Flexible Receiver Architecture for Pulse Doppler Radars

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Abstract:

This paper discuss about a flexible receiver architecture for pulse Doppler Radars. All Radars have a RF Receiver to receive weak target echo from antenna, amplify it, down convert to Intermediate Frequency (IF) and give to Signal Processor for extraction of target characteristics. Various schemes are adopted to design the receivers depending on the Radar operating frequency and the IF input required for signal processing. In this paper, a flexible receiver architecture is presented in which most of RF section of the receivers is common between various Radars except the front end. The front end does the down conversion of the incoming frequency to a common IF Signal.

Keywords:

Super heterodyne Receivers, Spurious, Image Frequency, Radar, Intermediate Frequency (IF), IMD, Local Oscillator, Front End

I. INTRODUCTION

Radars are used extensively for detection and tracking of targets. Operating frequency of a Radar is selected based on the detection accuracy and applications such as surveillance, tracking, imaging, fire control etc. Therefore, Radars are present across all the Radar frequency bands e.g. L, S, C, X etc.

The main function of the Radar receiver[1] is to receive weak echo from targets through antenna, amplify the weak echo, filter the unwanted frequencies and down convert the RF Signal to required IF. Super-heterodyne architecture followed by digital IF receiver is the most commonly used receiver architecture in present day Radars irrespective of the operating frequency bands. In digital IF receiver, the IF signal is converted into digital data using band pass sampling technique. Therefore, selection of the final IF, which is fed to digital IF receiver strongly depends on the availability of Analog to Digital Converters (ADC) with required dynamic range. The other intermediate frequencies of the RF receiver are chosen by spurious analysis and image rejection analysis for each mixing stage.

In this paper, a flexible receiver architecture for a pulse Doppler Radar is presented. The RF input frequency band of this architecture is chosen as S/C/X band throughout this paper. The receiver architecture is termed "flexible" due to its flexibility to use in any Radar frequency band and its modular nature of realization. Some stages of the receiver are kept common and reused across all the receivers with various RF input frequency bands keeping the final IF constant. The main advantage of this architecture is quick realization, faster implementation and reusability of IF stages among the various Radars. Section II describes super heterodyne receiver architecture followed by proposed flexible receiver architecture in Section III. Section IV shows spurious and image rejection analysis. Section V provides several concluding remarks.

II. SUPER HETERODYNE RECEIVER ARCHITECTURE

In super heterodyne receiver architecture[2], a Local Oscillator (LO) provides desired frequency band for down-converting the input RF to a fixed IF. If the IF is high enough so that it is not in the analog input range of an appropriate ADC, it can be further down converted to a lower frequency (typically VHF band). The lower frequency now can be sampled using an appropriate ADC. Super heterodyne receivers has got better selectivity, sensitivity, dynamic range and supports Doppler frequency extraction. Hence, this architecture is most popular for Radar applications. The generic block diagram of a double down conversion super heterodyne receiver architecture is shown in Fig. 1.

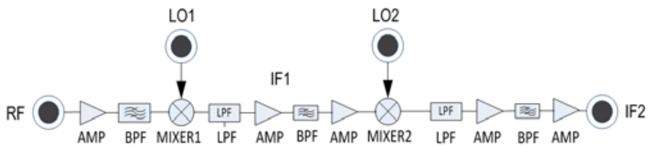

Fig. 1: Super heterodyne receiver architecture

The main drawback of super heterodyne receiver architecture is the rejection of image frequency for each mixing stage. This can be achieved either by filtering ahead of the mixer or by using an image rejection mixer.

III. FLEXIBLE RECEIVER ARCHITECTURE

The flexible Receiver Architecture[3] proposed in this paper is based on super-heterodyne receiver architecture. All the S/C/X band receivers can employ two stages of down-conversion to bring down the frequency from RF to final IF, which is typically at VHF range. The final IF is chosen in VHF range as many ADCs are commercially available with more than 70 dB dynamic range, which generally meets the receiver dynamic range requirements when used along with Sensitivity Time Control (STC) or Automatic Gain Control (AGC).

The RF inputs for S, C and X band receivers considered in this paper are 3.1-3.4 GHz, 5.4-5.9 GHz and 9.0-10.0 GHz respectively. In all the cases, 10% of RF bandwidth is considered as it is practically realizable by antenna subsystem. In first stage, RF inputs are down-converted to a common IF (IF1) of 1260 MHz and in second stage, the IF1 is down-converted to IF2 of 120 MHz. The two stage down conversion of the proposed architecture is shown in Fig. 2. Thus, the double conversion allows to obtain a reconfigurable multi-band receiver exploiting different front ends and a common IF receiver section.

