Table 2. Recommended Values to be used as the zero-millibell level of unpolarized flux density.

Channel No.s	Approx. Freq., MHz	S_o* Relative, db	S_o* 10^{-22} $w m^{-2} Hz^{-1}$	Channel No.s	Approx. Freq., MHz	S_o Relative, db	S_o 10^{-22} $w m^{-2} Hz^{-1}$
199–123	≤ 3	0	16.0	99,98	11	-18.0	0.25
122, 121	4	-0.9	13.0	97	11.3	-16.8	0.33
120, 119	4.5	-1.4	11.6	96	11.6	-15.4	0.46
118, 117	5	-2.4	9.2	95	12	-13.7	0.68
116	5.5	-3.2	7.7	94	12.3	-13.0	0.80
115, 114	6	-4.0	6.4	93	12.6	-11.7	1.1
113	6.5	-5.1	4.9	92, 91	13	-10.3	1.5
112, 111	7	-6.0	4.0	90	13.5	-8.7	2.2
110, 109	7.5	-7.0	3.2	89,88	14	-7.4	2.9
108	8	-8.2	2.4	87	14.5	-5.7	4.3
107	8.3	-9.2	1.9	86-84	15	-4.4	5.8
106	8.6	-10.2	1.5	83-81	16	-2.4	9.2
105	9	-13.0	0.80	80-78	17	-1.2	12.1
104	9.3	-14.2	0.61	77-74	18	-0.4	14.6
103	9.6	-17.0	0.32	73-71	19	-0.1	15.6
102, 101	10	-19.3	0.19	70-68	20	0	16.0
100	10.5	-19.4	0.18				

* S_o is the total unpolarized zero-millibell flux density.

Frank –
This is an earlier estimate I made. Unfortunately, I have misplaced John Schauble's improved estimate. I don't believe it was too different, though.

Tom
May 20, 1985

Chapter 5

Flux Density Calibrations of the Low-Band Channels of the Voyager PRA Multichannel Radiometers

by

Thomas D. Carr

5.1. Introduction

The Planetary Radio Astronomy (PRA) radiometer aboard each of the two Voyager spacecraft consists of a pair of orthogonal monopole antenna elements from which two signal intensity components, nominally left hand (LH) and right hand (RH) circularly polarized, are derived and are converted into digitized values at the receiver output. Each monopole extends 10m from the body of the spacecraft, the irregular shape of which modifies in a more or less uncertain way the directional patterns and polarization purity of the antenna system. The receiver output is sequentially multiplexed between the 198 channels (both polarizations) at center frequencies ranging from 40.2 MHz down to 1.2 kHz. A new frequency channel is sampled every 30 msec, 6 sec being required to sample the group of 198 channels. The channels from 40.2 MHz down to 1.3 MHz have bandwidths of 200 kHz each. The aggregate of these channels are referred to as the high band of the receiver. The low band consists of those channels from 1.2 MHz down to 1.2 kHz, each of which has a bandwidth of 1 kHz. Lang and Peltzer (1977) and Warwick et al. (1977) provide detailed descriptions of the PRA radiometer.

The directional pattern of each 10m monopole acting in conjunction with the spacecraft body is to a first approximation that of a free space dipole 20m in length. For frequencies up to about 15 MHz, the directional pattern of such a free space dipole is relatively well-behaved. Within any plane containing the dipole, the pattern consists of a single broad lobe centered on the forward normal to the dipole and another broad lobe in the backward direction, with nulls in the directions off the ends of the dipole. Above

15 MHz, however, the pattern breaks up into smaller lobes separated by new nulls. Whenever the direction of an incoming signal crosses one of these nulls, the signal phase undergoes a shift of 180°. Correction for such effects above 15 MHz is difficult at best, and is probably not feasible in most cases.

If the directional patterns of the two orthogonal co-centered free-space dipoles were in fact accurately equivalent to those of the actual monopoles and spacecraft body, correction could be made for directional effects below about 15 MHz provided the source direction and the polarization of the radiation were known. The polarization is of course not known, and the difference between the actual and equivalent patterns may be rather large because of the shape of the spacecraft body and the presece of extensive and irregular projections from it, such as the magnetometer boom. Direct measurement of the antenna characteristics prior to launch was not feasible. Pre-launch calculations by Sayre (1976) suggested that at frequencies around 1 MHz the effect of the magnetometer boom is to rotate the pattern by perhaps 30° from that of an equivalent dipole aligned with the actual monopole, and that the effect is different at different frequencies. For this reason, and for even more fundamental reasons that were addressed in Chapter 4, Voyager polarization measurements other than the determination of the sense of elliptical or circular polarization are not possible. Even the sense indication is of no value if there is any doubt as to which of the antenna pattern lobes the radiation was entering. Fortunately, such antenna pattern uncertainties are believed not to result in excessive errors in the measurement of total flux density (i.e., the sum of any two orthogonally polarized components), provide the sum of the nominal (i.e., indicated) RH and LH intensity outputs of the receiver is used for each frequency channel and a standard correction factor depending on the off-axis angle θ is applied, as advocated in Chapter 4.

