Optimized Optoelectronic/RF Probe for Low-Frequency (VHF) Wireless-over-Fiber Transmissions

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Abstract - **It is shown the development of a passive VHF-detector/optical-modulator (Tx module) for 88-108 MHz band. It uses illumination-type Light-Emitting Diodes (LEDs) at 650 nm as optical sources coupled to a POF, usually limited to ~ 100 m length. Reactance matching is achieved by taking into account the capacitance variation of the LED under the bias voltage.**

Index Terms – **LED, Loop Antenna, Optoelectronic, Radio – over - Fiber**

I. Introduction

Most of researches on Wireless-over-Fibre (WoF) technology are rightly focused on high-frequency analogue links (GHz) using single-mode and sometimes multi-mode silica optical fibres for transmitting, receiving, distributing signals or antenna remoting [1]. However, low-frequency WoF links typically below the "microwave-band" (say < 800 MHz) may be of interest due to the new wireless networks as those operating on 400 MHz carrier frequency in Europe and Australia [2], and 700 MHz in the USA. The Federal Communications Commission (FCC) is opening the frequency bands used in the past for the analogue services [3] now to be used in new digital services. Another systems of interest may work at even lower frequencies as < 120 MHz [4]. The latter lower-frequency bands are also of interest for military defence as the use for many antennas remoting on ships, use of High-Frequency (HF) band on the battlefield, etc [4-6]. Many commercially available analogue fibre-optic links are designed for broadband operation and, hence, are not optimized for many narrowband or low-frequency applications. Therefore, it is often necessary to design custom, impedance-matched fibre-optic transceivers for lowest loss within a selected frequency band or central frequency.

Usually, an impedance matching from 50 Ω of a generator to 2-20 Ω resistive impedance of a LD or LED is enough for the most of purposes. However, in case of a wireless transceiver that comprise an antenna, may becomes interesting to achieve a broadband resonating circuit that requires a nearly conjugate impedance matching.

In order to simplify the manufacturing, manipulation, to provide robustness and lowering the cost of low-frequency (starting at < 120 MHz) WoF systems, since 2006 our group have been carried out probably the unique efforts on systematic development of simple systems here named as "optoelectronic probes" or "WoPOFs" (see section 2). LEDs and Resonant-Cavity LEDs (RC-LEDs) coupled to PMMA or perfluorinated POFs may be used instead of laser diodes (LDs) and single-mode silica optical fibres. POFs are easier, safer and cheaper to handle than silica fibres [4,7], specially the connection among light sources, photo-detectors and POFs. RC-LEDs generate stimulated radiation instead of spontaneous as done by LEDs [7]. Therefore RC-LEDs are faster than LEDs and need less care than LDs. Furthermore, multi-GHz modulated light-emitting transistor at 4.3 GHz [8] and diodes at 7 GHz [9] are in active development.

Loop antennas are not new but are simple, well known, easy to build and useful for detection of RF magnetic fields. Furthermore, we have been witnessing a kind of applications "rebirth" of loop antennas [10].

This paper show new experimental results on the development of a passive 88-108 MHz RF-detector/optical-modulator (Tx module) using simple illumination-type Light-Emitting Diodes (LEDs) as visible optical sources. Such sources are efficiently coupled to Poly-Methyl-Methacrylate (PMMA) POFs. We believe this paper provides three new contributions:

1. Energy saving. It can be seen as minor and also major contributions. The former becomes from the energy saved because of the passive (without amplifiers) and optimized nature of the Tx module. The latter becomes from the potentially

widespread use of present simple WoPOF links for signal distribution to smaller cells covered with low-power antennas instead of feeding low-frequency band antennas with high-power.

2. Take into accounts the changes of LED impedance (resistance, and mainly the capacitance and capacitive reactance) [11] when the voltage or current bias is selected and the frequency varies, for the design of an (conjugate) impedance matching network.
3. Use of LEDs as optical sources. Because of noncoherent nature of LEDs, lower intensity fluctuations when compared with LDs [12] is expected, thus enabling larger signal-noise-ratio in analogue links. Although present commercial LEDs have slow response when compared with LDs, recent researches have shown multi-GHz modulated light-emitting transistor and diodes [8,9].

II. "OPTOELECTRONIC PROBES"

"Optoelectronic probes" are useful or potentially useful in many applications that require detection, measurement or tracking the waveforms and their frequency amplitude components from low to high frequencies radio signals propagating through the environment, as examples: antennas characterization, electromagnetic pollution monitoring, remote link to/from antennas, EMC tests, etc [4]. Furthermore, since 2000 there has been a growing interest in transceivers operating in low frequencies for many applications [4].

