

THE APPLICATION OF NEW LD-MOS TECHNOLOGY TO A UHF MULTIMEDIA TRANSMITTER DESIGN

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ABSTRACT

For the past 10 years, 28 to 32 volt Lateral Diffused Metal Oxide Silicon (LDMOS) FET devices have become the technology of choice for high power linear amplifiers for broadcast RF amplifier applications. Advantages, including ruggedness, reliability and linearity have already been well proven. Recently developed, high-power, 50 volt, LD-MOS FET devices have now become available for the UHF television broadcast band (470 – 862MHz).

This paper addresses the application of these new 50 volt high power LDMOS devices in a new transmitter design. Several key operational benefits will be discussed, these include:

1. Higher power density (more power per RF pallet) compared to existing designs.
2. Smaller transmitter footprint, requiring less physical room space.
3. Greatly improved AC to RF efficiency, resulting in lower operating costs and less waste heat to the room.
4. Simple, rugged design using fewer components, resulting in improved reliability
5. Power levels previously attainable only from tube based designs can now be realistically achieved using solid state, resulting in improved redundancy and reliability

The concept for a new UHF multimedia transmitter platform using the new RF devices will be discussed, including, exciter, power supplies and cooling systems.

UHF SOLID STATE DEVICE TECHNOLOGIES

Over the short history of broadcast television, solid state devices have now become widely used in high-power RF amplifying stages. Since the early 1970's, RF power device technology has developed rapidly. Indeed, UHF RF power devices are now used at increasingly high power levels and across a broad

spectrum of applications, including television and radio transmission. Over the past 35 years, different technologies for solid state UHF transmitter power amplifiers have been used – Silicon Bipolar transistors, Silicon Carbide Static Induction Transistors (SiT's) and MOS-FET's.

Bipolar Junction Transistors

Early Silicon bipolar RF power transistors had relatively low maximum power capability and exhibited low gain and poor linearity characteristics, compared to newer device technologies. RF amplifiers employing such devices were generally operated in Class AB but were biased heavily to minimize non-linear distortion and the resulting in-band intermodulation products which were extremely difficult to correct using the pre-correction techniques of that era. Because other technologies now provide superior performance, bipolar transistors are rarely, if ever, used in new designs for UHF linear power amplifiers.

Silicon Carbide RF Devices

An interesting technology that was pioneered for broadcast applications in the mid 1990's by Westinghouse, CBS and Northrop Grumman, used newly developed Silicon Carbide RF devices¹. Static Induction Transistor (SiT) RF power devices based on Silicon Carbide were developed for the UHF broadcast band. Silicon Carbide promised huge benefits and much higher power per device than existing devices based on bipolar junction transistors and MOS-FET technology. One of the primary characteristics that propelled significant interest and research was the fact that the SiC devices were capable of far higher junction temperatures than other devices. Junction temperatures well in excess of 225 deg C reduced cooling requirements and enabled higher power densities than any competing technologies of that era. Devices capable of up to 250 Watts CW power at 1dB compression were produced. Such devices were capable of approximately 70 watts of average power in a typical ATSC power amplifier design.

An experimental transmitter employing SiC devices was successfully put into full time service at KCTS in Seattle on January 30th, 1997. The author recollects

that this transmitter operated on Channel 18 at about 1kW of average ATSC power.

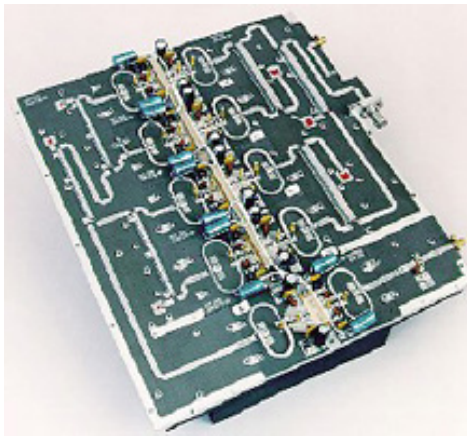


Figure 1 – SiC UHF power module, circa 1996

What happened to this exciting technology? Apparently, device yield was very low, due production difficulties and other factors, resulting in very few usable devices per wafer. Individual device costs never met the original target and thus never allowed manufacturers of transmission equipment to capitalize on the many benefits afforded by this approach. Over time, advancements in MOS-FET's overtook SiC devices in most parameters (except for maximum junction temperature) and provided a lower cost solution.

