Considerations for Application of AFCI Technology on Room Air Conditioner Cord Sets

The application of AFCI (arc fault circuit interruption) technology for room air conditioner (RAC) cord sets is not trivial nor should it be taken lightly. AFCI cord sets are required on room air conditioners manufactured for sale in the United States after August 1, 2004 [1]. Improper application of protection technology on RAC cord sets could result in application issues that may adversely affect the consumer and RAC manufacturer, and malign a promising technology that offers significant opportunity to improve fire safety. Texas Instruments has developed RAC cord sets that utilize its Arc Shield ™ technology. This article examines AFCI technology, specifically reviewing the application considerations when utilizing AFCI technology on the appliance cord set for room air conditioners.

TI AFCI Plug Cap for Appliances

AFCI Technology.

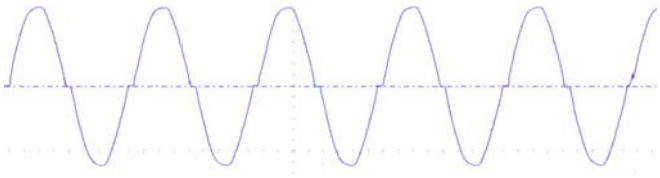
AFCI technology is a relatively new protection technology that is designed to prevent fires caused by unwanted arcing events. These dangerous arcing events can occur in the wiring of a dwelling, in the connection of a plug into a receptacle, inside an appliance, in the cord of an appliance, or in a wiring connection device such as an extension cord or surge protector strip. Typically these arcing events are caused by damage to the integrity of the wiring insulation or by a marginal electrical connection. There are numerous factors that can damage wire insulation or manifest poor electrical connections. The Consumer Products Safety Commission (CPSC) and the National Association of Fire Marshall's have extensive data that detail the dangers caused by arcing events, including damage due to fires and the resultant loss of life [2].

As a result, the 2002 National Electrical Code ® (NEC) requires AFCI protection in the bedroom circuits of most new homes constructed in the United States; and effective August 1, 2004, on the cord sets of room air conditioners. In addition to the requirement for application on room air conditioner cord sets and household circuit breakers, application of AFCI technology has also been proposed for wall receptacles and the cord sets of other appliances such as electric heaters, fans,

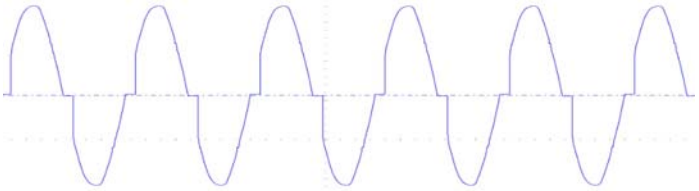
and vacuum cleaners. Most recently, at the May 2004 National Electrical Code Users Symposium and Exhibition in Salt Lake City, UT, members voted to expand the use of AFCI circuit breakers to all living areas in newly constructed homes effective with the publication of the 2005 version of the NEC ®.

Most AFCI technologies work by sensing anomalies in the flow of current that are indicative of unwanted arcing events. Since "good" arcing events also occur during many normal transients and operating conditions (i.e. when a set of contacts opens or closes, or in a brush motor), it is imperative that AFCI wiring devices distinguish between "good" arcs and "bad" arcs, such that they do not result in false or nuisance trips. Also, many loads have current signatures that can easily be misunderstood as indicative of arcing, yet are normal wave patterns of the device (i.e. dimmer switch).

Note the two wave forms shown below. The first shows an arcing wave form, while the second – although the wave form looks "worse" to the naked eye – actually depicts a typical dimmer type of load.



Arcing Wave Form



Typical Dimmer Load

Thus, in addition to discriminating between "good" arcs and "bad" arcs, the AFCI wiring device must distinguish between normal and abnormal conditions to effectively provide protection without causing unwanted or nuisance trips. Herein lies the key to effective application of this technology.

UL 1699.

AFCI technology in household wiring devices is covered by Underwriter's Laboratory ® specification UL 1699 [3]. UL 1699 was developed in the 1990s in response to recognition that many home fires in the United States were the result of arcing events that did not manifest themselves in over-current conditions. Traditional circuit breakers provide protection against over-current conditions, yet

it had been discovered that seemingly low level arcs also produced sufficient energy to cause ignition of adjacent materials without ever resulting in an over-current condition.

UL 1699 was originally drafted to cover the application of AFCI technology for household circuit breakers, wall receptacles, and portable AFCI devices. The specification for circuit breakers is divided into two sections; one with less stringent performance requirements for branch feeder circuits, and one with more stringent performance requirements for combination devices. Most household circuit breaker products that are qualified to UL 1699 today meet the *least stringent* performance levels of UL 1699. This is because the technology that was originally developed was not capable of meeting the more stringent UL 1699 requirements without being susceptible to nuisance tripping on the wide variety of loads to which the devices would be subjected. The UL 1699 specification for wall receptacles and portable AFCI devices (this includes RAC cord sets) requires that these AFCI protection products meet the *more stringent* performance requirements for UL 1699 combination-type devices.

