# A Bent Pipe Design for Relaying Signals Received by an Orbiting Deep Space Relay Station to a Ground Station

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*The ODSRS (Orbiting Deep Space Relay Station) would be a geostationary or geosynchronous earth satellite designed to receive signals from spacecraft at lunar or planetary distances. A communication link will be required to transfer the data received by the ODSRS to a ground station. This article examines the feasibility of using a "bent-pipe" type system to relay the entire RF signal received by the ODSRS together with its receiving system noise to the ground station.*

*The analysis and numerical results presented herein should provide an acceptable basis for selecting an ODSRS/ground link design. The use of a "bent-pipe" channel appears feasible for each of the three ODSRS applications considered herein. Of the three applications considered, the maximum ODSRS transmitter RF power output required was 5.3 watts for a 25 Mbps, uncoded, suppressed-carrier telemetry channel. This calculation assumed that the ODSRS/ground link frequency is 14 GHz, the ODSRS antenna diameter is 2 m, the ground antenna diameter is 5 m, and the ground receiving system uses an uncooled parametric amplifier. The results presented herein also indicate that ground adjustment of the ODSRS transmitter RF power output for different spacecraft, different spacecraft modes of operation, and changes in spacecraft/ODSRS range will normally be necessary to avoid violation of CCIR power flux density limitations.*

## I. Introduction

The ODSRS (Orbiting Deep Space Relay Station) would be a geostationary or geosynchronous earth satellite designed to receive signals from spacecraft at lunar or planetary distances and relay these signals to a ground station. The ODSRS antenna for the spacecraft/ODSRS link would be a large (about 30-m) parabolic dish capable of efficient operation at S-band, X-band, and K-band. A maser amplifier would be provided at each of these frequencies. The K-band receiving capability of the ODSRS would be at least 6 dB greater than the current X-band receiving capability of a DSN 64-m station in clear weather. The S-band and X-band receiving capability of the ODSRS would be significantly less than that of the DSN 64-m stations and would primarily be used for those radio metric measurements which require dual-frequency operation.

An important part of the ODSRS system design is the method used to relay to Earth either the signal received by the ODSRS from a spacecraft or the information carried by the signal. One method would be to extract the information carried by the signal and remodulate this information on the ODSRS/ground link. However, signal processing on the ODSRS would increase the complexity of the ODSRS and decrease its reliability and flexibility. Since the anticipated ODSRS lifetime is at least 10 years, such ODSRS equipment could become obsolete. An alternative, which will be the method considered in this article, is the use of a "bent-pipe" channel. In this method, the signal received at the ODSRS, together with the ODSRS receiving system noise, is translated in frequency, amplified and retransmitted. The method minimizes on-ODSRS equipment and maximizes ODSRS reliability and flexibility. However, the "bent-pipe" method will require a more powerful ODSRS/ground link transmitter and will have more difficulty meeting international restrictions on the power flux density that may be received from earth satellites than a method employing on-ODSRS signal processing.

One consideration which is important to the ODSRS/ground link design is the CCIR limitation on the power flux density that can be received from a satellite at any point on the earth's surface. Power flux density is the maximum received signal power per unit area in some specified bandwidth. In this article this bandwidth is assumed to be 4 kHz. When the ODSRS/ground link transmitter power is fixed, it may not be possible to meet international restrictions on the power flux density which may be received *from the ODSRS* over the range of signal levels which may be received *at the ODSRS*. Hence, this article also examines the impact of varying the ODSRS/ground link transmitter RF power output to always use only that power level necessary to achieve the required spacecraft/ODSRS/ground link performance.

Two other limitations impact the ODSRS/ground link design. First, as the ODSRS must be maneuvered to point its main antenna toward the spacecraft, the antennas for the ODSRS/ground link must be steerable in two axes. To minimize pointing problems, it would be desirable to make the diameter of this antenna about 2 meters. Second, one objective of the ODSRS system design is to locate the earth receiving station for the ODSRS/ground link at the site where the data is to be processed. Possible antenna locations might be the roof of the spaceflight operations center at JPL, Goddard, or Houston. Hence, ground receiving antennas with diameters much greater than 5 meters should be avoided.

