may be outweighed by features which are disadvantegeous to specific mission requirements. Therefore, the choice of a high-power output tube is not straightforward, but represents a series of tradeoffs to see what type of radar technology is best for a particular circumstance.

This report is not to imply that spectrum conservation should outweigh other operational and economic considerations in the choice of a radar output tube; but, to emphasize that spectrum conservation must be considered--along with other factors--and that considerable data are available on radar spectra to aid in the considerations.

We have made no attempt in this report to rank the desirability of output tube characteristic in any manner. On the contrary, this report contains spectrum data in as unbiased a form as possible. A Radar Spectrum Engineering Criteria (RSEC) limit has been plotted on the individual radar spectra. Even this October 1977 RSEC (NTIA, 1980) should not be regarded as a value judgment on a particular radar spectrum, because the particular radar many not be subject to the limits implied by that RSEC. The same RSEC limit was drawn on all of the radar spectra--regardless of what RSEC limits actually apply to that radar--to provide a single technical reference for comparison between radars. This RSEC contains some measurement bandwidth correction factors, described in a later section, which must be included if a valid comparison is to be made between radars. Merely observing the amplitude of the sidebands relative to the peak will often give misleading interpretation of these spectrum data.

We have selected an assortment of radar spectra for this report that give a representative view of the emission spectra available from various currently operational output tube technologies. In some cases, the selected radar spectra were chosen from among many examples of measurements made on a particular nomenclature. In these cases, the spectra were selected to show a spread of characteristics that were encountered. In other cases, we have only a very few (even single) examples of a spectrum. from a particular nomenclature. We would have no way of evaluating the degree to which these spectra are typical; however, we have not knowingly selected atypical data for inclusion here.

2. MEASUREMENT TECHNIQUES

2.1. The Radio Spectrum Measurement System (RSMS)

The RSMS is a computerized multi-stage superheterodyne receiver, tunable between 100 kHz and 18 GHz, that is integrated into a motorhome-type van for easy transportation and operation at remote sites. The van contains environmental controls and two 6-KVA RFI-shielded motor-generator sets to allow for operation independent of other logistic support.

Essentially all functions of the receiving system (Fig. 1.) are under computer control, and a very flexible digital data processing system is used to process real-time information or to record data for later analysis.

The antenna subsystem includes noise diodes to calibrate the system in absolute amplitude at the antenna terminals. Relays are used to select either a desired measurement antenna or the noise diode for calibration. This technique automatically accounts for switching or transmission losses involved in bringing the received signal from the antennas to the signal processing inputs of the receiver.

As required, 0-70 dB input attenuation may be inserted to bring the input signal within the measurement range of the receiver. The system software automatically connects the proper preselector/preamplifier, based on the frequency of the signal being measured. Below 500 MHz, fixed-tuned bandpass filters are used to keep out-of-band signals from interfering with measurement of the desired signals. The system uses YIG-tuned tracking preselectors and post selectors for received frequencies above 500 MHz. Preamplifiers are used to decrease system noise figure for frequencies below 12 GHz.

The signal is converted to an IF signal after several mixing stages. All of the local oscillators are derived from a single synthesized reference frequency, so that received signal frequencies can be tuned very accurately. Several IF/detector units are used for various types of measurements. A 3 MHz, narrowband IF unit allows a choice of ten bandwidths between 10 Hz and 300 kHz and gain adjustment from O to 50 dB in 10 dB steps. A 50 MHz wideband IF unit allows a choice of 1 MHz or 3 MHz bandwidths. Video bandwidths in excess of 10 MHz are available from a detector/log amplifier module driven directly from the preamplifiers. The AM, FM, cw, and SSB demodulator circuits are available to monitor the aural content of the signal. Peak and quasi-peak detectors are available to assist in making measurements of radar and broadband impulsive noise signals.

