A Market Forecast For High-Frequency, Space-Qualified, TWTs

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Satellite communications use various frequency bands, ranging from L-band (approximately 1 GHz to 2 GHz) to Ka-band (approximately 26 to 40 GHz). Travelling wave tubes (TWTs) are specialized and essential components for SATCOMs and are required in both the space and ground segments to create an end-to-end communications chain. The TWT market is dominated by two world players, **L-3 Communications** in the U.S. and **Thales Electron Devices** in Europe, who together hold nearly 90 percent of market share, mainly in the lucrative Ku-and Ka-bands. Growing pressures for faster and higher quality communication services are driving the need to find more bandwidth to serve the increasingly hungry data and broadcast applications (*e.g.*, interactive gaming, HDTV). To satisfy this insatiable demand, higher frequencies are being considered, which necessitates the development of TWTs operating at higher frequencies, namely Q & V bands.

This article provides an overview of the history of Ka-band satellite development, focusing on the satellite requirements for Ka-band TWTs. Presented is a forecast of the number of Ka-band TWTs that may be required over the next decade. Satellite companies need to consider higher frequency TWTs, at Q- and V-bands, to maintain pace with communications requirements. Market drivers for this are being seen from governments, business and consumers. Satellite operators, space agencies and others are showing increased interest in higher frequency TWTs. From this data, an outline assessment of the potential size of a Q/V-band TWT market is offered.

Terrestrial Provision?

Demand for video and broadband services are continuing to increase, with rich multimedia applications exacerbating demand for higher and higher data rates, services such as HDTV, 3DTV, and interactive gaming. Some suburban communities are still not fully served by high, or even adequate, broadband data connections; some rural communities, especially in developing countries, but also in parts of N. America, are not served at all. Terrestrial providers are continually upgrading their infrastructure to provide higher data rates through, for example, fibre optic broadband and wireless technologies (such as **LTE** – *Long Term Evolution*), but the cost of serving hard to reach communities is still seen as prohibitive. Despite the high cost of launching a satellite and providing the necessary ground equipment and operations (say, three to five hundred million dollars), reaching many of these communities is likely to be feasible only via satellite. Satellite communications can therefore continue to play an important part and capture and maintain reasonable, if not significant, market share.

TWT history — A Traveling Wave Tube from Hughes, circa 1970s

Potential Drivers For Higher Frequency (Q/V-band) Satellites

Satellite communication saw massive growth during the 1990's and early 2000's. Even at that time spectrum was recognized as the major challenge and satellite communication was predicted to move to Ka, Q & V frequency bands[1] fueled by broadcasting and data services across the Internet.

Digital communications and Internet technologies are now key infrastructures across the globe.

Several aspects have the potential to encourage development of high-frequency TWTs. Governments, business and the public all desire higher data-rate communications. European governments wish to eliminate the currently prevalent digital divide: as analogue-based services are removed/switched-off, the public are being encouraged to consume digital communications. Governments wish the public to make greater and better use of digital services in order to reduce cost, increase efficiency and to enable the provision of, and access to, richer services. To achieve the provision of economic and social benefits for citizens, the public require ubiquitous, fast and reliable broadband communications.

Service Drivers

Business nowadays relies upon Internet-based communications and services. Various sectors see potential for offering better, improved and novel services both to consumers (the public) and to corporate clients. This has been happening rapidly over the last decade or so and is set to continue, *e.g.*, within the Creative Industries sector (a sector that accounts for more than 6.4 percent[2] of the U.K.'s **GVA** (*Gross Value Add*), and one which is being supported by the U.K. Government).

The public are focused on services. These services, (*e.g.*, video streaming, loading personal video to social networking sites (*YouTube*), and gaming,) all demand high data-rates, a trend that is likely to continue as people move to using higher quality video (HD) and, in the future, 3D and 3D HD.

The military is also showing increasing interest in Ka-band and expanding their use of it, with manufacturers working on the technical challenges to achieve reliable *communications on-the-move*[3] (**COTM**), *e.g.*, for the ***Wideband Global SATCOM*** (***WGS***) satellites[4]; the military realize that Ka-band offers greater channel bandwidths and data throughput compared with lower frequency bands. For its operations, the military will wish to use applications similar to that used by the public, (*e.g.*, video streaming, (secure) internet access, high-speed data, voice/VoIP).

Socio-Economic Drivers

During 2009 and 2010, broadband provision to remote or rural areas was pulled into sharp focus as the European Commission offered significant funding to extend broadband reach into difficult-to-reach parts of the European Union[5]. **Avanti** in their January 2010 publication, *Connect*, citing a 2009 World Bank report, state clear socio-economic benefits in both the developed and developing world, with greater impact in the latter; for example, innovative services and applications, such as on-line education, are being developed to serve rural communities. There is thus considerable political impetus to ensure ubiquitous broadband connectivity.

Cost Drivers

The U.K. government estimates the cost of achieving 98 percent national coverage for fibre optic broadband is approximately 35 billion pounds. Cable companies have little incentive to serve the remaining 2 percent rural areas. Europe has more than 70 million homes with a terrestrial broadband connection of less than 2 Mb/s, and 24 million homes and businesses have no coverage at all.

Laying fibre or expanding a fixed-line (DSL) network is expensive and cable companies are unsure that such is cost-effective for rural locations. The large terrestrial cost makes satellite technology an attractive option, especially for these difficult-to-reach locations; a report to the *U.K. Space Leadership Council* estimates a global satellite broadband services market to be between 1.5 billion and 15 billion pounds by 2030[6].

