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IMPROVED RADIOFREQUENCY POWER STANDARDS

September 1973

Bendix Corporation
Kansas City, Missouri

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POWER STANDARDS

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IMPROVED RADIO-FREQUENCY POWER STANDARDS, MEP 72-74

September 1973

Prepared by D. W. Stone

Two types of Hewlett Packard radio-frequency power meters were modified to improve the accuracy of their calibration-factor-compensation circuits from 1 to 0.1 percent. The modification resulted in a continuously variable calibration-factor dial with a resolution of 0.01 percent and a 0.5 percent improvement in the confidence level of power measurements.

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SUMMARY

Recent state-of-the-art advancements in radio-frequency power measurement have resulted in the need to compensate thermistor mount inefficiencies to a greater accuracy than 1 percent. Two types of Hewlett Packard power meters were modified to improve their compensation accuracy to less than ± 0.1 percent without affecting other performance characteristics. Time-consuming calculations previously required to compensate for mount inefficiencies have been eliminated while the measurement confidence level of the meters has been increased by 0.5 percent.

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DISCUSSION

SCOPE AND PURPOSE

The Hewlett Packard (HP) Models 431C and 432A series power meters constitute the instrumentation packages for an external Model 478A radio-frequency (RF) thermistor mount which is used for RF power measurements at the Bendix Kansas City Division. They were designed to compensate for mount inefficiencies by including a circuit controlled by the Calibration Factor Dial (CFD). This circuit consisted of a variable resistance or voltage divider which provided greater sensitivity to the readout meter as the mount efficiency decreased. Since mount efficiency varies widely with frequency, the compensation circuits were designed to cover a CFD range from 88 to 100 percent in 1-percent steps.

Recent state-of-the-art advancements in the measurement of RF power have resulted in a need to compensate for mount inefficiency to a greater accuracy than 1 percent. The following design goals were established to improve this characteristic of the power meters used at Bendix.

- Compensation Adjustment: continuously variable
- Compensation Accuracy: ± 0.1 percent
- Compensation Resolution: ± 0.01 percent
- Compensation Range: 90 to 100 percent

ACTIVITY

Model 431C Calibration Factor Circuit Modification

Design

In the Model 431C instruction manual,¹ Figure 7-7 shows that the CFD decade switch, S4, consists of a nonlinear, current-carrying voltage-divider circuit. The modification selected for the metering circuit, shown in Figure 1, replaces the S4 decade switch assembly and resistor R33.

An operational amplifier and resistor R_C have been included in the modification to drive and control the required 0-to-1-mA current through the M1 meter to ground; in addition, the operational amplifier prevents loading of the compensation circuit which consists of R_A , R_B , R_D and R_L .

Figure 1. Model 431C Metering-Circuit Modification

Resistor R_B provides the correct current flow through Q_{11} , thus establishing the desired Q_{11} voltage range from 0 to -1.9 volt. Resistors R_A and R_D comprise a voltage divider; the value of R_D (10 k Ω) was selected to minimize the effect on R_B when R_A is adjusted. A 75,000- Ω linearizing resistor, R_L , was required to produce the correct CFD response over the full range from 90 to 100 percent.

Selection of Resistor R_A

The following is an outline of the method for selecting the value of R_A , along with the performance evaluation of the compensation circuit shown in Figure 2.

Figure 2. Compensation Circuit

Because the thermistor devices used with the Model 431C are essentially insensitive to power level, the following analysis is based on a V_{IN} maximum value of -1.9000 volt which occurs when the mount efficiency is 100 percent. Therefore,

$$V_{OUT} = 0.9 \times V_{IN} = -1.7100 \text{ volt.}$$

The required nominal value for R_A then can be calculated by use of the following equation.

$$\frac{V_{OUT}}{V_{IN}} = \left(\frac{R_D \times R_L}{R_D + R_L} \right) \div \left(R_A + \frac{R_D \times R_L}{R_D + R_L} \right) = 0.9, \quad (1)$$

where

$$R_D = 10,000 \, \Omega, \text{ and}$$

$$R_L = 75,000 \, \Omega.$$

Therefore,

$$R_A = 79,412 \, \Omega.$$

To verify that the parameters selected produced the desired theoretical results, V_{OUT} was calculated by the following ratio equation as V_{IN} was changed in 0.5-percent steps and the CFD was set to the corresponding position. (Refer to Figure 3.)

$$V_{OUT} = V_{IN} \left(\frac{a}{a+b} \right), \quad (2)$$

where

$$a = R_X + 79,412 \, \Omega,$$

$$b = \frac{(10,000 - R_X)(75,000)}{(85,000 - R_X)}, \text{ and}$$

R_X = the nominal difference in resistance between the 100-percent end of the R_D resistor and the actual position of the sliding contact determined by the setting of the calibration factor dial, as illustrated in Figure 2.

