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## Chaotic signal processing and generation in DRFM technologies: accounting for resource constraints

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**Abstract.** DRFM technology for storing radio frequencies does not require a large bit and is compatible (regular way) with the requirement to account for resource constraints (hardware and computing), but this applies to a single-signal situation. Significant complicates of signal processing arise in multi-signal situations at a large dynamic range: parasitic combination components appear, efficient separation (resolution) of signals is difficult. The article establishes that there is an alternative DRFM under construction device in such conditions, and it is digital multichannel filtering (DMF) of signals implemented in the device itself. However, if multiple bit processing of the representation and the current digital data is maintained, the multi-signal processing is greatly complicated. In order to reduce the effect of quantization and signal sampling effects, the article proposes to apply an unconventional approach, which is based on chaotic processing - randomization of tough ("low-bit") signal samples in the ADC. In addition, it has been found that in order to reduce DRFM discharge requirements, it is advantageous to apply a procedure for digitally subtracting the dominant signal from the input mixture, which accounts for a significant portion of the range (discharge).

**Keywords:** digital radiofrequency memory DRFM, digital multi-channel filtering, randomization, multi-signal mode, digital cut-off filtering, stochastic linearization, low-bit processing, coarse statistics, dominant signal

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### CONTENTS

1. INTRODUCTION AND PROBLEM DEFINITION (219)
  2. DESCRIPTION OF THE "BIT REDUNDANCY" EFFECT (221)
  3. CHAOTIC PROCESSING WITH LOW DIGIT CAPACITY: ROUGH STATISTICS (222)
  4. COMPENSATION OF THE DOMINANT SIGNAL (222)
  5. ANALYSIS OF SIGNAL TRANSMISSION (224)
  6. CONCLUSION (225)
- REFERENCES (225)

### 1. INTRODUCTION AND PROBLEM DEFINITION

Well known that DRFM technology was developed in 80s and found broad application in the systems of a radar-location, radio navigation, radio-electronic counteraction and a radio communication [1-9]. The priority belongs to works [1,6,8,9]. The DRFM technology allows to carry out storing and repeated reproduction of radio signals in a strip of frequencies several

hundreds of megahertz, with duration of signals tens of milliseconds and in the big dynamic range.

At the same time experience of use of DRFM technology revealed a number of problems which solution is defined by the prospects of its development and emergence of new technologies. The main problem consisted in obtaining digital copies of signals in the wide frequency and dynamic ranges.

Usually, the bearing frequency of entrance signals a priori is unknown, only frequency range, for example in the eighties, it is  $\sim 4\div 18$  GHz is often known. From the moment of emergence of DRFM for the last 40 years, in connection with continuous expansion of range of distribution of frequencies of the suppressed DEN, the main efforts of developers were directed to increase in operating range  $\Delta F_p$  of frequencies of DRFM, i.e. the problem was constantly aggravated.

It is known that the operating range of DRFM is defined by the frequency of sampling of signals in time and this dependence is set by expression:

$$\Delta F_p \leq \Delta F_d$$

where  $F_d = 1/T$  – frequency, and  $T$  – an interval (period) of sampling of a signal in time. Consequently, the only way of expansion of operating range of frequencies of the DRFM device is increase in its frequency of sampling which is 600 MHz today, and the GHz is required  $600\div 3000$ . Range of the remembered signals with  $\Delta F_p \leq \Delta F_d = 3000$  MHz is sufficient  $F$  for the majority of technical applications.

Power of entrance signals is also a priori unknown and can change in the range up to  $60\div 70$  dB. In these conditions there is a problem of transformation of signals to numeric words, their subsequent storing and investment of the created signals with interfering modulation, their transformation from "figure" to an analog form and strengthening.

It is known [10], that with the fixed signal amplitude for achievement of level of parasitic components of a signal no more minus 30 dB it is necessary to transform to two not less than 4 categories of (bit) long everyone. Total length of the numeric word has to be not less than 8 bits, and the volume of the memory device of the DRFM device has to be  $8 \cdot \Delta F_p \cdot W$  and bit where  $W$  – radio signal duration.

