Development of New Radar Beacon

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Abstract

The restrictions concerning the use of the radio waves have become severe, the marine radar with low spurious is being developed. Therefore, it is necessary to develop aids to navigation as a radar beacon can respond to new type of marine radar. Because the system of radar in the future is an indetermination, new radar beacon should correspond to old and new radar system during a transition period. New radar beacon that is also able to respond to pulse radar, pulse compression radar and FM-CW radar were considered in these years in Japan.

The sign of the response of Morse code in a new system is generated by the delay synthesis system. Computer simulation and actual examination using trial circuit were curried out. A big possibility was set up in the development of the new radar beacon that was able to correspond to old and new radar system. These results and the state of new radar beacon is mentioned in this paper.

Keywords: radar, radar beacon, radio/communication regulation, navigational aids

1. Introduction

Recently, the restrictions concerning the use of the radio waves have become severe as the amount of equipment using radio waves spreads. In instruments for navigation, it is assumed that the influence of spurious of radar emission is large. Therefore, the radar with low spurious is developed, and it is necessary to develop as aids to navigation as a microwave beacon can respond to old and new type of marine radar.

As results of two years works and examinations in Japan[1], it can be confirmed that a microwave beacon that is also able to respond to new types of radar. The current state of new radar beacon in Japan is introduced in this paper.

2. Current state concerning marine radar

As for the radar installed by the ship, the performance standard is provided for by IMO and ITU. New types of radar that combine new signal processing technologies are expected, with transmitters that don't depend on magnetron source but are semiconductor based in order to meet the new severe ITU standard. The following three types of new radar are mainly considered now.

(1) Pulse compression radar
(2) FM-CW radar
(3) Encoding radar

3. Current state concerning radar beacon

The radar beacons used in Japan are currently divided roughly into the Ramark beacon and the radar beacon. Because present radar beacons do not correspond to the new type of radar shown above, there is a pressing need for development. The requirement was brought together in a development as follows.

(1) Range of radar type that new radar beacons respond

The system has not been decided at this stage, though the new radar system is examined from the point-of-view of dealing with the new severe spurious emissions restriction. Moreover, prior to all the standards uniting, and when various systems coexist during the transition, it should be assumed the system that can respond as widely as possible to both new and old radar types. It is also a requirement that no special devices are needed on the radar to enable detection of the beacons.

(2) Insertion of identification signal

It should be assumed there is a need for a system for inserting the identification signal that shows that it is a beacon station as well as a past radar beacon. Therefore, it is necessary to examine the technology that inserts the sign in a long pulse, which is used by pulse compression and the FM-CW system.

(3) Range of frequency that new radar beacons respond

It should be assumed the system can cover all or as much as possible of the X-band range for both past and present radar beacons.

(4) Consideration to spurious emissions and interference problem

It should be assumed the system for the radar beacon station minimizes spurious emissions that can cause jamming.

(5) Function and performance

It should be assumed the system possesses, as much as possible, the function and the performance of a current radar beacon.

A new radar beacon using the "Delay synthesis system" was selected as a system with the possibility of filling the above-mentioned requirement in the current surveillance study. Here, calculation simulation and test module experiments were carried out. The examination of a system implementation, a technical problem, and the solution means are continued in detail.

4. Design of new radar beacon

The result of examining the design of the new radar beacon that can correspond to the new type of radar is now described.

4.1 Considering about systems

The principle of operation of the new “all-encompassing” microwave beacon using a single reflector is considered. The outline is shown in Fig.4-1. Simple reflector can return every type of incidence wave with same wave shape. The equivalent circuit is a system that transmits radio wave as incidence wave. When time delay are including in transmission radio wave, it is recognized as signal distant more on radar display. There is a possibility that coded waves can be generated when two or more delay elements are combined.

