Making Information Flows in Hybrid Space Tangible: an Analog RF Power Detector for Sonification of Wireless Network Traffic

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ABSTRACT

The paper presents a fully analog prototype device for sonification of electromagnetic power in the radio frequency range. The RF power detector was designed specifically for use in artistic performances, which attempt to make listeners aware of the hybrid space surrounding them, filled with information flows from wireless networks. The device is tuned to the RF range of 800Hz to 2.7GHz, to detect GSM, Bluetooth and WiFi network traffic. The modular design allows sonification using the power reading directly or through voltage to frequency converters, as well as leaves room for expansion using other signal processing circuits.

1. Introduction

The presented paper is a collaboration between artists and engineers. The driving concept of the project was to develop a method of sonification of the flow of information through wireless networks, a technology so ubiquitous that it has become unnoticeable. For this purpose, an analog device was developed that consists of a radio frequency (RF) amplifier and voltage to frequency converters. The modular device allows several methods of sonification of power fluctuations in the 800Hz-2.7GHz frequency range.

2. From Virtual Reality to Hybrid Space; theoretical background.

The omnipresent wireless and mobile technologies are one of the most important factors defining modern culture. They influence the evolution of communication, shape social relations, human perception and existential experiences.

Today's world can be perceived as a multidimensional space of relations, a dynamic emergent network in which material aspects of reality are inseparably tied to multidirectional information flows. The virtual information space constantly passes through and interacts with material reality.

Duality and clear separation of immaterial, pure information space and the material physical world, described in the analyses of network society by Manuell Castells [**1**], and the concept of the uncrossable "bits vs. atoms" dichotomy proposed by Nicholas Negroponte [**2**], were fundamental paradigms of the cyber culture of the 90s; however, they lost a lot of their currency with the advent of wireless communication. The virtual information networks are now all around us in the material reality. This phenomenon leads to emergence of the new form of environment called "hybrid space".

The term hybrid space was first introduced by architects Frans Vogelaar i Elisabeth Sikiaridi in 1999 [**3**], but only in the next decade the concept was widely received and debated mostly in the fields of media studies and sociology[**4**] [**5**] [**6**] [**7**] [**8**]. The development of hybrid space is closely connected with the progress of mobile and internet technologies, thanks to which digital space passes into and intertwines with material space. Pointing out the difference between the Internet of the 90s and the present day pervasive networks, Adriande de Souza e Silva states that the main characteristic of hybrid space is the crossing of the virtual vs. real dichotomy. She writes: "a hybrid space occurs when one no longer needs to go out of physical space to get in touch with digital environments. Therefore, the borders between digital and physical spaces, which were apparently clear with the fixed Internet, become blurred and no longer clearly distinguishable." [**9**]. A hybrid space appears when the experience of being in the material world and in cyberspace becomes hardly separable and users can be continuously on-line thanks to mobile technologies. The process of merging information space and material reality is two-way and involves both the materialization of virtuality as well as virtualization of the material space. The constant two-way flow of material and virtual data is a substantial component of a continuous heterogenic hybrid space.

The concept of hybrid space is based on the inclusion of digital technology into material space in such a way that its presence is only manifested through functionality. For this reason, the idea of ubiquitous computing is strongly connected to the presented project. The notion of "ubicomp" was introduced by Mark Weiser over 20 years ago [**10**]. Noticing the shortfalls of personal computers, Weiser foresaw the time when information technologies will become a natural element of the surroundings, will be integrated into the simplest everyday objects and spaces where human activity takes place. Such omnipresence of computer technology transforms the human living space and experiences, also influencing new forms of human relations. As Anne Galloway points out – "ubiquitous computing was positioned to bring computers to 'our world' (domesticating them), rather than us having to adapt to the 'computer world' (domesticating us)" [**11**].

Using a stationary PC was a form of tying a user to a machine and separating him from the external world. The essence of ubiquitous computing is the inclusion of technology into the environment, so that it appears natural, intuitive and connected with other activities of the user. Weiser contrasted the idea of universal computerization with the paradigm of virtual reality, foreseeing a third wave of digital revolution characterized by materialization of virtuality. In his words: „the opposition between the notion of virtual reality and ubiquitous, invisible computing is so strong that some of us use the term 'embodied virtuality' to refer to the process of drawing computers out of their electronic shells. The 'virtuality' of computer-readable data – all the different ways in which they can be altered, processed and analyze – is brought into the physical world" [**10**].

