# Project K0010

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| Document type | | Description | | Diagram | | Instruction |
| | | List | | Log | | Plan |
| | X | Report | | Request | | Specification |

Title: Evaluation of SAR test exclusion limits for Model J9P Type VJ955 (PJM) .
Date: 20/04/2021
File name: SAR_Analysis_j9p_vj955_rev02.doc
ID Doc: D00
Revision: 02
Author: G.Peserico and A. Bonan

**Revision History**

| Rev. | Date | Modification | | |
|---|---|---|---|---|
| | | Page | Section | Resume of modification |
| 01 | *13/04/2021* | 1 | 1:Abstract | Added reference to the fact that the system works only using Wi-fi at 2.4GHz |
| | | 1 | 1:Abstract | Correct value inserted in the table |
| | | 9 | 3.1: Autec system: Description | Added reference to the fact that the system works only using Wi-fi Iee802.11g-b at 2.4GHz |
| | | 10 | 3.1: Autec system: Description | Fixed the maximum value declared and added the references to the correct reports and documents |
| | | 14 | 4.2 Standalone SAR exclusion analysis for Autec radio | Fixed the maximum value declared and added the references to the correct reports and documents. Corrected the relative calculation. |
| | | 14-15 | 4.3 SAR test exclusion for simultaneous transmission | Fixed the maximum value declared and added the references to the correct reports and documents. Corrected the relative calculation. Calculation were done for 50 mm distance from body showing that the system ensures SAR test exclusion with quite smaller distances than the one imposed by the physics of the system |
| 02 | *20/04/2021* | footer | all | Removed confidential |
| | | 2 | Title | Added reference to FCC ID and IC |
| | | 3 | Abstract | Added reference to FCC ID and IC |
| | | 14 | 4.2 Standalone SAR exclusion analysis for Autec radio at 915MHz | Added reference to the ISED test report R20060201 |

| | Preparation | Check | Approval |
|---|---|---|---|
| Function | R&D Engineer | R&D Engineer | PM |
| Name | G.Peserico | A.Bonan | F.Masieri |



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# Evaluation of SAR test exclusion limits for Model J9P Type VJ955 (PJM).
# (Ref. : FCC ID: OQA-J9PVJ955
# IC: 9061A-J9PVJ955)

# Autec system concurrently operating radio at 915MHz for remote control functions and Wi-Fi link at 2.4GHz for video surveillance.






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# 1 Abstract

Scope of this analysis is to calculate the minimum distance from body sufficient to claim SAR test exclusion for a Model J9P Type VJ955 (PJM) Autec Transmitting Unit (which, for simplicity, will be called PJM in the following parts of the document) ( Ref. : FCC ID: OQA-J9PVJ955, IC: 9061A-J9PVJ955)

On the unit a COTS Wi-Fi module, that receives a video surveillance feedback, is operating concurrently along with an Autec proprietary 915MHz radio transmitter, used for remote control functions.

Firstly we present an analysis to identify the maximum theoretical duty cycle of a Wi-Fi system implementing Wi-fi and TCP, considering the peculiar communication parameter imposed by the Mikrotik wi-fi router used for sending data to the Wi-fi module inside PJM unit.

The analysis is done considering only Wi-fi using the 2.4GHz band, since the system configuration is imposed (and it is not accessible to the user) to Ieee802.11.b-g (which only provides this band)

This is done without considering any characteristics of the data stream used by the application; otherwise, the contribution of each layer of the stack is analyzed singularly and then combined in a final parameter.

At this point, the characteristics and structure of the complete Autec system, with its application- specific functions, are taken into account.

In particular, it is shown that the Wi-Fi module inside PJM unit is a “data sink” in the complete system and its transmission duty cycle at the physical layer is expected to be well below the maximum values estimated above for a generic node of a generic link.

A resume of the FCC constraints to assume SAR test exclusion analysis is also given.

Separate calculations of minimum distance from antenna to body parts are then shown for both the Wi-Fi module (sink device in the Wi-Fi link using the Mikrotik Router) and the Autec 915MHz radio transmitter (which performs the function of the remote control station)

Finally the two contributions are combined and the SAR exclusion limit for the complete PJM remote control station is shown, considering also where would be located the point giving the worst combination of exposure from the two sources.

With the following analysis it was found that the system is compliant to obtain the SAR text exclusion.

| | Minimum distance found to obtain the SAR test exclusion | Physical minimum distance in PJM unit | PASS or FAILED |
|---|---|---|---|
| Standalone SAR test exclusion for Wi-fi radio module, limb | 2.7 mm | 3,998 mm | PASS |
| Standalone SAR test exclusion for Wi-fi radio module, body | 6,8 mm | 132,635 mm | PASS |
| Standalone SAR test exclusion for Autec radio at 915MHz, limb | 3,56mm | 14,409 mm | PASS |
| Standalone SAR test exclusion for Autec radio at 915MHz, body | 8,91mm | 107,904 mm | PASS |

| | SAR test exclusion value [W/Kg] | Maximum value | PASS or FAILED |
|---|---|---|---|
| Simultaneous SAR test exclusion, limb | 0.37961 | 0.4 | PASS |
| Simultaneous SAR test exclusion, body | 0.1282 | 0.4 | PASS |



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# 2 Duty cycle constraints due to the  Wi-fi Standards

The following considerations are made to understand the IEEE802.11 (Wi-Fi) duty cycle.
Firstly it is introduced the general characteristics of all Wi-Fi system and then some additional considerations are made for a specific systema based on a  MiKrotik access point.

### 2.1 General considerations

IEEE802.11 (Wi-fi) is a standard protocol for the transmission of information in wireless system. It is figured out at the physical and data-link layer of ISO/OSI model.
It provides an Half-duplex transmission, CSMA/CA, use of feedback messages,  possibility of using different rate and modulations and  other characteristics.
Due to these features, it is not realistic to consider a continuous transmission for a single node of a wi-fi system.
In particular the half-duplex property is a strong constrain for the duty-cycle, since at every instant any node can alternatively  transmit or receive data. An acknowledge message is always needed to consider a  message as received; until the reception of this feedback message or until the time-out for its reception, there will be no further transmission.

Moreover, since the air medium is shared, also  the collision avoidance mechanism poses important constraints on  the duty cycle at the physical interface.
In particular this technique provides transmission of data only if the radio channel is sensed idle  for a  well defined period of time (DIFS+SIFS).
The mechanism to avoid collision also uses  an additional random time window which will further delay the physical transmission. This is thrown according to an uniformly distributed  random variable  related to the number of packet losses and/or collisions.

Clearly it is quite difficult to analyze the effect other devices in the network and to predict the probability of collisions from other networks in a real environment. But it is also clear that the maximum *continuous* transmit duty cycle of any node will be reached when no collision and no packet loss happen.

In appendix A can be found a table summarizing the transmission time for different signaling rates (according IEEE802.11b, IEEE802.11g) considering no collision and  no intervention of the “random time window” waiting  mechanism.
Times were calculated for packet  with payload of 1500 bytes , which being the maximum possible dimension it will require the longest transmission time in any condition.
Corresponding maximum achievable transmit  duty cycles are then estimated for a generic node in a Wi-fi system.

The results show that the duty cycle is inversely proportional to the baud rate.
It may range from  **78%**, when signaling at 54Mbps, to **97%** when the Baud rate is reduced to 1Mbps.


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## 2.2 MiKrotik Wi-fi implementation

It is possible to be perfectly compliant with the standards using many different real-time rate adaptation algorithms.
The MiKrotik system used by Autec is a specific implementation of a Wi-fi network, having its own rate adaptation algorithm, for which a description is available.
It's so possible to predict which rates will be used in stable condition, i.e. not only transiently and briefly during the assessment of the algorithm, in the absence of collisions.

This algorithm forces rate reduction after 3 consecutive packet losses, as well as it attempts to increase the rate after successful transmission of 3 consecutive frames.
Moreover in case of 3 consecutive losses at the lowest rate, it provides total stop of transmission for a time interval defined by the parameter "T_disconnect".

It is clear that in stable absence of losses and/or collisions, this type of algorithm will keep on with the maximum data rate (54Mbps), corresponding to a **maximum duty cycle 78%.**

Should any repetitive loss or collision occur, then the algorithm would be driven down to the minimum data rate, causing the duty cycle to rise to 97%.
But, if we assume this is a stable condition, very soon it will happen that three consecutive losses happen, thus causing total stop of transmission for T_disconnect second.
This will also reduce the maximum duty cycle to some intermediate value between 78 and 97%.

What happens precisely in the transitions between these two extreme situations, or with frequent (but not continuous) collision occurrences, can be left out.
In fact, this would only cause transitional and temporary operation at intermediate data rates/intermediate duty cycles. It will so have negligible impact on a time-integrated calculation like SAR.
Moreover, in those situations the system would have also to execute the standard requirements of waiting also for a random interval before re-transmitting, which would force the effective duty cycle significantly below the max value calculated under ideal conditions.


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## 2.3 Effect of the TCP protocol

The aforementioned considerations are valid for any generic Wi-Fi node.
But when we take into account also the specific data exchange protocol used in the network, it will be clear that not all nodes have the same privileges: some will show longer transmission intervals, other will be limited to very short responses.
In the analyzed system the TCP protocol is used.

TCP is a communication protocol at the transport ISO/OSI level. It can be transferred over wi-fi, which lays at a lower level.

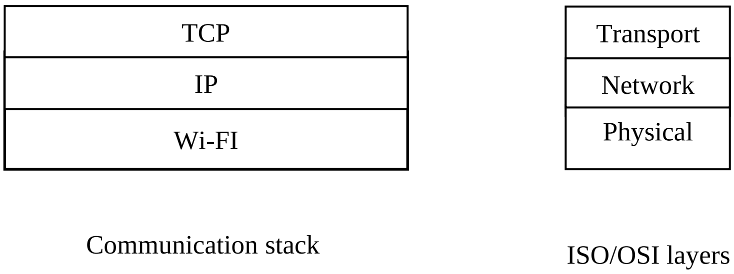


**Figure 2: communication stack of part implementing Wi-fi in ISO/OSI model**

Since the TCP protocol provides a point to point communication then it is possible to clearly identify a **SOURCE** device, which sends the main stream of data, and a **SINK** device, which transmits only acknowledgment packets after received data.
The impact of TCP on the transmission duty cycle depends on the way it uses acknowledgments: TCP specification allows to send an ACK packet every 65325 received bytes of information.
As intuitively understood but shown precisely in appendix B, this will have almost no effect on the SOURCE device
Instead, it will limit to 50% the theoretical transmit duty cycle of the SINK device, reaching this value when it is responding to the reception of empty data packets from the source.
The latter is clearly an unrealistic situation, or at least not useful.
Moreover, it must be considered that most implementations of the TCP protocol , as well as Mikrotik's (see appendix C), will send ACK back from the sink to the source every two or three data packets received, so the 50% value above mentioned will be in practice reduced to a lower value (25-33 %).


