Simulation of High Resolution Range and Separation Profiles Using a Stepped Frequency Radar Pulse

1985

Howard. Fain

University of Central Florida

Find similar works at: https://stars.library.ucf.edu/rtd

University of Central Florida Libraries http://library.ucf.edu

Part of the Engineering Commons

STARS Citation

https://stars.library.ucf.edu/rtd/4836

This Masters Thesis (Open Access) is brought to you for free and open access by STARS. It has been accepted for inclusion in Retrospective Theses and Dissertations by an authorized administrator of STARS. For more information, please contact lee.dotson@ucf.edu.
SIMULATION OF HIGH RESOLUTION RANGE AND SEPARATION PROFILES USING A STEPPED FREQUENCY RADAR PULSE

BY

HOWARD FAIN
B.S.E., University of Connecticut, 1982

RESEARCH REPORT

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Graduate Studies Program of the College of Engineering University of Central Florida Orlando, Florida

Fall Term
1985
ABSTRACT

Single frequency pulse, linear frequency pulse, and stepped frequency pulse are a few of the radar pulse waveforms used to obtain target range information. Using a basic single frequency pulse limits the radar's range resolution by the pulse width, has excessive energy requirements, and is more vulnerable to jamming. With the use of frequency modulation the radar's range resolution can be greatly enhanced. This report deals with some of the issues involved in using stepped frequency pulse trains to obtain high resolution target range and range autocorrelation profiles. Radar returns from stepped frequency pulse trains may be coherently processed to obtain the range profile, or noncoherently processed to obtain the range autocorrelation (or separation) profile. The inverse discrete Fourier transform (\(\text{DFT}^{-1}\)) of N coherently detected pulse returns from each range cell (where N is the number of pulses in the train) gives the high resolution range profile within that range cell. The DFT of the squared magnitudes of the pulse returns yields the autocorrelation of the range profile (the separation profile).
Range resolution is determined by the total bandwidth of the pulse train. Using a Fast Fourier Transform (FFT) algorithm for the DFT a simulation of the radar system is implemented on the University of Central Florida, College of Engineering Research VAX 11/750 computer. This simulation computes and plots the range and separation profiles.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Coherent Processing Overview</td>
<td>1</td>
</tr>
<tr>
<td>Noncoherent Processing Overview</td>
<td>4</td>
</tr>
<tr>
<td>The Stepped Frequency Pulse Train</td>
<td>5</td>
</tr>
<tr>
<td>Signal Processing</td>
<td>8</td>
</tr>
<tr>
<td>SYSTEM CONSIDERATIONS</td>
<td>11</td>
</tr>
<tr>
<td>Frequency Spacing And Aliasing</td>
<td>11</td>
</tr>
<tr>
<td>Number of Frequencies Required</td>
<td>15</td>
</tr>
<tr>
<td>COMPLEX RETURNS FROM AN ARBITRARY TARGET</td>
<td>16</td>
</tr>
<tr>
<td>Single Point Target</td>
<td>16</td>
</tr>
<tr>
<td>Distributed Target</td>
<td>17</td>
</tr>
<tr>
<td>THE RANGE PROFILE</td>
<td>19</td>
</tr>
<tr>
<td>DFT Implementation of Coherent Processing</td>
<td>19</td>
</tr>
<tr>
<td>DFT Derivation</td>
<td>21</td>
</tr>
<tr>
<td>Derivation of Course Range Bin Resolution</td>
<td>23</td>
</tr>
<tr>
<td>Derivation of Fine Range Bin Resolution</td>
<td>24</td>
</tr>
<tr>
<td>Range Delays and DFT Bin Ranges</td>
<td>25</td>
</tr>
<tr>
<td>Timing of the A/D Sampling Strobe</td>
<td>27</td>
</tr>
<tr>
<td>THE SEPARATION PROFILE</td>
<td>30</td>
</tr>
<tr>
<td>Noncoherent Processing</td>
<td>30</td>
</tr>
<tr>
<td>Advantages of Noncoherent Processing Over</td>
<td>32</td>
</tr>
<tr>
<td>Coherent Processing</td>
<td>32</td>
</tr>
<tr>
<td>DFT Implementation</td>
<td>33</td>
</tr>
<tr>
<td>COMPUTER SIMULATION OF RADAR SYSTEM</td>
<td>36</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>45</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>46</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>65</td>
</tr>
</tbody>
</table>
INTRODUCTION

Coherent Processing Overview

The stepped frequency pulse train waveform is created by transmitting a series of N pulses, each at a different frequency. By varying the frequency from pulse to pulse a better range resolution is obtained. Range resolution can be defined as the minimum distance between two targets, which yields separately distinguishable radar returns. The N frequencies may be generated from N different, stable but independent frequency sources (or a frequency synthesizer). Coherency is required at each of the N frequencies individually but not between each of the N frequencies. Known phase relationships between the different pulses in a stepped frequency pulse train are not required to obtain a high resolution range profile (Barton 1977). The radar must have a coherent-on-receive capability. Coherent processing requires compensation of any nonlinear differential phase shifts between the different carrier frequencies that occur in the front end of the radar due to component bandwidth limitations. Also, target doppler induced phase shifts in the pulse returns must also be compensated for.
The return from a distributed target as a function of frequency is the Fourier transform (FT) of the target range profile, weighted by the pulse shape. The FT of the range profile is obtained by measuring the complex returns from the target at a number of different frequencies. The range profile can be reconstructed by \( \text{FT}^{-1} \) of the set of complex returns at the different frequencies (Einstein 1984).
TABLE 1
GENERATION OF THE RANGE PROFILE - SUMMARY

1. Transmit a coherent pulse-to-pulse frequency stepped waveform with N pulses. Separate the return signals into in-phase and quadrature (I and Q) components.

2. Store the quadrature components of the N return signals. This is the target spectral signature (provided the pulse width is short relative to target fluctuation time).