A basic characteristic of the ubicomp paradigm is the transparency of tools. Technologies should „wave themselves into the fabric of everyday life until they are indistinguishable from it" [**10**].Invisible tools should not attract user's attention and work effectively outside her/his perception [**12**].According to Weiser, the spread of non-invasive *calm technology* will lead to a new user-friendly bio-technosphere, which would not limit human activity, but naturally expand and supplement every day existence. Presence and functionality of technology would be obvious, but unnoticeable. As Weiner stated in his manifesto - "the most profound technologies are those that disappear".

Referencing the relatively distant in time, although visionary, thesis of Mark Weiser [**10**] we attempt to show that since the first time the term pervasive computing was used it pointed out the important problem of transparency of technology. While the transparency is a desired aspect from the point of view of functionality and effectiveness, the invisibility of the technology limits the possibility of critical reflection on the role and influence of technology on its users. As Eric Kluitenber points out – the hybrid space became „a vernacular of contemporary life" and "like all vernacular it exists and operates primarily beneath the threshold of consciousness" [**7**]. As a consequence, "the environment is no longer perceived as a technological construct, making it difficult to discuss the effects of technology." [**13**]

3. Project Motivation – Making Hybrid Space Tangible

As wireless technologies became a constitutional element of the modern bio-technological ecosystem, the question of their influence on human lives is a fundamental problem, both practical and theoretical. The motivation of the presented project was the connection of both perspectives, through an unconventional means of perceiving wireless network traffic.

No media studies analyses are made in this paper. We will also not discuss the sociopolitical context of the hybrid space, although we are aware of the complexity of the concept. The main motivation for the project was developing a method to create a perceptual experience of the information flows in the wireless networks around us and address their invisible influence on the psychosomatic human condition.

The project focuses on the material, physical aspect of the wireless technologies, analyzing the intensity, deepness and variability of the electromagnetic signals that constitute the information flows.

Through sonification of electromagnetic activity generated by popular electronic devices, such as mobile phones, laptops and tablets, we attempted to create conditions that would allow users/spectators to experience the "subcutaneous life" in the hybrid space, outside of normal human perception.

The presented device for amplification and sonification of electromagnetic waves in the radio frequency range is one of the hardware elements of a system used by Maciej Ożóg in his concerts, performances and installations[**14**]. They are an artistic exploration of the interactions between biological activity of the body and the electromagnetic field generated by wireless devices, taking the form of a multisensory experience.

4. The RF Power Detector Device

The Analog RF Power Detector (ARFPD) is a device for real-time sonification of the power transmitted through wireless networks. The heart of the prototype is an ADL5513 logarithmic amplifier module, operating in the radio frequency range and with 80dB amplification. The module can boost signals in the 1MHz - 4GHz frequency range, but the peripheral electronic components were selected for to focus on the 800MHz - 2.6GHz frequency band. Thanks to this it is possible to sonify not only WiFi and Bluetooth network traffic, but also GSM network activity usually centered around 900MHz. The voltage at the output of the amplifier is dependent on the power

