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High-Power and Wideband Radio-Frequency Dummy Load

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Abstract:

A novel approach to designing dummy loads has been proposed that simplifies practical construction and simultaneously offers a satisfactory impedance matching over a wide frequency band for high-power radio-frequency applications. The concept involves a gradual impedance transformation of the guided electromagnetic wave to the short circuit using optimally shaped plates and making use of common tubular non-inductive resistors. Design process involves parametric analysis in a full-wave numerical simulator.

INTRODUCTION

For adjusting transmitters at standard operational conditions without any spurious interference with other services, dummy (or phantom) loads are exploited. For lower powers, dimensions of dummy loads can be considerably smaller than wavelengths. The issue that emerges as the power rises is that the loads cannot be designed small enough to be considered as lumped elements and simultaneously to be able to absorb the output power of the transmitter. As the dummy loads have to become distributed elements devices, such an approach to their design has to be undertaken to ensure their proper behaviour in the given frequency range.

The concept of dummy loads is introduced in [2] and practically expanded in [1] and [3]. Nevertheless, the designs are confined only to professional applications due to their complicated fabrication involving precise rotational symmetric cuts.

A novel approach has been proposed to provide a mechanically uncomplicated and simultaneously electrically expedient solution to the issue. The design procedure is demonstrated on a dummy load designed for frequencies up to 432 MHz and power up to short-time 3 kW.

CONCEPT OF THE DUMMY LOAD

The lossy element able to dissipate heat of the transformed electromagnetic power is proportioned in such a way preventing it to be considered as a lumped element regarding wavelength. For optimal power absorption without reflections harming the power amplifiers, impedance matching has to be ensured. Transition from the transmission line to the resistor has to be taken into account.

An optimal dummy load should ensure a transformation of electromagnetic power into heat without reflections of electromagnetic waves back to the source. To provide that behaviour, there should not be any abrupt step in the impedance inside the dummy load. The power of the forward electromagnetic wave has to be gradually absorbed as the wave approaches the short circuit at the foot of the dummy load. A gradual change of the wave impedance can be provided by a gradual change of the dimension of the waveguide inside the dummy load. As the wave approaches the short circuit, the wave impedance declines and the power is depleted by a resistive material within the dummy load.

Sophisticated applications in the field of measurements rely on a strictly coaxial shape of the dummy loads as the transmission lines usually take the form of coaxial cables. The disadvantage is a complicated manufacturing, especially in the case of a single-piece production. Nevertheless, even a deviation from an ideally coaxial arrangement can provide a very promising behaviour.

An arrangement with two shaped plates and two parallel planar metal walls has been proposed to provide a gradual transition from coaxial line to stripline and simultaneously from particular line impedance to the short circuit. The guided transversal electromagnetic wave propagating along tubular non-inductive resistor transfers its power to the resistive surface of the resistor.

Selection of a particular curve for the dummy load can be carried out using numeric simulation for selected mathematical functions and their behaviours. Generally, an arbitrary monotone and asymptotic function can be chosen.

DESIGN PROCESS AND NUMERICAL SIMULATION

A dummy load has been proposed capable to dissipate constantly 1 kW of electromagnetic power and simultaneously to withstand short-term power burst of 3 kW in a frequency band from zero up to 432 MHz. A drawing describing the practical implementation of the dummy load is depicted in Fig. 1.

