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HUYGENS
PROXIMITY SENSOR
DESIGN REPORT

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DOCUMENT HISTORY

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1	-	15.01.93	First Issue of the Document
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2	-	01.07.93	Updated for MRR in July '93
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4	0	07.11.94	Updated as result of EM MRR in September 1994 Section .5 removed, performance calculations restricted to theory and general examples (validation supported by design analysis). Section.7 removed now represented in AIV Plan. Appendices 1 & 2 now included in main document Appendix.3 removed to Design Analysis document Appendix.4 removed. Phase Noise available in test reports Appendices.5 & 6 removed to main document new section 5.

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1 INTRODUCTION

The HUYGENS probe is transported to SATURN by the CASSINI Spacecraft. On arrival it is separated from the main spacecraft and makes a controlled descent onto the moon TITAN. During the descent to the surface of TITAN, radar altimeters are used to provide altitude data, as telemetry (to be subsequently used with all other experimental data gathered) and to enable the correct functioning of other experiments. This radar altimeter subsystem is known as the PROXIMITY SENSOR sub-system.

1.1 Scope of this Document

This document defines the design and intended implementation of the Proximity Sensor subsystem. It describes the radar operation theory and provides, in particular justification of the design requirements range and accuracy. It is not intended to provide performance validation in any greater detail than, the demonstration that the design concept is adequate to fulfill the requirements. Further design analysis is supported by OD03 and performance validation is contained in the lower level validation documents.

1.2 Abbreviations

AIV	Assembly, Integration and Verification
CDMS	Command and Data Management System
CDMU	Command and Data Management Unit
CIL	Critical Items List
EM	Engineering Model
ENT	Equivalent Noise Temperature
FM	Flight Model
FMCW	Frequency Modulated Continuous Wave
RAU	Radar Altimeter Unit
RXA	Receive Antenna
TXA	Transmit Antenna

1.3 Definition of Terms

The mission related terminology used within this document conforms to the following basic mission phase definitions:

HUYGENS Probe Mission

The part of the CASSINI Mission from probe separation until loss of probe signal.

Ground Phase

All operations from equipment delivery to Earth escape.

Cruise Phase, Saturn Orbit Phase, Coast Phase and Entry Phase

All parts of the HUYGENS Probe Mission from launch until entry into the Titan atmosphere, in which the Proximity Sensor will be inactive.

Descent Phase

That part of HUYGENS Probe Mission during which the motion of the probe is constrained by the Descent Device and the Proximity Sensor will be operating.

2 DOCUMENTS

2.1 Applicable Documents

In the case of conflict between this specification and the requirements contained in the following Applicable Documents, the Applicable Documents will have precedence.
Applicable documents are referred as AD(x), where; x identifies the document within the following list.

AD01	Electrical Design and Construction Requirements AEROSPATIALE HUY-AS/c-100-SR-0030.
AD02	Mechanical and Thermal Design and Construction Requirements AEROSPATIALE HUY-AS/c-100-SR-0013
AD03	EMC/ESD Specification AEROSPATIALE HUY-AS/c-100-SR-0022
AD04	Environment and Test Requirements. AEROSPATIALE HUY-AS/c-100-SR-0044
AD05	System Specification AEROSPATIALE HUY-AS/c-100-SY-0043
AD06	Command and Data Management Performance Specification. AEROSPATIALE HUY-AS/c-370-SS-0012
AD07	HUYGENS EEE Parts Specification AEROSPATIALE HUY-AS/c-100-SP-0025
AD08	Materials, ,Processes and Non-EEE Parts Requirements AEROSPATIALE HUY-AS/c-100-SP-0026
AD09	AIV General Requirements AEROSPATIALE HUY-AS/c-100-SP-0042
AD10	Reliability Requirements AEROSPATIALE HUY-AS/c-100-SP-0029
AD11	Subcontractor PA Requirements AEROSPATIALE HUY-AS/c-100-SP-0048
AD12	Proximity Sensor Requirements Specification HUY-LABE-374-SS-0002

2.2 Reference Documents

Reference documents are referred as RD(x) where x identifies the document in the following list.

RD01	Component Selection and Control for ESA Space Systems. ESA PSS-01-60 Issue.02
RD02	Derating Requirements and Applicable Rules for Electronic Components. ESA PSS-01-301 Issue.1
RD03	ESA Preferred Parts List ESA PSS-01-603 Issue.2
RD04	The Manual Soldering of High Reliability Electrical Components ESA PSS-01-708 Issue.1
RD05	The Qualification of Two Sided Printed Circuit Boards (Gold Plated or Tin/Lead Finish). ESA PSS-01-710 Issue.1

RD06	The Repair and Modification of Printed Circuit Boards and Soldered Joints for Space Use. ESA PSS-01-728 Issue.1
RD07	High Reliability Soldering for Surface Mount and Mixed Technology Printed Circuit Boards ESA PSS-01-738 Issue.1 Draft
RD08	Qualified Parts List ESA/SCC QPL Issue 89/2
RD09	Electromagnetic Compatibility Requirements for Space Systems SPS/std/002
RD10	Contamination and Cleanliness Control ESA PSS-01-201 Issue.1

2.3 Other Documents

OD01	HUYGENS Radar Altimeter Technical Proposal. HUY-YLIN-374-PO-0001, VOL.II, Issue.1, Rev.1, 14-12-92.
OD02	HUYGENS Radar Altimeter; Management Plan HUY-YLIN-374-PO-0001; VOL.III, Issue.2, Rev.0. 29.06.93
OD03	HUYGENS Radar Altimeter; Design Analysis HUY-YLIN-374-AN-0008; Issue.2, Rev.1.

3 OPERATIONAL DESCRIPTION

The Proximity Sensor subsystem uses two totally redundant altimeters operating at different frequencies (15.4 GHz and 15.8 GHz). Each Altimeter is comprised of a single assembly, the Radar Altimeter Unit (RAU), which includes all microwave and signal processing functions, one antenna for transmission (TXA) and one antenna for reception (RXA).

Both radar altimeters operate in "hot" redundancy. Their operation is initiated by the application of D.C. power. This is intended to occur during the HUYGENS Probe descent phase, controlled by the Probe, Command and Data Management Unit (CDMU). Upon being powered each altimeter will sweep over the available altitude range until a correct radar return signal is detected. Upon detection each radar will lock to the return signal, reflected by the Titan surface.

Each radar altimeter then provides a digital representation of the measured HUYGENS Probe altitude, on request, by either (or both) of the Probe CDMU's. Both altimeters also provide continuous analogue outputs of the IF Signal and the AGC Status for the HASI experimental package. Both also provide a digital output signal which may be used to identify the timing of the radar frequency modulation.

3.1 The FMCW System Basics

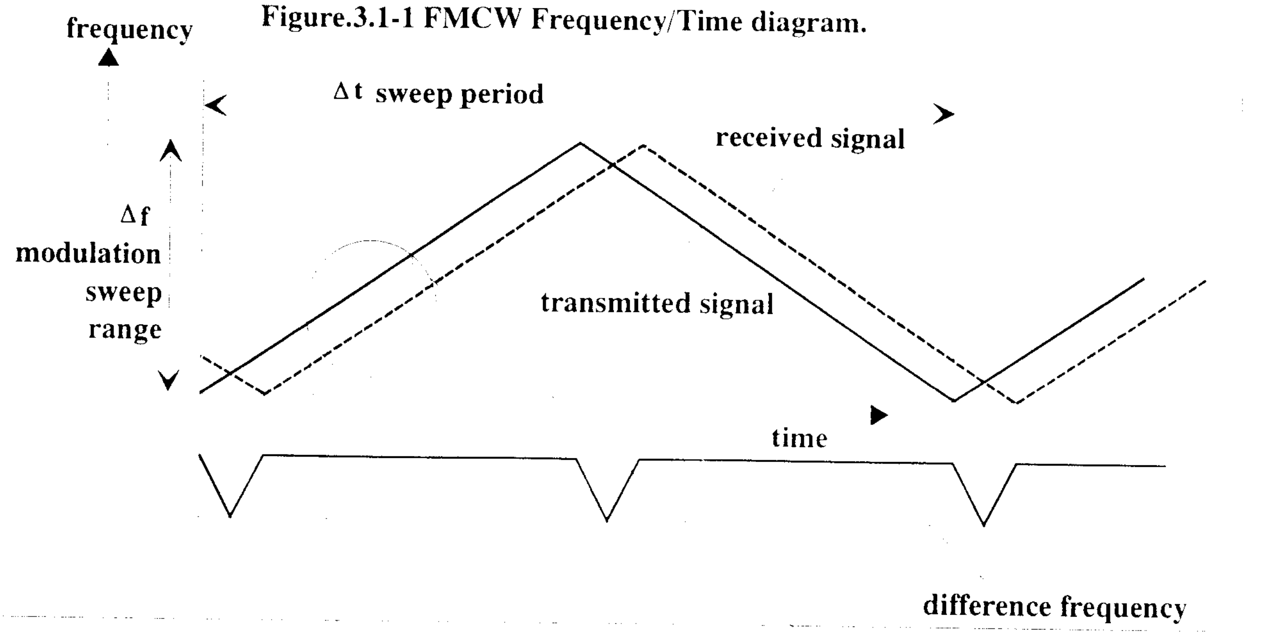
The Frequency Modulated CW method is commonly used for radar altimeter applications. A continuous transmitted signal is modulated, in frequency with a rising and falling ramp waveform. The resultant frequency modulation is shown in the frequency/time diagram, Figure.3.1-1

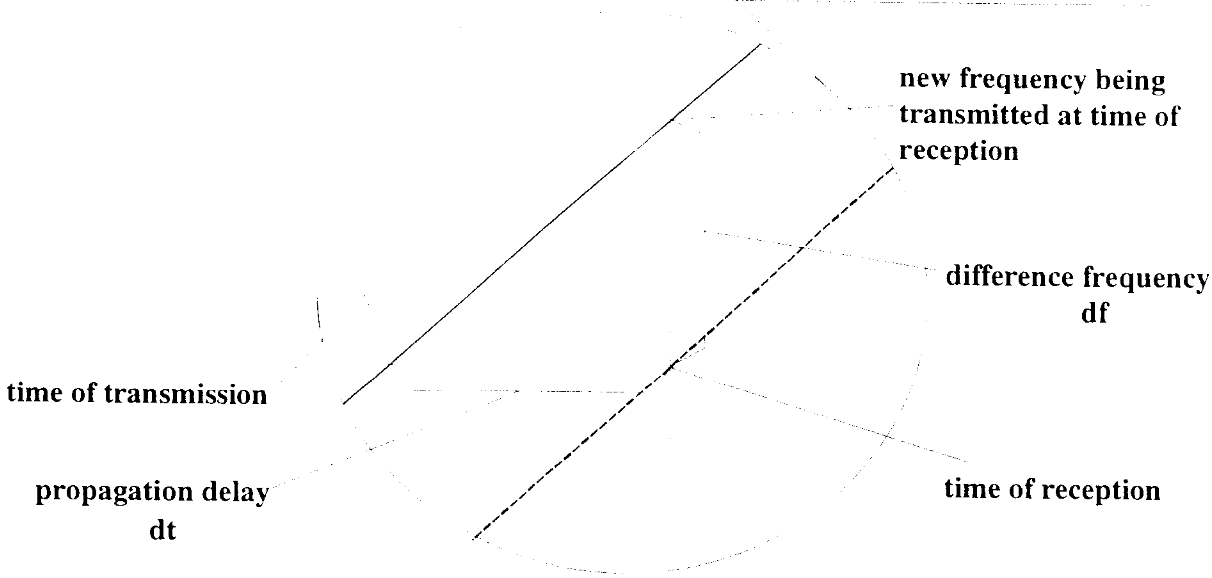
The received signal will be of a similar form. However the received signal will be delayed by the signal propagation time, from transmitter, to target and return to receiver. Thus at the instant of receiving one particular frequency within the ramp the transmitter will be transmitting another.

The range to target is proportional to the propagation time and (with a linear frequency modulation ramp) also proportional to the instantaneous frequency shift between the transmitted and received signals. The frequency shift may be obtained by mixing the transmit and received signals. This will generate a signal whose frequency is proportional to range.

Thus for constant range as shown in Figure.3.1-1, the lower trace shows the expected output signal. It should be noted that the difference frequency signal falls to zero after the ramp changes direction. This is not a problem but needs to be considered in the control circuitry as discussed later.

Figure.3.1-1 FMCW Frequency/Time diagram.





Thus the following relationship can be stated:

$$df = dt \times rate\_of\_change\_of\_frequency$$

And since $dt = (2 \times Range)/c$

where c = the speed of light

Then $$df = (2 \times Range \times rate\_of\_change\_of\_frequency)/c$$

3.2 The Servo-Modulation Technique

Thus the range may be determined by using a constant ramp rate and measuring the difference frequency. This is not convenient, since the range may vary over several orders (in this case from tens of metres to tens of kilometres) and thus the range of frequency variation will also be large, necessitating wideband receiver amplifiers.

Servo-modulation enables the use of a variable ramp rate. This ramp rate is controlled in a closed loop to maintain a constant difference frequency, df. If the "rate_of_change_of_frequency" is re-defined as:

= 2 x swept_frequency (Δf) / sweep_time (ΔT)

Where: ΔT is the sweep time for a complete sweep; up and down.

Then the previous relationship may be restated as:

Range = (df x c) / (4 x Δf/ΔT)

Thus by keeping the difference frequency (df) and the swept frequency range (Δf) constant, when the servo loop is in lock, the range will be proportional to the ramp sweep time (ΔT). This is directly measured and output as a digitally coded analogue of the altitude.

3.3 The Radar Equation

3.3.1 The Propagation Path

Conventional radar theory provides a method of calculating the expected losses of the propagation path from the Transmit Antenna to the Receive Antenna. This enables the determination of an expected receive signal strength from the proposed transmit signal power, which can then be related to the desired operational range.

Appendix 1 provides a calculation of the expected radar return. This is based on the following expression of the Radar Equation

$$P_r = \frac{\lambda^2 . P_t}{(4.\pi)^3} \int_{\substack{\text{area} \\ \text{illuminated}}} \frac{G_{ant}^2 \, \sigma}{R^4} \, dA$$

Where:
- λ = the wavelength
- P_t = the transmitted power
- G_{ant}^2 = the square of the antenna gain (in this case this will be $G_{\_ant\_tx}$ x $G_{\_ant\_rx}$)
- σ = the target surface reflectivity
- R = the range (slant range)

This assumes a uniformly illuminated target area and the integration above should be performed over this area. However, the antenna beam will not have a uniform energy density and thus an extra term to describe the antenna beam shape is included.

$$G = G_0 \times G(\theta,\phi)$$

Where:

G_0 = the basic boresight antenna gain.
θ = the off-vertical angle
ϕ = the off-boresight angle

Also the target reflection will depend upon the angle of incidence and is also included as:

$$\sigma = \sigma_0 \times \sigma(\theta)$$

Where: σ_0 = the reflectivity normal to the target

The elemental area illuminated (dA) may also be re-stated as:

$$dA = r \times dr \times d\phi$$

and since $r = h \,.\, \tan(\theta)$
$dr = h \,.\, d\theta \,/\, \cos^2(\theta)$

then $dA = h^2 \,.\, \tan(\theta) \,/\, \cos^2(\theta) \quad d\theta \,.\, d\phi$
and also since $R = h \,/\, \cos(\theta)$

the term from 3.3.1

$$dA/R^4 = (\sin(\theta) \,.\, \cos(\theta)) \,/\, h^2 \quad d\theta \,.\, d\phi$$

and thus

$$P_r = P_t \frac{\lambda^2 \sigma G_0^2}{(4.\pi)^3} \int_0^{\pi/2} \int_0^{2\pi} \frac{G^2(\theta,\phi)\ \sigma(\theta) \sin(\theta) \cos(\theta)}{h^2} \, d\theta \, d\sigma$$

The group of variable terms

$$= (\lambda^2 \,.\, \sigma_0 \,.\, G_0^2) \,/\, (4\pi)^3 \times h^2$$

can be separated from the remainder of the calculation. This integral need only be performed once providing the antenna beam shape is constant. The result of this integral is termed the Echo Constant (E_c).

3.3.2 The Echo Function E(h)

This is defined as a re-statement of the Transmitted and Received Power ratio:

$$E(h) = \frac{P_r}{P_t} = \frac{\lambda^2 \sigma G_0^2}{(4.\pi)^3} \int_0^{\pi/2} \int_0^{2\pi} \frac{G^2(\theta,\phi)\ \sigma(\theta) \sin(\theta) \cos(\theta)}{h^2} \, d\theta \, d\sigma$$

This equation requires that the integration be performed over the antenna beam (illuminated area). It will be noted that, the majority of the important variable parameters are excluded from the integration. Thus the resultant equation, can be simplified, removing all the specified parameters and variables, leaving a single **Echo Constant** which will solely be dependant upon the Antenna Beam pattern, free space losses and the surface model chosen. This can then be expressed in dB as:

$$E(h) = P_r / P_t = 2.G_{ant} - 20.\log(h) + \sigma_0 + L_{att} - E_c \text{ (Echo Constant)}$$

3.3.3 Design Values for the Echo Constant - E_c

Since the free space losses and the surface model are specified, only the Antenna Beam shape will be of importance. Thus this Echo Constant will only be re-calculated for different antenna; ie, for Pre-EM, EM, QM and FM.

In previous issues of this document, Echo Constants were calculated, using the Pre-EM declared Antenna design parameters. They were as follows:

Tilt Angle 0 deg.	E_c = -86.96 dB.
Tilt Angle 1 deg.	E_c = -86.97 dB.
Tilt Angle 2 deg.	E_c = -86.97 dB.
Tilt Angle 3 deg.	E_c = -86.98 dB.
Tilt Angle 4 deg.	E_c = -86.98 dB.
Tilt Angle 5 deg.	E_c = -87.00 dB.
Tilt Angle 6 deg.	E_c = -87.01 dB.
Tilt Angle 7 deg.	E_c = -87.03 dB.
Tilt Angle 8 deg.	E_c = -87.05 dB.
Tilt Angle 9 deg.	E_c = -87.07 dB.
Tilt Angle 10 deg.	E_c = -87.09 dB.

3.3.4 Engineering Model Echo Constant Values

During the EM Integration Measurements the Antenna beam patterns were measured. These were found to differ slightly from the design values. With this new measured data, the Echo Constants were recalculated for both redundancies, providing following values:

Redundancy A

Tilt Angle 0 deg.	E_c = -87.90 dB.
Tilt Angle 10 deg.	E_c = -92.88 dB.

Redundancy B

Tilt Angle 0 deg.	Ec = -88.24 dB.
Tilt Angle 10 deg.	E_c = -93.25 dB.

These results show a small improvement of between around 1 dB when using the real antenna measured data.

3.3.5 The Relation with Altitude

Using the above values of Echo Constant, a reflectivity of -10dB and the measured values of Antenna Gain (Red.A 25.88dB Red.B 25.77dB). The following values of attenuation were found:

		at 10km	at 20km
Redundancy A			
	Tilt Angle 0 deg.	E(h) = -128.14 dB.	= -134.16 dB.
	Tilt Angle 10 deg.	E(h) = -133.12 dB.	= -139.14 dB.
Redundancy B			
	Tilt Angle 0 deg.	E(h) = -128.70 dB.	= -134.72 dB.
	Tilt Angle 10 deg.	E(h) = -133.71 dB.	= -139.73 dB.

Thus the transmit power values, obtained from Integration Measurement IM17 after correction for the transmit antenna cables losses (measured for the EM during test IM.30), are Red.A. 20.35dBm, Red.B 20.70dBm. Thus the potential receiver input signal may be calculated as:

		at 10km	at 20km
Redundancy A			
	Tilt Angle 0 deg.	= -107.79 dBm.	= -113.81 dBm.
	Tilt Angle 10 deg.	= -112.77 dBm.	= -118.79 dBm.
Redundancy B			
	Tilt Angle 0 deg.	= -108.00 dBm.	= -114.02 dBm.
	Tilt Angle 10 deg.	= -113.02 dBm.	= -119.04 dBm.

It is emphasised that these values are included in this Design Report as an indication of the methods to be used only. Specific radar performance, from design to acceptance is held in lower level documents.

3.4 Receiver Performance

In the following sections, the system Equivalent Noise Temperature (ENT) referenced at the antenna is established. From this is determined an equivalent noise power at the antenna which corresponds to the intrinsic noise of all the sunsequent receiver stages.

The transition from "Searching" mode to "Locked" mode is determined by the detection of the reflected radar return signal. As will be discussed, the detection circuits are also sensitive to noise. The noise power level at which the detection circuits respond, is determined and then converted to an equivalent noise power referenced at the receive antenna. It should, and is shown to be higher than the intrinsic noise level of the receiver. If it were lower, the detection circuits would respond to the receiver generated noise.

The expected environmental noise power at the antenna interface is also calculated and compared with the noise detection power level. This environmental noise component should also be lower than the noise detection threshold. If it were higher the detection circuits would respond to the ambient noise level of the environment.

Having determined that the noise levels are correctly set, the minimum detectable radar return signal is also calculated at the antenna interface. The expected radar return power is then calculated for the maximum altitude requirement and compared with the receiver sensitivity. This should be, and will be seen to be higher thus verifying that the receiver will respond to the expected radar return at the required range.

