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european space agency
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S+S/X bands coherent transponder specification

Prepared by:
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VALIDITY

This issue of the 'S + S/X bands coherent transponder specification' in the ESA PSS series supersedes any previous issues.

The previous issue of this document bore the title: 'ESA general specification for an S-band TTC and ranging transponder. Issue 1 ref TRF/2382/MW/pe, 23 June 1976'.

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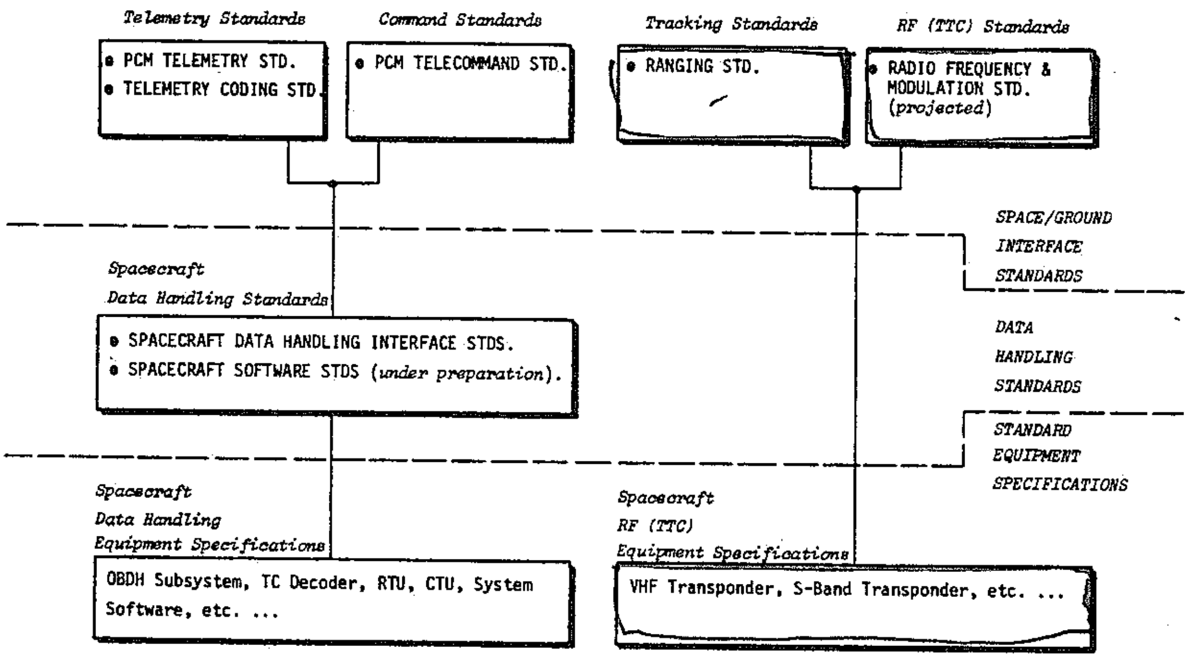
ABSTRACT

This design requirement standard is related to the Telemetry, Tracking, Command and Data Handling Standards of the European Space Agency. It represents one of the Standard Equipment Specifications. As such, it establishes and specifies an on-board transponder that will permit ESA spacecraft to communicate with and be tracked by ESA and NASA ground stations with maximum performance and safety.

ORGANISATION STRUCTURE

(April 1978)

This standard is a section of the Telemetry, Tracking, Command and Data-Handling Standards of ESA (ESA TTC & DH STDS), the organisational structure of which is shown diagrammatically below. It can be seen that, within this structure, the S + S/X Bands Coherent Transponder Specification represents one of the Standard Equipment Specifications (Level C).



CONTENTS

S AND S/X BANDS STANDARD TRANSPONDER SPECIFICATION

1. SCOPE

This specification describes a class of S and S/X Bands TTC and Ranging Transponders which will find increasing application on future ESA spacecraft. Since these spacecraft will impose different requirements on the transponder (frequencies, modulation schemes, etc.), it is essential to employ a modular construction allowing maximum flexibility and re-use of the same fundamental hardware in a succession of programmes, without major costs for modification. The transponder in its various versions shall be fully compatible with ESA and NASA ground networks.

2. APPLICABLE DOCUMENTS

PCM Telecommand Standard, ESA PSS-45(TTC.A.01) Issue 1.
PCM Telemetry Standard, ESA PSS-46(TTC.A.02) Issue 1.
Ranging Standard, ESA TTC.A.04, under revision.
Spacecraft data-handling Interface Standards, ESA PSS-47(TTC.B.01) Issue 1.
Fed Std 209 B.
ESA PSS-01(QRM-01) Issue 3. PSS-09(QRM-02T) Issue 2.
PSS-11(QRM-04T) Issue 1. PSS-15(QRM-05T) Issue 1.
QRM-10E Issue 2, Rev. 0; PSS-19(QRM-16) Issue 2; QRM-17E Issue 2, Rev. 0;
QRC-01 Issue 3, Rev. 0; QRC-02 Issue 1, Rev. 0; QRC-05 Issue 1, Rev. 0;
QRC-06 Issue 2, Rev. 1; QRC-31 Issue 2, Rev. 0; QRC-50 Issue 1, Rev. 0;
QRA-05 Issue 2, Rev. 0; QRA-06 Issue 3, Rev. 0; QRA-07 Issue 1, Rev. 0;
QRA-08 Issue 2, Rev. 0; QRA-10 Issue 2, Rev. 0; QRA-14 Issue 4, Rev. 0;
QRA-17 Issue 2, Rev. 0; QRA-19 Issue 2, Rev. 0; QRA-20 Issue 2, Rev. 0;
QRA-21 Issue 2, Rev. 0;

MIL-P-116E Preservation, Methods of. RF and Modulation Standard ESA TTC-A-05, to be published.
Aerospace Data Systems Standards: Standard 2.3 – S Band Ranging System Standard 1975-08-08.
Document 810-5 Rev. D DSN/Flight Project Interface Design TRK-30 Rev. A DSN Tracking System Ranging.

3. SPECIFICATION

3.1. USE OF TRANSPONDER

The receiver shall accept uplink signals in S band and provide a demodulated video. PCM/PSK telecommand signal for further processing in a command decoder. It shall also demodulate range tones from the carrier and provide video range tones to the transmitter for remodulation on an S or X band downlink. The transmitter shall also accept video telemetry from a telemetry encoder and modulate this on the downlink. It shall be possible to operate the receiver and transmitter as a coherent transponder so that range and range rate information can be derived by appropriate ground equipment. Such a transponder should be capable of being configured to be compatible with the following ground networks: ESA, NASA-STDN, NASA-DSN.

3.2. CONTENT OF TRANSPONDER

A transponder shall comprise a phase-locked loop receiver, a transmitter, a diplexer, and appropriate dc power converters. The transponder may exceptionally be provided with both S and X band transmitters operating simultaneously. The receiver and transmitters shall be capable of separate operation or operation together as a coherent or non-coherent ranging transponder. A 3 dB coupler shall also be designed and be available for combining redundant receivers if required. Some possible layouts of the RF equipment are shown in Figure 1, but flexibility should be such as to allow other possibilities with only a cabling change.

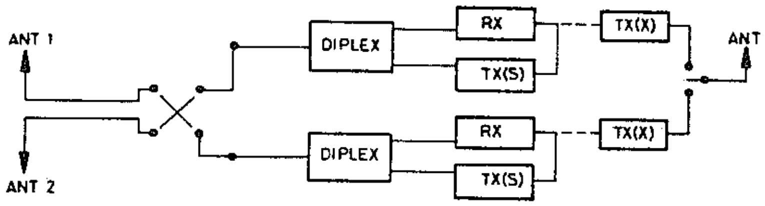
3.3. RECEIVER

3.3.1. Receiver type

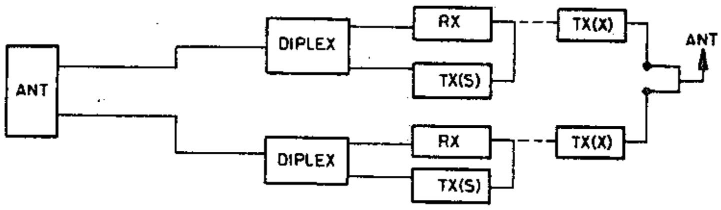
The receiver shall be of the superheterodyne type with a second-order phase lock loop tracking the carrier. All specifications shall be held for all operating modes of the transmitter and for additional amplitude and phase modulations which can be expected from the spacecraft antennas as a result of spacecraft spin (see Para 3.3.12. and Appendix F).

3.3.2. Noise figure

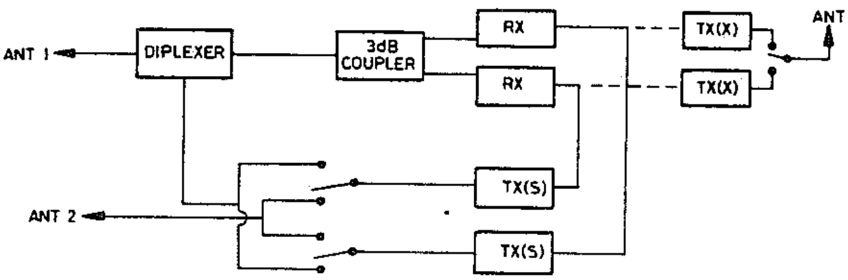
The noise figure measured at the input to the diplexer shall be $\leqslant 6.0$ dB, when measured in configuration 1 and 2 of Figure 1, and the noise figure of the receiver shall be less than 4.5 dB when measured in configuration 4 of Figure 1.



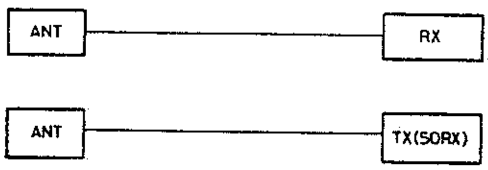
(1) REDUNDANT COHERENT OR NON COHERENT TRANSPONDER COUPLED TO TWO ANTENNAS VIA CHANGE OVER SWITCH



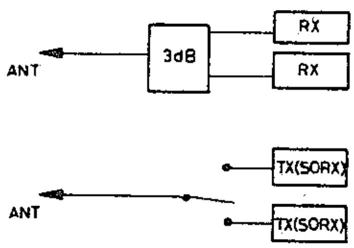
(2) REDUNDANT COHERENT OR NON COHERENT TRANSPONDER COUPLED TO DUAL MODE ANTENNAS



(3) REDUNDANT COHERENT OR NON COHERENT TRANSPONDER. RECEIVERS ACCESSED VIA ANT1. TXs TRANSMITTING VIA ANT 1 OR ANT 2



(4) SEPARATE RX OR SEPARATE TX NON REDUNDANT



(5) SEPARATE RXs OR TXs. REDUNDANT

Figure 1. Possible RF layouts of the transponder equipment.

3.3.3. Phase-lock loop bandwidth

The phase-lock-loop bandwidth $2BL_0$ shall be selectable at the time of manufacture with the options 20 Hz, 800 Hz at threshold.

The loop performance at strong signal, e.g. −50 dBm into the diplexer, shall be such as to maintain the specifications (particularly those relating to the amplitude of the video telecommand output and to the amplitude and phase stability of the video ranging tones).

3.3.4. Rest frequency

The receiver rest frequency (uplink frequency for zero SPE measured with 1 s integration time) shall be selectable at the time of manufacture in the range 2025 to 2120 MHz. The initial setting of the rest frequency shall be within ±10 kHz of the assigned value.

The rest frequency shall not vary by more than ±35 kHz from the nominal including initial setting inaccuracies and all voltage and temperature variations and by ±15 kHz due to ageing over seven years.

For the 2BL = 20 Hz version the following additional criteria must be met. The rest frequency shall not vary by more than 3.6 kHz at any one temperature in the range +10°C to +40°C in any period of 15 hours after a warm-up time of four hours.

Within the temperature range +10°C to +40°C the variation in rest frequency shall not be more than ±500 Hz/°C.

At any one temperature in the range +10°C to +40°C the rate of change of rest frequency due to crystal ageing shall not exceed ±6.3 kHz/year.

3.3.5. Carrier-acquisition threshold

The carrier acquisition threshold, defined as the input RF power at which the SNR in $2BL_0$ is about 10 dB, shall be at diplexer input −128 dBm for $2BL_0 = 800$ Hz and −144 dBm for $2BL_0 = 20$ Hz with an input noise level equivalent to 300 K.

3.3.6. Acquisition

The receiver shall acquire an uplink carrier swept through the rest frequency at a rate of $\leqslant A$ for all levels between carrier threshold and −50 dBm with a probability of 99%.

For $2BL_0 = 800$ Hz	A shall be	32 kHz/s
For $2BL_0 = 20$ Hz	A shall be	20 Hz/s

For $2BL_0 = 800$ Hz the receiver shall maintain lock while the uplink carrier is swept ±60 kHz about the nominal receive frequency at a rate of 32 kHz/s.

Lock shall also be maintained over a sweep range of ±80 kHz about the nominal frequency and ±115 kHz about the rest frequency at a rate of 3 kHz/s.

For $2BL_0 = 20$ kHz the receiver shall maintain lock while the uplink carrier is swept ±115 kHz about the rest frequency at a rate of 20 Hz/s.

3.3.7. Receiver input

The nominal impedance of receiver input shall be 50 Ω with a max. VSWR of 1.5. The receiver shall withstand an input power of 0 dBm for 5 minutes without permanent damage.

3.3.8. RX outputs

The following outputs shall be provided from the receiver:

1) VXCO output suitable for use in the transmitter as a coherent drive source when the turnaround ratio is 240/221 or 880/221.
2) Lock status signal for use by transmitter of a coherent transponder.
3) Video ranging output. The frequency capability of this channel should range from 3 BL_0 to 1.5 MHz, with the capability of setting the upper 3 dB bandwidth at the time of manufacture. The rms voltage delivered by this channel for all temperature, voltage, input power and Doppler conditions shall not vary by more than ± 0.5 dB.
4) Demodulated telecommands. The receiver shall be modular to allow a number of alternative command modulation schemes to be implemented. Those expected to be used are listed below.

4a) The 2 BL = 800 Hz version shall demodulate to baseband two alternative modulation schemes. The choice is to be made at the time of manufacture.
   i) Present ESA system PCM/PSK/AM/FM/PM. The baseband PCM/PSK/AM command message (see ESA PCM Telecommand Standard) is FM on a sinus 70 kHz subcarrier with a deviation of ± 5 kHz pk. The 70 kHz subcarrier is PM on the carrier with an index of between 0.5 and 1.5 rad pk.
   ii) Future ESA system PCM/PSK/PM. The PCM is NRZ-L at a bit rate which is submultiple of the PSK sinus subcarrier which may be at 16 kHz or (more likely) at 8 kHz. The baseband message is PM on the carrier with an index of between 0.5 and 1.5 rad pk.

4b. The 2 BL = 20 Hz version shall demodulate to baseband a message similar to the future ESA system (4a (ii)) above.

4c. The performance of the transponder shall be compared with that expected theoretically taking account of the noise figure, PM modulation loss ($2 J_1^2(m)$) and FM modulation loss

$$\left[\frac{3}{4}\frac{fd^2}{f_2^3 - f_1^3}\right]$$

(fd is FM peak deviation and $f_1 f_2$ are the frequencies defining the video output bandwidth). For 2BL = 800 Hz and the present ESA system with an uplink index of 1.2 rad the performance shall be within 1.5 dB of theoretical for input levels to the diplexer of between −109 and −85 dBm and the S/N density ratio shall not fall below the level for −85 dBm for powers between −85 dBm and −50 dBm. For the future ESA schemes for both 2BL = 800 Hz and 20 Hz versions the performance shall be within 1.5 dB of theoretical for input power to the diplexer between that theoretically required to produce 10 dB S/N in the bit rate and −85 dBm (2BL 800 Hz) or −105 dBm (20 Hz). At higher input powers S/N density ratio shall not fall below those at −85 dBm (2BL 800 Hz) or −105 dBm (20 Hz).

The rms signal plus noise delivered by the transponder into a decoder with a bandwidth of 20 kHz and an impedance of >10 kΩ in parallel with <500 pf shall be 600 mV ± 6 dB. The output impedance of the transponder shall be <300 Ω shunted by <300 pF.

The sense of the video telecommand output signal shall be the same as that generated on the ground, i.e. an advance of phase of the uplink RF carrier or increase in frequency of the FM subcarrier shall produce a positive-going video signal.

3.3.9. Telemetry monitoring

The following outputs shall be provided in accordance with the latest issue of the ESA Data Handling Interface Standards:

1) Receiver AGC
2) Receiver static phase error (or loop stress)
3) Lock status
4) Temperature of range delay sensitive part of receiver
5) Receiver converter voltages

The lock status shall also be passed to the transmitter to be used in the coherent mode switching logic.

3.3.10. Spurious responses

Response to image frequencies and other frequencies within ± 10 MHz of the nominal frequency inserted at the diplexer port shall be at least 60 dB below the acquisition threshold for the nominal frequency. Response to other frequencies outside ± 10 MHz about nominal shall be at least 80 dB below the threshold. The receiver shall be free from all indications of false lock, frequency pushing, self lock or instability both with and without the associated transmitter being powered. The spurious response requirement shall hold before, during and after acquisition.

3.3.11. Back radiation

The levels of back radiation leaking out of the receiver input port shall comply with MIL-STD-461A CE06 (-72.99 dBm). In addition the levels and the input filtering of the receiver shall be such that the input ports of two receivers can be connected together with any phase shift and with 6 dB of inserted isolation and still function correctly.

3.3.12. AGC

The receiver AGC response time shall be such as to ensure compliance with the specifications even in the presence of additional amplitude and phase ripple due to the spacecraft spin.

For the purpose of this specification the worst-case additional modulation due to spin shall be taken as simultaneous sine waves of frequency 36 Hz and peak amplitudes

$$\left\{\begin{array}{l}\text{amplitude } \pm 6 \text{ dB about nominal}\\ \text{phase } \pm 50^\circ \text{ about nominal}\end{array}\right\}$$

where the amplitude and phase modulation are $\pi/2$ out of phase. The above applies to the 800 Hz loop bandwidth.

For the 20 Hz version the extra modulation is to be taken as simultaneous sine waves of frequency 0.5 Hz and amplitude

$$\left\{\begin{array}{l}\text{amplitude } \pm 3\text{dB about nominal}\\ \text{phase } \pm 20^\circ \text{ about nominal}\end{array}\right\}.$$

If a conical scanning system is implemented on the spacecraft (2BL = 20 Hz) the receiver should provide AGC TM which is linear ($\pm 5\%$) at a rate of around 100 mV/dB.

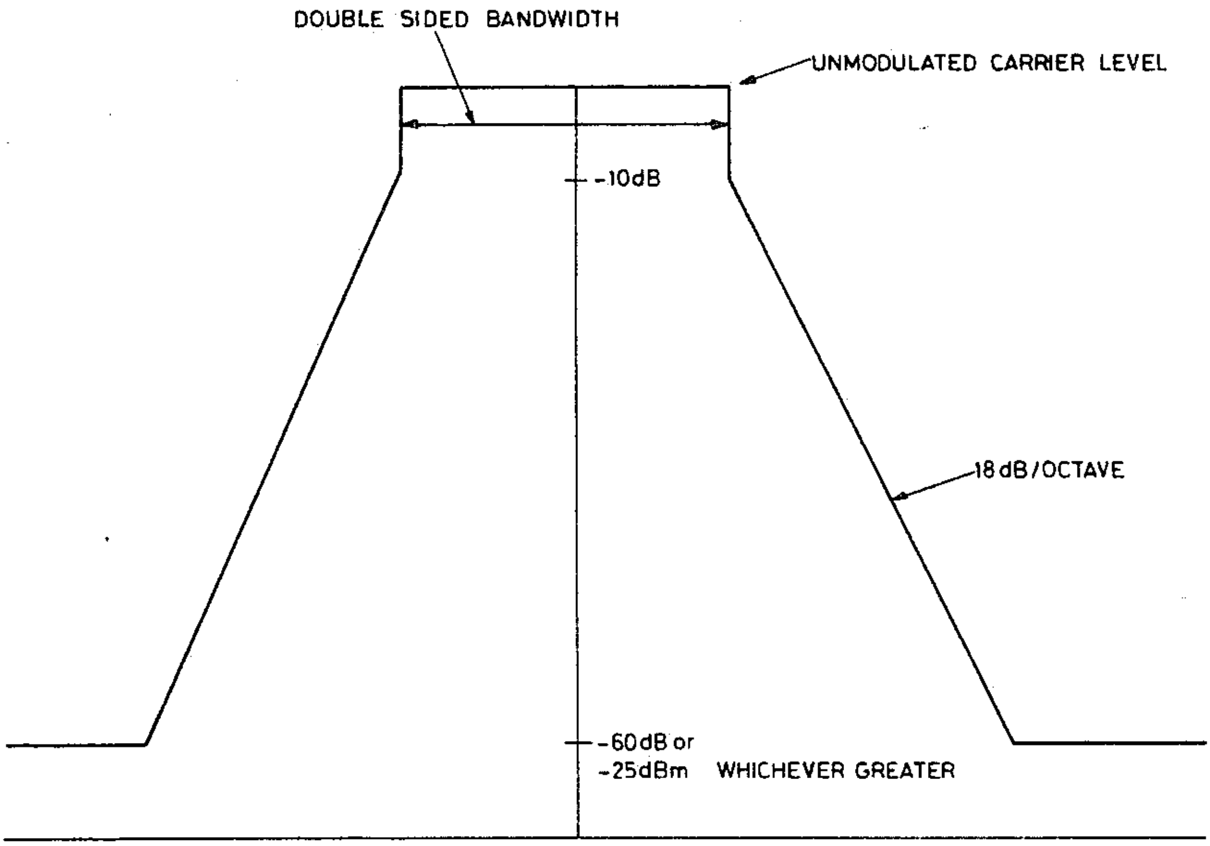


Figure 2. Definition of bandwidth allocation.

3.4. TRANSMITTER

The transmitter shall be in S band with a turnaround ratio of 240/221 or in X band with a turnaround ratio of 880/221. The hardware should be compatible with both schemes without major changes.

3.4.1. Power outputs

The S band power output under all specified conditions shall be ⩾2.5 watts or ⩾5 watts (selectable at the time of manufacture) measured at the output of the diplexer. The output impedance of both transmitter and diplexer shall be 50 Ω. The X band power output shall be > +12±1 dBm under all specified conditions. The output impedance shall be 50 Ω.

3.4.2. Spurious outputs

When unmodulated in both coherent and non-coherent modes, the transmitter shall show no spurious outputs higher than −60 dB with respect to the carrier. When modulated, the spectrum shall contain only the expected energy distribution and shall show no spurious outputs higher than −60 dB with respect to the unmodulated carrier. In both modulated and unmodulated states, the transmitter shall not give broadband noise which, measured in 0.1 kHz bandwidth, is higher than −60 dB with respect to the unmodulated carrier.

3.4.3. Mismatch

Any load of any phase placed at any of the transmitter or diplexer power outputs shall not cause the spectral output of the transmitter to change from the matched case nor shall it affect the output power by more than ± 0.5 dB.

3.4.4. Modulated spectrum

The spectrum of the modulated transmitter shall be within the mask of Figure 2 where the double-sided bandwidth of the transmission is defined. The spectrum shall be symmetrical to 1 dB.

3.4.5. Output frequency

The frequency shall be set at the time of manufacture. It will be within the range 2200 to 2300 MHz for S band or 8400 to 8500 MHz for X band and be derived either coherently from the receiver or non-coherently from an independent oscillator as chosen by telecommand.

3.4.6. Frequency stability

The initial setting of the frequency in the non-coherent mode shall be within $\pm 5 \times 10^{-6}$ of the nominal. The frequency when in the non-coherent mode shall be within $\pm 1.5 \times 10^{-5}$ of the nominal including initial setting inaccuracies and for all voltage and temperature excursions and shall not drift more than $\pm 7.5 \times 10^{-6}$ due to ageing over seven years.

For the 2BL = 20 Hz version the following additional criteria must be met. The downlink frequency in the non-coherent mode shall not vary by more than $\pm 1.5 \times 10^{-6}$ at any one temperature in the range +10°C to +40°C in any period of 15 hours following a warm-up time of 4 hours after switching into the non-coherent mode.

Within the temperature range +10°C to +40°C the variation of frequency in the non-coherent mode shall not be more than $\pm 0.2 \times 10^{-6}$/°C.

At any one temperature in the range +10°C to +40°C the rate of change of frequency in the non-coherent mode shall not exceed $\pm 2.5 \times 10^{-6}$ per year.

3.4.7. Phase noise

The phase noise of a downlink carrier in S or X band shall not exceed 5^0 rms when measured in a test receiver with 2BL = 20 Hz, i.e. the phase noise is integrated between BL (10 Hz) and an upper limit of 100 kHz. For this measurement the signal level into the test receiver shall be greater than 50 dB above the threshold of the test receiver and the uplink signal power to the transponder in the coherent mode shall be 20 dB above its acquisition threshold.

3.4.8. Modulation inputs

The transmitter shall accept 3 modulation inputs and provide a phase modulated downlink carrier. The inputs are one ranging and two TM channels.

1) Ranging baseband. The bandwidth shall be such that the voltage required to maintain a modulation index of 1 radian peak or less shall not vary by more than ± 0.5 dB in the frequency range 3.6 kHz to 1.5 MHz and over the specified temperature and voltage ranges and over the specified lifetime of seven years.
2) Telemetry video – either PCM bit stream direct or on a square-wave PSK subcarrier. The input level will be 3 V pp ± 5% and the input impedance shall be >100 kΩ. The basic bandwidth of each channel shall be 10 Hz to 1.5 MHz and provision shall be made for the

introduction of suitable high and low pass premodulation filters to be specified at the time of manufacture. The connection between filter outputs and modulator inputs shall be externally accessible. The voltage of the telemetry input of the transmitter required to maintain a modulation index of 1.5 radian or less, shall not vary by more than 1 dB in the frequency range 10 Hz to 1.5 MHz and over the specified temperature and voltage ranges and over the specified lifetime of seven years.

The telemetry channels shall be linear up to 1.5 rad and the ranging channel shall be linear up to 1.0 rad, i.e. the modulation index as a function of applied voltage shall not depart from a straight line by more than 3%. This should hold in the case where there is a signal on another channel not being tested such that the total peak modulation index does not exceed 1.8 rad. All three channels shall be capable of being switched on or off by telecommand independently.

3.4.9. **Residual AM**

Residual AM of the modulated transmitter shall be less than 2%.

3.4.10. **Telemetry monitoring**

The following telemetry shall be available:

Coherent/non-coherent status
Ranging ON/OFF
Data channel(s) ON/OFF
Output power monitor
Temperature of power transistors
Converter voltages

The telemetry outputs will be in accordance with the ESA PCM Telemetry Standard (ESA PSS-46(TTC.A.02) Issue No. 1 April 1978).

