APPENDIX A: RADIO SPECTRUM MEASUREMENT SYSTEM (RSMS)

A.1 Introduction

The NTIA RSMS is a mobile, self-contained computer-controlled radio-receiving system capable of many measurement scenarios over a frequency range of 30 MHz to 22 GHz. This appendix contains specifications on the vehicle, instrumentation, and operation of the RSMS when it is deployed for broadband spectrum survey measurements.

A.2 Vehicle

For maximum effectiveness, the spectrum measurement system must be readily transported to near or distant locations that may not be easily accessible, e.g., open fields or hilltops without an access road. To meet this need, the measurement system, including antennas and support hardware, is carried in a shielded, insulated, climate-controlled shell mounted on a Chevrolet truck cab and chassis. The assembled measurement system and vehicle unit is called “the RSMS.” The vehicle has a high power-to-weight ratio, four-wheel drive, and a low-geared transmission for use on rough terrain and steep grades. The RSMS is still sufficiently small and light to fit on C-130 or larger aircraft for rapid transport over long distances. The chief disadvantage of a smaller unit is the loss of operating room inside the shell.

Figure A-l shows the internal layout of the RSMS. Four full-height equipment racks are located transversely above the rear axle. These racks divide the box-like equipment compartment into two parts: one in front and one behind the racks. The forward area comprises the operator’s compartment with access to the equipment front panels, the main power panel and breaker box, work counters, two chairs, telephone, fax machine, and a cellular fax/modem. A built-in safe below the equipment racks provides storage for classified materials. A full-height cabinet in the forward driver’s side comer provides for storage of small, frequently used items. A compartment for the smaller of two telescoping masts is located behind this cabinet, and is accessed from outside the van.

Additional storage cabinets are available to the rear of the racks for larger and less-used items. Compartments for the large mast and the external-tap power cable and its electrically driven reel are located behind these cabinets, with outside access. The weight of the mast-rotator, power cable and reel is counterbalanced on the driver’s side by the I0-kW generator and two air conditioners. The rear area provides access to the back of the equipment racks. The generator compartment is accessed via an outside lift-up panel. The air conditioners are not readily accessible.

The tightly-shielded, windowless measurement compartment (shell) provides good radio frequency (RF) isolation between the measurement system and the outside environment. The small working compartment also reduces requirements for air conditioning and heating. Both of the telescoping masts are installed on rotators (at their bases) and will raise the antennas to a little over 8 m above ground.

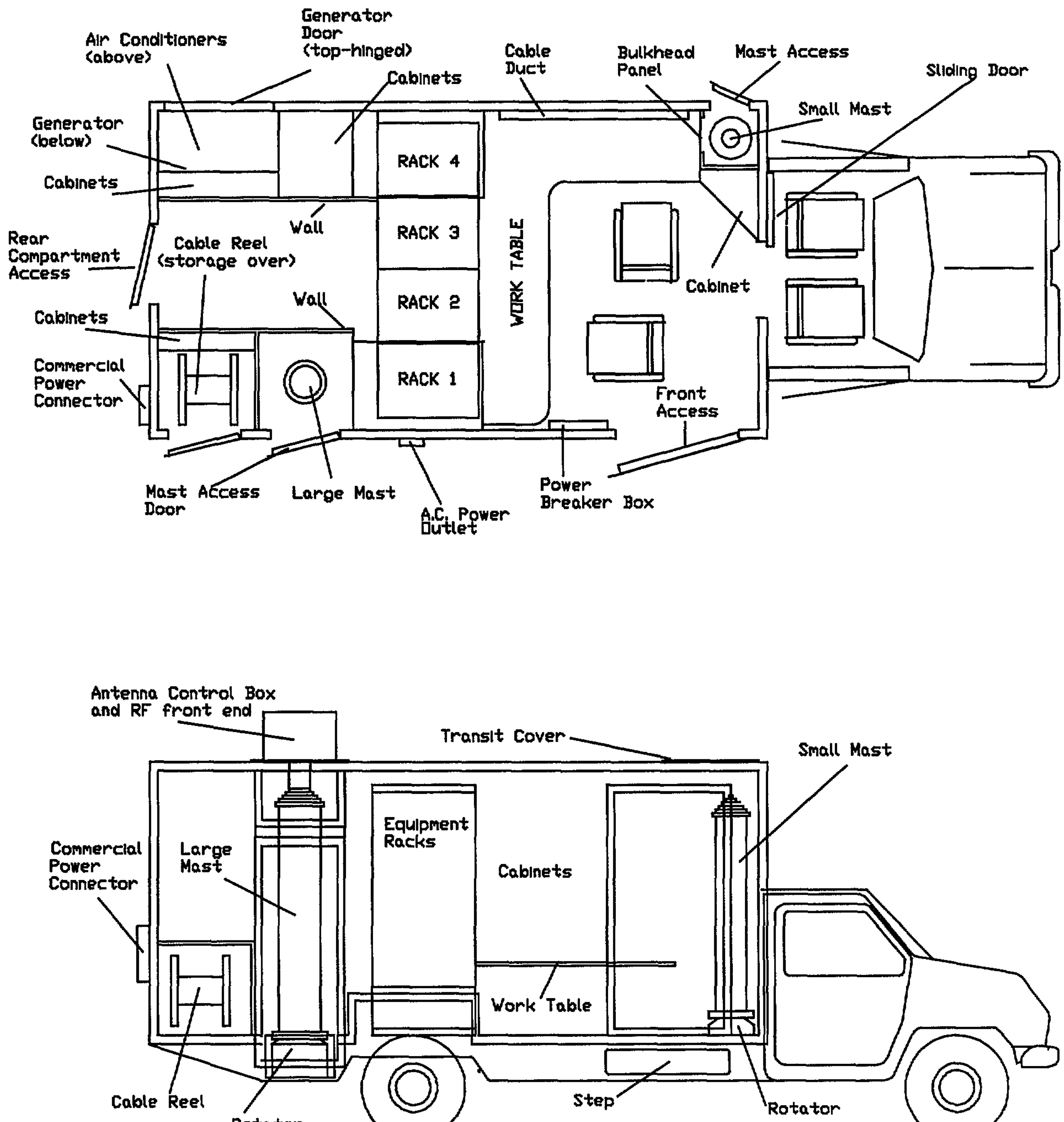

Figure A-1. Top and side view drawings of the RSMS.

A.3 Instrumentation

The RSMS is normally configured as two independent spectrum measurement systems, one optimized to measure lower frequency portions of the spectrum (System-l), and the other to measure higher frequencies (System-2) with some frequency overlap between the two systems. Figure A-2 is a fish-eye front panel view of the rack mounted instrumentation. Measurement and control instruments for System-l are in the two racks on the right of center; and for System-2, the two racks left of center. Both systems use RF front-ends that incorporate dynamic RF attenuation, low noise preamplification and tunable frequency preselection. These features allow the RSMS to achieve the best possible combination of dynamic range, sensitivity, and off-tuned signal rejection in its measurements.

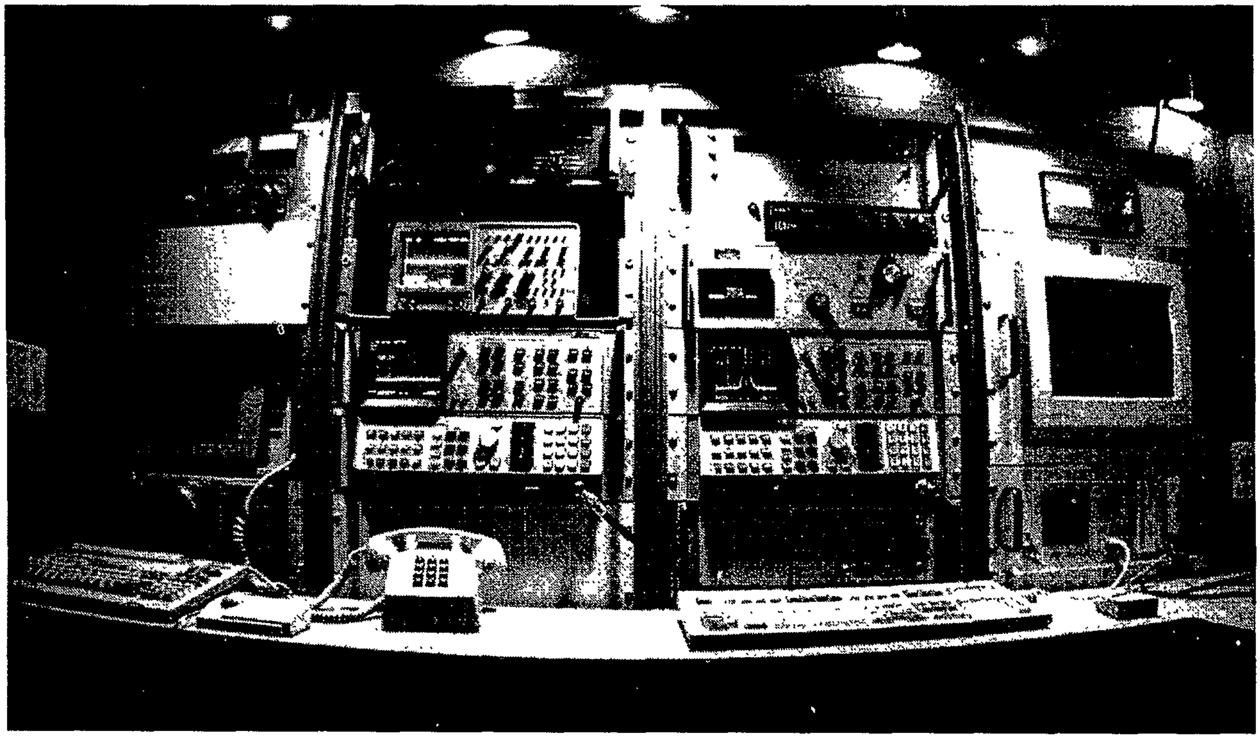

Figure A-2. Front panel of the RSMS instrument racks.

For spectrum surveys, the low-frequency system is usually operated between 100 MHz and 1 GHz, with its antenna(s) mounted on the smaller forward mast and its RF front-end located inside the operator's compartment. The high-frequency system is used for the remaining survey frequencies from 1-19.7 GHz, with its antenna(s) mounted on the larger mast and its RF front-end located at the top of that mast to overdrive the higher line losses that occur above 1 GHz. The RSMS receiver is depicted as a block diagram in Figure A-3. As the diagram shows, both the high and low frequency systems are designed around a 0-22 GHz range Hewlett-Packard 8566B spectrum analyzer, although the RSMS software will control other spectrum analyzers, such as the HP-70000 series. The selection of 1 GHz as the break point between the two systems in a site survey mode is determined primarily by the availability of antennas, which often begin or end their frequency response at 1 GHz.