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## 2.4 Source and sink devices in a Mikrotik system using TCP on Wi-fi at 54Mbps

The combination of the two analyses must consider that the two stacks (WI-FI and TCP) are independent.

TCP will prepare its packets of N bytes to be sent.
The transmission of the TCP packets over Wi-Fi will had some overhead. As shown below, it will require a time window $T_{connectionWnd_{NbytePacket}}$ longer than the time $T_{NbytePacket}$ strictly needed to transmit N bytes at the same signaling rate:

$$T_{connectionWnd_{NbytePacket}} = DIFS + T_{NbytePacket} + SIFS + T_{wifi_{ack}}$$

Where $T_{wifi_{ack}}$ accounts for the (very short) length of the ACK responses used by wi-fi to confirm reception of every packet, which give a small contribution to the total transmission time

TCP will also expect to receive its standard acknowledgement messages, having a length of 20 bytes (TCP header only), after $N_{packetPerAck}$ packets have been received.
This TCP ack will also trigger a Wi-fi Ack of length $T_{wifi_{ack}}$, as happens for data packets.

The complete exchange will require a time window lasting $T_{connectionWnd}$, inside which both source and sink will be effectively transmitting RF power for a time $T_{effectiveTx}$, so that

$$duty_{cycle_{TCP}} = \frac{T_{effectiveTx}}{T_{connectionWnd}}$$

### A) SOURCE device

$$duty_{cycle_{TCP-SOURCE}} = \frac{T_{effectiveTxSource}}{T_{connectionWnd}} =$$

$$\frac{N_{packetPerAck} * T_{NbytePacket} + T_{wifi_{ack}}}{N_{packetPerAck} * T_{connectionWnd_{NbytePacket}} + T_{connectionWnd_{20bytePacket}}}$$

The maximum duty cycle is achieved when the source device continuously transmit packet of maximum size (1500 bytes, $Nbyte = 1500$) without considering loss and collision.
The worst case for TCP feedback is when it occurs "the least possible", that is every $\left\lceil \frac{65325}{1480} \right\rceil = 45\ packets\ \left(N_{packetPerAck} = 45\right)$
With this number the maximum theoretical duty cycle results:

$$duty_{cycle_{TCP-SOURCE}} = \frac{T_{effectiveTx}}{T_{connectionWnd}} = \frac{45 * 254 + 34}{45 * 326 + 105.1494} = \mathbf{78}\%$$

This is a rather extreme situation considered only for determining the worst case.
In appendix D some curves are drawn with varying parameters can be found; they may help understanding what happens in a range of more practical conditions.


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### B) SINK device

The SINK device send only acknowledgement packets during the connection window.
We expect $N_{packetPerAck}$ wi-fi acks and one TCP ack, that is a Wi-fi packet having N= 20 bytes.
The time dedicated for that transmission is composed by $N_{packetPerAck}$ time window for the transmission of source packet and one time window for the transmission of the feedback message.

$$@2) \quad duty_{cycle_{TCP-SINK}} = \frac{T_{effectiveTxSink}}{T_{connectionWnd}} =$$

$$= \frac{N_{packetPerAck} * T_{wifi_{ack}} + T_{20bytePacket}}{N_{packetPerAck} * T_{connectionWnd_{NbytePacket}} + T_{connectionWnd_{20bytePacket}}}$$

Since the transmission of a wi-fi ack is longer than the transmission of the minimum TCP packet (20bytes), the highest theoretical $T_{effectiveTxSink}$ is obtained when the number of packet before a TCP ack is at its maximum, corresponding to ($N_{packetPerAck} = 45$).

If we combine this with the shortest duration of $T_{connectionWnd}$ at the denominator, occurring when all the packets received from the source are empty (i.e. they contain only the 20bytes of the TCP header), we can estimate the max duty cycle possible for the sink:

$$duty_{cycle_{TCP-SINK}} = \frac{T_{effectiveTx}}{T_{connectionWnd}} = \frac{45 * 34 + 33.1494}{45 * 105.1494 + 105.1494} = \mathbf{32\%}$$

Even in this case we are studying the worst possible scenario.
But continuous transmission of empty packets by the source is not a realistic behavior for a useable application.
Please refer again to in Appendix D which shows more realistic estimates obtainable at more likely settings of the parameters.

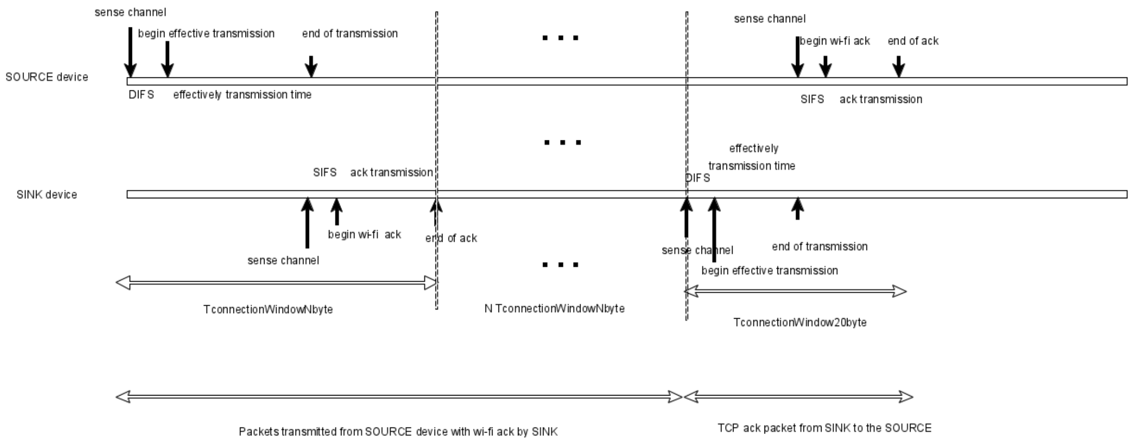


**Figure 3: temporal diagram of transmission**


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## 3. Autec system

It is now possible to take the whole Autec system (Figure 1) and its specific usage of Wi-Fi transmission, into consideration.

### 3.1 Description

The system is composed by:

- PJM control station, which includes both an Autec 915MHz FHSS radio for transmitting commands to a remotely controlled machine and a wi-fi module for receiving a video stream from a remote wi-fi access point
- Remote control base station, which receives the 915MHz signal and is remotely positioned on the machine, far from the operator, so it's out of interest in our SAR analysis
- A Wi-Fi access point from Mikrotik, physically connected via Ethernet to a videocameras. It is connected via wi-fi with a single client, namely the Wi-fi module included in the PJM control station. Like the remote control base station, the access point is positioned on the machine; so, it will not be considered for SAR analysis if not for its indirect effect on the duty cycle of the Wi-fi module placed on PJM unit. The access point is configured to use iee802.11b-g protocol, considering only Wi-fi using the 2.4GHz band. This system configuration is imposed and it is not accessible to the user.

The functioning is then based on two bidirectional data flows:

- The main Autec radio link is managed by PJM control station to the base station and its feedback path in the opposite direction.
- The Wi-fi network link is managed by the access point, using TCP data packets to send the video stream to the wi-fi module inside PJM control station part; the wi-fi module is then the sink of TCP packets and so it responds in the opposite direction with acknowledgment feedbacks only (Wi-fi and TCP).

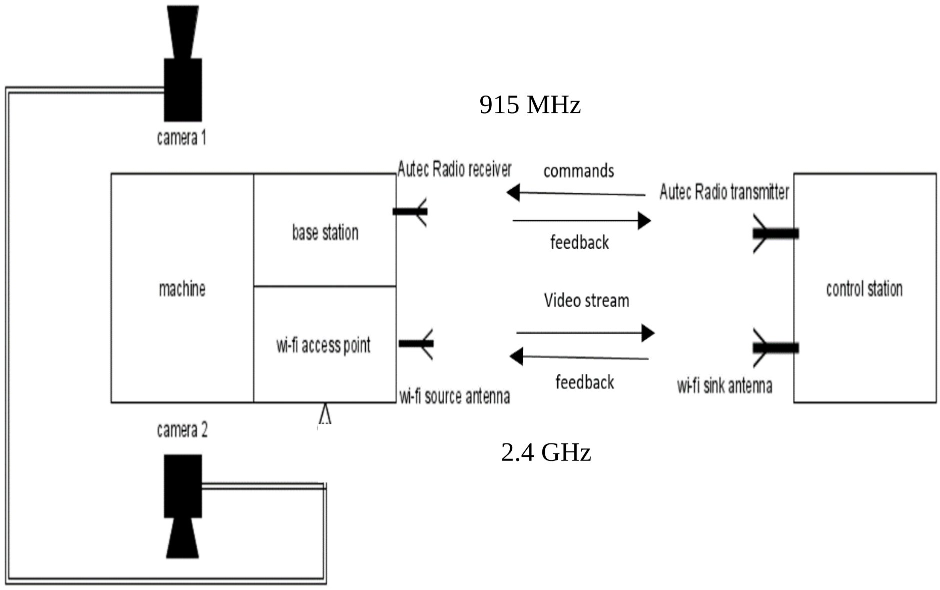


**Figure 4: complete system**



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As anticipated, we are interested to  SAR evaluation for the PJM unit only, because in it's normal usage it will be near to the operator's body for al long time, while other devices of the system that emit radio waves will be located at a distance from the operator.
Parameters of interest are maximum frequency of emissions, RF power, duty cyle.
For the 915 MHz transmission they are fixed and well known; measurements  from CMC, see report R20060101,  show fmax = 927.825 MHz. , RF Power = 41.69 mW measured at the connector, duty cycle = 42% . As a worst case, we'll consider also a 2 dB tune up tolerance, so we'll use a  max power  of 66mW in the calculations.
For the wi-fi  module, max frequency and power are dictated by radio European standards, so we'll consider the nominal values 2483.5MHz and 100mW.  This is the maximum allowed power for wi-fi in most countries. Actually, the module is expected to emit less power than  this, as  confirmed by the values reported in its FCC declaration (Grant XF6-RS9113SB DTS) and as declared in the module's data sheet (17dBm). Anyway, in  our calculations we'd prefer to use this value as  worst case, so as to obtain a more conservative estimation for  SAR test exclusion.
If we consider only  the arguments discussed in the previous sections for the SINK device,  we'd be pushed to use the "worst case" estimation of 32%
But, actually, we can demonstrate that in the specific application of the wi-fi and TCP protocols in Autec system a further (and lower) limit can be set to the maximum transmission duty cycle expected from the TCP SINK device  (implemented on the wi-fi module inside PJM unit).

