TRANSMITTER ARCHITECTURES FOR HIGH EFFICIENCY AMPLIFICATION

using

PowerSDR software and Hermes firmware

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2018

The dissipated heat dilemma

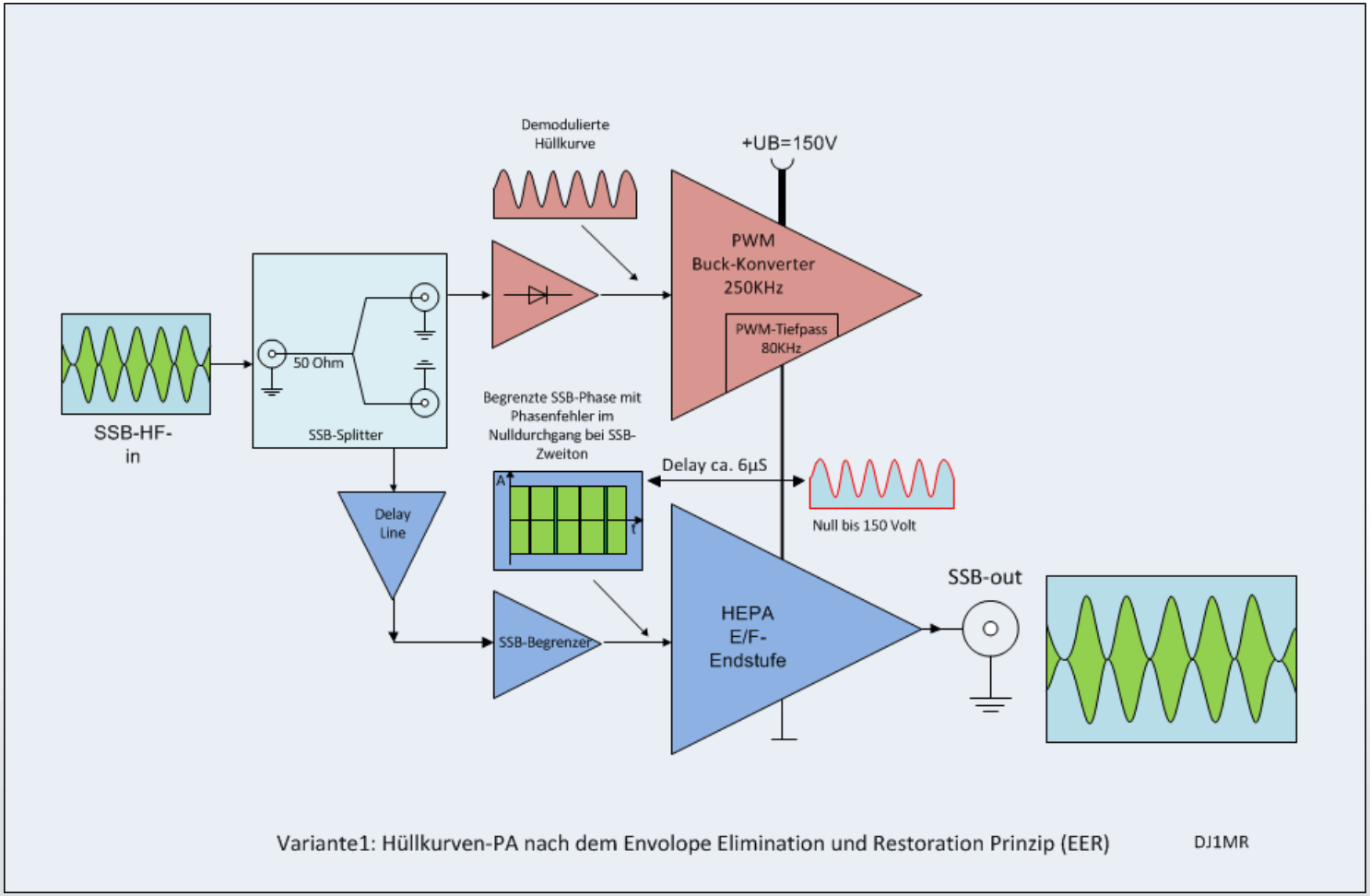
- Legacy linear RF power amplifiers consume large amounts of energy,
- dissipate heat take up space in RF power amplifiers,
- large heatsinks are increasing the weight and the expenses of the PA,
- fans are generating often too much noise,
- Significantly more efficient PA technology will be the future goal
- Basic requirements for future power amplifier technology
  - high linearity,
  - high efficiency
  - smaller dimensions
  - greater output power levels

1. Supply Modulated Transmitters

Principles of Supply Modulated Transmitters

- Envelope Elimination and Restoration (EER), (Kahn technique)
- Hybrid Envelope Elimination and Restoration (H-EER)
- Envelope Tracking (ET).
- **EER**
- EER technique combines a highly efficient, but nonlinear RF PA with a highly efficient envelope amplifier to implement a high-efficiency linear RF PA.
  - In its classic form, a limiter eliminates the envelope and allowing the constant-amplitude phase modulated carrier to be amplified efficiently by class-C, class-D, class-E, or class-F RF PAs.
  - Amplitude modulation of the final RF PA restores the envelope to the phase-modulated carrier creating an amplified replica of the input signal.

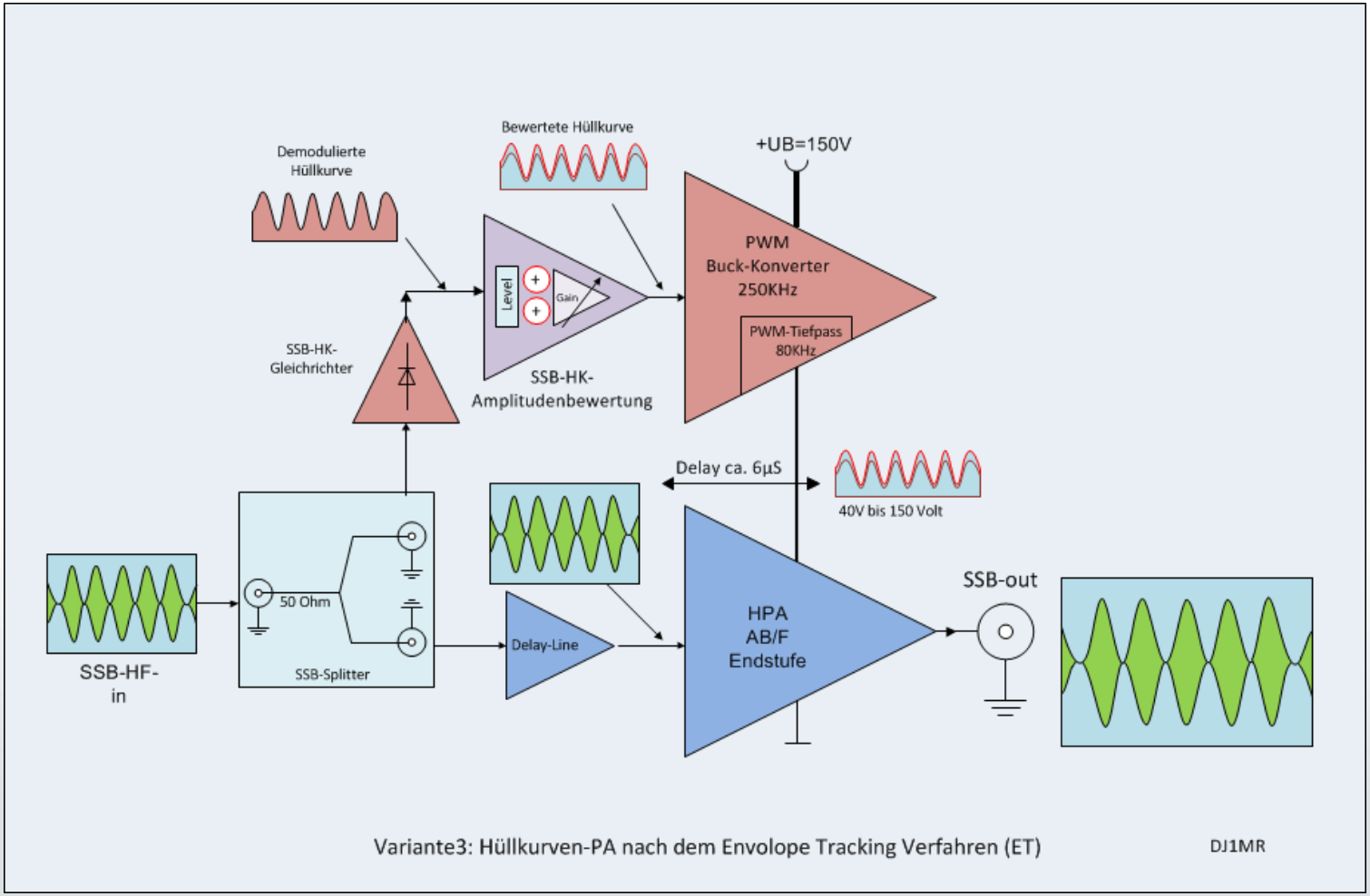
Transmitter based upon the *Kahn* EER technique



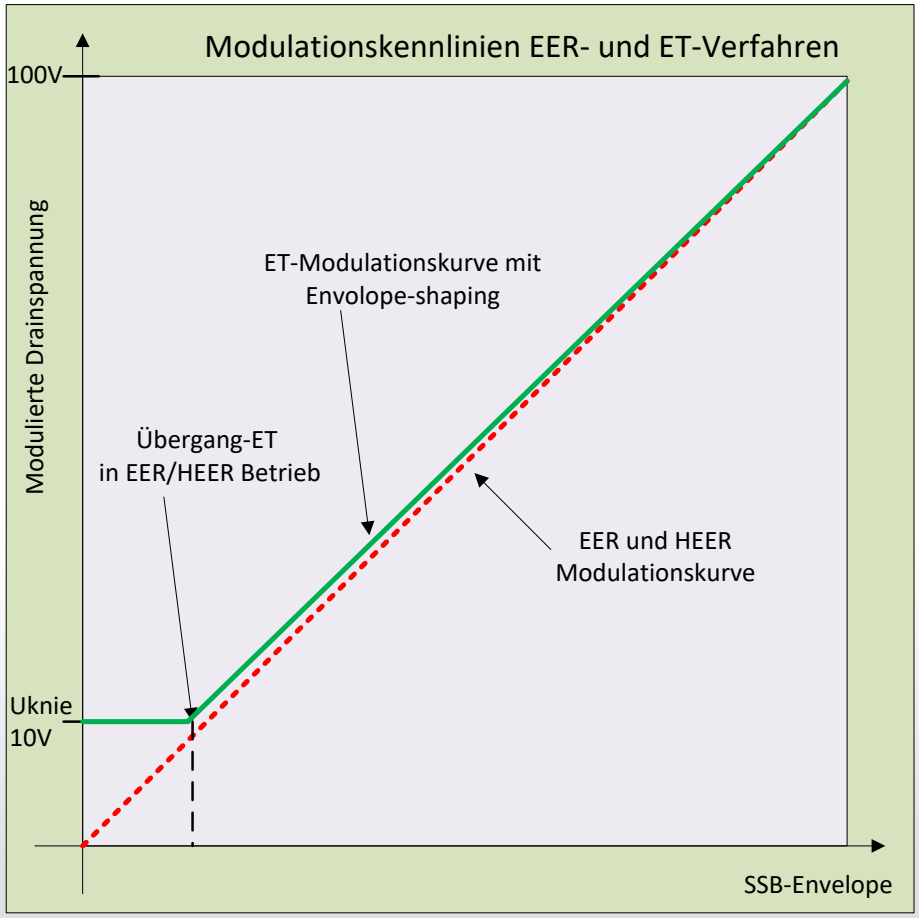
Principles of supply-modulated transmitters

- **ET**
- the input signal of the PA is not a constant envelope signal with phase information but a complex-signal envelope
- the ET transmitter has advantages of the H-EER transmitter, such as less precise time alignment between the envelope and RF paths.
- the envelope signal injected into the PA is no longer the original envelope and is adjusted for optimized performance
- V-offset is a bit greater than the knee voltage of the power mosfets and the severely nonlinear behavior caused by nonlinear capacitance impedance mismatch of the PA is prevented
- traditionally, linear PAs such as class-AB amplifiers, are utilized in ET transmitters to obtain good linearity with high efficiency
- the burden of sufficient IMD3 lays only on the HEPA

Transmitter based upon ET technique



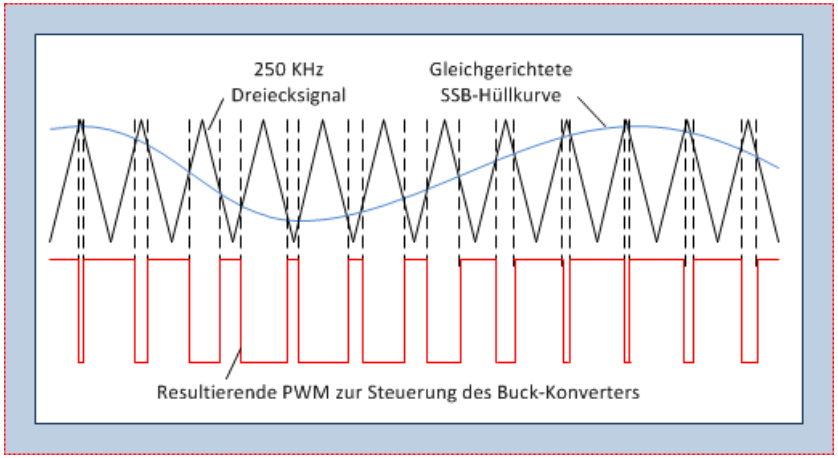
Modulation schemes of the power supply



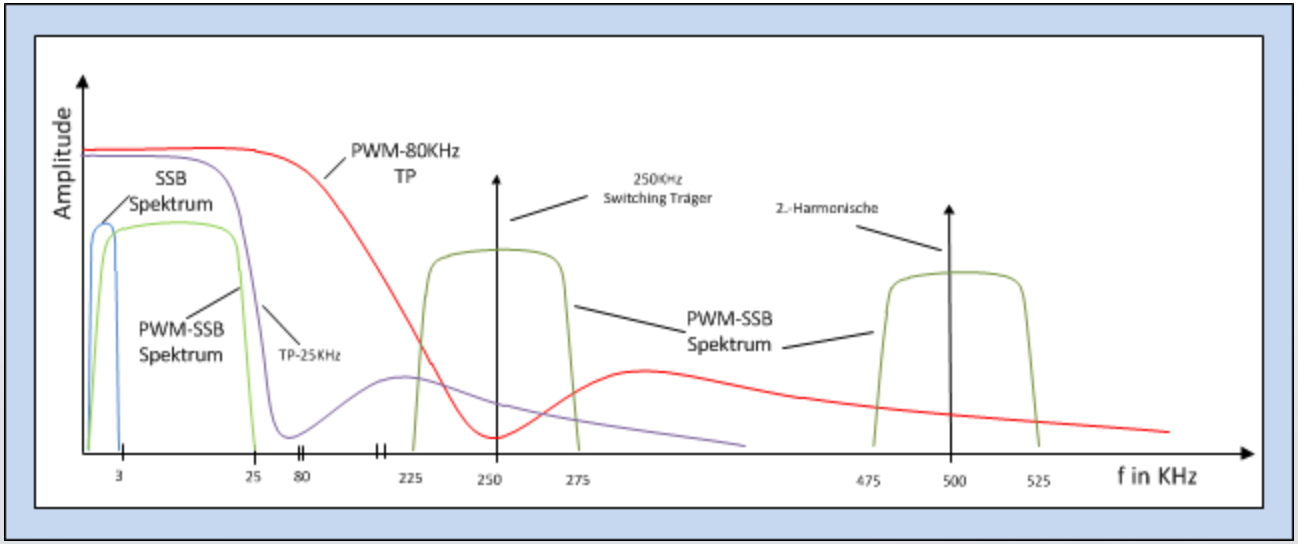
- Caracteristic modulation lines
- **red dashed**: conventional EER/H-EER Shaping Function, increases linearly
- **green continuous**: starts with U_{knee} offset value is one Type of ET Shaping Function