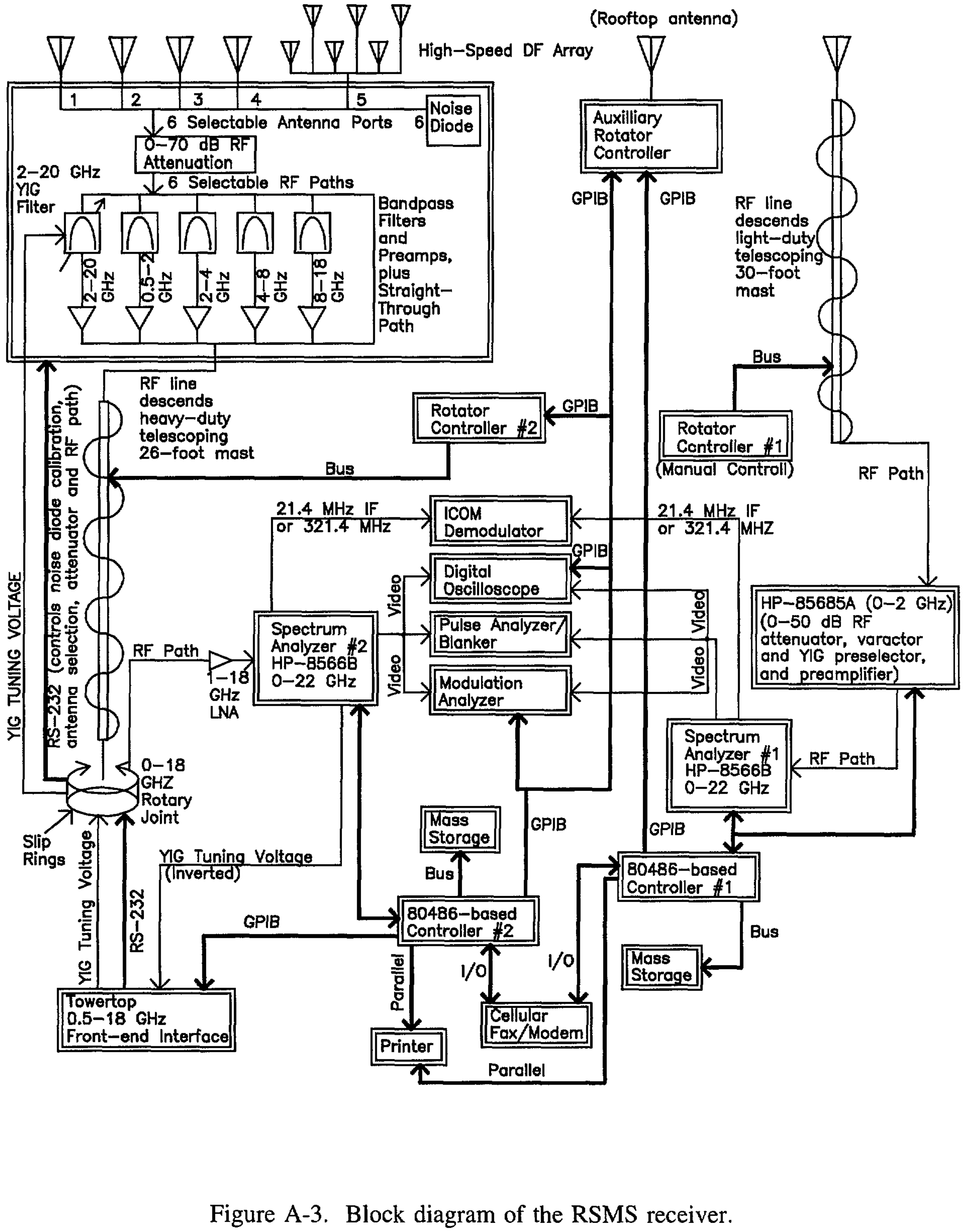

Figure A-3. Block diagram of the RSMS receiver.

Each of the measurement systems can be controlled in fully automatic, semiautomatic, and fully manual modes. In fully automatic operation, each system is controlled by ITS-written software (named DA, for Data Acquisition) that runs under Microsoft-DOS on 80486-based computers. Spectrum surveys are normally conducted in the fully automatic mode. RSMS operators are able to interrupt automatic measurements to perform work in semiautomatic and manual modes. These modes allow special measurements with varying degrees of automated assistance.

The two measurement systems utilize independent antennas, RF front-ends, masts, spectrum analyzers and computers, but share the use of auxiliary equipments for special measurements, analysis, and troubleshooting. Support equipments include a digital oscilloscope, pulse train analyzer, demodulator, modulation domain analyzer, rotator controllers, signal generators (frequencies range from a few kilohertz to 18 GHz), power supplies, low noise amplifiers, cables, connectors, and hand tools. Data from the oscilloscope can be downloaded to the controller computers. Data from the auxiliary devices are often used to determine specific characteristics of selected emitters during the course of a spectrum survey or other measurement.

The RF operational characteristics of the two measurement systems are shown as a function of frequency in Table A-l. The lower-frequency system can be operated across a frequency range of 100 Hz to 2 GHz, with fixed bandpass and varactor preselection at frequencies below 500 MHz and tracking yttrium-iron-garnet (YIG) preselection from 0.5-2 GHz. This system includes 0-50 dB of dynamically selectable RF attenuation in the front-end, and achieves a typical overall noise figure of 10 dB across its entire frequency range. The higher-frequency system can be operated across the 0.5-22 GHz range, with YIG preselection from 2-20 GHz. This system incorporates 0-70 dB of dynamically selectable RF attenuation in the front-end, and uses low noise preamplifiers to achieve a typical noise figure of l0-15 dB up to about 10 GHz, and a noise figure that increases from 15-25 dB at frequencies from l0-20 GHz. Better noise figures can be obtained by using the fixed bandpass filters for preselection instead of the YIG, but that arrangement is tenable only if there are no in-band signals strong enough to overload the preamplifiers.

A.4 Antennas

The RSMS normally carries a complement of broadband antennas that cover a 0.1-20 GHz frequency range. Other antennas necessary for measurements at higher or lower frequencies are stored at the ITS laboratory. Omnidirectional, slant-polarized biconical antennas are most frequently used for site surveys. These antennas provide a good response to circular, vertical, and horizontal signal polarizations. At frequencies from 0. l- 1 GHz, a slant-polarized log periodic antenna (LPA) may be used if (as in the San Diego survey) most of the radio activity in the area is confined to an area subtending 180” or less relative to the RSMS and a satisfactory omni antenna is not available. Besides the 0.1-l GHz LPA, the following omnidirectional slant-polarized biconical antennas are also carried: 0.5-20 GHz, 1-12 GHz, 2-8 GHz, and 8-20 GHz.

In addition to the LPA and omnidirectional antennas, a variety of broadband cavity-backed spiral (CBS) antennas are carried. These have antenna patterns that are most useful for direction-finding using differential methods at relative observation angles of 60” or 90”. They are also

Table A-l. Available RSMS RF Signal-processing Paths

Frequency Range	RSMS System	Dynamic RF Atten. (dB)	Type of Preselection and Low-noise Preamplification	Noise Fig.* (dB)
100 Hz - 2 MHz”	1	0-50	Fixed Bandpass; HP-85685A preamps’	10
2 MHz - 20 MHz”	1	0-50	5% Varactor; HP-85685A preamps+	10
20 MHz - 100 MHz”	1	0-50	5% Varactor; HP-85685A preamps	10
100 MHz - 500 MHz	1	0-50	5% Varactor; HP-85685A preamps	10
500 MHz - 2 GHz	1	0-50	0.2% Tracking YIG; HP-85685A preamps	10
500 MHz - 2 GHz	2	0-70	Fixed Bandpass; 0.5-2 GHz preamp*	10
2 GHz - 4 GHz	2	0-70	Fixed Bandpass; 2-4 GHz preamp*	10
4 GHz - 8 GHz	2	0-70	Fixed Bandpass; 4-8 GHz preamp*	10-15
8 GHz- 18 GHz	2	0-70	Fixed Bandpass; 8-18 GHz preamp*	15-25
2 GHz - 20 GHz	2	0-70	0.2% Tracking YIG; preamp l-20 GHz	15-25

* Noise figure is measured using a +25 dB ENR noise diode and Y-factor calibration. Calibration is performed at the antenna terminals.

** Due to the shortage of storage space for large antennas, this frequency range is not normally measured as part of an RSMS spectrum survey.

\+ The low-frequency input on the HP-85685A preselector must be used.

+/- Generally, this path is only used to perform azimuth-scans or special measurements during an RSMS spectrum survey, but may be used for normal survey bands if no high-amplitude signals are anticipated in the measured frequency range.

</–This path is normally used for all spectrum survey bands (except azimuth-scans, see note + above) in the 1-19.7 GHz frequency range. The YIG and preamplifier nominally operate in the 2-18 GHz frequency range, but have demonstrated adequate performance across a l-20 GHz range.

useful as auxiliary antennas for manual monitoring of emitters or spectrum of special interest and for use on side excursions to measure specific emitters of interest in the area of a site survey. The frequency ranges of these CBS antennas are 1-12 GHz, 8- 18 GHz, and 400 MHz-2 GHz. The latter is not normally carried due to its size.

A 1 -m parabolic dish antenna with a linear cross-polarized feed of 2-18 GHz is normally carried. This antenna may be used to perform azimuth-scanning measurements in the common carrier (point-to-point microwave) bands, but is primarily used for measurements on specific emitters (e.g., selected radars).

The receiving antennas are the only components of the RSMS that are not calibrated in the field. Because most RSMS measurements are performed to acquire relative emission levels, rather than absolute incident field strength values, the main requirement for RSMS antennas is that they have a fairly flat gain response as a function of measured frequency. If absolute incident field strengths must be known for received signals, then the gain factors (or, equivalently, the antenna correction factors) for the applicable antennas are determined from manufacturer-generated tables and curves, and the RSMS measurements are corrected in a post-acquisition analysis phase.

A.5 Attenuators, Preselectors, and Preamplifiers

All RSMS measurements are made using the RF front-ends depicted in Figure A-3. These front-ends incorporate dynamically switched RF attenuation, preselection, and preamplification. The Hewlett-Packard 85685A is used for frequencies below 2 GHz, and a unit designed and fabricated by ITS is used at frequencies between 2 and 20 GHz. The two boxes (HP 85685A and ITS designed unit) are functionally similar, but differ in significant details. For example, the 85685A provides 0-50 dB of RF attenuation, and the ITS box provides 0-70 dB of RF attenuation. This active attenuation allows the total dynamic range of the RSMS to be extended to as much as 130 dB.

