Applications of the Maury Noise Calibration Systems

APPLICATION NOTE / 5C-028

Maury Microwave

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Accuracy and Convenience in Noise Measurements

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Introduction

The purpose of this note is to describe the applications of the maury MT7000 series Noise Calibration System (NCS) and the advantages afforded by these systems over more common means of addressing such applications.

These systems are used for making very accurate noise figure or effective input noise temperature measurements (receiver noise performance factors), calibration of less accurate solid state noise sources, and performance evaluation and verification of satellite earth stations.

The NCS are available with 7mm precision connectors for broadband coaxial applications up to 18 GHz and in waveguide from WR430 to WR10.

System Description

The Maury Noise Calibration Systems are automatic, self-contained, highly accurate sources of RF and microwave noise power. Each system provides two (one Hot/one Cold) or three (one Hot/one Ambient/one Cold) accurately known noise temperatures (powers). Switching between sources is conveniently accomplished by means of a remotely controlled, accurately characterized switch or switches via a NCS Controller such as the Maury MT155J. This Controller can be located up to 25 feet from the NCS. Figure 1 shows the layout of the MT7208J; a typical, coaxial, tri-load system[1]. The photo at the top of this page shows the MT7208J with the MT155J Controller. Figure 2 is a photograph of the MT155J Controller[2].

The accuracy of the Maury NCS derives from the use of true thermal noise sources – the fundamental principle of noise generation – and accurate insertion loss meas-urements of the interconnecting switch (or switches in a tri-load system).

Every system is provided with noise temperature calibrations at the single output port.

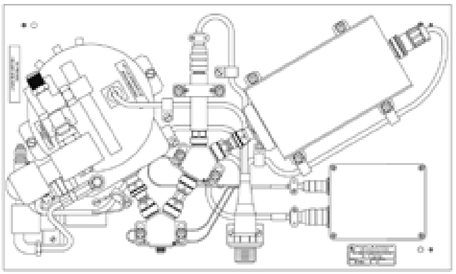

Figure 1. Top-view layout of the MT7208J99 tri-load noise calibration system.

Figure 2. The Maury MT155J NCS Controller.

Table 1

lists a sampling of NCS available from Maury Microwave.

Table 1. Typical NCS Models

Model	Frequency Range (GHz)	Transmission Line	Output Connector or Flange	System Type
MT7091J99	10.0 – 12.4	WR90	MPF90	Dual-Load
MT7093J99	10.0 – 15.0	WR75	MPF75B	Dual-Load
MT7094J99	15.0 - 22.0	WR51	MPF51B	Dual-Load
MT7095J99	18.0 - 26.5	WR42	UG595/U	Dual-Load
MT7097J99	33.0 - 50.0	WR22	UG383/U	Dual-Load
MT7149J99	75.0 - 110.0	WR10	UG385/U	Dual-Load
MT7098J99	DC - 18.0	Coaxial	7mm	Dual-Load
MT7208J99	DC - 18.0	Coaxial	7mm	Tri-Load

Noise Terminations

The cold temperature is provided by a well-matched, liquid nitrogen (LN_2) cooled termination with automatic LN_2 level sensing and fill control. In coaxial systems this is similar to the MT7118J[3] (see Figure 3). Gaseous helium at a maximum of 25 psi is used to purge the transmission line of contaminants (air, carbon dioxide, etc.), which could freeze and degrade the termination match as seen at the output port. The systems also include a helium pressure regulator.

Figure 3. The MT7118J Coaxial Cryogenic Termination, Shown here in its standalone configuration. The photo on page 1 shows the same unit in a tri-load system.

In tri-load systems, an ambient temperature termination such as the Maury 2659A[4] 7mm Coaxial Ambient Termination is also provided (see Figure 4). These units are assembled in massive, gold-plated, copper housings for stability. Temperature readings are displayed on the front panel of the Controller.

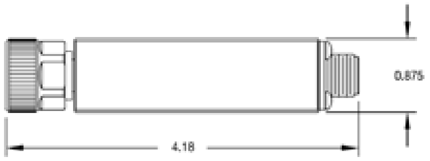

Figure 4. The Maury 2659A99 Coaxial Ambient Termination. The dimensions shown are in inches. The photo on page 1 shows this model in a tri-load system configuration.

