

A Novel RF Coupler for SMART Utility Meter Remote Antenna Applications

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In response to climate change nations across the globe have recognized the need for reducing their carbon emissions, and energy consumption.

Governments in the USA, Canada, China and Europe have jumped on the SMART Grid technology band-wagon, as a means of stimulating their depressed economies with green-tech jobs, by passing significant stimulus packages to subsidize utilities that are installing Wireless-enabled Automated Metering Infrastructure (AMI) and SMART Utility Meters⁽¹⁾.

As deployment rates rise, into the tens of millions of units per year, it is now estimated that 5%-10% of SMART utility meters, with internal antennas, cannot be read remotely due to insufficient local wireless coverage, underground installations or their vandal proof metal enclosures.

Ironically in these cases utilities are forced to either continue reading the SMART meter manually, that defeats their ROI and carbon emission objectives, or they can install an external remotely located antenna to increase the radio signal strength at the meter site and enable remote network connectivity.

When a decision to use a remote external antenna is made by an installer, careful consideration must be given to electrical safety of the installation. In low-cost residential meter installations, often times the power supply to the radio modem, sometimes called a Network Interface Card (NIC) is not isolated, from high AC supply voltage. This installation scenario, for an external antenna, dictates the use of a device that can safely isolate the NIC radio frequency (RF) connection to the remote external antenna while enabling a low-loss RF connection with a high degree of RF coupling for the external antenna.

In this paper the authors investigate and present a patent pending novel micro-strip coupler structure that exhibits very low RF insertion loss (high coupling) while insuring high electrical isolation (>10kV) between the wireless Network Interface Card (NIC) RF connection and the external antenna.

The problem: Electric utilities desire a safe and efficient means (low loss) of routing an RF cable, from the NIC inside the utility meter to an external remote antenna, to boost the wireless signal at certain installation sites. Traditional means of RF coupling, such as an external flex antenna placed on the outside of the meter cover to loosely couple to the internal antenna, are 'make-shift' in nature and highly inefficient resulting in typical coupling losses of -5dB to -6dB. Other proprietary forms of power isolator, that have been developed, use lumped element components (such as inductors and capacitors) that result in narrow band solutions that have inherent reliability issues.

The solution: A novel ultra wide-band RF coupler located integral to the cover of the utility meter (pictured in Fig 1.1) or alternately a stand-alone RF component coupler located within the confines of the utility meter housing (pictured in Fig 1.0).



Fig 1.0 Photo of RF Coupler Installed in GE Kv2C Meter (patent pending)

What about safety? In addition to withstanding >10kV surges, via the power line, the RF coupler was designed to meet industry guidelines for creepage⁽²⁾ and clearance without comprising the RF performance.

The key RF Coupler features and benefits are:

- Ultra-low RF loss (-0.2dB typical) for efficient RF coupling which results in improved network connectivity.
- Very high electrical isolation (>10kV) for safety compliance and personnel protection.



Fig 1.1 Photo of RF Coupler (prototype)
Meter Cover Mounted version on
Landis & Gyr Focus AX Meter

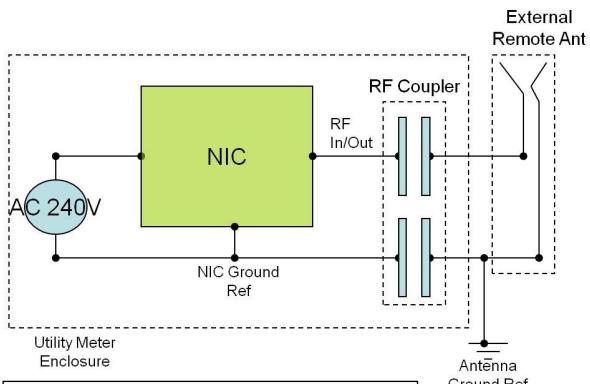


Fig 2.0 RF Coupler Schematic
External Antenna Application

Figure 2.0 shows the schematic of the RF coupler in the intended utility meter application illustrated in Fig 1.0. Here the RF Coupler resides within the confines of the meter enclosure effectively electrically isolating the common (high potential) power supply/RF ground and the RF signal path. Without the blocking feature of the RF coupler there exists the potential for the external antenna metalwork to sit at a high level risking electric shock to personnel touching external metalwork at the installation site.

