RF Cost Economics for Handsets

White Paper

The GSMA has commissioned RTT to research the impact of non standard band allocations on the cost and performance of cellular handsets and by implication, the impact of RF device and design trends on spectral allocation policy.

This **White Paper** highlights the key findings from the research and can be read in conjunction with a more detailed and fully referenced **Study.**

The **Study** is available as a **download from the RTT web site**

www.rttonline.com/research/RFCostEconomicsForHandsets-study.pdf

Market data for this White Paper and the study has been supplied by The Mobile World.

May 2007

LEGAL NOTICE

Introduction

The findings of this White Paper, ‘RF Cost Economics for Handsets’ and the supporting Study are based on interviews with technical, engineering, marketing and business executives employed by silicon vendors, their RF component and service suppliers, cellular handset manufacturers, RF design houses, test equipment vendors, type approval and conformance test agencies and network operators.

In particular we were asked to use these interviews to test the validity of a number of assumptions presently influencing global spectral allocation policy.

These assumptions are as follows

Assumptions used to justify a more flexible spectral allocation policy

With handset production volumes approaching and exceeding one billion units per year it might be assumed that sufficient scale efficiencies are available to support a wide range of standard and non standard band allocations.

The availability of GSM quad band and GSM/WCDMA quintuplet band handsets at competitive wholesale prices would seem to suggest that design and device solutions are already available that allow additional multi band multi mode functionality to be supported with minimal cost or performance penalties.

Higher levels of device integration combined with spectrally flexible architectures using micro electronic mechanical system devices (RF MEMS) and other device innovations will deliver software defined radios that will allow additional multiple bands to be introduced using multiple radio access technologies with minimal cost or performance penalties.

Sufficient engineering effort will be available to cost and performance optimise these solutions in a timely manner.

Intuitively it might seem that frequency specific costs, the RF ‘Bill of Materials’ also known as the RF BOM is reducing over time as a percentage of the overall BOM of the phone.

It might also be expected that the RF BOM in a high end phone represents a smaller percentage of the overall BOM than the RF BOM in a low end or mid tier phone.

Given that most of the non RF components share economies of scale irrespective of the frequency band in which they operate, it would seem that RF costs are becoming increasingly insignificant over time.

These assumptions together support the view that there is a reducing need to harmonise spectral allocations either on a local, regional or global basis and a reducing need to mandate technology standards.

A range of alternative assumptions
In this study, we draw on a wide range of industry inputs to suggest that these assumptions are largely invalid.

We identify **four cost components** in a cellular handset incurred as a result of introducing additional standard and non standard band allocations**, RF performance costs**, **RF component costs** (variable costs), **non recurring RF associated engineering costs** (fixed costs) and **opportunity costs.**

These costs are **volume dependent** and are **increasing rather than decreasing over time. Because of their volume dependence, such costs for any one vendor will be influenced by the number of vendors competing in a particular market.** We describe these as **'shared market costs'**

The study presents a realistic assessment of present emerging technology solutions and highlights some of the **engineering effort** needed to make these solutions cost and performance economic for mass market adoption. If too much engineering effort is required to implement a solution, it cannot become economically viable.

We highlight the impact of present industry **engineering resource constraints** and show how this results in **'opportunity cost multipliers'** that **significantly increase the real cost of spectrally non standard cellular handsets.**

We show that counter intuitively, **despite halving in value over the past three years**, **the RF BOM has stayed remarkably constant as a cost component and continues to represent between 7% and 10% of the overall cost of the phone.**

This ratio applies irrespective of whether the device is a low, mid or high tier handset.

These alternative assumptions are based on industry evidence. They support the view that there is **an increasing need to harmonise spectral allocations, locally, regionally and globally** and arguably **an increasing need to mandate technology standards.**

Present and future standard and non standard spectral allocations
Table 1 below shows the present 'standard' spectral allocations defined by the 3GPP [1] for present GSM and present and future UMTS deployment.

Table 1 Band Allocations for present GSM and present and future UMTS deployment

Band	3GPP	Allocation	Uplink	Duplex spacing	Downlink	Region
I	2100	2x60 MHz	1920-1980	190 MHz	2110-2170	Present UMTS
II	1900	2x60 MHz	1850-1910	80 MHz	1930-1990	US PCS
III	1800	2x75 MHz	1710-1785	95 MHz	1805-1880	GSM Europe, Asia, Brazil
IV	1700/2100	2x45 MHz	1710-1755	400 MHz	2110-2155	New US
V	850	2x25 MHz	824-849	45 MHz	869-894	US and Asia
VI	800	2X10 MHz	830-840	45 MHz	875-885	Japan
VII	2600	2x70 MHz	2500-2570	120 MHz	2620-2690	New
VIII	900	2X35 MHz	880-915	45 MHz	925-960	Europe and Asia
IX	1700	2x35 MHz	1750-1785	95 MHz	1845-1880	Japan

Apart from the range of bands, there are also differences between bands in terms of duplex spacing and guard band spacing which have a significant impact on RF device and design implementation. Additionally, individual countries may choose to propose additional allocations.

The present Consultation Document from Ofcom [2] in the UK, for example, proposes an auction of Band VII spectrum but with additional allocations at 2010 to 2025 and 2290 to 2300 MHz. The Consultation Document proposes that this spectrum should be allocated on a 'technology neutral' basis.

While it is possible that sufficient global market volumes may be available in Band VII to support multiple technologies, it seems unlikely that either regional or local scale efficiencies will be achieved in the 2010 to 2025 and 2290 to 2300 allocations either for single or multiple technologies.

Similar issues arise with the presently proposed repurposing of UHF spectrum for cellular radio.

This study quantifies the threshold market volumes needed to achieve scale efficiency for any specific spectral allocation.

It concludes that in terms of present industry structure, **country specific spectral allocations are intrinsically uneconomic.**

Japan and Korea provide two examples of country specific spectrally specific technology specific network implementation, PDC and PHS in Japan and more recently, Wi Bro in Korea. These deployments may be politically expedient but are generally uneconomic.

In reality, regionally specific spectral allocations are only economic for the two largest regional markets, India and China.

The remainder of this White Paper focuses on the quantification of these spectrally specific costs, related economies of scale and required market volume thresholds.

GSM market volumes and realized prices over the past ten years

Table 2 below gives the year on year subscriber growth for GSM between 1995 and 2006. (Market statistics from The Mobile World)

Table 2 Year on Year GSM Subscriber growth (in millions)

95	96	97	98	99	00	01	02	03	04	05	06 est
13.4	32.4	70.5	136	259	457	636	803	994	1289	1710	2033

The ASP of a low end GSM handset in 1995 was $250 dollars.

By 2005 prices had reduced to somewhere between $40 and $50 dollars.[3]

Over ten years there has therefore been a five fold reduction in wholesale average realized prices (ARP) equivalent to a 15% drop per year. This has largely tracked year on year reductions in component costs.

These cost reductions are a product of design improvements which result in a reduction in component count and therefore component cost. This is despite a year on year increase in radio functionality, for example the ability to support multiple band allocations and enhanced data services.

These design improvements are only realized through substantial non recurring engineering investment which needs to be recovered over substantial market volumes.

RF components do not generally fall in price as fast as mass market consumer electronics components. The reason for this is that RF functions are generally harder to integrate than digital/baseband functions and therefore do not benefit as directly from silicon geometry scaling.

RF BOM Cost Trends and future RF functionality
This overall ten year cost reduction trend still holds true today though some caveats apply.