First of all we must take into account that the access point (TCP SOURCE device) will collect  from the cameras  only data  packets of the maximum dimensions (1500 bytes).
Wi-fi parameters will be  factory set to avoid  aggregation or disaggregation of raw  data: this means TCP packets sent on wi-fi will keep their original dimensions.

Moreover  we need to  consider that the TCP  stack is configured by the SINK device to send acknowledgment  back every 2 TCP packets received.

Using  this further two constrains, due to the specific application and implementation, the theoretical upper bound of the duty cycle obtained with  the calculations of appendix D  falls to **about 13%**.

A further reduction can be expected also because the data stream coming  from the cameras will be less than 3 Mbps, which is only a small fraction of the throughput achievable with a continuous transmission at 54 Mbps rate.
For this reason the SOURCE device will not send continuously its packets,  and in turn the SINK device will reduce accordingly the occurrence of ACK packets.
A close form calculation of  this effect would be quite difficult, but it's reasonable to estimate that it will be close to reduce the actual SINK duty cycle to  3/54 of the theoretical value, meaning  an effective value **around 1%.**
This has been confirmed by experimental measurements, as shown in the next section

## 3.2 Experimental  measurement of transmission duty cycle of the wi-fi module inside PJM unit

The test set up can be seen  in Appendix D.
A complete system transmitting a typical video stream was set up and the  transmission power envelope of the Autec Wi-fi sink device was sniffed with a broad band power meter and sampled with an oscilloscope
A set of ten measurements (10s  and 10Msamples each) was recorded.
The duty cycle was then calculated as the ratio between number of samples "above trigger threshold" and total samples. Sampling time was chosen so as to be 10 times  shorter than the minimum duration of a transmission, so as to avoid any aliasing and to have a predictable relation between number of samples in a transmission and the estimated duration of the transmission itself. The results show that the values fall in the


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range [0.62-1.30] % in all measurements, while the mean value of all measurements was **0.88%**, which confirms the value of 1% roughly estimated in the previous section.

Here is an example showing the results obtained for the first measurement.

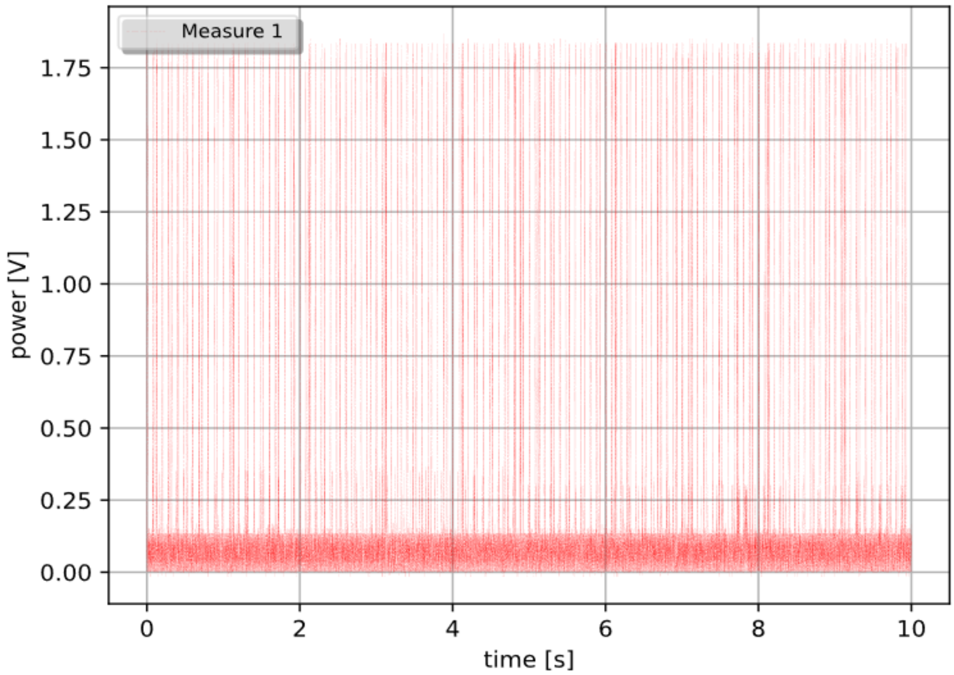


**Figure 3: sniffed Autec radio remote controller SINK device power, measure 1**

In this data set the RF power is measured higher than trigger threshold for a total of 842362 samples over 10.000.000, that is 0.0842362 s over 10s, so

$$dutycycle = \frac{transmissionTime}{totalMeasurementTime} = \frac{0.0842362}{10.0} * 100 = 0.84\ \%$$




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# 4 SAR exclusion analysis

In this section it will be verified if the Autec PJM portable unit described in section 3 satisfies the *SAR Test Exclusion Threshold* condition.

Please refer to FCC KDB document 447498 “RF EXPOSURE PROCEDURES AND EQUIPMENT AUTHORIZATION POLICIES FOR MOBILE AND PORTABLE DEVICES”, section “General SAR test exclusion guidance (4.3)”, subsection “Standalone SAR test exclusion considerations” (4.3.1, page 12).
There we read:
Given a system emitting radio signal, “ standalone 1-g head or body and 10-g extremity SAR evaluation for general population exposure conditions, by measurement or numerical simulation, is not required when the corresponding *SAR Test Exclusion Threshold* condition(s), listed below, is (are) satisfied.”

@3) $\frac{P_{max}}{d_{min}} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} < 7.5 \ with \ \ d_{min} \le 50mm \quad 10 - \text{g extremity SAR (limb)}$

$< 3 \ with \ \ d_{min} \le 50mm \quad 1 - \text{g extremity SAR (body)}$

While in same document, subsection “Simultaneous transmission SAR test exclusion considerations”, (4.3.2, page 13) we can find:

“Simultaneous transmission SAR test exclusion is determined for each operating configuration and exposure condition according to the *reported* standalone SAR of each applicable simultaneously transmitting antenna. When the sum of 1-g or 10-g SAR of all simultaneously transmitting antennas in an operating mode and exposure condition combination is within the SAR limit, SAR test exclusion applies to that simultaneous transmission configuration.”
“When an antenna qualifies for the standalone SAR test exclusion of 4.3.1 and also transmits simultaneously with other antennas, the standalone SAR value must be estimated according to the following to determine the simultaneous transmission SAR test exclusion criteria:”

@4) $SAR_{standalone,estimated} = \frac{P_{max}}{d_{min}} * \frac{\sqrt{F_{(GHz)}}}{x} * duty_{cycle_{max}} \qquad with \qquad d_{min} \le 50mm$

Using $x = 7.5$ for body and $x = 18.75$ for limb

For claiming simultaneous SAR test exclusion, the sum of the two antenna’s $SAR_{standalone,estimated}$ values shall be less than 0.4 [W/kg].

Specifically focusing on on the PJM control station, the above requirements imply to first discuss Standalone SAR test exclusion for both the Wi-fi radio module with its antenna and for the Autec 915MHz radio with its antenna.
Then simultaneous transmission from both antennas must be considered and the distance limits for exclusion of SAR testing can be calculated on the complete PJM control station.


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## 4.1 Standalone SAR exclusion calculation for the Wi-fi radio module

As pointed out, maximum frequency used by any wi-fi radio is 2.483 GHz, while maximum power will not exceed 100mW, which is a precautionary value, but which will be not ever reached as can be seen in the module FCC declaration.

For what regards duty cycle, we'll consider two extreme values: 13%, as calculated before for a generic Data Sink receiving packets of 1500bytes and responding with an ACK every 2 packets, and 1.3%, that is the max value experimentally measured.

The highest value will allow us to obtain a somewhat application independent evaluation, valid also if the video stream would saturate the throughput of the Wi-fi link

The lowest will give a more realistic view of the situation in practical scenarios.

By re arranging the formulas in @3, we obtain the minimum distance from Wi-fi antenna that justifies SAR test exclusion

for the worst case of Duty Cycle = 13%

$$d_{min,limb} > \frac{P_{max}}{7.5} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} = \frac{100}{7.5} * \sqrt{2.4835} * 0.13 = 2.7\ mm \quad \text{from limb}$$

$$d_{min,body} > \frac{P_{max}}{3} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} = \frac{100}{3} * \sqrt{2.4835} * 0.13 = 6.8\ mm \quad \text{from body}$$

for the realistic case of Duty Cycle = 1.3%

$$d_{min,limb} > \frac{P_{max}}{7.5} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} = \frac{100}{7.5} * \sqrt{2.4835} * 0.013 = 0.3\ mm \quad \text{from limb}$$

$$d_{min,body} > \frac{P_{max}}{3} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} = \frac{100}{3} * \sqrt{2.4835} * 0.013 = 0.7\ mm \quad \text{from body}$$

In appendix F we show that:
-the PJM portable unit is specified to be worn at waist with a dedicated belt

-the wi-fi antenna is located inside the plastic case at least 132,635 mm (≃ 132mm) from the case face leaning the operator's body

-its plastic walls are 3,998 mm thick,

Conclusion:
-with correct usage of the unit, the minimum distances will be always respected, even in the worst case of 13% duty cycle;

-if otherwise we consider the experimentally measured value of duty cycle, minimum distances will be still respected even with improper use by the operator.


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## 4.2 Standalone SAR exclusion analysis for Autec radio at 915MHz

We'll consider the values measured by CMC (Centro Misure Compatibilità S.r.l, independent test lab) and documented in FCC test report R20060101 and ISED test report R20060201, that is:

maximum frequency of 927.825MHz,

41.69 mW (measured at the connector), considering a tune up of 2 dB, it results a maximum transmission power of 66 mW

and the nominal duty cycle is of 0.42 according to Autec proprietary FHSS protocol specification.

