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Modified Filter Bank for Digital Down Converter of Pulse Radar Receiver

Ganesh P. Sonar[1], Prof. R.A.Patil[2], Mr J.S. Pillai[3]

Master in technology, Dept of Electronics Engineering, Veermata Jijabai Technological Institute, Mumbai, India [1]

Assistance professor, Dept of Electronics Engineering, Veermata Jijabai Technological Institute, Mumbai, India[2]

Scientist E, Dept of Atmospheric and Radar Society for Microwave Electronic Engineering& Research Mumbai, India [3]

Abstract: In Pulse radar receiver system Digital down converter is an important part. Digital down converter (DDC) demodulates the base band signal from the transmitted signal and also reduces the sampling rate of the signal. The most important part of DDC is filter structure, it uses large resources which increases the cost of the system. To overcome this problem we propose the new filter structure containing the cascade integrator combo filter (CIC filter), multi-rate FIR filter and Half-band filter. The proposed filter structure of DDC reduces the complexity and cost of implementation. The simulation results shows that the proposed filter structure of DDC achieves expected specification in application of pulsed radar receiver.

Keywords: Digital Down Converter (DDC); Cascade Integrator Combo Filter (CIC); Finite Impulse Response (FIR); Half Band Filter (HB filter); Analog To Digital Converter (ADC)

I. INTRODUCTION

The digital down converter is used in the high signal processing, receiver of modulated communication, medical image hardware and low level RF control for scientific research.

DDC demodulates the signal and reduces its sampling rate. Input of DDC comes from ADC. DDC cuts down the cost of ADC and CPU in a system and also reduces the complexity of the system. If the cost of the system is reduced, the efficiency increases. It makes the most flexible structure of DDC in application of pulsed radar receiver.

This application requires both amplitude and phase of the signal. This signal acquires high resolution and high speed ADC [1]. The information content does not occupy the entire Nyquist band of the ADC. For this case sample rate is reduced, only after the frequency shifting of the signal the band of interest down to DC [2]. It preserves the magnitude and phase of the signal along with the frequency of the signal both above and below of the target band. It also separates the component of the signal by 90 degree out of phase which must be retained. This signal is referred as in-phase (I) and quadrature (Q), which are complex in nature i.e. having real and imaginary components.

Digital down converter mainly consists of the following structure- software based numerically control oscillator (NCO), mixer, filter bank and decimation. Filter bank contains the CIC filter, multi-rate FIR filter and Half-band filter.

The paper is organized as follows. Section II presents the design of DDC structure, a modified filter bank, and builds a LABVIEW model. Section III LABVIEW programming based on mathematical model. Section IV shows the simulation and analysis results. Section V draws the conclusion of this paper.

II. DIGITAL DOWN CONVERTER DESIGN

Function of DDC is to extract the baseband signal from the modulated signal at high sampling rate. And it shifts IF spectrum to the baseband spectrum and decimate the sampling rate by the factor 1/300. In this section, a structure of DDC is designed, and a LABVIEW model is built.

A. DDC Structure

Structure of DDC mainly consists of the two channel I (n) and Q (n) as shown in fig.1. It consists of - mixer, filter bank and decimation factor. RF mixer does multiplication of two signal [3].Software based NCO generates two complex sequences of signal having same frequency 38 MHz but different phase 0 and 90 degree respectively. This frequency is called center frequency or zero frequency. Multiplication of real signal and complex sequence signal does shifting of IF spectrum into the baseband spectrum by using the mixer.After shifting the signal it needs filtering which removes sideband, imaging, and aliasing of signal. Sampling rate is reduced by decimation. Next section is modified filter bank which reduces the complexity of signal and make it flexible, efficient structure of DDC.

