MICROWAVE PERFORMANCE MONITOR APPLICATION AT THE BONNEVILLE POWER ADMINISTRATION

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ABSTRACT

This paper describes BPA experience with a BPA - developed automatic performance monitoring system which monitors pertinent operational parameters of seven major BPA microwave systems. The Microwave Monitor (MWM) System provides Operations and Maintenance personnel with continuous measurement of each system's performance. The MWM detects gradual MW system degradation and impending failures before an outage occurs. This allows maintenance visits to be scheduled in advance. In addition, the MWM isolates problems to specific sections of each microwave system allowing rapid location and repair. The MWM also performs automatic diagnosis, and only requires remote terminals at the ends of each microwave system. Having gained operational experience over several years, BPA can use the MW Monitor to evaluate BPA maintenance approach and procedures.

HISTORY AND BACKGROUND

BPA Microwave System

The Bonneville Power Administration (BPA) owns and operates a 300,000 square mile power transmission network spread over a region covering Oregon, Washington, Idaho and western Montana. To support this power transmission system, BPA operates a region wide microwave network for protective relaying, load and generator dropping, stability schemes, critical telemetering quantities, Supervisory Control and Data Acquisition (SCADA) systems, and Automatic Generation Control. Seven microwave systems make up the greater part of this microwave network. These systems, illustrated by the map in Figure 1, are designated as the A, B, D, K, N, Q and T systems.

The BPA microwave network consists of 141 microwave stations located at 80 mountain-top repeaters and 61 substations. The B, D, N, K, Q and T systems provide 600 channel capacity in the 7-8 GHz band, while the A system provides 1200 channel capacity. In the next five years, BPA will upgrade all the 600 channel systems (except B) to 960 channel. Each microwave system consists of a main backbone of mountain top repeaters with spurs to power substations. Due to the need for extensive drop-and-insert capability, remodulating Frequency Division Multiplex (FDM) is used at each radio station.

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Figure 1. BPA Microwave Network

Need for Microwave Performance Monitoring

Over the years, the utility industry has been moving towards the automatic control of its power systems. In order to accomplish this goal, a highly reliable (99.986%) telecommunications network is necessary. With this increased reliance on communications networks and a simultaneous reduction in substation operations personnel, any problem on the communications system could greatly reduce power system reliability. To improve system availability and reduce operating costs, BPA developed an automatic monitoring system which diagnoses microwave system problems and measures performance.

MICROWAVE MONITOR SYSTEM DESCRIPTION

The BPA Microwave Monitor System has a Remote Terminal Unit (RTU) at each end of the seven major systems in the BPA Microwave Network (Figure 2). Each RTU continuously monitors the following microwave system parameters:

- noise
- pilot level
- pilot phase hits
- intermodulation distortion
- turn-around crosstalk
- base band loading
- base band frequency response

Data from the 14 remotes is transmitted for final processing to the Master Terminal Unit (MTU) at the BPA Control Center in Vancouver, Washington. The data is transmitted over other microwave systems than the system being monitored. During normal conditions information on performance level is continuously available. During alarm conditions a diagnosis is made of the trouble and its location. The system accumulates outage data to provide microwave system availability statistics.

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Figure 2. Microwave Monitor System

Parameters

Noise

Noise is an important parameter on any microwave system, since high noise can render all circuits unusable. The source of a noise problem, however may be difficult to locate. Visits to several repeater stations may be necessary to isolate a problem to a particular microwave path. The desire to locate a noise problem source quickly and precisely led to the development of a noise source detection scheme.

The MW Monitor noise source detection scheme uses up to ten band-reject filters having notches in an unused portion of the FDM baseband spectrum. The baseband notch reject filters have the following characteristics:

- Pass band response ripple ± 0.2 dB
- Rejection notch depth 50 dB @ 700 Hz BW
- 3 dB rejection notch @ less than 10 kHz BW

Band reject filters are placed on each microwave system at points where noise source sectionalization is desired (Figure 3). At the endpoints of the system, noise is measured at the notch frequencies of the band reject filters and at an un-notched frequency (2157 kHz) using narrow bandwidth noise detectors.