This same report makes two key recommendations, namely that the satellite industry should migrate "existing satellite customers from older to new satellite services as a priority as new capacity becomes available" [meaning from Ku-to Ka-band], and "define further high-capacity satellite solutions with manufacturers and continue to develop innovative technologies, including the provision of seamless broadband and broadcast systems". As more and more customers move to Ka-band, it is inevitable that in order to satisfy continuing, voracious demand for higher data rates, further bandwidth will need to be made available.

Spectrum + Technical Considerations

Satellite communications traditionally provides access to broadband services through lower frequency bands (C- and Ku-), and more recently primarily through Ka-band spectrum. This spectrum is becoming crowded – spectrum for SATCOMs is at a premium and is the most valuable resource. Therefore, the problem to be solved is, "How can more data capacity be made available at Ka-band?"

Making capacity available at Ka-band significantly mitigates the need to manufacture higher-frequency (Q-and V-band) equipment for the public. Some of the downlink Ka-band capacity is used to communicate with 'gateways' that connect users to the Internet. By freeing-up this downlink capacity, more Ka-band spectrum would be available for users. Communication with the gateways may then be achieved at Q-band. (Due to legacy consumer and business equipment (receivers), it will be difficult (and slow) to move users to a different frequency band without strong user incentives, *e.g.*, improved, new, or richer services, cost subsidies for new user equipment.)

To make effective use of Q/V-band, some technical challenges need to be overcome: the design and space-qualification of TWTs at high frequencies; achieving an attractive efficiency; understanding the link budget at Q/V-band frequencies – mitigating the increased effects of rain fade, buildings, and foliage. None of these are seen as insurmountable and some of these are already under partial investigation through various studies (*e.g.*, in Europe and Canada).

This article shows that these (and other) market drivers will create Q/V-band satellite deployments; the only questions are, "When?" and, "How big?" both of which are answered below.

The Current Context – Ka-band Satellite Development

Before delving into the possibility and potential Q/V-band market, it is useful to understand where we currently are. Although there is considerable use of lower frequencies for satellite services (C and Ku-bands), we consider here only Ka-band, as that is likely to present a better guide to the development of Q/V-band.

Use of Ka-band (26.5 GHz to 40 GHz) had some initial serious consideration in the late 1980's / early 1990's. Developments during that decade led to eventual satellite deployments to use this band for broadcast and telecommunication services. Consumer uptake of Internet communications from around the mid 1990's and the advent of broadband communications helped to encourage the growth of Ka-band satellite communications during the latter part of the 1990's and into the current millennium. Satellite operators continue to provide high-data rate services and, to varying degrees, plan to launch more Ka-band satellites.

Satellite broadband continues to expand globally, as seen by recently launched Ka-band satellites, with new ones planned. For example, **Hughes**[7] launched its ***SPACEWAY***® ***3*** in 2007 to serve North America, and **Avanti**'s Ka-band ***HYLAS 1*** satellite was launched in late November 2010 to serve Europe. Ka-band satellite communication is growing across the globe; it promises fast broadband, Internet communications in order to satisfy consumer demand for ever higher increasing data rates and capacity.

Businesses are using media-rich services to gain and maintain a competitive edge; governments require high bandwidth both for secure internal communications and to communicate with their citizens, and the public (consumers) are tending to watch films, use social networking websites and browse the web simultaneously. Recent satellite launches[8] (Ku-band ***Atlantic Bird 7*** and hybrid Ku/Ka-band ***W3C***) by **Eutelsat** demonstrate demand in both existing and fast developing markets, and confirms video as the key revenue application, generating more than 67 percent of Eutelsat's revenue[9] (Q1 of their 2011/2012 year).

There are an estimated 30 million locations across Europe without access to broadband[10]. The **European Commission** (**EU**) wants full broadband coverage in the **European Union** (**EU**) by 2013. Satellite is likely to play a significant role, *e.g.*, Avanti believe that they can gain market share due to the underserved rural areas.

Artistic rendition of Hughes Spaceway3

Nations within the EU are funding initiatives to reduce/remove the Digital Divide, as seen in the U.K. through government grant funding. Avanti's HYLAS Ka-band satellites (***HYLAS 1***, and ***HYLAS 2*** to be launched within the next 12 to 18 months, with ***HYLAS 3*** at the planning stage) will be able to provide significant broadband and broadcast coverage to rural and remote areas that are poorly, or not, served by terrestrial networks.

Ka-band offers high bandwidth and frequency re-use capabilities across multiple beams (*e.g.*, a four-color frequency re-use map for spot beams, allowing localized content), which has helped to drive its growth for SATCOM. There are possibilities for aircraft, railway, military, and other mobile applications. For example, **Telenor**'s satellite ***Thor 7***[11] (due for launch at the end of 2013, with commercial service to be initiated as of Q1, 2014) will be fitted with a Ka-band payload to support the surge in demand for high bandwidth requirements from the maritime industry[12], and will deliver a bandwidth efficient service with high bit rates; it will cover areas including the North Sea, Norwegian Sea, the Red Sea, the Baltic Sea, the Persian Gulf and the Mediterranean. (Its main payload will be 11 Ku-band transponders to serve growing broadcasting requirements within Central and Eastern Europe.) The biggest driver today, and in the foreseeable future, is commercial high-speed Internet access.

