Innovation Through Technology™

Micrel
QwikRadio® and RadioWire®

ASK/OOK/FSK Receivers, Transmitters, and Transceivers

RF Basics Design Guide

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QwikRadio® and RadioWire®

300MHz to 1GHz ASK/OOK/FSK Receivers, Transmitters, and Transceivers

RF Basics Design Guide

About Micrel

Micrel Inc., is a leading global manufacturer of IC solutions for the worldwide analog, Ethernet and high bandwidth markets. The Company's products include advanced mixed-signal, analog and power semiconductors; high performance communication, clock management, Ethernet switch and physical layer transceiver ICs. Company customers include leading manufacturers of enterprise, consumer, industrial, mobile, telecommunications, automotive, and computer products. Corporation headquarters and state-of-the-art wafer fabrication facilities are located in San Jose, CA with regional sales and support offices and advanced technology design centers situated throughout the Americas, Europe and Asia. In addition, the Company maintains an extensive network of distributors and reps worldwide.

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Introduction

From remote keyless entry for use in the automotive market, to countless industrial, home and consumer applications, adding value has become all about RF. The ability to add wireless capability to any number of products, via RF technology has given rise to brand new markets as well as reviving mature products with innovative and convenient new features. RF technology has been around for many years. However, only recently has this technology been embraced by the semiconductor market in the form of providing innovative IC solutions that not only reduce system size but system cost as well. This surge in new RF IC solutions has made the technology viable for inclusion into a wide variety of systems where it was previously prohibitively expensive including the industry's most cost-sensitive consumer products. Increased integration, along with vastly improved development tools, has helped to ease the burden on the RF designer and sustained innovation continues to reduce time to market. For Micrel RF products, this translates into a nearly drop-in design approach, a key benefit for designers of wireless consumer goods.

For many years, Micrel has been a leader in the RF market with its line of highly integrated QwikRadio® RF receivers and transmitters. Micrel's QwikRadio® devices are ideally suited to the needs of all forms of remote control applications ranging from automotive RKE (Remote Keyless Entry) to consumer equipment. They are optimized for low power consumption and low cost. In addition, Micrel's RadioWire® products are a family of FSK (Frequency Shift Keying) highly integrated transceiver radio chips that can be programmed to operate at different frequencies. The family of products have low cost and high data rate, making them an excellent alternative to Bluetooth® and 802.11a/b/g solutions.

This pocket guide is intended as a tool for use by designers and engineers of QwikRadio® products. Key design parameters, including noise, sensitivity, bandwidth, selectivity and PCB layout among others, are covered. In addition, questions an engineer should ask when designing RF products are discussed, along with hints and guidelines for creating the most cost-effective, high performance RF-enabled applications possible.

Noise

Noise is defined as interference or an unwanted signal in the receiver input or transmitter output. It can be thermal noise or generated by resistance or active devices such as transistors and diodes. Noise from active devices can also be flicker and shot in nature, where the latter is a Gaussian white noise related to the transfer of charge in a PN junction, and the former is generally present from random trapping of charges in the oxide of a MOSFET. Noise can come from several different sources such as RF interference from different kinds of radios, a clock of a microcontroller, switching power supply ripple, car engine, appliances, or even from the RF system itself. Most noise can be substantially reduced by carefully designing the RF system as well as cautious layout of the PCB layout. To avoid the amplification of undesired noise, the RF system should have a useful bandwidth no wider than necessary and the layout should be compact, with the RF path as straight as possible, yielding excellent ground plane, power and ground separation from other circuits, etc. On the transmitter side, noise, which is also seen as harmonics, can be reduced by careful design of the output filter.

Figure 1 shows the dB which translates the signal-to-noise ratio (SNR) of the amplifier input over the signal-to-noise ratio of the amplifier output. This number should be as low as possible so noise is not added to the system. The predominant noise figure comes from the first stage. Thus, it is important to have a low noise amplifier in the front of the RF receiver system with a good amount of gain in order to increase the overall sensitivity. Thus,

$$NF = SNR_{IN}/SNR_{OUT}$$

Noise Ratio (NR). It is the numeric number of noise figure. It is calculated by,

$NR = 10^{NF/10}$ or vice-versa,

$$NF = 10x\log(NR)$$

Cascaded Noise is the contribution of noise of all RF stages. The dominant noise is normally from the first stage and almost insignificant from the last one. It is calculated by:

$$NRt = NR1 + (NR2-1)/G1 + (NR3-1)/(G1xG2) + ... + (NR_{n+1} -1)/((G1xG2x\ldots xGn),\ n = 1,2,3,\ldots$$

Where,

NR1 is the noise ratio of the first stage,

NR2 is the noise ratio of the second stage,

NR3 is the noise ratio of the third stage,

NRn+1 is the noise ratio of the last stage,

G1 is the gain of the first stage,

G2 is the gain of the second stage,

Gn is the gain of the stage before last of the entire system

Example: What is the total noise figure of the system below (where everything needs to be converted to numeric form, not in dBs),

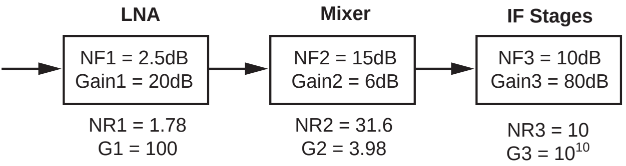


Figure 1. Stages of Noise for RF System

Plugging the values in the formula,

NRt = 1.778 + (31.6 – 1)/100 + (10-1)/(100x3.98)

NRt = 1.778 + 0.306 + 0.023 = 2.107 or

NF = 10 log (2.107) = 3.24 dB.

As stated before, one can see that the second and third stages contribute much less noise to the overall noise figure of the system.

Sensitivity

The sensitivity of a receiver is considered the minimum signal level it can demodulate the information with an acceptable amount of errors or distortion. It is calculated by:

Si = sensitivity = (-174 + NF + 10logBW + Required S/N) [dBm]

Where,

-174dBm is the thermal noise power at room temperature for 1 hertz bandwidth.

NF = final noise figure of the receiver system

$10\log_{10}$BW = final system bandwidth

Required S/N = required signal-to-noise ratio to demodulate the information under certain conditions of error or distortion

Thus, to increase sensitivity in a receiver system, one needs to reduce the overall noise figure, decrease the effective bandwidth and improve the demodulation scheme because a decreased signal-to-noise ratio is required. The required signal-to-noise ratio is an internal parameter that cannot be changed — it is dependent upon the IC design. The effective bandwidth can be decreased by reducing the baud rate to the amount of data being received per second. For example, if the effective bandwidth is decreased from 10kHz to 1.2kHz, then the total sensitivity will increase 9.2dB (using the sensitivity formula). The noise profile of the receiver can then be improved by cascading external amplifiers with better noise figure and a good amount of gain. Note that excessive gain will cause undesired oscillations which will contribute to noise and will ultimately cause the final performance to be less than desirable. Therefore, external amplifiers with gains above 22dB should be avoided, unless one is absolutely sure there will be no oscillations.

Effect on Sensitivity by Cascading Stages

Sometimes a higher sensitivity may be required for the RF system. This can be achieved by cascading external amplifiers. The final sensitivity is not a matter of simple math and cannot be achieved simply by adding the gain of an amplifier with the overall receiver sensitivity. Meaning, if the receiver has a sensitivity number of -95dBm and a 20dB gain amplifier is added in front of the receiver, then the final sensitivity is not going to be -115dBm. The noise figure of each stage plays a very important role in the final sensitivity calculation. As example, place a low noise amplifier that has 1dB of noise figure and 22dB gain, as seen in Figure 2.