Noise that enters a MW system between a notch filter and detector will cause that detector's output to increase. Noise entering a system on the other side of the filter would be rejected and not seen by the detector. Thus, by comparing system noise increases with a particular filter's corresponding detector output, the monitor can determine which direction from the filter that noise has entered the system. Notch filters at each backbone repeater allow the MW Monitor to isolate a noise source to a particular hop, by using a truth table algorithm.

Figure 3. MW Noise Model with Band Stop Filters

Pilot Level

Tone levels on the microwave network are quite important. They must remain correct within close tolerances throughout a microwave system. Microwave transfer trip equipment requires particularly close tone level tolerances. The remodulating nature of the BPA microwave system provides many opportunities for tone level variations to occur.

To detect problems of tone level variations, a group pilot or programmable multiplex out-of-band signaling tone from each substation spur on the microwave system, is measured at each Remote Terminal Unit. (Figure 4). In this simplified diagram, each microwave path is portrayed as a unity gain amplifier. A tone level change on a spur microwave path will change the measured value for the pilot from that particular spur station. A tone level change on a backbone path will result in changes in all pilots that pass through that path. By using truth table analysis, the monitor can isolate a path gain change to a particular spur or backbone path.

Figure 4. MW System Pilot Level Model

Pilot Phase Hits

Medium to high-speed digital data transmission is becoming more prevalent on the BPA communications network. As a result, pilot phase hits are monitored since they can effect microwave transfer trip circuits as well as SCADA and high-speed data circuits. Phase hits are generally caused by multiplex frequency generation abnormalities. Measurement of this parameter provides immediate identification of such problems when they occur at any of the substations.

Intermodulation Distortion

Intermodulation distortion is another major performance problem on microwave systems. Its sources include nonlinear operation of FM modulators, discriminators, and baseband

amplifiers. Other sources, which are more pronounced in wideband systems, include phase delay variations due to RF and IF filters and impedance mismatches in waveguides or coaxial cables.

Since we cannot perform end-to-end noise load testing on a microwave system (due to the spur configuration), an in-service testing technique is required. In-service intermodulation distortion monitoring is performed by placing three tones on the baseband at one end of the system. At the other end, measurements are made at two frequencies where high- and low-frequency second order intermodulation products will appear. In-service monitoring of intermodulation distortion provides an immediate indication of change anywhere on the system that adversely affects this distortion.

Turnaround Crosstalk

Turnaround crosstalk is another parameter of importance. High turnaround can result from problems such as cross coupling between transmit and receive cabling or improper termination of a baseband bridge at a repeater station. To measure this parameter, a low and high frequency tone is transmitted on the baseband from the measuring point and measured on the receiver baseband output at the same tone frequency. The level measured indicates the amount of turnaround from the microwave system at that frequency.

Baseband Loading

Currently under development is a detector card which will enable the Monitor to continuously measure baseband loading in order to detect system overload conditions possible during periods of heavy system use. Baseband loading data, correlated with intermodulation distortion data, will reveal if the current BPA baseband level standards are optimized. If current standards are too high, then excessive intermod noise will be caused during periods of high loading. If the current level standards are too low, then maximum SNR is not being realized.

Baseband Frequency Response

The levels of the three tones used for intermod distortion and turnaround crosstalk are monitored by detectors at the opposite system RTU. Any variation of the low- or high-frequency tones relative to the middle tone indicates that low or high end roll off has occurred.

Remote Terminal Unit

Each Remote Terminal Unit consists of two basic sections: the input interface section and the data processing section.

Input Interface Section

The input interface section converts each measured parameter (noise, pilot level and phase hits, distortion products, and turnaround crosstalk) to individual analog DC output voltages which can be sampled by a multiple input A-to-D converter. BPA designed the input interface hardware since commercial equipment was not available. The input interface consists of a wideband, high input impedance, low noise, low distortion amplifier which bridges across the microwave receiver baseband output line and drives individual signal detector boards.

RTU Data System

The Remote Terminal Unit data processing hardware at all fourteen locations is identical. The processing hardware is designed around the Motorola 6809 microprocessor. This data hardware is used by a variety of other data acquisition systems at BPA and was developed prior to the Microwave Monitor project. The analog d-c voltages from the input interface signal detectors are fed to a 12-bit A-to-D converter capable of up to 64 inputs. Both RAM and ROM memories are used to store the program. The major part of the program is stored in ROM. Programmable constants and the alarm detection algorithm software, which are downline loaded from the MTU, are stored in RAM. The A-to-D converter samples all 64 inputs in less than 5 ms, every 100 ms. The fast scan time of 5 ms allows near simultaneous readings of the input interface output voltages.