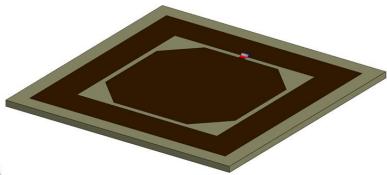


Fig 3.0 RF Coupler CAD model
implemented for EMSS EM simulation

RF Coupler Structure and Performance Attributes

Though the initial prototype was a handmade design whose performance attributes like the insertion loss were analyzed with RF measurements, more rigorous and comprehensive EM analysis with a similar approach is expensive or impossible and therefore the commercial 3D EM simulation software FEKO⁽³⁾ was used for the full-wave analysis of the coupler. Figure 3.0 shows the computer model used, in the FEKO EM software, to simulate the performance of the structure in the following illustrations.

The basic structure consists of two conductive center patches placed on top of each other on opposite sides of a dielectric printed circuit board (PCB), with an FR4 dielectric ($\epsilon_r \sim 4.1$), and dimensioned to be 50Ohms at the desired operating frequency. The patches are used to couple the RF signal path. The two outer conductor rings, formed around the patches on both sides of the PCB, are used to couple the ground plane. There is no physical connection between the conductors located on the top side and the conductors located on the bottom side. Various FR4 PCB thicknesses were evaluated. The dimensions of the structure take into account necessary creepage⁽²⁾ and clearance⁽²⁾ distances in order to achieve >10kV electrical isolation. Electrical isolation in excess of 20kV, without damage, has been demonstrated by actual measurements, the results are not shown here as they are outside the scope of this paper.

The 'cropped corner' features of the patch structure are there intentionally by design and serve to enhance and optimize the impedance match of the structure. The effects of the cropped corner, has been modeled, but the results are outside the scope of the paper so have not been presented here. It can be seen, by comparing Figure 4.0 and 4.1, that the simulated CAD model S21/isolation closely tracks that of the measured results for the prototype RF coupler. Similar results between simulated and measured VSWR were observed. The results have been excluded from this paper for brevity but demonstrated very broad-band and excellent performance (<1.3:1) from 500MHz through 2.5GHz, with the exception of a resonance, which is also present in the S21 response shown in Fig 4.1.

The present RF Coupler design has been shown to operate, with very low loss and excellent match, over nine-bands including; ISM 900MHz and ISM 2.45GHz (both suitable for mesh networked and Home Area Network applications) as well as public cellular bands (850/900/1800/1900/2100MHz), GPS L1 (1575MHz), and Iridium Satellite bands (1616MHz-1626MHz).

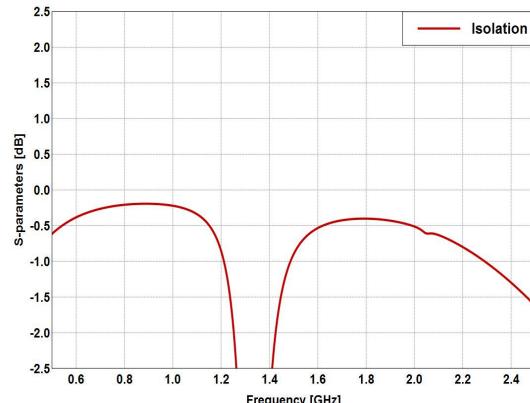


Fig 4.0 Simulated (S21) Insertion loss of RF Coupler structure (60mil PCB thickness)

