

Automatic Gain Control with adaptive setting time for Radio-over-Fibre Distributed Antenna Systems

Daniel BOURREAU^{*}¹, Hexin LIU¹, Camilla KÄRNFELT¹, Michel NEY¹ and Frédéric LUCARZ²
daniel.bourreau@telecom-bretagne.eu

Telecom Bretagne, Technopôle de Brest Iroise, CS 83818, 29238 BREST Cedex 3, France
¹ Microwave Department / LAB-STICC (UMR CNRS 6285), ² Optics Department

Abstract

A novel Automatic Gain Control (AGC) device with adaptive setting time is proposed for Remote Antenna Units (RAU) in Radio-over-Fibre (RoF) Distributed Antenna Systems (DAS). Its gain level is dynamically adjusted by all-analogue means configured in a feedback loop according to multiple setting times. A two-stage and dual-speed AGC device was implemented with low-cost and energy-efficient analogue circuits. Its performances were experimentally assessed on a RoF link for various link architectures. The EVM requirements (from 6Mbps to 54Mbps) are met for the total IEEE 802.11g dynamic range, demonstrating some improvement in performance over state-of-the art solutions. **Index terms:** AGC, RoF, DAS

1. Introduction

Providing sustainable wireless coverage in densely populated areas is a major challenge for the next generation of systems which will need to achieve substantial reduction in energy consumption, in order to bring operational costs down and prevent potential health risks of exposure to radiofrequency (RF) radiation [1]. In that regard, **Distributed Antenna Systems (DAS)** have gained considerable attention for their ability to lower RF emission levels [2, 3]. DAS also provide high flexibility to optimize radio coverage with minimum shadow areas.

Furthermore, DAS can take advantage of mature **Radio-over-Fibre (RoF)** technologies to interconnect large sets of distributed antennas or **Remote Antenna Units (RAUs)** through analogue optical fibre links that offer large bandwidths, immunity to RF interferences, enhanced energy efficiency and transparency with respect to various radio standards [4]. Hence, Radio-over-Fibre Distributed Antenna Systems (RoF-DAS) are deemed as good candidates to provide green and future-proof solutions for wireless access.

However, analogue RoF links are known to suffer from restricted input dynamic range in comparison to that of the received wireless signals, which is most critical on system uplinks. To circumvent this disadvantage, a compression of the dynamic range of the received RF signal can be achieved by an **Automatic Gain Control (AGC)** function at the RF receiver part of the RAU, before being transposed onto an optical carrier [4, 5]. An example of a bi-directional RoF-DAS architecture with AGC used to provide Wi-Fi coverage at 2.5 GHz in an office building is depicted in **Figure 1**.

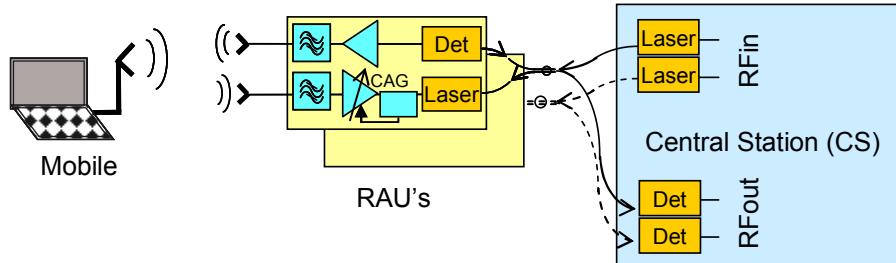


Figure 1. Example of a bi-directional RoF-DAS architecture with AGC

In the present paper, an experimental RoF link was implemented and characterised showing a limited input dynamic range. To overcome this limitation, a novel AGC device is proposed with all-analogue control means for dynamically adjusting its gain at multiple operation speeds (i.e. multiple setting times or loop bandwidths). The proposed AGC device was implemented and tested in our labs on a system uplink, using the Wi-Fi IEEE 802.11g standard. Its performances in terms of error vector magnitude (EVM) were assessed for various RoF link architectures.

2. Radio-over-Fibre link characterisation

A single unidirectional RoF link was assembled using discrete low-cost and low-energy-consumption components available from Finisar. The RoF link consists of a Transmit Optical Sub-Assembly (TOSA Finisar:

HFE6x92-x61) and a Receive Optical Sub-Assembly (ROSA Finisar: HFD6x80-418) interconnected by a standard single-mode optical fibre. The TOSA including a $0.85\text{-}\mu\text{m}$ Vertical Cavity Surface Emitting Laser (VCSEL) was mounted on a printed circuit board (PCB) together with a bias-T to combine input Wi-Fi signals and DC onto the laser input port, as shown in **Figure 2**. The ROSA was mounted on a similar PCB (not shown).