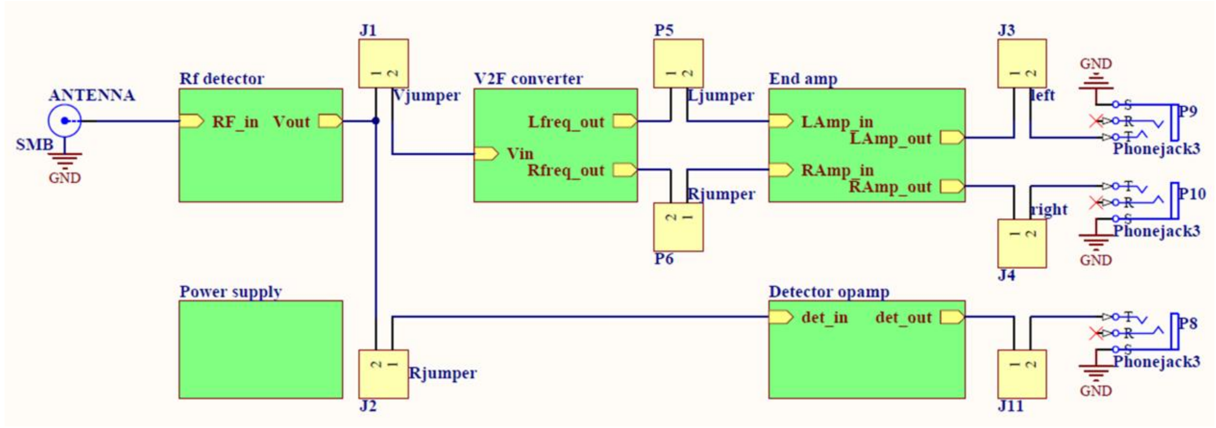

Figure 1: Block diagram of the RF detector.

delivered by the antenna to the input of the device – the higher the power, the higher the voltage.

The sound is generated by fluctuations in the received power, e.g. during transfer of data packets or calls through the wireless networks.

As seen on Figure 1 there are three mono jack outputs from the device – one directly after the RF amplifier and two after the voltage to frequency converters. All the ouptuts are relatively low power (100mW), enough for headphones, but require a separate power amplifier to send the signal to larger speakers.

4.1. RF detector

As previously mentioned the heart of the device is a logarithmic ADL5513 amplifier manufactured by Analog Devices [**15**]. The main features of the amplifier are a 1MHz - 4GHz frequency range, -70dBm sensitivity and 30mA current consumption. The large number of possible configurations make the amplifier ideal for “RF transmitter power amplifier linearization and gain/power control; Power monitoring in radio link transmitters ; RSSI measurement in base stations, WLAN, WiMAX, RADAR” [**15**]. The internal block schematic of the amplifier is shown in Figure 2.

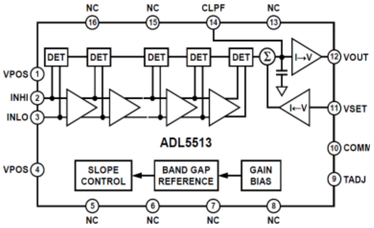

Figure 2: Functional block diagram of the ADL5513.

To avoid parasitic capacitance or inductance the ADL5513 is housed in a 16LFCSP (16-Lead Frame Chip Scale Package) 3mm x 3mm casing.

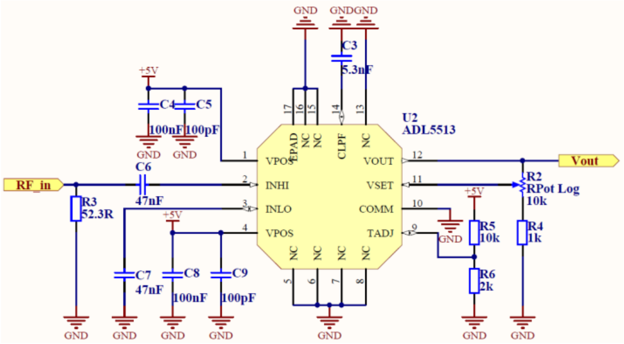

Figure 3: Circuit diagram of the detector module.

The electronic circuit built around the amplifier is based on the default schematic proposed by the manufacturer, but adjusted for the intended application. The default schematic (Figure 3) was adjusted in the following ways:

- the output frequency was capped to 20kHz by adjusting the capacitance of C_{FLT} (C3 in Figure 3: Circuit diagram of the detector module.) according to the formula:

$$C_{FLT} = \frac{1}{2\pi \cdot 1.5k\Omega \cdot 20kHz} - 3pF \approx 5.3nF \tag{1}$$

- temperature compensation was set to provide consistent response for signals of frequency around 2.4 GHz (typical for Wireless and Bluetooth traffic). According to the ADL5513 data sheet the voltage at the TADJ pin for 2.4 GHz should be 0.833V. This was achieved through a voltage divider made using R5 and R6. Setting R6 to 2kΩ lead to the formula for R5:

$$R5 = 2k\Omega \cdot \frac{5V - 0.833V}{0.833V} \approx 10k\Omega \tag{2}$$

- matching the output sensitivity. Setting *R4*=1kΩ to protect the amplifier output when *R2*=0Ω, leads to:

$$R2 = R4 \cdot \left(\frac{slope2}{slope1} - 1\right) \tag{3}$$

Where: *slope1* = 20mV/dB is the nominal amplification and *slope2* the desired amplification.

