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Architectural benefits of wide bandgap RF power transistors for frequency agile basestation systems

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Abstract – **The variety of standard - frequency band combinations with mobile communication systems is increasing. This has led to the request for software radio basestations that offer Multiband and Multistandard capability. Multiband capability is offered through frequency agile basestation systems that can be reconfigured to operate at different frequency bands and different standards, thus providing a flexible air interface. This paper focuses on how specific characteristics of wide band gap RF power transistors at device level map to benefits at architectural level with those frequency agile systems.**

Index Terms – **Frequency Agility, Reconfiguration, SDR, wide bandgap, SiC, GaN, Basestation Architecture, distributed Filtering, interstage filter**

1 Introduction

More and more standards and frequency bands are introduced for mobile communication (Fig. 1). This has led to the request for frequency and standards agile basestation systems that can be reconfigured to operate at different frequency bands and standards.

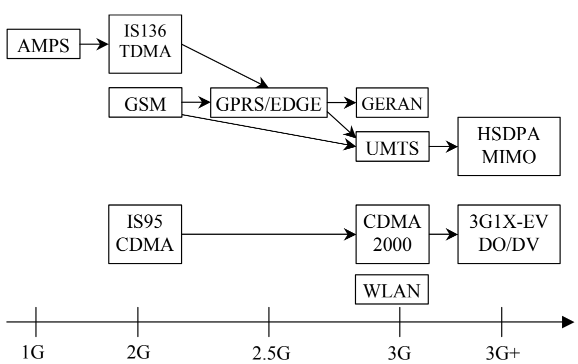

Fig. 1: Evolution of mobile communication standards

Multistandard capability is mainly reflected in the baseband processing and the primary focus of software radio. Frequency agility is a further term settling in literature and is mainly reflected in the RF path of a basestation system. Frequency agility can be seen as a further aspect of software radio and is realized by altering properties of the RF chain, like switching filters and resonators to address different bands (Table 1). With the approach of reconfiguration, RF is still processed in an analog manner, so it is not a true software radio based approach through processing RF or IF in digital format e.g. by sampling directly at the antenna. Instead of reconfiguring a digital path, an analog path is reconfigured. However reconfigurable radio function blocks used with the RF path of a frequency agile radio have a digital interface that is programmed by software [1]. This justifies calling it still a software radio approach.

f/ MHz	Duplex gap/ MHz	GSM GPRS EDGE GERAN	CDMA CDMA2000 3G1X EVDO/DV	UMTS FDD TDD HSDPA
450	2.4	X	X	
480	2.8	X	X	
850	20	X	X	X
900	10	X		X
1800	20	X		
1900	20	X	X	X
2100	130		X	X
2600	70		X	X

Table 1: Frequency bands used with mobile communication

In a basestation system all instances have to support frequency agility, implying that not only the radio and the duplexer must be reconfigurable, but also the power amplifier. With antennas there are already antennas on the market that support multiple frequency bands but with power amplifiers this is still a great challenge.

Multiband capability clearly has to be distinguished from broadband capability in the way that a Multiband device only supports one band at a time and needs reconfiguration to make it operate at another band. This may for instance mean that RF matching networks need to be switched when moving to another band. In contrast to this, broadband devices support a wide frequency range inherently without having to do any modifications to the signal path.

With the advent of wide band gap RF power devices there is a great opportunity to efficiently realize frequency agile power amplifiers either by a broadband or reconfiguration approach or part of both. There are specific characteristics of those devices, which make them perfectly suited for frequency agility especially in the context of demanding modulation formats with 3G.

2 Classes of device non-linearities

There are different classes of non-linearity with RF power devices, which have different implications on the transmitters architecture manifesting themselves in the amount of bandwidth enlargement and computational effort needed in the transmit chain with digital predistortion techniques for Linearization [2,3,4].

2.1 Distortion free devices

These devices are not realistic for real life. They would be ideally linear and wouldn't introduce any kind of spectral regrowth, so the bandwidth enlargement factor is 1.