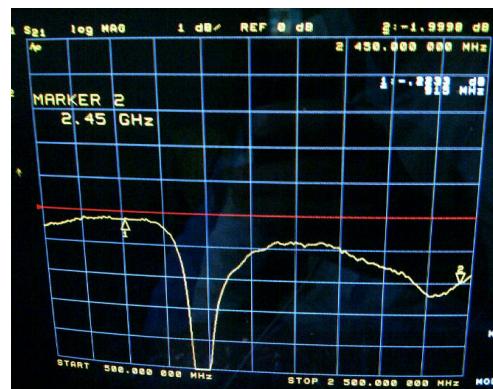


Fig 4.1 Measured (S21) Insertion loss of RF Coupler structure (60mil PCB thickness)

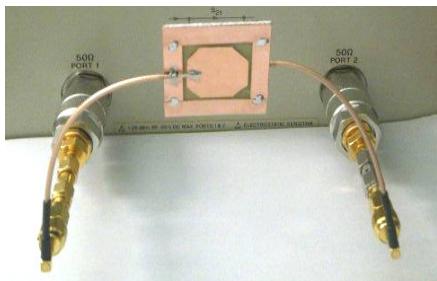


Fig 3.1 Prototype RF Coupler Structure Test Set Up on Vector Network Analyzer.

By scaling the dimensions of the center patch and outer ring the RF Coupler can be made to operate at other frequencies beyond those that are presented in this paper.

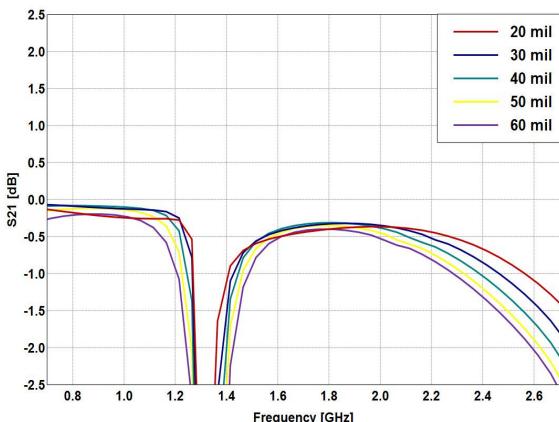


Fig 4.2 Simulated Insertion Loss (S21) of RF Coupler structure with varying PCB thickness

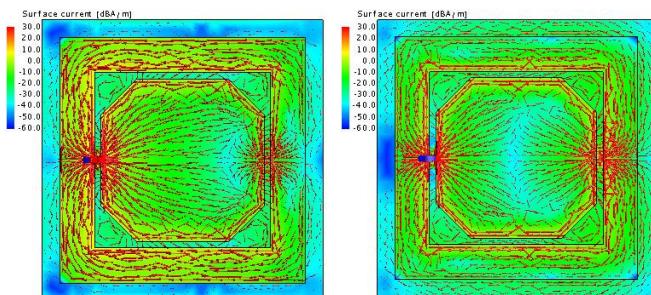


Fig 5.0 Comparison of Simulated currents flowing in top and bottom conducting surfaces of structure @915MHz.

Fig 5.0 shows the direction of conducted current flow on the surface of the structure at 915MHz. The current is increased where the concentration of arrows is denser. Also the green coloration are areas that represent a tighter coupling between the patch and ring pairs. Similar results were observed at 2.45GHz but these have been omitted for brevity.

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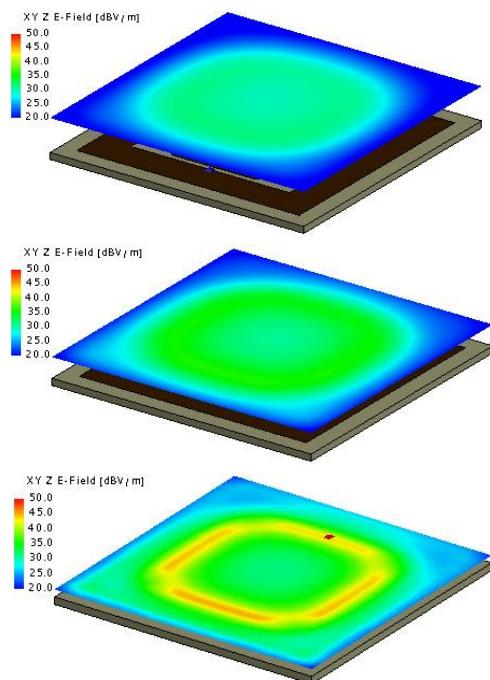