3.4.1 System Noise Temperature

3.4.1.1 Basic Calculation Method

The standard equation for calculating the equivalent noise temperature referenced to the antenna is as follows:

$$T_R = T_A + T_0(G_{\_cb\_rxant} - 1) + T_0.(F_{lna} - 1)/G_{\_cb\_rxant} + T_0.(F_m - 1)/G_{\_cb\_rxant}.G_{lna} + T_0.(F_{if} - 1)/G_{\_cb\_rxant}.G_{lna}.G_m$$

Where:

- T_A - is the antenna viewing temperature
- T_0 - is the ambient temperature
- $G_{\_cb\_rxant}$ - is the receive antenna cable gain (actually a loss)
- F_{lna}- is the Low Noise Amplifier noise figure
- F_m - is the Mixer noise figure
- F_{if} - is the IF Amplifier noise figure
- G_{lna} - is the Low Noise Amplifier gain
- G_m - is the Mixer gain (actually the conversion loss)

3.4.1.2 Circuit Performance Parameter Values

The performance parameters of the individual circuit blocks remain basically unchanged from issue 3.0 of this document.

T_A, the antenna viewing temperature is derived from AD04. The TITAN temperature and pressure curve indicates that at the low operating altitude of the Proximity Sensor the ambient temperature will be below 100deg.K. This value is thus taken as the worst case.

T_0, the ambient temperature is taken as the normal standard of +17deg.C (290deg.K). This also approximately corresponds to the declared operating temperature of the Proximity Sensor electronics.

$G_{\_cb\_rxant}$, the receive antenna cable losses are derived from the Engineering Model measurements. They have been measured as:

Redundancy.A	-0.8134 dB.
Redundancy.B	-0.9318 dB.

Thus the general value of 1.0 dB is taken as a worst case.

G_{lna}, the Low Noise Amplifier gain and F_{LNA}, the noise figure, are specified by design as 22.5 dB and 2.10 dB.

G_m, the Mixer conversion loss has been specified by design as being 9 dB and, F_M, the Mixer noise figure as also 9dB. This was based upon a prototype measurement of separate representative mixer. Due to the physical layout, it has not been possible to make a measurement of either prototype or EM units. The conversion loss of the stand alone mixer was shown to be relatively constant at LO power levels above -8dBm. Below that value the loss is seen to increase rapidly.

It is suspected, by reference to overall gain figures, that the actual value is higher. This will be verified by direct measurement during QM integration. The System Noise level calculation specified above is relatively in-sensitive to this parameter showing less than 2dB change between -19dB and -9dB. Thus at the present time its value is taken as the nominal integration acceptance level of -13dB.

F_{if}, the IF Amplifier noise figure, is taken as the design value of 1.5dB.

3.4.1.3 Receiver Noise Levels

Using the above formula and values the equivalent noise temperature, referenced at the antenna is calculated as 425.63 deg.K. This corresponds to an equivalent noise power in the receiver band of -130.55dBm.

Removing the antenna temperature T_A component lowers the ENT by 100deg.K which leaves an indication of the receiver noise contribution of -131.71dBm.

3.4.2 Signal Detection

3.4.2.1 Detection Mechanism

The function of detection is performed by a Phase Locked Loop (IC01) part of the Main Electronics PCB Assembly (93006). Detection will occur when a sufficiently large return signal can be recognised by the PLL, enabling it to phase lock its internal oscillator to the signal input.

As will be seen in more detail in OD03, the signal detection PLL, will have a return radar signal input with a certain added noise. As further discussed within this document, the significant noise components will be due to the environmental thermal noise, system noise and transmit signal phase noise leakage.

These represent a wideband noise signal throughout the receiver upto the I.F. Filter. This filter band limits the noise to +/-7.5kHz. Thus the PLL input will "see" the impulse response of the filter, which will contain considerable frequency components at 200kHz. In the condition where the PLL "sees" truly wideband noise, the individual noise components around 200kHz will have comparatively little energy and in this condition the PLL will be able to detect a desired signal considerably smaller than the noise level. Signal-to-Noise ratios of -17dB have been measured in the laboratory, using this PLL and wideband noise.

At power levels (signal and noise) considerably higher than the minimum PLL input levels, the ratio of Signal to Noise approaches a constant value (dependant upon the bandwidth). However, when the noise is band limited (by the IF Filter) for the same S/N ratio the noise energy will thus be much larger. It will have large components around the 200kHz IF frequency. The PLL is "looking" for sinusoids around 200kHz and thus will in some conditions of low input signal, mistake noise for a valid radar return signal. It has been demonstrated, as discussed in OD03, that at the detection threshold the signal-to-noise ratio is not a reliable criteria for determining detection. Thus the following detection criteria are now defined.

3.4.2.2 Detection Criteria

At and near the PLL input minimum, two separate effects are noted, which give rise to a variable Signal-to-Noise ratio, which is not readily usable as a criterion for "lock" detection. Thus two separate detection criteria are proposed as follows:

SDT - the minimum Signal Detection Threshold.
NDT - the maximum Noise Detection Threshold.

If the PLL input noise level is above the "Noise Detection Threshold" the PLL will attempt to lock to the spurious 200kHz signal components of the IF Filter output noise. Due to the effect of the modulation ramp control circuitry this attempted lock leads the system to a low altitude status, where it will remain, indicating a "lock" status at the minimum range.. Thus these noise components must be set to a level below the "Noise Detection Threshold - NDT". This is achieved by the resistor division network R01, R02, R03 and R04. From the document OD03 the "Noise Detection Threshold" has been determined by Pre-EM measurement approximately 18mV rms.

The radar return will also not be a single phase/frequency signal, due to the scattering effect of the target and because of the range differences between bore sight returns and those from the edges of the illuminated target area. To achieve acquisition of the return signal it must be greater than the "Signal Detection Threshold - SDT". From the document OD03 the "Signal Detection Threshold" has been determined by Pre-EM measurement approximately 11mV rms.

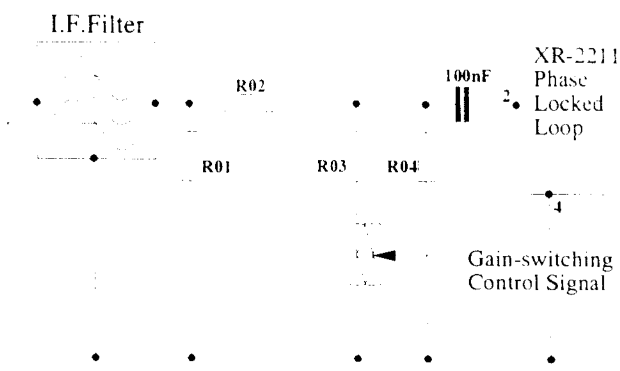
At extremes of altitude, the noise level is noticeably lower than when the radar is operating at low or minimum range. This is believed to be due to components of the modulation signal which will be in the kHz range during low altitude operation but only a few Hz at high altitude. Thus if the NDT is set for a low altitude condition it will be less than optimally sensitive to the desired signal at higher altitudes. Conversely, if the NDT is set for optimum signal detection at high altitudes, there then appears the possibility of lock to noise, when the search mode sweeps through the low altitude condition.

Thus an automatic "Gain Switching" circuit is introduced which de-sensitises the receiver at lower altitudes, allowing the maximum sensitivity to be utilised at higher ranges.

3.4.2.3 Gain Switching

This is shown in Figure.3.4.2.3-1 where the resistor R03 is automatically switched out of the circuit when the ramp control circuits are constraining the radar to search for "lock" at higher altitudes. The mechanism of "lock" to noise is not recognised as a problem since, by design, the noise is set below the "Noise Detection Threshold" and thus cannot cause a ambiguous altitude "lock". The "Gain Switching" allows more signal sensitivity at higher altitudes. Also, as the probe descends the return signal quickly becomes dominant ensuring a correct altitude indication.

Figure.3.4.2.3-1 Proximity Sensor Radar Lock Detection Gain Switching Circuit Diagram



The IF Filter Output voltage required to support the PLL input rms voltage V_{pll} will be:

$$V_{if\_out} = V_{pll} (R02 (R03^{-1} + R04^{-1}) + 1)$$

Thus the required IF Filter output power will be:

$$P_{if\_out} = V^2_{if\_out} [R01^{-1} + (R02 + (R03^{-1}+R04^{-1})^{-1}]$$

$$= V^2_{pll} (R02 (R03^{-1} + R04^{-1}) + 1)^2 [R01^{-1} + (R02 + (R03^{-1}+R04^{-1})^{-1}]$$

This can be applied equally for noise and signals. For the Figure.4.2.2-1 circuit diagram, these resistor values are R01=825R, R02=8k25, R04=24k3. In the specific case of the high altitude initial lock acquisition the "Gain Switching" modification will ensure that 1/R03 = 0. Thus with the declared SDT of 11mV rms, the required I.F. filter rms voltage output will be

$$\text{Min. } S_{if\_out} = V^2_{pll}(R02/R04 + 1)^2 [R01^{-1} + (R02 + R04)^1]$$

$$= 11mV^2(8250/24300 + 1)^2 [825^{-1} + (8250 + 24300)^1]$$

$$= -36.5 \text{ dBm}$$

and similarly the maximum tolerated IF Filter output noise power (derived from the NDT) will be

$$\text{Max. } N_{if\_out} = -32 \text{ dBm}$$

3.4.3 Signal and Noise Calculations

The receiver signal path from antenna to detector circuitry has the following signal processing components; antenna cable, low noise amplifier, mixer, I.F. amplifier and detector input divider. Each component will provide a gain(or loss) and noise contribution to the received signal.

3.4.3.1 Calculation Method

As specifically requested by ESA, at the Proximity Sensor design review (LA-HY-DT-MN-0014-94; 20th.& 21st.March 1994, Page13), the signal and noise power levels are now calculated for each successive stage within the receiver. As an example a single stage calculation is shown, assuming;

stage gain	G	dB
noise figure	F	dB
power input	P_{in}	dBW
noise power input	N_{in}	dBW
stage bandwidth	B	Hz

Single stage output signal power

$$P_{out} = P_{in} + G$$

Single stage output noise power

$$N_{out} = 10.\log(10^{(Nin/10)} + (k . B . (10^{(F/10)} - 1) . T_o)) + G$$

Where:

k - is Boltzmann's Constant (1.38 e-23 J/deg.K)

T_o - is the single stage ambient operating temperature - assumed as 290 deg.K.

Thus the signal and noise power can be calculated at the output of each stage of the receiver and the signal-to-noise ratio also established.

3.4.3.2 Circuit Performance Parameter Values

The performance parameters of the individual circuit blocks remain basically unchanged from issue 3.0 of this document. In addition to the parameter values define in section.3.4.1.2, the following parameters are also used.

$G_{\_amp\_if}$, the IF Amplifier gain, is taken as the design value of 90dB, which is in agreement with the values obtained during EM Integration measurements.

$G_{\_fif\_ib}$, the IF Filter gain (actual loss) in the filter passband is a design value, -3dB, which will be re-assessed on receipt of the flight standard components.

$B_{\_fif\_ib}$, the IF Filter bandwidth is also a design value, 15kHz, which will also be re-assessed when new data is forthcoming.

3.4.3.3 Receiver Signal & Noise Levels

Using the baseline design parameters for each stage, as defined in OD03, the overall receiver gain when working at high altitudes and attempting to lock to the return signal will be approximately

$$= G_{\_cb\_rxant} + G_{\_lna} + G_{\_m} + G_{\_amp\_if} + G_{\_fif\_ib}$$
$$= (-1) + (22.5) + (-13) + (90) + (-3)$$
$$= 95.5\text{dB}$$

and thus using the required IF Filter output power, for SDT as obtained in the previous section, the minimum detectable received signal power will be

$$= -132.0 \text{ dBm}$$

The maximum receiver noise input corresponding to the previously calculated (NDT) noise power at the IF Filter output can be calculated, in this baseline example, by applying the formula defined in 3.4.3.1 to each individual circuit stage. In this case we obtain the following progression:

Noise detection Threshold PLL input power	= -32.22 dBm (from 3.4.2.3)
Equivalent IF Filter input noise power	= -29.22 dBm
Equivalent IF Amplifier input noise power	= -119.30 dBm
Equivalent Mixer input noise power	= -106.74 dBm
Equivalent LNA input noise power	= -130.76 dBm
Equivalent Rx. Antenna output noise power	= -130.45 dBm

Thus for correct operation the input noise ambient should be less than -130.45 dBm.

3.4.4 The Noise Sources and their Contributions.

Apart from the receiver noise contributions the system will need to tolerate the ambient noise of the radar target and phase noise leakage from the transmitted signal.

3.4.4.1 Ambient Thermal Noise Contribution

The TITAN target temperature has been quoted as -100deg.K. This is defined in section 3.4.1.2 and is derived form AD04. Thus when calculated, using twice the IF Filter bandwidth (Double sideband noise), the in-band thermal noise at the receiver input will provide:

$$N_{th} = k \times 2 \times B_{\_fif\_ib} \times T_A \times 10e6 \qquad \text{(mWatts)}$$

$$= -133.83 \text{ dBm}$$

3.4.4.2 Transmit Signal Phase Noise Leakage Contribution

Values DRO phase noise (200kHz from the carrier) of -119dBc/Hz and -114dBc/Hz are available from the Engineering Model integration measurements. As a reasonable baseline value -115 dBc/Hz is chosen for this report. Applying the theoretical phase noise degradation, expected due to the frequency multiplication and value of -109 dBc/Hz is reached. Using this value the in-band phase noise power is:

$$N_{ph} = N_{ph200} + 10.\log(B_{\_fil\_ib}) - L_{iso} + P_t$$

$$= -135.02 \text{ dBm.}$$

Where:

- N_{ph} - is the phase noise power in dBm.
- $NPR_{\_cb\_txant}$ - is the measured phase noise relative to the transmit signal offset by 200kHz.
- $G_{\_tx\_rx}$ - is the transmit to receive antenna isolation, obtained from laboratory measurement of the isolation between two representative antennas at the mounting separation distance.
- $P_{\_cb\_txant}$ - is the transmitted signal power.

3.4.4.3 Total Noise Prediction

It is proposed that the total noise expected is calculated by assuming that these two contributions are purely additive. This is probably a worst case assumption and is thus proposed until a better model is available. The effective combined noise power may be calculated as:

$$= 10.\log(\,10^{(Nph/10)} + 10^{(Nth/10)}\,)$$

$$= -131.37 \text{ dBm}$$

3.4.5 Design Validation Summary

The generalised assessment of the design is now summarised:

Step.1

i) calculate the receiver system noise contribution
ii) calculate the receiver noise detection threshold
iii) if i) is less than ii) then the receiver will not respond to its' own noise

Step.2

iv) calculate the expected noise level at the receiver input.

v) if iv) is less than ii) the receiver will not respond to the operational ambient noise

Step.3

vi) calculate the minimum signal which the receiver will detect and "lock"

vii) calculated the expected radar return signal based on the altitude requirement

viii) if vii) is greater than vi) the receiver will successfully detect the radar return signal at the specified altitude.

The following table provides the first line comparison and justification that the design will meet the altitude requirements.

Table.3.4.6-1 System Noise Performance Comparison (Step.1)

	Parameter Definition	Value	Units	Section Reference
i)	System Noise Level ref. Rx. Input	-131.71	dBm	Section.3.4.4.3
ii)	Noise Detection Power ref. Rx. Input	-130.45	dBm	Section.3.4.3.3
iii)	"Lock" to System Noise	NO		

Table.3.4.6-2 Environmental Noise Performance Comparison (Step.2)

	Parameter Definition	Value	Units	Section Reference
iv)	Environmental Noise ref. Rx. Input	-131.37	dBm	Section.3.4.4.3
ii)	Noise Detection Power ref. Rx. Input	-130.45	dBm	Section.3.4.3.3
v)	"Lock" to Environmental Noise	NO		

Table.3.4.6-3 Signal Performance Comparison (Step.3)
- at max. tilt angle 10 deg.
- using Engineering Model Echo Constants

	Parameter Definition	Value				Units	Section Reference
		at 10km		at 20km			
		Red.A	Red.B	Red.A	Red.B		
vi)	Min. Receiver Signal Sensitivity	-132.00	-132.00	-132.00	-132.00	dBm	Section 3.4.3.3
vii)	Expected Radar Return Signal	-112.77	-113.02	-118.79	-119.04	dBm	Section 3.3.5
viii)	"Lock" to radar return	YES	YES	YES	YES		

It is again emphasised that this is based wholly on design parameters, with some prototype information, subsequent justification and validation being relegated to lower level validation and acceptance documents.

However, it can be stated that these calculated values indicate that:
- the system noise is just below the detection threshold
- the expected environmental noise is just below the detection threshold.
- the expected radar return is well above the detection threshold

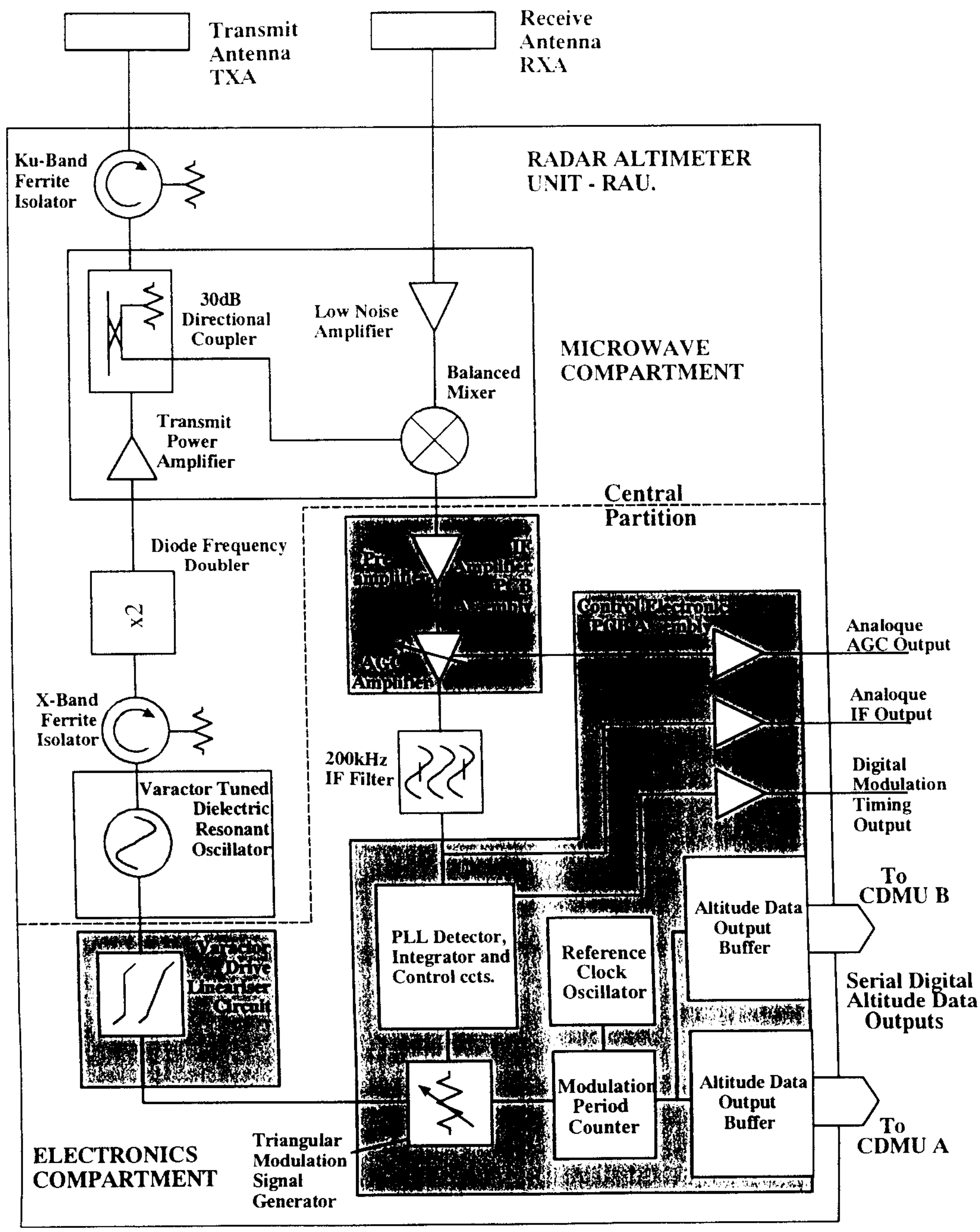
Thus this radar design has been set for maximum range performance by placing the noise floor at the margin of detection. In this condition the range measurement is well in excess of the requirements.

