TRIDENT - A Triple Band GSM Reference Design

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GSM is a digital cellular radio standard operating in over 150 countries around the world. The standard provides almost complete coverage in Western Europe and also growing coverage in the Americas, Asia, Africa, Australasia and elsewhere in the world. The unique roaming features of GSM allow cellular subscribers to use their services in any GSM service area in the world in which their provider has a roaming agreement. In this way, GSM has rapidly become the leading world standard for mobile telephones, since it's inception in the early 1980's. However, due to local constraints, the standard may be implemented in different regions in any of three frequency bands. The services are denoted GSM900, GSM1800, or GSM1900 depending on the frequency band utilised (in MHz.) Given this worldwide coverage, first generation handsets that have been designed to operate in a single frequency band are now being superseded by dual- and triple-band handsets. This paper describes some of the design considerations and measurement issues relating to the design of the transmitter for a second generation triple-band GSM RF reference design, termed TRIDENT.

Market pressures and the requirement for manufacturers to differentiate their products have meant that the task of the multiband handset designer has not been simple. Key drivers have been cost, size and power consumption. Furthermore, customer expectations have demanded that these driving parameters have been comparable, or even more aggressive, than for single band products.

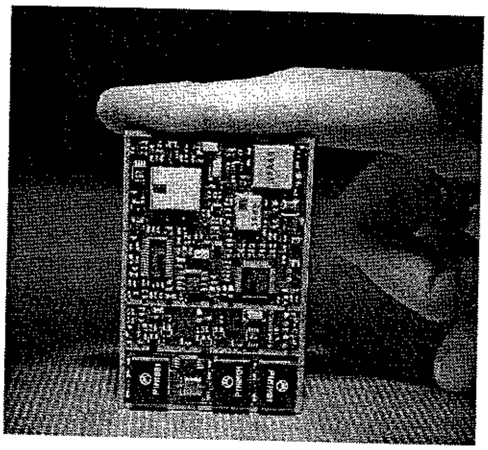

Figure 1 – The Trident Radio board

An obvious strategy to reduce the cost of a multiband handset is to avoid the duplication of components between frequency bands. To this end, the TRIDENT design adopts a compromise between the use of shared components (such as RF filters, VCO's, PA's, transmit and receive IC's and synthesiser chip) and duplicity to enable efficient splitting of the different frequency bands for single- and dual-band applications. Furthermore, the architecture has been designed such that costly components are avoided.

Both of the issues of duplicity and cost have been addressed in the TRIDENT design, by the use of an Upconversion Loop to generate the transmitted signal. The Upconversion Loop derives it's name from the fact that the modulation, which is introduced into the loop at baseband frequency, is transferred by way of a phase locked loop to a Transmit VCO operating at the final transmit frequency. In the TRIDENT design, the modulation is introduced into the loop by application to one input of a phase detector. The output from the phase detector drives the Transmit VCO, whose output is then mixed down to an IF by way of a Channel Select VCO. This IF is filtered to remove unwanted mixing products and subsequently fed back to the phase detector. The output signal from the Transmit VCO is therefore modulated in order that the loop maintains phase lock with the components of the reference modulation within the loop bandwidth. The Upconversion Loop principal is illustrated by way of a block diagram in Figure 2.

The first benefit of the Upconversion Loop for multi-band design is that by judicious choice of frequency plan for each frequency band of operation, the filters within the loop can be designed as fixed filters to suit all bands of operation. Thus, the duplication of RF and IF filters between different frequency bands of operation is avoided. Additionally, the IF filter can be a relatively simple low pass filter, replacing the more demanding requirement for an image reject filter in a conventional IF upconversion architecture.