3.5. RANGING

3.5.1. **ESA standard ranging and STDN standard ranging** (for S band downlinks 2BL = 800 Hz)

For details of tones to be used etc. see ESA Ranging Standard, Aerospace Data Systems Standards – Standard 2.3 S Band Ranging System Standard.

The ranging channel performances shall be held for input power to the transponder between −105 dBm and −50 dBm with simultaneous telecommand as defined in Subsection 3.8.4. and between −109 dBm and −50 dBm with ranging alone. The performances shall be held for frequency offsets of ±115 kHz about the rest frequency or ±80 kHz about the nominal frequency. In addition all performances other than that on downlink index (Para. 3.5.1.3) shall be held for uplink powers down to −115 dBm.

3.5.1.1. *Uplink index*

The uplink modulation indices will be 0.7 rad pk for the major tone transmitted alone and 0.7 rad pk and 0.7 rad pk when a major tone is transmitted with a minor tone.

3.5.1.2. *Major-tone-delay stability*

The ranging tone delay through the transponder for the 100 kHz tone will be constant to within ±50 ns over the full range of Doppler, input level, temperature, voltage and 7 years life. Using telemetered data of voltage and temperature and predicted Doppler, it shall be possible to know the on-board delay to ±5 ns at any time.

3.5.1.3. *Downlink index*

Downlink modulation index of any one tone must always be greater than 0.3 rad pk for an uplink consisting of major and minor tones at a power level as specified in Para. 3.5.1.

N.B.: Limiting to avoid excessive noise peaks is likely to cause phase variation on the ranging tones as a function of signal level and should be avoided.

3.5.1.4. *Ambiguity resolution*

There shall be a linear relationship between the ranging tone delay, expressed in terms of phase, and the tone frequency (within the tone frequency range 3.5 kHz to 100 kHz). Departures from this relationship should be less than ±5° of phase with a goal of ±3°.

3.5.1.5. *Polarity*

A positive phase shift on the uplink shall give rise to a positive phase shift on the downlink.

3.5.2. **DSN ranging** (For S-band or X-band downlink 2BL = 20 Hz)

For details see 'DSN Tracking System, Ranging (Doc 810-5 Rev D)'.

The ranging channel performances shall be held for uplink *carrier* powers between −130 dBm and −70 dBm and for frequency offset of ±60 kHz about nominal.

3.5.2.1. *Uplink index*

The uplink modulation index may be chosen at any value up to 1.3 rad pk.

3.5.2.2. *Ranging-signal-delay stability (DSN)*

For both S-band and X-band transmitters the delay of a 500 kHz square wave transmitted through the transponder will be constant to ±30 ns over the Doppler range of ±60 kHz, the specified voltage and temperature variations and 7 years life. Using telemetered data of voltage and temperature and Doppler offset it shall be possible to know the on-board delay to ±5 ns. For these measurements an integration time of 1 second shall be used with an uplink index of 1.2 rad pk.

In the case where both S- and X-band transmitters are implemented, and fed from the same S-band receiver, the variation between the delays of a 500 kHz square wave through the S/S and S/X transponders shall be less than 3 ns over the Doppler range, the specified voltage and temperature variations and 7 years life.

3.5.2.3. *Downlink index*

The downlink index should be settable at the time of manufacture at any value from 0.2 to 1.0 rad pk for a high signal level on the uplink. A method of controlling the modulation of ranging channel noise on the downlink shall be employed.

3.5.2.4. *Ranging-channel frequency response*

In the frequency region 3 kHz to 500 kHz the response of the ranging channel (RF in to RF out) shall be flat ±0.5 dB.

The upper 3 dB limit (3 dB down on the maximum response) shall be >1.2 MHz and the lower 3 dB limit shall be <1 kHz.

3.5.2.5. *Polarity*

A positive phase shift on the uplink shall give rise to a positive phase shift on the downlink.

3.5.2.6. *Carrier phase stability*

In the coherent mode the carrier phase delay variation from the S-band RX input to the S-band or X-band transmitter outputs shall not exceed 1.5 ns pp over the temperature range +10°C to +40°C or 3.5 ns pp over the specified temperature range. The differential carrier phase delay variations between the S-band and X-band transmitter outputs shall not exceed 0.75 ns pp over the temperature range 10°C to 40°C or 1.8 ns pp over the specified temperature range. For these measurements an integration time of 1 s should be used with an uplink index of 1.2 rad pk.

3.6. DIPLEXER

3.6.1. **Frequencies**

The diplexer shall operate with a receive frequency band of ±1.2 MHz about a nominal value in the range 2025 to 2120 MHz, and a transmit frequency band of ±1.6 MHz about a nominal value in the range 2200 MHz to 2300 MHz. The diplexer design shall be readily adjustable to any frequency pair in the given ranges.

3.6.2. **Power handling of diplexer**

The diplexer shall not be damaged during corona test when fed with 10 W at the transmit frequencies, the antenna port being terminated with a load of VSWR = 9 : 1 any phase.

3.6.3. **Impedance**

Input and output impedances of the diplexer within the above specified bands and for the specified frequencies shall be nominally 50 Ω with a max. VSWR of 1.2.

3.7. RF SWITCH

Deleted from requirements.

3.8. GENERAL TRANSPONDER PROPERTIES

3.8.1. **Mass**

The mass of a single S/S transponder shall be less than 3.0 kg. The mass of a single S/X transponder shall be less than 2.9 kg. The mass of a single transponder with both S- and X-band transmitters shall be less than 4.0 kg.

3.8.2. Power consumption (main bus)

The consumption of the S-band RX shall be <3 W.

The consumption of the S-band TX shall be <16 W for 2.5 W output and <31 W for 5 W output

The consumption of the X-band TX shall be <10 W.

3.8.3. Dimensions

The external unit dimensions, including unit base and connectors, shall be designed to minimise the required spacecraft volume and mounting area on the equipment platforms.

The height of the unit measured from the mounting plane should not exceed twice the dimension of the shortest side.

3.8.4. Modes of operation

When the transmitter is energised by a rising voltage it will select the non-coherent mode with the ranging channel switched off but one data channel switched on. By telecommand it will be possible to switch to the coherent mode provided that the receiver is locked. If the receiver loses lock for more than 0.1 s, then the system will revert back to non coherent. Alternatively, it shall be possible to telecommand the change back to non coherent. The ranging channel and second telemetry channel, if implemented, will be switched on and off by separate telecommands. Telecommands will be in accordance with the ESA D.H. Interface Standard. Appropriate monitoring shall be provided.

Normally simultaneous telecommanding and ranging will not be a mission requirement. However, the transponder must be capable of providing this mode of operation, the decision on its use being made on overall satellite system considerations.

The following operational modes of the transponder shall exist:

A) TX Modes	Coherent	Not coherent
1. Ch. 1 alone	×	×
2. Ch. 2 alone	×	×
3. Ch. 1 + Ch. 2	×	×
4. Ch. 1 + ranging	×	×
5. Ch. 2 + ranging	×	×
6. Ch. 1 + Ch. 2 + ranging	×	×

B) Receiver Modes

1. Telecommand only
2. Ranging only
3. TC + Ranging

N.B.: During manufacturing it shall be possible to select an optional arrangement in which the loss of coherence also switches off the ranging channel.

3.8.5. **Interfaces**

3.8.5.1. *Power interfaces*

The satellite power supply S/S will supply main bus power to the transponder in two ways.

For the receiver, the supply will be permanently connected to the main bus through a foldback current limiter (provided in the spacecraft power system).

For the transmitter, the supply will be fed through a current limiter/switch which will be used to turn the transmitter ON and OFF. (This current limiter/switch will be provided in the spacecraft power system together with appropriate status monitoring.)

Converters shall operate at a frequency to be specified at the time of manufacture between 10 kHz and 80 kHz. The free-running frequency stability shall be $\pm 5\%$. The converters shall have the capability of being locked to an external source. This control signal shall conform to the ESA D.H. Interface Standard. The inputs may be shunted by up to 350 pF of harness capacitance. The control signal input (synch.) should provide isolation by pulse transformer or differential amplifier. The voltage likely to be delivered to the transponder (*after* current limiting/switching by the spacecraft) on future ESA satellites is 27 V $\pm 2\%$ or 49 V $\pm 2\%$.

3.8.5.2. *Grounding*

Isolation between primary power and signal returns shall be provided. Further details are given under Para. 3.8.5.3. (EMC requirements). A bonding stud shall be provided giving chassis ground.

3.8.5.3. *EMC requirements*

The requirements of Appendix A are applicable. It is to be expected that there will be spacecraft (e.g. applications satellites) where the requirements will be less severe in terms of emission control, but in such cases the susceptibility levels will probably also increase.

3.8.5.4. *Environmental requirements*

3.8.5.4.1. Temperature

Qualification temperatures	−30°C, +50°C, 6 hours at each temperature
Acceptance temperatures	−20°C, +40°C, 6 hours at each temperature
Humidity	12 hours at 90%
Storage	−10°C, +60°C, 12 hours

NOTE: The junction temperature of RF power transistors (acceptance) shall be < 110°C.

Thermal vacuum test: 24 hrs. hot; 24 hrs. cold (operating, with cold start demonstrated).

3.8.5.4.2. Vibration and acceleration

The transponder shall be capable of operating through a launch by Thor Delta or Ariane or Shuttle. Relevant levels are given in Appendix B.

3.8.5.4.3. Corona

The energised transponder shall show no permanent or temporary degradation due to corona or multipaction when the pressure is slowly reduced from normal sea level value to 10^{-7} torr.

3.8.5.4.4. Space environment

Because of the possible use of new technology in the transponder, it should be stressed that, besides the normal very low pressure, the space environment comprises potentially dangerous radiation and energetic particle fluxes. See Appendix E for details.

3.8.5.5. *Mechanical attachment design*

3.8.5.5.1. General

The attachment points shall guarantee the exact connection of the transponder unit to the satellite structure and shall ensure that this connection withstands all static and dynamic loads without deforming the unit or the structure. The unit configuration itself shall not hinder the installation and removal of the attachment bolts.

3.8.5.5.2. Number of lugs

The selection of the number of attachment points depends on the dimensions, weight, centre of gravity, mass, moment of inertia, and on the specified requirements of the environmental tests.

3.8.5.5.3. Dimension of lugs

The lugs shall be designed to be in accordance with the following: (refer to lug drawing, see Figure 3).

- Minimum contact area for mounting lugs shall be 16×22 mm with the 22 mm dimension adjacent to the unit.
- When a web is necessary the thickness shall not exceed 2 mm.
- Free area diameter for attachment bolts is: 11 ± 0.5 mm for M4
- The depth under this free area shall be: 4 mm ± 0.1 mm
- The mounting area A (cm^2) of each lug shall also satisfy the thermal control requirements. The minimum value of this area shall be determined from the formula $A = \frac{2kQ}{n}$ where Q = the maximum internal dissipation (watts), n = the number of attachment lugs and $k = 1\ cm^2/W$.

The minimum recess depth between the mounting plane of the lugs and the unit shall be 1 mm ± 0.1 mm. The use of an approved interface filler can be proposed to improve thermal properties.

The mounting surface of each unit shall be machined to obtain a surface finish of 1.6 microns or better and a surface flatness of less than 0.05 mm across the mounting plane.

The edges of the contact surfaces shall be rounded with a radius 0.5 mm to prevent local deformations of the structure.

3.8.5.5.4. Attachment bolts

The unit shall be mounted to spacecraft honeycomb platforms by means of M4 metric size bolts tightened to a torque of 4 Nm.

3.8.5.5.5. Attachment-hole pattern

The diameter of the attachment holes shall be for M4:

$4.3 \begin{smallmatrix} +0.1 \\ -0.0 \end{smallmatrix}$ mm.

A reference hole can be determined as preferred, but must carry a clear identification on the

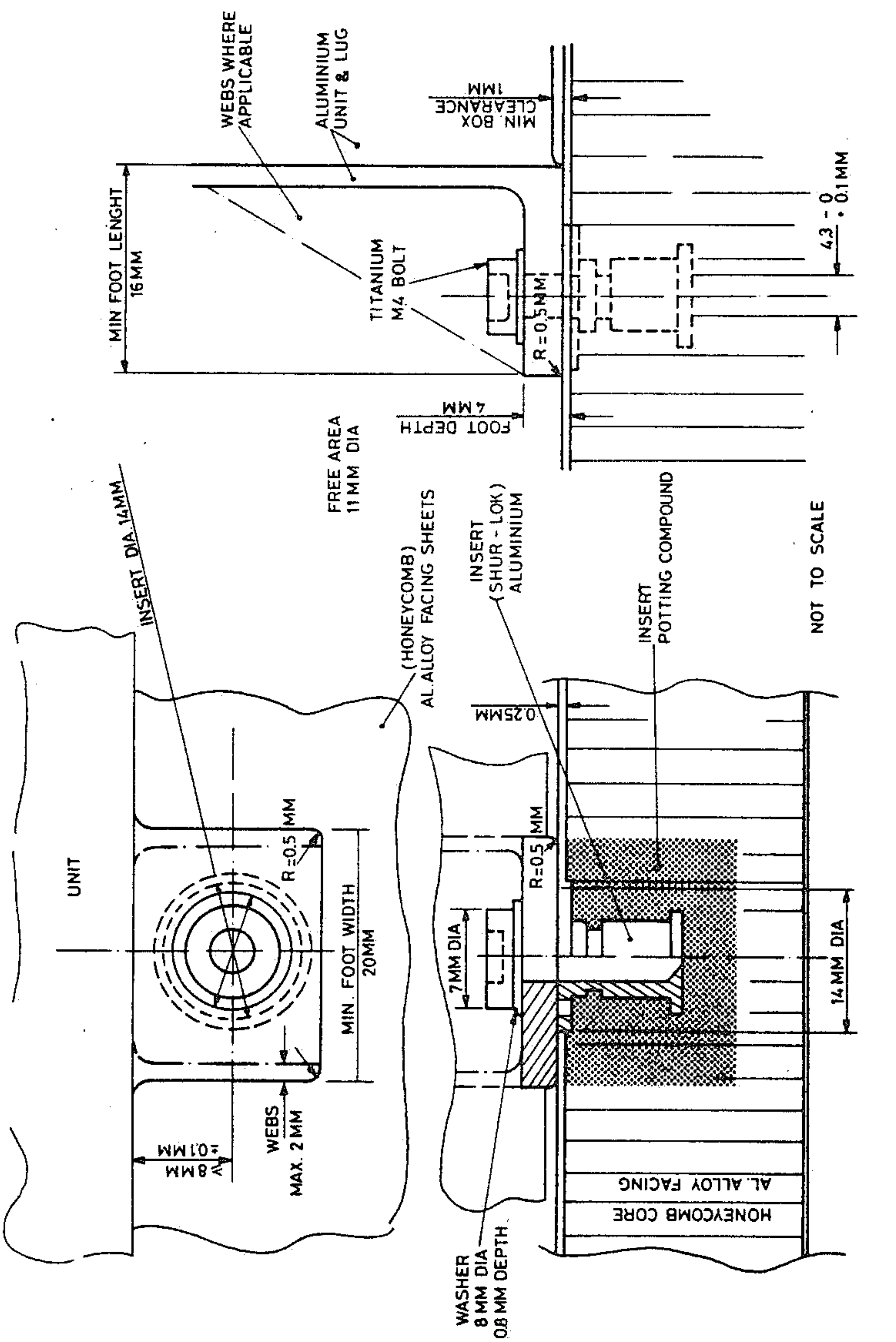


Figure 3. Mechanical attachment.

mechanical drawing of the unit. All hole-centre line dimensions shall utilise the reference hole as a common datum. The centre-to-centre distance of the holes from the reference hole shall be maintained to ± 0.1 mm: pitch circle diameter tolerance shall be ± 0.1 mm; angular tolerance shall be $+1$ minute.

The maximum distance between two attachment holes is determined by the maximum dimensions of the unit.

The minimum distance between two attachment holes is 25 mm $-$ 0.0 mm. The minimum distance between a hole axis and the unit side is 8 mm.

Perpendicularity of the attachment holes with respect to the mounting surface shall be $90° \pm 30'$.

3.8.5.5.6. Accessibility

The design of the attachment shall be such as to enable the mounting and removal of a unit with normal, standard tooling.

3.9. DESIGN FEATURES

3.9.1. Mechanical layout

The following shall be considered:

a. Module interconnection with minimum lead length.
b. Thermal connection to structure of power stages of transmitter and converters.
c. Ease of replacement of modules in case of repair.
d. Separability of transmitter, receiver, diplexer and power converters for flexibility in flight spare provisioning.
e. Grounding.
f. Efficiency of the mechanical structure.
g. Ease of access for final adjustment of modulation indices.
h. Ease of access to test points.
i. All parts of the transponder to be properly vented to the ambient.

3.9.2. Test points

The following readily accessible test points shall be provided as a minimum on a separate connector from the normal functional connectors.

a. RX AGC
b. RX SPE
c. RX Lock Status
d. RX PM demodulator output
e. Ranging video output
f. Appropriate returns and chassis ground.
g. In addition, the connection between premodulation filter input and TX modulator shall be an external one to facilitate testing.

It shall be possible to open or short-circuit or connect any of the test points to $+5$ V without causing permanent damage to the transponder. A metallic cover shall be provided to cover test points when not in use.

3.9.3. Parts, materials and processes

All electronic parts and materials used, for the production of qualification models, flight models

and flight spares, shall be included in the following lists to be submitted to ESA for approval.
(a) Declared Materials List;
(b) Declared Parts List.

The following ESA documents are applicable:

ESA PSS-07(QRM-01)	Guidelines for space materials selection.
ESA PSS-09(QRM-02T)	A screening test method employing a thermal vacuum for the selection of materials to be used in Space.
ESA PSS-11(QRM-04T)	Screening test method for the selection of space materials and small assemblies by thermal cycling under vacuum.
ESA PSS-19(QRM-16)	Qualification of materials and materials lists applicable to space projects.
QRC-01	Minimum requirements for selection of space-quality electronic parts.
QRC-50	Guidelines for the procurement of non-standard electronic, electrical and electromechanical parts for ESA projects.

3.9.3.1. *Parts*

All electronic parts shall comply with the requirements of ESA PSS-42(QRA-10), Derating Requirements and Application Rules for Electronic Parts.

Preference shall be given to European qualified components. Maximum use of procurement specifications issued within the SCC specification system shall be made.

Connectors for RF shall be SMA type (e.g. Radial RiM series) and shall be female. Connectors for other signals shall be Deutsch UR Series rectangular connectors (non magnetic). For all signal and power lines other than RF, appropriate return pins shall be provided on each connector. Pin redundancy shall be provided. Protection of hi-rel connectors shall be by saver connectors with a maximum of 5 mating/demating cycles.

All connectors shall be identified with a serial number. Connectors should be placed on side faces of the transponder and it shall be possible to remove any given connector without first removing other connectors.

3.9.3.2. *Non-magnetic material*

Non-magnetic materials shall be used for all parts except where magnetic parts are essential (see Appendix A).

3.9.3.3. *Ferrous and non-ferrous metals*

Ferrous and non-ferrous metals shall be of the corrosion-resistant type or suitably treated to resist corrosion caused by atmospheric conditions prevailing in storage or normal operational service.

3.9.3.4. *Dissimilar metals*

Unless suitably protected against electrolytic corrosion, dissimilar metals with an EMF exceeding 0.25 V shall not be used in direct contact.

3.9.3.5. *Organic and inorganic materials*

Organic and inorganic materials shall be of low-outgassing types and shall be stable in atmospheric and high-vacuum environments (WLT = 1.0% max. VCM = 0.1% max.).

The materials shall not cause any kind of destructive stress when applied in combination with sensitive parts.

3.9.3.6. *Processes/technologies*

Certain processes/technologies such as printed-circuit boards, thick- and thin-film hybrid microcircuits require ESA qualification. The following ESA documents are applicable:

ESA PSS-05(QRM-10E) Qualification test specification for two-sided printed-circuit boards;
ESA PSS-50(QRM-17) Qualification test specification for two-sided printed-circuit boards (reflowed tin-lead plating);

QRC-05, Specification for the evaluation and qualification of thin-film hybrid microcircuits;
QRC-06, Specification for the evaluation and qualification of thick-film hybrid microcircuits;
QRC-30, Procedure for internal inspection of thin-film hybrid microcircuits;
QRC-31, Generic procurement specification for qualified thick-film hybrid microcircuits.

3.9.4. **Short-circuit protection**

It shall be possible to short-circuit any of the inputs or outputs of the transponder or its constituent parts, i.e. converters, TX, RX, or diplexer, without causing permanent damage.

3.9.5. **Expected design life**

Note: Materials and processes for which a continued state of qualification until 1986 cannot be reasonably expected must *NOT* be used in the transponder.

3.9.6. **Finishes**

The transponder shall be suitably finished so that it meets all other requirements of this specification. It shall be possible to paint the transponder for thermal control reasons.

3.9.7. **Workmanship**

The transponder shall be built to standards normally associated with satellite hardware and shall particularly meet the requirements of ESA PSS-14 (QRM-08P).

3.9.8. **Transport and storage**

A packing case shall be provided for the transponder which will enable it to be transported or stored for at least five years under the following environment:

Temperature	−35°C to +70°C
Humidity	70%

An air filter to eliminate 99% of dust over 100 microns shall be provided.

The package shall protect the transponder from the rough handling test specified in MIL-P-116.

3.9.9. **Reliability**

The reliability should be such that any of the redundant configurations shown in Figure 1 would function satisfactorily over a period of 7 years in space plus 1 year in satellite integration environment, and that of the non-redundant configurations would function satisfactorily for 0.5 year in space plus 1 year in satellite integration environment. It may be assumed that the antennas would be failure free for the purpose of this specification.

Satisfactory functioning means that TC reception, TM transmission and ranging shall comply with this specification. For reliability purposes it is assumed that only a single transmitter (in S or X band) is implemented per transponder.

3.9.9.1. *Reliability assessment*

An assessment shall be made of the failure rates of individual units. Design-aim failure rates are as follows:

Receiver	3000 fits
Transmitter	3000 fits
Diplexer	100 fits

The following ESA documents are applicable:

QRA-14, Failure Rates

QRA-17, Reliability Assessment

3.9.9.2. *FMECA*

Systematic analyses of failure modes and effects leading to assessment of their criticality to mission success shall be carried out and documented. Based on the FMECAs a critical-item list (CIL) shall be prepared consisting of:

(a) A summary of single-failure points
(b) Redundant elements not capable of check out
(c) Redundant elements whose loss is not readily detectable
(d) All redundant elements that can be lost by a single credible cause or event such as contamination.

The following ESA document is applicable:

QRA-07, Failure Modes, Effects and Criticality Analysis.

3.9.10. **Maintainability**

The design of equipment shall be such that replacement of modules or submodules can be readily carried out at the manufacturer's plant. Any cover plates shall be easy to remove without using special tools and without causing secondary effects. All test points required for electrical tests shall be easily accessible.

3.10. DOCUMENTATION

The following documentation shall be provided:

1) Full electrical and mechanical engineering and manufacturing drawing package down to the lowest level
2) Design description
3) Parts list
4) FMECA
5) Materials list
6) Reliability prediction
7) Parts stress derating
8) Critical items list

9) Separate unit specifications for RX, TX, diplexer and converters
10) Worst case analysis (response of design to all worst-case conditions). On request.

3.11. TESTING

The transponder shall be tested to prove compliance with these specifications. Testing shall be carried out by the contractor in either the contractor's or other facilities, ESTEC having the right to approve the proposed facilities. The electrical tests listed in Appendix D shall be made. The contractor shall draw up a test procedure complying with QRA-21 which must be submitted to ESTEC for approval at least 6 weeks before the start of the tests. ESTEC reserves the right to witness, take part in or carry out any of the tests. A test report shall be prepared by the contractor and submitted to ESTEC within two weeks of the conclusion of the tests.

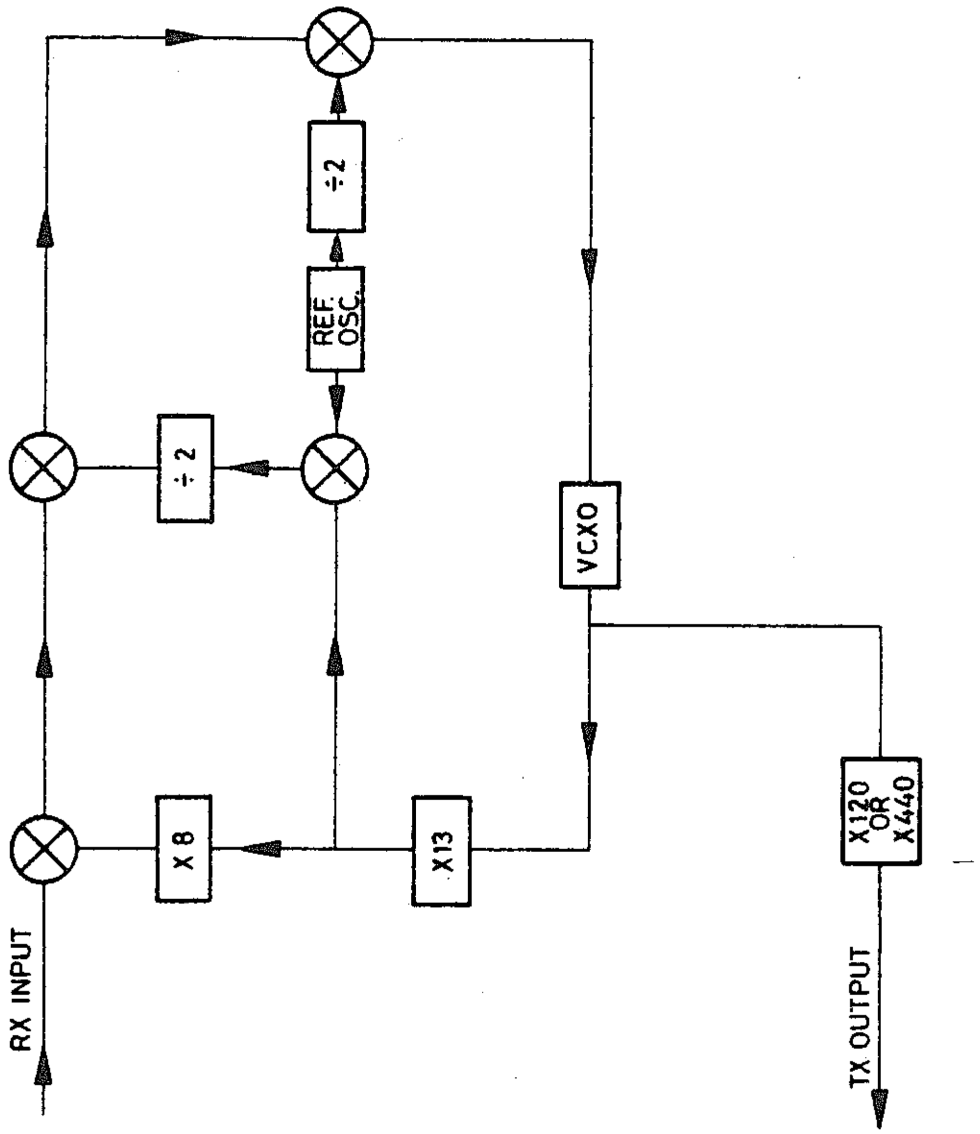


Figure 4. Possible frequency scheme for the transponder.

