Application Note

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System Considerations for Short Range RF Devices

By Laurent GAUTHIER
Access and Remote Control
Toulouse, France

Introduction

This application note presents some considerations concerning Short Range Devices (SRD) at a system level. These allow sizing a system for a given level of performance.

System Overview

A system using an RF link should be designed by keeping in mind the level of performance it should meet. Range is affected by the power of the transmitter, the sensitivity of the receiver, the efficiency of the antennas at both sides and the nature of the field itself.

Before beginning any design, some basic calculations can be done to evaluate if the required performances are possible with the available components. Once every system parameter is validated, it is then possible to begin the design of the electronic parts. If the calculation shows some limits, it is not realistic to imagine that the system will work.

Due to the complex nature of the propagation in a real field, some final field measurements should validate the system. A reasonable margin taken during the design will improve the reliability of the RF link.

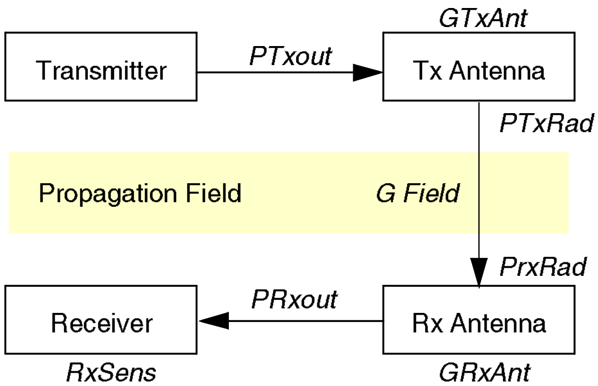
System Description

From a system point of view, an SRD application[1] can be seen as:

- the transmitter delivers a power PTxout to the Tx antenna
- the Tx antenna radiates a power PTxRad
- the propagation field attenuates the radiated power
- the Rx antenna receives a power PRxRad
- the receiver receives a power PRxin

The parameters[2] of the system are:

- System
  - F: frequency of operation expressed in MHz
- Transmitter:
  - Ptxout: the output power expressed in dBm[3]
  - GTxAnt: the gain of the antenna expressed in dB[4]
- Propagation field:
  - D: distance between the Tx antenna and the Rx antenna expressed in metres
  - GField: path attenuation, a function of D, F and the field itself
- Receiver:
  - GrxAnt: the gain of the antenna expressed in dB
  - RxSens: the minimum signal power the receiver can process



1. SRD applications include remote control and data communications.
2. All the “gain” and “attenuation” parameters have the same meaning: a positive value means some gain, and a negative value means some attenuation, whatever the parameter is called “Gain”, “Attenuation”, “Margin” or “Loss”.
3. The dBm is a logarithmic power unit relative to a milliwatt: PdBm = 10.Log(P), with P expressed in mW.
4. A gain expressed in dB (A dB) can be calculated with the scalar gain (A): A dB = 10.Log(A)

Field Attenuation

The field attenuation increases with the distance D and the frequency F. It also depends on the field itself. Some objects around the line of RF transmission can have great influence, because they can reflect the signal, and the receiver will see the sum of the direct wave and many reflected ones. Because the phase of the various signals will vary, if those objects or the transmitter or the receiver will move, this fading can lead to non reliable transmission.

All the computations we will see are based on a “Far Field” approximation[1] and the model is valid for most applications.

With F in MHz and D in metres:

$$GField = 27.6 - 20 \times \log(F) - n \times \log(D)$$

n is the Path Loss Factor that depends on the field itself, and takes into account different scenarios of multi-path transmission.

Field	n	Comment
Free space	20	applies to open-view line-of-sight propagation
Open field	25	Tx and Rx 1.5 m above the ground, in a large open space
Open office	30	indoor open office and retail space
Dense office	40	dense cubical office space

Additional Path Loss

To the above attenuation should be added an additional loss that will depend on the object causing the path loss:

Object	Gadd	Comments
Wall (indoor)	-10 to -15 dB	
Wall (exterior)	0 to -40 dB	decreases as number of windows increases
Floor	-10 to -30 dB	
Window	0 to -30 dB	metal tinted windows cause high loss

1. The “Far Field” approximation supposes that the receiver is at least at a distance $D > 10.\lambda$, with $\lambda = c/F$ ($c = 3.10^8$ m/s).