2. Pulse Width Modulation (PWM) using Hermes and PowerSDR software

PWM principles, PWM spectrum



- The width of pulses is varied in proportion to the instantaneous amplitude of the SSB envelope
- The digital PWM signal has more bandwidth than the original SSB signal (25 to 32 KHz)
- Around the switching carrier and the harmonic carriers you see also the digital PWM LSB and USB



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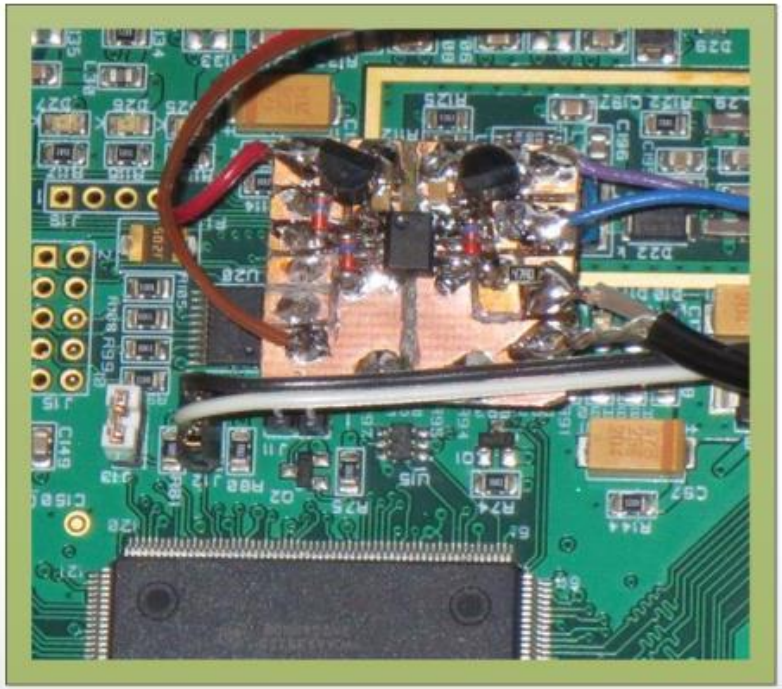
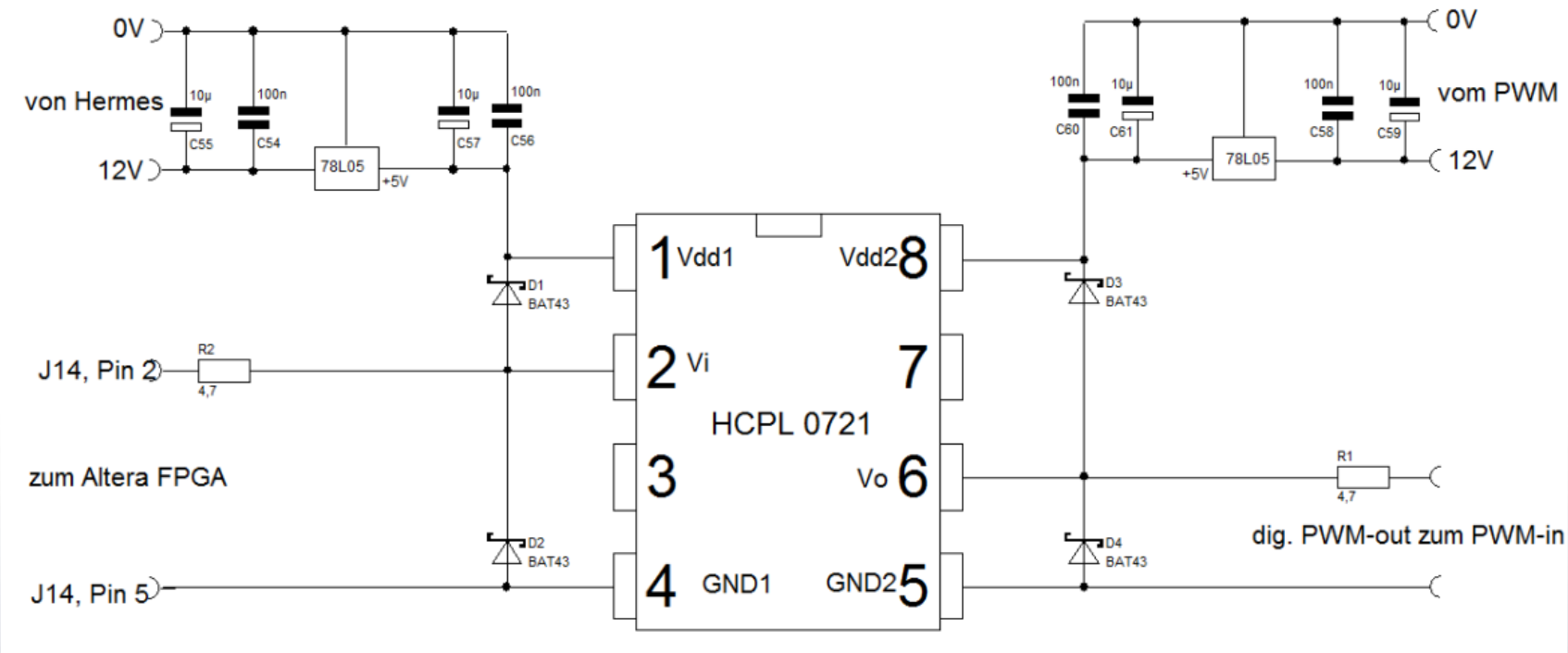
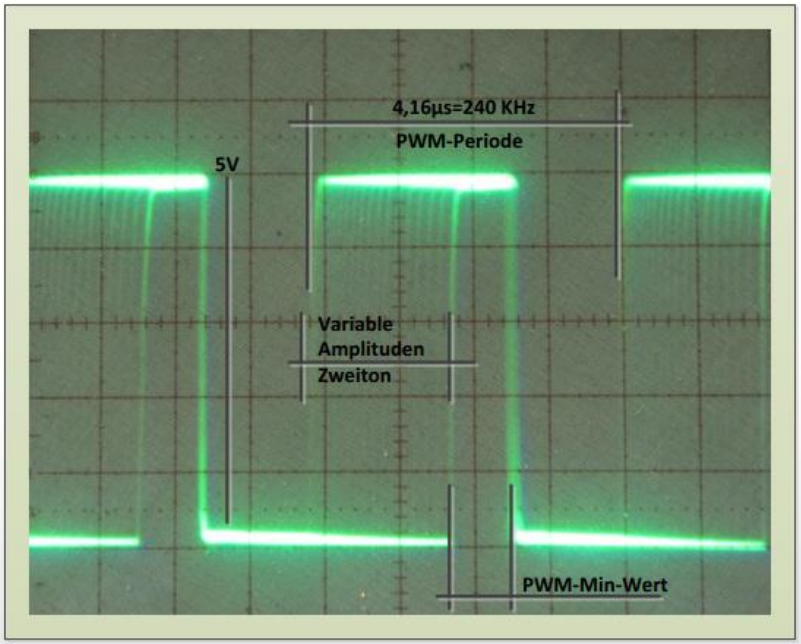
Getting PWM from Hermes board on J14/Pin2