If amplitude of an entrance signal changes in the range up to 60 dB ( $10^3$  time), then for achievement of an identical step (increment) of quantization  $\Delta$  quadrature with any amplitude of a signal it is necessary to increase word length up to  $18\div 20$  of categories, and STORAGE volume to  $(18\div 20) \Delta F_p \cdot \tau_i$  and bit. Compression of dynamic range by means of the amplifier with logarithmic characteristic allows to squeeze dynamic range in  $\sim 100$  times and to respectively reduce length of the numeric word to 12 bits. The serious constraint reduces the length of the digital words to  $8\div 10$  bits. In both cases, additional parasitic components of the spectrum of the reproduced signal on the harmonics of the carrier frequency are generated. Serious difficulties arise in the case of wide carrier change bands of  $\sim 100\div 500$  MHz or more when several signals at different frequencies enter the DRFM operating band. In this case, signal restriction generates additional parasitic signal components, which cannot be eliminated without special measures.

Method of dynamic range compression with the help of AGC circuits does not eliminate problems of multi-signal situation, as well as method of separate amplitude and phase conversion [10]. Also, traditional approach the range width which it is commensurable with a working strip of frequencies  $\Delta F_p$  and it does not solve a problem of storing and reproduction of broadband signals. Signal restriction produces additional parasitic components in the spectrum of the reproduced signal, the levels of which may be significant. This also applies to coarse

quantization, which in the first approximation prevents such a transition.

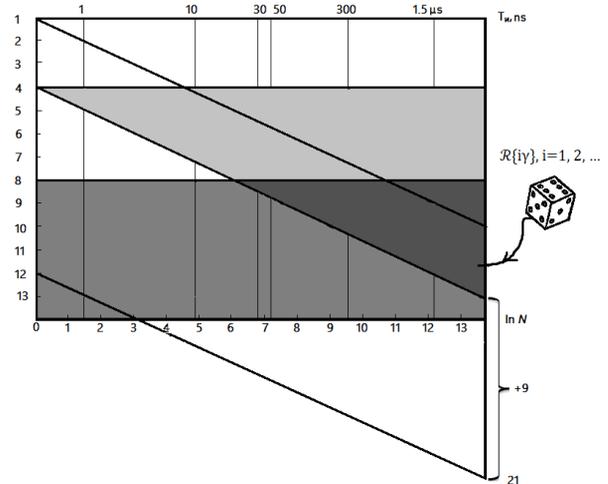
It is generally accepted that a large dynamic range of processed signals and A/D converter bit are interconnected. On noise of the receiver  $\sigma$  it is taken away 1-3 category ADC, consider quantization commotion SD  $\sigma_{\Delta} = \Delta / 2\sqrt{3} \approx 0.6\Delta$ , where  $\Delta$  - the price of the younger category ADC and at big word length of the  $L$  of ADC ( $L \gg 1$ ) neglect commotion of quantization. For  $F_d = 3$  GHz at  $L = 12$  we have the forecast of volume of the memory device at quadrature processing  $2 \cdot 12 \cdot \Delta F_p \cdot \tau_i$  and bit on an entrance at 3 selections of two 12-bit words approximately for 1 nanosecond.

Due to the widespread introduction of the TO methods, emergence PLD and DSP, an opportunity to redistribute strengthening of a path, to carry out the digital multichannel filtration (DMF), to make narrower strips of certain canals and, thus - to increase extreme sensitivity opened (even for short impulses from 10÷50 of nanosecond).

Regardless of the counting system, the rounding method, the representation of digital data in "integers," with a "fixed" or "floating" comma, simply increasing the sampling rate of the ADC  $F_d$  to 3 GHz results in a substantial increase in the bit rate resulting in "bit redundancy" in the TO path.

**2. DESCRIPTION OF "BIT REDUNDANCY" EFFECT**

**Fig. 1** shows the dependence of the increase in the bit capacity of the ADC on the duration of the stored radio signal  $W$  from 0 to 1.5  $\mu$ s (accordingly increase of number of samples from 1 to  $2^{13}$  and more) At  $F_d \approx$  of 3 GHz, which results (in limit) in output bit increase to 21 (the lower straight line) and possibilities of realization of dynamic range of a path up to 120 dB that on 70÷100 dB exceeds necessary, i.e. is superfluous.