Margin and Link Reliability

The range is computed as a limit. That means you need some margins that will depend on the reliability of the RF link you want. In fact, the common way to increase the reliability of a system is to increase the signal level at the receiver side.

Applications	Link reliability	Margin
Car locking, Toys	<50%	0 dB
Door chimes	>90%	-10 dB
Monitoring systems	>99%	-20 dB
Professional telemetry	>99.9%	-30 dB
Critical radio link	>99.99%	-40 dB

Range Computation

The different power levels and parameters of the system, when expressed in dB units (dBm), are linked as follows.

$$PTxRad = PTxout + GTxAnt$$

$$PRxRad = PTxRad + GField + Gadd + Mar$$

$$PRxin = PRxRad + GRxAnt$$

The range of the system is the distance D that implies a received signal power equal to the sensitivity of the receiver, plus the margin defined. So:

$$PRxin = RxSens$$

and

$$RxSens = GRxant + GTxAnt + 27.6 - 20 \times \log(F) - n \times \log(D) + Gadd + Mar + PTxout$$

Then:

$$Range = 10^{\frac{PTxout + GTxAnt + GRxAnt - RxSens + 27.6 - 20 \times \log(F) + Gadd + Mar}{n}}$$

Radiated Power Limits

Regulations of each country limit the power radiated for RF applications. This limits, most of the time, the performance of the system (when the receiver is optimized).

For SRD applications, the limits are given in the following table.[1]

Frequency	PTxRad	RF Field @3m	Country	Regulation
916.5 MHz	-13.3 dBm	82 dBµV/m	USA	FCC 15.231.A-D
	-21.3 dBm	74 dBµV/m	USA	FCC 15.231.E
868.3 MHz	+14dBm	109 dBµV/m	Europe	EN 300 220
433.92 MHz	+10 dBm	105 dBµV/m	Europe	EN 300 220
	-14.4 dBm	81 dBµV/m	USA	FCC 15.231.A-D
	-22.5 dBm	73 dBµV/m	USA	FCC 15.231.E
418 MHz	-6 dBm	89 dBµV/m	UK	(out of date regulation)
<322 MHz	-41.3 dBm	54 dBµV/m	Japan	Bijaku
>322 MHz	-64.4 dBm	31 dBµV/m	Japan	Bijaku
315 MHz	-19.6 dBm	76 dBµV/m	USA	FCC 15.231.A-D
	-27.5 dBm	68 dBµV/m	USA	FCC 15.231.E

Some care should be taken when comparing those numbers. For example, in Europe, radiated power is expressed as peak power, and in the USA it is expressed as average power. Some examples of computation for peak and average power are given in the following sections.

System Performance Examples

An Excel sheet is available online[2] to help system evaluation. It computes the range and the field levels, given all the parameters of the system.

433.92 MHz ETSI Compliant System

ETSI regulations limit the transmitted power to 10 mW or 10 dBm in the 434 MHz band. Some margin should be taken to not exceed this limit over production dispersion, a few dB is enough.

Because it is easier to compare the performance of systems outdoors, we will define a remote control to have the maximum range with a given technology.

- Application:
  - frequency: 433.92MHz
  - European application: $PTxRad = +10\text{ dBm max}$
  - not a critical remote control: $Mar = 0\text{ dB}$
- The transmitter is a small remote control:
  - an integrated PLL delivering to an amplifier: $PIcout = 2\text{ dBm}$
  - an amplifier delivering to the antenna: $PTxout = 11\text{ dBm}$

1. Motorola provides this general information on the various regulations without guarantee of accuracy or completeness. Please consult each country for the latest information.
2. http://e-www.motorola.com/webapp/sps/site/taxonomy.jsp?nodeId=01M0ymXyR46.