The hot noise temperature is provided by a proportionally controlled, heated termination maintained by the MT155J Controller at 373.1 K for coaxial systems, or at 350 K for waveguide systems. The Controller also provides a digital readout of the heated termination physical temperature. The MT7090J[5] is a typical waveguide unit (see Figure 5).

Figure 5. The Maury MT7090J Thermal Termination (left) and MT151C Controller (right) are provided in a foam-lined Instrument case (top) when sold as a standalone unit. In a tri-load or dual-load system only the termination is used.

Noise Performance Factors

Noise in linear transducers (receivers, amplifiers, transistors, etc.) is usually characterized in terms of noise figure (noise factor) or effective input noise temperature. Complete development of these quantities is beyond the scope of this Application Note, and the reader is invited to consult references 6 through 11 for an understanding of the theory involved.

The modern method of measuring these quantities is to successively apply two known noise powers (noise temperatures) to the input of the transducer under test and measure the ratio of the resultant noise powers at the transducer output (Y-factor). The method is illustrated in Figure 6.

Noise figure or effective input noise temperature is then calculated from a knowledge of the source temperatures and the measured Y-factor using Equations (1) or (2).

$$F(\mathrm{dB}) = 10\,\mathrm{LOG}_{(10)}\left[\frac{ENR - Y\left(\frac{Tc}{290} - 1\right)}{Y - 1}\right] \tag{1a}$$

$$Te = \frac{290\left(ENR - Y\frac{Tc}{290} + 1\right)}{Y - 1} \tag{1b}$$

$$F(\mathrm{dB}) = 10\,\mathrm{LOG}_{(10)}\left[\frac{\left(\frac{Th}{290} - 1\right) - Y\left(\frac{Tc}{290} - 1\right)}{Y - 1}\right] \tag{2a}$$

$$Te = \frac{Th - YTc}{Y - 1} \tag{2b}$$

F(dB) = noise figure of the test device in dB.
Te = effective input noise temperature of the test device in kelvins.
Th = hot temperature of the noise source in kelvins.
Tc = cold temperature of the noise source in kelvins.
Y = ratio of noise power output of the test device when the noise source is hot to that when the source is cold.
ENR = excess noise ratio: a measure of the hot temperature of a noise source usually applied to solid state noise generators given by Equation (3).

$$ENR = \frac{Th}{290} - 1 \tag{3}$$

Equations (2) are normally applied when the noise source is specified in terms of absolute hot and cold temperatures such as with the NCS or other thermal noise generators. Equations (1) are applied when the generator output is given as ENR such as with solid state noise sources.

It should be noted that ENR and Y-factor are normally expressed in dB and must be converted to ratio form before substitution in Equations (1) and (2).

Noise figure meters coupled with solid state noise generators perform this measurement and calculation automatically, quickly and conveniently[12] however, the trade-off for the convenience of such measurement systems is that they suffer a lack of accuracy, particularly when today's measured devices routinely exhibit noise figures of less than 1dB.

When higher accuracy than that afforded by such automatic set-ups is required, the solid state noise generator is usually replaced by individual thermal noise sources – typically, a liquid nitrogen cooled termination and a hot, temperature-controlled termination (or in some cases, an ambient termination).

There is often reluctance to resort to such individual thermal sources because:

- Two connections are required.
- There were concerns over system drift while thetest device was disconnected from the cold loadand connected to the hot load and fast, automaticswitching between the source was unavailable oruncalibrated.
- The LN_2 container requires periodic, manual refilling.