Effective bandpass preselection is required if low noise preamplifiers (LNAs) are used; this is the case for essentially all RSMS measurements. Preselection prevents strong off-tuned signals from overloading the front-end LNAs. At frequencies below 500 MHz, preselection in the HP-85685A is provided by fixed filtering, up to 2 MHz, and by 5% tracking varactors from 2-500 MHz. Tracking YIG filters are used in the frequency ranges of 500 MHz to 2 GHz and 2 GHz to 20 GHz YIG filters provide the narrowest preselection (15 MHz wide at 500 MHz to about 25 MHz wide at 20 GHz), but at a cost of about 6 dB of insertion loss. Using fixed bandpass filters can reduce the preselection insertion loss to about 1 dB; fixed bandpass filters in an approximately octave progression are available in the ITS front-end (see Figure A-3). These can only be used if no signals are present in the band which are strong enough to overload the LNAs.

LNAs are used to achieve the best possible sensitivity, coupled with (ideally) just enough gain to overdrive the noise figure of the rest of the measurement system. Operationally, at frequencies below 1 GHz, line losses are sufficiently low to allow placement of the RF front-end inside the operator’s compartment with an RF line to the antenna mounted on the mast. At frequencies above 1 GHz, however, the line loss is 10 dB or more, and thus the LNAs (and the rest of the RF front-end) must be positioned at the top of the mast. (Consequently, the mast must be sturdier than the lower-frequency system mast.) If a single LNA at the top of the mast were used, it would have to overdrive at least 41 dB of signal loss (6 dB of insertion loss, 10 dB of RF line loss, and at least 25 dB of spectrum analyzer noise figure). Thus, to achieve an overall noise figure of 10 dB, a single LNA would have to have a noise figure of about 8 dB, and a gain of at least 33 dB. Because LNAs to accomplish this are not available, low noise preamplification is provided by cascaded preamplifiers located at two points in the high-frequency system: one at the top of the mast (overdriving YIG insertion loss, mast line loss, and the 4-dB noise figure of the second LNA) and one at the input to the spectrum analyzer (to overdrive the analyzer noise figure).

A.6 Calibration

RSMS calibrations are performed with noise diodes and a Y-factor excess noise ratio (ENR) technique described in detail in Appendix D. Typically, a noise diode ENR source is used to calibrate an entire signal path for measurements about to be performed. Resultant frequency-dependent noise figure and gain calibration curves are used to automatically correct the measured amplitudes of all received signals. This calibration technique has proven very successful for field-deployed systems. It is a fast way to determine sensitivity and gain-correction values for a measurement system, and it is also very useful for isolating the gain and loss factors of individual system components.

A.7 Additional Measurement Capabilities

When deployed for general spectrum occupancy measurements (broadband spectrum surveys), the RSMS is also equipped to perform other measurements. Following are brief descriptions of other measurement capabilities currently available.

Extended Emission Spectra: Measurements of radiated and in-guide emission spectra of individual radio transmitters, particularly radars, are a major strength of the RSMS program. A combination of high sensitivity and interactive front-end RF attenuation make it possible to routinely measure the emission spectra of radio emitters across several gigahertz of spectrum. Specialized RSMS measurement techniques and algorithms support spectrum measurements of intermittently received emitters, such as scanning radars, without the need to interrupt or interfere with their operations. The RSMS uses a stepped measurement routine that allows for measurements that are faster, have more dynamic range, and are more repeatable than swept measurements. Accurately tracked YIG and varactor-tuned preselection make stepped measurements highly resistant to problems of overload from strong center-frequency signals while measuring low-amplitude emissions in adjacent parts of the spectrum.

Azimuth Scan: This special measurement routine is used to determine the receivability of selected signals at particular locations, even if those signals propagate via unconventional (nonline-of-sight) routes. The RSMS parabolic dish antenna is rotated through 360” on the horizon while recording received signal strength. This results in data showing the receivability of signals at all azimuths, and reveals nonline-of-sight propagation routes, if any exist. Azimuth scanning may be used to support spectrum surveys.

Transmitter Equipment Characteristics: The RSMS is capable of measuring and recording signal characteristics of multiple transmitter types. As part of any measurement scenario, certain received signals may be singled out for monitoring and detailed analysis. These special measurements may be used to determine radiated emission characteristics of known transmitters or identify the source of unknown transmissions. Measured transmitter (signal) characteristics include: tuned frequency or frequencies, beam-scanning method (regular rotation, sector scan, etc.), beam scan interval, radiated antenna pattern, modulation type (AM, chirped, etc.), pulse width, pulse repetition rate, pulse jitter, pulse stagger, and intrapulse modulation. Although the RSMS can observe the presence of phase coding in pulsed signals, no phase measurement capability is explicitly included in RSMS capabilities.

APPENDIX B: DATA ACQUISITION SOFTWARE

B.1 Introduction

The RSMS is designed to identify and characterize spectrum usage at certain frequencies or in selected bands, and to perform in-depth analysis of factors such as system compatibilities with each other or with spectrum assignments. Because of the diverse signal types encountered when measuring an extended spectrum, the measurement system must be able to detect all or at least most of the signals and to display or record as much information about them as possible. Obviously, a general-purpose measurement system cannot receive every signal type; however, the RSMS receiver detects almost every signal type encountered. As shown in Appendix A, the RSMS hardware can be configured as a receiver for practically all signal types occurring within an extended frequency range spanning 100 Hz to 19.7 GHz.

The key to efficient use of this extended measurement capability is rapid reconfiguration. The RSMS uses software developed by ITS to control all measurement system functions via computer. This control program, called "DA" (for Data Acquisition), runs on any DOS-based computer with sufficient memory. It interfaces via general-purpose interface bus (GPIB) with the measurement system at rates limited only by the computer's operating speed and functional speed of the managed hardware (interfaces, switches, components, etc.). DA will support many combinations of RF front-ends, spectrum analyzers, and auxiliary analysis equipment. DA also controls noise diode calibration of the RSMS and characterizes the noise figure and gain for individual components and entire measurement signal paths.

The DA program is basically four control subroutines that direct operation of multiple subroutine kernels that in turn control every function of the measurement system. This appendix includes descriptions of the four control subroutines (receiver algorithm, spectrum analyzer, RF front-end, and calibration) and the resultant system functions. As DA program development continues to meet new measurement demands, these functional descriptions may change with time.

B.2 Receiver Algorithm Subroutine

The DA receiver algorithm subroutine provides software management for up to 32 measurement algorithms (called band events for RSMS operations; see Section 2.3.1). Any one of these algorithms, when coupled with spectrum analyzer and front-end selections (described later in this appendix), becomes a customized measurement system for receiving certain signals or signal types. Because the characteristics of emitters and the requirements for data on those emitters vary considerably, many different algorithms have been developed. However, all of the algorithms are based upon either a frequency sweep across the spectrum of interest, or a series of discrete steps across that spectrum.

For spectrum surveys, sweeping algorithms are generally used to examine spectral bands occupied by high duty cycle emitters such as mobile radios and television transmitters, and stepping algorithms are used to monitor spectral bands occupied by low duty cycle emitters such as radiolocation equipments (radars), Following are brief descriptions of the algorithms used during a spectrum survey.

Swept: This algorithm controls a conventional spectrum analyzer' sweep across a selected portion of spectrum. Any type of detection available in the analyzer (i.e., positive peak, sample, etc.) can be used. Repeated sweeps may be programmed, and multiple sweeps incorporating the maximum-hold spectrum analyzer mode may also be performed. This algorithm also allows for sweeping a spectral band in several sub-bands (scans). This feature is important if a narrow bandwidth (e.g., 10 kHz) must be used to measure a spectral band that is more than 1000 times the width of the measurement bandwidth, e.g., measuring 900-930 MHz with a 10-kHz bandwidth requires at least three scans to ensure no loss of data.

Swept/m3: This is a swept measurement (as described above) that produces three data traces across a measurement range. At each of the 1000 frequencies measured on each individual spectrum analyzer sweep, the maximum, minimum, and (log) mean received signal levels are measured. Repeated sweeps are made across the spectrum of interest, and for each of the measurement points returned from each sweep, the three registers for current maximum, minimum and mean are updated. This process continues until it is halted programmatically. The total amount of time for each sweep, and the total number of sweeps to be performed, are specified in advance by the operator. The duration of each individual sweep may be a few milliseconds, with a typical Swept/m3 measurement (hundreds of sweeps) lasting a total of several minutes. These cumulative three-trace Swept/m3 measurements are saved on magnetic media, and may themselves be cumed (see Section 3.3) in the analysis phase of a site survey to yield long-term Swept/m3 curves, Typical RSMS site surveys use Swept/m3 measurements for mobile radio bands.

Stepped: Stepping measurements consist of a series of individual amplitude measurements made at predetermined (fixed-tuned) frequencies across a spectrum band of interest. The measurement system remains tuned to each frequency for a specified measurement interval. This interval is called step-time, or dwell. The frequency interval for each step is specified by an operator, and is usually about equal to the IF bandwidth of the measurement system. For example, measurements across 200 MHz might use 200 steps at a l-MHz step interval and a l-MHz IF bandwidth. Computer control of the measurement system is needed for this (step, tune, and measure) process to be performed at maximum speed.

Stepped measurements are usually performed to capture peak signals occurring on an intermittent basis. A prime example is a periodically scanning radar. If the step-time (dwell) is set slightly longer than the rotation or scanning interval of the radar beam, then the maximum receivable level from the beam will illuminate the RSMS at some

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'For most RSMS operations with DA software control, any GPIB-interfaced spectrum analyzer that processes at least 1000 points (frequencies) per display sweep may be used.

time during that interval. The RSMS, which is fixed-tuned for the entire dwell period, records each peak-detected point during that interval and the maximum amplitude recorded is saved for that frequency. The RSMS then tunes to the next frequency (one step), and repeats the process until the entire specified spectrum has been measured.

For intermittently received signals, such as scanned-beam radars, the stepped algorithm has advantages over swept measurements. Stepping is faster, allows more dynamic range (attenuation can be added and subtracted as a function of measured frequency to extend the total available dynamic range of the measurement system), and has better repeatability than swept measurements.

The RSMS uses stepped measurements to gather data in radiolocation bands where measurements can be tailored to transmitter characteristics; i.e., dwell times, IF bandwidths, step widths, etc. are determined as a function of the parameters of the radiolocation equipments which normally operate in the band.