These Remote Terminal Units continuously monitor baseband noise, group pilot levels, group pilot phase hits, intermodulation, turnaround crosstalk, baseband loading and frequency response. Under normal conditions, each terminal stores the maximum value, minimum value, average value, and number of excursions above or below a programmable alarm level. At the end of a five minute measurement period, this information is transmitted from each remote terminal to the MTU at the BPA Control Center for further analysis.

When any of the measured parameters exceed programmable alarm limits, the RTU goes into the alarm mode and all measured parameters for the particular alarm category at the RTU in question will be immediately transmitted to the MTU for analysis.

A query mode is included to aid in microwave system testing and maintenance. On command, current data from any RTU can be retrieved.

Master Terminal Unit

MTU Hardware

The Master Terminal Unit (MTU) is the major part of the Microwave Monitor System. A basic system block diagram is shown in Figure 5. The MTU computer is a DEC PDP-11/24 with 1 megabyte of memory. It uses an asynchronous input multiplexer capable of up to 16 inputs, of which 14 are presently used, to transmit and receive data from the RTUs. Three of the 14 RTUs are located at the BPA Control Center, thus their data outputs are directly input to the MTU. The remaining eleven RTUs transmit their data via modems using an alternate microwave route than the systems being monitored.

The Master Terminal Unit has 10 input/output ports. The first port connects to a high speed video terminal (DEC VT-100) which is used for routine operator interaction with the MTU. The second port connects to a teletype terminal (LA-36 Decwriter) which provides hard copy logging of output data when required. The third port connects to a floppy disc mass storage unit which is used to store data for historical data summaries. The fourth port connects to a console staffed by the Control Systems Monitor (CSM). The CSM is a person who keeps track of the various control system monitoring and alarming systems and notifies maintenance personnel if action is required. Additional ports are provided for transmission of microwave system performance

information to terminals at field maintenance headquarters.

Figure 5. Master Terminal Unit Block Diagram

MTU Software Unique Characteristics

Under normal conditions, the Master Terminal Unit receives summary data from each remote at five minute intervals. From this data, the master derives and stores such information as average parameter levels, performance factor values, and indications that minor trend variations have occurred. When trend variations are detected, an audible alarm alerts Operations personnel and a statement is shown on a video display. In addition, the MTU condenses the five-minute performance factor values into hourly, daily, weekly, monthly, and yearly summaries.

During alarm conditions, alarm data is received from a remote and immediately processed. Again, an audible alarm and alarm statement are generated. The outage time that results from these alarm conditions is tabulated, weighted by the number of channels affected, and converted to a system availability figure which is sent to a summary report an example of which is shown in Figure 6.

Capability exists for adding explanatory comments to alarm messages. These comments are added by the user when the exact cause of the alarm condition has been determined. At the end of each day a hard copy record of alarm conditions, with user comments and system performance summary data, is logged.

Automated Data Analysis Performance Factor

Manual trend analysis of the data is time consuming. In addition, the analysis requires a

great deal of familiarity with the microwave system and the placement of the noise band reject filters. In order to solve these problems, techniques for automated data analysis are required.

Also required is a method of combining the measured values for different parameters to give some relative indication of microwave system performance. In order to meet this objective, a general purpose index called "performance factor" was invented. The performance factor (PF) is a number between 0 and 100, with 100 indicating ideal performance. The lower the value of this performance factor, the further that particular quantity is from its ideal value. Determining the sensitivity of the system performance factor to individual system parameters involves making value judgments. Operating experience will show if the initial value judgments were valid. Currently, the weighting of the individual parameter performance factors in calculating the system performance factor are:

Noise	30%
Pilot Level	30%
Phase Jitter	20%
Imod Distortion	10%
Turnaround Crosstalk	10%

For noise, the performance factor value is scaled so that a level of measured noise power equal to twice the system ideal noise power level will give a performance factor value of 50 (this is equivalent to a noise power level that is 3 dB above the system ideal noise level, or approximately a 10 dB increase in the noise of a single hop). If the measured noise power doubles again, the performance factor will drop to 25. The performance factor can be expressed as follows:

$$\text{Performance Factor} = 100 \times \frac{\text{Ideal Level}}{\text{Measured Level}} \quad (\text{Eq. 1})$$

where the ideal value and measured value are expressed in milliwatts. This same scaling is used for intermodulation distortion and turnaround measurements.

