Doherty Architectures in UHF White Paper

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1. Introduction

In the past, power amplifier blocks for UHF broadcast were straightforward to design. In most cases the requirement was a class AB broadband amplifier covering 470-860 MHz. A pallet approach (two transistors in balanced mode) was the most common implementation. Key parameters for this pallet are power (> 200 Wavg DVB-T), efficiency and linearity.

In the cellular industry, Doherty amplifiers were already introduced to enhance efficiency without too much cost increase and maintaining a small size. Because of its narrowband character, it required more time in the broadcast industry to switch over to Doherty amplifiers. Nowadays almost all new UHF transmitters make use of Doherty amplifiers. In recent years, new Doherty architectures have been developed which offer more efficiency and more bandwidth.

In this paper a brief discussion will be given to explain these new Doherty architectures and to help customers finding the best solution for their transmitter. Ampleon's transistor family BLF8xx can support these Doherty architectures.

Solutions with GaN technology will not be discussed.

2. Doherty Architectures

The following main Doherty concepts will be discussed in this paper:

- Classical 2-Way Doherty architecture
- Ultra wide band 2-Way Doherty architecture (single ended)
- Odd-mode Ultra Wideband 2-Way Doherty architecture
- Higher efficiency architectures

2.1 Classical 2-Way Doherty Architecture

The classical 2-Way Doherty configuration can be seen in Fig 1a and 1b. The power blocks M and P represent 50 Ω amplifiers, respectively for Main and Peak side. Both amplifiers include matching networks towards 50 Ω and a balun.

By changing the output coupler of the well-known broadband class AB pallet to a Doherty combiner, it is easy to implement this symmetric Doherty concept. The different DC gate setting for Main and Peak amplifier will provide a correct back-off power point and maintain sufficient linearity.

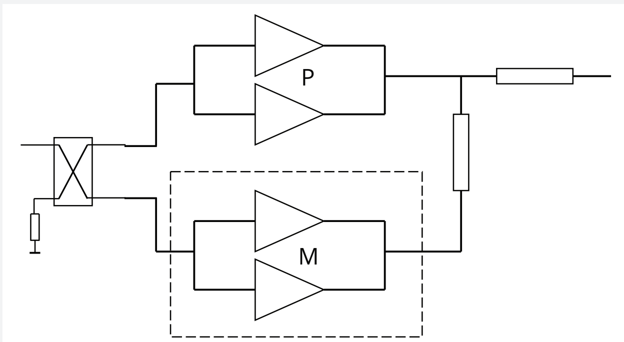


Fig. 1a. Classical (a)-symmetric 2-Way Doherty

Benefits
- Small size
- High power (240 W in a Pallet)
- Balun (cancellation of 2nd harmonic)
- Low cost
- Standard Pallet configuration

Disadvantages
- Narrowband
- Limited power in broadband amplifier design

This concept can cover approx. 50 MHz bandwidth so this concept needs many Doherty combiners to cover the full UHF band. See also application note AN11325.

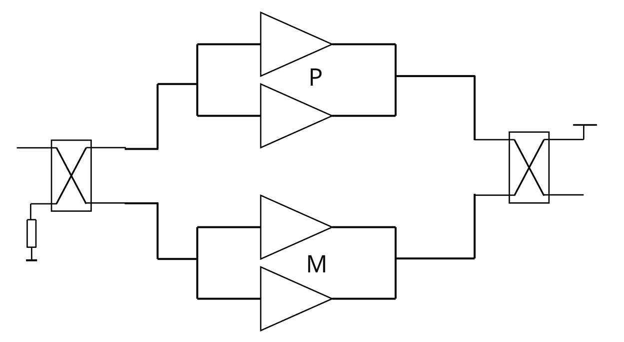


Fig. 1b. Classical (a)-symmetric 2-Way Doherty, hybrid variant

The classical 2-Way Doherty variant with input and output hybrids. Advantage is the compact implementation which is normally used in a balanced class AB pallet. Note that the output hybrid has a zero ohm load (or an infinite load) to realise the correct Doherty transformations.

Reason for the narrowband behaviour of this concept is the phase shift already introduced in the broadband amplifiers before the Doherty combiner.

Another disadvantage of the classical concept for UHF is the limitation in power when using full broadband amplifiers.
A too high power level will reduce the impedance level at the transistor lead and this results in an unpractical broadband design.

An average power level of 220 W with 45% efficiency is feasible by using Ampleon's BLF888A/B transistors. The best solution is to use a combination of BLF888A in the Peak amplifier and BLF888B in the Main amplifier: BLF888B for best efficiency and BLF888A for improved ruggedness behaviour.

The classical architecture can also be used in an a-symmetric Doherty configuration: this will increase both power level and efficiency (e.g. by using the same Main amplifier with a larger Peak amplifier). This is shown in Fig. 2a: the instantaneous efficiency has a 2nd optimum at 8 dB back-off (red line, α = 0.4) which fits much better on the probability density function (pdf) of a DVB-T signal. The average efficiency (Fig. 2b) will increase (theoretically) 2-3% compared to a-symmetric 2-Way Doherty. This concept can be realised with Ampleon's BLF888B in the Main amplifier and BLF898 in the Peak amplifier: BLF898 (900 W) has approx.1.5x more peak power than BLF888B (650 W) which results in a factor α of 0.4. It must be noted that a full broadband amplifier at 1.5x the power level of BLF888A is very difficult to realise, so that in practice the broadband amplifier needs to be split into two sub-bands (e.g. 470-650 MHz and 650-800 MHz).

Obviously this has impact on maintenance and logistic and therefore a careful consideration is needed whether the power/efficiency advantage justifies this concept.

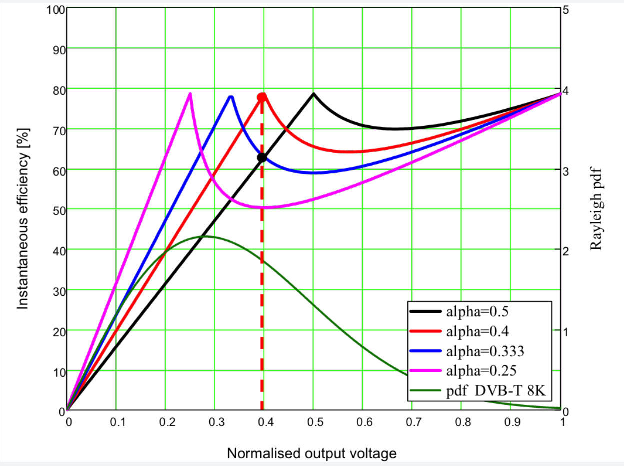


Fig. 2a. Instantaneous efficiency and pdf DVB-T

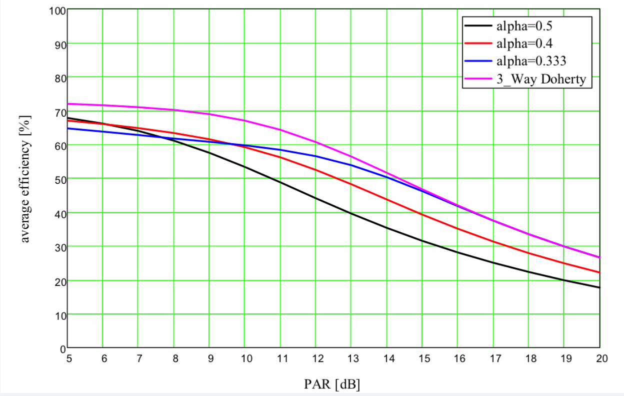


Fig. 2b. Average efficiency as function of PAR

α = PM/(PM+PP), α defines power and back-off point

back-off power: 10·log(α²) ≈ -8 dB when α = 0.4

PM and PP are respectively max. power in Main and Peak amplifier

Total power (= PM+PP) with α = 0.4 is 25% higher than in case of α = ½.