Swept/az-scan This is ***not*** currently a selectable algorithm in DA, but is a hybrid routine using the Swept algorithm (above) with a rotating dish antenna. The dish is targeted on the horizon then rotated 360” while the Swept algorithm is running with positive peak detection and Maximum-Hold screen mode on the spectrum analyzer. The result is an analyzer display that shows the maximum activity across a band in an omnidirectional receiver sense, but with the effective gain of a dish antenna. This routine is most useful for nondynamic bands where received signal levels tend to be weak. Good examples are the common carrier (point-to-point) microwave bands; their transmitters are fixed-tuned, operate continuously, and do not move. The transmitters are also low-powered, and use high-gain antennas which further reduce their probability of intercept.

B.2.1 Receiver Parameters

Following are brief descriptions of the DA program input parameters needed to run the above subroutines (algorithms). Brackets identify the corresponding column headings as they appear in the band event tables of Section 2.3.1. For example, [algorithm] in the tables shows which of the above described subroutines is controlling the band event.

Start and Stop Frequencies [start (MHz)] [end (MHz)]: The value in megahertz of the first and last frequency point to be measured. These numbers must be equal to or fall outside the event frequency band range.

Passes: The number of times the algorithm iterates for each run command. This value is always one for spectrum surveys.

Scans [scans (# of)]: The number of measurement sub-bands to occur between the start and stop frequencies. This value is usually determined by comparing measurement bandwidth and frequency range. For example, a 30-MHz frequency range measured with a 100-kHz IF bandwidth would ensure sampling of all frequencies (1001 points) in One scan. However, if a 10-kHz IF bandwidth were used in the above example, three scans would be required to ensure sampling of all frequencies.

Sweeps [sweeps (# of)]: The number of sweeps in each scan. DA processes each sweep so increasing this number can add greatly to measurement time; however, increasing this value also increases the probability of intercept for intermittent signals.

Steps [steps (# of)]: The number of frequency steps to occur between the start and stop frequencies. This parameter is only used with stepped algorithms.

Graph Min and Graph Max: The minimum and maximum values in dBm for the graphical display of measured amplitude data.

B.3 Spectrum Analyzer Subroutine

The DA spectrum analyzer subroutine manages configuration control strings (via GPIB) for the spectrum analyzer. The operator selects spectrum analyzer parameters (listed in the following subsection) from menus in the DA program. Generally, parameters are selected that will configure the analyzer to run with a receiver algorithm for a desired measurement scenario. The software protects against out-of-range and nonlinear configurations but the operator can control the analyzer manually for unusual situations.

B.3.1 Spectrum Analyzer Parameters

When the DA program sends command strings to the analyzer, all signal path parameters are reset according to the operator selections for the measurement scenario. Following are brief descriptions of the analyzer parameter choices controlled by DA. Brackets identify the corresponding column headings as they appear in the band event tables in Section 2.3.1.

Attenuation: May be adjusted from 0-70 dB in 10-dB increments. The spectrum analyzer subroutine determines whether or not RSMS front-end attenuators are available and if so will set them to the selected value. Spectrum analyzer attenuation is set to zero when RSMS attenuation is active; if however, RSMS attenuators are not available, the spectrum analyzer attenuation will be set to the selected value.

IF Bandwidth [IFBW (kHz)]: May be selected from 0.01-3000 kHz in a 1, 3, 10 progression.

Detector [detector type]: +/-peak, positive peak, negative peak, sample, maximum hold, and video average modes are available. See Appendix C for discussions on detector selection for receiver algorithms.

Video Bandwidth [VBW (kHz)]: May be selected from 0.01-3000 kHz in a 1, 3, 10 progression.

Display: Amplitude graticule choices in dB/division are: 1, 2, 5, and 10. This parameter selection applies to both the analyzer and the system console displays.

Reference Level [RL (dBm)]: May be adjusted from -10 to -70 dBm in 10-dB increments.

Sweeps [MH/VA (#swps)]: Number of analyzer-processed sweeps per scan. This parameter is only used with maximum hold or video-averaged detection.

Sweep Time [swp/stp (sec)]: This parameter (entered in seconds) specifies sweep (trace) time if used with swept algorithms, or specifies step time (dwell) if used with a stepped algorithm.

B.4 RF Front-end Subroutine

The DA software handles the RF front-end path selection differently than other routines. Most of the RF-path parameters are predetermined by the measurement algorithm so operators need only select an antenna and choose whether preamplifiers are turned on or off. Preselection is also controlled by the antenna selection.

The antenna selection is made from a list of antenna choices that is stored in a separately maintained library file called by the RF Front-end Subroutine. Antenna information stored in the file includes:

- antenna type (omni, cavity-backed, etc.);
- manufacturer (may include identification or model number);
- port (tells the computer where signals enter the RSMS and includes particulars on any external signal conditioning such as special mounting, additional amplifiers, or extra path gain or loss);
- frequency range;
- vertical and horizontal beam widths;
- gain relative to an isotropic antenna;
- front to back gain ratio; and
- side lobe gain levels.

B.5 Calibration Subroutine

The calibration subroutine may be run at any time the operator chooses, but measurements must be interrupted. The software is interactive and flexible, allowing the operator to choose any calibration path desired. RSMS calibrations are performed with noise diodes and Y-factor excess noise ratio (ENR) techniques, as described in Appendix D.

APPENDIX C: INTERPRETATION OF SPECTRUM SURVEY DATA

C.1 Introduction

RSMS spectrum survey measurements are performed with a variety of receiver algorithms (see Section B.2 of Appendix B). These algorithms provide various combinations of frequency-sweeping or frequency-stepping, positive-peak or sample detection, and data-processing capabilities during the data acquisition phase of the spectrum survey. Additional processing is performed on the data after the acquisition phase. Measurement algorithms are assigned on an individual basis to optimally measure spectrum use in each band.

Each algorithm has a particular response to noise and signal activity. It is critical to understand the noise and signal response of each algorithm if the RSMS data are to be used accurately. This appendix describes the algorithms currently used for RSMS site surveys. The noise and signal response of each algorithm is described, along with the types of spectrum occupancy it is best suited to measure. Some of the data-processing techniques are also discussed to fully explain the measurement algorithms.

C.2 Signal Probability of Intercept Factors

RSMS measurements are intended to achieve a high probability of intercept for the types of signal activity occurring in each spectral band. Factors that are considered include:

- the types of emitters allocated to the band (e.g., land mobile radio, radiolocation, or broadcasting);

- the percentage of time individual transmitters in the band typically operate (e.g., 100% on-air time by broadcasters vs. intermittent radio dispatch messages);

- the dependence (or nondependence) of band activity on diurnal and other cyclic occurrences (e.g., radionavigation beacons with no time dependence vs. marine mobile activity which varies as a function of time-of-day and day-of-week);

- the time interval that individual transmissions usually occupy (e.g., air traffic control communications vs. cellular telephone communications);

- the periodicity, if any, of individual transmissions (e.g., a highly periodic search radar beam that completes a rotation every 4 s vs. mobile communications that occur in a random distribution over time);

- the directional gain, if any, of antennas used by the transmitters (e.g., an omni-directional navigation beacon vs. a point-to-point microwave link);

- the typical peak and average power outputs of transmitters in the band (e.g, 4 MW peak power from a radar vs. perhaps a fraction of a watt from a typical land mobile radio);

- the signal duty cycle (e.g., a 30-dB duty cycle for a typical radar vs. a near 0-dB duty cycle for a two-way radio transmission);

- the relative abundance or paucity of systems using the band (e.g., a band used largely by airborne fire-control radars vs. a band used by thousands of local voice-communication radios); and

- the polarization of typical transmitted signals in the band.

These factors are used to optimize the receiver parameters for the selected band, select the measurement algorithm, and determine how measurement time should be allocated. The relative amount of time devoted to measure each band is roughly proportional to the dynamics of band usage. For example, point-to-point microwave bands are not very dynamic, because the transmitters in these bands normally operate 24 hours/day, 365 days/year, at uniform power levels, and fixed beam directions. Their operations are not normally affected by external factors, such as weather or local emergencies, Consequently, these bands are measured only once during a spectrum survey. In contrast, activity in land mobile radio bands is highly dynamic, varying significantly with time-of-day, day-of-week, and other factors such as local emergency conditions. Consequently, these bands are measured frequently throughout a site survey, so that a maximal number of time-dependent signals will be intercepted. Slightly less dynamic bands, such as those used by tactical radars, are measured less frequently than the mobile bands, but more frequently than the point-to-point microwave bands. Bands whose use varies with local weather, such as those used by weather radars, are measured on different clear-weather and foul-weather schedules.

Swept-spectrum measurement techniques are used in highly dynamic bands. Stepped-spectrum techniques are used in bands occupied by periodic emitters, such as radars. A slow dish antenna sweep of the horizon coupled with simultaneous swept-spectrum measurements is used in point-to-point microwave bands. These measurement techniques are detailed in the following subsections.

A parabolic antenna is used to measure signals from fixed-beam, highly directional transmitters in the point-to-point microwave bands (see the description of azimuth scanning in Section C.8). For bands in which signals are expected to originate primarily from a single quadrant as seen from the RSMS location, a moderately directional antenna (such as a cavity-backed spiral or a log-periodic antenna) is used. For bands in which signals are expected to originate from any direction with an approximately constant probability, such as bands used by airborne beacon transponders and air-search radars, the RSMS uses omnidirectional antennas.

Slant (antenna) polarization is used for all RSMS measurements except those in the point-to-point microwave bands. Slant-polarized biconical omnidirectional antennas are usually used above 1 GHz, and slant-oriented log-periodic or conical omnidirectional antennas are usually used below

1 GHz. Slant polarization provides adequate response to all signals except those having a slant direction orthogonal to the RSMS antennas. Orthogonally oriented slant-polarized signals are rare. In the point-to-point microwave bands, the transmitted signals are always vertically or horizontally polarized, and thus RSMS receive polarization in those bands is alternately vertical and horizontal, with the results being combined into a composite scan.

The end result of these selections (number of measurements made in each band, selection of antenna type and polarization, and selection of measurement algorithm) is to optimize the probability of intercept for signals present during the course of the RSMS site survey. Inevitably, some signals will be missed; however, the standard RSMS spectrum survey data set should provide a good measure of the relative number, levels, and types of signals in each of the bands between 100 MHz and 19.7 GHz.

C.3 Overview of Swept Measurement Techniques

To fully understand the measurement algorithms described in this appendix, it is necessary to describe how the spectrum analyzers perform swept-frequency measurements.

The HP-8566B spectrum analyzers used in the RSMS sweep across the spectrum in individual segments called spans. The frequency range of each span is in turn broken into 1001 individual frequency bins. When the spectrum analyzers perform sweeps across a selected span, they spend a finite amount of time measuring received power in each of the 1001 bins. For example, a 20-ms sweep time divided by 1001 measurement bins per sweep yields a 20-us measurement time in each frequency bin. Within each bin measurement interval (in this example, 20 us), the power measured in the waveform may take on multiple values. However, the spectrum analyzer can only provide a single power measurement per bin.