4 FUNCTIONAL DESCRIPTION

Each redundant half of the Proximity Sensor is implemented as a single unit with two antennas mounted externally to the HUYGENS Probe. Thus the total complement of units is:

- Radar Altimeter Unit.A	RAU.A (operating at 15.4 GHz.)
- Transmit Antenna. A	TXA.A
- Receive Antenna. A	RXA.A
- Radar Altimeter Unit.B	RAU.B (operating at 15.8)GHz)
- Transmit Antenna. B	TXA.B
- Receive Antenna. B	RXA.B

Figure.4.0-1 Proximity Sensor Functional Block Diagram



A functional block diagram of one Proximity Sensor radar is shown in Figure.4.0-1. Each RAU has two separate circuit types. Microwave microstrip circuits and the standard C-MOS and Analogue circuits. These are essentially separate sections each forming half of the FMCW servo control loop. For reasons of isolation and ease of access they are mounted either side of a central RAU case partition. The apportionment of the circuit functional blocks between the two compartments is also shown in Figure.4.0-1

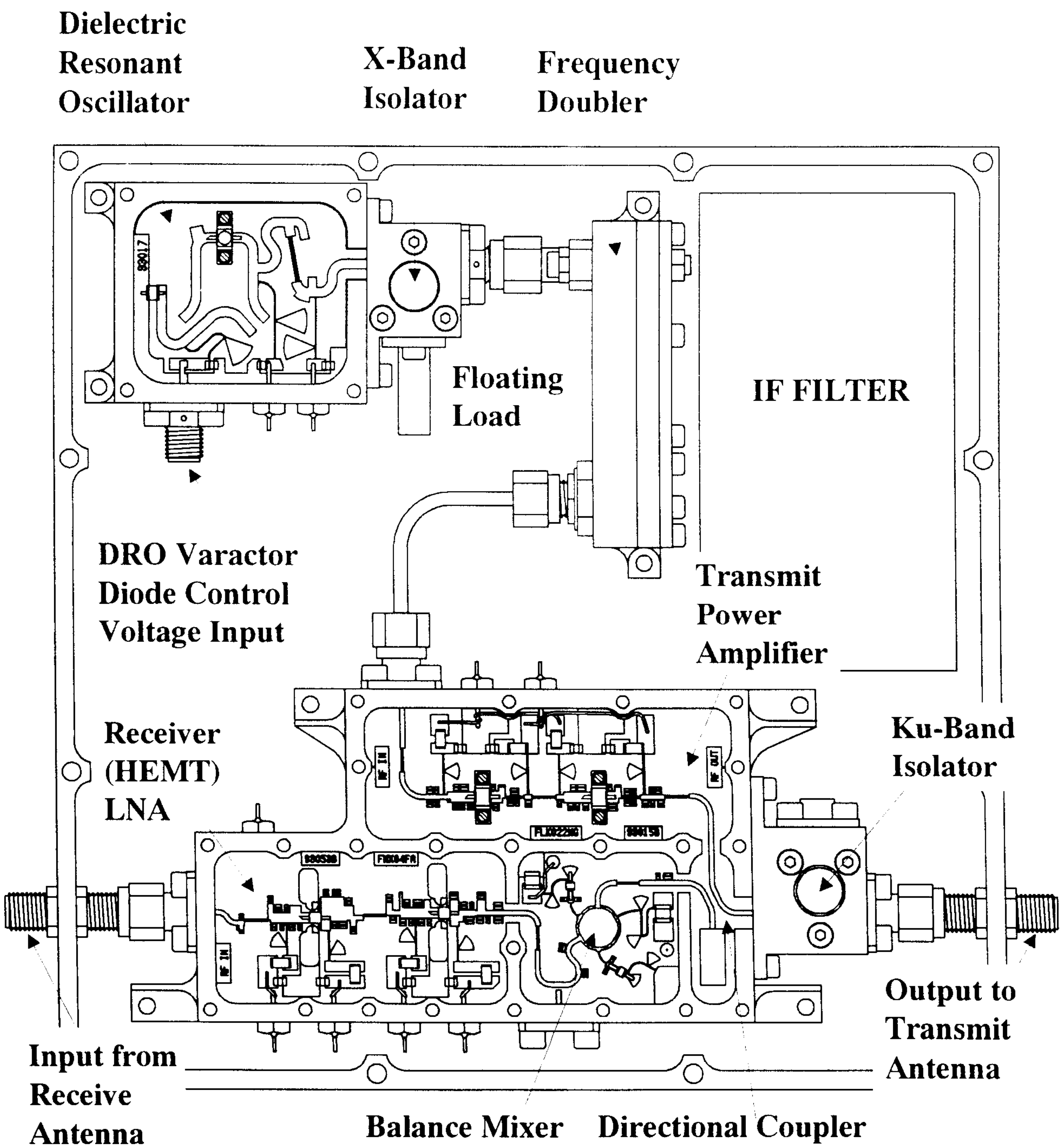


Figure.4.1-1 Proximity Sensor Radar, Microwave Compartment

4.1 The RAU Microwave Assembly

The microwave components are built on soft Teflon based substrates using microstrip technology. The overall function of this section is:

- to generate the transmit signal.
- to amplify the received signal.
- to mix the two signals and provide the frequency difference I.F. component output.

These functional blocks are built into machined microwave component enclosures. The physical implementation is shown in Figure.4.1-1, the microwave circuit diagram is provided in Figure.4.1-2.

4.1.1 Transmit Signal Generation

4.1.1.1 The Transmit Signal Source

In order to maintain an instantaneous difference frequency of 200kHz., at the minimum range (150 metres) it will be necessary to sweep the transmit signal over the 30MHz frequency range in = 2 x 30MHz x 150metres / 200kHz x c
= 150uSecs.

and thus the highest ramp rate is:

$= (2 \times 150\text{uSecs})^{-1}$

= 3.33kHz.

Using a similar calculation, at the requirement range maximum of 10km the range frequency will be 50Hz.

A dielectric resonant oscillator, tuned by a hyperabrupt constant gamma GaAs varactor diode is implemented to obtain the required 30MHz sweep range with acceptable phase noise. This uses a Fijitsu GaAs Field Effect Transistor. The phase noise of the DRO and the frequency doubler is measured, during integration only, by using a CW-test mode. The varactor driver port of the DRO has SMA-connector, which can be used under the phase noise measurements having constant varactor input voltage.

4.1.1.2 The Frequency Doubler

The DRO operates at half of the required output frequency; 7.7Ghz for redundancy.A and 7.9GHz for redundancy.B. The phase.B design baseline used a power amplifier, at nominal frequencies 7.7GHz and 7.9GHz to provide a high level of drive to a step recovery diode (SRD) multiplier, the output then being filtered with a bandpass filter.

During the component qualification assessment process the SRD chosen was found to have a severe de-rating penalty. To meet the de-rating requirements the input power would need to be drastically reduced to a point where the SRD became very inefficient and more amplification would be required.

In the EM baseline design, Figure.4.1-2, the SRD is driven at low power (19dBm) directly from the DRO. Highpass filtering is achieved by suitable waveguide structure, eliminating the need for a specific bandpass filter. Adequate transmit power levels are then achieved by a subsequent amplifier.

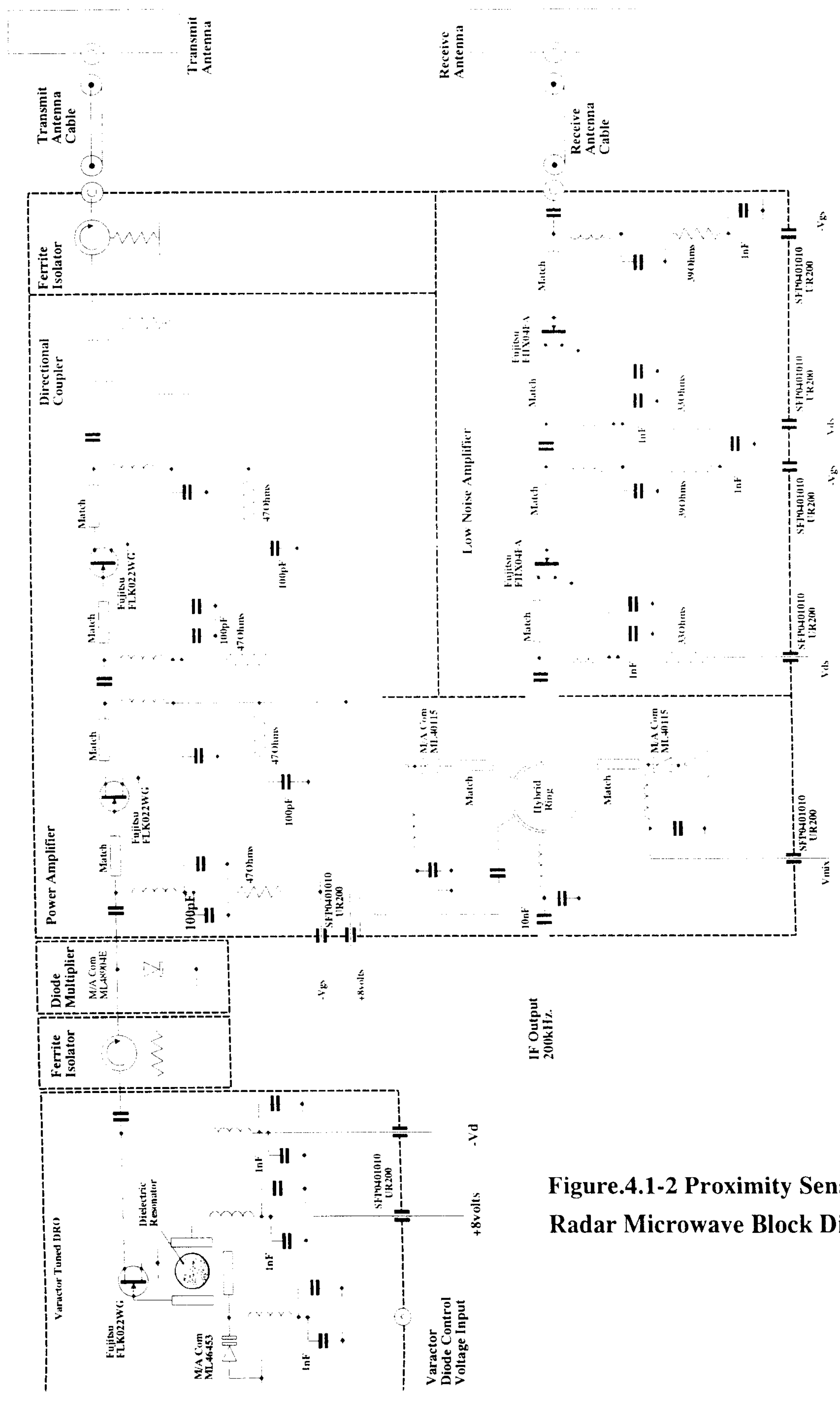


Figure.4.1-2 Proximity Sensor Radar Microwave Block Diagram

4.1.1.3 The Transmit Amplifier and Output

The signal level is amplified, from 14dBm to 23dBm, using a two stage FET amplifier. The output signal is conveyed on the same microstrip PCB to a 30dB microstrip coupler and then to a separate output isolator.

The isolator provides 25dB of rejection to any signal reflected from the transmit antenna. This provides protection for the Transmit Amplifier FETs. The microstrip coupler provides approximately -7dBm Local Oscillator power to the receiver mixer.

4.1.1.4 The Receiver.

The baseline EM, LNA design uses a two stage, low noise HEMT amplifier. This has a signal gain of 22.5dB with and noise figure of 2.10dB. This amplifier is fabricated on the same PCB as the transmit amplifier and mixer, although within separate screened compartments. The output of this LNA is fed directly to the mixer.

The balanced mixer is a hybrid ring configuration which provides a direct mixing of transmit and received signals. The I.F. output at 200kHz is fed by a coaxial cable through the centre dividing wall to the I.F. amplifier within the electronics compartment.

4.2 The RAU Electronics

The RAU electronics are previously shown in the block diagram Figure.4.0-1. Due to their different operational frequency and functions, they are fabricated on three PCB assemblies:

- the I.F. Amplifier (93002KK)
- the main electronics control and measurement circuit (93006KK)
- the varactor lineariser circuit (93003KK)

The I.F. Filter, although being mounted, within the microwave compartment , has its connections accessed within the electronics compartment and is regarded as being part of the electronics system.

4.2.1 The I.F. Amplifier and Filter

The I.F. Amplifier circuit diagram is shown in Figure.4.2.1-1 It amplifies the output signal of the microwave mixer and supplies it to the I.F. Filter. It consists of an ultra low noise pre-amplifier and an automatic gain controlled (AGC) second stage amplifier.

The pre-amplifier is a fixed gain SL561B integrated circuit amplifier. At the input to this amplifier is a simple high pass filter with a cut-off frequency around 160kHz. This is required since, the modulating ramp will provide low frequency components, within the I.F. band. These will increase in amplitude and frequency becoming possibly becoming sufficient to saturate the pre-amplifier at low ranges, without the filter. This first stage, provides broadband amplification, of 40dB around the I.F. frequency, 200kHz.

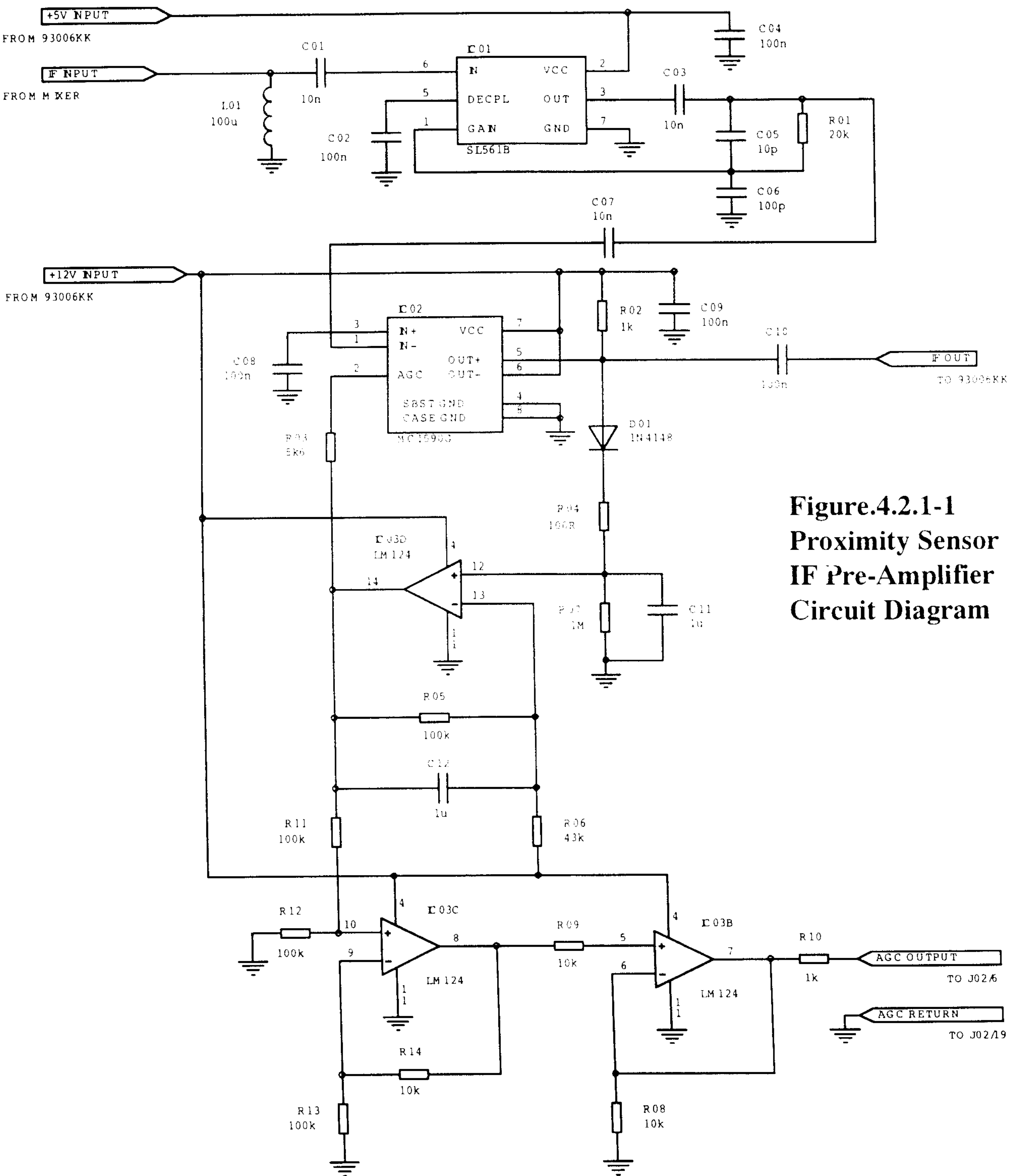


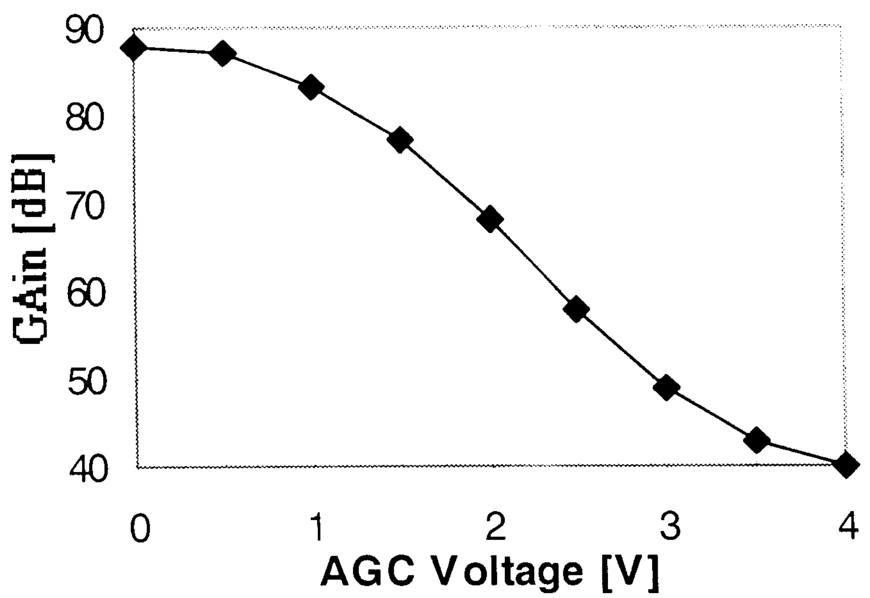
Figure.4.2.1-1 Proximity Sensor IF Pre-Amplifier Circuit Diagram

The output signal is fed to the MC1590G, AGC amplifier. Without the AGC. circuit functioning this amplifier will provide an extra 50dB gain. A simple diode circuit is used to detect the I.F. signal amplitude. This D.C. signal is then used to adjust the gain of the circuit. This is used to limit the amplitude output signal when the radar is measuring low ranges (a large echo return) and to prevent saturation of subsequent stages.

The Figure 4.2.1-2 shows the IF gain as a function of the AGC voltage. The dynamic range of the AGC-amplifier is 50dB. The time constant of the AGC circuitry is approximately one second. The AGC signal is also buffered and provided as an analogue output.

The I.F. Filter is an LC type device. Signal bandwidth is 200kHz +/-7.5kHz, and insertion loss of less than 3dB, with less than 2dB in-band ripple. Stopband attenuation is greater than 60dB outside the 200kHz +/-17kHz frequencies.

Figure.4.2.1-2 Proximity Sensor Radar
IF Gain - AGC Voltage relationship



4.2.2 The Main Electronics Circuit

The Main Electronics circuit diagram is shown in Fig.4.2.2-1 and Fig.4.2.2-2. The altimeter has two operating modes, "search mode" and "locked mode". When D.C. power is applied, the radars start operation in the search mode. When a signal is found, the equipment will adjust the operation to be able to detect and follow the signal frequency. When the altimeter is in this "locked mode", valid altitude data will be available, in the output buffer, which can then be transferred to the CDMU, upon receipt of a valid read operation request from the CDMS.

When in "locked mode" this main electronics circuit provides the servo loop controlling function, monitoring the I.F. frequency deviations from the nominal 200kHz and adjusting the ramp rate to ensure that the I.F. frequency remains at 200kHz.

When the echo return signal is below the signal detection threshold level this circuit is in "search mode". It provides a controlled ramp rate variation from the equivalent minimum to maximum altitude conditions.

4.2.2.1 The I.F. Filter/PLL Interface

As previously discussed, the I.F. signal is derived by mixing the transmit and receive signals. When the system is in "lock" the IF signal is maintained at a 200kHz centre frequency by the Proximity Sensor control circuits. As discussed in section 3.4.1 the output of the IF Filter is attenuated to set the correct detector input level, with the noise floor below the NDT and the minimum signal expected at maximum range higher than the SDT

This signal is also buffered by IC.25 (LF156AH), which has an ac gain of unity. This will provide an output with a quiescent "no signal" state of approximately +3.0 volts with a +/-1.5 volts peak-to-peak, I.F. sinewave amplitude excursion..

4.2.2.2 The Phase Lock Loop Detector

The detection of the return radar signal is implemented using a single, XR-2211M phased locked loop (PLL) integrated circuit. This comprises pre-amplifier, phase detector and precision voltage controlled oscillator (VCO). The preamplifier is used as a limiter such that the input signal levels are amplified to a constant high signal level.

The internal phase detector mixes the input radar return with the internal PLL VCO output. This PLL VCO is set by external resistors and capacitors to have a free running frequency of nominally 200kHz. The subtractive mixing product is selected and used to control the VCO frequency. When the PLL achieves lock the output of the phase detector will have a dc component proportional to the phase error between the radar return signal and the internal VCO. As the radar return changes in phase away from the nominal 200kHz IF, this voltage is output to re-adjust the ramp rate, to reduce the phase error.

Lock detector comparator output pin 6 is "1" if the IF-signal frequency is in the correct frequency range and of sufficient amplitude.

At the end of every frequency sweep the modulation ramp changes direction. During this short period the IF-frequency goes to zero. The ramp limit comparator IC04 detects the modulation ramp max. and min. conditions and blanks the lock status and the integrator operation. The Pin.7 output of IC01 drives the analogue switch IC06b. This switch is maintained "open", by Pin.6 IC01, when the system is "searching" and the integrator is not controlled by the Pin.7. output. When "lock" has been established, this switch is "closed" and the Pin.7 output voltage controls the integrator status.