4. COMMENTARY ON THE SPECIFICATION

The following discussion will give the reasoning behind some of the demands of the specification. The commentary is arranged by reference to the specification paragraph numbering system.

1. SCOPE

There are several identified users of the equipment defined by this specification. Apart from the ongoing projects EXOSAT and International Solar Polar Mission, the projects SEOCS. EXUV and Astrometry, which are in the Phase A stage, and the French project SPOT are all potential users. It would clearly be wrong for each of these projects to lead to a separate development. The alternative is a modular approach in which as much as is possible of the basic hardware can be re-used, and those parts which have to be changed can be replaced cheaply without impact on the remainder.

It should be noted that frequency schemes employing a fixed second IF frequency will have a great advantage in that change of RF frequency can be achieved without alteration in the critical areas. Similarly, separate processing of command and ranging channel will give the possibility of alternative modulation schemes such as might be required for deep-space applications or new telecommand modulation schemes.

While it can be argued that a modular flexible approach will increase complexity, it is to be expected that the use of up-to-date technology such as MIC at microwave frequencies and hybrid IC mixers, amplifiers and demodulators will actually lead to reductions in cost, mass and power consumption when compared with presently available equipment.

A suggested frequency scheme and a modularity scheme are shown as Figures 4 and 5.

3.3.2. Noise figure

ESTEC has qualified the NEC transistors 25C 1268 and 25C 1336 with noise figures of 3.5 dB at 4 GHz and 3 dB at 2 GHz respectively, which would enable this specification to be met.

3.3.3. Phase-lock-loop bandwidth

The 20 Hz option will be for use on deep-space missions whereas 800 Hz will be suitable for near-earth applications. The 20 Hz allows the recovery of signals at great distance, but the acquisition time will be long since such a loop will not accept a rapid sweep of the uplink frequency. For near-earth work, there is no problem with signal level, and faster acquisition is an

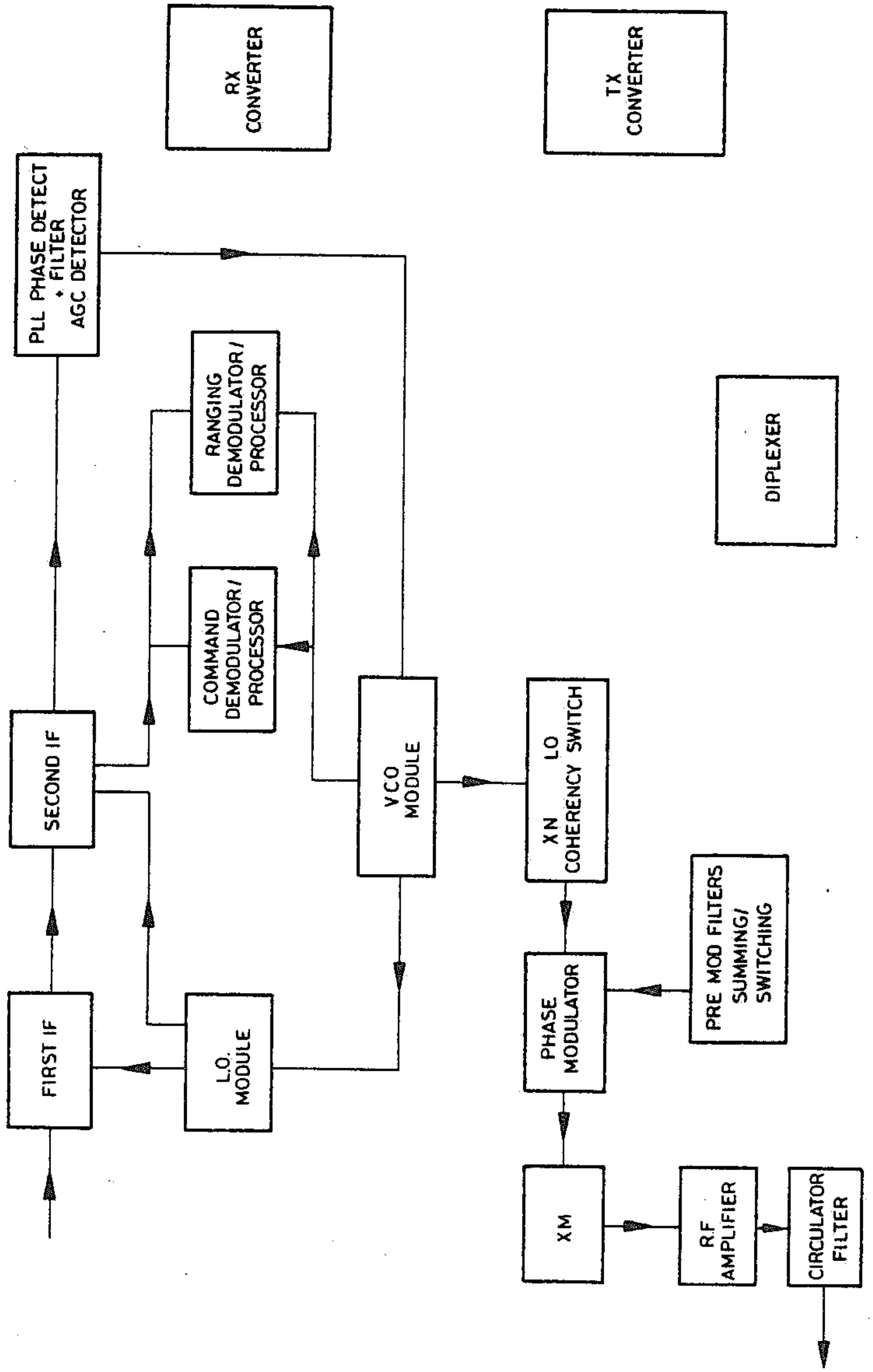


Figure 5. Possible modularity scheme.

advantage. For the present specification an acquisition time of about 10 seconds results.

The use of an 800 Hz loop bandwidth at threshold appears to be acceptable in preventing excessive phase errors on the demodulated 4 kHz ranging tone provided that the 2nd IF bandwidth is reasonably narrow, thus preventing undue expansion of the loop bandwidth at high signal levels.

3.3.4. **Rest frequency**

When very narrow PLL bandwidths are used for carrier acquisition in deep-space missions, it is important to have a good knowledge of any frequency offsets, so that these can be minimised from the ground and acquisition completed in the shortest possible time.

3.3.5. **Carrier-acquisition threshold**

Contrary to the opinion expressed in the previous issue of this document that both coherent and non-coherent AGCs would be required to meet the requirements, it now appears that the use of coherent AGC only may be sufficient.

3.3.6. **Acquisition**

The sweep rates give a factor of about $\sqrt{2}$ margin on the theoretically expected figure for a damping factor of 0.707 at threshold.

The hold-in range of ± 60 kHz for the 800-Hz loop represents the allowed on-board instability of ± 50 kHz plus the accuracy of setting of Doppler compensation of ± 5 kHz plus a safety margin. It is the amplitude of the sweep to be used for acquisition. After acquisition is verified, the sweep waveform is decayed to zero and the Doppler compensation likewise. Thus the stress on the loop becomes that due to Doppler and Doppler rate. For near-earth applications the maxima expected for these parameters are ± 80 kHz and ± 3 kHz per second which with some margin gives the specified figures.

For deep-space work, more reliance is placed on accurate knowledge of the on-board frequency and on the Doppler prediction. After acquisition the Doppler compensation is maintained active so that loop stress is minimised.

3.3.7. **Receiver input**

The requirement to withstand an input power of zero dBm is designed to prevent accidents on the ground where typical checkout transmitters can deliver power of this order.

3.4.1. **Power outputs**

5 watts in S band is chosen to satisfy most scientific spacecraft where data are transmitted at high rates. For applications spacecraft, TM requirements are less and 2.5 W should give ample margin, even with a small ground station. In X band it is intended to follow the transponder with a power amplifier, e.g. a 20 W TWTA with a gain of ~ 40 dB.

3.4.4. **Modulated spectrum**

ESA experience indicates that, when an SPL/PSK/PM downlink modulation scheme is used, the mask is defined by the levels of components at even multiples of the PSK subcarrier and that, provided the premodulation filtering cuts out the third and higher harmonics of the PSK subcarrier, the measured levels agree quite well with those calculated on the basis of a sinusoidal subcarrier.

3.4.6. **Frequency stability**

For the additional requirements on the 2BL = 20 Hz version, see the discussion under 3.3.4.

3.5.1.3. *Downlink index*

The STDN ground equipment cannot handle demodulated signals resulting from an index lower than 0.2 radian.

3.5.1.4. *Ambiguity resolution*

If the phase errors between tones are larger than 5° the STDN may produce false decisions during ambiguity resolution.

3.5.2.2. *Ranging-signal-delay stability (DSN)*

Differential delay between S-band and X-band transmitters driven from the same receivers is important when there is a need to perform measurements on the charged particles along the path between the spacecraft and ground for scientific reasons or to correct the range.

3.5.2.3. *Downlink index*

Both limiting and AGC control of a linear amplifier have been used in previous deep-space probes. It is not clear what the relative advantages of these two schemes are.

3.5.2.6. *Carrier-phase stability*

This is an important parameter if the so called DRVID system is to be used to measure, for scientific interest, changes occurring, over periods of several hours, in the integrated electron content along the path to the spacecraft.

3.6.2. **Power handling of diplexer**

If the transponder is called upon to operate during launch it will face the combined environment of high VSWR due to the metal shroud on the launch vehicle and also a transition to low pressure through the corona region. 10 W is chosen as input power to ensure a safe margin over the 5 W *minimum* output power specified at the diplexer output. It is to be expected that, if allowance is made for power reductions in the transmitter due to extreme voltages or temperatures, the normal power delivered to the diplexer during launch will be of the order of 7 or 8 W.

3.7. RF SWITCH

This has been deleted from the specification, since it is easily procured directly from Teledyne or Transco as an off-the-shelf item and in any case the actual configuration of switching required tends to vary quite a lot from spacecraft to spacecraft.

Approved for publication on 3 July 1978.

APPENDIX A

EMC AND GROUNDING REQUIREMENTS FOR S-BAND TRANSPONDER

A1. SCOPE

This appendix provides the performance requirements for electromagnetic, magnetic and electrostatic compatibility applicable to the ESA standard S-band transponder. The basis of the document is the past and present satellite requirements for experiments and subsystems (see annex for further details).

It also defines the test setups and methods to be used to demonstrate compliance with the stated requirements.

A2. REFERENCE DOCUMENTS

Military specification: bonding, electrical and lightning protection for aerospace systems: doc. no. MIL-B-5087B (ASG).

MIL-STD-462.

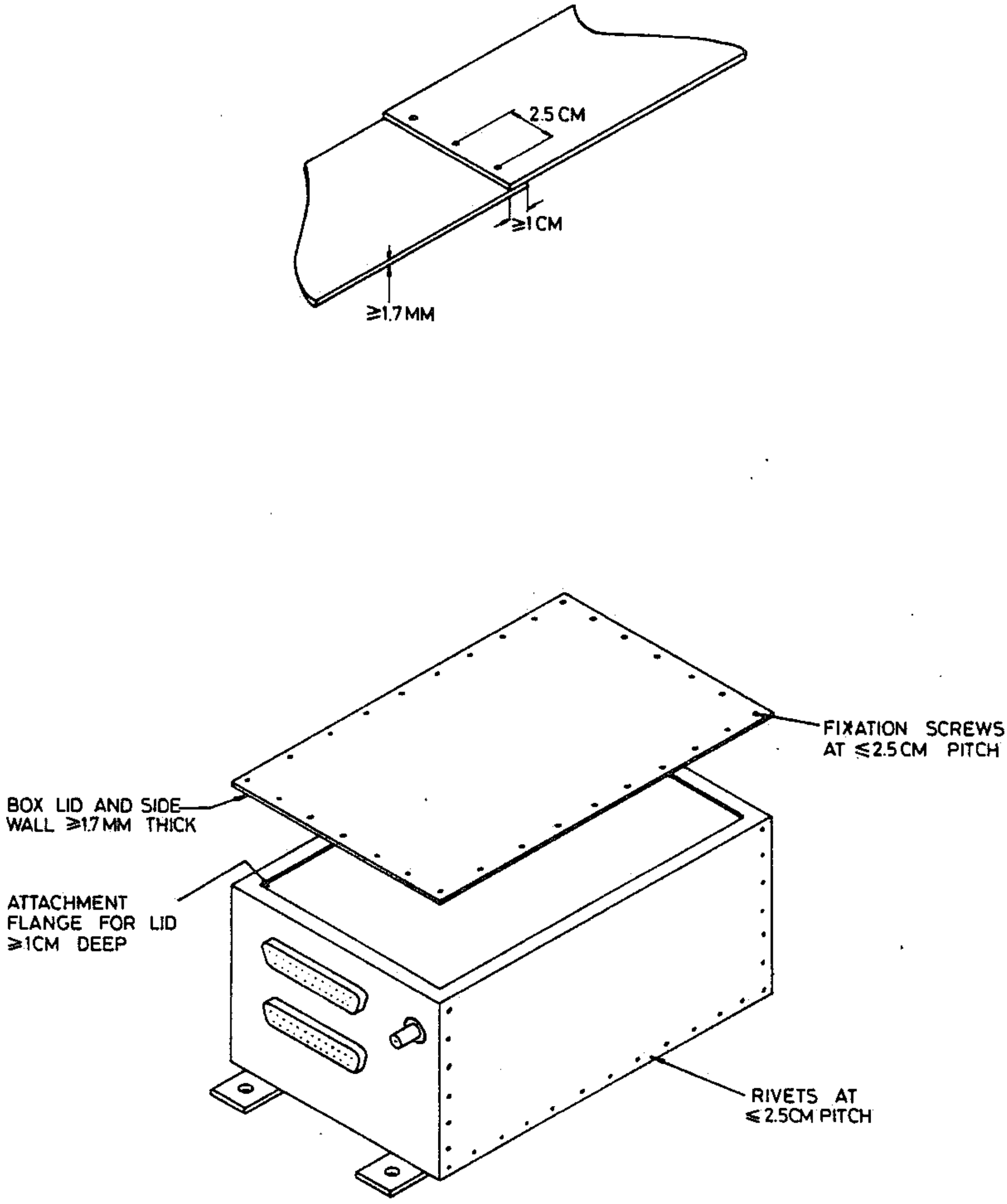
A3. BONDING OF CASE PARTS

A3.1 REQUIREMENTS

A3.1.1 The transponder shall be enclosed in a non-magnetic metallic case which shall form an all-enclosing shield for electromagnetic fields generated by the equipment.

The minimum thickness of the case wall shall be selected to ensure an attenuation loss of 60 dB or better for electromagnetic fields in the frequency range of 150 kHz to 3 GHz. For magnesium, for example, this means a wall thickness of at least 1.7 mm.

A3.1.2 The number of physical discontinuities in the case shall be minimised, and at each one special care shall be taken to ensure a good electrical bond across the discontinuity along its whole length.



LID — PAINTED, ETC, BUT FLANGE MATING FACE CLEAN METAL OR GOLD PLATE

BOX — PAINTED, ETC, BUT APPLIED AFTER ASSEMBLY OF CLEAN METAL COMPONENTS FLANGES CLEAN METAL OR GOLD PLATED.

Figure A1a. Case joint requirements.

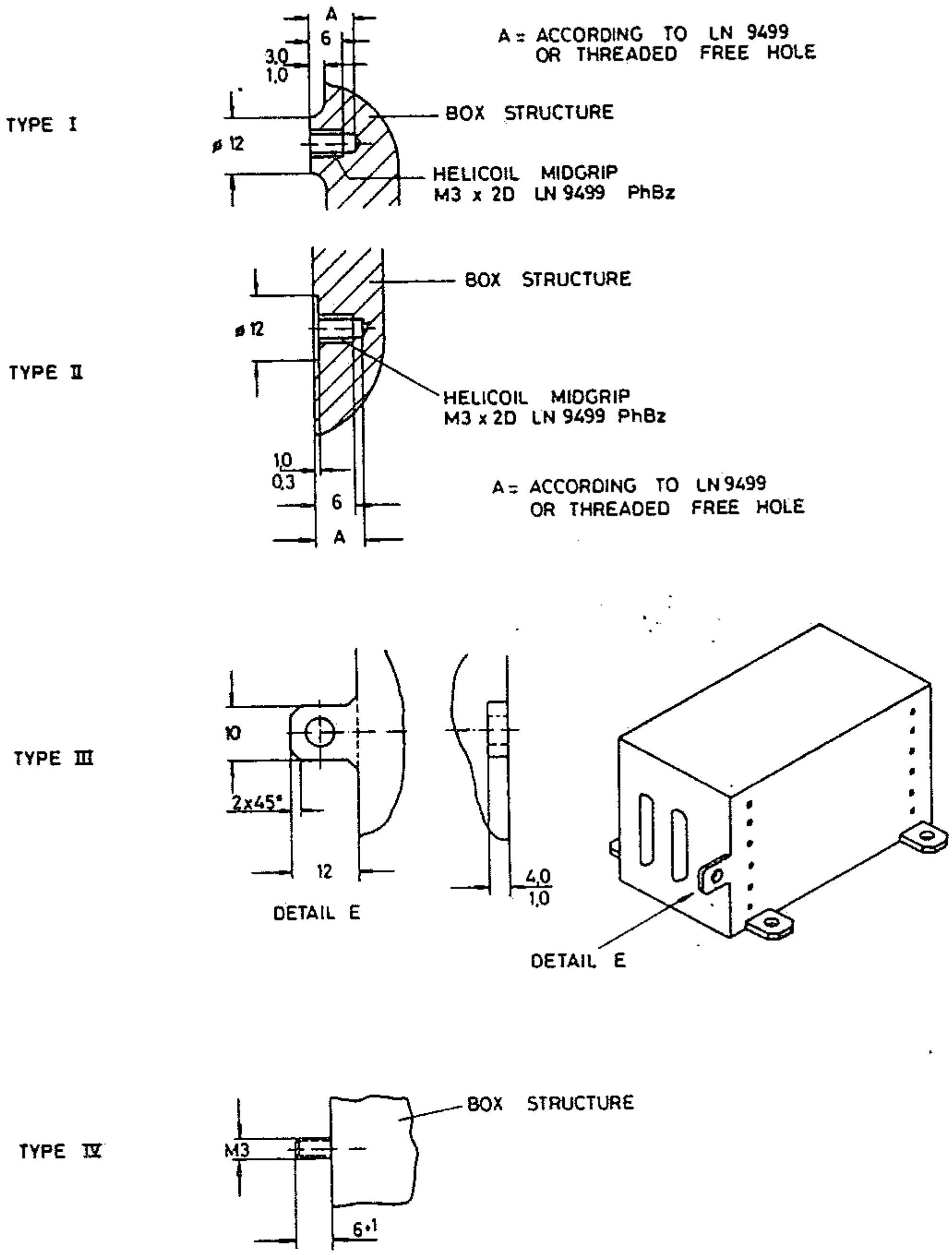


Figure A1b. Bonding methods.

When case parts are joined by a means that does not extend without interruption along the length of the join (e.g. riveting, spot-welding), the distance between adjacent bond points along the join should not exceed 2.5 cm and the minimum overlap of the two case parts at the join should be 1 cm; this is shown in Figure A1 (a).

Join faces shall be flat and clean before assembly; the only permitted surface finishes for join faces are:

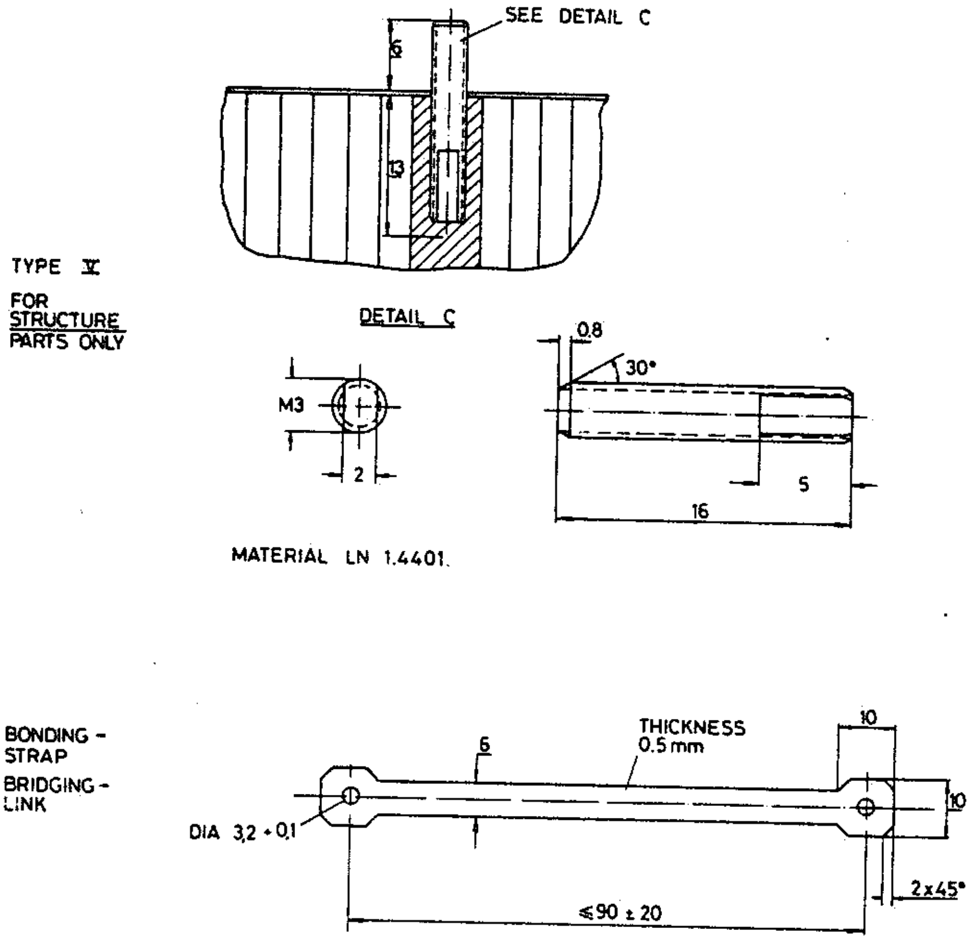


Figure A1c. Bonding methods.

- clean metal
- gold plate on the base metal.

Any other anticorrosion finish (e.g. anodising) shall be removed from the join faces before bonding.

A3.1.3 The case shall be ultimately grounded to the satellite structure via the equipment box feet. Therefore, the contact area of the underside of each foot shall be not less than 1 cm^2 and shall have only one of the surface finishes mentioned in Para 3.1.2 above. The box case shall also carry a bonding stud, insert or lug, close to one of the box feet for attachment of a bonding strap. This will be used when necessary on particular spacecraft for bonding the box case to vehicle structure, e.g. when the vehicle has a non-metallic platform. Techniques to be used are illustrated in Figure A1 (b) and A1 (c).

A3.1.4 In general the MIL-B-5087B (ASG) standard should be used as a practical guide for bonding techniques.

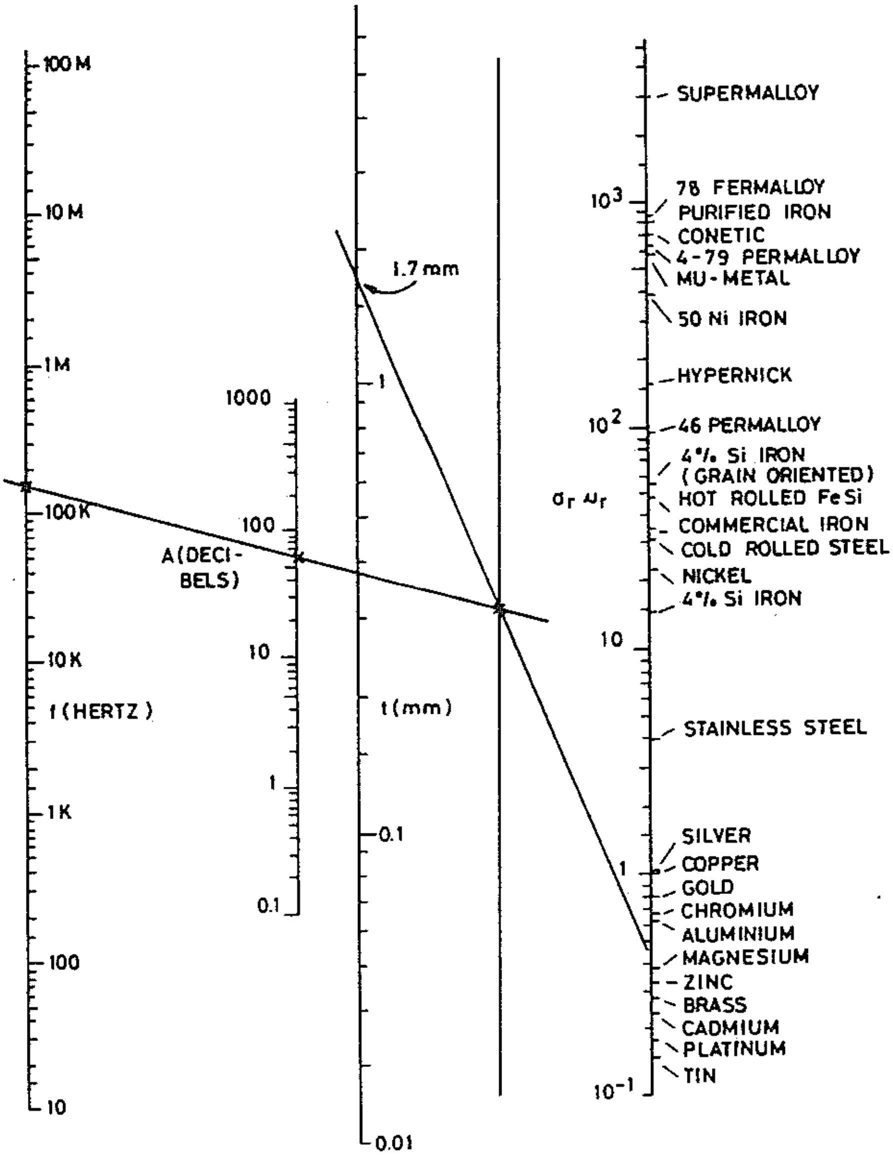


Figure A2. Nomograph of absorption losses for electromagnetic fields.

A3.1.5 Electrical connectors are to be considered as part of the case; all connectors shall include a metallic outer shell such that when the mating cable harness connector is inserted in the box mounted part, the whole connector is completely shielded. The shell of the box mounted part shall be bonded to the equipment case as required by this specification.

