RF Power Measurement Techniques for Digital Communication Systems

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ABSTRACT

The measurement of radio frequency power in digitally modulated and post-combiner signals presents a challenge due to the high peak to average power ratios found in 8-VSB, COFDM, and other non-constant envelope signals. Testing was conducted as a result of this supposition to compare square-law diode detector based power meters to other methods of power measurement. Data was collected using two different digital modulation types while using a CW power source to establish reference data. The testing was performed at the laboratories of an international transmitter manufacturer during March of 2001. The results indicate that properly designed square-law diode detectors yield the same accuracy as the traditional standards for RF power measurement, the calorimeter and the thermocouple based power meter.

INTRODUCTION

Calorimetric power meters have been used for power measurements in broadcast transmission applications for sixty years. Calorimetric accuracy depends upon careful use and the consideration of many factors, including:

- Thermometer accuracy
- Flow meter accuracy
- Coolant physical characteristics (specific gravity and specific heat)
- RF load thermal efficiency
- Stabilization time
- Operator training

Calorimetric systems measure the true heating power of a signal, including the fundamental frequency, all harmonics and sidebands, and other modulation related contributions. The calorimeter will measure the total aggregate power contained in the signal. The calorimeter is a device that responds to heat and will measure the heating power of a low frequency (50 or 60 Hz) in exactly the same manner in which the calorimeter will respond to RF signals, which may be related to national standards at agencies such as NIST. The typical accuracy of a calorimetric power meter is +/-4%.

Bolometric or thermocouple based instruments are also used for RF power measurement. These types of meters measure the true RMS value of the signal corresponding to the heating caused by the RF power in the signal being measured. These instruments are very accurate but must be operated well above the noise floor of the instrument itself and are limited in the amount of power that may be applied without damage to the meter. Typically, thermocouple or bolometric power meters are designed for power levels of no greater than three watts. Extending the measurement range of these instruments to power levels used in broadcast applications requires the use of an appropriate attenuator or directional coupler. These instruments are subject to errors that include:

- Power reference uncertainty
- Calibration factor uncertainty
- Mismatch error
- Attenuation error
- Linearity problems
- Temperature drift

The combination of these errors yields a worst-case system accuracy of +/-13.3% and a probable error (RSS) of +/-5%. The primary alternative to calorimeters for measuring RF power in broadcast applications is the in-line power meter which samples RF power contained in both the forward and reflected traveling wave. These power meters are comprised of a short length of precision transmission line fitted with a dual directional coupler. The output of the directional coupler is fed to a simple diode detector and then scaled and displayed on a meter movement. While this approach has served the broadcast industry for many years, the use of simple in-line power meters in complex modulated signal systems has been questioned due to the inability of simple diode detectors to respond to signals with very high peak to average power characteristics common to digital modulation formats.

Diode detectors in conventional in-line power meters are operated largely over the non-linear portion of their dynamic range with their accompanying meter scales calibrated to read average power, even with the diode operating in a non-linear fashion. This approach works fine, so long as the power meter is used to measure a single defined waveform or a closely related signal, such as CW or FM modulation. An alternative approach using diodes that works well in systems carrying complex modulation is to operate the detector diodes below approximately -20 dBm in an area known as the "square law" region of the diode's dynamic range. In this region, diode detectors behave in much the same manner as thermal detection devices, where at low signal levels, the diode's rectified output is a function of the square of the RMS input voltage.

For a full-wave diode detector, the relationship between input and output voltages may be defined as:

$$Vout = (Vin/5.77)^2$$

where all voltages are in millivolts. This relationship holds as long as the total excursion of the signal being measured is contained within the square law region. The theoretical bounds for this range are from approximately -20dBm on the high side to the noise floor as determined by the bandwidth of the measurement at the lower end. Measurement ranges of 50 dB are possible in most systems.

TEST PLAN

Testing was designed to compare the performance of two types of radio frequency power meters, the thermal power meter and the square law based diode detector power meter, when used to measure the average power of complex, digitally modulated signals. The test plan also included comparing the performance of the Bird BPM power meter, a square law based diode instrument, and the other power meters to the readings obtained on a calorimeter used as the measurement standard. An older generation in-line power meter was included in the test to be compared with newer square law based instruments. Readings obtained with a directional coupler/ thermal power meter standard would be compared with in line power meters using square law based diode detectors.

