A Rugged Microstrip Tapered Balun Printed Dipole Reference for SAR System Verification

Miguel Richard, Michael Kanda, Carlo DiNallo and C. K. Chou
Motorola Florida Research Labs, Corporate EME Research Lab, Ft. Lauderdale, FL, 33324, U.S.A.

Abstract – **Strict regulatory requirements for SAR compliance testing around the world has increased the need for accurate and precise testing methodologies. Such requirements are also required conform to quality management accreditation guidelines such as ISO/IEC 17025. Equipment calibration, environmental conditions, tissue simulating solution characteristics, measurement setup all contribute to the accuracy of a SAR measurement. System verification is one way to help assure accurate and precise measurements by verifying the measurement repeatability of a reference on a daily basis. A tuned ½ wave dipole is recommended by the standards for this standards. This study proposes a printed dipole as a reference for daily system verification that meets all requirements of IEEE 1528, FCC Supplement C, and CENELEC EN 50361. The printed design adds the benefits of being more cost effective, robust, and easier to position for testing.**

I. Introduction

The *specific absorption rate* (SAR) is the dosimetric quantity defined by the most widely adopted scientifically-based safety standards for the human exposure to RF energy [1]-[2]. The Federal Communication Commission (FCC) has recently adopted [10] incorporating most of the recommendations of the IEEE draft standard [7], whereas the CENELEC standard has been ratified in July 2001 and must be adopted by all the European Community nations by July of 2002. Motorola has led the development of SAR measurement techniques and the related equipment for the last twenty years [3]-[6]. Likewise, Motorola has played a crucial role in harmonizing the SAR compliance testing standards development worldwide, involving the IEEE, the International Electrotechnical Commission (IEC), and the European CENELEC [7]-[9].

The strict regulatory requirements for SAR compliance testing around the world have increased the need for accurate and precise testing methodologies. Such requirements are also required conform to quality management accreditation guidelines such as ISO/IEC 17025. Equipment calibration, environmental conditions, tissue simulating solution characteristics, measurement setup all contribute to the accuracy of a SAR measurement. Though rigorous steps are taken to assure the previously mentioned conditions are within strict specifications, system verification is one way to help assure that total system is operating within specification. System verification promotes accurate and precise measurements by verifying the measurement repeatability of a reference source on a daily basis. A conventional tuned ½ wave dipole is recommended by the standards for this reference. This study proposes a printed dipole as a reference for daily system verification.

II. Purpose

The purpose of this paper is to propose a printed dipole for use as a reference for the daily system verification. This study focuses on 835, 900 and 1800 MHz. The dipole needs to meet all requirements of the IEEE 1528, FCC Supplement C, and CENELEC EN 50361 standards. The added benefits of a printed dipole are that it is more cost effective, robust, and easier to position for testing. The cost is especially important because the standards require dipoles that meet the requirements for many different tissue simulating liquids and frequencies. A typical SAR measurement setup may require 8 – 10 different dipoles.

III. Requirements

System verification is the daily check of the entire SAR measurement system to insure proper operation. This is done by measuring the SAR of a reference antenna in the appropriate mixture corresponding to the device that is to be tested during that day. Setup of the system verification is shown in Figure 1 and uses a flat phantom and a dipole antenna set at a specified distance which can be determined by a lossless spacer.

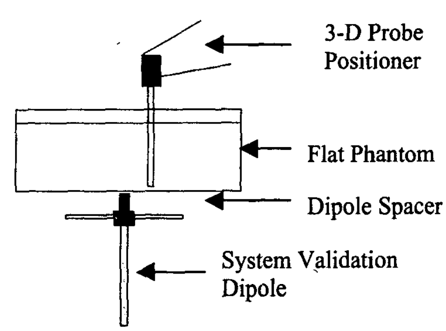

Fig. 1. System Verification Setup

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The specific phantom, liquid, power, and dipole requirements are found in each standard. The separation distance is 15.0 mm, from the tissue medium surface to the dipole axis at the feed-point location. The dipole requirements are fairly well harmonized between the standards and follow:

1. The distance between the liquid surface and dipole center is specified within +/- 0.2 mm for each test frequency (+/- 0.1mm for CENELEC).
2. The dipole return loss is less than –20 dB at the test frequency to reduce the uncertainty in the power rating.
3. The dipole arms are parallel to the flat phantom surface with a precision better than 2 degrees.