Average efficiency is given for a 2-Way (α = 1/3 , α = 0.4, α = ½) and a 3-Way Doherty (α2 = 1/3 and α = ½, see also the instantaneous efficiency curve of this 3-Way Doherty in Fig.10a)

PAR = Peak to Average Ratio

DVB-T signal PAR:

PAR of an amplifier output signal is approx. 8 dB at 0.01% probability on CCDF,

PAR of the input signal is 9.5 dB at 0.01% probability on CCDF

Note that more (average) efficiency advantage in Fig. 2b is achieved with a 3-Way Doherty (in theory approx. 9% more average efficiency compared to a symmetric 2-Way Doherty with α = ½), this will be discussed further in Chapter 2.4.

2.2 Ultra Wideband 2-Way Doherty Architecture

In order to achieve more bandwidth than the classical Doherty, the Ultra Wideband Doherty (UWD) concept was developed. Using an ideal matching network/transistor (no parasitics) and a minimum phase shift of the Doherty combiner, the maximum bandwidth is presented in Fig. 3a. An ideal symmetric UWD concept (α = ½) can easily cover the full UHF bandwidth (relative BW approx. 0.65). In practice however, bandwidth is limited by:

- Transistor output capacitance and bond-wire inductance
- Non ideal Doherty combiner network
- Output transformer Ropt/2 to 50 Ω
- (2^{nd}) Harmonic influence

The UWD concept is given in Fig. 4 and is well described in [1],[5].

In practice, using Ampleon's BLF888D transistor, the full UHF band (relative BW approx. 0.52) can be covered with approx. 40% efficiency at an output power of 115 Wavg (DVB-T). Note that the UWD concept is the only solution where a full bandwidth is obtained without changing anything in the application when switching to different channels.

The efficiency is limited by the critical output network design (combiner plus transformer) but also by the harmonic load condition. The output transformer is transparent for 2^{nd} harmonic reflections coming from the channel filter of the transmitter. Especially in a full broadband design, this influence is difficult to prevent and can lower efficiency up to five points. Combining of UWB Doherty amplifiers is therefore important, this will be discussed in more detail in Chapter 2.2.2.

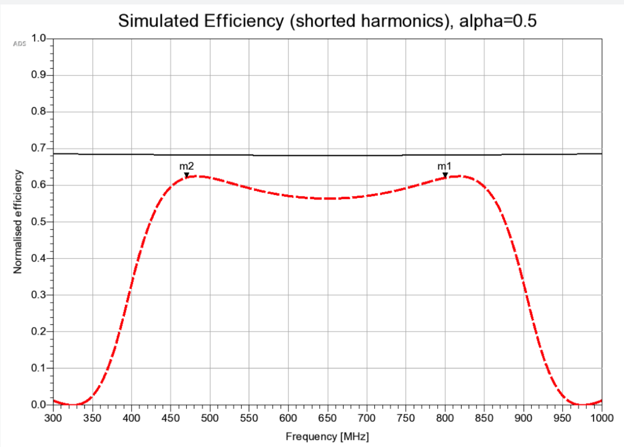


Fig. 3a. Ideal bandwidth α = 0.5 (symmetric)

back-off power at -8 dB
black = efficiency at full power, red = efficiency at back-off

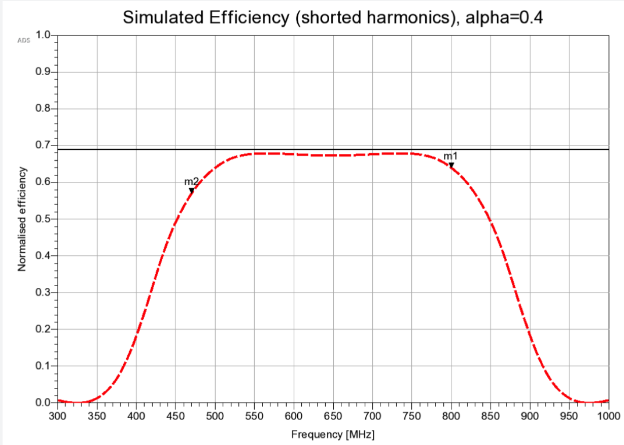


Fig. 3b. Ideal bandwidth α = 0.4 (a-symmetric)

back-off power at -8 dB
black = efficiency at full power, red = efficiency at back-off

Power/efficiency can be improved when the UHF band is split up in three sub-bands: 470-600 MHz, 600-700 MHz and 700-800 MHz. Ampleon's application board with BLF888D shows 45%/130 Wavg in sub-band one (470-600 MHz). Reason for the higher efficiency is the improved matching and less influence of 2^{nd} harmonic reflections.

In order to improve power/efficiency further, this concept can also be realised as an a-symmetric UWD amplifier. Fig. 3b shows clearly that the ideal bandwidth decreases significantly (compare α = ½ and α = 0.4), the ideal relative bandwidth is then approx. 0.5. In practice this means that the full bandwidth (470-800 MHz) cannot be achieved with this concept while maintaining a flat efficiency response (note that peak power bandwidth is not influenced).

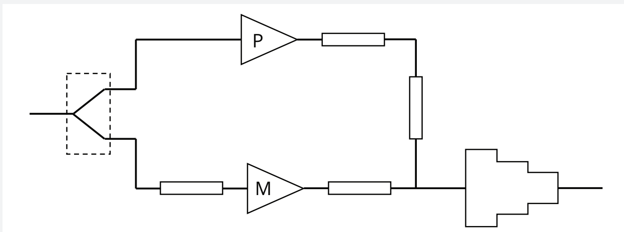


Fig. 4. Ultra Wideband 2-Way (a)-symmetric Doherty

Benefits

- Broadband (full band solution is feasible)
- High power (115-150 W designs)
- Efficiency (a-symmetric 2-Way Doherty is feasible)

Disadvantages

- Use of 10 mil pcb
- Larger size
- No balun

2.2.1 Efficiency in High Power Transmitters: introducing BLF888E

In high power transmitters, efficiency is becoming more and more important over bandwidth:
Higher efficiency means:

- Lower cost of a transmitter (less cooling, smaller size)
- Lower electricity cost

Less bandwidth gives an increase of:

- Maintenance cost
- Logistic cost

Unfortunately, with the present technology, there is a trade-off between efficiency and bandwidth.

The choice for a symmetric UWD with full bandwidth or an a-symmetric UWD with two or three sub-bands is made differently by region, transmitter requirements (e.g. power/efficiency) and end-customer preferences.

This could also be influenced by future plans to decrease the available UHF band lower than 790 MHz (e.g. in Europe).

In order to enable higher efficiency, Ampleon has developed BLF888E: an a-symmetric Doherty transistor of 150 W/50% efficiency to be used in UHF in three sub-bands: 470-610 MHz, 600-700 MHz and 650-800 MHz. These applications are described in more detail in Chapter 3.

2.2.2 Combining of UWD Amplifiers

The most commonly used combiners are a Wilkinson, a 90° coupler (3 dB hybrid) and a balun. All of these combiners have different benefits/disadvantages. In this case (dealing with 2nd harmonic reflections), focus is on the balun and the 90° coupler.

As mentioned earlier, the combiner should provide some amount of isolation to prevent too much influence of 2nd harmonic reflections on the Doherty amplifier.

Balun:
The most commonly used combiner in UHF broadband amplifiers is a balun. An ideal balun provides:

- Balanced to unbalanced conversion or vice versa
- Impedance transformation at fundamental frequencies (optional)
- Cancellation of even harmonic signals towards the load (prevent even harmonic reflections from the channel filter)
- An “open” for even harmonic signals seen at the balun input

(this is illustrated in the Smith Charts in Fig. 5a/b for odd-mode and even-mode signals when respectively a 50 Ω load and full mismatch (all phases) is applied).

