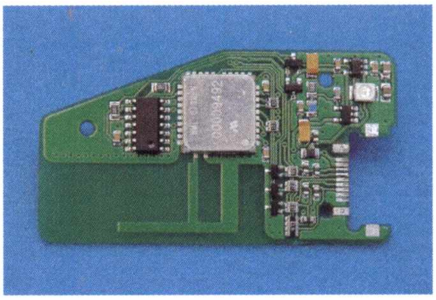
1 Introduction

The *BionicLinkModule* is used for cordless configuration and diagnosis of prosthetic devices. Using this module, it is possible to connect the artifical limb to the PC without cables. Potentially problematic connectors (corrosion due to human sweat) and the loss of impermeability of the prosthesis can be avoided this way.

It uses *Bluetooth®* technology, because this technology allows an easy connection to a PC a PDA or a similar device. These devices either must have Bluetooth functionality incorporated or have to use an external Bluetooth interface like a USB dongle or a Compact Flash- or PC-Card.



The *BionicLinkModule* is conceived as modular device, which can be permanently built into other products of Otto Bock.

The *BionicLinkModule* uses an onboard PCB antenna, to achieve a higher antenna efficiency compared to the wide spread ceramic antennas. The goal is to maximize the connection range without increasing the output power of the RF components. This avoids unnecessary spurious emissions and minimizes the power drain out of the battery of the prosthetic device.

2 Worst case scenario in respect of RF exposure

The worst case concerning specific absorption rate, would be the *BionicLinkModule* mounted below the inner surface of the plastic housing of the prosthesis and another body part touching the outer surface of the prosthesis. The following calculation will show, which mounting requirements mus be met, to fullfill the RF exposure requirements.

3 Calculation of possible power density

Input data:

- Alltough the BionicLink is used only under controlled conditions and on the peripheral parts of the extremities, we assumed that it has to comply with FCC Part 2, § 2.1093 (d)(2), i.e. 0.08 W/kg averaged over the whole body and 1.6 W/kg averaged over one gram of tissue.
- The maximum measured equivalent istropically radiated power (EIRP) is 1.71dBm.
- The average density of human tissue is ρ = 1.04 g/cm^3. Its conductivity is σ = 1.78 S/m at f = 2.45 GHz (acc. to [2] Appendix C).
- The minimum patient mass is 45kg.
- Calculation is done according to [1] and [2].
- The maximum dimension of the antenna is l_{ant} = 19 mm.

Calculation:

Averaging over whole body (average SAR):

$$EIRP = 1.71\ dBm = 1.48\ mW$$
$$EIRP / m = 1.48\ mW / 45\ kg = 22\ \mu W / kg << 0.08\ W / kg$$

Averaging over 1g of body tissue (peak SAR):

Fig. 1 shows 1g of body tissue of cubic shape. It absorbs the power of the incoming RF field partially.

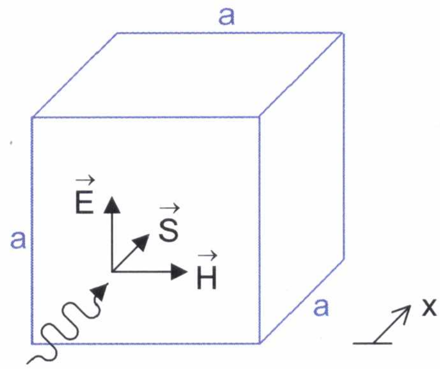


Fig.1 1g of body tissue absorbing an incoming RF field

The dimension of the cube can be calculated using the value for the average density of human tissue:

$$\rho = a^3 / 1\ g = 1.04\ g / cm^3 \Rightarrow a = 9.87\ mm$$

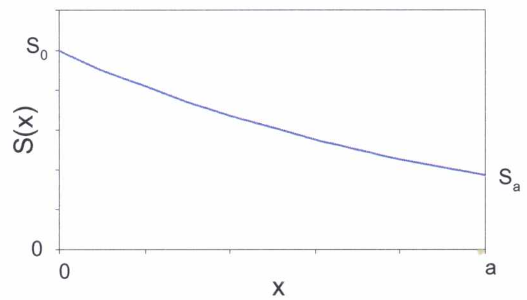


Fig. 2 Power flux density is decreasing inside the cube

The power flux density in the cube is decreasing exponentially (Fig.2) and the remaining value S(x = a) = S_a on the opposing side of the cube is:

$$S_a = S_0 \cdot e^{-2 \cdot a / \lambda_D} \quad \text{with} \quad \lambda_D = \sqrt{\frac{2}{2 \cdot \pi \cdot f \cdot \mu_0 \cdot \sigma}} = 7.62\ mm$$

The absorbed power in the cube and the resulting peak SAR can be calculated as follows:

$$P_{1g} = a^2 \cdot (S_0 - S_a) = a^2 \cdot S_0 \cdot (1 - e^{-2 \cdot a / \lambda_D}) \qquad SAR_{pk} = P_{1g} / 1\ g \le 1.6\ W / kg$$

So the maximum permissible absorbed power per 1g of tissue and the corresponding input power flux density S_{0max} are:

$$P_{1g\max} = 1.6\ mW \qquad S_{0\max} = 17.76\ W / m^2$$

The area surrounding an antenna can be devided into a reactive near field region, where the powerflux density reaches its maximum, an transition region where S(x) ist proportional to app. 1/x and a far field region where S(x) decreases with $1/x^2$.

The reactive near field of the antenna ends at a distance of:

$$d_{rnf} = 0.25 \cdot \frac{l_{ant}^2}{\lambda} = 0.73\ mm \quad \text{with} \quad \lambda = \frac{c_0}{f} = 123\ mm \quad \text{and} \quad \begin{array}{l} c_0 = 299792458\ m/s \\ f = 2450\ MHz \end{array}$$

The far field of the antenna where power flux changes with $1/x^2$ starts at:

$$d_{ff} = 2 \cdot \frac{l_{ant}^2}{\lambda} = 5.9\ mm$$

In the far field of the antenna power flux density can be calculated as follows:

$$S(x) = \frac{EIRP}{4 \cdot \pi \cdot x^2}$$

Calculating $S(x = d_{ff}) = 3.38\ W/m^2$ at the start of the far field region, it is clear, that the minimum permissible distance lies in the transition region. Because $1/x^2$ rises stronger for small values of x than 1/x, the far field behaviour can be used as a worst case estimation for the transition region. Using the values for S_{0max} and EIRP, we can calculate d_{min}:

$$d_{min} = \sqrt{\frac{EIRP}{4 \cdot \pi \cdot S_{0\max}}} = 2.57\ mm$$

Therfore we can define a minimum distance of 3mm between the upper side ob the printed circuit board and any human tissue to be sufficient to fullfill the SAR limits.

Conclusion:

It can be shown mathematically that even under worst case conditions the SAR will be lower than the limits stated in FCC Part 2, § 2.1093 (d)(2), when the BionicLinkModule is built into another product in such a way, that assures, that human tissue cannot get closer than 3mm above and below the printed circuit board.

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