The single value derived from the multiple values occurring within each bin-sampling interval depends upon which spectrum analyzer detector mode has been selected. The detector modes available in the RSMS spectrum analyzers are positive peak, negative peak, sample, and "normal." (Note: positive peak detection is different from the maximum-hold display mode discussed in Section C.6.) Positive peak detector mode will latch to the highest power value attained by the measured waveform during the sampling interval (continuing the example above, this would be 20 us) for each bin. Similarly, the negative peak detector mode latches to and displays the lowest power level measured during each bin interval. In sample detector mode, the value displayed is the power level that the input waveform has assumed at the end of the bin measurement interval. If the bin sampling interval is uncorrelated with respect to the input waveform, then this value can be considered to be randomly selected from the input waveform. Finally, in "normal" detection mode, alternate bins use positive peak and negative peak detection.

If the analyzer's video bandwidth is substantially narrower than the IF bandwidth, and if a white noise source (such as thermal electron noise in a circuit or a noise diode) is being measured, then an average value of the noise will be displayed, irrespective of the detector mode which has been selected.

If the analyzer's video bandwidth is equal to or greater than the IF bandwidth, and if a white noise source is being measured, then the displayed power level will vary as a function of the detector mode. Positive peak detection will display noise values approximately l0-12 dB higher than the RMS noise level, and negative peak will display values about l0-20 dB below the RMS noise level. "Normal" detection used on such a noise source will display an illuminated band about 20-30 dB wide, with an average value equal to the RMS level of the noise. Normal detection mode is useful for estimating the duty cycle of a signal (the wider the illuminated band underneath a signal peak, the lower the duty cycle of the signal).

C.3.1 Description of the Swept/m3 Measurement Algorithm

The Swept/m3 algorithm, developed by ITS, is an extension to the swept measurements just described. In Swept/m3 mode, frequency-domain data traces are measured repeatedly across a band on the spectrum analyzer. Each sweep is returned individually to the PC controller, but the data traces are not individually recorded. Instead, for each of the 1001 frequency bins that the analyzer returns in each sweep, the PC sorts the returned values as follows: the value in each bin is compared to the highest and lowest values so far observed in that bin, and if the new value represents a new maximum or minimum in that bin, then it is saved as such. (This is, in effect, a software-implemented version of maximum-hold and minimum-hold trace mode.) Also, the current value of each bin is included in a running average of all the values returned for that bin in previous sweeps. This is an average of measured power in the selected detector mode (i.e., the decibel values are averaged). Thus, the maximum, minimum, and mean (m3) signal levels in a band are simultaneously obtained over the time interval (typically several minutes) that the spectrum analyzer continues sweeping. This real-time cuming process compresses data volume by several orders of magnitude, but the compression causes loss of the original data sweeps, and thus precludes the possibility of processing the original data sweeps with different algorithms during postmeasurement analysis. Figure C-l shows how the Swept/m3 cumulative processing is integrated with the normal RSMS processing path. All other cumulative processing is accomplished during postmeasurement analysis.[1] In the diagram, all measured data identified as "RSMS data output for lab analysis" is considered to be postmeasurement data.

C.4 Description of Swept/m3/Sample Data Collection

If the Swept/m3 algorithm (described in Subsection C.3.1) is performed using the sample detector (see Section C.3 for a description of the sample detector in the RSMS analyzers), then the data are referred to as "Swept/m3/sample."

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[1]All band events measured more than once during the same survey are cumed as explained in this appendix. Stepped and swept data records are processed for maximum, mean, and minimum received signal levels. Swept/m3 data already contains this information so a maximum of maximums, mean of means, and minimum of minimums is extracted for survey graphs.

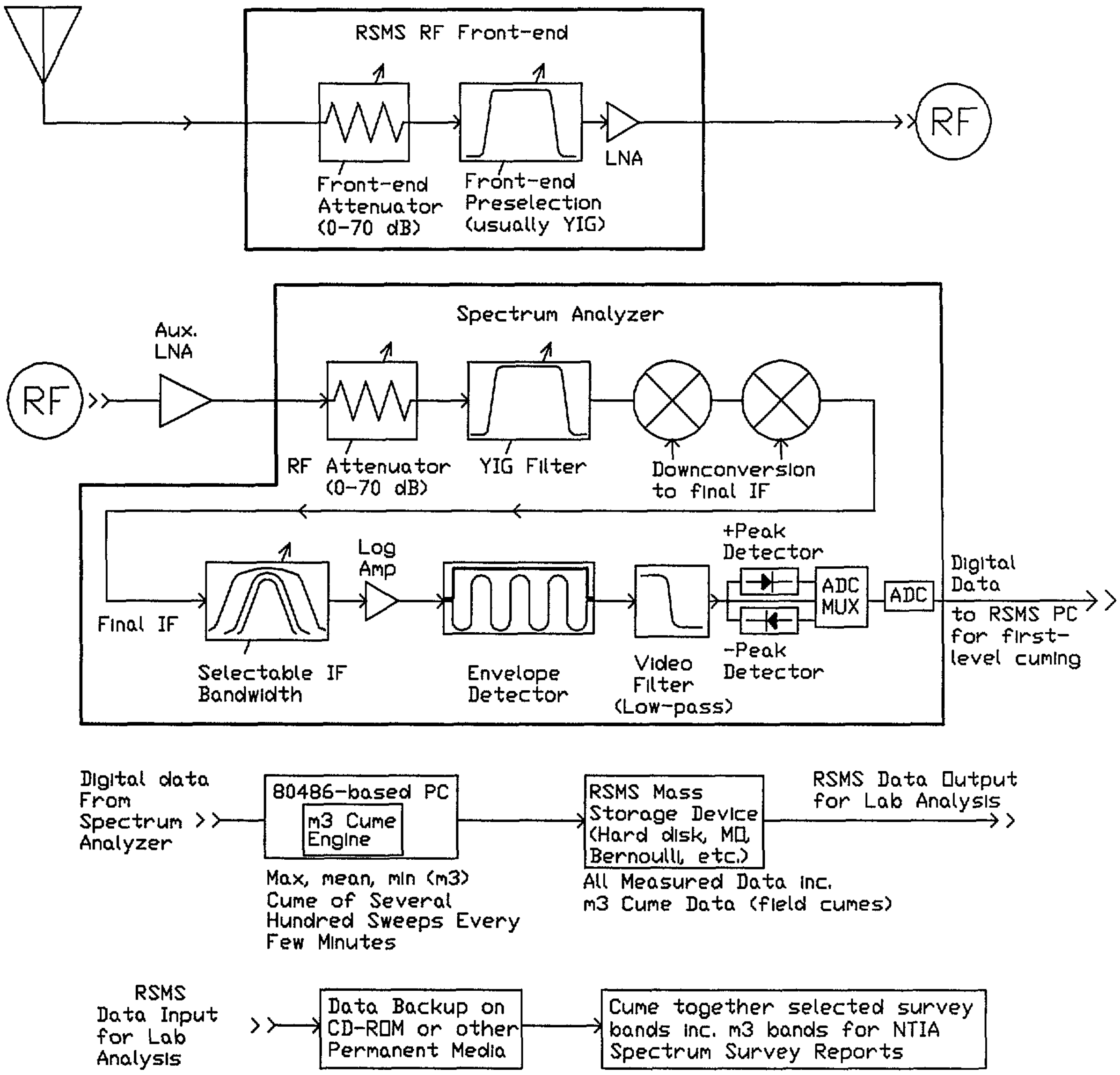

Figure C-1. Functional diagram of the RSMS signal-processing path for cumulated data.

C.4.1 Interpretation of Noise Responses in Swept/m3/Sample Data

The noise level displayed by a measurement system using the sample detector will be equal to [kTB + (measurement system noise figure) - 2.5 dB].[2] With a 1-MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the average noise level would occur at -104 dBm.

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[2]kTB is derived from the Nyquist Theorem for electron thermal noise, where: k is Boltzmann's constant ($1.38 \cdot 10^{-20}$ mW·s/K), T is system temperature (290 K for these measurements), and B is measurement IF bandwidth in Hz. For B = 1 Hz, at room temperature: kTB = -174 dBm. In a 1-MHz IF bandwidth, kTB = -174 + 10log(10^6) = -114 dBm.

If the video bandwidth (that is, the postenvelope detector, low-pass filtering bandwidth) is significantly narrower than the IF bandwidth, then the variance in the measured average noise will be very small (approximately 1 dB). This mode is normally used only for calibrations in the RSMS.

However, if the video bandwidth is set to a value equal to or greater than the IF bandwidth (which is the case for RSMS spectrum survey measurements), then the maximum level sampled on thermal noise will be about l0-12 dB above the average, and the minimum level sampled on thermal noise will be about l0-20 dB below the average.

C.4.2 Interpretation of Signal Responses in Swept/m3/Sample Data

Because the sample detector value displayed for each bin is the value of the waveform at the end of each bin interval, the value displayed for a signal with a duty cycle of 100% will be equal to the peak power of the signal (if the signal was present for the entire bin interval). However, if a signal has less than a 100% duty cycle (and is not present during the entire bin interval), then the probability that the signal will be sampled is less than one. For example, if the signal is only present for half of the bin interval, there is only a 50% chance that the sample detector will capture the value of the signal (and a 50% chance that the measurement system's thermal noise will be displayed). For typical radar signals, which operate with a duty cycle of about 1: 1000, the probability that a bin will display the radar signal value is only about l/1000 (0.1%). The same rationale holds for impulsive noise; sample detection mode tends to display high-duty cycle signals, but not low-duty cycle signals such as radars and impulsive noise. This makes sample detection a desirable option for measurements in bands handling mobile communications, where the signals of interest have high duty cycles, and where measurement of impulsive noise is not desirable for the purposes of the RSMS project.

For Swept/m3/sample data, the highest curve shows the maximum signal ever captured by the sample detector on any trace at each measured frequency. This represents the highest value ever attained by high-duty cycle signals at each measured frequency; impulsive energy could have been present at even higher values, but would have been discriminated against by the sample detector. At frequencies where no signal was ever measured, the maximum curve will have a value of kTB + measurement system noise figure + (nearly)10 dB. This value will be 10 dB higher than the average noise (middle) curve. Since a signal displayed on the maximum curve can occur with different amplitudes at different times, there is no way to determine, solely from examination of the maximum curve, how frequently the displayed signals were measured.