A3.1.6 The DC resistance across the electrical bond between any two adjacent case parts shall not exceed 2.5 mΩ. This level shall apply for both directions of polarisation across the bond.

A3.2 TEST METHODS

A3.2.1 Each and every bond on the equipment case shall be tested for compliance with

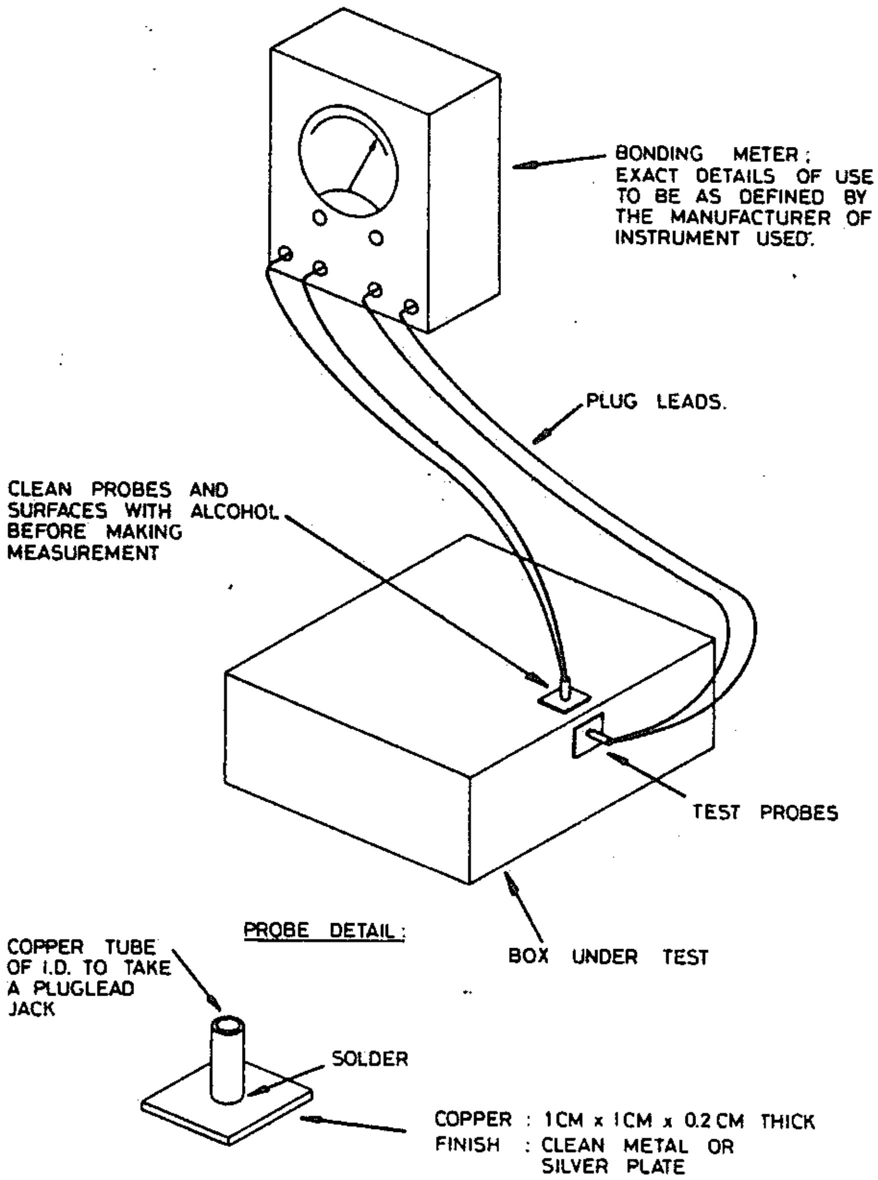


Figure A3. Case bonding test setup.

Para A3.1.6 by using the test setup shown in Figure A3. Each test shall be made twice, the test leads being reversed between the two tests in order to detect any nonlinearities in the bond.

A3.2.2 The shield attenuation shall be verified by analysis. A nomograph for absorption loss is given in Figure A2 to facilitate this analysis.

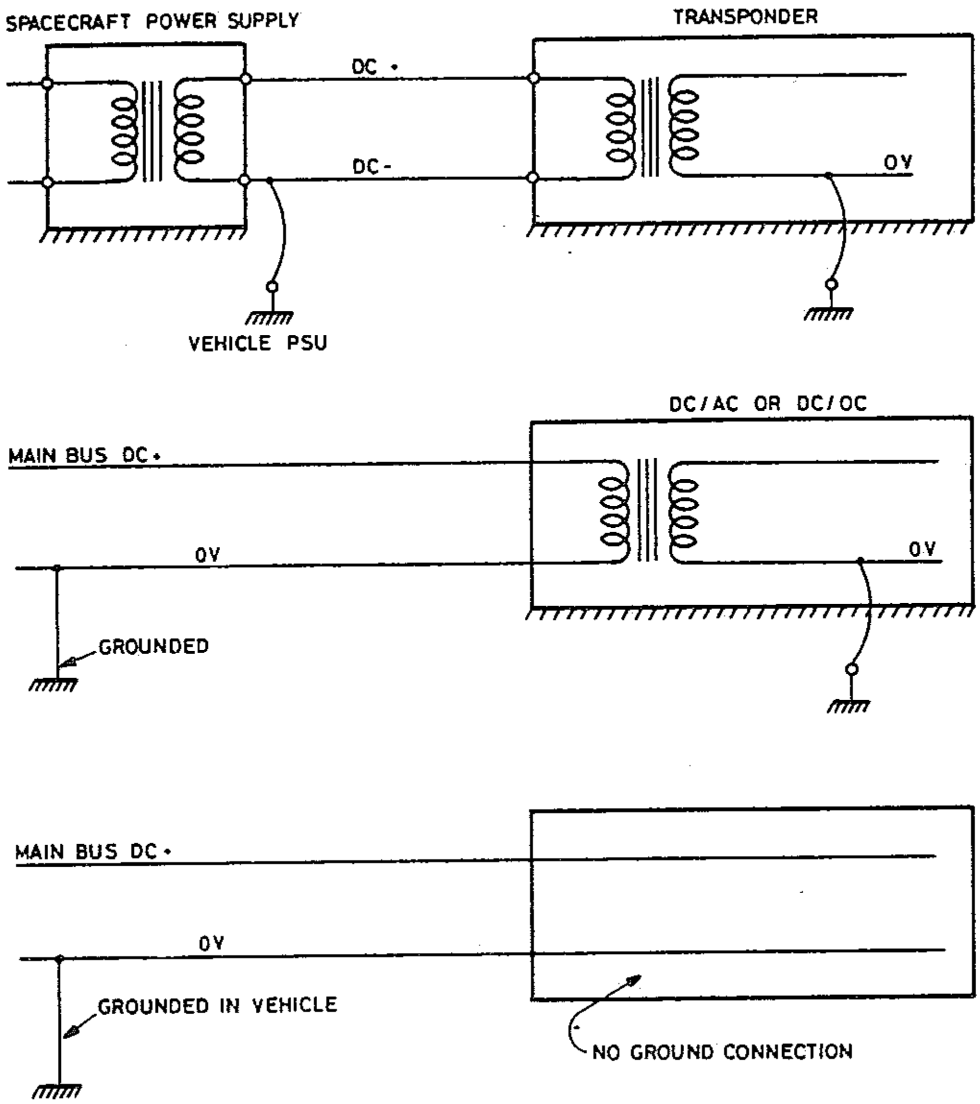


Figure A4. Examples of distributed single-point grounding system.

A4. ISOLATION OF ELECTRONICS FROM CHASSIS. GROUNDING OF RETURNS. GROUNDING OF CABLE SHIELDS

A4.1 OBJECT

The aim of this section is to ensure the production of a logical and necessary grounding/return scheme for the transponder that will correlate with the conducted noise limits, specified in Section A5 and help guarantee a viable and predictable spacecraft system performance. At the same time the transponder ground scheme must be adaptable to the spacecraft system grounding concept.

A4.2 GENERAL REQUIREMENTS

A4.2.1 There are three possible grounding/return configurations that can be used for space vehicles; these are:

(a) Centralised single-point ground (CSPG) system.

Both primary and secondary power returns and all circuit references are isolated from structure throughout the system, the reference to structure being made at one common point (this point often being called the 'star' ground point).

Sometimes the primary and secondary power circuits are referenced at two separate star points, which are not the same physical point. This is in reality the system described under (b) below.

The aims of the CSPG concept are:

- to keep noise currents out of the structure, i.e. keep the structure clean;
- to control the signal and power return paths to a known, defined routing.

The origins of these aims are multifarious and covered in the literature. However, it should be noted that any CSPG system is *only* truly SPG at low frequencies, owing to the action of stray reactances between returns and structure at HF.

(b) Distributed single-point ground (DSPG) system

In this concept, shown in Figure A4,

- *each* primary power source is single-point referenced to structure. (All primary power sources are otherwise mutually isolated.)
- secondary power is single-point referenced to structure *at each secondary power subsystem user.* (All secondary power subsystem users are otherwise mutually isolated.)

This approach presents an attempt to adapt the SPG system to a physically large vehicle where to implement a CSPG system would necessitate extremely long wires to the star point. The consequent wire impedance, even at LF, would cause the generation of high common-mode conducted noise and the ground system would not fulfil its purpose.

If the DSPG system is to be effectively implemented, attention has to be paid to the isolation achieved at the interfaces between subsystems; this is covered further below.

A second complication concerns the sharing of power lines: if one secondary power subsystem feeds more than one user or equipment from the *same* secondary bus, then the users *share* one reference point. There can *only* be more than one reference point in such a case if the users have separate and mutually isolated secondary supply lines, i.e. a multi-output winding transformer is used in the power subsystem.

(c) Structure return system

As its name implies, this concept deletes the power and signal return lines and uses the vehicle structure instead. It is based on the fact that the latter represents the lowest impedance conductor available, and the principal defect of the SPG systems, common-mode noise generation, is thus minimised.

The chief disadvantages are:

- the structure is now dirty;
- return current paths are no longer clearly defined;

- positive lines cannot be twisted with their returns in order to reduce stray field emission and susceptibility.

For these reasons this concept would not normally be applied to a vehicle carrying sensitive experiments.

A4.2.2 It is conceivable that a combination of some or all of the above concepts could be used: however, for ESA vehicles this shall *only* be when approved by the project for a particular reason.

A4.2.3 Of the three concepts described above, the *only* one that when used on a *transponder* is adaptable to any of the three concepts on the *system level* is the DSPG concept. That is to say, if the transponder is designed as a star-grounded or structure-return *subsystem* with isolation at the power and signal interfaces, it can be used in, for example, the CSPG *system* concept, either as it stands or with the interface isolation shorted out externally to the subsystem. To adapt a CSPG or pure structure-return transponder, on the other hand, is far more difficult and costly, and there is a higher risk that the resulting system design will not be trouble free in operation.

A4.2.4 Therefore, the grounding concept used for the transponder shall be that compatible with the DSPG system.

A4.3 DETAIL REQUIREMENTS

The following requirements are additional to the general requirements given above.

A4.3.1 All transponder converters shall isolate primary power from secondary power.
At the transponder level, there shall exist:

- an isolation of at least 1 MΩ in parallel with at the most 1 nF between each of primary power positive or return, and structure;
- an isolation of at least 1 MΩ in parallel with at the most 1 nF between:
  - primary power positive and secondary power positive;
  - primary power return and secondary power return.

A4.3.2 Within the transponder it is permissible to ground secondary power returns to the chassis of the equipment, provided the requirements on isolation between primary and secondary power and other transponder inputs and outputs as described in Paras. A4.2.1 (b) and A4.3.4 are implemented. Connection of secondary power returns to chassis shall be implemented (where used) in accordance with the requirements of the RF circuit design and shall *not* be via special demountable grounding straps. The transponder should in this case be contained electrically entirely within one box, which may be mechanically subdivided into modules. An example is shown in Figure A5.

A4.3.3 To provide the means to operate the transponder in a structure return *system*, it shall be possible at the time of manufacture to connect primary power returns to structure in such a way that the *total* impedance between the electrical references and the vehicle structure shall be:

- less than 10 mΩ at DC,
- less than 20 mΩ at 1 MHz.

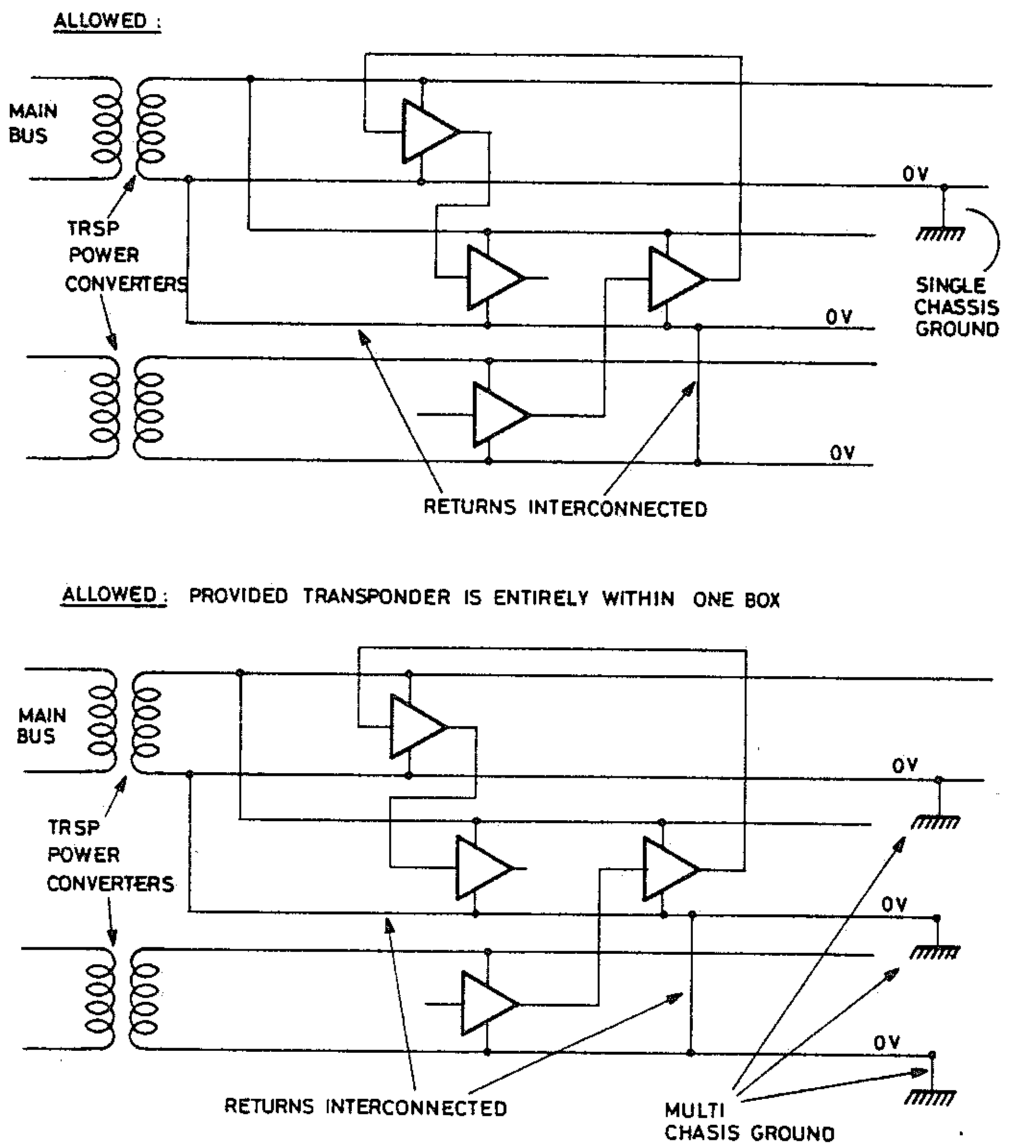


Figure A5. Ground interconnections within TRSP.

These restrictions shall apply for both directions of voltage polarisation across the bond.

For reference, the inductance of a flat metallic strap may be taken to be given by:

$$L = 0.002\,A \quad 2.303 \log \frac{2A}{B+C} + 0.5 + 0.2235 \frac{B+C}{A}$$

where L is inductance in μH
A is length in cm
B is width in cm
C is thickness in cm

A4.3.4 Care shall be taken that the signal connectors do not invalidate the defined grounding philosophy. Where it is necessary to interconnect the transponder with other items, it should be assumed that these are separately ground referenced, and use shall be made of:

- opto couplers
- differential input circuits
- pulse transformers
- isolating output circuits

in order to maintain isolation between signal ground systems.

In such cases, all command input circuits of a subsystem shall maintain a DC isolation of at least 1 MΩ between each command positive or return line and vehicle structure. This applies to both powered and unpowered status. This requirement can be relaxed if it can be shown that the total current (AC + DC) injected into the structure is controlled and does not exceed 1 mA *per box* in the frequency band DC to 50 MHz. Such deviations require approval by ESTEC.

A4.3.5 Cable shields used to prevent the transmission or reception of electromagnetic fields shall be grounded at both ends of the cable to the equipment metallic case, i.e. to spacecraft structure.

A4.3.6 Such shields shall not be connected to power returns or signal returns, nor shall they be used as return lines for signal or power.

A4.3.7 The preferred method of dealing with outer conductors of coax cables is to ground them to the equipment metallic case.

A4.3.8 Shields shall be led through electrical connectors on separate pins/contacts. Shields shall not be daisy-chained together for connection to the ground point but shall be connected independently.

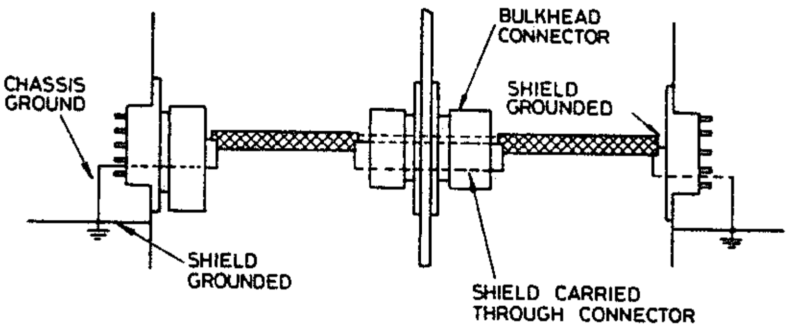
NOTE: This latter requirement means that the contractor shall provide separate connector pins for cable shields. Pins should be provided for the following shields: PCM telemetry from encoder, and video commands to decoder.
Figure A6 shows schematically the grounding requirements for cable shields.

A4.3.9 The DC resistance across the bond between any shield and the ground point shall not exceed 10 mΩ. This level shall apply for both directions of polarisation across the bond.

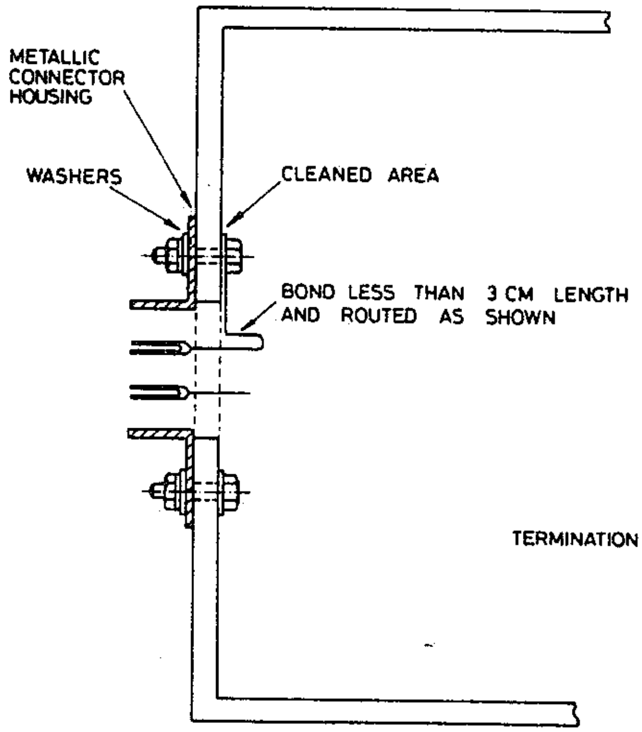
A4.4 DESIGN GUIDELINES

It should be noted that:

- the capacitive isolation between primary and secondary power circuits is best achieved by incorporating an interwinding screen (shield) in the transponder power transformer. Such a shield shall be grounded to the structure; this may be done via the equipment case;
- it is necessary to use care in selecting mounting methods for transistors, diodes capacitors etc., on to the box chassis. For example, the use of mica washers under transistors mounted in TO3 cans can introduce a stray capacitance of around 100 pF per transistor. It is recommended that beryllium oxide or boron nitride washers be used instead, since the increased thickness



TERMINATION OF SHIELDED WIRES



TERMINATION OF SHIELDS

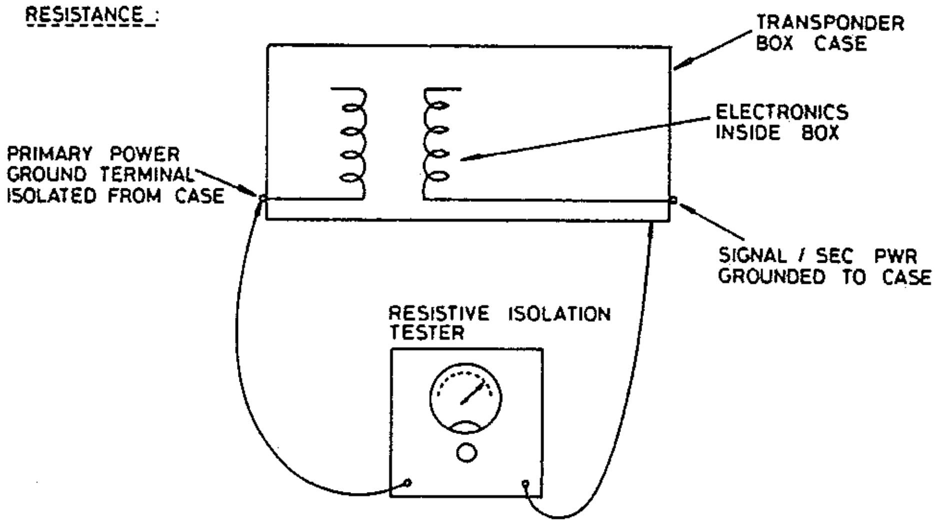
NOTE : A DEDICATED BONDING STUD OR SCREW IS SUPERIOR TO INDICATED ASSEMBLY

Figure A6. Provisions for terminating shields.

reduces the capacitance to around 20 pF;
- similar considerations apply to the mounting of capacitors (the can is one terminal!), transformer and chokes (the core has a capacitance to the windings!), etc.

A4.5 TEST METHODS

A4.5.1 The requirements set out in Para. A4.3.1 shall be tested by means of the test setup shown



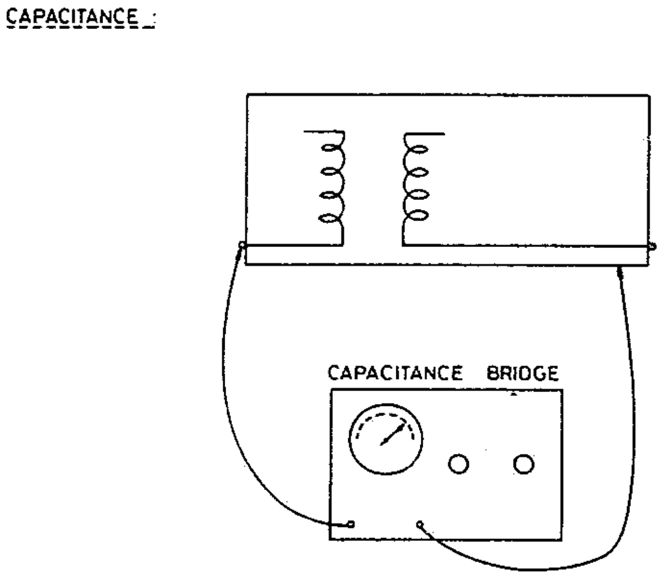


Figure A7. Test setup for measuring the isolation between electronics and case, and between ground systems.

in Figure A7. Each measurement shall be made twice, the test leads being reversed between the two tests to detect any nonlinearities in the isolation.

A4.5.2 The DC requirements of Para. A4.3.3 shall be checked by means of the setup shown in Figure A7. Each measurement shall be made twice, the test leads being reversed between the two tests to detect any nonlinearities in the bond. Each and every bond between a subsystem return and vehicle structure shall be tested in this way.

A4.5.3 The AC requirements of Para. A4.3.3 shall be verified by analysis.

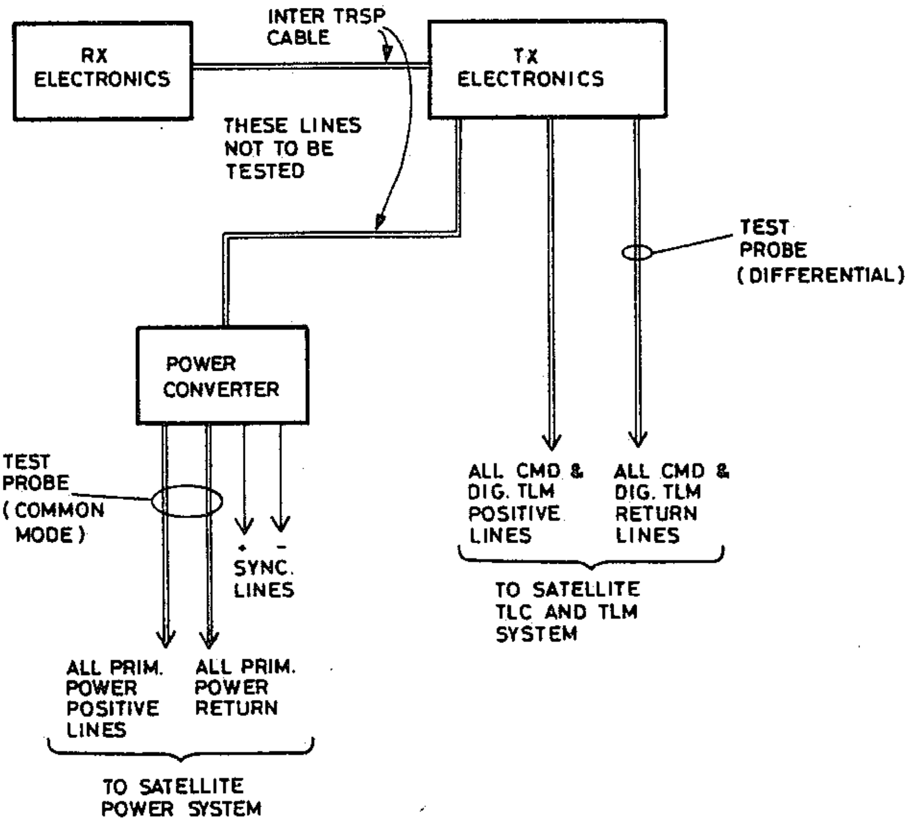


Figure A8. Conducted noise emissions — application of specification levels.

