Chapter XIII
Short Range Wireless Devices - Building a global license-free system at frequencies below 1GHz

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Introduction:

The term "Short Range Device" (SRD) is intended to cover radio transmitters which provide either unidirectional or bi-directional communication and which have a low capability of causing interference to other radio equipment. Due to the many different services provided by these devices, there is no exhaustive list covering the SRD application space, however, the following categories are amongst those covered:

- Tele-control for Home/Building Automation systems
- Wireless sensor applications
- Alarms
- Automotive, including Remote Keyless Entry & Remote car start applications
- Wireless Speech and Video.

When designing a SRD wireless system, careful consideration needs to be paid to the choice of frequency on which your radio will be communicating over. In most cases, the designer is limited to those portions of the spectrum which allow license-free operation once certain specifications and conditions on usage are met. Table 1 lists the frequency bands available globally.

For designers who are hoping to build systems which can operate world-wide, the obvious choice has been 2.4GHz, which has become the frequency of choice for such standards as Bluetooth, WLAN and Zigbee.

5.8GHz has also attracted some attention, for example in cordless phones or the 802.11a version of WLAN.

However for systems which require both range and low power, the sub-1GHz bands remain compelling due to reduced co-existence issues and greater transmission range, both of which impact on power consumption an important consideration in battery powered applications.

The improved propagation range for lower frequency radiators can be seen from a simplified version of Friis Transmission Equation which states that:

$$P_r = \frac{P_t \lambda^2}{(4\pi d)^2} = \frac{P_t c^2}{(4\pi d)^2 f^2}$$

Where P_r is the available power at the receive antenna and Pt is the power delivered to the transmit antenna. In this case we are assuming a unity gain for both antennas. The equation shows that for a fixed distance d and transmit power Pt, the received power will increase with the square of the wavelength or alternatively will decrease with the square of the frequency, f. If the received power goes below the minimum power needed to demodulate the signal correctly (called the sensitivity point), the link will break down.

Global Frequency Allocations	**Comments**
13.56MHz	Used for near-field communications
40MHz	Not often used
433MHz	Need to reduce power for U.S.
2.4GHz	Popular global band
5.8GHz	Some systems up-banding from 2.4GHz
Other common allocations	
868MHz/915MHz	Europe/US only

Table1

Worldwide Frequency allocations below 1GHz

A more detailed description of the various sub-1GHz standards are given in Table2. This is not an exhaustive list but more detail can be found by following the links provided in the table.

The 433MHz is one option for global usage, with a slight frequency modification required for Japan which is easily handled by most modern frequency flexible transceivers, like the ADF7020 or ADF7021. A block diagram is shown in Figure1. However less than 2MHz of bandwidth is available and in addition applications like voice, video, audio or continuous data transmission are typically not allowed in this band, somewhat restricting its use. Thus it is most commonly used for keyless entry systems and basic tele-control.

Region	Relevant Standards	Frequency Bands (MHz)	Relevant links
Europe	ERC REC 70-03 EN 300 220 (Sept. '00) EN 300 220 (Feb.'06)	 433.05 – 434.79 868.0 – 870 863.0 – 870	 http://www.ero.dk/ http://www.etsi.org
U.S.	FCC Title 47 Part. 15.231 Part 15.247	 260 – 470 902 – 928	http://www.access.gpo.gov/nara/cfr/waisidx_04/47cfr15_04.html
Canada	RSS-210	260 – 470 902 – 928	http://strategis.ic.gc.ca/epic/internet/insmt-gst.nsf/en/sf01320e.html
Japan	ARIB STD-T67	426.0375 – 426.1125 429.175 – 429.7375	http://www.arib.or.jp/english/
China	RADIO REGULATIONS OF THE PEOPLE'S REPUBLIC OF CHINA	315.0 - 316.0 430.0 - 432.0	http://ce.cei.gov.cn/elaw/law/lb93i1e.txt

Table2

A more useful band is either around 868MHz in Europe or 902MHz to 928MHz in the U.S. This does not provide restrictions on applications as well as allowing a more compact antenna implementation.

Prior to the latest EN 300-220 specification however, the U.S. and European bodies took vastly different approaches to regulate usage. The U.S. adopted a frequency hopping approach while in Europe duty-cycle limits were applied in each of the sub-bands as described in the ERC REC-70 document. While both of these implementations are useful in minimizing interference, it meant that a manufacturer who was designing a system for both regions, needed to completely re-write the Media Access Layer (MAC) in his communication protocol.