The circuits IC05d and IC05a form the integrator. Dependant upon the output of the analogue switch IC06b (Pin.10) the integrator will reduce or increase the charge of capacitor C12 and thus the output voltage from pin.1 of IC05a.

Thus if the input (nominal 200kHz) I.F. is low or high the integrator output voltage will be lowered or raised to correct the I.F. back to 200kHz.

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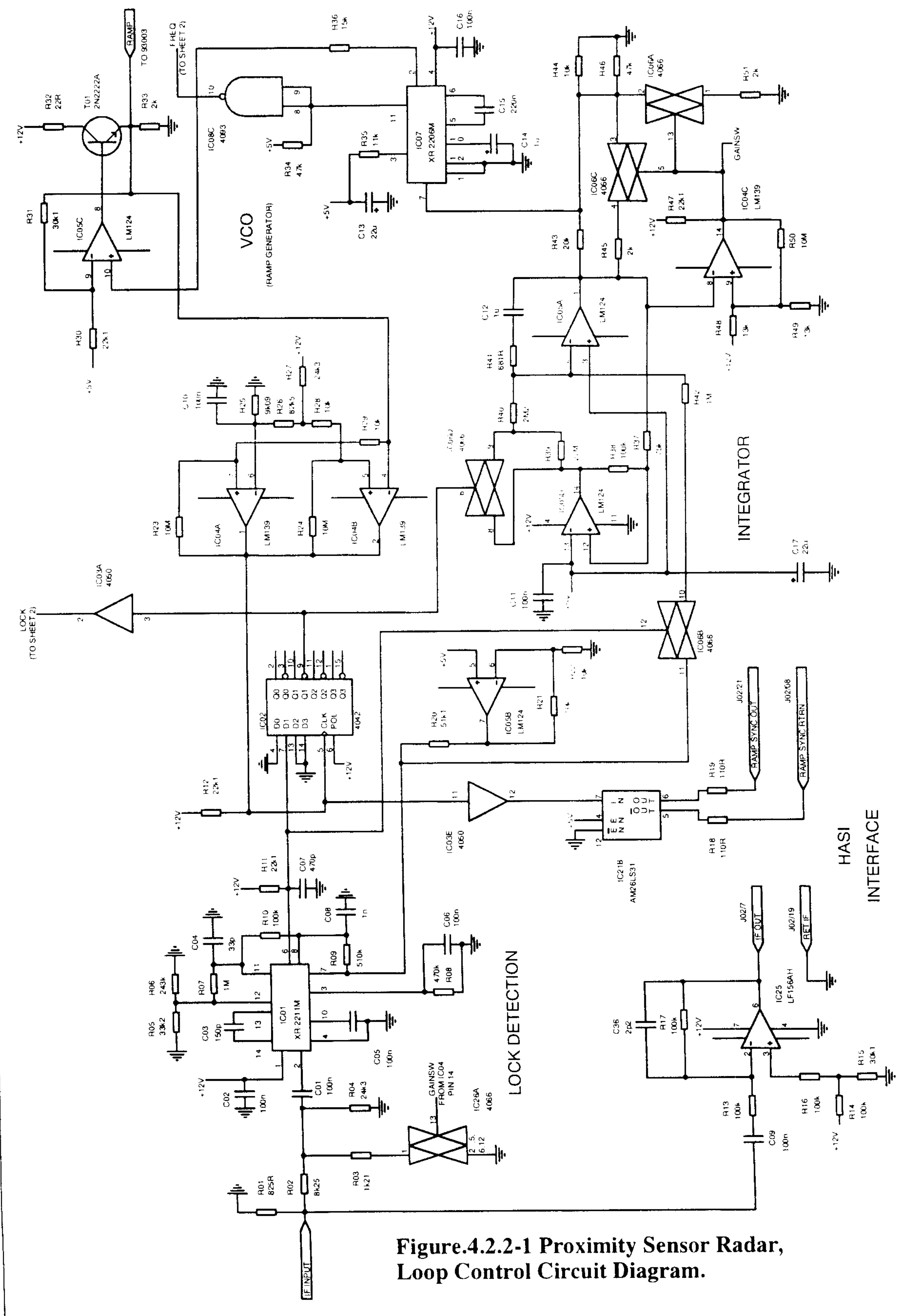

Figure.4.2.2-1 Proximity Sensor Radar, Loop Control Circuit Diagram.

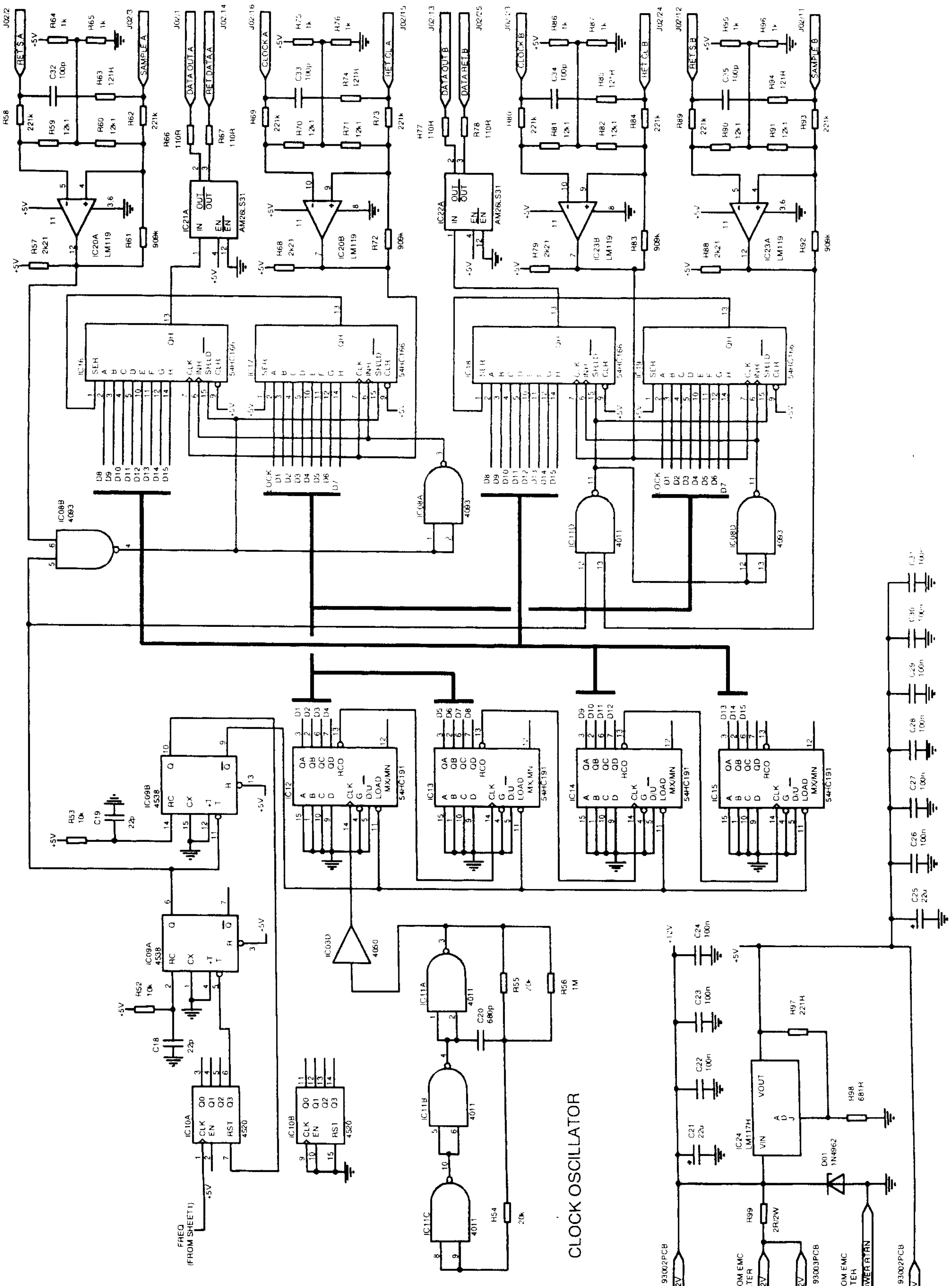

Figure.4.2.2-2 Proximity Sensor Radar Altitude Measurement Circuit Diagram

4.2.2.3 The Ramp Generator VCO

The frequency modulation ramp is generated by IC07 the XR-2206M. The frequency of this ramp is controlled by current drawn from Pin.7 by input from the integrator output. The modulating ramp is output at Pin.2 and supplied to the Varactor Lineariser, via the amplifier IC05C and emitter follower T01. The Varactor Lineariser circuit provides a linearity compensation of the varactor diode drive voltage, which will frequency modulate the DRO.

The IC07 Pin.11 output provides a squarewave corresponding to the ramp period. This is supplied to the ramp period counter.

4.2.2.4 The Ramp Synchronisation Interface

Ramp sync is bi-level signal being "0" when the ramp changes direction and elsewhere "1". The bi-level signal will be buffered to the output interface by the IC21b (AM26LS31).

4.2.2.5 The Ramp Period Counter and Oscillator

The ramp period counter is shown in Figure.4.2.2-2. IC12 to IC15 form a serial 16 Bit counter driven by the clock oscillator. To obtain the correct scaling the IC07 ramp period signal is divided by sixteen, IC10a and then used to enable the ramp counter. This then counts the reference clock oscillator pulses for sixteen ramp periods. Altitude data updating time is maximum 640ms at 20km decreasing linearly to 4.8ms at the altitude of 150meters. The resulting digital value is then parallel loaded to the output registers IC16/IC17 and IC18/IC19. The timing diagram of RAU electronics is presented in Figure 4.2.2.6-1.

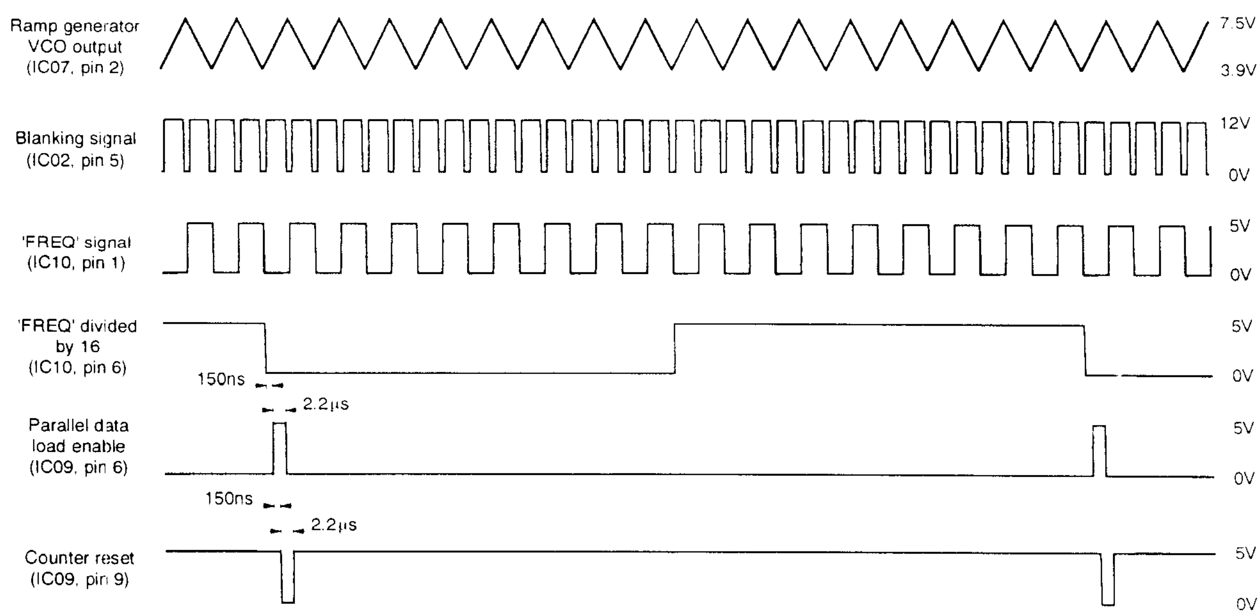

Figure.4.2.2.6-1 Proximity Senser Radar Control Loop Timing Diagram.

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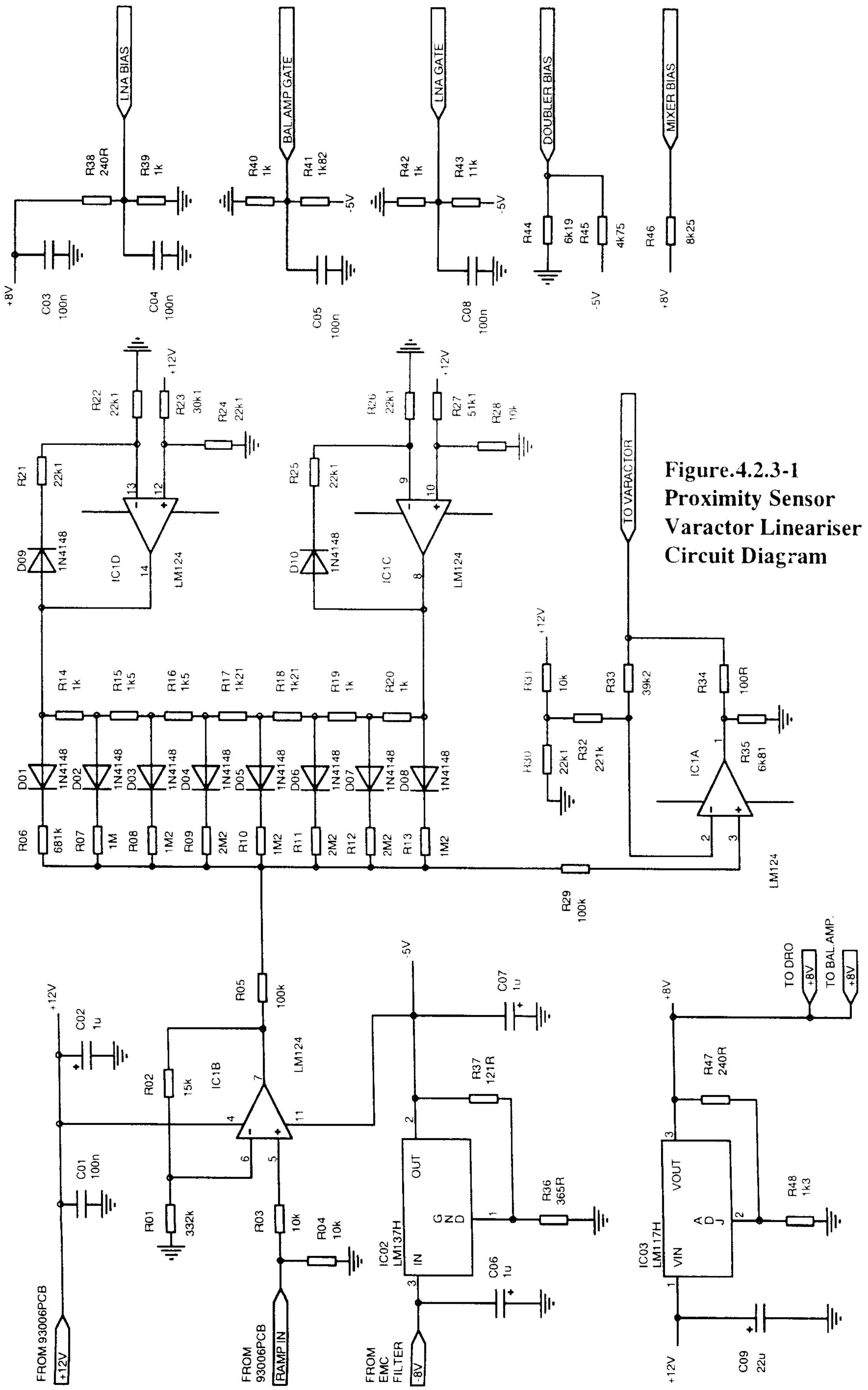


Figure.4.2.3-1
Proximity Sensor Varactor Lineariser Circuit Diagram

4.2.2.6 The Serial Digital Output Interface

The output registers will be continually loaded with new altitude data as it is generated. During the parallel load process one of the output register parallel load inputs is derived from the lock status line of the lock detector. Thus one of the bits (D0) of each Serial Digital word will indicate lock status, which may be used to ensure that the data is valid.

When the Serial Digital "Sample" signal is received it inhibits the parallel load mechanism and serially outputs the current data under control of the Serial Digital "Clock" signal.

Because the 54HC191 is a synchronous counter and loading to 54HC166s occurs synchronously there is no possibility of reading invalid data from counters to shift registers. Parallel altitude information data is loaded from counters 54HC191 to shift registers 54HC166s by a short latch pulse (IC09/6), when a count is finished. Rising edge of this pulse transfers data from ICs 12-15 outputs to ICs 16-19 input buffers. After data is transmitted to 54HC166s counters are zeroed and a new counting activity starts. The latch pulse (IC09/6) is inhibited, when SAMPLE input is active. So data is not changed in ICs 16-19 during the reading cycle and the output of invalid data is not possible.

4.2.3 The Varactor Lineariser

The combined varactor diode and DRO will not provide a truly linear control voltage to output frequency relationship. It must be ensured, for correct radar "lock" maintenance, that the frequency sweep does not exceed the I.F. filter +/-7.5kHz bandwidth. Thus a simple diode "breakpoint" ladder is used to compensate for the varactor non-linearity. This is shown in Figure.4.2.3-1.

The Varactor Lineariser assembly also hosts two voltage regulators, providing +8 Volts and -5 Volts, which provide suitable bias for the transmit amplifier , the receiver LNA, frequency doubler diode and mixer.

4.3 Antennas and Cables

4.3.1 Antenna Description

The Proximity Sensor antenna is a planar slot array radiator. The array is organised in square fashion with eight waveguide feed sections. Each waveguide feed section is of reduced height type and each has ten radiating slots. These waveguide sections are centrally fed by a waveguide to suspended substrate transition. The eight transitions are fed symmetrically by a Wilkinson power divider network implemented on a suspended substrate.

The radiating slots are tapered to provide a constant illumination over the waveguide section length, which will ensure maximum gain. The Wilkinson power divider is reactively matched with symmetrical power division, to also maximise the gain. The waveguide section broad dimension is slightly reduced to eliminate grating lobes. The array is centrally fed both in E- and H-plane to eliminate beam boresight squint. The feed network losses are typically 2 dB.

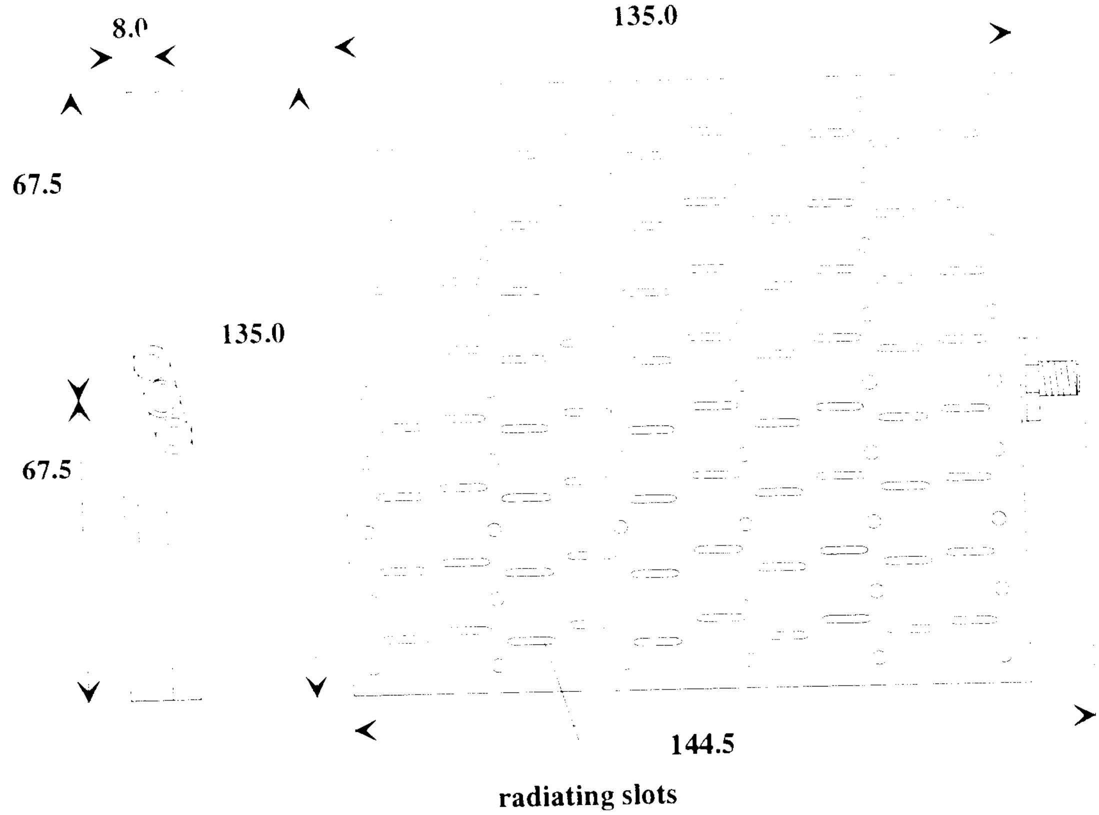


Figure.4.3.1-1 Proximity Sensor Radar Antenna

The mechanical realisation is an aluminium tri-plate construction with a thin (0.15mm) teflon substrate clamped in a milled channel of dimensions 2 x 4 millimetres. Channel dimensions are selected for 16 GHz operation to prevent waveguide-type propagation. Input connector is female SMA with a stress relieved centre conductor connected to the suspended substrate.