During the first decade of the millennium, many operators showed direct interest in providing Ka-band communications. 2010 and 2011 were the years in which Ka-band reached adulthood. Operators and manufacturers made numerous announcements[13] of launches and planned launches of Ka-band satellites, and will now compete[14] with one another across various sectors (commercial, maritime, business). However, Ka-band spectrum is becoming congested, even full in various parts of the World. (**Telesat** see little available Ka-band capacity in Canada.) Operators are looking to use higher frequencies, *i.e.*, Q- and V-bands, either to augment services at Ka-band through hybrid communications, or to deploy broadband (and broadcast) communications in the same way that has been done at Ka-band.

By considering satellites that have Ka-band capability, we can estimate the number of Ka-band TWTs that are in operation and forecast to be in flight. (*See Figure 1.*) What this graph shows is that Ka-band SATCOM technology is now mature, with satellites due to come into service and with others planned in the near future. Some initial surge in Ka-band from 2004 has been witnessed (which may have happened earlier, if it were not for the dot-com bust during 2000 and 2001), with sustained Ka-band deployment starting in 2010 and expected to continue for several years. The expected number of Ka-band tubes during 2010 to 2014 is at least 120 per annum (including spares). The numbers for 2007 and 2012, which are off-the-scale, are skewed by Hughes' SPACEWAY® 3 and Jupiter satellites; ignoring these outliers, an approximate number of Ka-band TWTs per satellite appears to be approximately one hundred; to a first order approximation, this correlates with TESAT's claim that it manufactures some two to three hundred TWTAs per annum.

The Current Ka-band Market

Futron[15], a well-respected market research firm active in the aerospace and space sectors, forecasts strong and sustained world-wide growth in the satellite communications market. Its 2010 forecast report[16] indicates an overall growth during this decade from 4 percent to more than 12 percent, depending upon application and service. (Some applications (*e.g.*, video distribution, carrier back haul) are expected to have zero growth.) TV services represent the largest proportion of demand (in terms of transponders), and consumer TV markets continue to expand: a growth of more than 5 percent CAGR for DBS is expected over the decade.

Another market survey supports the strong demand for satellite TV. Its report[17] forecasts that payTV revenues will climb to US$173 billion in 2016[18] . On-demand revenues will increase much faster than subscription revenues, reaching US$5.7 billion (or 3.3 percent of the total) by 2016[19] . The U.S., the world's largest payTV revenue earner, may see its revenues drop (by nearly US$ 3 billion between 2010 and 2016), but Brazil and India are expected to see some "impressive" growth. The growth of on-demand is interesting as that implies more localized, targeted content, which may be better delivered by spot beams, the deployment mechanism for Ka-band (and potentially higher frequencies also).

Demand is being seen across the globe: Developing markets seek coverage to capture areas where there is little or no service (new and more capacity); developed markets seek high power capacity for more and improved services on the back of higher data rates and faster connectivity. The 'digital revolution' that is bringing digital, IP-based connectivity and services is strengthening. Rural and other hard-to-reach communities can be expensive to serve through terrestrial infrastructure; satellite communications will therefore continue to play an important and essential part, with demand in rural areas being stimulated through subsidised equipment and services. There is continued growth in the military market, which is increasingly relying upon the use of commercipercent percent over the decade.

To meet this demand, operators worldwide are launching and planning to launch more satellites with Ka-band capability, as this offers growth and new services respectively to operators and consumers. Operators are putting into service either hybrid satellites (multi-band) or dedicated Ka-band satellites. However, spectrum at Ka-band is filling-up.

Ka-band TWTs

Travelling Wave Tubes make up the largest component within the Microwave and Millimetre Wave *Vacuum Electron Device* (**VED**) market, with a market share of approximately 65 percent in 2010, and forecast to maintain that share in 2015[20]. Klystron and magnetron devices are next with respectively about 16 and 13 percent market share. TWTs also have the largest share within the space market at 53 percent (2010 and 2015).

Table 1 indicates that, over the next three to four years, the TWT market is expected to remain flat. However, other market indicators suggest that the Ka-band space-TWT market will be fairly buoyant given the planned satellite launches.

The Microwave and Millimetre Wave VED market is dominated by three main players, **Thales**, **L-3Com** and **CPI**, with 2010 market share respectively 26 percent (~$260 million), 23 percent (~$230 million) and 23 percent, respectively. Considering the non-space market, CPI leads with 30 percent market share and $230 million in revenue. Further detail are shown in *Figure 2*.

The Space TWT market (approximately $260 million) is dominated by two main players, Thales and L-3Com, as shown in *Figure 3*. 'Other' players account for an almost meager 11 percent of the space-TWT market.