RF MOS-FET Technology

Early MOS-FET semiconductors for RF applications were VMOS devices (Vertical Metal Oxide Silicon). These devices provided excellent linearity and gain performance but were mostly suited for lower frequency VHF-TV and FM applications. In VHF, they typically had operating voltages from 26V to 50V and came in various power levels up to approx. 100W. Low input impedances made it extremely difficult to use VMOS FET's in fully broadband designs. Most equipment manufacturers opted for single channel PA modules or developed quasi-broadband designs where 3 or 4 module designs covered a specific Television band.

LDMOS FET Technology

LDMOS (Lateral Diffused Metal Oxide Silicon) FET devices provided the leap that broadcast manufacturers needed for viable UHF power amplifier designs. Improvements in Gain/bandwidth and much better thermal characteristics made the design of truly broadband amplifiers for UHF much simpler and cost-effective. Because of these benefits and the exceptional linearity and ruggedness that LDMOS devices provide, today, every major UHF Television transmitter manufacturer uses 28-32 volt LDMOS technology in their current designs. Indeed, power levels to 60kW

analog and over 30kW in ATSC digital operation have been installed. Such transmitters provide excellent performance, large levels of built-in redundancy and very high reliability.

Figure 2 shows how over time the maximum frequency of operation for LDMOS RF devices has increased.

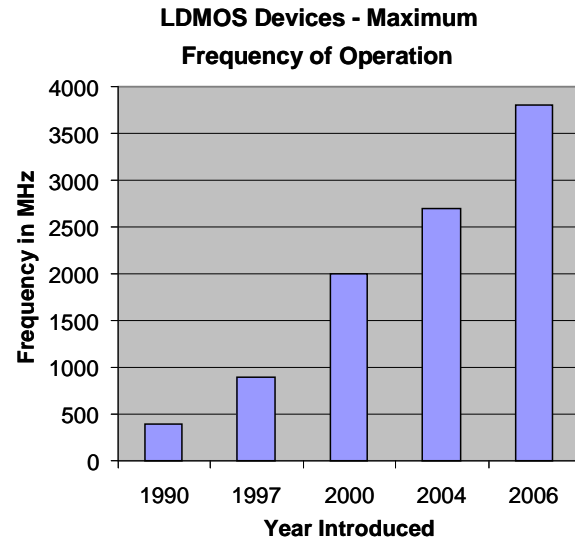


Figure 2 - LDMOS maximum frequency vs. year introduced²

50 Volt LDMOS Technology

LDMOS technology has a demonstrated track record of providing outstanding reliability with nearly 20 years of widespread deployment in the demanding cellular infrastructure market. In recent years, the large cellular market has propelled the development of RF devices

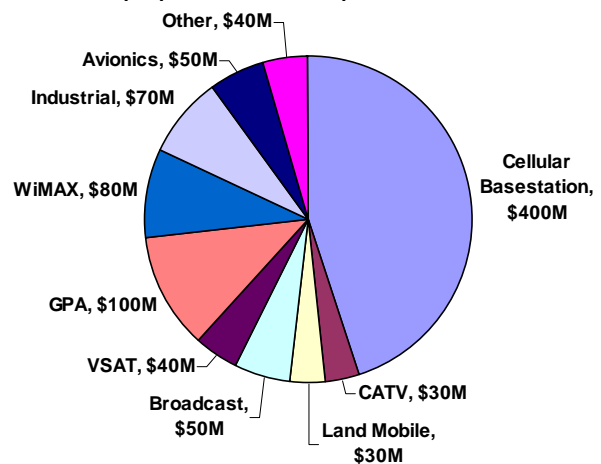


Figure 3 – Market segmentation for LDMOS devices (2008)²

with higher power capabilities along with increased gain and efficiency.