**Fig. 1.** Diagram of increase of ADC converter digit capacity  $L$  depending on pulse duration  $W$ .

On the top straight-line growth (on the module) is shown to word length for binary ("it is binary – sign") quantization below – 4-bit, allowing to have the output dynamic range of 50÷80 dB sufficient for high-quality reproduction of the digital copy of a signal. Simply increasing the bit rate during processing (without taking special measures) does not lead to reduction of quantization noise, because in a system with "fixed point" at accumulation of quantization error (in the absence of receiver noise) have (from count to count) the same value and sign (+ or –) and at summation in the TF ("accumulate," i.e. are not mutually compensated), and there is no improvement in the quantization signal-to-noise ratio.

In order to maintain the required dynamic range of the CP path under "rough quantization" conditions, it is proposed to select commotion from the following principle condition (1) (described by the expression):

$$\sigma \ll \Delta. \tag{1}$$

This means, that current intermediate counts "can be" rough. Weak signals, commensurate or smaller quanta, in the first approximation can be lost (inside the quant), and in other situations, on the contrary – to be emphasized (at the boundaries of the quanta).

### 3. CHAOTIC PROCESSING WITH LOW DIGIT CAPACITY: ROUGH STATISTICS

The chaotic DCP has been applied before. Consequently, stochastic ADCs and other structures were considered in [11]: it did not address special issues related to reducing sampling and quantization noise in DRFM devices.

In work [11] it is proposed to use stochastic interpolation of "rough" range samples to measure the range. When measuring target coordinates in this manner (essentially by the Monte-Carlo method), an interpolation task such as range  $D$  has been reduced to an interpolation additive measurement task  $\Delta_x$  by measuring the associated probability  $p = \Delta_x / \Delta$ , where  $\Delta$  is an element of discreteness, a quantization step by the measured parameter  $x$ .

In step [12-13], analysis of processing and generating signals in the radars with VTs was performed using randomization techniques. Solutions to eliminate uncertainty in the setting of probe signal parameters and in the selection of methods of processing and decision-making under resource constraints in VTs systems are justified, but this issue is solved in order to miss the suppression of passive interference in IR radio interference.

The works [14-19] consider a stochastic approach to solving traditional radar problems: detection, evaluation, filtering. Stochastic radar [14] is based on the concept of introducing artificial stochasticity into the process of processing and generation of radar signals, which assume, along with natural stochasticity due to random nature of input signals, randomization of reception-transmission process conditions. The solutions given therein are analogs.

The theoretical base of stochastic radar, and similar to the proposed approach, is the Monte-Carlo method. Further we will understand an essence of this method in relation to a solvable task in which signals in delta  $\Delta$  are not excluded from processing, and we turn into some probability. Analogy of problem solution (by

VT<sub>s</sub> systems type in radar [13]) also determined the necessity of rational use of dynamic range, with respect to analyzed signal, and - subtraction of interference (dominance) before processing.

### 4. COMPENSATION OF THE DOMINANT SIGNAL BY "IF-CP" TYPE OF CIRCUIT IN STS SYSTEM

In the case under consideration, the injector filter (IF) is designed to compensate (subtract) the dominant signal (passive interference) from the sum of signals in a multi-signal situation in order to reduce the dynamic range of the MMF circuit made in [13] in the form of a multi-channel coherent storage device (DRFM of the total signal) with their subsequent separation.

The object of the CO in this pattern is the vibration coming from the receiver output  $\dot{x}$ , which is the sum of the analyzed signal  $\dot{S}$  and the dominant signal  $\dot{C}$ .

The input signals for the ADC are the quadrature components  $x_c$  and  $x_s$  - respectively, the real (cosine) and imaginary (sine) parts of the complex vector  $\dot{x}$ .