Three years ago, the RF BOM for a triple band (GSM900/1800/1900) mid tier multi media handset was just over twelve dollars. [4]

The equivalent quad band (GSM900/1800/1900/850) RF BOM today is six dollars. [5] This suggests that year on year RF costs have decreased at 20% rather than 15% per year.

This would seem to be an alarming trend for vendors of RF components and suppliers of RF design expertise.

However substantial new application layer functionality has been added to cellular phones over this period, for example enhanced imaging and audio functionality and more recently advanced positioning capabilities. Through this process of added value, the largest of the component suppliers, design houses and handset vendors have been able to maintain profit levels.

To realise value from these advanced capabilities, network operators need to have handsets with enhanced RF physical layer functionality. This includes an ability to support higher **downlink and uplink data rates** and an ability to support **multiple simultaneous per user variable rate data streams.**

For RF component and system vendors, this is a fortuitous trend, helping to prevent further price erosion and providing opportunities to stabilise or in some instances increase RF BOM value.

Table 3 below provides examples of where the industry is trying to get to, even if it hasn't quite arrived yet. In present parlance, this RF physical layer functionality is described as a Flexible Layer One or FLO [6]. Flexibility in this context is the ability to support variable data rates and multiple simultaneous per user data streams.

The table uses the established OSI seven layer model to describe the functionality and 'value' of different levels of functionality in the phone.

The physical layer is the mechanism by which network operators capture user and content value.

Value generation at the higher layers of the protocol stack has to be 'preserved' by the physical layer. This is why RF performance and RF functionality is important.

Table 3 Five PHYS named FLO

	UMTS HSDPA	Bluetooth	WiFi	DAB/DMB	DVB-H
Flexible PHY	1,2,4 or 6 simultaneous bidirectional traffic streams voice, image, video,3gtxt, audio, data	3 simultaneous bidirectional traffic streams voice,data and device control	3 simultaneous bidirectional traffic streams voice, video and best effort	3 simultaneous uni directional traffic streams eg DAB plus two separate stream decodes	4 simultaneous uni directional traffic streams IP data, IP info, IP audio, IP TV
Flexible MAC	Multiple users per channel, multiple channels per user	Voice, data and device profiles	Contention or connection based MAC	Unidirectional MAC	Unidirectional MAC
Flexible network layer	IP voice, IP audio, IP video, IP data, multiple QoS data streams per IP address (IPV4/IPV6)				
Flexible transport layer	TCP/IP and UDP fixed length packets, virtual paths and virtual circuits using tunnelling and fixed routing trajectories.				
Flexible session Layer	Session initiation and session management protocols (SIP) and bandwidth reservation techniques (RSVP, Diffserv, MPLS, SMIL)				
Flexible presentation layer	XML and multimedia presentation and management protocols.				
Flexible application layer	Multitasking, flexible O/S and flexible GUI implementation				

Although much attention is paid to headline data rates, it can be seen from the above that this is only part of the picture and that considerable design attention is now being directed towards ensuring that cellular radio functionality can co exist with other transmit/receive and receive only functions.

For example receive only functions such as digital TV or GPS, are easily desensitised by locally generated transmit power in the handset.

This implies a need for additional filter components. These will increase the recurring costs of the RF BOM. Adding a new band to a handset is therefore a significantly more complex design task which implies an increase in non recurring engineering cost and related opportunity cost.

RF BOM recurring costs might initially seem to be insignificant, about 4 dollars for a dual band GSM phone, 5 dollars for a tri band phone and 6 dollars for a quad band phone. These costs [7] represent the additional filtering required in the receive and transmit paths of the handset.

If adding an additional non standard band to a handset only incurs a dollar or so of incremental RF BOM cost, then it would seem reasonable to assume that it would be relatively easy to ensure an adequate supply of cost competitive performance competitive handsets.

In practice however, each incremental band has a performance cost and substantial NRE and opportunity cost that taken together, invalidate many apparently viable cellular radio business plans.

These performance costs, **NRE costs and opportunity costs** are increasing rather than decreasing over time. In particular, these costs **increase as the level of integration increases.** At the same time recurring costs are decreasing.

Risk distribution, software/hardware value and the cellular industry value chain

The seven layer model (Table 3) can also be used to describe the allocation of risk across the industry value chain and the shift that has taken place in terms of the relative values attributed to general hardware development, general software development and RF specific hardware and software development.

An analogue cellular phone in the 1980s had 10,000 lines of software code, a GSM phone in the 1990's had 100,000 lines of code, a 3G phone today has well over one million lines of code. This trend would seem to diminish the importance of RF functionality.

In practical terms however, changes of RF functionality including new frequency band allocations have a profound impact on software functionality.

Traditionally Layer 1, the Physical Layer, has been regarded as hardware intensive. In cellular handsets this functionality depends on passive hardware such as the antenna, front end filters and the RF integrated circuit (RFIC).

Some vendors are presently promoting the concept of software defined radios capable of accessing a broad range of frequency bands supporting a broad range of access technologies.

In practice these technologies are not yet ready for mass market adoption and present significant integration challenges [8].These challenges add major NRE costs.

However there are substantial **existing** software costs associated with RF functionality. Present RF integrated circuits have to be designed to work with baseband IC's. These in turn have to be programmed to control and respond to changing RF channel and traffic conditions.

Thus an additional standard or non standard band allocation will require RF related hardware and software engineering effort and investment - NRE costs - that will need to be recovered over the production life of the handset.

The actual cost of RF components may be a relatively small percentage of the overall BOM of the phone. However the RF costs associated with **non standard band** allocations come with substantial **risk multipliers** in terms of cellular handset **performance**, cellular handset **functionality**, cellular handset **availability** and **unsupportable hardware cost premiums** particularly **for smaller markets.**

Quantifying Performance Costs for standard multi band handsets
15 years of GSM production experience has helped develop a considerable body of knowledge of cellular phone performance including the performance costs associated with additional frequency band support.

Initial handsets were single band 900 MHz. Dual band 900/1800 handsets were introduced from 1995, tri band 900/1800/1900 from 2000 and quad band (adding in GSM850 for the US) from 2005.

From an RF design perspective, the half wave /quarter wave relationship between 900 and 1800 MHz provided opportunities to develop novel and effective RF architectures though at the time these phones still represented a significant design challenge.

Subsequent band additions have all introduced new design challenges and required optimised design solutions. All have been successfully accomplished but at considerable NRE cost.

Theoretically the additional insertion losses implicit in these multi band designs could 'cost' a dB or so per band in terms of lost sensitivity.

In practice, these potential losses have been more than balanced out by overall improvements in GSM RF performance. Handsets in 1992 struggled to meet the conformance sensitivity specification of -102 dBm [9] but on average improved by approximately 1 dB per year. By 1997, phone sensitivity could typically be measured at -107 dBm. Over the past ten years this has improved to about -110 dBm. Further improvements will be harder to achieve as GSM approaches its fundamental bandwidth/ noise limits.

These steady improvements are due to the engineering effort invested in component optimisation, design optimisation and manufacturing techniques including device self calibration.

They are also partly the result of production volume. As production volume increases, handset manufacturers can demand that their suppliers more closely control the tolerance and/or device to device batch to batch performance spread of RF components.

These effects hold true for standard band allocations provided there is sufficient market volume to fully amortise engineering design effort and sufficient market volume to achieve volume related performance gains.

Quantifying performance costs for non standard bands
None of the above necessarily applies for non standard band allocations.

The performance cost in terms of sensitivity loss will depend on what other bands are supported in the handset and the spectral relationship of the newly allocated bands to other bands. For example sensitivity will be dependent on the amount of guard band between the allocated band and adjacent occupied spectrum, and the duplex and diplex spacing.