For pilot levels, the performance factor was scaled so that when levels dropped to a point where half of the operating margin on a microwave transfer trip was left, the performance factor would be -50. A minus sign is used to indicate that the level is lower than ideal. For most BPA microwave transfer trip equipment, the operating margin is 6 dB below the normal level. Hence, a 3 dB drop in level will give a -50 performance factor value. Similarly, a 3 dB increase in level will give a performance factor of 50.

The equations are:

For measured pilot levels less than the ideal value,

$$\text{Performance Factor} = -100 \times \frac{\text{Measured Level}}{\text{Ideal Level}} \quad (\text{Eq. 2})$$

For measured pilot levels greater than ideal value,

$$\text{Performance Factor} = 100 \times \frac{\text{Ideal Level}}{\text{Measured Level}} \quad (\text{Eq. 3})$$

The performance factor for intermodulation distortion, turnaround crosstalk, frequency response and baseband loading are calculated in a similar manner. All level values are expressed in milliwatts. Note that equation 3 is the same as

equation 1 (performance factor for noise and other parameters). When all parameters are expressed in performance factor values they can be averaged together to derive one number, in a range of 0 to 100, that describes the relative performance of the microwave system. The different parameters are weighted according to their importance as a performance indicator.

Output Summary Reports

Once the MW Monitor System has collected and processed data from the remotes, it will provide various summary reports. Figures 6a and 6b illustrate the most general reports produced by the Monitor. Figure 6a is an annual summary of system composite performance factor. Figure 6b is system availability. The system availability percentage is derived by weighting individual path outage times according to the number of channels affected. On January 1 of each year, each system availability is set to 100%. As outages occur, the monitor subtracts weighted percentage values.

Figure 6a - Annual System Performance Summary Report

Figure 6b - System Availability Summary

Another report provided by the monitor is a summary of significant microwave outages, illustrated in figure 7. Only outages longer than 21 seconds, weighted by the percentage of channels disabled, will show on this report. An operator can manually add additional comments to this report as required.

Figure 8 is a map of the portion of the BPA "D" MW system in northeastern Washington State which is referred to in the summary report examples shown in Figures 6, 7, and 9. In the interest of clarity, the remaining portions of the system map and reports are not shown.

Figure 9 shows the annual System Path Performance Summary. The monitor also produces a monthly summary, from which the annual summary is derived.

1986 Significant Microwave Outages

"D" SYSTEM (Outage times weighted by percentage of total channels affected)
(Significant outages are 21 seconds or more in duration)

DATE	OCCR	CLR	TOTAL	RTU	EVENT NAME
6/9	0000	1552	0:00:22	B	PH J1T OUTAGE GCRS (-50.0 DEG) SG FREQ GEN PROBLEM AT GCRS. PROBLEM WITH 'B' AMPLIFIER IN 41035 SG CXR GENERATOR SHELF. RDR
7/21	1109	1113	0:1:26	B	BK BONE OUTAGE MALA-FOST(-20.6 DB) SEE ALARM BELOW. {05} MALA>WATR
7/21	1308	1310	0:0:51	B	BK BONE OUTAGE MALA-FOST(-6.9 DB) SEE ALARM BELOW. {05} MALA>WATR
7/21	1313	1350	0:0:36	B	BK BONE OUTAGE MALA-FOST(-8.0 DB) B O G O G O G O C O C-B S-8 E-9 {05} MALA>WATR SCHED MAINT BEING PERFORMED ON PATH. 'B' PATH WAS OUT OF SERVICE WHEN 'A' PATH FREQ MOVED OFF. PROBLEM WAS A BAD TX AFC XTAL MOUNTING AT MALA. A LEVEL PROBLEM WAS CORRECTED WHEN A BROKEN WIRE WAS FOUND IN 'A' AUX AMP MALA. .....FM
7/21	1313	1331	0:0:57	B	INTMOD OUTAGE I1872(-35.5 DBMD) SEE ABOVE ALARM. {05} MALA>WATR
7/29	0930	0931	0:0:38	E	NOISE OUTAGE FOST+SPUR(31.5 DB S/N) 'A' PATH WAS DOWN FOR MAINTENANCE WHEN B NOISEDD UP. PROBLEM WAS CORRECTED BY WIGGLING THE TRANS. H HV INTERLOCK ON A TRANS. AT CHJO *****JN {09} CHJO>FOST
7/29	1326	1327	0:1:6	E	NOISE OUTAGE FOST+SPUR(30.0 DB S/N) DUE TO SYSTEM ALIGNMENT {09} CHJO>FOST