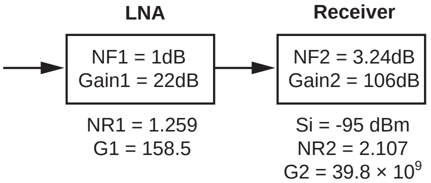


Figure 2. Improving Sensitivity by Adding a LNA

Using the same formula for the cascaded noise figure, one can obtain:

NRt = 1.266, and

NFt = 1.024dB

Plugging the new noise figure into the sensitivity formula, one is able to improve the final sensitivity by just 2.2dB, that is, the receiver now will have a final sensitivity of -97.2dBm. So, the most effective way to externally improve the sensitivity of the RF Receiver system is to decrease the amount of data being transferred and by carefully reducing the overall system bandwidth.

Bandwidth

Bandwidth is generally defined as the difference between the upper and lower frequency (f2- f1) for a certain amount of attenuation (3dB points, 20dB points, etc.).

Quality Factor

Q or circuit Q is a figure of merit that shows how selective a circuit is. The higher the Q, the narrower is the bandwidth and the higher the selectivity of a resonant circuit.

$$Q = \frac{fc}{f2 - f1}$$

Shape Factor

The shape factor is the ratio of an attenuation factor related to the 3dB points to another attenuation factor. The lower the ratio, the more selective the circuit. Also, the estimated shape factor at 30dB of the figure above is:

$$SF = \frac{30dB}{3dB}$$

$$SF = \frac{390.6 - 389.6}{390.2 - 389.9}$$

$$SF = 3.3$$

Therefore, the 3dB points bandwidth is 300kHz, and the 30dB points bandwidth is 1MHz. Some RF systems require even steeper shape factors which can be obtained with the addition of front-end filters such as SAW filters.

Selectivity

This parameter is defined as the extent to which a receiver can differentiate between the desired signal and other signals that are not wanted. Other signals can be either other radio signals or noise. Thus, the receiver must select a single signal out of many, while eliminating all others. Good selectivity is obtained by careful design of the entire receiver system from the front-end filters, PCB Layout, and choosing the receiver device that gives the proper rejection from other noise sources. The final selectivity will be the cascaded effect of each stage and the contribution of noise getting in the final amplifier stages which will be translated to errors or distortion.

Blocking, Adjacent Signal Interference

It is the unwanted signal most which causes the receiver to decrease its final sensitivity with errors and distortion in the information.

Figure 3 below shows a normalized frequency response of a receiver. The 0dB means the worst sensitivity for a certain amount of errors or distortion. At -10dB, the signal-to-noise ratio is 10dB above the worst case sensitivity. If a blocking signal is an average of 30dB stronger and its frequency is outside of the normalized useful bandwidth and near to it, then the information signal will be blocked. And, if the same interference signal is outside of the useful bandwidth of this receiver and it is 30dB less than the desired signal, it will not cause any errors or distortion. However, if the interference is in the useful bandwidth of the given receiver, only the stronger signal will win out or 'go through'. Hence, just as in interference No 1 (around -20dB, inside of the useful bandwidth), the signal to-noise ratio must be 20dB or better for this receiver to work. This means the final sensitivity dropped 20dB. Further to this example, if it was -110dBm before, with the interference signal No 1, then the final sensitivity would now be -90dBm. Below 386MHz and above 394MHz, the blocking capability of this receiver is around 50dB or better.

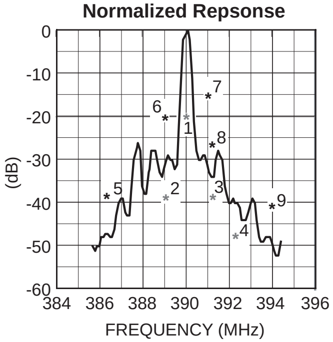


Figure 3. Effect of Interfering Signals on Sensitivity

Referencing Figure 3, one can see that the interfering signals, 1 through 4, will cause errors, distortion or even total disruption of the desired signal, if the information signal is not stronger than the interfering signal. This is in contrast to the interfering signals 5 through 9, which will not cause any problems.

Image Frequency

It is an undesired RF frequency prone to superheterodyne receivers that create the same intermediate frequency as the desired input signal. It can be reduced by narrow front-end filters and image reject mixer. See Figure 4 for desired signals versus image frequency.

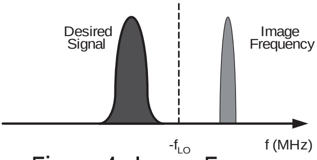


Figure 4. Image Frequency

Image Reject Mixer

The image reject mixer makes use of a complex mixer (two mixers) that takes advantage of the relationship between the desired signal and the undesired image frequency. See Figure 5. When mixed down, the wanted signal is added and the image frequency is canceled or reduced. Two LO signals in quadrature drive two mixers, that is, the I signal or in phase, and the Q signal or in quadrature. The wanted signal is added and the image frequency is subtracted. The distinction between the wanted signal and the image is possible because the two signals lie on different sides of the LO frequency.

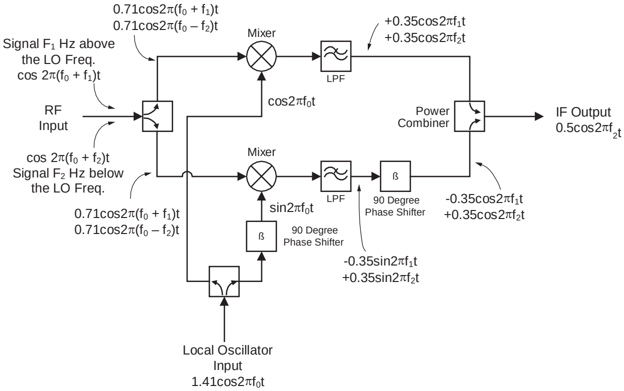


Figure 5. Image Reject Mixer

Matching

A suggested matching network is made of a series capacitor and a shunt inductor (L-matching). The shunt inductor also provides additional ESD protection for the Antenna pin. The suggested matching may vary due to PCB variations and also be done with different topologies. Either the input impedance value or S-parameter is needed to calculate the matching elements. Then, the matching values can be found by either plotting the input impedance in a Smith Chart (done by software – Winsmith, by Noble Publishing), or by Calculation. For matching values, look up the useful tables section ahead.

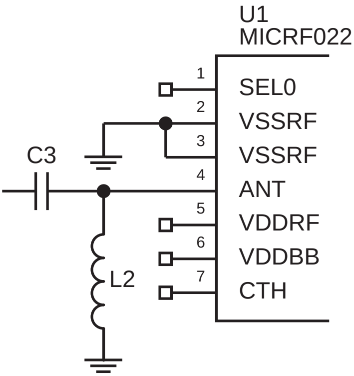


Figure 6. Suggested Matching Circuit

See the example in Figure 6. A device has an input impedance of Z = (18.6 – j174.2) ohms @ 433.92MHz. Find a L-matching networking circuit that presents a high pass filter response. The solution is made possible by following the equations below for the results and comparing the solution given with the WinSmith software.