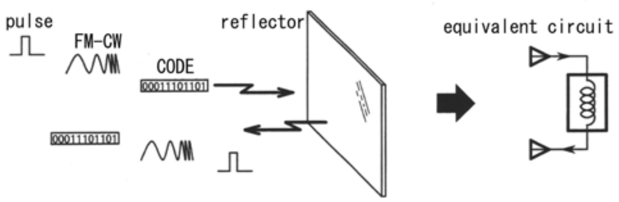


Figure 4-1.Concept of reflector action

The example of the delay element is shown in Fig.4-2 when the sign for the letter "K" (-.-) is generated to one input pulse. It is a composition in which two or more delay lines (unit delay blocks) corresponding to the input pulse are combined. A simple pulse of 0.5μs is assumed to be an input for Figure 4-2, and the output is assumed to have a short point of 1μs, and line length of 3μs.

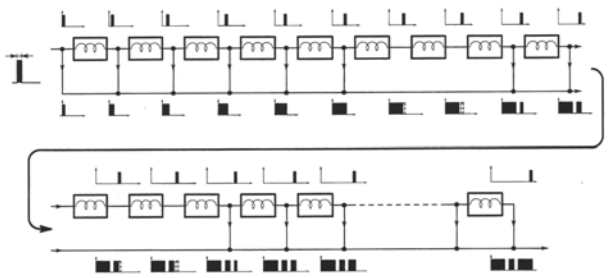


Figure 4-2.Concept of delay lines for sign "K"

There is a method of using an analog delay element and a digital method that achieves the delay. It is also possible that the analog form can treat a high frequency, and processes the radar frequency directly because of the wideband. However, the elements are very expensive, and it is not realistic to think that there will be much use of these delay elements to generate the coding. Moreover, the insertion loss is large and so combining and using two or more delay elements is a remote possibility from a technical perspective. On the other hand, a device that converts the radar signal to an intermediate frequency, where there is a narrow band, because the processing of a digital system in the radar frequency band is impossible may solve the problem. However, the circuit scale is also small and there is an advantage that agreed change etc. can be easily done only by rewriting software. Thus achievement by a digital method is made assumption thereafter.

4.2 Basic design

Concerning with basic design when the new radar beacon using the delay synthesis system is achieved with a digital circuit, the block diagram is shown in Fig.4-3.

The radar wave received with the antenna is amplified with a low noise amplifier (LNA), it mixes with the local oscillator (LO) signal using the mixer, and it converts it into the intermediate frequency etc. This signal is converted into a digital signal with the analog to digital converter, a delay and synthetic processing are achieved by the operation of devices such as FPGA (Field Programmable Gate Array), and the sign is generated. The signal is converted into analogue again with the digital to analog converter, and it returns it to the radar frequency band through use of a local signal. This is amplified up to a necessary output power with a power amplifier (PA), it transmits from the antenna, and it sends it back to the radar as a response wave.

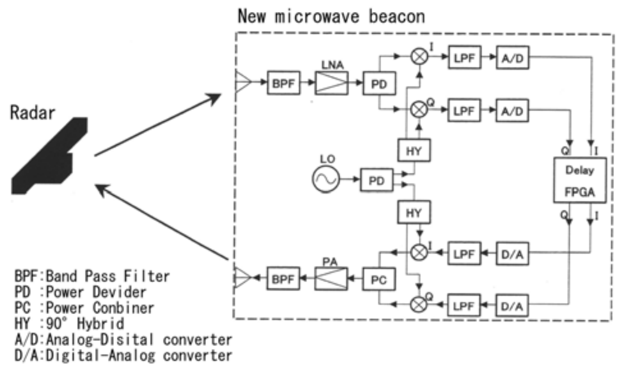


Figure 4-3.Block diagram of delay synthesis system radar beacon

Simulated result concerning the basic characteristic of the new radar beacon by the delay synthesis system is shown. However, ideal conditions are assumed here.

i) A transmission frequency of radar and the center frequency of processing of the new radar beacon are corresponding.

ii) The distance resolution of radar and the processing unit delay time of the new radar beacon are corresponding.

iii) The signal is not saturated in the new radar beacon system.