RF characteristics of the RoF link were measured, showing a rather high noise figure (NF) of up to 40 dB, a low third-order input intercept point (IIP3) of -7 dBm and an overall link gain of -1.6 dB. From the measured RF characteristics, it is shown that input dynamic range of the RoF is weak due to its strong NF and low IIP. **Figure 3** illustrates the dynamic range of a typical IEEE 802.11g Wi-Fi input signal, in comparison to the input dynamic range of the experimental optical link.



Figure 2. VCSEL test bench

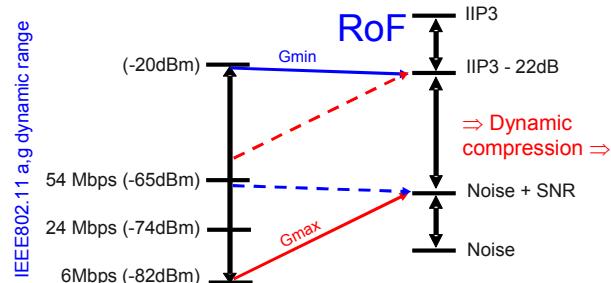


Figure 3. Wi-Fi signal vs. optical link dynamic ranges

In order to avoid poor link performances, the large dynamic range of the input Wi-Fi signal needs to be greatly compressed, so that it fits within the input dynamic range of the analogue optical link, thereby meeting its noise and non-linearity constraints for EVM optimisation. This dynamic compression can be achieved by a variable gain amplifier and in particular, an AGC device, which plays an essential role in RoF-DAS.

3. All-analogue automatic gain control device with multiple setting times

Energy consumption is a major concern for large-scale deployments of RoF-DAS [2, 3, 4] with several hundreds of RAUs that need to be fed with electrical power. Avoiding digital processing in RAUs as much as possible may lead to substantial reduction in power consumption and costs [1]. Yet, this approach has not been widely applied to AGC design which relies mainly on digital or mixed analogue-digital but not all-analogue implementations. All-analogue AGC devices for RoF transceivers have already been described [4] either in a feed-back loop configuration [6] or in a feed-forward loop configuration [5]. Feed-forward loop design is constrained by gain control and detector sensitivity.

A technical problem occurring in AGC loops is that the loop bandwidth or setting time can greatly degrade the system performances, due to a mismatch between the speed at which the loop gain is adjusted and the time variations of the received signals [5]. For instance, upon reception of a burst (preamble), a short setting time is needed for the AGC loop to quickly adjust its gain level according to the fast increases in the RF power of the incoming burst. However, as data is being received (after the preamble), a long setting time is required to avoid any undue adjustment of the loop gain for instance in the presence of noisy spikes, which may lead to signal envelope distortion resulting in data loss. Thus, there is a need to provide all-analogue AGC devices with adaptive setting time. The two-stage AGC feed-forward loop described in [5] is set with only one setting time, which is not suitable for the transmission of data bursts regardless of wireless standards.

To solve this problem, we propose a novel AGC device configured in a feedback loop, with two distinct setting times controlled by all-analogue means (Figure 4). This AGC device is adapted to avoid symbol losses, at the beginning of a burst (or preamble) during which the AGC setting time is set. It also prevents any loss of data due to distortions of the signal envelope while effective data is being received. Therefore, the AGC loop tunes its gain according to two distinct operation speeds for two different regimes: (i) start of a burst (short setting time) and (ii) data reception within a burst (long setting time). A delay is also required between the two regimes, so that desired gain level in the first regime is rapidly obtained and after the delay the second setting time is applied.

As depicted in **Figure 4**, the proposed AGC device comprises a conventional analogue AGC part and a rise time controller (RTC) to adjust the setting time. The AGC part is composed of a filter (TA0532A), a variable gain amplifier (HMC287) and a first Received Signal Strength Indicator (RSSI₁: AD8362) including a detector

and a high gain comparator according to first reference voltage V_{set} . The RSSI₁ output is connected to the gain control to achieve stable output amplitude according to V_{set} . The RTC is composed of an RC delay element, a low serial resistance switch (ADG888), a capacitor (C_{ext1}) and a second RSSI (RSSI₂: AD8362) according to a second reference voltage $V_{compare}$. The RSSI₂ output is connected to the switch to control the setting time applied to RSSI₁.