The objective of this analysis is to determine, given the limitations on antenna size discussed previously, the feasibility of using a bent-pipe design for relaying signals received by the ODSRS to the ground. For the purposes of this article, a feasible ODSRS/ground link design is one for which the received power flux density at the ground does not exceed the CCIR limitation. In addition, to minimize the impact on the ODSRS power system, the RF power amplifier for the ODSRS/ground link should not require more than 100 to 200 watts of raw power. Since the power amplifier must be a linear amplifier, its efficiency may be as little as 5 percent. Thus, 100 to 200 watts of raw power corresponds to an RF power output of 5 to 10 watts.

The ODSRS/ground telemetry link should be capable of supporting a wide variety of applications. In this article three such applications, chosen to be limiting cases, are examined in detail.

It is expected that a suppressed carrier system will be used when the telemetry bit rate exceeeds 250 kbps. As 25 Mbps appears to be the highest data rate that might be required, the first application considered is a 25-Mbps, suppressed carrier telemetry link. Of the three applications considered herein, this one should require the greatest ODSRS/ground link transmitter RF power output. The results obtained herein show that the CCIR limitations can be met for this application with a fixed 2.6 watt ODSRS/ground link transmitter RF power output if the allowable spacecraft/ODSRS/ground link degradation caused by the ODSRS/ground link is 0.2 dB or greater.

The second application considered herein is a 250-kbps, discrete carrier telemetry system with 1-dB carrier suppression by ranging. The ODSRS feed-through channel noise bandwidth was assumed to be 5 MHz for this application. This is sufficiently wide to pass most of the harmonics of the 500-kHz square wave ranging modulation. The results obtained herein show that the *maximum* ODSRS/ground link transmitter RF power output required for this application is 0.093 watts if the allowable degradation of the spacecraft/ODSRS/ground link performance by the ODSRS/ground link is 0.2 dB. If the allowable spacecraft/ODSRS/ground link degradation caused by the ODSRS/ground link is less than about 0.7 dB, the actual RF power output must be adjusted to use only the minimum value required. By making this adjustment, the CCIR restrictions on power flux density can be met whenever the allowable degradation of the spacecraft/ODSRS/ground link by the ODSRS/ground link is 0.2 dB or greater.

The third application considered herein is a 250-kbps discrete carrier telemetry channel with 1 dB carrier suppression by DOR (differential, one-way ranging) modulation. Because of the bandwidth of the DOR modulation, the ODSRS feed-through channel noise bandwidth for this application must be about 50 MHz, about 10 times that used in the preceding example. The results obtained in this report show that the maximum ODSRS/ground link transmitter RF power output for this application is 0.84 watts if the allowable spacecraft/ODSRS/ground link degradation by the ODSRS/ground link is 0.2 dB. By adjusting the ODSRS/ground link transmitter RF power output to use only the minimum value required, the CCIR power flux density limitations can be met whenever the allowable spacecraft/ODSRS/ground link degradation by the ODSRS/ground link is 0.2 dB or greater.

## II. Analysis

A functional block diagram of the ODSRS "bent pipe" feed-through channel is shown in Fig. 1. The receiver, which follows the maser amplifier, consists of a bandpass filter, linear amplifier, and frequency translator. A power-controlled AGC system adjusts the gain of the linear amplifier to hold the power level at the receiver output at some constant value. The transmitter consists of a linear power amplifier whose input power level, in those applications which require a variable ODSRS/ground link transmitter RF power output, can be controlled by a variable attenuator.

The required performance of the spacecraft/ODSRS/ground link can be measured in terms of the required signal-power-to-noise spectral density ratio $(P/\Phi)_{REQ}$ at the ground receiver. Let $P_1$ be the total power received at the ODSRS from the spacecraft and let $\Phi_1$ be the one-sided noise spectral density of the ODSRS receiving system. Let $P_2$ be the total power received at the ground from the ODSRS and let $\Phi_2$ be the one-sided noise spectral density of the ground receiving system. Then, if $B$ is the one-sided noise bandwidth of the ODSRS feed-through channel and

$$\delta = \frac{\dfrac{P_1}{\Phi_1}}{\left(\dfrac{P}{\Phi}\right)_{REQ}} \tag{1}$$

$$\left(\frac{P_2}{\Phi_2}\right)_{REQ} = \frac{B + \delta\left(\dfrac{P}{\Phi}\right)_{REQ}}{\delta - 1} \tag{2}$$

Note that $(P_2/\Phi_2)_{REQ}$ becomes infinite as $\delta$ decreases to one. Thus, delta must always be greater than one to achieve the required overall link performance.

