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CONCEPTS FOR DESIGN OF CW RADARS FOR AIRBORNE APPLICATIONS

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ABSTRACT

In this paper it is discussed some concepts in signal design and processing intended to increase the potential capabilities of CW radar system with double modulation to cover certain applications. The signal is phase modulated by pseudo random sequence and frequency modulated by sinewave. The first system is based on parallel range gates and group of doppler filter banks which is suitable for airborne surveillance. It enables automatic detection of several targets simultaneously and measuring range with high resolution, velocity unambigiously and bearing. It also suppresses the leakage and reflections from close-in clutter which are the main problems facing classical CW radars. The second system discussed used the idea of filtering several harmonics of the FM spectrum in the receiver instead of filtering only the third harmonic, then the detected outputs are further combined. This approach enables, beside suppressing leakage, to reduce the losses of power in the receiver. It offers opportunity to increase the maximum range substantialy, nearly double the value, as compared to system using the 3rd harmonic only. This option can use smaller value of the FM frequency. The presented version is suitable for airborne fire control application. The system is evaluated showing advantages in addition to the properties attained by the system using double modulation.

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I. INTRODUCTION

Waveform design and processing represent a basic consideration when designing modern radar systems. The optimum transmitted waveform must contain sufficient energy irrespective of its peak value to achieve detection of the smallest aircraft at the longest range as given from the radar equation. This concept of importance of energy and not power favoures the use of smaller transmitter size having average power eaual to the peak power which enhances the use of CW radars in comparison to pulse radars for airborne applications. This choice is encouraged by the great development in microwave integrated circuits and semiconductor transmitting elements which makes it easier to develop a CW transmitter of very small size which is capable of producing a considerable energy. For simultaneous measurement of range and velocity with high precision, the waveform must have high energy to noise ratio E/N_0 and / or have large time-bandwidth product $\alpha\beta$.

As far as we are concerned with resolutions in range and velocity, large $\alpha\beta$ can greatly improve these properties, while the ambiguity function represents the criterion of judjment of the potential capabilities inherent in any waveform from point of view of resolution, ambiguity and clutter rejection.

Several works have been devoted to the development of CW radars [3] and associated modulating waveforms [1,2] . Nevertheless the greatest problems in CW radar receivers are the following. Firstly, leakage signals from transmitter to receiver which are dictated by the use of one antenna for transmission and reception especially for airborne applications. In addition exist also reflected signals from close-in targets in low altitude flight conditions or in severe weather clutter conditions. It is necessary for this reason to suppress these signals and provide the receiver with a sort of time AGC similar to that used in pulse radars. Secondly, it arises the inability of simple CW radar for range measurement except with some type of modulation and even in this case high resolution may not be realized. Such range resolution needs a design of signal which takes into consideration the resolution properties of the modulating waveform and the used type of modulation as reflected from its ambiguity function behaviour. Several approaches for solving the above mentioned problems have been treated extensively by several authors [1,2,3,4].

A new direction has been presented and analized [5,6] based on signal design approach using double modulation and proper design of receiver. We have intended in that case to design a suitable waveform for achieving , high resolution in range measurement along with suppressing leakage and simultaneously measuring velocity unambigiously.

In the next two sections it will be presented and investigated two new alternate forms of signal processor for this signal intended to increase the potential capabilities of systems using this type of signal for different applications. In section II it is presented a version of range gates CW radar system with double modulation suitable for surveillance and automatic detection. While in section III it is investigated a modified form of CW radar system suitable for search and track for fire control.