The phase B design antenna was rectangular with dimensions 12.5 x 15.0 cm. This design was found to have the beamwidth in E-plane which was too narrow. The current antenna design structure is square with dimensions 13.5 x 13.5cm. This provides adequate antenna gain with a symmetrical beamwidth. The physical implementation is shown in Figure 4.3.1-1.

4.3.2 Antenna Function Measurements

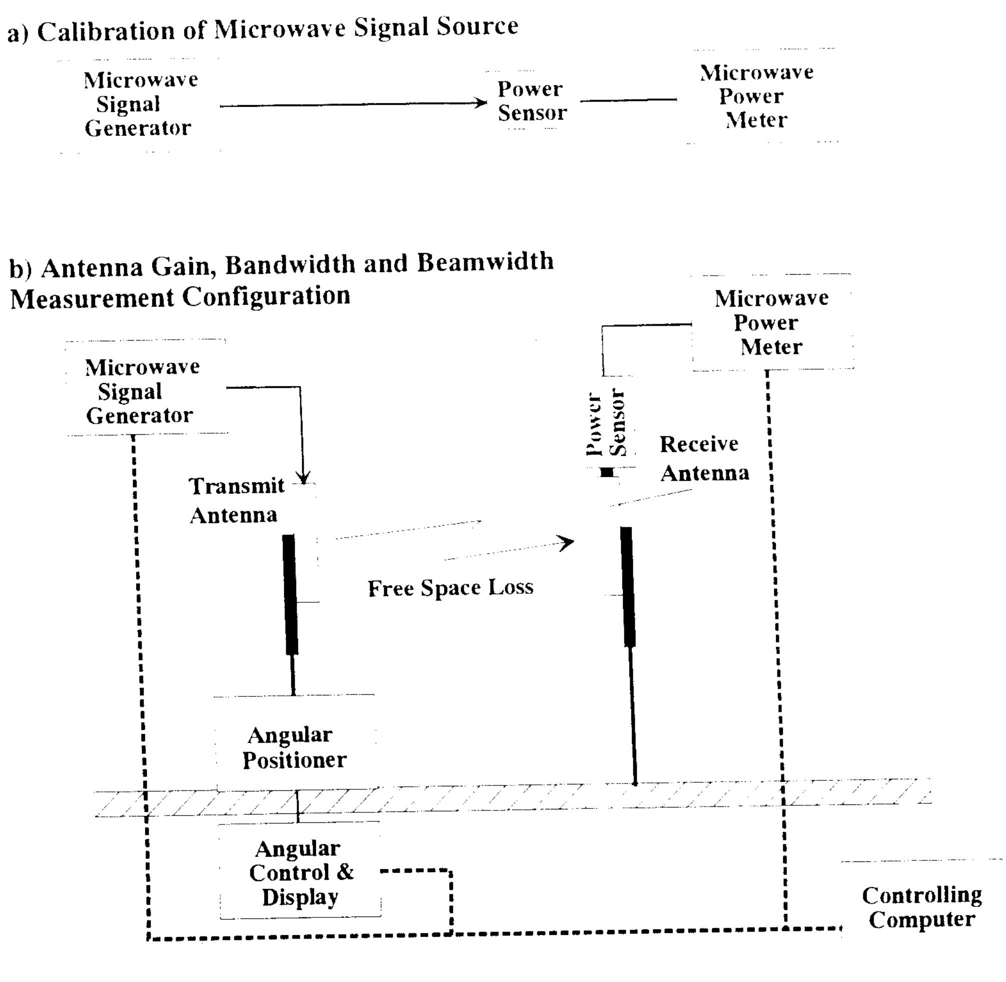
To verify the performance of these antennas the following measurements have to be performed:

1. Absolute Antenna gain.
2. Relative Antenna gain/frequency response
3. Antenna beam pattern
4. Input port match (return loss)

4.3.2.1 Absolute Antenna Gain

Figure 4.3.2.1-1 illustrates the gain measurement configuration. A CW stimulus signal is initially calibrated by measurement using an R.F. Power meter. This is then applied to the Transmit Antenna and the power output by the received antenna (situated at some distance along the boresight axis) is then measured using the same power meter:

Figure.4.3.2.1-1 Proximity Sensor Radar Antenna Measurement Configurations



The difference between these two measurements will represent the antenna gain of both antenna and the free space loss between them. Since the free space loss can be calculated the combined antenna gain can be determined.

It is valid to assume that these devices are reciprocal and have equal gain and that the gain of one antenna can be determined as half the total. Even if this is not a validate assumption, these gain values are used together in the range calculations and thus any imbalance will have no effect upon the overall performance characterisation.

$$P_r = P_t + G_{ant\_rx} + G_{ant\_tx} + L_{free\text{-}space}$$

Measurements are made in the Ylinen anechoic chamber. Antenna pointing angles are carefully adjusted until the maximum power is received ensuring that the main lobes are towards each other. The distance between antennas is nominally 5 meters, to ensure that they are operating in the far-field region.

The formula for free-space propagation is:

$$L_{free\ space} = 10.\log(\lambda / 4\pi r)^2$$

Where:

- P_r = received power (dBm)
- P_t = transmitted power (dBm)
- G_{ant_rx} = receive antenna gain (dB)
- G_{ant_tx} = transmit antenna gain (dB)
- r = distance between antennas (m)
- λ = wavelength (m)

Thus at 5 meters separation

L free-space (15.4GHz) = -70.17dB

L free-space (15.8GHz) = -70.39dB

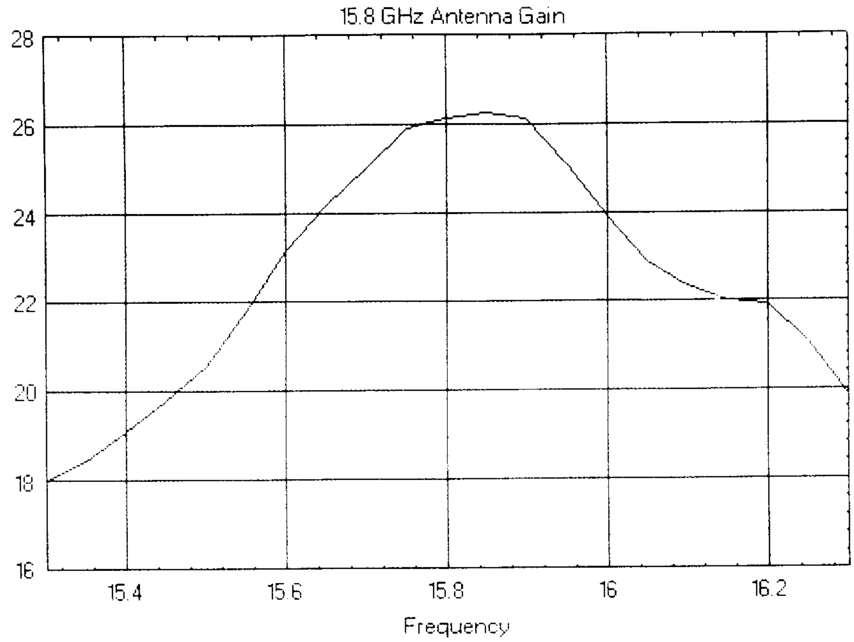
4.3.2.2 Relative Antenna Gain/Frequency Response

After determining the absolute Gain, the signal source frequency is stepped across a band of frequency values. At each new frequency the power meter indication is noted. Thus the relative performance with frequency of the antenna pair is established and their bandwidth may be determined.

The results of the 15.8 GHz and 15.4GHz antenna gain measurements are shown in figure 4.3.2.2-1, and figure.4.3.2.2-2. As seen in the figure the antenna gain is 26 dB at operating frequency and the 3 dB gain bandwidth is larger than 400 MHz. The centre frequency of the measured antenna is not perfectly correct, these figures being obtained from pre-EM units for example only.

In a consequence of the lower operating frequency the 15.4 GHz antenna gain has a reduction of 0.5 dB compared to the 15.8 GHz antenna gain.

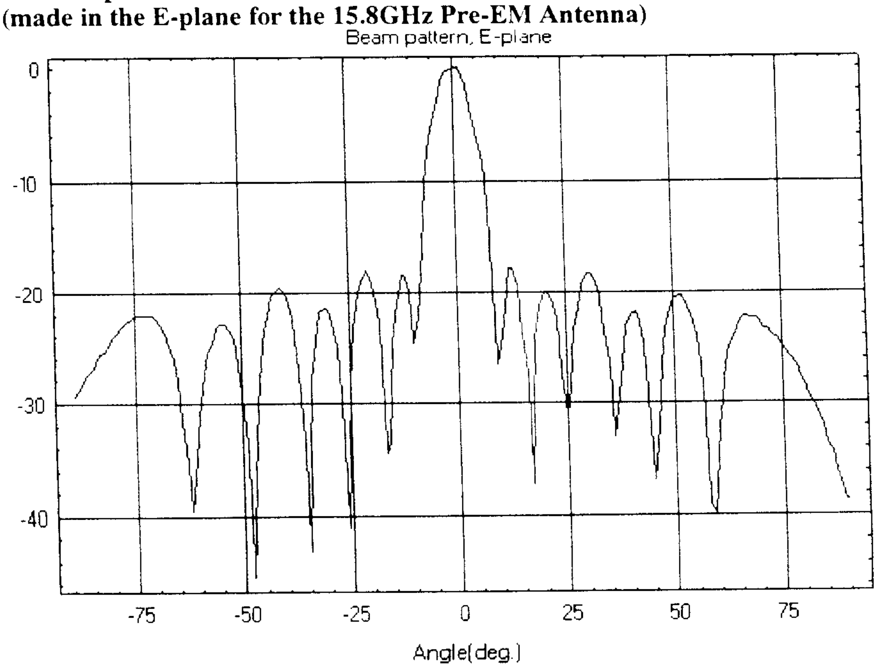
Figure.4.3.2.2-1 Proximity Sensor Radar
An example of the Antenna Gain v Frequency Response
(Pre-Engineering Model Antennas)



4.3.2.3 Antenna Beam Pattern

The antenna beam patterns are measured in the same anechoic chamber as the gain. Beam patterns are determined in both E and H-planes by rotating the antenna under test and measuring the received power with a spectrum analyser. Figures 4.3.2.3-1 shows the 15.8 GHz antenna beam pattern in E- and H-planes. Estimation by calculating the patterns

Figure.4.3.2.3-1 Proximity Sensor Radar
An example of the Antenna Gain v Beam Position Measurement
(made in the E-plane for the 15.8GHz Pre-EM Antenna)



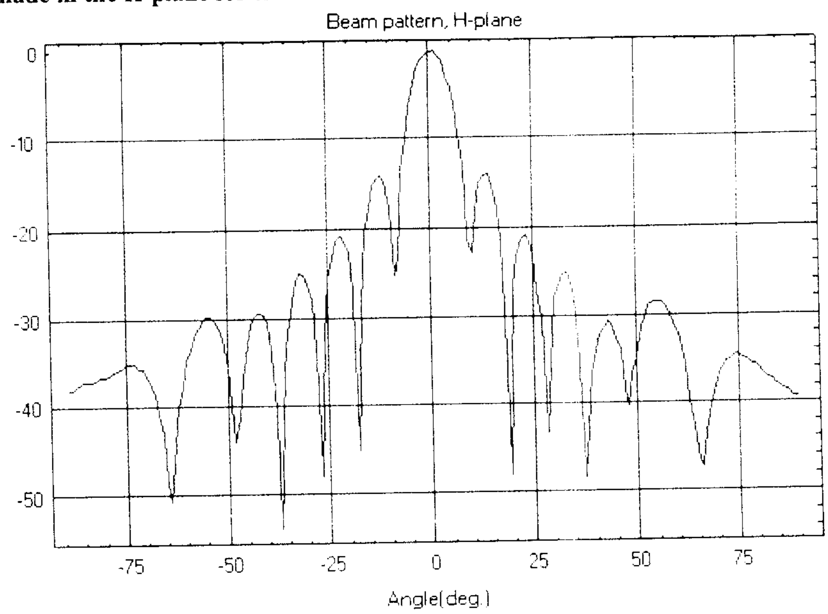
numerically we'll get the value of 25.7 dB. This is the mean value of the E- and H-plane calculations when assuming them rotationally symmetrical.

The beam pattern of the 15.4 GHz antenna, has been found to be almost identical to the 15.8 GHz antenna. The main difference is a little increase in beamwidth (3 dB beamwidth increases from 7.8° to 8.0°). Side lobe levels are nearly equal.

Figure.4.3.2.3-2 Proximity Sensor Radar

An example of the Antenna Gain v Beam Position Measurement

(made in the H-plane for the 15.8GHz Pre-EM Antenna)



4.3.2.4 Input Port Match

Return losses of the 15.8 GHz and 15.4 GHz antenna have been measured with a vector network analyser across the wide frequency bandwidth. Return loss better than -15 dB covers approximately the 80 MHz bandwidth and at the centre frequency return loss reaches the level of -30 dB. The final centre frequency will be moved by the frequency shift due to temperature variation. Since it is impossible to make frequency/gain response measurements during temperature cycling, the return loss will be used as the indicator of the centre frequency shift with temperature.

4.3.3 Antenna Cables

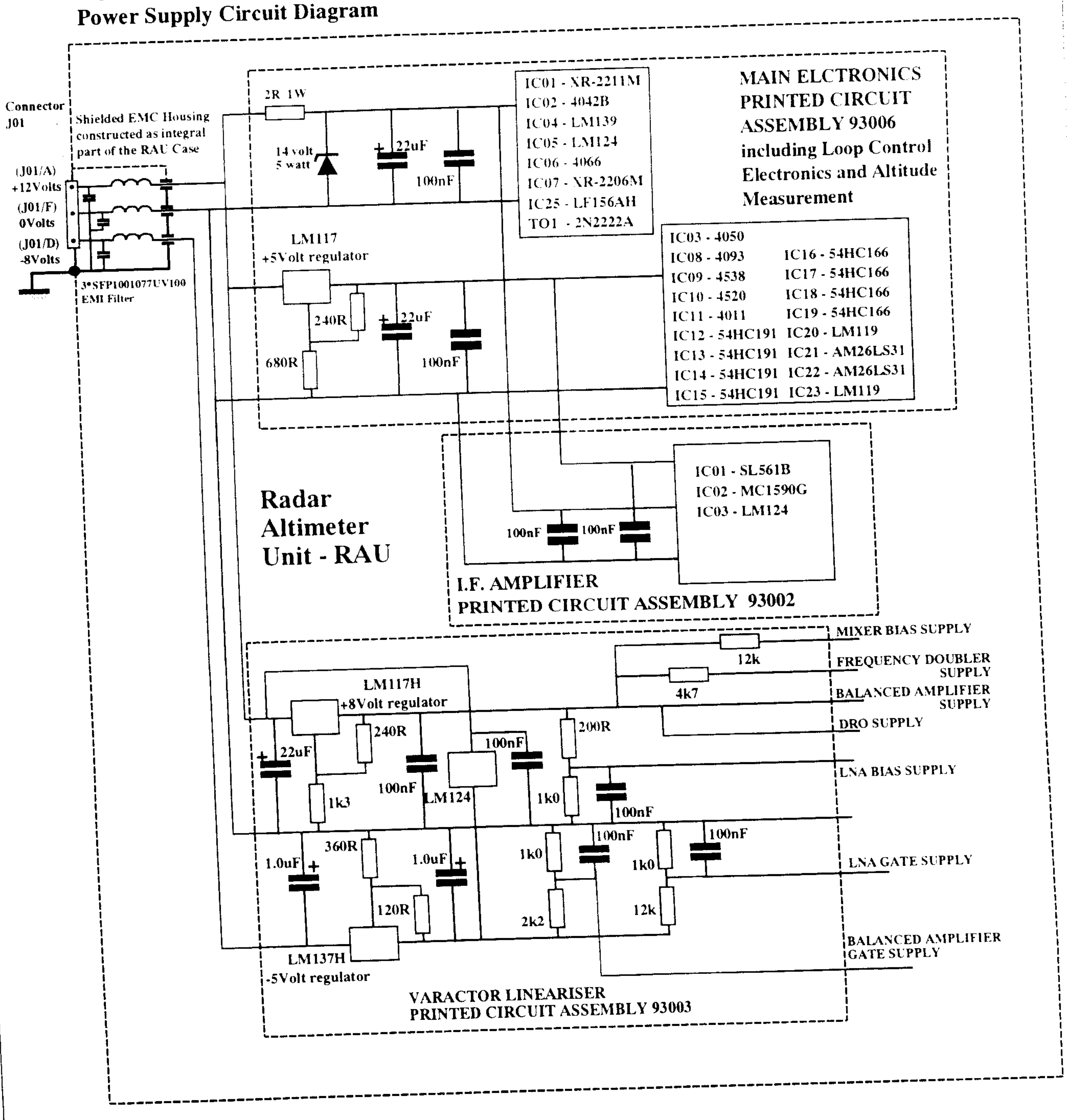
The coaxial cables making connection between the RAU and the antennas are 0.141" semi-rigid cables. The jacket is silver plated copper and the centre conductor is silver plated beryllium-copper. This is the provisionally proposed construction. At the time of publication of this document, an ECP is pending, which will authorise a rigorous thermal testing to validate the correct performance of these cables, under the extreme -200deg.C operational environment. The cable connectors are SMA straight plug soldered type.

Should these proposed cable types be inadequate, they will be substituted by specialised semi-rigid cables with silicon dioxide dielectric material.

4.4 Power Supply and Grounding

The Proximity Sensor does not include a DC/DC-converter. The Power supply lines are routed from secondary power lines of the CDMU. The power supply lines consist of +12 volt and -8 volts lines as well as common power return line. The power supply circuitry of the Proximity Sensor is presented in Figure 4.4-1.

Figure.4.4-1 Proximity Sensor Radar Power Supply Circuit Diagram

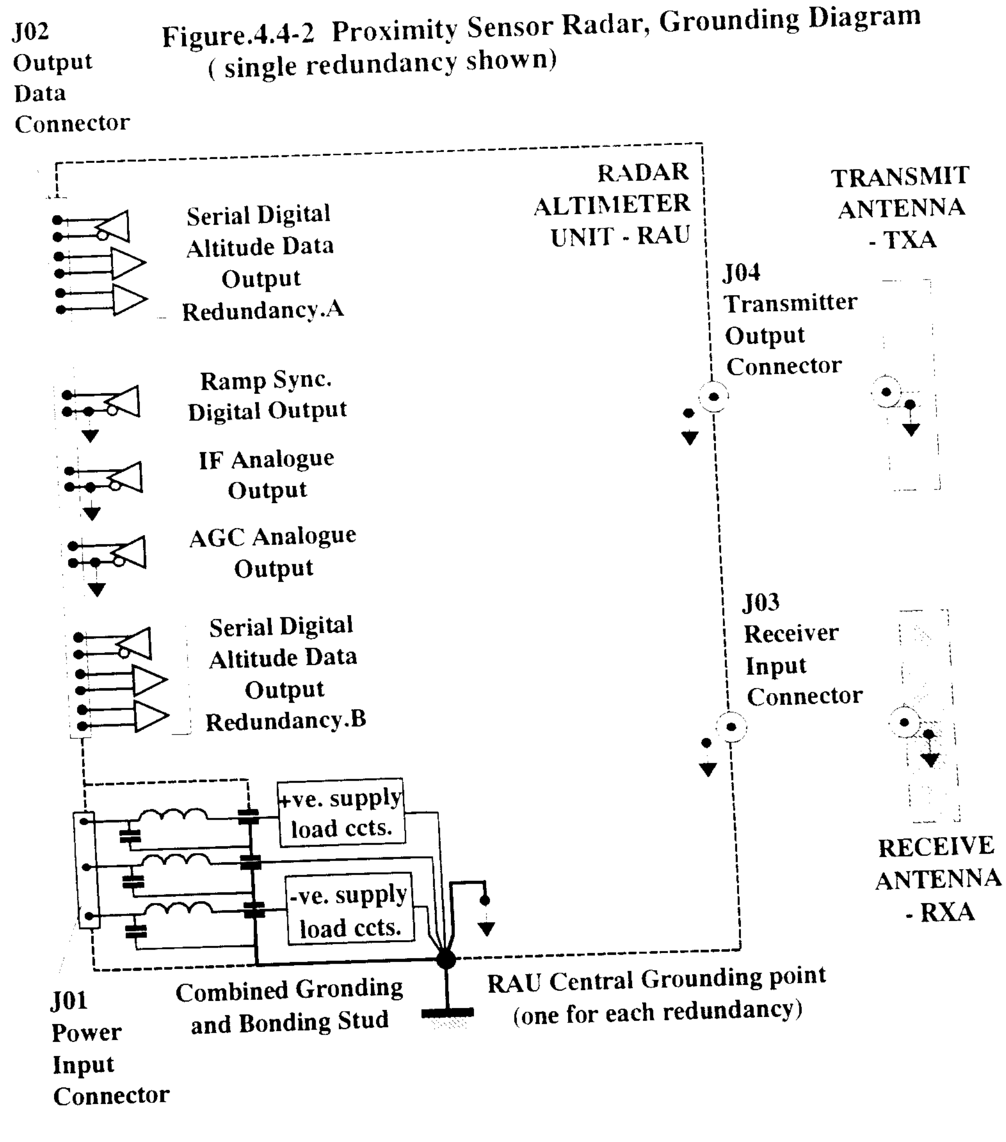


Each power supply line is routed via EMI-filter within EMC shielded compartment. The EMI-filter SFP 100 1077 UV100 is π-type filter manufactured by Eurofarad. Typical specified attenuation as a function of frequency is shown below:

Frequency	Attenuation
50 kHz	14 dB
100 kHz	20 dB
500 kHz	32 dB
1 MHz	35 dB
5 MHz	60 dB
10 MHz	70 dB

The +12Volts line goes through the current limiter resistor 2Ohms/1Watt followed by shunt zener voltage limiter 14Volts/5Watts and filtering capacitors. The +5Volts and +8Volts power lines are regulated from the +12Volts line by the linear regulators LM117H. The +8Volts line is taken before the current limiter resistor because of the amount of the power dissipation demanded by DRO and Power Amplifier. The -5Volts power line is regulated from the -8Volts line by the linear regulator LM137H. The grounding diagram of the Proximity Sensor is presented in Figure 4.4-2.