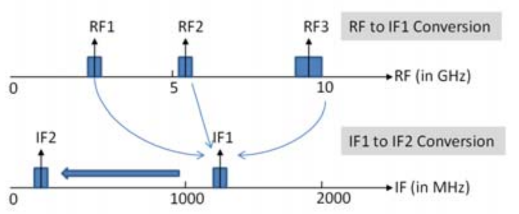

Fig. 2: Two stage down-conversion of proposed architecture

The block diagram of the proposed receiver architecture is shown in Fig. 3. This architecture has the flexibility of keeping the IF stages (IF1 and IF2) followed by digital IF processing stage common among the various frequency bands.

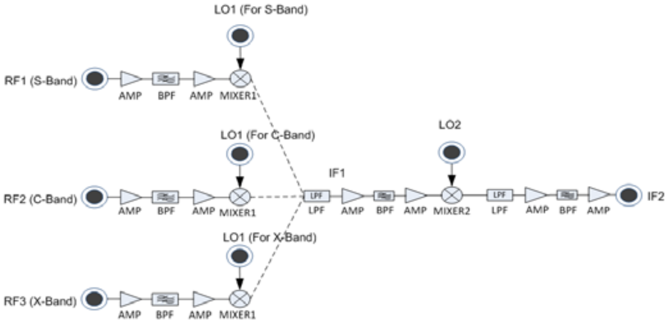

Fig. 3: Two stage down-conversion of proposed architecture

IV. ANALYSIS AND RESULTS

The most important parts of designing the flexible architecture are selection of LO1 and LO2. These are carried out primarily based on mixer spurious analysis[4] and image rejection analysis. These are described in the following sections.

A. *Spurious Analysis*

Heterodyne is a process of mixing two signals in a non linear device. In Radar receivers, Mixers are used for mixing RF signal with LO signal due to its non linear behaviour. Since, the mixing process happens in the non linear domain, the required RF Signal is present along with the other frequency components which are known as intermodulation products. This process can be mathematically represented by the equations given below:

$$V_{out} = f(V) = a_0 + a_1 V + a_2 V^2 + a_3 V^3 + \ldots\ldots\ldots + a_n V^n \ \ldots\ldots\ldots\ldots\ldots \text{Eq(1)}$$

$$V(t) = V_{RF} Sin(\omega_{RF} t) + V_{LO} Sin(\omega_{LO} t) \ldots\ldots\ldots\ldots\ldots \text{Eq(2)}$$

$$V_{out} = a_0 + a_1\{V_{RF} Sin(\omega_{RF} t) + V_{LO} Sin(\omega_{LO} t)\} + a_2\{\ \}^2 \ldots\ldots + a_n\{\ \}^n \ \ldots\ldots \text{Eq(3)}$$

Expanding the square term, we get

$$\frac{V_{RF}{}^2}{2}\{1 - \cos(2\omega_{RF} t)\} + \frac{V_{LO}{}^2}{2}\{1 - \cos(2\omega_{LO} t)\} +$$

$$V_{RF} V_{LO}\ \{\cos(\omega_{RF} - \omega_{LO})\, t - \cos(\omega_{RF} + \omega_{LO})\, t\} \ldots\ldots \text{Eq(4)}$$

The inter-modulation products generated by the mixing process is of the order of m+n (as shown in the nonlinear equation). The most critical inter modulation product is the 3rd order product as it provides the worst rejection performance among all products.

As explained in the previous section, the first down conversion stage is band specific and different for all frequency bands till the first mixer. It consists of RF components such as LNA for better Noise Figure, BPF for out of band interference rejection and amplifiers for boosting the input signal level. LO1 is decided based on the input frequency band where as LO2 is fixed.

Spurious Analysis is carried out for the first mixing stage for all the three frequency bands (S, C and X band) separately. Spur chart for first mixing stage for these are shown in Fig. 4, Fig. 5 and Fig. 6 respectively.