II. RANGE GATES CW RADAR SYSTEM WITH DOUBLE MODULATION.

The waveform proposed for this system is the pseudo random binary sequence (P.r.b.s)used for biphase modulating the CW carrier (PHM) in addition to a secondary modulation performed by a sinewave for frequency modulating (FM) the CW carrier [6]. The generated signal is transmitted through circulator via antenna. The block diagram of the processor along with the rest of the system is shown in Fig.1. The received signal from antenna through circulator is passed to RF mixer where it is mixed with LO signal which is the FM carrier before being applied to the RF. PH modulator. The output of the mixer which is a zero IF signal with spectrum due to PHM and FM is amplified in the code amplifier having the required bandwidth and securing the minimum noise figure. The output of the code amplifier is applied to N parallel range gated channels. In each channel the signal is multiplied in a code demodulator with the properly shifted reference code [P.r.b.s] out of the bit K of shift register in agreement with target range corresponding to range gate K. The range gate having target will peak corresponding to maximum correlation as compared to side-lobe in other range gates having no targets.

The third harmonic of the FM spectrum with its doppler components out of the selective circuit is fed to the 3rd harmonic detector along with the corresponding harmonic derived from the FM sinewave generator. The doppler frequency signal of target is applied to a doppler filter bank, where it peaks in the proper filter indicating the target velocity. The PHM by P.r.b.s. achieves measurement of range with high resolution determined by the code subpulse τ_0 given as inverse of the clock pulse frequency F_c , along with unambigious measurement of velocities of interest. The FM by sinewave leads to distributing doppler frequency components of the received signal around harmonics of the FM spectrum having amplitudes weighted by Bessel functions corresponding to harmonic order $J_n(\beta)$ with argument β depending on range [5] . Selecting the third harmonic in the receiver leads to zero response $J_n(\beta)=0$ when argument of the 3rd order Bessel function β gets zero for zero range securing suppression of leakage from transmitter and reflections from close - in targets. The advantage of this system that it offers opportunity of automatic surveillance for airborne applications giving informations about several aircrafts including range, velocity beside bearings along with suppressing leakage which is the main problem in classical CW radars.

III. MODIFIED CW RADAR SYSTEM WITH DOUBLE MODULATION

In this section, it will be discussed the variation of the parameters of the signal with double modulation for the sake of increasing the capabilities of the system to cover specific requirements in certain applications. It will be proposed also the associated system configuration . Let us suppose that the frequency of the carrier varies according to sinusoidal law $f_n = f_o + \Delta f_o \sin \Omega t$ and the carrier phase ϕ is varied between two states o or π according to the change of P.r.b.s. between the states ± 1 i.e $V(t) = \cos [\phi(t)]$