Figure 3. Schematic for Equation 2
Calculation of V_{OUT}

The results, shown in Table 1, indicate that the maximum percent deviation of V_{OUT} from the nominal value of -1.7100 volt was less than 0.01 percent. From these results, the conclusion was reached that the power meter could be modified with some assurance that the design goals would be achieved. The modification, initial adjustment, and calibration procedures follow.

Modification Procedure

The parts required for the modification of the Model 431C Calibration Factor Circuit are shown in Table 2. The engraving for the 10-turn micrometer dial is shown in Figure 4. The following numbered paragraphs outline the modification procedure.

1. Remove the top and bottom covers of the power meter.
2. Drill required holes and mount IC socket and three trimmer potentiometers as indicated in Figure 5.
3. Remove the CFD switch assembly S4 from the power meter and unsolder four black wires, one yellow-purple-white wire, and one yellow-green-white wire from the switch deck.
4. Drill the micrometer dial-positioning hole according to instructions on the dial.
5. Install 10-turn, 10 k Ω potentiometer and micrometer-dial assembly in the S4 mounting hole.

Table 1. Results of V_{OUT} Calculations for
Different Values of V_{IN}

V_{IN}	CFD Setting	V_{OUT}	V_{OUT} Percent Deviation From 1.7100
-1.90000	100.0	-1.71000	0.000
-1.89050	99.5	-1.71006	+0.004
-1.88100	99.0	-1.71011	+0.006
-1.87150	98.5	-1.71013	+0.008
-1.86200	98.0	-1.71015	+0.009
-1.85250	97.5	-1.71015	+0.009
-1.84300	97.0	-1.71014	+0.008
-1.83350	96.5	-1.71012	+0.007
-1.82400	96.0	-1.71010	+0.006
-1.81450	95.5	-1.71007	+0.004
-1.80500	95.0	-1.71004	+0.002
-1.79550	94.5	-1.71001	+0.001
-1.78600	94.0	-1.70997	-0.002
-1.77650	93.5	-1.70994	-0.004
-1.76700	93.0	-1.70992	-0.005
-1.75750	92.5	-1.70990	-0.006
-1.74800	92.0	-1.70989	-0.006
-1.73850	91.5	-1.70990	-0.006
-1.72900	91.0	-1.70991	-0.005
-1.71950	90.5	-1.70995	-0.003
-1.71000	90.0	-1.71000	0.000

Table 2. Parts Required for Model 431C Modification

Quantity	Description	Manufacturer	Type
1	10-Turn Potentiometer (10 k Ω) linearity ± 0.5 percent*	TRW	5000-000
1	Trimmer Potentiometer (1 k Ω)	IRC	600-00M
1	Trimmer Potentiometer (2 k Ω)	IRC	600-00M
1	Trimmer Potentiometer (100 k Ω)	IRC	600-00M
1	Operational Amplifier	Fairchild	μ A 741
1	IC Socket	Cinch-Jones	8-ICS
1	10-Turn Micrometer Dial (modification, Figure 4)	Amphenol	1350
1	Resistor, 75 k Ω , ± 5 percent		

*If a substitution is used, verify that the shaft is long enough to attach micrometer dial. The panel is extra thick.

Figure 4. Potentiometer
Dial Engraving

- Solder four black wires together and connect them to chassis ground at the grounding strap on the NULL capacitor.

Figure 5. Top View of Power Meter With Cover Removed

7. Prior to wiring the potentiometer, set the resistance values of each trim pot to the approximate value indicated below and cut off the unused lead:

$$R_A = 79,000 \Omega,$$

$$R_B = 1400 \Omega, \text{ and}$$

$$R_C = 630 \Omega.$$

8. Wire the modification according to Figure 1.

Initial Adjustment Procedure

The following equipment is required for the initial adjustment of the modified Model 431C.

- Power Meter Calibrator, HP Model 8402B
 - 0.01 percent dc DVM, 0.9 to 2.0 volt, HP Model 3460B
 - Thermistor Mount, HP Model 478A
1. Connect the thermistor mount to the power meter under test (MUT).
 2. Connect the power-meter calibrator, Model 8402B, to the MUT.
 3. Turn the equipment on and allow it to warm up.
 4. Connect the DVM + to Pin 6 of the operational amplifier and ground. (Refer to Figure 1.)
 5. Position the MUT and calibrator to the 1-mW range.
 6. Zero the MUT.
 7. Position the calibrator FUNCTION switch to CALIBRATE.
 8. Position the CFD to 90.0 percent.
 9. Adjust R_B for a DVM indication of -1.9000 volts, or as close as possible to -1.9000 volts.
 10. Position the CFD to 100 percent.
 11. Adjust R_A for a DVM indication of 90 percent of the value set in Step 9.
 12. Repeat Steps 8 through 11 until no further adjustment is required.
 13. Position the calibrator FUNCTION switch to OFF.
 14. Connect the DVM to the DVM OUTPUT connector of the MUT.
 15. Zero the MUT by observing the DVM for an indication of 0.0000.
 16. Position the CFD to 100.0 percent.

