CORDIC Based FM Demodulator for Digital Telecommand Receiver

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***Abstract*—Telecommanding enables the control of a launch vehicle during the flight. The Command system uses FM modulation on a UHF-Band link. In this paper, an FM demodulator based on CORDIC algorithm is presented. CORDIC is an efficient method which provides iterative solutions for trigonometric, hyperbolic, arctangent functions etc.**

***Keywords*—FM demodulation, CORDIC, telecommanding, MATLAB**

I. INTRODUCTION

The purpose of the telecommand system is to serve as a primary control link between ground station and space vehicles. It plays a vital role in telecommunicating the information necessary to the success of a space vehicle's mission, which cannot be loaded into the space vehicle, prior to launch.

Many commands are necessary to the routine operation and control of spacecraft functions. Some are meant for changing mission emphasis if unusual or unexpected conditions are encountered. Some others are required to correct the erratic operations or partially salvage the mission if spacecraft failure modes occur. Usually, all of the commands will fall into two categories (1) the real time (RT) commands for switching scientific experiments and inhouse subsystems (ON/OFF), activating deployment mechanisms, terminating the flight in case the launch vehicle fail posing danger to the safety of the people and (2) the data commands for initiating orbital manoeuvres and remote programing of spacecraft computers. While the real time commands constitute definite word patterns, a data command can have any pattern.

Command systems are characterised mainly by the number of commands that they are capable of handling. Three types of command systems are in use in space vehicles. They are tone, tone-digital, and digital command systems. Early satellites used tone command system or tone digital command system. Both the systems are prone to transmission errors and have limited handling capacity of RT commands. Typical spacecraft of present day requires commands of the order of one to two thousand. Digital command systems have the capability of supplying large number of commands at a high command rate. This system is amenable to incorporation of error control techniques for guarding the commands against induced errors and scrambling techniques for maintaining privacy. Telecommanding is a digital communication process. A general model of TC system comprising of two segments, namely, ground and on-board is shown in Fig. 1.

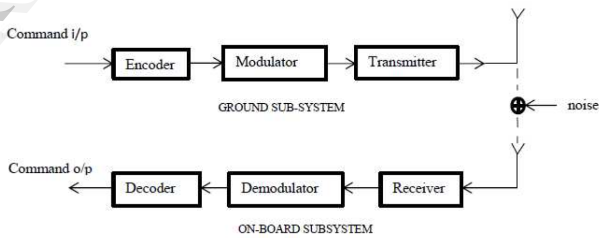

Figure 1. General model of TC system

Modulation technique used for telecommanding is Frequency Modulation (FM).The design and operation of a command system is influenced by the need for high accuracy and reliability . Accuracy is measured by the system's ability to receive commands without error or at least within the limits of some prescribed error probability. It is a function of communication link capabilities as well and limitations, and channel noise.

In this paper, an FM demodulator based on CORDIC algorithm is presented. CORDIC which stands for Coordinate Rotation DIgital Computer was introduced by Jack Volder in 1959[1]. Initially it was used to calculate sine and cosine functions. It is a hardware efficient algorithm which uses only shift and add operations. In systems where multiplication and division are computationally expensive operations and memory is limited, CORDIC algorithms are very useful.FM modulation basics and FM Digital receivers are discussed in Section II. Section III discusses implementation of CORDIC algorithm based FM demodulator in MATLAB. Section IV shows simulation results.

II. FM MODULATION AND DIGITAL FM RECEIVERS

A. FM Modulation

Let the message signal and carrier signal be,

$$x_m(t) = A_m \sin\omega_m t \qquad (1)$$
$$x_c(t) = A_c \cos\omega_c t \qquad (2)$$

then frequency modulated signal is given by,

$$y(t) = Ac \cos(2\pi f_c t + 2\pi k \int x_m(\tau))d\tau) \qquad (3)$$

$$\int x_m(\tau)\, d\tau = A_m \cos(2\pi f_m t) / 2\pi f_m \qquad (4)$$

where k is the maximum frequency deviation

$$y(t) = A_c \cos(2\pi f_c t + k\, A_m \cos(2\pi f_m t) / 2\pi f_m)$$
$$= Ac \cos(2\pi fct + \beta\cos(2\pi f_m t) \qquad (5)$$

Where β is the modulation index given by,

$$\beta = k / f_m \qquad (6)$$

B. Digital Telecommand Receiver

Frequency modulated signal is received by the telecommand receiver. It is a double superheterodyne receiver. After passing through RF and IF stages, FM signal is down converted to an intermediate frequency of 10.7MHz. Conventional type of telecommand receivers used analog FM demodulators. Digital signal processing can offer more system flexibility, programmability & easy upgrading than fixed analog systems. Therefore analog IF signal is sampled and a complex baseband FM signal is generated out of it. Complex data is generated by mixing the FM signal with a cosine and sine local oscillator as shown in the Fig. 2.