If two Doherty amplifiers are combined via a balun in a conventional way (Fig. 5c) this will give 2nd harmonic resonances, where the resonance frequency is dependent on the total phase length from balun to the internal transistor drains. Unfortunately this phase length is so large that in-band resonances (0.94-1.6 GHz) cannot be avoided, which will result in severe power and efficiency loss at some channels. Therefore this method can fundamentally not be used for a design covering the whole UHF band. When the UHF band is split up in e.g. three sub-bands this method is however an option, taking into account the correct phase lengths needed to avoid these resonances in-band. An example is given in Fig. 5d/e where 120 MHz bandwidth is feasible without having the even-mode resonances. Note that in practice this solution might be difficult to realise due to the low impedance balun which is required.

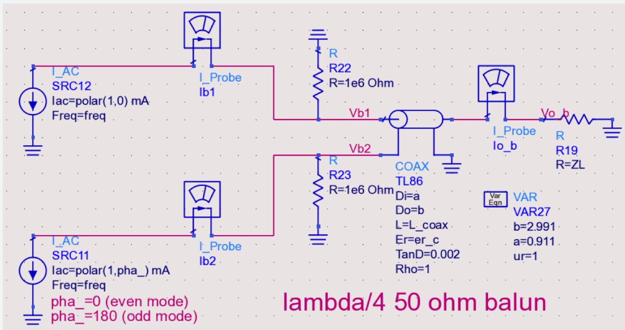
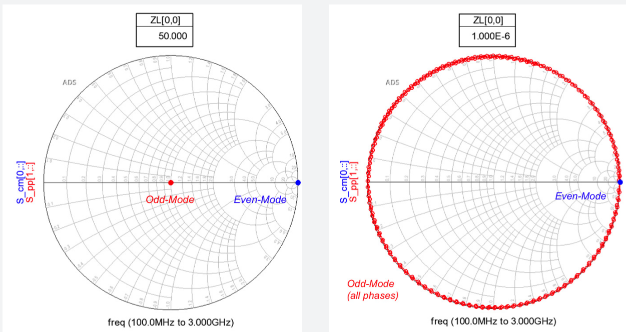


Fig. 5a. Ideal balun schematic



Even/odd mode impedances of a 50 Ω balun with 50 Ω load

Even/odd mode impedances of a 50 Ω balun with 0 Ω load

Fig. 5b. Ideal balun behaviour, ZL = 50 Ω or short

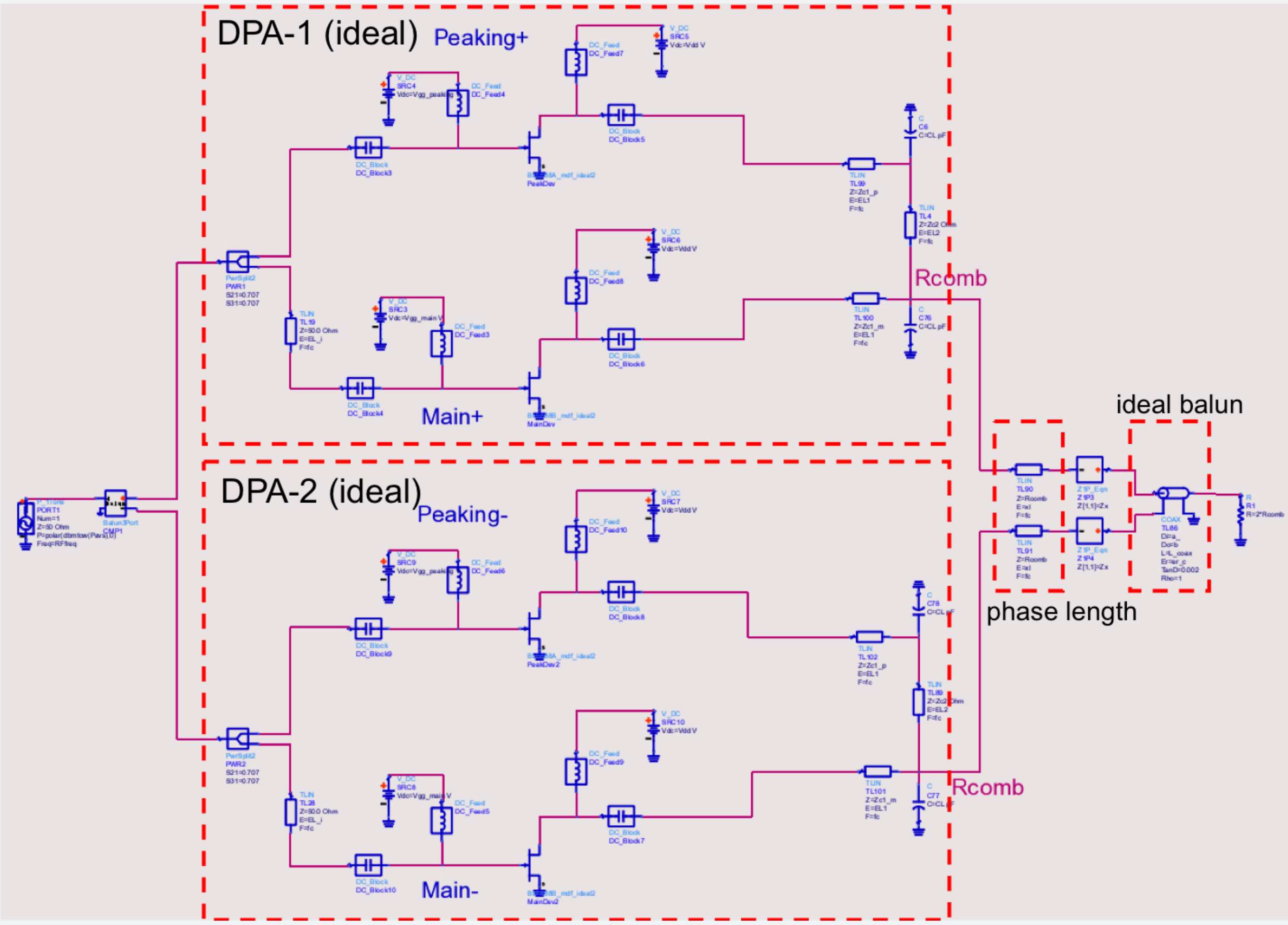
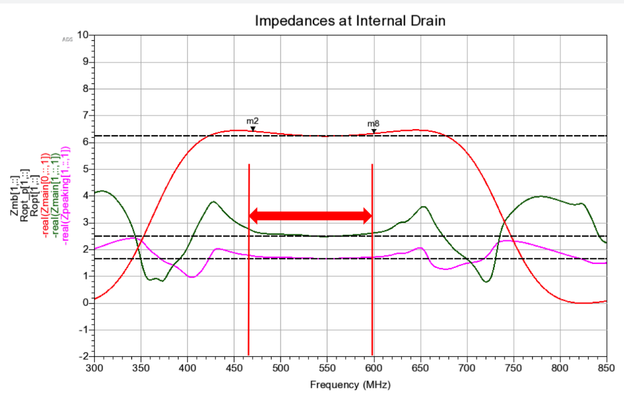
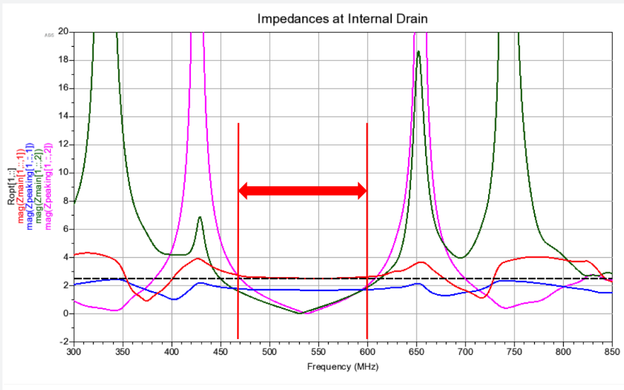