17. Position the calibrator FUNCTION switch to ON.
18. Adjust R_C for a DVM indication of 1.0000 volt.
19. Position the calibrator FUNCTION switch to OFF.
20. Disconnect the calibrator from the MUT.

CFD Calibration

The following equipment is required for the CFD calibration.

- 0.01 percent dc DVM, HP Model 3460B
- Thermistor Mount, HP Model 478A

1. Connect the thermistor mount to the power meter under test (MUT).
2. Connect the DVM to the DVM OUTPUT connector of the MUT.
3. Position the following MUT controls as indicated.

RANGE	1 mW
CALIBRATION FACTOR	90.0 percent
MOUNT RESISTANCE	200 Ω

4. Adjust the MUT ZERO control for an indication of 1.0000 volt on the DVM.
5. Position the CFD to 90.5 percent and record the DVM indication.
6. Repeat Step 5 for each position of the CFD listed in Table 3.

NOTE: The nominal DVM indications recorded in Table 3 were determined by the following ratio:

$$\text{Nominal DVM Indication} = \frac{90.000}{\text{CFD (percent)}}$$

Table 3. Calibration Results

CFD (Percent)	Nominal DVM Indication	HP Model 431C S/N 707-05552		HP Model 432A S/N 092-03816	
		Actual DVM Indication	Percent Deviation From Nominal	Actual DVM Indication	Percent Deviation From Nominal
90.0	1.00000	1.0000	-----	1.0000	-----
90.5	0.99448	0.9945	+0.002	0.9945	+0.002
91.0	0.98901	0.9890	-0.001	0.9890	-0.001
91.5	0.98361	0.9835	-0.011	0.9836	-0.001
92.0	0.97826	0.9782	-0.006	0.9783	+0.004
92.5	0.97297	0.9729	-0.007	0.9730	+0.003
93.0	0.96774	0.9677	-0.004	0.9678	+0.006
93.5	0.96257	0.9625	-0.007	0.9627	+0.013
94.0	0.95745	0.9574	-0.005	0.9575	+0.005
94.5	0.95238	0.9523	-0.008	0.9525	+0.013
95.0	0.94737	0.9473	-0.007	0.9475	+0.014
95.5	0.94241	0.9423	-0.008	0.9425	+0.011
96.0	0.93750	0.9374	-0.011	0.9376	+0.011
96.5	0.93264	0.9325	-0.015	0.9328	+0.017
97.0	0.92784	0.9277	-0.008	0.9280	+0.017
97.5	0.92308	0.9229	-0.020	0.9232	+0.013
98.0	0.91837	0.9182	-0.019	0.9185	+0.014
98.5	0.91371	0.9135	-0.023	0.9138	+0.010
99.0	0.90909	0.9089	-0.021	0.9092	+0.012
99.5	0.90452	0.9042	-0.035	0.9045	-0.002
100.0	0.90000	0.9000	0.000	0.9000	0.000
*CFD Certification Accuracy: ± 0.1 percent **DVM Measurement Accuracy: ± 0.01 percent ***Acceptable Percent Deviation Limits: ± 0.06					

Model 432A Series Calibration Factor Circuit Modification

Design

In the Model 432A instruction manual,² Figure 7-12 shows that the CFD compensation circuit consists of a linear voltage divider. The divider incorporates twelve 10-ohm resistors mounted on the CALIBRATION FACTOR switch, A4S1, in series with an 880-ohm resistor to ground.

The required modification to this circuit was quite simple since the divider could be replaced with a 100-ohm, 10-turn potentiometer and a 900-ohm fixed resistance. The modification is shown in Figure 6. Incorporated is a 1-k Ω potentiometer for establishing the 900- Ω value. In the modified circuit, R_a replaces A4R₁, R₂, R₃, R₄, R₅, R₆, R₇, R₈, R₉, and R₁₀; R_b replaces A4R₁₁, R₁₂, and R₁₃.

Figure 6. Model 432A Circuit Modification

Modification Procedure

The parts required for the modification of the Model 432A Series Calibration Factor Circuit are shown in Table 4. The engraving for the 10-turn precision dial is shown in Figure 4.