However the latest European EN 300-200 regulations which were due for release at the time of writing in February 2006 has extended the frequency bands to allow for frequency hopping spread spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS) making the MAC implementations similar to those designed for the U.S, although some fine-tuning will still be required. We will discuss some of the aspects of the new specification and areas the SRD system designer needs to be aware of in the below sections.

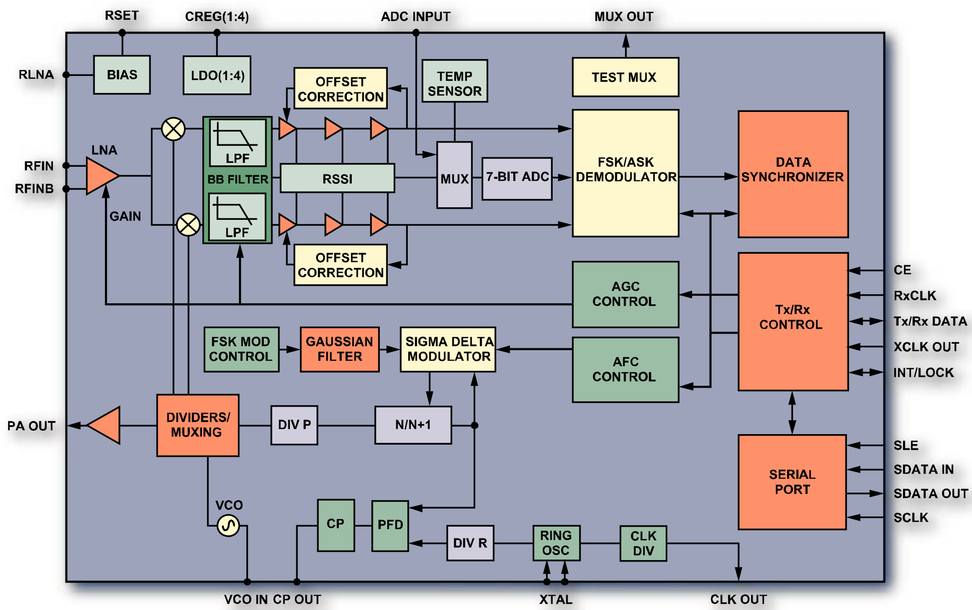

Figure1. A block diagram of the ADF7020 SRD transceiver

Frequency Hopping Systems

Frequency Hopping Spread Spectrum (FHSS) is a transmission technology which spreads energy in the time domain by dividing up the spectrum into several channels and switching between these, using a pseudorandom sequence. This pseudo-random sequence or “hopping code” must be known by both the receiver and transmitter. To facilitate new nodes joining the network the controller node typically sends out a beacon signal at regular intervals which the new node can synchronize onto. This synchronization time depends on both the beacon interval and number of hopping channels. Both the U.S. and European standards specify a maximum dwell time (the time spent at a particular frequency during any single hop) of 400 ms and a similar number of hopping channels.

Table 3 shows the extended frequency band in Europe below 870MHz when either FHSS or DSSS is used. This compares to the 2MHz available previously. In fact, up to 7MHz is now available once either the Listen Before Talk (LBT) or duty-cycle limits are met.
Listen Before Talk is a ‘polite’ communication protocol which scans the channel for activity before initiating a transmission. It is also often called a Clear Channel Assessment (CCA) operation. The key point here is that for systems using Listen Before Talk with frequency hopping there are no duty cycle limitations.

Sub-band	Number of Hop Channels	Power/Magnetic Field	Other requirements
865MHz to 870MHz	≥ 60	≤ 25 mW e.r.p.	LBT or <1% Tx Duty cycle
863MHz to 870MHz	≥ 47	≤ 25 mW e.r.p.	LBT or <0.1% Tx Duty cycle

Table 3

Wide Band Modulation: DSSS

In Direct Sequence Spread Spectrum (DSSS) systems, a narrow band signal is multiplied by a high speed pseudo random (PR) sequence to generate a spread signal. The bit rate (known as chip rate) determines the bandwidth over which the signal is spread. The bandwidth of this spread signal is much wider than the original data bandwidth with a corresponding reduction in peak spectral density (see Figure 2).

On the receive side, the incoming spread spectrum signal is multiplied with the same PR code which de-spreads the signal. This allows the original narrow band signal to be extracted. At the same time, any narrow band interferers at the receiver are spread and appear as wideband noise to the demodulator. The allocation of different PR codes to each user in the system allows isolation between users in the same frequency band. This is known as Code Division Multiple Access (CDMA).