$(P_2/\Phi_2)_{REQ}$ decreases monotonically as $\delta$ increases. Since $(P_2/\Phi_2)_{REQ}$ becomes infinite as $\delta$ decreases to one, the ODSRS/ground link must be designed for some acceptable minimum value of $\delta$. Let $\delta_M$ be the minimum value of $\delta$. Then

$$\left(\frac{P_2}{\Phi_2}\right)_{MAX\,REQ} = \frac{B + \delta_M\left(\dfrac{P}{\Phi}\right)_{REQ}}{\delta_M - 1} \tag{3}$$

is the maximum required ODSRS/ground link signal-power-to-noise spectral density ratio.

International agreements limit the amount of signal power per unit area that can be received from an earth satellite at any ground station in any 4-kHz frequency band. Let *PFD* be the maximum received signal power at the ODSRS/ground link receiving station in any 4-kHz band, let $L_R$ be the factor by which the received signal power $P_2$ is reduced by the ODSRS/ground link polarization loss, receiving antenna pointing loss, and receiving system circuit loss, and let $A_R$ be the effective area of the ground antenna for the K-band ODSRS/ground link. Then, if the ODSRS transmitter RF power output is held constant at its maximum required value (for $\delta$ equals $\delta_M$), the worst case power flux density will be

$$\underset{\delta_M \leq \delta \leq \infty}{(PFD)_{MAX}} = \frac{\Phi_2}{L_R A_R}\;\frac{MAX\,(4000, \eta_s B) + \delta_M \eta_s \left(\dfrac{P}{\Phi}\right)_{REQ}}{\delta_M - 1} \tag{4}$$

where $MAX\ (x,y)$ is the greatest of $x$ and $y$. For all practical applications $\eta_s B$ should be greater than 4000. However, *if only the minimum required ODSRS transmitter RF power output is used for each value of* $\delta$,

$$\underset{\delta_M \leq \delta \leq \infty}{(PFD)_{MAX}} = \frac{\Phi_2}{L_R A_R}\;\frac{4000 + \delta_M \eta_s \left(\dfrac{P}{\Phi}\right)_{REQ}}{\delta_M - 1} \tag{5}$$

## III. CCIR Power Flux Density Limitation

Although the results presented herein somewhat arbitrarily assume that the ODSRS/ground link RF frequency is 14 GHz, the actual RF frequency which will be used for the ODSRS/ground link is unknown. Consequently, the CCIR limitation on power flux density is also unknown. However, the CCIR limitation for RF signals in the 12.5-GHz to 12.75-GHz frequency band appears to be typical of those that might be imposed on the ODSRS/ground link. For this frequency band, the maximum allowable power flux density is $-118$ dBm/m$^2$

for angles of arrival ($\delta_A$) between 0 and 5 degrees, -118 + $(\delta_A - 5)/2$ dBm/m$^2$ for angles of arrival between 5 and 25 degrees, and -108 dBm/m$^2$ for angles of arrival greater than 25 degrees. Note that the angle of arrival for any particular ground point is the elevation angle of the ODSRS at that ground point.

The ODSRS/ground link design presented herein will assume that the allowable power flux density which can be received at any point of the earth's surface is -118 dBm/m$^2$. The angular separation, as seen from the ODSRS, between a ground station where the ODSRS elevation angle is 30 degrees and a ground point at which the ODSRS angle is 5 degrees is only 1.14 degrees. Thus, a minor operational error in pointing the ODSRS antenna could easily cause it to be pointed at a ground point where the ODSRS elevation angle is 5 degrees or less.