A pulse-blanking system is used to isolate a single radar from a multi-radar environment, so that measurements may be made on that radar only. A pulse train separator and a pulse repetition frequency filter provide a means of determining when the desired radar pulses are present. This equipment operates with a high-speed switch to gate only the desired radar pulses into the measurement circuits. A peak detector is used to measure the amplitude of the selected

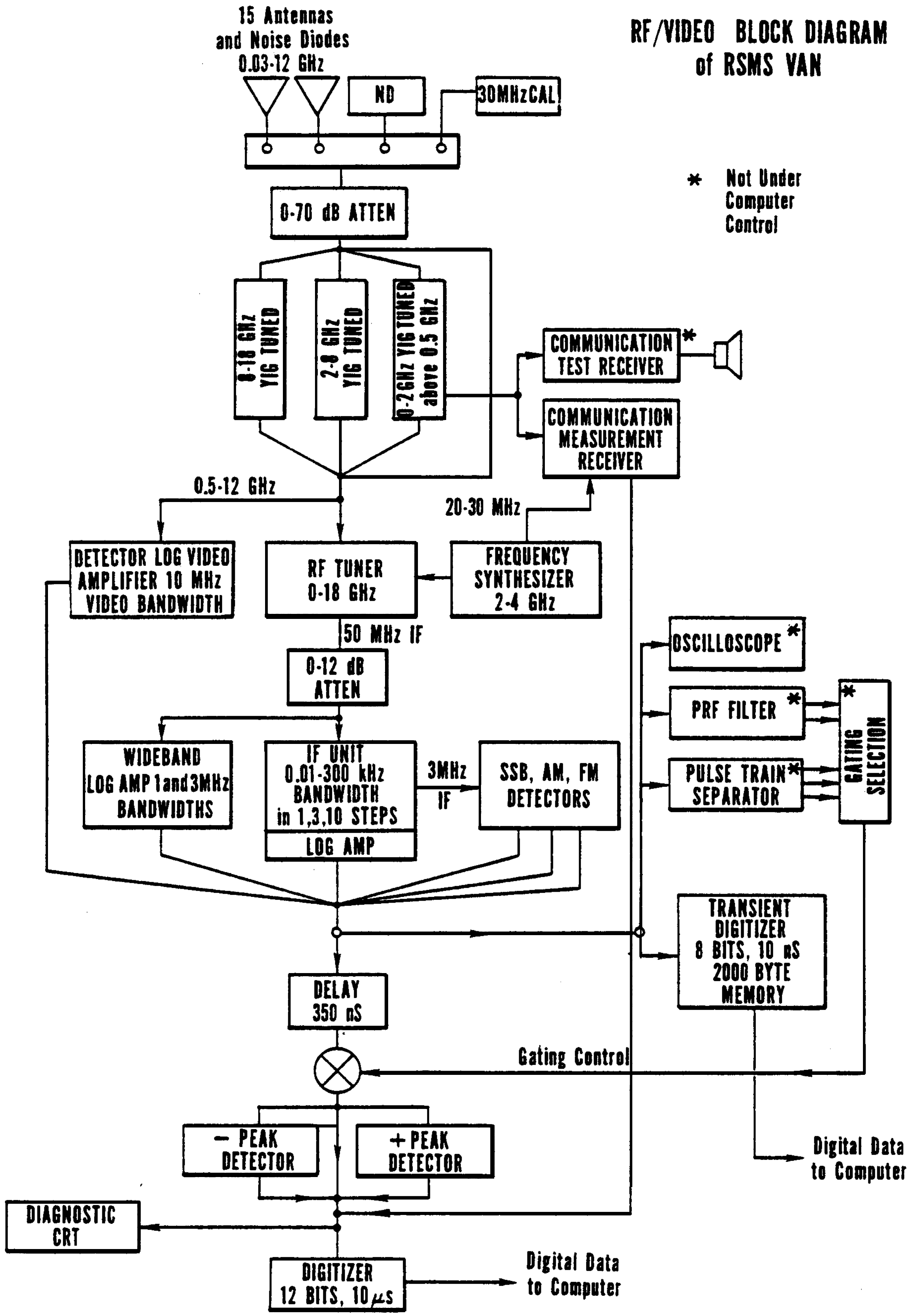

Figure 1. Rf/video block diagram of RSMS van.

pulses.