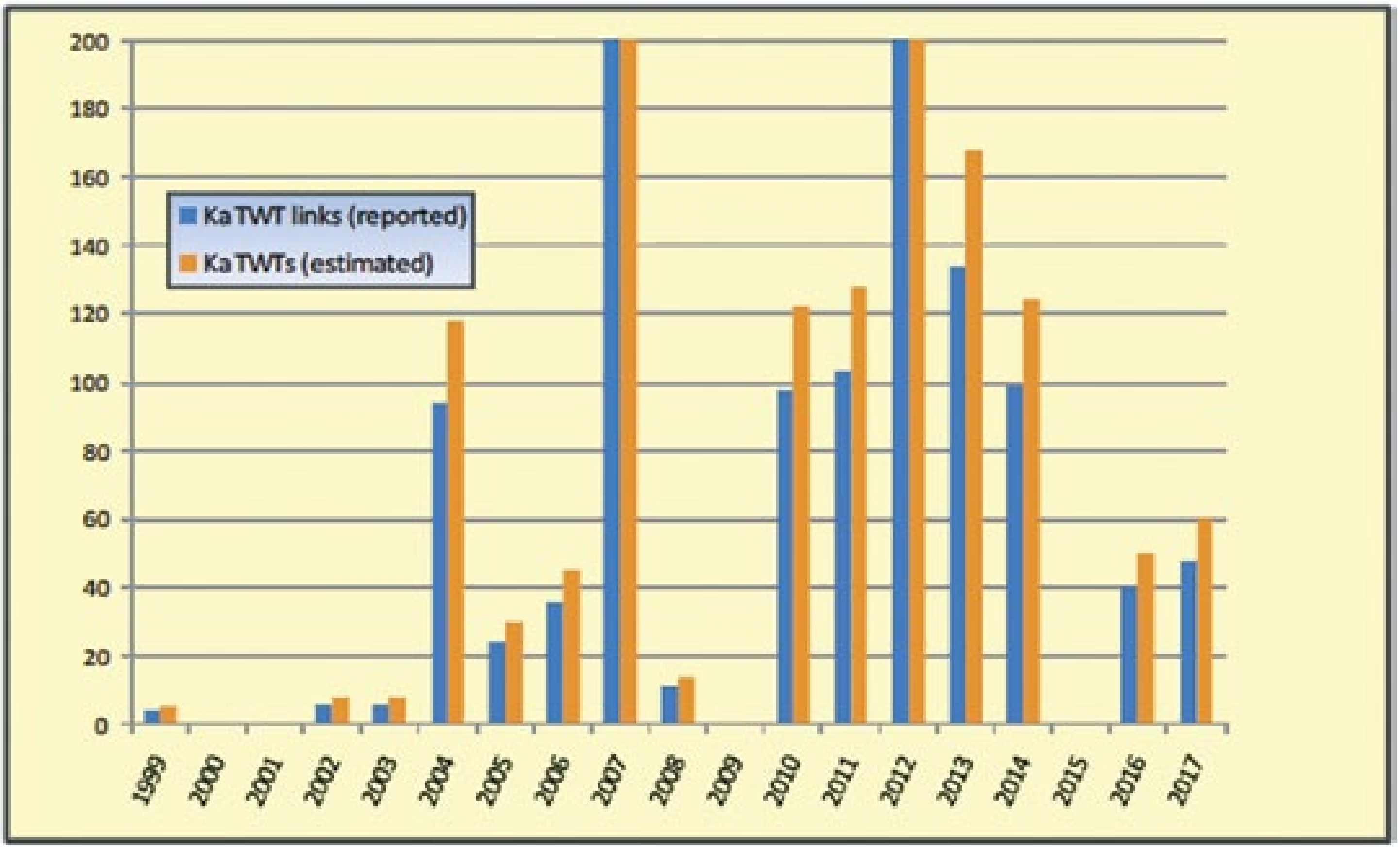

Figure 1. Estimated number of Ka=band TWTs per annum and forecast

Ka-band Applications

Principal applications for Ka-band are TV and data services as previously described. Other applications are also envisaged (outlined later in the article), and these other uses will put pressure on Ka-band spectrum availability. Later, some of these applications, e.g., airborne and military communications, may themselves use Q/V-band spectrum.

Meteorology— **ESA** has recently issued **ITTs** (*Invitation to Tender*) to provide "an operational satellite system able to support accurate prediction of meteorological phenomena and the monitoring of climate and air composition through operational applications for the period of time between 2017 and 2037." Some of these tenders call for Ka-band communications, *e.g.*, AO/160030, MTG-ITT36 Common Platform / Ka-Band Transmitter, and AO/160031, MTG-ITT37 Common Platform / Ka-Band Antenna[21].

Airborne Communications— **JetBlue** and **GoGo**, two U.S. companies, have set in motion their plans to provide air passengers high-speed broadband whilst in-flight. JetBlue have partnered with ViaSat to use Ka-band[22]. GoGo, building on their existing provision of air-to-ground communications, will use Ka-band satellite coverage to provide capability in the U.S. by 2013 and then globally by 2015[23]. In May 2010, **Northrop Grumman** announced[24] that it had successfully completed flight testing of an airborne satellite communications system, part of a network that will significantly enhance communications capabilities for war fighters. The flight-test used the communications terminal system installed on a modified business jet aircraft to connect with a **WGS** (***Wideband Global SATCOM***) satellite via the Ka-band link.

