



## RESEARCH ARTICLE

# Design RF Frontend Unit to Avoid Intermodulation Using Arduino Uno

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## ABSTRACT

Designing a radiofrequency (RF) frontend is vastly realized for determining the level of integration that is required in the signal chain inside the receivers to be idealistic. The receivers are susceptible to harmful intermodulation due to nonlinear RF frontends. In this paper, intermodulation distortion is avoided by a selective prototype hardware design of RF fort end which is connected with the Arduino Uno for controlling the power levels or automatic level control. The measurements are tested out as a result of injecting a signals within x-band frequencies and chosen different power levels are assumed. These measurements are revealed an accepted results for the intermodulation avoidance.

**Keywords:** Frontend, intermodulation, automatic level control, X-band receiver, Arduino Uno

## INTRODUCTION

An RF frontend is a device or module that incorporates all the circuitries between the antenna and at least one mixing stage of a receiver and possibly the power amplifier of the transmitter. It is used in a wide variety of RF products and applications such as conventional communication systems, radar systems, and Electronic Warfare systems (EW). RF hardware challenges for the applications of joint communication and radar sensing are studied.<sup>[1]</sup> The development of designing the frontend module has attracted in the recent years in modern communication and radar systems at X-band frequencies as a targeted this band due to its prospective opportunities for research related to new forthcoming applications, also it is consider a good candidate band for the detection of normal size objects in radar applications.<sup>[2-4]</sup> There are several approaches to combine a radar systems and communication systems. One can use an existing radar system and add communication functionalities.<sup>[5]</sup> The receiver chain in such systems is suffered from the intermodulation products which they effect receiver operation, since in a nonlinear circuit, a two mixed signals can cause a product of intermodulation distortion. The intermodulation produced when high power signal passed through an uncontrolled level gain amplifier and mixers and the generated unwanted frequencies which are confused the receiver to get real information about the target and give a false alarm, the avoidance of this undesired phenomenon is essential by proposing an achievable schemes a design of frontend circuits.<sup>[7,8]</sup> The frontend is collaborated with Arduino for controlling and interfacing data as good result can be attained.<sup>[9]</sup> This paper proves that Arduino Uno with a digital

variable attenuator in x-band can keep the input level signal with the acceptable range that is required before entering down frequency converter unit. To avoid the intermodulation problem, which is vital at high-power signal input to the mixer in RF down convertor, the automatic level control circuit is needed to be keeping the signal on a certain level. Therefore, digital variable attenuator (DVA) is used and it is controlled by the digital word. The digital word is generated by Arduino Uno according to the readout of the power level of the signal from the alarm circuit.

## Microwave Receivers

In this section, the most common traditional radio receiver architectures are presented.<sup>[10]</sup> Figure 1 shows microwave receiver block diagram. The major difference between electronic warfare receiver (EWR) and other conventional receivers is that their input signals are unknown. In addition to the complexity of the signal, EWR deliberately keeps some of

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the input signals in covert mode to inhibit detection, because it is desirable to obtain as much information as possible from the electronic order of battle (eob) in a very short period.

The requirements for EWR are becoming more demanding. The receiver must have a wide input bandwidth with fine frequency resolution, high sensitivity, and dynamic range to receive as many signals as possible. The receiver must also have the capacity to process simultaneous signals.

Furthermore, the receiver should be able to measure the angle of arrival (AOA) of the input signal.<sup>[11]</sup> The basic function of a radio front end is to take the modulated carrier signal from the antenna, amplify and down converter the signal, select the wanted channel, and finally extract the baseband information. From this point of view, a radio receiver does not appear to be very complicated. However, when considering that the signal could be very weak or very strong depending on how far from the transmitter the receiver is, or even worse when the wanted signal is very weak but another strong interferer (blocker) is present, then the true challenges of radio receiver design are brought into the light. There exist several different ways to build a receiver that takes care of all those issues in one way or the other.