3. Take an inverse Fourier transform (FT⁻¹) of the frequency components to obtain the range profile.

4. Apply target velocity and radar distortion corrections (Tice 1982).
Noncoherent Processing Overview

If the frequency sources used to generate the pulse train are not all phase stable and/or the radar does not have a coherent-on-receive capability, then the high resolution range profile cannot be generated. The autocorrelation of the high resolution range profile by noncoherent processing of the pulse returns can, however, be obtained. The autocorrelation of the high resolution range profile has as its output the distances between target scatterers. Hereafter, this function will be referred to as the separation profile. Noncoherent processing computes the inverse FT of the received power (voltage amplitude squared) of the pulse returns. Coherent detection is not needed, just amplitude detection. Note, the separation profile may be obtained from the range profile, but the range profile cannot be obtained from the separation profile. Noncoherent processing is not affected by nonlinear differential phase shifts, or by target motion (Einstein 1984).
The Stepped Frequency Pulse Train

The transmitted signal in a stepped frequency pulse train is modeled by

\[ S(t) = \sum_{n=0}^{N-1} \text{RECT}\left(\frac{t-nT}{\tau}\right) \times \cos\left(\left(\omega_c + n\omega_o\right) (t-nT)\right) \]

where:

- \( N \) = \# pulses in the train (\# freqs)
- \( \omega_c \) = carrier frequency
- \( \omega_o \) = incremental pulse to pulse freq. change
- \( T \) = interpulse period
- \( \tau \) = pulse width

The received return signal is modeled by

\[ E(t) = \sum_{n=0}^{N-1} B(t) \text{RECT}\left(\frac{t-nT-2R/c}{\tau}\right) \cos\left(\left(\omega_c + n\omega_o\right) (t-nT-2R/c)\right) \]

(Barton 1977, Rihaczek 1969).

The transmitted signal is depicted in Figure 1.
Figure 1. Stepped Frequency Pulse Waveform.
<table>
<thead>
<tr>
<th>Advantages of Stepped Frequency Pulse Trains Over a Single Swept Frequency Pulse Having the Same Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lower instantaneous BW required.</td>
</tr>
<tr>
<td>The radar system transfer function from transmitter thru receiver is not required to possess the full</td>
</tr>
<tr>
<td>bandwidth associated with the desired resolution as it is with other techniques.</td>
</tr>
<tr>
<td>2. Easier to generate the waveform.</td>
</tr>
<tr>
<td>At millimeter wave frequencies maintaining linearity in a chirp waveform may be difficult.</td>
</tr>
<tr>
<td>3. Lower sampling rate required.</td>
</tr>
<tr>
<td>Using this method only one sample per pulse is taken (Tice 1982).</td>
</tr>
</tbody>
</table>
Signal Processing

The basic steps used to obtain the range and the separation profiles are illustrated in figures 2 and 3.

Radar returns

\[ X \xrightarrow{\text{LPF}} \xrightarrow{\text{FT}} \]

LO

Range profile

Figure 2. Basic Steps in Generating the Range Profile.

Radar returns

\[ X \xrightarrow{\text{LPF}} \xrightarrow{\text{LPF}} \xrightarrow{\text{FT}} \]

LO

Scatterer separation profile

Figure 3. Basic Steps in Generating the Separation Profile.
Note that the separation profile is

\[ \int f(t)f(t-x) \, dt = F \{F*F^*\} \]

This is an autocorrelation of the range profile (Cameron 1985).

A system model is shown in Figure 4.
Figure 4. System Model (Tice 1982).
SYSTEM CONSIDERATIONS

Frequency Spacing and Aliasing

When the Fourier transform is implemented in terms of a DFT, an implicit requirement is that the frequency spacing between the N frequencies of the pulses in the train be uniform. This requirement applies regardless of whether coherent or noncoherent processing is used, and is most easily met by using a coherent frequency synthesizer as the variable frequency source. The frequency diverse pulses are effectively frequency samples of a continuous frequency swept waveform. Therefore, limitations of the Nyquist sampling theorem apply. Since the sampling is performed in frequency rather than time, the frequency spacing must be small enough to prevent aliasing of the high resolution range (or separation) profile (to prevent undersampling) (Einstein 1984).
Usually, the period of the time samples ($\Delta t$) determines what frequency resolution ($\Delta f$) can be recovered.

From Nyquist

\[ F_{\text{max}} = \frac{1}{2\Delta t} \quad \text{(Shanmagum 1979, Stremler 1977)} \]

Note, in the case of $\sin(2\pi ft) - F_{\text{max}} \leq f \leq F_{\text{max}}$
t is the independent variable.

If $f_1$ is the maximum frequency that can be recovered for the sampling period ($\Delta t$), then $f_2 = 2f_1$ will alias to zero.

Figure 5. Two Frequencies Sampled at Times $x$. 
Figure 6. Spectrum of the Two Frequencies with $f_2$ Aliased to Zero (Cameron 1985).
With the stepped frequency waveform, $\Delta f$ is analogous to $\Delta t$ in the previous example and $\Delta r$ is analogous to $\Delta f$ of the same example. With the stepped frequency waveform the frequency spacing ($\Delta f$) determines what range resolution ($\Delta r$) can be recovered (Cameron 1985).

From Nyquist

$$T_{\text{max}} = \frac{1}{(2\Delta f)} \quad \text{ (Tranter 1976)}$$

Note that here, for $\cos(2\pi ft)$ $-T_{\text{max}} \leq t \leq T_{\text{max}}$ the independent variable is $f$.

The maximum frequency spacing between pulses in the train should be no greater than half the single pulse bandwidth $1/(2T)$.

$$F_{\text{max}} = \frac{1}{(2T)}$$

For example,

if $T = 100\text{ns}$, then $\Delta f = 5\text{MHz}$.
Number of Frequencies Required

The number of frequencies (pulses) required is

\[ N = \frac{\text{the pulse train bandwidth}}{\text{frequency spacing between pulses}} = \frac{160\text{MHz}}{5\text{MHz}} = 32 \]

The minimum number of frequencies required equals twice the time bandwidth product obtained by multiplying the pulse train bandwidth by the width of a single pulse (Einstein 1984).

For example, a pulse width of 100nS and a total bandwidth of 160MHz, will result in \( 2 \times (160\text{MHz}) \times (100\text{nS}) = 32 \) pulses within each train.
COMPLEX RETURNS
FROM AN ARBITRARY TARGET

Single Point Target

The transmitted signal and the return signal are mixed together at the radar receiver.