DSSS modulation is used in the IEEE802.15.4, IEEE802.11 and GPS systems to name but a few. The main advantages of DSSS are:

1) Interference resilience: The essence behind the interference rejection capabilities of DSSS is that the useful signal gets multiplied twice (spread and de-spread) by the PN code while any interferes are just multiplied once (spread).
2) Low power density and therefore minimal interference with existing narrowband systems.
3) Security: Very resilient to jamming due to spreading/de-spreading. Also each unit is allocated an individual PN code.
4) Mitigation of multi-path effects.
5) No network synchronization needed as in the FHSS case. This minimizes power consumption.

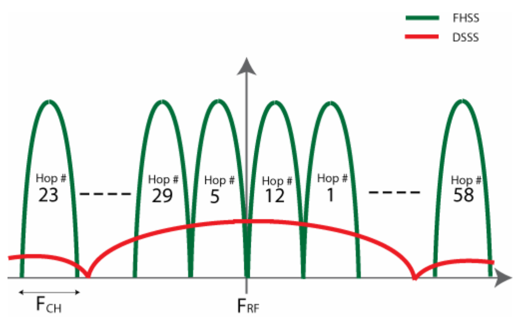

Figure 2: Power Spectral Density for FHSS and DSSS

Wideband Modulation other than DSSS or FHSS.

An interesting aspect of provisions for spread spectrum in the regulations is that wideband modulation schemes other than FHSS and DSSS are also provided for. FSK/GFSK modulation with an occupied bandwidth greater than 200kHz is considered wideband modulation under the European regulations. Table 4 highlights the main specifications which apply to wideband modulation schemes (including DSSS) in Europe:

Sub-band	**Occupied Bandwidth**	**Max radiated power density e.r.p.**	**Requirements**
865 MHz to 868 MHz	0.6 MHz	6.2 dBm/100 kHz	1 % TX duty cycle or LBT
865 MHz to 870 MHz	3.0 MHz	-0.8 dBm/100 kHz	0.1 % TX duty cycle or LBT
863 MHz to 870 MHz	7.0 MHz	-4.5 dBm/100 kHz	0.1 % TX duty cycle or LBT

Table 4: Maximum radiated Power density, bandwidth and duty Cycle Limits for spread spectrum modulation (other than FHSS) and wideband modulation.

An example of a device that can take advantage of this wideband standard using FSK modulation is the ADF7025. To operate in the sub-band 865-870MHz the maximum occupied bandwidth (99%) and maximum power density limits must be complied with. An edge of channel (or band) maximum power limit of -36dBm is also specified.

With the ADF7025 setup as shown in Table 5, all three of these limits were met. Figure 3 shows the occupied bandwidth as 1.7569MHz and the spectral density as -1.41dBm/100kHz . The edge of band (=/- 1.5MHz) requirement of -36dBm can be seen to be easily met in the first plot.

Frequency	867.5MHz
Modulation	FSK
Frequency Deviation	+/- 250kHz
Data Rate	384kbps

Table 5: ADF7025 parameters for Wideband Modulation Experiment

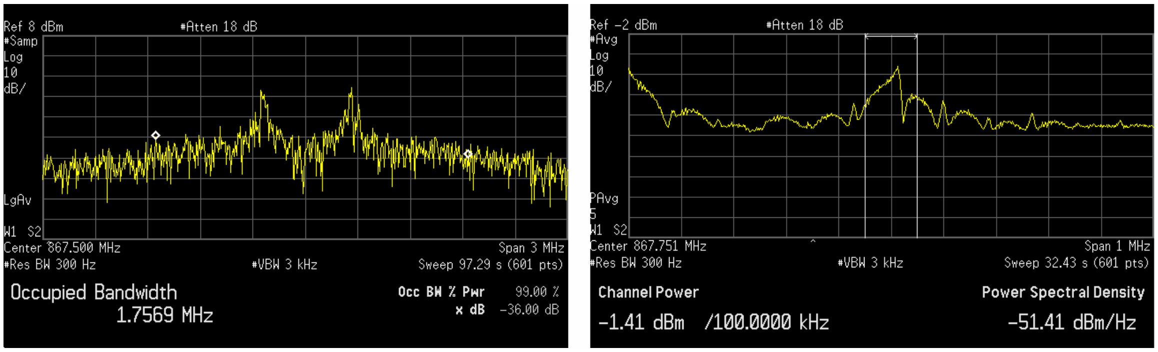

Figure 3: Results for Wideband Modulation Experiment on ADF7025: Occupied Bandwidth, Power Spectral Density/100kHz & Band Edge Power Limit.

The advantage of using the ADF7025 under wideband modulation is the extra data rate possible (in this case 384kbps) without the need for complex DSSS transceivers. These higher data rates allow the transmission of audio and medium quality video (a few frames/s).

