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# Doherty project description

This project was focused to the complete design and verification of the first UHF DTV doherty power amplifier (pallet) for broadcast equipments which can be used in the field. The pallet was designed basically on some mechanical restrictions (compatibility with dimensions and screws positions of wideband pallets) in order to be able to reuse splitters, combines and liquid cooling systems.

The goal was the design of a new generation of amplifiers with higher efficiency and smaller mechanical dimensions (from the previous 19’’ 5 rack units to the actual 3 rack units of air cooled amplifiers) with the same target of output power of the current wideband amplifiers (>700 Wrms with MER > 36dB after DPA). The design should evaluate the possibility to reduce as soon as possible the HW configurations needed to cover the whole UHF TV band (reduce at minimum the HW changes for the channel tuning, needed for doherty architectures, but maintaining the highest efficiency and the highest linearity).

Main requirements of the pallet:

Supply voltage: 50V
Pout (DVB-T 8MHz): 200W
MER (DVB-T 8MHz): >34 dB after DPD
Input connections: solder tabs, fixed positions, symmetrical with respect to the centre x axis
Output connections: solder tabs, fixed positions, symmetrical with respect to the centre x axis
Thermal tracking: yes
Bias regulation: manual, directly on board

For this doherty amplifier two MRFE6VP8600H have been implemented on each pallet. The available pallet dimensions are (only) 115 x 85 mm, and this was the main hard restriction of this development. No more info can be added at the moment for intellectual property reasons.

Output simulators layout was available in GDFII or DXF format. This layout file was imported by Screen Service PCB designers and then was integrated to the layout of the bias circuit and ground filled areas by using a standard CAD environment which was used to generate gerber files too, including those needed for the carrier. Special components for testing purposes were purchased directly by Screen Service, including LDMOS transistors, carriers, and PCBs.

The list of instruments needed to test the prototype is reported below:

n.1 spectrum analyzer Agilent E4401B
n.1 Network analyzer Agilent E5070B
n.1 Power meter Agilent E4418B + E9301 power sensor
n.1 Power supply unit HP 6675A
n.1 Generic test bench power supply unit 50V 0-3A adjustable
n.1 DTV Test Set R&S EFA with DVB-T option
n.1 Coax dummy load 50 ohm 1GHz >200W Bird
n.1 multiple ways power directional coupler (4 links or more) 1KW 45-50dB compensated couplers
n.1 DVB-T UHF exciter (20 - 36dBm adjustable) with adaptive non linear precorrector
n.1 DVB-T driver 8-10W with at least 38dBc of shoulders level at fc +- 4.2MHz
n.1 Test fixture with fan for power tests
n.2 solder stations WS81 (or PU81) Weller
Cables, adaptors and attenuators (SMA and N types)

All of these instruments were available directly in Screen Service lab and have been fully dedicated to the doherty design and tests.

The doherty project officially starts in 1st week of August 2011 and ends in March 2012. From March 2011 and August 2011 I collect all infos needed to focus all possible features which can be implemented in practice for doherty applications. In August 2011 the 1st contract was signed with SSBT to develop the first prototype and then starts the real design (simulations, etc.). In September the PCB prototype was released and all test were started in 1st week of October. In 2nd week of November the first doherty prototype starts to works for the first time. In January 2012 was signed the 2nd contract with SSBT to start the optimized amplifier for mass production and in parallel starts the design of the new mechanics (smaller dimensions, from 19'' 5 rack units to 3 rack units). The doherty 1st project officially ends in March 2012, then a 2nd doherty project (differential topology) started in july 2012 and was released in november 2012.

No-one transistor was destroyed during lab tests, only one transistor flashes inside the prototype module for thermal stress when there were some ATSC evaluation tests because the fans used initially were not the same fans chosen for productions equipments. This was the only failure we have had at the moment. Actually there are more than 700 doherty pallets up and running around the world distributed to friend labs and customers for tests and for evaluation purposes, tuned to many different channels within the whole UHF TV band, fully working 24 hours a day.

Advantages of doherty amplifiers should not be limited to the efficiency improvements but should be extended also to mechanics cheaper and more compact, this due to the reduction of dimensions and costs of cooling and power supply systems. But generally the physical dimensions of a doherty amplifier are larger with respect to the wideband solutions (at the same output power). For this reason I decide to avoid to stress the wideband performance of my design, I preferred to concentrate the effort to design a new doherty amplifier in the same space occupied by a wideband standard amplifier.

Based on my pallet design two new subrack have been redesigned by Screen Service by using doherty technology: the first is a 700Wrms amplifier in 19'' 3 rack units (1kW in ATSC) equipped by using 4 pallets (8 differential Freescale LDMOS cooled only by 2 high flow fans), and then second is a new 1.4KWrms ( 2KW in ATSC) in 19'' 5 rack units equipped by using 8 pallets (cooled by 2 larger air flow fans) , both for air cooled systems. But if requested another 1.4KWrms in 3.5 rack units liquid cooled doherty amplifier can be available too by using the standard previous mechanics, combiners, etc.

Please note that the digital predistortion algorithm of the exciter have been also adapted by Screen Service engineers in order to prevent some doherty strange behaviour which can't guarantee a sure convergence during the adaptive precorrection of doherty amplifiers (higher polynomial handling of the non linear AM-AM and AM-PM distortions).

I did only the design and the tests of the doherty prototypes and the tests of some of the doherty pallets delivered for the mass production. The real design has been done by myself in Rome, all tests have been done in Brescia in the SSBT lab and their test plant. All of other tasks have been done by SSBT doherty Task Force Team, including PCB and mechanics design and the manual components mounting of all prototypes. I was the RF-HW leader of the doherty Task Force Team too; the role of the System Manager and the other main product leaders were covered by SSBT people.