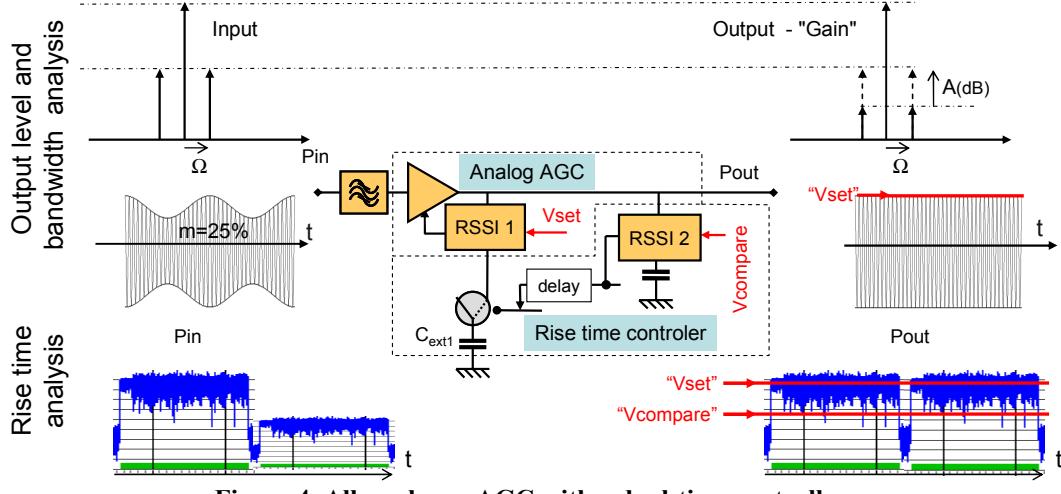


Figure 4. All-analogue AGC with a dual-time controller

First, without any input signal, the RTC is inactive since its RSSI₂ is OFF. In that case, no external capacitor is connected to the RSSI of the analogue AGC part (RSSI₁) and the setting time (τ) is minimal: $\tau=R.C_{int}$ (where C_{int} is the loop internal capacitance). Thereafter, in the presence of an input signal and when the equivalent output level is greater than the RSSI₂ threshold ($V_{compare}$), the switch is activated by RSSI₂ and is ON after a time lapse due to the RC delay. In that case, the external capacitor (C_{ext1}) is connected to RSSI₁ and the setting time becomes very large: $\tau=R.(C_{int}+C_{ext1})$.

Due to the large dynamic range of wireless signals (typically from -82dBm to -20dBm for WLAN IEEE 802.11g), two analogue AGC parts need to be cascaded as suggested in [5]. To obtain the best system performances in terms of SNR and EVM, both cascaded AGC parts must be controlled separately (not represented). V_{set} was adjusted to obtain -35dBm output power on each AGC part, according to the input linearity of the RoF link. The compression of the dynamic range becomes effective with the second AGC part to obtain best NF and SNR. The AGC prototype was implemented as shown in **Figure 5**.

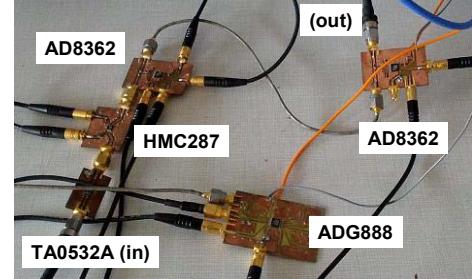


Figure 5. AGC prototype including RTC

The EVM performance of the unidirectional RoF link was experimentally assessed and compared for five different link architectures, with and without the novel AGC device, as described below in reference to **Figure 6**.

- **First architecture (Figure 6.a):** The EVM measurement of the previously characterised optical link shows a very low input dynamic range due to its very high NF (~39 dB).
- **Second architecture (Figure 6.b):** After inserting a fixed-gain Low Noise Amplifier (LNA) at the input of the optical link, the dynamic range remains unchanged, except that it is down-translated to lower RF input powers, with an optimal input power set to -50 dBm (instead of -25 dBm as for the first architecture). The NF decreases, which also makes the IIP3 decrease.
- **Third architecture (Figure 6.c):** By replacing the previous LNA by a single AGC device the dynamic range obtained with the second architecture can be significantly increased. Since both the NF and IIP3 depend on the AGC gain and hence on RF input signals, they are minimal when the gain is maximal (low signal). However, the IIP3 is not significantly modified in the presence of high input signals.
- **Fourth architecture (Figure 6.d):** After inserting a fixed-gain LNA in combination with the AGC device, it is shown that the dynamic range as initially obtained by the AGC device in the third architecture remains unchanged but down-translated to lower input powers, as seen for the second architecture.

These results are not suitable for DAS-RoF deployments, namely because they do not match the EVM requirements for WLAN IEEE 802.11g over the full input dynamic range, as specified in the standard. To

overcome this limitation, a fifth architecture (**Figure 6.e**) with two cascaded double-stage AGC-RTC devices was tested, showing by far the largest input dynamic range (from -82dBm to -20dBm) in compliance with EVM requirement (56.2% to 5.6%).

