1 ap

X-551-71-512

PREPRINT

65837

A RADAR ALTIMETER-DRIFTMETER FOR SMALL PLANETARY PROBES

J. W. BRYAN

(NASA-TM-X-65837) A RADAR ALTIMETER-DRIFTMETER FOR SMALL PLANETARY PROBES J.W. Bryan (NASA) Dec. 1971 18 p CSCL 22B

N72-19517

Unclas
G3/14 20728

FAC (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

DECEMBER 1971

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-551-71-512

A RADAR ALTIMETER-DRIFTMETER

FOR

SMALL PLANETARY PROBES

J. W. Bryan

Flight Mission Analysis Branch

December 1971

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland

PRECEDING PAGE BLANK NOT FILMED

A RADAR ALTIMETER-DRIFTMETER

FOR

SMALL PLANETARY PROBES

J. W. Bryan

Flight Mission Analysis Branch

ABSTRACT

This paper describes a light weight radar altimeter-driftmeter applicable to landing planetary probes. The system utilizes a small light weight phased array antenna to generate three independent radio frequency beams. The range and doppler along each of these beams is measured. The six measured quantities are then combined with a resulting range (altitude) accuracy of 75 meters and a horizontal drift velocity accuracy of 6 cm/sec. The entire system weighs less than 3.7 kilograms and requires less than 9 watts of d.c. power.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The proper interpretation of atmospheric and near planet scientific data obtained from planetary probes requires a knowledge of the height above the planet surface, the descent rate relative to the surface and the horizontal velocity over the planet surface during the descent phase. Soft landing probes also require this type of information for controlled landing. The Surveyor and the Apollo Lunar Module used multibeam FM/CW doppler ranging systems to provide the required velocity and altitude data. For these missions the velocity relative to the surface was determined from the doppler shift along three independent antenna beams. The three signals were combined to give three orthogonal velocity components in a spacecraft oriented X, Y, Z system. The altitude measurements were made using a linearly modulated FM/CW ranging system on a fourth antenna beam. In these altimeters the velocity or doppler component in the altitude determination system was removed using the output of the multibeam velocity sensing system. The characteristics of these systems are tabularized in Table I. The resulting velocity vectors and the altitude were used in these programs for attitude and descent rate control.

If the altitude and velocity information is telemetered to the earth along with the scientific data from a free falling or passive controlled (i.e., parachute) descent to a remote planet much can be determined about the atmospheric parameters close to the planet. This paper describes an altimeter-driftmeter compatible with small scientific probes. It measures the altitude (slant range)

Table I

	Surveyor	Apollo	Viking (Proposed)
Velocity (3 axis)	0.5-1000 m/s	0.5-1000 m/s	1-2000 m/s
Accuracy	2% + 0.5 m/s	1.5% + 0.5 m/s	1% or 0.3 m/s
Altitude	5-16,500 m	2-13,000 m	5-50,000 m
Accuracy	5% + 1.3 m	1.4% + 2.6 m	
Weight	15.9 kg	16.3 kg	14.6 kg
d.c. Power	590 watts	132 watts	48.8 watts

and velocity along each of three r.f. beams which are arranged in a right triangle normal to the vertical (Z) axis. The described system conserves weight and d.c. power at the expense of overall accuracy when compared with the systems of Table I.

DESIGN CONSTRAINTS

The most severe constraint placed upon a horizontal velocity sensing radar for small planetary probes is antenna aperature size. Because of the small area available for the antenna(s), it is imperative that the area be used as efficiently as possible.

A second constraint which also impinges upon the antenna size is the operating frequency. Many factors must be considered in the selection of the operating frequency. Among these are; d.c. to r.f. efficiency of the transmitter, atmospheric attenuation of the planet to be observed, velocity precision, and geometric parameters of the reflecting surface.

Other constraints and the values assumed for this paper are given in Table II.

Table II

Maximum Range for Velocity	10km
Maximum Range for Altitude	5km
Velocity Accuracy	±6 cm/s
Altitude Accuracy	Greater of 1.5% or 75 meters
Weight (maximum)	3.7 kg
d.c. Power	9 watts

The least complex and the most accurate of all radar velocity sensors is the Continuous Wave (CW) doppler sensing system. However, the requirement of receiver-transmitter isolation precludes the use of a CW system on a small probe. For this reason a pulsed or Interrupted Continuous Wave (ICW) system must be employed.