The transmitted signal S(t) is therefore in the form

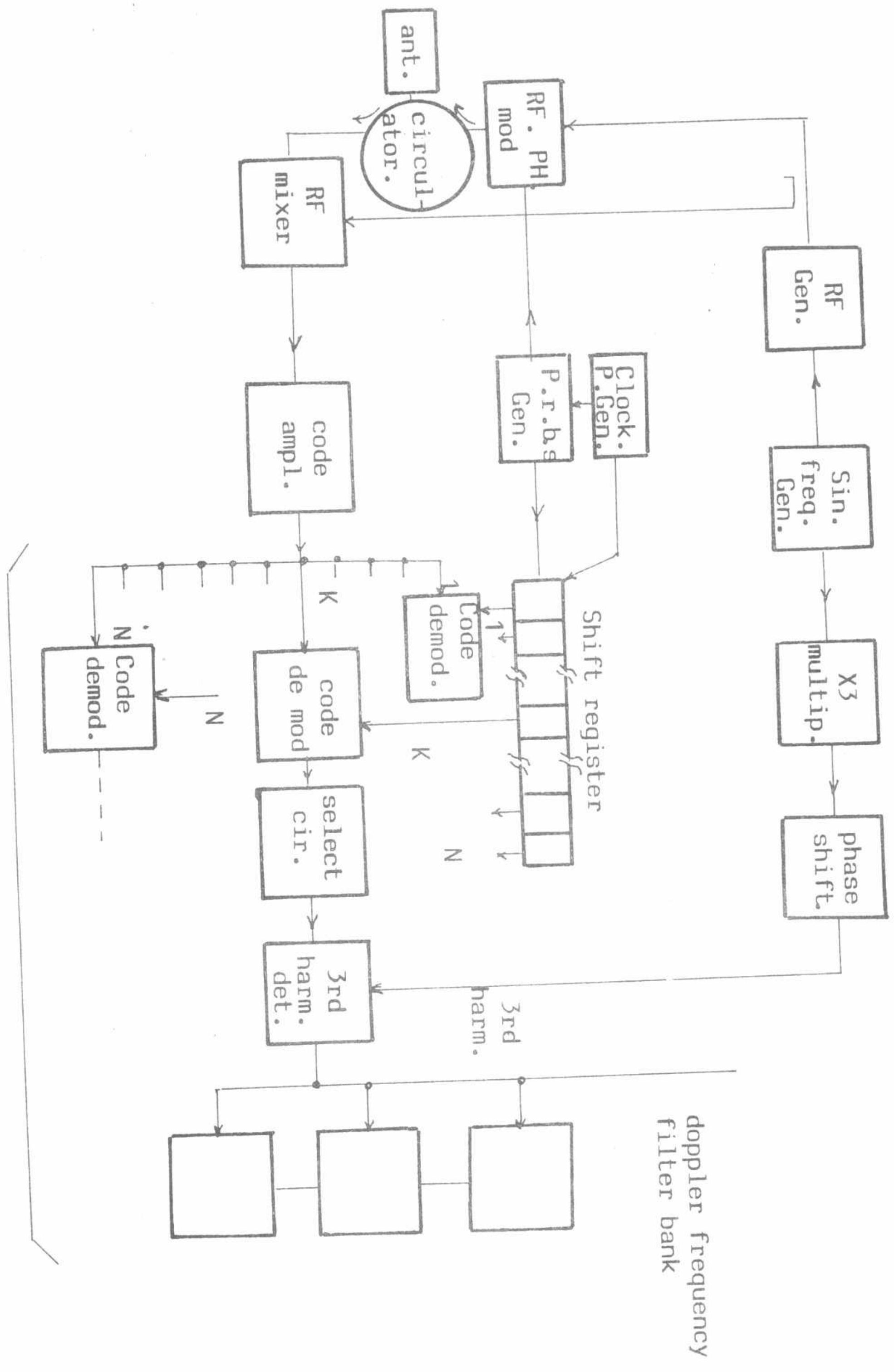

Fig.1.
Range gates CW radar system with double modulation

$$S(t) = U_t \cos[\omega_o t - \frac{\Delta f_o}{f} \cos \Omega t + \phi(t)] \qquad (1)$$

or equivalently

$$S(t) = U_t V(t) \cos [\omega_o t - X \cos \Omega t] \qquad (2)$$

The maximum range is governed by the phase modulation parameters and frequency modulation parameters [5] as illustrated by the following two inequalities

$$F_c \leqslant L \frac{C}{2R_{max}} \qquad (3)$$

, F_c is clock frequency, L is length of P.r.b.s.

$$2F_{dmax} < f \leqslant \frac{C}{4R_{max}} \qquad (4)$$

, f is the FM frequency, F_{dmax} is the maximum doppler frequency.

From relation (3) it is apparent that R_{max} can be increased by increasing the code length L as far as F_c is assigned a value given by the required resolution in range. Increase of cod length L for maximum length P.r.b.s. generated by linear feed back shift register is still an feasible option. This R_{max} must satisfy for the FM frequency the right hand side of inequality (4) which suggests smaller value of f for larger value of R_{max} which is a feasible option too as far as f is still greater than the maximum expected doppler frequency F_{dmax}

If we are confined with airborne fire control application where F_{dmax} can reach a relatively small value, then this situation suggests the use of smaller value of f with the consequence of increasing greatly R_{max} . The reduction of f results in increase of the depth of modulation X and consequently the increase of the maximum value β_{max} of the argument β of the Bessel function $J_n(\beta)$. The argument β is dependent on range [5].