Additionally low market volumes will typically not attract sufficient engineering effort to optimise the RF design of the phone including practical aspects such as antenna optimisation.

This may result in phones being 2 or 3 dB less sensitive than equivalent phones optimised for standard band allocations.

To put a dollar cost on this, a one dB loss of sensitivity equates to a need to increase network density by 10% to maintain an equivalent link budget. A loss of sensitivity will decrease downlink data rates and increase dropped call/dropped session rates.

The same principles apply on the transmit side of the cellular phone. Considerable design effort is needed to deliver acceptable error vector magnitude (EVM) and low adjacent channel power (ACPR) levels. A poorly implemented transmit chain will have a direct impact on uplink data rates.

In terms of production costs there is also the issue of **RF yield**.

RF yield is the percentage of handsets that pass their RF transmitter and receiver performance and functionality tests at the end of the production line.

Provided phones are at least 4 to 5 dB better than the basic conformance specification on the receive side and preferably several percentage points within the EVM specification, RF yield will be high (close to 100%).

If phones are closer to the conformance specification limit, RF yield will drop. Some phones may be able to be reworked but a substantial percentage may need to be scrapped. Note it is not just the RF components that get scrapped but possibly the whole phone so the cost impact can be dramatic particularly with higher end phones. Low production yield can also introduce time to market delay.

Component Costs

We have said that the direct component costs for supporting a non standard band, assuming it is additional to existing standard bands, are relatively trivial, in the order of one or two dollars per handset.

These costs are made up in GSM by additional front end switching and routing and a diplex filter. In UMTS, additional duplex filtering will be needed. There may be a requirement for a special to type antenna.

Other costs depend on what else is included in the phone. Higher end phones with Bluetooth and/or WiFi and/or DVB and/or GPS functionality may require additional filtering and reciprocal mixing to eliminate unwanted inter modulation products

This is however only part of the story. RF devices generally take a signal, do something to it (filter or amplify for example) and then pass the signal on to another device. In the process, the devices need to be power matched or noise matched – a semi black art known as conjugate matching. [10]

So any additional RF function will usually require additional RF matching components. If these are discrete devices there will be a production cost implication - more components to place, more component variability and a harsher production test regime. [11]

Any increase in production testing will be directly reflected in the final cost of the device. The additional component count and RF device to device variation will also reduce RF yield, adding further to costs.

The effect of increased levels of device integration
One well established route to reducing component costs is to increase integration level.

In the past, previously discrete functions such as the frequency synthesiser and VCO have been ‘off chip’. These are now (usually) integrated on to the RFIC.[12]

Future plans include the use of RF MEMS to allow diplexing and duplexing functionality to be integrated together (rather ambitiously) with the RF PA into a ‘single chip software definable phone’.[13]

However as and when this happens the effect is that **the RF BOM decreases** but **the RF NRE increases.** Thus from the perspective of the manufacturer, to design a highly integrated phone, high volumes become imperative in order to recover the NRE. This makes producing for non standard bands of questionable profitability unless high volumes can be assured or the manufacturer can sell low volumes for very high prices.

Conversely a decision could be made to implement a phone for a non standard band using relatively low levels of integration. This will reduce the NRE investment but increase component count and component cost and size. With that, both the cost and the size and weight of the phone also increase.

RF performance may or may not be worse or better (a good discrete design can work rather well) but will be more variable. Higher levels of device integration will generally yield more consistent performance.

So engineering effort has to be focussed on finding optimum trade offs between device performance and device cost. SAW filter vendors differentiate their products for example on the basis of low insertion loss and/or small form factor, minimal height being a presently important metric for ultra slim handsets.

Active device vendors differentiate their products on the basis of efficiency, linearity and phase accuracy. There are hundreds of subtle but significant device and design decisions that need to be made during the development process.

These decisions are always critical but especially critical for ultra low cost handsets where performance margins may be less generous. This suggests that **non recurring engineering costs may be higher for ultra low cost handsets.**[14] This makes it challenging for vendors other than Tier 1 vendors to address this market.

Non Recurring Costs
Performance cost multipliers and component cost multipliers for non standard bands are important but in practice are relatively insignificant when compared with non recurring engineering costs.

Non recurring engineering costs, specifically, in the context of this study, non recurring **RF** engineering costs are incurred by silicon vendors and their supporting component vendors, for example SAW and BAR filter suppliers, handset vendors and operators. NRE costs include type approval testing and conformance testing. These tests alone can comfortably exceed one million dollars. [15] Interoperability and drive testing by operators can easily equal or exceed this figure.

Typically a silicon vendor will need to spend at least three million dollars developing an RF chip set for a new standard or non standard band. This includes type approval testing.[16]

A handset manufacturer will take this device and **typically spend two million dollars on developing a working cellular phone including the internal resource needed to get the product through the conformance test process** and fit for production. [17]

A network operator should do drive testing and interoperability testing. This might be a once off process but has an unpleasant habit of becoming a semi recurring expense, particularly as network deployments evolve over time. Hence **our probably conservative figure of one million dollars.** [18]

So the **total NRE costs** associated with a standard or non standard additional band allocation total **six million dollars.** [19]

In the context of an 800 million unit annual market, these figures look insignificant. However the NRE costs are insignificant compared with the opportunity cost multipliers that presently have to be applied in the industry to meet acceptable shareholder and stakeholder return on investment expectations. This is why allocation of non standard spectrum may lead to fewer and more expensive phone models than regulators (or operators on the spectrum) expect.

Opportunity Costs

Opportunity costs, effectively 'lost opportunity costs' were described by a number of respondents (summarised and paraphrased) as follows;

'Consider a choice which is basically to take 50 or 100 scarce and expensive engineers and put them on a cost and performance optimisation project for a mainstream product, for example a triple band GSM or quad band GSM product. I know I can ship five, ten or possibly ten or even twenty million devices per month to my major tier one customers. This is a known market with a known cost base and well documented growth history.

If that team produce a cost saving of 50 cents a phone which altruistically I share on a 50/50 basis with my customers- or 25 cents each- then I can show a direct and immediate beneficial impact on my profit, $15 million, $30 million or $60 million a year. If the team produces a cost saving of $2.0 per phone, I could profit by as much as $240 million per year. My customers and I will have consolidated our competitive position in that volume sector of my business.

I have to have that volume component otherwise I know I will be unable to match R and D investment to future market opportunity.

My alternative option is to take the same engineering team and ask them to produce a chip set and reference design for an unknown market with a non existent growth history and potential rather than proven growth prospects. It would be very unlikely that I could get an assured ten or hundred million dollars of profit.

Additionally if my competitors take the decision to cost and performance optimise mainstream products and I don't, then I could be placed at a catastrophic market disadvantage'.

This explains why it is common particularly at silicon vendor level to use an opportunity cost multiplier of between ten and twenty times the estimated NRE costs when validating uncertain or unknown market opportunities.

Thus our figure of 6 million dollars to develop a phone for a non standard band now becomes a minimum of 60 million dollars.

Shared market costs

However this is a single vendor view. In practice, as most purchasing managers will agree, it is a good idea to have at least **five potential suppliers** competing for business of which typically two might be chosen to provide primary and secondary sourcing. This is a necessary precondition for an efficient market. [20]

However an efficient market also has to have sufficient volume to allow for NRE recovery. Thus a single vendor has to consider the risk of other vendors dividing down the available market volume. This risk has to be expressed as a cost multiplier, the **'shared market cost.'**

GSM-R provides an example of a very small market (tens of thousands of handsets). GSM–R is deployed into a 4 MHz band of spectrum below the cellular 900 MHz bands and is set aside for use by European railway companies. There is only limited vendor support and handsets cost $1500 dollars. [21]

TETRA, the Trans European Trunked Radio Access networks deployed in Europe in high band VHF and UHF allocations have marginally higher volumes but multiple vendors. Handsets cost between $300 and $500 dollars.