**FURTHER INFORMATIONS**

Doherty architecture is the the simplest way to increase efficiency on digital power amplifiers. The only limitation is the bandwidth which couldn't be wide enough to cover the whole UHF TV band.

But since the available high power LDMOS are designed only for AB class push pull amplifiers there are two main differences between possible architectures of doherty power amplifiers which can be implemented at the moment:

1. differential doherty power amplifiers (push pull);
2. single-ended doherty power amplifiers.

**The first type** is the easiest way to implement a doherty power amplifier starting from a standard DTV amplifier architecture (the same way used by Rohde & Shwarz): it consists to use a standard 90° hybrid coupler as the -3dB input splitter (constant phase), then two identical wideband UHF stages (pratically a couple of amplifier stages used for wideband AB class amplifiers) with different bias at gate level. Then a narrowband doherty output coupler which can be designed in different ways in order to have the best trade-off between flexibility for channel tuning, bandwidth and efficiency.

**The second type**, the most complex, is a special application of differential LDMOS devices. It consists of the complete redesign of the power stages by using the internal chips of a commercial push pull LDMOS separately, one for the main amplifier and the other one for the peak amplifier. In this way you have a complete doherty amplifier by using a single package LDMOS device that includes both type of amplifiers. Then, it is possible to combine two doherty amplifiers on a single pallet (two devices) by using a standard 90° hybrid coupler. The channel tuning is performed by replacing two daughter boards on each pallet and by changing the length of the output matching microstrip of each power amplifiers. Actually this is the solution which has been adopted by Screen Service Broadcasting Technologies (SSBT).

Anyway I designed both type of doherty architectures for Screen Service by using the same mechanical outline dimensions of their pallets, in order to have both capability for the market, but at the moment customers want ONLY the single ended type.

The differential doherty architecture has many advantages with respect to the other, it has best efficiency (about +2% more than the single ended architecture), lower costs and easier way to change channels. But it has a very big drawback: the working temperature of the main amplifier is higher with respect to the working temperature of the same device that works in a standard AB class amplifier. This because in a doherty architecture main amplifiers always work in compress mode (about +2dB more of input power) and this have a very big impact to their thermal profile.

Viceversa, in the single ended doherty architecture, even if the main amplifier chip is stressed, it dissipates heat by the same flange (source contact) of the peak amplifier chip which is normally colder. In this way, by using the same heater, the temperature of the overall transistors is lower with respect to the same used in a standard AB class amplifier and this can really reduce the outline dimensions of all heaters, power supply devices and mechanics in general without any risk of device degradation due to thermal stress. On the contrary this doherty architecture have less efficiency (about -2% due to the extra combiner needed to couple two devices on the same pallet) and more complexity for channel tuning, this because it must be tuned two doherty combiners on the same pallet. Furthermore the higher complexity of input and output matching transformers impacts to the overall costs of the pallet (more high Q ceramic capacitors needed with respect to the differential architecture).

Obviously in order to optimize efficiency of a doherty power amplifier also main and peak amplifiers efficiency should be stressed as much as possible and this can be done by choosing different set of output matching capacitors each one useful for three or four different sub-band. This can help you to gain two or three point of efficiency more, especially for single ended doherty architecture that implies more complex impedance matching.

The gain of a doherty power amplifier is about 2dB less of a standard AB class wideband power amplifier which uses the same LDMOS. This have a direct impact on the driver linearity which should guarantee very good linearity at higher level of output power (driver should guarantee at least 37-38 dBc of shoulders level at max power with respect to the centre of the envelope). Sometimes a more robust driver is required for doherty applications.

For SSBT implementation the Freescale MRFE6VP8600H LDMOS have been preferred with respect to the NXP BLF888A/B because it has an higher drain voltage breakdown level. This parameter is fundamental for doherty applications for two main reasons: 1. generally peak amplifiers have higher harmonic levels with respect to standard AB class amplifiers: 2. the doherty combiners are not isolated and the node where the RF powers are “in phase” coupled corresponds to the peak amplifier output. This means at this node you have the maximum level of RF peak voltage envelope and this can increase much more if there is some power mismatch at the output. For this reason the robustness of devices at high reflected power is recommended. Anyway by using the rugged Freescale LDMOS the overall power gain is lower with respect to the NXP choice.

According to the Freescale indications for their optimized layout of a standard AB class wideband power amplifier based on the MRFE6VP8600H LDMOS, I designed a new broadband pallet by using two LDMOS in order to measure the different efficiency between topologies. Obviously the efficiency of two coupled devices is lower with respect to the efficiency of a single stage (e.g. the Freescale demo), this because it has to be consider the insertion loss of the output coupler and the unbalance between the two stages at different frequencies. Anyway, at 200Wrms of output power with MER > 33dB in a broadband pallet by using Freescale devices we have measured a minimum efficiency of 20.9% around CH57 and a maximum efficiency of 30.7% around CH33. With a single ended doherty topology, by using the same device at the same output power and at the same channels, the minimum efficiency will increase at 36.9% and the maximum one will increase at 41.3%. With a differential doherty topology the minimum efficiency obtained is 38.8% and the maximum is 43.2%. By stressing the efficiency of amplifiers by tuning them on some specific channels the maximum efficiency can increase to 46-48% at 210 Wrms with MER = 33dB but these numbers can't be certified for the field.

Finally, in order to have an idea about the costs of a complete doherty UHF-DTV implementation oriented to the single ended architecture will not be less than 70-80k euros (without including VAT, PCBs development, materials, instruments, travel costs, hotel, etc.) and the time needed will not be less than 6-8 months. Obviously the costs of a complete doherty implementation oriented to the differential topology will be less and it will speed-up the time to delivery too.

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