Frequency 433.92MHz, Input Impedance Z = 18.6 – j174.2Ω

Equivalent parallel = B = 1/Z = 0.606 + j5.68 msiemens

Rp = 1 / Re (B); Xp = 1 / Im (B)

Rp = 1.65 kΩ; Xp = 176.2Ω

Q = SQRT (Rp/50 + 1)

Q = 5.831

Xm = Rp / Q

Xm = 282.98Ω

Resonance Method For L Matching

Lc = Xp / (2.Pi.f); Lp = Xm / (2.Pi.f)

L1 = (Lc.Lp) / (Lc + Lp); C1 = 1 / (2.Pi.f.Xm)

L1 = 39.8nH

C1 = 1.3pF

PCB Layout Considerations

The first rule of design is to make traces as short as possible. Long traces alter the matching network and then the values suggested are no longer valid. Suggested Matching Values may vary due to PCB variations. A PCB trace 100 mills (2.5mm) long has about 1.1 nH inductance. Optimization should always be done with exhaustive range tests. Make individual ground connections to the ground plane with a via for each ground connection. Do not share vias with ground connections. Each ground connection equals one or more vias. The ground plane must be solid and if possible, without interruptions. Avoid putting the ground plane on top next to the matching elements. This normally adds additional stray capacitance which changes the matching. Do not use phenolic material, only FR4 or better materials. As phenolic material is conductive above 200MHz. The RF path should be as straight as possible, avoiding loops and unnecessary turns. Separate ground and V_{DD} lines from other circuits (microcontroller, etc). Known sources of noise should be laid out as far as possible from the RF circuits. Avoid thick traces, the higher the frequency, the thinner the trace should be in order to minimize losses in the RF path.

Antennas

Antennas are the component element that are used to capture or irradiate electromagnetic waves. In order to do this, they require free space around their elements. Near-by metallic objects, components, etc., should be avoided and under no circumstances should anything be touching the antenna. The more space available around an antenna, the better it will do its job. Whip antennas should be straight as possible. Normally, special equipment is required to optimize an antenna, such as RF Network Analyzers, Spectrum Analyzers, Power Meters, etc. If no such equipment is available, copy suggested antennas without changing 1mm of it. Any insignificant changes, no matter how small they are, will make the antenna behave differently. Also, a fraction of the wavelength (one-quarter and one-half wave) can be used as long as the antenna is kept straight and end effects are taken into account due to smaller ground plane. Normally, end effects cause the antenna length to be slightly shorter than the calculated values (3% to 5% less). Small antennas do not resonate in the used frequency, thus, additional matching elements are required in the RF system. PCB antennas are dependent upon the PCB material, copper weight, process and other factors. Whenever changing a PCB house or ordering new boards, a comparison test with previous results is required. Small antennas and PCB Antennas normally require part of the ground plane as part of their performance. When copying suggested antennas, copy the distance from the ground plane exactly as shown in Figures 7 and 8. The bottom ground plane must be solid without interruptions.

Antenna Examples

1. Helical PCB. It resembles and behaves like a helical antenna. Designed for the 300MHz-450MHz band. It is capacitive in na-

ture. It showed excellent performance in comparison with one-quarter wave monopole. It requires just 1.385 x 0.33 inches of additional PCB area. For additional information, contact local Micrel sales offic or representive.

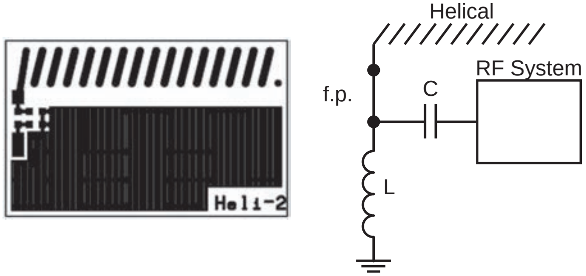


Figure 7. Example of a Helical PCB

2. Multi-element PCB. It does not resemble any known antenna. Designed for the 850-950MHz band, it is inductive in nature. It showed good performance in comparison with one-quarter wave monopole. It requires just 1.32 x 0.4 inches of additional PCB area. For additional information, please contact a local Micrel sales office or representive.

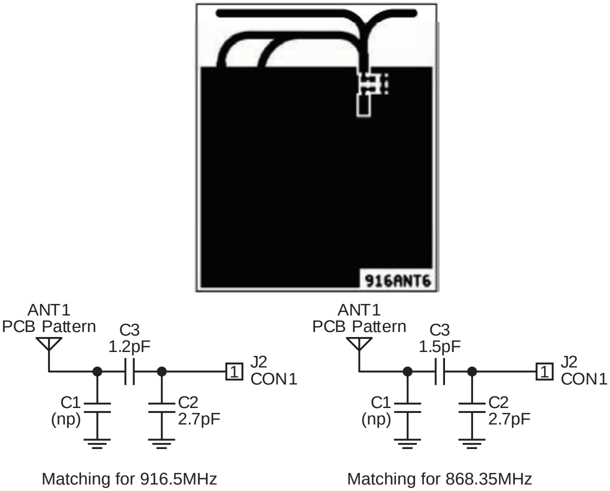


Figure 8. Example of a Multi-Element PCB

QwikRadio® Applications

When designing a wireless solution, one needs to take into consideration all phases of the project in order to guarantee a successful design. Preferably, a high level block diagram should be drawn and even broken down into smaller ones, reference Figure 9.

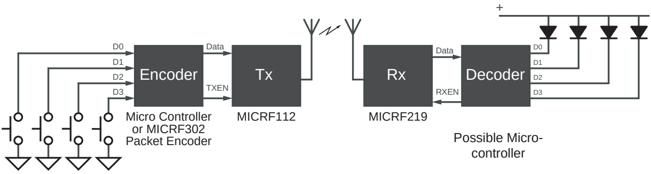


Figure 9.   Block Diagram of a Wireless Application

Most of applications will have some kind of actuation (switches), or data to be processed like temperature, an encoder, which is secure or non-secure depending upon the application, a transmitter, a transmitter antenna, a receiver antenna, a receiver, a decoder, and finally some sort of action happening, that is, a door opening or closing, lights turning on and off, a display showing some information, etc.

Questions for a Successful Design

A number of key questions should be asked and answered before continuing with the design phase of a wireless project. Not answering the questions or ignoring them may cause undesired delays in the project or even result in total failure of the project due to issues not solved.

Below are examples of questions that could be relevant to a wireless project:

1. What countries is the RF system going to be used? It is important to know it so one can determine the carrier frequency, the maximum allowed power, occupied bandwidth, harmonics and spurs, etc.

2. What is more important, cost, performance, or time to market? Often, because time to market is seen as the over-riding factor, designs are not considered carefully enough. Later on, they find out that the requirements for the project are tougher and whatever they have designed and the build does not meet the final requirements. Careful considerations here will lead to a design close or exactly to what is needed. Keeping this in mind, it is impossible to have the best design (performance) with the lowest cost in the fastest possible time. There are always trade-offs.

3. What is the worst case range or distance? In what conditions – indoors or outdoors? The higher the range, the more expensive the project will be or the longer it will take to get it

right. Budget the range for what is really needed. Range will be dependent upon many factors including how much power is available (countries to be used); or technology limitations, such as the transmitter not providing all the power allowed; or limitations in the DC power because of the battery maximum voltage and current; or even terrible loss in the antennas. Other range-dependent parameters include receiver sensitivity and selectivity and baud rate chosen — the higher the baud rate, the less range that is possible. Other issues could be limiting factors such as the RF system being enclosed in a sealed box, the antenna touching objects, mismatch in the receiver input or transmitter output, wrong receiver setup (SEL0 or SEL1 for the demodulator bandwidth), or wrongly recommended component values (C_{TH} and C_{AGC} capacitors), just to name a few. Every block of an RF system must be taken into consideration and analyzed carefully to ensure that all aspects are covered and that there is a greater chance that the final RF System will offer the best range for its price.

