THE NEED TO MEASURE MAN-MADE RADIATION FROM ORBIT FOR SPECTRUM MANAGEMENT

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Introduction The spectrum is a natural resource which has been valueed at $4 billion per megahertz. When the supply of spectrum exceeds the demand, spectrum management can be non-existent. As time progresses, the supply/demand ratio continues to allow implementation of necessary services. This need was formally recognized fifty years ago with the formation in 1922 of the Interdepartment Radio Advisory Committee (IRAC) to make effective use of radio frequency assignments to Government stations. Today there are over 120,000 assignments, and there are over 50,000 new applications annually (1). With this tremendous number of transmitters, Management of the radio spectrum is a complex multi-agency function. Monitoring of the radio frequency spectrum is required by the spectrum managers to (a) only authorized users are radiating, (b) that these radiations within the authorized limits, and (c) that the spectrum is allocated optimally.

Monitoring of the spectrum is usually accomplished with aircraft and terrestrial spectrum analyzers. Satellites offer another method for acquiring data on the utilization of the radio spectrum.

It is not clear where or when the idea of measuring man-made radiation from orbit first occurred. In recent years studies of the feasibility of such measurements have been made (2) and experiments have been performed to demonstrate the technique (3). In addition, measurements have been made from the air (4) at altitudes from 1 km to 10 km which can be directly related to data that would be obtained from a 400 km orbit.

One detailed study (1) of orbital measurements concluded that satellites would have the following uses:

A. Preparing environmental maps
B. Comparing actual environment with data banks such as FCC and ECAC
C. Optimizing spectrum utilization on world-wide, regional, and national basis
D. Contributing to engineering of specific communication systems
E. Locating low noise areas for siting economical satellite communication systems

F. Determining interference potential between spacecraft
G. Protecting and siting radio astronomy stations.

Measurements of electromagnetic fields from orbit in the VHF frequency band showed the ability to detect signals that could be associated with specific equipment known to be operating at various frequencies within view of the satellite (3). Measurements were made of the average and maximum signals for 71 frequency scans of a receiver in the LES-5 satellite over the United States between July 1967 and March 1968. The analysis identified AN/FRT-49 ground-to-air transmitters operating at 254.4, 261.2, 261.4, 261.6, 276.4, 276.7, and 278.6 MHz. This experiment demonstrated the usefulness of spaceborne spectrum analyzers for identification of terrestrial noise sources.

Studies and experiments to date have indicated the potential application of space for collecting data to assist in spectrum management and the facilities required (5)(6)(7). Technology developments are required to improve the spatial resolution. Experiments being planned will provide information that should aid in the formulation of mathematical models to minimize the amount of data that must be collected to provide continuous monitoring of the spectrum.

The Spectrum Management Problem The spectrum management information need requires:

A. Collection of spectrum occupancy statistics for different geographical locations.
B. Location, characterization and identification of single sources of known frequency somewhere in a large geographical region.
C. Characterization of equipment characteristics.
D. Development of mathematical models to describe the environment and minimize the data needed.

Once the necessary information is obtained, it should be possible to make more intelligent decisions regarding frequency allocations and sharing.

The primary unfulfilled spectrum management need is information on how the spectrum is presently being utilized. Knowledge of present spectrum utilization is a prerequisite to the determination of the additional uses that can be accommodated. Existing electromagnetic environment data files such as those at the Electromagnetic Compatability Analysis Center (ECAC) in Annapolis contain extensive information on electronic equipments; their nominal characteristics and geographical location. These files contain little information on spectrum occupancy statistics. There is now no way of knowing if any of the equipment is ever turned on or for how long. It is difficult to decide if a given frequency band can accommodate another transmitter when the present occupancy statistics of that band are unknown. Satellites offer the potentiality of obtaining real time data on actual spectrum occupancy including temporal periods (diurnal, weekly, and seasonal) and long-term trends. And satellites offer the potentiality of obtaining this data for many different locations on the globe.

The existing environment files provide no information or clues to the presence of intruders. Previous intrusions that resulted in sattellites being erroneously commanded have not been eliminated by location and identification of the intruder. These previous problem have been eliminated by advertising our grief to the broadcasting community to encourage their voluntary departure. Ultimately it seems desirable to have the capability of locating, characterizing and identifying sources of known frequency somewhere within a large geographical region.

The existing environment files provide no information on the spectral signatures, in-situ antenna patterns and other equipment characteristics necessary for prediction of spectrum occupancy statistics. As operating system crowd closer together in both space and frequency, it becomes more important to know the out-of-band spectral characteristics and radiation patterns. These and other equipment characteristics can be expected to change with time and depend upon equipment aging and the maintenance history. The diversity of equipment appears to make it unrealistic to assume that adequate characteristic data can be acquired and maintained from ground measurements. It appears desirable to have the capability of characterizing equipment in place from an orbiting satellite for spectrum management needs.