A5. CONDUCTED NOISE EMISSIONS ON POWER AND SIGNAL LINES

A5.1 GENERAL CONDITIONS

A5.1.1 This section applies only to the complete transponder subsystem.

A5.1.2 The levels defined in this section are specified for groups of wires and not for single wires in a group. Further, the specification is only applicable at the interface of the transponder subsystem with the spacecraft system; Figure A8 makes these distinctions clear.

A5.1.3 The levels are defined for particular interface impedances, e.g. the satellite main bus impedance for power-line-conducted noise. This means that the tests must be done with the aid of the particular source or load impedance, therefore, Para. A6.3 carefully defines a special test setup for these tests.

A5.1.4 The limits of this section are applicable for all operating modes of the transponder subsystem.

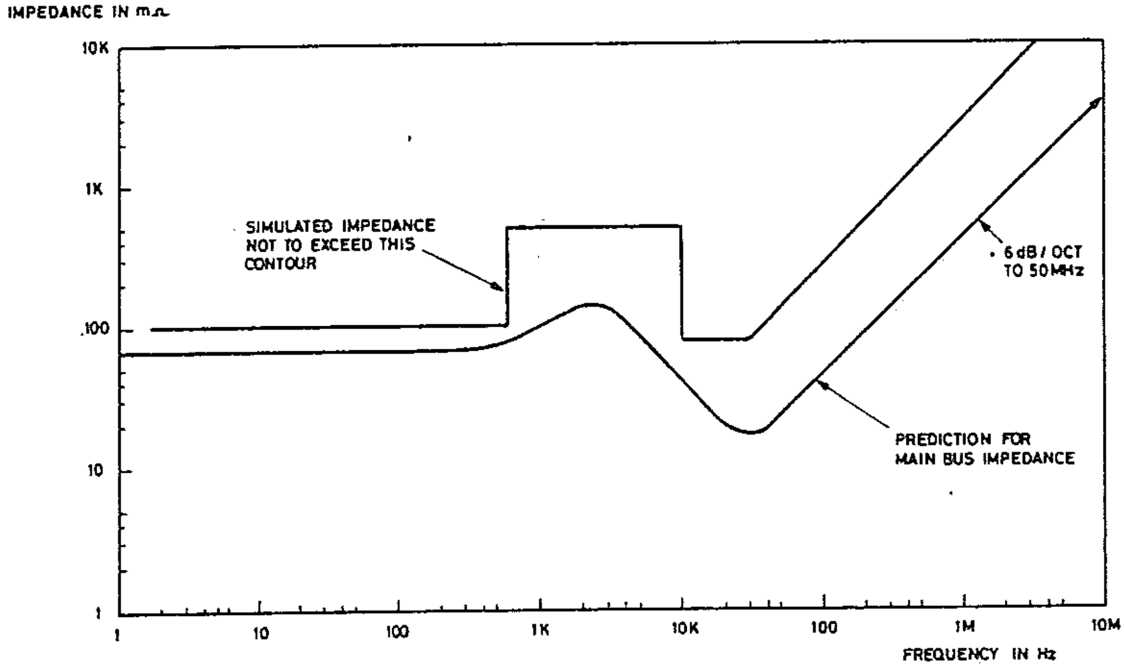


Figure A9. Satellite main bus impedance characteristics.

A5.1.5 The limits of this section are also applicable to any other type of electrical interface that is not specifically called up in the test. In case of difficulty, ESTEC is to be contacted for advice on which particular limits to apply to such an interface.

A5.2 REQUIREMENTS

A5.2.1 **Differential conducted emissions**

A5.2.1.1 *Primary power lines*

Within the band 20 Hz – 50 MHz, the differential noise appearing on all the positive or return

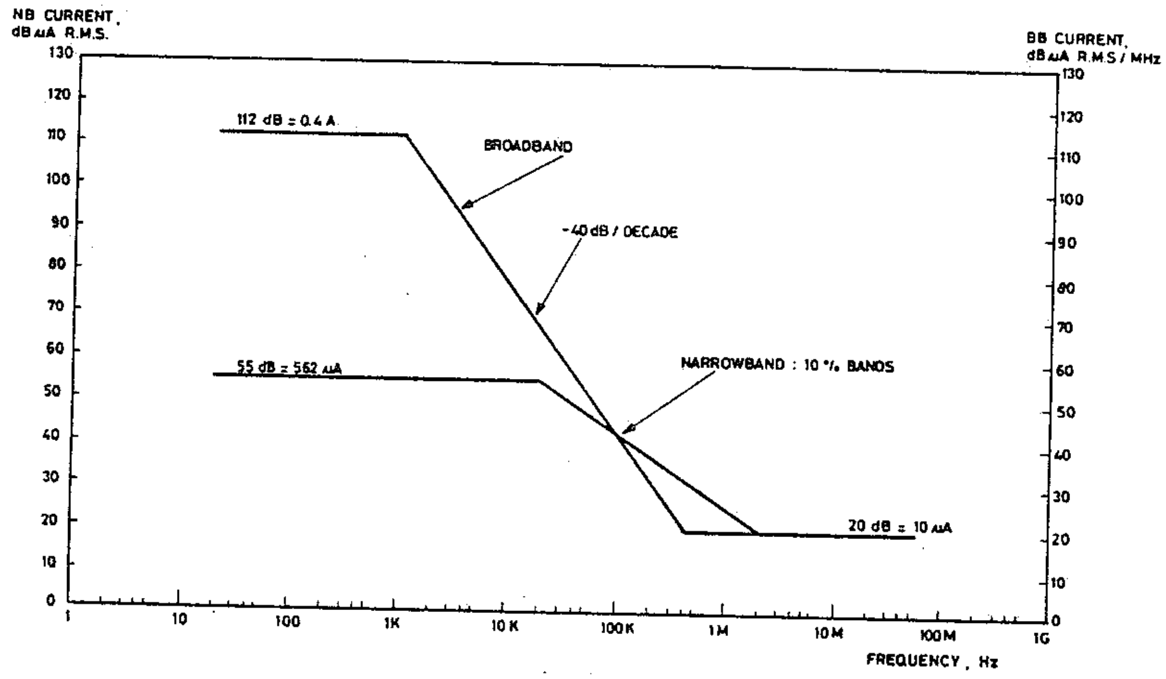


Figure A10. Primary power lines differential noise.

primary power lines, when loaded with an impedance of the characteristic shown in Figure A9, shall be within the following limits:

(a) Narrowband spectral conducted current: as shown in Figure A10. Measurement bandwidths, β, as defined on the Figure.
(b) Broadband spectral conducted current; as shown in Figure A10.
(c) Time domain conducted current ripple and spikes: not required.
(d) Time domain conducted voltage ripple and spikes shall be less than 280 mV pp.

A5.2.1.2 *Command and digital telemetry lines*

Within the band 20 Hz – 50 MHz the differential noise appearing on the positive or return command or digital telemetry lines, when each line is loaded with a shunt capacitance of 330 pF to telemetry return as shown in Figure A11, shall be within the following limits:

(a) Narrowband spectral conducted current: as shown in Figure A12. Measurement bandwidth, β, as defined on the Figure.
(b) Broadband spectral conducted current: not required.
(c) Time domain conducted current ripple and spikes shall be less than 10 μA pp.
(d) Time domain conducted voltage: not required.

These levels shall apply to digital lines in both logic '1' and '0' states. The time domain current limit of (c) also applies to the transition state between '1' and '0' or '0' and '1'.

A5.2.1.3 *Converter synchronisation lines*

Within the band 20 Hz – 50 MHz the differential noise appearing on the positive or return converter sync. lines, when loaded with a shunt capacitance of 330 pF as shown in Figure A11, shall be within the following limits:

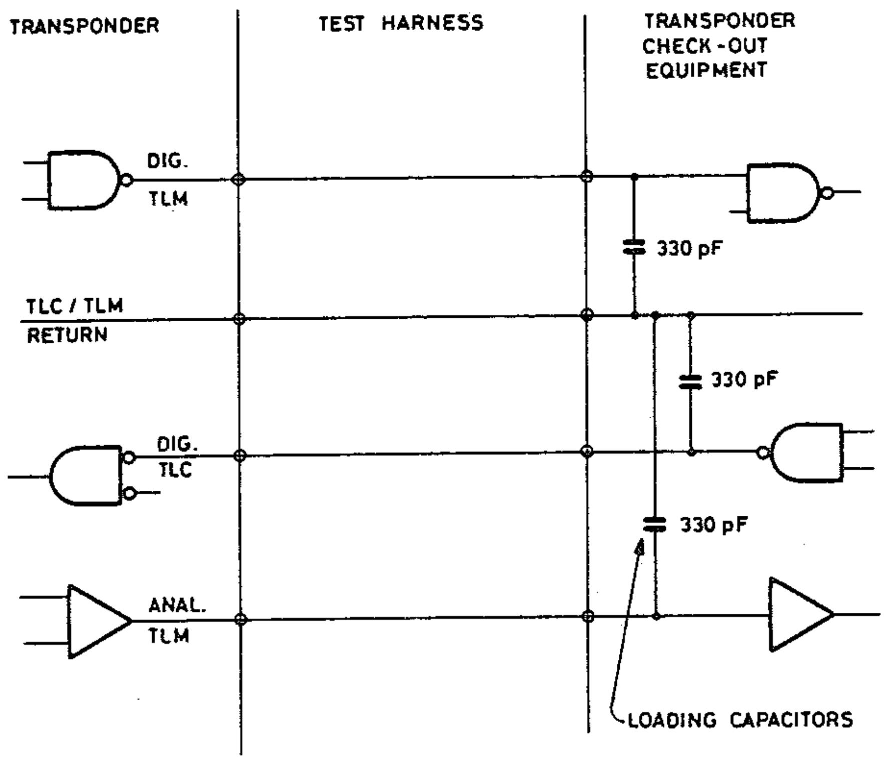


Figure A11. Capacitive loading of the command and telemetry lines.

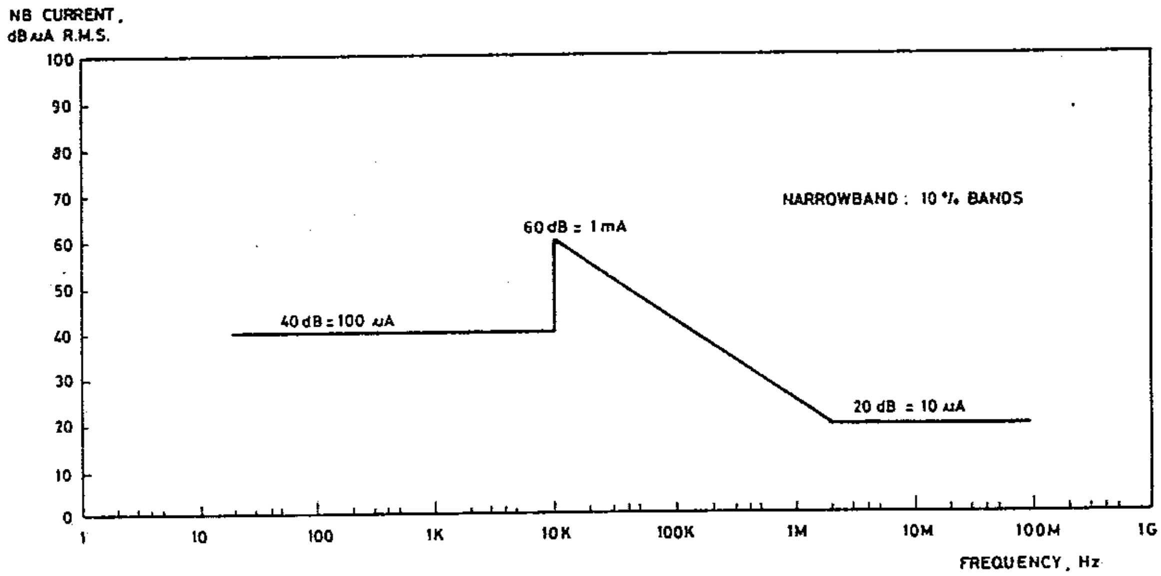


Figure A12. CMD clock and TLM differential noise.

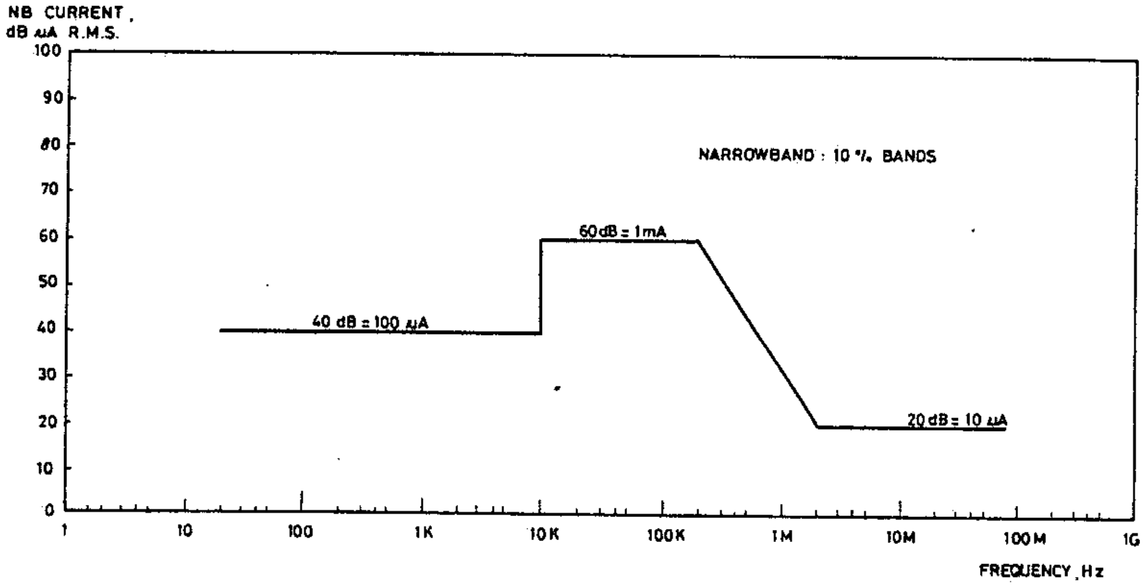


Figure A13. Converter synchro conducted noise.

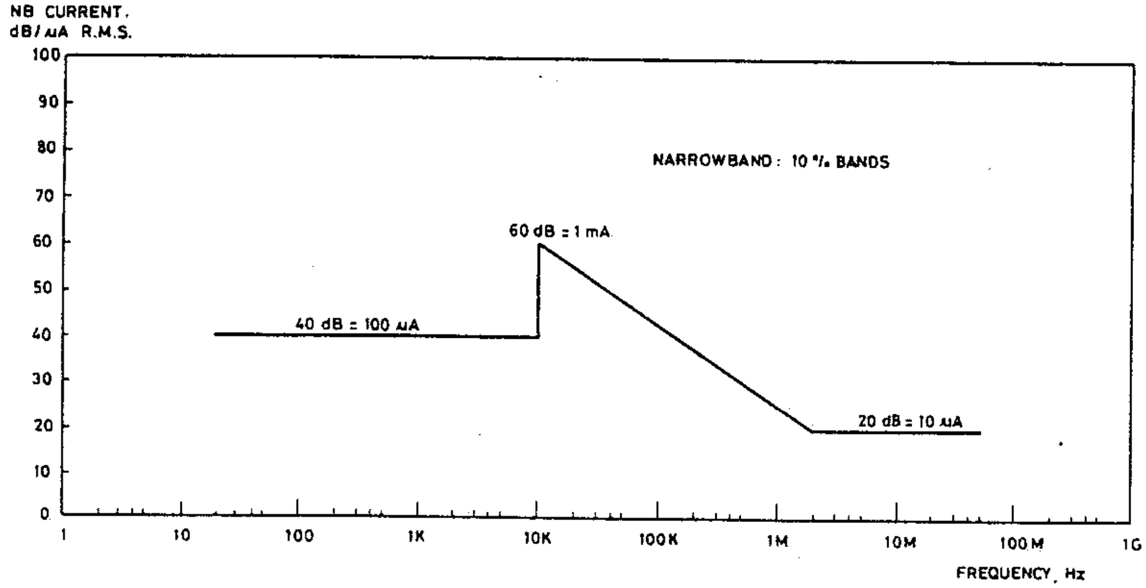


Figure A14. Analogue telemetry conducted noise.

(a) Narrowband spectral conducted current: as shown in Figure A13.
Measurement bandwidth, β, as defined on the Figure.
(b) Broadband spectral conducted current: not required.
(c) Time domain conducted current ripple and spikes shall be less than 10 μA pp.
(d) Time domain conducted voltage ripple and spikes shall be less than 300 mV pp.

These levels shall apply to the sync. input in both logic '1' and '0' states. The time domain current and voltage limits of (c) and (d) also apply to the transition state between '1' and '0' or '0' and '1'.

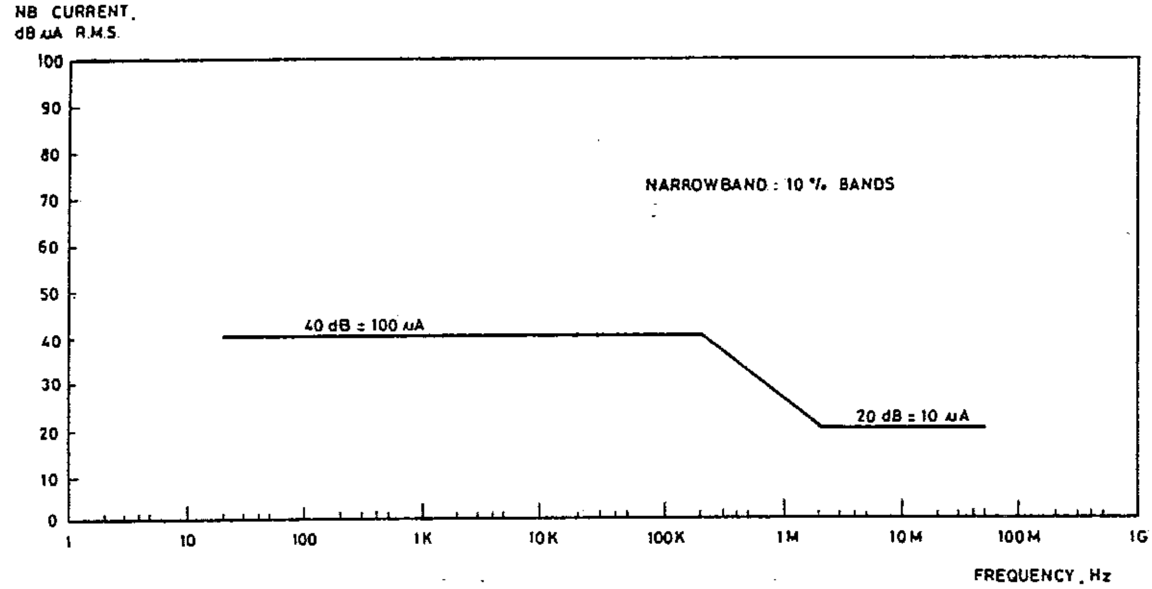


Figure A15. Primary power lines common mode noise.

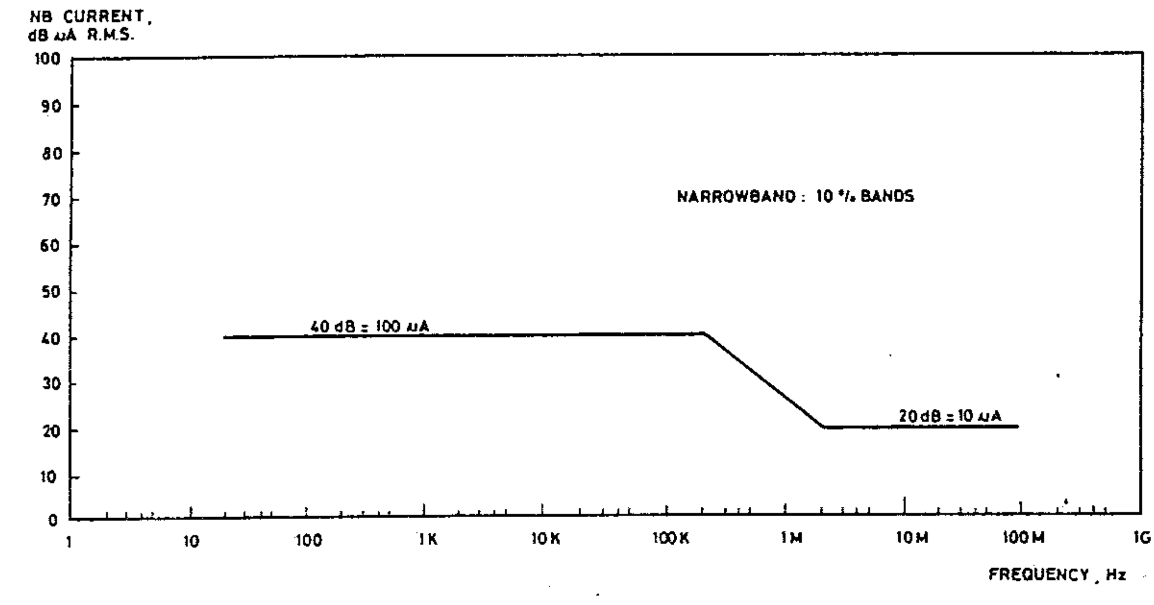


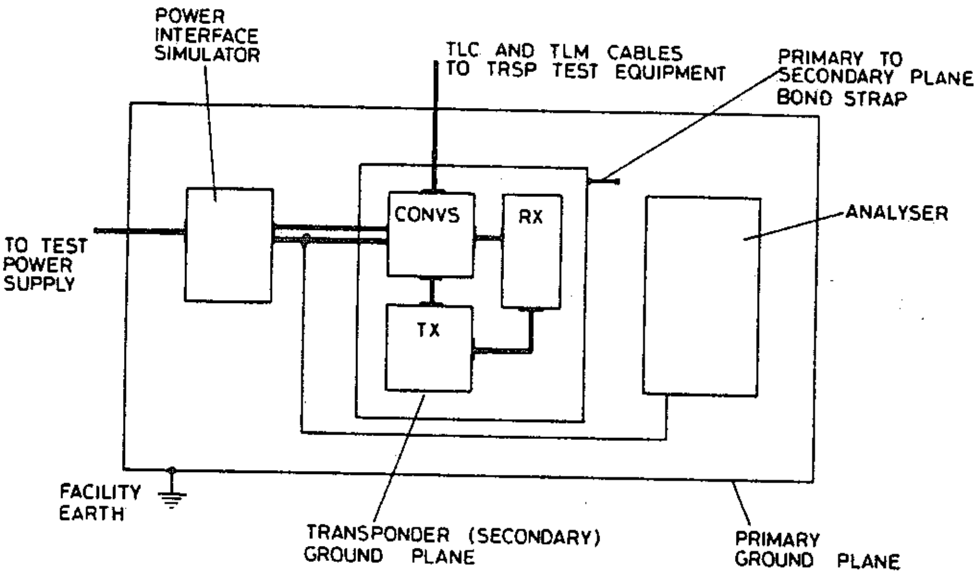
Figure A16. Common mode induced structure noise.

A5.2.1.4 *Analogue telemetry lines*

Within the band 20 Hz – 50 MHz the differential noise appearing on the positive or return analogue telemetry lines, when each line is loaded with a shunt capacitance of 330 pF to telemetry return as shown in Figure A11, shall be within the following limits:

(a) Narrowband spectral conducted current: as shown in Figure A14.
Measurement bandwidth, β, as defined on the Figure.

(b) Broadband spectral conducted current: not required.



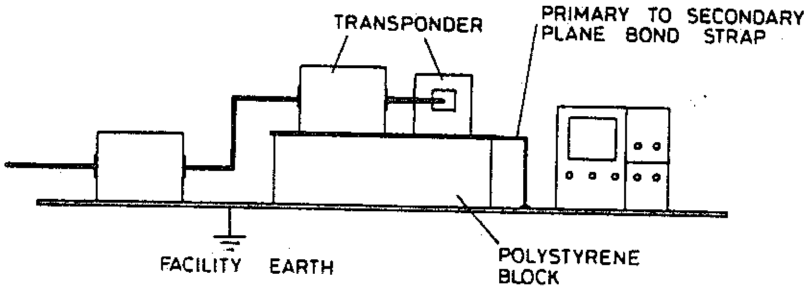


Figure A17. Conducted noise test setup — physical.

(c) Time domain conducted current ripple and spikes shall be less than 10 μA pp.

(d) Time domain conducted voltage ripple and spikes shall be less than 20 mV pp. (This should enable a system accuracy of 2% or better to be met.)

A5.2.2 **Common-mode conducted emissions**

A5.2.2.1 *Primary power lines*

Within the band 20 Hz – 50 MHz the common mode noise appearing on the primary power lines shall be within the following limits:

(a) Narrowband spectral conducted current: as shown in Figure A15.
Measurement bandwidths, β, as defined on the Figure.

(b) Broadband spectral conducted current: not required.

(c) Time domain conducted current ripple and spikes shall be less than 5 mA pp.
(d) Time domain conducted voltage ripple and spikes shall be less than 100 mV pp.

A5.2.2.2 *Command and digital telemetry lines*
Converter synchronisation lines
Analogue telemetry lines

There are no direct requirements stipulated for these lines.

A5.2.2.3 *Common mode induced structure noise* (as measured on the primary-plane to secondary-plane bond strap).

Within the band 20 Hz – 50 MHz the conducted noise appearing on the bond strap between the primary and secondary ground plane shall be within the following limits:

(a) Narrowband spectral conducted current: as shown in Figure A16.
Measurement bandwidths, β, as defined on the Figure.
(b) Broadband spectral conducted current: not required.
(c) Time domain conducted current ripple and spikes shall be less than 5 mA pp.
(d) Time domain conducted voltage ripple and spikes: not required.

A5.3 TEST METHODS

A5.3.1 Tests to determine the conducted noise emissions on power and signal lines shall be performed on the setup shown in Figures A17 and A18.

A5.3.2 The complete subsystem shall be mounted on secondary ground plane. Each experiment equipment case shall be bonded to the plane in the same manner as on the satellite and according to the bonding criteria set out in Para. A3.1. The primary power return shall be bonded to the primary plane at the impedance simulator. The bonds shall be proved by the methods set out in Para A3.2.

A5.3.3 The ancillary test equipment shall be mounted on the primary plane, and shall be ground-referenced to the plane and to no other point, care being taken to remove the normal connection of the instrument to the test facility ground in order to avoid ground loops.

The bonding criteria shall be those laid down in Para A3.1, and tests shall be made according to the methods described in Para 3.2.

Of course, large equipment need not be stood on the plane, but must be grounded to it.