The Composite Cost Calculation for cellular handsets

These are extreme examples but illustrate the effect of small (TETRA) or very small (GSM-R) market volumes.

In general, in more mainstream markets, network operators will be competing with entry level handsets with a wholesale cost of 40 to 50 dollars. In these markets, component vendors, handset manufacturers and network operators will need to recover NRE costs which we have established as being at least 6 million dollars.

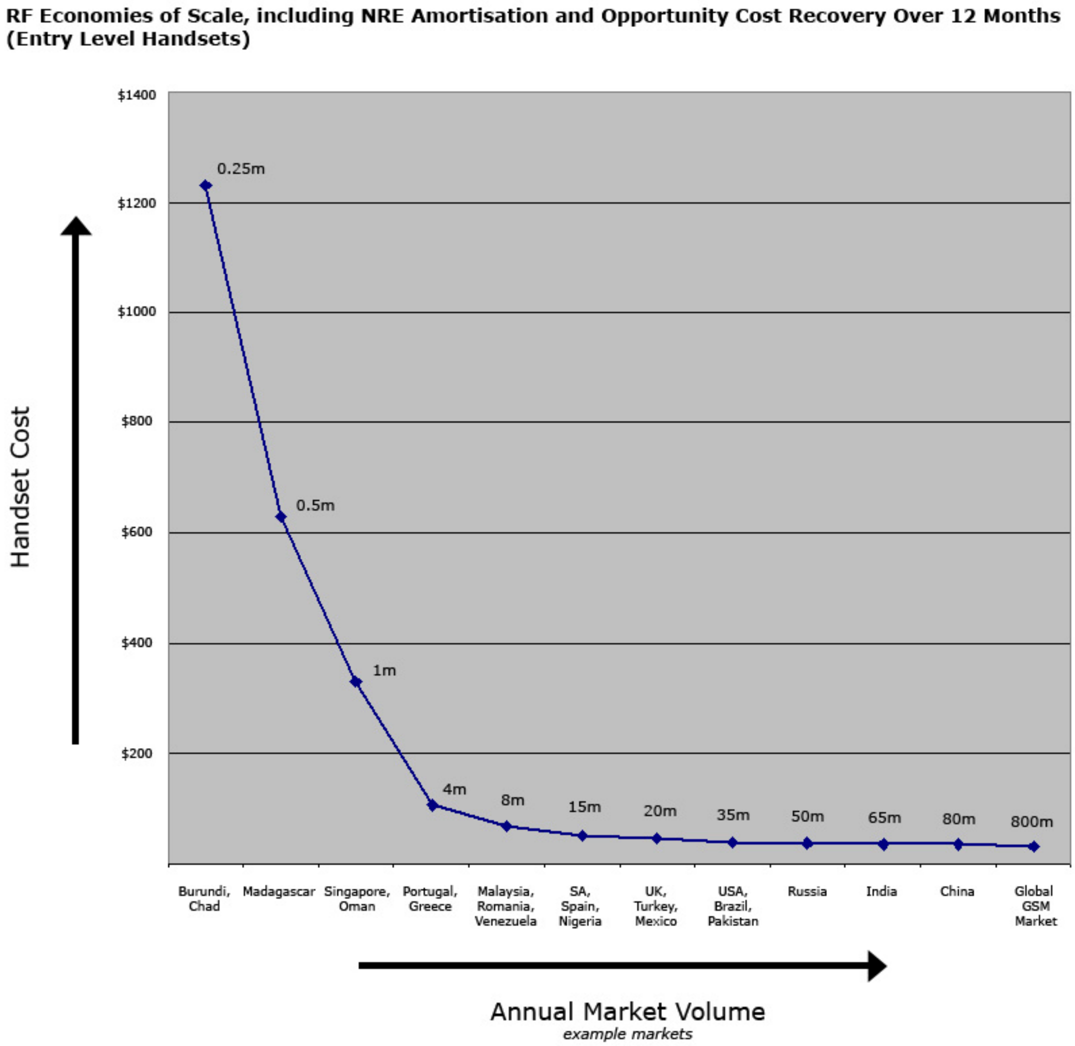
These costs then have to be multiplied by a factor of at least 10 to account for the 'opportunity cost' of supporting a non standard band allocation.

Finally these costs have to be multiplied by the number of vendors sharing the available market volume (the shared market cost) yielding the following calculation.

NRE (6 million dollars) X10 (typical opportunity cost multiplier) X 5 (shared market cost multiplier) = 300 million dollars.

The calculated sum can then be applied to present market volumes. [22]

Graph 1 Cost Curves 0.2 to 800 million units per year.



For comparison purposes, the market is divided into three tiers, Global, Regional and Local.

The Tier 1 global market is **800 million** units per year.

Tier 2 Large Regional Markets are in the order of **80 million** units per year. China is an example. Other Tier 2 regional markets include India where year on year growth is presently faster than China. The US, Brazil and Pakistan each represent about 35 million units per year. The US and Brazil together therefore constitute a 70 million unit market however the fragmentation of technology choice in the US and Latin America arguably invalidates the possible regional scale benefits.

Tier 3 Local markets are in the order of **8 million** units per year. Malaysia, Romania and Venezuela are all individual examples. Scandinavia is another example.

The 'reference product' is an ultra low cost handset at 30 dollars.

Amortising 300 million dollars of NRE, opportunity cost and shared market cost over **800 million units** (the Tier 1 global market) adds less than 40 cents (37.5 cents) of real cost to the phone. The total **handset cost** is therefore **30.375 dollars.**

The volumes are over one year. Note it would be considered imprudent to assume a return on investment over more than 12 months given that the redesign cycle is close to 18 months (possibly also reducing over time).

The same sum is then done for Tier 2 markets, for example China, at **80 million units** per year and India (65 million but will soon be 80 million) and it can be seen that NRE costs are still sustainable, adding just under 4 dollars (3.75 dollars) per handset. The total **handset cost** is therefore **33.75 dollars.**

The same sum is done for Tier 3 markets at **8 million units** per year, for example Malaysia, Romania, Venezuela, with, as you would expect a cost penalty of just below 40 dollars (37.5 dollars). The total **handset cost** is therefore **67.5 dollars**.

Costs then rise to nearly **1200 dollars** per handset for markets of a **quarter of a million units per year.**

In practice it can be seen that only markets like India, China or equivalent regional markets can sustain a spectrally specific band allocation.