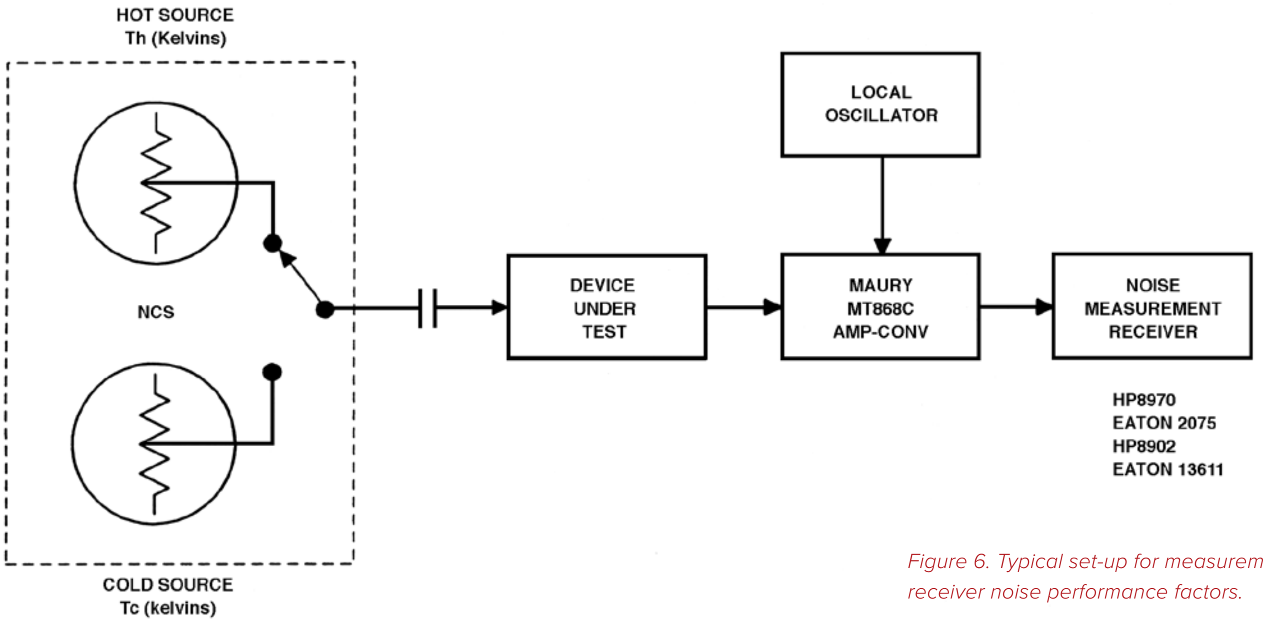

Figure 6. Typical set-up for measurement of receiver noise performance factors.

The Maury NCS removes these concerns with an automatic LN_2 refill system, remote switching from cold to hot, and accurate noise temperature calibration at the switch output port. Thus the NCS offers an unparalleled combination of measurement accuracy and convenience.

Accuracy Considerations

The primary reason for using a hot/cold thermal noise source is to improve measurement accuracy. In a simple noise measurement there are three unrelated potential error sources originating as instrumentation uncertainties: the hot source temperature, the cold source temperature, and the Y-factor. The advantage of using the NCS over a solid state noise source can be seen almost intuitively.

The typical worst case uncertainty in ENR of a solid state noise source is ±0.25 dB, which equates to about ±595 kelvins uncertainty in hot temperature for a source with a 15.5 dB ENR. The worst case uncertainty in either the hot or cold load noise temperature of a Maury NCS is ±2 K.

For reference, Figure 7 plots hot temperature of a solid state source and its uncertainty for a 0.25 dB ENR uncertainty versus ENR (dB) as calculated in Equations (3) and (8).

The overall measurement uncertainty can be derived by taking the partial derivatives of the measurement equation with respect to each of the error sources. Since these sources are uncorrelated, the individual contributions can be combined as root-sum-squares (RSS). Equation (4) illustrates the technique as applied to Equation (2b), and the results are shown in (5) through (7).