Since the link performance calculations presented in this article will yield, using Eq. (4) or (5), estimates of the power flux density at the ODSRS/ground link ground station, it will be convenient to restate the CCIR limitation in terms of the maximum allowable power flux density at the ODSRS ground station. The difference between the power flux density at the ODSRS ground station and other points on the Earth's surface will depend on the differences in space loss (range), ODSRS antenna pointing loss, and atmospheric attenuation for the two signal paths. For the narrow beam (0.67 degree) ODSRS antenna, any increase in power flux density due to reduced range would be more than offset by increased ODSRS antenna pointing error. Hence, neglecting atmospheric attenuation, the maximum power flux density will occur on that point on the Earth's surface where the ODSRS antenna is pointed.

The allowance in Table 1 for ODSRS antenna pointing loss is 0.5 dB. This corresponds to a pointing error of 0.14 degree. Thus, the distance between the ODSRS ground station and the point on the Earth's surface at which the ODSRS antenna is pointed could be as much as 93 km. The combined atmospheric attenuation due to water vapor (0.27 dB) and rain (6.45 dB) could occur on the path from the ODSRS to the ground station, while only that due to water vapor occurs on the path to the point at which the ODSRS antenna boresight is pointed. Thus, the difference in atmospheric attenuation for the two paths could be as much as 6.45 dB. Combining the 6.45-dB possible differential in atmospheric attenuation with the 0.5-dB differential in ODSRS antenna pointing loss, the power flux density at any point on the Earth's surface cannot be more than 6.95 dB greater than that at the ODSRS/ground link ground station. Thus, the maximum allowable power flux density at the ground station is -124.95 dBm/M$^2$.

## IV. Applications

In this section the results obtained in the previous sections of this article are applied to three ODSRS applications: a 25-Mbps wideband telemetry channel, a 250-kbps telemetry channel with two-way ranging, and a 250-kbps telemetry channel with differential one-way ranging. For each of these three ODSRS applications, the ODSRS/ground RF link parameters, with the exception of the RF transmitter power output, will be those listed in Table 1. Note in Table 1 that, for a transmitter RF power output of 1 watt, $P_2/I_2$ is 91.07 dB · Hz. Thus the required ODSRS/ground link transmitter RF power output will be

$$(P)_{\substack{MAXIMUM \\ REQUIRED}} = \left(\frac{P_2}{\Phi_2}\right) - 91.07 \text{ dBW} \tag{6}$$

where $(P_2/\Phi_2)_{REQ}$ has units dB · Hz.

The results obtained in the preceding sections and Eq. (6) can be used to determine the maximum required $P_2/\Phi_2$, the maximum required ODSRS transmitter RF power output, and the worst case ground station power flux density as a function of $\delta_M$ for the three ODSRS applications. Remember $\delta_M$ is the amount the spacecraft effective radiated power must be increased to offset the degradation caused by the ODSRS/ground link.

The results of these calculations are tabulated in Tables 2, 3, and 4, which have a common format. Column 1 is the independent variable $\delta_M$. Column 2 is the maximum $P_2/\Phi_2$ required; this was calculated using Eq. (3). Column 3 is the maximum ODSRS transmitter RF power output required; this was calculated using Eq. (6). Column 4 is the worst case ground station power flux density, assuming that the ODSRS transmitter RF power output *remains fixed at the maximum required value for the particular application*; this was calculated using Eq. (4). Column 5 is the worst case ground station power flux density, assuming that the ODSRS transmitter power is *varied to use only the minimum ODSRS transmitter power required to attain the specified spacecraft/ODSRS/ground link performance*; this was calculated using Eq. (5).

### A. 25 Mbps, Uncoded, Suppressed Carrier Telemetry Channel

For a 5 X 10$^{-3}$ bit error probability, the $(P/\Phi)_{REQ}$ for a 25-Mbps, uncoded, suppressed carrier telemetry channel will be about 80.19 dB · Hz; $\eta_s$ will be -37.96 dB and $\eta_s\ (P/\Phi)_{REQ}$ will be 42.23 dB. The maximum $P_2/\Phi_2$ required, the maximum ODSRS transmitter RF power output, and the worst case ground station power flux densities, for constant and minimum ODSRS transmitted power outputs, are shown in Table 2 as a function of $\delta_M$. The data presented in Table 2 is for a ODSRS feed-through channel with 50-MHz noise bandwidth.