A5.3.4 The primary plane shall be bonded to the test facility ground point.

A5.3.5 Differential noise current tests shall be made by clamping the current probe first round the positive lines and then round the return lines. The noise voltage tests shall be made between the positive and return lines.

A5.3.6 Common-mode noise current tests shall be made by clamping the current probe round the positive and return lines *together*. The voltage tests shall be made first between the positive lines and chassis and then between the return lines and chassis.

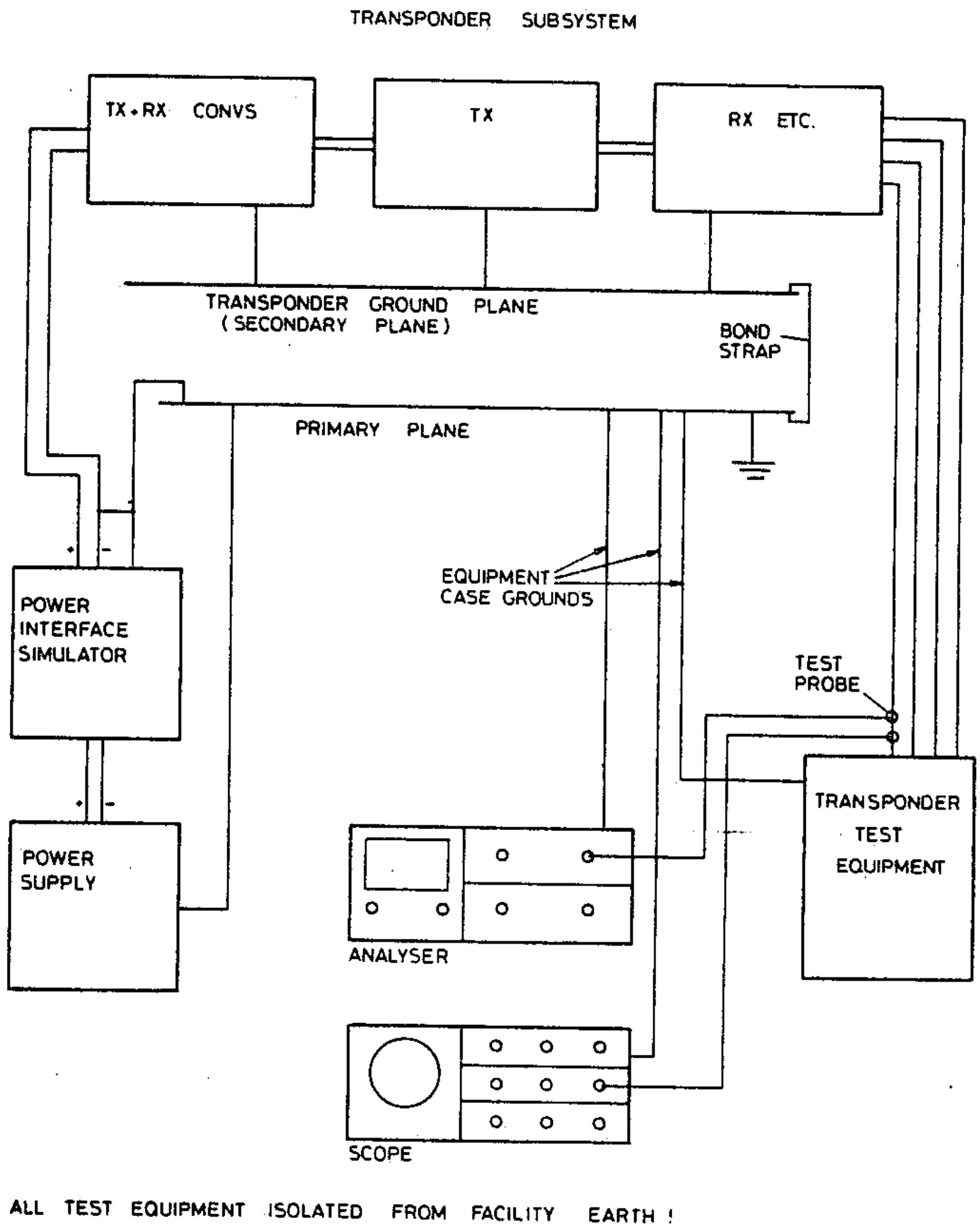


Figure A18. Conducted noise test setup — electrical.

A6. SUSCEPTIBILITY TO CONDUCTED NOISE ON POWER AND SIGNAL LINES

A6.1 GENERAL CONDITIONS

A6.1.1 This section is only to be applied to the complete transponder subsystem, i.e. TX, RX plus power converters, and not to individual pieces of equipment.

A6.1.2 The specification is only applicable at the interface between the transponder subsystem

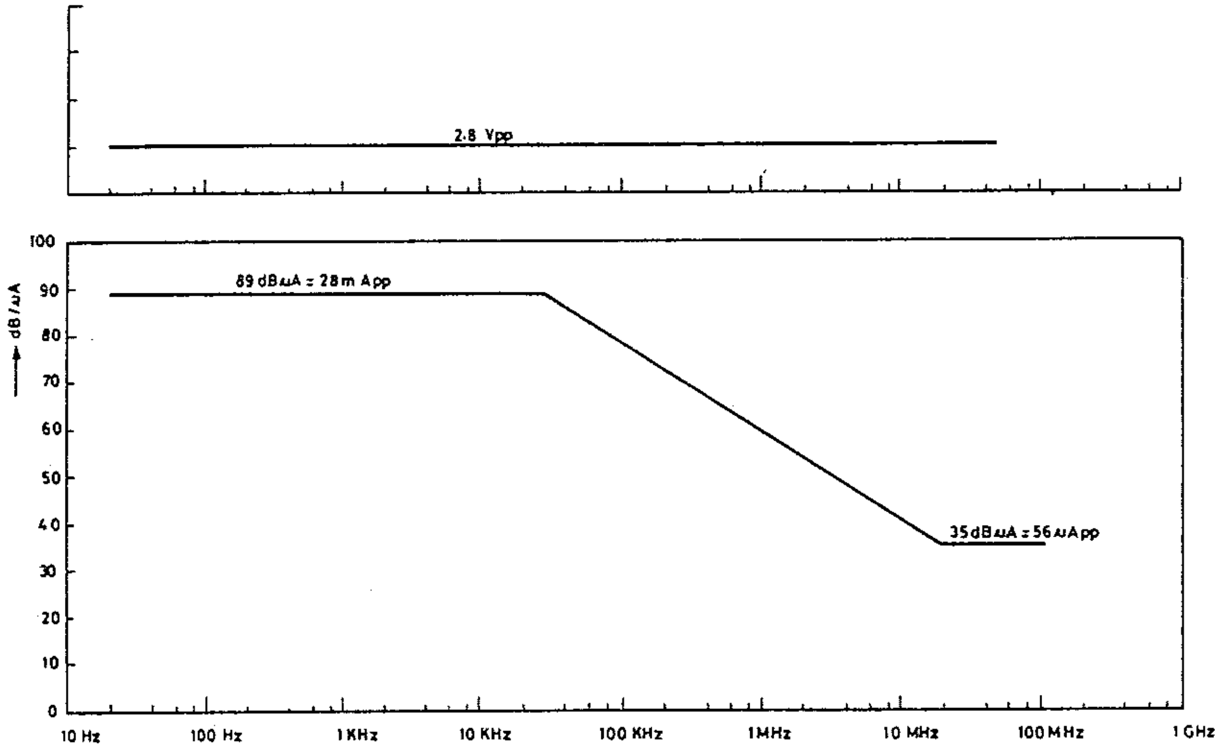


Figure A19. Limits for power-line susceptibility, voltage/current.

and the spacecraft system, e.g. at the satellite main power bus input. For example, it is not to be applied within the transponder.

A6.1.3 The specification is applicable to all operating modes of the transponder subsystem.

A6.2 REQUIREMENTS

The transponder subsystem shall not exhibit failures, malfunctions or unintended responses when any of the signals detailed below are injected on the specified lines. In most cases both a current and a voltage limit is given; whichever of these two limits is first reached shall constitute the test case.

A6.2.1 **Primary power lines**

A6.2.1.1 *Broadband noise and spikes*

A swept squarewave:

Amplitude:	peak-to-peak voltage of 10% of supply voltage or current limit of Figure A19, whichever is reached first.
Frequency:	20 Hz to 50 MHz p.r.f.
Markspace ratio:	1 to 1
Rise time:	$\leqslant$ 10 ns.
Fall time:	$\leqslant$ 10 ns.
Sweep rate:	1 decade/min.

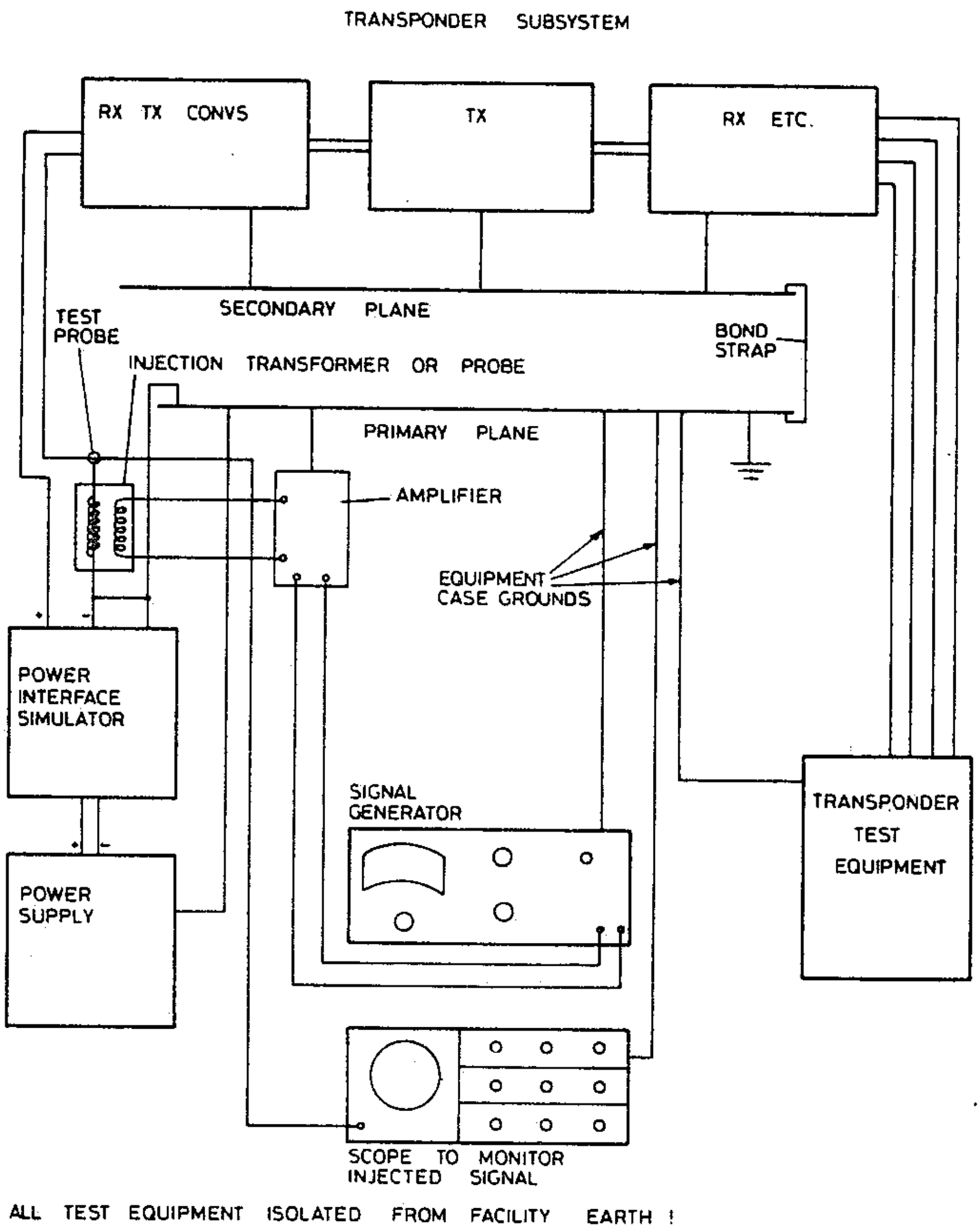


Figure A20. Conducted susceptibility test setup — electrical.

Test signal to be injected between:
(a) Primary power positive and primary power return
(b) Primary power return and structure.

A6.2.1.2 *For debugging of test failures only:*
A swept sinewave:
Amplitude: as A6.2.1.1
Frequency: 20 Hz – 100 MHz
Sweep rate: 1 decade/min.

A6.2.2 Telecommand inputs – command lines

The transponder shall not fail or respond when a voltage pulse train, of pulse width less than the standard command pulse width, is injected between positive and return on any command input.

The details of the pulse train shall be:

Frequency:	20 Hz, 1 kHz, 38.8 kHz, 116.5 kHz, 194 kHz, 500 kHz, 1 MHz, 50 MHz
Pulse width:	20 ns, 200 ns, 2 μs, 20 μs at each frequency step, when allowed by p.r.f. period and consistent with 50% duty cycle.
Rise time:	⩽10 ns
Fall time:	⩽10 ns
Amplitude:	+5 V pk

A6.2.3 Telemetry outputs

There is no requirement stipulated for telemetry output lines.

A6.3 TEST METHODS

A6.3.1 For the susceptibility tests defined in Para A6.2, the electrical test setup shown in Figure A20 shall be used. The physical setup is the same as that referred to in Para A5.3, i.e. as shown in Figure A17, with the addition of the injection transformer.

A6.3.2 The setup criteria set out in Paras A5.3.2, 3 and 4 shall apply here also.

A6.3.3 The appropriate signal shall be injected into the specified lines and the resultant noise current and voltage monitored on the line under test. The injected level shall be increased at each frequency until either the specified current or voltage level is reached.

If the transponder fails the test, the injected signal level shall be reduced until it passes. This level shall be noted.

A7. STATIC ('DC') MAGNETIC FIELD EMISSIONS

A7.1 REQUIREMENTS

A7.1.1 The equipment shall be depermed, in the de-energised state, with a field of 50 Oe at 3 Hz for 10 min, in each of the three orthogonal axes. After this the maximum DC magnetic field for the energised, but quiescent, equipment shall not exceed 0.4 nT when measured at any point one metre from the equipment's C of G.

The value so obtained is the combined level of perm field plus stray field.

NOTE: If hot spots are detected in an equipment, this equipment shall be depermed by 100 Oe/3 Hz/10 mins in each axis, provided that no permanent magnets have been intentionally used in the construction, e.g. in a latching relay.

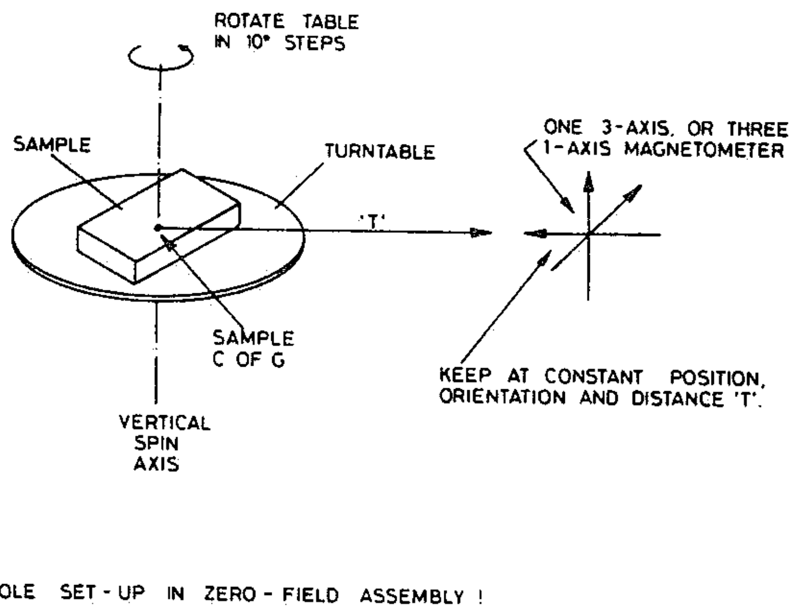


Figure A21. DC magnetic field test setup.

A7.1.2 After the depermed, de-energised equipment has been exposed to a 30 Oe DC perm field along an axis, the maximum DC magnetic field for the energised, but quiescent, equipment shall not exceed 20 times the limit set in Para. A7.1.1, i.e. 8 nT for the permed state. This shall apply for perming in each of the three orthogonal axes.

A7.2 TEST METHODS

A7.2.1 Tests shall be performed on the test setup shown in Figure A21.

A7.2.2 The sample's C of G is to be aligned with the table axis. The table is rotated in 10° steps and the field levels for each magnetometer axis are recorded at each step.

A7.2.3 Data required by ESTEC:
- magnetometer readings at each 10° step
- distance, *r*, between table axis and magnetic centre of magnetometers
- height, *h*, between plane of table and magnetometer centres
- height, *d*, between plane of table and sample's C of G.

A7.2.4 The zero field shall be checked before and after each measurement. If the drift is greater than 2 nT the measurement of the sample shall be repeated.

A8. AC MAGNETIC FIELD EMISSIONS

A8.1 REQUIREMENTS

A8.1.1 No formal requirements are stipulated for AC magnetic field-emission levels (see Annex for rationale).

A8.1.2 A 'sniff' test shall be made over the transponder with an AC magnetic search probe as a means of qualitatively detecting leaks in the equipment shielding case and 'hot spots' within the equipment.

A8.1.3 The 'sniff' test requirements shall be:

Frequency:	20 Hz to 20 kHz
Bandwidth:	nominally 10%, but selected to suit spectrum detail, analyser, etc.
Probe-to-box separation:	approx. 5 cm, but constant
Probe orientation relative to box:	to give max. analyser level, but constant for each test
Scan:	whole surface of each box, paying particular attention to joints and connectors
Criterion:	$> \pm 3$ dB amplitude change at any frequency to be explained.

A8.1.4 Any leaks or hot spots found shall be rectified before delivery of the transponder.

A8.1.5 In order to provide permanent visual evidence of the box RF tightness, photographs shall be taken of the analyser traces for, as a minimum, the probe in front of each of the box faces.

A8.2 TEST METHODS

A8.2.1 For tests, the test setup shown in Figure A22 shall be used.

A8.2.2 With the probe at a constant distance from the box and the plane of the probe coil at a constant orientation to the box surface, the probe shall be moved slowly over the entire box surface while the analyser trace is observed for level changes.

A9. AC ELECTRIC FIELD EMISSIONS

A9.1 REQUIREMENTS

A9.1.1 There are no formal requirements stipulated for AC electric field emission levels (see Annex for rationale).

A9.1.2 A 'sniff' test shall be made over the transponder with an AC electric search probe as a means of qualitatively detecting leaks in the equipment shielding case and 'hot spots' within the equipment.

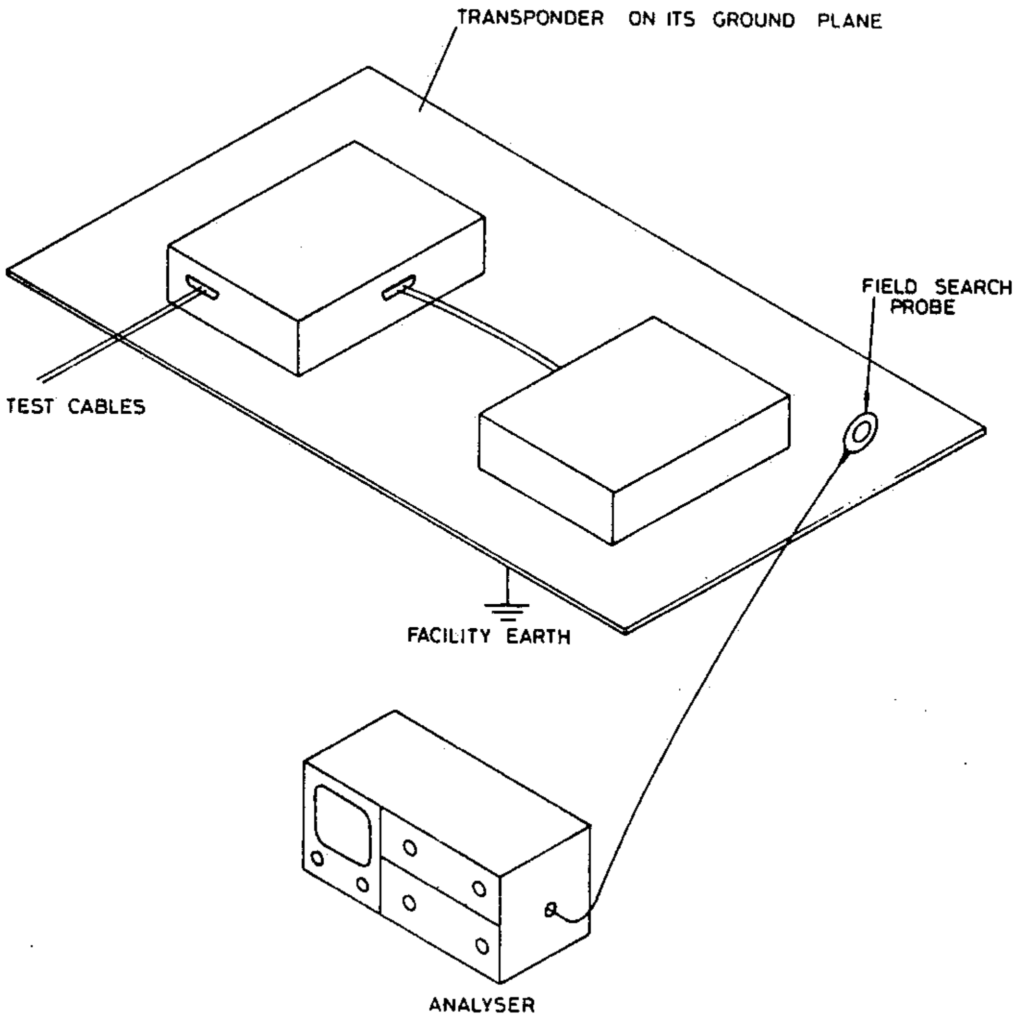


Figure A22. Test setup for radiated-field sniff tests.

A9.1.3 The 'sniff' test requirements shall be:

Frequency:	14 kHz – 500 MHz
Bandwidth:	nominally 10%, but selected to suit spectrum detail, analyser etc.
Probe-to-box separation:	approx. 5 cm but constant
Scan:	whole surface of box, paying particular attention to joints and connectors
Criterion:	$> \pm 3$ dB amplitude change at any frequency to be explained.

A9.1.4 Any leaks or 'hot spots' found shall be rectified before delivery of the transponder.

A9.1.5 In order to provide permanent visual evidence of the box RF tightness, photographs shall be taken of the analyser traces for, as a minimum, the probe in front of each of the box faces.

A9.2 TEST METHODS

A9.2.1 For the tests, the methods set down in Paras A8.2.1 and A8.2.2 shall be applied, the magnetic probe being replaced by an electric probe.

A10. SUSCEPTIBILITY TO RADIATED AC MAGNETIC FIELDS

There is no formal specified requirement for immunity to AC magnetic fields or for tests (see Annex for rationale).

A11. SUSCEPTIBILITY TO RADIATED AC ELECTRIC FIELDS

There is no formal specified requirement for immunity to AC electric fields or for tests (see Annex for rationale).

A12. ANTENNA-CONDUCTED SPURIOUS EMISSIONS

The test methods and limits for CE06 of MIL-STD-462 31.7.67 shall apply.

A13. LAUNCH VEHICLE COMPATIBILITY

A13.1 ARIANE

The relevant passages from the Ariane Users' Manual are reproduced below. Levels expressed in terms of fields in the Users' Manual have been converted to power on the assumption of 0 dBi antenna gain and near-field conditions. The transponder should not generate at its antenna terminals powers in excess of those shown below.

1) In Ariane Telecommand Band:
   f_c is in 400 MHz band, probably 450 MHz
   Between f_c and ± 0.5 MHz, -110 dBm in 200 kHz B.W.
   Between ± 0.5 MHz and ± 1 Mhz, -95 dBm in 100 kHz B.W.
   Between ± 1 MHz and ± 2 MHz, -75 dBm in 100 kHz B.W.
   Between ± 2 MHz and ± 3 MHz, -60 dBm in 100 kHz B.W.
2) In Ariane Radar Reception band, 5690 MHz ± 50 MHz, -82 dBm in 20 MHz.
3) Discrete lines at other frequencies (see Figure A23(a)). Spacecraft transmit bands are excluded.
4) Wide band noise at other frequencies. See Figure A23(b).

A13.2 DELTA

There are no formal requirements other than general EMC which is covered by other parts of this specification.

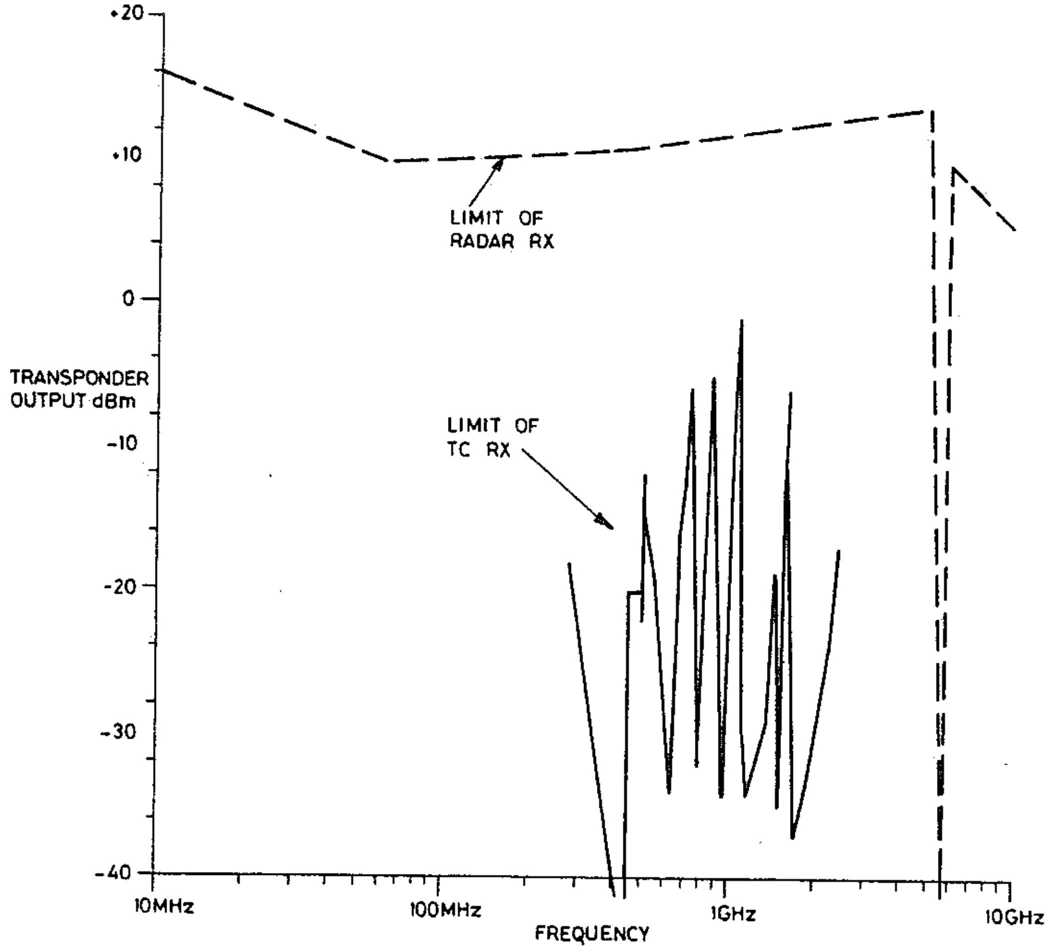


Figure A23(a). Narrowband limits for compatibility with Ariane.