Figure.4.4-2 Proximity Sensor Radar, Grounding Diagram (single redundancy shown)



4.5 Design Summary

The Proximity Sensor technical specification is summarised in the Table 4.5-1.

Table 4.5-1. Design Summary.

Measuring Principle	**Servo Modulation FMCW**
Output Centre Frequency	**15.4 GHz or 15.8 GHz**
Output RF-power	**> 20 dBm**
Sweep Range	**30 MHz**
Intermediate Frequency	**200 kHz**
Receiver IF-bandwidth	**15 kHz**
IF-amplifier Type	**linear**
IF-gain	**90 dB**
Antennas	**Two separate Planar Slot Radiators**
Antenna Gain	**> 25 dB**
Minimum Altitude *	**111 meters**
Maximum Altitude *	**20 km**
Accuracy	**- 0.013% ... + 2.4%**
Operating Temperature Range **	**- 20 °C ... + 50 °C**

*** altitudes given indicate the functional ability of the modulation range only.**
****not including the antenna operational temperature range.**

5 BUDGETS

5.1 Mass Budget

The Mass budget is shown below. This indicates overall mass for the complete Proximity Sensor subsystem. It will be seen that all these figures are derived from actual measurements made during the Engineering Model inspection programme.

Table.5.1-1 Mass Budget

Unit Name	Symbol	Red.	Mass	Units	Source of Data
Radar Altimeter Unit	RAU	A	1185.70	gms.	EM, INS.10; TP30/94
Transmit Antenna	TXA	A	264.00	gms.	EM, INS.10; TP30/94
Receive Antenna	RXA	A	265.40	gms.	EM, INS.10; TP30/94
Transmit Cable	TXCBL	A	56.30	gms.	EM, INS.10; TP38/94
Receive Cable	RXCBL	A	23.90	gms.	EM, INS.10; TP38/94
Tx. Antenna bracket	Ser.No105	A	103.60	gms.	EM, INS.10; TP30/94
Rx. Antenna bracket	Ser.No106	A	108.80	gms.	EM, INS.10; TP30/94
Radar Altimeter Unit	RAU	B	1189.30	gms.	EM, INS.10; TP30/94
Transmit Antenna	TXA	B	271.70	gms.	EM, INS.10; TP30/94
Receive Antenna	RXA	B	272.20	gms.	EM, INS.10; TP30/94
Transmit Cable	TXCBL	B	52.60	gms.	EM, INS.10; TP38/94
Receive Cable	RXCBL	B	29.20	gms.	EM, INS.10; TP38/94
Tx. Antenna bracket	Ser.No107	B	108.10	gms.	EM, INS.10; TP30/94
Rx. Antenna bracket	Ser.No108	B	105.60	gms.	EM, INS.10; TP30/94
Total Proximity Sensor Mass			4036.40	gms.	

5.2 Power Budget

Two power budgets are shown below. These have been directly from the measurements made during Engineering Model electrical testing. They show the steady state power consumption in the two operational modes searching and locked. They are derived from the Engineering Model integration measurements.

Table.5.2-1 Power Budget - Search Mode

Unit Name	Power Supply Parameters				Power		Source of Data
	Voltage - volts		Current - mA		Total	Units	
RAU - A; Search Mode							
Low supply	11.40	-7.60	325.00	-15.00	3.82	W	ET.02 16.2.94
Nominal supply	12.00	-8.00	329.00	-15.00	4.07	W	ET.02 16.2.94
High supply	12.60	-8.40	329.00	-15.00	4.27	W	ET.02 16.2.94
RAU - B; Search Mode							
Low supply	11.40	-7.60	338.00	-15.00	3.97	W	ET.02 16.2.94
Nominal supply	12.00	-8.00	340.00	-15.00	4.20	W	ET.02 16.2.94
High supply	12.60	-8.40	341.00	-15.00	4.42	W	ET.02 16.2.94
TOTAL Power Consumption				Low	7.79	W	
				Nom.	8.27	W	
				High	8.69	W	

Table.5.2-2 Power Budget - Locked Mode.

Unit Name	Power Supply Parameters				Power		Source of Data
	Voltage - volts		Current - mA		Total	Units	
RAU - A; Locked Mode							
Low supply	11.40	-7.60	324.00	-15.00	3.81	W	ET.02 16.2.94
Nominal supply	12.00	-8.00	326.00	-15.00	4.03	W	ET.02 16.2.94
High supply	12.60	-8.40	327.00	-15.00	4.25	W	ET.02 16.2.94
RAU - B; Locked Mode							
Low supply	11.40	-7.60	335.00	-15.00	3.93	W	ET.02 16.2.94
Nominal supply	12.00	-8.00	337.00	-15.00	4.16	W	ET.02 16.2.94
High supply	12.60	-8.40	339.00	-15.00	4.40	W	ET.02 16.2.94
TOTAL Power Consumption				Low	7.74	W	
				Nom.	8.19	W	
				High	8.65	W	

6 GROUND SUPPORT EQUIPMENT

6.1 Introduction

The Ground Support System comprises mainly Electrical Ground Support Equipment (EGSE) is used to simulate and verify the proper function of the HUYGENS radar altimeter. One of the most important validation requirements is to ensure that the Proximity Sensor radars will operate over the correct altitude range. Using the proposed EGSE the signal delay and attenuation from the probe to TITAN surface and return can be simulated electrically. Also, altitude data, output by the Proximity Sensor, can be displayed and validated by comparison with the known value of altitude being simulated by the EGSE.

Two different sets of Proximity Sensor EGSE are proposed. Their functions are determined by their requirements for use within the programme phases. The Factory Acceptance EGSE (FA-EGSE) is required to fully validate the proper function of the different models of the Proximity Sensor radars, within house, prior to delivery . The Link Simulation EGSE (LS-EGSE) is a deliverable item to be used by the customer. It enables the realisation of a limited subset of acceptance tests at the higher integration levels after proximity sensor delivery. Two FA- EGSE and two LS-EGSEs will be built, to test both redundant halves of the proximity sensor (15.8/15.4 GHz).

6.2 Link Simulation EGSE (LS-EGSE)

6.2.1 Operational Description

6.2.1.1 Configuration

The full configuration of EACH Redundancy LS-EGSE is shown in Figure.6.2.1.1-1 and will include the following items:

Transmit Antenna Cap
- supplied permanently mated with the Proximity Sensor radar transmit antenna.

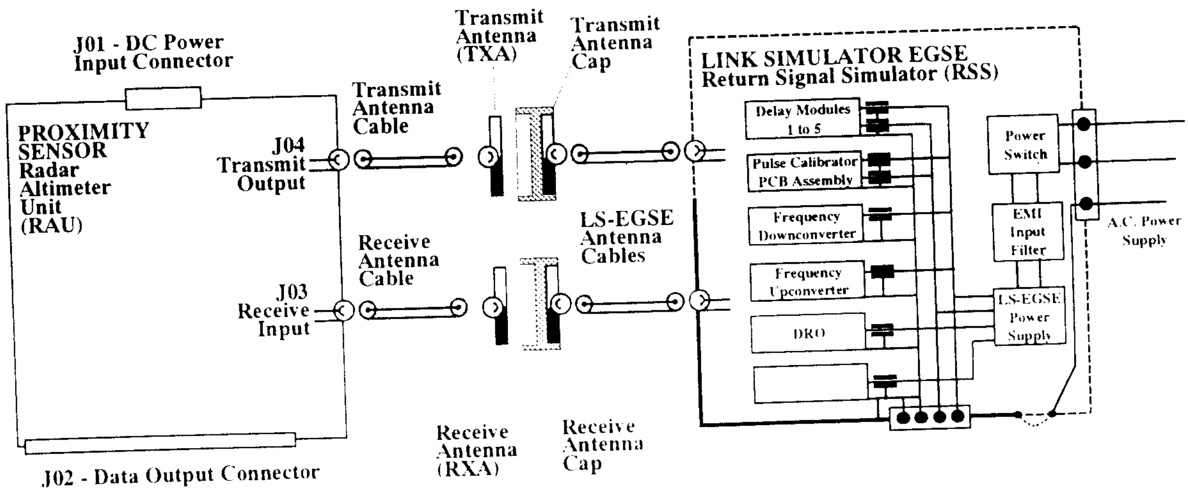
Transmit LS-EGSE cable
LS-EGSE Return Signal Simulator
Receive LS-EGSE cable
Receive Antenna Cap
- supplied permanently mated with the Proximity Sensor radar transmit antenna.

Mains Supply Cable

6.2.1.2 Operation

The LS-EGSE can be connected to each Proximity Sensor radar during all stages of integration, where the antennas are accessible and not covered by other probe structures. Switch selectable delays and attenuations can be used simulate different altitudes and propagation path conditions. The unit is not computer controlled and may simply be adjusted manually. The data output by each Proximity Sensor radar may be collected by each CDMU and the corresponding numerical value of altitude reported, compared with the LS-

Figure.6.2.1.1-1
Proximity Sensor Radar Altimeter
LS-EGSE Ground Test Configuration



6.2.2 Functional Description

The LS-EGSE operates as a radar Return Signal Simulator (RSS). The functional block diagram of an LS-EGSE RSS is presented in the Figure 6.2.2-1. The transmit signal from each Proximity Sensor radar is received by the LS-EGSE where it is down-converted to an IF frequency (250 MHz). The radar transmitted signal can also be monitored for performance tests and calibration via a test coupler output prior to frequency conversion.

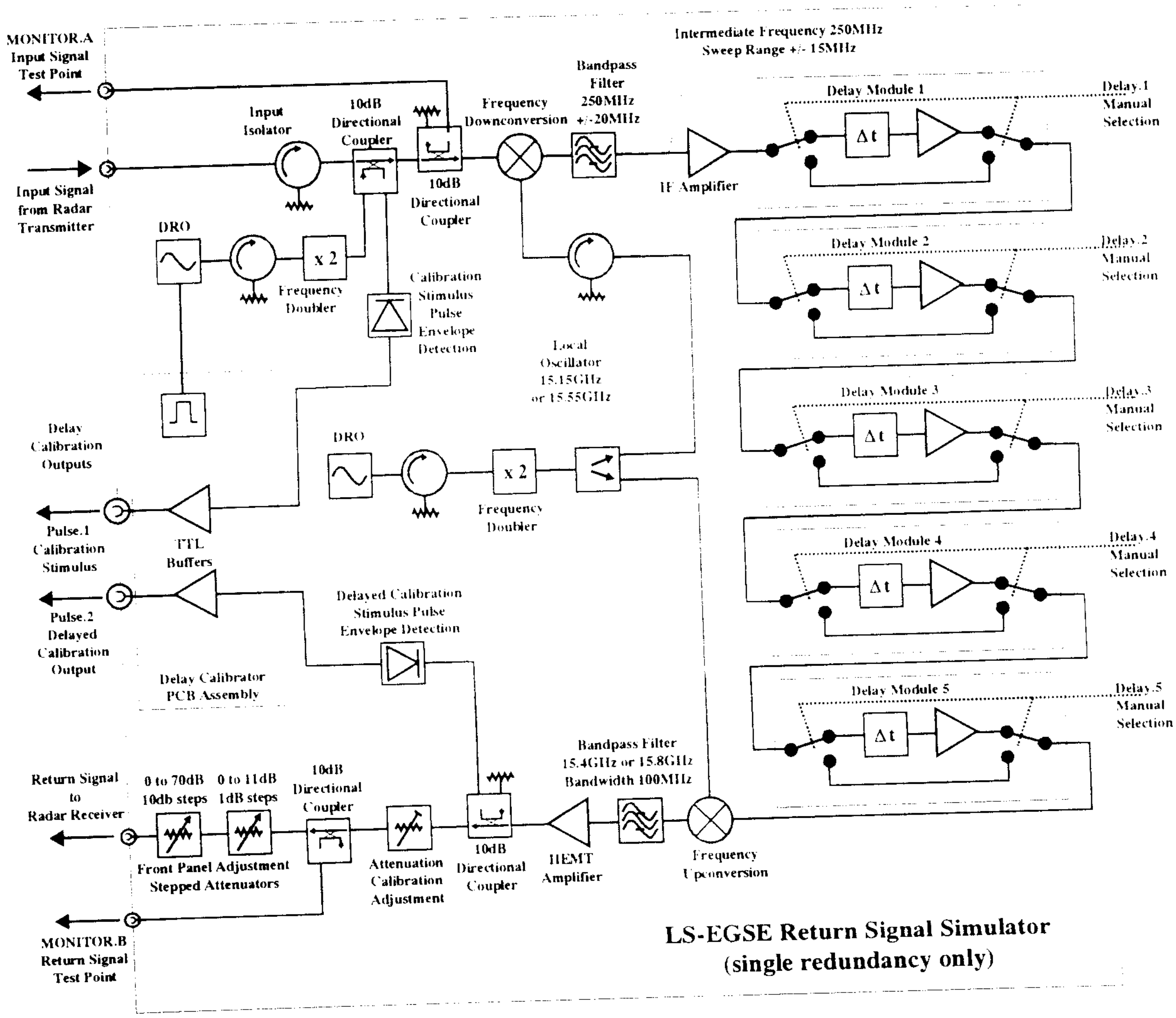
The frequency down-converted signal is then delayed using a switch selectable bank of active delay modules. The heart of each of these delay modules is a surface acoustic wave (SAW) delay line. These modules include IF amplifiers to compensate for the attenuation of the delay lines, which is dependant upon the value of the delay.

After delaying the signal it is re-converted to the radar receive frequency. This delayed and up-converted signal can be monitored via a test coupler output, prior to the setting of its' final output level and output to the radar receiver.

Manually operated, step attenuators are used, in conjunction with the fixed attenuation of the conversion/delay circuits, to simulate the attenuation of the signal path from the probe to TITAN surface and back.

Coupling to the Proximity Sensor radar is performed by the use of Antenna Caps. These are copies of the radar transmit and receive antennas, mounted in absorbing cases and which can then be fixed over the Proximity Sensor antennas, forming a calibrated RF coupling system between radar and RSS.

Figure.6.2.2-1 Proximity Sensor Radar LS-EGSE Return Signal Simulator Functional Block Diagram



6.2.2.1 Transmit Antenna Coupling and Cables

Several methods of achieving a suitable RF connection to the Proximity Sensor were proposed in the initial programme phases. The main alternative would have been to use permanent test couplers. These would exclude the antennas from the validation path as well as introducing mass, accommodation and power penalties. Consequently the antenna cap approach was adopted. The use of antenna caps does not provide a truly representative interface to the Proximity Sensor radars but does keep the antennas in the validation path, which can be then calibrated.

Each antenna cap consists of a copy of the radar transmit and receive antennas (which are identical). They are mounted in an absorbing cases, the few centimetres between the active faces of the Proximity Sensor and EGSE antennas being also filled with absorbing material. This is not intended to simulate the full propagation attenuation but will reduce the antenna beam distortion, due to the antenna load being non-representative of free space. The attenuation needed between Proximity Sensor and EGSE antennas, to reduce antenna beam distortion is about 20dB. This amount of attenuation is also needed to drop the signal amplitude to the level low enough for the input of the down-converter. The absorbing material is glued to the surface of the EGSE antenna which then forms an integral part of the antenna cap. The whole antenna cap may be then attached to the antenna of the probe by non-galvanic means.

The EGSE RF cables between the antenna caps and the LS-EGSE (both transmit and receive paths) are SUCOFLEX cables of 2m long. It is intended that this will allow the LS-EGSE to be situated conveniently close to the HUYGENS probe during integration. Their attenuation has been measured as approximately 2.0dB. This is accommodated in the overall EGSE calibration and higher values, i.e.; longer cables are not recommended. Longer cables will require an additional calibration exercise and if very long may make the RSS amplitude operating point and thus the simulated attenuation non-representative.

Ferrite isolators are used within the LS-EGSE, to reduce any effects of poor standing wave ratios of these cables and also to reduce the direct reflection from the EGSE receiver antenna to the receiver antenna of the probe.

6.2.2.2 LS-EGSE Input Circuitry

The LS-EGSE transmit signal input port, ferrite junction isolator, as shown in Figure 6.2.2-1, has 30dB of isolation and about 0.5dB of attenuation. The first directional coupler is used to inject an rf-pulse for RSS delay time calibration purposes. It is a stripline coupler designed for 12-18GHz bandwidth. The coupling factor is about 10dB and the main path attenuation about 0.5dB.

A second and similar coupler is also included, having a 10dB coupling factor in the 12 -18GHz frequency band. It is used to provide an test output signal, to monitor the radar transmit signal.

6.2.2.3 Transmit Signal, Frequency Down-converter

The transmit signal down-converter provides a reduction of the input radar transmit signal to an intermediate frequency, centred at 250MHz. The radar transmit signal will be centred at either 15.4GHz or 15.8GHz (dependant upon redundancy) and thus the chosen Local Oscillator frequency will be either 15.15GHz or 15.55GHz. During normal "locked" mode radar operation the transmit signal is swept +/-15Mhz about the nominal centre frequency and thus the IF signal will also sweep between 235MHz and 265MHz.

This down-converter is a balanced mixer which is biased to operate with large signals. It is a rat-race structure using Hewlett Packard, 5082-2774 stripline Schottky diodes, which are biased with 1.3mA to operate in this large signal condition. About 7dBm of local oscillator power is needed to drive the diodes. RF/IF (conversion loss) attenuation is approximately 7dB and RF/LO isolation 25dB. An isolator is used in the local oscillator port to prevent the relatively high power, RF input signal coupling to LS-EGSE output (to the radar receiver) via the common local oscillator circuits. It is also provides a constant match to the local oscillator port.

The mixing process will provide first order products at 250MHz and above 30GHz. This 30GHz signal is not likely to be propagated further in the LS-EGSE circuit. However, some higher order mixing products and particularly those products due to the modulation sweep components may be propagated through the IF sections. Thus a band-pass filter is included after the down-converter to filter out these unwanted mixing products. The filter centre frequency is 250 MHz and bandwidth 40 MHz. It is a two-stage elliptical filter using lumped components, providing an attenuation of 1.5dB.

6.2.2.4 The Local Oscillator

The local oscillator is a dielectric stabilised FET-oscillator using a Fujitsu FLK022WG FET as the active component. The oscillator design is basically the same as used in the Dielectric Resonant Oscillator (DRO) of the Proximity Sensor radars but without the varactor tuning circuit being included. The output power of this DRO is nominally 16dBm and frequency 7.775/7.575 GHz.

This local oscillator DRO is followed by an isolator and a multiplier. The junction isolator, with a floating match, is also the same design as used in the DRO of the Proximity Sensor radars. It is used to match the output of the DRO and the input of a subsequent frequency multiplier. The attenuation of the isolator is about 0.5dB.

The multiplier structure is also basically the same as used in the Proximity Sensor radar, however, the multiplier diode used is MA/COM´s MA48701E SRD-diode. The multiplier is a waveguide type structure with a coaxial low pass filter as an input stage. The bias to the multiplier (nominally +2V) is fed from the DRO via an electrical connection through the isolator. The attenuation of the multiplier is nominally 5dB.

The multiplier is followed by a "Wilkinson" power divider which divides the DRO local oscillator output power, to supply the LO input to both the down-conversion and up-conversion mixers. The attenuation of the divider is about 4dB. A nominal value of 6-7dBm of local oscillator power is thus available to drive the diodes of the up and down-converter mixers.

6.2.2.5 The Signal Delay Unit

The signal delay modules are also shown in the Figure.6.2.2-1. Their common circuit schematic is shown in the Figure.6.2.2.5-1. Each delay line module is implemented in a separate sheet metal-box with all necessary amplifiers, switches and the SAW delay device. Using two SPDT switches in the input and output of the delay circuit, enables the delay to be switched into, or out of, the overall circuit, with a common TTL control signal. When the module selection TTL control signal is in the "off" status, the IF radar signal bypasses the delay circuits using an on-board RG 178U coaxial cable. When the TTL control signal is in the "on" status, the IF radar signal is delayed by the internal SAW delay unit. Several of these modules may be serially connected and by selecting the individual delay module status the required delay time can be selected.

The delay lines are non dispersive surface acoustic wave (SAW) delay lines packaged in manufacture's own cases which are soldered to the PCB board of the delay unit. The delay is based on the low velocity of the acoustic waves in the crystalline structure of the delay material (LiNb). The manufacturer of the delay lines is Andersen Laboratories. The centre frequency of the delay lines is 250 MHz and the bandwidth is 40 MHz.