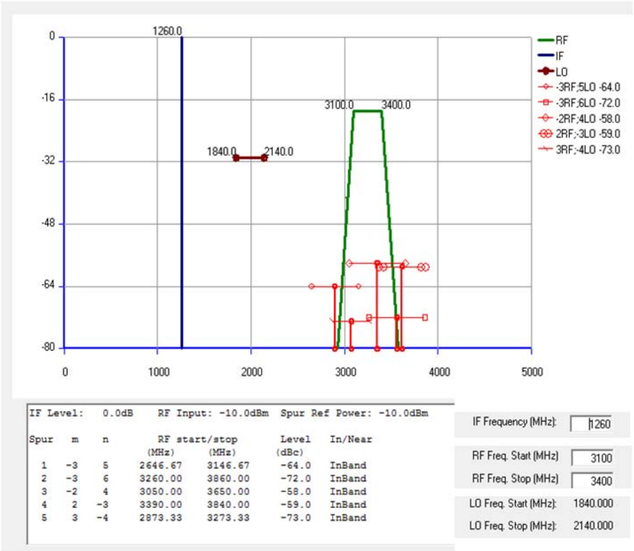

Fig. 4: Spurious analysis for S-Band receiver for mixing stage

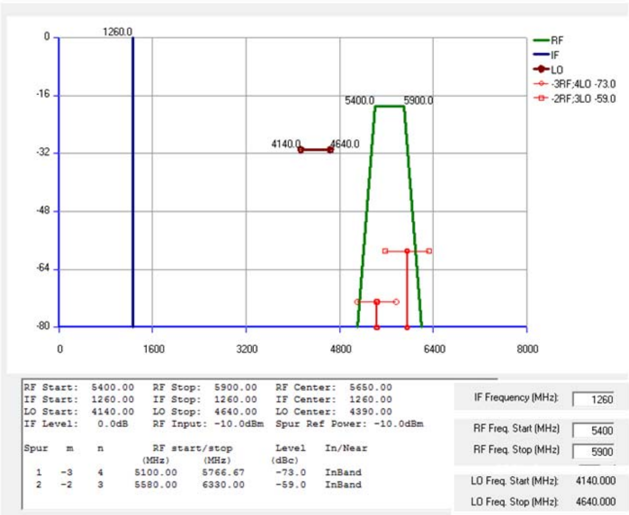

Fig. 5: Spurious analysis for C-Band receiver for first mixing stage

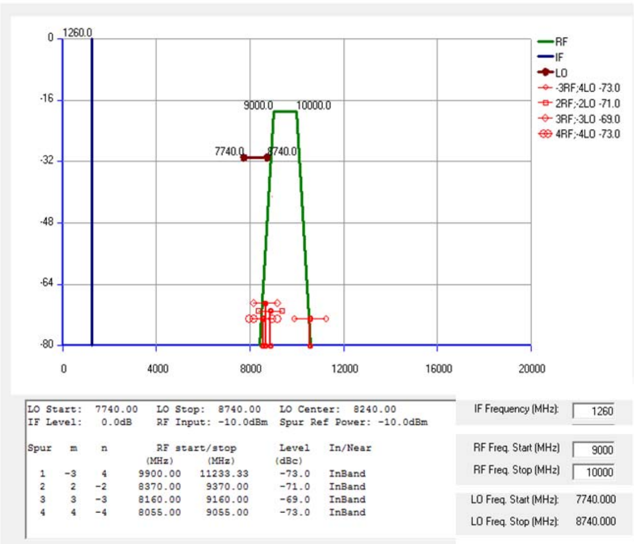

Fig. 6: Spurious analysis for X-Band receiver for first mixing stage

Spurious Analysis for the second mixing stage, which is common to all the receivers is shown in Fig. 7.

Fig. 7: Spurious Analysis for second mixing stage

Table1 shows the spurious analysis of three different frequency bands for the common IF stage. In general, mixers show good rejection characteristics for intermodulation products above 4th order. From Table1, it is clear that there is no 3rd Intermodulation product present in the passband for all the three frequency bands and other spurious will be suppressed significantly by the mixer itself. The worst case spurious is of 4th order. Suitable mixer must be chosen, which has better 4th order spurious rejection.

TABLE1
SPURIOUS ANALYSIS

RF Input Freq (GHz)	1st IF (MHz)	2nd IF (MHz)	Spurious (1st Mixer)	Spurious (2nd Mixer)
3.1-3.4	1260	120	(2,-3), (-2,4)	(2,-2)
5.4-5.9 GHz	1260	120	(-2,3), (-3,4)	(2,-2)
9.0-10.0 GHz	1260	120	(-2,-2), (3,-3)	(2,-2)

B. *Image Frequency Analysis*

Image frequencies are the frequencies which generates the same Intermediate Frequency when mixed with LO. The difference between the LO and RF is same as the difference between the LO and image frequency. After the selection of the LO frequencies, the image frequencies are calculated and feasibility for rejection of the image frequencies are carried out. Table 2 shows the image frequencies for the first and second mixing stages.

TABLE2
IMAGE FREQUENCIES FOR THE MIXING STAGES

RF Input Freq (GHz)	LO1 (GHz)	LO2 (GHz)	Image Freq 1 (GHz)	Image Freq 2 (GHz)
3.1-3.4	1.84-2.14	1.14	0.58-0.88	1.02
5.4-5.9	4.14-4.64	1.14	2.88-3.38	1.02
9.0-10.0	7.74-8.74	1.14	6.48-7.48	1.02

It can be observed from Table 2 that the image frequencies are sufficiently away from the RF input frequency and can be suppressed significantly using proper band pass filters.

V. CONCLUSIONS

This architecture works on a very simple principle. If the same Intermediate Frequency is used in all the receivers with different RF input frequencies, the down conversion stages can be common across all the receivers. The criticality of designing a flexible receiver architecture lies in the selection of LOs such that the spurious signals are rejected significantly and image frequencies are sufficiently away from the RF input frequency to have the best rejection.

This scheme helps in reducing the time spent in designing the receiver, reduces the cost of implementation and helps in better spare management. Moreover, this scheme has got the flexibility of keeping the digital IF section common among the various frequency bands.

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