The middle curve of Swept./m3/sample data shows the power average (average of the measured decibel values) of all of the raw data traces gathered in the band. Qualitatively, the closer this curve comes to the maximum curve at any given frequency, the higher the percentage of scans in which the signal was observed. Quantitatively, it is not possible to derive an actual percentage of scans in which the signal was present. This is because the signal may not have always been received at the same level, and the level received on raw scans is not recorded. If, however, the average curve comes close to touching the maximum curve, then the signal must have been present in nearly 100% of the raw data traces. Conversely, if the maximum and mean curves are far apart, then the signal was probably observed in a lower percentage of raw data scans. If no signals were ever measured at any given frequency, then the middle curve will show measurement system noise at a value of kTB + measurement system noise figure, about 10 dB below the maximum noise curve.

Finally, the lowest curve shows the minimum power level measured in any raw data trace, at each measured frequency bin. If no signal is measured in a bin during any sweep, then this curve will have a value of: kTB + measurement system noise figure - (l0-20 dB). This is l0-20 dB lower than the average curve. If a signal is present in 100% of the measurement sweeps, then a bump will occur in the minimum curve at that frequency. The amplitude of the bump will be equal to the minimum power measured for the signal. Thus, this curve serves the purpose of showing signals that are continuously present during the spectrum survey.

In this report, the nominal levels of the measurement system noise for the maximum, minimum and mean curves are indicated by tick marks on the lower left side of each swept/m3/sample graph. The tick marks, labelled "max sample noise," "avg sample noise," and "min sample noise," are intended to assist report users in determining which graphed features are signal and which graphed features are measurement system noise.

C.5 Description of Swept/m3/+Peak Data Collection

If the Swept/m3 algorithm is performed using the positive peak (+peak) detector (see Section C.3 for a description of the +peak detector in the RSMS spectrum analyzers), then the data are called "Swept/m3/+peak."

C.5.1 Interpretation of Noise Responses in Swept/m3/+Peak Data

The average noise level displayed by a measurement system using a +peak detector will be equal to kTB + measurement system noise figure + approximately l0- 12 dB. With a l-MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the average +peak noise level would occur at -174 dBm/Hz + 101og(10^6 Hz) + 10-dB noise figure + l0-dB peak detector offset = -94 dBm.

If the video bandwidth (the postenvelope detector, low-pass filtering bandwidth) is equal to or greater than the IF bandwidth (which is the case for RSMS site survey measurements), and if the sweep time is short (a few tens of microseconds per bin), then the maximum level sampled on thermal noise will be about 10 dB above the average; the minimum level of thermal noise will be about 10 dB below the average, Note that this +/-l0-dB value for maximum and minimum levels of +peak noise is the same as the +/-l0-dB offset levels for sample detection, but that the maximum, mean, and minimum peak-detected levels are 10 dB higher than the corresponding sample-detected levels.

Positive peak detection shows less than a +/-l0-dB difference between the maximum, mean, and minimum as sample times increase (i.e., as sweep times become longer). This is because the positive peak detector will have a higher probability of latching to a high noise level if it samples the noise for a relatively long interval. In this case, the minimum and average noise levels will approach the maximum noise level to within a few decibels. The maximum will be 2-3 dB higher than the short sweep-time values.

C.5.2 Interpretation of Signal Responses in Swept/m3/+Peak Data

Because the +peak detector latches to the highest value that the waveform assumes during each bin interval, the value displayed for a signal will be equal to the peak power of the signal (assuming that the measurement system is not bandwidth-limited in its response) regardless of the signal's duty cycle. This makes +peak detection mode useful for measuring impulsive activity such as radar signals. (This also means that +peak detection will also record impulsive noise in the spectrum.) Thus, the +peak detector is used in RSMS spectrum surveys to measure radiolocation bands and other bands where activity is dominated by impulsive (low-duty cycle) transmissions.

For Swept/m3/+peak data, the highest curve shows the maximum signal ever captured by the +peak detector on any trace in each measured frequency bin. At frequencies at which no signal was ever measured, the maximum curve will have a value of kTB + measurement system noise figure + about l0-dB peak detector offset + 10 dB. If the sweep time is short (a few tens of microseconds per bin), this will be about 10 dB higher than the average peak detector response. If the sweep time is much longer, the average will be higher, coming to within a few dB of the maximum. There is no way to determine, solely from examination of the maximum curve, how frequently the displayed signals were observed.

The middle curve of Swept/m3/+peak data shows the power average (average of the antilogs of the measured decibel values) of all the data traces that were gathered in the band. Qualitatively, the closer this curve comes to the maximum curve at any frequency, the higher the percentage of scans in which the signal was observed. Quantitatively, it is not possible to derive a percentage of time the signal was present, because the signal may not always be received at the same level. If, however, the average curve nearly touches the maximum curve, then the signal must have been present in nearly all of the raw data traces. Conversely, if the maximum and mean curves are far apart, then the signal was probably observed in a low percentage of scans. If no signals were measured at a frequency, and if sweep time is a few tens of milliseconds, the middle curve will show measurement system noise at a value of kTB + measurement system noise figure + about l0-dB peak detector offset. This value will be nearly 10 dB higher if the sweep time is appreciably longer.

Finally, the lowest curve shows the minimum power level measured with the +peak detector in any sweep, in each frequency bin. If no signal is measured at a frequency, and if the sweep time is a few tens of milliseconds, this curve will have a value of: kTB + measurement system noise figure + about 10 dB peak detector offset - 10 dB, which is 10 dB lower than the mean peak detector curve. If the sweep time is longer, the minimum curve will approach the maximum and mean curves. If a signal is observed at a frequency in every data sweep, then a bump will occur in the minimum curve at that frequency. Thus, this curve shows signals that are continuously present during the spectrum survey.

In this report, the nominal levels of the measurement system noise for the maximum, minimum and mean curves are indicated by tick marks on the lower left side of each swept/m3/+peak graph. The tick marks, labelled "max +peak noise," "avg +peak noise," and "min +peak noise," are intended to assist report users in determining which graphed features are signal and which graphed features are measurement system noise.

C.6 Description of Swept/Max-Hold Data Collection

If a frequency-sweeping algorithm is performed using the +peak detector (see Section C.3 for a description of the +peak detector in the RSMS spectrum analyzers) while the spectrum analyzer display is being operated in the Maximum-Hold mode, then the data are referred to as "Swept/max-hold"

The measured data are peak-detected, maximum-hold scans. Each scan represents an interval of a few minutes of maximum-hold running on the measurement system. The scans do not contain mean or minimum information. They are intended only to show the presence of intermittent, low-duty cycle signals, and therefore no additional information is obtained,

The individual scans are cumed for the site survey report, and as a result, the final graphs show maximum, minimum, and mean curves. However, the distribution of maximum-hold data is narrow when noise is being measured, and so the difference between these curves is only about +/-3 dB on noise, instead of the +/-10 dB difference which usually characterizes swept/m3 data.

C.6.1 Interpretation of Noise Responses in Swept/Max-Hold Data

The maximum, mean, and minimum curves displayed by a measurement system will be nearly identical if the hold time is more than a few tens of microseconds per bin. If white noise is measured,' the three curves will all have a value of about kTB (at room temperature) + measurement system noise figure + about l0-dB peak detector offset + 10 dB. With a l-MHz IF bandwidth and a l0-dB measurement system noise figure, for example, the noise level is about - 174 dBm/Hz + l0log(10^6 Hz) + l0-dB noise figure + l0-dB peak detector offset + 10 dB = -84 dBm.

[3] In Maximum-Hold mode, the spectrum analyzer repeatedly sweeps a portion of spectrum, and saves the highest value measured in any sweep in each screen display bin. Thus, Maximum-Hold mode generates a maximum-level trace which is analogous to the maximum-level trace generated by RSMS software in the Swept./m3/+peak mode.

If the video bandwidth is equal to or greater than the IF bandwidth, then the maximum level sampled on thermal noise in maximum-hold mode is about 2 dB above the mean, and the minimum level sampled on thermal noise is about 2 dB below the mean.

C.6.2 Interpretation of Signal Responses in Swept/Max-Hold Data

Swept/max-hold measurement mode is ideal for capturing low-duty cycle signals from intermittently operating systems. It can be used in bands occupied by impulsive emitters that operate intermittently (e.g., airborne radars). A Swept/max-hold measurement displays the maximum activity observed in a band for an interval of a few minutes. No information is collected to indicate mean or minimum activity during that interval.

For cumed Swept/max-hold data, the highest curve shows the maximum signal ever captured by the +peak detector on any maximum-hold trace at each measured frequency. Since a signal displayed on the maximum curve could have occurred with different amplitudes at different times, there is no way to determine, solely from examination of the maximum curve, how frequently the displayed signals were actually observed.

The middle curve of cumed Swept/max-hold data shows the power-average (average of the antilogs of the measured decibel values) of all individual maximum-hold data traces that were measured in the band. Qualitatively, the closer this curve comes to the maximum curve at a frequency, the higher the percentage of scans in which the signal was observed. Quantitatively, it is not possible to derive an actual percentage of time that the signal was present, because the signal may not have always been received at the same level. If the mean curve nearly touches the maximum curve, then the signal must have been present in most of the raw data traces. If no signals were ever measured at any given frequency, then the middle curve will be about 3 dB lower than the maximum curve.

Finally, the lowest curve shows the minimum power level ever measured with the +peak detector in any maximum-hold data trace, at each measured frequency. If a signal was present in every scan, then the curve shows a bump at that frequency. Otherwise, the curve will show noise 3 dB below the mean curve. Thus, this curve serves the purpose of showing signals that were present in all of the scans.

C.7 Description of Stepped/+Peak Data Collection

Although most spectrum analyzers are routinely operated by sweeping in the frequency domain, this is not the most efficient method for the measurement of spectral emissions from pulsed emitters like radars. An alternative method, called stepping, is usually faster and can provide measurement results with wider dynamic range than is possible with sweeping.

Stepping is performed by tuning the measurement system to a frequency in the radar spectrum, and then performing a time-scan at that frequency over a span of zero hertz. Positive peak detection is always used. For rotating radars, the interval (called dwell time) for a single time-scan is set equal to or greater than the radar rotation time. (For electronically beam-scanning radars, this interval is selected on the basis of the typical recurrence of the radar beam at the measurement site.) For example, if a radar has a 10-s rotation time, then the dwell time at each measured frequency might be set to 12 s. Thus, the emitter's rotating main beam would certainly be aimed in the direction of the measurement system at some moment during the 12-s time-scan. At the end of the dwell period, the highest-amplitude point that was measured is retrieved, corrected for calibration factors, and stored. This process of waiting at a frequency in a O-Hz span and recording the highest point measured during a radar rotation (or beam-scanning) interval is called a "step." When each step is completed, the measurement system is tuned to another, higher frequency, and the process is repeated.