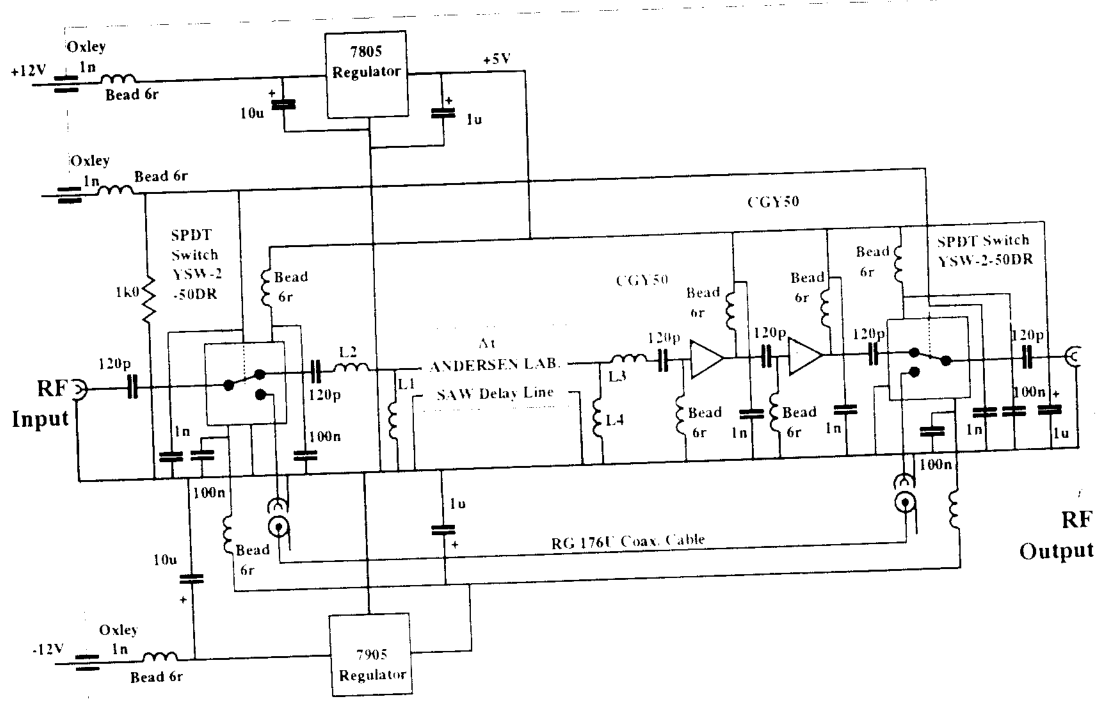


Figure.6.2.2.5-1 Proximity Sensor radar, LS-EGSE Return Signal Simulator, Signal Delay Module Circuit Diagram.

The attenuation of the longest delay lines is 23dB (max). These delay line SAW devices require a matching circuit in front of, and after, the delay case connections. The values of those discrete components is determined during prototype assembly, being matched to the individual SAW delay component.

The delay amplifier is a two-stage amplifier using Siemens CGY-50 MMICs. The gain of the amplifier is nominally 21dB and is designed to compensate for the loss introduced by the SAW delay line devices. Each CGY-50 is internally matched and no further matching is required, before or after the integrated circuit package. It is only required to provide a 50ohm microstrip line input and output.

The delay selection switches are "Mini Circuit" type YSW-2-50DR SPDT. These are specified up to 5 GHz, with a very fast (3 ns) switching response and isolation of approximately 50 dB (at 250MHz). The "on" status attenuation of a single switch is nominally 1dB.

It is required that the two redundant LS-EGSE's provide different delays. These are specified as being required to simulate an altitude difference of 15%. The minimum range requirement (150 metres) is simulated by a dedicated 1.0uS delay. The maximum range requirement is simulated by cascading four other delays. The combinations of delay line timing, switch selection data and the nominal simulated altitudes are shown in tables.6.2.2.5-1 and 6.2.2.5-2.

Table.6.2.2.5-1 LS-EGSE Redundancy A, Delay Selection

Switch Selection Status					Delay Total uSecs.	Simulated Altitude metres
S1 (1uS)	S2 (6.67uS)	S3 (20uS)	S4 (20uS)	S5 (20uS)		
on	off	off	off	off	1.00	150
off	on	off	off	off	6.67	1,000
off	off	on	off	off	20.00	3,000
off	on	on	off	off	26.67	4,000
off	off	on	on	off	40.00	6,000
off	on	on	on	off	46.67	7,000
off	off	on	on	on	60.00	9,000
off	on	on	on	on	66.67	10,000

Table.6.2.2.5-2 LS-EGSE Redundancy B, Delay Selection

Switch Selection Status					Delay Total uSecs.	Simulated Altitude metres
S1 (1.15uS)	S2 (5.67uS)	S3 (17uS)	S4 (17uS)	S5 (17uS)		
on	off	off	off	off	1.15	172.5
off	on	off	off	off	5.67	850.0
off	off	on	off	off	17.00	2,550
off	on	on	off	off	22.67	3,400
off	off	on	on	off	34.00	5,100
off	on	on	on	off	39.67	5,900
off	off	on	on	on	51.00	7,650
off	on	on	on	on	56.67	8,500

6.2.2.6 The Return Signal Up-converter

After being delayed, the IF signal is mixed with the original RSS local oscillator to restore the signal centre frequency to that required for stimulus of the Proximity Sensor radar receiver. The mixer design is identical to the down-converter, with IF to RF attenuation nominally 7dB and LO RF isolation better than 25dB. The same bias point is the set, an IF power of about 0 dBm driving the up-converter at a saturation level minimising amplitude ripple on the delayed IF signal.

A band-pass filter is used after the up-converter to reject the unwanted mixing products. The first order being expected at 14.9GHz (or 15.3GHz) with the local oscillator signal break through being at 15.15GHz (or 15.55GHz). The filter is designed as a 5-stage DR filter, with nominal in-band attenuation of 2dB and bandwidth 80 MHz.

6.2.2.7 The Return Signal Output Circuit

A HEMT amplifier is included after the up-converter and filter to provide a sufficient signal level to drive the calibration system detector circuitry (see next section). A Siemens CFY65-12 HEMT is used, providing a nominal gain of 10dB.

This amplifier is followed by two 10dB directional couplers, identical to those used in the transmit signal input circuit. These enable accurate samples of the delayed receiver stimulus to be directed to the delay calibration circuit and also output to a test connector for external measurements purposes.

The signal returned to the Proximity Sensor radar receiver must be adjustable in amplitude, to simulate various radar propagation path attenuations. This is achieved by the inclusion of two step attenuators. These enable the basic attenuation of the signal path, from the transmitter output and including cables, antennas and caps and the remainder of the LS-EGSE, to be increased in a controlled manner. They provide 0 to 70dB in 10dB steps and 0 to 11dB in 1dB steps, respectively.

As mentioned, these attenuators are provided to simulate the expected attenuation of the operational altitude and also to determine the maximum attenuation which can be supported by the operating radar, thus enabling the verification of the operational range margin.

6.2.3 LS-EGSE Attenuation Calibration

6.2.3.1 Basic RSS Attenuation Calibration

In order to simulate the signal path attenuation from the Proximity Sensor radar to TITAN surface and return, the losses of the LS-EGSE have to be measured for all delay line combinations used (see tables 6.2.2.5-1 and 6.2.2.5-2). During this loss measurement the step attenuators are set to zero and the total basic system attenuation is measured. These losses are measured from the radar altimeter unit (RAU), transmitter output to the RAU, receiver input and may be designated as - L_{rss_tot}.

This circuit path includes the co-axial cables from the RAU to the antennas, the antennas themselves (fitted with the antenna caps) and the coaxial cables from the antenna caps to the LS-EGSE RSS as well as the RSS attenuation. The attenuation of the antenna and antenna cap combination is known to vary by a small, but significant amount after each demating and re-mating. This is unavoidable and cannot be compensated by any other means than the repeat of this overall calibration.

OPERATIONAL CONSTRAINT NOTE:
Thus the following LS-EGSE operational constraint is defined and should be observed, unless recalibration is intended. The antennas and their caps should NOT be demated after this calibration exercise, which is performed at the manufacturing facility. They are delivered as mated pairs and shall be integrated to the probe as such, without separation.

6.2.3.2 Cable Attenuation Compensation

Due to practical reasons, the semi-rigid coaxial cables, connecting the RAU to the antennas, as fitted to the probe, are not used during this calibration. Instead they will be replaced by longer and more flexible cables. The attenuation of these "test antenna cables" will also be measured during the factory acceptance calibration and supplied as part of the calibration data package. These attenuation values will be designated as - L_{tx_test} and L_{rx_test}.

The attenuation of the actual cables to be integrated to the probe will also be measured prior to delivery. These will be designated L_{tx_ant} and L_{rx_ant}.

To enable this minor difference of configuration to be compensated the following re-calculation of the overall attenuation (L_{rss_tot}) will be performed after probe integration of the Proximity Sensor. The new value of the overall attenuation to be used during validation shall then be:

$$new.L_{rss\_tot} = old.L_{rss\_tot} - (L_{tx\_test} + L_{rx\_test}) + (L_{tx\_ant} + L_{rx\_ant})$$

These losses are measured using a CW signal for the minimum, maximum and the middle value of the transmitted RF frequency range and a mean value is calculated. A present co-axial Attenuator is then used to adjust the signal level in the output circuit of EGSE to the desired value.

6.2.3.3 Adjustable Attenuation Calibration

The LS-EGSE, RSS adjustable step attenuators are measured as separate units during LS-EGSE assembly. They are regarded as highly stable units and are not re-calibrated unless unusual or anomalous results indicated that they are suspect. Their measured attenuation values are supplied with the acceptance data package.

6.2.3.4 Monitor Point Calibration

To measure the probe output signal characteristics (mean/peak power) the loss from the probe transmitter output to Monitor A (Figure 6.2.1-1) has to be measured. This loss is calibrated, using a vector network analyser the Attenuator values and delay combinations being ignored. When mean/peak power is measured via the Monitor A the calibrated loss is added to the measured value.

6.2.4 Delay Calibration

The actual delay time corresponding to the delay line combination used, (see tables 6.2.2.5-1 and 6.2.2.5-2) is calibrated using an internally generated pulsed rf-signal, without connection to the Proximity Sensor radar. This is internally signal is injected to the down-converter via an internal coupler. This simulated transmitted RF pulse is also AM detected at the point of injection. The resultant delayed pulse is also detected at immediately prior to the output return path to the Proximity Sensor radar receiver.

Both detected pulses are fed to squaring circuits, which provide TTL compatible output at BNC front panel calibration connector of the LS-EGSE, RSS. The time difference between these two pulses is entirely due to the delays of the LS-EGSE, RSS. Thus their relative delay may be measured using accurate laboratory test equipment (interval counter) and the delay value used as an accurate measurement of the RSS delay setting.

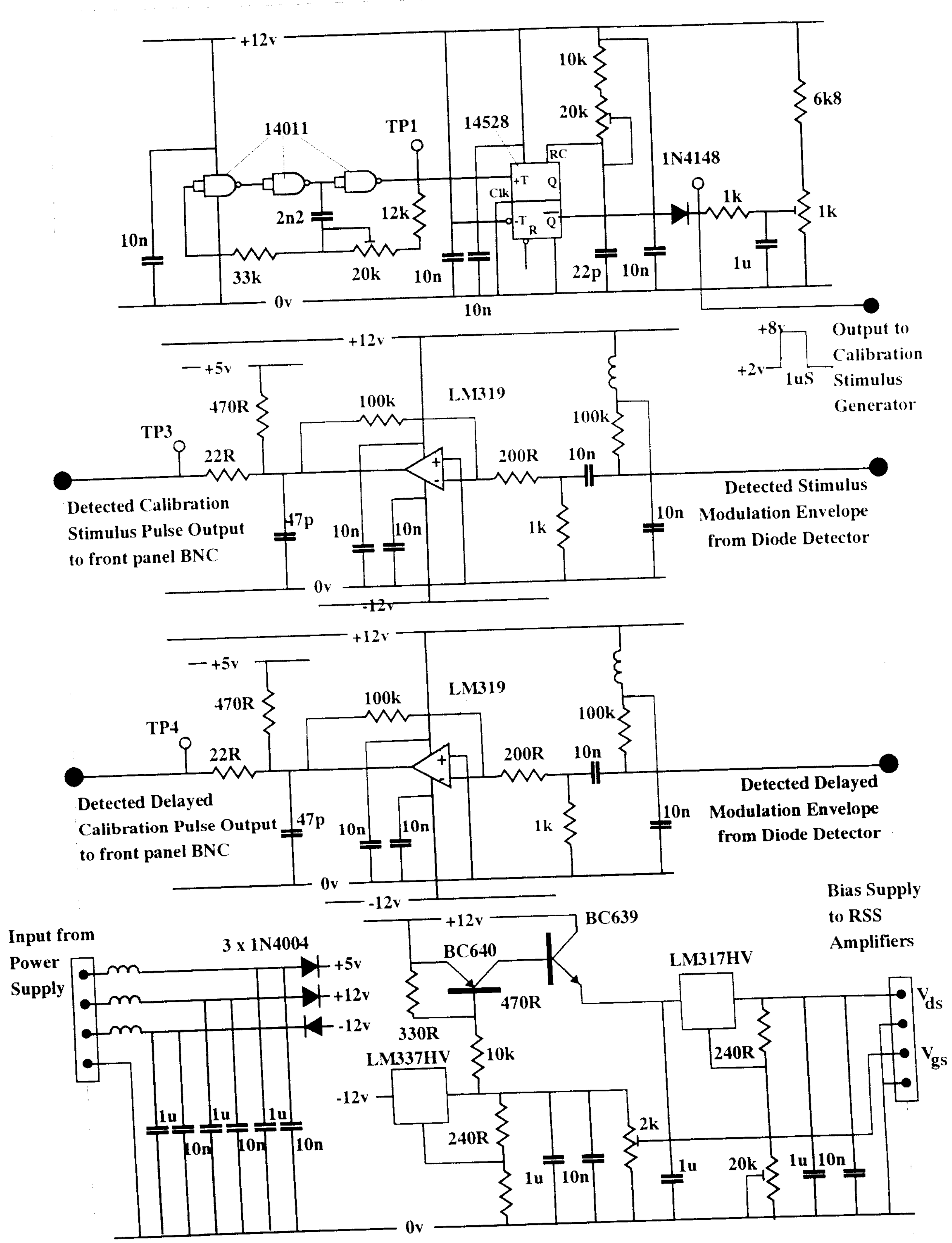


Figure.6.2.4-1 Proximity Sensor Radar, LS-EGSE Return Signal Simulator Delay Calibrator PCB Assembly Circuit Diagram

The electronics for the internal calibration pulse generator, diode detector squaring and the bias supplies for the various RSS amplifiers is implemented on a single PCB, whose circuit diagram is shown Figure 6.2.4-1. The internally generated delay calibration pulse duration is 1us and the frequency is nominally 10kHz. These values are not calibrated since only the relative timing between the edges of the two pulses (stimulus and delayed) are of interest.

The amplitude of the stimulus pulse is switched from +2V to +8V. It is fed to the frequency multiplier bias where it effectively switches the stimulus signal on and off, with a nominal ratio of 30dB. The DRO-isolator-multiplier chain is identical to that used for the local oscillator, the centre frequency being tuned to the radar operational centre frequency, 15.8/15.4 GHz. The diode detectors used are Hewlett Packard, type 5082-2774 schottky devices.

6.2.5 Interface Definition

6.2.5.1 Mechanical Construction and Interfaces

Each LS-EGSE Return Signal Simulator and its power supply unit are assembled in a commercial rf-shielded modular case manufactured by Knurr. The case dimensions are 400.7x448x132.5 mm. The front panel drawing of the case showing connectors is presented in the Figure 6.2.5.1-1.

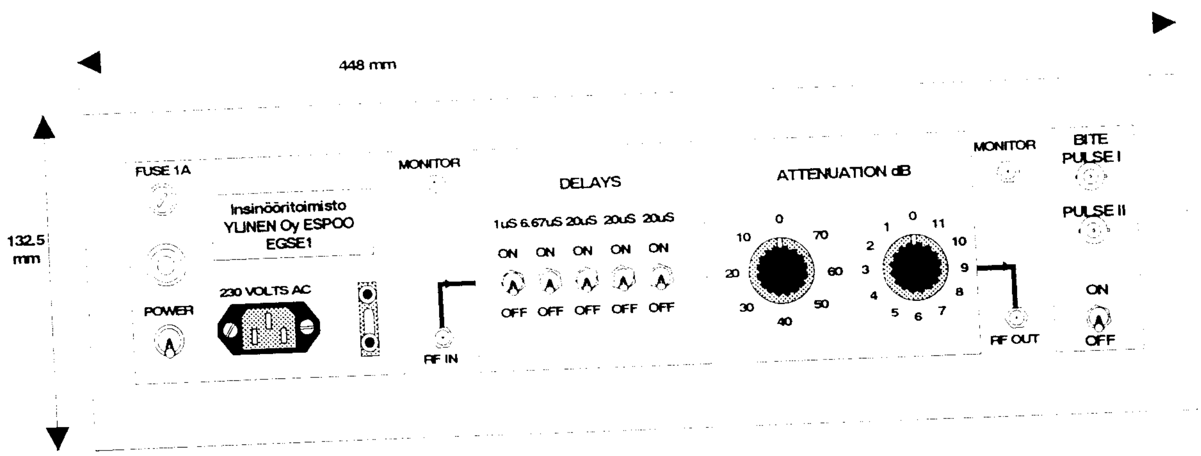


Figure.6.2.5.1-1 Proximity Sensor Radar Link Simulator EGSE Front Panel

6.2.5.2 Power Supply and Grounding System

The LS-EGSE power supply and grounding system is presented in the Figure 6.2.5.2-1. It consists of a power switch, a 1A fuse, a line filter (Schaffner FN 52-1.5/2) and a toroidal isolating transformer (2 x 15V/1.25A). The isolated secondary outputs are rectified by two rectifiers (VARO VS 247) and linear regulators then provide -12V, +5V, +8V and +12V for the LS-EGSE RSS circuits.

The complete LS-EGSE RSS is constructed within an RFI shielded equipment case. The power receptacle, switch, fuse, pilot light and line filter are all enclosed within a separate shielded assembled mounted internally, directly on the rear of the front panel, providing an emissions. The toroidal transformer and the rectifier bridges are assembled internally, to the rear case wall together with the electronics PCB which is grounded at one point only, to the case. All microwave components are mounted on the chassis. The delay switches are mounted to the front panel.

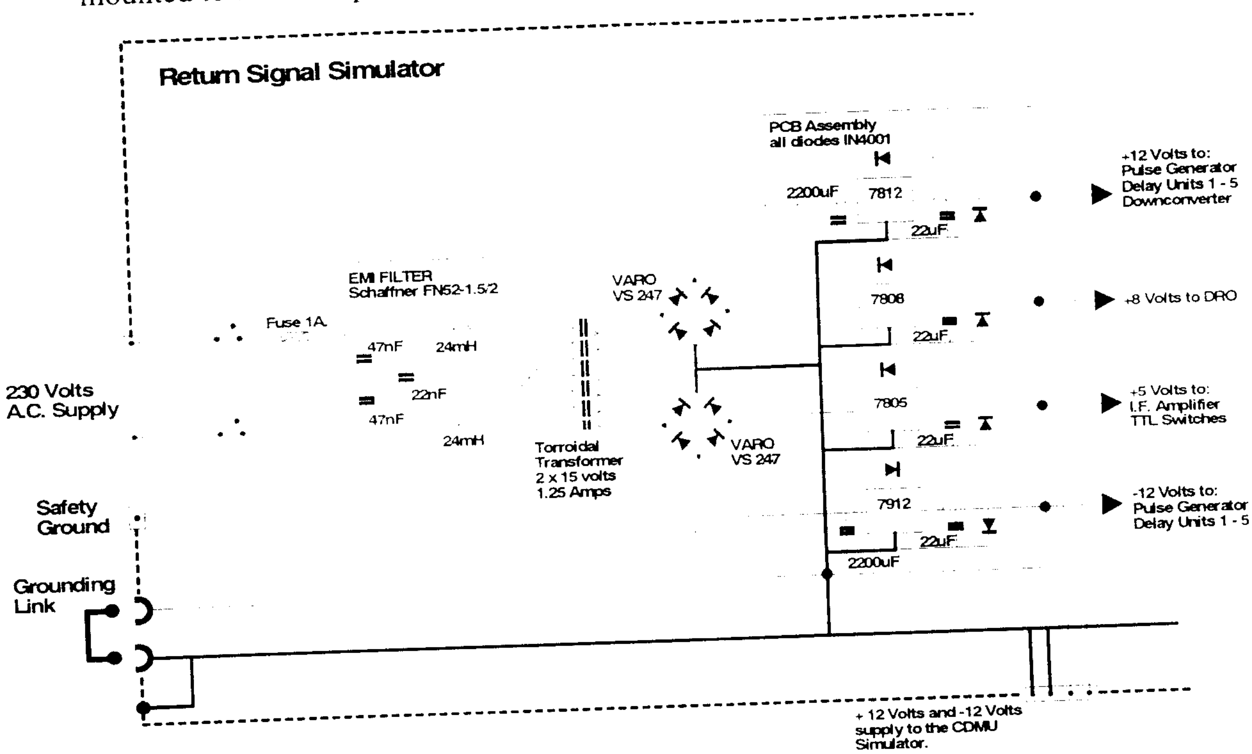


Figure.6.2.5.2-1 Proximity Sensor Radar
LS-EGSE Return Signal Simulator Power Supply Unit.