$$\Delta Te = \sqrt{\left(\left|\frac{\partial Te}{\partial Th}\right| \Delta Th\right)^2 + \left(\left|\frac{\partial Te}{\partial Tc}\right| \Delta Tc\right)^2 + \left(\left|\frac{\partial Te}{\partial Y}\right| \Delta Y\right)^2} \quad (4)$$

$$\frac{\partial Te}{\partial Th} \Delta Th = \frac{\Delta Th}{Y-1} \quad (5)$$

$$\frac{\partial Te}{\partial Tc} \Delta Tc = \frac{\Delta Tc}{1-1/Y} \quad (6)$$

$$\frac{\partial Te}{\partial Y} \Delta Y = \frac{Tc - Th}{(1-1/Y)^2} \left(\frac{\Delta Y}{Y}\right) \quad (7)$$

Figure 8 is a plot of the combined RSS uncertainty in effec-tive input noise temperature for three noise sources:

- A solid state source with 15.5 dB ENR.
- A solid state source with 5 dB ENR.
- A hot/cold NCS using liquid nitrogen and boiling water physical temperatures.

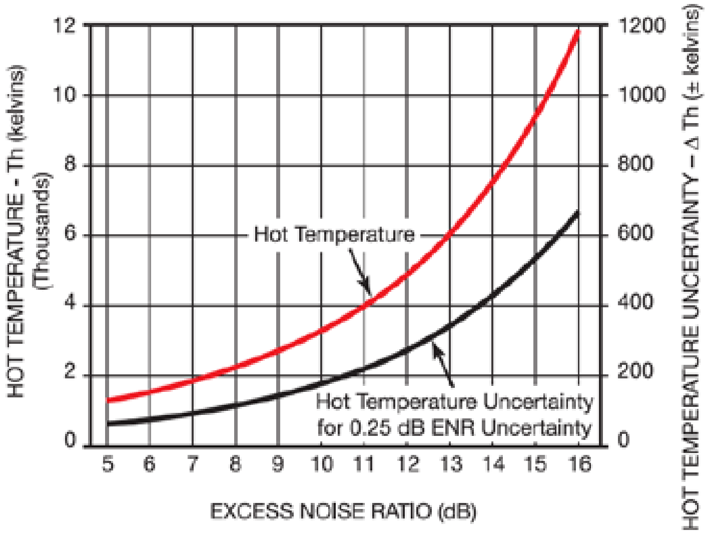

Figure 7. Plot of noise source hot temperature (Th) and uncertainty in Th versus ENR..

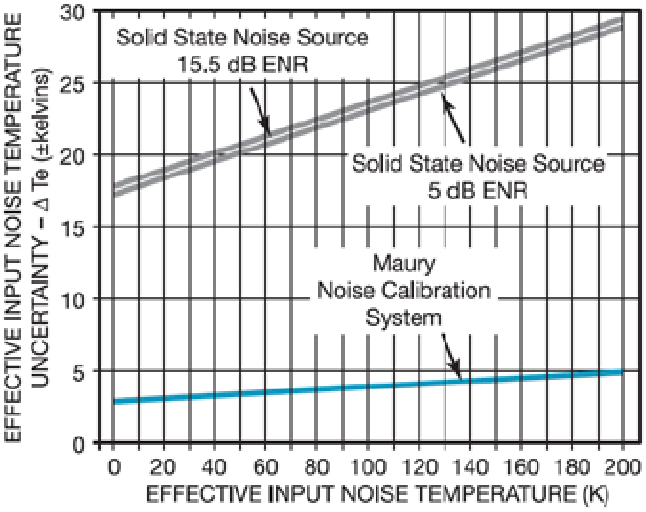

Figure 8. Plot of effective input noise temperature uncertainty for solid state sources and the NCS.

Figure 9 is the same information expressed as a percent of uncertainty. Both plots dramatically illustrate the very significant improvement in measurement uncertainty that can be gained by utilizing the NCS rather than a measurement system based on a solid state noise source.

The parameters for this analysis are typical of commercially available instrumentation. For reference these are shown in Table 2.