It is given as

$$\beta = 2x \sin \Omega \frac{R}{c} \quad , \quad \beta_{max} = 2x \qquad (5)$$

The argument of the Bessel function β gets zero for ranges given by

$$R = W \cdot \frac{C}{2f} \quad ; \; W = 0, 1, 2, \ldots \qquad (6)$$

The first zero of β denoted β_{oo} is given for W=o in relation (6) which secures for us the suppression of leakage since $J_n(o) = o$, whereas the second zero of β denoted β_{o1} for W=1 corresponds to $R=\frac{C}{2f}$ which is the first blind range other than the zero range. Therefore R_{max} must be less than R given by this value, this will be denoted as the maximum possible operating range $R_{max\ o}$. The value of R corresponding to maximum of β i.e β_{max} is denoted as the recommended maximum range $R_{max\ r}$

For increase of β_{max} we propose filtering several higher harmonics of the FM spectrum in the receiver instead of choosing only the third harmonic. Then detecting the doppler frequency component in each harmonic spectrum and adding outputs will lead to a resultant weighting factor, for the doppler signal amplitude, composed of addition of higher order Bessel functions. We investigate the addition of $J_n(\beta)$ from n = 3 up till n = 9, since n > 9 adds only a little improvement. It is shown in Fig.2 the dependence of normalized $Y_{3-M} = \sum_{i=3}^{M} J_n(\beta)$, M = 4,5,...,9. It is shown also for comparison $Y_3 = J_3(\beta)$. The graph shows that:(1) the loss due to using only the third harmonic is improved by adding output from several harmonics. (2). The argument β_{max} corresponding to the peak of the curve is increased with the increase of the number of harmonics added M which means increase of the maximum recommended range $R_{max\ r}$ (3). The second zero β_{o1} is shifted further away on the β axis and increases with M which means increase of the maximum possible operating range $R_{max\ r}$. The above measures are indicated quantitavely for subsequent added harmonics in Table 1. where R_{max} is calculated relative to the values for the 3rd harnonic

Table (1)

Y_{3-M}	Y_3	Y_{3-4}	Y_{3-5}	Y_{3-6}	Y_{3-7}	Y_{3-8}	Y_{3-9}
$Y_{3-M\ max}$	0.3246	0.5836	0.7683	0.8755	0.9402	0.9823	1
G [dB]	0	2.5477	3.7418	4.3091	4.6187	4.8090	4.8865
β_{max}	4	4.5	5	5.5	5.5	6.5	6.5
$R_{max\ r}$	1	1.125	1.250	1.375	1.375	1.625	1.625
β_{o1}	6.25	7	7.6	8.25	9.1	11.5	12.75
$R_{max\ o}$	1	1.120	1.216	1.320	1.456	1.840	2.040