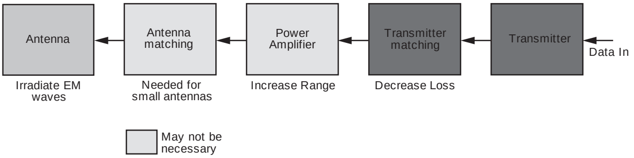


Figure 10. Transmitter Block Diagram

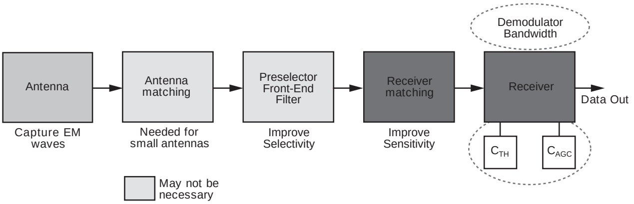


Figure 11. Reciever Block Diagram

4. What kind of antennas will be used in the system? Antennas are normally the last thing to be considered. This could be the cause of the first major design mistake in the RF system. A good RF system will make the antenna one of the first considerations in the design phase. Some antennas can have a loss as much as 30 dB, such as the loop kind. Antennas require space to irradiate or capture the electromagnetic waves and if they are confined, touching something, or around other circuits, they will not work well.

5. Is it possible to transmit the information necessary? Regulations do not allow continuous data to be transmitted unless

very low power is used or a higher frequency band is utilized which makes the design more difficult to achieve. Sometimes schemes like frequency hopping are required.

6. What is the area available for the PCB? How much of that will be used for the RF circuits? It is very important to have a reserved area just for the RF portion of the design. Often, the entire system does not work well because the RF circuits are mixed in with other noisy circuits. Follow basic design guidelines for a good PCB layout. Make sure, if the antenna used is of a PCB kind, that the antenna area is separate enough so that it will be far away from metal surfaces, wires, and other objects.

7. What kind of data pattern should be used? Many times before the data can be transmitted, some kind of encoding is required in order to guarantee the proper operation of the receiver. Moreover, the information needs to be encrypted when secure applications are the case (remote keyless entry, alarms, etc). Some receivers only work with RZ (return to zero) type of data. If NRZ or non-return-to-zero type of data is used, then the data will need to be changed before being transmitted. Examples are Manchester Encoded Data, 33/66 format, etc). Furthermore, a preamble with at least 10 data periods and 50 percent duty cycle is recommended. The preamble will make the receiver go to its steady-state operation sothat, when data is transmitted, the decoder or microcontroller can process the data immediately without losing the first bits that are demodulated by the receiver, see Figure 12. In addition, the data type will dictate how much capacitance is needed for the data slicing circuits (C_{TH} capacitor) and AGC circuits (C_{AGC} capacitor).

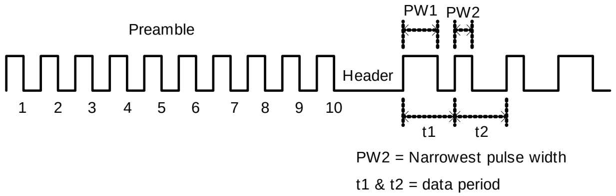


Figure 12. Suggest Data Pattern

8. What is the shortest pulse width of the data stream? The narrowest pulse will dictate how much receiver final bandwidth is required. Ideally, the bandwidth should be set no more than necessary, so no loss of sensitivity happens, as previously explained. Conversely, the bandwidth should not be set to a level

less than necessary, otherwise the pulse will stretch causing errors in the data processing. The required bandwidth is calculated by 0.65/shortest pulse.

9. Are there any known sources of noise? In what frequency? No matter how hard it is to answer this question, one must find out what kind of environment the RF System is going to operate within. A suitable and appropriate front-end circuit will reduce the noise to acceptable levels and will guarantee the functionality of the system. The more selective is the front-end, the more range or distance the RF system will have. If it is very difficult to know the answer to this question, one should try multiple approaches to guarantee the success of the design. Below are some examples of front-end circuits:
   - Remote and Passive Keyless Entry and Car Alarm (Figures 13 and 14)
   - Band-pass-filter + matching network
   - High-pass-filter + matching network
   - Wide band SAW filter + matching network
   - Narrow band SAW filter + matching network
   - Wide band SAW filter + LNA + matching network
   - Narrow band SAW filter + LNA + matching network

10. Additional questions that should be asked include: what is the voltage or voltages needed? Is current consumption important? If so, how polling will be achieved? What kind of ripple the power supply will have? Is data squelching required?

QwikRadio® Application Examples

The most common examples of applications for this type of RF Systems are:

- Remote and Passive Keyless Entry and Car Alarm (Figures 13 and 14)
- Tire Pressure Monitor System
- Car Entertainment System
- Garage Door Opener
- Home Alarm and Appliances
- Automation – Smart Systems
- Remote Control Units
- Telemetry (Figure 15)