Table 4 Amortising 300 million dollars of NRE Costs over various market volumes

300 million dollars of NRE cost amortised over	**800 million units per year**	**80 million units per year**	**8 million units per year**
Implies a per unit recovery of	**37.5 cents**	**3.75 dollars**	**37.5 dollars**
Resulting in a 30	**30.375 dollars**	**33.75 dollars**	**67.5 dollars**

dollar handset costing			
The example is relevant for a	**Tier 1 Global Market**	**Tier 2 Regional Market India, China**	**Tier 3 Country Malaysia, Romania Venezuela**

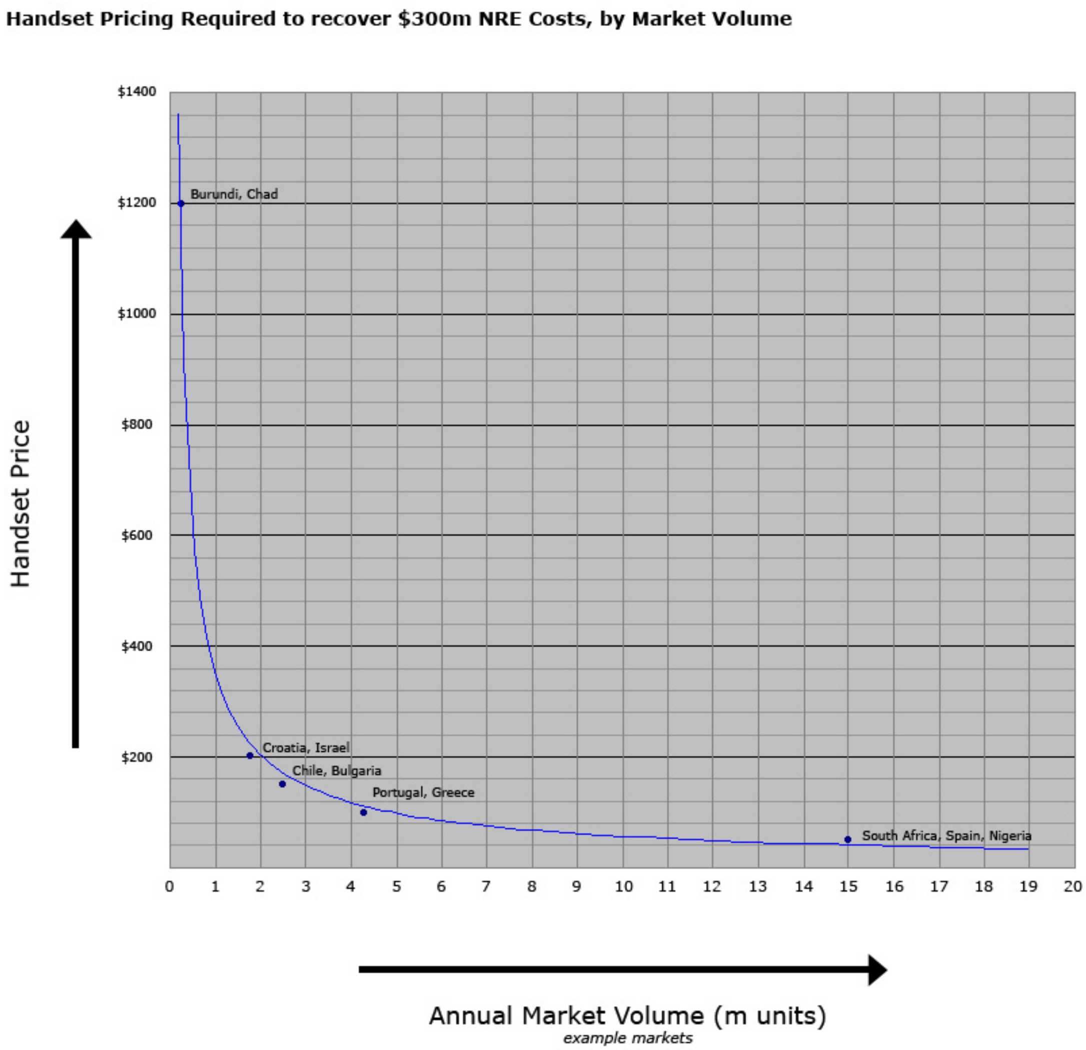
Pricing effects in Tier 2 and Tier 3 markets
Table 5 applies the same assumptions to a cross section of Tier 2 and Tier 3 markets. A 30 dollar handset is used as the reference point. At **15 million units** per year **a 30 dollar handset will cost 50 dollars**, at **4.28 million units** per year a 30 dollar handset will cost **70 dollars**, at **2.5 million units** per year a 30 dollar handset will cost **150 dollars**, at **1.764 million units** a 30 dollar handset will cost **200 dollars**, at **0.25 million units** per year a 30 dollar handset will cost **1200 dollars.**

Table 5 Tier 2 and Tier 3 Market Handset Costs

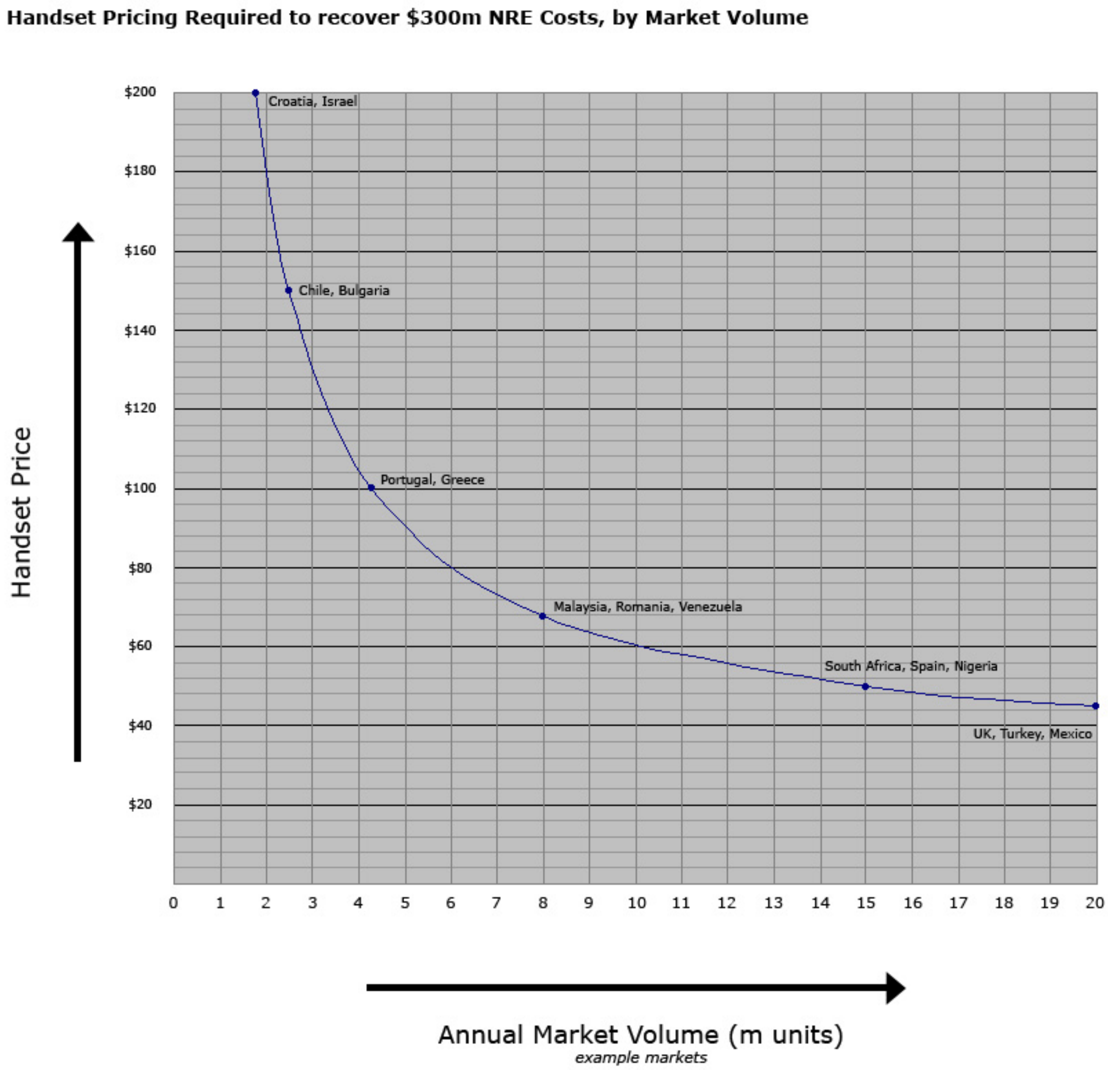
A 30 dollar handset selling at	**$50**	**$100**	**$150**	**$200**	**$1200**
Provides a per unit contribution of	**$20**	**$70**	**$120**	**$170**	**$1170**
To recover an NRE cost of 300 million dollars requires an annual market volume of	**15 million units**	**4.28 million units**	**2.5 million units**	**1.764 million units**	**.25 million units**
Typical countries include	**South Africa Spain Nigeria**	**Portugal, Greece**	**Chile**	**Singapore Oman**	**Burundi or Chad**

Graphs 2 and 3 show the related cost curves scaled over 0.2 to 20 million units per year and 2 to 20 million units per year.