This paper is focused on "optoelectronic probes" as the basic block that is useful itself, but may also be extended to operate as a WoF repeater for remoting antennas or to cover an electromagnetically shielded environments, to precisely measure the complete RF waveforms [4], etc.

An "optoelectronic probe" comprise three modules: Tx, fibre and Rx. This paper aims to optimise the Tx module that in turn comprises also three sub-modules as shown in Figure 1: the antenna, the impedance matching network and the optical source. The other modules are the fibre that links the Tx with Rx, and the Rx. The latter essentially comprises an amplified photo-diode and a broadband electrical connector enabling the use of oscilloscopes or electrical spectrum analyser (ESAs) for signal display and processing. A Bias Tee is used to combine the DC bias from a voltage source and the RF signal generated by the antenna to drive the LED. At the same time, the Bias Tee isolates the loop antenna and the voltage source from the DC bias and the RF signal, respectively.

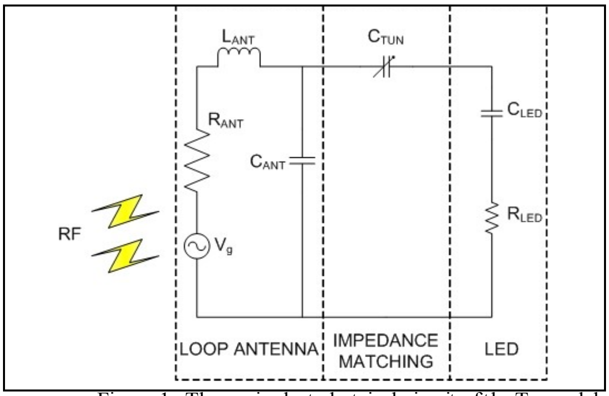

Figure 1. The equivalent electrical circuit of the Tx module

III. THE IMPEDANCE UNMATCHED TX – THE FIRST VERSION OF THE "OPTOELECTRONIC PROBE"

Figure 2 shows a picture of the first version (unmatched circuit of Tx) of an "optoelectronic probe" prototype for 88-108 MHz frequency range.

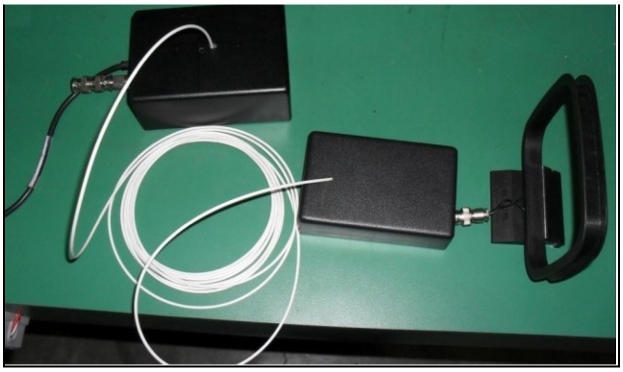

Figure 2.The first version of the "optoelectronic probe" prototype for 88-108 MHz frequency range

The first version of the "optoelectronic probe" uses a Tx comprising a circuit as shown in Figure 1 using a 10x12 cm rectangular one-turn loop antenna with BNC connector, a PCB type T1G model Bias Tee (10 kHz – 1 GHz) from Thorlabs, an 650 nm hyper-red model LED from DieMount GmbH [13] coupling 4 mW @ 20 mA into to 5m of PMMA POF and the 150 MHz bandwidth amplified Si photo-receiver PDA10A model from Thorlabs as the Rx.

Figure 3 shows the FM spectrum radiated from the far-field highlighting the 10 (A-J) channels detected and measured on site "A". The vertical and horizontal axes are in pW and MHz scales, respectively. All channels could be detected and demodulated in audio band when the "optoelectronic probe" was connected to an ESA/VNA MS2034A model from Anritsu.

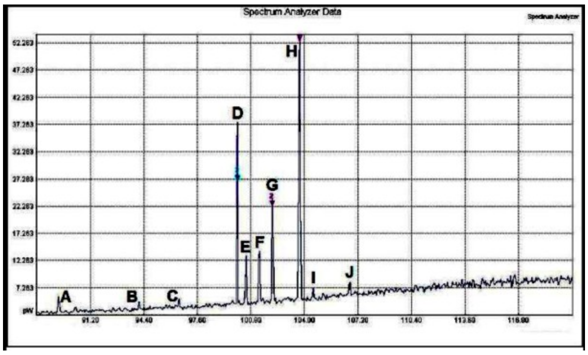

Figure 3. The measured FM spectrum on site "A" by using the "optoelectronic probe" shown in Figure 2. Vertical axis: 2.262 - 52.263 pW and 5 pW/div. Horizontal axis: 88 - 120 MHz and 3.2 MHz/div.