The second benefit of the Upconversion loop is that a front-end duplexer is not required. The duplexer is normally required to reject transmitted noise that falls within the receive band and is both costly as well as bulky. Transmit noise in the receive band is stringently controlled by the ETSI GSM radio standards. The high level of rejection stipulated in the standards historically demanded the use of a highly selective duplexer to reject the unwanted receive band noise. However, the Upconversion Loop avoids this requirement by allowing the use of a high level Transmit VCO. A high signal to noise ratio is inherently achieved by the use of a high power VCO and the high ratio is easily preserved, even after passing through a power amplifier of moderate noise figure. This is in contrast to the lower signal to noise ratio obtained if the transmit signal is passed through a more noisy device, such as a mixer, as with conventional IF upconversion architectures. Since a high signal to noise ratio is achieved at the antenna, a simple transmit/receive switch can replace the duplexer, saving cost and space.

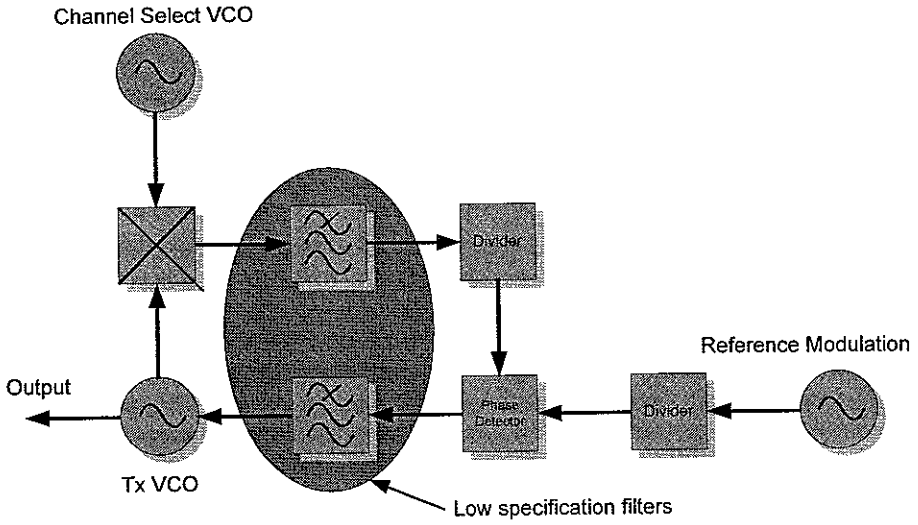

Figure 2 – Upconversion Loop Diagram

A significant issue that typically complicates the development of an Upconversion Loop is the generation of transmitter spurii. Numerous mechanisms exist relating to the generation of spurii, which are best analysed using a simulator. During the TRIDENT development, simulation software was written that performed a time domain analysis of the loop, in order that spurii could be identified in the frequency domain. By performing the analysis in the time domain, the loop could easily be modelled to component level. Second order effects, such as component imperfections and unwanted coupling mechanisms are particularly significant in this type of application and these could also be included in the simulation. Valuable information influencing not only the circuit topology, but also the pcb layout was obtained in this way. Finally, when prototypes were built and unexpected spurii found, the simulator could be used to experimentally introduce unwanted coupling mechanisms and circuit imperfections to help isolate likely causes of the spurii. In this way, hours of practical experiment were avoided and a picture of the contributing mechanisms developed.

However, a significant compromise exists in Upconversion loop designs. This relates to the choice of closed loop bandwidth, which is subject to two main requirements. The first requirement is that the loop bandwidth must be large enough such that the loop is capable of tracking the wanted modulation. During the Trident development, it was found by simulation and then proven by experiment that a loop bandwidth of around 800KHz was required to satisfy this criteria. Failure to accommodate the modulation and associated harmonic components results in an increase in transmit signal phase error, which is a measure of signal quality. However, widening the loop bandwidth results in less attenuation of the VCO noise floor at higher offsets from the carrier. This directly affects the amount of transmitted noise generated in the receive band, which may be as close as 10MHz away from the transmit band. Therefore, a wider loop bandwidth results in a requirement for a high order loop filter that rejects quickly above the frequency of the highest useful component of the modulation. This in turn leads to a requirement for a larger pcb area, as well as the possible addition of extra inductors, which are undesirable due to their tendency to pick up unwanted interference. Following careful analysis, a loop filter design was developed for Trident, which was then subjected to a comprehensive Monte Carlo analysis to ensure that both criteria were met under all anticipated operating conditions.

