The Effect of Pulse Signal Waveform on Bandwidth in Pulse Radar System

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***Abstract*—In this paper, we have investigated the effect of pulse waveform on bandwidth in pulse radar system. The correlation between the rise/fall times of the pulse signal and the bandwidth and the effect of the underdamped response on the bandwidth have been described. To efficiently manage spectrum for pulse radar system and to coexist other systems, rise /fall time should be considered for frequency bandwidth because the rise/fall times are dominant factor to decide the bandwidth of B_{-40dB}.**

***Keywords*—pulse radar, bandwidth**

I. INTRODUCTION

Radar is a system that emits an electromagnetic wave signal, receives a reflected wave coming back and forth from the target, and analyzes the received signal to determine information such as the distance, direction, and speed of the target. Radar systems work in a wide band of transmitted frequencies from 3MHz to 100GHz for various applications such as speed measurement, surveillance, navigation, image acquisition, meteorological observation etc. There are various kind of classifications of radar systems in different ways based on such as frequency, waveform, and applications.

Radar systems have generally been allocated in bands where they do not share with other radar systems and communication systems. But in recent years, the increasing demand for wireless communication services and radar systems leads to the consideration for sharing or coexistence between a radar system and other radar systems or wireless communication services in radar bands[1]-[3]. In the viewpoint of interference between radar systems, the frequency band around 9GHz is very congested with diverse radar applications. In the frequency-band which is called as X-band (8 to 12 GHz), the relationship between used wave length and size of the antenna is considerably better than in lower frequency-bands and the attenuation characteristic caused by propagation loss and precipitation loss is relatively better than higher frequency-bands. So this frequency band is popular radar band for many civilian applications like weather radars in aircraft, maritime civil navigation radars, Vessel Traffic System (VTS) radars, airport surveillance radars, and Synthetic Aperture Radar (SAR) imaging etc.

The pulse signal which is generated by magnetron or klystron is still used for the transmit signal in detection and surveillance radars such as weather radar and VTS radar which is requiring long range detection. In order to efficiently use and manage the frequency-bands and to minimize the interference between radar applications, the center frequencies of for each radar application which is used pulse signal as transmit signal in X-band are separated with specific designated frequency. By using different center frequency, the interference between radar applications has been minimized and managed in X-band. But recently, as the demand for various radar applications in X-band is increased, the necessity of specifying and managing the frequency band is more increasing.

In this paper, we describe the fundamental characteristics of pulse signal on the viewpoint of frequency bandwidth to specify and manage these frequencies. First, the various bandwidth definitions made in ITU-R are described. Next, the effect of pulse signal waveform on frequency bandwidths is described, such as rise/fall time and damping shape etc.

II. DEFINITION OF BANDWIDTHS FOR PULSE SIGNAL

In the pulse signal, pulse width is the time between 50% amplitude points, rise time is the time between 10% and 90% amplitude points and fall time is the time between the 90% and 10% amplitude points. Figure 1 shows the schematic of sample pulse signal for the pulse width (T), rise time (T_r), and fall time (T_f).

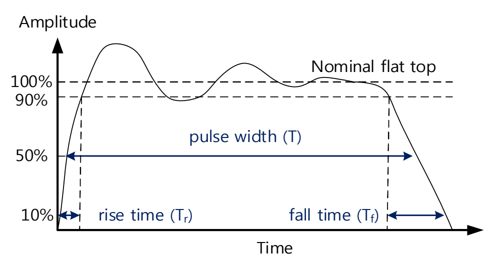

Fig. 1. Schematic of pulse signal for rise time, fall time, and width

Necessary bandwidth and occupied bandwidth are defined in the Radio Regulation Article 1 of ITU-R. The definitions of the terms is as follows.

- Necessary bandwidth (No. 1.152): For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions.

- Occupied bandwidth (No. 1153): The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage β/2 of the total mean power of a given emission. Unless otherwise specified in an ITU-R Recommendation for the appropriate class of emission, the value of β/2 should be taken as 0.5%.

The necessary bandwidth of the unmodulated pulse signal with either a trapezoidal or rectangular pulse shape is defined in in the recommendation ITU-R SM.853 as the value of 20dB

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below the peak of the theoretical envelope of the pulse spectrum[4].

Both necessary bandwidth and occupied bandwidth (OBW) are focused on the transmitting signals themselves. When a wanted signals for certain purpose are transmitted, unwanted signal also transmitted in adjacent frequency bands. To coexist with the service of the other frequency bands, the leaked unwanted emissions except in-band must be defined. The unwanted emission in adjacent bands is called as OoB (Out-of-Band) and the emission in the outside bands except the OoB are called as spurious emission. In the recommendation ITU-R SM.1541 is described the OoB domain for radar systems. The start of OoB domain is defined as 40dB below the peak power for pulsed radar systems[5]. In this paper, the bandwidths of 20dB and 40dB are nominated as B_{-20dB} and B_{-40dB} respectively. In the viewpoint of spectrum management, the required bandwidth of pulsed radar system must be the bandwidth of B_{-40dB} if coexistence with other systems is considered.

