# Feasibility of Dual UWB Heart Rate Sensing and Communications under FCC power restrictions

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*Abstract*—**This article explores the viability of an application that can perform both, biomedical sensing and communications using the same transceiver operating at Ultra Wideband (UWB) range of frequencies. Among the numerous signals that can be measured employing UWB techniques, this work focuses on the heart rate (HR) and its variability over time (HRV). The approach exploits the fact that UWB radar sensing has long been proved possible especially for breath and HR. Founded on similar principles, UWB based communications showed great potential and some devices are already hitting the market. Still, there is no single application that can perform both tasks at the same time. A simple and approximate power budget is used to show the feasibility of sensing even under actual stringent FCC regulations and a standard communication device is chosen to show the potentialities of the combined strategy.**

*Index Terms*—**Biomedical monitoring, communication systems, radar, radio communication, remote sensing.**

## I. Motivation

THE motivation behind this topic comes from the interest of the author in the area of pervasive computing technologies for healthcare (pervasive healthcare for shortness) and wearable healthcare IT systems [1]. Most of the applications proposed on those areas basically need two components: a sensor of some kind and a communication infrastructure (transceiver and protocols) to share the data gathered by the former. The proposer hypothesizes that the bio-sensors needed to boost the idea of pervasive healthcare have to be: non invasive, contactless and wirelessly networkable.

Pervasiveness automatically calls for non invasiveness mainly because the paradigm not only involves pathological patients but also healthy people that for the sake of prevention and/or early diagnostics would like to be constantly health monitored. Contact could be also a deterrent to pervasiveness mostly related to comfort or wearability of the bio-sensors. Long term monitoring of activities of daily living (ADL) definitely benefits from contactless bio-sensors. Finally, wireless networkability is necessary to share the monitored data with other systems and/or central repositories. Also, several networked sensors could be used together to increase the accuracy of one particular measurement.

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UWB technology offers transceivers and antennas of small size, low power consumption, and high data rate making it ideal for the envisioned sensor. For breath rate, HR and HRV, UWB radar sensing has been proved possible and meets the requirements of non invasiveness and contactless. On the other hand, UWB communications is maturing rapidly and making its way into the market. Therefore UWB technology seems suitable to come up with networkable biosensors that can be highly integrated, small and power efficient.

## II. Feasibility Study

As UWB communications technology matures, chipsets will start hitting the market. One such example comes form Time Domain's Corp. that has been offering its P210 UWB evaluation kit for some time. Another comes form Freescale Semiconductor [7], as well as many other companies. Common to all products is the fact that, to be commercially viable (at least in the USA for the moment), they must comply with the power emission mask ruled by the FCC in 2002 [8]. This mask imposes severe power emission restrictions which still allow for communications at significant rates but render radar sensing challenging particularly in high attenuation media.

This section aims to test if the power available from commercial UWB communications devices as regulated by the FCC is enough to perform radar sensing at a reasonable range (i.e. between 15 cm and 1 m).

### *A. Power budget of a monostatic radar based on a commercial UWB communications transceiver*

This example is based on the Time Domain's P210 UWB Evaluation Kit which has been on the market from quite some time already [6]. The objective is to check if this transceiver "as is" could be used for radar HR sensing.

The procedure is general because the power spectral mask is common to all manufacturers. Just by changing some manufacturer's specific parameters, the procedure could be applicable to any other Direct Sequence UWB (DS-UWB) chipset.

The P210 operates with the following specifications:

- Center frequency: $f \cong 4.7$ [GHz]
- Bandwidth: $B = 3.2$ [GHz] = 35.05 [dBMHz]
- Pulse Repetition Frequency: $PRF = 9.6$ [MHz]
- Raw data rate: $rb = 600$ [kbps]

The analysis that follows is done in the far field, however since the distances being considered are rather short with respect to $\lambda \approx 6.39$ [cm], only a full wave analysis could give a more reliable estimate.

In the far field, the fraction of power $P_i$ intercepted by the target is: $P_i = \frac{P_t \cdot G_t}{4\pi R^2} \cdot RCS$ ; where $G_t$ is the transmitting antenna gain and *RCS* is the radar cross-section of the target. The estimation of *RCS* requires special care, but for the sake of this approximate power budget, the following is assumed:

*"The heart is spherical and it behaves as an isotropic radiator sending back a spherical wave with the same polarization as the transmitted signal."*

The heart, in the adult, measures about 12 [cm] in length, 8 to 9 [cm] in breadth at the broadest part, and 6 [cm] in thickness [9]. Thus from the assumption made before, the target can be considered as a sphere of radius a = 6 [cm].