TABLE-1
PARAMETER OF DDC

Parameter type	value
Sample rate input	*250MHz*
Sample rate output	*0.83MHz*
Down sample factor	*300*
Multi rate FIR filter pass band edge frequency	*4KHz*
Stop band edge frequency	*5kHz*
Pass band ripple	*0.01db*
Stop band	*100db*
i/p frequency carrier+ baseband	*212001000 Hz*
o/p frequency of base band	*1000Hz*

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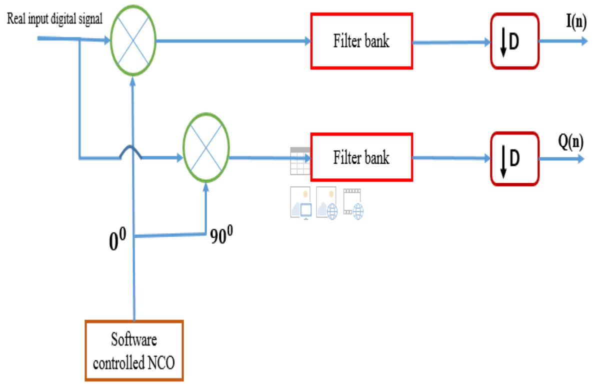

Figure 1. Structure of DDC

B. MODIFIED FILTER BANK

In this paper modified filter bank contains a 3-tap CIC filter, 322-order multi rate FIR filter, 17 –order half band filter. All filters work on the principle of multi-rate signal processing.

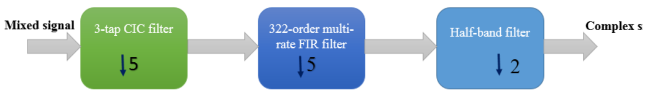

Figure 2. Filter bank

a. CIC Filter

CIC filter is derived from recursive running sum filter, also it is special class of linear phase FIR filter, it is more efficient than the conventional FIR filter .CIC filter does not require the multiplication and it only requires addition, subtraction and register. Hence it requires minimum storage space. It is used to reduce the sampling rate by large sampling frequency conversion factor [4]. It is a combination of integrator and combo filter with sampling conversion factor.

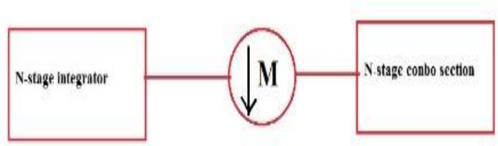

Figure 3. CIC filter structure

$$H(z) = H_i^N(Z).H_c^N(Z)$$

$$= \frac{(1-z^{-RM})^N}{(1-z^{-1})^N} \text{ , for single stage}$$

$$= (\sum_{k=0}^{RM-1} z^{-k})^N, \text{ for N stage}$$

Z- Complex variable, I-basic integrator section,c- basic combo section,M- sampling frequency conversion factor,R- Differential delay, N- Number of stage, D- is number of averaging points.

$$N=\frac{D}{R}$$

b. Multi-Rate FIR Filter:

FIR filter is known as non-recursive filter or convolution filter, it operates at past and present value of input, simplest design to be implemented. In multi-rate, the system is operated at different sample rate. If the sample rate is reduced by the factor M then every M-1 sample will be removed. It causes the input frequency have one half the sampled rate to be aliased frequency band from DC to Nyquist frequency band. This creates aliased signal spectrum. For the requirement of aliased free spectrum low-pass filter is used, the combination of this system is known as multi-rate FIR filter. Let X (n) be the input sequence and h (n) is the coefficient of low pass filter, Length is K, decimation by factor M

$$Z\,(n)=\sum_{k=0}^{k} h(k)X(n-k)$$

Output of signal after decimation y(r) = z (r M) when sampling rate is reduced by the factor M

$$Y(r) = \sum_{k=0}^{k} h(k).x(rM-k)$$

C. Half Band Filter:

HB filter is FIR filter, as its transition region is centered at one quarter of sampling rate or fs/4. The end of pass band and begin of stop band are equally spaced. Half band filter is used as decimation filter because half of the coefficient are zero in time domain. It reduces computation for filtering. Half band filter is M^{th}band filter when M=2, which satisfies the following equation:

$$h\,(2n+k)= \begin{pmatrix} c\,, n=0 \\ 0\,, n\neq 0 \end{pmatrix} \text{ , c is mostly 0.5 .}$$

III. LABVIEW PROGRAMMING BASED ON MATHEMATICAL MODEL

Input of DDC comes from ADC, which is a modulated signal having the frequency w_1 =212 MHz carrier and the baseband signal having frequencyw_2 = 1kz and sampling frequency is f_s =2000 MHz .The number of sample is 2000000.