For additional information on the RSMS capabilities, refer to the references at the end of this report.

2.2. Radar Emission Spectra Measurements

The emission spectra measurements presented in this report were collected as part of a several-year series of radar band spectrum occupancy surveys and special radar measurements conducted as part of the NTIA frequency management program.

Some of the radar spectra were measured with a direct connection to a suitable coupler on the radar output. This technique usually provided the best dynamic range, though often entailed some feedthrough problems due to the high signal levels. In other cases, the RSMS was located at a distance from the radar and used an antenna to obtain a sample of the radar spectrum. This allows working with smaller signal amplitudes but introduces the problem of isolating the radar spectrum from other signals in the environment.

In this case, several techniques were used to minimize the influence of other radars on the measurement. A parabolic dish antenna was usually used for these measurements. The dish provided considerable angular discrimination against other radars, in addition to giving extra system gain necessary to measure farther down on the skirts of the radar spectrum. If necessary, the pulse blanking capability could be used to help eliminate other radars from the measured emission spectrum.

The radar spectra measurements utilize a program (Wide Band Scan) that allows the specification of many operating parameters, including frequency range, number of frequency steps within the specified range, dwell time on each frequency step, bandwidth, rf attenuation, IF gain, peak hold, and receiving antenna. The program steps across a selected band of frequencies, starting at the lower end of the frequency range and continuing until the upper end of the frequency range is reached. A typical frequency range selected is 200 MHz, with 200 steps within this range. If a l-MHz or greater measurement bandwidth is also selected, the entire 200-MHz segment is sure to be measured. At each frequency, the system waits for a specified dwell time (typically 5 seconds for S-band radars) continually measuring the peak amplitude of the signal and updating its measurement when a stronger pulse occurs. The dwell time is chosen somewhat longer than the rotation period of the radar antenna, to ensure that the peak measurement recorded for each frequency will contain the period of time during which the radar antenna's main lobe was aimed directly at the RSMS. Of course, if operational constraints allow it, the radar can be continuously pointed at the RSMS, permitting a very short dwell time, reducing the time required to complete the measurement. As the measurements are made, the measured data are graphed. The operator may add or subtract rf attenuation in 10-dB steps as required to keep the signal within the linear measurement range of the system. Software compensates for rf attenuation so that the graphed data are continuous and appear to have been measured by a system with larger dynamic range. In some extreme situations where the combination of preelection and attenuation did not' provide sufficient dynamic range, a notch filter--tuned to the radar center frequency--was inserted at the measurement system input. The insertion loss of the filter is compensated by the noise diode system calibration routine to give a correct center frequency power measurement for the radar spectra. Whenever operational constraints permitted, sequential frequency segments were measured until the received radar signal fell below system noise as illustrated by Figure 3a.

3. DATA ANALYSIS

The RSEC was established to help ensure an acceptable degree of electromagnetic compatibility among radar systems. A detailed explanation of the RSEC is found in section 5.3. of the Manual of Regulations and Procedures for Federal Radio Frequency Management (NTIA, 1980).

The RSEC bases an allowable emission bandwidth, B, on certain radar operational parameters including the radar type, transmitted power, pulse characteristics, frequency, and procurement or major overhaul date. For purposes of technical comparability, the same RSEC was applied to the spectra of all radars presented in this report, even though a different RSEC category may correctly apply to the spectra. For the -40 dB bandwidth we selected:

$$B_{(-40\ dB)} = \frac{7.6}{\sqrt{t\ t_r}}\ ,\ \text{or}\ \frac{64}{t}\ ,\ \text{whichever is less,}$$

where t = radar pulse width and t_r = radar pulse risetime.

It will be noted, Figure 5, for example, that the RSEC limit often starts several decibels above the peak response of the radar. This difference is from a correction factor that was added because the measurement bandwidth was larger than the emission bandwidth.