FCC Supplement C adds the following requirements:

1. The current distribution along the two arms of the dipole should be matched within 5% of each other.
2. The thickness of the dipole must not exceed the separation distance between the outer surfaces of the dipole and the phantom shell by 20%.

A printed antenna has the advantage of being robust, there are no fewer risks of bent dipole arms or broken solder joints. The spacer can also easily be integrated into the design, leading to easier positioning. Calibrated commercial dipoles can cost as much as $2,500. Even if the cost of calibration is subtracted, the printed dipole will only cost a fraction the amount. The printed design is also easier to modify for different frequencies and mediums.

IV. Design Considerations

There have been many different designs for printed dipole antennas and baluns, including coplanar strip dipoles fed by a coplanar waveguide [11], a stripline balun [12], and a printed quasi-Yagi antenna proposed in [13]. The frequency independent balun design picked for this study was designed by M. Gans is found in [14], and is an adaptation of the work found in [15]. The design is shown in Figure 2.

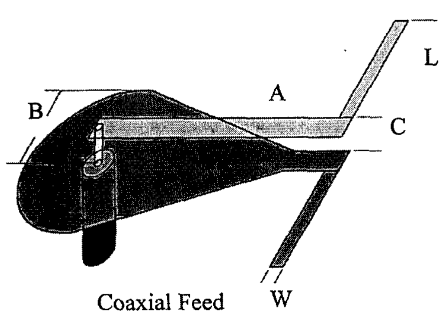

Fig. 2. Printed Dipole Design

A = Width of the Microstrip Line
B = Radius of Microstrip Ground
C = Thick of Substrate
L = Dipole Arm Length
W = Dipole Arm Width

The balun was designed to meet the criteria B>>A>>C mentioned in the report as best as possible.

The frequency independence of the balun is especially attractive because a single balun design can be used for many different antennas, if the printed dipole arms are trimmed to the proper length.

V. Experimental Results

A. Return Loss

The antenna was first demonstrated on a Teflon substrate. With this design, good balance was achieved but the pliability of the material made it difficult to position. A more rigid halogen-free material produced by Hitachi was chosen and the antenna shown in Figure 3 was designed. The Hitachi substrate is low cost and has permittivity = 4.5 at 800 MHz, similar to FR-4 (permittivity = 4.3) but a lower loss tangent at 0.008 (compared to 0.022 for FR-4). The Hitachi material also has better stability in permittivity and loss tangent across temperature than the FR-4.

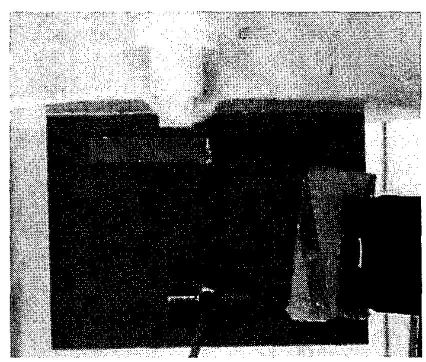

Fig. 3. Realized Printed Dipole

The initial design of the antenna had dipole arms 3 mm in width. This design didn't have the return loss required by the standards as shown by the "Hit 3mm" line in Figure 4.

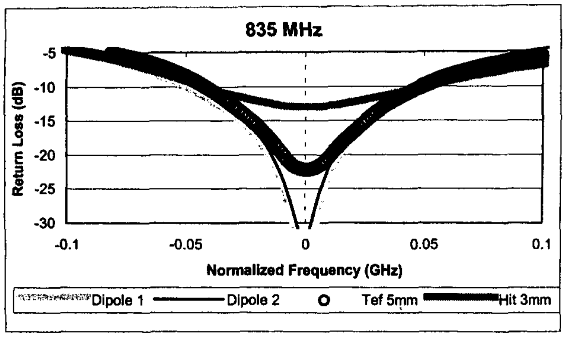

Fig. 4. Dipole Return Loss Comparison

The impedance of the printed dipole with 3 mm arms was determined to be 32.7 + j7.1 Ω. To improve the return loss, we looked to increase the resistance closer to 50Ω. Approximating the printed dipole with the results found in Figure 9.8 of [17], showing the input resistance and reactance of wire dipoles, the input impedance of the dipole would increase by increasing the electrical length of the dipole. Unfortunately, this simultaneously increases the reactance but the reactance can be reduced by increasing the ratio of the dipole length to the arm width. This approach was taken with our printed dipole by widening the arms and tuning to the proper frequency. The improvement can be seen in Figure [5].