$$X(t) = sinw_1t + sinw_2tX(n) = sin\theta_1n + sin\theta_2n$$

$$X(n) = 2\,sin\left(\frac{\theta_1+\theta_1}{2}\right)n.cos(\frac{\theta_1-\theta_2}{2})n\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Resampled by $f_s = 250Mhz$. In equation $1\frac{\theta_1+\theta_1}{2} = \theta_3$,

$$\frac{\theta_1-\theta_2}{2} = \theta_4$$

$$X(n) = 2\,sin\left(\frac{\theta_3}{f_s}\right)n.cos(\frac{\theta_4}{f_s})nX(n) = 2\,sin\,\Omega_1 n\,.cos\,\Omega_2 n\ldots\ldots \quad (2)$$

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NCO generates two signal at frequency Ω_3 =38MHz and the phase is 0 and 90 degree respectively. Mix the input signal and the complex sequence generated by NCO. This will result in the IF band shifting to baseband spectrum [5].

$$X_Q(n) = I^{st}\ Q\ signal = X(n).\ sin\Omega_3 n \ldots\ldots\ldots .(3)$$
$$X_I(n) = I^{st}\ I\ signal = X(n).sin(\Omega_3 + 90)n \ldots\ldots\ldots\ (4)$$
$$= X(n).\ Cos\Omega_3 n \ldots\ldots\ldots\ldots\ldots\ (5)$$

Then signal is passed through the CIC filter and this reduces the sample rate by factor 5. 3-tap CIC filter is used and input sampling frequency is 250 M Hz.

$$X_{2I}(n) = \frac{1}{D}[X_I(n) - X_I(n-D)] + X_{2I}(n-D) \ldots\ldots\ (6)$$

M-cascade CIC filter D $=(RN)^M$,R-decimation factor, N-sampling delay after decimation=$\frac{1}{250MHZ}$

$$X_{2Q}(n) = \frac{1}{D}\left[X_Q(n) - X_Q(n-D)\right] + X_{2Q}(n-D) \ldots\ldots\ (7)$$

Now the signal is passed through multi-rate FIR filter – order is 332, decimation factor is 5, sampling frequency is 50 MHz, transition region is in between the 4 MHz – 5 MHz, pass-band attenuation is 0.001dB and stop-band attenuation is 100 dB.

$$X_{IF}(n) = \sum_{k=0}^{k} h(k).\, x_{2I}(n-k) \ldots\ldots\ (8)$$

After decimating, multi-rate system is

$$X(r) = X_{IF}(r\ n)\ ,\ X_{IF}(\ n) = \sum_{k=0}^{k} h(k).\, x_{2I}(r\ n-k) \ldots\ldots\ (9)$$

Similarly for Q channel

$$X_{QF}(n) = \sum_{k=0}^{k} h(k).\, x_{2Q}(r\ n-k) \ldots\ldots (10)$$

Signal is passed through the low pass half band filter-order is the 17, sample rate is decimated by 2, sampling frequency is 10MHz, roll off is 0.1 and stop-band attenuation is 100 dB

Length of the filter N=4m+2

After realization of signal,

$$I(n) = \sum_{k=0}^{\frac{N}{2}} X_{IF}(n - 2k).\, h(2k) + 0.5X_{IF}(\ n - 2m - 1)$$

$$Q\ (n) = \sum_{k=0}^{\frac{N}{2}} X_{QF}(n - 2k).\, h(2k) + 0.5X_{QF}(\ n - 2m - 1)$$

IV. SIMULATION AND ANALYSIS RESULT

Input signal to DDC is 212 MHz + 1 kHz frequency of signal, Input of Digital down converter comes from the ADC. Simulated signal is shows as follow-

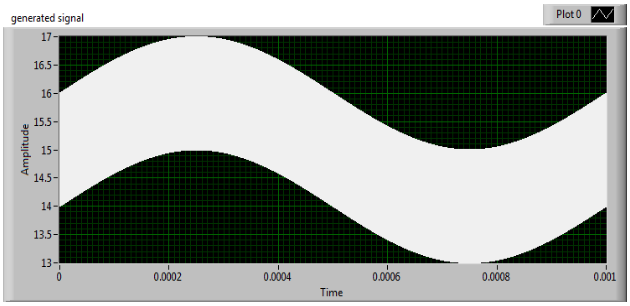


Figure 4. Simulated signal

Then the signal is resampled at the 250 MHz, because the two different frequency signals should have same start and end point of the signal as follows-