Noise Generator

	MAURY	SOLID STATE	SOLID STATE
PARAMETER	NCS	#1	#2
ENR (dB)	N/A	15.5	5.0
ΔENR (±dB)	N/A	0.25	0.25
Thot (K)	365	10,580	1,207
ΔThot (±K)	2	593	53
Tcold (K)	85	294*	294*
Δ Tcold (±K)	2	0.5	0.5

** Assumed ambient temperature.*

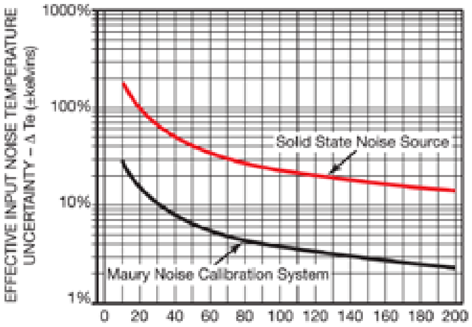

Figure 9. Plot of effective input noise temperature uncertainty (%) for solid state sources and the NCS.

Table 2. Uncertainty Analysis Parameters.

The Y-factor uncertainty used in these calculations is the linearity specification (including the guard band) of the Agilent 8970B: 0.005 dB/dB Y-factor.

ENR, Y-factor, and their uncertainties are normally expressed in dB. For reference Equation (8) relates hot temperature uncertainty to that of ENR in dB, and Equation (9) shows the relation between the fractional Y-factor uncertainty and that of Y-factor in dB.

$$\Delta \mathrm{Th} = \frac{290\ \mathrm{ENR}}{4.34}\ \Delta\, \mathrm{ENR\ (dB)} \qquad (8)$$

$$\frac{\Delta \mathrm{Y}}{\mathrm{Y}} = \frac{\Delta \mathrm{Y\ (dB)}}{4.34} \qquad (9)$$

Noise Generator Calibration

Thermal noise sources are used as noise standards throughout the world; in fact, the U.S. national coaxial standard is an LN_2 cooled load identical in concept to the cryogenic load used in the Maury NCS. Conceptual simplicity, accuracy, and use of the fundamental principle of noise generation make the Maury NCS an ideal noise standard for use in calibrating solid state noise generators.

The general principle used for such calibrations is a comparison noise measurement and is illustrated in the block diagram shown in Figure 10. The general procedure is to measure the noise performance of the comparison receiver using the noise standard, then repeat the measurement using the generator to be calibrated. The ENR of the latter can then be calculated using Equations (10) and (3).

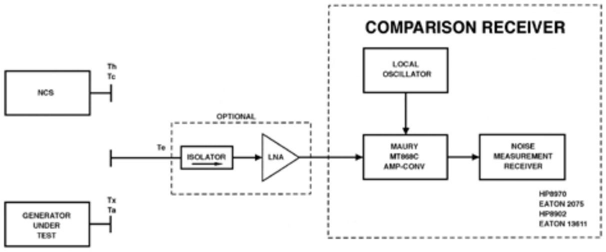

Figure 10. Typical set-up for calibration of solid state noise generators.

In practice, only the Y-factors are measured. If the switching between the hot and cold condition is done quickly – as is possible with the NCS – gain variations in the receiver are essentially eliminated as an error source. Equation (10) is derived by combining Equation (2b) for the two different noise sources.

Another similar technique in common use makes use of a reference noise generator to eliminate potential errors due to changes in the noise performance of the comparison radiometer during the measurement. Figure 11 illustrates the measurement set-up. The procedure consists of four Y-factor measurements:

- Using the noise standard (NCS)
- Using the reference with the standard connected.
- Using the unknown generator.
- Using the reference with the unknown connected.

$$\mathrm{Tx} = (\mathrm{Yx} - 1)\left[(\mathrm{Ta} - \mathrm{Tc}) + \left(\frac{\mathrm{Th} - \mathrm{Tc}}{\mathrm{Ys} - 1}\right)\right] + \mathrm{Ta} \qquad (10)$$

where, Tx = hot temperature of the noise source being calibrated in kelvins.
Th = hot temperature of the noise standard (NCS) in kelvins.
Tc = cold temperature of the noise standard (NCS) in kelvins.
Ta = ambient temperature in kelvins (assumes the DUT is a solid state source with ambient as the cold temperature).
Yx = Y-factor measured using the noise source being calibrated.
Ys = Y-factor measured using the noise source.