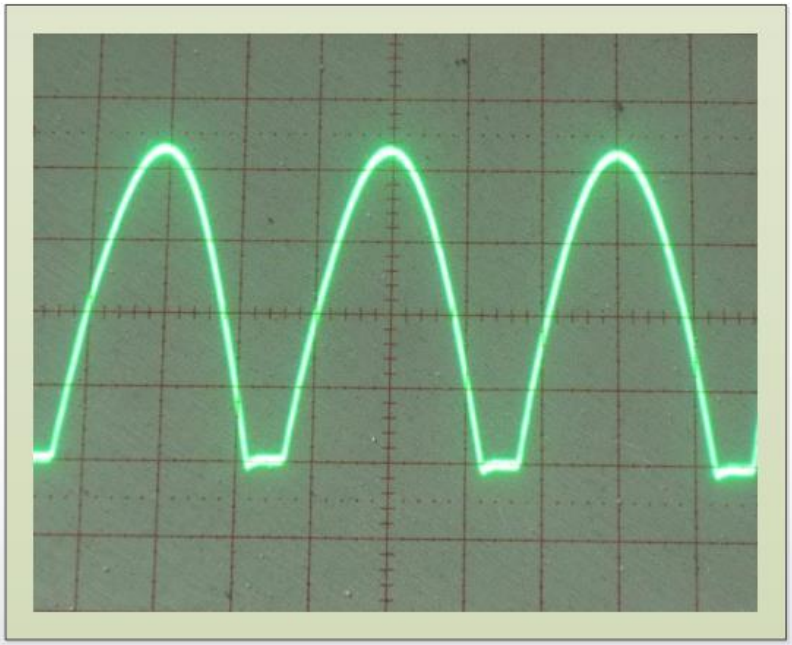
Circuit diagram PWM adapter



PWM Two Tone and Analog PWM Envelope Signal

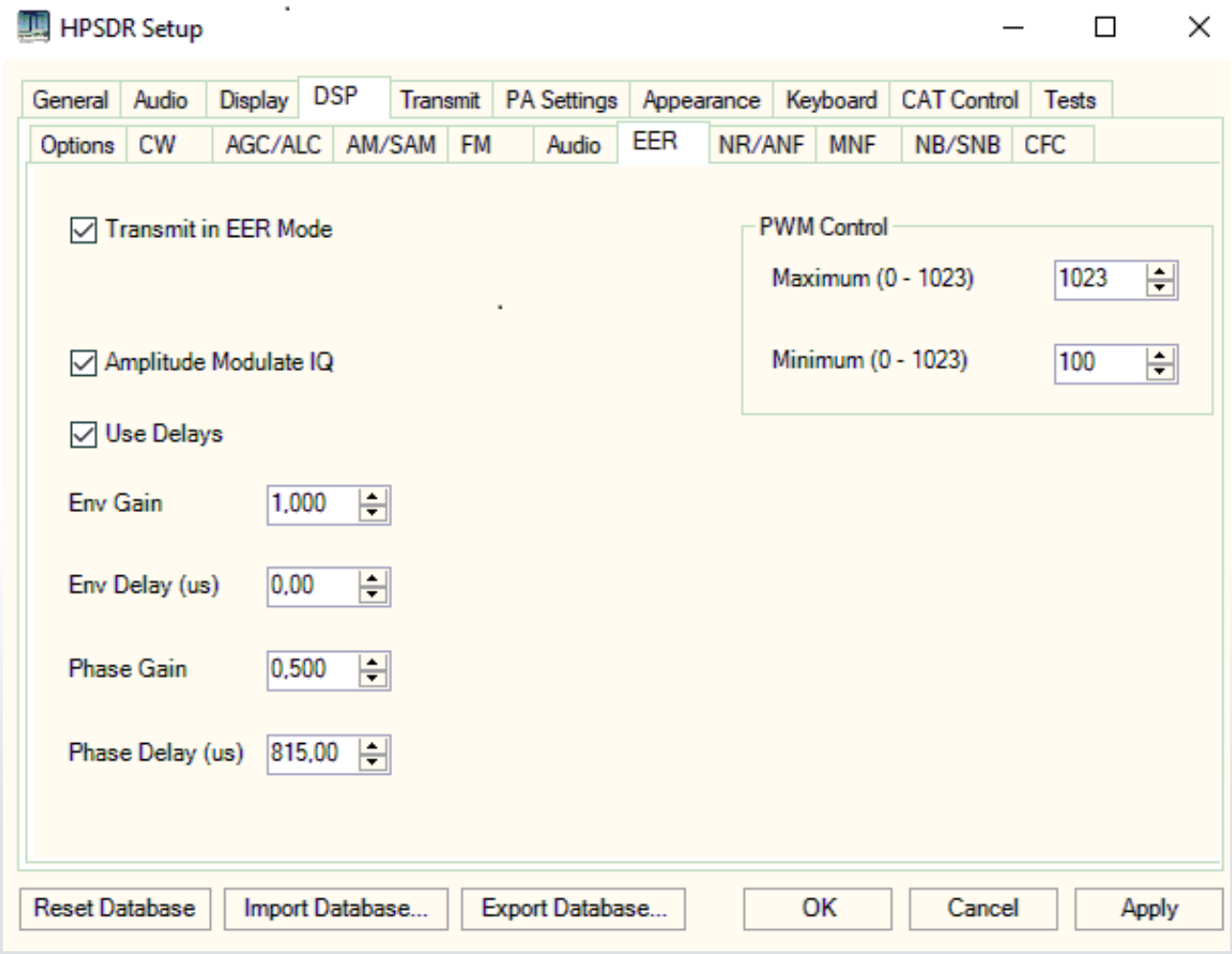


Digital 5 volts PWM



Filtered Analog Envelope Signal

EER menu in Power SDR software



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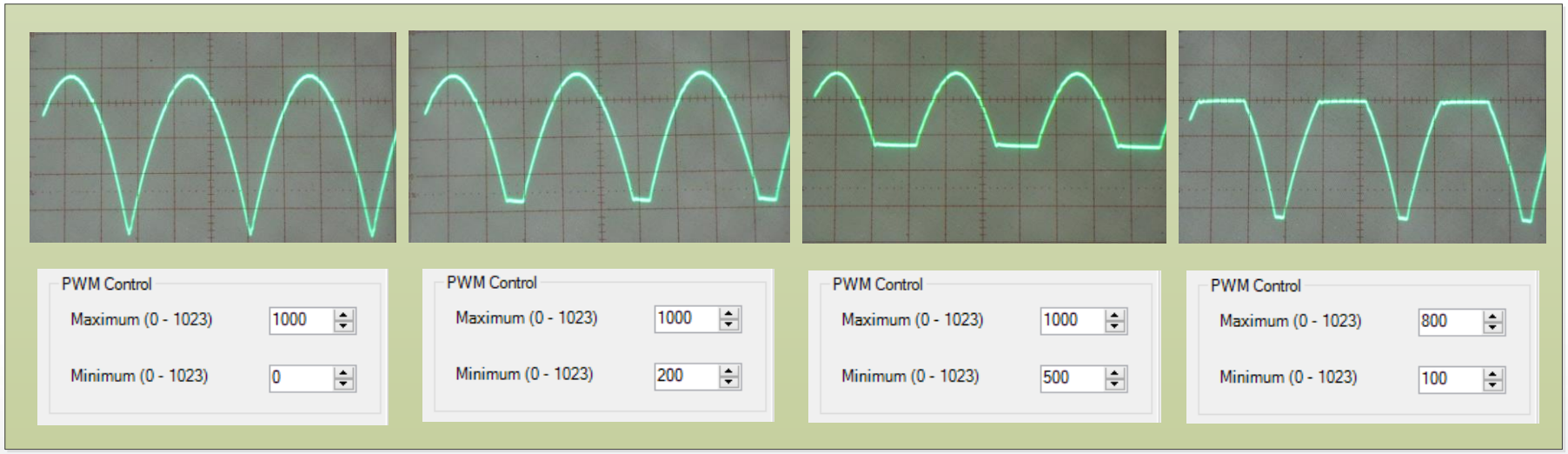
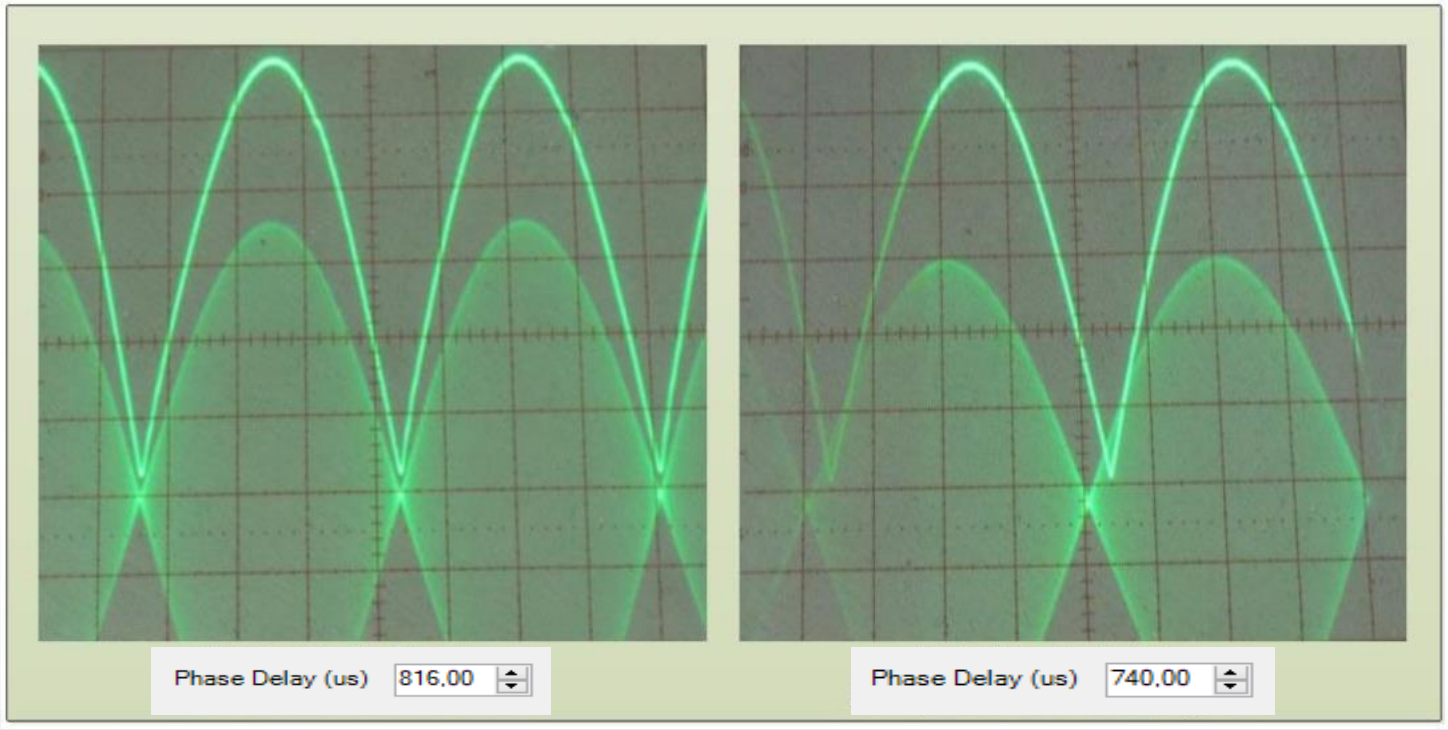
PWM control function in PowerSDR



EER Mode ET Mode ET Mode ET Mode

Time alinment between Envelope and Phase



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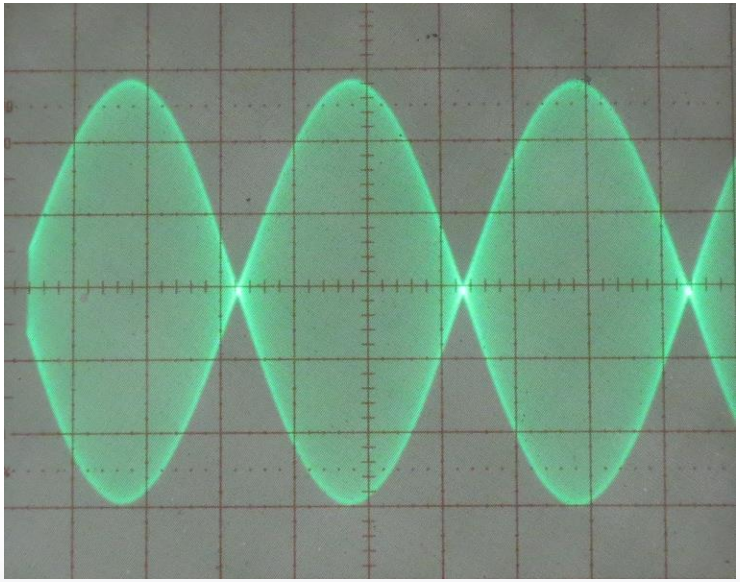
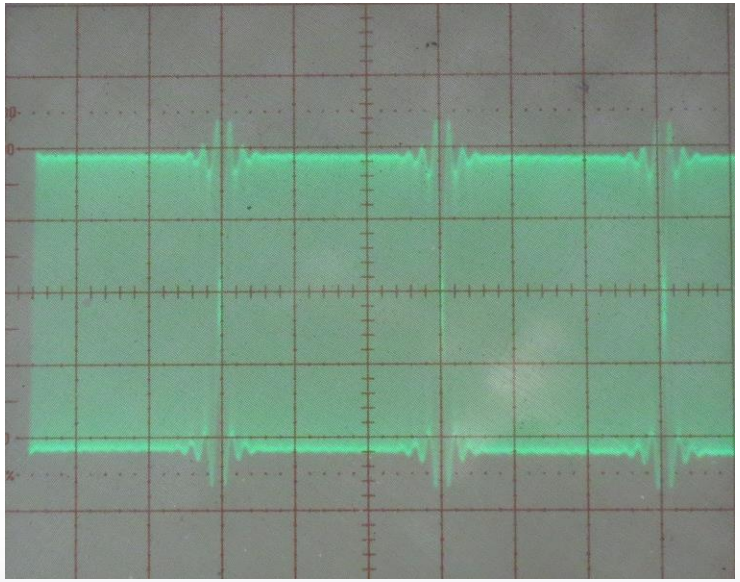
Two types of SSB Phase Signals



☑ Amplitude Modulate IQ

Amplitude Modulate Phase Signal

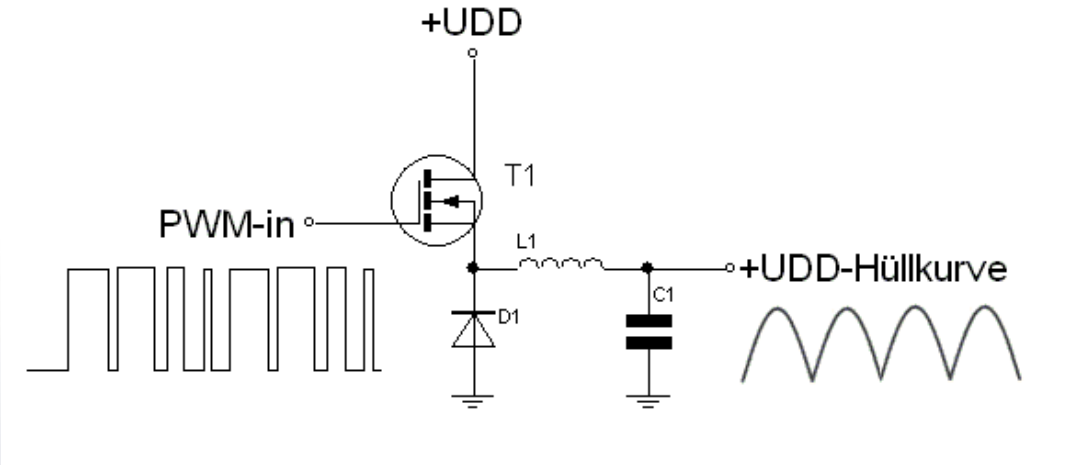


☐ Amplitude Modulate IQ

Constant Amplitude Phase Signal

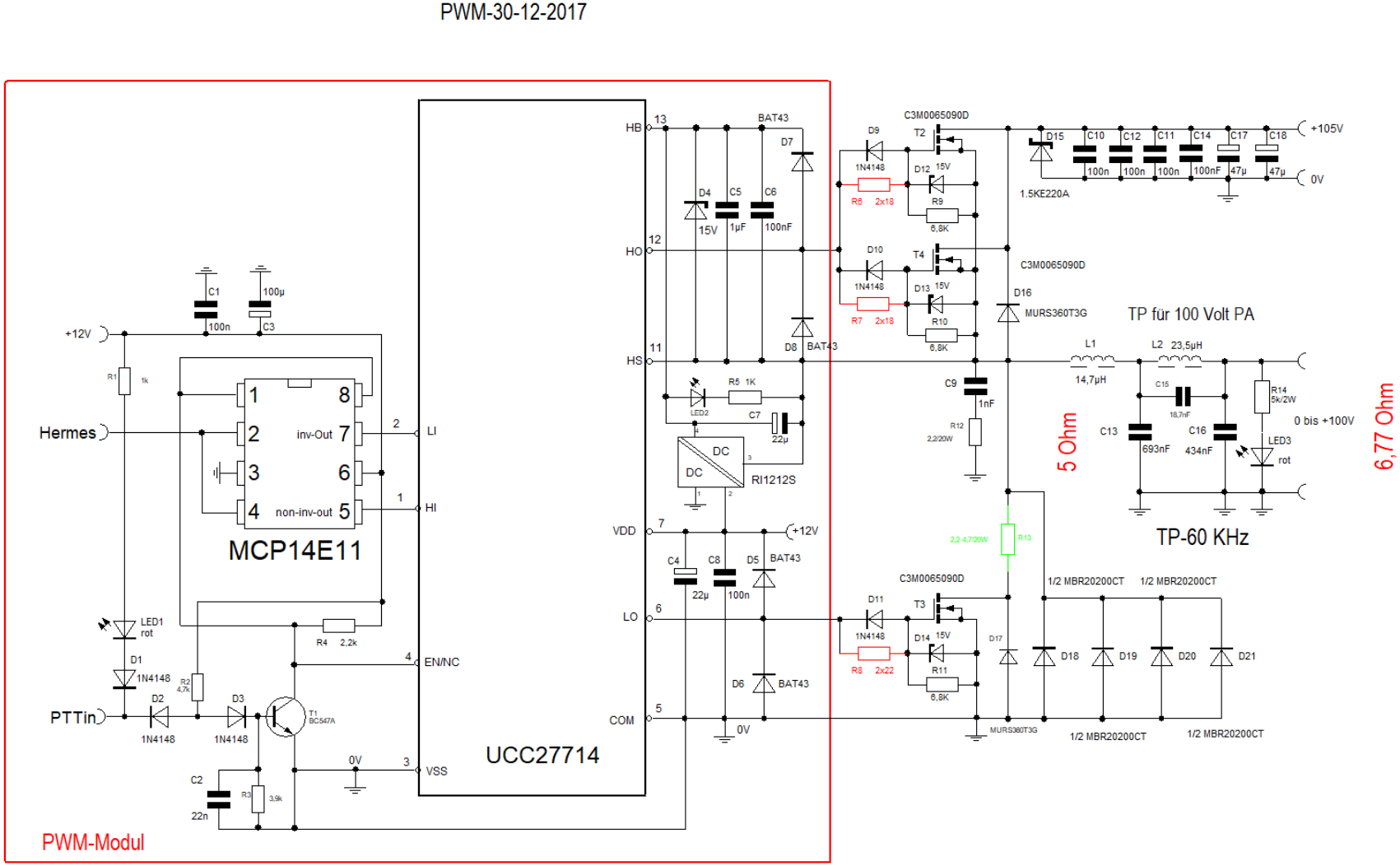
PWM Class S-modulator

- In PWM the most widely used high-level modulator is class S
- A transistor and diode act as a two-pole switch to generate a rectangular waveform with a switching frequency several times that of the output signal (for instance 240 KHz and higher).



- The width of pulses is varied in proportion to the instantaneous amplitude of the desired output signal, which is recovered by a low-pass filter.
- Class S is ideally 100% efficient and it can have high efficiency over a wide dynamic range.