**INTERMODULATION PROBLEM**

When a receiver provides only the frequency information and does not measure the amplitude information on the input signal, the dynamic range can be determined by its frequency measurement capability. Since the frequency measurement is considering to be the primary performance of an EW receiver, the dynamic range is often determined by this capability, even the receiver measures signal amplitude, under this situation, one may quote two dynamic ranges for the same receiver. One is related to its amplitude measurement capability and the other is related to frequency measurement capability. The lower limit of the dynamic range is usually defined as the weakest signal level where the measured frequency error is within a certain predetermined range, the upper limit of the dynamic range is the strongest signal level where the measured frequency error is within a certain predetermined range. If a strong signal is received, there are some components in the receiver become work in the nonlinear region, the additional signal may appear at the output of the receiver, for example, a mixer may be generating strong intermodulation product and an amplifier may produce second harmonics when they are saturated, often, the dynamic range of a receiver is referred to as the single-signal super-free dynamic range. With this dynamic range, if one signal is present at the input of the receiver, the receiver will not generate superior signals. Mathematically, the possible harmonics available at the mixer IF port are given by the equation: <sup>[12]</sup>

$$f_{IF} = nf_{LO} \mp mf_{RF} \quad (m \text{ and } n \text{ are all integers}) \quad (1)$$

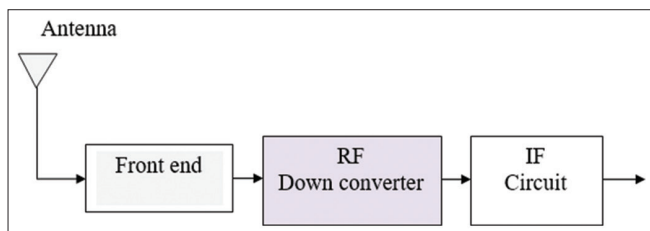


Figure 1: Microwave receiver block diagram

Because the only one desired output frequency (when  $n = 1$  and  $m = 1$ ), the existence of all other harmonic terms creates significant problems. Elimination of these distortion products is a key goal in mixer design.

**THE RF FRONTEND DESIGN**

The frontend unit has a very important function to keep the receivers operating in the linear region of the mixer and signal amplifiers behavior without entering the non-linear regions were to avoid generating unwanted frequencies that generated by intermodulation within the intermediate frequency working range, and to ensure that it operates within its operating frequency band, and to maintain signal levels entered at a specific and controlled level. Figure 2 shows the main elements of the frontend unit.

**Protection Unit**

The function of this unit as shown in Figure 3 is to protect the receiver from high-power level frequencies emitted from very close radars. The RF switch single-pole single-throw (SPST) is used to protect the system from any high-power signal, which is detected by the crystal detector (CD) after the input signal is amplified by low noise amplifier (LNA) 40 dB and efficiently integrating directional coupler (DC) circuitry with other circuit elements of an RF frontend, then sent to the alarm circuit passing through video amplifier (VA). This circuit measures the amplitude and creates an order to open the path when high power signal input. The path can be opened as given order with high priority from the alarm circuit when it senses a high-level signal present.

The total insertion loss in the protection units is stated in Table 1.

By the total gain of the protection, circuit can estimate the high-power signal before coming too close to our station and (switch off) disconnect the signal path to the receiver system. The order of switch-off is coming from the alarm electronic circuit which has a comparator circuit with a reference voltage