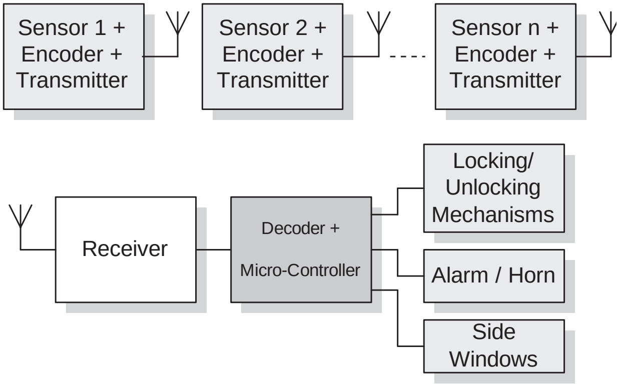


Figure 13. Remote Keyless Entry Application

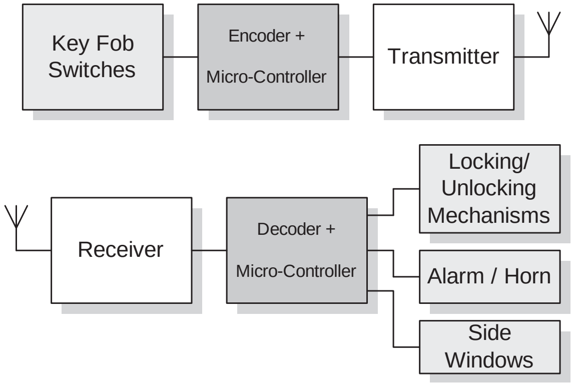


Figure 14. Alarm Application

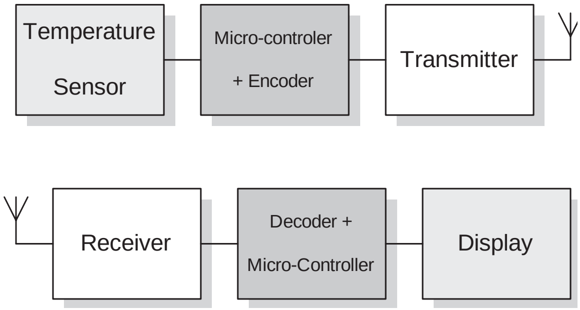
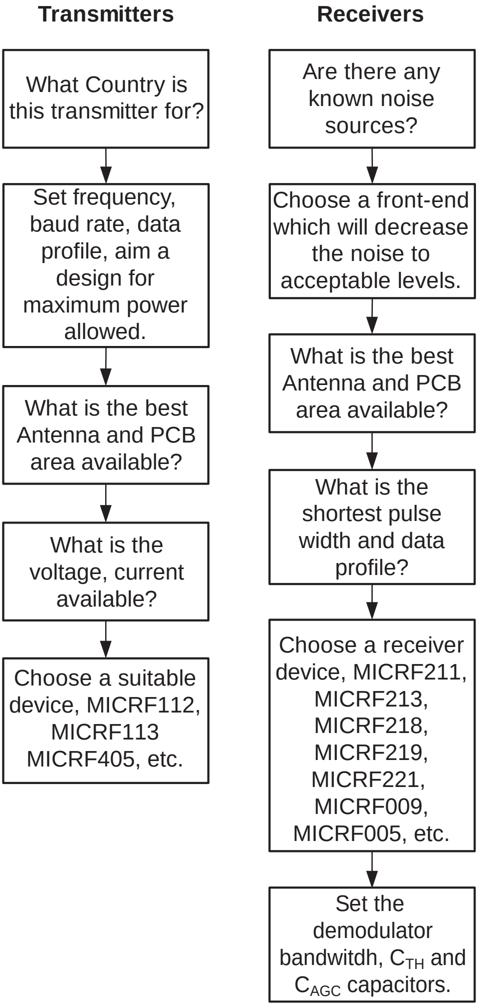


Figure 15. Telemetry Application

QwikRadio® Transmitter and Receiver Design Flow



dBm x dBW x dBuV/m x uV/m x P x V

dBm – decibels referenced to 1 milliwatt

dBW – decibels referenced to 1 watt

µV – micro volts (volts x 10^{-6}), mV – milli volts (volts x 10^{-3})

V – voltage referenced to 50 ohm load, P – power referenced to 50 ohm load

dBµV/m – decibels referenced in electric field to 3 meters

V/m – electric field referenced to 3 meters

milli (m) = 10^{-3}, micro (µ) = 10^{-6}, nano (n) = 10^{-9}, pico (p) = 10^{-12}, femto (f) = 10-^{15},

atto (a) = 10^{-18}

dBm	dBW	dBµV/m	V/m	P (watt)	V (volts)
-120	-150	-24.77	57.74n	1.0f	0.224µ
-115	-145	-19.77	102.67n	3.16f	0.399µ
-110	-140	-14.77	182.57n	10.0f	0.709µ
-105	-135	-9.77	324.67n	31.6f	1.26µ
-100	-130	-4.77	577.35n	0.1p	2.24µ
-95	-125	0.229	1.03µ	0.316p	3.99µ
-90	-120	5.23	1.83µ	1.0p	7.09µ
-85	-115	10.23	3.25µ	3.16p	12.6µ
-80	-110	15.23	5.77µ	10.0p	22.4µ
-70	-100	25.23	18.26µ	100p	70.9µ
-60	-90	35.23	57.74µ	1.0n	224µ
-50	-80	45.23	182.57µ	10.0n	709µ
-45	-75	50.23	324.67µ	31.6n	1.26m
-40	-70	55.23	577.35µ	0.1µ	2.24m
-35	-65	60.23	1.03m	0.316µ	3.99m
-30	-60	65.23	1.83m	1.0µ	7.09m
-25	-55	70.23	3.25m	3.16µ	12.6m
-20	-50	75.23	5.77m	10.0µ	22.4m
-15	-45	80.23	10.27m	31.6µ	39.9m
-10	-40	85.23	18.26m	100µ	70.9m
-5	-35	90.23	32.47m	316µ	0.126
0	-30	95.23	57.74m	1.0m	0.224
5	-25	100.23	106.67m	3.16m	0.399

ISM Band Transmit Power Limits

Band	Max. Power
160-190kHz	1 watt
510-1705kHz	100 mwatts
1.705-10MHz	100 µV/m @ 30 meters
13.553-13.567	10 mV/m @ 30 meters
26.96-27.28MHz	10 mV/m @ 3 meters
40.66-40.70MHz	1 mV/m @ 3 meters
49.82-49.90MHz	10 mV/m @ 3 meters
88-108MHz	250 µV/m @ 3 meters
174-216MHz	1.5 mV/m @ 3 meters
260-470MHz	See graphics
902-928MHz	500 mV/m @ 3 meters
2435-2465MHz	500 mV/m @ 3meters
5785-5815MHz	500 mV/m @ 3meters
10500-10550MHz	2500 mV/m @ 3 meters
24075-24175MHz	2500 mV/m @ 3 meters

Useful Formulas:

1. Ohm’s Law, V = R x I, P = V x I
2. Series Resistance, Rs = R1 + R2 + … + Rn
3. Parallel Resistance Rp = 1/((1/R1) + (1/R2) +…+ (1/Rn))
4. Series Inductance, Ls = L1 + L2 + … + Ln
5. Parallel Inductance Lp = 1/((1/L1) + (1/L2) +…+ (1/Ln))
6. Inductive Reactance XL = 2 x Pi x f x L
7. Series Capacitance, Cs = 1/((1/C1) + (1/C2) +…+ (1/Cn))
8. Parallel Capacitance Cp = C1 + C2 + … + Cn
9. Capacitive Reactance Xc = 1/(2 x Pi x f x C)
10. Si = sensitivity = (-174 + NF + 10logBW + Required S/N) [dBm]
11. Dynamic Range ~ 2/3 (input intercept – noise floor) [dB]
12. Noise Figure: NF = SNR_{IN}/SNR_{OUT}
13. Noise Ratio: NR = $10^{NF/10}$
14. Noise Figure having noise ratio: NF = 10xlog(NR)
15. Cascaded noise ratio:
    NRt = NR1 + (NR2-1)/G1 + (NR3-1)/(G1xG2) + ... + (NRn+1

-1)/((G1xG2x… xGn), n = 1,2,3,…

16. Quality Factor: Q = fc/(f2-f1)
17. Matching: B = 1/Z, Rp = 1 / Re (B); Xp = 1 / Im (B), Q = SQRT (Rp/50 + 1), Xm = Rp / Q, Lc = Xp / (2.Pi.f), Lp = Xm / (2.Pi.f), L1 = (Lc.Lp) / (Lc + Lp); C1 = 1 / (2.Pi.f.Xm)
18. Resonance f = 1/(2x Pi x SQRT (LC))
19. One-quarter wave monopole antenna = ((3x108/f)/4)x0.97 [meters]
20. 1 meter = 100 cm = 1000 mm
21. 25.4 mm = 1 inch = 1000 mills
22. Bandwidth required = 0.65/shortest pulse
23. P_{1dB}(output) = (P_{1dB}(input) + (Gain – 1)) [dBm]
24. Path Loss in Free Space, Loss = 20 log (4 x Pi x d / wavelength) [dB]
25. S11 to Z11, Z11 = 50 x (1 + S11) / (1 - S11)
26. Z11 to S11, S11 = ((Z11/50) - 1) / ((Z11/50) + 1)