Gen 2 PWM circuit diagram for Hermes transceivers



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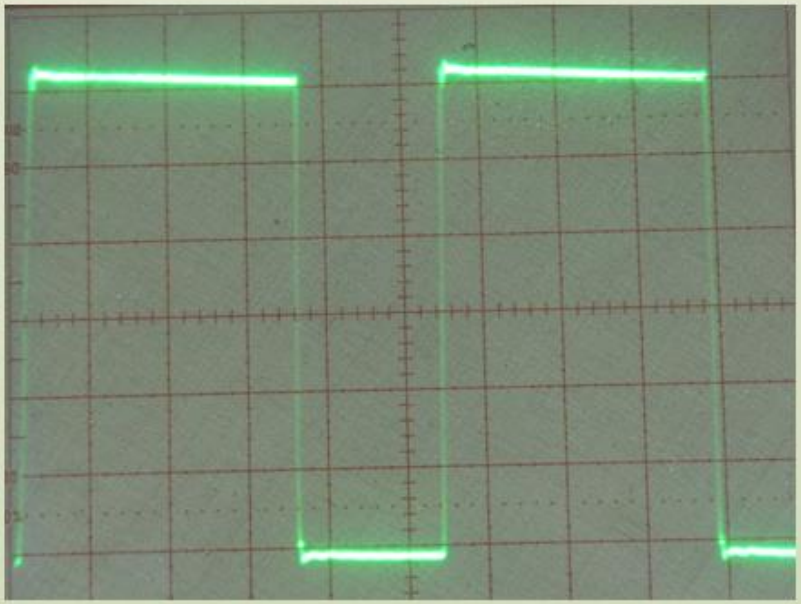
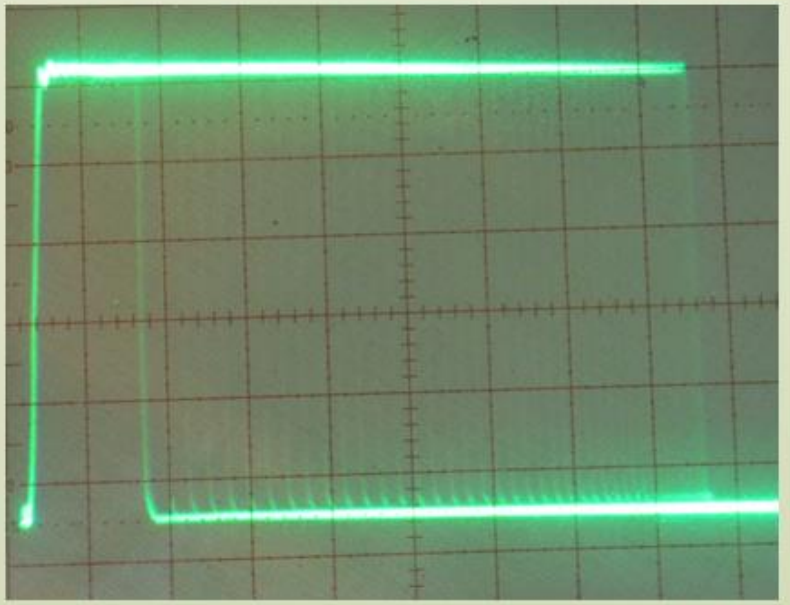
Impulses on HS PIN UCC27714

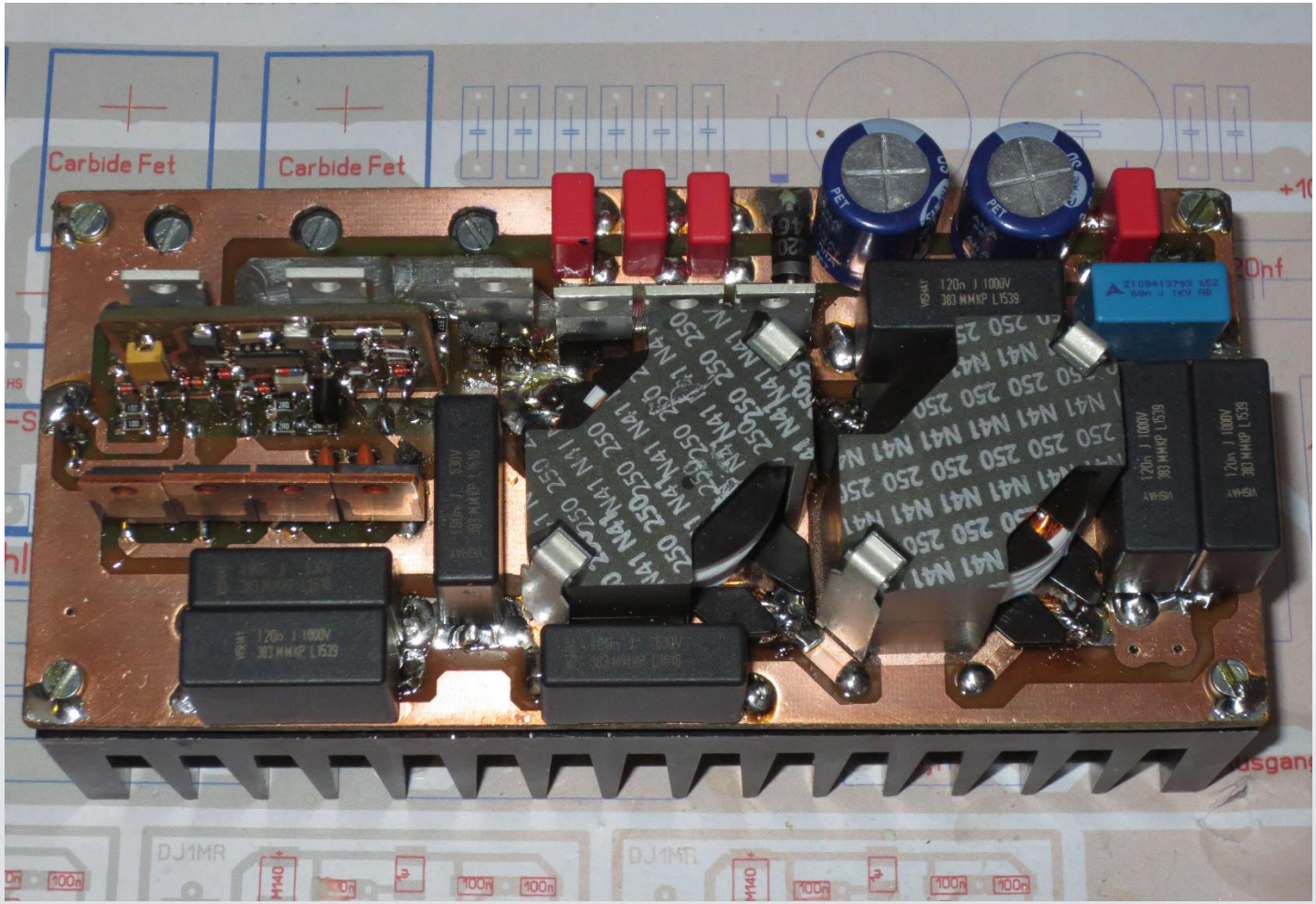


Impulse an MP1 für einen unmodulierten HF-Träger

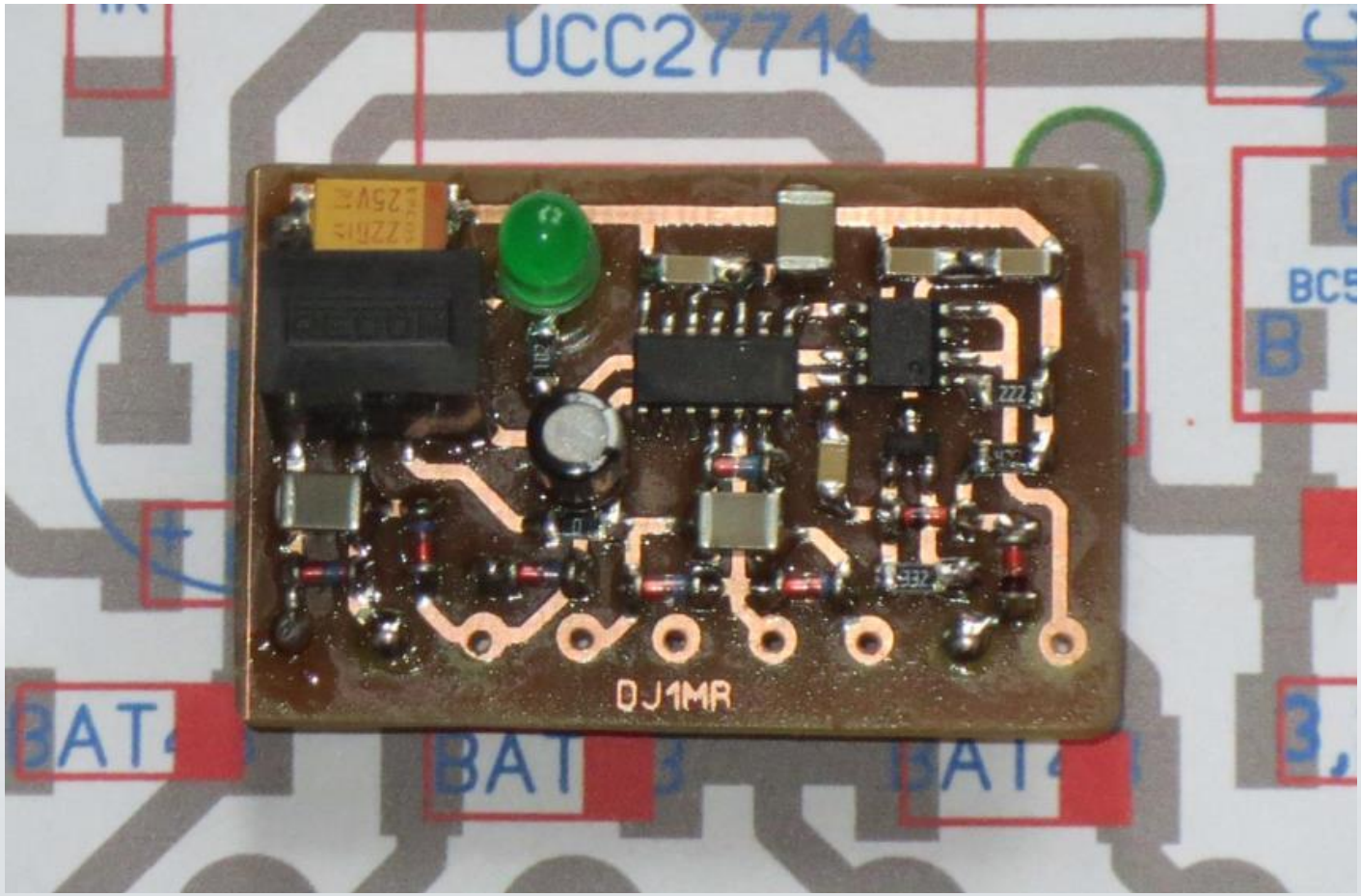


Impulse an MP1 für einen SSB-Zweiton

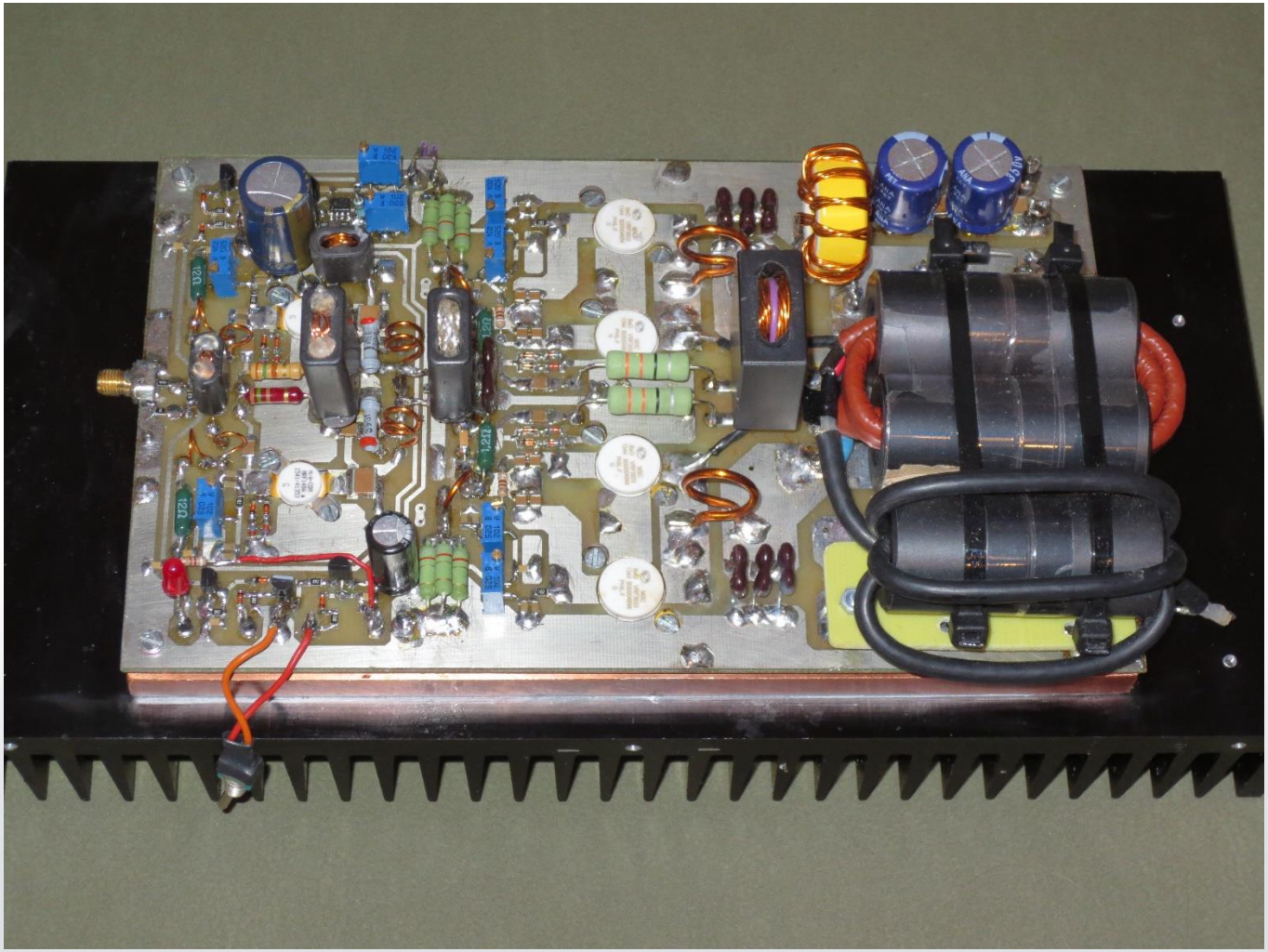
Gen 2 1KW PWM Prototype



PWM control driver modul



Realized 160 m – 6 m 1 KW ET amplifier



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IMD3 with linearity 750 W out