The radar cross-section is $RCS = | A_{tgt} \cdot \Gamma_{tgt} \cdot G_{tgt} |$; where $A_{tgt}$ is the area of the target, $\Gamma_{tgt}$ its reflectivity at the polarization of the radar's receiver antenna, and $G_{tgt}$ the antenna-like "gain" of the target [10]. The reflectivity $\Gamma_{tgt}$ will be considered later on in the attenuation as part of the path loss. The worst case $G_{tgt}$=1 is assumed. Following [10] procedure, $A_{tgt}$ cannot be taken directly as the optical cross-section because in this case the wavelength λ is not much smaller than the circumference 2πa. Using the *sphere RCS vs. frequency* chart depicted in [10], one gets $A_{tgt} = RCS = 1.47 \times 10^{-2}$ [m$^2$]. Therefore the fraction of the effective radiated power intercepted and backscattered by a target of spherical cross-section becomes $RCS/(4\pi R^2)$. Some amount of this power will be captured by the receiving antenna aperture $A_e = G_r \cdot \lambda^2/(4\pi)$ where the receiving and transmitting antenna gains are given the value $G_r = G_t = 0$ [dBi] as it is the usual practice for UWB communications systems.

So far the received power $P_r$ can be recast into a product of three factors:

$$P_r = (P_t G_t) \cdot \left[ \frac{RCS}{4\pi R^2} \right] \cdot \left\{ \frac{A_e}{4\pi R^2} \right\} \quad (1)$$

where:

$P_t$ Peak transmitted power.

$\left\{ \frac{A_e}{4\pi R^2} \right\}$ Fraction of the effective radiated power intercepted and backscattered by the heart assuming it has a spherical cross-section.

$\left[ \frac{RCS}{4\pi R^2} \right]$ Fraction of the resulting scattered power captured by the receiving aperture.

The expression (1) is basically the radar equation assuming a lossless propagation medium. $P_t$ is tied to the FCC's maximum average power density, that for the frequencies under consideration is PSD = -41.3 [dBm/MHz]. Thus the EIRP = -41.3 [dBm/MHz] + 35.05 [dBMHz] = -6.25 [dBm] or 237.2 [μW]. The pulse used by UWB transmission systems usually has the shape of some derivative of the Gaussian pulse, but for the sake of simplicity let's assume it is rectangular of duration τ ≈ 2 [ns] and repetition period $Ts = 1/PRF$. Under this assumption the average power is $P_{av} = \tau/Ts \cdot P_t$ and the peak power becomes:

$$P_t = \frac{Pav}{\tau \cdot PRF} = \frac{237.2 \times 10^{-6}}{2 \times 10^{-9} \cdot 9.6 \times 10^6} = 12.36 \text{ [mW]}$$

### B. Propagation loss

For the calculation it is assumed that the waves travel perpendicularly (normal incidence) to the planar interface formed by multiple strata of lossy media which represent the different layers of tissue that constitute the chest and the path from the skin to the heart. The thickness of each of these layers as approximated by [2] are given in Table I.

TABLE I
THICKNESS OF THE DIFFERENT LAYERS OF MEDIA ENCOUNTERED IN THE CHEST OF A PERSON ALONG THE PATH FROM THE SKIN TO THE HEART [2]

| Media Type | Thickness [cm] |
|---|---|
| Fat | 0.96 |
| Muscle | 1.35 |
| Cartilage | 1.16 |
| Lung | 0.578 |

Data from Gabriel et al. [3]-[5] at 4 [GHz] where used to compute the values of Table II. These values were used to model the total path loss L ≈ 71.79 [dB] depicted in Fig. 1.

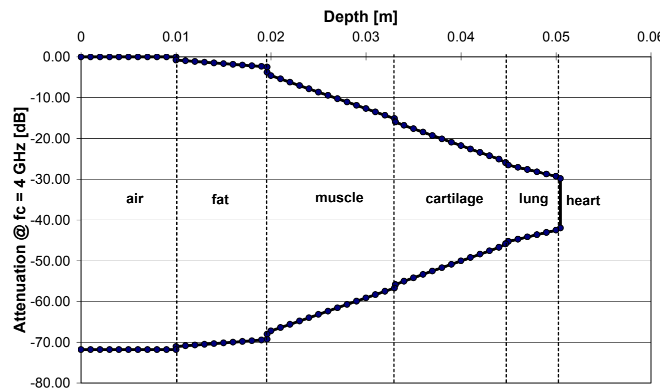


Fig. 1. Attenuation that would suffer a hypothetical pulse on its path from the transceiver antenna, located at a distance of 1cm from the skin, to the heart and bounce back, following the layout proposed in [2]

### C. The effect of noise

To estimate the maximum range $R_{max}$ beyond where the heart cannot be sensed, the received signal power $P_r$ in (1) must equate the minimum receiver sensitivity $P^r_{min}$. According to the theoretical curves *BER vs. Eb/N<sub>eff</sub>* for QFTM4 modulation given in [11]; for BER = $10^{-5}$ one gets $Eb/N_{eff}$ = 7.4 [dB]. By neglecting the interference from other sources the effective noise $N_{eff}$ becomes only thermal limited, thus:

$$P^r_{\min} = \frac{Eb}{No} \cdot \frac{1}{\kappa} \cdot kTo \cdot N_F \cdot rb \text{ [W]} \quad (2)$$