Summary of Regulations

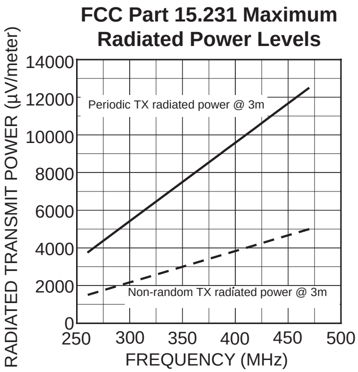
FCC Standards for Transmitters

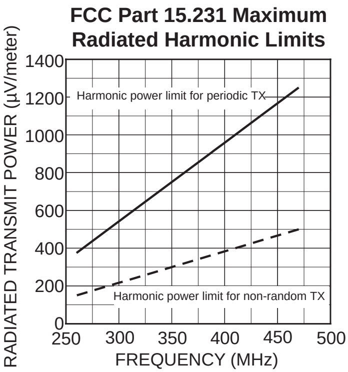
The following FCC regulations may be referenced: the Volume 47 of the Code of Federal Regulations, Part 15, Chapters 15.209 and 15.231. There are two categories governing transmitters, periodic transmitters and non-periodic (or continuous) transmitters. The following regulations pertain to ISM band operation from 260MHz to 470MHz:

Regulations:

1. Transmit power is measured in terms of field strength, measured at a distance of three meters from the radiating antenna. The maximum transmit power level ranges from 3750µV/meter to 12500µV/meter for the frequency band of 260MHz to 470MHz, respectively. The maximum level for any frequency between 260MHz and 470MHz may be determined by linear interpolation between the lower and higher limits for the two respective frequencies. (Refer to the attached chart.)

2. Maximum harmonic and spurious levels must be 20dB below the transmit carrier. The maximum spurious power level ranges from 375µV/meter to 1250µV/meter for the frequency range of 260MHz to 470MHz, respectively. The maximum level for any frequency between 260MHz and 470MHz may be determined by linear interpolation between the lower and higher limits for the two respective frequencies. (Refer to the attached chart.)
3. The bandwidth of an emission shall be no wider then 0.25 percent of the center frequency of the transmit carrier. Bandwidth is defined at points 20dB down from the peak of the modulated carrier.
4. Emissions shall be measured up to the tenth harmonic of the fundamental carrier frequency for the intentional radiator.





Frequency (MHz)	Rad. Power @ 3m (µV/meter)	Max. Harmonic Level (µV/meter)
260.00	3750	375.00
300.00	5417	541.67
303.85	5577	557.71
315.00	6042	604.17
387.00	9042	904.17
390.00	9167	916.67
400.00	9583	958.33
418.00	10333	1033.33
433.92	10997	1099.67
470.00	12500	1250.00

Table 1. Maximum Levels for Random or Periodic Intentional Radiators

Calculation Formulas for Table 1:

Radiated Power @ 3 meters is a function of:

$E = 41.6667 \times F - 7083.3333 \mu V/m$

where F is frequency in MHz

Harmonic Amplitudes must be attenuated by at least 20dB below the carrier level.

Where:

$H = E - 20dB$ (volts) or $H = E/10$

Frequency (MHz)	Rad. Power @ 3m (µV/meter)	Max. Harmonic Level (µV/meter)
260.00	1500	150.00
300.00	2167	216.67
303.85	2231	223.08
315.00	2417	241.67
387.00	3617	361.67
390.00	3667	366.67
400.00	3833	383.33
418.00	4133	413.33
433.92	4399	439.87
470.00	5000	500.00

Table 2. Maximum Levels for Non-Periodic or Continuous Intentional Radiators

Calculation Formulas for Table 2:

Radiated Power @ 3 meters is a function of:

$E = 16.6667 \times F - 2833.3333 \mu V/m$

where F is frequency in MHz

Harmonic Amplitudes must be attenuated by at least 20dB below the carrier level.

Where:

$H = E - 20dB$ (volts) or $H = E/10$

European Standards for Transmitters

The following regulations may be referenced to the European Regulatory Commission (ERC) document CEPT/ERC/70-03. This document defines the regulations for operation at 433MHz and 868MHz. Test methods and signal level limits are defined in ETSI-EN-300-220.

The summary of regulations will be based on system requirements at 433MHz, no specified channel spacing for a wide band transmit signal. Wide band is defined at a transmitter modulated band with greater then 25kHz.

Conditions:

1. Class 1e operation from 433.050MHz to 434.790MHz
2. No system channel spacing specified
3. Tests are performed with a spectrum analyzer set for RBW = 100Hz and VBW = 10kHz
4. Modulation is AM/ASK

Regulations:

1. Maximum power allowed is 10mW (conducted and referenced to 50Ω).
2. When the transmitter is operational, the maximum spurious (and harmonic) emission limit is –36dBm (conducted and referenced to 50Ω).
3. When the transmitter is stand-by mode, the maximum spurious (and harmonic) emission limit is –57dBm (conducted and referenced to 50Ω).
4. Frequency Error (transmit center frequency) is not regulated in systems with no specified channel spacing (however, the modulated signal bandwidth must remain inside the band limits of 433.050MHz to 434.790MHz).

5. Transmitter band width is greater then 25kHz, but less then the width of the 433.050MHz to 434.790MHz band.
6. The transmitter shall either stay on frequency or cease operation when power supply level reduced from the operating voltage to zero.

Japanese Standards for Transmitters

For the actuation application market the allowed power levels in Japan (Figure 16) are much less then the United States (FCC) and Europe (ETSI). The same applies for harmonics and spurs. At three meters, and up to 320MHz, the maximum power allowed is 54dBμV/m (approximately -41dBm), and above 320MHz the maximum power, harmonics and spurs allowed is 31 dBμV/m (approximately -64dBm). There are other regulations specific for other applications such as the Arib one, where higher power levels are allowed.

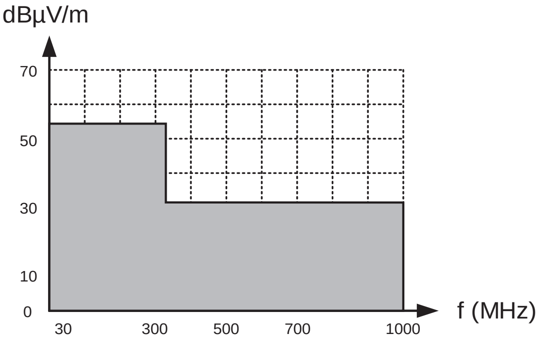


Figure 16. Power Levels for Japanese Regulation

Product Briefs

MICRF112

300MHz to 450MHz +10dBm ASK/FSK Transmitter

General Description

The MICRF112 is a high performance, easy to use, single chip ASK / FSK Transmitter IC for remote wireless applications in the 300MHz to 450MHz frequency band. This transmitter IC is a true “data-in, antenna-out” monolithic device.

MICRF112 is high performance in three areas: power delivery, operating voltage, and operating temperature. In terms of power, the MICRF112 is capable of delivering +10dBm into a 50Ω load. This power level enables a small form factor transmitter (lossy antenna) such as a key fob transmitter to operate near the maximum limit of transmission regulations. In terms of operating voltage, the MICRF112 operates from 3.6V to 1.8V. Many transmitter ICs in the same frequency band stop operating below 2.0V. The MICRF112 will work with most batteries to the end of their useful limits. In terms of operating temperature, the MICRF112 operates from -40°C to +125°C. This wide operating temperature range makes MICRF112 an ideal candidate for the demanding applications such as a tire pressure monitoring system.

The MICRF112 is easy to use. One only needs a reference frequency (RF carrier frequency divided by 32 times) generated from a crystal with a few additional external parts to create a complete versatile transmitter.