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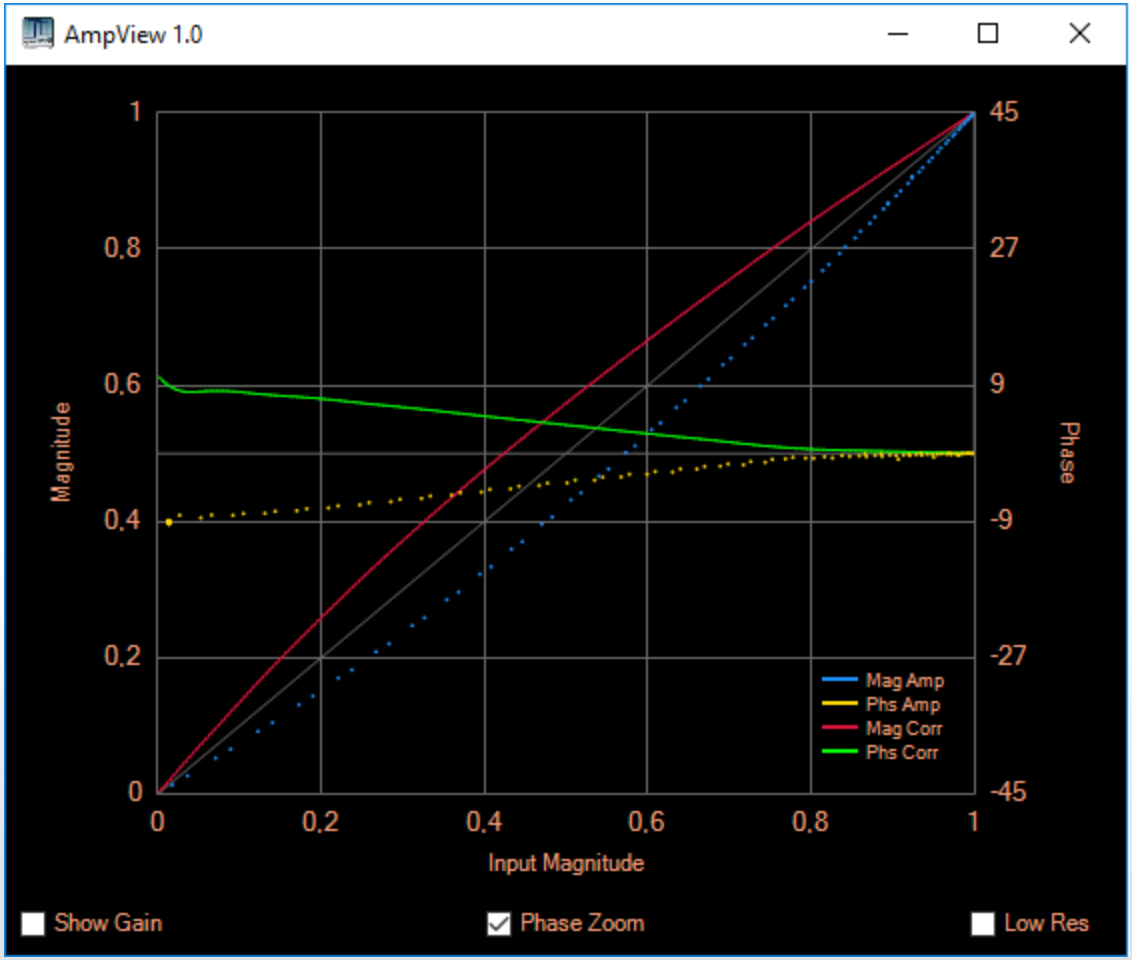
Linearity correction with PowerSDR



- AmpView ET PA 750 Watt
- No memory effect

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3. Helpful entry in PWM technology using CREE Evaluation Boards

CREE Evaluation Board for Buck Converter

KIT8020-CRD-5FF0917P-2

Evaluation Board for Cree's SiC MOSFET in a TO-247-4 Package

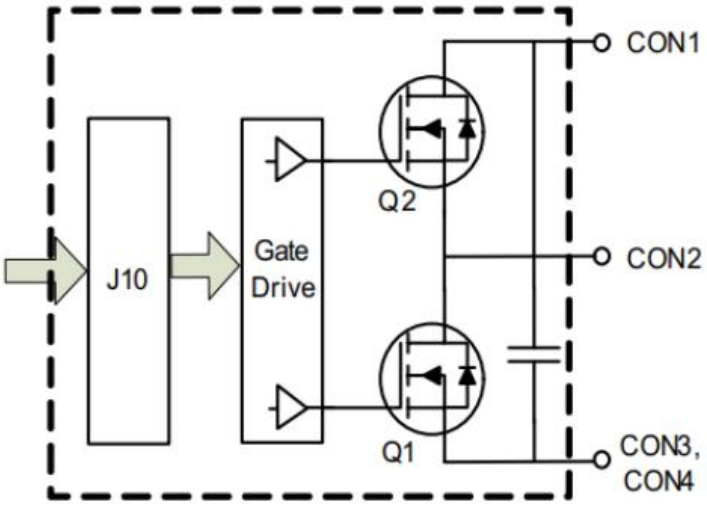

Figure 5. Block Diagram of Cree KIT8020-CRD-5FF0917P-2 evaluation board

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CREE Evaluation Board for Buck Converter

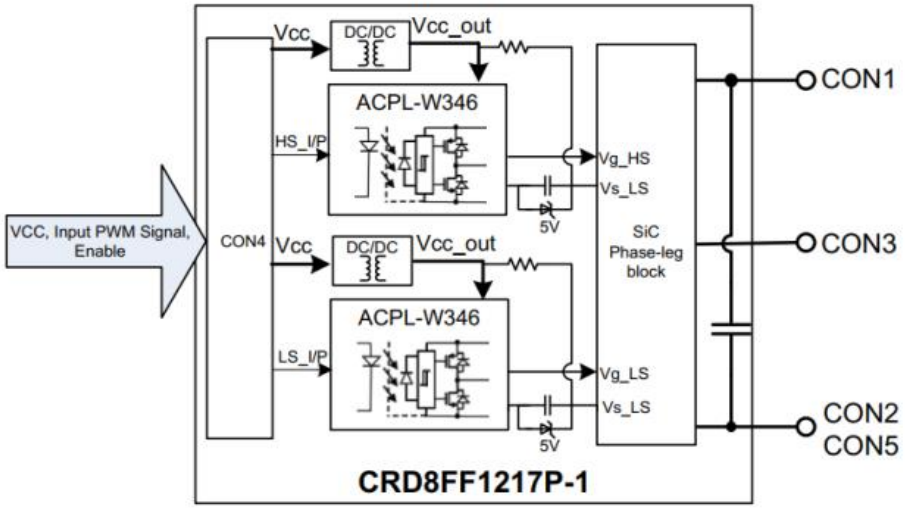

Figure 2. CRD8FF1217P-1 Block diagram with ACPL-W346

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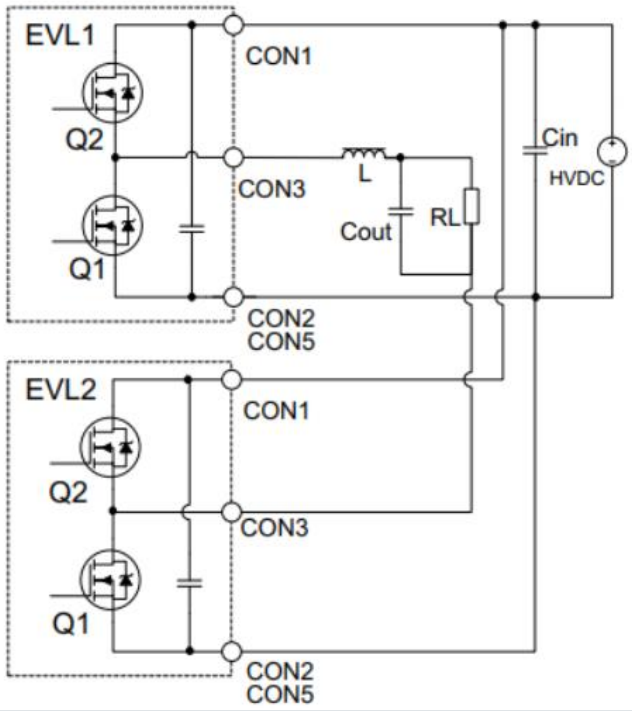
Full bridge converter with two CREE boards

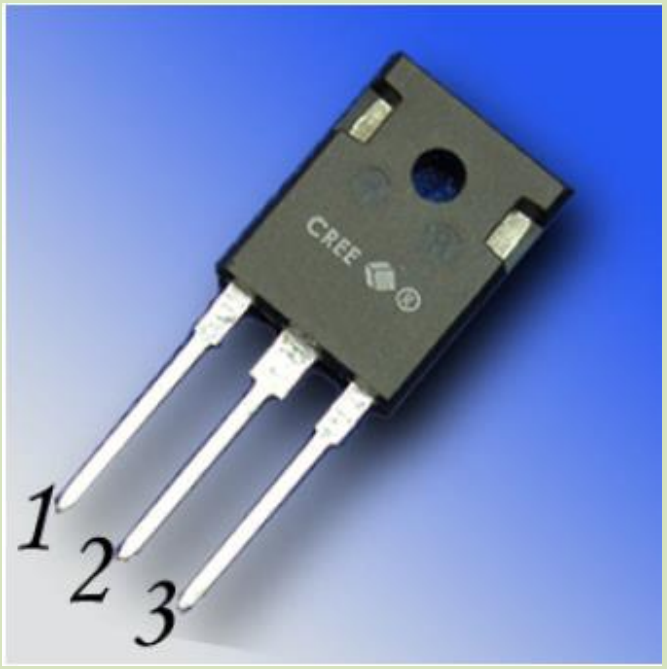
Option Seven:

H bridge topology configuration using two EVL boards



- Full bridge converter with Phase shift or resonant
- single phase DC/AC inverter

Usable Carbide Power Mosfets from CREE



Typ: C3M0065090D
Package TO247-3

Typ: C3M0065090J
Package 7L-D2PAK

Usable Carbide Power Mosfets from CREE

CREE

C3M0065100K

Silicon Carbide Power MOSFET
C3M™ MOSFET Technology
N-Channel Enhancement Mode

V_{DS}	1000 V
$I_{D\ @\ 25°C}$	35 A
$R_{DS(on)}$	65 mΩ

Features

- New C3M™ SiC MOSFET technology
- Optimized package with separate driver source pin
- 8mm of creepage distance between drain and source
- High blocking voltage with low on-resistance
- High-speed switching with low capacitances
- Fast intrinsic diode with low reverse recovery (Q_{rr})
- Halogen free, RoHS compliant

Benefits

- Reduce switching losses and minimize gate ringing
- Higher system efficiency
- Reduce cooling requirements
- Increase power density
- Increase system switching frequency

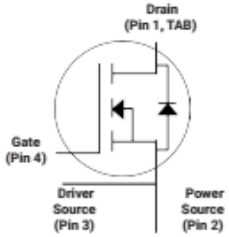
Applications

- Renewable energy
- EV battery chargers
- High voltage DC/DC converters
- Switch Mode Power Supplies

Package

Halogen-Free

RoHS



Part Number	Package	Marking
C3M0065100K	TO 247-4	C3M0065100K

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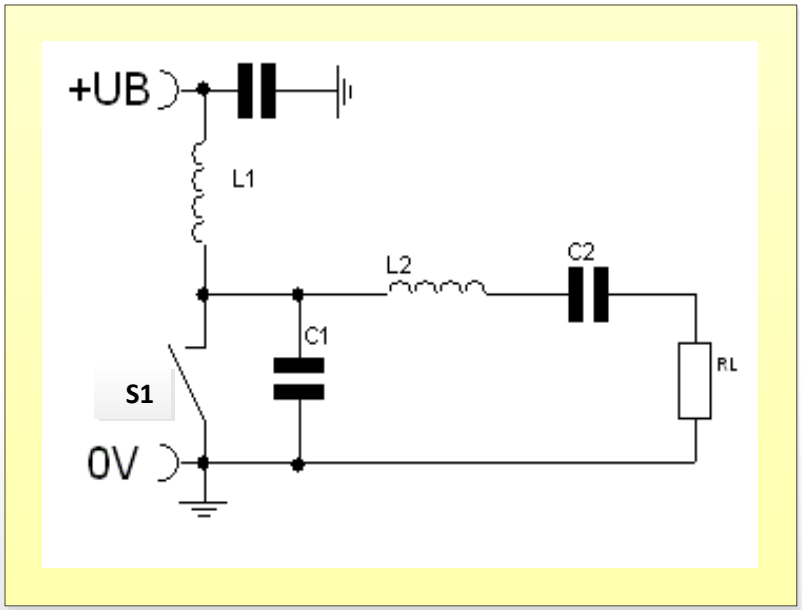
4. Optional:

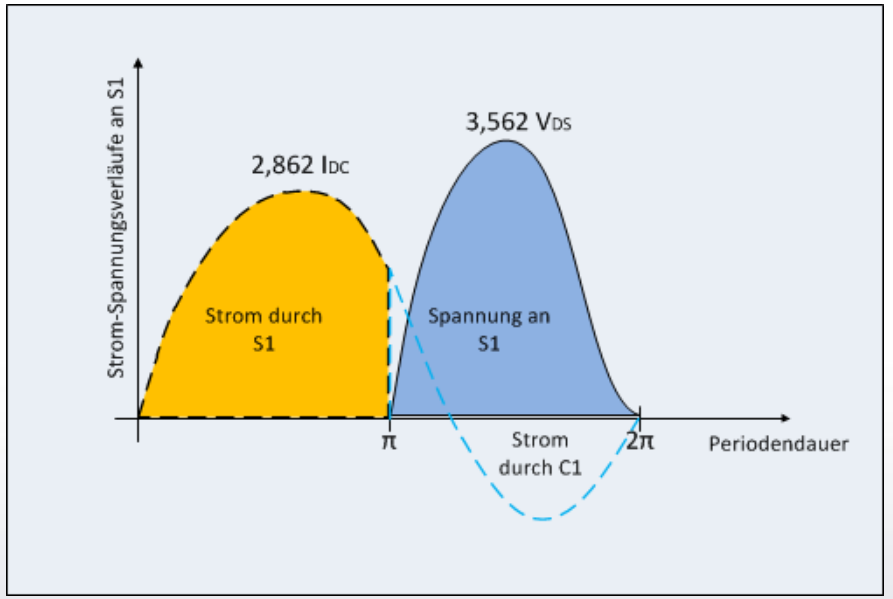
Switch Mode PA technology

Switch mode PA technology

- the main idea behind switch-mode PA technology is to operate the transistor in saturation,
- either voltage or current, depending on amplifier class, is switched on and off.
- For our discussion of fundamental properties,
  - the transistor can be replaced by a switch.
  - when the switch is open, only voltage is present over the transistor.
  - when closed, current flows through it.
- Since there is no overlap in time between voltage and current, power is not dissipated and one obtains 100% theoretical efficiency.