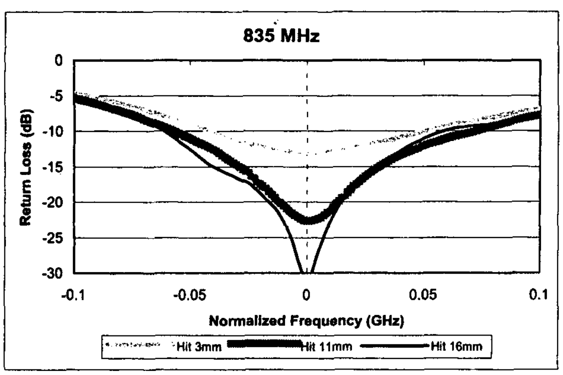

Fig. 5. Dipole Arm Width Comparison

At 16 mm, the impedance was seen to be 54.5 + j0.9 Ω and the return loss improved significantly as seen in the third column of the following table.

TABLE I
BANDWIDTH (MHZ) AND RETURN LOSS (DB)
COMPARISION OF DIFFERENT DIPOLES AND VARYING ARM WIDTHS OF THE PRINTED DIPOLE

835 MHz	20 dB BW	10 dB BW	RL (dB)
Dipole 1	30	100	-63.4
Dipole 2	26.25	87.5	-32.6
Teflon 5mm	20	90	-22.2
Hitachi 3mm	0	91.25	-13.0
Hitachi 11 mm	25	130	-22.7
Hitachi 16 mm	30	120	-31.4

The 20 dB Bandwidth of the printed dipole is also similar to the conventional dipoles with an actual increase in 10dB bandwidth. The bandwidths may be improved with further optimization.

For a 900 MHz dipole, the dipole arm length and width were incrementally changed so the change in impedance could be determined. As the width (w) of the arm was increased, the length (l) of the dipole was also increased to provide proper tuning. The results are shown in Figure 6.

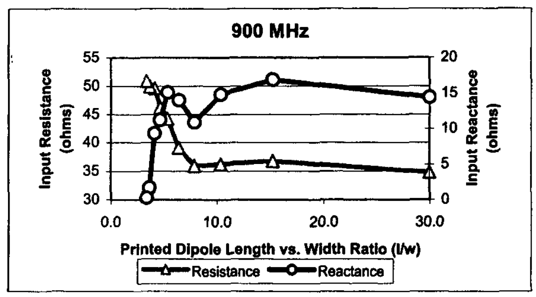

Fig. 6. 900 MHz Dipole Impedance

Another method explored to improve the return loss of the antenna was using a single section ¼ λ Transformer placed in the microstrip line where the antenna impedance was seen to be purely real. For a dipole with 3-mm arms, this method produced a return loss of –65 dB and a –20 dB bandwidth of 28.5 MHz. The advantage is that this matching method allows thin dipole arms to meet the FCC Supplement C requirement limiting the thickness of the dipole arms stated above. The disadvantage is that the transformer eliminates the broadband nature of the balun.

B. Balance

The balance of the antenna was checked by measuring the point SAR along the axis of the dipole arms in a filled flat phantom. The results can be seen in Figure 6. (The solid lines show measurement along one arm and the discrete markers show the superimposed measurement from the other arm. Comparisons of the equivalent E-fields between the arms of all three dipoles have differences less than 3%.

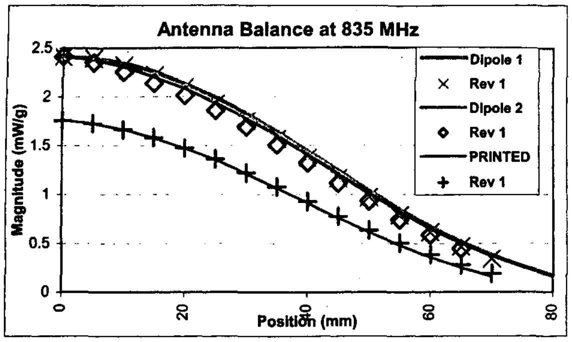

Fig. 7. Antenna Balance Comparison

V. CONCLUSION

This study showed that a printed dipole can be designed to have performance characteristics comparible to typical system verification dipoles and meets the requirements of the standards. The printed dipoles have added advantages of being low cost, robust, and easily tunable for use with other frequencies or tissue simulating tissue liquids.

ACKNOWLEDGEMENT

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