Higher voltage LDMOS FET's have been developed recently³. 50 volt devices have become available that have been optimized specifically for the broadcast

applications. Devices are now available from the major suppliers of RF devices that offer increased power density, efficiency and ruggedness, compared to 28 volt devices.

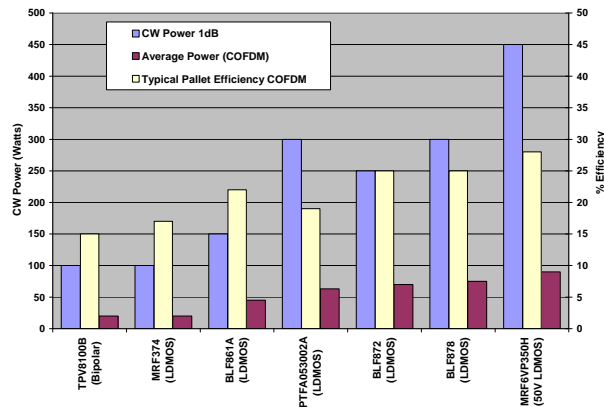


Figure 4 – UHF RF device comparison

A comparison showing maximum RF power and typical efficiency between various bipolar, standard LDMOS and the new 50V LDMOS devices is depicted in figure 4.

The new 50 volt LDMOS devices provide significant advantages of the current generation. In particular, power density and efficiency, to be considered for a new solid state transmitter design.

A NEW UHF RF AMPLIFIER DESIGN USING 50 VOLT LDMOS DEVICES

Because of the significantly higher gain and increased power capability of the new LDMOS devices, an early architectural decision was made to “keep it simple” in terms of RF power amplifier design. There can be a tendency by engineers to over-complicate amplifier design, resulting in the final product being technically excellent in terms of performance and features but almost impossible for the average technician to troubleshoot and repair, should a problem develop later. For the new design, a single gain stage comprising four parallel pallets was developed. The overall power amplifier module utilizes only eight LDMOS devices, versus twenty or more in typical designs seen today. Since the new devices have significantly higher power density, proper cooling becomes an even more important factor than before. The device manufacturer requires that this device be soldered to a copper heat spreader to ensure excellent heat transfer and to maintain lowest possible device junction temperatures. A photograph of an LDMOS device with heat spreader is shown in figure 4.

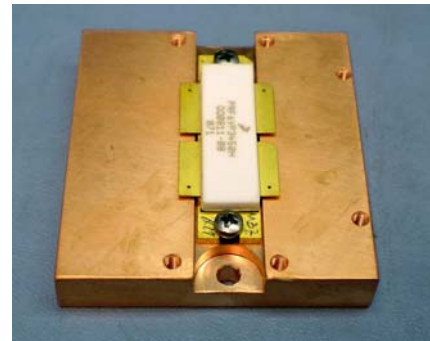


Figure 5 – 50V UHF LDMOS device mounted on copper heat spreader

RF pallets each use two push-pull LDMOS devices, to provide 180 Watts of average COFDM power and a total amplifier power of 650 Watts, which allows for combining losses within the module. Simple stripline RF power dividers and combiners are used.



Figure 6 – 50V UHF LDMOS RF pallet

The module is liquid cooled to provide an excellent means to efficiently transfer waste heat away from the devices and out of the transmitter room. Liquid cooling is not a new technique and has been successfully used in various transmitter architectures for many years.