Fig. 5c. Combining via a balun



Red line = back-off Main impedance (real)
Green line = full power Main impedance (real)
Magenta line = full power Peak impedance (real)

Fig. 5d. Fundamental bandpass



Red/blue line = full power fundamental impedances of Main/Peak (magnitude)
Green/magenta line = full power 2nd harmonic impedances of Main/Peak (magnitude)

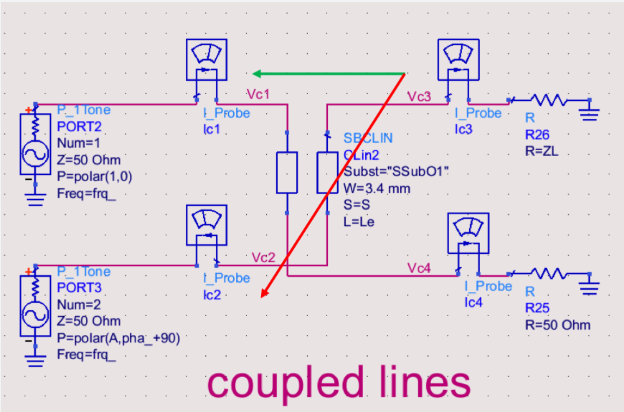
Fig. 5e. Even-mode resonances

90° Coupler:

Nowadays, in most cases the combiner used with UWD amplifiers is a 90° coupler.

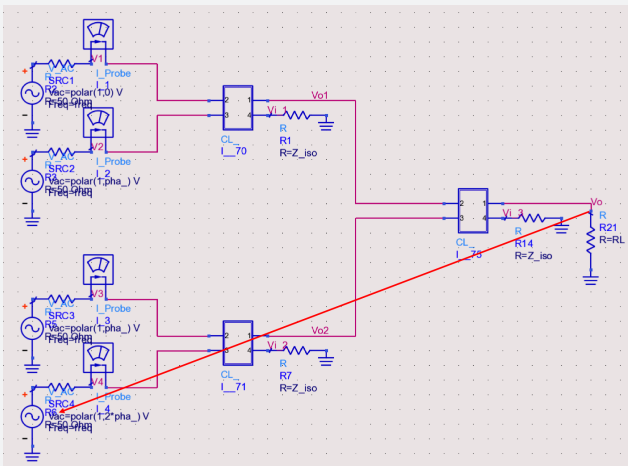
The 90° coupler which is discussed here, is a coupled line variant, see Fig. 6a.

As can be seen, this 90° coupler has a direct path which isolates 2nd harmonic reflections and the 90° path which pass on 2nd harmonic reflections. This means that only one amplifier will see a harmonic reflection. In case a structure with more 90° couplers is used (see Fig. 6b: three couplers used) only one transistor out of four will see a full reflection. Note that this is not valid for a branch line 90° coupler.



Green arrow = direct path, without 2nd harmonic reflection
Red arrow = 90° path

Fig. 6a. 90° coupler and 2nd harmonic reflection



Red arrow = 2nd harmonic reflection towards one amplifier

Fig. 6b. 90° coupler network

The 90° coupler combiner gives a workable solution but still there is reflection to one or more amplifiers, which will influence efficiency, power and ruggedness. Therefore a more fundamental solution was invented and the next paragraph will discuss this.

2.3 Odd-Mode Ultra Wideband 2-Way Doherty Architecture

As was seen in the previous chapter, the (single ended) UWD concept could not deal with even harmonic reflections. This needed to be solved in the combiner architecture, however it is not possible to suppress these reflections wideband without changing performance.

For that reason the Odd-Mode UWD concept was developed. A simplified schematic is given in Fig. 7.

Two transistors are working in push-pull as Main and Peak amplifier, a balun is part of the output transformer network and will provide an a-symmetric signal to ground.

This concept deals with even harmonic reflections in a more fundamental way by introducing broadside coupled lines and a balun. The fundamentals are well described in [3],[6].

The concept makes use of broadside coupled lines which are placed at lambda / 8 phase length (fundamental frequency) from the internal transistor drain. Because a broadside coupled line does not propagate even-mode signals, this will act as an open for a 2nd harmonic signal coming from the transistor. Thus, by choosing the correct TL (a micro-stripline) length between the broadside coupled line and the transistor, a short for a 2nd harmonic signal can be created at the internal drain current source. This means that the 2nd harmonic voltage will be small at the internal drain and any influence of the 2nd harmonic load will be minimised.

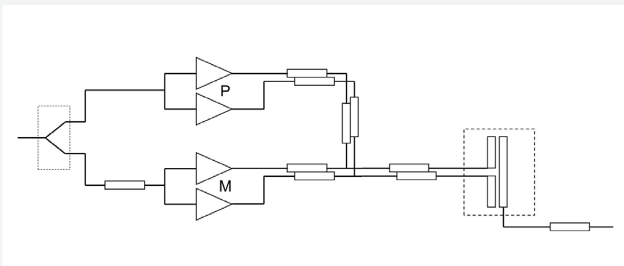


Fig. 7. Odd-Mode Ultra Wideband (a)-symmetric Doherty

Benefits

- Broadband (full band feasible)
- High power (250 W in Pallet)
- Efficiency (a-symmetric 2-Way Doherty feasible)
- Balun (no 2nd harmonic influence)

Disadvantages

- Use of 10 mil pcb
- Higher cost (multilayer pcb)
- Complexity
- Thermal measures needed
- No tuning of broadside coupled lines

The design is made in such a way that two Doherty combiners plus part of the transformer are placed on top of each other via a multilayer pcb (Fig. 8a). This will decrease space and increase impedance level by two (both sides working in odd-mode).

The first design was made with Ampleon's BLF888A/B transistors and delivered 220 Wavg broadband (from 470–800 MHz) with approx. 40% efficiency (Fig. 8b/c).

The concept has major advantages for reasons already mentioned, however it also has some disadvantages as listed in Fig. 7. The use of a multilayer pcb unfortunately will increase cost and needs thermal measures for the TL's. Also tuning of the circuit (e.g. the Doherty combiner) is significantly more difficult as some layers are buried. This implicates accurate modelling is mandatory. Note that some of these disadvantages are only valid for the implementation which was chosen in the present demonstrators.