Measuring power levels directly next to typical WiFi routers (D-LINK DI-524 and TP-LINK WR740N, both with 5dBi antennas), the average power level was -60dBm, so this value was chosen as the saturation level of the amplifier (V_{max}=4.7V), thus:

$$slope2 = (-60dBm + 87dBm)/4.7V \approx 170mV/dB \tag{4}$$

The final value of R2 can be found:

$$R2 = 1k\Omega \cdot \left(\frac{170mV/dB}{20mv/dB} - 1\right) = 7.5k\Omega \tag{5}$$

As such a potentiometer would be difficult to obtain, a 10kΩ linear potentiometer was chosen.

At maximum sensititvity the slope is:

$$slope2 = \left(\frac{R2}{R4} + 1\right) \cdot slope1 = \left(\frac{10k\Omega}{1k\Omega} + 1\right) \cdot 20\frac{mV}{dB} = 220mV \tag{6}$$

and the amplifier will saturate at:

$$Pin = \frac{Vout}{slope} - Pintercept = \frac{4.7V}{220mV/dB} - 87dBm \approx -66dBm \tag{7}$$

Due to the internal circuit topology of the ADL5513 amplifier, the output voltage is offset by +0,47V.

4.2. Voltage to Frequency Converter

To obtain a variable sound at the output an LM331N [**16**] voltage to frequency converter from Texas Instruments was used. The element produced a pulse train at a frequency precisely proportional to the input voltage. The circuit diagram for the converter module is presented in Figure 4.

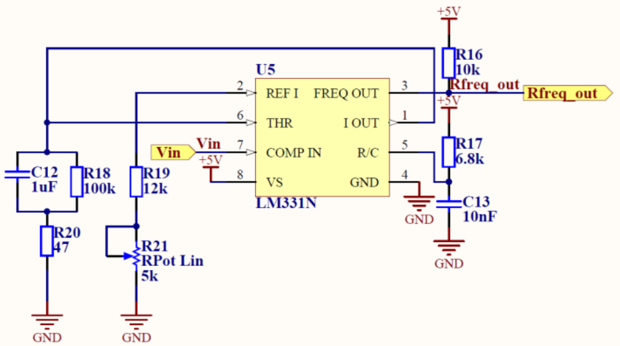

Figure 4: Circuit diagram of one of the two voltage to frequency converter modules.

In case of small power fluctuations at the output of the ADL5513 amplifier the converter will output a constant frequency. In case of large variations in power (e.g. during packet exchanges between a router and a laptop) the output frequency will fluctuate significantly.

In accordance to the LM331N datasheet, the R19 resistor was changed to 6kΩ to obtain a lower frequency limit of 200Hz.

$$Fout_{min} = \frac{Vin_{min}}{2.09V}\cdot\frac{R19}{R18}\cdot\frac{1}{R17\cdot C13} \qquad (8)$$

According to the datasheet of ADL5513, the Vin_{min} is 0.47V and Fout_{min} comes out to approximately 200Hz. The upper frequency limit is 10 times higher (2kHz).

4.3. Power amplifiers

Power amplifiers configured as inverting amplifiers were used as current buffers for the LM331N converters and the ADL5515 amplifier, due to their low current efficiency. The C16 and C17 capacitors remove the DC component from the signal. The R13 potentiometer paired with resistor R25 regulate the amplification according to the formula:

$$V_{out} = -\frac{R13}{R25}\cdot V_{in} \qquad (9)$$

Leading to a maximum possible amplification of 10.

The R22 and R23 resistors create an artificial grounding point, so that the amplifier can work powered by a single 0-5V potential.

The output power is only approximately 100mW, so an audio amplifier is needed for scenic use of the device.