The complex signal return from a point target at range $r$ at the output of the receiver mixer is given by

$$V(t) = A_t e^{j(2\pi f_x - \Phi_t - Y_k(t-x) + Y_k(t))}$$

(Einstein 1984).

where:

- $A_t$ and $\Phi_t$ are the amplitude and phase of the target's complex reflection coefficient.
- $x = 2R/c$ (round trip delay time), and
- $Y_k(t) = $ the phase drift of the oscillator.
Distributed Target

The received signal from a distributed target and the local oscillator are mixed, the result is given by (Einstein 1984)

\[
V(f,t) = [e^{j(2\pi f t + \theta)} k^k k^k \int p(x)s(t-x)e^{-j(2\pi f x)} \text{ dx}] *
\]

\[
-\frac{j(2\pi f t + \theta + Y(t))}{\text{ dx}}
\]

\[
= e^{jY(t)} \int p(x)s(t-x)e^{-j(2\pi f x)} \text{ dx}
\]

where:

\[p(x) = \text{complex scattering profile of the target}\]
\[s(x) = \text{pulse shape}\]
let \( Q(f, t) = \int p(x) s(t-x) e^{-j(2\pi f x)} dx \)

note, \( Q(f, t) \) is the sum of returns of the scatterers.

output of the mixer

\[ V(f, t) = e^{-j\gamma_k(t)} Q(f, t) \]

It is seen that \( Q(f, t) \) and \( p(x)s(t-x) \) are Fourier transform pairs. Let \( q(x, t) = p(x)s(t-x) \), then \( Q(f, t) \) and \( q(x, t) \) are Fourier transform pairs with \( f \) and \( x \) being the transformation variables. Time \( t \) is the sample time and \( q(x, t) \) is the scattering profile of the target, weighted by the pulse shape \( s(x) \) (Einstein 1984).
DFT Implementation of Coherent Processing

Since the sum of the returns from the scatterers, $Q(f_k, t)$, and the scattering (range) profile, $q(x, t)$, are a FT pair, $q(x, t)$ can be computed from $Q(f_k, t)$ by inverse FT.

$$q(x, t) = \int Q(f_k, t) e^{j2\pi fx} \, df$$

$$p(x)s(t-x) = \int e^{jY(t)} V(f_k, t) e^{j2\pi fx} \, df$$

$e^{jY(t)}$ represents the phase drift of the oscillator.

$V(f_k, t)$ represents the complex output voltage of the mixer.
The measurements of $V(f_k, t)$ are made at discrete frequencies, $f_k$, hence the integral is replaced by a summation yielding

$$p(x)s(t-x) = q(x, t) \approx \sum_{k=0}^{N-1} e^{jy(t)} k e^{j2\pi f_k x}$$

If the source is stable and there are no nonlinear differential phase delays as a function of frequency (if $|y(t)| \leq \pi/4$ for $t<2r/c$) then $y(t) \approx 0$ (Einstein 1984).

The variables are again defined for clarity:
- $x =$ range to target in units of round trip delay time
- $t =$ sample time relative to transmit time
- $V(f_k, t)$ = complex mixer output sampled at time $t$
- $f =$ carrier frequency the $k$'th pulse is transmitted at
- $q(x, t)$ = complex, pulse shape weighted, high resolution range profile of the distributed target as a function of range $x$. 
DFT Derivation

Fourier Transform (FT)

The fourier transform pairs are defined by

\[ f(t) \leftrightarrow F(w) \]

\[ F(w) = \int f(t)e^{-jwt} \, dt \]

\[ f(t) = \frac{1}{2\pi} \int F(w)e^{jwt} \, dw \quad (Schwartz \ 1980) \]

Discrete Fourier Transform (DFT)

The DFT is a numerical and discrete technique to evaluate the Fourier transform of a continuous function \( f(t) \). First, \( f(t) \) is sampled to obtain a sequence of sample points. \( f(t) \) is sampled every \( T \) seconds to obtain \( N \) samples over the interval \((0,NT)\). The sequence is given by \( f KT = f(0), f(T), f(2T), \ldots, f((n-1)T) \).
For the discrete case $f(t) \rightarrow f(KT)$  

\[ F(n\Omega) = \sum_{K=0}^{N-1} f(KT) e^{-jn\Omega KT} \quad n=0,1,\ldots,N-1 \]

\[ T = NT \quad \Omega / (2\pi) = 1/(NT) \]

\[ \Omega = 2\pi/(NT) \quad \Omega T = 2\pi/N \quad (\Omega \text{ in radians}) \]

Substituting these variables, the DFT becomes

\[ F(n\Omega) = \sum_{K=0}^{N-1} f(KT) e^{-j2\pi nK/N} \quad n=0,1,\ldots,N-1 \]

Note $\Omega$ and $T$ do not appear explicitly in the DFT. They are used as scale factors in interpreting the results.

From Nyquist, the highest frequency component that can be determined is $1/(2T)$.

\[ T = 1/(N\Delta f) \quad T = 2\pi/(N\Omega) \quad (\Omega \text{ in radians}) \]

where $\Delta f = \Omega / (2\pi)$

\[ w_{\text{max}} = N\Omega/2 = (N/2)\Omega = n\Omega \text{ so } n = N/2. \]

Therefore, the highest frequency component which can be determined is $n=N/2$ or $N\Omega/2$ radians/sec (Belkerdid 1984).
Derivation of Coarse Range Bin Resolution

The variables necessary for the derivation are defined below.

\[ \tau = \text{the pulse width} \]

\[ \tau \times c = \text{range spanned by a single pulse} \]

\[ \tau = \frac{1}{(2\Delta f)} \quad \text{(since } \Delta f = \frac{1}{(2\tau)}) \]

\[ \text{time} = \frac{1}{\text{bandwidth}} \]

\[ \Delta x = \frac{1}{BW} \]

\[ \Delta x = \frac{1}{(N\Delta f)} \]

\[ N\Delta x = \frac{1}{\Delta f} \]

\[ \tau = \frac{1}{(2\Delta f)} = N\Delta x/2 \]

The coarse range bin resolution can be computed from the parameters \( \tau, \Delta f, \) or \( N\Delta x, \) as follows:

Coarse range bin resolution = \( \tau \times c = \frac{c}{(2\Delta f)} = \frac{cN\Delta x}{2}. \)

- for \( \tau = 100\text{nS} \) \quad R = 30 \text{ meters}
- for \( \Delta f = 5 \text{ MHz} \) \quad R = 30 \text{ meters}
- for \( \Delta x = \frac{1}{(32*5\text{MHz})} = 6.25 \text{ nS} \) \quad R = 30 \text{ meters}

What if \( \tau = \frac{1}{4\Delta f} \) ?  \text{(shorten the pulse width)}

\[ N\Delta x = \frac{1}{\Delta f} \]

\[ \tau = \frac{1}{(4\Delta f)} = N\Delta x/4 \]

resolution = \( \tau \times c = \frac{c}{(4\Delta f)} = \frac{cN\Delta x}{4} \)

So halving the pulse width halves the coarse range bin resolution (Einstein 1984).
Derivation of Fine Range Bin Resolution

Figure 7 depicts the model used for the fine range bin resolution derivation.