Graph 2 Cost Curves 0.2 to 20 million units per year.



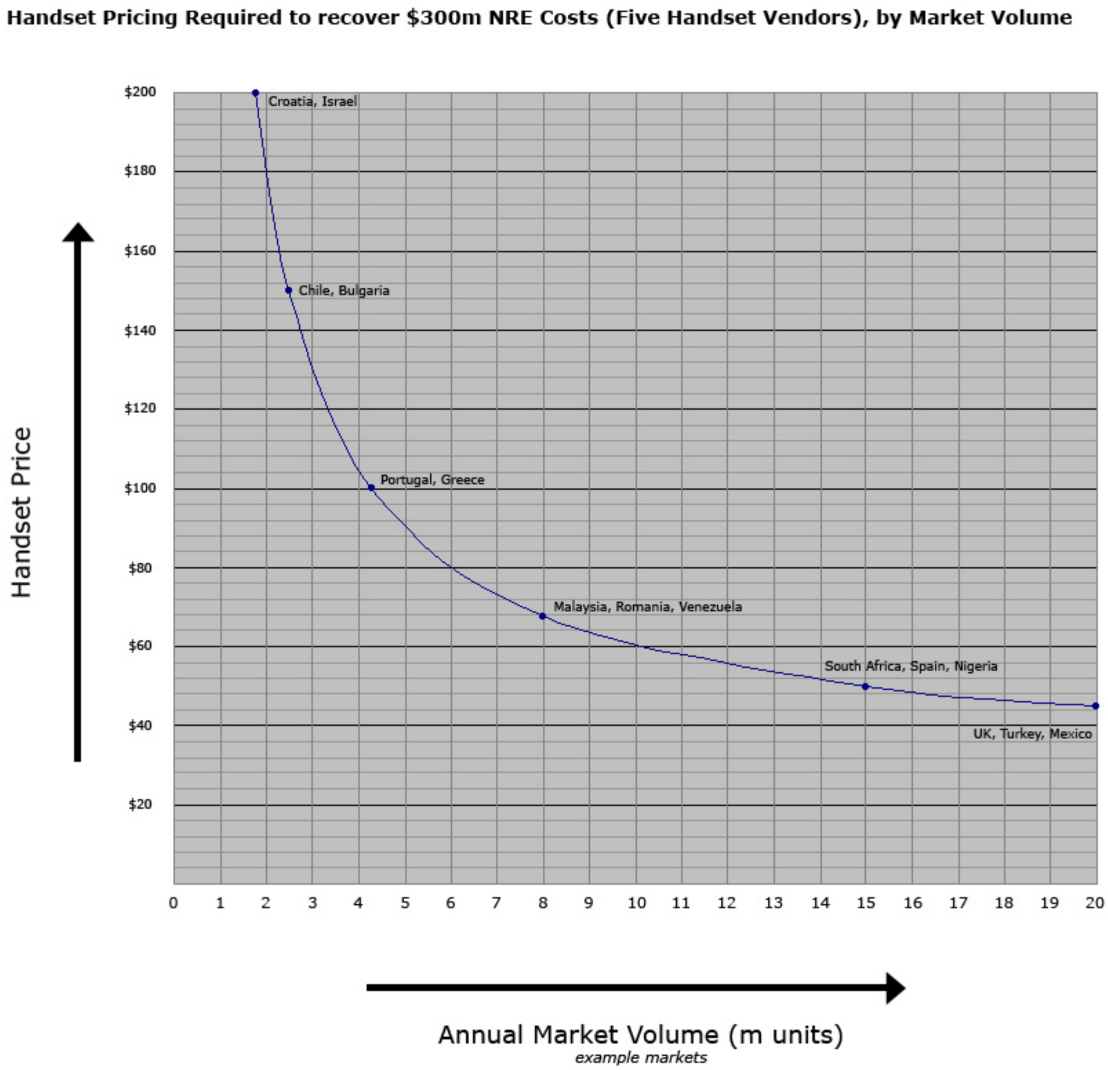
Graph 3 Cost Curves 2 to 20 million units per year.



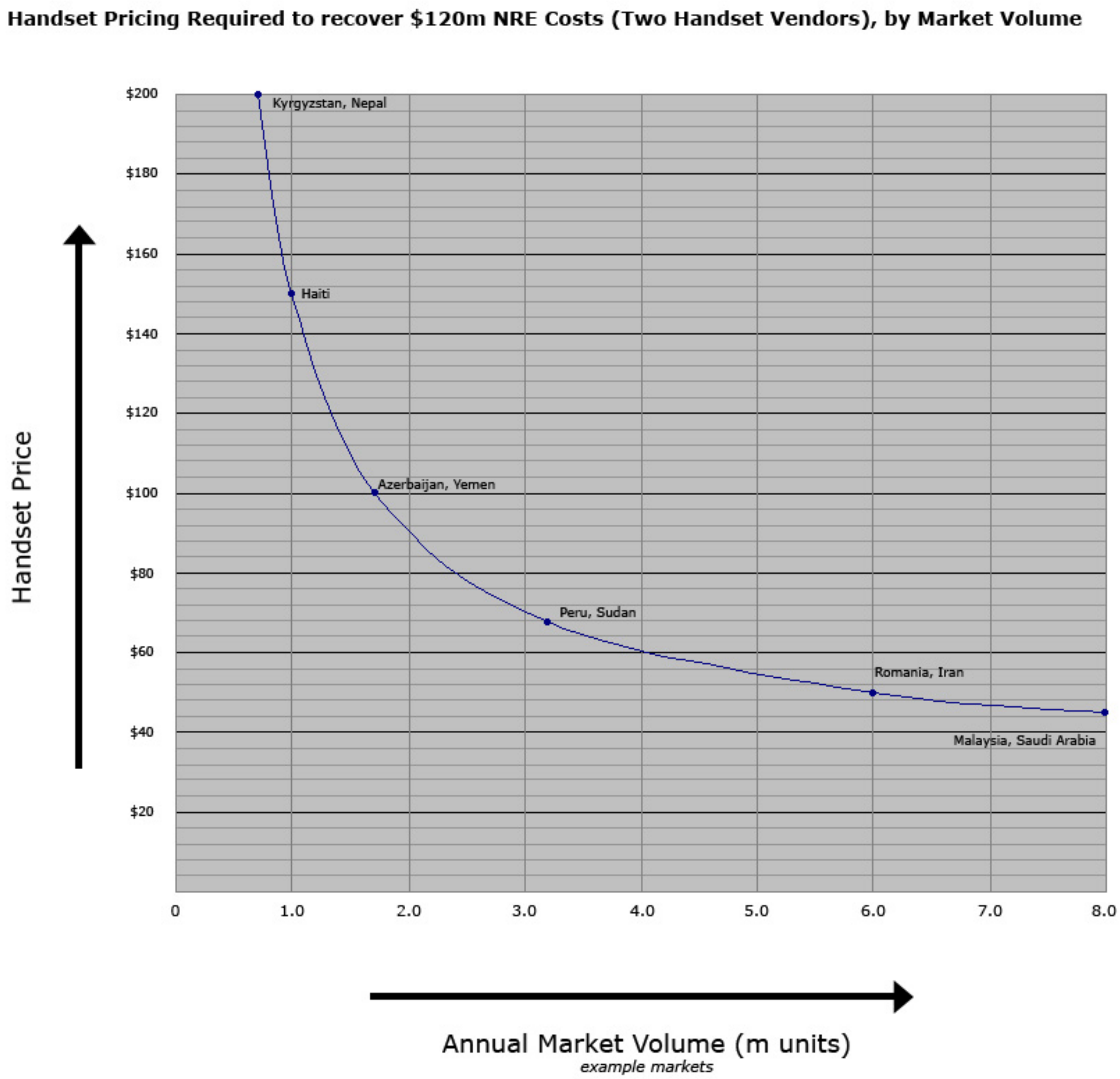
Handset pricing assuming one vendor or two vendor supply
Although we have said that having less than five vendors servicing a market implies a supply inefficient market, it may be that a single vendor or perhaps two vendors competing with one another might choose to supply an 'undersized' market for strategic reasons**.**