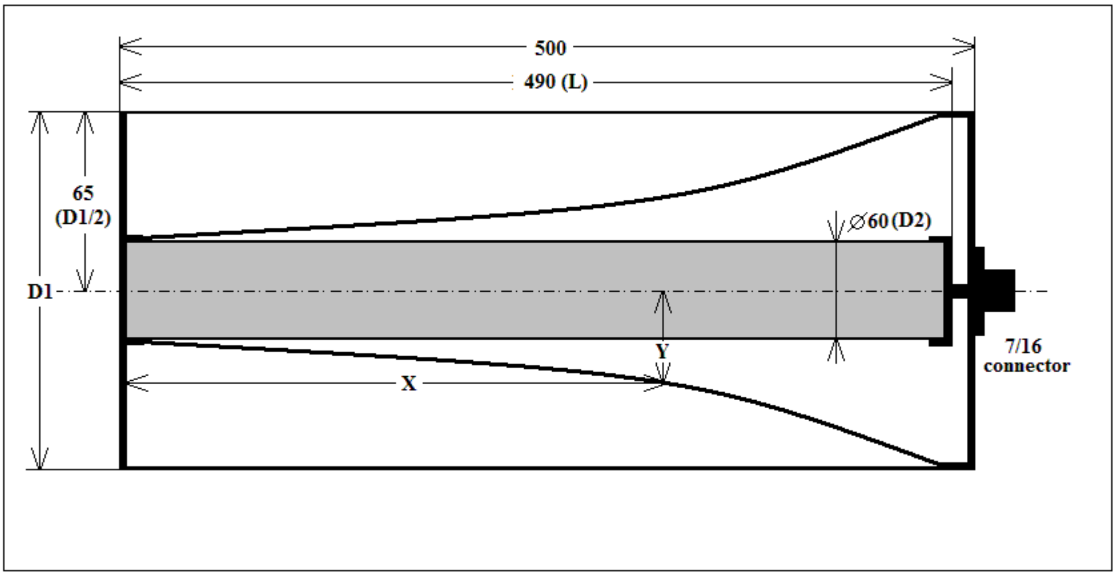


Fig. 1: Side view of the proposed dummy load including dimensions

For determining the shape of curved plates, a numerical model was established in CST Microwave Studio, a full-wave electromagnetic field simulator. As suitable mathematical functions, the exponential and generalized hyperbolic tangent were chosen.
The exponential function as

$$y = \frac{D_2}{2} \cdot \mathrm{e}^{\frac{\ln \frac{D_1}{D_2}}{L} \cdot x} = \frac{D_2}{2} \cdot \left(\frac{D_1}{D_2} \right)^{\frac{x}{L}} \qquad (1)$$

can be introduced, whereas the left expression was used for exponential cones in [1]. As is rewritten using the right expression of the equation, the base of the exponential is not the base of natural exponentials (Euler number), however it is a ratio of the dimensions of the dummy load.
Formula (1) can be generalized in such a way that it provides a possibility to choose whatever part of the behaviour of the function, to scale it, and to set the base of the exponential function, as can be seen in (2):

$$y = \frac{D_2}{2} + \left(\frac{D_1}{2} - \frac{D_2}{2} \right) \cdot \frac{a^{\left(\frac{x_2 - x_1}{L} \cdot x + x_1 \right)} - a^{x_1}}{a^{x_2} - a^{x_1}} \qquad (2)$$

An even more generalized form of expression can be achieved if the exponential function is replaced with a general function as in (3). In this respect, a generalized hyperbolic tangent function was implemented where the base of the exponentials is a general real number, not only the base of natural logarithms.
A parametric analysis was carried out and impedance matching observed to identify an optimal combination of parameters, which can be practically set. The models as well as the behaviours of the standing wave ratio can be seen in Fig. 2 and Fig. 3. The set of curves is an example for various values of the bases a and interval boundaries x_1 and x_2. Optimal values were found (those providing evenly low reflexions) and practically realized in the prototype.
Another output from simulations is a depiction of the power density distribution which can be observed in Fig. 4 as a relative chart using the colour scale. This type of information provides useful information to designing of an optimal cooling for the dummy load.