With these parameters: :

$$d_{min,limb} > \frac{Pmax}{7.5} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} = \frac{66}{7.5} * \sqrt{0.928} * 0.42 = 3.56\ mm \quad from\ limb$$

$$d_{min,body} > \frac{Pmax}{3} * \sqrt{F_{(GHz)}} * duty_{cycle_{max}} = \frac{66}{3} * \sqrt{0.928} * 0.42 = 8.91\ mm \quad from\ body$$

As can be seen in appendix E, the minimum distance of the 915MHz antenna from the external faces of the plastic case is 107,904 mm (≃108mm), so the above distances will always exceeded in any usage condition, even if improper.

## 4.3 SAR test exclusion for simultaneous transmission

To obtain the simultaneous transmission SAR test exclusion for limb, it must be verified that :

$$SAR_{simultaneous,estimated}\ _{limb} = SAR_{standalone,estimated}\ _{Autec\,radio_{limb}} + SAR_{standalone,estimated}\ _{Wi-Fi_{limb}} < 0.4$$

Where $SAR_{standalone,estimated}\ _{Autec\,radio_{limb}}$ and $SAR_{standalone,estimated}\ _{Wi-Fi_{limb}}$ are calculated using @5) and x=18.75

Since the limb is composed by a vast tissue, it can not be summarized with a single point.
For this reason it is considered the case where the limb simultaneously touch the 2 maximum emission point for the two antennas. Considering the physical constraints of the system (see Appendix F) it results that for the wi-fi antenna $d_{min} = 3{,}998\ mm$ while for the Autec radio $d_{min} = 14{,}409mm$

$$SAR_{standalone,estimated}\ _{Wi-Fi_{limb}} = \frac{P_{max}}{d_{min}} * \frac{\sqrt{F_{(GHz)}}}{x_{limb}} * duty_{cycle} = \frac{100}{3{,}998} * \frac{\sqrt{2.483}}{18.75} * 0.13359 = 0.28081$$

$$SAR_{standalone,estimated}\ _{Autec\,radio_{limb}} = \frac{P_{max}}{d_{min}} * \frac{\sqrt{F_{(GHz)}}}{x_{limb}} * duty_{cycle} = \frac{66}{14{,}409} * \frac{\sqrt{0.928}}{18.75} * 0.42 = 0.0988$$



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And so it results:

$$SAR_{simultaneous,estimated\ limb} = SAR_{standalone,estimated\ Autec\,radio_{limb}} + SAR_{standalone,estimated\ Wi-Fi_{limb}} =$$

$$= 0.0988 + 0.28081 = 0.37961 < 0.4$$

And the simultaneous transmission test exclusion is achieved.

As seen in the previous paragraphs, the operator's body will normally stay at least 132mm far from wi-fi antenna and 108mm far from Autec radio 915MHz antenna, so the estimated simultaneous SAR for body can be expected to be negligible

Anyway, just for checking, here we give the calculation's results considering a distance of 50 mm, which ensures a smaller value also for bigger distances.

$$SAR_{simultaneous,estimated\ body} = SAR_{standalone,estimated\ Autec\,radio_{body}} + SAR_{standalone,estimated\ Wi-Fi_{body}} < 0.4$$

Where $SAR_{standalone,estimated\ Autec\,radio_{body}}$ and $SAR_{standalone,estimated\ Wi-Fi_{body}}$ are calculated using @5) and x=7.5

And specifically with $d_{min} = 100mm$ for both the antennas (due to the radio remote controller constraints), it results;

$$SAR_{standalone,estimated\ Wi-Fi_{body}} = \frac{P_{max}}{d_{min}} * \frac{\sqrt{F_{(GHz)}}}{x_{body}} * duty_{cycle} = \frac{100}{50} * \frac{\sqrt{2.483}}{7.5} * 0.13359 = 0.0561$$

$$SAR_{standalone,estimated\ Autec\,radio_{body}} = \frac{P_{max}}{d_{min}} * \frac{\sqrt{F_{(GHz)}}}{x_{body}} * duty_{cycle} = \frac{66}{50} * \frac{\sqrt{0.928}}{7.5} * 0.42 = 0.0712$$

$$V_{exclusionSARbody} = V_{exclusionSARbody_{AutecRadio}} + V_{exclusionSAR\ body_{Wi-fi}} =$$

$$= 0.0561 + 0.0712 = 0.1282 < 0.4$$

# Conclusion

From the above analysis it results that the Autec Radio Remote controller is compliant to claim the SAR test exclusion for limb and body , both for standalone or simultaneous emission of the two radios, given the minimum distances warranted by its physical construction and the constraints to its wi-fi emission due to the specific application.
Correct wearing of the unit will anyway ensure that body SAR limits will never be exceeded, even without taking any application-specific constraint into consideration.



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## Appendix A: maximum Ton time and physical level duty cycle for a generic Wi-Fi node transmitting packets 1500 bytes long

| | DATA | 1 MBps | | | 2 MBps | | |
|---|---|---|---|---|---|---|---|
| | | Bitrate | Length(bits) | Time(μs) | Bitrate | Length(bits) | Time(μs) |
| | DIFS | | | 50 | | | 50 |
| D A T A | PHY header: PLCP preamble | 1 | 144 | 144 | 1 | 72 | 72 |
| | PHY header: PLCP header | 1 | 48 | 48 | 2 | 48 | 24 |
| | MAC headers (28 bytes) + MAC body | 1 | 12224 | 12224 | 2 | 12224 | 6112 |
| Effective Transmission time | | | | 12416 | | | 6208 |
| | SIFS | | | 10 | | | 10 |
| A C K | PHY header: PLCP preamble | 1 | 144 | 144 | 1 | 72 | 72 |
| | PHY header: PLCP header | 1 | 48 | 48 | 2 | 48 | 24 |
| | MAC headers (28 bytes), no MAC body | 1 | 112 | 112 | 2 | 112 | 56 |
| Total window for transmission | | | | 12780 | | | 6420 |
| Effective Transmission time over total window | | = 0.9715 | | | = 0.9669 | | |
| | DATA | 5.5 MBps | | | 11 MBps | | |
| | | Bitrate | Length(bits) | Time(μs) | Bitrate | Length(bits) | Time(μs) |
| | DIFS | | | 50 | | | 50 |
| D A T A | PHY header: PLCP preamble | 1 | 72 | 72 | 1 | 72 | 72 |
| | PHY header: PLCP header | 2 | 48 | 24 | 2 | 48 | 24 |
| | MAC headers (28 bytes) + MAC body | 5.5 | 12224 | 2223 | 11 | 12224 | 1111 |
| Effective Transmission time | | | | 2319 | | | 1207 |
| | SIFS | | | 10 | | | 10 |
| A C K | PHY header: PLCP preamble | 1 | 144 | 72 | 1 | 72 | 72 |
| | PHY header: PLCP header | 2 | 48 | 24 | 2 | 48 | 24 |
| | MAC headers (28 bytes), no MAC body | 5.5 | 112 | 21 | 11 | 112 | 11 |
| Total window for transmission | | | | 2496 | | | 1374 |
| Effective Transmission time over total window | | = 0.9291 | | | = 0.8785 | | |


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| | DATA | 6 MBps | | | 9 MBps | | |
|---|---|---|---|---|---|---|---|
| | | Bitrate | Length(bits) | Time(µs) | Bitrate | Length(bits) | Time(µs) |
| | DIFS | | | 28 | | | 28 |
| D A T A | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes) + MAC body | 6 | 12246 | 2044 | 9 | 12246 | 1364 |
| | signal extension time | - | - | 6 | - | - | 6 |
| Effective Transmission time | | | | 2070 | | | 1390 |
| | SIFS | | | 10 | | | 10 |
| A C K | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes), no MAC body | 6 | 134 | 24 | 6 | 134 | 24 |
| | signal extension time | - | - | 6 | - | - | 6 |
| Total window for transmission | | | | 2158 | | | 1478 |
| Effective Transmission time over total window | | = 0.9590 | | | = 0.9405 | | |
| | DATA | 12 MBps | | | 18 MBps | | |
| | | Bitrate | Length(bits) | Time(µs) | Bitrate | Length(bits) | Time(µs) |
| | DIFS | | | 28 | | | 28 |
| D A T A | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes) + MAC body | 12 | 12246 | 1024 | 18 | 12246 | 684 |
| | signal extension time | - | - | 6 | - | - | 6 |
| Effective Transmission time | | | | 1050 | | | 710 |
| | SIFS | | | 10 | | | 10 |
| A C K | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes), no MAC body | 12 | 134 | 12 | 12 | 134 | 12 |
| | signal extension time | - | - | 6 | - | - | 6 |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total window for transmission | | | | 1126 | | | 786 |
| Effective Transmission time over total window | | = 0.9325 | | | = 0.9033 | | |
| | **DATA** | **24 MBps** | | | **36 MBps** | | |
| | | **Bitrate** | **Length(bits)** | **Time(μs)** | **Bitrate** | **Length(bits)** | **Time(μs)** |
| | DIFS | | | 28 | | | 28 |
| D A T A | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes) + MAC body | 24 | 12246 | 512 | 36 | 12246 | 344 |
| | signal extension time | - | - | 6 | - | - | 6 |
| Effective Transmission time | | | | 538 | | | 370 |
| | SIFS | | | 10 | | | 10 |
| A C K | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes), no MAC body | 24 | 134 | 8 | 24 | 134 | 8 |
| | signal extension time | - | - | 6 | - | - | 6 |
| Total window for transmission | | | | 610 | | | 442 |
| Effective Transmission time over total window | | = 0.8819 | | | = 0.8371 | | |
| | **DATA** | **48 MBps** | | | **54 MBps** | | |
| | | **Bitrate** | **Length(bits)** | **Time(μs)** | **Bitrate** | **Length(bits)** | **Time(μs)** |
| | DIFS | | | 28 | | | 28 |
| D A T A | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers (28 bytes) + MAC body | 48 | 12246 | 256 | 54 | 12246 | 228 |
| | signal extension time | - | - | 6 | - | - | 6 |
| Effective Transmission time | | | | 282 | | | 254 |
| | SIFS | | | 10 | | | 10 |
| A C K | PHY header: PLCP preamble | - | - | 16 | - | - | 16 |
| | PHY header: PLCP header | 6 | 24 | 4 | 6 | 24 | 4 |
| | MAC headers | 24 | 134 | 8 | 24 | 134 | 8 |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | (28 bytes), no MAC body | | | | | | |
| | signal extension time | - | - | 6 | - | - | 6 |
| Total window for transmission | | | | 354 | | | 326 |
| Effective Transmission time over total window | | = 0.7966 | | | = 0.7791 | | |


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# Appendix B: theoretical effect of TCP on duty cycle

### *A) For the SOURCE device*

The maximum duty cycle is achieved when the source continuously send its message and it receives the minimum possible number of ack.
Supposing to have an half duplex medium, it results that transmitting an ack every 65325 byte, the duty cycle is of:

$$duty_{cycle_{TCP-SOURCE}} = \frac{N_{TCP_{ack}} * \left\lceil \frac{65325}{NbytePerPack} \right\rceil + 65325}{N_{TCP_{ack}} * \left\lceil \frac{65325}{NbytePerPack} \right\rceil + 65325 + N_{TCP_{ack}}}$$

Since the TCP has a minimum header of 20 bytes, considering to have a packet with payload of 1500 bytes (and so of 1480 bytes TCP payload), it results

$$duty_{cycle_{TCP-SOURCE}} = \frac{20 * \left\lceil \frac{65325}{1480} \right\rceil + 65325}{20 * \left\lceil \frac{65325}{1480} \right\rceil + 65325 + 20} = 0.999698$$

It is clear that the impact of TCP over maximum duty cycle of the SOURCE is not relevant. Anyway, since it is not common to have an ack every 65325 byte, but it is more common to have an ack every 2/3 packets (also since with an ack every 65325 bytes it is too common to have retransmission). Some additional details are proposed in the appendix A, where the analysis of a WI-Fi+ TCP system varying the number of byte for packet and the number of packet before an ack is presented.