The grounding jumper is available for separation of the ac power supply safety earth from the enclosure and RF earth. This link should be in place for single redundancy Proximity Sensor radar testing, where there is no other "clean" test facility grounding point. As shown in Figure.6.2.5.2-2, it is recommended that when there is a specific integration facility "clean earth" both Proximity Sensors and LS-EGSEs should be star connected and the LS-EGSE grounding link removed. This is to avoid a direct connection from the integration facility "clean earth" to the external supply earth and the possibility of circulating earth interference currents.

NOTE: This is a RECOMMENDATION ONLY and should be addressed by the site responsible EMC and Safety Officers. NO RESPONSIBILITY IS ACCEPTED BY YLINEN ELECTRONICS FOR OPERATION WITHOUT THESE GROUNDING LINKS.

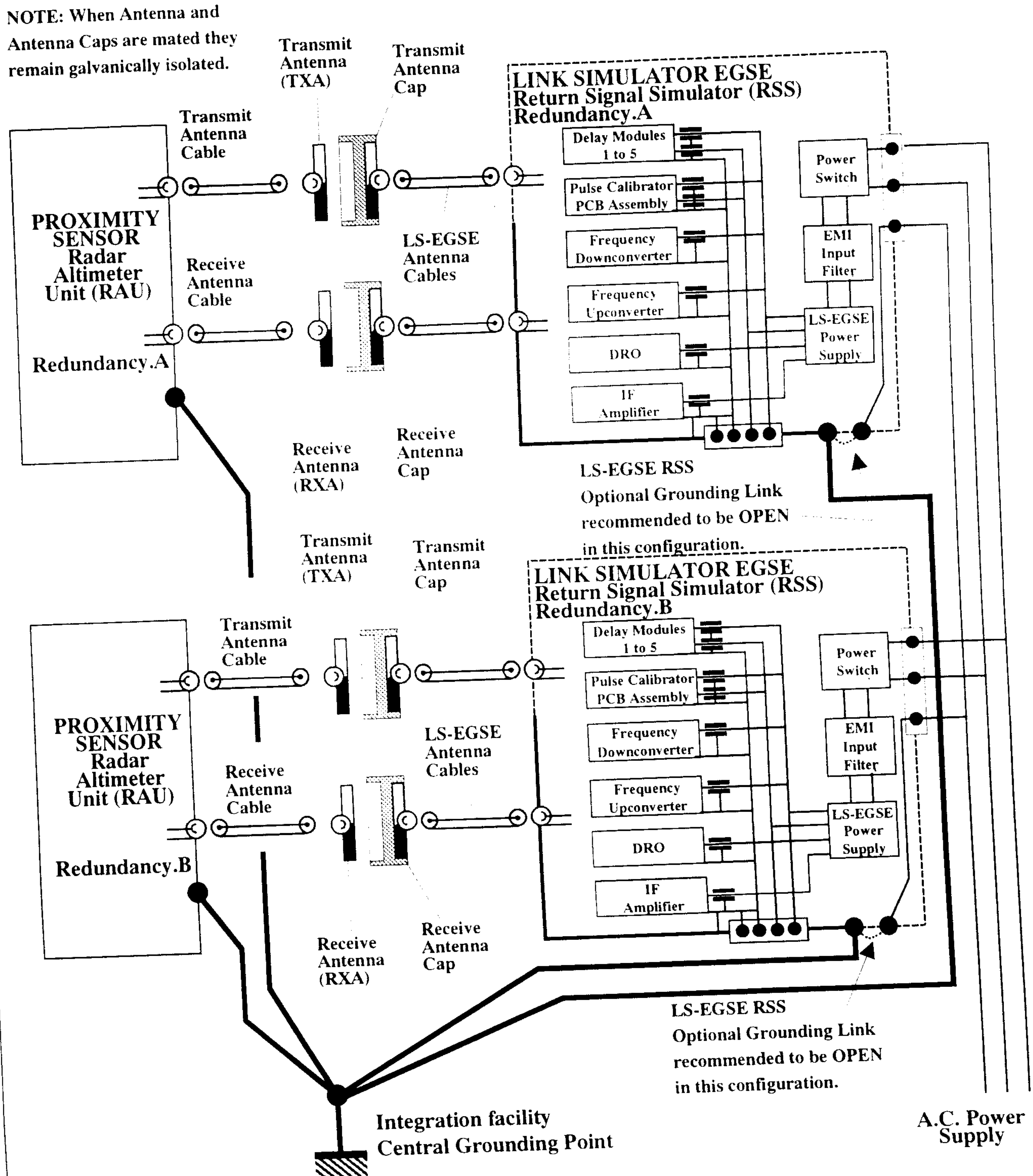


Figure.6.2.5.2-2 Proximity Sensor Radar Probe Level Test Configuration

6.3 Factory Acceptance EGSE (FA-EGSE)

6.3.1 Operational Description

6.3.1.1 Configuration

The full configuration of EACH Redundancy of the FA-EGSE is shown in Figure.6.3.1.1-1 and will include the following items:

- RF Assembly;
  - Transmit Antenna Cap
  - Transmit FA-EGSE cable
  - FA-EGSE Return Signal Simulator
  - Receive FA-EGSE
  - Receive Antenna Cap
  - FA-EGSE Mains Supply Cable
- Data Assembly;
  - CDMU Simulator
  - RAU Data Cable and Break-out-Box
  - CDMU Power Supply Cable
- Power Supply Assembly;
  - Laboratory Linear Power Supplies
  - RAU Power Supply Cable including LISN/Break-out-Box

6.3.1.2 Operation

The FA-EGSE is used with each Proximity Sensor radar during test stages leading up to and including factory acceptance, prior to delivery. The main element of the FA-EGSE is a Return Signal Simulator, similar to the LS-EGSE RSS but with the single exception that it requires an external local oscillator input signal.

In addition to the RSS the FA-EGSE also provides dc power, from standard laboratory, linear regulated power supplies. The dc supply to the RAU is conveyed by a combined Line Impedance Simulation Network (LISN) and Break-out-Box (B-o-B), which provides a simulation of the CDMS power supply impedance and enables direct stimulus and measurements of this power interface.

Also the CDMU Simulator provides the necessary stimulus to operate the Serial Digital data output interface, extract the digital altitude data and display this directly to the test operator. The CDMU Simulator also provides outputs derived from the IF analogue, AGC analogue and Ramp Sync. digital interfaces. A Break-out-Box is also included to enable direct test connection and monitoring of the serial digital interface.

None of the FA-EGSE units are computer controlled, all being simply adjusted manually. The Proximity Sensor data output is displayed by the CDMU Simulator directly as an altitude and may be compared with the FA-EGSE RSS settings to validate the correct altitude measurement function.

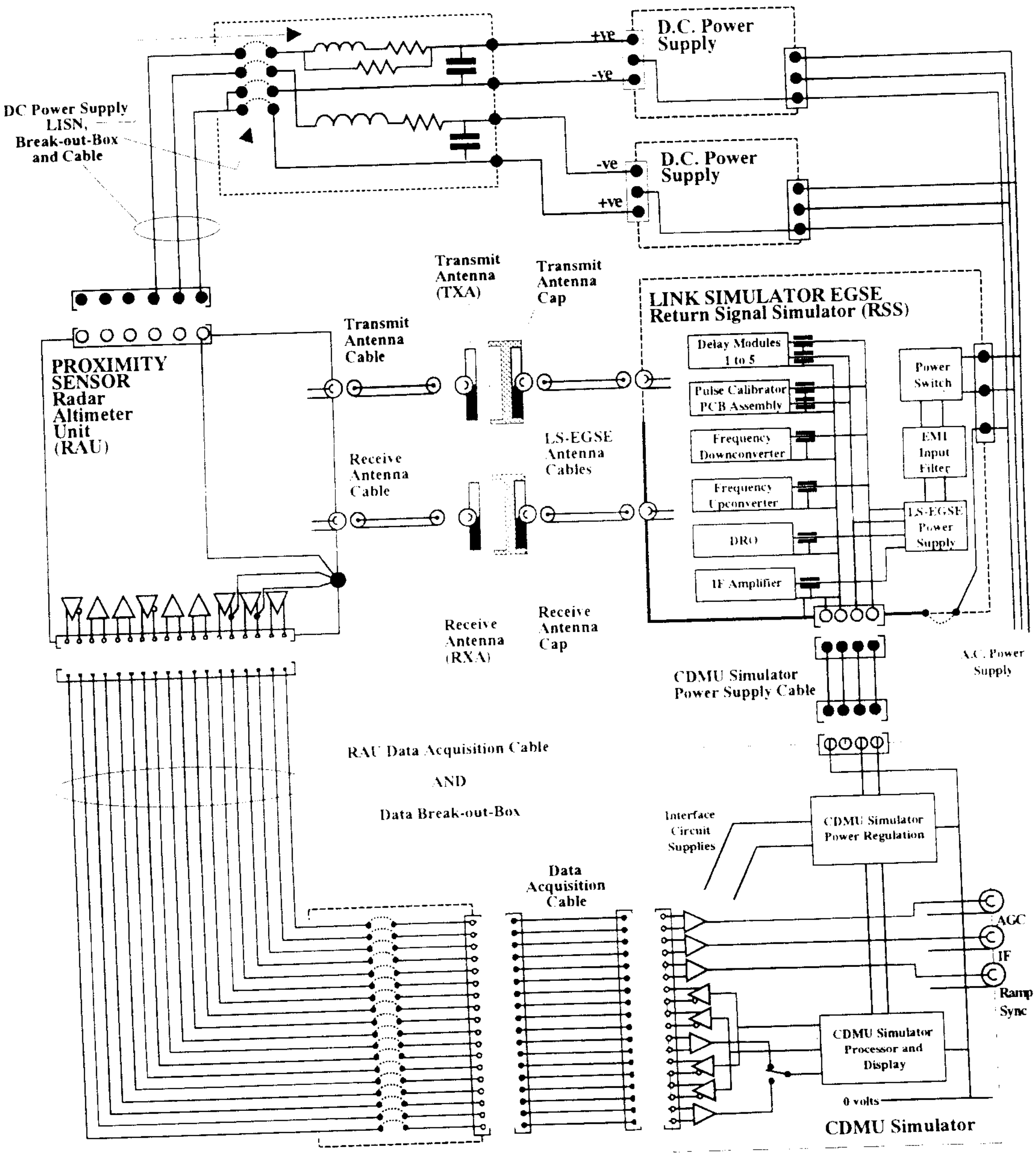


Figure.6.3.1.1-1 Proximity Sensor Radar, FA-EGSE Test Configuration.

6.3.2 Functional Description

The FA-EGSE RSS is similar to the LS-EGSE, with the single exception of requiring a separate local oscillator drive signal. The proposed external local oscillator is a Gigatronics signal generator Mod. 600. Like LS-EGSE, the FA-EGSE RSS delays and attenuates the proximity sensor radar transmit signal and used this as a stimulus to the proximity sensor radar receiver, simulating a nominal return target echo signal. Two RSS units are provided to test both redundant halves of the proximity sensor. Both FA-EGSE RSS use delay line-units with the same delay values.

The functional block diagram and circuit diagrams of the FA-EGSE RSS is not presented since the similarity with the LS-EGSE is sufficient that Figure.6.2.2-1 may be directly used. The functional description and the performance of these return signal simulator have also already been adequately described in sections 6.2.2 and are not further discussed

6.3.2.1 CDMU Simulator

The CDMU simulator provides a simulation of the CDMU interface. The simulator is presented in the Figure 6.3.2.1-1. The altitude data is displayed with 5-digit 7-segment display. Both of the redundant altitude data outputs, available from each Proximity Sensor radar, can be switched to be displayed. The lock/no-lock RAU operational mode is indicated with by "Lock/Search" LED. The "IF", "AGC" and "Ramp Sync" signals are available from BNC connectors of the simulator.

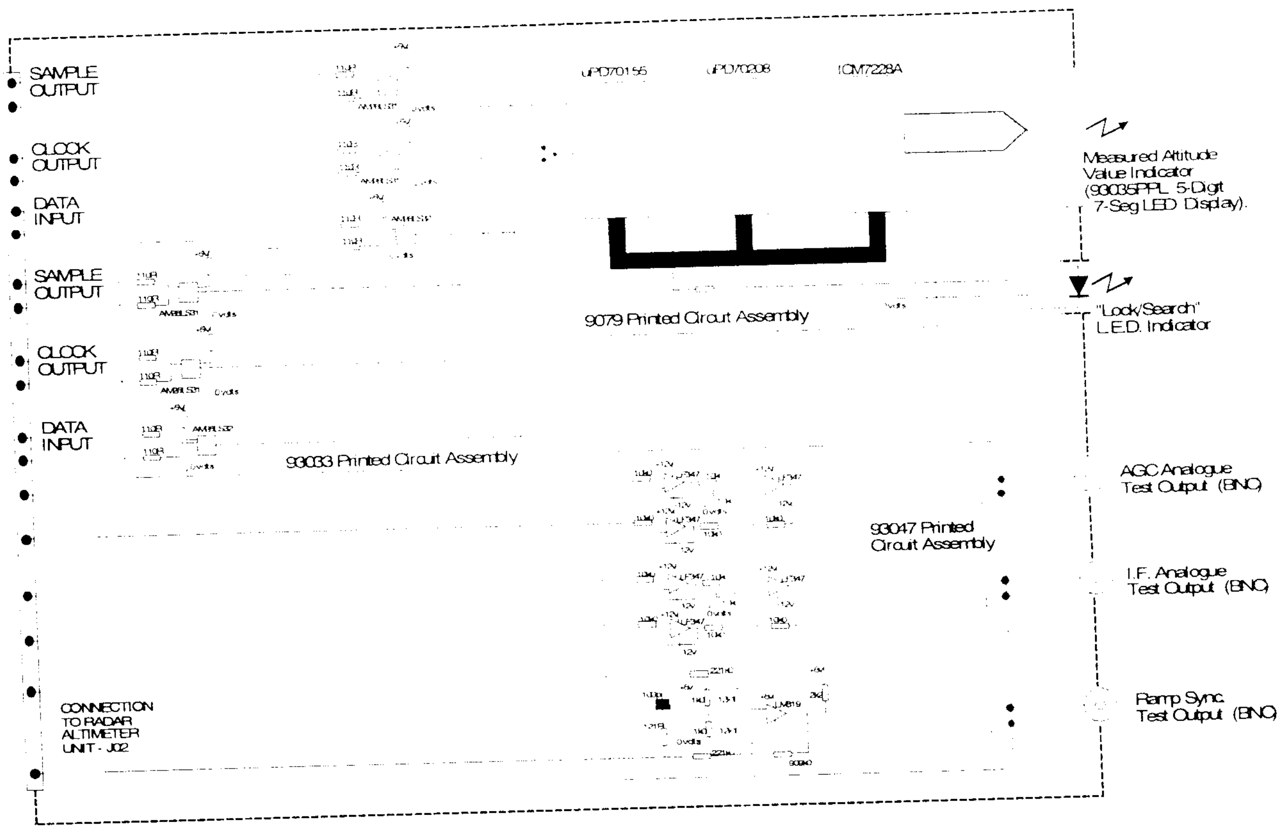


Figure.6.3.2.1-1 FA-EGSE CDMU Simulator, Functional Block Diagram.

6.3.3 Calibration

Calibration requirements are summarised as follows. It is emphasised that this is an explanatory summary only and that the full calibration definition will be defined and controlled by lower level validation documents.

6.3.3.1 Attenuation Calibration

The principle of the attenuation calibration is described in section.6.2.3, LS-EGSE Attenuation Calibration, which is valid due to the similarity between the FA and LS-EGSE RSS units.

The overall path attenuation will be checked on a regular basis, after six months periods or after at the start of each new programme validation phase (EM, QM, FM, etc). Calibration is performed using HP 8510C vector network analyser and/or a calibrated power sensor (HP 8485A) and a signal generator. The overall attenuation will be calibrated by this measurement for every delay line and combination. This shall be accomplished with the step attenuators set to zero. The step attenuators are then also calibrated separately at each of their set positions.

6.3.3.2 Delay Calibration

The principle of the delay calibration is described in the Internal Calibration System for the LS-EGSE (section 6.2.3.2). The counter used within house will be Fluke counter/timer model 1953A. The simulated delays are calibrated every six months using the Fluke counter.

The additional delay corresponding to the input and output circuit and antennas of the FA/LS-EGSE (not included to the internal delay calibration path) is assumed and calculated to be negligible. This assumption was tested during EM integration and significant (i.e., measurable) delay was not discovered.

6.3.4 Interface Definition

6.3.4.1 Mechanical Construction and Interfaces

The Return Signal Simulator of the FA-EGSE and its power supply unit are assembled in a commercial rf-shielded modular case, identical to the LS-EGSE RSS. Its dimensions are 400.7x448x132.5 mm (depth, width, height). The front panel drawing for the LS-EGSE (Figure 6.2.5.1-1) is valid for the RSS of the FA-EGSE with the exception of a LO-connector (SMA), which is located between the Monitor and the rf-out connectors.

The CDMU simulator is assembled in an Optibox commercial modular case. Its dimensions are 307x288x102 mm (depth, width, height). The CDMU Simulator power supply requirement -12Volts and, +12Volts dc, is provided by a separate output from the rear panel of the FA-EGSE RSS power supply unit.

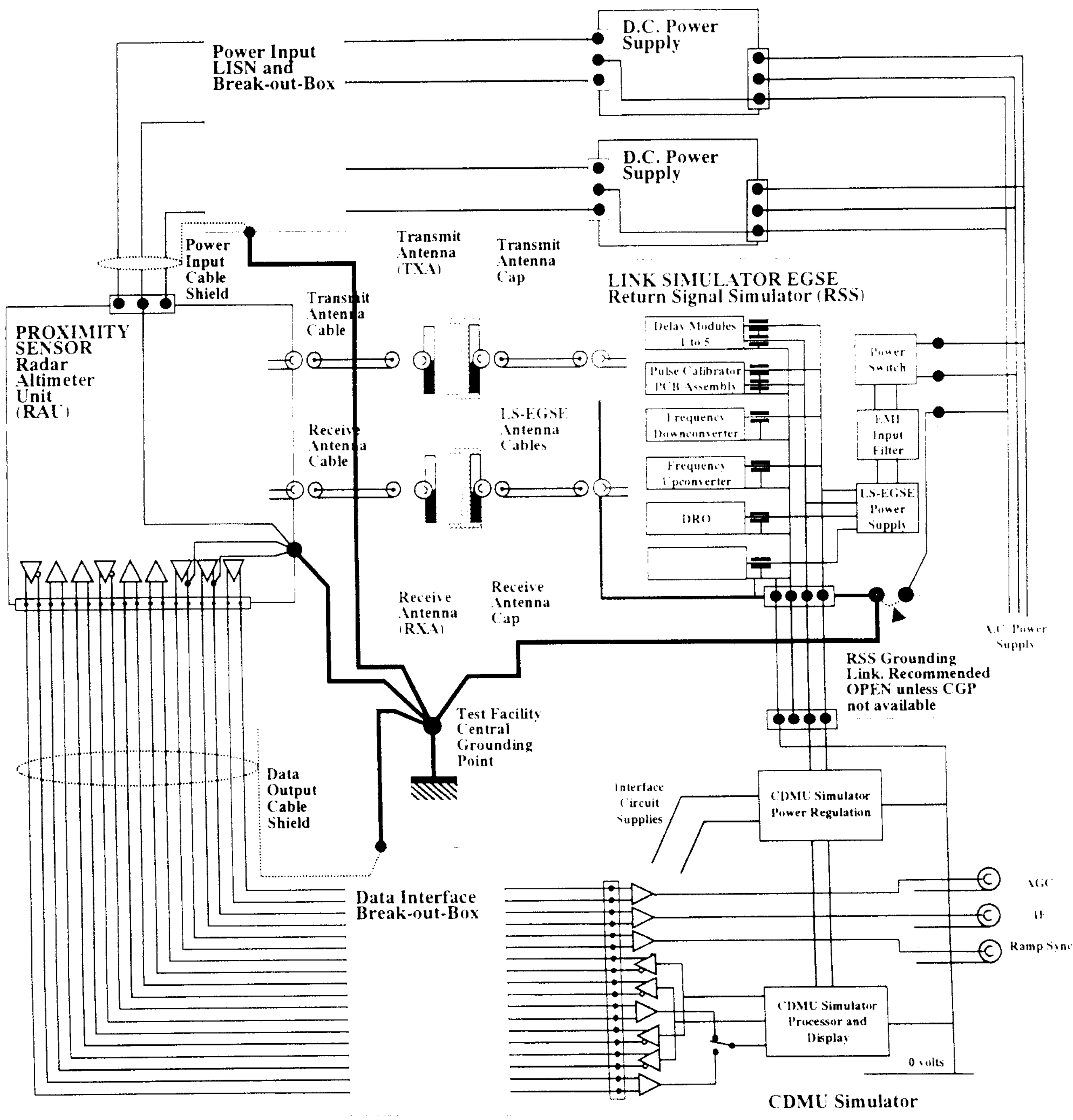


Figure.6.3.4.2-1 Proximity Sensor Radar, FA-EGSE Configuration and Grounding diagram.

6.3.4.2 Power Supply and Grounding System

The power supply and grounding system for the RSS of the FA-EGSE is presented in the Figure 6.3.4.2-1. This is valid for within house acceptance testing and is provided for information only.