Military Payloads[25]—Countries are increasingly considering the use of commercial satellites to host military payloads either directly or through public/private partnerships. On behalf of the **U.K. Ministry of Defence**, Astrium will operate the Paradigm Secure programme on the ***Skynet*** satellites – military satellites operated by a private company. Another example is the agreement between the **Australian Ministry of Defence** and the U.S. **DoD** to contract to own/operate UHF capacity on an **Intelsat** satellite. Similar arrangements are also being considered for other bands, including Ka- and X-band, including the potential use of the ***Inmarsat-5*** satellites, notably, Ka-band satellites, for military services. The growing interest in, and use of, such payloads may support the deployment of more commercial satellites for both military and commercial services. As part of the **Global MilSatCom** conference[26,27], an associated half-day event considered the question, Why Ka-? Understanding the benefits and shortcomings of Ka-Band Mobile Satellite Systems[28]. A recent **IET** seminar[29,30] also considered the use of commercial satellites to host military payloads, including at Ka-band. Under a contract with the U.S. Department of Defence, **Hughes**[31] is conducting a study of commercial communications satellite system architectures to meet future tactical communications-on-the-move (COTM) needs of the U.S. military, using Hughes existing ***SPACEWAY***® ***3*** and future ***JUPITER***™ satellites. The strong interest in using Ka-band for military SATCOMs certainly across both sides of the Atlantic is likely to put pressure on commercial uses of Ka-band spectrum,

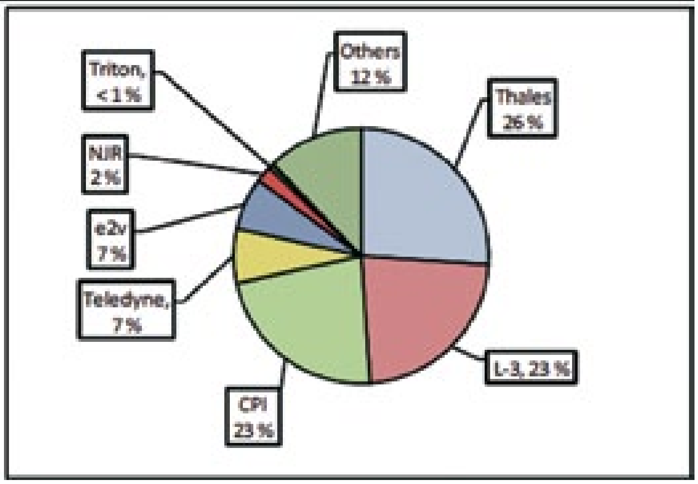

Figure 2. Total Microwave and Millimeter Wave VED Sales by Vendor, World Market 2010

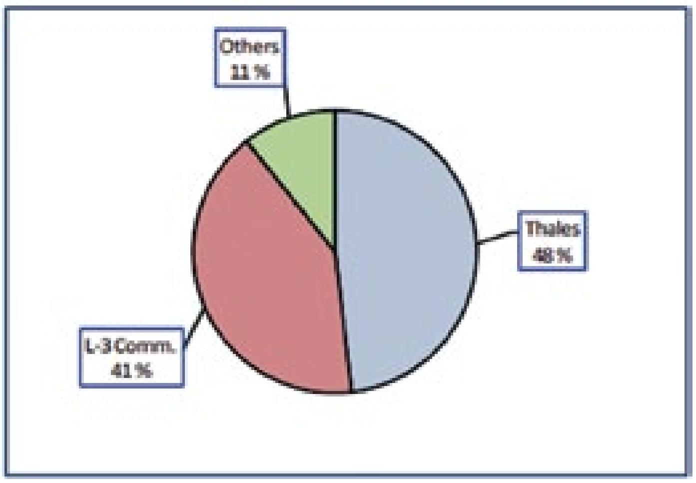

Figure 3. Total Microwave and Millimeter Wave Space TWT Sales, by vendor, World Market 2010

Total TWT Device Sales								
World Market, Forecast: 2010 to 2015								
Forecast sales		2010	2011	2012	2013	2014	2015	CAGR (10-15)
Total TWT Device Sales	($ Millions)	660	658	656	654	652	650	-0.3%
Total TWT Device Sales - NOT Space	($ Millions)	405	405	405	405	405	405	0.0%
Total TWT Device Sales - Space	**($ Millions)**	**255**	**253**	**251**	**249**	**247**	**245**	**-0.8%**

Table 1. Total TWT Device Sales World Market Forecast

potentially increasing congestion. Use of higher frequency bands would help to meet demand.

Interest In Q/V-Band

As early as 1997, there was demonstrated interest[32] in the use of Q/V-band. Operating in the fixed satellite service (FSS) bands of 37.5 -40.5 GHz (downlink) and 47.2 -50.2 GHz (uplink), twelve organisations filed fourteen applications for Q/V-band systems with the FCC in September 1997, thus effectively staking a claim to these new frequencies.

In a 1998 **IEEE** paper[33], the commercial prospects for these 14 Q/V-band systems were studied, taking into account the technical challenges (*e.g.*, propagation effects) and the then current reality that Ka-band systems were still being developed and launched. The paper concluded that companies are unlikely to use Q/V-band until Ka-band is saturated, such congestion is starting to occur.

Evidence across satellite operators supports the views of agencies (*e.g.*, ESA) that Ka-band is likely to become congested and that new, higher frequency bands will be required. Demand for spectrum is across the globe, with that from developing countries being much stronger than in the developed World. Increasing interest from various user groups (the public, businesses, government and defence) in Ka-band will put pressure on available spectrum. Communication needs do not show any sign of slowing, but rather increasing almost exponentially. Such qualitative evidence is strongly supportive of the use of higher frequencies for SATCOMs.

Eutelsat[34]

Results of **Eutelsat**'s operations in the first half of 2007 – 2008[35] show strong growth for the company through TV and broadband services, with video providing some 75 percent of Eutelsat's consolidated revenues; data services also strengthened. HDTV services accelerated, driven by Poland, Russia and Turkey, with major broadcasters (including Sky) deploying services. Eutelsat are encouraging reception from a single dish by deploying satellites near each other, thus allowing users to receive more services at reduced costs. Compared to Ku-band, Ka-band technology is reducing costs[36] significantly.