The MICRF112 operates with ASK/OOK (Amplitude Shift Keying/On-Off Keyed) UHF receiver types from wide-band super-regenerative radios to narrow-band, high performance super-heterodyne receivers. The MICRF112’s maximum ASK data rate is 50Kbps (Manchester Encoding). It operates with FSK receivers as well. The chip is designed to support narrow band FSK (Frequency Shift Modulation) by switching an external capacitor in parallel with the reference crystal. The MICRF112’s maximum FSK data rate is 10kbps.

- Complete UHF transmitter
- Frequency range 300MHz to 450MHz
- Data rates up to 50Kbps ASK, 10Kbps FSK
- Output Power to 10dBm
- Low external part count
- Low standby current <1µA
- Low voltage operation (down to 1.8V)
- Operate with crystals or ceramic resonators

MICRF113

300MHz to 450MHz +10dBm ASK Transmitter in SOT23-6

General Description

The MICRF113 is a high performance, easy to use, single chip ASK Transmitter IC for remote wireless applications in the 300MHz to 450MHz frequency band. This transmitter IC is a true “data-in, antenna-out” monolithic device. The MICRF113 has three strong attributes: power delivery, operating voltage and operating temperature. In terms of power, the MICRF113 is capable of delivering +10 dBm into a 50Ω load. This power level enables a small form factor transmitter (lossy antenna) such as a key fob transmitter to operate near the maximum limit of transmission regulations. In terms of operating voltage, the MICRF113 operates from 1.8V to 3.6V. Many transmitter ICs in the same frequency band stop operating below 2.0V. The MICRF113 will work with most batteries to the end of their useful limits. In terms of operating temperature, the MICRF113 operates from -40°C to +85°C.

The MICRF113 is easy to use. It requires a reference frequency (RF carrier frequency divided by 32 times) generated from a crystal with a few additional external parts to create a complete versatile transmitter.

The MICRF113 operates with ASK/OOK (Amplitude Shift Keying/ On-Off Keyed) UHF receiver types from wide-band super-regenerative radios to narrow-band, high performance super-heterodyne receivers. The MICRF113’s maximum ASK data rate is 10Kbps (Manchester Encoding).

The MICRF113 transmitter solution is ideal for industrial and consumer applications where simplicity and form factor are important.

- Complete UHF transmitter
- Frequency range 300MHz to 450MHz
- Data rates up to 10Kbps ASK
- Output Power to 10dBm
- Low external part count
- Low voltage operation (down to 1.8V)
- Operate with crystals or ceramic resonators

MICRF219

300MHz to 450MHz ASK Receiver with Auto-Polling

General Description

The MICRF219 is a 300MHz to 450MHz super-heterodyne, image-reject, RF receiver with Automatic Gain Control, OOK/ASK demodulator and analog RSSI output. The device integrates Auto-Poll, Valid Bit-Check, Squelch and Desense features. It only requires a crystal and a minimum number of external components to implement. It is ideal for low-cost, low-power, RKE, TPMS, and remote actuation applications.

The MICRF219 achieves -110dBm sensitivity at a data rate of 1Kbps (Manchester encoded). Four demodulator filter bandwidths are selectable in binary steps from 1625Hz to 13kHz at 433MHz, allowing the device to support data rates to 10Kbps. The device operates from a supply voltage of 3.0V to 3.6V, and consumes 4.0mA of supply current at 315MHz and 6.0mA at 433.92MHz. A shutdown mode reduces supply current to 0.5uA. The Auto-Polling feature allows the MICRF219 to sleep and poll for user defined periods, thus further reducing supply current. The Valid Bit-Check feature, when enabled in Auto-Poll mode, fully awakes the receiver and sends bits to the microcontroller once a valid number of bits are detected. During normal operation an optional Squelch feature disables the data output until valid bits are detected. An optional Desense feature reduces gain by 6dB to 42dB, distancing the receiver from distantly placed, undesired transmitters.

- –110dBm Sensitivity at 1Kbps with BER 10E-02
- Supports Data Rates up to 10Kbps at 433.92MHz
- 25dB Image-Reject Mixer
- No IF Filter Required
- 60dB Analog RSSI Output
- 3.0V to 3.6V Supply Voltage Range
- 4.0mA Supply Current at 315MHz (continuous receive)
- 6.0mA Supply Current at 434MHz (continuous receive)
- 0.5uA Supply Current in Shutdown Mode
- Optional Auto-Polling (sleep mode, current < 0.1mA)
- Optional Valid Bit-Check in Auto-Poll Mode
- Optional Programmable 6dB to 42dB Desense
- Optional Data Output Squelch until Valid Bits Detected
- 16-pin QSOP (4.9mm x 6.0mm)
- 2kV HBM ESD Rating

MICRF221

3.3V, QwikRadio® 850MHz to 950MHz Receiver

General Description

The MICRF221 is a third generation QwikRadio® receiver, offering all the benefits of Micrel's earlier QwikRadio® products with significant improvements, including: enhanced sensitivity, automatic duty-cycle feature and RSSI output.

The MICRF221 is a super-heterodyne receiver, designed for OOK and ASK modulation. The down-conversion mixer also provides image rejection.

The MICRF221 receiver provides a SLEEP Mode for duty-cycle operation and an enhanced, customer programmable "WAKE" function. These features are further combined into a wholly integrated "self-polling" scheme that is ideal for low and ultra-low power applications, such as RKE and RFID.

All post-detection data filtering is provided on the MICRF221 receiver. Any one of four filter bandwidths may be selected externally by the user in binary steps, from 1.25kHz to 10kHz. The user needs only to program the device with a set of easily determined values based on data rate, code modulation format, and desired duty-cycle operation.

- Complete Receiver on a Chip
- -109dBm Sensitivity, 1Kbps and BER 10E-02
- Image Rejection Mixer
- 850MHz to 950MHz Frequency Range
- Low Power, 9mA @ 868 MHz, Continuous on
- Data Rates to 10Kbps (Manchester Encoded)
- Auto Polling (sleep mode, current < 0.1 mA)
- Analog RSSI Output
- Programmable "Low Sensitivity" mode
- No IF Filter Required
- Excellent Selectivity and Noise Rejection
- Low External Part Count
- Additional Functions Programmed through Serial Interface

MICRF302

RF Remote Control Packet Generator

General Description

The MICRF302 RF remote packet generator translates push-button closures into Manchester encoded packets, greatly reducing design time and replacing the need for a costly microcontroller. It is ideal for cost-sensitive, one-way remote control applications such as Home Automation, lighting control, fan control, thermostats, RKE and Garage Door Openers. The MICRF302 is designed to easily connect to Micrel's family of low-power, low-cost, 300MHz to 1GHz, ASK RF transmitters, such as the MICRF112 or MICRF113. Each MICRF302 contains a 20-bit Poly-Fuse Progammable Read-Only Memory (PPROM) which is programmed at the factory and offers over 1 Million unique addresses. A pair of logic-level inputs allows the device to be set to support data rates of 0.6, 1.0, 3.0 or 4.8kbps. The internal clock requires no external components and maintains an accuracy of +/- 10%. Four logic-level input pins support 1 to 15 external switches. Upon any switch closure, the device is immediately awoken from Standby Mode, a TX enable signal is sent to awake the accompanying transmitter, and a Manchester encoded packet is generated. Each packet includes a pre-amble, sync, address, data and an 8-bit Cyclic Redundancy Check (CRC) which allows the decoder to check for errors in the packet. Each packet is transmitted 4 times to improve the probability of a received signal. After transmission the device is immediately placed in low-power standby mode. The MICRF302 consumes 0.3uA in standby mode and 130uA during operation from a 1.8V to 3.6V power supply.