A13.3 SHUTTLE

There are no formal requirements other than general EMC which is covered by other parts of this specification. Shuttle payloads are assumed to keep their transmitters off until separation.

A14. INTERMODULATION SUSCEPTIBILITY OF RECEIVER

The test methods and limits of MIL STD 462 Notice 3 Method CS03 shall apply.

A15. REJECTION OF UNDESIRED SIGNALS AT ANTENNA INPUT TERMINALS

The test methods and limits of MIL STD 462 Notice 3 Method CS04 shall apply.

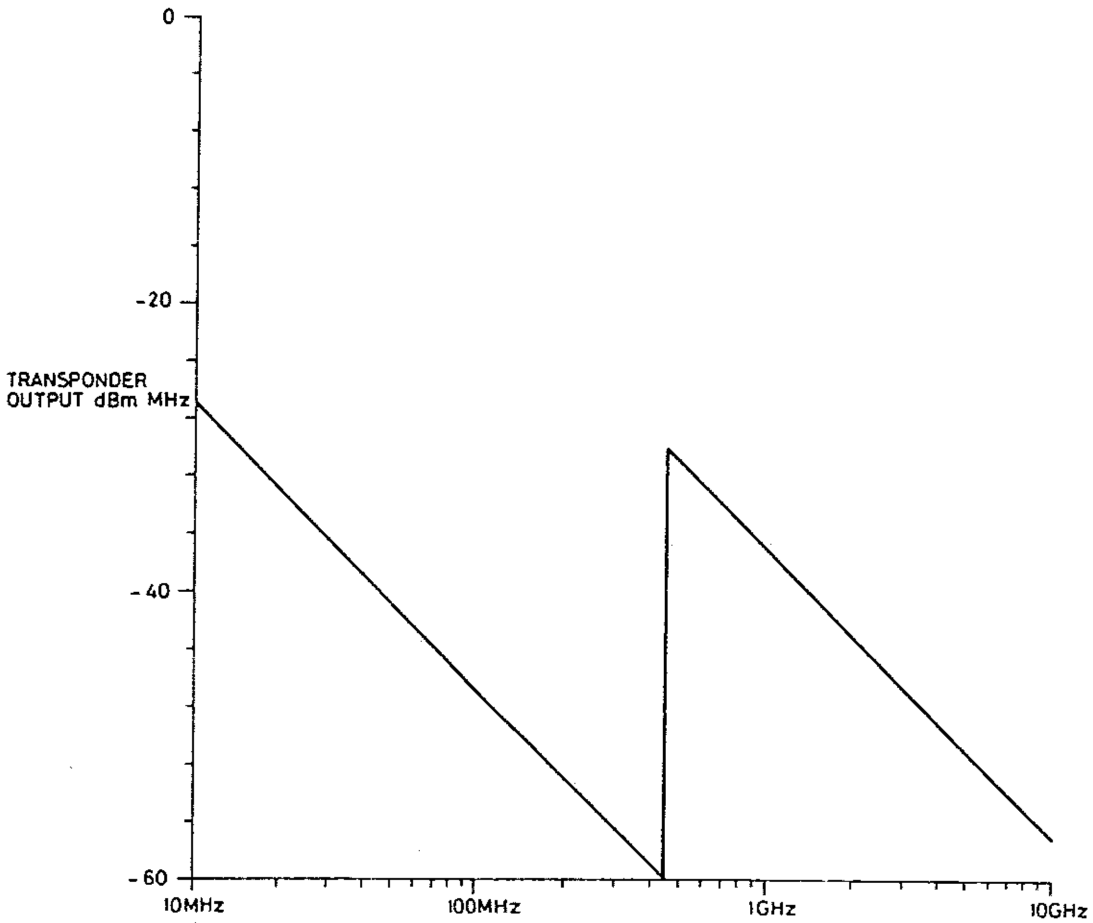


Figure A23(b). Broadband limits for compatibility with Ariane.

A16. CROSS MODULATION

The test methods and limits of MIL STD 462 31.7.67 Method CS05 shall apply.

A17. TEST EQUIPMENT

A17.1 EQUIPMENT LIST

The tests specified in this procedure are to be performed with the aid of the following equipment, or equipment of equivalent performance.

A.17.1.1 **Primary ground plane**

Material:	copper or brass
Minimum thickness:	0.25 mm for copper 0.60 mm for brass
Minimum area:	2.25 m^2
Finish:	clean material; untreated

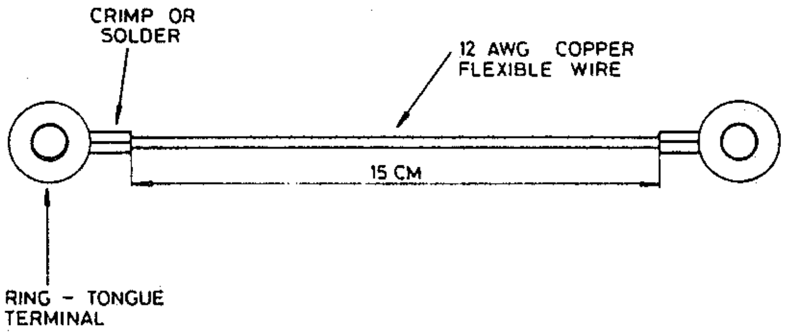


Figure A24. Ground plane bond strap.

A17.1.2. **The secondary ground plane is the transponder chassis**

This chassis shall have a single bond strap attached to it to enable it to be single point grounded to the primary plane. This strap is defined in Figure A24.

A17.1.3 **Expanded polystyrene block to support transponder**

Thickness:	10 cm minimum
Surface area:	that of the secondary plane

A17.1.4 **Expanded polystyrene blocks to support the test cable forms off the ground planes.**

Thickness:	5 cm minimum
Surface area:	as suitable for cable forms

A17.1.5 **Main bus impedance simulator**

See Para. A17.2.2 for details

A17.1.6 **Signal interface shunt loading capacitors**

Capacitance:	330 pF ± 20%
Type:	ceramic
Voltage:	10 V DC working minimum

A17.1.7 **Spectrum analyser**

HP 141T main frame plus plug-in units:
HP 8556A tuning section, 30 Hz to 300 kHz
HP 8553B tuning section, 1 kHz to 110 MHz
HP 8552B IF section

or: equivalent system, 20 Hz to 100 MHz.

A17.1.8 **Oscilloscope**

Tektronix 546 main frame plus two 1A4 differential input plug-in amplifiers, or: equivalent system, DC to 50 MHz.

A17.1.9 **Current probes**
Tektronix P6042
or: equivalent, 20 Hz to 50 MHz.

A.17.1.10 **Voltage probes**
Tektronix P6008
or: equivalent, DC to 50 MHz, capacitance matching.

A.17.1.11 **Square wave generator/sine wave generator**

HP 200CD	5 Hz to 600 kHz	sine wave
plus HP 606B	50 kHz to 65 MHz	
HP 8007B	square wave	
or: equivalent system	– 20 Hz to 50 MHz continuously variable	
	– rise and fall times $\leqslant$ 10 ns	
	– 1 : 1 mark/space ratio	
	– $\geqslant$5 V pp output into 50 Ω	

A17.1.12 **Pulse generator**

HP 8007B	
or: HP 8013B	
or: equivalent system	– 20 ns to 20 μs pulse width, continuously variable
	– rise and fall times $\leqslant$ 10 ns
	– 20 Hz to 50 MHz p.r.f., continuously variable
	– 0 to 5 V pp output, continuously variable, into 10 kΩ

A17.1.13 **Amplifier**

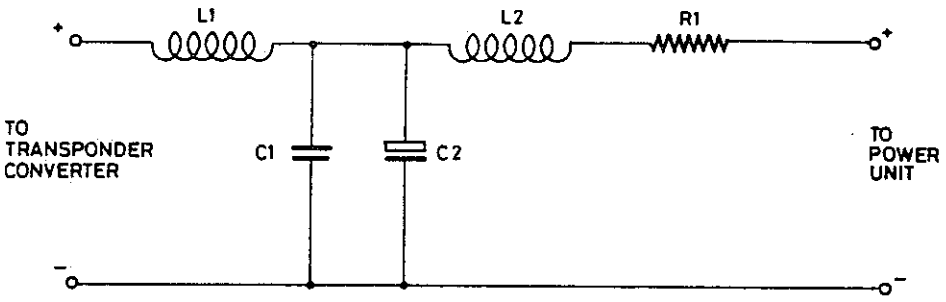
HP 467A	20 Hz to 1 MHz
Plus HP 461A	1 kHz to 150 MHz
or: equivalent system	– 20 Hz to 150 MHz
	– $\geqslant$ 10 × gain (20 dB), continuously or step variable
	– 50 Ω input inpedance
	– $\leqslant$ 50 Ω output impedance

A17.1.14 **Isolation/injection transformer**

Solar 6220 - 1A	20 Hz – 250 kHz
plus Tektronix P6022 current probe	
	935 Hz – 150 MHz

Note: When driven with a signal, a current probe can be used as an injection transformer,
or: equivalent system, 20 Hz to 150 MHz.

CIRCUIT :



L1 : 77 nH ± 10 % 8 TURNS OF 18 AWG ENAMELLED COPPER WIRE ON AN 8 mm. DIAM. AIR-CORED FORMER

L2 : 10.5 μH ± 10 % 5 1/2 TURNS OF 18 AWG ENAMELLED COPPER WIRE ON AN ITT C18-315-SA500L FERRITE POT CORE WITH AIR GAP

R1 : 67 mΩ ± 10 % NON-INDUCTIVE (BIFILIAR) WOUND.

C1 : 1 μF ± 10 %, 35 VDC CERAMIC

C2 : 376 μF ± 10 %, 35 VDC DRY TANTALUM (= 8 x 47 μF IN PARALLEL)

Figure A25. Power interface simulator.

A17.1.15 **Resistive isolation tester**

Marconi TF 2700

or: equivalent, – 10 Ω to 100 MΩ
– ⩽10 V pp working voltage
– ± 5% accuracy

A17.1.16 **Capacitance bridge**

Marconi TF 2700

or: equivalent – 100 pF to 100 nF
– ± 5% accuracy
– ⩽ 10 V pp working signal

A17.1.17 **DC bonding meter**

Shallcross 673A or 673D

or: equivalent – 0.5 mΩ to 50 mΩ
– ± 5% accuracy
— ⩽ 10 V pp working voltage

A17.1.18 **DC power source**

— 28 V ± 1%

— emitted 10% bandwidth noise less than 20 dB μA RMS across the band 20 Hz to 50 MHz.

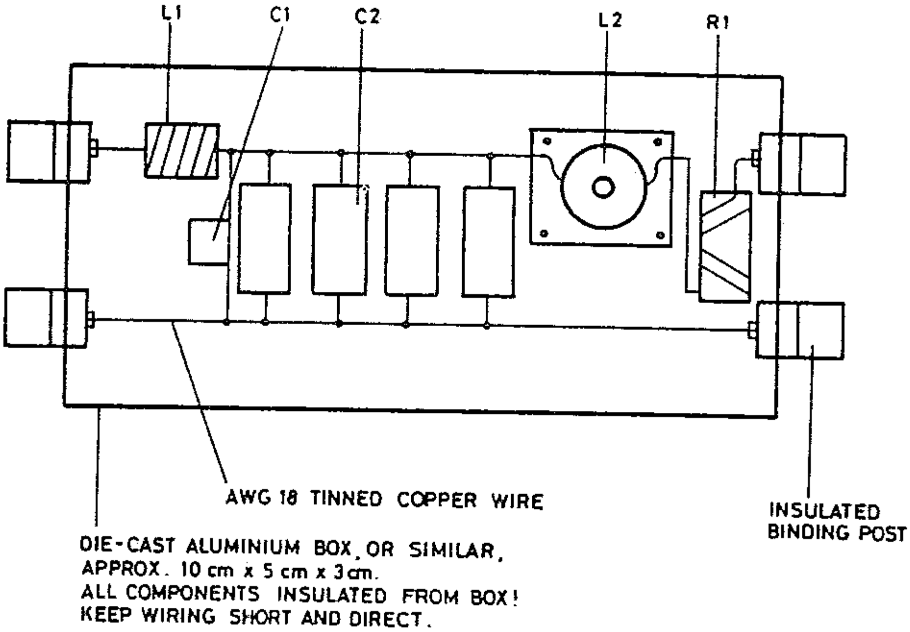


Figure A26. Simulator construction.

A17.1.19 **AC magnetic field search probe**
Fairchild MFA-25
or: equivalent 20 Hz to 20 kHz

A17.1.20 **AC electric field search probe**
Singer EFP-25
or: equivalent 14 kHz to 500 MHz.

A17.2 DETAILS OF SPECIAL EQUIPMENT POWER INTERFACE SIMULATOR

This unit is designed to simulate the impedance of the spacecraft main bus as seen by any equipment converter in the band of interest.

The circuit and component details are given in Figure A25. Figure A26 shows a suggested construction.

Whatever construction is actually used, the important points are:

- inductors L1 and L2 have to carry a DC current of 2 A.
- the component layout on the circuit board should follow the theoretical circuit so that the required impedance curve may be closely followed.

A18. TEST FACILITIES

A18.1 CONDUCTED EMISSION, CONDUCTED SUSCEPTIBILITY, BONDING AND ISOLATION TESTS

These tests may be performed in any normal electronics laboratory; a special shielded chamber is not required.

A18.2 AC ELECTRIC AND AC MAGNETIC FIELD TESTS

These tests may be performed in any normal electronics laboratory, unless at the time the ambient noise proves to be too high for a meaningful test to be done.

A18.3 DC MAGNETIC FIELD TESTS

These tests require a special facility designed for magnetic testing.

The minimum performance specification for the facility shall be:

(a) Capability to create a 'zero field' with a sphere of homogeneity of radius $\geqslant 1$ m.
(b) Stability of 'zero field' to be better than ± 2 nT during any single measurement.
(c) Ambient field stability better than ± 2 nT.
(d) Instrumentation resolution better than 0.1 nT.
(e) Positioning error of the sample and the magnetometers to be less than $\pm 1.5\%$.
(f) The sphere of homogeneity of the perm/deperm field shall have a radius $\geqslant 0.5$ m.

A19. BANDWIDTH CONVERSIONS

A19.1 The spectral requirements of this specification have been given in terms of 10% bandwidths, i.e. a bandwidth of 10% of the centre frequency. This is because the limits are derived from the requirements of ISEE-CFE-0163/A which uses this convention, and because conversion to any other bandwidth, e.g. 1 Hz, will not remove the need to convert to actual analyser bandwidths during testing.

A19.2 In order to convert the specified limits to other bandwidths, or vice-versa, it shall be assumed that all noise is impulse noise and therefore coherent, and that furthermore the separate impulses are also coherent.

Hence the level in volts or amperes (or dB μV, dB μA) is directly proportional to bandwidth, as long as the line spacing is less than the conversion bandwidth.

Thus to convert, for example, a level at 100 Hz bandwidth to an equivalent at 1 kHz bandwidth:

$$\mathrm{dB}\,\mu\mathrm{A}_{1\,\mathrm{kHz}} = \mathrm{dB}\,\mu\mathrm{A}_{100\,\mathrm{Hz}} + 20\log\left(\frac{1\,\mathrm{kHz}}{100\,\mathrm{Hz}}\right)$$

As long as the line spacing at 100 Hz bandwidth is less than 1 kHz; otherwise the levels are the *same* at *both* bandwidths.

or:

$$\mu\mathrm{A}_{1\,\mathrm{kHz}} = \mu\mathrm{A}_{100\,\mathrm{Hz}}\left(\frac{1\,\mathrm{kHz}}{100\,\mathrm{Hz}}\right)$$

A20. PROCEDURES AND REPORTS

A20.1 TEST PROCEDURES

The contractor shall provide a written test procedure for the transponder. This shall contain, as a minimum, the following information in the order shown:

(1) List of contents
(2) Applicable documents.
(3) Purpose of test.
(4) Test sample excitation and performance monitoring.
(5) Test cables.
(6) Dummy loads.
(7) Power supplies.
(8) Grounding and bonding during tests.
(9) Procedures for each test stating:
   - applicability
   - test setup
   - limits and frequency range
   - operating procedures for the experiment operating and monitoring equipment
   - transponder operating modes
   - test pass/fail criteria.

A20.2 TEST REPORTS

In order to provide a degree of uniformity and facilitate the analysis and review of results by ESTEC, the contractor shall produce a test report containing, as a minimum, the following information in the order shown:

(1) List of contents.
(2) Introduction and purpose of tests.
(3) Modifications to the procedure.
(4) Summary of results, including any modifications made to the experiment hardware as a result of the tests.
(5) Conclusions.
(6) Detailed review of results on a test-by-test basis, giving:
   - test setup
   - collated and reduced results (graphs etc.)
   - problems encountered with corrective actions.
(7) Working copy of procedure.
(8) Originals of chart recording and photographs.

ANNEX TO APPENDIX A

RATIONALE FOR THE TYPE OF REQUIREMENTS AND TEST SPECIFIED

In this specification we have endeavoured to impose such requirements as will ensure that the transponder can be used on a wide variety of spacecraft. Of necessity such spacecraft will range from those with very light noise-emission requirements, such as ISEE-B, to those that provide a relatively severe noise environment for subsystems, such as Exosat and OTS. The latter will affect the susceptibility requirements. Thus, the end result is a specification with (apparently) very wide discrepancies between emission and susceptibility requirements, but this is unavoidable.

In addition we have endeavoured to impose what is necessary and useful whilst omitting those requirements that are either completely irrelevant or marginally valuable. We have also conditioned the requirements with the practicalities of what can be realistically tested.

Hence, starting from the basic ISEE-B system requirements of:

- very low structure noise
- very low radiated fields

we can state that:

- it is important to control the noise currents injected into the equipment chassis via stray capacitances and resistances. This has led to requirements on common mode conducted noise and structure noise, and to a special test setup utilising a double ground plane that allows the structure noise to be measured directly;
- it is important to control box radiations; but it also is difficult (and hence costly) to make a test setup that eliminates the test cable radiations and allows one to 'see' the box. It is more efficacious to make sure by visual inspection and electrical bonding tests that the box is completely closed and to leave radiated tests to system level when we can obtain the box plus spacecraft harness fields together, this being what is finally required anyway. A 'sniff' test with a small uncalibrated probe suffices to give final confidence in a box at box level.

It should also be borne in mind that at system level most radiation comes from the harness and that this is controlled by:

- limiting the conducted noise on the harness
- properly designing the harness.

A test of susceptibility to radiated noise has been omitted, because, if a subsystem has a radiated noise susceptibility problem, this is primarily due to the fact that it has a conducted noise susceptibility problem on its interface cables. This is because the harness acts as an antenna and converts the radiated noise to conducted noise; hence a specification covering susceptibility to conducted noise can cover susceptibility to radiated noise as well.

The slight chance of radiation going directly into the box is removed by ensuring that the box is adequately shielded, bonded and grounded.

APPENDIX B

VIBRATION AND ACCELERATION LEVELS

For the Delta vehicles these levels are now reasonably well documented, but for Ariane and Shuttle the levels are estimates which cannot be confirmed until test flights have taken place.

It is felt that, of the three launch vehicles, Ariane represents the severest environment and the transponder should be designed to comply with this. The Delta levels are given for comparison.

VIBRATION

DELTA SINUSOIDAL VIBRATION

Acceptance Levels:

Thrust axis	5 – 7.5 Hz:	12 mm D.A.
	7.5 – 15 Hz:	2.3 g
	15 – 21 Hz:	6.8 g
	21 – 100 Hz:	17 g
Lateral axis	5 – 14 Hz:	12 mm D.A.
	14 – 100 Hz:	6.0 g

Qualification Levels:

Thrust axis	5 – 7.5 Hz:	18 mm D.A.
	7.5 – 15 Hz:	3.5 g
	15 – 21 Hz:	10.2 g
	21 – 100 Hz:	25.5 g
Lateral axis	5 – 14 Hz:	18 mm D.A.
	14 – 100 Hz:	9.0 g

RANDOM VIBRATION (all 3 axes)

Acceptance Levels:

20 – 300 Hz +4 dB/oct up to 0.06 g^2/Hz)	$g_{RMS} = 8.3$
300 – 700 Hz 0.06 g^2/Hz	
700 – 2000 Hz –3 dB/oct	

Qualification Levels:

20– 300 Hz	+4 dB/oct up to 0.135 g^2/Hz	$g_{RMS}=13.1$
300– 700 Hz	0.135 g^2/Hz	
700–2000 Hz	−3 dB/oct	

ARIANE SINUSOIDAL VIBRATIONS

Thrust Axis	*Acceptance*	*Qualification*
5– 10 Hz	12 mm. D.A.	18 mm. D.A.
10– 34 Hz	12 g	18 g
34–2000 Hz	17 g	26 g

Lateral Axis	*Acceptance*	*Qualification*
2– 4 Hz	12 mm. D.A.	18 mm. D.A.
4– 17 Hz	13 g	18 g
17–200 Hz	6 g	9 g

Random Vibrations (All Axes)	*Acceptance*	*Qualification*
3–2000 Hz	0.075 g^2/Hz	0.15 g^2/Hz

DELTA ACCELERATION

	Acceptance	*Qualification*
Thrust axis	Not applicable	25.5 g
Lateral axes		6.2 g

ARIANE ACCELERATION

Thrust axis		8 g
Lateral axes		6.2 g

APPENDIX C

CANCELLATION EFFECTS IN THE PHASE ERRORS RESULTING FROM THE TRACKING OF LOW-FREQUENCY RANGE TONES BY THE PLL OF A COHERENT S-BAND TRANSPONDER

The phase relationships in the S-Band Transponder are shown in Figure C1. We can write the relationships as follows:

$$\theta_{in} - 104\,\theta_x = \theta_{If1}$$

$$\theta_{If1} - 6.5\,\theta_x + 0.5\,\theta_o = \theta_{If2}$$

$$\theta_{If2} - 0.5\,\theta_o = \theta_{video}$$

$$\theta_{video} = \theta_{in} - 110.5\,\theta_x$$

Even if there are various phase delays in the IF the final result will still be true.

Treating the receive chain as a simple receiver, we can relate the phase of the LO (i.e. $110.5\,\theta_x$) to the incoming phase through the behaviour of the phaselocked loop.

$$\frac{110.5\,\theta_x(s)}{\theta_{in}(s)} = H(s)$$

where Laplace transforms are used and H(s) is the loop filter transfer function.

$$\theta_x(s) = \frac{H(s) \cdot \theta_{in}(s)}{110.5}$$

The output phase of the transmitter is the sum of the phases originally present on the VCXO and introduced by the modulator. The VCXO derived phase will be

$$120\,\theta_x \text{ or } \frac{120}{110.5}\,H(s) \cdot \theta_{in}(s).$$

The phase introduced by the modulator will be dependent on the modulation index chosen. If the downlink index is A times the uplink index, the phase introduced by the modulator will be

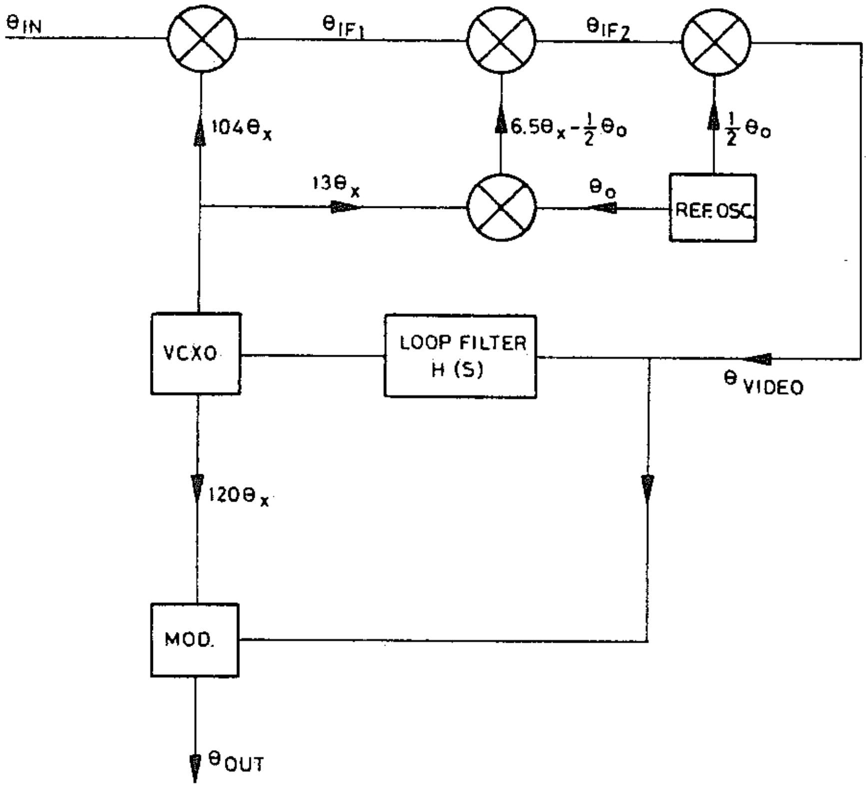


Figure C1. Phase relationships in the transponder.

$A \cdot \theta_{video}$. Therefore the transmitter phase will be in total:

$$\frac{120}{110.5} H(s) \cdot \theta_{in}(s) + A\left[\theta_{in} - 110.5\, \theta_x\right]$$

or

$$\frac{120}{110.5} H(s) \cdot \theta_{in}(s) + A\, \theta_{in} - AH(s)\, \theta_{in}$$

This can be written as:

$$\theta_{in} \cdot \left(A + H(s)\left[\frac{120}{110.5} - A\right]\right)$$

It can be seen that the effects introduced by the PLL (represented by H(s)) can be made equal to zero by the choice

$$A = \frac{120}{110.5}$$

Such a choice of A is not very sensible, as it implies an excessively high modulation index for the ranging downlink of 0.76 radian (0.7 rad uplink). Nevertheless the above analysis shows quite clearly that PROVIDED PROPER CONTROL OF PHASING IN THE TRANSPONDER IS MAINTAINED there is a partial cancellation of the phase errors introduced on the ranging tones by the phaselocked loop.