DESIGN CONCEPTS

The antenna design presents the most difficult problem. The sensing of a horizontal velocity vector requires multiple, narrow r.f. beams. The small size of the planetary probe and the necessity of narrow beams makes the use of multiple aperatures impractical. For this reason a planar array has been selected for the conceptual design. A small, light weight stripline array has been built by Teledyne Ryan, San Diego, for the Navy under contract N62269-70-C-0251. The Ryan array is a four beam array but modification to three beams only reduces the complexity.

Since this antenna is designed for the upper end of X-band and since present aircraft navigational systems development have resulted in state of the art small, efficient, light weight, reliable components in this frequency range, a frequency of 13 GHz has been selected. This short wavelength is also compatible with narrow r.f. beams from relatively small apertures and large doppler offsets for velocity measurements.

The altimeter-driftmeter conceived to fulfill the constraints and requirements is an ICW system having the parameters given in Table III. It uses the single antenna array properly phased to generate three beams for both transmitting and receiving. The system uses one transmitter which is switched from

Table III

Transmitter	
P_t (per beam)	50 mw
Modulation Rate	10 KHz
Frequency (nominal)	13 GHz
Receiver	
Noise Figure	12.0 dB
IF bandwidth	1.0 MHz
PLL bandwidth	100 Hz
Antenna (Planar Array)	
Gain (per beam)	21.0 dB

beam to beam in synchronism with the modulation. A separate receiver is required for each beam. Isolation between the received beams is accomplished by disabling each receiver when no return is desired. The receivers are enabled only during that portion of time when returns may be expected along its antenna beam. For range and velocity determination each receiver includes the appropriate tracking loops.

A system block diagram is shown in Figure I and the transmitter/receiver synchronization in Figure II.

All frequencies required by the transmitter modulator and receivers (including antenna and receiver enable switch timing) are coherently synthesized from a single crystal oscillator. The use of single oscillator to develop the three receiver local oscillators reduces the phase jitter between the three IF amplifier outputs. Doppler along each beam is tracked in a frequency locked loop whose output is the doppler plus the IF. Synchronous demodulation of the IF output produces the envelope of the return signal for range (altitude) determination.

VELOCITY MEASUREMENT

Velocity or doppler measurements are made using a 100 Hz frequency locked loop in each receiver as shown in Figure III. Assuming a maximum velocity of 10 meters per second the doppler offset will be less than 1 KHz along each beam. For the proposed loop bandwidth, repetition rate and the maximum doppler, no acquisition problems will be encountered and the loop will acquire without searching. The doppler along each beam will be converted to a digital