Fig 6.0 Comparison of near field surface currents at progressively larger stand-off distances above the conductor surface, (1mm, 3mm & 5mm)

Fig 6.0 shows the near field currents on the surface of the RF coupler structure at varying stand-off distances from the surface. This demonstrates that the structure is very tightly coupled and has good immunity to radiated emissions, beyond a few millimeters from the surface of the device. This is an important RF property to help prevent unwanted or stray RF signals from inadvertently coupling into the RF system via this structure.

A Far field analysis was simulated (Fig 7.0) with the EMSS EM software. The results shown here validate that the coupler is a poor antenna/radiator (-30dBi peak radiation) by-design.

Conclusions, Ramifications and Further Work

The authors have shown through EM CAD simulation, using EMSS USA Inc. FEKO EM Software, as well as RF measurements of this novel RF coupler structure, that a low loss highly-coupled microstrip structure can be designed to produce a device capable of high amounts of electrical isolation (>21kV) while allowing a low loss RF path (<0.2dB) through the structure with a good match presented to the RF input and output (~ 50 Ohms) at radio frequencies. The example illustrated operates as a Nona band RF coupler (nine bands). The high band performance can be improved with a thinner dielectric PCB, as shown in Fig 4.2, or may be made to operate at higher or lower frequencies simply by re-scaling the structure dimensions for operation at the desired frequency.

Modification of the dielectric insulator from FR4 to higher dielectric materials, such as quartz or ceramic, are expected to yield a physically smaller component with equal or better RF performance than the prototype model presented here and arguably better electrical isolation.

As a result of this novel structure, electric utilities, and electric meter manufacturers, now have a means of safely connecting remote external antennas to their NIC within the utility electric meter while enhancing the radio system efficiency and RF performance compared with inefficient traditional means of coupling to the internal antenna in the meter.

Intellectual Property Rights Assertion/Acknowledgement

The RF Coupler presented in this published work is patent pending with the US PTO. All intellectual property rights are reserved by the owners (RF Savvy LLC and AMC USA Inc.) This work may not be used, copied, distributed or published in whole or in part without the explicit written permission of Alpha Micro Components USA Inc.

Notwithstanding these IP rights, the owners acknowledge and would like to thank EMSS USA Inc for their applications engineering support/analysis work and for their participation in this publication.

1. American Recovery Reinvestment Act (ARRA) Feb 17th 2009
<http://www.recovery.gov/>
2. See www.creepage.com for definitions
3. www.feko.info

ABOUT THE AUTHORS:

Norman Smith is President and CEO of Alpha Micro Components USA Inc. He is a creative entrepreneur with a track record for RF innovation in the SMART Meter market. He is a successful businessman with over 25 years experience in the Wireless industry for companies that include; Nokia, GEC-Marconi, Hewlett Packard, Agilent Technologies, Symmetricom and his own successful start-up RF Savvy LLC. Norman obtained his Bachelor's degree in Electrical and Electronics Engineering from the University of Hertfordshire (England) and also holds an OND and HNC in Electronics and Telecommunications Engineering. He has spent the last 10 years successfully innovating embedded antennas and RF components for electric utility meters that have been used in; Landis & Gyr, GE, Itron, Elster Electric and other automated meter reader solutions. Norman can be reached at norman.smith@alphamicro.net.



About AMC USA Inc.