![Figure 7. Scatterer at a Distance R from the Radar.](image)

Distance is equal to rate times time, i.e.,

c\(t = 2R\)

R\(= ct/2\)

Taking the differential of both sides of the above equation yields \(\Delta R = c\Delta t/2\).

The time resolution \(= 1/BW\)

\(\Delta t = T = 2\pi/N\Omega = 1/(N\Delta f)\). Which yields a range resolution equal to \(\Delta R = c/(2N\Delta f)\).

Hence, the range resolution is dependent on the bandwidth (Mensa 1981).

For example,

\(N = 32, \Delta f = 5\text{MHz} \) yields \(\Delta R = 0.94\) meters

\(N = 64, \Delta f = 5\text{MHz} \) yields \(\Delta R = 0.47\) meters
Range Delays and DFT Bin Ranges

The range delay $x$ is given by $x = x_0 + n\Delta x$

where

$\Delta x = \text{range resolution for 1 fine range bin}$

$x_0 = \text{arbitrary constant range delay}$

$n = \text{DFT bin index } n = 0,1,2,...,N-1$

$x_0 = M/\Delta f \quad \text{M is an integer}$

For example,

choose $M=8$

$x_0 = 8/5\text{MHz} = 1.6\mu\text{s}$

Each bin in the range profile corresponds to a specific range delay interval to a scatterer. This range delay is ultimately displayed in units of distance. For the example given, the fine range bin resolution is $\Delta x = 1/(N\Delta f) = 1/\text{waveform BW} = 1/(32*5\text{MHz}) = 6.25\text{ns}$. The range delay of each bin can now be calculated using the expression $x = 1.6\mu\text{s} + n(0.00625\mu\text{s})$ where $n$ is the bin index from 0 to $N-1$.

The FT output represents the range profile of the target over a range extent of $cN\Delta x/2 = c/(2\Delta f) = 30$ meters relative to a starting point of $cx_0/2 = 240$ meters with range resolution $c\Delta x/2 = c/(2N\Delta f) = 0.9375$ meters. (Einstein 1984).
The range extent and corresponding delay times are checked as seen in figures 8, 9, and 10.

**Figure 8.** Transmit a 100nS Pulse.

**Figure 9.** Pulse Reaches Scatterer 240 Meters Away.

The round trip delay time for a scatterer 240 meters away is

\[ 2r/c = 2(240)/c = 1.6\text{uS}. \]

**Figure 10.** Pulse Reaches Scatterer 270 Meters Away.

The round trip delay time for a scatterer 270 meters away is

\[ 2r/c = 2(270)/c = 1.8\text{uS}. \]
Timing of the A/D Sampling Strobe

The sample time $t_x$ affects the amount of attenuation of the range profile by the pulse shape, but has no effect on the location of the profile in the FT output. Figure 11 shows the pulse return from two scatterers. Figures 12 and 13 illustrate the attenuated response of a scatterer when the A/D sample strobe does not occur at the peak of the target return.

Figure 11. Pulse Return from Two Scatterers.
Figure 12. Attenuated Response of Scatterer A Due to Sampling at $x_B$.

Figure 13. Attenuated Response of Scatterer B Due to Sampling at $x_A$. 
For strobes synchronized to $\Delta f = 1/2T$ the strobes are 2 pulse widths apart, causing scatterers near boundaries to be attenuated by the pulse shape. To alleviate this problem a second set of sampling strobes are used at the boundaries, these two sets are meshed together properly (Einstein 1984).

Figure 14. Sample Range Profile for three scatterers.
THE SEPARATION PROFILE

Noncoherent Processing

The separation profile is defined as the autocorrelation of the range profile and is given by

\[ R_q(z,t) = \int q^*(x,t)q(x+z,t) \, dx \]

where \( t \) is the sampling time (treat as a constant). Since \( Q(f,t) \) and \( q(x,t) \) are Fourier transform pairs, then

\[ |Q(f,t)|^2 \quad \text{and} \quad R_q(z,t) \]

are also Fourier transform pairs since multiplication in one domain is convolution in the other.

Knowing \( V(f,k,t) = e^{-j\pi f_k t} Q(f_k,t) \) and

\[ |Q(f,t)|^2 = |V(f,t)|^2 \]

therefore

\[ R_q(z,t) = \int |V(f,t)|^2 e^{j2\pi f z} \, df \]
Note, only the magnitude of $V(f,t)$ is needed in order to obtain the separation profile. The above continuous autocorrelation function can be easily transformed to a discrete autocorrelation yielding

$$R_q(z,t) = \sum_{k=0}^{N-1} |V(f_k,t)| e^{2j\pi f z} e^{k \Delta f}.$$

$R_q(z,t)$ is not affected by phase drift $Y_k(t)$ of the local oscillator, differential phase delays as a function of frequency in the system, or target radial velocity. This requires approximately the same amount of computation as for the range profile (Einstein 1984).

This autocorrelation function is computed in the simulation program listed in the appendix.
TABLE 3

Advantages of Noncoherent Processing Over Coherent Processing

1. A coherent radar is not required.
2. No motion compensation is required (Eaves 1983).
3. When using a DFT, the tolerance on the deviation of the frequency with respect to uniform frequency spacing is two to three orders of magnitude greater than in coherent processing (Einstein 1984).
This is very similar to coherent processing. Again uniformly spaced samples \( f_k = f_0 + k\Delta f \) are desired. The range delay variable \( z \) can be expressed \( z = n\Delta z \) where \( \Delta z = \text{range delay resolution} \).

\[ \Delta z = 1/(N\Delta f) \quad \text{(just as in the coherent case).} \]

DFT equation is:

\[
R_q(n\Delta z, t) = \sum_{k=0}^{N-1} |V(f_k, t)| e^{j2\pi kn/N} . \Delta f
\]

In general, \( R_q \) is complex, but only its magnitude is of interest. Since \( |V(f_k, t)| \) is real, the magnitude of its transform is an even function of \( n \).

\[ |R_q(n\Delta z, t)| = |R_q(-n\Delta z, t)| \]

Since the DFT is periodic:

\[ |R_q(n\Delta z, t)| = |R_q((N-n)\Delta z, t)| \]

The range extent covered by \( R_q \) is \( N\Delta z = 1/\Delta f \).
The maximum extent of the target range profile being processed is effectively limited to the pulse width $r$ because of attenuation from the envelope of the individual pulses.