A distinctive feature of the RO(PO) circuit is the presence of a random additive generator (RAG) designed to generate a random noise voltage  $\vec{\xi}_{r+N}$  additive with elements  $\vec{\xi}_i$ ,  $i = 1, 2, \dots, r+N$ . The coherent store KN-TMF, distributes a set of harmonicas of "a group signal" on the separate "streamlets" forming "narrow" channels in a working strip  $\Delta F_p$  can be realized on DPF algorithm:

$$z = \sqrt{f_c^2 + f_s^2}, \quad (2)$$

$$\dot{f}(k) = f_c + jf_s = \sum_{i=0}^{N-1} \dot{x}_i e^{-jia_k}, \quad (3)$$

where  $a_k = 2\pi k/N$  - setting of  $k$ -th channel for inter-period run of signal phase from target;  $N$  - number of analyzed pulses in the packet and simultaneously (for DMF) number of frequency channels;  $k = 0, 1, 2, \dots, N-1$  - channel number;

$\dot{x}_{iP\Phi} = x_{ci} + jx_{si}$  - temporary quadrature samples of signal at RF output.

As an indicator of system efficiency, we use the improvement factor [15]:

$$J = r_{out}/r_{in} = K_G/K_C \tag{4}$$

where  $r_{out} = P_{Cout}/P_{Gout}$ ,  $r_{in} = P_{Cin}/P_{Gin}$  is the ratio of the power of the useful signal to the power of the dominant signal at the output and input, respectively;  $K_G = P_{Cin}/P_{Gin}$  is the suppression factor of the dominant signal;  $K_C = P_{Cin}/P_{Cout}$  is the transmission factor of the analyzed signal.

First, we will analyze the passage of the dominant signal. **Fig. 2** shows the canonical diagram of one quadrature channel of RF of  $r$  order, which for binomial weighting coefficients

$$a_i = (-1)^i C_r^i (i = 0, 1, 2, \dots, r), \tag{5}$$

where  $C_r^i$  is the number of combinations from  $r$  to  $i$ , identical to the scheme  $r$ -FIR.

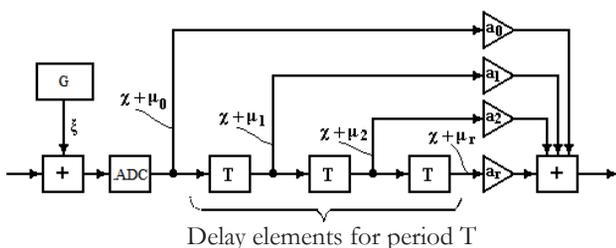
In deterministic quantization, the current digital count is related to the level of compensated interference (dominant signal) ratio (Fig. 2,  $\xi = 0$ ):

$$C = X\Delta + \Delta_C$$

where  $X = E\{C/\Delta\}$  is the function of the whole part,  $\Delta_C = R\{C/\Delta\}$  is the fractional fraction of the relation  $C/\Delta$ .

Let  $\xi \in [0, \Delta]$ , then at the output of ADC digital samples are generated  $X + \mu_i$ ,  $i = 1, 2, \dots$ , where

$$\mu_i = \begin{cases} 1, & \text{with probability } p = \Delta_C / \Delta, \text{ for } \xi > \Delta - \Delta_C; \\ 0, & \text{with probability } q = 1 - p, \text{ for } \xi \leq \Delta - \Delta_C. \end{cases}$$



**Fig. 2.** Canonical scheme of stochastic IF  $r$ -th order.

Using the accepted symbols, the power of the dominant signal  $P_G$  at the output of the RF is represented as:

$$P_s = M \left\{ \left[ \Delta \sum_{i=0}^r (-1)^i C_r^i \left( \frac{C - \Delta_C}{\Delta} + \mu_i \right) \right]^2 \right\}, \tag{6}$$

where  $M\{\dots\}$  is the mathematical expectation operator.