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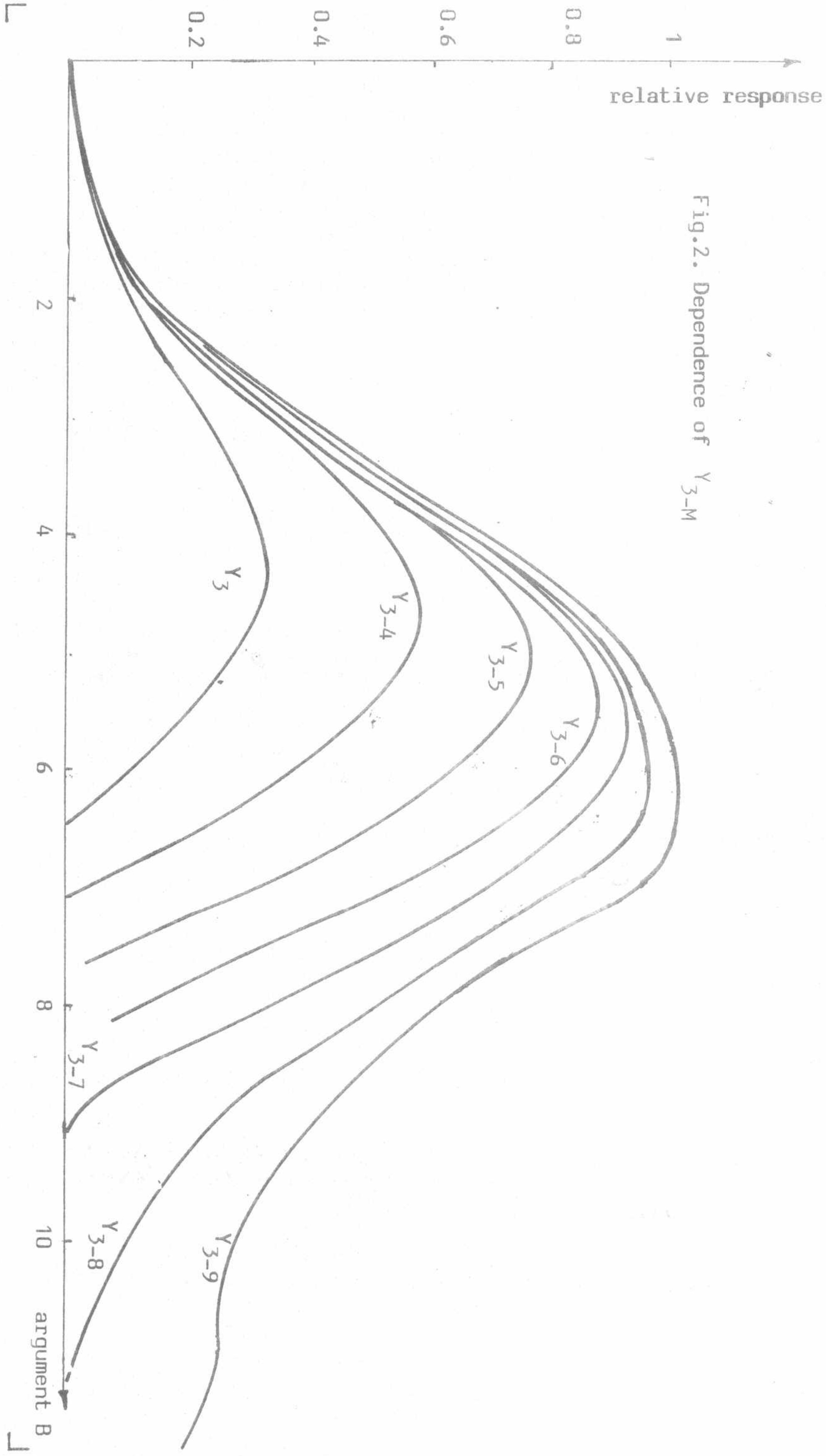

Fig.2. Dependence of Y_{3-M}

The block diagram of this system using several harmonics is illustrated in Fig.3. The output from the code demodulator is applied to 6 parallel channels, each channel m is filtering one harmonic of the FM spectrum from 3 to 9 and its doppler components which further will be detected in the mth harmonic detector. The detector is fed also by the mth harmonic obtained from the sine frequency generator by frequency multiplication. Then the outputs from several harmonics are added. The velocity is determined using the doppler filter bank, while the range is found using phase shifter 1 and the controller. These are adjusted either manually or through range tracking unit. The rest of the system is similar to that presented in section II.

IV. CONCLUSION

In this paper it is presented two alternate forms of CW radar systems with double modulation. From these the following remarks are noticeable.

1. The system discussed in section II using parallel range gates is suitable for surveillance and automatic detection of several targets in the same time with simultaneous measurements of range with high resolution, velocity and suppressing leakage.

2. The system analized in section III which combines the output from several harmonics of the FM spectrum, offers a substantial increase in maximum range and reduction in signal loss as compared with system using only the third harmonic.

This suggests its utility for airborne fire control applications using relatively longer range air to air guided missiles.