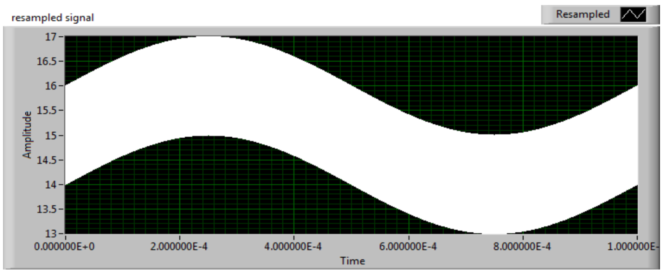
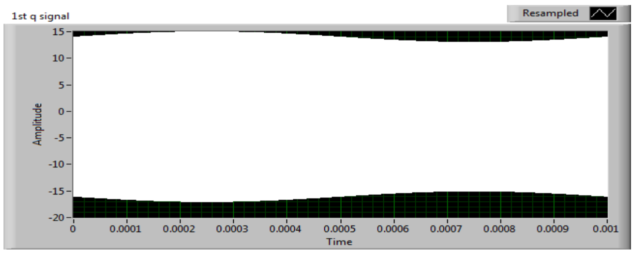


Figure.5 Resampled signal

Resampling signal is mixed with the sine and cosine signals. This produces first I (n) and Q (n) signal respectively and shifts the spectrum to the base band.



ssFigure 6. I – I signal

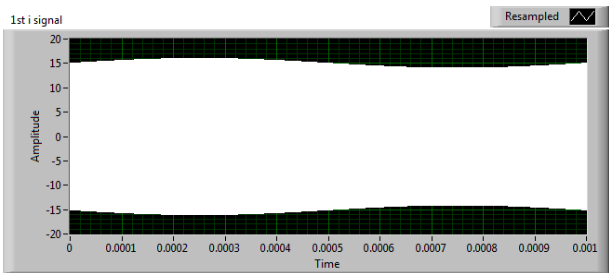


Figure 7. I- Q signal

Then signal is passed through the CIC filter tap - 3, filter factor is 5, i/p sampling frequency is 250MHz, pass-band frequency is 5MHz, pass-band distortion is 0.6882dB and aliasing distortion is 93.8dB.

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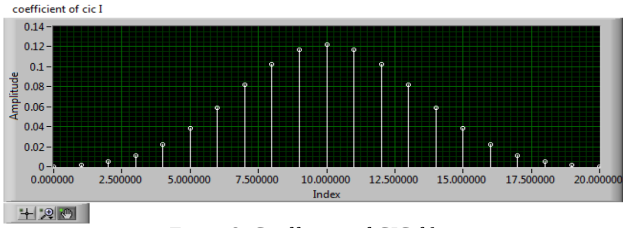

Figure 8. Coefficient of CIC filter

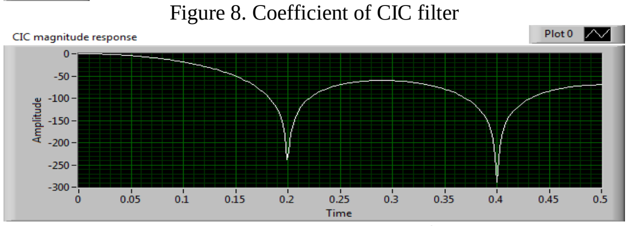

Figure 9. Magnitude response of CIC

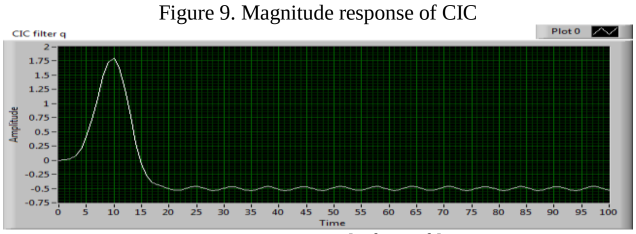

Figure 10.o/p I signal of CIC filter

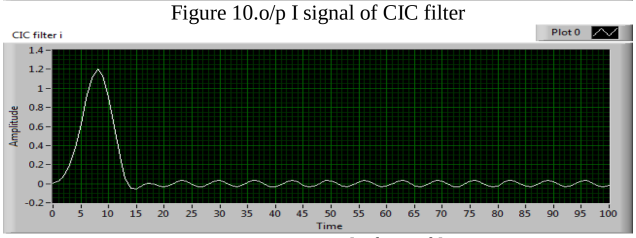

Figure 11.o/p Q signal of CIC filter.