The UL 1699 specification can essentially be broken down into three types of testing for arcing: arc detection tests (Section 56), nuisance trip tests (Section 57), and masking load tests (Section 58). When UL 1699 was originally written, the focus was on ensuring robustness against nuisance tripping on generic load types (i.e. motors, lights, electrical controls, etc.) Subsequent application of this specification mandating AFCI protection for appliance cord sets has resulted in a situation where an AFCI cord set is required to be used for a dedicated appliance (i.e. RAC) however, none of the UL 1699 tests specifically utilize the specified appliance. That is, for room air conditioner cord sets, an AFCI device can pass the UL 1699 requirements, yet potentially not be “fit-for-use” on the very appliance it is designed to provide protection for since none of the nuisance or masking loads include a room air conditioner.

Additionally, new classes of loads and operating conditions have been discovered that are not covered in UL 1699, yet it is imperative that an AFCI device address nuisance and masking load performance such that the product is “fit-for-use” in a wiring device application. These include power line communication devices, certain types of fan speed controllers, and others.

It is expected that some of these loads and operating conditions will be included in future revisions of UL 1699.

Application of AFCI Technology on RAC Cord Sets.

Application of AFCI technology on RAC cord sets requires three levels of design consideration. The “ticket to entry” or “table stakes” is qualification to UL 1699. However, it is not good enough to simply meet UL 1699. One cannot rely on compliance to UL 1699 if the product exhibits nuisance trips or other unwanted performance characteristics that adversely impact the application. Application

and engineering experience at Texas Instruments has indicated that satisfying these “fit-for-use” requirements is critical for many applications – especially AFCI protection of room air conditioner cord sets.

Given the quirks of the standards as outlined in the previous section, it is imperative that the designer of an AFCI cord set product ensure that it is “fit-for-use” in the appliance it is being applied in. This would not only include additional AFCI tests related to the specific appliance the AFCI cord set is designed to be used with, but also tests that capture the application of the AFCI cord set in conjunction with the appliance.

Lastly, good design practice dictates that the AFCI cord set have a level of robustness over and beyond what the UL 1699 specification and “fit-for-use” tests would provide. This is to provide for an additional margin of surety for any unforeseen performance or application conditions.

How does an AFCI designer accomplish these considerations? Compliance to UL 1699 is necessary to be considered for an RAC cord set application. Numerous patents have been filed for arc fault detection. In fact, arc detection is a fairly easy task. The real challenges lay in distinguishing between “good” arcs and “bad” arcs, not nuisance tripping, and detecting arcing in the presence of masking loads. Ideally, the sensitivity of the AFCI algorithm will be such that it not only passes UL 1699 requirements, but is also robust enough to provide the earliest reasonable detection of unwanted or unsafe arcing. Many AFCI technologies are marginal in meeting certain of the UL 1699 requirements due to the trade-offs between sensitivity to arcing conditions and susceptibility to nuisance tripping. While these AFCI technologies can be UL 1699 listed, they are “fragile” and may be susceptible to performance anomalies under various arcing conditions in the application, or insufficiently robust to provide the earliest reasonable detection of unwanted or unsafe arcing.

Meeting room air conditioner and various manufacturer “fit-for-use” tests is a special challenge. Not only must the AFCI cord set designer be knowledgeable about the appliance, but they must also take into account a wide variety of product models and configurations from numerous manufacturers. Firstly, an AFCI cord set designer must review UL 1699 and determine what tests might also be appropriate to substitute a room air conditioner as the test load. Remember, none of the standard UL 1699 tests involve a room air conditioner, even though the NEC requires this protection on all cord sets for room air conditioners manufactured after August 1, 2004 (see UL 484)[4]. To accomplish this, it is logical to substitute an RAC in place of some of the standard loads called out in UL 1699. For instance, Texas Instruments re-ran various UL 1699 tests substituting a room air conditioner in place of the specified load (i.e. RAC in place of the vacuum cleaner in Section 57.3 and 58.2). Because the signal characteristics can vary significantly from appliance to appliance, Texas Instruments used room air conditioners from various manufacturers across a

wide range of ratings (15 A – 35 A; 115 VAC and 240 VAC) and sizes (6,000 BTU – 14,500 BTU).

In addition, we have worked with many of the RAC manufacturers to understand any peculiar performance characteristics or other application scenarios that might impact the desired AFCI cord set performance. From this collaboration, we determined that the act of switching the mechanical rotary control knob between positions could cause unwanted trips on some competitor's AFCI devices – essentially making it impossible to turn the room air conditioner on. This is because every time the switch changes position, a set of contacts are opened and closed, creating an arc (a "good" arc). The size of the air conditioner directly correlated to how susceptible the AFCI device was to nuisance tripping during this switching. We found that even on the smaller BTU models, rapid switching of this speed control knob (as a homeowner might do when turning their RAC to maximum when entering a hot room on a summer day) induced a nuisance trip on competitor's devices. This could obviously result in product returns by the consumer.