IV. THE IMPEDANCE MATCHED TX - THE SECOND VERSION OF THE "OPTOELECTRONIC PROBE"

A. *The conjugate impedance match network*

Figure 4 shows a picture of the loop antenna which is now connected to a male SMA connector by means of a reactance conjugate match network using a single capacitor. The latter is a few pF ceramic UHF capacitor. The male SMA connector was placed for convenience, i.e. to connect the antenna for characterization and then to connect the group antenna + capacitor with the LED source. It should be observed that Figure 2, in comparison with Figure 4, shows the 2-wires directly welded to the (BNC) connector, i.e. without the conjugate impedance matching capacitor.

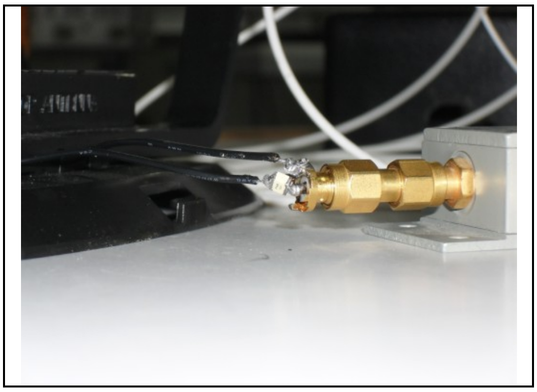

Figure 4. Picture of the loop antenna and its 2-wires (left) welded to the impedance match capacitor (middle) in turn welded to the male SMA connector (right)

Figure 5 shows a picture of the female SMA connector welded to the red LED.

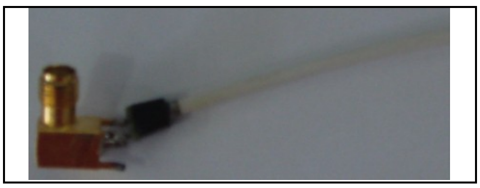

Figure 5. Picture of the female SMA connector (left) welded to the Diemount 650 nm POF-coupled LED (right)

B. *The characterization of the devices*

Figure 6 shows the plot of the resistive and reactive impedance of the DieMount LED under 2.3 V bias voltage measured in the FM-band.

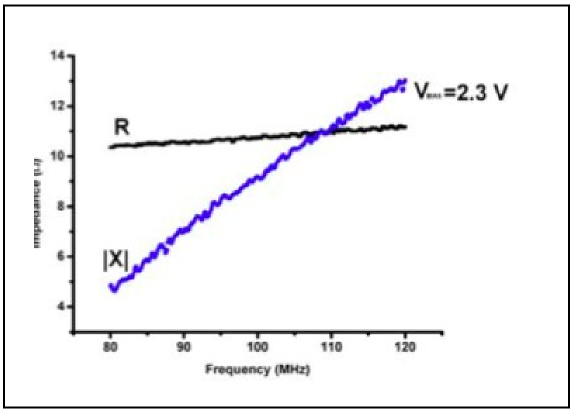

Figure 6. Plot of the resistive and reactive impedance of the 650 nm Diemount LED under 2.3 V bias voltage from 80 to 120 MHz

From Figure 6 we achieve 10.5 Ω resistive impedance almost constant. When the LED is forward biased, the charge separation and/or dielectric constant of medium change. Indeed, simple calculations from the reactance measured at 80 and 120 MHz show that under 2.3 V bias voltage applied, the LED capacitance varies from to 400 to 100 pF, respectively.

Figure 7 shows rather small resistive impedance for the loop antenna in the FM-band. A negative effective reactance was achieved that yields the predominance of capacitive reactance.

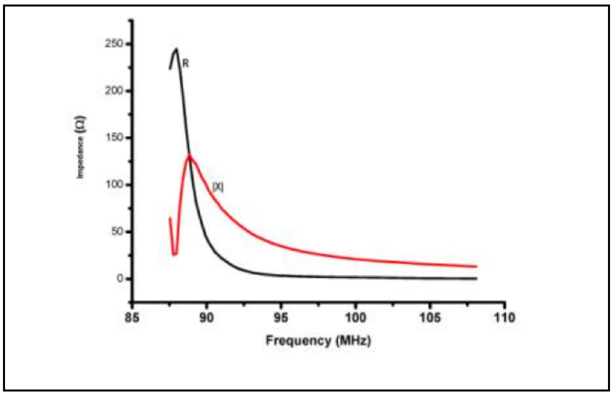

Figure 7. Plot of the measured resistive and reactive impedance of the N = 1 loop antenna in the FM-band spectrum.