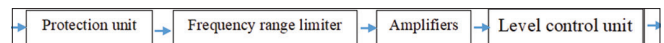


Figure 2: Main units of RF frontend block

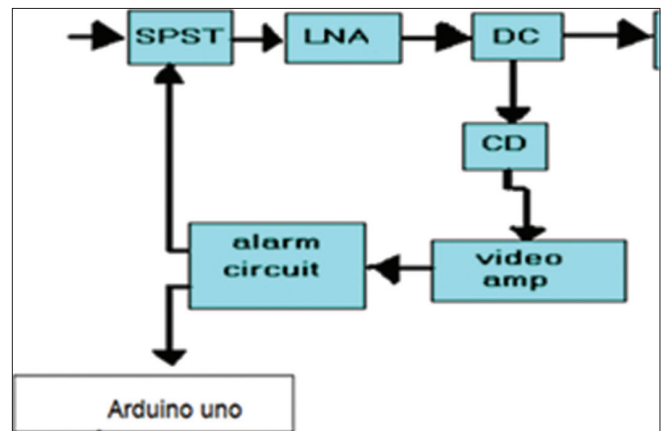


Figure 3: Protection unit block diagram

to produce logic high (1) or low (0) to switch on or off, and this circuit can be set manually to select the value of high power which consider high-power signal and must be stopped to pass to the receiver. Therefore, we can consider the input signal with four different levels, as shown in Table 2.

Table 2 shows that the signal level higher than (0 dBm) must be stopped to keep the RF components in the frontend woke in safe and not exceed input signal higher than 1 Watt.<sup>[13]</sup> The alarm circuit has a function when high input power is present, the function of this circuit is to generate a digital word (3 bits), which sends the command to the RF switch (in frontend unit) to stop the running signals in the system. The input level signal will compare with the known reference level, which is representing the maximum level can the system handling with. According to that level, the order will be for a pass then no pass to the signal or the switch ON then OFF order.

The digital word has high priority and is independent whatever the mode of the scan or search in processing. So that, the output of this circuit will be connected to (OR gate) and other input will be supplied from Arduino Uno to stop the running signal in the system. The state of the comparator output will feed Arduino Uno to know why the system is halt and give the order to running again later. Figure 4 depicts the main block diagram of the alarm system.

### Frequency Range Limiter

Acceding to the design consideration, the frontend work with X-band, the bandpass filter will pass only the frequencies between 8 and 12 GHz and stop or reject all frequencies out of that range, Figure 5 shows the characteristic of the filter which attenuates out the band of frequencies within 70 dB power range.<sup>[14]</sup>

### RF Amplifiers

The preamplifier is a one type of the amplifiers in frontend block diagram which is used to improve the signal level that it is lost part of power in the RF path due to the insertion loss of

the elements and cables. This type of amplifier prefers to be a limiter amplifier. The specifications of this amplifier are shown in Table 3.<sup>[15]</sup>

Figure 6 shows the characteristic behavior of the amplifier that can cover all the bandwidth with the gain around 30 dB and noise figure around 3 dB.

### Automatic Level Control (ALC)

Because the EWR deals with unknown signal and different power signals, near and far sources of the signal. ALC circuit has a function, which is adding the RF path, attenuation as requested according to the level required to down frequency convertor. This circuit sends a word to the digital attenuation needed to add, which will do according to Table 4. B0, B1, B2, B3, and B4 are the binary bits that must be generated from Arduino Uno according to the input level measuring. The ALC can receive the value that needed for attenuation from the alarm circuit which sends overflow indication to the processor or direct from the processor after measuring the amplitude of the signal. Then, it will send an order to control on a certain level. In this way, the close loop of ALC is satisfied.<sup>[16]</sup>

Table 4 shows the amount of insertion loss in the attenuator according to feeding digital word.

### INSERTION GAIN MEASUREMENT

It can measure the minimum signal level and maximum signal level within the consideration of design which gives trustworthy results at the output. Figure 7 demonstrates all the connected elements in the frontend with showing corresponding insertion gains.