Having made the best feasible correction (under the circumstances) yielding an approximation to the sum of the nominal RH and LH intensity values that would have been obtained if the radiation had been normally incident to the antenna plane, we must now make use of pre-launch receiver calibration data and our knowledge of the antenna dimensions to arrive at a value for the total flux density. This procedure for the low band, described in this chapter, is simpler than it is for the high band; the latter is treated in Chapter 6.

5.2. Pre-Launch Calibration Data

The pre-launch calibration data, from which the values of the flux density conversion factors for the various receiver channels must be derived, are as follows:

a) The length of each of the two orthogonal monopole antennas is 10 meters, and its diameter is 0.5 inch. The sum of the capacities of the antenna-base feed-thru insulator, the preamplifier input, and the interconnecting wire is 75 pf, with an uncertainty of perhaps 10 pf. The preamplifier input resistance is 22 megohms. This information has been provided by Joseph K. Alexander of Goddard Space Flight Center.

b) The antenna impedance and directional characteristics at frequencies below 7.5 MHz are available in the report by Sayre (1976). These data were obtained by computer simulation of the monopole and spacecraft (including the magnetometer boom). Sayre found that in the low band (below 1.4 MHz) and in that part of the high band between 1.4 and 7.5 MHz, each monopole in combination with the spacecraft acts impedance-wise like a short monopole of effective length, ℓ, of 6 meters, perpendicular to an infinite conducting plane at its base. The equivalent circuit, he found, is a source of emf of ℓE volts (E = electric field intensity) in series with a 75 pf capacitor and a resistor of less than 10 ohms.

c) A white-noise signal of 1 $\mu V/kHz^{1/2}$ applied to the input of one of the two preamplifiers of a receiver will produce a decalibrated output in the 1.23 MHz low band receiver channel of 2300 mB (millibels) RH-circular component and 2300 mB LH-circular component. Essentially the same outputs are produced in all the other low band channels. Since the bandwidth of each low band channel is 1 kHz, the effective rms voltage from the above white-noise signal at the preamplifier input is 1 μV (Riddle, 1979).

d) The high band receiver gain has been so adjusted that a flat-spectrum white noise generator produces the same output in each high band channel as in each low band one, despite the fact that the high-band bandwidth is 200 kHz, 200 times that for low band (Riddle, 1979). This information will be used in Chapter 6.

5.3. Calculation of Flux Density Conversion Factor for Low Band

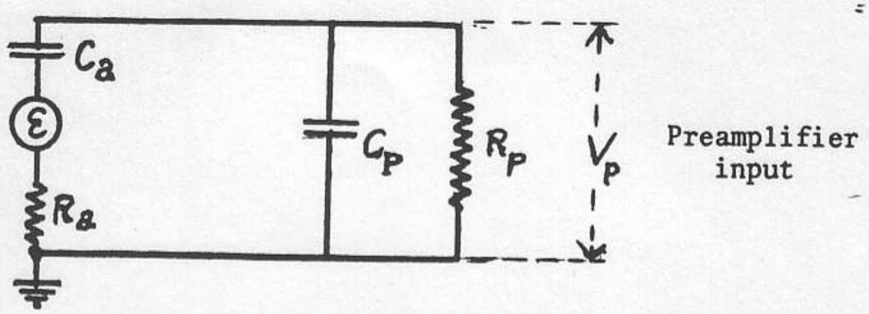
As stated above, a 1 μV white noise signal of 1 kHz bandwidth applied to one preamplifier input, with zero volts applied to the other, yields 2300 mB in the LH output and 2300 mB in the RH output of any low band channel. If a voltage V_2 is m millibels higher than a voltage V_1, then by definition,

$$m = 2000 \log \frac{V_2}{V_1} .$$

Thus if V_0 is the single-preamplifier input voltage (the other being zero) for which zero mB LH and RH outputs are obtained,

$$\begin{aligned} V_o &= (1\ \mu V)\ 10^{-\frac{2300}{2000}} \\ &= 0.0708\ \mu V. \end{aligned}$$

The equivalent circuit of one monopole (together with the perpendicular conducting plane) and the associated preamplifier input is shown in Fig. 1. The numerical values are from Sec. 5.2.