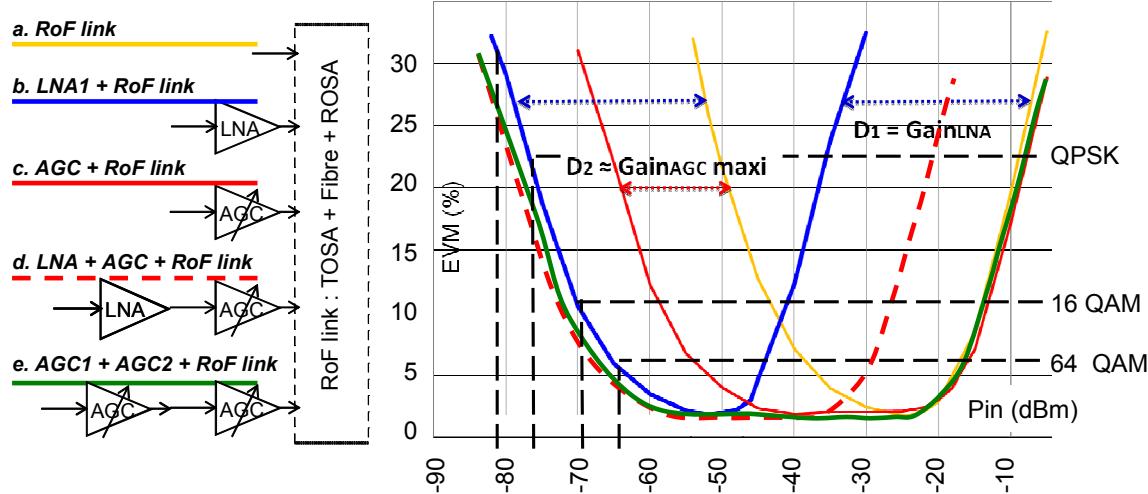


Figure 6. Comparison of EVM performances of a RoF link for 5 different architectures

4. Conclusion

The present paper reports on a novel AGC device to overcome the inconvenience of limited input dynamic range of analogue optical links in RoF-DAS. The proposed AGC device is adapted to operate according to two setting times controlled by all-analogue means configured in a two-stage amplification feedback loop. The AGC device was tested in several RoF link architectures, showing enhanced EVM performances that fully comply with the IEEE 802.11b/g standard specifications. The different setting times (very fast and very low) are compatible with all TDD (Time Division Duplex) standards.

Finally, the multiple setting time AGC solution does not need any digital processor and the added components have low power consumption, which is attractive for green aspects. This promising AGC solution has lead to the filing of a patent application [7] which is currently under examination in France and Europe.

As a result, the novel AGC device is appropriate for RoF-DAS deployment.

5. Acknowledgements

The authors acknowledge the financial support of Institut Mines Télécom in 2009-2012, without which this work could not have been carried out. The authors are grateful to the members of the Optics and the Microwave Departments of Telecom Bretagne who have been active members of the CapilR™ platform team.

6. References

1. H. Hu, Y. Zhang and J. Luo, *Distributed Antenna Systems: Open Architectures for Future Wireless Communications*, Auerbach Publications, June 2007, § 3.2.3 Power Efficiency of DASs, p. 68.
2. T. J. Hall *et al.*, "Radio-over-fibre access for sustainable digital cities", *Annals of Telecommunications*, Vol. 68, Issue 1-2, Feb. 2013, pp. 3-21.
3. D.H. Hoglund, "Distributed Antenna Systems for Healthcare", White Paper IT Horizons 2010, pp. 32-38.
4. M. Sauer, A. Kobyakov and J. George, "Radio Over Fiber for Picocellular Network Architectures », *Journal of Lightwave Technology*, Vol. 25, No. 11, Nov. 2007, pp. 3301-3320.
5. Y-X. Guo, V. Hung Pham, M.-L. Yee and L. Chuen Ong, "Improved Radio-Over-Fiber Transponder with Multistage Automatic Gain Control", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 11, Nov. 2009, pp. 2816-2823.
6. D. Whitlow, Tutorial on Analog Devices: *Design and operation of automatic gain control loops for receivers in modern communications systems*, AN-934 and AD8362 Data Sheet (operation in controller mode).
7. F. Lucarz, D. Bourreau, P. Pajusco, H. Liu, "Circuit à contrôle automatique de gain à temps de réaction variable ajusté analogiquement et dispositif récepteur comprenant un tel circuit", *French Patent Application FR201260845*, Nov. 11, 2012, and *International patent application PCT/EP2013/073777*, Nov. 11, 2013.