So that for low-level signal, the DVA will be setting on 1.5 dB as attenuation which gives the net gain (NG).

$$NG = -0.1 + 40 - 1 - 2 + 35 - 1.5 - 1 = 69.4dB \quad (2)$$

For high-level signal

$$NG = -0.1 + 40 - 1 - 2 + 35 - 48 - 1 = 22.9dB \quad (3)$$

If it considers the frequency, down converter needs around -10 dBm signal level which gives the minimum signal detection (MSD) as in:<sup>[17]</sup>

$$MSD = -10 - 69.4 = -79.49dB \quad (4)$$

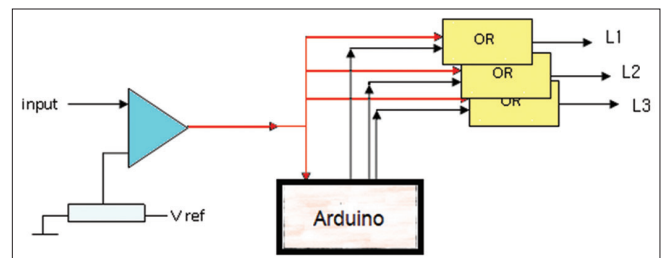
The results of the estimated input signal levels in Table 5 show obviously that the input level has the power greater than -30 dBm is stopped by the alarm circuit.

**Table 1:** Insertion loss of protection unit

Element	Insertion loss or gain (dB)
1 SPST	-0.1
2 LNA	+40
3 DC	-10
4 CD	-1
5 VA	+20
Total	58.9

**Table 2:** Input levels and measured levels at CD block

Level no.	Estimate input level	Level at CD
1	-70 dBm	-41.1 dBm
2	-50 dBm	-21.1 dBm
3	-10 dBm	-27.1 dBm
4	0 dBm	+28.1 dBm



**Figure 4:** Alarm circuit diagram

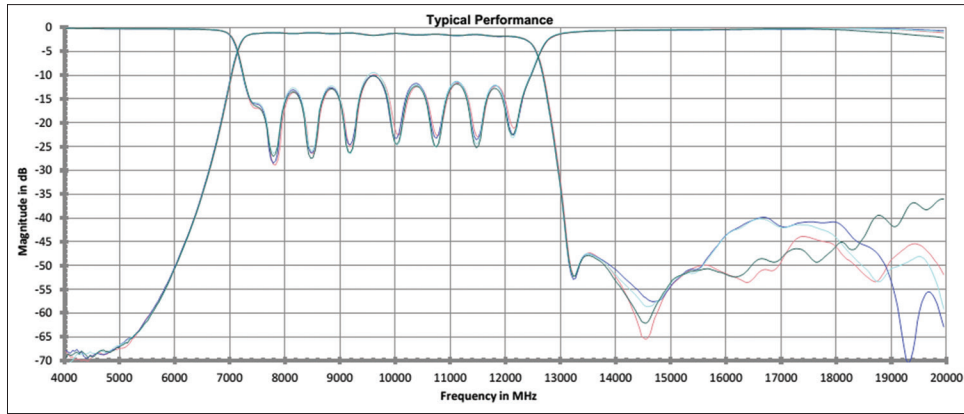


Figure 5: Characteristics of the bandpass filter

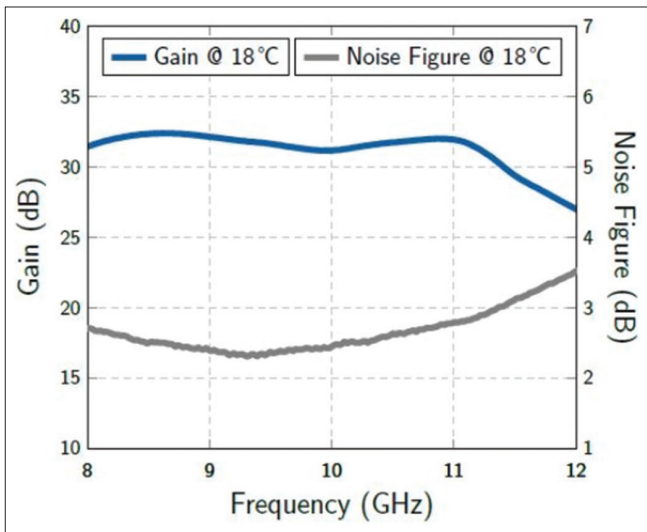


Figure 6: Characteristics of the small-signal amplifier.