III. PULSE WAVEFORM AND SPECTRUM BANDWIDTH

In the radar system, the duty cycle is the ratio between period repetition interval (PRI) and pulse width (T), which means the ratio of the time that the transmission energy can be transmitted compared to the pulse repetition interval. In the general case of pulse radar, the pulse repetition interval is larger than the pulse width by more than tens of times. Therefore, from the viewpoint of the required frequency of the pulse radar, the frequency bandwidth could be calculated with a single pulse signal source. In this paper, we analyze the frequency bandwidth by assuming a single pulse instead of a repetitive pulse when calculating the frequency bandwidth.

A. *Effect of rise/fall time on Bandwidth*

The spectrum of a trapezoidal pulse signal is expressed as equation (1), when the pulse width is T and the rise/fall times are Tr, where A is the magnitude of the signal. Because trapezoidal pulse is the convolution the rectangular pulse with width T and the rectangular pulse with T_r, the spectrum in frequency is the product of sinc functions based on two pulse signals. So, the slope in logscale is 20dB/decade between $1/T$ and $1/T_r$, and that is 40dB/decade after $1/T_r$.

$$Envelope \quad = AT\left|\frac{\sin(\pi T f)}{\pi T f}\right|\left|\frac{\sin(\pi T_r f)}{\pi T_r f}\right| \qquad (1)$$

Figure 2 shows the waveform of the rectangular and trapezoidal pulses and figure 3 shows the spectrums of them expressed in logscale. Where, A=1, the pulse width is 1μs and rise/fall time is 0.1μs, and the spectrums of magnitude are normalized values to the peak power respectively.

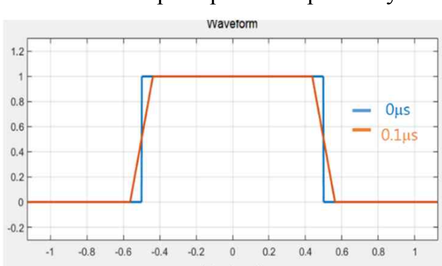


Fig. 2. Waveform of rectangular and trapezoidal pulse

In figure 4, the various bandwidths defined in chapter II according to the rise/fall time are expressed. B_{-20dB} and B_{-40dB} were calculated with reference to rec. ITU-R SM.1541. The results in figure 4 show that the trapezoidal pulse with rise and fall times require narrower bandwidths in B_{-20dB} and B_{-40dB} than ideal rectangular pulse. And, the occupied bandwidth is similar to B_{-20dB} in trapezoidal pulse signal. Typically the fall time of pulse signal is longer than the rise time. In figure 5, occupied bandwidth is shown according to the ratio fall time (T_f) and rise time (T_r). It makes predictable that the shorter time in both T_f and T_r is dominantly influenced by the bandwidth when the rise time and fall time is not equal.

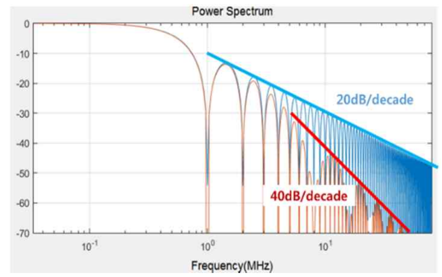


Fig. 3. Specrtrum of rectangular and trapezoidal pulse in logscale of frequency

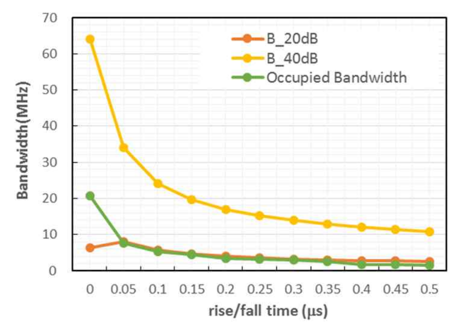


Fig. 4. The bandwidth according to the rise/fall time

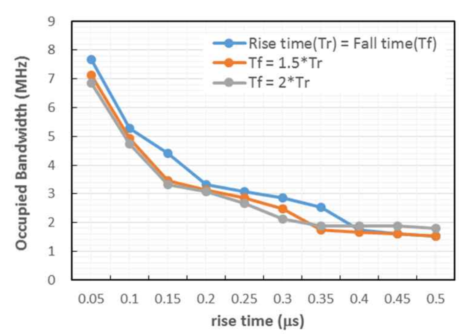


Fig. 5. The bandwidth according to the ratio of rise and fall time

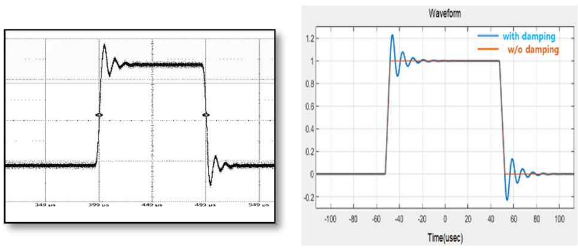
B. *Effect of underdamped response on Bandwidth*