- Factory programmed 20-bit address with >1M unique addresses
- 4 push-button switch inputs supports 1 to 15 switches
- Manchester Encoded Packets
- 8-bit Cyclic Redundancy Check (CRC)
- Selectable data rates of 0.6, 1.0, 3.0 and 4.8kbps
- Internal clock generation requires no external components
- 0.3uA current consumption in Standby Mode
- 130uA current consumption during operation
- 1.8V to 3.6V Supply Voltage Range

MICRF505/ MICRF505L /MICRF506

433MHz, 868MHz and 915MHz ISM Band Transceiver

General Description

The MICRF505, MICRF505L, and MICRF506 are true single chip, frequency shift keying (FSK) transceiver intended for use in half-duplex, bidirectional RF links. The multi-channeled FSK transceiver is intended for UHF radio equipment in compliance with the North American Federal Communications Commission (FCC) part 15.247 and 249, as well as the European Telecommunication Standard Institute (ETSI) specification, EN300 220.

The transmitter consists of a PLL frequency synthesizer and a power amplifier. The frequency synthesizer consists of a voltage-controlled oscillator (VCO), a crystal oscillator, dual modulus prescaler, programmable frequency dividers, and a phase-detector. The loop-filter is external for flexibility and can be a simple passive circuit. The output power of the power amplifier can be programmed to seven levels. A lock-detect circuit detects when the PLL is in lock. In receive mode, the PLL synthesizer generates the local oscillator (LO) signal. The N, M , and A values that give the LO frequency are stored in the N0, M0, and A0 registers.

The receiver is a zero intermediate frequency (IF) type which makes channel filtering possible with low-power, integrated low-pass filters. The receiver consists of a low noise amplifier (LNA) that drives a quadrature mixer pair. The mixer outputs feed two identical signal channels in phase quadrature. Each channel includes a pre-amplifier, a third order Sallen-Key RC low-pass filter that protects the following switched-capacitor filter from strong adjacent channel signals, and a limiter. The main channel filter is a switched-capacitor implementation of a six-pole elliptic low pass filter. The cut-off frequency of the Sallen-Key RC filter can be programmed to four different frequencies: 100kHz, 150kHz, 230kHz, and 340kHz. The I and Q channel outputs are demodulated and produce a digital data output. The demodulator detects the relative phase of the I and the Q channel signal. If the I channel signal lags behind the Q channel, the FSK tone frequency is above the LO frequency (data ‘1’). If the I channel leads the Q channel, then the FSK tone is below the LO frequency (data ‘0’). The output of the receiver is available on the DataIXO pin. A receive signal strength indicator (RSSI) circuit indicates the received signal level.

Selection Guide

RF Remote Packet Generator

Device	Data Rate	Internal Address	Address Combos	CRC	Supply Current	Supply Current	Temperature Range	Package
MICRF302	<4.8Kbps	20-bit	>1M	8-bit	130µA	1.8V to 3.6V	-40°C to +85°C	MLF®-10 (2.5mm x 2.5mm)

RF Transmitters (QwikRadio® and RadioWire®)

Device	Frequency Range	Modulation	Data Rate/ Modulation	Output Power	Supply Current	Supply Voltage	Temperature Range	Package
MICRF405	290MHz to 980MHz	ASK FSK	<200Kbps FSK <50Kbps ASK	+10dBm	18mA	2.2V to 3.6V	-40°C to +125°C	MLF®-24 (4mm x 4mm)
MICRF113	300MHz to 450MHz	ASK OOK	<10Kbps	+10dBm	12.3mA	1.8V to 3.6V	-40°C to +125°C	SOT-23-6 (2.8mm x 2.8mm)
MICRF112	300MHz to 450MHz	ASK FSK	<50Kbps ASK <10Kbps FSK	+10dBm	8.5mA 12.5mA	1.8V to 3.6V	-40°C to +125°C	MSOP10 (3.0mm x 4.9mm)

RF Receivers (QwikRadio®)

Device	Frequency Range	Modulation	Maximum Data Rate	Sensitivity	Supply Current	Supply Voltage	Temperature Range	Package
MICRF221	850 to 950MHz	ASK/OOK	<10Kbps	-109dBm@1Kbps	9.0mA	3.0V to 3.6V	-40°C to +105°C	QSOP-16 (4.9mm x 6.0mm)
MICRF219	300 to 450MHz	ASK/OOK	<10Kbps	-110dBm@1Kbps	4.0mA	3.0V to 3.6V	-40°C to +105°C	QSOP-16 (4.9mm x 6.0mm)
MICRF218	300 to 450MHz	ASK/OOK	<10Kbps	-110dBm@1Kbps	5.5mA	3.0V to 3.6V	-40°C to +105°C	QSOP-16 (4.9mm x 6.0mm)
MICRF213	300 to 350MHz	ASK/OOK	<7.2Kbps	-110dBm@1Kbps	3.9mA	3.0V to 3.6V	-40°C to +105°C	QSOP-16 (4.9mm x 6.0mm)

RF Receivers (QwikRadio®)

Device	Frequency Range	Modulation	Maximum Data Rate	Sensitivity	Supply Current	Supply Voltage	Temperature Range	Package
MICRF211	380 to 450MHz	ASK/OOK	<10Kbps	-110dBm@1Kbps	6.0mA	3.0V to 3.6V	-40°C to +105°C	QSOP-16 (4.9mm x 6.0mm)

RF Transceivers (RadioWire®)

Device	Frequency Range	Modulation	Maximum Data Rate	Sensitivity	Output Power	Supply Current	Supply Voltage	Temperature Range	Package
MICRF505	850 to 950MHz	FSK	<200Kbps	-111dBm@2.4Kbps	+10dBm	13.5mA Rx 28mA Tx	2.0V to 2.5V	-40°C to +85°C	MLF®-32 (5mm x 5mm)
MICRF505L	850 to 950MHz	FSK	<200Kbps	-111dBm@2.4Kbps	+10dBm	13.5mA Rx 28mA Tx	2.25V to 5.5V	-40°C to +85°C	MLF®-32 (5mm x 5mm)
MICRF506	410 to 450MHz	FSK	<200Kbps	-113dBm@2.4Kbps	+11dBm	12.0mA Rx 21.5mA Tx	2.0V to 2.5V	-40°C to +85°C	MLF®-32 (5mm x 5mm)

RF Transceiver Modules

Device	Frequency Range	Modulation	Maximum Data Rate	Sensitivity	Output Power	Supply Current	Supply Voltage	Temperature Range	Package
MICRF600	902 to 928MHz	FSK	<20Kbps	-111dBm@2.4Kbps	+9dBm	13.2mA Rx 28mA Tx	2.0V to 2.5V	-20°C to +75°C	11.5 x 14.1
MICRF610	888 to 870MHz	FSK	<15Kbps	-111dBm@2.4Kbps	+8.5dBm	13.6mA Rx 26mA Tx	2.0V to 2.5V	-20°C to +75°C	11.5 x 14.1
MICRF620	430 to 440MHz	FSK	<20Kbps	-110dBm@2.4Kbps	+10dBm	12mA Rx 23mA Tx	2.0V to 2.5V	-20°C to +75°C	11.5 x 14.1

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