The spectrum interval between adjacent measured frequencies is approximately equal to the IF bandwidth of the measurement system. For example, if a l-MHz IF bandwidth is being used, then the frequency interval between steps will be about 1 MHz. The IF bandwidth is determined from the inverse of the emitter pulse width. For example, if 1 us is the shortest pulse width expected from emitters in a band, then a I-MHz measurement (IF) bandwidth is used. In this manner, the entire spectrum is convolved with the measurement bandwidth across the band of interest.

Stepped measurements are used for all dominantly radiolocation (radar) bands. IF bandwidth and dwell times are optimized for typical radars in the band. The individual stepped measurement scans are cumed for spectrum surveys and the final graphs show a maximum, minimum, and mean value for each dwell time at each measured frequency during the entire survey.

C.7.1 Interpretation of Noise Responses in Stepped/+Peak Data

The mean noise level displayed by the measurement system in the +peak detector stepped mode will be equal to kTB (at room temperature) + measurement system noise figure + 10-dB peak detector offset. With a l-MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the mean +peak noise level is -174 dBm/Hz + 10log(10^6 Hz) + 10-dB noise figure + 10-dB peak detector offset = -94 dBm.

The difference between the maximum and minimum levels measured for noise in the stepped mode is small; the maximum and minimum curves will be about +/-2 dB relative to the mean curve.

C.7.2 Interpretation of Signal Responses in Stepped/+Peak Data

Stepped/+peak measurement mode is ideal for capturing low-duty cycle signals from systems that direct energy at the measurement site at regular intervals (e.g., rotating radars). If the dwell time is greater than or equal to the rotation time of the radar, then the stepped algorithm will completely fill the emission envelope.

The maximum curve on each site survey graph for stepped measurements depicts the maximum envelope of the spectral emissions of the emitters observed in the band. The result is a representation of the spectrum occupancy when emissions (usually radar beams) are directed at the measurement site.

The minimum curve represents the lowest signal ever measured at each frequency step during the survey. If an emitter is turned off during a single scan, then this curve will be at the system noise level for that emitter. At frequencies where this curve is above the noise level, but well below the maximum curve, the difference represents either varying emitter power output levels, varying emitter-scanning modes, varying propagation between the emitter and the measurement site, or a combination of these factors.

The mean curve represents the linear mean (the average of the antilogs of the decibel values of received signal level) for each frequency step in the band of interest during the site survey. This is not necessarily the same as the mean signal level transmitted by a radar to the measurement location. For example, a radar that was turned on during half the stepped scans, and turned off during the other half would appear, after cuming, with a maximum curve that is its emission envelope, a minimum curve that is the measurement system noise floor, and a mean curve roughly midway between the radar envelope and the noise. However, the radar would never have been measured at the amplitudes shown on the average curve.

C.8 Description of Swept/AZ-scan Data Collection

In bands dominated by point-to-point fixed microwave communication systems, the main beams of the transmitters are seldom pointed towards the RSMS. To enhance the probability of intercepting signals from these sources, a dish antenna is used. However, the site survey data must include signals received from all points on the horizon. These two apparently contradictory requirements are reconciled by performing azimuth scanning with the dish antenna. The RSMS dish antenna is pointed at the horizon and slowly rotated through 360”. Simultaneously, a spectrum analyzer sweeps the band of interest with positive peak detection and maximum-hold scan mode. Such measurements are called “Swept/az-scan.”

The dish antenna is rotated at approximately 6^{o}/s (1 rpm), while the sweep time across the band is set at 20 ms. At the highest frequencies, where the dish beamwidth is about l^{o}, the dish rotates through one beamwidth in l/6 s (170 ms). This is long enough for 7 or 8 sweeps (170 ms/20 ms) within the beam width. Thus, every point on the horizon is sampled at least 7 or 8 times across the entire band of interest. Maximum-hold mode and positive peak detection ensure that any signal that arrives at the RSMS site is retained on the scan.

The dish is rotated twice around the horizon: once with horizontal polarization and once with vertical polarization. The purpose is to observe signals from point-to-point links utilizing either polarization. The two polarization scans are combined to show the maximum envelope of both scans on a single data curve.

The single data curve is corrected for noise diode calibration factors and recorded. Unlike other RSMS site survey measurements, this measurement is only performed once at each survey location and no cuming is performed on this data. Activity in these bands does not vary much with time and little information is gained by measuring these bands repetitively.

C.8.1 Interpretation of Signal Responses in Swept/AZ-scan Data

Swept&-scan data show the presence of a signal at some point or points on the horizon. The data curve does not reveal the direction of any signals, but does show the aggregate occupancy of the spectrum by all point-to-point signals detected omnidirectionally on the horizon.

Generally, two types ‘of signals will be noted in the az-scan graphs: those having narrow emission spectra, and those having wider emissions. The narrow signals are analog links, and the wider signals are digital links. Because a single transmitting tower (a single point on the horizon) may have many channels in operation (often located next to each other in the spectrum), clusters of signals with uniform amplitudes will be observed. Space-to-earth and earth-to-space links in these bands are not normally detected by the RSMS.

APPENDIX D: CALIBRATION OF THE MEASUREMENT SYSTEM

D.1 Introduction

Measurement system calibration is performed prior to and during every RSMS site survey. Calibration curves, as in Figure D-1, showing system noise figure and gain corrections as a function of frequency across the entire frequency range are generated. As measurements are performed, gain corrections are automatically added to every raw data point that is collected. Gain and noise figure curves are used by RSMS operators to determine the relative health of the measurement system, and are also used to pinpoint locations in the measurement system RF path that are operating suboptimally.

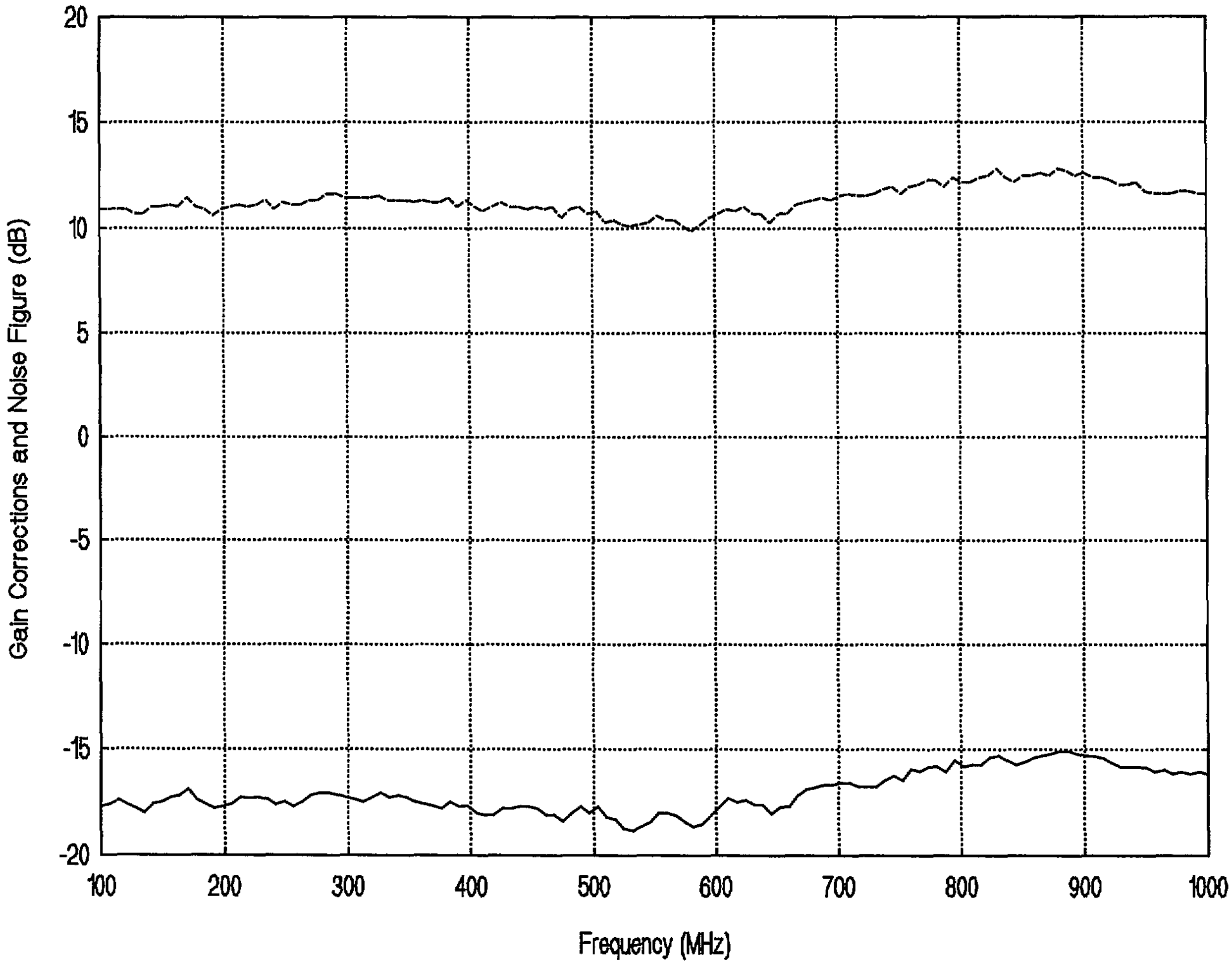

Figure D-1. Example calibration graph for RSMS System-1 showing noise figure (upper; dashed curve) and correction factors (lower; solid curve).

RSMS calibrations are performed exclusively with noise diodes such as the one shown in Figure D-2. Although the technique of noise diode calibration is not as well known in electrical engineering activities as other techniques (e.g., signal generators or vector network analyzers), noise diodes are commonly used for calibration of measurement systems where minimal size, weight, and power consumption are required. Noise diodes provide these features while maintaining high calibration accuracy and this is why they are used for RSMS calibrations.[1] This appendix describes the theory and operation of RSMS noise diode calibrations.

Figure D-2. A typical noise diode solid state noise source. A +28-volt potential applied to the BNC connector on the right produces +24-dB excess noise ratio from the type N connector on the left.

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[1] Another example of noise diode use for measurement system calibration is the Cosmic Background Explorer (COBE) satellite, which recently produced a whole-sky map of 2.5-K background radiation. The same features that make noise diodes attractive for critical satellite calibrations also make them attractive for RSMS work at field locations.

D.2 Theory

RSMS calibrations are implemented as a variant of the y-factor calibration method [l]. The y-factor method of amplitude calibration provides for a simple, yet accurate characterization of the amplitude response and noise figure of an RF receiver system. Using noise diodes, amplitude uncertainties of 1 dB in calibration may be achieved in field calibrations over a frequency range of more than 18 GHz.