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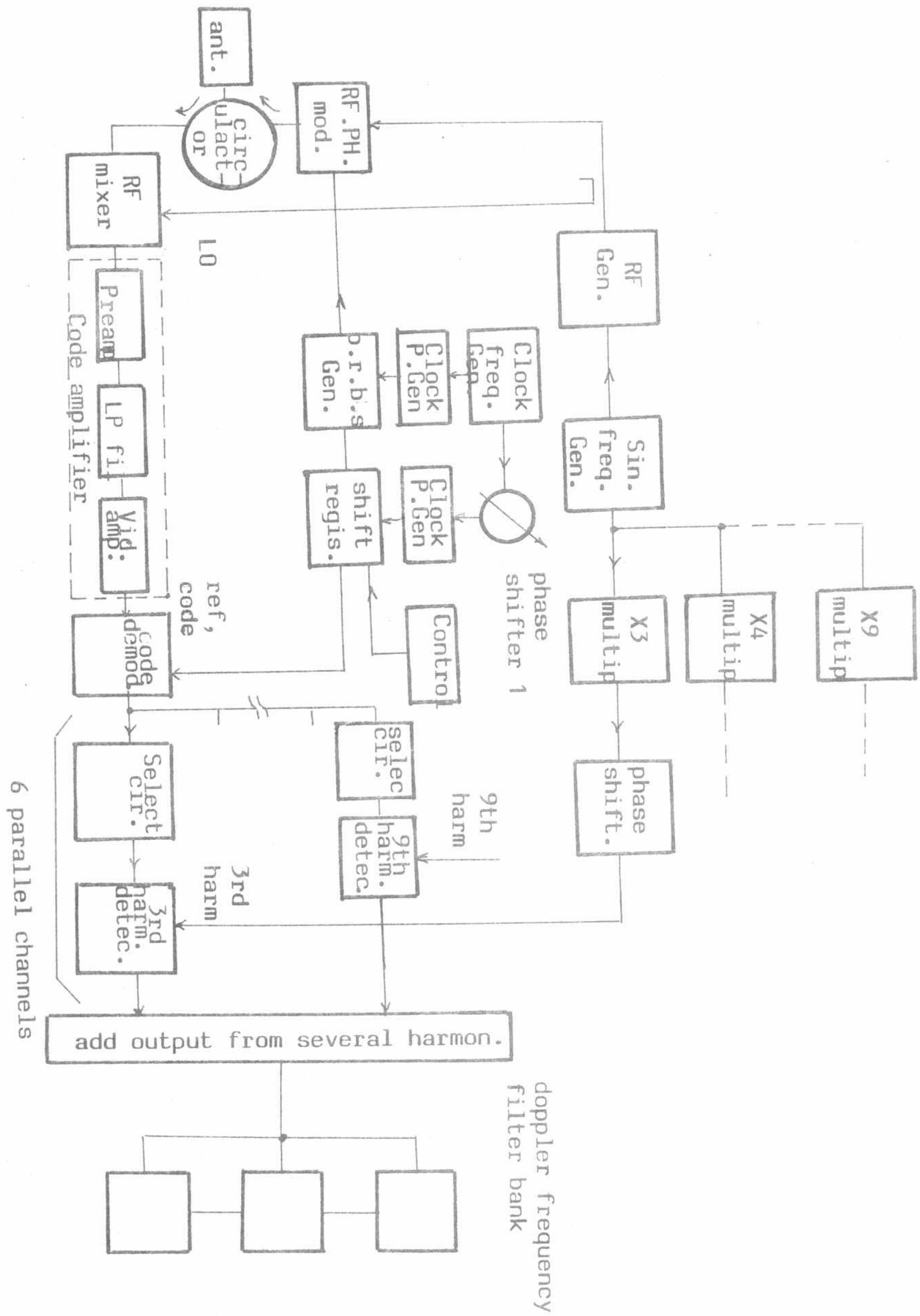

Fig.3. Modified CW radar system with double modulation.