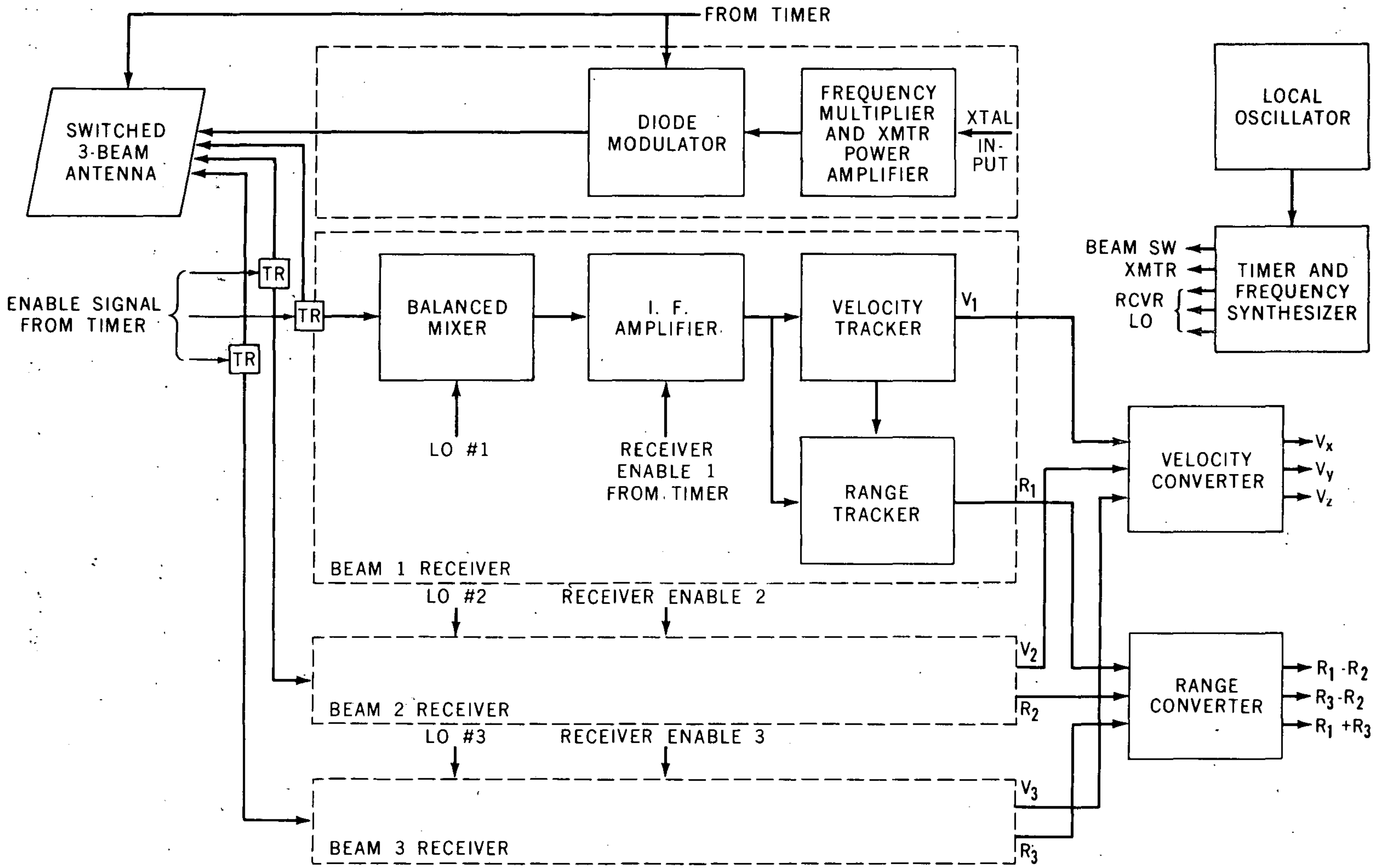

Figure I. Block Diagram

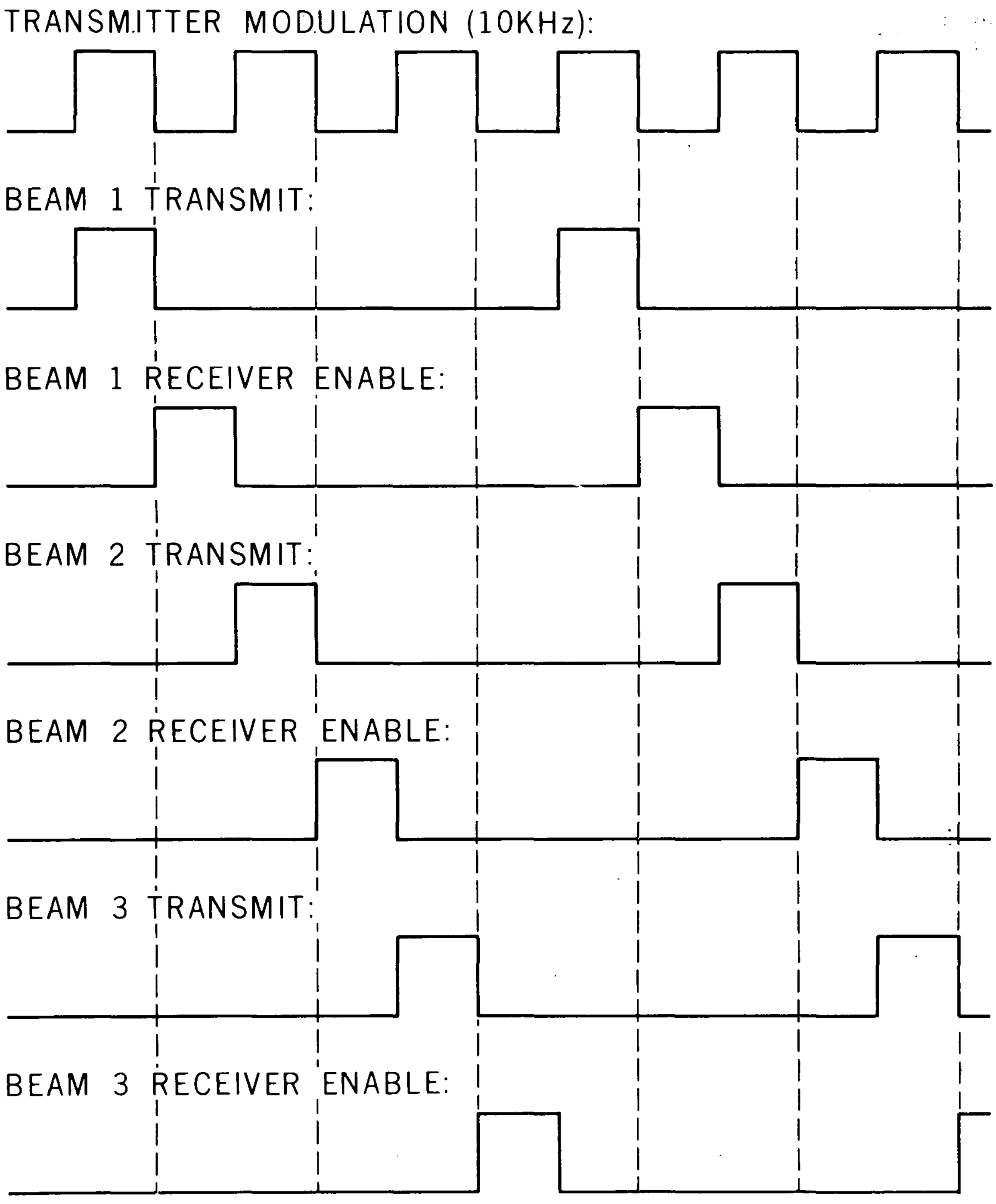

Figure 11. Receiver-Transmitter Synchronization

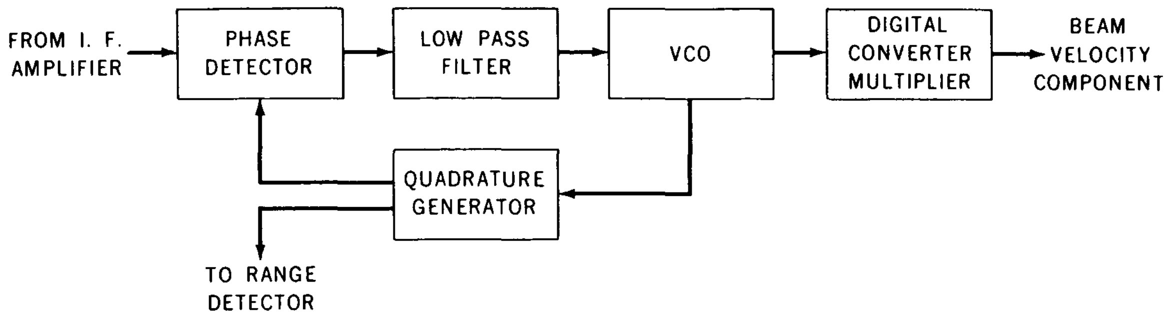

Figure III. Velocity Tracking Loop

velocity measurement in a digital converter multiplier. The measured velocities can then be combined to give the three velocity components in a spacecraft oriented X, Y, Z system.