The noise diode calibration of a receiver tuned to a particular frequency may be represented in simple, lumped-component terms as in Figure D-3. In this diagram, the symbol labelled E represents a power-summing function that linearly adds any power at the measurement system input to the inherent noise power of the system. The symbol labelled g represents the total gain in the measurement system. The measurement system noise factor is denoted by nf_s and the input is a noise diode with an excess noise ratio of enr_d.[2]

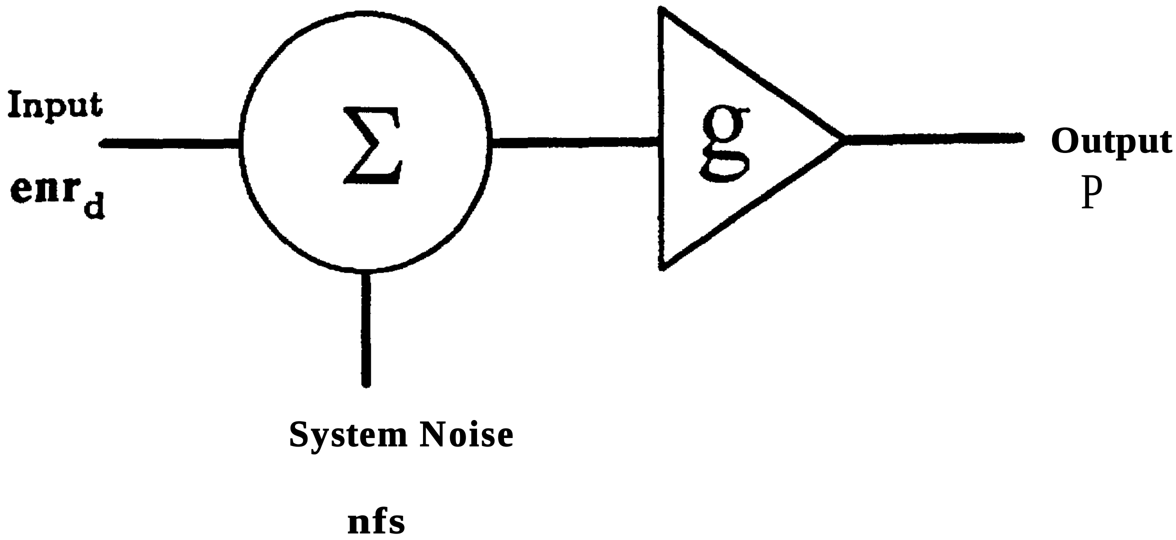

Figure D-3. Lumped-component noise diode calibration schematic diagram; reference equations (Dl) and (D2).

Note that in this appendix all algebraic quantities denoted by lower-case letters, such as "g," represent linear units. All algebraic quantities denoted by upper-case letters, such as "G," represent decibel units. Lower-case and upper-case quantities are connected to each other by the

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*Many references do not offer a clear explanation of the difference between noise factor and excess noise ratio. Noise factor is the ratio of noise power from a device and thermal noise, (n_{device}/kTB). The excess noise ratio is equal to the noise factor minus one, making it the fraction of power above (in excess of) kTB. The noise figure of a system is defined as 10 log of the noise factor, forcing a solution for noise factor in the calculations. However, since many noise sources are specified in terms of excess noise ratio, that quantity must sometimes be used.

relation (UPPER CASE TERM) = 101og(lower case term); for example, G = 101og(g), or if enrd = 100 mW, then ENR, = 20 dBm.

In noise diode calibration, the primry concern is the difference in output signal when the noise diode is switched on and off. For the (noise diode = on) condition, the linear expression is:

$$p_{on} = (nf_s + enr_d) \times gkTB, \quad \text{(D1)}$$

and for the noise diode = off condition:

$$p_{off} = (nf_s) \times gkTB. \quad \text{(D2)}$$

The quantity k is Boltzmann's constant, equal to $1.38 \cdot 10^{-20}$ mW.s/K (milliwatt seconds per kelvin). T is the system temperature in kelvin, and B is the bandwidth in hertz. The ratio of these two quantities is called the Y factor:

$$Y = (P_{on}/P_{off} = (nf_s + enr_d)/(nf_s) \quad \text{(D3a)}$$

$$\mathbf{Y} = 10\log(Y) = 10\log(p_{on}/p_{off}) = P_{on} - P_{off} \quad \text{(D3b)}$$

From equation (D3), we solve for the system noise factor:

$$nf_s = (enr_d)/(y-1). \quad \text{(D4)}$$

The measurement system noise figure is 10 log of the noise factor:

$$NF_s = 10\log(enr_d/(y-1)) \quad \text{(D5)}$$

$$= ENR_d - 10\log(y-1)$$

$$= ENR_d - 10\log(10^{y/10} - 1).$$

Solving equations (Dl) and (D2) for gain, g, yields:

$$g = (P_{on} - p_{off})/(enr_d \times kTB) \quad \text{(D6a)}$$

$$G = 10\log(p_{on} - P_{off}) - 10\log(enr_d \times kTB) \quad \text{(D6b)}$$

$$= 10\log(10^{p_{on}/10} - 10^{P_{off}/10}) - ENR_d - 10\log(kTB). \quad \text{(D6c)}$$

In RSMS calibrations, equation (D6c) is used to calculate gain from measured noise diode values. Note that this calculation utilizes the difference between P_{on} and P_{off} rather than the y-factor ratio of these values. Thus, the RSMS noise diode calibration is a variant of the standard y-factor calibration technique.

Although equation (D5) could be used to calculate measurement system noise figure, the implementation in RSMS software uses an equivalent equation. It is derived from (D1):

$$nf_s = P_{off} / gkTB \tag{D7a}$$

$$NF_s = 10\log(P_{off}) - 10\log(gkTB) \tag{D7b}$$

$$= P_{off} - G - 10\log(kTB).$$

Substituting expression (D6b) for gain into (D7b) yields:

$$NF_s = P_{off} + ENR_s - (10^{P_{on}/10} - 10^{P_{off}/10}). \tag{D7c}$$

In RSMS calibrations, equation (D7c) is used to calculate noise figure. Whenever an RSMS calibration is performed, P_{on} and P_{off} are measured at 100 frequencies across the frequency range to be measured, and equations (D6c) and (D7c) are then used to calculate system gain and noise figure for each of those 100 calibration points. The result is the gain response and noise figure of the system as a function of frequency for the frequency range of the measurement. Negative values of the system gain are stored in look-up tables, and are added to raw data values as a correction factor. The gain-corrected power values are stored as spectrum survey data.

Antenna gain corrections are not routinely added to the raw data points as part of RSMS spectrum survey measurements; if incident field strength is required, then antenna correction factors are subtracted separately, after the measurement has been completed. The conversion from power measured in the 50-ohm RSMS circuitry to incident field strength in free space is:

$$FS_{free\ space} = (P_{meas}) + (77.2\ dB) + (20\log(f)) - G_{iso} \tag{D8}$$

where

$FS_{free\ space}$ = incident field strength, dBuV/m;

P_{meas} = power measured in 50 ohms, dBm, corrected for RSMS path gain calibration;

f = measurement frequency, MHz; and

G_{iso} = gain of the measurement antenna, dBi (dB relative to isotropic antenna).

Alternatively, if the receiving antenna correction factor (ACF) is known, instead of the antenna gain relative to isotropic, then the incident field strength conversion equation is:

$$FS_{free\ space} = (P_{meas}) + (107\ dB) + ACF \tag{D9}$$

where

ACF = antenna correction factor, dB.

D.3 Application

Excluding the receiving antenna, the entire signal path within the RSMS is calibrated with a noise diode source both before and during a spectrum survey; a noise diode, such as shown in Figure D-2, is connected at the point where the RF line attaches to the receiving antenna. The connection may be accomplished manually or via an automatic relay, depending upon the measurement scenario. The noise level in the system is measured at 100 points across the desired frequency range with the noise diode turned on (ON) and turned off (OFF). The RSMS control computer stores all of the ON vs. OFF noise diode values. The control computer then uses the measured difference between ON and OFF at each of the 100 calibration points to solve the calibration equations (D6c) and (D7c) shown above. The gain values are inverted in sign to become correction values. The resulting set of 100 noise figure and gain correction values are stored as a function of system frequency in look-up tables on the computer disk. The frequency-dependent gain-correction curve is used to automatically correct the measured amplitudes of all received signals in subsequent measurements. Figure D-l shows the gain-correction curve and noise figure curve for a typical RSMS measurement.

This calibration technique has proven very successful for field-deployed radio spectrum measurement systems. It is a fast way to determine sensitivity and gain-correction values for a measurement system, and it is also very useful for isolating the gains and losses through individual components of the measurement system, such as RF lines and amplifiers. Compared to alternative calibration equipment, such as signal generators or vector network analyzers, noise diodes have several advantages:

- The physical size and weight of a noise diode are comparatively small: dimensions are typically less than 5” long and less than an inch diameter; weight is a few ounces.

- Power consumption is low, at about 50 mA of direct current at a +28 volt potential.

- Cost is low, at a few hundred dollars or less for a noise diode.

- Because noise diode sources are inherently broadband (typically 100 MHz to 18 GHz or more), there are no frequency-tracking problems in the calibration, as are encountered with many other calibration techniques.

All of these features lend themselves to measurements in the field, where small size and weight, low power consumption, and simplicity of operation are all at a premium. Moreover the low cost and small requirements for size, weight, and power make it possible to locate several noise diodes at various places in the measurement system, and to carry spares in the event that a noise diode fails. Noise diodes can themselves be calibrated by such entities as the National Institute of Standards and Technology.

At frequencies below 12 GHz, accuracy of noise diode calibration with spectrum analyzers installed in the RSMS is good to within a decibel. At frequencies from 12- 18 GHz, accuracy falls to about +/-2.5 dB due to a higher system noise figure. For noise diodes producing an ENR of about +25 dB, as are used for RSMS measurements, calibrations cannot be performed in a practical sense if system noise figure is more than about 30 dB or is less than about 1 dB. This is because the difference between P_{on} and P_{off} becomes too small to measure reliably in the first case, and too close to the rated ENR of the noise diode to measure reliably in the second case. Noise diode calibrations will not provide information on phase shift as a function of frequency; if a measurement system must be calibrated for phase shift, then additional or alternative calibration methods must be used.

D.4 Reference

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NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement System to collect data for spectrum utilization assessments. This report details such a data collection effort spanning all of the spectrum from 108 MHz to 19.7 GHz in the metropolitan area of San Diego, California, during February and March of 1995.

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