CIC o/p signal is passed through the multi-rate FIR filter order -332, decimation factor 5, pass-band edge frequency-4 kHz, stop-band edge frequency 5 KHz, o/p sampling frequency 10MHz, pass band ripple 0.001dB and stop-band attenuation 100dB by using Kaiser Window technique.

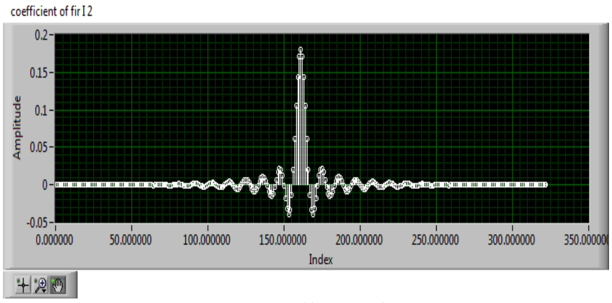

Figure 12 coefficient of FIR,

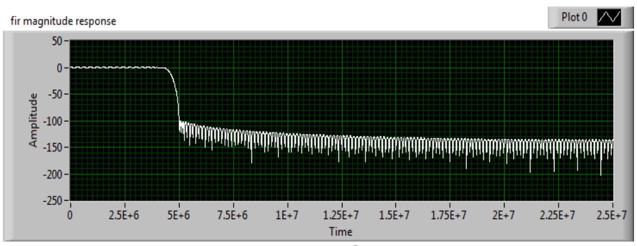

Figure-13 magnitude response

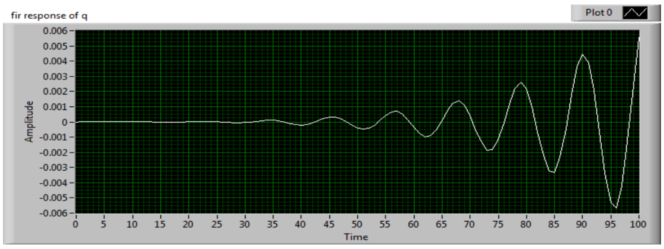

Figure-14 0/p I signal FIR response,

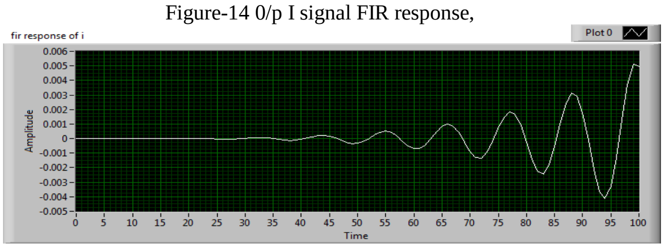

Figure-15 o/p Q signal FIR filter.

Then signal is passed through the HB filter order is -17, roll of 0.1 and stop attention is 100 dB.