Several aspects of the data presented in Table 2 are of particular interest. First, note the rapid increase in the maximum ODSRS transmitter RF power output required as $\delta_M$ decreases. This is typical of "bent pipe" feed-through systems. The transmitter RF power output required is proportional (approximately) to $1/(\delta_M - 1)$ and, hence, increases rapidly as $\delta_M$ approaches one. Second, note the relatively small difference between columns 4 and 5 of Table 3. *For this application*, using only the minimum required ODSRS transmitter RF power output does not substantially reduce the worst case ground station power flux density. Third, note that for the values of $\delta_M$ shown in Table 2, the worst case ground station power flux density exceeds the $-124.95$ dBm/m$^2$ allowable value only for $\delta_M$ as small as 0.1 dB. Assuming it is necessary to make $\delta_M$ as small as 0.1 dB, only a relatively small increase in the ground antenna diameter would be required to reduce the power flux density to an acceptable level.

## B. 250-kbps Viterbi Coded (Rate1/2), Discrete Carrier Telemetry Channel and Ranging with 1-dB Carrier Suppression

For a $5 \times 10^{-3}$ bit error probability, the $(P/\Phi)_{REQ}$ for a 250-kbps Viterbi (rate 1/2) coded telemetry link is 56.62 dB · Hz, $\eta_s$ is $-15.21$ dB, and $\eta_s\ (P/\Phi)_{REQ}$ will be 41.41 dB. If ranging modulation causing 1-dB carrier suppression is added, the $(P/\Phi)_{REQ}$ will increase to 57.62 dB · Hz, $\eta_s$ will decrease to $-16.21$, and $\eta_s\ (P/\Phi)_{REQ}$ will remain unchanged. This assumes, of course, that the increase in the fraction of the spacecraft signal power in a 4000-Hz band centered on the carrier frequency caused by intermodulation products of the telemetry and ranging modulation can be neglected. The maximum $P_2/\phi_2$ required, the maximum ODSRS transmitter RF power output, and the worst case ground station power flux densities, for constant and minimum ODSRS transmitter RF power output are shown in Table 3 as a function of $\delta_M$. The data presented in Table 3 is for a ODSRS feed-through channel with 5 MHz noise bandwidth.

Several aspects of the data presented in Table 3 are of particular interest, especially when compared with the results presented in Table 2. First, the maximum required ODSRS transmitter RF power outputs shown in Table 3 are substantially less than those shown in Table 2. The maximum ODSRS transmitter RF power output required increases with both $B$ and $(P/\Phi)_{REQ}$ and both of these parameters are significantly smaller for this application than they are for the application for which data is presented in Table 2. Second, there is a very significant difference between columns 4 and 5 of Table 3. Thus, *for this application*, using only the minimum ODSRS transmitter RF power output required does substantially reduce the worst case ground station power flux density. Third, when only the minimum required ODSRS transmitter RF power output is used, the power flux density is less than the $-124.95$ dBm/m$^2$ limit for all values of $\delta_M$ for which data is shown in Table 4. When the ODSRS transmitter power is held constant at the maximum required value, the worst case ground station power flux density will exceed the $-124.95$ dBm/m$^2$ allowed for $\delta_M$ less than about 0.7 dB.

## C. 250-kbps Viterbi-Coded (Rate 1/2), Discrete Carrier Telemetry Channel and Differential One-Way Ranging with 1-dB Carrier Suppression

This example differs from that in the preceding section only in that the bandwidth of the ODSRS feed-through channel has been increased to 50 MHz to accommodate the high-frequency sidebands created by the 19.125-MHz sinusoidal differential one-way ranging modulation. The $(P/\Phi)_{REQ}$ is 57.62 dB · Hz, $\eta_s$ is $-16.21$ dB, and $\eta_s\ (P/\Phi)_{REQ}$ is 41.41 dB · Hz. The maximum $P_2/\Phi_2$ required, the maximum ODSRS transmitter RF power output, and the worst case ground station power flux densities, for constant and minimum ODSRS transmitter RF power output, are shown in Table 4 as a function of $\delta_M$.