In 2008, Eutelsat estimated that about 10 percent of the population was poorly served ("under-served") by DSL (Digital Subscriber Line), and that some 15 million households would not be served by DSL in 2010. They see Ka-band exploiting/serving this gap. Eutelsat are also interested in "value-add services", such as serving rail passengers.

KA-SAT Eutelsat's primary Ka-band satellite, has 82 spot beans covering Europe, part of North Africa and much of the Middle East. Primary services will be data and video, with service launch scheduled for May 2011. At the **Cabsat Dubai** conference (held from Feburary 8th through 10th, 2011), Eutelsat showcased their capability to deliver 3D TV *Direct-to-Home*[37] (**DTH**).

Artistic rendition of the KA-SAT satellite, courtesy of Astrium

Hughes Network Systems[38]

Hughes recognizes the demand for capacity that is fuelling the worldwide deployment of Ka-band satellites[39], as Ku-band is rapidly becoming saturated. The high bandwidth available at Ka-band and frequency re-use capabilities across multiple beams enables the delivery of more capacity at faster speeds to smaller dishes. Hughes is committed to Ka-band through their ***SPACEWAY® 3*** satellite and the use of **Avanti**'s ***HYLAS*** satellites[40].

The military are becoming increasingly interested in Ka-band technology. The U.S. DoD contracted[41] Hughes to investigate, and report back in July 2011, how commercial Ka-band communications satellites can meet their future tactical COTM needs.

SES Astra[42]

In contrast to other operators, **SES Astra** believe that Ka-band in Europe is under-utilized[43] (although Ku-band they say is congested). Currently, SES do not see a strong need to use higher frequency bands (Q & V), implying that they feel there is sufficient capacity. They are nevertheless aware that there are Q/V-band developments ongoing and believe that future growth and products for these bands are some five to ten years away.

Inmarsat[44]

Inmarsat currently do not see any need to use new satellite bands and potentially still see opportunity available in Ka-band. Their three new satellites, ***Inmarsat-5*** (**I-5**) constellation, are all Ka-band due to be launched in 2013/2014 at a cost of $1.2 billion[45]. However, in the Company's 2010 results, they recognize Ka-band spectrum difficulty and increasing competitiveness at Ka-band.

Telesat[46]

Telesat are considerably up-beat about the need for Q/V-band satellite communications and are doing the following in this respect:

- In discussion with ESA regards Q/V-band
- Intending to launch a hybrid satellite in 2016/17 containing a Q/V-band payload
- Recognize population migration in Canada from urban/suburban to rural where there is no coverage, thus giving rise to a new customer base. Recognise that Ka-band spectrum over Canada is full
- Involved in two Canadian Space Agency (CSA) studies: One project, funded by the Canadian government, is a Q/V-band costing study, the other is investigating the use of 40 GHz for the downlink and 50 GHz for the uplink

Artist's concept of the Inmarsat-5 satellite, courtesy of Inmarsat

- See that the industry is moving towards Q/V-band, e.g., passive component
- See its use for very high-speed broadband for forward (down) link and uplink

Space Agencies

National space agencies are also showing interest in the Q and V frequency bands. **CNES**, the French Space Agency, commissioned a study[47] into low bit-rate emergency communications. Although the results of this study imply that Q/V-band is not particularly favourable for this application, it nevertheless demonstrates the growing interest for communications in these bands.

The **European Space Agency** (**ESA**) is keen on Q&V-band developments ('technology push') as illustrated through several tenders listed in their ***ARTES*** work programs, e.g., ARTES 5.1 201048 and 201149 work plans. ESA clearly states its rationale within these work plans, and is paraphrased here:

The need for bandwidth in satellite communications and broadcasting is constantly increasing. "It is prospected that the capacity at Ka band will soon become, in some specific areas, crowded due to emerging applications such as broad-band internet, satellite-HDTV, live video, telemedicine, interactive gaming, video conferencing, and others" (e.g., 3DTV). Despite the recent commercial exploitation of Ka-band, preparations must be made for the next generation of broadband satellites able to satisfy this growing demand. This will require the availability of higher numbers of beams on the user side and new frequency bands such as Q/V-band, initially for the feeder link, and in a second stage for the user link.

The exploitation of the higher frequency Q/V-band will offer a substantial increase in capacity for all satellite users, public and private. ESA believe that Q/V-band will first be employed by gateways and then by individuals, similar to what happened in Ka-band.

Satisfying the demand for broadcast and broadband is the most important due to market size and revenue; other additional applications for Q/V-band are secure communication links between high altitude platforms (HAP) and low or geostationary orbit satellites; and UAVs, especially for those that fly above the clouds; inter-satellite communications / links. ESA has projects planned to address key

Q/V-band technical areas and thereby stimulate technology developments; some of these key areas are:

- An LNA (low noise amplifier) to allow Q/V-band use for feeder links
- A Local Oscillator (LO) unit
- Frequency converters, and high-frequency filters

ESA's technology push is encouraging also demonstrating the requirement for other Q/V-band equipment, in addition to TWTs, to ensure a full communications chain. ESA believes that the path for Q/V-band communications is likely to follow a similar route to that of Ka-band.

Spectrum demand from various groups (science, aircraft, military) will exacerbate the need for more spectrum; operators will have to provide a solution if they wish to see company growth. There is clear interest in the use of Q/V-band by National Space Agencies and, to varying degrees, by satellite operators.