Equipment used for test:
1. Bird Model 6085 Calorimetric Power Meter
2. Bird Model 8665 Moduload Heat Exchanger
3. Bird Model 8745 Water Cooled Load Resistor
4. Bird Model BPM6 In-Line RF Power Meter (BPM 6)
5. Bird Model 3129 Power Meter Display
6. Bird 6-1/8", 15 kW Analog Power Meter (Analog)
7. Putnam RF Systems 6-1/8" Precision Directional Coupler
8. Agilent EPM Series Thermal Power Meter and Sensor (TPM 1 & 2)

Power measurements were to be performed with signals using two types of digital modulation while using a CW power source to establish reference data. Specifically, modulation types used were:

- Coded Orthogonal Frequency Division Multiplex (COFDM)
- Eight Level Vestigial Sideband (8-VSB)
- CW Signals (no modulation)

TEST RESULTS

All tests were conducted at the test lab of an international transmitter manufacturer during March of 2001. Transmitters produced with 8-VSB and COFDM modulators were used for testing purposes. Tests were conducted with Bird Electronic Corporation employees and the transmitter manufacturer's employees present. The transmitter manufacturer supplied a power standard for the testing, while Bird supplied the Bird 6085 Calorimeter, the Bird BPM6 Broadcast Power Monitor system, the Bird Analog RF Power Meter, the Agilent EPM Thermal Power Meter, and the Putnam Directional Coupler.

Testing proceeded through three distinct phases. Phase one compared power readings of a continuous wave carrier (CW) as measured on the BPM6, the manufacturer's standard, the Bird standard, and the Bird analog power meter. Phase two compared the same meters under 8-VSB modulation, and phase three repeated the testing under COFDM modulation. The Bird BPM6 power meter, the thermal power meter, the Bird analog power meter, and the calorimetric power standard were configured as a system. The manufacturer's power standard was used as a separate test component.

Please note that while the power levels during testing remained consistent during all three phases, the units used on the vertical (Y) axis of the graphs that follow vary in order to show the best detail and the full excursion of the traces. All results show the Percentage of Deviation of the reading from the calorimeter readings) used as a standard during the testing.

CW Comparison: The test began by applying power to the systems under test with no modulation applied into a 50-ohm load. Under this signal condition, the power meters in the

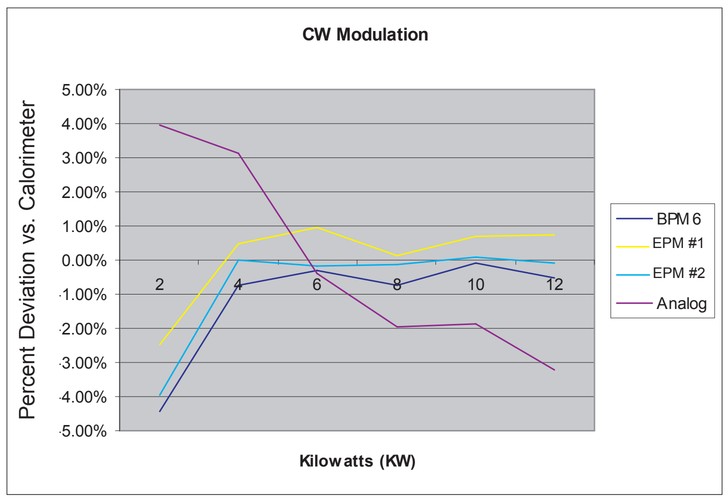

FIGURE A

BPM 6: The BPM 6 Power Meter was used with the BIRD Model 3129 Power Meter Display
EPM #1: Agilent EPM Series Thermal Power Meter and Sensor
EPM #2: Agilent EPM Series Thermal Power Meter and Sensor
Analog: Bird 6-1/8", 15 kW Analog Power Meter

system, including the calorimeter should produce very similarreadings. These readings were used as a baseline for the remainder of the tests. Power readings were recorded for various power levels between 2 and 15 kW.

Test Results for CW Test: In CW testing, with no modulation applied, the performance of all of the power meters was within published specifications, +/- 5%. Test results are shown in Fig. A.

8-VSB Comparison: The second phase of the testing required connecting the calorimeter and the four in-line power meters to a source of 8-VSB modulated RF power to demonstrate the performance of the various meter types under 8-VSB modulation. The procedure for the previous CW testing was repeated using the same power levels.