At independent tests  $M\{\mu_i\} = p$ ,  $M\{\mu_i^2\} = p^2$ ,  $M\{\mu_i \mu_j\} = M\{\mu_i\} M\{\mu_j\} = p^2$ , get

$$P_G = \Delta^2 pq \sum_{i=0}^r (C_r^i)^2 = P_{GO}. \tag{7}$$

Signals from the output of the dominant signal compensator in the DMF unit are subjected to transformations (1) and (2). Considering (for simplicity) the operation of one ("central") channel numbered  $k = N/2$  ( $N$  is even), the expression for power deterministic at the output of the  $N$ -point DFT block:

$$P_{Gout} = M \left\{ \left[ \Delta \sum_{j=1}^N \left( \sum_{i=1}^r (-1)^i C_r^i \left( \frac{C - \Delta_C}{\Delta} + \mu_{j-i} \right) \right) \right]^2 \right\}, \tag{8}$$

Because for this channel  $\alpha_k = \pi$ ,  $\sin j\pi = 0$ ,  $\cos j\pi = (-1)^j$ .

Without disturbing the commonality for the same frequency channel, the expression (8) taking into account (7) is converted to a view

$$P_{Gout} = \Delta^2 Npq \sum_{i=0}^r (C_r^i)^2 = NP_{GO}.$$

Considering further that the maximum value of the dominant signal is  $C = \Delta 2^{L-1}$ , and also that the amplitude of the analyzed signal, for example at the Nyquist frequency ( $d_k = \pi$ )v, after passing through the IF and the CH is increased by a factor  $2^r N$ , it is desirable to characterize the degree of suppression of the dominant signal for the PO processing by a normalized suppression factor.

$$K_{GNR} = \frac{\Delta^2 2^{2(L-1)} (2^r N)^2}{P_{GO} N} = \frac{2^{2(L-1)} 2^{2r} N}{pq \sum_{i=0}^r (C_r^i)^2}. \tag{9}$$

The minimum value of the suppression factor is achieved for the interference lying in the middle of the quant (for them) ("antinode" are formed):

$$K_{GNRM} = 2^{2L} \frac{2^{2r} N}{\sum_{i=0}^r (C_r^i)^2} = 2^{2L} \eta. \quad (10)$$

At the determined quantization the dominating signals lying in quantum completely are suppressed, and the dominating signals lying on its borders are suppressed to a lesser extent as the level of not compensated remains at the exit of the IF and KN can reach the size  $N2^{(r-1)}\Delta$ . Therefore, the value of the normalized suppression factor for deterministic processing:

$$K_{GNDM} = \frac{\Delta^2 2^{2(L-1)} (2^r N)^2}{N^2 2^{2(r-1)} \Delta^2} = 2^{2L}. \quad (11)$$

Next, in expression (8), the coefficient  $\eta > 1$ , i.e., PO, has advantages over deterministic processing (DP). Actually  $\left(\sum_{i=0}^r C_r^i\right)^2 > \sum_{i=0}^r (C_r^i)^2$ , since, a  $\sum_{i=0}^r C_r^i = 2^r$ , we get:

$$\eta = \frac{2^{2r} N}{\sum_{i=0}^r (C_r^i)^2} > \frac{2^{2r}}{\left(\sum_{i=0}^r C_r^i\right)^2} = \frac{2^{2r} N}{2^{2r}} = N \geq 1. \quad (12)$$

Analysis of expression (9) shows that degree of suppression of dominant signals in case of RO is determined not only by bit  $L$  of ADC, but also by order  $r$  of IF, as well as by number  $N$  of accumulated samples in DMF unit. By selecting  $N$  and  $r$  respectively, the number of quantization levels of the input ADC can be significantly reduced  $M = 2^L$  to achieve the desired suppression. Programming on the PLD divides the CP into two units: IF and CP the implementation of which is significantly simplified due to the sharp reduction of the CP discharge. In DO processing, as seen in (19), the degree of suppression is determined by ACD converter discharge  $L$ , wherein the specific suppression per bit does not exceed 6 dB.

### 5. ANALYSIS OF SIGNAL TRANSMISSION

The passage of weak signals commensurate with quantum and less was analyzed. The nonlinearity of the step amplitude characteristic can show results in that, if the amplitude of the useful signal  $S < Q\{x/\Delta\}\Delta$ , where  $x = C \pm S$ ,  $Q\{x/\Delta\}$  is a function of the distance to the nearest integer  $x/\Delta$ , such a signal is lost during processing due to nonlinearity of the "dead zone" type. Randomization of the processing allows linearizing said nonlinearity and thus detecting the signal from the target located inside the quant of the ADC [13].