TABLE II
FIELD PARAMETERS, ATTENUATION, TRANSMISSION AND REFLECTION COEFFICIENTS FOR 4GHZ

| Media | σ | $\varepsilon_r$ | $(\sigma/\omega\varepsilon)^2$ | α | η | $\Gamma^b$ | $T^b$ | $\eta_1/\eta_2 * \lvert T^b \rvert^2$ | $T^b$ [dB] | $\eta_1/\eta_2 * \lvert T^b \rvert^2$ [dB] |
|---|---|---|---|---|---|---|---|---|---|---|
| air | 0.00 | 1.00 | 0.00 | 0.00 | 376.73 | | | | | |
| fat | 0.25 | 5.50 | 0.04 | 20.08 | 160.64 | -0.40 | 0.60 | 0.84 | -2.23 | -0.77 |
| Muscle | 3.50 | 50 | 0.10 | 93.24 | 53.28 | -0.50 | 0.50 | 0.75 | -3.03 | -1.26 |
| Cartilage | 3.00 | 35 | 0.15 | 95.52 | 63.68 | 0.09 | 1.09 | 0.99 | 0.37 | -0.03 |
| Lung | 1.50 | 20 | 0.11 | 63.18 | 84.24 | 0.14 | 1.14 | 0.98 | 0.57 | -0.08 |
| Heart | 4.00 | 55 | 0.11 | 101.60 | 50.80 | -0.25 | 0.75 | 0.94 | -1.24 | -0.27 |

σ: Conductivity of the medium [S/m]; $\varepsilon_r$: Relative Permittivity; ω = *2πf*: Frequency [rad/s]; α: Attenuation constant [1/m]; η: Intrinsic impedance [Ω]. Notice that the factor $(\sigma/\omega\varepsilon)^2$ is almost always << 1 which assures the validity of the approximations made for α and η where

- Implementation Loss $\kappa$ = -1 [dB] from reference [11]
- Thermal noise density $kTo$ ($k = 1.38\text{x}10^{-23}$ W/K·Hz, $T_o$=290 K)
- Receiver noise factor $N_F$ = 4.73 [dB] from reference [11]
- Transmission data rate $rb$ = 600 [kbps]

Replacing and computing $P^r_{min} \approx$ -103 [dBm]. Combining (1), (2) and L the $R$max becomes:

$$R\text{max}=\left(\frac{c^2}{64\pi^3}\cdot\frac{P_t}{P^r_{\min}}\cdot\frac{RCS}{f^2}\cdot\frac{1}{L}\right)^{\frac{1}{4}}$$

Replacing and computing $R\text{max} \approx$ 15 [cm]

This means that with this system, based on the Time Domain's UWB RF transceiver "as is", (i.e. without any further modification), one can be able to detect the heart at approximately 15 cm away and transmit the readings at 600 kbps, which is quite good for a contact-less sensor with the functions envisioned here. As such, the sensor would benefit from the small size, highly integrated electronics and antenna of the standard embodiment provided from factory. This will in turn make communications with peer sensors effortless, freeing the designer of this problem to concentrate on the signal processing and protocol functions needed to obtain a meaningful reading.

### *D. Possible improvements to increase range*

There is still room for improvement of range. Here are some possibilities:

- Transmitted power: On March 10, 2005 the FCC approved a waiver in which gated UWB systems can transmit at higher power levels and then sit quiet, as long as they still meet the same limits for average power density [12]. According to [12] DS-UWB system under the waiver provision can achieve up to four times better performance.
- Antenna Gain: Here it was assumed an isotropic unity gain transmitting/receiving antenna. This can also be manipulated to increase range as long as the *EIRP* is kept under the FCC limits. Care must be taken with directivity since this could affect the communication capabilities of the sensor with its neighbors.
- Data rate: Lowering the data rate reduces the noise power and thus increases the sensitivity $P^r_{min}$ which in turn increase the range.
- Frequency range: The FCC mask stipulate the frequency range $0 \le f \le 960$ MHz to have also a power spectral density of -41.3 [dBm/MHz]. These frequencies are less attenuated when penetrating human tissues, thus improving range. Maybe without much effort and by just introducing minor modifications (i.e. dynamically adjusting external circuits like the clock and output filters) the chipset can be made to work in these frequencies for radar sensing, clocking it back to 4 GHz for communications.
- Heart model: The assumption used to model the heart is clearly too coarse. An accurate model could probably offer better results hopefully increasing the range.

## III. Conclusion

The actual range is quite good but it would be nice to increase it to about 1 m because this would provide more flexibility to the application. Tweaking the parameters mentioned before seems to be an affordable and easy way to approximate to that objective. The solution is definitely not impossible because there were some prototypes that achieved sensing distances of 3 m [13]; 1 m behind a 20 cm thick brick wall or 5 m without obstacles [14]; and 0.1 to 3 m in [15]. However there are big differences between these systems and the one proposed here: First, they are not modulated, that is, they radiate the pulse in baseband, therefore including low frequency components that are less attenuated in tissues. Second, they use directional antennas, typically some kind of horn with gain > 1. Third, they were not thought to respect the FCC rules, thus they do not respect emission levels of the FCC and cannot be commercialized. Four, and the most important for the sake of this work, they do not provide communications capabilities, therefore they cannot be part of a sensor network, nor they can increase detection accuracy by processing multiple signals coming from nearby peer neighbors.

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