The extent of the separation profile for a two scatterer target with range extent $r$ is $2r$.

For the separation profile not to be corrupted by aliasing, the extent $N\Delta z$ covered by $R_q$ must be greater than the target's actual separation profile $2r$.

$$N\Delta z > 2r$$

From above we know $N\Delta z = 1/\Delta f$. From these two equations we get

$$\Delta f < 1/2r$$

This constraint on $\Delta f$ prevents aliasing of the separation profile. From Nyquist, the sample spacing (for this case in frequency) of a sampled function (the pulse returns) must be less than half the period of the highest "frequency" component (pulse width) to avoid aliasing (Einstein 1984).
An example of a separation profile is given in Figure 15. In this profile each bin represents a separation distance between scatterers. It can be seen the separation profile is symmetric about its center bin.

Figure 15. Example of a Separation Profile.
COMPUTER SIMULATION OF RADAR SYSTEM

A simulation of the signal processing aspects of this radar technique is modeled on the UCF College of Engineering Research VAX 11/750. The objective of the simulation was to prove that the high resolution range and separation profiles can actually be generated using the methods described in this paper.

Inputs to the simulation are as follows:

Waveform Parameters:
- Pulse Width
- Base Frequency
- Frequency Increment
- Total Bandwidth

Scenario Parameters:
- The Number of Point Scatterers
- Range of Each Scatterer
- Gaussian Noise
System Parameters:

- Sampling Time
- Sampling Rate (Δf)
- Range Window of Interest

Outputs from the simulation are of two forms, numerical displays and plot displays.

Numerical Displays:

- Course Range Bin Resolution
- Fine Range Bin Resolution
- Range of Interest
- Range and Time Delay to Each Scatterer
- Frequency Increment Limit (Nyquist)

Plot Displays:

- Transmitted Signal (example)
- Range Profile
- Separation Profile
A flowchart of the simulation follows on the next five pages.

Input
waveform parameters
scenario parameters
system parameters

Calculate resolution
and area of interest

Calculate range
delay times to each scatterer

? model Gaussian
noise into system?
yes → Create Gaussian noise array
no → A

Figure 16. Flowchart
Set scattering matrix for each scatterer

Calculate mixer output voltage with noise added (I and Q channels)

Store result as target spectral signature (TSS)

Call FFT
B

Store range profile

2

| TSS |

CALL FFT

Store separation profile

Program Driver:

1-Run again
2-Plot transmitted signal
3-Plot received signal
4-Plot mixer output
5-Plot range profile
6-Plot separation profile
7-Plot noise distribution
8-end
1. Reset values to zero
   - Return to beginning of program

2. Plot sample pulse train
   - Return to driver

3. Plot sample return signal
   - Return to driver

4. Plot mixer output
   - Return to driver
5

Plot range profile

Return to driver

6

Plot separation profile

Return to driver

7

Calculate noise distribution

Plot noise distribution

Return to driver
An example of the range and separation profiles from the simulation are given below.

Figure 17. Range Profile for Two Scatterers.

Figure 18. Separation Profile for Two Scatterers.
Figures 17 and 18 were obtained with the following parameters: 32 frequency steps starting at 35 GHz and incrementing by 5 MHz each step. A range of interest from 240 meters to 270 meters from the radar, and two scatterers located at 247 meters and 258 meters away.

Note that Figure 18 is the autocorrelation of Figure 17. This can be seen by noting in the separation profile the distance between the center peak and the secondary peak is the same distance as that of the two peaks in the range profile.
CONCLUSION

This paper has examined some of the issues involved in using the stepped frequency pulse waveform to obtain high resolution range and separation profiles. It was shown that the resolution is proportional to the bandwidth of the entire pulse train. Since the pulses are sampled once for each frequency, the frequency diverse pulses are effectively frequency samples of a continuous frequency swept waveform. Therefore the frequency step is limited by the Nyquist criteria to prevent undersampling. By examining the complex returns from an arbitrary scatterer, it was determined that by appropriate mixing and filtering the target spectral signature could be obtained. The target spectral signature and the range profile are a Fourier transform pair, therefore an inverse Fourier transform of the spectral signature gave the range profile. It was also shown that the separation profile is dependent on the magnitude of the pulse returns and therefore can be obtained by taking the magnitude of the mixed signal and inverse Fourier transforming. To prove the concept, a simple simulation of the radar system is implemented on the UCF College of Engineering Research VAX 11/750 computer.
APPENDIX

PROGRAM LISTING

C******************************************************
C       RR.FOR
C       *
C       * THIS PROGRAM IS A SIMPLE MODEL OF A STEPPED-FREQUENCY
C       * PULSE RADAR USED TO GENERATE HIGH RESOLUTION RANGE PROFILES
C       * AND RANGE PROFILE AUTO-CORRELATION FUNCTIONS (SEPARATION PROFILE).
C       *
C       * ALTHOUGH THE MODEL ITSELF IS VERY BASIC, IT WOULD NOT BE
C       * DIFFICULT TO ADD MORE ADVANCED FEATURES IF NEEDED (THE FRAMEWORK FOR
C       * SOME OF THESE FEATURES ARE ALREADY IN PLACE).
C       *
C       * PARAMETERS WHICH CAN BE SIMPLY VARIED ARE PULSE WIDTH,
C       * BASE FREQUENCY, FREQUENCY INCREMENTS, NUMBER OF STEPS (TOTAL BANDWIDTH
C       * OF SYSTEM), SAMPLING TIME, RANGE WINDOW, NUMBER OF POINT SCATTERERS,
C       * AND DISTANCE OF EACH SCATTERER. GAUSSIAN NOISE CAN ALSO BE INTRODUCED
C       * INTO THE SYSTEM.
C       *
C       * HARDCOPY PLOTS OF THE RESULTS ARE AVAILABLE FROM THE TEKTRONICS
C       * PLOTTER.
C       *
C       * THIS PROGRAM MUST BE RUN ON EITHER A VT240 OR A TEKTRONICS TERMINAL.
C       *
C******************************************************

TO LINK PROGRAM:

*LINK RR,FROM,FFT,gcom1

C
CHARACTER*1 INF
COMPLEX*16 V(0:200), Q(0:200), VI(0:200)
COMPLEX*8 A(0:31), TEMP(0:31), A2(0:31,1), Rq(0:31,1), B(0:31)
REAL*8 SCAT_MX(100,2), SCAT_POS(100), X(100), SAVE_SCAT(100)
REAL*8 PI, FRQ, TIME, FRQ_INC, RNGPR0(0:200), LAMBDA
REAL*8 C, PWIDTH, STRT_FRG, END_FRG, PLEN, PCENTER, DAT(200)
REAL*8 STRT_TIM, END_TIM, TC, Vmag(0:200), AMP(4096), PHASE(4096)
REAL*8 Rmag(0:200), NOISE(0:200), TM, TEMP
REAL*4 N(100), XXARR(22), P(22), XVAL(135), YVAL(135)
REAL*4 XARR(0:31), YBUF(0:31), SINE(8), T(16), E(135), EI(135)
INTEGER M(3), INV(8), CT

COMMON /DAT/ FD, TFLO, TFHI, NUM

PI=3.14159
PWIDTH=100E-9 ! TOTAL LEN OF EACH FRG PULSE (IN SECONDS)
NUM_FRQ=32 ! SET # OF FREQ STEPS
STRT_FRG=35E9 ! SET BASE FREQ (IN Hz)
STRT_TIM=1.6E-6 ! SET TIME (in sec) WINDOW OF INTEREST = M/FREQ_INC (M IS AN INTEGER)
END_TIM=STRT_TIM+2*PWIDTH
TIME=1.7E-6 ! SET SAMPLE TIME TO MIDDLE OF PULSE
C=2.9979E8 ! SPEED OF LIGHT (M/S)
SEED=357653287 ! SET SEED FOR RANDOM # (CHANGE THIS FOR DIFFERENT SEQUENCE OF #’S)

1

TYPE *, 'ENTER # OF SCATTERERS' ! INPUT # OF SCATTERERS AND POSITIONS
READ(*, '(I)') NUM_SCATS
DO L=1, NUM_SCATS
   TYPE *, 'ENTER SCATTERER POSITION # ' , L
   ACCEPT *, SCAT_POS(L)
END DO
PLEN=PWIDTH+C
Tc=(END_TIM-STRT_TIM)/2 + STRT_TIM
PCENTER=Tc*C/2
FRQ_INC=1/(2*PWIDTH)

RESOLUTION=C/(2*NUM_FRGS*FRQ_INC)
NYQUIST_FRQ_INC=1/(2*PWIDTH)
COURSE_BIN_RES=C/(2*FRQ_INC)
TIME_RES=1/(NUM_FRGS*FRQ_INC)

TYPE #1, 'THE RANGE PROFILE OF THE TARGET COVERS A RANGE'
TYPE #1, 'EXTENT OF COURSE_BIN_RES, METERS RELATIVE TO A'
TYPE #1, 'STARTING POINT OF COURSE_BIN_RES, METERS WITH'
TYPE #1, 'A FINE RANGE RESOLUTION OF COURSE_BIN_RES, METERS.'
TYPE #1, '
TYPE #1, 'CENTER OF COURSE RANGE BIN = PCENTER, METERS.'
TYPE #1, 'NYQUIST FRQ INC UPPER LIMIT = NYQUIST_FRQ_INC/1E6, MHz'
TYPE #1, 'FREQUENCY INCREMENT USED = INT(FRQ_INC)/1E6, MHz'
TYPE #1, 'RND TRIP DELAY TIME TO CENTER OF COURSE RANGE BIN = Tc, s'
TYPE #1, '
TYPE #1, 'AREA ILLUMINATED ON GROUND IS: COURSE_BIN_RES, METERS'
TYPE #1, 'STRT_TIM/2, METERS TO'
TYPE #1, 'COURSE_BIN_RES, METERS'

LENGTH OF PULSE (IN METERS)
RND TRIP TIM TO CENTER OF COURSE RNG BIN
DISTANCE TO CENTER OF COURSE RANGE BIN IN METERS
HERE IT IS SET TO NYQUIST LIMIT (MAY BE SET DIFFERENTLY)
RANGE PROFILE BIN RESOLUTION
MAX FRQ_INC FROM NYQUIST
COURSE RANGE BIN RESOLUTION (IN METERS)
RESOLUTION (BINWIDTH) IN SECONDS
DO I=1, NUM_SCATS
   X(I)=2*SCAT_POS(I)/C
   !X(I) IS RND TRP TIME DELAY TO TARGET
   TYPE *, 'RANGE DELAY TO SCATTERER 'I,' = ',X(I), ' s'
   TYPE *, 'DISTANCE TO SCATTERER 'I,' = ',SCAT_POS(I), ' METERS'
   TYPE *, '

C
   WRITE(3,10)I,X(I)
C10   FORMAT(* RANGE DELAY ',I,' = ',E12.4)
END DO
CALC GAUSSIAN NOISE VALUES

TYPE *, *
TYPE *, *
TYPE *, 'MODEL NOISE INTO SIMULATION? (1-Y 2-N)' ACCEPT *, IG
IF (IG .EQ. 2) THEN
  DO I=0, NF
    N(I)=0
  END DO
ELSE
  TYPE *, 'STANDARD DEVIATION'
  ACCEPT *, S
  TYPE *, 'MEAN'
  ACCEPT *, MEAN
  RK=1000
  TYPE *, 'K VALUE (ACCURACY)' ACCEPT *, RK
  NN=NUM_FRQS
  TYPE *, '# OF NUMBERS WANTED'
  ACCEPT *, NN
  DO I=1, NN
    TT=0
    DO J=1, RK
      R=RAN(JJ)
      TT=TT+R
    END DO
    N(I)=S*SQRT(12/RK)*(TT-RK/2)
  END DO
  TYPE *, 'NOISE VAL= ', N(I)
END IF
FRQ=STRAT_FRO
DO NF=0, NUM_FRQS-1
  XARR(NF)=NF
  TYPE *, 'FREQ = ', FRQ+NF*FRQ_INC
  WRITE(3,1,FRQ+NF*FRQ_INC
  FORMAT('FREQ = ',E12.6)
**FIND SCATTERERS WITHIN PULSE AT TIME. X(J)=TIME DELAY FOR SCAT J**