Graph 4, Graph 5 and Graph 6 together show the handset pricing required to recover $300 million dollars (five vendors), $120 million (two vendors) and $60 million (one vendor). As expected, the two vendor and single vendor examples show a lower additional cost but this has to assume that the vendors do not exploit their monopoly or near monopoly position. Additionally there may be a risk that product choice may not be sufficient to meet market expectations.

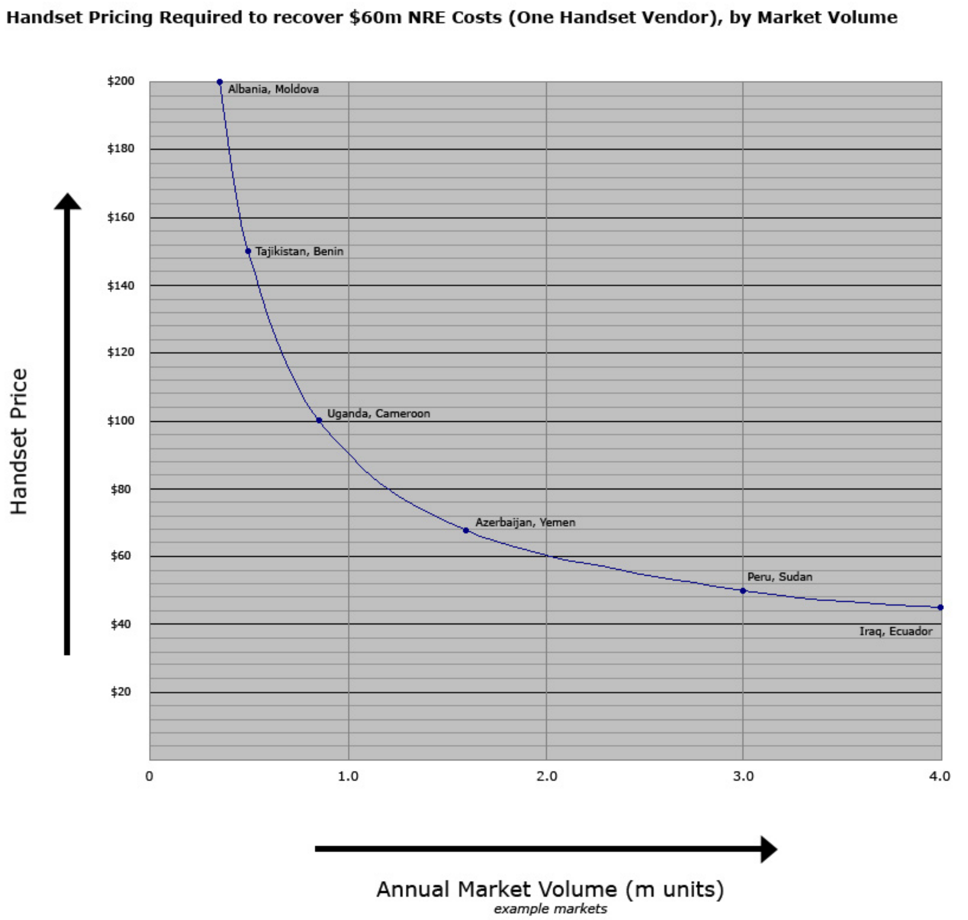
Graph 4 Cost curves assuming five vendors



Graph 5 Cost curves assuming two vendors



Graph 6 Cost curves assuming one vendor



The Relevance of 80/20 Learning Curve Effects to Tier 2 and Tier 3 markets
Some present parallel work to this study by other parties on UMTS900 handset availability suggests a' learning effect' which causes production costs to reduce by 20% every time cumulative volume doubles.

While this effect may apply to Tier 1 markets and possibly to Tier 2 markets, it is unlikely to apply to Tier 3 markets where insufficient volumes exist for volume related production gains to be achieved. The absence of a learning curve effect on pricing in Tier 2 and Tier 3 markets therefore places these markets at an additional disadvantage. [23]

The 'Broadening Spread Effect'
Note that as cellular handset cumulative volumes increase over time, the volumes of standard handsets increase and costs decline. However the relative cost difference between handsets for standard and non standard handsets will increase. [24]

The relative ‘penalty’ cost of delivering non standard regionally or locally spectrally specific products therefore increases over time.

The impact of RF Economies of Scale on Spectral policy
In summary, the impact of non standard band allocations on the cost of handsets when considered purely in terms of component cost additions seems trivial.

However on closer inspection, we find we need to factor in substantial non recurring **engineering costs**. Further more, these costs are **increasing as integration levels increase.**

Component integration is a major factor enabling ultra low cost phones. Thus NRE costs will be substantial in order to deliver equivalent phones for non standard spectrum in developing countries.

Additionally vendors need to apply rigorous **opportunity cost multipliers** to avoid a dangerous dissipation of design engineering resource. These are typically at least ten times the estimated baseline and are the result of realistic return on investment expectations given **present engineering resource limitations** and **shareholder value growth expectations.**

Finally this is a single vendor view. If there was a single vendor supplying the market then there would be additional NRE amortisation volume but scant incentive to provide competitive pricing.

Thus by default these are going to be **multiple vendor markets** and as such **available volumes will be divided down by the number of competitors participating in that market.**

This effectively invalidates most business models predicated on non standard band allocations.

Similar arguments could be made to show that **a lack of a harmonised mandated standards policy will have an equally dramatic effect on handset technology costs.**

Conclusion
Contrary to popular belief, RF performance costs, non recurring RF associated engineering costs and foregone market opportunity costs are increasing rather than decreasing over time.

In particular, **non recurring engineering costs increase as integration levels increase**. This holds for high, mid, low and ultra low tier handsets. **These costs are not volume dependent but their recovery is. While these costs are non recurring, they have to be recovered across significant market volume.**

Present industry engineering resource constraints introduce generally **under estimated opportunity cost multipliers** that **significantly increase the real cost of cellular handsets intended for non standard spectrum**.

The competitive structure of the industry further increases these costs through the **'shared market effect'**.

Despite halving in value over the past three years, the RF BOM has stayed remarkably constant as a cost component and continues to represent between 7% and 10% of the overall cost of a cellular phone.