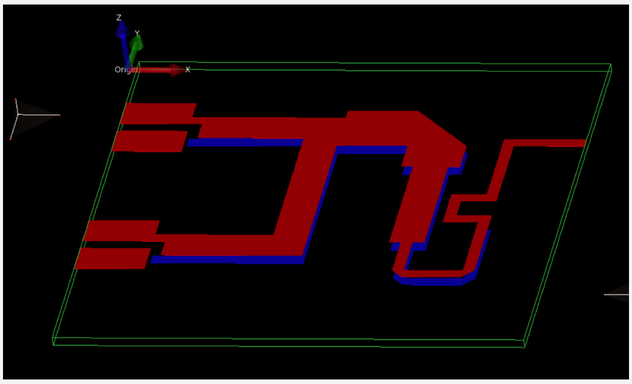


Fig. 8a. Odd-Mode UWB (a)-symmetric Doherty concept

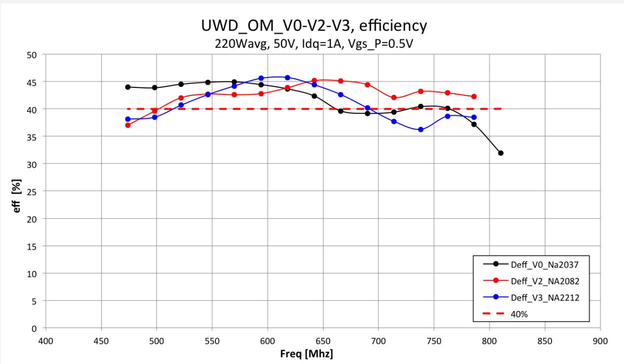
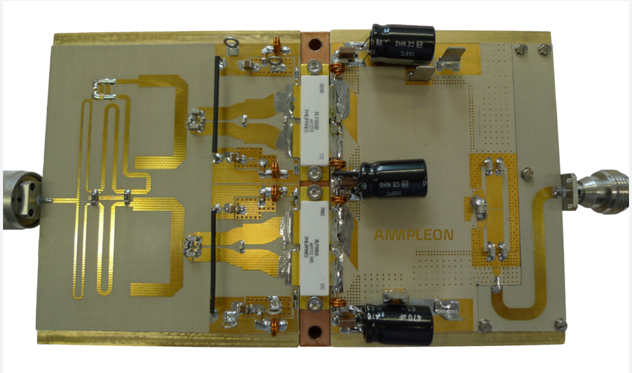


Fig. 8b. Symmetric Odd-Mode UWB efficiency

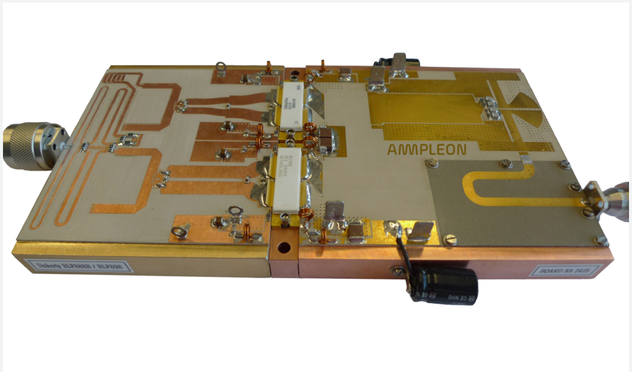
A-symmetric Odd-Mode Doherty:

For similar reasons as in the SE UWD amplifier the trend to higher efficiency also require the use of an a-symmetric Odd-Mode variant. This can be made using Ampleon's BLF888B (Main) and BLF898 (Peak) transistors, which gives the ideal back-off point (at 8 dB) as described earlier. This improves efficiency as was seen earlier at the cost of bandwidth.



Dimension = 200 x 100 [mm]

Fig. 8c. Odd-Mode UWB symmetric demo



Dimension = 210 x 100 [mm]

Fig. 8d. Odd-Mode UWB a-symmetric demo

The design method is similar to the symmetric variant, however, more attention is needed to deal with a higher power level (lower impedance level, thermal measures) and design with different transistors in Main/Peak (e.g. amplitude/phase alignment of input network). A picture of the a-symmetric odd-mode Doherty is shown in Fig. 8d.

The first iteration of the a-symmetric design has been measured and gives 250 Wavg with 45% efficiency. This is below the target of 50% and therefore a re-design is necessary. The next step is to optimise the characteristics (Po/eff) and improve the concept further on tuning possibilities and a decrease of cost level. Several thermal measures have been implemented in this design and this resulted in temperature levels of the coupled lines closer to acceptable values. This only needs minor improvements to keep the temperature level below 100° at full power.

2.4 3-Way Doherty Architecture

The architectures described so far, increased bandwidth (UWD variant(s)) and to some extent efficiency (a-symmetric Doherty variant). Further improvement of efficiency will generally be at the cost of bandwidth. Higher order Doherty amplifiers can provide more efficiency by providing a flatter efficiency characteristic in back-off. An example is a 3-Way Doherty structure. The Novel 3-Way Doherty (see [4],[7],[8]) provides (ideal) instantaneous efficiency curves as given in Fig. 10a, without an abrupt load-line discontinuity as in the classical 3-Way Doherty. The average efficiency increase of a Novel 3-Way Doherty ($\alpha2$ = 1/3 , $\alpha1$ = ½ respectively back-off points at -9.5 dB and -6 dB) above a symmetric Doherty is (in theory) about 9% as shown before in Fig. 2b.

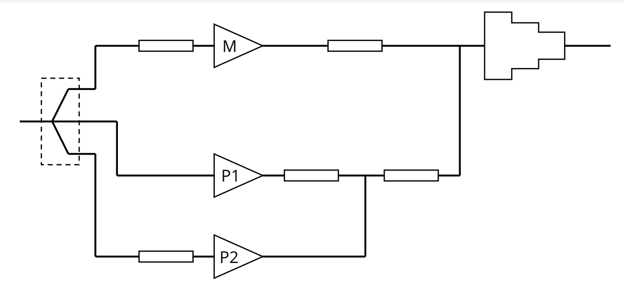


Fig. 9. 3-Way Doherty

Benefits
- High power
- Best efficiency
- Optimum in DVB-T and ATSC

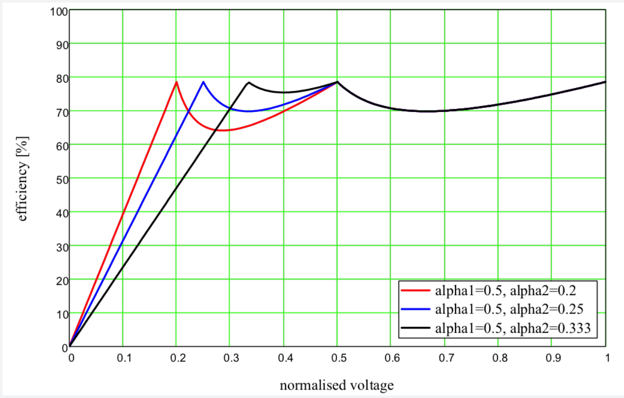
Disadvantages
- Bandwidth (needs more investigation)
- Complexity
- Stronger DPD needed
- No Balun

Implementation of a 3-Way Doherty can be done at 50 Ω level by adding the combiner structure at 50 Ω (narrowband version, using 50 Ω amplifiers and add e.g. 3-4 TL's as in the Novel concept) or designing the 3-Way Doherty by integrating the transistor parasitics in the Doherty combiner structure, similar to the UWD concept, see Fig. 9 (wideband version). The last concept obviously gives the highest bandwidth. Simulation of an ideal Novel 3-Way architecture shows approx. a relative bandwidth of 0.3, which is interesting for an improved (efficiency) UHF Doherty amplifier.

Note that a 3-Way Doherty with 50 Ω wideband amplifiers has the advantage of handling 2nd harmonic reflections in case a balun is used in the 50 Ω amplifier.

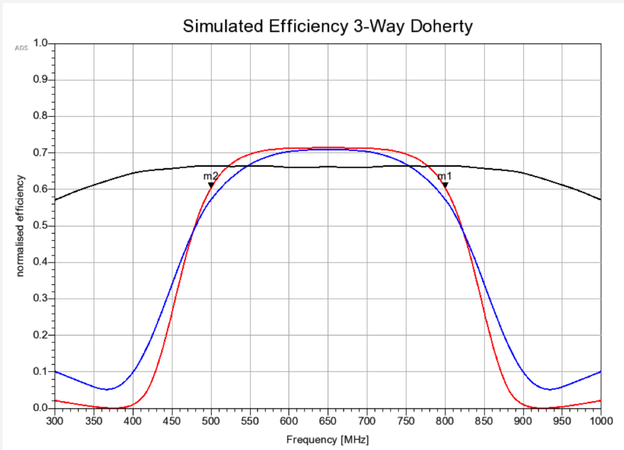
Advantage of the Novel 3-Way Doherty is the use of three equal size transistors and the higher power level compared to a 2-Way Doherty amplifier, e.g. using Ampleon's BLF888A/B transistors will raise average power to approx. 360 Wavg. As can be seen in Fig. 9, the flat efficiency characteristic will also improve efficiency for signals with different PAR's like DVB-T and ATSC.