Class E RF amplifier





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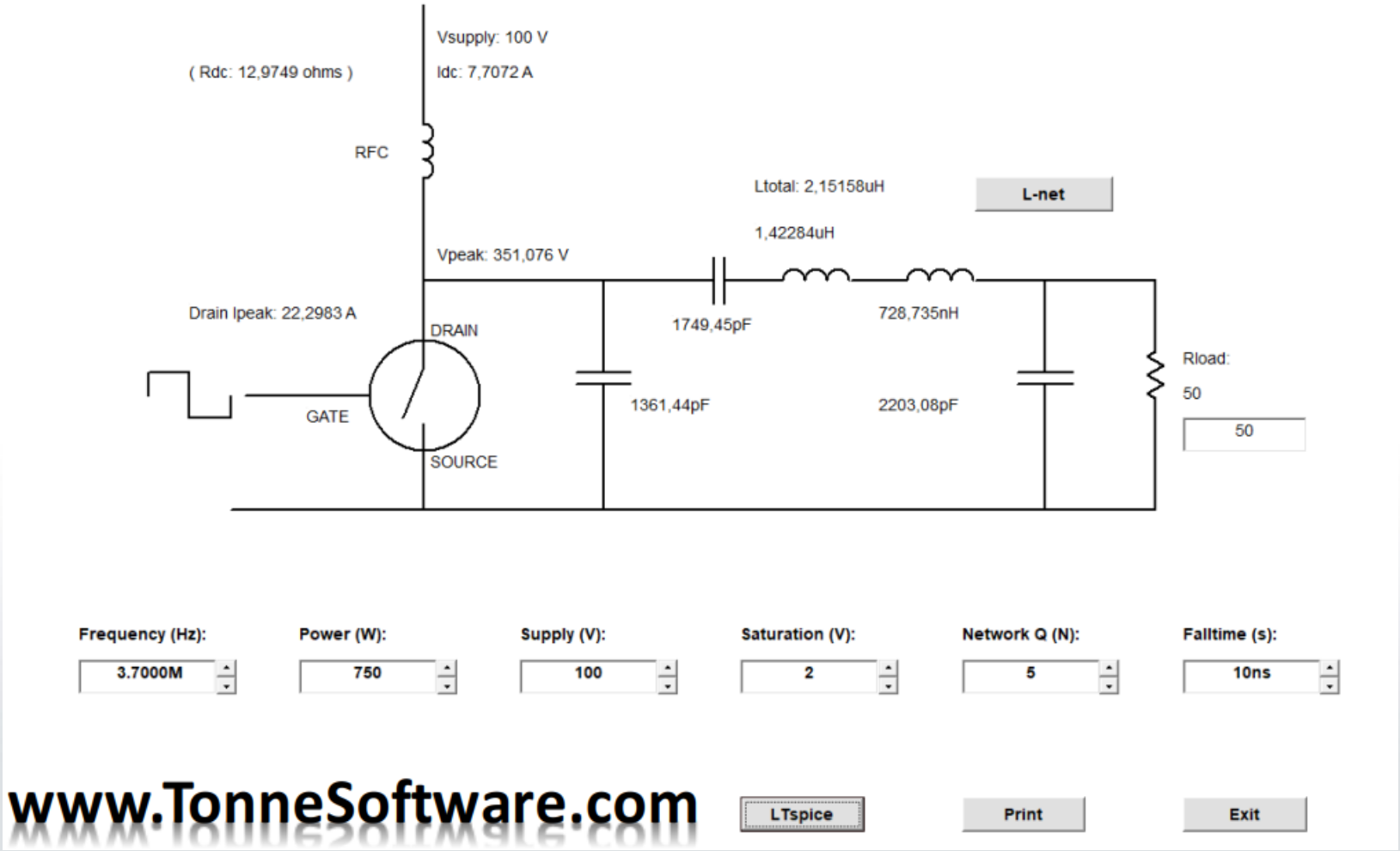
Class E RF amplifier simulation with Tonne freeware



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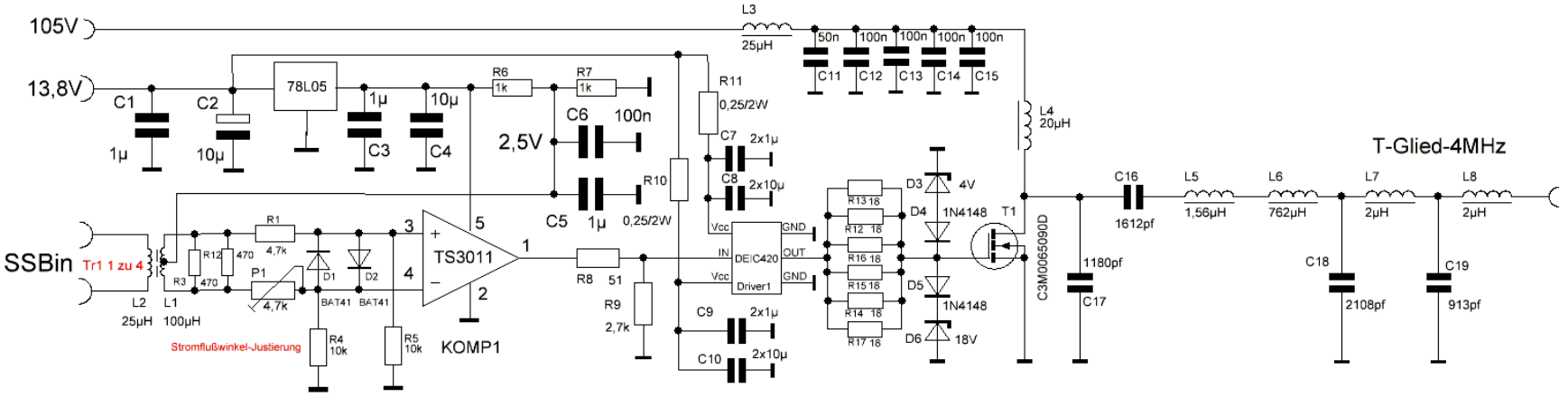
E-RF Power amplifier 750 Watt 80 meters



750 Watt E-Verstärker DJ1MR 15.04.2018

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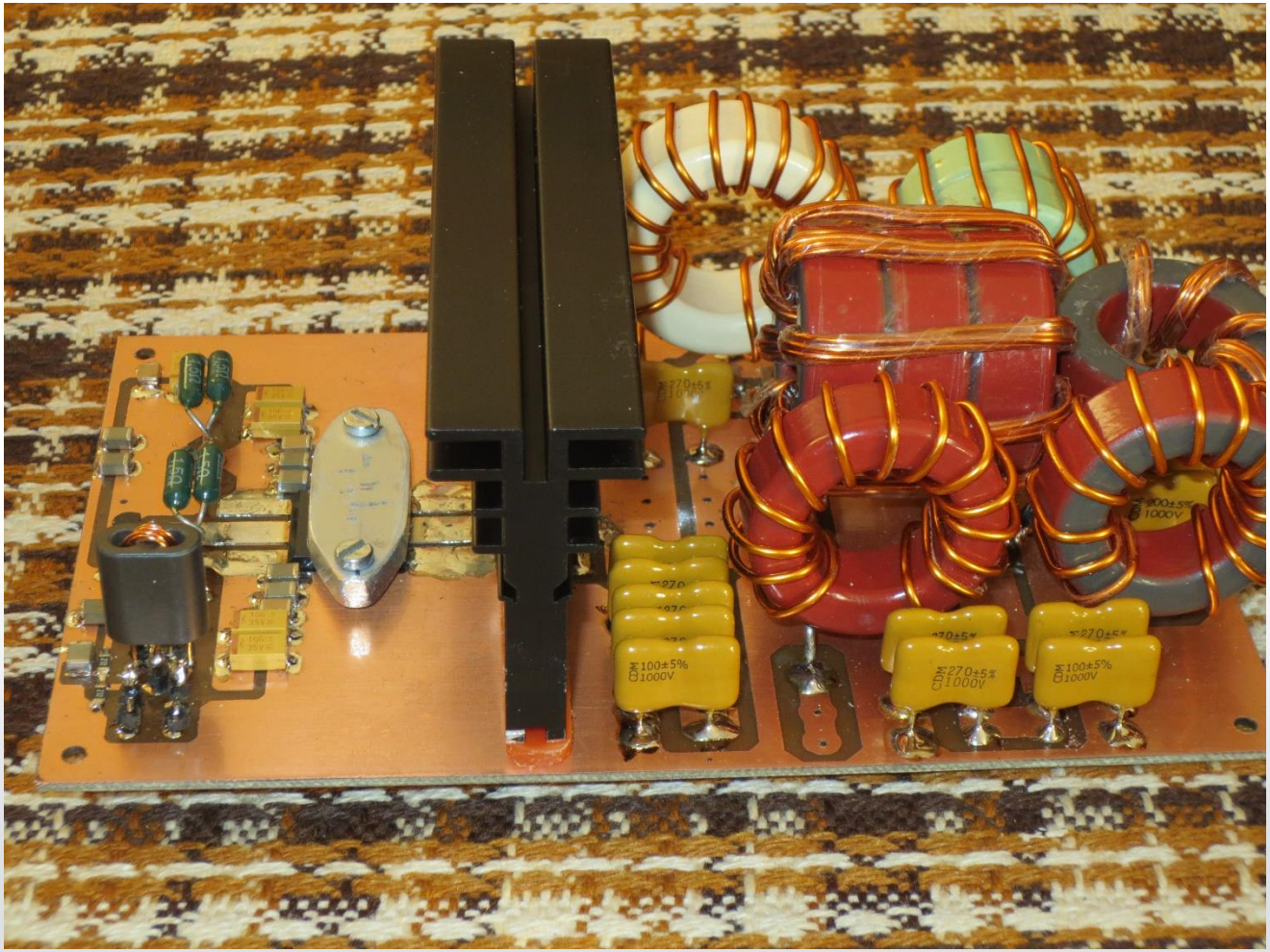
Prototype E-RF power amplifier 750 Watt 80 meters



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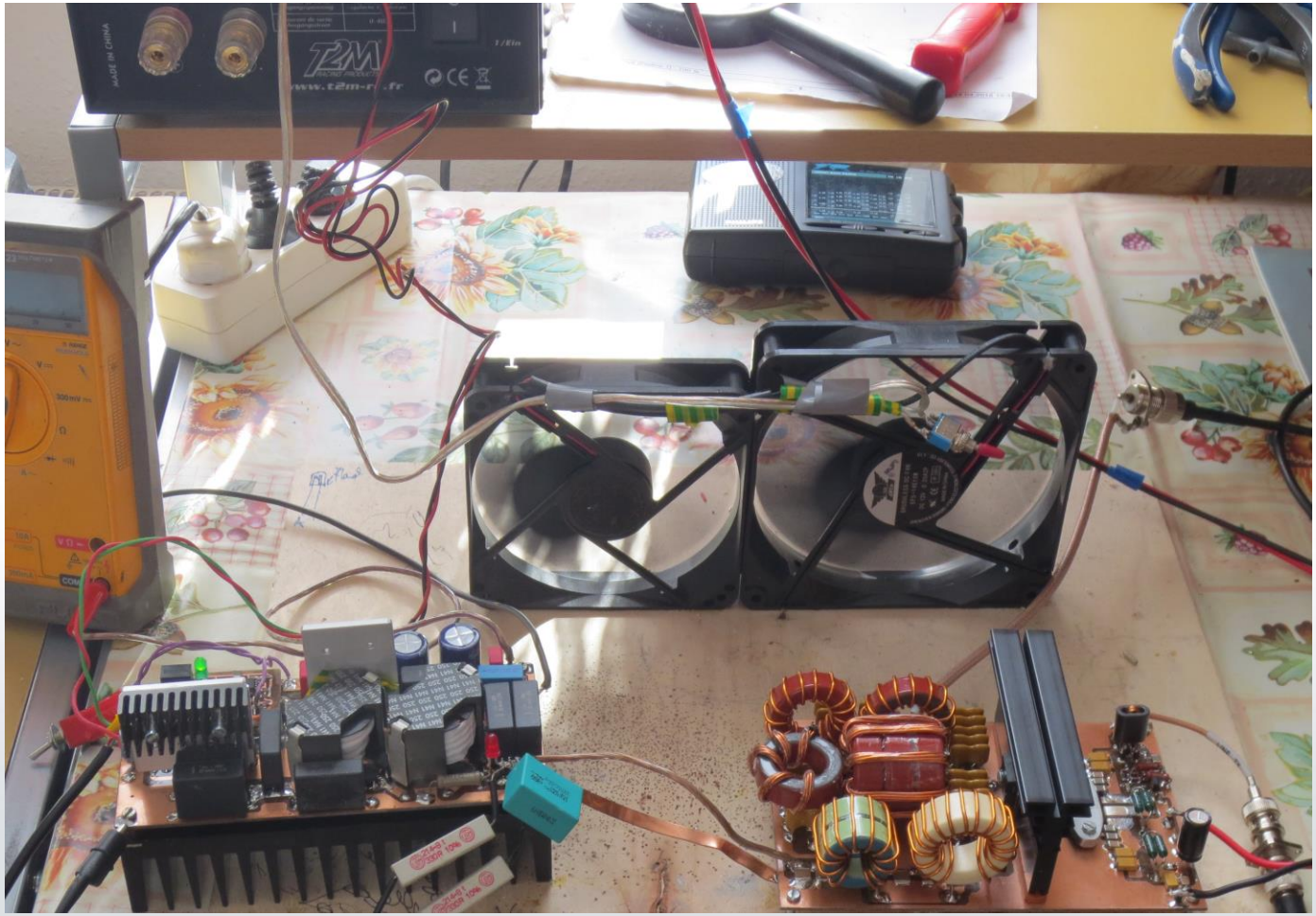
E RF amplifier coupled with PWM