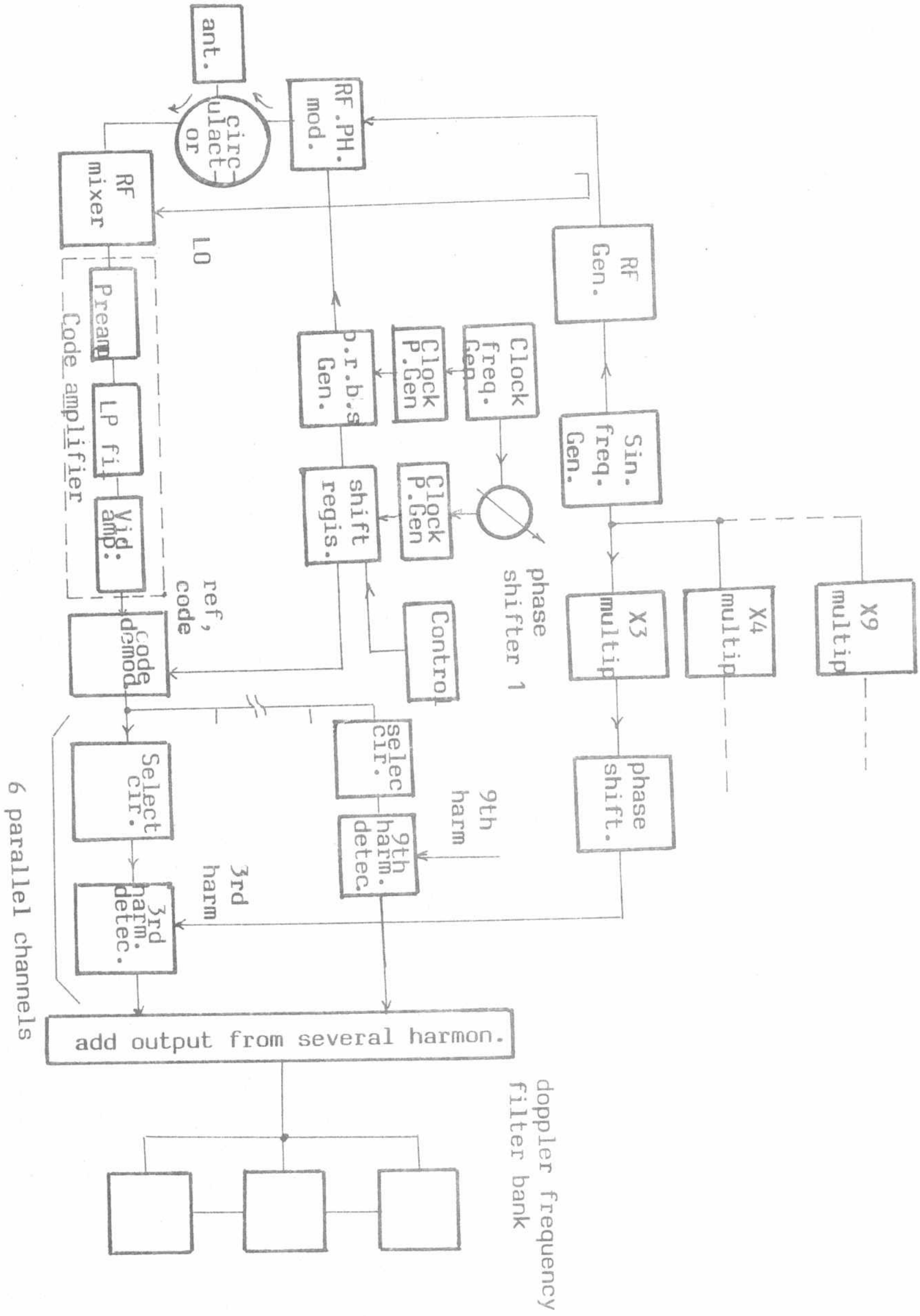

Fig.3. Modified CW radar system with double modulation.