This concept is in practice not yet realised for UHF frequencies and therefore needs more investigation.



3-Way Doherty with three different efficiency optimums for 2nd back-off point

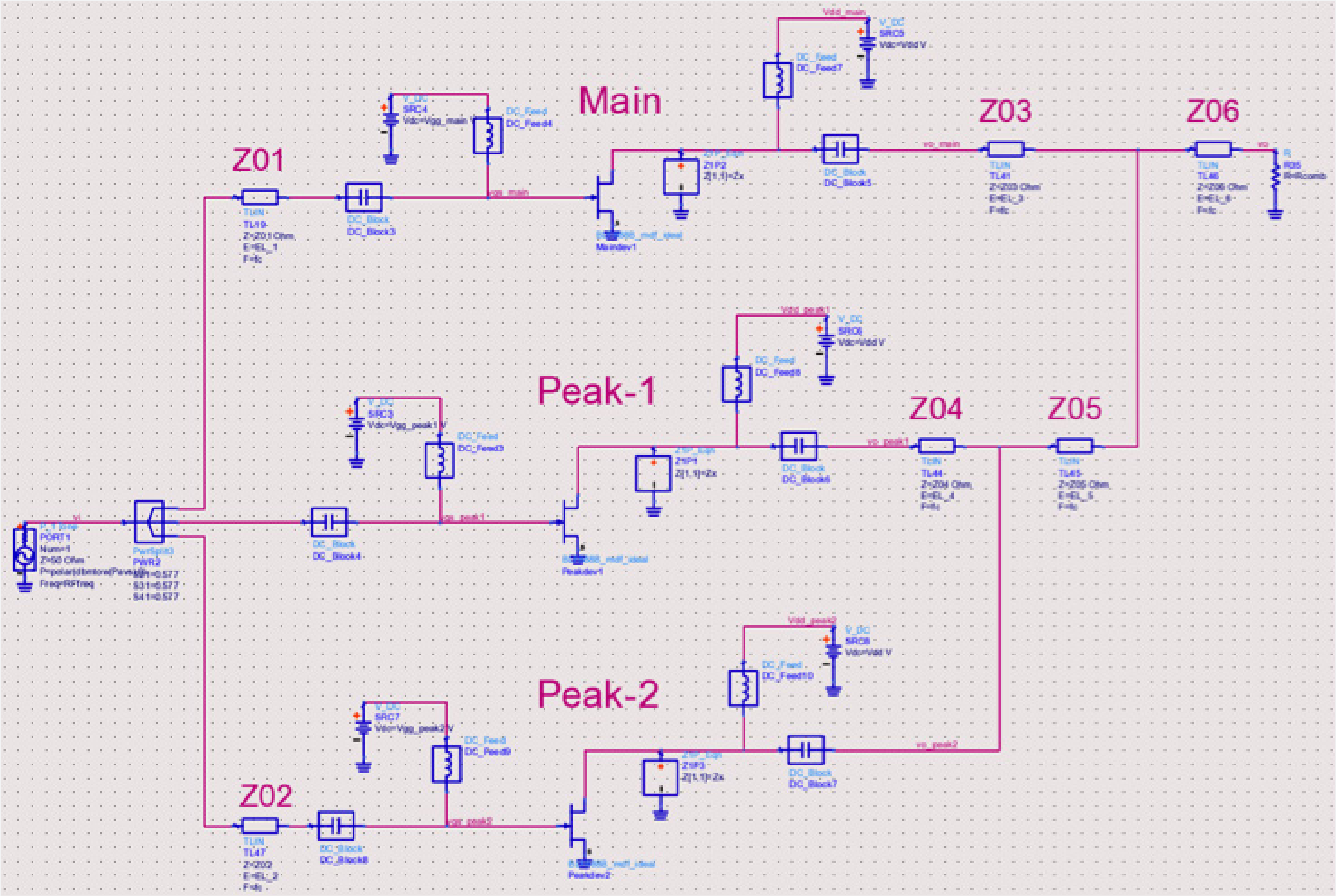
Fig. 10a. 3-Way Doherty efficiency (examples)



black line = full output power
blue line = approx. 6 dB back-off power
red line = approx. 9.5 dB back-off power

Simulated ideal network with shorted even/odd harmonics

Fig. 10b. Novel 3-Way Doherty ideal bandwidth



VAR
Device_Parameters4
Z01=50 {t}
Z02=50 {t}
EL_1=90
EL_2=90

VAR
Device_Parameters3
Z03=61.2*Ropt/50
Z04=50*Ropt/50
Z05=30.6*Ropt/50
Z06=35.4*Ropt/50
EL_3=90
EL_4=90
EL_5=90
EL_6=90

Normalised TL values of an ideal Novel 3-Way Doherty combiner (Z01 –Z06)

Fig. 5c. Combining via a balun

3. BLF888E

This chapter covers the BLF888E reference designs. The UHF band is split up as follows:

- Band 1: 470 - 610 MHz
- Band 2: 600 - 700 MHz
- Band 3: 650 - 800 MHz

These three designs are illustrated below in more detail.

All three demonstrators were designed on two different output pcb's (with different thicknesses) in order to have practical impedance lines in the Doherty combiner and be able to handle the full power in the 50 Ω output line. In all three designs Rogers 3010_10 mil and Rogers 2006_25 mil substrates were used. The pcb's were soldered on the heatsink for best reproducibility. The losses in the (output) transformer were limited to approx. 0.4 dB. More details of the demonstrators can be found in the three Ampleon application reports (see the corresponding report numbers in the tables below).

The low band design has different dimensions than the mid/high band designs. Main reason is that the high band design has a very small external length of the impedance inverter TL which limits the layout shape. The mid band design was derived from the high band design.

Input/output networks were designed in ADS. Due to limitations in modelling of transistor and circuit, the designs needed more iterations, e.g. the high band design was done in two iterations, where the tuning of the 1st iteration was done on the pcb (mainly the Doherty combiner needed extra tuning).

The transformer design is optimised on matching (> 30 dB RL), low loss (< 0.4 dB) and low 2nd harmonic impedance.

The input/output biasing circuitry influences a.o. low frequent (LF) stability. The output bias inductor parallel to the transistor Cds determines the LF resonance, which can be a cause of oscillation. Therefore the output inductor should be a compromise between influence on the RF network (inductor too small) or a too low resonance (inductor too large). In the case of a too large inductor, damping in the biasing network may be compulsory to avoid oscillation. Furthermore, a too large inductor will also increase memory effects which limit the pre-correction needed to achieve -38 dBc shoulder distance.

A more detailed design file of BLF888E can be obtained at Ampleon.