### *B) For the SINK device*

The sink device only acknowledges the packet received. This device reaches its maximum duty cycle when it has to send a feedback message to each received packet and specifically when the received packet are of the minimum size possible (and so their transmission time is minimum).
Supposing to have an half duplex medium, transmitting an ack every packet and receiving packet of minimum size (only TCP header), then the duty cycle results:

$$duty_{cycle_{TCP-SINK}} = \frac{N_{TCP_{ack}}}{N_{TCP_{ack}} + N_{TCP_{pack\,null\,payload}}} = \frac{20}{20+20} = 0.5$$

It is clear that a sink device that only acknowledge message, only implementing TCP reaches a maximum duty cycle of 0.5.


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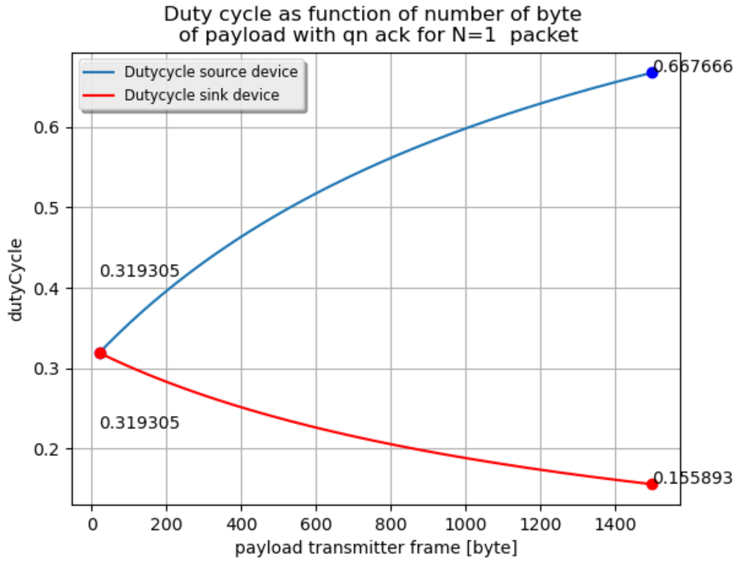
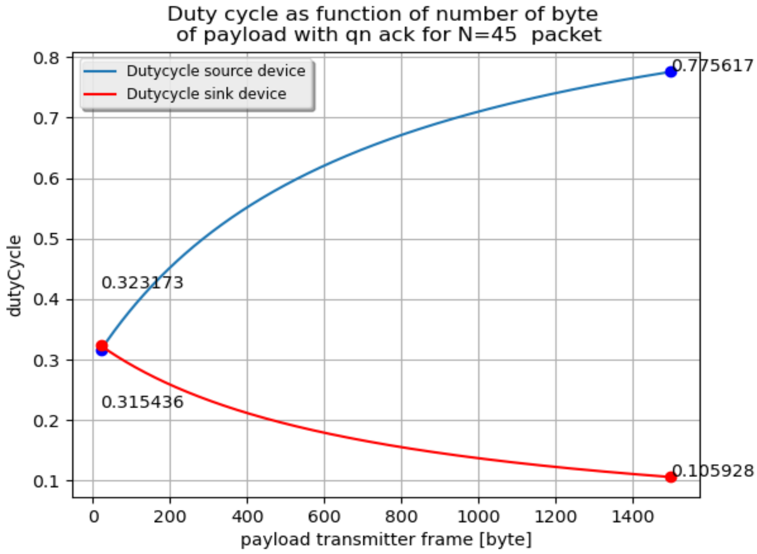
## Appendix C: MiKrotik with TCP duty cycle as function of $N_{byte}$ and $N_{packetPerAck}$

In this appendix some results are reported to show that the proposed maximum duty cycle are correct .
These results are moreover reported to highlight the fact that in normal condition the duty cycle is commonly very smaller.
Given the general formulation @1) for the calculation of duty cycle for SOURCE and the general formulation @2) for the calculation of duty cycle for SINK, in this appendix the results obtained varying the parameter $N_{packetPerAck}$ and $Nbyte$ are presented.
In particular:

- Duty cycle as function of $N_{byte}$ with $N_{packetPerAck} = 1$




- Duty cycle as function of $N_{byte}$ with $N_{packetPerAck} = 45$







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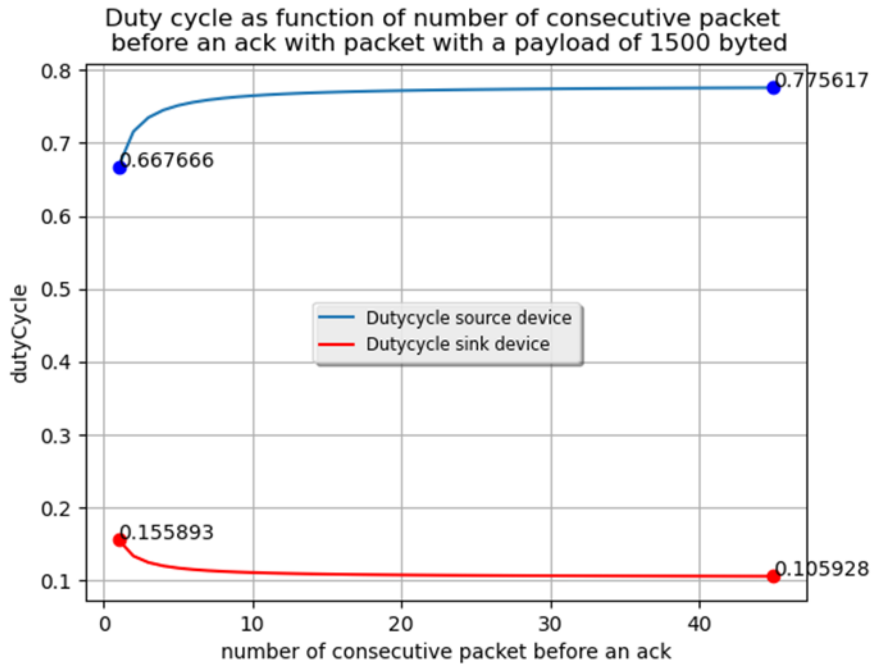
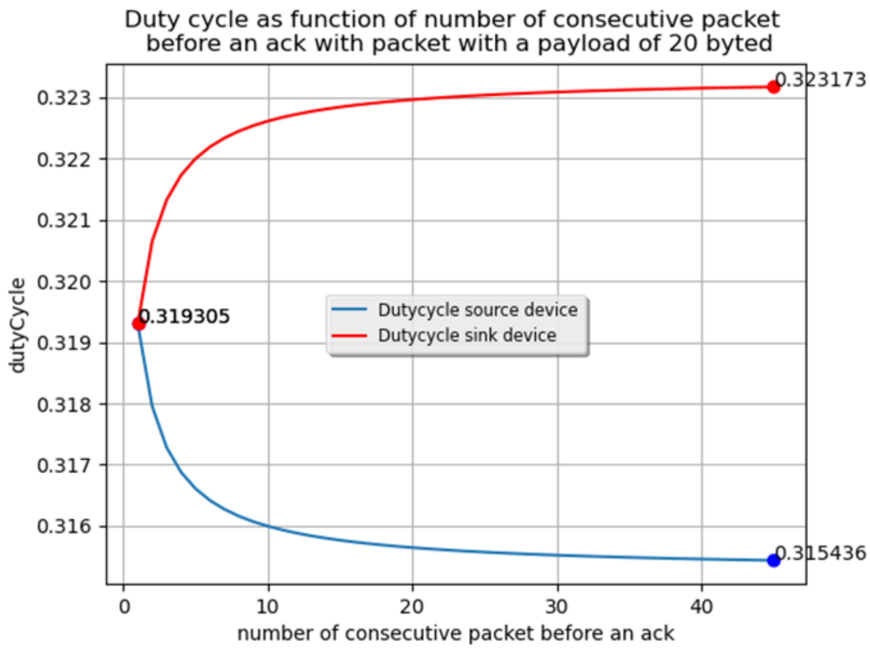
- Duty cycle as function of $N_{packetPerAck}$ with $N_{byte} = 1500$




-

- Duty cycle as function of $N_{packetPerAck}$ with $N_{byte} = 20$







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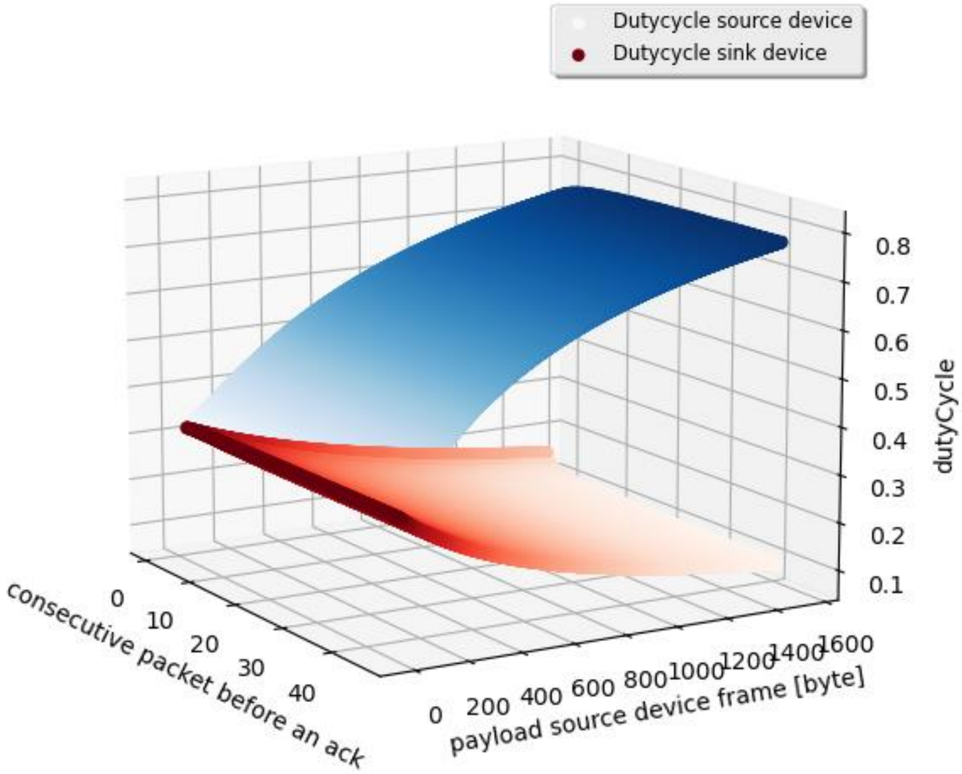
- Duty cycle as function of $N_{packetPerAck}$ and of $N_{byte}$





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## Appendix D: test bench description.