Several aspects of the data presented in Table 4 are of particular interest, especially when compared to the results presented in Table 3. First, the increase in the ODSRS feed-through channel noise bandwidth, from 5 MHz for the data in Table 3 to 50 MHz for the data in Table 4, has resulted in an almost proportionate increase in the maximum ODSRS transmitter RF power output required and the worst case ground station power flux density that can be expected when the ODSRS transmitter power output is held constant at the maximum value required. Second, the increase in the ODSRS feed-through channel noise bandwidth from 5 MHz to 50 MHz has *no* effect on the worst case ground station power flux density when only the minimum required ODSRS transmitter RF power output is used. Third, when the ODSRS transmitter RF power output is held constant at the maximum value required, the worst case ground station power flux density exceeds the $-124.95$ dBm/m$^2$ allowed for all values of $\delta_M$ shown in Table 4.

# V. Conclusion

The use of a "bent-pipe" feed-through channel appears feasible for each of the three ODSRS applications considered herein. Assuming the ODSRS/ground link is designed for $\delta_M$

equal 0.2 dB, the maximum ODSRS transmitter RF power output required for any of the three applications considered is 2.6 watts for the 25 Mbps, uncoded, suppressed-carrier telemetry channel. Assuming the efficiency of the linear power amplifier is 5 percent, this RF power output would require 52 watts of raw power. Note that this power level assumes that the ODSRS/ground link RF frequency is 14 GHz, the ODSRS antenna diameter is 2 m, the ground antenna diameter is 5 m, and the ground receiving system uses an uncooled parametric amplifier.

The results shown indicate that, unless the applications of the ODSRS are to be unduly restricted, ground control of the ODSRS transmitter RF power output will be necessary to meet the expected CCIR power flux density limitations. The ODSRS transmitter power output to be used will depend both on the communication functions to be performed, and, in many cases, on the spacecraft/ODSRS link margin above threshold. Thus, the ODSRS transmitter RF power output to be used may be different for different spacecraft, may be different for different operational modes of the same spacecraft, and may vary with the spacecraft/ODSRS range. By using only the minimum ODSRS transmitter RF power output required, the CCIR power flux density limitation can be met for each of the three ODSRS applications considered.

Note that setting the ODSRS transmitter power output to the proper level requires knowledge of $P_1/\Phi_1$, the ratio of received signal power to receiving system noise spectral density at the ODSRS. An uncertainty in $P_1/\Phi_1$ would reduce the effectiveness of varying the ODSRS transmitter power output, particularly when the allowable overall link degradation caused by the ODSRS/ground link must be small. Additional work is needed to assess the impact of such uncertainties.

Performance estimates for the spacecraft/ODSRS link can be made by considering only the spacecraft/ODSRS link and using the threshold relationship

$$\left(\frac{P_1}{\Phi_1}\right)_{REQ} = \delta_M \left(\frac{P}{\Phi}\right)_{REQ} \tag{7}$$

where $(P_1/\Phi_1)_{REQ}$ is the spacecraft/ODSRS link threshold. Now note in Tables 2, 3, and 4 that, when $\delta_M$ is nearly 0 dB, small changes in $\delta_M$ correspond to large changes in $(P_1/\Phi_1)_{MAX\ REQ}$. Conversely, when the design value of $\delta_M$ is nearly 0. dB, large changes in $(P_2/\Phi_2)$, caused by the ODSRS/ground link parameter variations, correspond to only small changes in $\delta_M$. Thus, for example, if the design value of $\delta_M$ is 0.2 dB, a ±3 dB change in $(P_2/\Phi_2)$ corresponds to only about a +0.1 dB, -0.2 dB change in $\delta_M$. In most cases this uncertainty in $\delta_M$ and the corresponding uncertainty in $(P_1/\Phi_1)_{REQ}$ will be small in comparison with the tolerances on the spacecraft/ODSRS link parameters. Thus, when the design value of $\delta_M$ is nearly 0. dB, the ODSRS/ground link transmitter RF power output need be sized only for the required ODSRS/ground link *design value* performance. The effect of favorable or adverse ODSRS/ground link parameter variations will be reflected in only a minor increase in the favorable and adverse tolerances on the spacecraft/ODSRS link performance margin.