3.1 BLF888E Demonstrators

BLF888E Low Band Design:

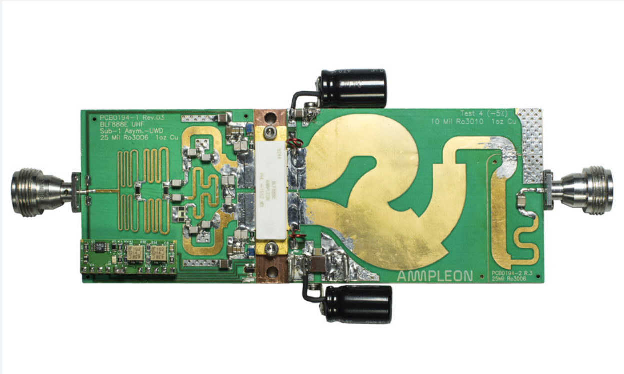


Fig. 11. BLF888E Low band design

Key Features

- Bandwidth 470-610 MHz
- Efficiency > 50%
- 150 W DVB-T
- Gain 17 dB
- Shoulder < -38 dBc
- Size: 147 x 56 mm
  Report: AR162048

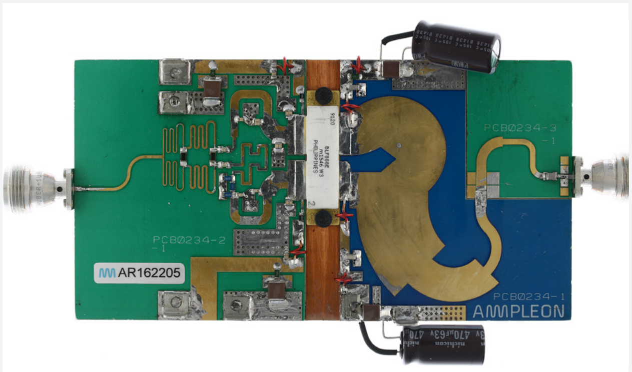


Fig. 12. BLF888E mid band design

Key Features

- Bandwidth 600-700 MHz
- Efficiency > 50%
- 150 W DVB-T
- Gain 16 dB
- Shoulder < -38 dBc
- Size: 125 x 80 mm
  Report: AR162205

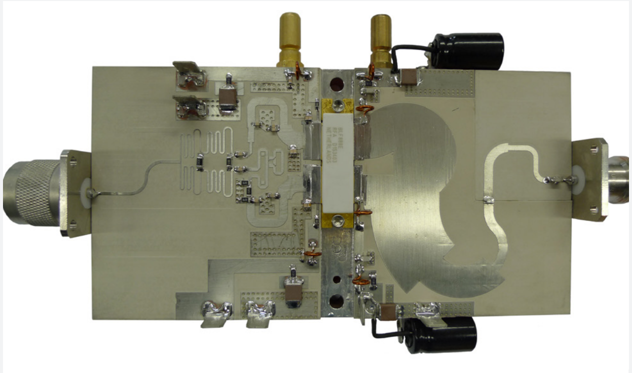


Fig. 13. BLF888E high band design

Key Features

- Bandwidth 650-800 MHz
- Efficiency > 48%
- 150 W DVB-T
- Gain 15 dB
- Shoulder < -38 dBc (depending on DPD)
- Size: 125 x 80 mm
  Report: AR151004

The measurements are presented in Fig. 14a/b. Where needed the Vgs_peak voltage was set differently to have the optimum trade-off between peak power and efficiency. Shoulder distance was measured at 4.3 MHz from Fcenter and is given with/without DPD. As can be seen, the whole UHF band can be covered with sufficient linearity (≤ -38 dBc).

Note: the high band is defined between 650-800 MHz, below 690 MHz there was too much AM-AM/AM-PM distortion for the DPD used to handle. A stronger DPD should be able to correct this amplifier.

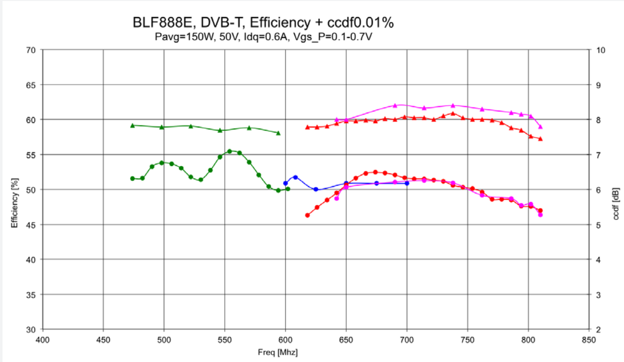
Note that a 2-band solution with BLF888E might be feasible with similar performance. More investigation in the low band design is needed to see if an extension to 650 MHz is a workable solution.

3.2 BLF888E thermal behaviour

A thermal example of a typical application of BLF888E is given in Fig. 15.

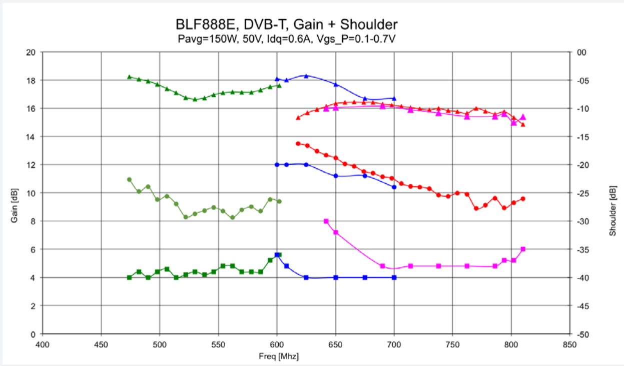
Remarks:

- Pd_main/Pd is dependent on PAR, Po and Vgs_p, chosen ratio Pd_main = 0.75·Pd
- Tc = 100 °C (assumption), is dependent on mounting of the device
- Rth = Pd_main/Pd ·Rth_main, Rth is dependent on PAR, Po and Vgs_p
- Rth _main ≈ 0.27 K/W (approx. 2·Rth of a similar symmetric device)



Measurement condition: Idq = 0.6 A, Vgs_p = 0.5 V (low-mid band), 0.1-0.7 V (high band)
Green = low band, blue = mid band, red/magenta = high band (red curve without precorrection).

Fig. 14a. BLF888E: ccdf + efficiency



Measurement condition: Idq = 0.6 A, Vgs_p = 0.5 V (low-mid band), 0.1-0.7 V (high band)
Green = low band, blue = mid band, red/magenta = high band (red curve without precorrection)

Fig. 14b. BLF888E: Gain + Shoulder

Po	150	[W]
PAR	8	[dB]
Efficiency	50	[%]
Pd_main/Pd	0.75	
Pdiss	150	[W]
Pdiss_main	112.5	[W]
Pdiss_peak	37.5	[W]
Tc	100	[°]
Rth_main	0.27	[K/W]
Rth_peak	0.27	[K/W]
Tj	130.38	[°]
Tj_peak	110.13	[°]
Rth (device)	0.203	[K/W]

Po=output power
PAR = Peak average ratio
Pd_main = dissipation main amplifier
Pd_peak = dissipation peak amplifier
Pd = dissipation full device
Tc = case temperature
Tj = junction temperature main amplifier
Tj_peak = junction temperature peak amplifier
Rth_main = Rth_j-c main amplifier
Rth_peak = Rth_j-c peak amplifier
Rth = Rth of full device
Tj = Pd_main·Rth_main + Tc

Fig. 15. BLF888E estimation of junction temperature

Conclusions:

- Tj (full device) ≈ 130 °C at 150 W/50% ,which ensures a high reliability
- Rth (full device) ≈ 0.2 K/W, is significantly lower than Rth_main (due to dissipation in the peak amplifier)
- Tj of BLF888E (150 Wavg/50%) will not be higher than Tj of BLF888D (115 W/40%) due to the increase in efficiency (+10 points)

3.3 BLF888E Configuration in a Transmitter

In order to have an 1 kW transmitter/amplifier, an option is to combine 8x BLF888E:

Ideal combining of 8x BLF888E gives 1200 Wavg. A max. loss of 0.8 dB is then allowed for 1 kW output power. This should include several losses over the required bandwidth:

- Coupling loss (3 dB hybrids)
- Insertion loss (of combiner and channel filter)
- Directivity loss
- Matching loss

It will depend strongly on the quality of the components whether the max. loss of 0.8 dB is feasible.