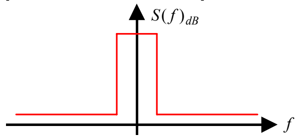

Fig. 2: Principal spectral shaping of a UMTS signal with linear amplification

With real devices at least some backoff is necessary to get close to such a behavior. However this gain in linearity comes at the price of loosing amplifier efficiency.

2.2 Devices with static non-linearity (no memory)

Those devices have no memory, so the past is not impacting the actual amplification. However those devices may suffer from strong AM-AM and AM-PM conversion effects. Such a behavior is typical for small to medium power devices.

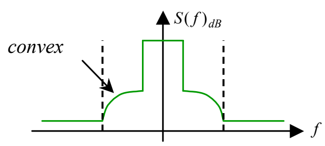

Fig. 2b

Fig. 3: Principal spectral shaping of a UMTS signal with memoryless non-linear amplification

Due to the memory free behavior a two-tone test shows mainly constant level of intermodulation products independent of tone spacing. As typically the third order intermodulation products dominate the spectral regrowth, it is limited to the first neighbor channel on both sides of the wanted channel. The bandwidth enlargement factor therefore is 3. It is important to mention that if the spectrum is plotted in logarithmic scale (i.e. dB) the shaping shows a convex bending inside the neighbor channels.

2.3 Devices with dynamic non-linearity

These devices have memory effects, so the history of the signal that is amplified affects the actual amplification. With UMTS signals, the past may have to be modeled very precisely up to 50 chips back in the past, equal to 13 µs. This implies a huge complexity with digital predistortion algorithms. The strong memory behavior is typical for large devices offering high output power.

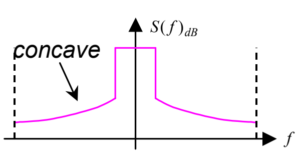

Fig. 4: Principal spectral shaping of a UMTS signal with memory contained non-linear amplification

The sources of memory are not totally understood by today, but there is consensus that both, electrical and thermal effects contribute to memory, often also in a coupled fashion. Due to the time constants associated with the electrical and thermal memory effects a two-tone test delivers varying intermodulation levels depending on tone spacing. The bandwidth enlargement with those devices is typically 5 to 7 reflecting massive spectral regrowth. When the spectrum is plotted logarithmically a concave bending of the spectral shaping can be observed.

2.4 Combined case

With real devices both classes of non-linearity (section 2.2 and 2.3) are present resulting in a superposition of the corresponding spectral shapes. Due to overlap of concave and convex bending an inflection point can be observed with logarithmic scaling.

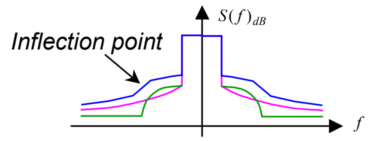

Fig. 5: Principal spectral shaping of a UMTS signal with memory contained non-linear amplification

Typically the spectral components due to static and dynamic non-linearity are of the same order. Therefore if one effect is not correctly modeled with the device, the spectral shape is wrong by about 3 dB [4].

3 Consequences of bandwidth enlargement

Bandwidth enlargement by the RF power device has a massive impact on the transmitter chain of a basestation. The signal processing chain for digital predistortion needs to reflect the same amount of bandwidth than the non-linearity, which implies that for a 5 MHz wide UMTS signal, the predistortion bandwidth may easily increase up to 35 MHz, assuming bandwidth enlargement by factor 7. This implies that the D/A conversion has to support such a broad bandwidth. So about 100 MSa/s converters are needed. But what is even more demanding, the whole RF chain has to support this bandwidth. In the context of a direct mixing architecture it can be said that digital predistortion more or less runs contrary. There is this great advantage of direct mixing architectures that the I and Q path only need to run at the signal bandwidth. This allows for slow speed, low performance converters, that can also be integrated with the direct mixer. Given the bandwidth enlargement with digital predistortion those advantages of direct mixing vanish.