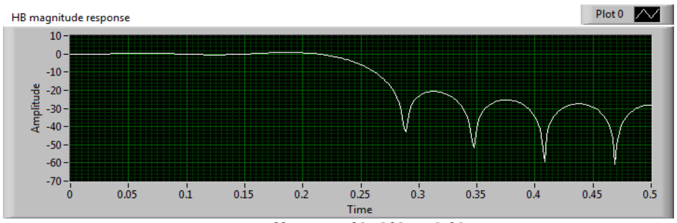

Figure -16 coefficient of half band filter,

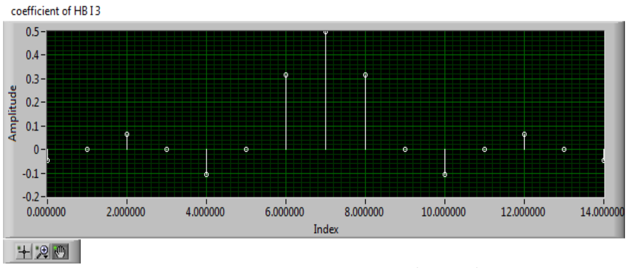

Figure -17 magnitude response half band filter

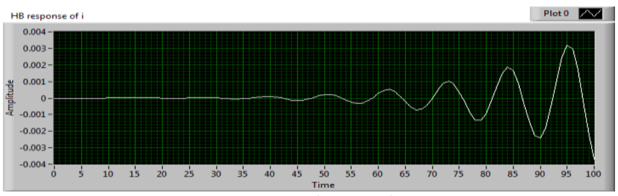

Figure-18 o/p I signal form half band signal

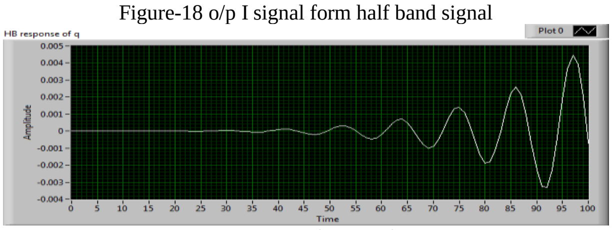

Figure -19 o/p Q signal form half band signal.

Decimating the signal by certain factor to get a decimated signal and its sampling rate is low. This is I (n) and Q (n) signal.

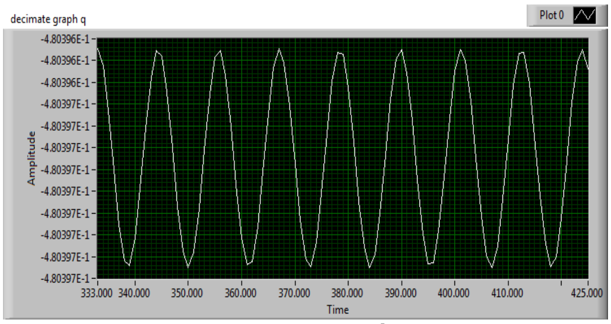

Figure-20 Q signal

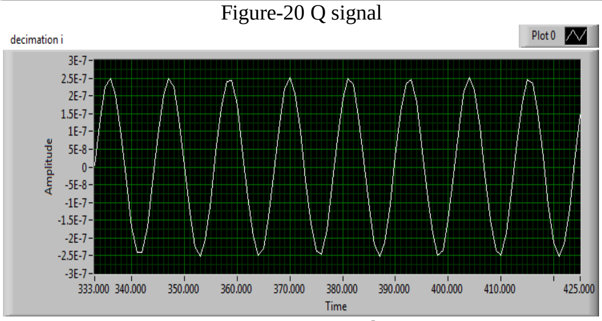

Figure 21 I signal

Particular frequency of signal and reduced sampling rate is found by using the FFT transform technique shown by the following graph:

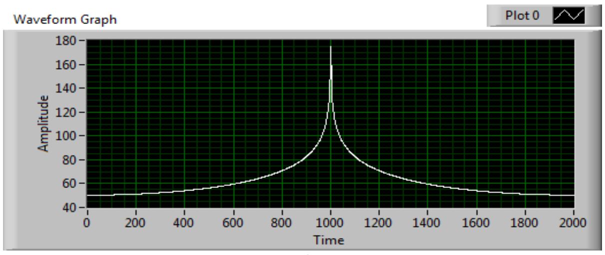

Figure -23 FFT of complex signal**.**

V. CONCLUSION

In this paper we implemented DDC with new filter bank on LABVIEW for pulse radar appliances. DDC's main part is filter bank which uses the resources of a system. It comprises of three filters- Cascade integrator combo filter, Multi rate FIR filter and half band filter. CIC converts wide band signal to narrow band signal with high sampling frequency conversion factor. It is a simple structure to implement, doesn't use multiplication so requires minimum resources and reduces the complexity of the system. Multi rate FIR filter compresses the signal. Half band filter's half of the coefficients are zero, therefore the length of the filter is decreased and requires low computation for the realization of the filter. The modified filter bank requiring less resources as compared to the conventional filter bank, thus reducing the size, cost and complexity and hence increasing the efficiency.

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