As indicated before, the channel filter will reflect 2nd harmonic component (generated by the transistors) and in Fig. 16a this will reflect towards one amplifier (= amplifier 8, also each of the seven ballast resistors will dissipate the same amount of 2nd harmonic power). In Fig. 16b this will reflect towards four amplifiers, also here, the four ballast resistors will dissipate the same amount of 2nd harmonic power.

Note that use of 3 dB hybrids will give unequal load impedances towards the Doherty amplifiers!

See the examples below for eight amplifiers with seven hybrids (Fig. 16c) and with four hybrids (Fig. 16d): RL = 20 dB (output load), S11_1 – S11_8 are unequal.

To compensate for this mismatch, each BLF888E (Doherty) amplifier needs a different matching network optimised for the load impedance seen by this amplifier. This would result in an unpractical solution.

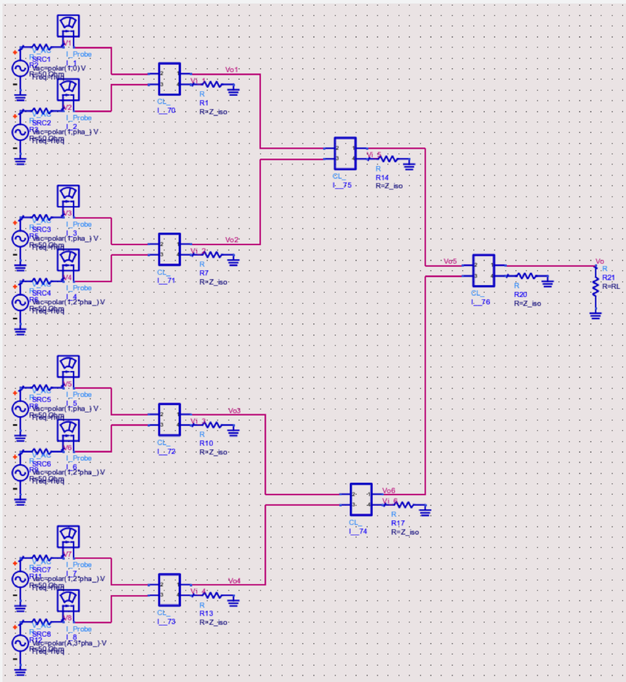


Fig. 16a. Combining with 7 hybrids

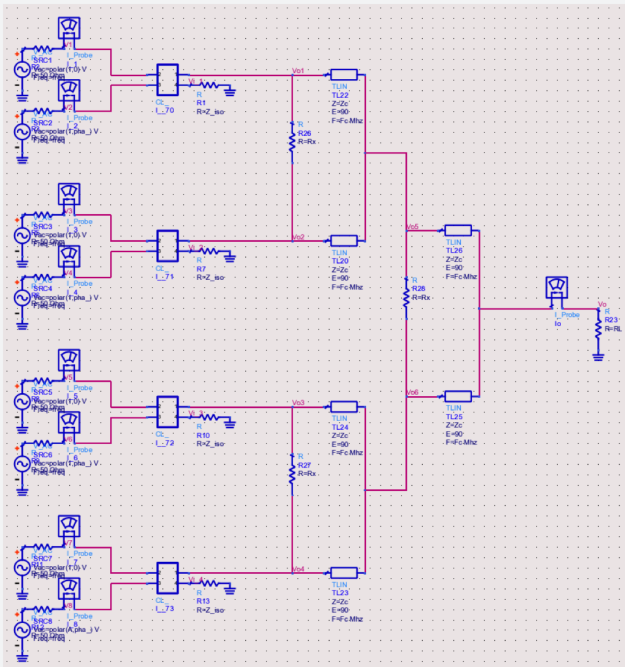
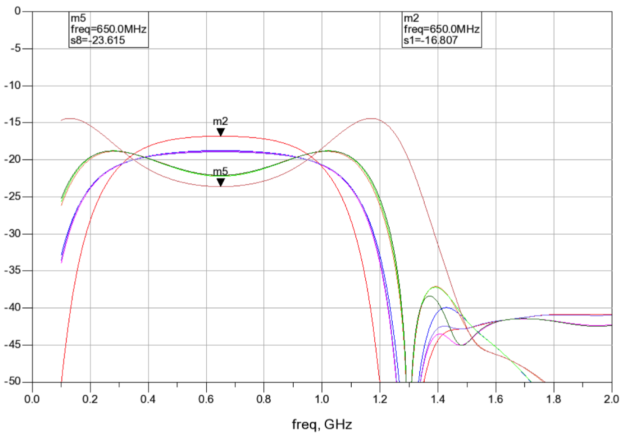
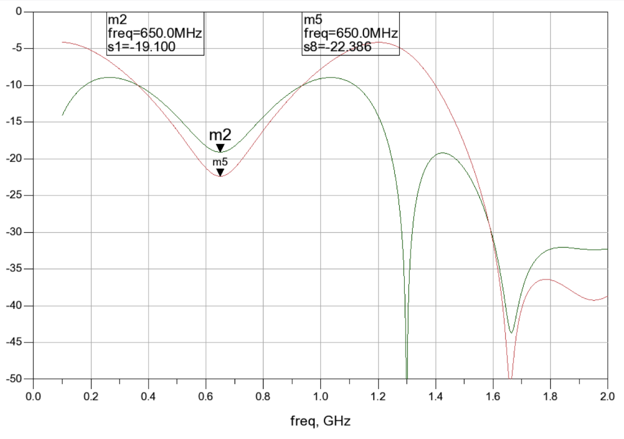


Fig. 16b. Combining with 4 hybrids + 3 Wilkinsons



Simulation: return loss 20 dB (output RL = 50 Ω/1.22), simulated S11 seen by eight amplifiers (s1 – s8)

Fig. 16c. Combining with 7 hybrids / s1-8



Simulation: return loss 20 dB (output RL = 50 Ω/1.22), simulated S11 seen by eight amplifiers (s1 – s8)

Fig. 16d. Combining with 4 hybrids + 3 Wilkinson / s1-8

Note that the hybrid solution performs much better regarding bandwidth compared to a single stage Wilkinson coupler (a Wilkinson can be improved on bandwidth by choosing a multi-section variant).

A Gysel combiner is preferred above a Wilkinson in case of higher power levels because of low IL and having the ballast resistors to ground.

4. Summary

Nowadays, more and more efficiency is required in broadcast transmitters.

The Doherty concept is chosen by almost all broadcast manufacturers because of easy implementation, only a small cost increase and low complexity. Depending on regional differences and other requirements, there is a demand for different solutions and trade-off's.

Several Doherty architectures were discussed in this paper which should help to make the best choice/trade-off. Ampleon's new Doherty devices BLF888D and in particular BLF888E support Ultra Wideband Doherty concepts and raise the efficiency to a level above 50%.

In case a full band coverage with one amplifier design is needed (no tuning), UWD with BLF888D gives a solid solution. BLF888E provides a high efficiency solution (50%) when a split-up of the UHF band is allowed (two or three bands).

The Odd-Mode Doherty concept solves fundamental harmonic problems in the single ended UWD amplifier but is still in a development phase. Feasibility has been proven in the symmetric variant where 220 Wavg/40% was measured full band. However, the full band design was sensitive and furthermore there is need for more efficiency than 40%. The a-symmetric variant can provide higher efficiency but needs a redesign to achieve the required target levels (250 Wavg/50% in a 2-band design).

Future concepts will need more efficiency and the Novel 3-Way Doherty can give a significant increase but also needs more investigation.

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