Q/V-band is not without its challenges. As others50 have also commented, to achieve higher capacities, increased bandwidths are needed, which impacts upon the difficulty of antenna design due to the increasing ratio of (bandwidth : center frequency). This implies higher centre frequencies such as those available at Q/V-band, with associated challenges to address, such as tighter manufacturing tolerances, difficult link budget – higher RF, propagation and rain-fade losses, lower efficiency electronics, amongst others.

Potential Market For Space-qualified Q/V-Band TWTs

In their 2010 report, **Futron** identify ten separate satellite applications or services. Some have direct potential to use Q/V-bands, whereas others indirectly affect its use. For example, the infrastructure part of Internet access (gateways), is relatively easy to move (from a user viewpoint) to Q- and V-bands. This frees up Ka-band spectrum in order to serve more users. There is pressure from TV services: As Ka-band spectrum fills up, e.g., as more local TV is demanded, requiring more spot beams, or the need to serve new, under-served (or not at all served) communities means that other, and more, spectrum is needed. This is summarised in *Table 2*.

An estimate of the initial (starting point) total of Q/V-band TWTs may amount to around 90 in number. In addition, there may be pressure to use Q- and V-bands for business mobile use

Application	Transponder Equivalent		Estimated no. of Q/V band transponders (2019) (%)	Estimated no. of Q/V band transponders (2019)
	2009	2019		
Internet back haul	200	200	10	20
Direct Internet access	400	1200	2	20
DTH / DBS	1700	2850	1	30
Wireless back haul	200	400	5	20
Total:				***90***

Table 2. Estimated TWT figures from Futron's forecast.

(commercial mobility), military communications (who may find it attractive due to the initial inherent security afforded by lack of specialized, expensive equipment), and airborne communications. This estimated figure is similar to that for initial Ka-band use (see *Figure 1*), which shows that by 2004 there were approximately 100 Ka-band TWTs in operation.

Although the estimates in *Table 2* imply equipment requirements by 2019, the timing is difficult to determine. Ka-band history would indicate some years later, but the pace of change is accelerating. The end of the decade is likely to have some, but less than the tabulated figure, requirements. Other aspects also influence this, for example, the technology readiness and competitiveness of Q/V-band technology compared with Ka-band. If Ka-band SATCOM development is a guide to Q/V-band satcoms, then the first commercial, experimental satellite could be launched towards the end of this decade, with a full commercial service a few years later. Telesat is more proactive – it plans to launch a hybrid satellite, with a Q/V-band payload in 2016/2017.

As stated earlier, there are two major manufacturers of space qualified TWTs: **L-3Com** in the U.S. and **Thales Electron Devices** (**TED**), in France and Germany.

L-3Com is a large conglomerate of numerous companies; its subsidiary **Electron Technologies Inc**. manufacturers TWTs. To be of use, a TWT must be incorporated into a **TWTA** (TWT Amplifier) or an **MPM** (*Microwave Power Module*). There are several TWTA manufacturers, with the most relevant being **Electron Technologies** (**L-3Com**), **Thales** and **TESAT**. To realize Q/V-band SATCOMs, tubes will be needed for both the space and ground segments.

Both L-3 and TED make TWTs across all frequency bands. In the main, TED supplies TESAT with its space-qualified TWTs who then make the space-qualified TWTAs. (TESAT only supply space-qualified TWTAs.)

L-3's Ka-band TWTs do not appear to be particularly competitive in terms of performance[51],[52], having relatively low efficiency (max. 60 percent), and high mass. In their product brochure[53], L-3 claim to have tubes at frequencies covering the range 40 – 46 GHz, and MPMs covering the range 26.0 – 40.0 GHz, *i.e.*, around Q-band.

Thales Electron Devices claim to make Q-and V-band TWTs. In a Ka-band TWT brochure[54], a graph of capability indicates that they either make, or have capability for, such space-qualified tubes. A further brochure on pulsed TWTs[55] clearly claims

Company	Product	Comments
MCL www.mcl.com (UK reseller: UKRF)	Q-band TWTA[57] V-band TWTA[58]	Claim to make TWTs, but cannot find on website. Do not make space-qualified TWTAs.
dB Control (www.dbcontrol.com)	TWTAs: 1 to 40 GHz (i.e., just includes bottom end of Q-band).	Do not make space-qualified TWTAs.
TMD Technologies Ltd[59]. (www.tmd.co.uk)	TWTs[60] and TWTAs for Radar, EW, Communications, EMC RF testing, and lab. applications.	Do not make space-qualified TWTs and TWTAs. Claim to be able to make (source?) TWTs/TWTAs for space.
Comtech Xicom Technology (www.xicomtech.com)	Claim to have TWTAs at Q and V band.	Do not make space-qualified TWTs and TWTAs.
Comments: • *MCL is a wholly owned subsidiary of Miteq[61].*		

Table 3. Suppliers of Q- and V-band TWTs/TWTAs

Band	Reference	Frequency (GHz)	Output power (W)	Small-signal gain (dB)	Conversion AM/PM °/dB	Intermodulation (dBc)	Cooling
EHF	TH 4031	40.5 - 42.8	40	40	5	-29	Conduction
	TH 4034C	43.5 - 45.5	100	40	5	-29	Conduction

Table 4. Thale's two SATCOM uplink products

that TED make Q-& V-band tubes respectively at frequencies 37 – 42 GHz and 60 -65 GHz, but it is unclear whether these are space-qualified. Within their SATCOM uplinks brochure[56], Thales list two SATCOM uplink products (*see Table 4*), designated for the EHF band (30 – 300 GHz), effectively Q-band; they appear to be ground based equipment.