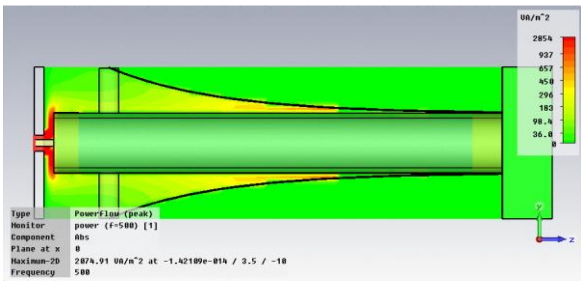
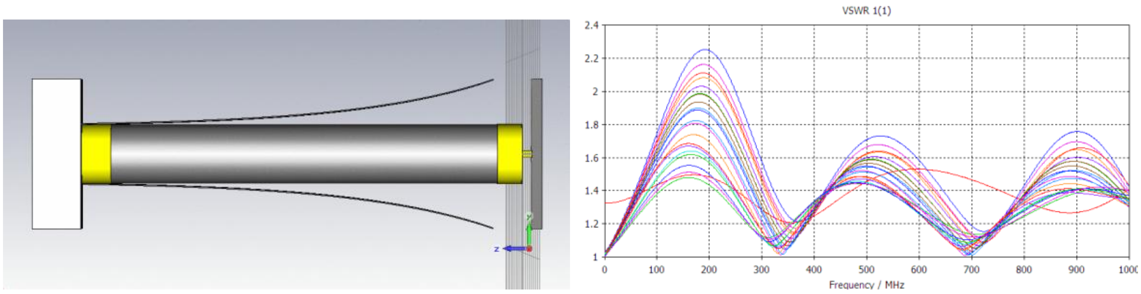


Fig. 4: Power density distribution within the proposed dummy load relatively demonstrated using colour scale

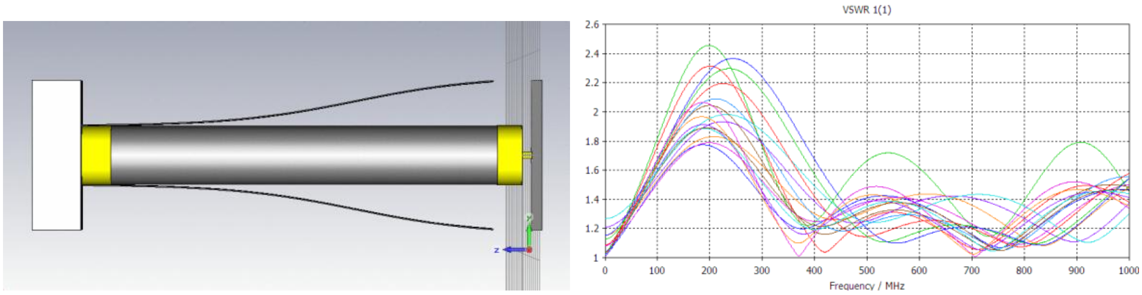
A prototype was realized as can be seen in Fig. 5, 6 a 7 using the shape of the curved plates found during the simulation.

$$y = \frac{D_2}{2} + \left(\frac{D_1}{2} - \frac{D_2}{2} \right) \cdot \frac{\mathrm{f}\left(\frac{x_2 - x_1}{L} \cdot x + x_1 \right) - \mathrm{f}\left(x_1 \right)}{\mathrm{f}\left(x_2 \right) - \mathrm{f}\left(x_1 \right)} \qquad (3)$$



a) b)

Fig. 2: a) Side view of the proposed dummy load with exponential shape of the matching plates; b) demonstrative example of the voltage standing wave ratio dependence on the function parameters determining the shape of the matching plates for the case of exponential function



a) b)

Fig. 3: a) Side view of the proposed dummy load with generalized hyperbolic tangential shape of the matching plates; b) demonstrative example of the voltage standing wave ratio dependence on the function parameters determining the shape of the matching plates for the case of generalized hyperbolic tangent function