From the simulation, it was clarified that the delay synthesis system radar beacon was able to display the desired identification signal all the radar systems types under an ideal condition.

5. Measurement and evaluation of basic character istic

Results of varying the operating conditions are considered and the comparison of results from computer simulation and the prototype are shown in this chapter.

5.1 Interference problem

The close proximity of the reception antenna and the transmitting antenna on a microwave beacon can potentially cause interference problems (see Figure 5-1) with the transmitter potentially transmitting directly back to its own receiver. Therefore, the isolation, or lack of it, between the sending and receiving antennas can potentially cause abnormal operation

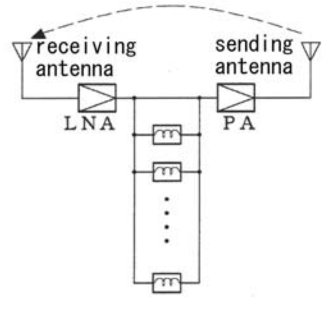


Figure 5-1.Interference problem

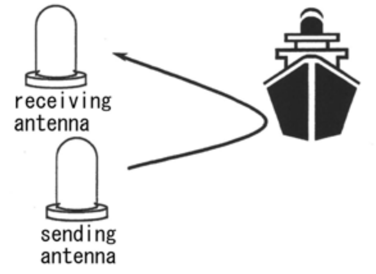


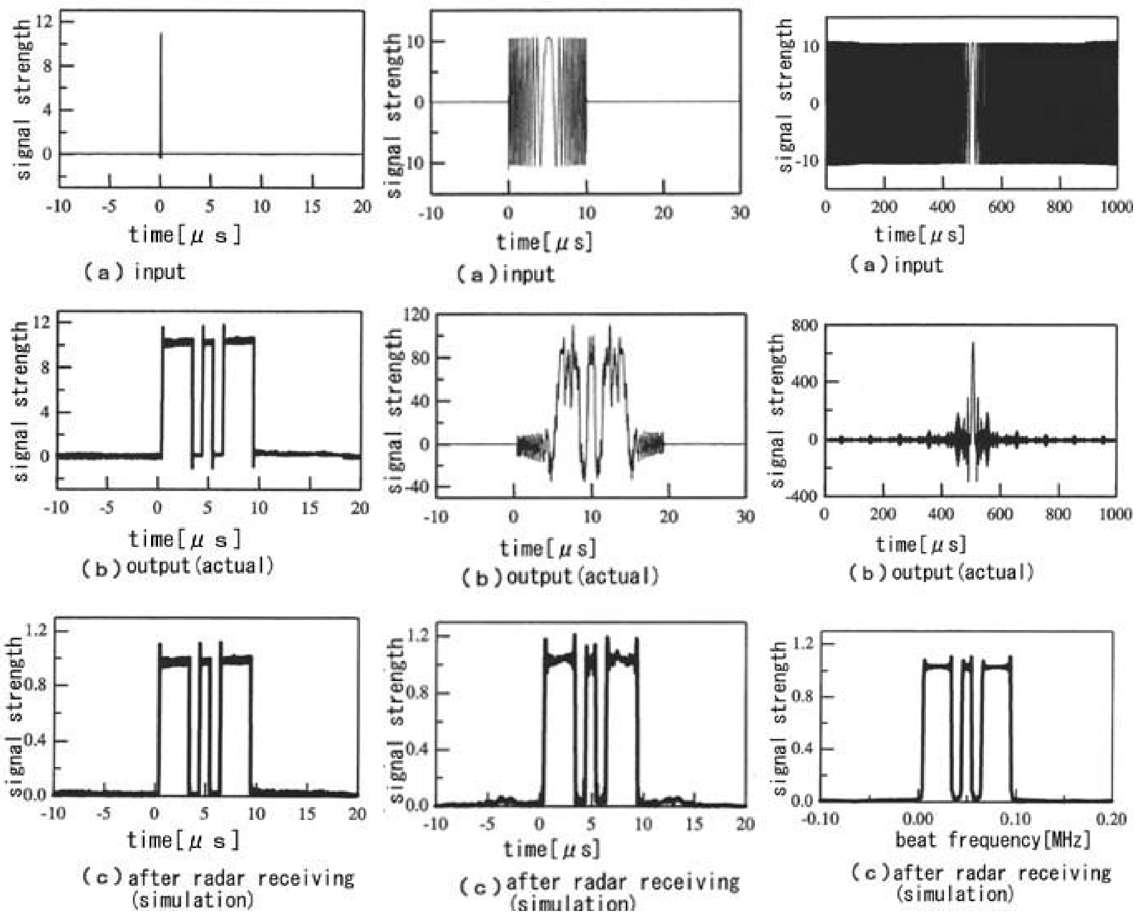
Figure 5-2.Strong reflection in close proximity