In this appendix the test set to obtain the duty cycle and its working principle is presented.
The test set was composed by the radio remote controller containing the Wi-Fi SINK device, a power detector, a passband filter, an attenuator, the access point and an oscilloscope.
The power detector was used to measure the effective transmission power, which was visualized through the oscilloscope. Specifically the power detector was conducted linked to the Wi-Fi SINK antenna, in such way it was possible to correctly measure the out power. Moreover to measure only the signal of interest (frequency between 2.4-2.5GHz), a passband filter was used. Also an attenuator was used to keep the signal in the linear characteristic of the power detector.
Finally the access point was set up with an attenuated antenna to avoid to sniff its transmission power.
The scheme of the complete working system is presented in figure B.1, while the photos of the system are presented in figure B.2-7

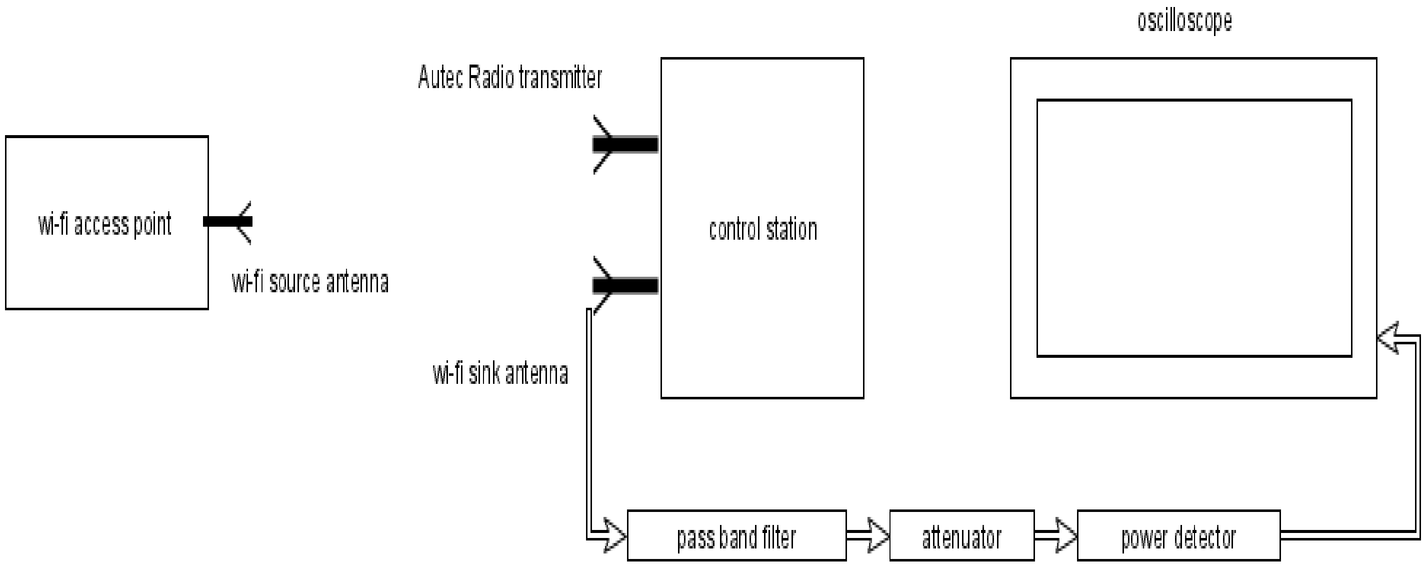


**Figure D.1: scheme of the measurement test set**


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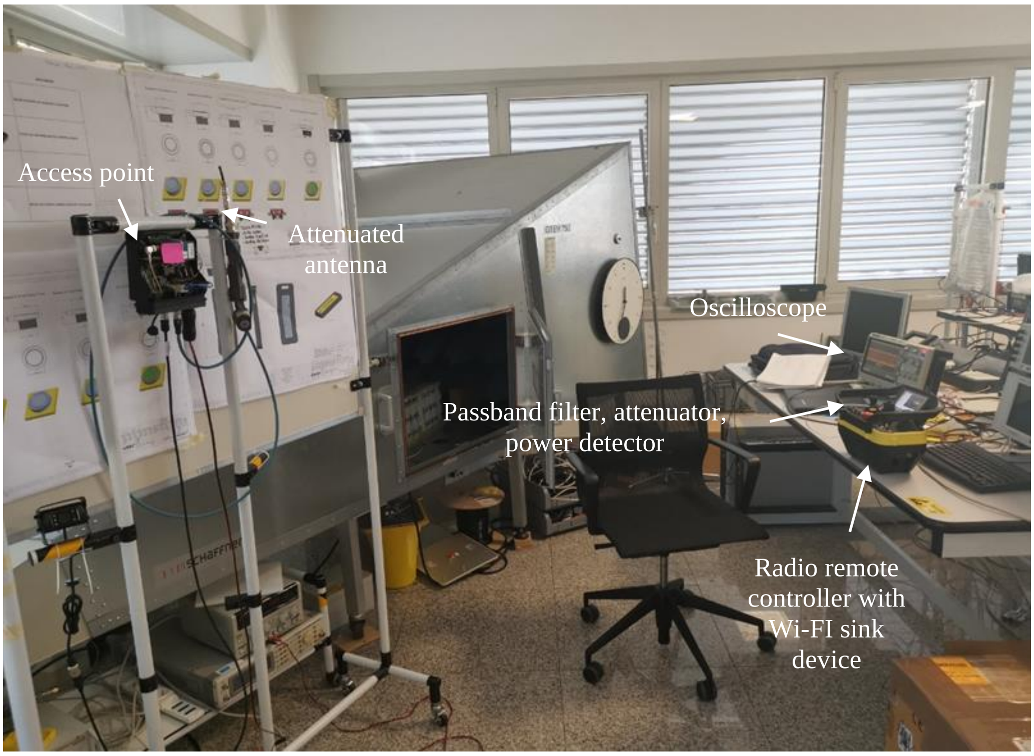


**Figure D.2: complete testbed set up**


**Figure D.3: Radio Remote Controller with Wi-Fi Sink with passband filter**


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**Figure D.4: oscilloscope, Radio Remote Controller with Wi-Fi Sink , attenuator and power detector**


**Figure D.5: further details of radio remote controller and the passband filter**


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Once sampled the SINK device transmission power with the described measurement system, 10 measure sets were created exporting the samples in csv file. Each of them contains the time and the sniffed power for 10 s. Every set was plotted through Python and then it was calculated the relative total transmission time. Specifically this data was calculated summing the different period where the sniffed power was bigger than a threshold, avoiding to consider the noise.
Finally the duty cycle was calculated as the ratio between the calculated time and the total measurement time (which coincides with 10s):

$$dutycycle = \frac{transmissionTime}{totalMeasurementTime}$$


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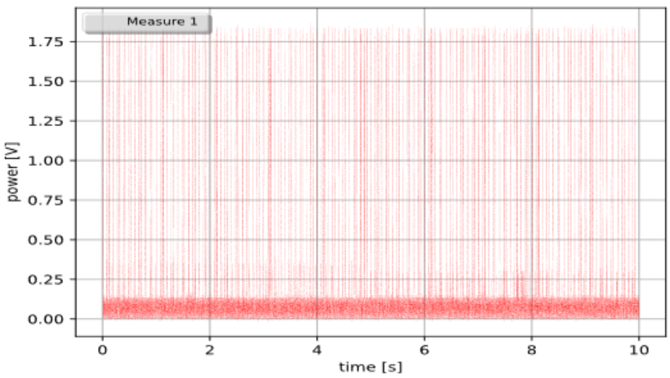
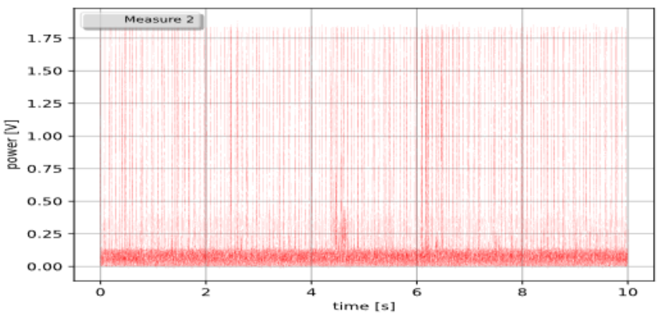
# Appendix E: duty cycle measurement results.