The resulting accuracy of the instrument is not only a function of the instrumentation but also a function of the resulting signal to noise ratio (SNR). The system SNR is:

$$\mathrm{SNR} = \frac{P_t \; G^2 \; \lambda^2 \; \sigma^\circ \; A}{(4\pi)^3 \; H^4 \; KTB \; \overline{NF} \; L \; F_{at}} \tag{1}$$

where

- P_t = Peak transmitter power
- G = Antenna gain
- λ = Operating wavelength
- σ° = Radar cross section per unit surface area
- A = Reflecting surface area
- H = Altitude
- KT = Thermal noise per Hertz of bandwidth
- B = Bandwidth (Hertz)
- $\overline{NF}$ = Receiver noise figure
- L = System losses
- F_{at} = Atmospheric losses

Since the reflecting surface area is a function of the altitude:

$$A = \pi \left(H \tan \frac{\theta}{2}\right)^2 \tag{2}$$

where θ is the antenna beamwidth, equation (1) can be simplified.

$$SNR = \frac{P_t \; G^2 \; \lambda^2 \; \sigma^\circ \left(\frac{\theta}{2}\right)^2}{64\pi^2 \; H^2 \cdot KTB \; \overline{NF} \cdot L \; F_{at}} \tag{3}$$

Equation (3) assumes θ to be small as is the case in this altimeter-driftmeter antenna. The SNR for the velocity processor is calculated by substituting the values of Table IV in equation (3).

Table IV

Parameter	Velocity System	Altitude System
P_t (milliwatts)	+17.0 dBm	+17.0 dBm
G^2	+42.0 dB	+42.0 dB
λ^2 (meters)	-32.7 dB	-32.7 dB
σ° (assumed)	-15.0 dB	-15.0 dB
$\left(\frac{\theta}{2}\right)^2$ (radians)	-17.0 dB	-17.0 dB
$64\pi^2$	+28.0 dB	+28.0 dB
H^2 (meters)	+80.0 dB	+74.0 dB
KT (milliwatts)	-174.0 dB	-174.0 dB
B (Hertz)	+20.0 dB	+60.0 dB
$\overline{NF}$	+12.0 dB	+12.0 dB
L	+14.0 dB	+14.0 dB
F_{at}	+9.0 dB	+9.0 dB
SNR	+5.3 dB	-28.2 dB

The resulting SNR for the velocity determination is 5.8 dB per beam.

The velocity error due to thermal noise is given by:

$$\sigma_{\dot{R}} = \frac{K\ f_d}{T\sqrt{2\ SNR}} \tag{4}$$

where

K is the loop gain constant

f_d is the Doppler frequency

T is the integration time

Substituting the SNR from Table IV and assuming a loop gain constant of 0.1 meter per Doppler cycle, the velocity error due to thermal noise is 3.84 cm/sec.

Since the actual surface roughness factor is not known for most of the remote planets, the rms error in velocity due to the terrain cannot be calculated. Therefore a value of 3.5 cm/sec is assumed. This is approximately the value for the moon's surface roughness.

The quantization error depends upon the wavelength, the smoothing time and the data word length. The Doppler scale factor for the velocity at 13 GHz is 0.43 Hz/cm/sec. Using a smoothing time of 10 seconds and an output scale factor of 6 cm/sec results in a quantization error of 3 cm/sec.

The root sum square of the velocity errors results in an accuracy of 6 cm/sec.

RANGE DETERMINATION

Range or propagation delay along each radar beam is measured from transmitted trailing edge to the trailing edge of the received modulation. The block diagram of range tracking instrumentation is shown in Figure IV. The reference signal source for the synchronous demodulator is indicated in Figure III.