In the context of a frequency division duplex system there is a further problem. With above example assuming a UMTS signal and a bandwidth enlargement factor of 7 the maximum frequency offset in the TX chain to be handled is 17.5 MHz. In some cases this offset may be even higher than the duplex gap between uplink and downlink frequency band (Table 1), which means that spectral components falling into the receive band of the basestation are generated within the transmit chain and at the output of the amplifier.

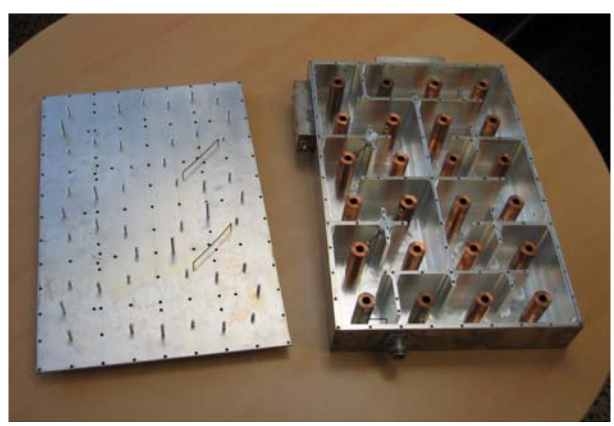

Fig. 3: Typical Duplex-Filter with a UMTS basestation

To prevent desensitizing the receiver, a duplex filter with high stopband attenuation has to be selected, which causes high costs due to high Q needed (about 5000) and great number of cavities (Fig. 3).

It would be desirable to avoid bandwidth enlargement at all. However even reducing the amount of bandwidth enlargement would result in savings. This can be done by selecting devices with low to no memory.

4 Specifics of wide bandgap devices

There are several characteristics of wide band gap devices, which are beneficial for the system. In the following a mapping from characteristics at device level to advantages at system level is performed.

4.1 High power density

Typically this is measured in W/mm. For silicon based LDMOS FETs this figure is typically 1 to 2 W/mm whereas wide bandgap devices achieve values between 3 and 30 W/mm (Source: Cree). For a given output power a higher power density leads to smaller chips. This is of no direct benefit for the system as the device size is mainly determined by the device package, however there is an indirect advantage in the way that a smaller chip size means less input and output capacitance, reducing the reactive part of the impedance. This increases the operational bandwidth of wide band gap devices and easies the matching.

4.2 High breakdown field

This makes wide band gap devices suited for higher operation voltage. The higher operation voltage leads to an increased real part of the matching. Doubling the supply voltage theoretically goes along with multiplying the impedance by 4.

As an example an SiC device [5] at 10W offers around 10 to 14 Ohm output impedance whereas an LDMOS device sticks to low values in the order of 1 or 2 Ohms, which is complicate to match and thus sometimes a prematching needs to be done inside the package of the LDMOS device.

4.3 High thermal conductivity

The improved thermal conductivity reduces thermal memory effects, which reduces the bandwidth enlargement factor of the device.

4.4 Easy matching

Due to the high real part of the output impedance and the low reactive part an easy matching is facilitated for SiC and GaN devices.

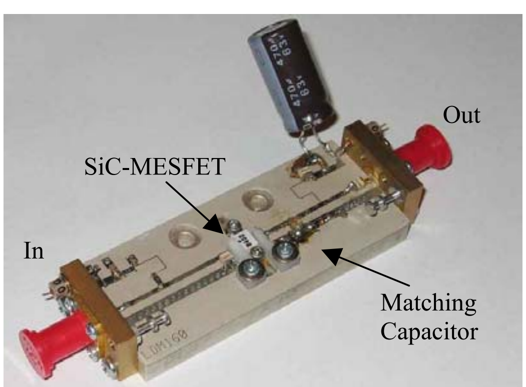

Fig. 6: SiC Test board by Cree

In Fig. 6 it can be seen that the SiC device is directly connected to 50 Ω lines and that matching is done simply by a capacitor to ground. Simply moving the capacitor along the lines does addressing different frequency bands [5].