*CNT=0*

DO J=1, NUM_SCATS
   IF ((SCAT_POS(J), GE, PCENTER-LEN/2) . AND. (SCAT_POS(J), LE, (PCENTER+LEN/2))) THEN
      CNT=CNT+1
      SAVE_SCAT(CNT)=J
      TYPE #='SCAT', 'J', 'WITHIN PULSE'
      WRITE(*(,10,J))
      END IF
   END DO

*CALC SCAT_MX AMP & PHASE CHANGES FOR EACH SCATTERER*

DO I=1, CNT
   SCAT_MX(SAVE_SCAT(I),1)=1.0 !AMPLITUDE
   SCAT_MX(SAVE_SCAT(I),2)=0.0 !PHASE
END DO
MIX E(NF) WITH LO AND LPF

\[\cos(a)\cos(b) = \frac{1}{2}(\cos(a+b) + \cos(a-b)) \Rightarrow \text{LPF} \Rightarrow \frac{1}{2}\cos(a-b)\]

\[\cos(a)\sin(b) = \frac{1}{2}(\sin(a+b) - \sin(a-b)) \Rightarrow \text{LPF} \Rightarrow -\frac{1}{2}\sin(a-b)\]

\[\cos(2\pi(F+nf)(Ts-2Rt/c)) \Rightarrow \text{LPF} \Rightarrow N_c(t)\cos(W_{ct+\theta})\]

\[\sin(2\pi(F+nf)(Ts-2Rc/c)) \Rightarrow \text{LPF} \Rightarrow -Ns(t)\sin(W_{ct+\theta})\]

Ns = noise component
Nc = noise component
f = frequency step size
n = step index
Ts = sample time
Rc = distance to center of course range bin
Rt = distance to scatterer
F = base frequency
DO I=1, CNT
   V<NEF>=(1,0)*(SCAT_MX*(SAVE_SCAT(I), 1)*)
   DCOS(4*PI*(FRG#NF#FRQ_INC))
   (PCENTER-SCAT_POS(I))/C) +
   N<NEF>*(DCOS(4*(PI*(FRG+NF#FRQ_INC))
   (PCENTER-SCAT_POS(I))/C)) +
   (0, 1)*(SCAT_MX*(SAVE_SCAT(I), 1)*)
   DSIN(4*PI*(FRG+NF#FRQ_INC))
   (PCENTER-SCAT_POS(I))/C) -
   N<NEF>*(DSIN(4*(PI*(FRG+NF#FRQ_INC))
   (PCENTER-SCAT_POS(I))/C)) +
   V<NEF>=(V<NEF>)*V<NEF> + Vi<NEF>
   WRITE(B, 37>NF, V<NEF>, FRQ, FRQ INC, SCAT POS(I)
   END DO
   C38 CNT=0.
C37 END DO

C****************************************************************
C* PRINT OUT V<NEF>
C****************************************************************

DO I=0, NF-1
   WRITE(3, 41)I, V(I)
END DO
C41
C*******************************************************************************
C* CALC RANGE PROFILE USING XFORM                                           *
C*******************************************************************************

FD=1E-20                                ! SET PARAMETERS FOR XFORM
TFLO=0
TFHI=31
NFFT=32
NUM=32
ITYPE=1

DO I=0,NUM_FRGS-1                     ! MAKE COPIES OF MIXER OUTPUT DATA FILES
  A(I)=V(I)
  Rq(I, 1)=V(I)
  A2(I, 1)=V(I)
END DO

DO I=0,NUM_FRGS-1
  AMP(I+1)=REAL(A(I))
  PHASE(I+1)=AIMAG(A(I))
END DO

CALL XFORM(AMP, PHASE, NFFT, ITYPE)

C*******************************************************************************

DO I=0,NUM_FRGS-1
  RNGPRO(I)=SORT(AMP(I+1)**2 + PHASE(I+1)**2)
C
  RNGPRO(I)=SORT((REAL(A(I)))**2 + (AIMAG(A(I)))**2)
END DO

DO I=1,15
  TEMP2=RNGPRO(I)
  RNGPRO(I)=RNGPRO(NUM_FRGS-I)
  RNGPRO(NUM_FRGS-I)=TEMP2
END DO
C****************************************************************
C* PRINT OUT RANGE PROFILE
C****************************************************************
C47  DO I=0, NUM_FRGS-1
     TYPE * 'RANGE BIN ',I,' ',RNGPRO(I)
     WRITE(I,50)I,RNGPRO(I)
C50   FORMAT('RANGE BIN ',I,' = ',F13.5)
C     END DO
C PAUSE
C****************************************************************
C* CALC SEPARATION PROFILE
C****************************************************************
FD=1E-20                    ! SET PARAMETERS FOR XFORM
TFLO=0
TFHI=31
NFFT=32
NUM=32
ITYPE=1

DO I=0, NUM_FRGS-1
     AMP(I+1)=REAL(A2(I,1))**2 + (AIMAG(A2(I,1))**2)
     PHASE(I+1)=0
END DO

CALL XFORM(AMP,PHASE,NFFT,ITYPE)

DO I=0, NUM_FRGS-1
     B(I)=ABS(AMP(I+1)*AMP(I+1))
END DO

C PRINT OUT SEP PROFILE
C DO I=0, NUM_FRGS-1
     TYPE * 'SEP BIN ',I,' ',REAL(B(I))
C END DO
C PAUSE
C****************************************************************
C*
C* PROGRAM DRIVER
C*
C*
C****************************************************************

65
TYPE *, '
TYPE *, '1-RUN AGAIN (remember to code ANSI)'
TYPE *, '2- PLOT TRANSMITTED SIGNAL (FOR DEMO ONLY)'    ! NOT ACTUAL TRANSMITTED SIGNAL
TYPE *, '3- PLOT RECEIVED VOLTAGES FROM SCATS (FOR DEMO ONLY)'    ! NOT ACTUAL RETURNED SIGNAL
TYPE *, '4- PLOT MIXER OUTPUT (REAL, THEN IMAGINARY)'
TYPE *, '5- PLOT RANGE PROFILE'
TYPE *, '6- PLOT SEPARATION PROFILE (AUTOCORRELATION)'
TYPE *, '7- PLOT NOISE DISTRIBUTION'
TYPE *, '8- END (remember to code ANSI)'
ACCEPT *, IZ
GOTO (101, 70, 75, 80, 85, 90, 200, 999), IZ

C******************************************************************
* * * * *
* PLOT TRANSMITTED SIGNAL (ABBREVIATED) *
* (4 representative PULSES) *
* * *
******************************************************************