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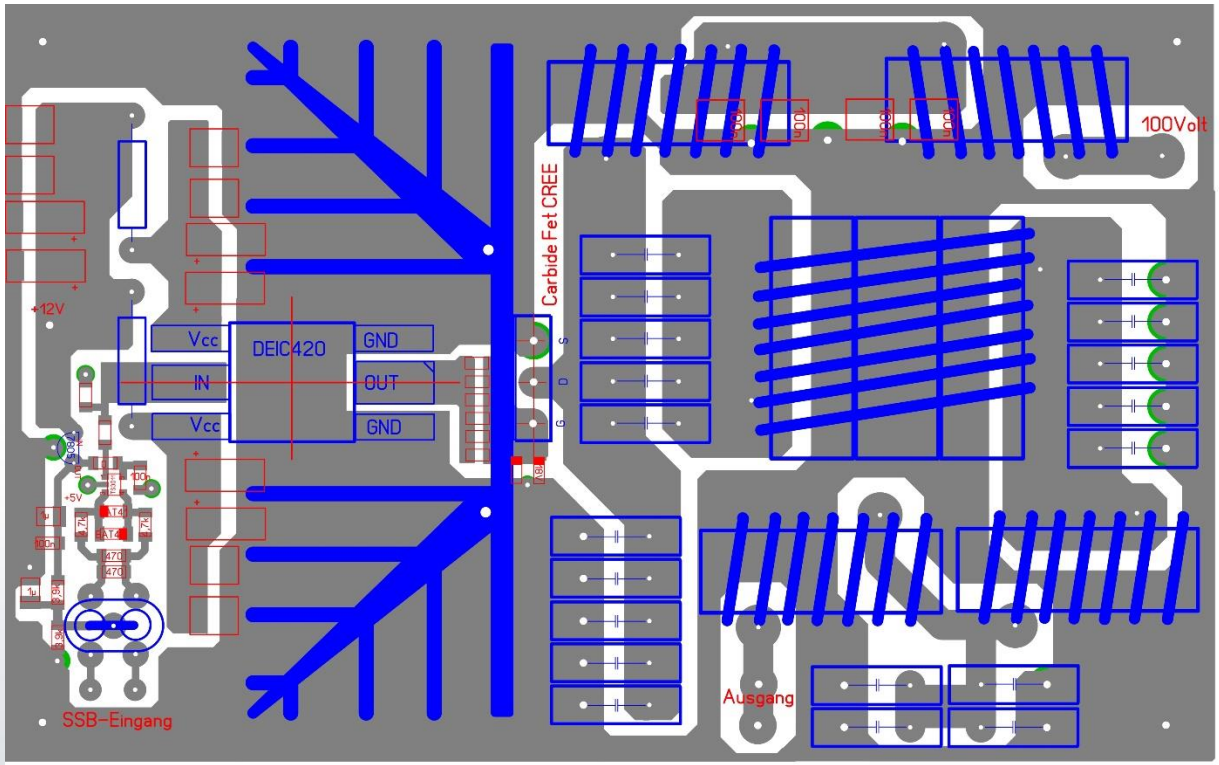
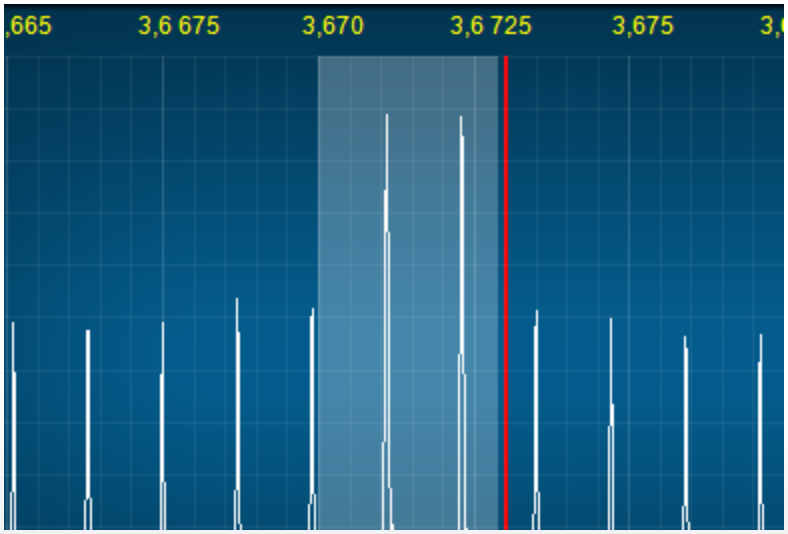
PCB layout E RF power amplifier



EER-PA DJ1MR 100 x 160 mm für 80 Meter

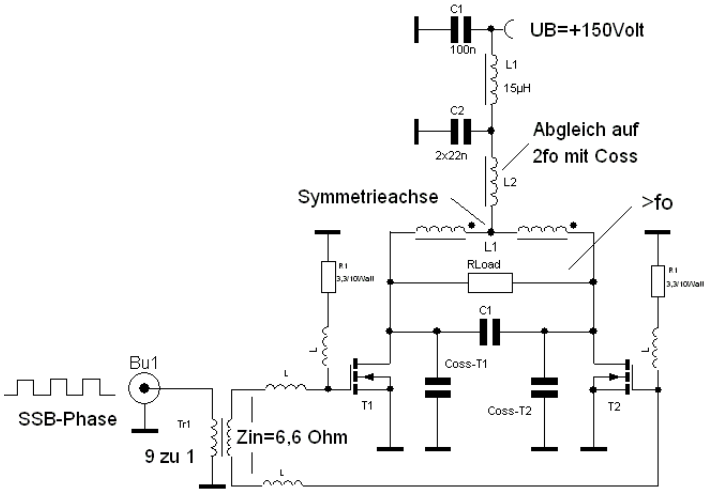
IMD3-E RF power amplifier 750 Watt out without PD

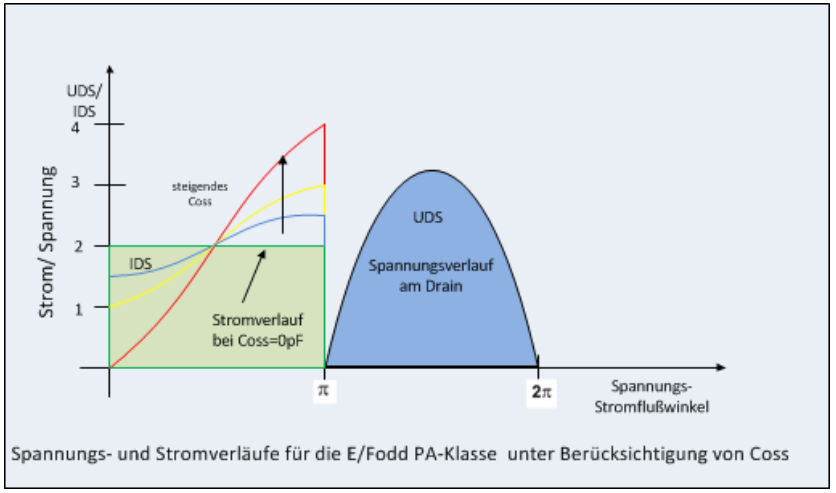


Basic requirements on switch mode Rf amp

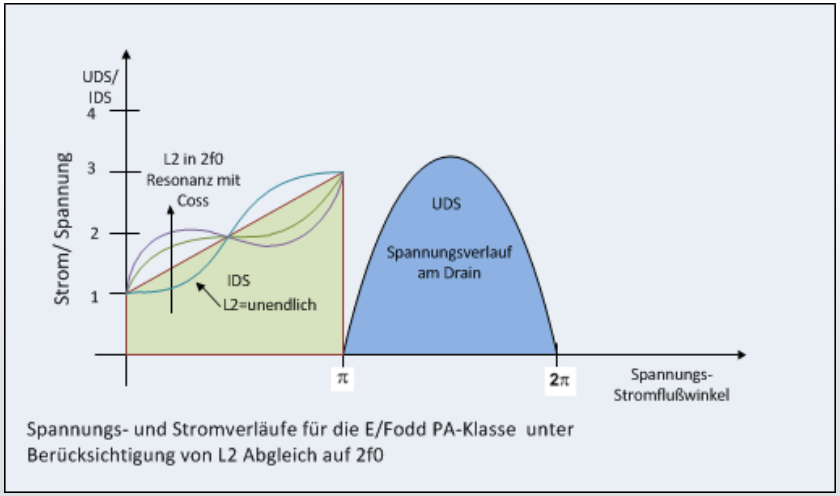
- In reality, a transistor is not a perfect switch and overlap does, in fact, limit efficiency.
- In the switch-mode power amplifier, an output resonator helps to shape the waveform by blocking harmonic components of the voltage and current and to keeps these components from reaching the load.
- Consequently, only fundamental current is passed to the load and only fundamental voltage is generated over the resonator.
- A flywheel effect is created generating sinusoidal voltage and current in the load.

Class-E/F Family of ZVS switching amplifiers





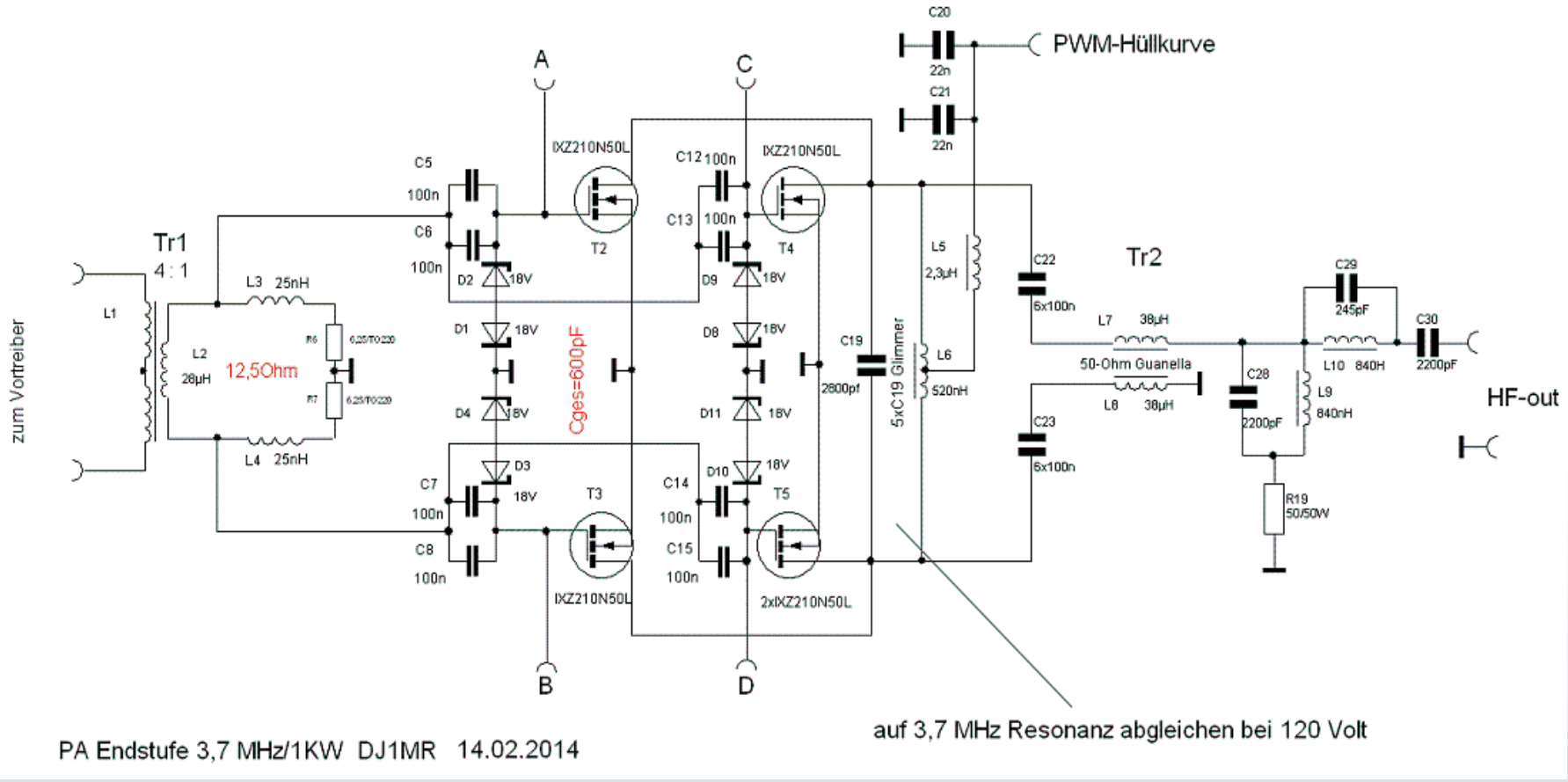
Spannungs- und Stromverläufe für die E/Fodd PA-Klasse unter Berücksichtigung von Coss



Spannungs- und Stromverläufe für die E/Fodd PA-Klasse unter Berücksichtigung von L2 Abgleich auf 2f0

- to achieve the benefits of class F or F-inverse tuning by construct-ing a hybrid tuning taking on characteristics of both E and F.
- The new class-E/F amplifier family is a method of achieving such a hybrid tuning between E and F-1.