POWER AMPLIFIER POWER SUPPLIES

The power supply that provides DC to the power amplifier module must be reliable and provide the necessary regulation to avoid problems if the incoming AC voltage varies, as is frequently the case at remote transmitter sites, often at the end of a long power line. Because power supplies tend to be rather complex and difficult to repair, it was determined that a modular approach using small power blocks would be a better alternative than one single power supply. In this design, individual power supplies provide regulated 50 volt DC power separately to each device. This

provides excellent redundancy due to the 1:1 power supply to RF device ratio.

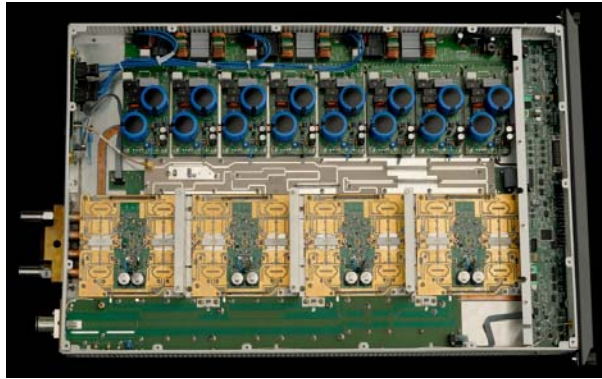


Figure 7 – Complete power amplifier module with four 50 Volt LDMOS pallets & modular power supplies

Other components included in each power amplifier module are the AC distribution and Control Board. The cooling plate (or “cold plate”) provides the means to liquid cool the module. An aluminum plate with an embedded copper pipe provides a path for the coolant. By routing the copper pipe directly underneath the key heat generating components (LDMOS devices, DC power supplies and combiner reject loads), waste heat is efficiently removed and passed to the coolant where it is dissipated outside the building, using conventional pumps and heat exchangers.

EXCITER CONSIDERATIONS FOR A MULTIMEDIA TRANSMITTER

Another key component in the transmitter system and perhaps the most important one is the exciter.

While the USA and some other countries have successfully transitioned to digital broadcast, other countries have not yet begun, or are in the midst of such a move to digital. In addition, new standards, or enhancements to existing standards, are constantly emerging. Recent examples are the ATSC M/H and DVB-T2 standards. Ideally, a transmitter manufactured today should be capable of operation on any worldwide standard, analog or digital, if it is to be manufactured cost-effectively. It should also provide a future-proof acquisition for the customer.

A solution to this problem is to ensure that all components of the transmitter system will operate properly on any of the standards. It is important as one evaluates offers from a range of technology suppliers the inclusion of a true multimedia exciter is the cornerstone of the transmission system to ensure future compatibility⁴. In addition to supporting multiple standards, it is critical that the exciter offers adaptive digital pre-correction to maximize transmitter operating

performance, and ensure technical compliance. While some older systems offer fixed pre-correction, adaptive correction constantly monitors the performance of the transmitter, and adjusts for non-linear distortion in the amplifier and linear distortion in filter system, which can change due to varying temperatures and changes in the antenna system. Multimedia exciters are available today that provide the ability to support all of the popular analogue and digital standards today coupled with real time adaptive pre-correction. Since these new designs employ software controlled modulation, they can have the ability to be converted to whatever standards evolve in the future.

GETTING THE HEAT OUT

Medium-to-high power solid state transmitters can be very effectively cooled using liquid as the heat transfer medium. Liquid cooling has been used in TV and radio transmitter systems for over 40 years and it has been found that a well designed liquid cooling system is not only reliable; but also quiet and efficient.⁵ Since the power amplifier modules are liquid cooled, it makes sense to liquid cool as many other components that generate heat as is practical. By removing as much heat as possible from the transmitter system and transferring it to the outside of the room, significant savings in cooling requirements for the building can be achieved. The power amplifier and its associated DC power supplies, RF combiners and reject loads are all liquid cooled in the new transmitter design.

Cooling systems can be made reliable and in most cases dual pumps are used in a main/standby configuration with auto changeover capability. Multiple fluid coolers with fans that cycle on and off as needed are used to transfer the liquid heat to the atmosphere.