70 continue               ! FOR DEMONSTRATION ONLY

fx<0
fo=1e-20
flio=0
ffh=1024
nfft=1024
num=1024
itype=1
type e. 'to change term to graphics mode:'
type e. 'setup, code tek, daem n, setup'
type e. 'then clear screen (s eras) and continue (c)'
type e. 'if already in graphics mode then (s eras), c'

pause
call erscrn
erom=0
sh=1024
ylom=-1.5
yhi=1.5
call window(zero, sh, ylo, yhi)
call frame
call moves(zero, zero)
do i=1,128
   yy=cos((i-1)*3.1415/32)
   xx=i
call drawa(xx, yy)
end do
do i=129,256
   yy=0
   xx=i
call drawa(xx, yy)
end do
do i=257,384
   yy=cos((i-112)*3.1415/24)
   xx=i
call drawa(xx, yy)
end do
do i=385.512
  yy=0
  xi=i
  call drawa(xi,yy)
end do
do i=513.639
  yy=cos((i-234)*3.1415/18)
  xi=i
  call drawa(xi,yy)
end do
do i=640.768
  yy=0
  xi=i
  call drawa(xi,yy)
end do
do i=769.893
  yy=cos((i-362)*3.1415/8)
  xi=i
  call drawa(xi,yy)
end do
do i=894.1024
  yy=0
  xi=i
  call drawa(xi,yy)
end do
read(5,1000)
format(a1)
type *, 'if finished with current series of plots:'
type *, 'setup. code ansi. setup. (s erase). c'
type *, 'else (s erase). c'
pause
go to 65
PLOT RECEIVED VOLTAGES FROM SCATTERERS

GO TO 70

PLOT MIXER OUTPUT (REAL AND IMAG.)

DO K=0,31
   YBUF<K>=DIMAQ<V<K>
   END DO

DO K=0,31
   CALL T~KPLT<~BUF>
   END DO
DO K=0,31
   YBUF(K)=MIN(YBUF(K),X(K))
END DO

DO K=0,31
   call tekplt(ybuf)
GOTO 65
END

CALL PLOT SEPARATION PROFILE (AUTOCORRELATION)

DO K=0,31
   YBUF(K)=X(K)
END DO

call tekplt(ybuf)
GOTO A5

CALL PLOT RANGE PROFILE

DO K=0,31
   call tekplt(ybuf)
GOTO 65
END

CALL PLOT SEPARATION PROFILE (AUTOCORRELATION)
200 DO I=1,NF
   IF (N(I).LT.-1) P(I)=P(I)+1
   IF (N(I).GE.-9).AND.(N(I).LT.-8) P(2)=P(2)+1
   IF (N(I).GE.-8).AND.(N(I).LT.-7) P(3)=P(3)+1
   IF (N(I).GE.-7).AND.(N(I).LT.-6) P(4)=P(4)+1
   IF (N(I).GE.-5).AND.(N(I).LT.-4) P(6)=P(6)+1
   IF (N(I).GE.-3).AND.(N(I).LT.-2) P(8)=P(8)+1
   IF (N(I).GE.-2).AND.(N(I).LT.-1) P(9)=P(9)+1
   IF (N(I).GE.-1).AND.(N(I).LT.0) P(10)=P(10)+1
   IF (N(I).GE.0).AND.(N(I).LT.1) P(11)=P(11)+1
   IF (N(I).GE.1).AND.(N(I).LT.2) P(12)=P(12)+1
   IF (N(I).GE.2).AND.(N(I).LT.3) P(13)=P(13)+1
   IF (N(I).GE.3).AND.(N(I).LT.4) P(14)=P(14)+1
   IF (N(I).GE.5).AND.(N(I).LT.6) P(16)=P(16)+1
   IF (N(I).GE.7).AND.(N(I).LT.8) P(18)=P(18)+1
   IF (N(I).GE.9).AND.(N(I).LT.10) P(20)=P(20)+1
   IF (N(I).GE.11) P(22)=P(22)+1
END DO

DO ZI=-1,1.05,1
   IF=IF+1
   XXARR(IJ)=ZI
END DO

CALL PLOT ROUTINE HERE

QOTO 65
C****************************************************************
C* RESET VALUES TO ZERO AND RETURN TO TOP OF PROGRAM *
C****************************************************************

101 DO L=1,10
  X(L)=0
  SCAT_POS(L)=0
  SAVE_SCAT(L)=0
  SCAT_MX(L,1)=0
  SCAT_MX(L,2)=0
END DO

DO L=0,200
  V1(L)=(0,0)
  V2(L)=(0,0)
  Q(L)=(0,0)
  RNGPRO(L)=0
  Rmag(L)=0
  Vmag(L)=0
END DO

DO L=0,31
  A(L)=0
  A2(L,1)=0
  Rq(L,1)=0
  TEMP(L)=0
  B(L)=0
  XARR(L)=0
  YBUFF(L)=0
END DO

DO L=1,22
  P(L)=0
  XXARR(L)=0
END DO

CT=0
GOTO 1

999 CONTINUE
END
subroutine tekplt(ybuf)

character*1 inp
real*4 ybuf(0:31)

find ybuf min and max

ymin=ybuf(0)
ymax=ybuf(0)

do i=1,31
  if (ybuf(i) .gt. ymax) then
    ymax=ybuf(i)
    end if
  if (ybuf(i) .lt. ymin) then
    ymin=ybuf(i)
    end if
  end do

fo=1e-20
tflo=0
tfhi=31
nfft=32
num=32
itpe=1

type 0, 'change term to graphics mode: '
type 0, 'setup, code tek, dam n, setup'
type 0, 'then clear screen (s eras) and continue (c)'
type 0, 'if already in graphics mode then (s eras), c'
CALL ERSCRN
ZER0=0
XH=31
YLO=YMIN
YHI=YMAX
CALL WINDOW(ZERO, XH, YLO, YHI)
CALL FRAME
CALL MOVEA(ZERO, ZERO)
DO I=1, 32
   YY=YYBUF(I-1)
   XX=I
   CALL DRAWA(XX, YY)
END DO
READ(5, 100) INP
FORMAT(A1)

TYPE *, 'IF FINISHED WITH CURRENT SERIES OF PLOTS:'
TYPE *, 'SETUP.CODE ANSI.SETUP.(S ERASE).C'
TYPE *, 'ELSE (S ERASE).C'
PAUSE
RETURN
END
BIBLIOGRAPHY