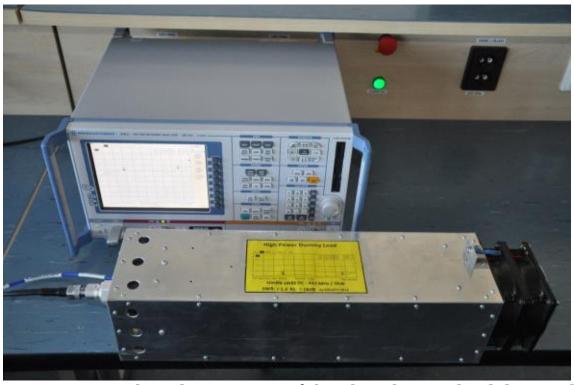


Fig. 5: Final implementation of the 3kW dummy load designed for frequencies up to 432 MHz during measurement

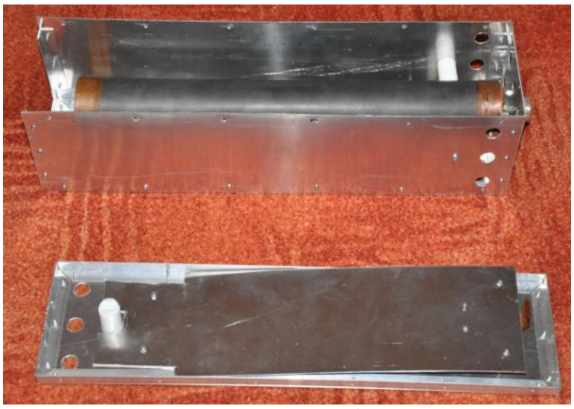


Fig. 6: Mechanical implementation of the 3kW dummy load prototype

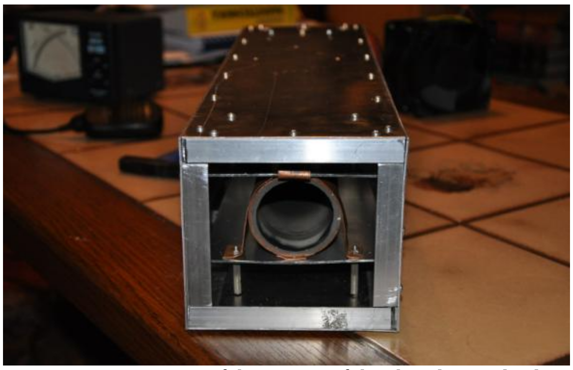


Fig. 7: Termination of the resistor of the 3kW dummy load

MEASUREMENTS AND RESULTS

Using the vector analyzer, real properties of the dummy load were evaluated. Voltage standing wave ratio, return loss and impedance were measured to be compared with the data from numerical simulation.

Fig. 8 shows the dependence of the negative values of reflection loss for the dummy load. The curve in red depicts data from the simulation whereas the green curve is from the measurement. The blue and cyan curves show the behaviour of the dummy load as voltage standing wave ratio for the prototype and for the model respectively.

The impedance was measured and together with the simulated impedance depicted in the Smith chart in Fig. 9. Here, the red curve depicts the simulated data whereas the measured data are in green.

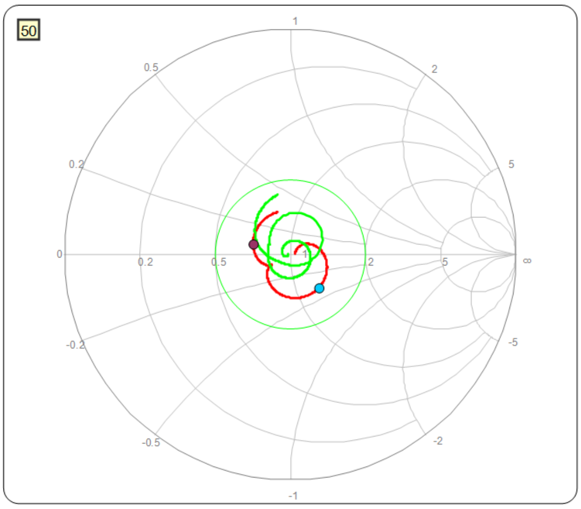


Fig. 9: Smith chart for the proposed dummy load in the frequency range from zero to 500 MHz. The red curve represents the simulation providing best results, the green one comes from the measurement

DISCUSSION AND CONCLUSION

When evaluating the simulated and measured data, one can see that in the frequency range up to 300 MHz, the real behaviour surpasses the expectation from the simulation. It can be seen that reflexion loss as well as voltage standing wave ratio are better for the prototype.