through self-oscillation, by triggering of the transmitter from the previous beacon transmission back into the receiver, this in turn causing another signal to be emitted from the receiver and so on. Further, it is also possible that a similar effect can occur when there is an object with a large radar cross-section in close proximity to the beacon, with the transmitted signal being returned to the receiver and possibly triggering self-oscillation. This is especially likely when a microwave beacon is installed in a buoy. Thus it is important to understand the environment in which a vessel passes through the neighborhood of the beacon is shown in Figure 5-2 thus it is important to understand the environment of the beacon. The isolation that the new radar beacon needs is at least -66 dB. Figure 5-1 shows the issue between sending and receiving antennas. The isolation between the sending and receiving antennas was measured and compared to calculated result. The transmission antenna and the reception antenna were set up in the anechoic chamber, and the amount of transmission was measured with the network analyzer. The output of the network analyzer was amplified to measure it so that low level transmissions could be measured and hence the required dynamic range was achieved.

The characteristic frequency response versus antenna separation was observed. As a result isolation of -70dB or more could be secured in the frequency response. As the antenna separation interval D is changed the isolation improves, as would be expected and it is roughly -25dB/m. In addition, as the distance extends, from a theoretical viewpoint the isolation is proportional to $1/D^2$. Moreover, it is thought that a rough approximation of the level of isolation can be obtained by calculation in future using these results. It could be confirmed that there was an isolation of -66dB in the anechoic chamber.

Next, experiments were carried out to consider the effect of having a strong reflection in close proximity. It turns out that at least -66dB of isolation is needed and this could not be achieved by changing the distance between the object causing the reflection and the antenna within the range of 40-160cm in the anechoic chamber. As calculated result, it is confirmed that the distance of 20m or more is necessary to secure -66dB of isolation. Moreover, it was confirmed that measurement result comparatively follows the radar equation of free space when there is a reflector about the antenna very near.

As above, the isolation between antennas has the possibility that -66dB is kept when there is no reflector to be near. However, when the new radar beacon was installed, it was confirmed that the great caution was necessary for closely reflector.



(1) pulse radar (2) pulse compression radar (3)FM-CW radar

Figure 5-3.Response for ideal input

5.2 Response for ideal input

It was confirmed whether to obtain the theoretical shape of waves by delay synthesis processing. It is necessary to input an ideal signal that meets the following requirements here.

1) Radar resolution = Unit delay time of new radar beacon(0.1μs)
2) Radar frequency = Center frequency of processing of new radar beacon (There is no detuning).
3) Single signal input (synthesizing and overlay none of two or more signals)

The output of the new radar beacon is shown in Fig.5-3 when the shape of waves of the simple pulse radar, pulse compression radar and FM-CW radar are input

(a) is input, (b) is output of delay synthesis radar beacon and (c) is detecting signal of radar. It was confirmed the delay synthesis radar beacon was able to display an identification code of the desire to the all type of radar under an ideal condition.

5.3 Minimum unit of amount of delay and disagreement of distance resolution of radar

The delay synthesis system is a system that combines multiple short delay circuits to obtain the desired sigh length. When "Unit delay time" that is the minimum unit of the amount of the delay corresponds to the pulse width of radar, an ideal response is achievable. It is actually for the disagreement.

