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THE EFFECTS OF A SATELLITE POWER SYSTEM ON GROUND-BASED ASTRONOMY

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Bands allocated to radio astronomy occur at roughly octave intervals across the radio spectrum. Threshold levels for harmful interference in these bands are specified in CCIR Report Number 224-4, and are based upon observations with a single antenna which are the most sensitive observations to radio interference. They also assume reception of an unwanted signal in sidelobes of 0 dBi gain. These levels for the principal radio astronomy bands are shown in Figure 1.

In considering the effects of the SPS on radio astronomy the following components of the SPS spectrum must be included.

The Power Signal The typical level at an observatory not nearer than 100 km to a rectenna is estimated to be 0.01 Wm^{-2}, increasing by 5 dB if phase lock is lost at a satellite. This level, received in 0 dBi sidelobes of radio telescope, produces a signal of 10^{-5}W which is 35 dB above the overload threshold for a typical parametric amplifier, or 10 dB above the overload threshold for an FET amplifier. At present most radio astronomy receivers contain little or no filtering between the antenna and the first amplifier stage, to avoid the noise resulting from loss in ambient temperature filters. Cryogenically cooled filters, when developed, will prevent overload from the SPS power signal with little loss in sensitivity for most bands other than 2.69-2.70 GHz and 4.99-5.0 GHz. In these last two bands, which are close to the power signal and its second harmonic, impaired performance is likely to result.

Harmonics of the Power Signal Of several harmonics that fall close to radio astronomy bands the second presents a serious problem since it is likely to cause overloading when antennas are pointed close to the satellites.

Transmitter-Generated Noise Bands of noise generated by the power transmitting system will be centered on 2.45 GHz and low-order harmonics. For klystrons, Arndt and Leopold (1978) estimate that the noise should be less than the CCIR-224-4 level in the 2.69-2.70 GHz band. Crossed-field tubes and transistors are also being considered as power generating devices and may have significantly different noise properties.

Thermal Noise From The Collector Arrays The collector array on each satellite subtends a maximum solid angle of 0.5 sq arcmin at the earth and operates at a temperature of approximately 360 K. The thermal emission from 60 satellites, assuming unit emissivity is shown in Figure 1 for an observer's local midnight when the 60 satellites appear most nearly broadside-on. The actual emissivity of the cell arrays is not known, but probably results in a flux density level 3 to 10 dB lower than shown in Figure 1, i.e., very close to the CCIR 224-4 levels. Thus, for pointing angles closer than the separation of the 0 dBi sidelobe level from the main beam of the radio astronomy antenna, interference can occur.

Intermodulation Products Intermodulation products are to be expected from interaction of the power signal in nonlinear elements such as corroded joints in towers and fences, receiving systems and possibly the ionosphere. Widely distributed signals such as television broadcast signals are most likely to be

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involved.

Failure Related Signals With 6×10^6 tubes in orbit, a tube lifetime of 220,000 hours results in 26 failures per hour. Some failures may be associated with increased noise, development of parasitic oscillations or phase-lock failure. Klystrons are believed to be much less likely to produce such unwanted emissions than other types of microwave-generating devices. However, since so many units are involved, relatively rare failure modes will occur. Life testing of a large number of units is required to evaluate this effect.

Rectenna Radiation Some incident power will be reflected from the rectennas (Arndt and Leopold 1978) and noise and harmonics will be generated in the rectification process. The mean distance between 60 rectennas within the U.S. will be about 350 km. Choice of rectenna sites must make use of mountain ranges to obtain adequate isolation of observatory sites.

Synthesis arrays in which the signals from many antennas are combined in pairs to produce maps of the sky with high angular resolution are less susceptible to radio interference than single-antenna radio telescopes by factors that range from 10 to 40 dB depending upon the frequency, antenna spacing, bandwidth and other observing parameters (Thompson 1979). Observations using very long baseline interferometry (VLBI) are the least susceptible of all to radio interference (Burke 1979). Thus in Figure 1 the area between the lines marked VLBI and CCIR 224-4 represents the range of harmful interference thresholds for the various types of radio astronomy instruments. Unfortunately synthesis arrays and VLBI systems are not applicable to all types of astronomical investigations.

The principal effects of the SPS on radio astronomy can be summarized as follows. (1) For any type of radio astronomy system there will be an angular distance from the satellites within which harmful interference will occur. The width of this precluded zone depends upon various parameters of the observing instrument and is estimated to vary from 20° for a single antenna to a few degrees for a VLBI system. (2) For the 2.69-2.70 GHz and 4.99-5.00 GHz radio astronomy bands sufficient filtering to prevent overloading by the power signal or its second harmonic may not be achievable without significant impairment of sensitivity resulting from filter insertion loss. (3) Conflicts between site requirements for observatories and rectennas are likely to occur.

The above three effects represent the minimum likely interaction with radio astronomy, and are sufficient to cause significant restrictions. The effects of intermodulation products and failure-related signals discussed above could be much more serious, but should be more amenable to mitigation. The quality of SPS engineering and maintenance appears crucial to the coexistence of radio astronomy.

Radar astronomy, like radio astronomy, uses large antennas and highly sensitive receivers. Interference effects (David 1979) differ from those for radio astronomy chiefly in the following ways. (1) Bandwidths are usually much less than in radio astronomy, resulting in harmful thresholds 10-40 dB higher than the CCIR 224-4 levels. (2) 2380 MHz is an important frequency, particularly at the National Astronomy and Ionosphere Center, Arecibo, Puerto Rico. This is so near to the SPS power frequency that impairment of sensitivity will result. (3) Radar astronomy targets lie close to the ecliptic, and antenna pointing angles will generally be within 30° of the geosynchronous orbit.