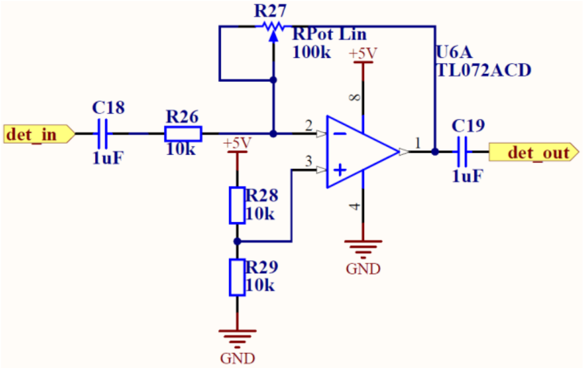

Figure 5: Circuit for the output power amplifier.

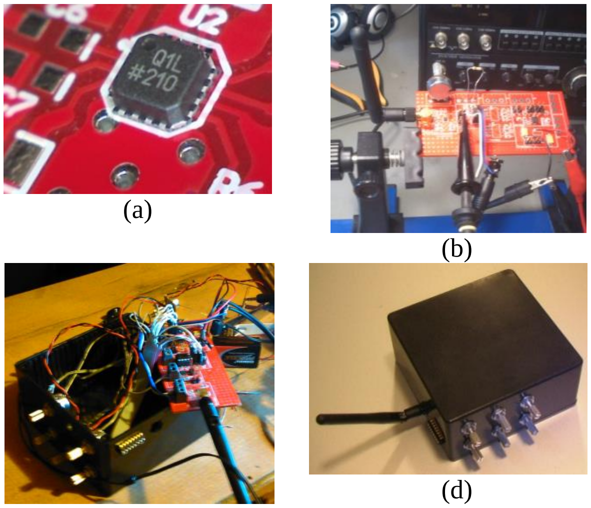
(a)
(b)
(c)
(d)

Figure 6: Soldering, testing and assembly phases: (a) ADL5513 chip soldered on the PCB board., (b) soldering and testing, (c,d) final “black box” enclosure.

5. Construction and testing

The final PCB board is 110mm x 50mm x 1.6mm with 70µm 2-side copper layer.The circuit board was designed in accordance to typical rules for RF circuits:

- vias for mass connections between layers no larger than 1/20 λ (so for 2.4GHz the wavelength is 125cm, and the through-holes are 6.25mm and 3.125mm in close proximity to the ADL5513 amplifier)
- voltage paths are distributed in a star topology, so that interference emitted by the ADL5513 amplifier

and LM331N converters does not leak to the voltage source,

- antenna connector placed as close as possible to ADL5513 input
- ADL5513's Exposed Pad is soldered to low impedance ground plane by multiple vias to the bottom layer, which minimizes parasitic inductance and capacitance [**17**].

The device is powered by a 9V battery with an LDO stabilizer set to 5V. The battery was chosen as the power source to remove the possibility of interference from the mains power. The current drain is approximately 10mA, which allows for approximately 50 hours of performance.

The casing shown in Figure 6: Soldering, testing and assembly phases: (a) ADL5513 chip soldered on the PCB board., (b) soldering and testing, (c,d) final "black box" enclosure. d) was chosen by the artist to be an unknown "black box" with three unmarked jack ports and six potentiometers.

5.1. Test recordings

The output of the RF detector was connected to a laptop PC and several test signal recordings were made with different wireless devices in the proximity.

Waterfall plots of these recordings are presented in Figures Figure7-Figure 10: Tuning of the voltage to frequency converter. The horizontal axis is in seconds and vertical axis in Hz. The color intensity translates to the power of the signal in the given frequency band.

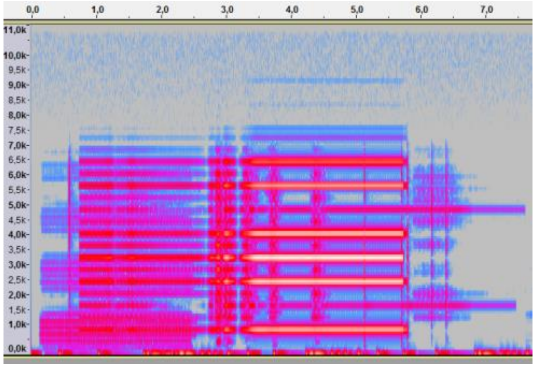

Figure7: Bluetooth module broadcasting in search of other devices.