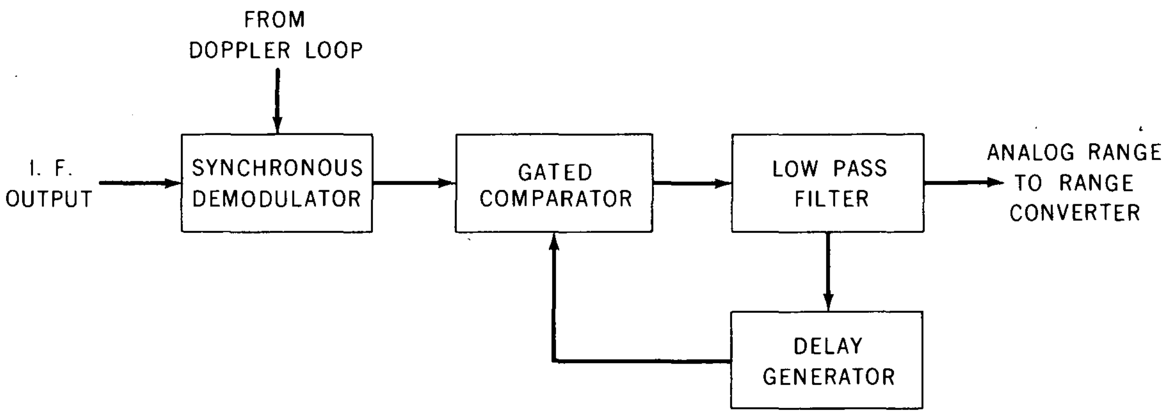

Figure IV. Range Extractor

The output of the synchronous detector is sampled at the delay estimate established by the preset range delay generator. The time delay (range) is determined and updated as follows. If, when the detector output is sampled a return signal is present, the time delay (range estimate) is too short and the delay is incremented to increase the delay. Likewise if the signal is not present when the detector output is sampled, the time delay is decreased.

The achievable accuracy of the altimeter is determined not only by the detailed circuit design and data extraction technique but, like the velocity accuracy, is dependent upon the resulting SNR. Using the link characteristics given in Table IV with an altitude of 5 km, the altitude error budget can be established. However, for the altitude error due to thermal noise the IF bandwidth of 1.0 MHz must be considered. The error due to a finite SNR is:

$$\sigma_R = \frac{C}{2B\sqrt{2\ \mathrm{SNR}}\ \sqrt{N}} \tag{5}$$

where C = velocity of light

N = number of pulses integrated

The error due to the resulting -28.2 dB SNR in the IF bandwidth is 47.7 meters.

The ranging system is conceived as employing a 10 MHz clock and a 100 nanosecond delay generator increment. This results in quantization error of 21 meters. A random error due to filter delay variations, loop dynamic lag and other circuit variables of 25 meters is estimated for this system.

The altitude error due to the A/D converter is assumed to be 0.8% of the altitude or 40 meters maximum. A summary of the various altitude noise type errors is given in Table V.

Table V

Thermal noise error	47.7 meters
Quantization error	21.0 meters
Circuit variables	25.0 meters
A/D converter	40.0 meters

The estimated error due to random noise is 73.5 meters.

DATA OUTPUT

The outputs of the Velocity Converter (Figure I) consist of:

V_x - 7 bit word (V_x max. 10 m/s)

V_y - 7 bit word (V_y max. 10 m/s)

V_z - 9 bit word (V_z max. 30 m/s)

These values will be consistent with ten second averaging and can be read out at a 5 per minute rate.

The ranges along the three beams are combined in a Range Converter whose outputs are:

$$\left.\begin{matrix} R_1 - R_2 \\ R_3 - R_2 \\ R_1 + R_3 \end{matrix}\right\} \quad \begin{matrix}\text{(Subscripts indicate} \\ \text{the associated} \\ \text{antenna beam)}\end{matrix}$$

Each of these quanities is outputted as a 7 bit word. The quantities $(R_1 - R_2)$ and $(R_3 - R_2)$ may be employed to ascertain some attitude information, while $(R_1 + R_3)$ is the range along a spacecraft oriented Z axis to the planet.

WEIGHT AND POWER

Based upon the present state of the art, the following weight and power table was generated.

Table VI

	Weight	Power
Antenna Assembly	1.2 kg	0.5 watts
Transmitter	0.5 kg	2.3 watts
Receiver (3)	1.4 kg	6.0 watts
Misc. Hardware	0.45 kg	—
Totals	3.55 kg	8.8 watts

ACKNOWLEDGEMENT

The author expresses his gratitude to the technical staff of Teledyne Ryan Aeronautical Company for their implementation concepts and the information on the design and operation of the Surveyor, LEM and proposed Viking Landing Altimeters.