The concept of the effect due to disagreement between the pulse width of radar and unit delay time of the new radar beacon is shown in Fig.5-4. As for (a), when the input pulse width and the unit delay are completely corresponding, the desired sign length is generable by delay synthesis. However, when the pulse length is long as shown in (b) the response becomes comb-like. When the pulse width is short, as shown in (c) the response becomes like stairs by piling-up of the shape of waves.

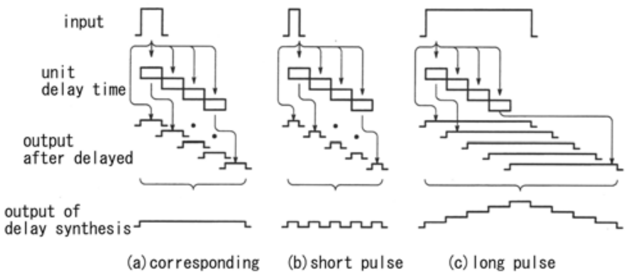


Figure 5-4.Concept of the effect due to disagreement between the pulse width of radar and unit delay time

The results of computer simulation are shown in Fig.5-5. When the pulse width corresponds to the unit delay time, the responding shape of the waves this is the minimum requirement because the spectrum also reproduces an ideal code.

On the other hand, when the pulse width is short, an unnecessary spectrum has been generated in the comb-like response. When the pulse width is long, the responding shape of wave dulls, but an unnecessary spectrum has not been generated.

Next, the FM-CW radar that easily obtains a high distance resolution is assumed to be a representative example, and the calculated result and the measured result are verified. The result is shown in Fig.5-6 when the delay synthesis processing is done

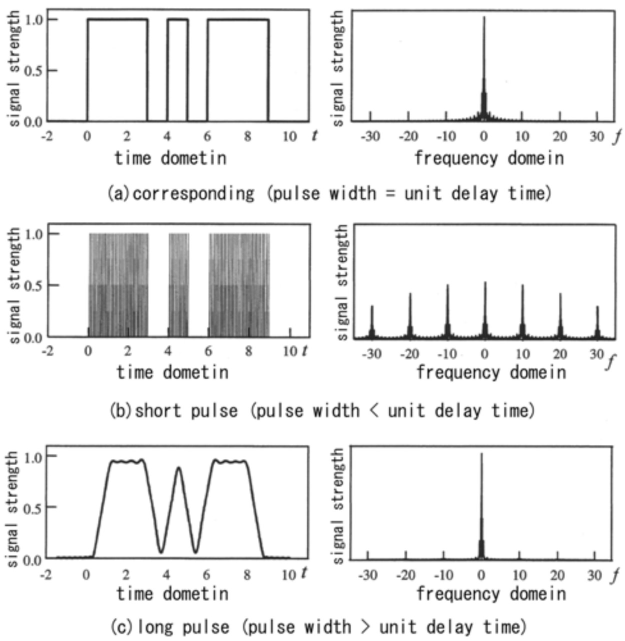


Figure 5-5.Results of computer simulation

at unit delay time 0.1μs to the input chirp frequency of 50MHz. Left side (A)(B) are calculation results, and right (a)(b) is measurement results. It was able to be confirmed that a comb demodulation response was obtained and that the spectrum had, as expected, extended in the measurement results. The calculation result corresponds to the measurement extremely well, and it an be said that the theory concerning the delay synthesis system and the wave generation that responds abnormally will be correctly captured.

