across the plates. The maximum capacitance that this capacitor can be tuned, when $V_1$ is applied, is given by:

$$C_{\max} = \frac{\varepsilon A}{d_1 - d_1/3} = \frac{\varepsilon A}{2d_1/3} = 3C/2 \tag{2}$$

On the other hand, the minimum capacitance that this capacitor can be tuned, when $V_2$ is applied, is given by:

$$C_{\min} = \frac{\varepsilon A}{d_1 + d_1/3} = \frac{\varepsilon A}{4d_1/3} = 3C/4 \tag{3}$$

## 3. MEMS varicap design and analysis

The bootstrap circuit utilizing feedback capacitance was originally introduced to ensure circuit stability. However, in designing a BTA circuit for a particular optical receiver, the optimum value of the feedback capacitor must be found in order to maximize the bandwidth performance of the system. Therefore, the main emphasis of this work was on the analysis of the appropriate value of feedback capacitor for optimizing the frequency response of the BTA circuit. As such, a MEMS varicap was chosen for the feedback

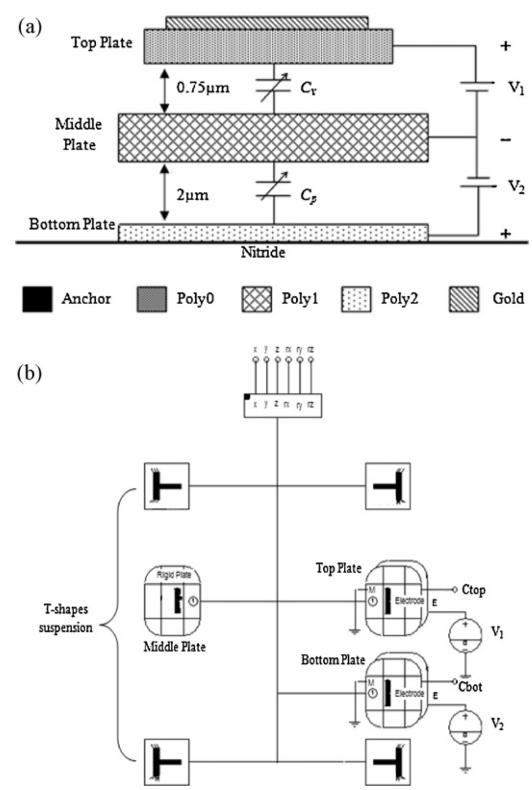


**Fig. 3.** (a) The cross section view, and (b) the schematic circuit of a three parallel plate MEMS variable capacitor.