The following results were found:
-measurement set 1:



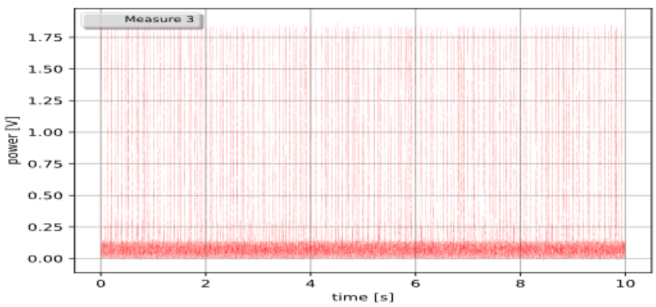

duty cycle: 0.84236%

-measurement set 2:



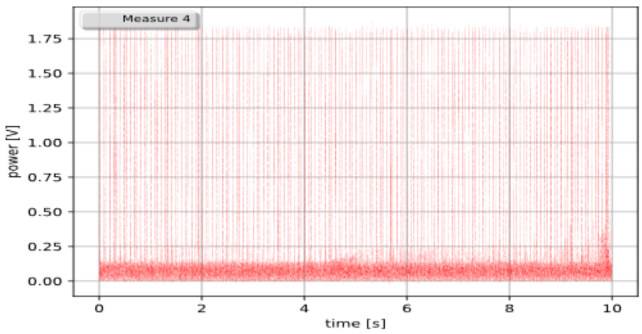

duty cycle: 0.97416%

-measurement set 3:




duty cycle: 0.90900 %

-measurement set 4:




duty cycle: 1.10614%



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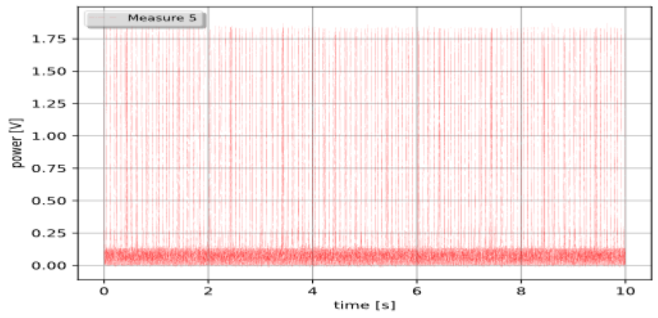
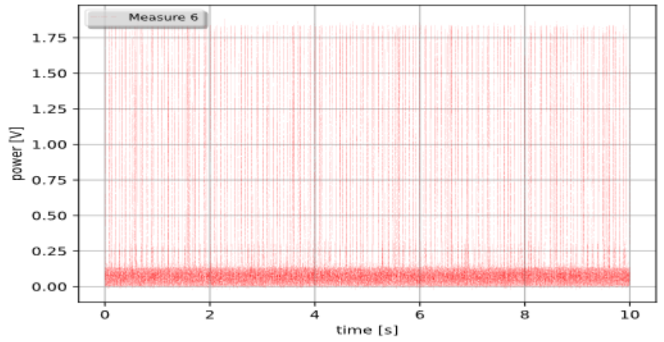
-measurement set 5:



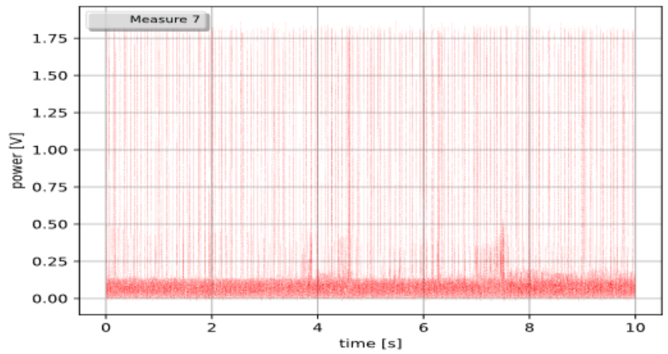

duty cycle: 0.96313%

-measurement set 6:



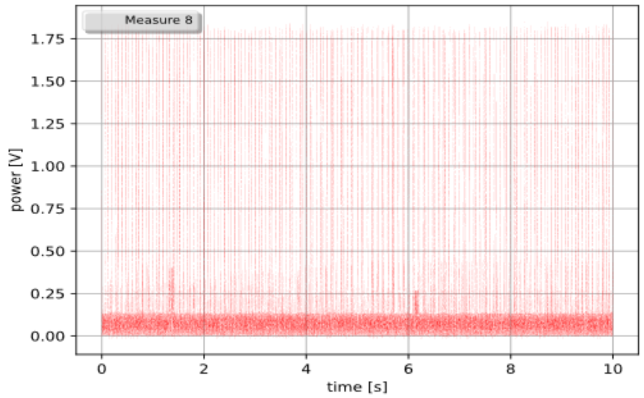

duty cycle: 0.79686%

-measurement set 7:




duty cycle: 0.70359%

-measurement set 8:




duty cycle: 0.62472%



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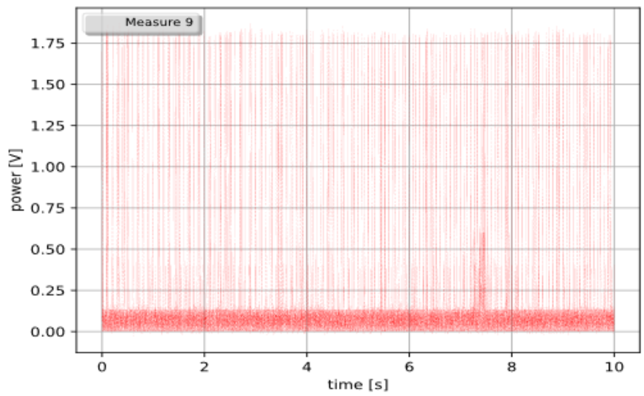
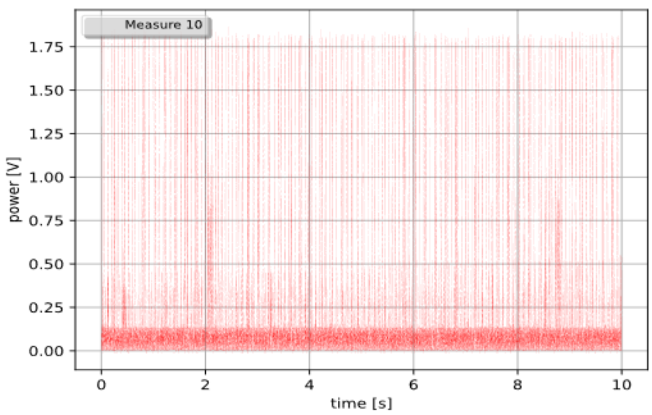
-measurement set 9:




duty cycle: 0.68689%

-measurement set 10:




duty cycle: 1.30120%

Mean duty cycle: 0.89%



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# Appendix F: physical system constraints

In this appendix is presented the PJM portable unit and its physical constraints.
The design of the unit is presented in the following image (Figure: F.1).


**Figure F.1: model of PJM unit**

From the following figures (Figure: F.2-F.3) it is possible to appreciate the minimum distance of the body (**132,635mm**) and of the limb from the wi-fi antenna (**3,998mm**).

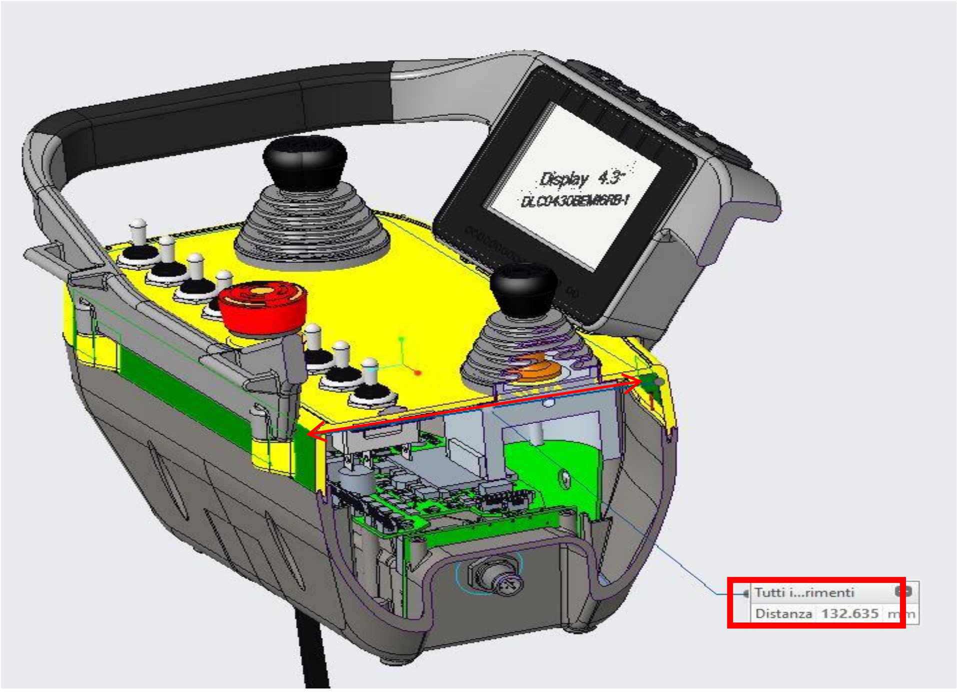


**Figure F.2: The PJM unit model: minimum distance of body from Wi-fi antenna**


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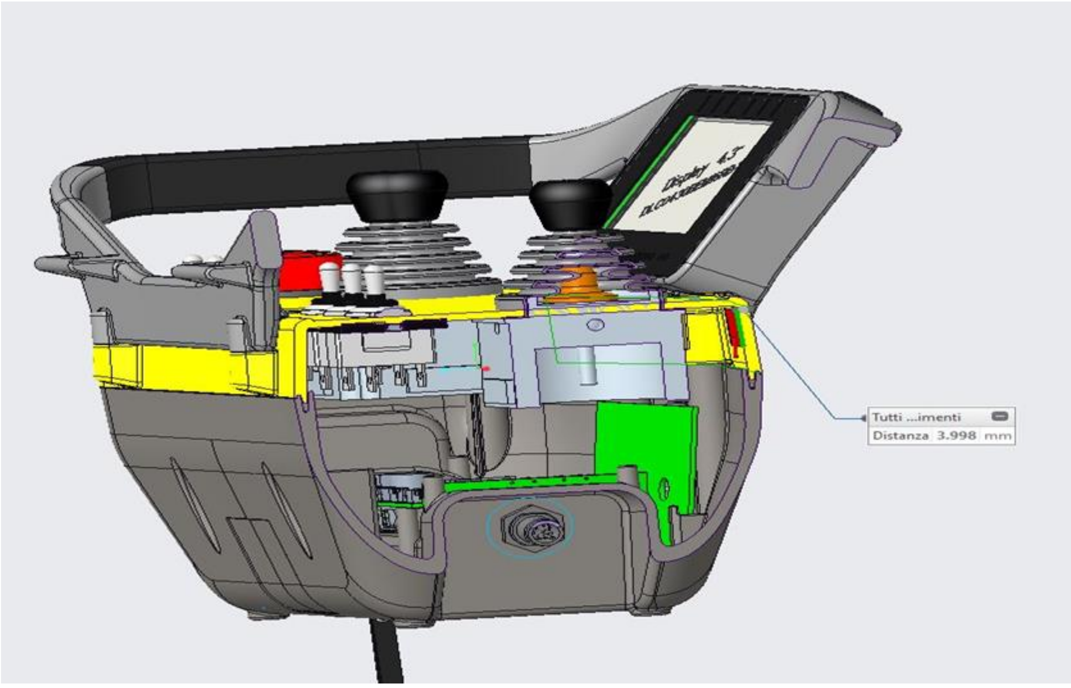


**Figure F.3: The PJM unit model: minimum distance of limb from Wi-fi antenna**

Instead from the following figures (Figure: F.4-F.5) it is possible to appreciate the minimum distance of the body(**107,904mm**) and of the limb (**14,409mm**) from the Autec radio antenna at 915MHz.