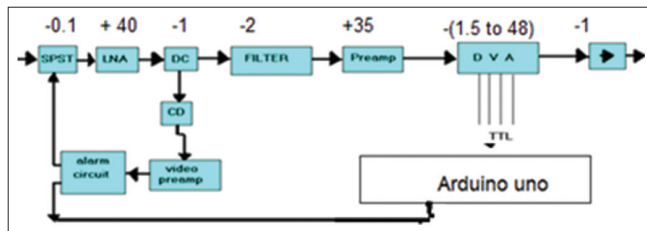


Figure 7: The frontend block diagram

### ARDUINO UNO CONNECTION AND PROGRAMMING

As shown in Figure 8 the connection of RF frontend to Arduino Uno for controlling the level of the signal and protect the circuit from a high-level signal as follows:

- The connection to SPST by three digital pins (2, 3, and 4) as output.
- The connection of video signal of alarm circuit by analog pin (A1) as input.
- The connection of digital variable attenuator (DVA) by four digital pins (13,12,11, and 10) as output.<sup>[18]</sup>

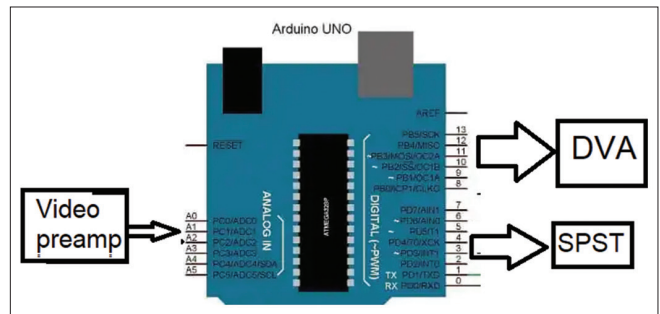


Figure 8: Arduino Uno connection

Table 3: Amplifier specification

	Specification	Description
1	Frequency band	8–12.4 GHz
2	Gain	35 dB
3	Noise figure	<4 dB
4	Max. output	+13 dBm
5	Impedance	50 ohm
6	Power supply	+15 volts 300 mA

The program was written by C++ programming with help of the Arduino simulator, and the following chart of programming is shown in Figure 9. The first block represents the initial setting to receive any weak signals so that pins (2, 3, and 4) must be logic high at the output to keep SPST in ON state, and pins (13,12,11, and 10) must be logic low to set DVA as minimum attenuating value (1.5 dB). The second block for reading the value of signal level and comparing with the reference level which is considered high signal level, that will be in the third block, the decision from the 4<sup>th</sup> block, if that level is high so the decision to stop receive the signal by setting pins (2, 3, and 4) high to change SPST to off, and waiting for time delay and change pins (2, 3, and 4) again. The setting of pins (13, 12, 11, and 10) according to the reading of analog port A1 and changing in logic level to get accept level at frequency down converter to avoid intermodulation problem.