**Table 1. ODSRS/ground link communication system performance estimate for a one-watt transmitter RF power output**

| | | |
|---|---|---|
| Transmitting system parameters | | |
| (1) | RF power output (1W) | 30.00 dBm |
| (2) | Circuit loss | −1.00 dB |
| (3) | Antenna gain (2-m dia., 70% eff.) | 47.79 dB |
| (4) | Antenna pointing loss | −0.50 dB |
| Path parameters | | |
| (5) | Spaceloss<br>Frequency = 14 GHz<br>Range = 38611.91 km | −207.11 dB |
| (6) | Atmospheric attenuation[a] | −6.72 dB |
| Receiving system parameters | | |
| (7) | Polarization loss | 0.00 dB |
| (8) | Antenna gain (5-m dia., 70% eff.) | 55.76 dB |
| (9) | Antenna pointing loss | −0.10 dB |
| (10) | Circuit loss | 0.00 dB |
| (11) | Noise spectral density<br>System noise temperature = 366K<br>30° elevation angle, rain (31 mm/hr)[b] | −172.95 dBm/Hz |
| (12) | Received signal power | −81.88 dBm |
| (13) | Received signal power/receiving system noise spectral density | 91.07 dB Hz |

[a]The atmospheric attenuation consists of 0.27 dB due to water vapor and 6.45 dB due to 31 mm/hr rain.
[b]Rain will exceed the 31 mm/hr rate during 0.01% of the year at Goldstone and 0.05% at Goddard and Houston.

**Table 2 Required ODSRS transmitter RF power output and worst case ground station power flux density for a 25 Mbps, uncoded, suppressed carrier telemetry channel**

| $\delta$M, dB | Maximum $P_2/\Phi_2$ required dB·Hz | Maximum required ODSRS transmitter RF power output, W | Ground station worst case power flux density | |
|---|---|---|---|---|
| | | | Constant RF power, dBm/m$^2$ | Minimum RF power, dBm/m$^2$ |
| 0.1 | 98.29 | 5.3 | −123.90 | −124.66 |
| 0.2 | 95.29 | 2.6 | −126.90 | −127.64 |
| 0.3 | 93.54 | 1.8 | −128.65 | −129.37 |
| 0.4 | 92.32 | 1.3 | −129.87 | −130.58 |
| 0.5 | 91.37 | 1.1 | −130.82 | −131.52 |
| 0.7 | 89.94 | 0.77 | −132.25 | −129.92 |
| 1.0 | 88.46 | 0.55 | −133.73 | −134.37 |
| 1.5 | 86.81 | 0.37 | −135.38 | −135.97 |
| 2.0 | 85.67 | 0.29 | −136.52 | −137.06 |

**Table 3. Required ODSRS transmitter RF power output and worst case ground station power flux density for a 0.25 Mbps, Viterbi (rate 1/2) coded, discrete carrier telemetry channel and ranging with 1-dB carrier suppression**

| $\delta_M$, dB | Maximum $P_2/\Phi_2$ required, dB·Hz | Maximum required ODSRS transmitter RF power output, W | Ground station worst case power flux density | |
|---|---|---|---|---|
| | | | Constant RF power, dBm/m$^2$ | Minimum RF power, dBm/m$^2$ |
| 0.1 | 83.81 | 0.19 | −116.63 | −125.31 |
| 0.2 | 80.76 | 0.093 | −119.68 | −128.29 |
| 0.3 | 78.95 | 0.061 | −121.49 | −130.03 |
| 0.4 | 77.67 | 0.046 | −122.77 | −131.24 |
| 0.5 | 76.66 | 0.036 | −123.78 | −132.18 |
| 0.7 | 75.11 | 0.025 | −125.33 | −133.69 |
| 1.0 | 73.45 | 0.017 | −126.99 | −135.05 |
| 1.5 | 71.50 | 0.011 | −128.94 | −136.66 |
| 2.0 | 70.05 | 0.0079 | −130.39 | −137.76 |

Note: 5 MHz ODSRS feed-through channel noise bandwidth.