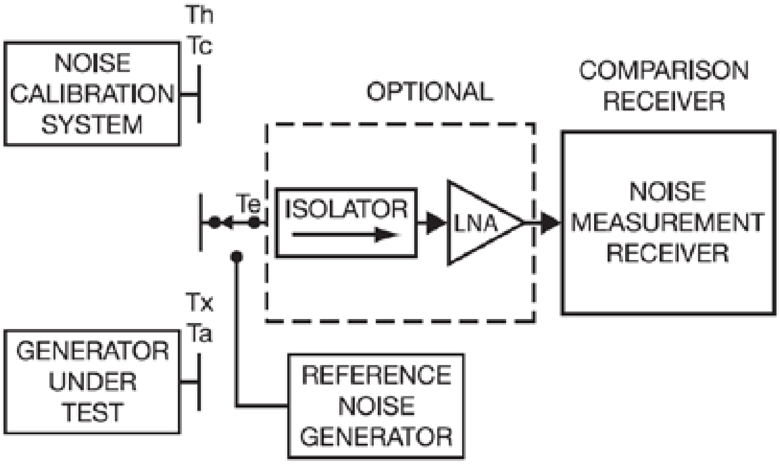

Figure 11. Set-up for calibration of solid state noise generators using a reference generator.

Earth Station Receiver Verification

The NCS is an ideal tool for measuring the noise performance of the low noise amplifiers (LNA) of an earth station receives. The calibrated switched output, remote LN_2 level sensing and fill system, helium pressure regulator, and remote hot load temperature sensing of the NCS now make it practical to monitor the noise performance of the off-line LNA of a redundant system at all times. If a problem is suspected, the LNAs are switched, and the LNA that had been on-line can be measured while the known, good LNA handles the traffic.

The measurement is the same as the standard effective input noise temperature measurement described earlier. Most satellite systems will include a separate downconverter and detector to facilitate maintenance measurements so as not to disturb normal traffic reception. Figure 12 is a simplified block diagram of a typical, dual redundant LNA set-up.

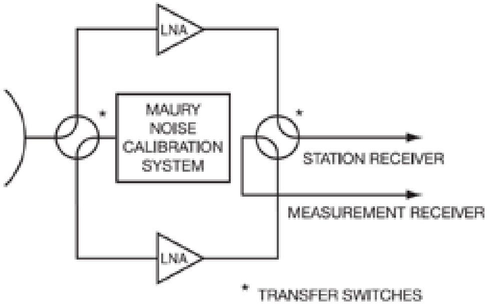

Figure 12. Typical earth station measurement set-up.

The measurement equation is shown in (11).

$$\mathrm{Tx} = \left(\frac{\mathrm{Yx}-1}{\mathrm{Yrx}-1}\right)\left(\frac{\mathrm{Yrs}-1}{\mathrm{Ys}-1}\right)\left[(\mathrm{Ta}-\mathrm{Tc})(\mathrm{Ys}-1) + (\mathrm{Th}-\mathrm{Tc})\right] + \mathrm{Ta} \qquad (11)$$

where, Yrs = Y-factor measured using the reference generator while the noise standard is connected to the input.
Yrx = Y-factor measured using the reference generator while the generator being calibrated is connected to the input.

All other quantities are as previously defined.

Summary

The Maury NCS is a highly accurate source of RF and mi-crowave noise that is used for precision measurements of noise performance factors (noise figure, effective input noise temperature, etc.) and as a noise standard for calibrating other noise generators. By providing:

- A calibrated means of switching between the hot and the cold noise source;
- An automatic nitrogen fill system; the NCS maintains the accuracy associated with true thermal noise sources while offering the convenience of an automatically switched noise source.

References

[1] Maury data sheet 4E-009.

[2] Maury data sheet 4E-003.

[3] Maury data sheet 4A-008.

[4] Maury data sheet 4C-008.

[5] Maury data sheet 4D-008.

[6] "IRE Standards on Electron Tubes: Definitions of Terms, 1957 (57 IRE 7.52)", Proc. IEEE, Vol. 45, July 1957, pp. 983-1010..