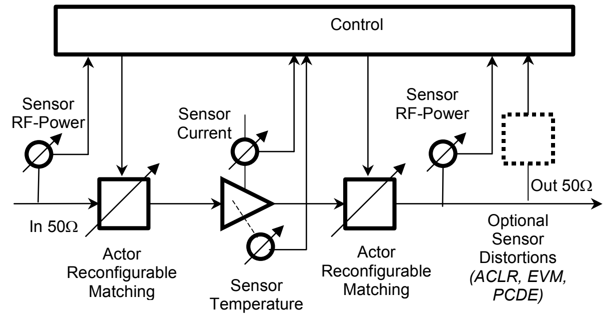

Fig. 7: Reconfigurable PA approach

This opportunity to reconfigure a PA for different frequency bands has led to the approach to make capacitances switchable e.g. through RF-MEMS and by that facilitate the realization of a frequency power amplifier according to the architecture depicted in Fig. 7 [1,2,3,10].

4.5 Broadband capability

Broadband capability has to be understood in two ways, first with respect to the bandwidth of the center frequency with the signal to be amplified and secondly with respect to the modulation bandwidth of the signal. Wide band gap devices are superior in both ways. They can cover a broad frequency range e.g. from 450 MHz up to 2600 MHz (Table 1) and at the same time support multicarrier signals like e.g a 3 carrier UMTS signal occupying a span of 15 MHz. Selecting a device with a bandwidth enlargement factor of 7 would result in tremendous effort. The transmitters signal bandwidth would need to be 105 MHz and converters running around 250 MSa/s would at least be needed.

Due to the good linearity behavior wide band gap devices are also well suited for demanding modulation formats like 16 QAM with UMTS-HSDPA and CDMA-EVDO.

5 Analyzing Memory effects

Distortions of an RF power device can be analyzed in various domains. The spectral domain typically is the most critical one. Here a limit is given through ACPR (Adjacent Channel Power Ratio). A further domain is the code domain. Here the limit is given through PCDE (Peak Code Domain Error) indicating leaking power from one code to another code. In the time domain the limit is formulated as EVM (Error Vector Magnitude).

A new approach is presented here. The memory effects are analyzed in the IQ constellation plane by applying artificial test signals that are close to the signal waveforms occurring under real operation. A gaussian pulse was selected as a test signal. It had a width of around 3 UMTS chips and occupied around 5 MHz.

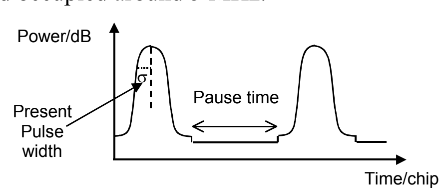

Fig. 8: Gaussian test pulse

A gaussian pulse was found to be very advantageous out of several pulses looked at due to several reasons. Gaussian pulses have the smallest time bandwidth product. Therefore a minimal time is occupied assuming a given bandwidth. The short pulse allows for analyzing the amplifiers behavior after the pulse immediately during the pauses. For that purpose the test pulse was equipped with a plateau as shown in Fig. 8. The bandwidth limitation was also found advantageous due to the fact that the devices were measured together with the supplied test fixtures and those are typically limited in their bandwidth.

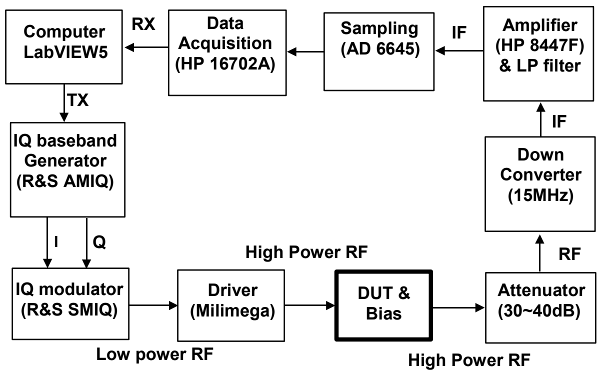

Fig. 9: Test Set-up for analyzing memory effects

The test setup (Fig. 9) comprised a digital pattern generator that cyclically supplied the artificial test signal. The power was ramped up according to the test signals profile along the real axis (lower right picture in Fig. 10).