Circuit diagram 800 watts E/F power amplifier



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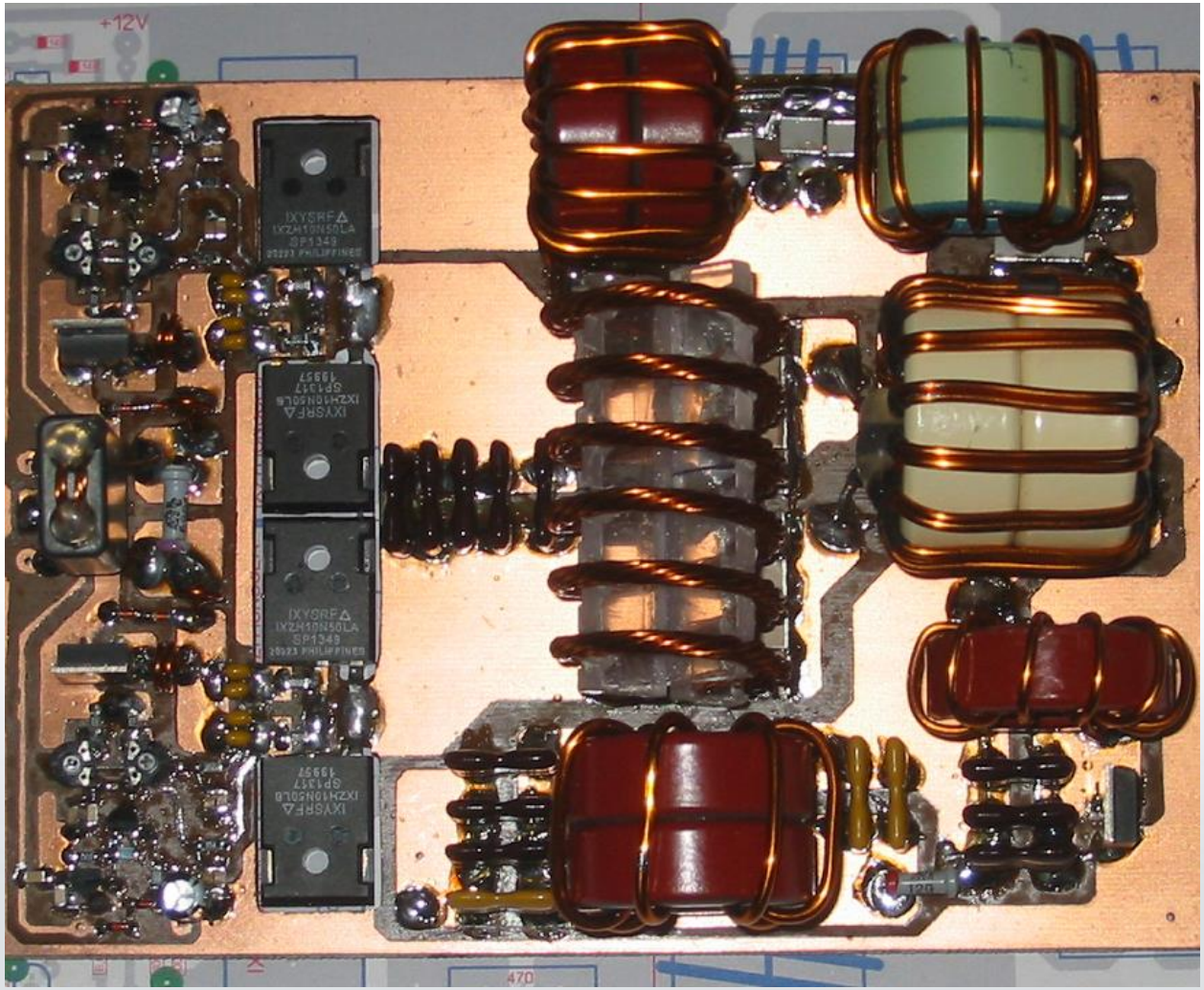
Some design problems of E/F switching power ampl.

- practical PA design problem is the nonlinear behavior of the output capacitance as a function of the supply voltage
- allows proper output matching only for a limited drain voltage range.
- Tank circuit Q, capacitively or magneticly coupled 1:1 to the load,
- means Q=3,6
  - Very high RF current in the tank circuit
- egress coupling balanced to unbalanced with Guanella transformer
- low pass filtering, diplex circuit
- ingress matching with LC lpf to compensate the gate-source capacity of the power mosfets
- overvoltage protection

Realzed 80 meters 800 watts EF switching amplifier



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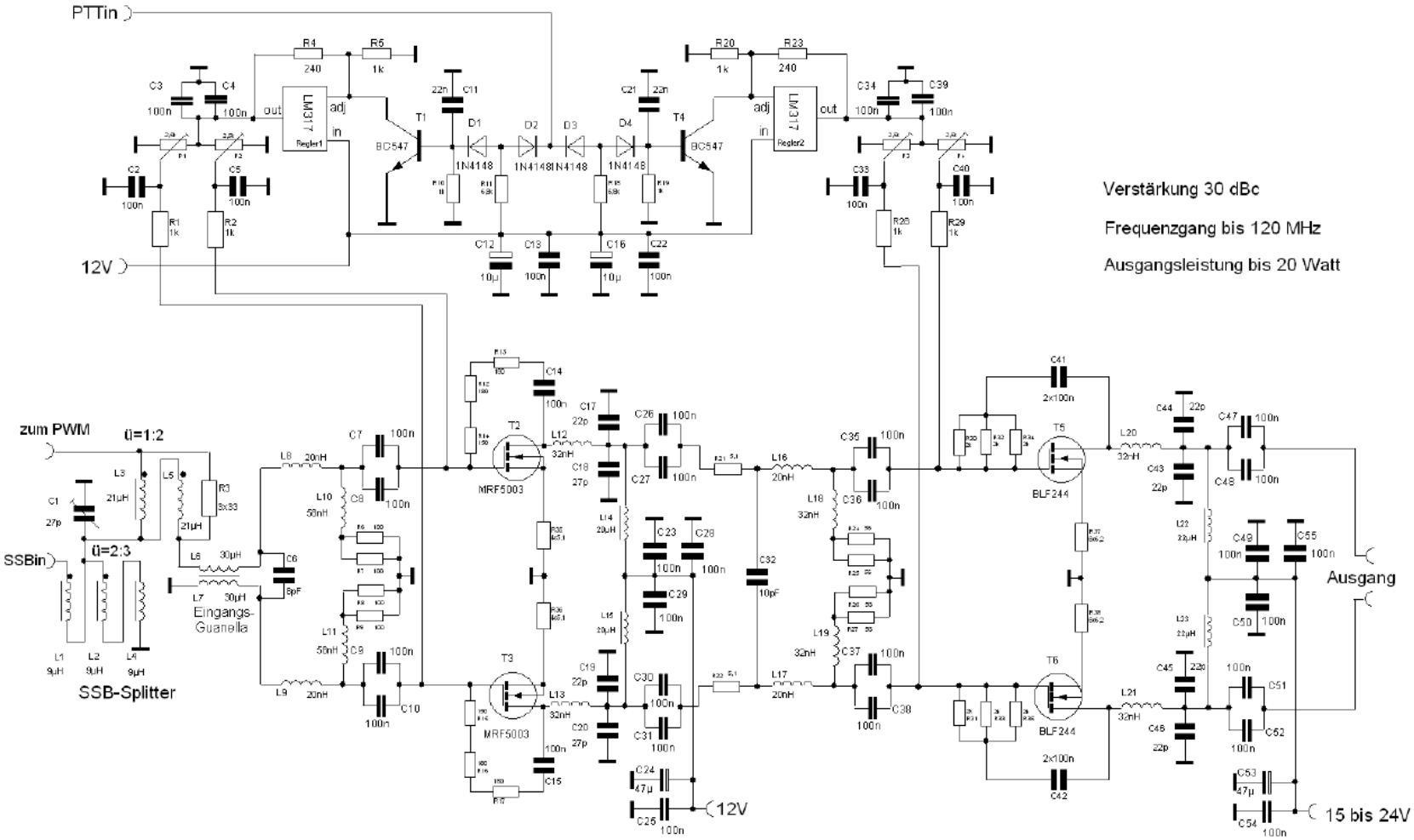
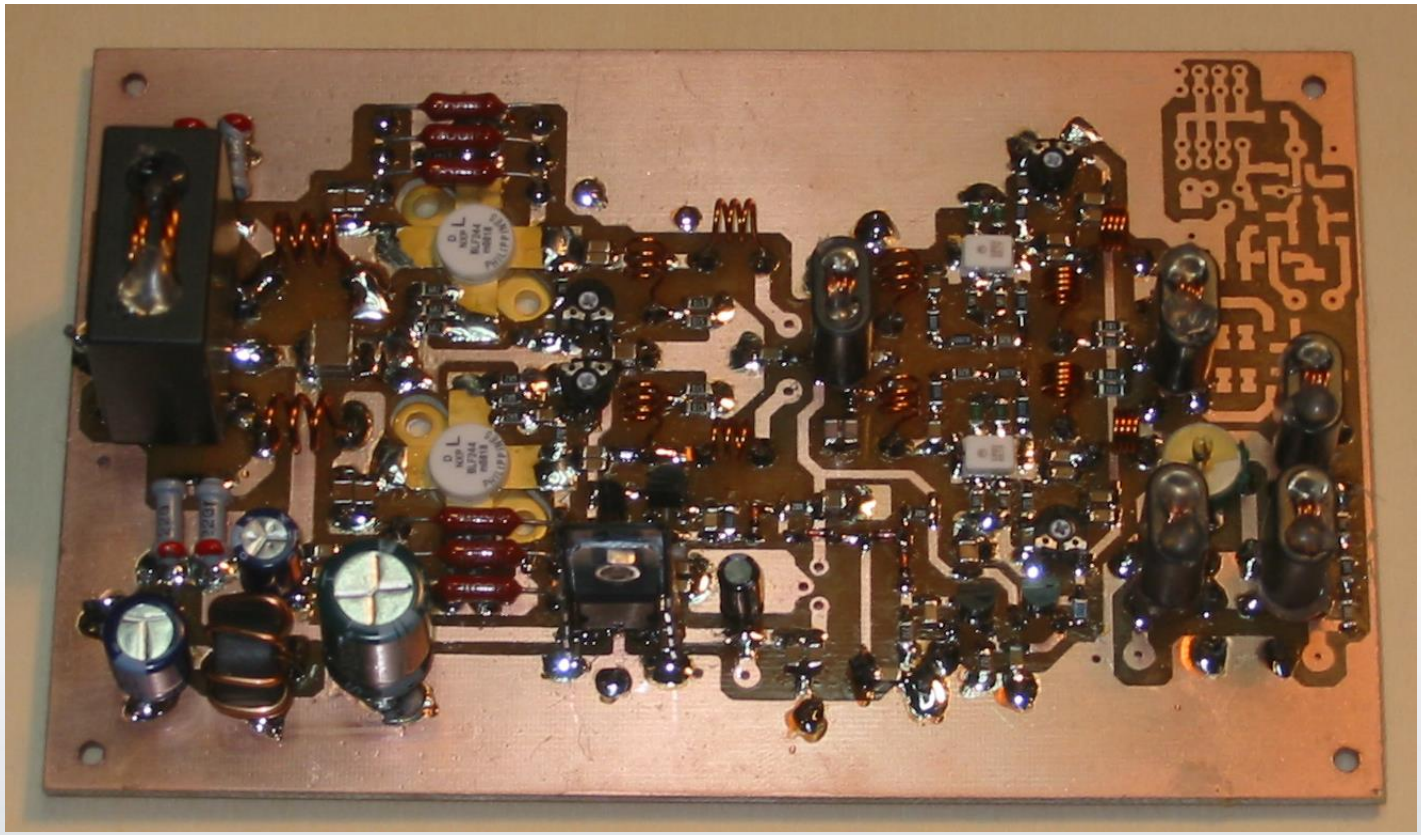
Circuit diagram of a two stage driver amplifier



two stage driver amplifier



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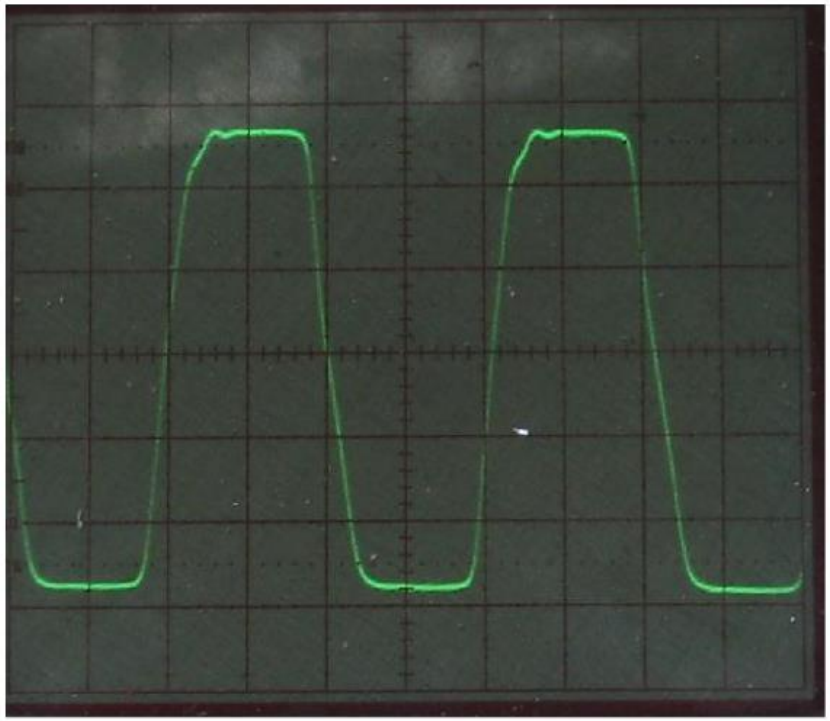
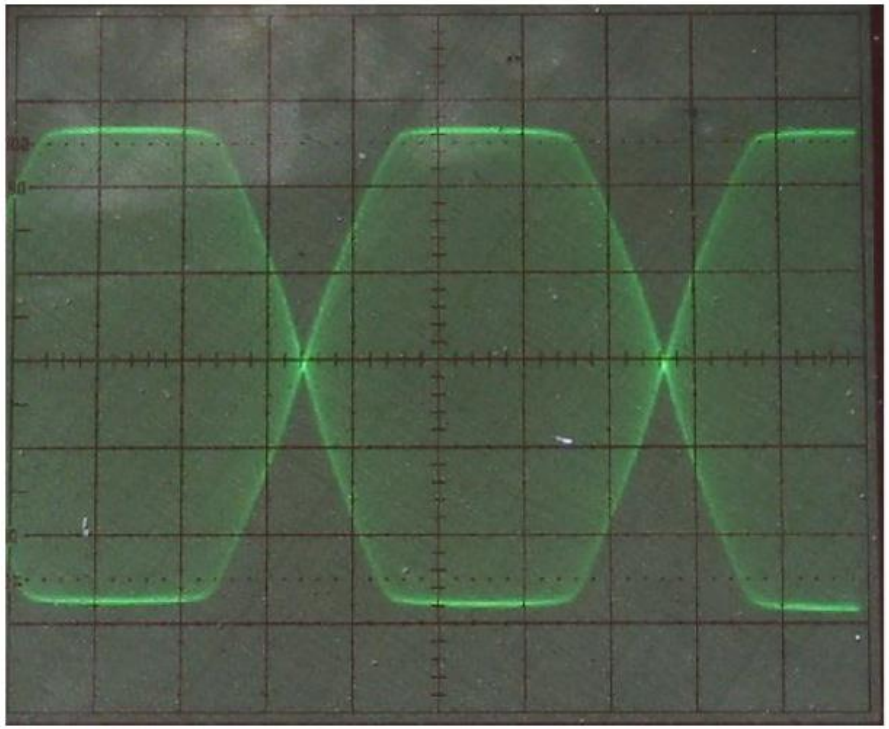
Driver signals in limiting mode



limited 80 meter carrier



limited two-tone signal

THANK YOU

QUESTIONS?

- URL for more information:
- http://www.dl0sdr.de/forum/