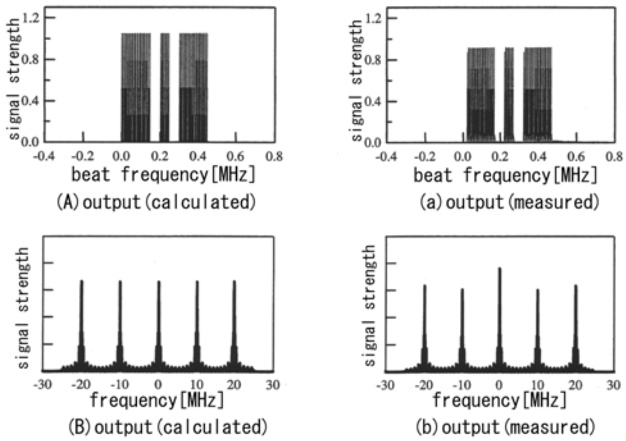


Figure 5-6.Calculated and measurement results of abnormal response due to disagreement

Next, the band limiting to deal with the shape of waves that responded abnormally was examined. Two kinds of filters were used for the band limiting. The result of filtering using the Butterworth characteristic is shown and the result of filtering the using Bessel characteristic is shown in Figure 5-7 and Figure 5-8.

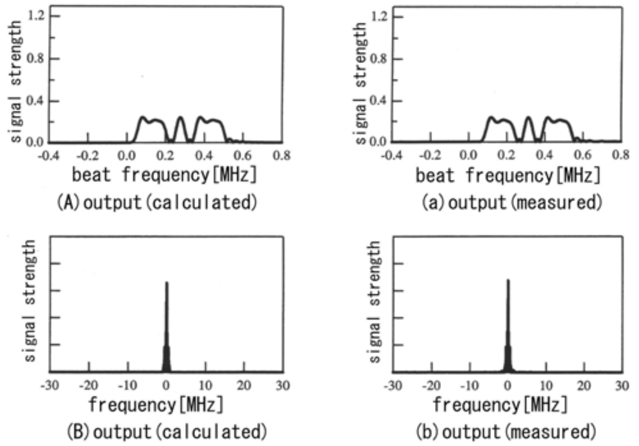


Figure 5-7.Effect of Butterworth filter

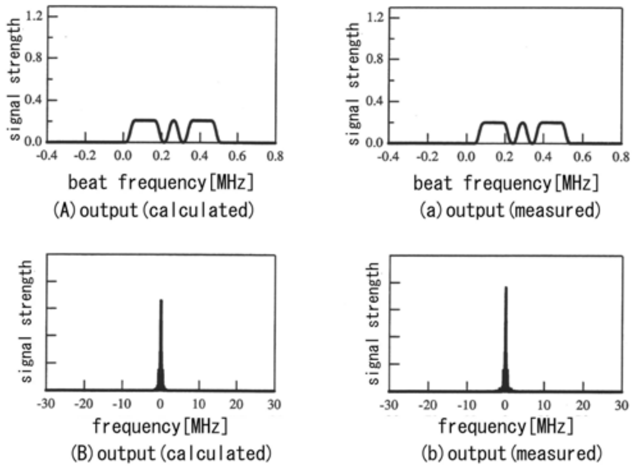


Figure 5-8.Effect of Bessel filter

After Butterworth filtering, abnormal comb-like shape was changed to normal response and thus the filtering was effective.

After Bessel filtering, it was also proven that the normal wave shape could be obtained as well as with Butterworth filter. Moreover, it was confirmed that the distortion of the shape of wave was little compared with the Butterworth characteristic.
The results thus show that in cases where it occurs, abnormality in the wave shape caused by non-ideal conditions can be dealt with by filtering.

5.4 Disagreement between center frequency of processing and center frequency of radar

The new radar beacon of the delay synthesis system by digital processing is converted into the intermediate frequency band mixing the reception signal with a local signal because the received radar signal cannot be processed at the higher frequency. Therefore, the frequency of a local signal will decide the center frequency of processing in the new radar beacon. At this time, the problem of using a non-ideal situation is considered; the calculation result and the measurement value are shown in the situation where a center frequency of the processing of a new radar beacon does not corresponding to the center frequency of the radar transmission wave (detuning) this situation can be generated naturally.

The case without the center frequency of processing agreement with center frequency of radar first of all, that is, detuning is shown in Figure 5-9 as an example of the simple pulse radar.