In optical astronomy the effects of the SPS result mainly from the increase in sky brightness caused by diffuse reflection of sunlight from the satellites and subsequent scattering of the light in the earth's atmosphere. The effects are discussed in several papers in the report of the Battelle Workshop on Satellite Power Systems Effects on Optical and Radio Astronomy. They are difficult to quantify precisely because there is at least a factor of two uncertainty in the diffuse albedo of the satellites and the atmospheric scattering depends to some extent upon atmospheric conditions. In a zone 10° to 20° wide centered on the satellites, light contamination will cause impaired performance that cannot be compensated for by increased observing time. Noticeable effects will be seen over a band of sky at least 60° wide. The effects on ground-based optical astronomy are probably more severe than upon radio astronomy.

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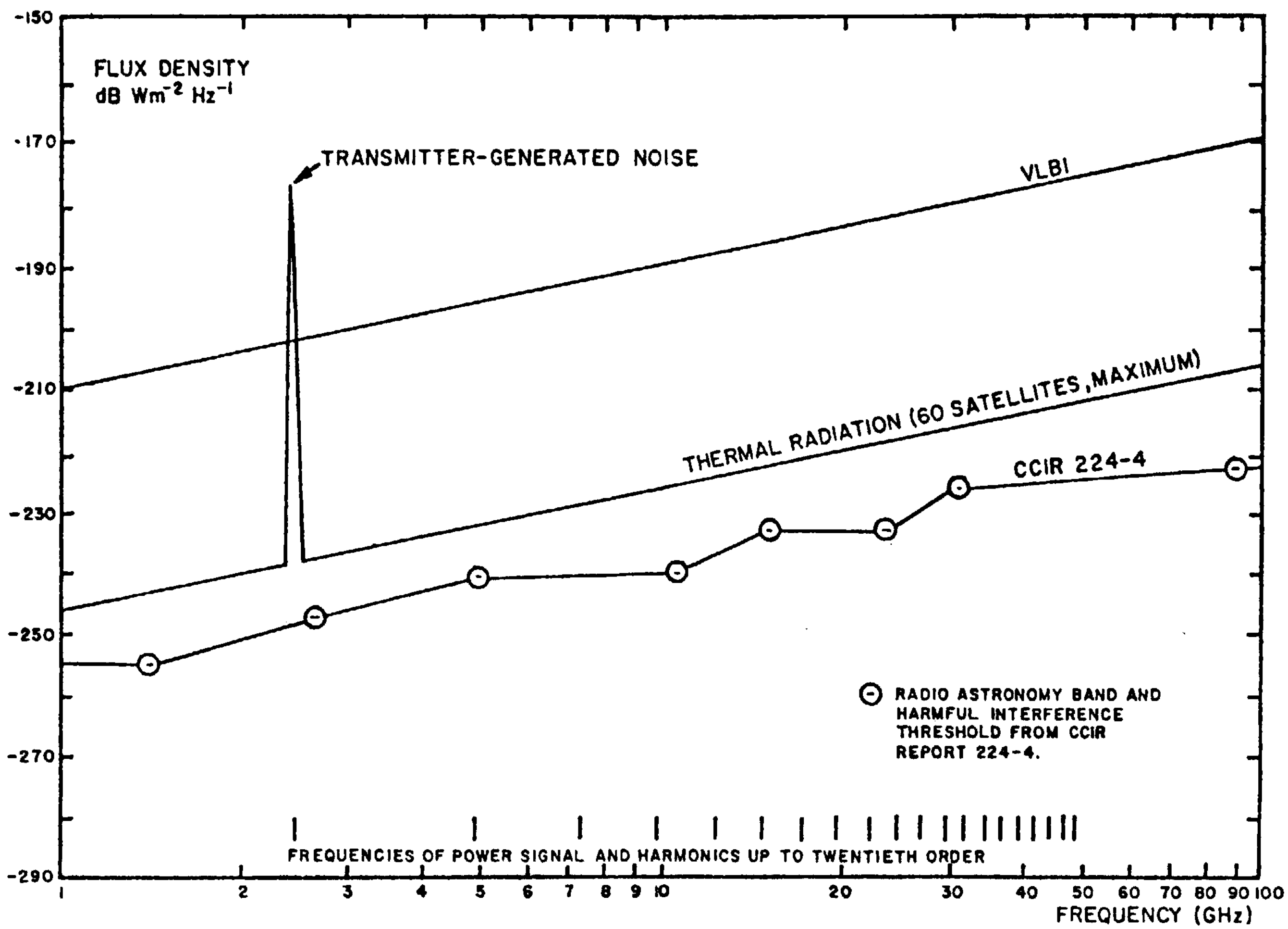

Figure 1: The spectrum of radiated noise from the SPS compared with harmful thresholds for radio astronomy. The line defined by the CCIR 224-4 points represents the harmful threshold as a function of frequency for total-power observations with single-antenna telescopes, which are the type of observations most sensitive to radio interferences. The line marked VLBI is from Burke (1979) and represents the threshold for observations using Very Long Baseline Interferometry which are the least sensitive to interference. The area between the CCIR 224-4 and VLBI lines represents the range of harmful thresholds for different types of radio astronomy instruments, when interference is received in antenna sidelobes with gain 0 dBi. The transmitter-generated noise at 2.45 GHz is from Arndt and Leopold (1978) and applies to klystrons. Similar bands of lesser amplitude will occur at the low-order harmonic frequencies.