APPENDIX D

TESTS

RECEIVER TESTS

1. Acquisition of carrier and maintenance of lock. (1) (2)*
2. Rest frequency of VCXO and its stability with time. (1) (2)
3. DC power consumption. (1) (2)
4. Test of overload capability.
5. Test of short circuit protections.
6. Test of input VSWR. (1) (2)
7. Check for back radiation, including simulation of 2 RXs fed from 3 dB coupler. (1) (2)
8. Test TM channels O/P impedance. (1)
9. Test Lock status O/P impedances. (1)
10. Test dynamic range. (1) (2)
11. Calibrate AGC TM channel. (1) (2)
12. Test spurious responses. (1) (2)
13. Telecommand channel output impedance. (1)
14. Telecommand output amplitude (as function of mod index and drive level).
15. Telecommand output distortion. (1) (2)
16. Telecommand output bandwidth. (1) (2)
17. Telecommand output S/N ratio vs. drive level. (1) (2)
18. Ranging channel output impedance. (1)
19. Ranging channel output amplitude. (1) (2)
20. Ranging channel output delay as function of tone frequency and drive level. (1) (2)
21. Ranging channel output S/N ratio. (1) (2)
22. Coherent drive channel output impedance. (1)
23. Coherent drive channel output amplitude. (1) (2) } function of input frequency
24. Coherent drive channel frequency and spurious. (1) (2) } function of input frequency
25. Coherent drive channel S/N ratio (phase noise) (1) (2)
26. Check performance with antenna modulation. (1) (2)
27. Calibrate lock status TM and signal to TX and calibrate SPE. (1) (2)
28. EMC Tests as specified in Appendix A.

* (1) to be performed over temperature range.
(2) to be performed over voltage range.

TRANSMITTER TEST

1. TX frequency stability for non-coherent mode. (1) (2)
2. TX power consumption. (1) (2)
3. TX RF output power. (1) (2)
4. TX output spectrum with nominal load. (1)
5. TX with high VSWR load.
6. Phase noise of TX carrier in non-coherent mode. (1) (2)
7. Modulation indices. (1) (2)
8. Modulation spectrum symmetry. (1)
9. Modulation linearity. (1) (2)
10. Modulation input short circuit protection.
11. Modulation input impedance.
12. Modulation input frequency response. (1)
13. Intermodulation products.
14. Residual AM Modulation. (1)
15. Ranging input frequency response. (1)
16. TX command operation.
17. TX noise in the RX bandwidth. (1) (2)
18. EMC tests as specified in Appendix A.
19. TM O/P levels.
20. TM O/P impedance.
21. TC I/P impedance.
22. Calibration output power TM (in manufacture).
23. Delay variation. (1) (2)
24. Lock status input impedance and operation.
25. Coherent drive input impedance. bandwidth.
26. Mode status on being energised from rising voltage.

DIPLEXER TESTS

1. Bandwidths (1)
2. Insertion loss and isolations (1)
3. Impedances (1)
4. High power test in low pressure.
5. EMC tests as specified in Appendix A (DC magnetic only)

INTEGRATED TRANSPONDER TESTS

1. Desensitisation of RX by TX (all modes) (1) (2)
2. Range tone delay variation with Doppler, input level, tone frequency (1) (2)
3. Phase noise of TX in coherent mode. (1) (2)
4. Control by RX of coherent/non coherent operation (1) (2)
5. Noise figure. (1) (2)
6. EMC tests as specified in Appendix A.

APPENDIX E

RADIATION DOSAGE

Calculation of the general radiation dose expected is difficult, since it is very dependent on the orbit chosen for the satellite. Examples are presented here to show the type of environment which may be expected.

Exosat has a highly elliptical polar orbit and as such will encounter a significant dosage of electrons and protons only when close to the Earth. The geosynchronous orbit by contrast is at the outer edge of the radiation belt around the Earth at a position where few protons are found. However, the total electron dosage is higher than that of Exosat since the spacecraft is permanently on the edge of the radiation belt. To obtain the dosage for seven years, the Figures E1 and E2 should be scaled by 3.5.

The Solar Polar Mission is one in which the spacecraft passes through the radiation belts around Jupiter. In these belts there are very high energy particles and although the passage is relatively short the total flux is relatively high.

The raw figures quoted in Figures E1, E2 and E3 have to be modified by the shielding to be expected from both spacecraft structure and the transponder chassis itself before the spectrum to which the electronic components are exposed can be calculated. After that is done the potential for damage is normally expressed, by a weighted integral of the energy spectrum, in terms of rads (the unit in which component radiation hardness is usually expressed). As an example, Figure E4 represents the number of rads reaching components in 7 years geostationary orbit as a function of the shielding provided by transponder and spacecraft chassis. As a general assumption the shielding provided by the spacecraft itself will be 3 to 4 mm of aluminium. For further information contractors are advised to contact ESTEC TQC, where advice on the susceptibility of various components and on methods of radiation dose calculations is available.

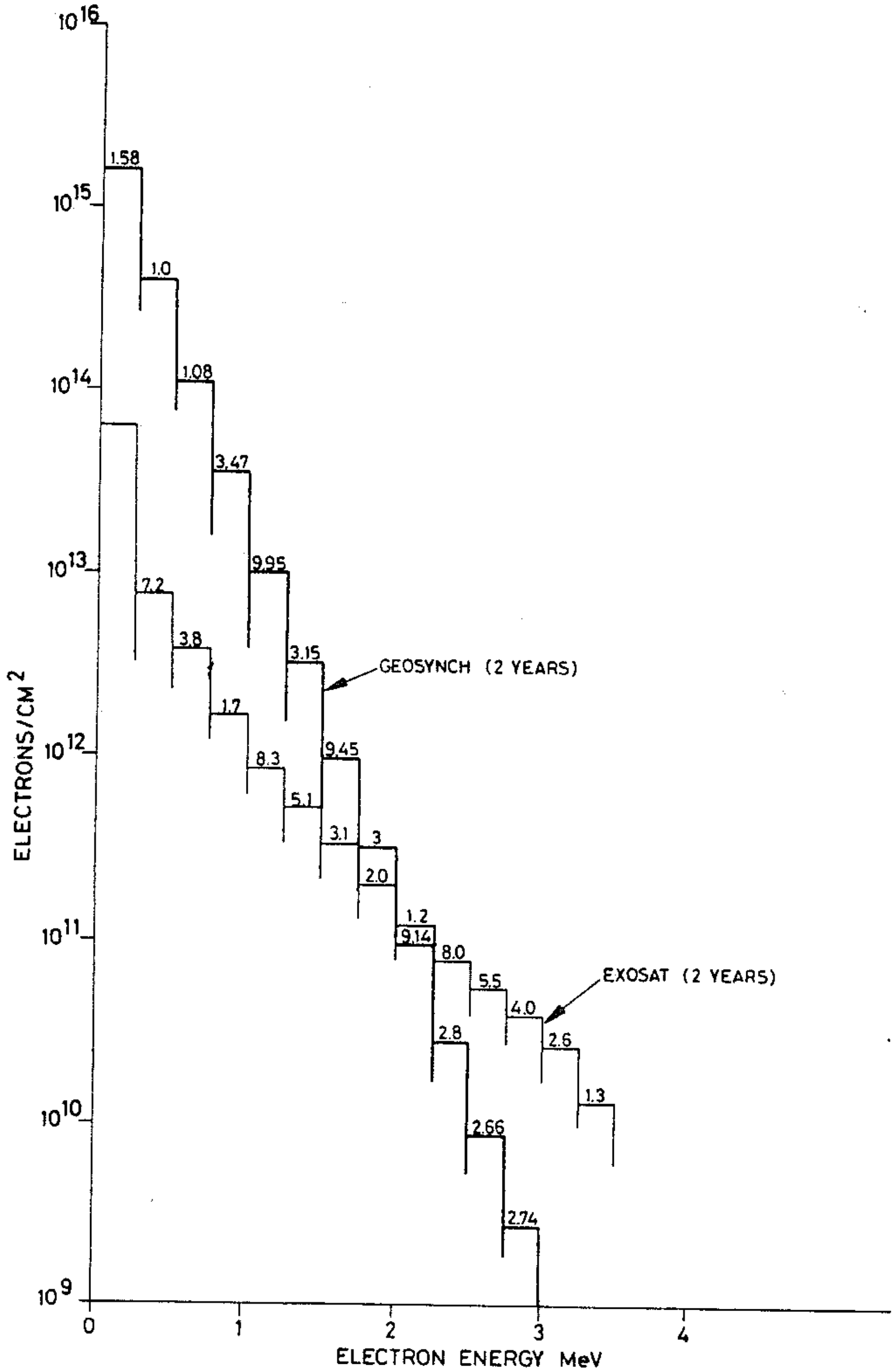


Figure E1. Density distribution for electrons during two years at Exosat and geosynchronous orbits.

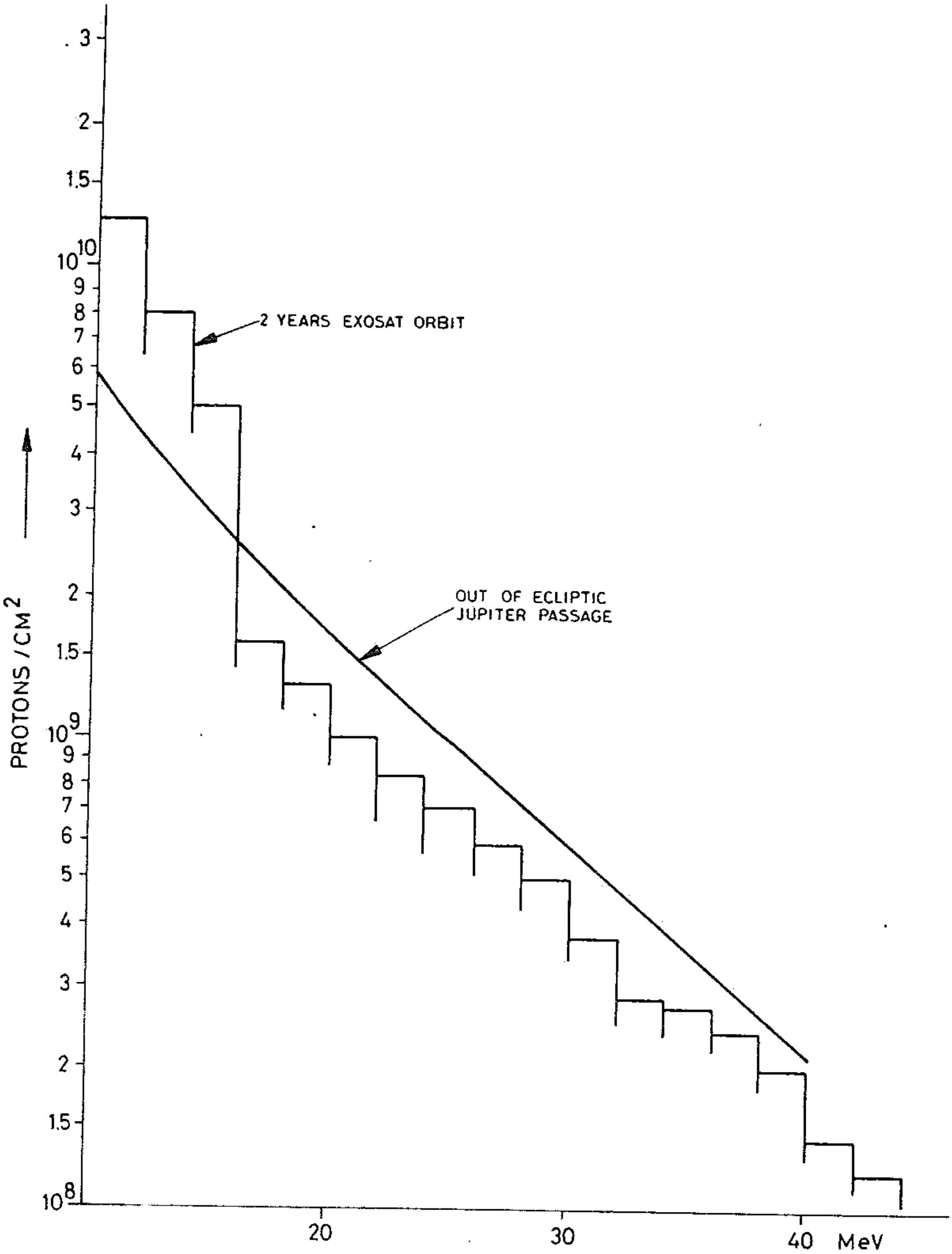


Figure E2. Density distribution for protons.

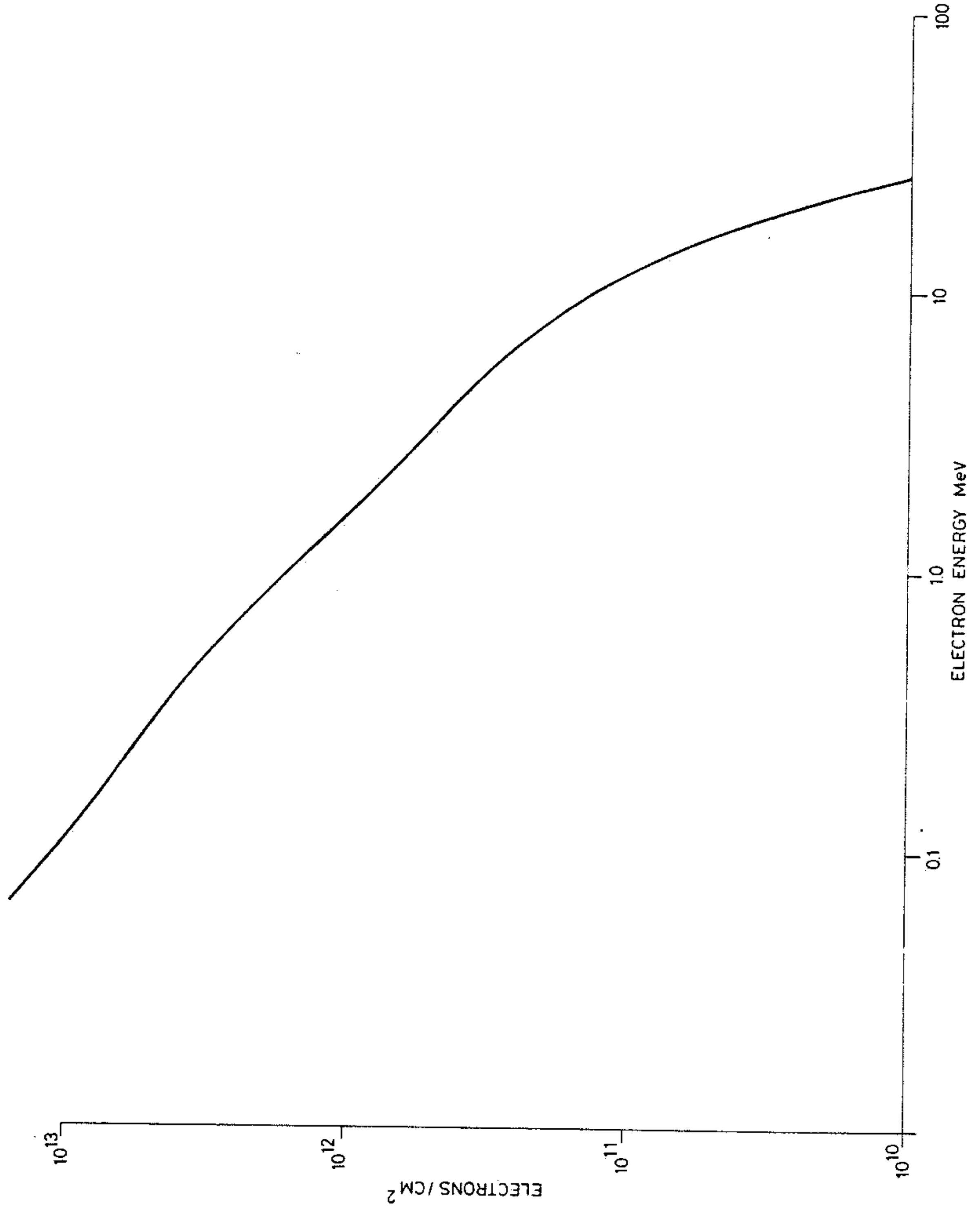


Figure E3. Electron flux through Jupiter passage out of ecliptic.

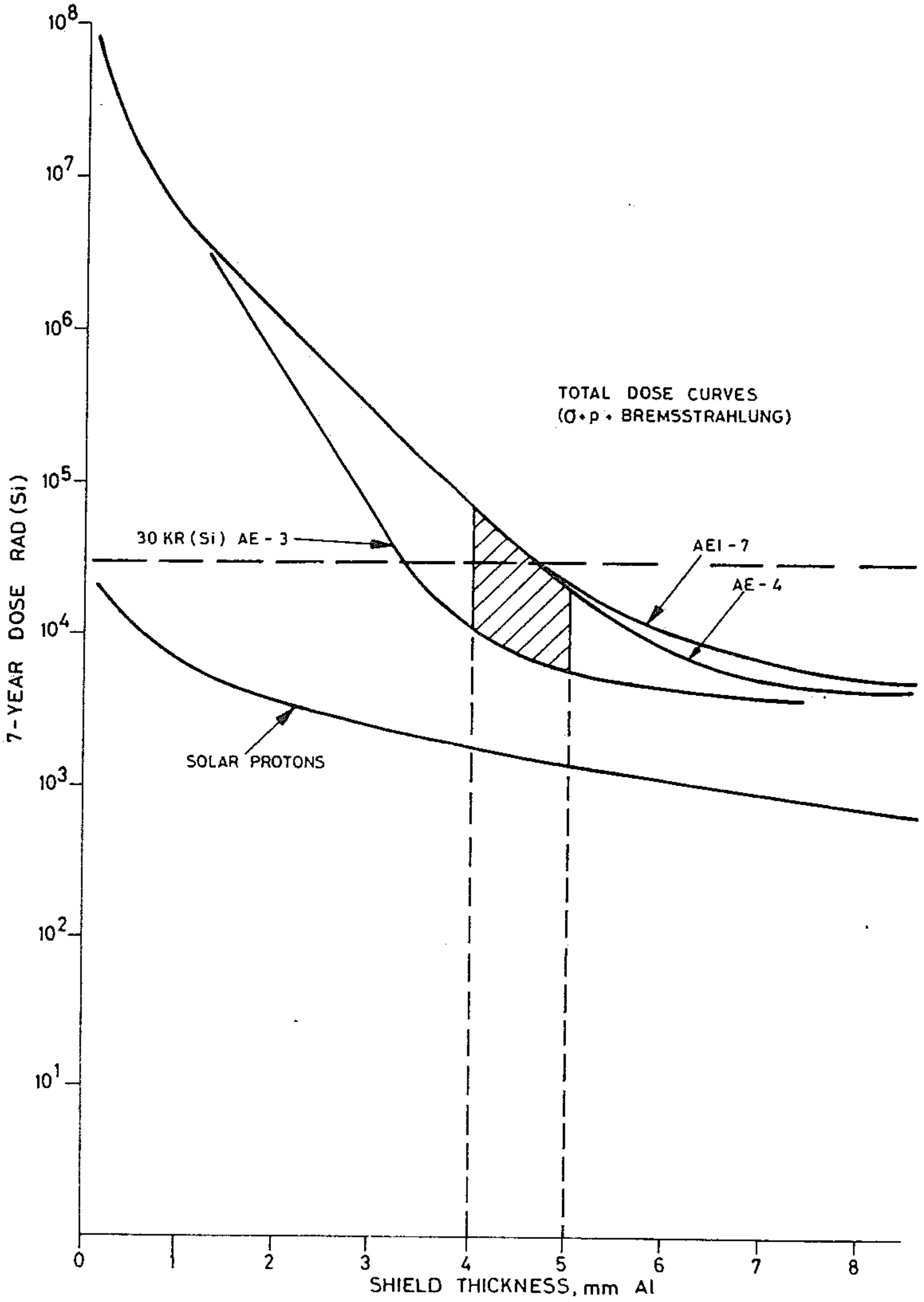


Figure E4. Fulmer geostationary orbit estimates (Manual, 1977).

APPENDIX F

ON-BOARD S-BAND TT & C ANTENNA PHASE AND AMPLITUDE RIPPLE FOR A SPINNING SATELLITE

F1. ASSUMPTIONS

In the following analysis of the causes and likely magnitude of the various contributions to the above, the following quantitative assumptions have been made:

Maximum spacecraft diameter	3 m
Maximum spacecraft spin-rate	120 rpm
Maximum antenna frequency	2.3 GHz

It has further been assumed that the link margin is such that a marked variation ($\sim$8 dB pp) in gain is acceptable, although deep holes are not.

F2. BASIC ANTENNA PATTERN

The antenna itself is likely to have only a slowly changing pattern as the spacecraft rotates. For a boom-mounted antenna, the main period is typically between one and four times the satellite spin frequency, depending upon the actual antenna design. The extent of the variation also depends upon the design but is typically up to 2 dB and 60 electrical degrees peak to peak.

More significant variations would be obtained from a 'ring' array; figures of around 5 dB peak to peak and a period of around $2\frac{1}{2}-5$ degrees of satellite rotation would not be unusual.

In addition, the antenna may have a fundamental, linearly varying, 360 electrical degree phase change per spacecraft revolution.

F3. ANTENNA OFFSET

If the antenna is offset from the spin axis there will be a large phase ripple which is at a maximum around the spacecraft equator. The amplitude of the ripple will depend on the offset of the antenna and the period will be 360°.

Making worst-case assumptions for an antenna on the edge of the satellite body of:

$r = 1.5$ m, $\lambda = 13$ cm (corresponding to 2.3 GHz)

we find an amplitude of 8308 degrees peak to peak.

In addition, even if the antenna is aligned with the nominal spacecraft spin axis, there will always be some residual phase modulation due to AOCS errors etc. Assuming the true and nominal spin axes are within a maximum of 1.5 degrees, and that the separation between their point of coincidence and the antenna phase centre does not exceed 3 m, the resultant phase ripple is likely to be of the order of 360° amplitude.

F4. REFLECTIONS OFF THE SPACECRAFT

As the spacecraft rotates, the relative phase of the signal from the antenna and the reflections off the spacecraft will change. The amplitude of the resultant phase and amplitude ripples will depend upon the relative strengths of the reflections, and the period upon the separation of the antenna and the reflection points in the plane orthogonal to the spin axis.

If a very simple single-reflection model is used, it is quite easy to correlate the relative reflection level with the resultant amplitude and phase variation, viz:

Reflection level (dB)	*Amplitude Ripple (dB pp)*	*Phase Ripple (degs. pp)*
− 6	10	55
−10	6	35
−16	3	20
−20	2	10

whilst the minimum ripple period would be around 5 degrees of spacecraft rotation (if the antenna is mounted on-axis) to $2\frac{1}{2}$ degrees (antenna mounted near spacecraft edge).

Clearly, the situation will, in practice, be significantly more complex than this, with several reflections all contributing to the overall ripple. However, it is felt that a maximum amplitude and phase ripple due to this cause of around 6 dB and 35 degrees respectively would be a reasonable assumption for spin-axis boom-mounted antennas, especially in the equatorial plane where the ripple is fastest.

F5. BOOMS

For a normal configuration, reflections off any spacecraft booms will tend to be significantly less than those off the spacecraft itself. However, the booms themselves can extend much further from the spin axis when deployed and so the resultant ripple will be much faster. Typical boom reflection levels are likely to be of the order of −20 dB to −30 dB or less at distances of around 3 m, resulting in ripples of 2 dB and 10 degrees or less peak to peak with a period of around 5 degrees of spacecraft rotation (the period would not be the minimum possible of around $2\frac{1}{2}$ degrees of rotation since the boom will not reflect maximally as it swings through the normal to the line of sight).

F6. OVERALL RIPPLE

Since the effect of offsetting the antenna from the spacecraft spin-axis tends to dominate the phase-variation, two cases have been considered:

F6.1 ANTENNA ON SPIN-AXIS

Source	*Amplitude pp dB*	*Phase pp*	*Period*	*dB/ms max.*	*Error Response⁺ of loop for 1 rad/s dB*	*Error in⁺ loop*
Antenna ripple	2	60°	90°	0.05	−40	0°
Antenna offset wrt spin axis	0	360°	360°	0	< −40	°0
Spacecraft body	6	35°	5°	2.71	− 3	±24°.8
Booms	2	10°	5°	0.90	− 3	± 7°.1
Basic antenna	0	360°	linear	0	—	0°*

F6.2 ANTENNA ON RIM OF SPACECRAFT BODY (r = 1.5 m)

Source	*Amplitude pp dB*	*Phase pp*	*Period*	*dB/ms max.*	*Error Response⁺ of loop for 1 rad/s dB*	*Error in⁺ loop**
Antenna ripple	2	60°	90°	0.05	−40	0
Antenna offset wrt spin axis	0	8308°	360°	0	−40	0
Spacecraft body	6	35°	2.5°	5.42	−0.7	±32.9
Booms	2	10°	5°	0.90	−3	± 7.1
Basic antenna	0	360°	linear	0	—	0*

Note * for a high gain loop
⁺ calculated for $\omega_n = 754.72$ rad/s and spin rate of 120 rpm.

F6.3 CONCLUSION

As far as the rate of change of signal level and the phase error in the loop are concerned, the most severe reflections are those from the body and booms of the spacecraft.

F7. IMPACT ON TRANSPONDER DESIGN

Where possible S-band antennas should be boom mounted on the spin axis of a spinning satellite but the use of body-mounted low-gain antennas for filling in otherwise empty parts of the pattern is sometimes resorted to. In such cases there are often obstructions on the spin axis (e.g. apogee motor, separation ring) and so an offset design has to be used. The S-band transponder with 800 Hz 2BL must work with the antenna pattern of 6.1 described above and as far as possible with the antenna pattern of 6.2 above. The 20 Hz transponder will experience lower spin rates (typically 0.08 Hz) and interaction of the antenna patterns with the spacecraft body can be expected to be somewhat reduced, but conscan may be used. Therefore a peak-to-peak amplitude of 6 dB with a peak-to-peak phase variation of 30° at a frequency of 6 Hz should also be accommodated.

ESA PSS-48 (TTC.C.10) Issue 1
European Space Agency
SPACE COMMUNICATIONS DIVISION, ESTEC
S + S/X bands coherent transponder specification.
March 1979
vi + 78 pages, 36 figures. In English.

This design requirement standard is related to the Telemetry, Tracking, Command and Data Handling Standards of the European Space Agency. It represents one of the Standard Equipment Specifications. As such, it establishes and specifies an on-board transponder that will permit ESA spacecraft to communicate with and be tracked by ESA and NASA ground stations with maximum performance and safety.

Price code: C1

Subject category: 17

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Spécification pour un répéteur cohérent en bandes S et S/X.
Mars 1979
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