The collection of data from orbit for spectrum management would require an extensive storage capability if it was necessary to rely exclusively on empirical measurements. It therefore appears desirable to develop mathematical models to describe the environment and minimize the data needed.

While it is important to acquire information an spectrum occupancy and equipment location and characteristics, it is also important to acquire the capability of describing this environment quantitatively mathematically to reduce the number of measurements required for routine monitoring. The program of measuring fields from orbit should therefore include the prior generation of mathematical models that can be verified by the measurements.

There is also a need to be able to predict the electromagnetic environment to be encountered by a future mission from the data collected on a prior field measurement mission. The measurements made in one orbit by an antenna with one field of view will have to be extrapolated to other orbits and spacecraft antennas with other fields of view.

The creation of mathematical models to describe the environment must contain this extrapolation capability.

Frequency allocation is the process of reserving specific portions of the spectrum for particular communication services. The addition of space services to the previously allocated terrestrial services has resulted in a situation in which almost all space services must share frequencies with terrestrial services. Figure 1 shows the allocations to space and terrestrial services in the frequency range 100 MHz to 15 GHz. The bars between the horizontal dashed lines are the cumulative space and terrestrial allocations.

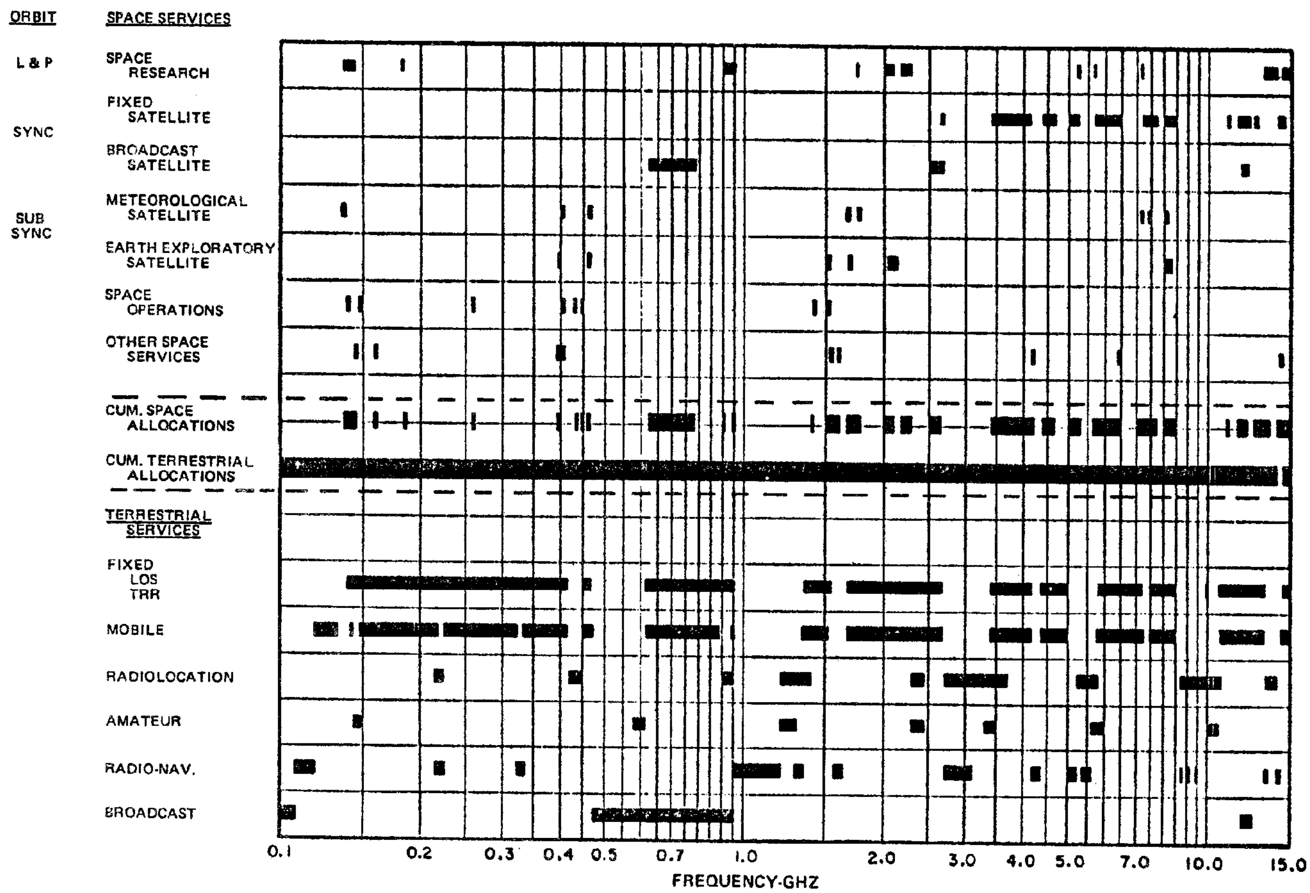

Figure 1 COMPARISON OF SPACE AND TERRESTRIAL FREQUENCY ALLOCATIONS

Technology Needs The complete set of measurement needs described above appear to be somewhat beyond the present technical state-of-the-art. The frequencies of interest will eventually extend above the range shown in Figure 1, although that range is more than adequate for present needs. The fabrication of flight receivers to cover this range is feasible now. There are some receiver technology improvements that would be desirable including the attainment of a low noise figure at the higher frequencies, the elimination of all spurious responses within the band, and improved rejection of out-of-band signals.

The major technological challenge is in the development of flight antennas to produce a narrow beam for high resolution (5 km) at the low end of the frequency band (100 MHz). Ideally, it would be desirable to have a single antenna that could cover the entire band and be able to zoom from a 130° field of view to a 2° field of view in low earth orbit. At the low frequencies this implies an aperture of about 70 meters. The advent of the shuttle (Sortie Lab) will allow the use of man for the development of the technology of erecting large apertures in space.

Technology Development and Measurement Program A program is needed to perform the measurements and develop the technology described in the above sections. Such a program would include the pursuit of a mathematical description of the environment for comparison with the measured data. The output of the program would include data to supplement existing environment files and improved technology to permit more refined future measurement.