Table 4. Parts Required for Model 432A Modification

Quantity	Description	Manufacturer	Type
1	10-Turn Potentiometer (100 Ω)*	TRW	5000
1	20-Turn Trim Potentiometer (1 k Ω)	Bourns	3065S-1-102
1	10-Turn Micrometer Dial, Miniature (modification, Figure 4)	Amphenol	1370
*Maximum diameter for this potentiometer is 0.5 inch.			

The following numbered paragraphs outline the modification procedure.

1. Remove the top and side panels of the power meter.
2. Remove the A1 printed circuit board assembly.
3. Remove the A4S1 switch assembly.
4. Drill required holes and mount the 20-turn trim potentiometer (R_b) approximately 1-1/2 inches below the A4S1 mounting-bracket hole. Position R_b horizontally with its adjusting screw facing toward the outside.

NOTE: Preset the value of R_b to approximately 900 ohms.

5. Mount the 10-turn potentiometer (R_a) in the front-panel hole formerly occupied by the A4S1 switch assembly.
6. Install the 10-turn micrometer dial on the extension shaft.
7. Wire the circuit as indicated in Figure 6.
8. Install the A1 circuit board.

Initial Adjustment Procedure

The following equipment is required for the initial adjustment of the modified Model 432A.

- Power Meter Calibrator, HP Model 8477A
- 0.01 percent dc DVM, HP Model 3460B

1. Connect the Model 8477A calibrator to the power meter under test (MUT).
2. Position the calibrator controls as indicated.

ZERO/TEST	ZERO
FUNCTION	200 Ω
POWER	1 mW

3. Connect the DVM to the RECORDER OUTPUT of the MUT.
4. Turn the equipment on and allow it to warm up for 15 minutes, minimum.
5. Position the MUT controls as indicated.

RANGE	1 mW
CALIBRATION FACTOR	100 percent
MOUNT RESISTANCE	200 Ω

6. Adjust the calibrator ZERO control for an indication of 0.0000 on the DVM.
7. Position the calibrator to TEST.
8. Adjust R_p for an indication of 1.0000 volt on the DVM.
9. Position the calibrator to ZERO.
10. Position the calibrator POWER switch to 0.3 mW.
11. Position the RANGE switch of the MUT to 0.3 mW.
12. Position the calibrator to TEST.

13. Adjust the calibrator ZERO control for an indication of 0.9000 volt on the DVM.
14. Position the CFD on the MUT to 90.0 percent.
15. The DVM should indicate 1.0000 volt; if not, readjust R_b using the following logic: if the DVM indication is below 1.000 volt, adjust R_b to increase the reading to a value approximately the same magnitude above 1.000 volt that it was previously below 1.0000 volt.
16. Position the CFD to 100.0 percent.
17. Repeat Steps 13 through 16 until no further adjustment is required.

CFD Calibration Procedure

The following equipment is required for calibration of the CFD.

- Power Meter Calibrator, HP Model 8477A
- 0.01 percent dc DVM, HP Model 3460B

1. Connect the calibrator to the MUT.
2. Position the calibrator controls as indicated.

ZERO/TEST	ZERO
FUNCTION	200 Ω
POWER	1 mW

3. Connect the DVM to the RECORDER OUTPUT of the MUT.
4. Turn the equipment on and allow it to warm up.
5. Position the MUT controls as indicated.

RANGE	1 mW
CALIBRATION FACTOR	90.0 percent
MOUNT RESISTANCE	200 Ω

6. Position the calibrator to TEST.

7. Adjust the calibration ZERO control for an indication of 1.0000 volt on the DVM.
8. Position the CFD on the MUT to 90.5 percent and record the DVM indication.
9. Repeat Step 9 for each position of the CFD listed in Table 3.

NOTE: The nominal DVM indications shown in Table 3 were previously determined for the Model 431C Calibration Factor Circuit Modification.

ACCOMPLISHMENTS

Modifications were made to two power meters which satisfied the design goals without affecting other performance characteristics. The calibration results listed in Table 3 show a maximum measured deviation from the nominal indication of 0.035 percent for the Model 431C and 0.017 percent for the Model 432A modified meters. Time-consuming calculations previously required to correct for mount inefficiencies have been eliminated, and the measurement confidence level of the meters has been increased by 0.5 percent.

REFERENCES

¹Operating and Service Manual, Model 431C Power Meter, Hewlett-Packard, Palo Alto, California, March, 1967, p 7-5.

²Operating and Service Manual, Power Meter 432A, Hewlett-Packard, Palo Alto, California, July, 1969, p 7-13.