C. *The complete Tx module*

Figure 8 shows a picture of the complete Tx under operation. In the present stage of development, an external DC voltage source is used to polarize the LED. The RF signal from the antenna and the DC voltage are both coupled to the

LED by means of a ZFBT – 4R2GW model Bias Tee device from Mini-Circuits.

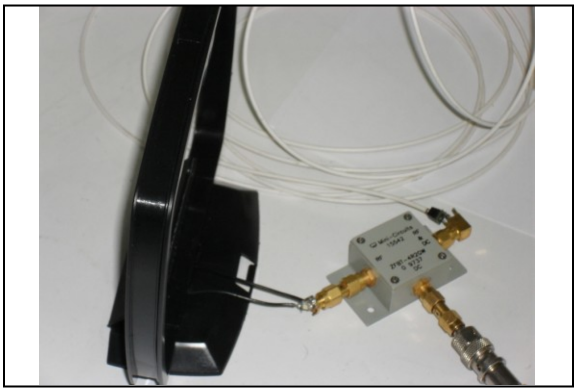

Figure 8. Picture of the complete optimised Tx. We can see the ZFBT-4R2GW model Bias Tee in the middle and the red LED shining in the right

D. The PMMA-POF based "optoelectronic probe" for 88-108 MHz

Figure 9 shows a picture of the PMMA-POF based " optoelectronic probe " for 88-108 MHz (FM-band) under operation. The present optical link use the same length of PMMA POF. At right of Figure 9, we can see the 150 MHz bandwidth amplified Si photo-receiver PDA10A model from Thorlabs and the simple optical coupling between the POF and the active photo-diode chip. The coaxial cable from the photo-receiver may be connected to an oscilloscope or ESA. The other cable provides the bias voltage to the photo-diode and their integrated amplifier.

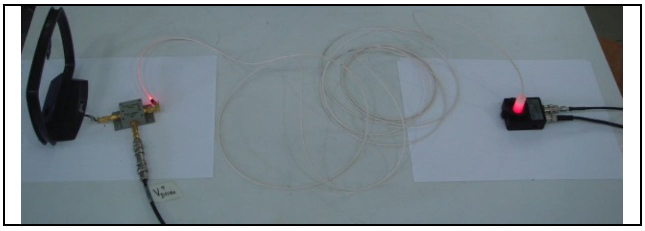

Figure 9. Picture of the PMMA-POF based "optoelectronic probe" for 88-108 MHz under operation

V. RESULTS AND DISCUSSIONS

Figure 10 shows an expanded 10-300 MHz spectrum. The vertical and horizontal axes are in mV and MHz scales, respectively. The FM-band is again detected with lower resolution, but two peaks around 55.8 MHz and 68.0 MHz are now appearing.

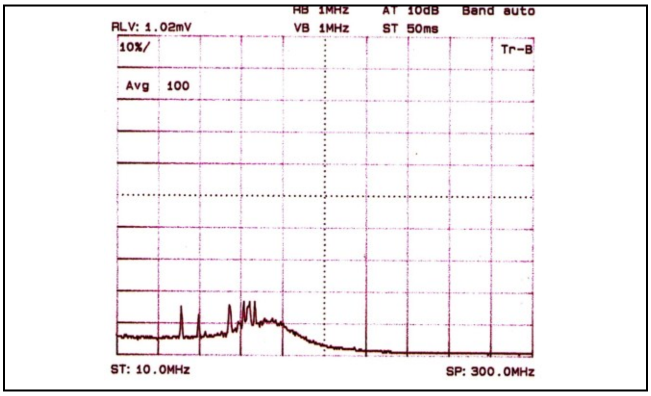

Figure 10. Plot of the extended 10-300 MHz band spectrum as measured with the "optoelectronic probe" of Figure 9 without the impedance matching circuit. Vertical axis: 0 – 1.02 mV and 0.1 mV/div. Horizontal axis: 10 - 300 MHz and 29 MHz/div.