- a shortened λ/4 antenna: $GTxAnt = -5\ dB$
- The receiver is defined by:
  - a shortened λ/4 antenna: $GRxAnt = -5\ dB$
  - a receiver composed of:
    - a low noise amplifier
    - a saw filter
    - an integrated receiver
    - overall sensitivity: $RxSens > -105\ dBm$
- The propagation Field:
  - the field is open: $n = 25$
  - free line of sight: $Gadd = 0\ dB$

With this definition, the system is compliant with ETSI regulations, because the radiated power is:

$$PTxRad = PTxout + GTxAnt = 11 - 5 = 6\ dBm$$

We can use the Excel file AN2611XLS to do the range computation.

Frequency	*F :*	433.92	MHz
Tx Output power	*Ptxout :*	11	dBm
Tx Antenna gain	*GTxAnt :*	-5	dB
Rx Antenna gain	*GRxAnt :*	-5	dB
RX sensitivity	*RxSens :*	-105	dBm
Additional losses	*Gadd :*	0	dB
Margin	*Mar :*	0	dB
Path Loss Factor	*n:*	25	
Open field	Car locking, Toys		
Radiated power	*PTxRad :*	6.00	dBm
		3,981.072	µW
Measuring distance	*d :*	3.00	m
Free space field Level	*VField :*	101.26	dBµV/m
		115,578.95	µV/m
	HField :	49.73	dBµA/m
		306.58	µA/m
Field Level at RX	*PrxRad :*	29.75	dBµV/m
		30.72	µV/m
Range	***D :***	**1,714.24**	**m**
		5,624	ft

The range is then 1714 m.

315 MHz FCC Compliant System

The FCC regulation limits the transmitted power to -19.6 dBm in the 315 MHz band. This power is measured using a CISPR quasi-peak detector that is equivalent to an average filter.

The duty cycle of the transmission depends on the modulation used. For OOK (On/Off Keying), the transmission is cut during low levels, but for FSK (Frequency Shift Keying), the transmission is at constant power.

Then, for an OOK Manchester coding modulated frame, with no pause between successive frames, the duty cycle is 50%; and for an FSK Manchester coding modulated frame, the duty cycle is 100%.

The average factor gives an improvement of: $AF(dB) = -10 \times \log(DC)$

This gives 3 dB in OOK and 0 dB in FSK.

The maximum allowed radiated peak power is -19.6 dBm in FSK and -16.6 dBm in OOK.

Some margin should be allowed to make sure this limit is not exceeded, over production dispersion; a few dB is enough.

Because it is easier to compare the performance of systems outdoors, we will define a remote control to have the maximum range with a given technology.

- Application:
  - Frequency: 315 MHz
  - USA application: $PTxRad = -19.6\ dBm\ max$
  - Not a critical remote control: $Mar = 0\ dB$
- The transmitter is a small remote control:
  - An integrated PLL delivering to the antenna: $PTxout = +5\ dBm$
  - A small loop antenna: $GTxAnt = -30\ dB$
- The receiver is defined by:
  - A shorten λ/4 antenna: $GRxAnt = -5\ dB$
  - A receiver composed of:
    - An integrated receiver: $RxSens < -105\ dBm$
- The propagation Field:
  - The field is open: $n = 25$
  - Free line of sight: $Gadd = 0\ dB$

With this definition, the system is compliant with FCC regulation because the radiated power is:

$$PTxRad = PTxout + GTxAnt = 5 - 30 = -25\ dBm$$

We can use the Excel file RANGE.XLS to do the range computation.

Frequency	*F :*	315	MHz
Tx Output power	*Ptxout :*	5	dBm
Tx Antenna gain	*GTxAnt :*	-30	dB
Rx Antenna gain	*GRxAnt :*	-5	dB
RX sensitivity	*RxSens :*	-105	dBm
Additional losses	*Gadd :*	0	dB
Margin	*Mar :*	0	dB
Path Loss Factor	*n:*	25	
Open field	Car locking, Toys		
Radiated power	*PTxRad :*	-25.00	dBm
		3.162	µW
Measuring distance	*d :*	3.00	m
Free space field Level	*VField :*	70.26	dBµV/m
		3,257.46	µV/m
	HField :	18.73	dBµA/m
		8.64	µA/m
Field Level at RX	*PRxRad :*	26.97	dBµV/m
		22.30	µV/m
Range	***D :***	**127.45**	**m**
		418	ft

The range is then 127m.

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