Figure 7 - Example of Significant MW Outage Report

Figure 8 - Partial Map of "D" MW System

In the report, each path has two lines. The top line labeled "O" is an indication of the actual Outage time in un-weighted minutes for each parameter. The bottom line, labeled "P", is the actual number of minutes the Performance factor for the particular parameter on that path was reduced to

less than 50. The symbol "... " indicates the parameter does not apply to that path. The system INTERMOD value indicates baseband loading. P/S is the ratio of total Path outage time (due to performance degradation) to total System time.

----- YTD -----						
PATH	N	L	P	I	T	TOTAL

MALA>WATR	0 0.0	8.3	3.1			11.5
P	10	0	4120			4130
WATR>MALA	0 0.0	0.1	0.0			0.1
P	0	0	0			0
WATR>FOST	0 0.0	0.0	0.0			0.0
P	0	0	0			0
FOST>WATR	0 0.0	0.0	0.0			0.0
P	0	0	0			0
CHJO>FOST	0 1.9	0.0 0.3	....			2.2
P	0	0 0	....			0
GCPH>GCSY	0 0.0	0.0 0.1	....			0.1
P	100	0 0	....			100
GNUX>GCSY	0	0.0 0.1	....			0.1
P	6330	0 ....	....			6330

GCSY>PLUM	0 0.0	0.0 ....	....			0.0
P	0	0 ....	....			0
GCRS>PLUM	0 0.0	0.1 3.1	....			3.2
P	0	0 10	....			10
SYS(EACC)	0 ....	....	....	0.0 0.0		0.0
P ....	....	....	....	0 0		0
SYS(BELL)	0 ....	....	....	0.0 0.0		0.0
P ....	....	....	....	0 30		30

Legend: N = Noise
L = Pilot Level
P = Pilot Phase Hits
I = Imod Noise
T = Turnaround

Figure 9 - Annual Path Performance Summary
(Partial "D" System)

The following examples illustrate how Operations and Maintenance people use these reports.

Figure 6b shows a drop in system availability in June 1986. The Significant MW Outage Report (Figure 7) indicates this was due to phase jitter at Grand Coulee Radio Station. The System Path Performance Summary (Figure 9) shows the outage was due to Grand Coulee RS-Plum (GCRS-PLUM) multiplex phase jitter.

Here is another example of the use of the these reports: Figure 6b (System Availability) shows an availability drop in July 1986. The Significant Outage Report (Figure 7) indicates this was due to the Malaga-Foster Creek (MALA-FOST) section of the Malaga-Waterville (MALA-WATR) path and spur noise from the Chief Joe-Foster Creek (CHJO-FOST) spur. The path summary log (Figure 9) indicates the outage and path degradation on the MALA-WATR and CHJO-FOST paths. Figure 9 also indicates these problems are isolated events and are deviations from normal operation.

Thus, to summarize the use of these reports, the System Performance and Availability Reports (Figure 6a,b) indicate that a problem has occurred, the Significant Outage Report (Figure 7) indicates the

problem details; while the Path Performance Summary (Figure 9) defines the path that caused the performance degradation and indicates the trends on performance and outages by path for maintenance program evaluation. A drop in availability with no significant outage events logged indicates a series of small outages caused the drop rather than a significant outage. This will be evident from the Path Summary Report (Figure 9).