For the frequencies beyond 300 MHz, there can be seen a ripple in the behaviour of the characteristics. The frequency of approximately 370 MHz, at which this effect occurs, corresponds to the wavelength equal to twice the length of the proposed dummy load, so it can be dedicated to slight resonant behaviour of the chassis of the dummy load that was not fully involved in the numerical model. This behaviour can be seen well in the Smith chart as the loop about the centre of the complex plane of the reflexion coefficient.

A dummy load was designed and implemented utilizing a novel approach based on gradual impedance matching, which can manage without sophisticated manufacturing techniques. The design process involves parametric optimization utilizing full-wave numerical simulation to find optimal parameters of mathematical functions that determine the shape of metal plates embedded within the dummy load.

The designed dummy load was prototyped and measured. The measured data correspond to the data from numerical simulation and represent a dummy load with a voltage standing wave ratio of 1.5 and better, which is a value guaranteeing an exploitation of the dummy load in moderately demanding applications.

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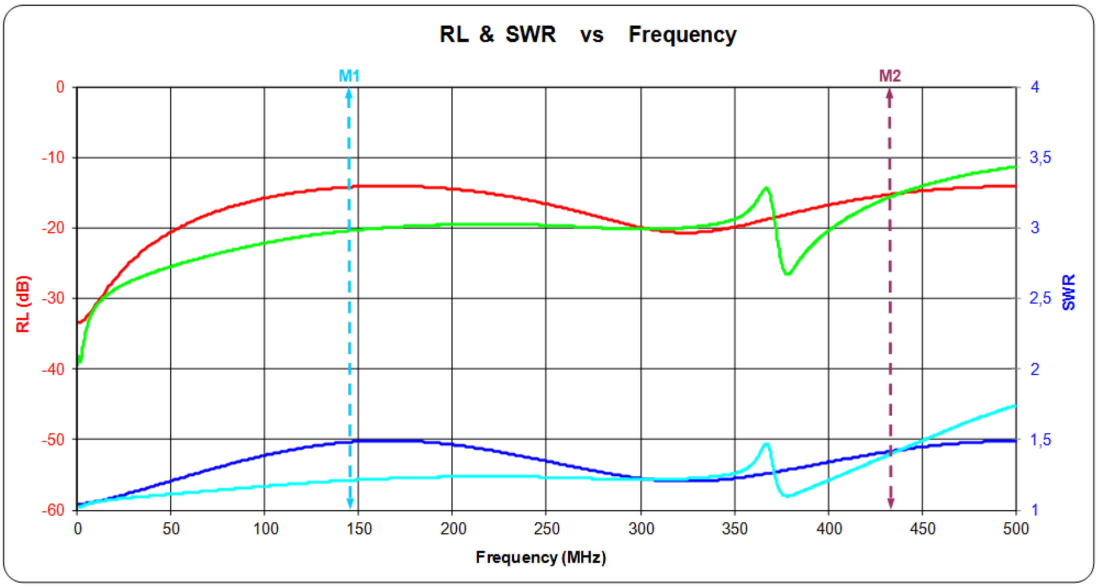

Fig. 8: Frequency dependence of negative return loss (red and green curve) and voltage standing wave ratio (blue and cyan curve) for the proposed dummy load. The red and blue curves come from the simulation, the green and cyan ones from the measurement