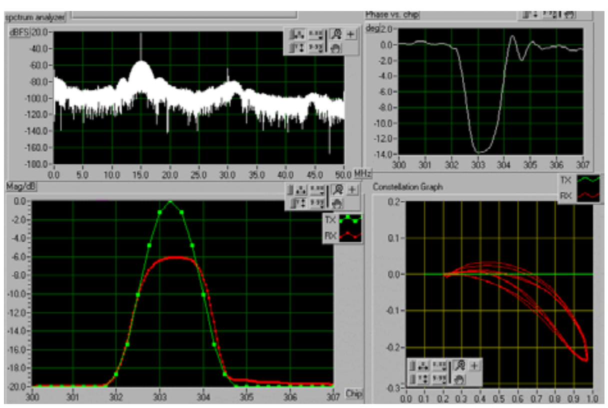

Fig. 10: Screen shot of measurement with LDMOS

Furthermore lower right, the reaction of the LDMOS device is shown. What is immediately apparent is that a different trace is shown for ramping power up and down. This is also visible with the time domain shown lower left.

The screenshot further shows the spectral regrowth upper left and the phase distortion upper right. The test condition was that the device is driven 6 dB into compression as can also be seen from the vertical axis lower left.

Fig. 11 shows the same measurement now with an SiC-MESFET. The great opening typical for LDMOS with up- and downtrace in the lower right picture no longer is there. This indicates no to lower memory. There is still some phase compression but this occurs for very small part of the trace due to the extreme overdrive condition.

From the measurements it can be concluded that the LDMOS device shows strong dynamic linearity whereas the SiC-MESFET shows no to minor static non-linearities.

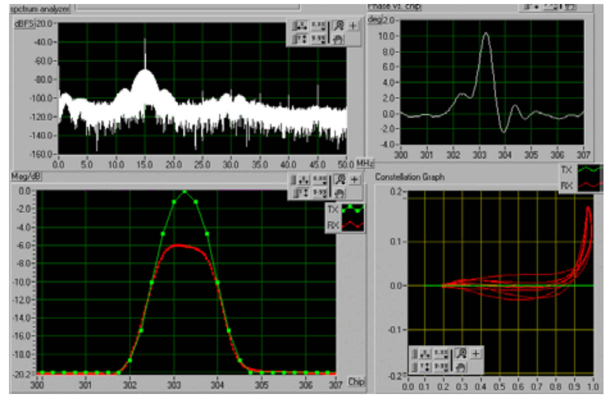

Fig. 11: Screen shot of measurement with SiC-MESFET

This goes along with the fact that the LDMOS device introduces bandwidth enlargement around 5 to 7 whereas the SiC MESFET introduces no or maximal 3 times bandwidth enlargement.

6 New architectural approach

After having elaborated on the benefits of wide band gap devices at device and PA level this section now focuses on the benefits at system level.

6.1 Local versus global Linearization

Digital predistortion can be seen as a "global" linearization technique, because it introduces big loops along the whole transmit chain. It suffers from the problem that the whole transmit chain including digital, IF and RF processing has to reflect the bandwidth enlargement. As said before, this is contrary to the benefits of direct mixing and the benefits that could be obtained from an interstage filter in terms of reducing wideband noise. In contrast to this there are also "local" linearization techniques like analog RF predistortion performed locally inside the PA. Typically those schemes are not able to mitigate memory effects so they can only compensate static non-linearities. If there is the wish to stand away from digital predistortion, just to avoid bandwidth enlargement and allowing a higher integration level and the use of interstage filters, only PA devices with static non-linearity are acceptable.