We also learned from some manufacturers that many arcing events (and resultant fires) in room air conditioners are related to the wiring that is inside the RAC box. In fact, the CPSC and an RAC manufacturer are presently conducting a recall on product for this condition.[5] Alternate technologies that are allowed by UL 484 do not protect against this type of arcing condition, as they only protect the integrity of the appliance cord; whereas AFCI technology may protect against arcing inside of the room air conditioner. Texas Instruments has developed tests that specifically demonstrate the ability of our Arc Shield ™ algorithm to protect against arcing of the wires inside of the air conditioner.

Another piece of feedback received in the development process related to the potential susceptibility of AFCI technology to certain types of EMI, such as might be caused by some power line communication devices that can be found in many homes. To address these concerns, Texas Instruments developed additional tests that demonstrated that our Arc Shield ™ algorithm was not susceptible to these types of EMI emissions, or other similar signals.

Passing UL 1699 and ensuring device "fit-for-use" are necessary application tasks. But to ensure a complete solution, an AFCI cord set designer must provide a robust device. UL 1699 and RAC manufacturer "fit-for-use" tests cannot reasonably capture all application and fault conditions. Who among its original designers would have imagined the many uses of the common screwdriver? Due to the nature of arcing, good design practice dictates designing in additional margins of surety against arcing conditions that could lead to fires, as well as additional performance margins against nuisance or unwanted trips.

Design attributes that address robustness should be focused on the AFCI performance as well as the electro-mechanical attributes of the cord set. TI has designed its Arc Shield ™ algorithm to meet AFCI test levels for arc detection and resistance to nuisance tripping beyond those required by UL 1699, as well as address newly identified loads that are likely to be incorporated into future revisions of UL 1699.

For instance, the TI Arc Shield ™ cord sets have been designed to detect series arcs as low as 0.5 amps, per the procedure in section 58.1 of UL 1699. Moreover, we have also ensured that our Arc Shield ™ device does not nuisance trip when tested with two newly identified types of fan speed controller loads that have been found to cause nuisance trips in some present generation household AFCI circuit breakers. It is likely that future revisions of UL 1699 could require that AFCI devices do not nuisance trip under these loads. As such, it is prudent that today's AFCI cord sets can address these loads. It is these and other similar tests that help to ensure that the AFCI algorithm is robust.

The electro-mechanical aspects of the cord set should also be robust. Of particular concern with AFCI cord sets is the robustness of the contact system. A marginal contact system can cause the cord set to malfunction when it is needed most. Particular note should be taken of the contact system performance under point contact testing and similar arcing conditions that require the cord set to repeatedly interrupt high current. High current such as these could lead to contact welding, erosion, or even catastrophic failure if the design of the contact system is not robust. Texas Instruments has seen this type of condition manifested in various competitive and similar products.

Lastly, it is also desirable for the cord set to have an indication light. Otherwise, it is virtually impossible to tell whether or not the cord set has tripped. This is a desirable feature when the consumer cannot otherwise understand why their air conditioner is not running.

Thus, to manufacture a device with a robust design, Texas Instruments identified a number of AFCI tests that helped to ensure the reliability of the AFCI algorithm to reliably detect arcing conditions at the earliest reasonable time, demonstrating resistance to nuisance tripping under numerous other conditions not included in UL 1699, and detecting arcs in the presence of masking loads beyond the levels specified in UL 1699. We have also considered the electro-mechanical and aesthetic aspects of the product to provide a functional protection device that can meet the true needs of the application.

Summary.

It is readily apparent that application of AFCI technology to room air conditioner cord sets is not merely a straightforward matter of technology application and packaging. There are numerous design considerations related to UL 1699 and "fit-for-use" issues that must be taken into account in the application of AFCI

technology in appliance cord sets. Cord sets with Arc Shield ™ by Texas Instruments have been designed to address the issues noted in this article. In fact, AFCI technology also addresses the concerns of room air conditioner manufacturers against arcing that has been documented to occur inside of the RAC box. Approved alternate technologies can not provide this type of protection.

The issues identified in this paper can directly impact the consumer, and need to be a critical concern for the appliance manufacturers, regulatory bodies, and the protection industry as AFCI technology becomes more widely applied. Failure to address the potential pitfalls created by an improper application of AFCI technology could not only lead to the damning of an important new safety technology and the resultant diminishment of household safety and fire protection, but also cause unwarranted harm to room air conditioner manufacturers and consumers.

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1. NEC ® 2002, Article 440.65
2. "AFCI Inquiry and Report", Consumer Product Safety Task Force, National Association of State Fire Marshals dated August 1, 2002
3. Underwriter's Laboratory ® Specification UL 1699 Entitled: "Arc-Fault Circuit-Interrupters"
4. Underwriter's Laboratory ® Specification UL 484 Entitled: "Room Air Conditioners"
5. U.S. Consumer Products Safety Commission Release # 04-151 dated June 3, 2004