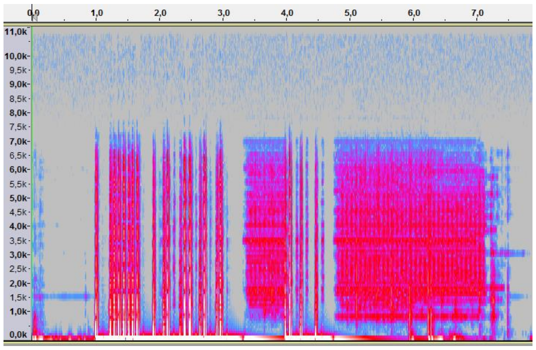

Figure 8: GSM module dialing a number.

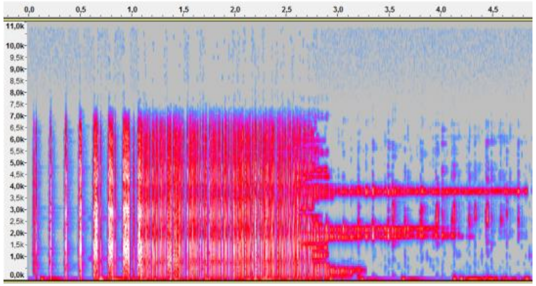

Figure 9: WiFi module in a laptop during bandwith test.

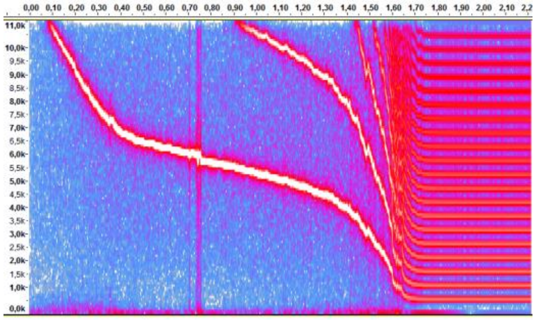

Figure 10: Tuning of the voltage to frequency converter.

The recordings should be available as supplementary materials in the electronic version of the conference proceedings.

6. Discussion

The design of the presented prototype stems directly from the theoretical artistic background and specific performance goals. The device allows to sonify wireless network traffic. Due to its small size, it is a good mobile „radar" that can be used to explore and express the diverse nature of hybrid space in various spatial, temporal and social contexts. The device can create an auditory representation of the invisible „information landscape", thus allowing a new way to perceive and experience everyday reality. At the same time the sound „map" of information flow is a base for studying and critical analysis of the social, economic, political, geographical and cultural factors that determine the access to the universe of information and in form of participation in the internet society.

The ARFPD is intended not only as a tool for registering information flows, but also for creative use of electromagnetic waves. In this aspect, the information flows are treated as an immaterial *objet trouvé*, that transforms and gains new meaning when moved to a different context. On one hand they can be used directly as raw ingredients in the artistic composition. On the other they can be used as a source of signals for control of external devices for sound creation, and in the future for image manipulation. In addition to the „raw" sound which is a direct representation of the electromagnetic activity, the device has two converters that allow modulation and modification of the signal in real time. This makes the ARFPD a tool not only for monitoring and sonifciation of information flows, but also a specific instrument for sound synthesis. The large potential of the device comes from its modular and open design, allowing to use a number of signal paths and expand the device in the future by adding more sound processing and synthesizing modules.

7. Conclusions and future plans

The presented prototype device allows simple analog sonification of activity in the electronic spectrum responsible for wireless communications. It was designed as a tool for artistic performances aimed at making audiences aware of the information flows in the "hybrid space".

Thanks to its modular design, the ARFPD prototype can be easily equipped with additional filters, converters or other signal processing circuits.

The next planned expansion of the device will be connecting it to a PC or a microcontroller for frequency analysis and generation of MIDI commands depending on the detected RF power, e.g. reaching an amplitude threshold by a 10kHz signal for 500ms would generate an instrument change message. This will open up the possibility of connecting with a wide range of MIDI compatible devices and synthesizers.

Field trials in locations of large wireless traffic (e.g. public hot spots) will allow to gather more data on typical traffic loads and further improve the device, which is currently used for live artistic performances.

8. References

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