Next, the result of an input when delay synthesis processing is done using the center frequency of processing of the new radar beacon and 5MHz detuning of the pulse is shown in Fig.5-10. The comb shape of waves and unnecessary spectrum shown in theory could be confirmed by actual measurement.

Next, Butterworth filter to deal with this abnormal shape of wave was examined. The result is shown in Fig.5-11. An abnormal shape of the comb type seen in Figure 5-10 after it is filtered is proven to have a normal shape of wave, with an improved frequency spectrum.

Some distortions remain in the shape of wave in the Butterworth filter. Little distortion remain in it in the Bessel filter. However, because the shape dulls, code (K ; -.-) may change for the worse. When filter is set, it is necessary to consider both influences.

It was confirmed to be able to deal with the abnormal response by band limiting filtering when the center frequency do is detuned.

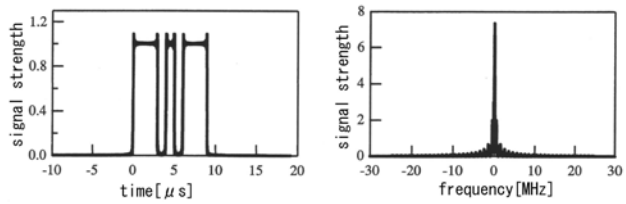


Figure 5-9.Response of ideal situation

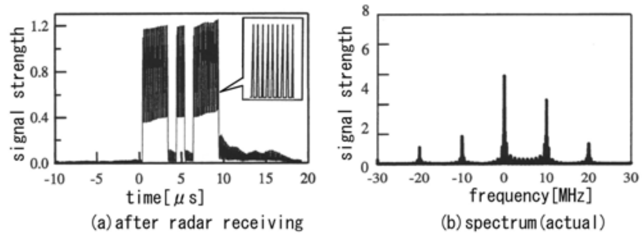


Figure 5-10.Response of detuning the center frequency

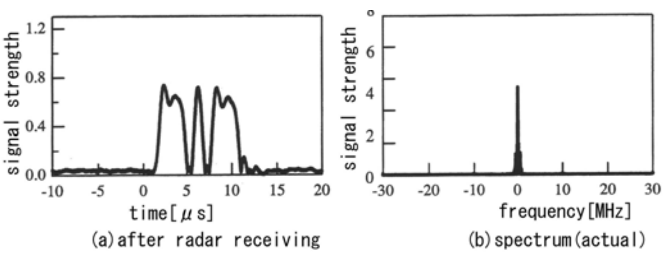


Figure 5-11.After filtering in abnormal shape of wave

5.5 Reception of two or more radar waves simultaneously

It is necessary to consider the influence of more than one radar signal arriving simultaneously when the delay synthesis system is used.

The state of the reply signal to each radar was examined by actual measurement when the radar wave of a different system was input simultaneously to the delay synthesis system. The input pulse is assumed to be the following three kinds.

1) pulse radar: 1μs pulse width
2) pulse compression radar: 20μs, 10MHz chirp shape of waves

3) FM-CW radar: 1ms, 2MHz sweep wave

Fig.5-12 shows the case where these three kinds of radar signal are synthesized and used as an input. The input wave synthesized from the transmission waves was as shown in (a). The center of each signal timing was not simultaneous. (b)-(d) are shown states in each radar. When the input timing of three kinds of radar was not corresponding, it was proven to be able to reproduce the signal with each radar even if two or more radar signal superimposed it.