Figures 11 and 12 and shows an expanded 10-300 MHz spectrum detected and measured with the complete "optoelectronic probe" shown in Figure 9 using C_{TUN} = 7.5 pF and C_{TUN} = 3.3 pF capacitance for the conjugate match capacitor network, respectively. The vertical and horizontal axes are both again in mV and MHz scales, respectively.

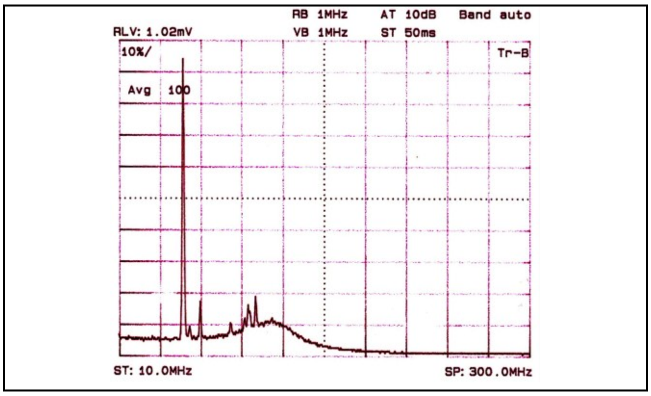

Figure 11. Plot of the extended 10-300 MHz band spectrum as measured with the "optoelectronic probe" of Figure 9 with the impedance matching circuit (C_{TUN} = 7.5 pF).

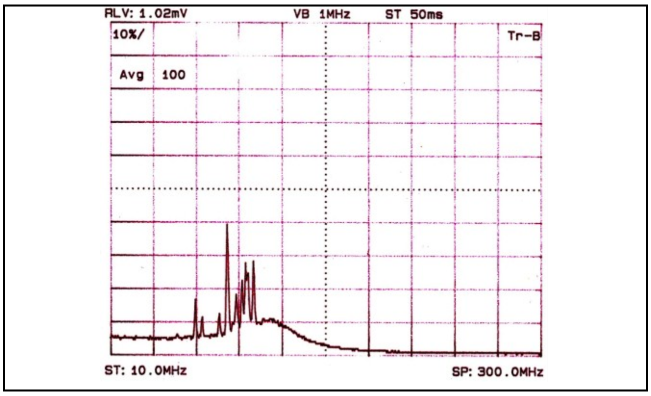

Figure 12. Plot of the extended 10-300 MHz band spectrum as measured with the "optoelectronic probe" of Figure 9 with the impedance matching circuit (C_{TUN} = 3.3 pF).

In all measurements shown by the spectra in Figures 3, 10-12, tests were done to confirm the true wireless over fibre transmission. In the first test, the loop antenna is disabled from the circuit. In the second test, the POF is unbound from the photo-receiver. Finally, in the third test the DC bias voltage is turned off. In all three cases the signal seen in the oscilloscope or ESA have desappeared.

Assuming an equivalent electrical circuit of Figure 1, simple calculations may be carried out in order to approximately explain the spectra of Figures 11 and 12 when compared with Figure 10. The influence of the Bias Tee is negligible for high values of Bias Tee inductance and capacitance [14].

VI. CONCLUSIONS

By using simple and low cost commercially available components, including a non-Telecom LED and plastic optical fibres, a WoPOF with passive Tx can be built to work in the FM-band.

In a first prototype version, none conjugate matching was used in the Tx circuit. The "optoelectronic probe" thus built was able to display 20 channels along the FM-band (88-108 MHz). Furthermore, it was possible to "hear" many FM commercial channels by using an ESA capable of audio demodulation.

In a second prototype version, a simple conjugate matching network using a single ceramic capacitor (3.3 pF capacitance) was designed from a simple model based on the complete impedance measurement of the loop antenna and the LED. The latter procedure can be seen as a design of an optimized "optoelectronic-RF circuit" intended to be broadband for a specific RF-band. Indeed the placement of the tuning capacitor raises the FM-band as a whole, although the channels around 90 MHz are the most improved according with the simple model outlined. However, when the 7.5 pF capacitor was placed in the circuit, the 55.8 MHz channel was highly enhanced while the model fails because it lead to a resonance peak around 67 MHz. One of the probably reason becomes from the use of capacitance values of the LED and loop antenna at 90 MHz, instead of 55.8 MHz.

Therefore, a minor contribution to the energy saving becomes from the non-amplified nature of the Tx module. A major contribution may become from the potentially spreading use of present simple WoPOF links instead of antennas fed with high-power in low frequency band.

Further design can be improved the performance of the "optoelectronic probe" by using a little more sophisticated impedance matching circuits.

VIII. ACKNOWLEGEMENTS

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