When a pulse width is controlled using a physical hardware device made up of the components such as R, L, and C in the circuit, the output pulse signal generally has the unit step response of second-order system. Since a normal pulse signal has an underdamped response of second-order response, the damping signal has a specific damping frequency (ω_d) and an exponentially decreasing magnitude. This signal can be expressed as follows, where ξ is damping factor and ω_n is natural frequency of system.

$$y(t) = A\left(1 - \frac{1}{\sqrt{1-\xi^2}} e^{-\xi\omega_n t} \cdot \sin\left(\omega_n\sqrt{1-\xi^2}t + \phi\right)\right) \quad (2)$$

where $\omega_d = \omega_n\sqrt{1-\xi^2}$ and $\phi = \tan^{-1}\left(\sqrt{1-\xi^2}/\xi\right)$

For modeling the actual pulse signal, a pulse was generated using Keysight's signal generator (Model E4433B), and the characteristics of the pulse signal were extracted. The measured pulse wave using signal generator is shown in the figure 6. The pulse width is 100μs and the rise time and the fall time are measured as 3.3μs and 3.7μs, respectively. Based on the measured signal, the pulse waveform is modeled by adjusting the coefficient of equation (2).



(a) measured signal (b) modelled signal

Fig. 6. Waveform modeling from measured signal

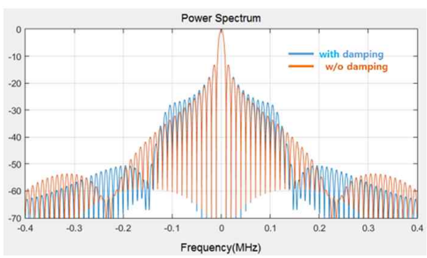


Fig. 7. The bandwidth according to the rise/fall time

In the figure 7, the compared the spectrums with and without damping are shown. The underdamped response leads to a change in spectrum, which can lead to a change in bandwidth. Because the shape of damping is decided with the component consisted of the pulse generating circuit, although we change the pulse width, the shape of damping is kept without deformation.

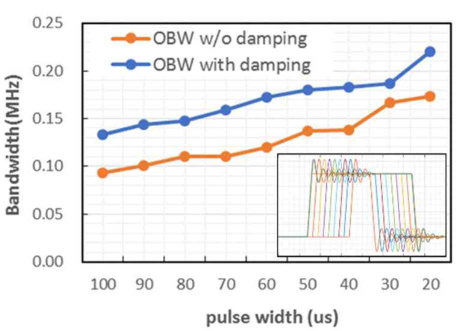


Fig. 8. OBW corresponding to pulse width with same damping shape

Figure 8 shows the change of the occupied bandwidth (OBW) corresponding to changing the pulse width with same damping shape. It shows that the OBW is increasing about 30% when the underdamped response is considered. In figure 9, the effect of damping ratio on OBW is shown. As damping ratio is increasing, the magnitude of overshoot is decreasing and the rise/fall times are increasing. It shows that the damping ratio under 0.5 has a considerable impact on bandwidth in underdamped response.

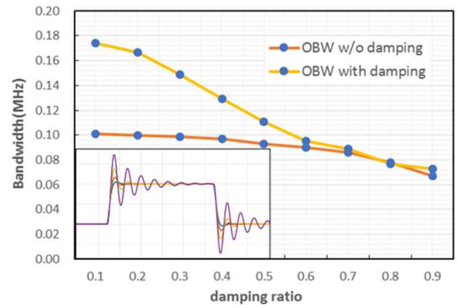


Fig. 9. OBW corresponding to different damping ratio

IV. Conclusion

In this paper, the effects of rise / fall times and underdamped response of pulse waveform on the frequency bandwidth have been investigated. Most of the radar systems that use pulse signals generally define pulse widths as system parameter, but rarely provide information about rise / fall times of pulse signals which is dominant to decide the bandwidths like B_{-20dB}, B_{-40dB} and OBW. Especially, B_{-40dB} which is the starting point of OoB is very important when considering interference with other systems or services. So, when designating and managing the frequencies of a specific radar system, rise and fall times should be considered as system parameters.

References

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