$C_a = 75$ pf $C_p = 75$ pf $R_a < 10$ ohms $R_p = 22$ megohms

$\mathcal{E} = \ell\ E$ $\ell = 6$m

Fig. 5.1. Equivalent circuit of one monopole and the associated preamplifier input for frequencies below 3 MHz.

Suppose that unpolarized radiation of total flux density S is incident on both monopoles from their directions of maximum response. The emf in each of the two equivalent circuits is ℓE, where E is the electric field intensity for one linear polarization plane. If S is made to have such a value that the 1 kHz-equivalent voltage across each preamplifier input is 1 μV, the RH and LH output powers will each be twice what they were (2300 mB) when 1 μV was across one preamplifier input and zero μV across the other. Thus the millibel levels will be 2600 mB for RH and 2600 mB for LH. It should be noted that for unpolarized radiation 0 mB corresponds to 0.0501 μV across each preamplifier input.

The available power per unit area in each orthogonal polarization component of unpolarized radiation within the bandwidth Δf is $E^2/120\pi$(in MKS units), where E is the rms electric field due to the frequency components within Δf. Thus the total flux density is

$$S = \frac{E^2}{60\pi\Delta f} \tag{5.1}$$

In Fig. 5.1,

$$\frac{V_p}{\mathcal{E}} \approx \frac{C_a}{C_a + C_p} ,$$

so

$$E = \frac{C_a + C_p}{C_a} \frac{V_p}{\ell} \tag{5.2}$$

Thus,

$$S = \left(\frac{C_a + C_p}{C_a}\right)^2 \frac{V_p^{\ 2}}{60\pi\ell^2\Delta f} \tag{5.3}$$

Putting in the values listed in Fig. 5.1, we get for the Low Band,

$$S = 5.9 \times 10^{-7}\ V_p^{\ 2}. \tag{5.4}$$

Thus the total unpolarized flux density corresponding to 2600 mB RH and LH outputs is

$$S = 5.9 \times 10^{-7}\ (10^{-6})^2$$

$$= 5.9 \times 10^{-19}\ \mathrm{wm}^{-2}\ \mathrm{Hz}^{-1}.$$

From this we find that the unpolarized flux density level for which the RH and LH millibel readings are both zero is

$$S_0 = 5.9 \times 10^{-19} \times 10^{-\frac{2600}{1000}}$$

$$= 1.5 \times 10^{-21} \text{ wm}^{-2}\text{Hz}^{-1}$$

Thus, if unpolarized radiation is incident normally to both monopoles, and the RH and LH outputs for a low band channel are both m millibels, then the total unpolarized flux density at the frequency of the channel is

*

$$S = \frac{S_o}{2} \left(10^{\frac{m_R}{1000}}\right) + \frac{S_o}{2} \left(10^{\frac{m_L}{1000}}\right)$$

$$= S_o \left(10^{\frac{m}{1000}}\right). \qquad (5.5)$$

The millibel readings m_R and m_L are also equal if the radiation is linearly polarized, and (5.5) applies in this case as well. For RH circular radiation, m_L in (5.5) is $-\infty$ (actually -20,000), and for LH circular radiation $m_R = -\infty$. For elliptically polarized radiation, $m_R \neq m_L$, neither being $-\infty$.

In practice, a background largely due to interference from within the spacecraft is also present, in addition to the radition being measured. This background may be slightly different for the RH and LH channels. If the millibel readings for incident radiation and the background combined are m_R and m_L, and for the background alone are m_R' and m_L', then (5.5) must be replaced by

$$S = \frac{S_o}{2}\left(10^{\frac{m_R}{1000}} - 10^{\frac{m'_R}{1000}} + 10^{\frac{m_L}{1000}} - 10^{\frac{m'_L}{1000}}\right), \qquad (5.6)$$

where as before, $\frac{S_o}{2} = 7.5 \times 10^{-22}\ \mathrm{wm^{-2}Hz^{-1}}$.

The foregoing analysis is for radiation incident normally to the monopole plane. If the incidence is oblique, at the angle θ with respect to the normal, S as found from (5.6) should be multiplied by the factor

$$\frac{2}{1 + \cos^2\theta},$$

as indicated by (4.73) in Chapter 4. The accuracy of this correction for various types of polarization of the incident radiation is given in Table 4.1.