In the US, FCC Part 15.247 has a very similar allocation which gives provisions for frequency hopping systems operating in the 902-928 MHz, 2400-2483.5 MHz and 5725-5850MHz, while also giving provisions for "digitally modulated" signals. This is a loose term and covers both spread spectrum (DSSS) and other simpler forms of modulation (FSK, GFSK), thus similar to the "Wideband Modulation" specification in the ETSI regulations. The two main requirements are listed below:

1. The minimum 6 dB bandwidth shall be at least 500kHz.
2. For digitally modulated systems, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

If one does not wish to employ a FHSS system then normally they would have to abide by section 15.249 which limits the field strength (@3m) to 50mV/m (-1.5dBm ERP). What makes this "digital modulation" so attractive is that the maximum output power is 1 Watt (while still complying with < 8dBm in any 3kHz bandwidth). Also, with the wider signal bandwidths, higher data rates are possible. Thus to operate a simple FSK/GFSK transceiver under these regulations a wide enough FSK/GFSK frequency deviation is chosen to ensure the 6dB bandwidth is greater than 500kHz. The output power can then be 1 Watt, ensuring that there is no greater than 8dBm in any 3kHz b/w of the modulation (maximum will be at the one/zero peaks in the FSK/GFSK modulated signal).

So similar wideband modulated systems can now be employed in both the US and Europe, thus simplifying engineering of products intended for worldwide markets. The ADF7025 transceiver architecture lends itself to operation in both the "digital modulation" mode as defined in the US standards and the "Wideband Modulation" mode as defined in the new European regulations.

Transient Power Requirements

A new specification which engineers should be aware of is the restrictions put on transient power. Transient power is defined as the power falling into adjacent spectrum due to the switching of the transmitter on and off during normal operation. A transient power limit has been added to the latest regulations to prevent spectral splatter when a transmitter is turning on and off.

The increase (turning on) or decrease (turning off) in current to the PA causes the load seen by the Voltage Controlled Oscillator (VCO) to change causing the PLL to unlock for an instant, producing spurious emissions or spectral splatter, as the loop acts to re-acquire. In systems where a unit is transmitting at intervals the splatter can significantly increase the power falling into neighbouring channels.

Figure 4 highlights the problem of spectral splatter. The yellow trace shows the PA output from the ADF7020 with the PA being turned on and off once every second while the spectrum analyzer is kept on max hold. The blue trace shows an un-modulated continuous wave signal from the ADF7020 transmitter. It can be seen that significant power is falling into channels either side of the carrier. Specification 8.5 of

ETSI EN 300 220-1 puts a limit on the amount of power falling into these adjacent channels.

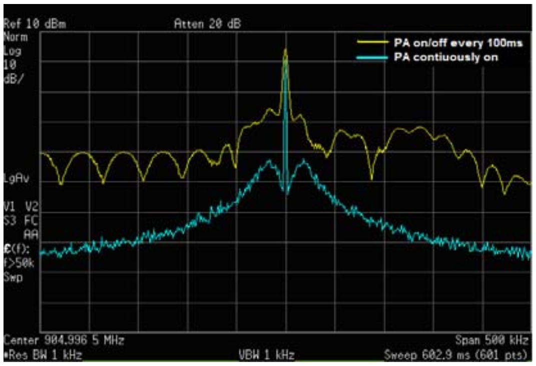

Figure 4

The measurement procedure requires that the transmitter be turned on and off five times at maximum output power and the power falling into the channels located 2, 4 and 10 channels either side of the carrier are measured. The limits are shown in Table 6.

Channel	Limit
2	≥ 40dBc with out the need to be below -27dBm
4, 10	≥ 50dBc with out the need to be below -36dBm

Table 6

To simplest way to ensure compliance with this specification is to ramp the PA when turning it on and off. This is normally accomplished by manually turning on/off the PA in stages. With the ADF7020 transceiver, it is possible to step the PA from off to +14dBm in a maximum of 63 steps. An even simpler approach is to use a transceiver with an automatic PA ramp. The ADF7021 has a programmable ramp where both the number of steps and duration of each step can be set by the user.

Communication Protocol Considerations

The new European regulations impose very specific requirements for over-the-air protocols in the 863-870 MHz bands. Whether a system uses a single channel protocol, FHSS or DSSS there are very specific rules which must be abided by. This of course complicates the protocol design. However, the upside to these new ETSI regulations is that they mirror the FCC Part 15.247 regulations in a lot of aspects, thus simplifying the design of a protocol intended for "worldwide" use.

ADI are currently in the process of updating their ADIismLINK (Version 2.0) protocol which can be used with any of the ADF702X transceivers. This protocol is intended for use in the worldwide sub-1GHz bands, and incorporates the new European regulations. It is based on a star based network as highlighted in Figure 4.