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[8] Haus, H.A., et. al., "Description of the Noise Performance of Amplifiers and Receiving Systems", Proc. IEEE, Vol. 51, March 1963, pp. 436-442.

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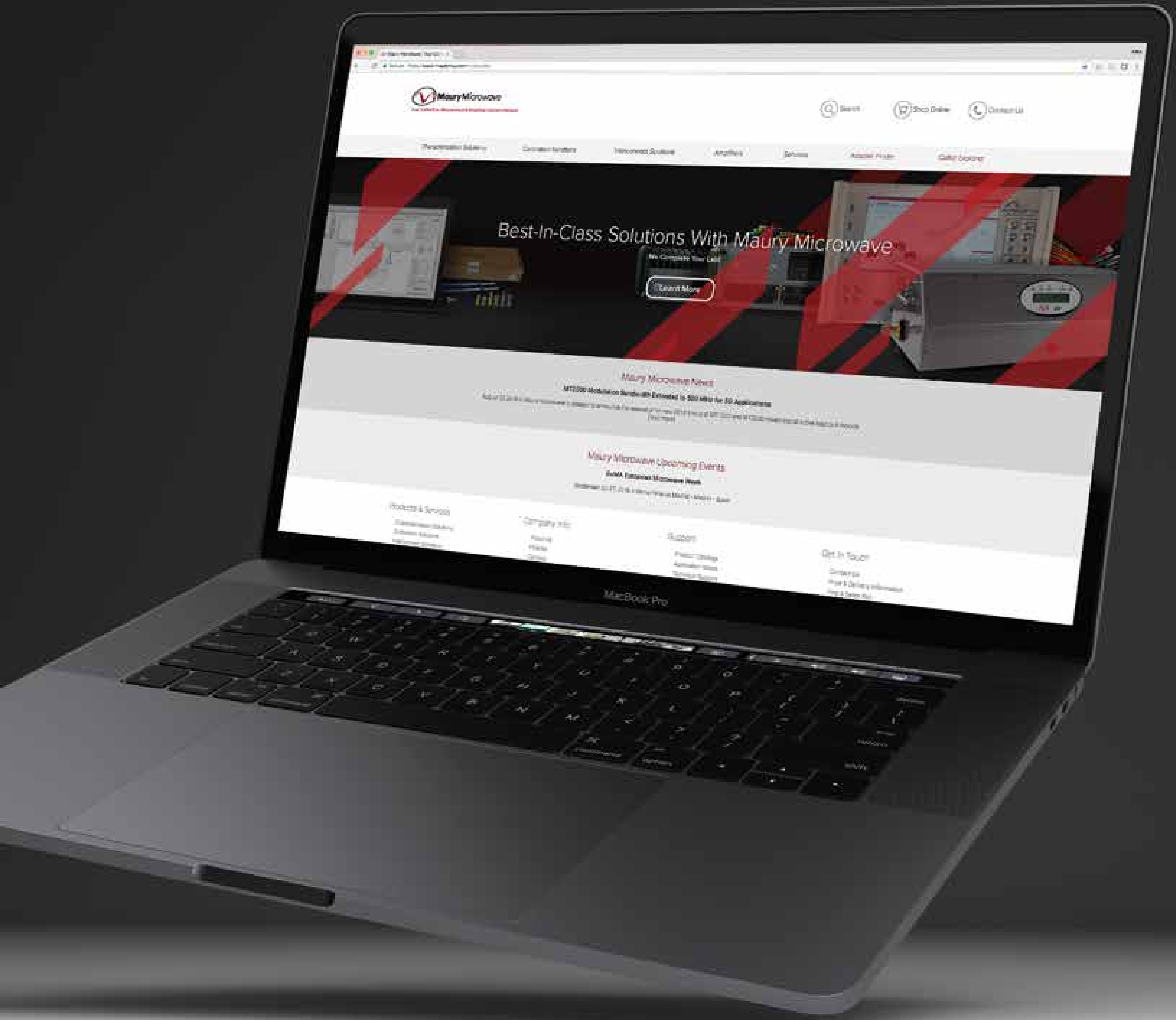

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