**Table 4. Required ODSRS transmitter RF power output and worse case ground station power flux density for a 0.25 Mbps Viterbi (rate 1/2) coded telemetry channel and downlink one-way ranging with 1-dB carrier suppression**

| $\delta_M$, dB | Maximum $P_2/\Phi_2$ required, dB·Hz | Maximum required ODSRS transmitter RF power output, W | Ground station worst case power flux density | |
|---|---|---|---|---|
| | | | Constant RF power, dBm/m$^2$ | Minimum RF power, dBm/m$^2$ |
| 0.1 | 93.37 | 1.7 | −107.07 | −125.31 |
| 0.2 | 90.31 | 0.84 | −110.13 | −128.19 |
| 0.3 | 88.49 | 0.55 | −111.95 | −130.03 |
| 0.4 | 87.20 | 0.41 | −113.24 | −131.24 |
| 0.5 | 86.19 | 0.33 | −114.25 | −132.18 |
| 0.7 | 84.62 | 0.23 | −115.82 | −133.59 |
| 1.0 | 82.92 | 0.15 | −117.52 | −135.05 |
| 1.5 | 80.91 | 0.096 | −119.53 | −136.66 |
| 2.0 | 79.40 | 0.068 | −121.04 | −137.76 |

Note: 50 MHz ODSRS feed-through channel noise bandwidth.

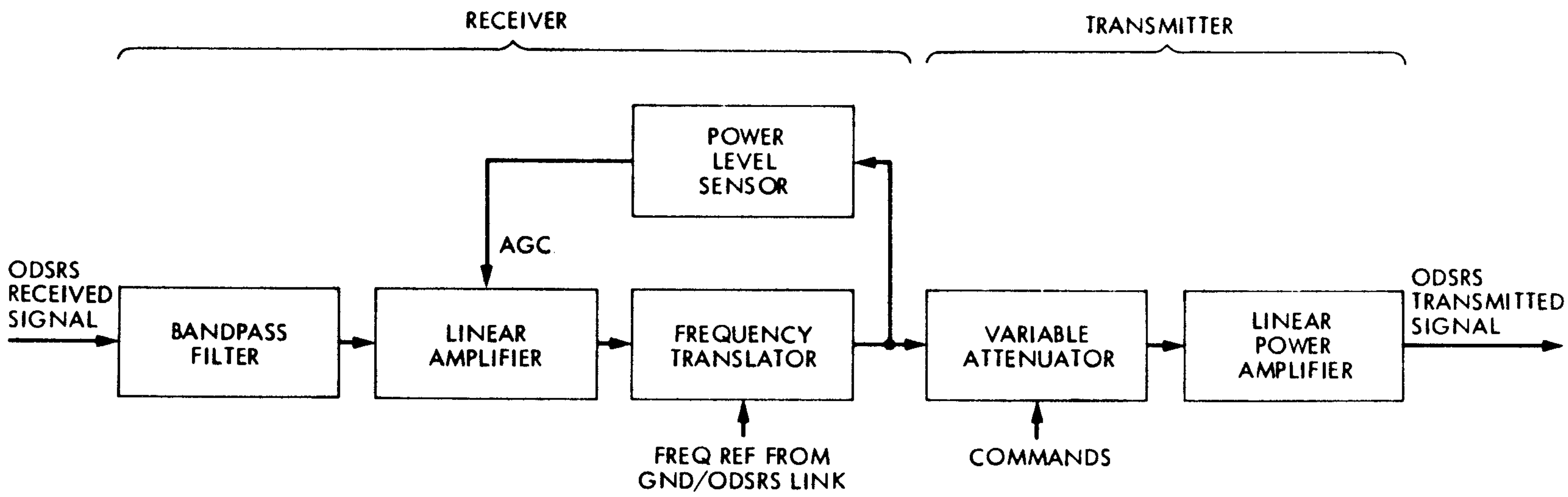


Fig. 1. ODSRS feed-through channel functional block diagram