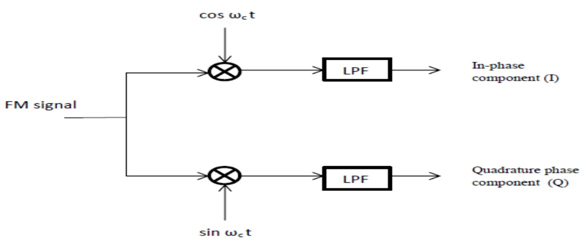

Figure 2. Generation of complex baseband FM signal

The cosine mixing term and sine mixing term are multiplied with the incoming FM signal. Both mixers oscillate at the FM carrier frequency w_c. The total mixing operation produces a real (in-phase) and imaginary (quadrature-phase) baseband component. Adding the in-phase and quadrature-phase baseband components results in the complex baseband FM signal.

$$I = A_C/2\{ Re [e^{jy(t)}] \} \qquad (7)$$
$$Q = jA_C/2\{ Im [e^{jy(t)}] \} \qquad (8)$$

Complex baseband FM signal is given by,

$$y(t)_{fm\text{-}baseband} = A_C/2\{ Re [e^{jy(t)}] + j\, Im [e^{jy(t)}] \} \qquad (9)$$

This complex baseband signal is used for FM demodulation. Basic idea behind all FM demodulators is to extract phase from the modulated signal and then differentiate for the recovery of original message signal.

III. CORDIC ALGORITHM

CORDIC algorithm translates a point along a unit circle to implement various trigonometric and hyperbolic functions. These functions corresponds to mapping between rectangular and polar coordinate systems. It has two operating modes namely Vectoring mode and Rotation mode[2]. Vectoring mode converts a vector from Cartesian coordinate system to polar coordinate.

$$x = R\cos\theta \qquad (10)$$
$$y = R\sin\theta \qquad (11)$$
$$\theta = \tan^{-1}(y/x) \qquad (12)$$
$$R = (x^2+y^2)^{1/2} \qquad (13)$$

These are classic equations for translation between rectangular and polar system. For FM demodulation vectoring mode of CORDIC algorithm is used.

Consider a point (x_{in},y_{in}) offset from x-axis at an angle α. A new point (x_{final},y_{final}) can be created by rotating the initial point around unit circle by an angle θ.

$$x_{in} = R \cos\alpha \qquad (14)$$
$$y_{in} = R \sin\alpha \qquad (15)$$

$$x_{final} = R \cos(\theta+\alpha) \qquad (16)$$
$$y_{final} = R \sin(\theta+\alpha) \qquad (17)$$

using trigonometric identities,

$$x_{final} = R [\cos\alpha \cos\theta - \sin\alpha \sin \theta] \qquad (18)$$
$$y_{final} = R [\sin\alpha \cos\theta + \cos\alpha \sin \theta] \qquad (19)$$

from above equations,

$$x_{final} = x_{in} \cos\theta - y_{in} \sin\theta \quad (20)$$
$$y_{final} = y_{in} \cos\theta + x_{in} \sin\theta \quad (21)$$

if coordinates x_{in} and y_{in} are known and if $(x_{final}, y_{final}) = (R,0)$ angle swept will be equal to θ. This is rectangular to polar conversion[2]. In case of complex baseband FM signal, at each sample point let,

x_{in} = in-phase component (I)
y_{in} = quadrature phase component (Q)

The vector is then rotated until $y_{final} = 0$ in a series of angle steps θ_i that when summed gives θ (phase of the vector) as shown in Fig. 3.Then x_{final} gives the magnitude.

$$\theta = \sum \theta_i$$

θ_i is chosen so that

$$\tan\theta_i = \pm 2^{-i} \quad (22)$$

When $+2^{-i}$ is used, rotation will occur in a counter-clockwise direction. When -2^{-i} is used, rotation will occur in a clockwise direction.
Iterative rotation is expressed as,

$$d_i = -\operatorname{sgn}(y_i) \quad (23)$$

$$x_{i+1} = x_i - d_i\, y_i\, 2^{-i} \quad (24)$$
$$y_{i+1} = y_i + d_i\, x_i\, 2^{-i} \quad (25)$$
$$z_{i+1} = z_i - d_i \operatorname{atan}(2^{-i}) \quad (26)$$

Here (x_0,y_0) =(I,Q) and z_0 =0. After a number of iterations, number of subrotations (N) becomes large,
$y_N \rightarrow 0$, $z_N \approx \operatorname{atan}(y_0/x_0)$ and $x_N = (x^2+y^2)^{1/2}/K$.
where $K = \cos(\operatorname{atan}(2^{-i}))$.
z_N will give phase of the vector θ. Original message signal can be retrieved by differentiating phase of the signal.