Founded in Jupiter Florida in 2000, Alpha Micro USA Inc. is a successful independent specialist franchised distributor servicing the Machine to Machine (M2M), telematics, medical, energy monitoring, security and automotive sectors with components from world-leading manufacturers. Its franchised product lines include GlobalTop Technology, Maxtena Inc, Yokowa, Lantronix and the company's own 'AMC' and 'RF Savvy' range. Like its parent company, Alpha Micro Components Ltd, in the UK, Alpha Micro USA Inc has built an enviable reputation offering excellent customer service and innovative products to its customers. Newly formed as Alpha Micro Wireless the company brings together over 40 years of combined industry expertise in tailoring and distributing cellular/GPS/Wi-Fi/Bluetooth & ISM band wireless technologies coupled with synergistic patent pending as well as COTS embedded antenna designs for a rich and unique value proposition to the M2M, Telematics, Military and SMART Meter Wireless markets. For further information, please visit www.alphamicrowireless.com

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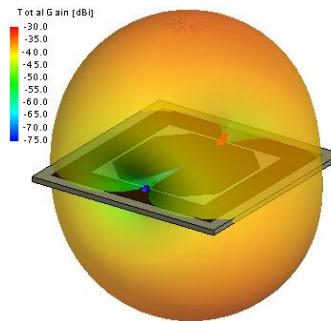


Fig 7.0 Far-field analysis @915MHz- shows the RF Coupler to be a poor radiator by design.

ABOUT THE AUTHORS:

Gopinath Gampala is an experienced Application Engineer with EM Software & Systems (USA) Inc. He has experience working in the fields of passive microwave components, metamaterials/high impedance surfaces and electrically small antennas. He received his Bachelor's degree in Electronics and Communications Engineering from Jawaharlal Nehru Technological University, Hyderabad, India in 2005 and his master's degree in Electrical Engineering from the University of Mississippi, USA, in 2007. He then joined EM Software & Systems (USA), Inc. in 2008, where he is currently working as an application engineer. Gopinath can be reached at gopi@emssusa.com



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Dr. Reddy received B. Tech. Degree in Electronics and Communications Engineering from Regional Engineering College, Warangal, India in 1983. He received Ph.D. degree in Electrical Engineering from Indian Institute of Technology, Kharagpur, India, in 1988. From 1987 to 1991, he worked at SAMEER (India). In 1991, he was awarded NSERC Visiting Fellowship to conduct research at Communications Research Center, Ottawa, Canada. Later in 1993, he was awarded a National Research Council (USA)'s Research Associateship to conduct research in computational electromagnetics at NASA Langley Research Center, Hampton, Virginia. Dr. Reddy worked as a Research Professor at Hampton University from 1995 to 2000. During this time, he developed various FEM codes for electromagnetics. Particularly development of his hybrid Finite Element Method/Method of Moments/Geometrical Theory of Diffraction code for cavity backed aperture antenna analysis received Certificate of Recognition from NASA.

Dr. Reddy is a Senior Member of IEEE and also a Senior Member of Antenna Measurement Techniques Association (AMTA). Dr. Reddy serves as a member of IEEE MTT Society Technical Committee TC-24 (RFID Technologies). He is elected as Fellow of the Applied Computational Electromagnetic Society (ACES) in 2012 and served as a member of Board of Directors from 2006 to 2012. He published 35 journal papers, 54 conference papers and 17 NASA Technical Reports to date. Dr. Reddy was the General Chair of ACES 2011 Conference held in Williamsburg, VA during March 2011. He is also co-General Chair for ACES 2013 to be held in Monterey, CA during March 2013. Dr. Reddy can be reached at cjreddy@emssusa.com

About EM Software and Systems (USA) Inc.

EM Software & Systems (USA) Inc. is established to distribute and support FEKO (www.feko.info) in North America. FEKO is a leading electromagnetic simulation code for the analysis of: antennas (wire antennas, patch antennas, horn antennas, integrated antenna systems, etc.), antenna placement on electrically small and large structures, electromagnetic compatibility, microstrip circuits and antennas in stratified media and dielectric bodies.

All the simulations in this paper were performed using the commercial software FEKO. FEKO is a state of the art comprehensive EM simulation software that includes both full-wave (MoM, FEM and MLFMM) and asymptotic (PO, GO and UTD) solvers, to help engineers understand the challenges and converge on the respective solutions.

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