Having obtained a modulated carrier, the signal must be then be amplified to a prescribed signal level, prior to being presented to the antenna. GSM, being a Time-Division-duplexed system requires that the transmitted signal is present during active time slots, but at a low level at all other times. In order that the transmit signal spectrum is retained within the nominal channel bandwidth, the signal must be ramped up to and down from the required output level very carefully during an active burst. Ramping that occurs too quickly results in Transient Splash, whereby frequency components of the transmit signal are generated outside the transmit channel. The allowable level of these products is again defined in the ETSI GSM standards. In the past, the most common method of obtaining a specified ramp profile has been by the use of closed loop power control. In this method, a fraction of the output power is coupled to a detector diode, which passes this detected measure of the output level to a level comparator, to be compared with a reference ramp signal from the baseband. The output error signal from the level comparator is then used to vary the forward transfer function of the amplifier in order that the required ramp profile is achieved. The principal drawback of using this method has normally been the large variation in loop gain obtained as a result of operating over a significant proportion of the dynamic range of the detector diode. Additionally, it has usually been very difficult to compensate the loop dynamics versus temperature.

To avoid the complexity of a closed loop power control circuit, an open loop control method was developed for the TRIDENT design. Instead of detecting the output RF power level, the supply voltage to the power amplifier is instead measured and controlled versus a reference ramp voltage. In this way, the complexity of an RF feedback loop is reduced to effectively a dc feedback loop.

In order that this technique is successful, the amplifying device must have a linear output power relationship versus supply voltage and adequate temperature stability. After suitable trials, it was found that GaAs FETs exhibited such behaviour and a commercially available three stage GaAs amplifier was identified as a suitable candidate device. Pulse shaping techniques were then adopted to allow a linear ramp profile to be sufficient to generate a suitably smoothed power ramping profile that satisfied the ETSI GSM specification power-time templates. Timing advance was then implemented in the power control loop that automatically advanced the ramp profile relative to the requested output power level. This is a subtle effect that greatly improves the centering of the ramp profile within the power-time templates. It was found that the temperature stability of the output power level greatly exceeded that of a closed loop architecture, being around 0.6dB over the entire dynamic range of the amplifier. Consequently, temperature compensation was not required in the Trident design, thus simplifying the circuit design and also minimising component count.

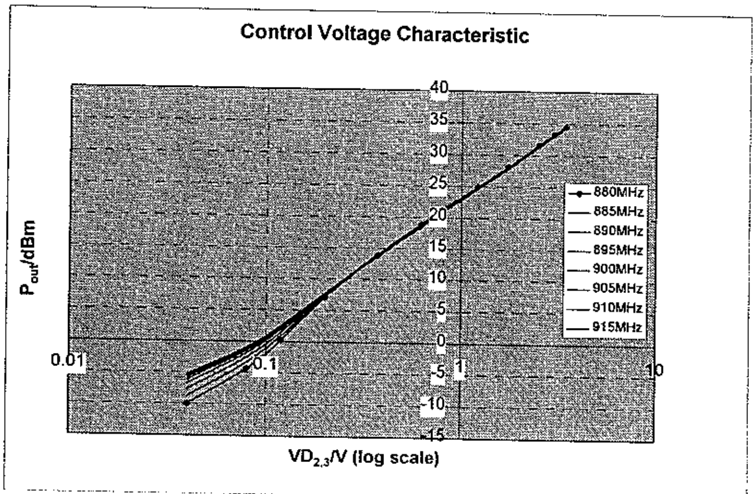

Figure 3 - GaAs PA Control Characteristic (Log scale)

Additionally, it was found that the square law relationship between control voltage and output power was very consistent over the required dynamic range of the amplifier. This means that the Trident power amplifier need only be calibrated at a single point in the dynamic range. Having calibrated this point, it can then be assumed that the control voltage to achieve any other output power level can be found by a simple square law extrapolation from the calibration point. Finally, this method of power control is very attractive for use in a multiband design, as a common circuit can be used to generate the supply voltage and apply it to any number of PA's in parallel. The power amplifiers not in use can be disabled, leaving the wanted amplifier to be solely controlled. This parallelling technique is simple to effect at low frequencies, whereas the sharing of power detect and control circuitry at RF is far more difficult.