This ratio applies irrespective of whether the device is an ultra low tier, low tier, mid tier or high tier handset.

The RF functionality in the phone directly dictates the revenues that vendors and operators can realise from the device. These **revenues** in turn are **dependent on the overall RF performance of the device.**

This performance can be seriously compromised in handsets supporting non standard band spectral allocations unless manufacturers invest substantial engineering resources. **Compromised RF performance increases cost and reduces revenue.**

Overall, non standard band allocations introduce incremental costs that in the case of specific spectral allocations in small developing countries can exceed 1000 dollars per phone.

These costs invalidate otherwise plausible spectral and network investment business models. For this reason, regulators in such countries should be exceptionally careful in allocating non standard spectrum.

For a full report on the research undertaken for this White Paper download the supporting **Study**

http://www.rttonline.com/RFcosteconomics/handsets/study

References

1) Band allocations proposed by the 3GPP as part of the ETSI led spectral and technology standards process. http://www.3gpp.org/
2) Ofcom Consultation document http://www.ofcom.org.uk/consult/condocs/2ghzawards/
3) Prices researched by Arete in September 2005 and included in the GSMA abstract 'Optimizing Spectrum for Future Mobile Service Needs' published in June 2006.

4) Costs provided 3rd October 2006 by a UK Design House based on a detailed RF BOM including RF software costs for a mid tier multi media phone assuming one million units per year and validated from other multiple sources. Note that this implies that RF devices reduce in price at half the rate of other baseband/digital devices (for example computer chips). This is because RF devices are harder to integrate and therefore do not follow Moore's Law (a doubling of density every 18 months) in terms of geometry scaling cost reduction. RF devices do however benefit from volume related production efficiencies (RF yield) and volume related performance gain which are quantified in more detail in the **Study**, (Chapter 2 sections 8 and 9). There is of course no guarantee that these cost reductions will continue over time either for RF Devices or other non RF devices. Issues such as current leakage become increasing important as silicon geometries scale to 90 or 65 nm and may introduce fundamental scaling limits. It does however mean that RF devices are more volume sensitive that baseband computer chips, hence the additional and usually understated RF cost multipliers implicit in non standard band allocations.
5) Costs provided by a Tier 1 RF PA manufacturer 6th October 2006 and verified from other multiple sources. Additional feedback from silicon vendors in early December 2006 suggested these figures might be on the high side. Additionally it has been suggested that our figures for NRE might be low with $12 to $15 million dollars being a closer estimate of the present 'real' costs of designing and developing a handset rather than our stated $6 million dollars. This would of course increase rather than decrease the cost differentials shown in the cost curve graph.
6) The term FLO was originally used by Ericsson to describe EDGE dual transfer mode functionality and subsequently, UMTS Release 99 functionality. It has also been used subsequently by other vendors, for example Qualcomm's Media FLO broadcast technology where it means '**F**orward **L**ink **O**nly'
7) See Chapter 2, Section 30 in the **Study.**
8) Chapter 2, Sections 18 to 21 **Study**
9) Sections 8 and 9 Chapter 2 **Study**
10) Section 12in the Background Notes on Technology section of the **Study.**
11) Section 29 Chapter 2 of the **Study.**
12) Section 21 Chapter 2 **Study**
13) Section 19 Chapter 2 **Study**
14) Section 11 in the 'Background Notes on Technology' section of the **Study** includes the Conformance test costs implicit in ULCH handset development.
15) Our thanks to RFI Global http://www.rfi-global.com for providing detailed information on conformance test costs for GSM and UMTS handsets. For additional detail go to Chapter 6 Section 11 in the **Study** Document.
16) Phone briefing Tier 1 silicon vendor, 9th October 2006 and verified from other multiple sources.

17) Phone briefing Tier 2 handset vendor, 3rd October 2006 and verified from other multiple sources.
18) Information provided 3rd October by a Conformance test house, corroborated 10th October by Tier 1 test equipment vendor 6th December 3G World Congress Hong Kong and other sources. NRE costs for an entry level phone calculated at $12 to $15million dollars, using **ULCH negotiation methodologies** and provided to network operators at 44 dollars. Note that multiple technologies deployed in any market whether deployed into standard or non standard bands will also have the effect of increasing NRE costs. Additional responses from Tier 1 vendors have highlighted the variability and unpredictability of RF related NRE costs on any particular project. RF transceiver and/or RF IC designs often fail to work at the first design iteration. It is not uncommon for vendors to have to go through as many as ten design iterations before a design is production friendly or in other words can be delivered at a consistent cost with a high RF yield, delivering consistent RF performance. Thus a $3 million dollar NRE becomes a $30 million dollar NRE. This unpredictability in itself determines ROI policy and has to be reflected in chipset profit margins which therefore implicitly have to be significantly higher for Tier 2 or tier 3 markets. Note that this includes the possibility, sometimes probability that handsets will fail interoperability tests at network level. The probability of failing interoperability tests will be significantly higher for phones designed to work in non standard frequency bands. Note that ULCH negotiation methodologies typically consist of multiple operators exerting pressure through their trade associations to persuade individual competitive vendors to reduce their ROI expectations on the basis of promised future market volume. Such tactics can cause short term distortions in market pricing. Qualcomm's Rangela phone for the Indian market is a possible recent example.
19) Chapter 2 of the **Study** suggests that RF BOM costs have halved over the past 3 years implying a year on year real decrease in costs of 20%. Anecdotally real reductions of 15% per year are more usual in the industry as additional functionality is usually introduced to off set these declines in ARP. The assumption of a 20% cost reduction for every doubling of cumulative market volume suggests that unless cumulative markets double annually **per individual vendor** then ARP reductions will be higher than achieved cost reductions and therefore margins will reduce. This explains why vendor consolidation occurs in more mature markets. However the **combination of** some **production efficiency gain from the learning effect**, albeit not 20% **with silicon geometry scaling** and aggressive year on year integration could mean that real cost reductions of 20% could be achievable for some Tier 1 vendors. This requirement however makes it even more unlikely that Tier 1 vendors could contemplate risking investment in speculative Tier 2 or Tier 3 market specific spectrally specific designs. In other words, vendors need to have visibility to at least a 20% reduction in real cost per year in order to remain

competitive. Low volume markets will not deliver these required cost reductions. See section 15 in the Background Notes Section of the **Study** for a more detailed discussion of this topic.

20) See Reference 23, Chapter 7 of the **Study**.
21) Chapter 3 Section 6 of the Study documents GSM-R as an example of a market where volumes are in the low tens of thousands. This market size is too small to support an efficient mix of vendors. There are two subsidiary vendors and one main vendor servicing the market and handsets cost 1500 dollars each. The market is supply inefficient due to insufficient volume. TETRA is an additional example where volumes are higher but again a limited number of vendors compete for the available business. Nokia's exit from the TETRA business underlined the high opportunity costs implicit in servicing these smaller volume markets. CDMA 450 provides a similar example, a low volume market supplied by a limited number of vendors. The difference with CDMA450 is that handset prices and handset functionality, particularly form factor, are expected to be directly comparable with other cellular products.
22) Chapter 5 of the **Study** provides a detailed analysis of present cellular market dynamics and the related impact on industry costs and margins. Market statistics supplied and analysed by The Mobile World. www.themobileworld.com
23) Section 15, Chapter 6 of the **Study** – Learning Curve effects, cost and ARP reductions and the impact on vendor margins
24) As an example, the US in the early 1980's constituted over 80% of the world market but is today a minority market when compared to the overall global cellular subscriber base.

ENDS
7,500 words
Please feel free to provide feed back on this document including any suggestions of changes that should be made.

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