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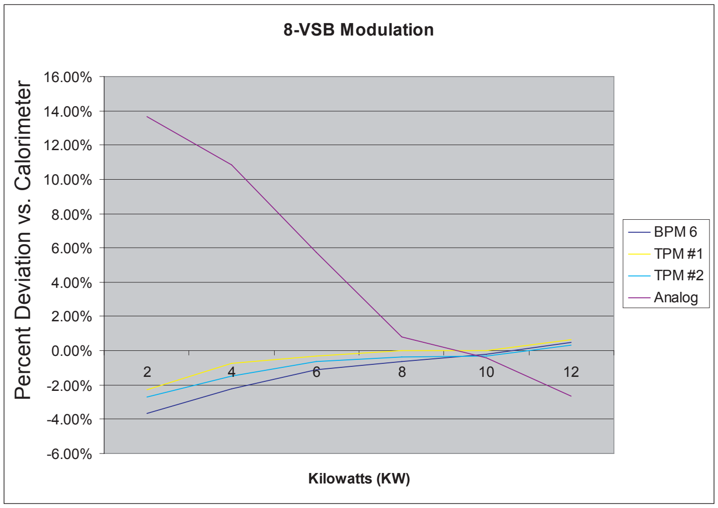

FIGURE B

BPM 6: The BPM 6 Power Meter was used with the BIRD Model 3129 Power Meter Display
TPM #1: Agilent EPM Series Thermal Power Meter and Sensor
TPM #2: Agilent EPM Series Thermal Power Meter and Sensor
Analog: Bird 6-1/8", 15 kW Analog Power Meter

Test Results for 8-VSB Test: The results of the 8-VSB test are shown in Fig. B. The test data illustrates that the thermal and square-law based diode power meters track the calorimetric system to within 3% across the power ranges tested. In the case of the conventional diode power meter however, errors at low power levels approach 14%.

COFDM Comparison: In the third phase of testing, the calorimeter and the four in-line power meters were connected to a source of COFDM modulated RF power in order to demonstrate the performance of the various power meter types under COFDM modulation. The test procedure as outlined in the previous steps was followed, again using the same power levels as used during the CW and 8-VSB testing.

COFDM Test Results: The COFDM test results are indicated in Fig C. In this testing, the accuracy differences between the thermal and square law diode power meters and the conventional power meter were even more pronounced than in the previous testing. The results show that the true average responding power meters were consistently within 2% of the calorimeter, while the conventional power meter was as much as 20% in error.

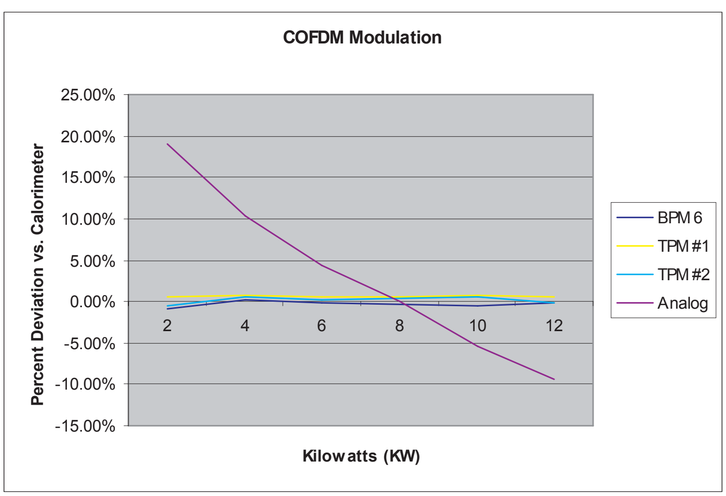

FIGURE C

BPM 6: The BPM 6 Power Meter was used with the BIRD Model 3129 Power Meter Display
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TPM #2: Agilent EPM Series Thermal Power Meter and Sensor
Analog: Bird 6-1/8", 15 kW Analog Power Meter

CONCLUSION

Based upon the data collected during this testing, it is clear that the square-law based diode power meter and the thermal power meter/ directional coupler combination are capable of the measurement of signals using complex modulation with accuracy approaching a calorimetric power measurement system. By contrast, the older generation products incorporating diode detectors operated either in the linear region of their dynamic characteristics or in the transition region between square law and linear operation are not able to provide accurate results under these conditions. It is also worthy to note that all of the power meters tested demonstrated acceptable performance when measuring unmodulated signals. The information presented in this report should enable broadcast engineers to make good choices with respect to the selection of RF power meters for use in new digital broadcast applications.

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