In this context further it has to be mentioned that also the termination of the device not only at the fundamental but also at the low frequency envelope range and the harmonics has an impact on memory effects. Devices seem to be very sensitive with respect to the impedances of the bias-Ts. Practical experiments showed a 6 dB improvement in ACPR with a redesign of bias-T. Lowering the impedance at envelope frequencies seems to reduce memory. Therefore a careful design of bias and matching networks can also be seen as a "local" linearization technique.

6.2 System architecture

Assuming now a PA device with solely static non-linearity and no memory effects is selected, a "local" linearization technique inside the PA can be applied. This avoids the bandwidth enlargement in the transmit chain, allowing for obtaining all the benefits of a direct mixing architecture. These benefits are for instance with the possibility for high integration and the extendability to frequency agility. Architectural studies performed in the context of a project funded by the German federal ministry of Research and Education (BMBF) have shown that the direct mixing is the most suited architecture to be extended to frequency agility.

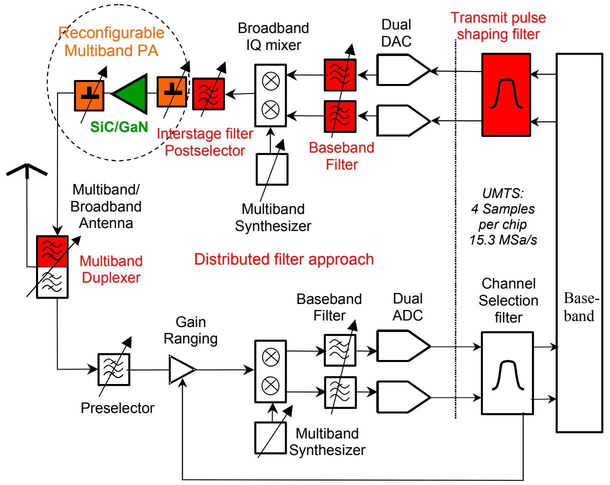

Fig. 12: Architecture of frequency agile basestation system

Now as bandwidth enlargement with digital predistortion as a global linearization technique is avoided, an interstage filter can be placed between the transmitter and the PA (Fig. 12). This allows for an optimized distributed filter approach along the transmit chain comprising the transmit pulse shaping filter, the analog baseband filter, the interstage filter and the duplex filter. Of course in a frequency agile system, the interstage filter needs to be tunable. Preferably the center frequency and the bandwidth are both tunable so to accommodate different frequency bands and standards. Due to its tuneability it may also be called a post-selector in relation to the preselector used with the receiver. The big benefit from the postselector will be the reduction of wideband noise and spurs at greater frequency offsets from the carrier. Especially with respect to spectral components falling into the receive band, a relaxation on the duplexers stopband attenuation can be obtained, resulting in a smaller number of resonators with the duplexer and thus lower costs. The reduction in number of resonators is also desirable from the perspective that in a frequency agile system also the duplexer should be frequency agile. Typically the resonators are equipped with stepper motors to tune the resonance frequency. Relaxing the requirements and thus reducing the number of resonators of course means less effort with motor tuning and less required accuracy in tuning.

Looking at the architecture a high selectivity is built into the RF path of the transmitter and receiver. Broadband not necessarily is always beneficial as the missing selectivity implies the risk of generating unwanted harmonics and wide band noise. Frequency agility goes along with selectivity, focusing just on the band of operation.

7 Conclusion

It has been shown that the characteristics of wide band gap transistors at device level lead to massive gains and savings at the architectural level. An experiment analyzing memory effects in the IQ plane showed that SiC-MESFET has less to no memory compared to LDMOS devices. The specific characteristics of wide band gap devices allow for a new approach in terms of distributed filtering with a frequency agile basestation system obtaining savings especially at the cost intensive duplex filter, while going along with a gain in terms of flexibility expected from a frequency agile software radio architecture.

8 Acknowledgements

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9 References

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