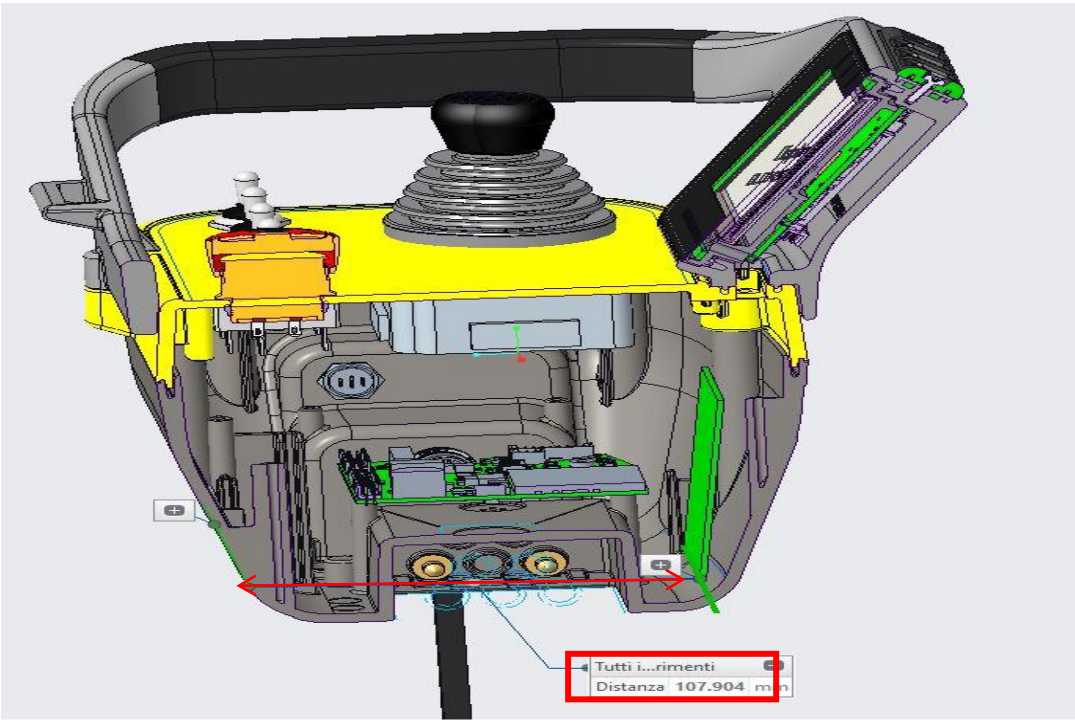


**Figure F.4: The PJM unit model: minimum distance of body from Autec radio 915MHz antenna**


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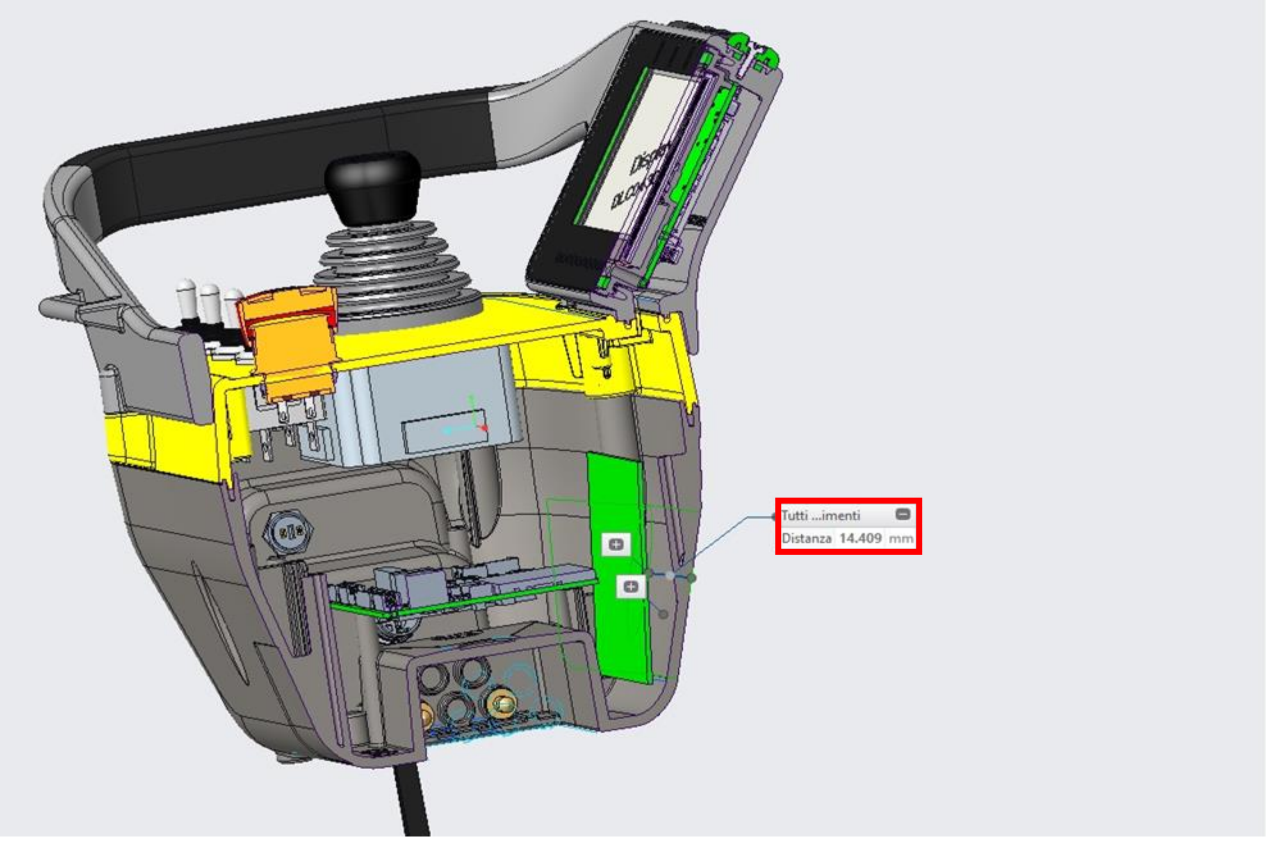


**Figure F.5: The PJM unit model: minimum distance of limb from Autec radio 915MHz antenna**

Furthermore from the following figures it is possible to appreciate how the PJM unit is used and why the presented measures are the minimum ones for body and limbs. Moreover it is possible to notice how the presented distances of limb are calculated for the worst case of use, which is quite far from a realistic use of the unit. Indeed the correct and common use of the unit s presented in figure.


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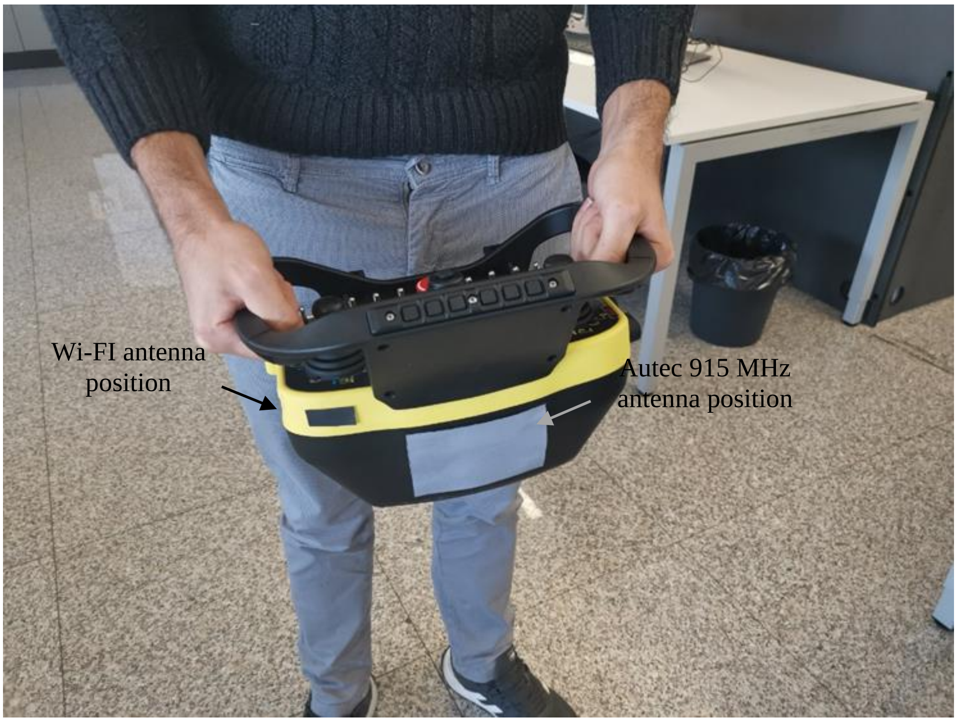


**Figure F.6: Correct working position using PJM unit, front view**

**Figure F.7: Correct working position using PJM unit, lateral view**

**Figure F.8: Worst case working position for limb using PJM unit, front view**

**Figure F.9: Worst case working position for limb using PJM unit, lateral view**



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**Figure F.10: Correct working position using PJM unit with belt, front view**

**Figure F.11: Correct working position using PJM unit with belt, lateral view**



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**Figure F.12: Correct working position using PJM unit with belt  and with hand on the unit, lateral view**

**Figure F.13: Correct working position using PJM unit with belt  and with hand on the unit, front view**



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**Figure F.14: Correct working position using PJM unit with belt  and with hand on the unit (with additional details about the internal positions of antennas), front view**



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