Coolant must of course be capable remaining liquid even during the coldest winter weather. Use of anti-freeze solutions using either propylene glycol or ethylene glycol with the correct characteristics and mixed with the appropriate volume of water, ensures that no possibility of freezing can occur at temperatures down to as low as -46°C.

POWER DENSITY AND TRANSMITTER FOOTPRINT

The improvement in LDMOS device power levels have directly resulted in major improvements in transmitter power density, resulting in more compact transmitter designs. Recent solid state designs from only a few years ago could achieve about 3.4kW average COFDM power and 10kW peak sync analog power per 19” rack cabinet. As newer RF device technology has emerged, several manufacturers have taken advantage of the

higher per-package power levels of these devices to develop transmitter power levels up to 5kW to 7kW average power and up to 16kW analog peak power. Today, the newest 50 volt LDMOS devices have allowed another big step forward in power density, compared to very recent designs that use 150W to 250W devices.

By using the new 50 volt, 450 Watt, LDMOS devices, power density has now been increased to power levels of 8.7kW COFDM, 12.3kW ATSC average power and 25kW peak analog power per transmitter rack cabinet. Indeed, multiple cabinet configurations now approach or even exceed power levels that in the past could only be approached by vacuum tube technology. Is the end of an era finally in sight?

EFFICIENCY AND LONG TERM COST OF OWNERSHIP

While there are a multitude of factors that can affect long term cost of ownership, perhaps the most important and most often misrepresented by suppliers is the overall transmitter efficiency. For digital transmitters, the efficiency can be calculated as the average power out divided by the AC power input. RF device data sheet efficiency at CW is of little value to the customer. Actual circuit efficiency at average digital power levels, operating at good MER and usable crest factors is more important. The new 50 volt devices can provide over 25% typical PA module efficiency (AC power in versus RF power out), resulting in overall transmitter efficiencies typically in the range of 20% to 22%. When compared to previous designs, this represents an efficiency improvement of up to 7 percentage points, or an overall improvement of 35% or more from the original figure.

Example:

- Typical 6.2kW DVB-T transmitter – Efficiency 13%, AC power input 47.7kW
- New transmitter at 6.2kW DVB-T – Efficiency 20%, AC power input 31kW
- Improvement in AC power input $16.7\text{kW} = 16.7/47.7 = 35\%$ savings

Other factors affecting long term cost of ownership should not be ignored; these include initial purchase cost, cost of maintenance/repair and cost of air conditioning of the transmitter heat load to the building. Each broadcaster will have their own criteria and cost assumptions which will affect the resulting calculation.

ENVIRONMENTAL CONSIDERATIONS - KEEPING "GREEN"

Until recently, few broadcasters have given a lot of thought about hazardous materials and the use of toxic substances in equipment of this type. Today, new regulations are being enforced in many countries regarding the use of potentially hazardous materials in electronic equipment. One such recent regulation is the WEEE/RoHS directives (Waste Electrical and Electronic Equipment / Reduction of Hazardous Substances) that apply to many European countries. This requirement has been taken into consideration in the new multimedia transmitter platform and is a standard feature of the product. In addition to this requirement, all other environmental safety regulations must of course be observed. In addition, the reduction in AC power requirements obviously goes a long way to helping reduce greenhouse gases emitted at the power generation plant.

SUMMARY

By applying new technology, including the new high power 50 volt LDMOS FET's, the following improvements can be accomplished in a UHF broadband multimedia transmitter design

- Higher power density transmitter designs, reducing floor spaces requirements and saving money.
- Higher efficiency – Over 30% power savings improvement from typical systems using current technology LDMOS devices
- Fewer devices per PA module (due to higher power devices) resulting in a simpler design and higher reliability.
- Very high power levels from a solid state design – perhaps eliminating the need for vacuum tubes in many cases.

ACKNOWLEDGEMENTS

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