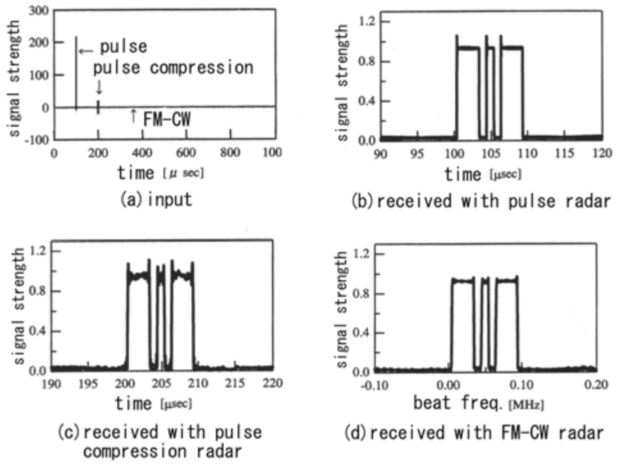


Figure 5-12.Response for synthesized input (not simultaneous)

Next, the input timing of three kinds of radar shows the case where all three are simultaneous in Fig.5-13. In this case, it has been understood that it won't reproduce the signal in any radar.

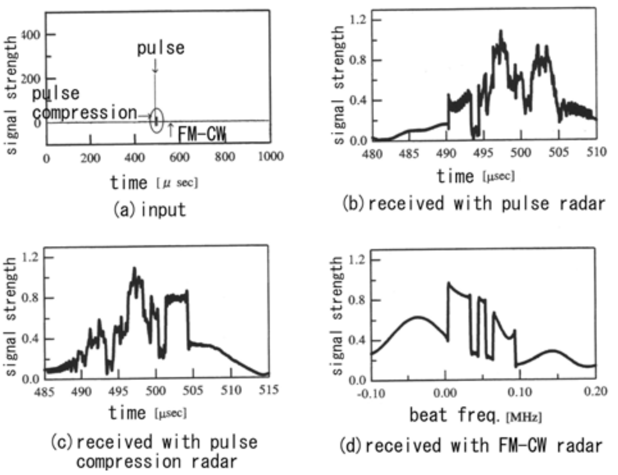


Figure 5-13.Response for synthesized input (simultaneous)

In actual operation, each radar is not synchronized, the situation to which timing is completely corresponding does not occur. The influence can be removed by the function of the radar.

5.6 Others

Besides this, the points that should be considered in the design are the signal level, frequency range and response timing etc.

The power output of the order of several W is assumed for the FM-CW radar while current radar has an output of the order of about several tens of kW. It is therefore necessary to design into the new radar beacon a capability to be able to deal with a power difference of about 40dB.

Moreover, to cover all frequency bands of radar, the local oscillator frequency is swept. This allows for the necessary alignment of the centre frequency of the processing with the centre frequency of the radar.

6. Conclusions

The delay synthesis system was examined as a potential new radar beacon that was able to respond to both the new types of radar system that are likely to spread in the near future and in addition to the older pulse radar. This was carried out by both simulation and experimental means.

The achieved main results were reported as follows.

(1) It could be verified that the new radar beacon that was able to respond to the new types of radar system.
(2) The spectrum of new beacon will fit to ITU new standard.
(3) It was confirmed that one circuit was able to respond to three kinds of radar system.
(4) It was possible to confirm that the simulation and the measurement values corresponded well, and when the circuit was designed, it was able to confirm the detailed performance shown by the simulation.

This research and development made FPGA the chief method by which the signal processing was carried out experimentally on the bench confirming the signal processing results. In the future it is necessary to undertake sea trials to demonstrate the performance under true working conditions. Therefore, the problem with which it should grapple about the following matter aiming at practical use is shown.

(1) The experiment station license is acquired, and the performance in the sea is confirmed home manufacturer is experimenting on development of the FM-CW radar and the pulse compression radar now.
(2) The system that responds only to the azimuth of radar with transmitting is examined. The purpose is to prevent an unnecessary signal being radiated and to respond to transmitting from a lot of radar appropriately.
(3) A new radar beacon that can also be set up in a buoy is examined. It is necessary to operate with stability even if the sending and receiving antenna is in extremely close proximity.

Acknowledgement

Authors sincerely express gratitude to members of the committee of "Investigation study group concerning the development of the new microwave beacon", the Japan Coast Guard, the Ministry of Public Management, Home Affairs, Posts and Telecommunications, and Mr. N HIRAKI as technological member, and The Nippon Foundation that promoted it.

Reference

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