The power of the useful signal at the output of the ADC+N-Surgical DMF processing device was defined as the increment of the sum power, which is caused by the analyzed signal. It is shown that at PO the power of the analyzed signal, even if it is inside the quantum  $\Delta$  ( $B = 0$ ), at the output of the DC device is not equal to zero. Absence of "dead zone" in amplitude characteristic of RP device is explained by effect of "linearization of nonlinearity" of ADC.

Linearized characteristic of ADC is shown in Fig. 3: Dependencies are built on the amplitude  $P_{cont}$  for the analyzed signal  $S$  at  $\Delta_c = 0$  (curve 1) and  $\Delta_c = \Delta/2$  (curve 3). The same figure shows that the corresponding constraints at NO (curves 2 and 4). As can be

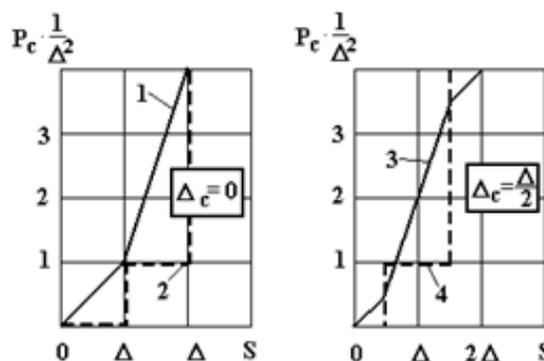


Fig. 3. Relations of normalized power of output signal  $S$ , commensurate with quant size for compared CA methods.

seen from the figure (curves 1 and 3), the effect of eliminating the "dead zone" in which weak signals were lost, was found. Consequently, linearization of non-linearity of the "dead zone" type allows to detect weak signals, the amplitude of which is commensurate and less than quantum  $\Delta$ .

If the amplitude of the useful signal is not too small compared to  $\Delta$ , its power at the output of the RO device:

$$P_{Cout} = \frac{(N2^r S)^2}{2} = N^2 2^{2r-1} S^2.$$

Given that  $P_{Cin} = S^2/2$ , the gain of the useful signal is represented by

$$K_C = P_{Cout} / P_{Cin} = N^2 2^{2r}. \tag{13}$$

It follows from the obtained formulas that the specified coefficient of improvement of the SDT-P filter with the corresponding selection of parameters  $N$  and  $r$ , IF and CD can be achieved with less than the deterministic processing of the number of quantization levels in the input ADC. Gain (equivalent) digit capacity of ADC on an entrance  $\Delta L_{eq} = \log_2 \eta$ , where  $\eta$ , is determined by formula (10). In this example, the dominant signal was taken at frequency 0. For other cases, the IF circuit is supplemented by a phase changer, which is automatically adjusting IF HX "zero" to a frequency channel numbered " $k$ ," in which the dominant signal is detected.

For RO, by introducing random factors into the CP process as an addition to the digital copy of radio signals and a digital copy of random perturbations under CMF conditions, the levels of parasitic components in the spectrum of reproduced signals are reduced by 20-30 dB.

Consequently, digital multichannel frequency filtering (DMF) of the signals in the DRFM device itself and the randomization of rough samples are an alternative to traditional construction, but with multi-bit processing.

**6. CONCLUSION**

The article explores the possibility of using "low-discharge" ("Rough") readings (statistics) in radio frequency storage technology (DRFM technologies).

It is proposed to use randomization of measurements by the Monte Carlo method, which uses "rough" ("Boolean") statistics in statistical tests to reduce ("smooth") quantization noise.

In order to reduce the requirements for dynamic range in multi-signal mode, it is recommended to identify the dominant signal and exclude it from further processing.

The obtained recommendations are useful for developers of DRFM technology, and the knowledge gained is needed for specialists in the field of randomization of physical measurements.

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