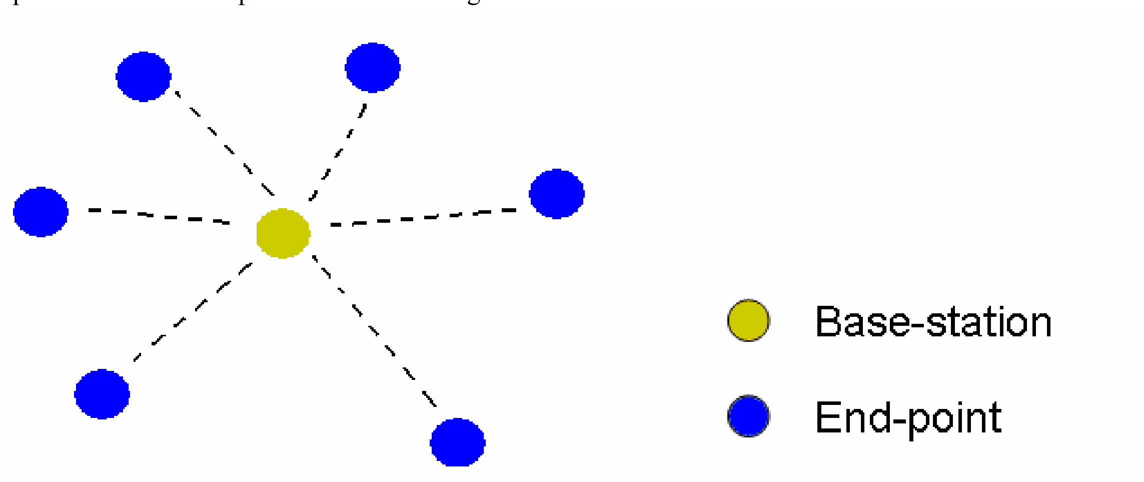

Figure 1: Star Network Topology

At the heart of the protocol is a non-slotted, non-persistent Carrier Sense Multiple Access scheme with Collision Avoidance (CSMA-CA). The End-point (EP) listens to the channel (LBT) before transmitting, thereby avoiding collisions.

The non-slotted aspect of the protocol means that EPs can transmit as soon as they have data, subject to first performing a Listen Before Talk operation. This also ensures no synchronization is required. If an EP senses the channel is busy, it backs off for a random period before performing another LBT. The number of times this back-off can occur is limited, hence the non-persistent nature of the protocol. In FHSS mode the protocol uses this CSMA-CA system on each hopping channel, thus fulfilling the LBT requirement for the new European regulations.

The Physical Layer (PHY) parameters and Media Access Layer (MAC) parameters of the ADIismLINK protocol are highly configurable thus allowing thorough device and system evaluation. Source code is also provided simplifying the system development procedure. The protocol comes as part of the ADF702x Development Kit (ADF70xxMB2). A system overview of ADIismLINK is shown in Figure 5. More information on this is available through the ADI website (ADF702X Development Kit).

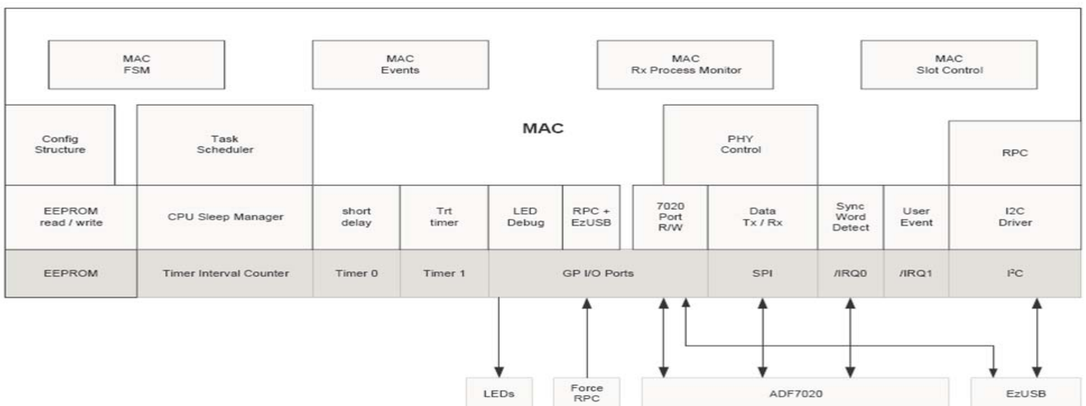

Figure5. ADIismLINK system Overview