A complete program would make use of existing flight opportunities and future planned missions for data collection. Low-orbit missions offer the possibility of better spatial resolution than higher orbits. High inclination angle missions offer the possibility of global data collection. Non-sun-synchronous orbits will permit data collection at different times of the day to characterize the diurnal variations. An on-board tape recorder on a low-orbiting satellite permits data to be collected beyond the view of ground stations for later relay to earth. A geostationary orbit allows frequent sampling of the environment from the same orbit point to collect good temporal statistics. A dedicated satellite minimizes the amount of on-board equipment that could interfere with the measurements. A manned mission with large size and weight capability permits the development of technology that would be expensive if attempted on unmanned missions.

There is also data available from previous and present missions that could be analyzed to provide information on global signal levels. It is desirable to review present data and data analysis programs to make maximum use of existing data.

Data Reduction and Analysis Electromagnetic field data can be processed, analyzed and presented in a variety of ways to describe the variations in received power with geographical position, time and frequency. Some of the possible output presentations are shown in Figure 2.

The specific analysis performed on the data depends upon the types of signals received and the purpose of the analysis. These factors can be different for the different frequency bands.

Presentation	Parameter	Remarks
Average Power Spectral Density	Power Spectral Density Versus Frequency	Antenna Pointing and Satellite Location are Fixed
RFI Power Versus Time of Day	Total Power in a 1 MHz Band Versus Time	Antenna Pointing, Satellite Location and Frequency are Fixed
RFI Power Versus Spacecraft Longitude	Total Power in a 1 MHz Band Versus Spacecraft Longitude	Antenna Pointing, Time of day and Frequency are Fixed
Channel Occupancy Rate	Percent Time Channel Occupied Versus Frequency	At 5 dB Threshold and Fixed Longitude
Probability That Ordinate Length of Message is Exceeded	Time Between Message Versus Probability of Occupancy	Frequency is Fixed
Probability That Ordinate Time Between Messages is Exceeded	Time Between Message Versus Probability	Frequency Fixed
Probability That Ordinate Power Density Will be Exceeded	Power Spectral Density Versus Probability	Frequency Fixed
Quick Look Power Spectral Density	Power Spectral Density Versus Frequency	Date, Time, Antenna Pointing, and Satellite Location are Fixed
Movie Frame of PSD Display	PSD Versus Frequency	Frame No. Date, Time Z Lat., Long.
Geographic Location Movie Frame	Latitude Versus Longitude	RF I MAP DATA Frame No. Dates Time Time Z Frequency Fixed
Difference Plot	Difference in db Versus Frequency	Antenna Pointing and Satellite Location are Fixed
Scatter Plot	Power Measured in 1 MHz Versus Predicted Power	Antenna Pointing and Satellite Location Fixed
Total Power in 1 MHz Band	Power in 1 MHz Band Versus Frequency	Antenna Pointing and Satellite Location Fixed

Figure 2. EM Field Measurement Data Presentation Formats

Conclusion The experience of NASA has indicated the importance of being able to predict (and thus avoid) harmful RFI. A measurement program is required to gather data to provide an insight into the electromagnetic fields to be expected in orbit. Several satellites could provide platforms for such measurements. The manner in which these platforms could be used have been described (6,7).

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