**Table 4:** Insertion loss amount based on four generated bits

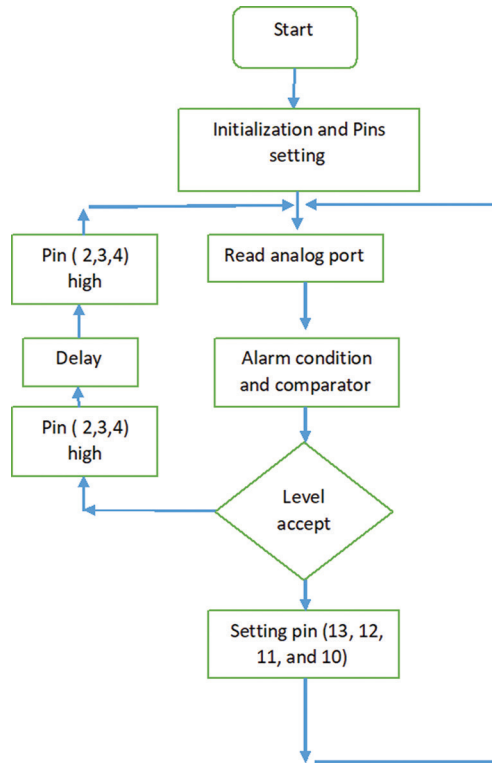
B4	B3	B2	B1	B0	IL (dB)
0	0	0	0	0	1.5
0	0	0	0	1	3
0	0	0	1	0	4.5
0	0	0	1	1	6
0	0	1	0	0	7.5
0	0	1	0	1	9
0	0	1	1	0	10.5
0	0	1	1	1	12
0	1	0	0	0	13.5
0	1	0	0	1	15
0	1	0	1	0	16.5
0	1	0	1	1	18
0	1	1	0	0	19.5
0	1	1	0	1	21
0	1	1	1	0	22.5
0	1	1	1	1	24
1	0	0	0	0	25.5
1	0	0	0	1	27
1	0	0	1	0	28.5
1	0	0	1	1	30
1	0	1	0	0	31.5
1	0	1	0	1	33
1	0	1	1	0	34.5
1	0	1	1	1	36
1	1	0	0	0	37.5
1	1	0	0	1	39
1	1	0	1	0	40.5
1	1	0	1	1	42
1	1	1	0	0	43.5
1	1	1	0	1	45
1	1	1	1	0	46.5
1	1	1	1	1	48

**Table 5:** The output powers based on the input powers

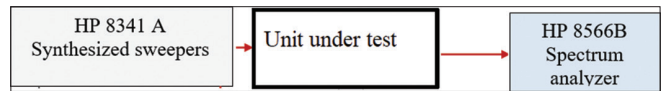
	Estimate input level	NG require	Level at frequency down converter
1	-70 dBm	60 dB	-10 dBm
2	-50 dBm	40 dB	-10 dBm
3	-40 dBm	30 dB	-10 dBm
4	-30 dBm	22.9 dB	-8 dBm
5	-27dBm	*	*

**TESTING AND RESULTS**

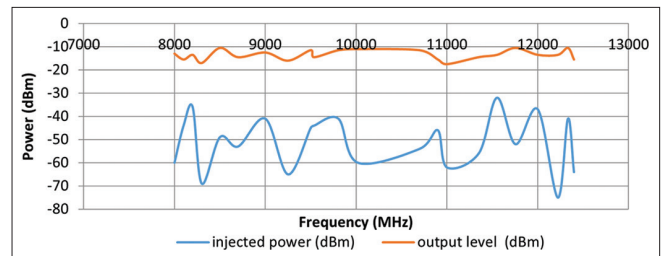
The test was done using Synthesized sweepers HP 8341 A as simulating the signal was injected to frontend units and out signal was measured by spectrum analyzer HP8566B, as shown in Figure 10.



**Figure 9:** Flowchart



**Figure 10:** The frontend laboratory testing



**Figure 11:** The injected signal and the output signal level

Figure 11 shows the input result within (-75—32) dBm and the output result within -10.5–17.5 dBm. These results will be accepted to avoid the intermodulation problem.

**CONCLUSION**

The measurement was done by injected signals to the frontend unit with different power levels and frequencies lies in x-band (8000 MHz–12,400 MHz). The results showed in Figure 11 are illustrated the output signal level appeared with the range (-10 dBm—17.5 dBm) and it indicates a good result to avoid the intermodulation distortion problem. The fluctuation at the output range depended on steps of DVA which is 1.5 dB per step. Furthermore, the time duration of processing gives the inversely proportional with the accuracy. The designed frontend unit can be used as an RF head for radar warning receiver (RWR) with a crystal detector.



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