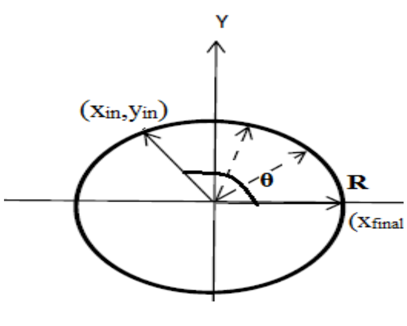

Figure 3 Rotation of a point about a circle

IV. Simulation Results

The proposed FM demodulator was tested & verified using MATLAB software from Mathwork. An FM modulated signal is generated with f_m = 15KHz and f_c = 400MHz. At the receiver, FM signal is downconverted to 10.7MHz. It is then sampled and mixing is done to generate complex baseband FM signal. Demodulation is done using CORDIC algorithm. A look-up table containing arctan values is created and number of iterations taken as N = 40. At the demodulator output a smoothening low pass filter is also provided to remove spikes and spurious components.

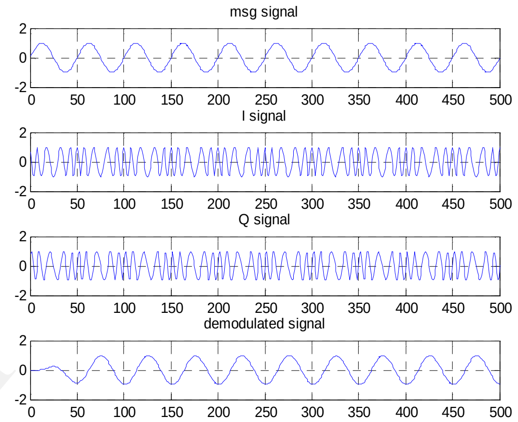

Figure 4. MATLAB Simulation Results

Comparison of input SNR versus output SNR plot for CORDIC based FM demodulator, arctan FM demodulator [6] and baseband delay FM demodulator is shown in Fig. 5. CORDIC based FM demodulator provides acceptable values of SNR than arctan demodulator. Frequency spectrum of the same demodulators are shown in Fig. 6. CORDIC based demodulators has very less harmonic distortion compared to other two.

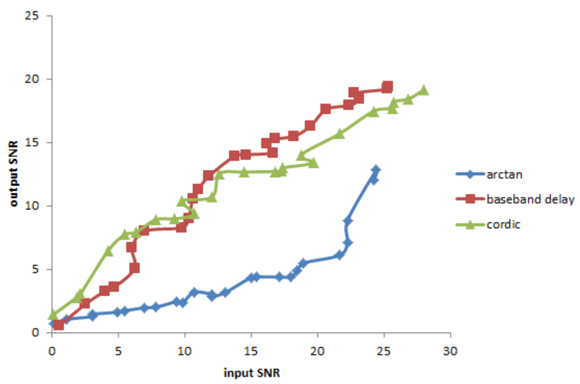

Figure 5.Input SNR Vs output SNR

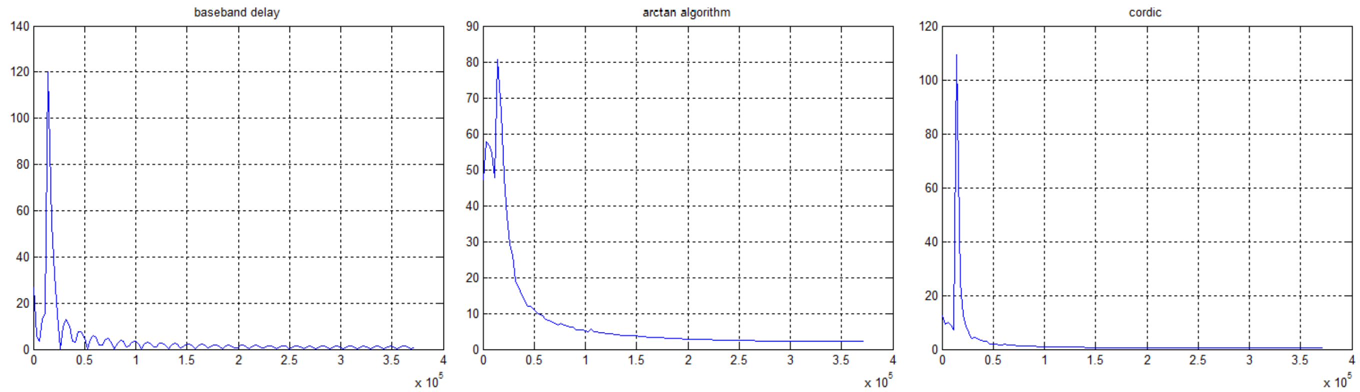

Figure 6. Frequency spectrum of three different FM demodulators

V. CONCLUSIONS

Based on the CORDIC algorithm, a digital FM demodulator has been introduced. This method is based on quadrature demodulation and is suitable for integration in digital telecommand receivers. MATLAB simulation results shows that this FM demodulator gives acceptable performance in terms of SNR and harmonic distortion.

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