Design, Installation and Maintenance Evaluation

In recent years the size and complexity of BPA's communications system has increased with no corresponding increase in the number of personnel. The Microwave Monitor provides an opportunity to evaluate the effectiveness of communication system design, installation and maintenance to achieve maximum operational availability.

Design

The Microwave Monitor has proven useful in determining what design changes are required to the communications system. One notable example was when the Monitor traced periodic system noise increases to a particular hop on one of the microwave systems. Maintenance personnel sent to one end of the hop noticed that the noise was correlated with wind gusts. The wind gusts caused longitudinal deflection of a nearby passive reflector tower which resulted in signal fades. The problem was solved by replacing the tower with one designed to withstand the wind velocities in the area.

Installation

Improper alignment of radio, antennas and auxiliary equipment and improper shielding and grounding can result in high noise pick-up and turnaround crosstalk at radio stations. Noise pick-up problems are especially critical at substations because they can delay the operation of protective relaying systems. An example of this was well illustrated after new baseband interface equipment was installed at BPA's Malin Substation, on the Oregon-California border. The Monitor indicated noise bursts on the microwave system whenever power apparatus operated. Maintenance people traced the pick-up to improper baseband shield grounding.

Maintenance

The Microwave monitor can be used as a maintenance tool for evaluating different maintenance approaches to facilitate maintaining more equipment and improving system availability with a limited staff. For example, a coordinated scheduled maintenance program which involves performing maintenance on both ends of a hop at the same time was recently instituted on BPA's oldest and newest microwave systems. Traditionally, maintenance people performed scheduled preventative maintenance at one radio site at a time. At the onset of the new program, a maintenance team performed coordinated scheduled maintenance with one day allocated to each hop. If a transmit klystron required changing, two days were allowed for klystron settling time and noise loading. Any special problems not resolved in that one-to-two day period were handled as a special job immediately following the coordinated alignment period. On completion of the alignment, only performance degradations reported by the MW Monitor or failures reported by the MW Fault Alarm System were corrected. If maintenance people were called to a site for other than radio related problems,

only radio meter readings were allowed. No adjustment changes ("tweeking") were allowed. Maintenance personnel took action only for catastrophic failures or when system performance degraded below a performance factor of 50 (operating margin reduced to one-half). At the same time, the MW Monitor remotes at each end of the system were calibrated to the optimum parameter values. A special work report form was used to record the original optimum operating conditions. Maintenance people carefully recorded all time spent on corrective maintenance activities. At the end of the one-year period, the same procedure was repeated for each of the hops. The final work reports documented any degradation which took place. The BPA Microwave Monitor Operating Committee is evaluating the effectiveness of the coordinated scheduled maintenance program. Other maintenance approaches are being planned and the MW Monitor will again be used to help evaluate the effectiveness of these programs.

CONCLUSION

Several years of experience using the Microwave Monitor System have resulted in continuing benefits in the following areas:

Sectionalization of catastrophic system problems has resulted in more rapid restoration of service. Due to rapid data collection (100 ms), even intermittent problems were properly diagnosed, thus establishing a starting point for maintenance personnel.

The Monitor provided a tool for measuring the effectiveness of maintenance and the performance of the equipment. Thus, gradual system degradation situations were detected, sectionalized, and repaired before they resulted in a major outage. In many cases, maintenance personnel were able to examine the effects of their adjustments before leaving the station.

The Microwave Monitor has contributed to the more efficient use of maintenance personnel in the field. For example, the Monitor has proven to be a useful tool in determining if maintenance intervals, procedures, and noise loading can be established on an as-needed, rather than a fixed time period basis.

By using MW Monitor data, turnkey or in-house additions to the BPA microwave communications system were evaluated for:

- a. Specification requirements
- b. Degradation to the existing system
- c. Long- and short-term stability
- d. Evaluation of contractor supplied equipment for future system additions

Data links to field maintenance personnel provide system performance visibility. This will hopefully encourage the development of a team concept between Operations and Maintenance personnel in providing the best performance for the lowest cost. In addition, the individuals performing the work can see the impact that their effort has had on the system.

With the implementation of automatic control and protection of BPA's power system, any unforeseen outage of our communications network could place the power system in jeopardy. At a time when costs are

soaring, the Monitor enables BPA to determine ways to hold costs down and improve performance through the development of a more efficient maintenance philosophy.

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