Having amplified the transmit signal to the required output level, the signal is presented to the transmit/receive switch. The Trident design utilises a PIN diode switch. Now, advances in the power handling capability of GaAs has meant that GaAs switches are gaining popularity as lower insertion losses can be achieved. The insertion loss of a transmit switch is a key handset parameter as it directly influences the signal level that the power amplifier must generate to achieve the desired output power at the antenna. The power amplifier signal level in turn directly affects the talktime of the handset – a parameter that is extremely visible to the consumer.

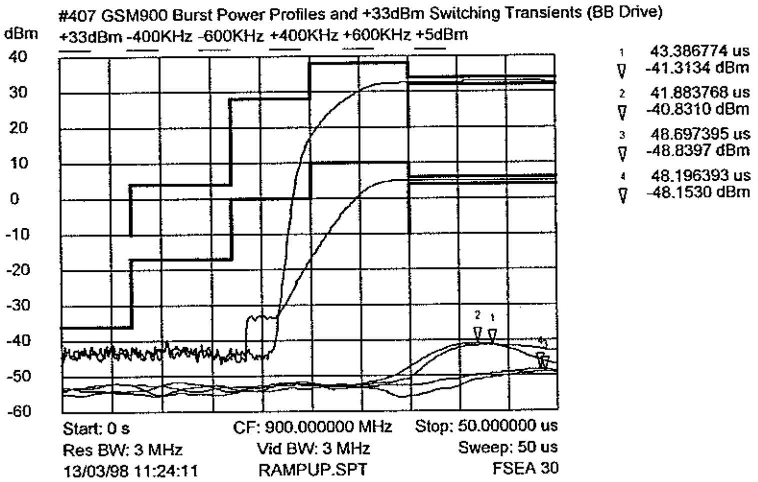

Figure 4 - Trident PA Ramping Profile

GSM transmitter performance measurements are complicated by the fact that GSM is a Time-division-duplexed system. Thus, any measurements must be made within a time window triggered relative to a known point in the GSM transmit frame structure. The most common measurement that is made in the time domain is the measurement of the burst power profile. This is typically performed using a spectrum analyser, set up with the complex limit lines that define the ETSI burst profile requirements. Furthermore, by offsetting the spectrum analyser centre frequency, the level of transient splash products may be observed, although these may also be observed in the frequency domain.

A frequency domain measurement is made to study the GSM GMSK modulation spectrum. Again, an ETSI template defines the required spectral shape. The measurement is triggered relative to a known point in the GSM frame structure, but also made within a time window that excludes the power ramping at each end of the burst, which would otherwise considerably distort the result.

Finally, the most frequently quoted parameter describing transmitted signal quality is the transmit phase error. GSM uses a phase modulation scheme (GMSK) and the transmit phase error is a measure of the phase error between ideal and measured phase trajectories averaged over a burst. The measurement requires the transmitted signal to be demodulated and is typically performed using either a dedicated GSM test set, or a vector signal analyser, set up to demodulate GMSK modulation.

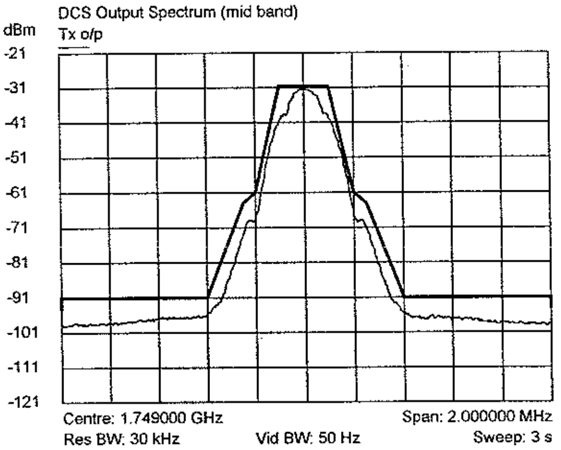

Figure 5 - Trident Transmit Modulation Spectrum