- **— Output power (W)**
  40 100
- **— Small-signal gain (dB)**
  40 40
- **— Conversion AM/PM o/dB**
  5 5
- **— Intermodulation Cooling (dBc)**
  -29 Conduction -29 Conduction

There is potential competition to L-3 and TED from other TWT suppliers. The few listed in *Table 3* claims to make Q-and V-band TWTAs, some also claim to make TWTs, but none currently claim to make space-qualified TWTs/TWTAs.

There are several other TWT manufacturers who currently do not make Q/V-band TWTs. By way of illustration, **e2v Technologies** (U.K.) **plc** manufacture a range of quality TWTs[62], such as *Coupled-Cavity TWT*s for high performance multi-function radars, their market-leading *helix TWT*s for Ka-band satellite uplink, and a range of other vacuum electron devices.

Despite these and other TWT manufacturers (see *Figure 2*), the space-qualified TWT market will be difficult for others to enter (even assuming that they may wish to do so). Space tubes are harder to make, require more infrastructure (*e.g.*, clean rooms) and capability, not to mention the 'space heritage' that satellite manufacturers and operators will demand to protect their huge investments. With the current market being essentially duopolistic in nature (see *Figure 3*), a new entrant will have to demonstrate some compelling reason why it should be chosen ahead of the established players.

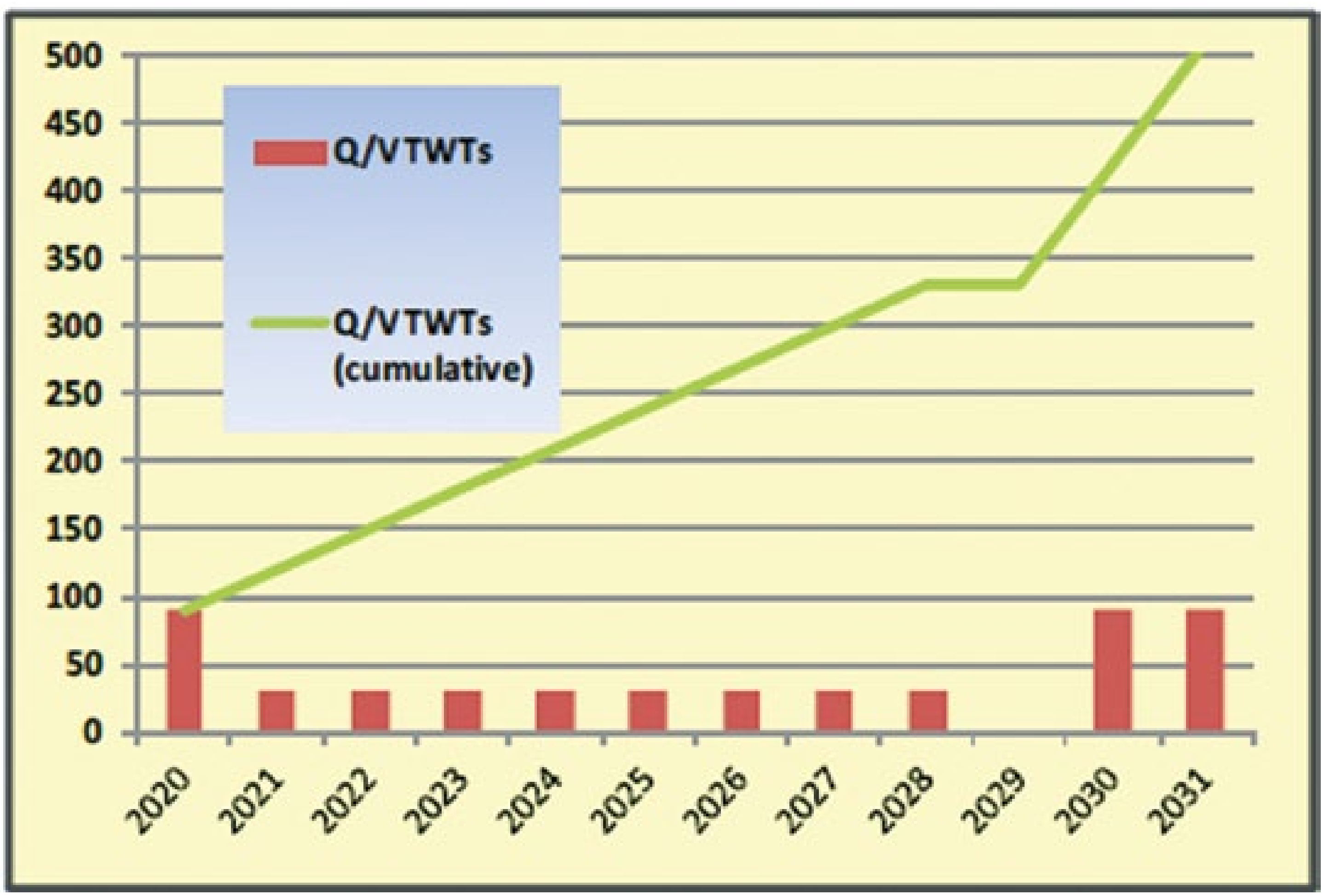

Figure 4. Estimated Q/V-band Market — TWT Numbers

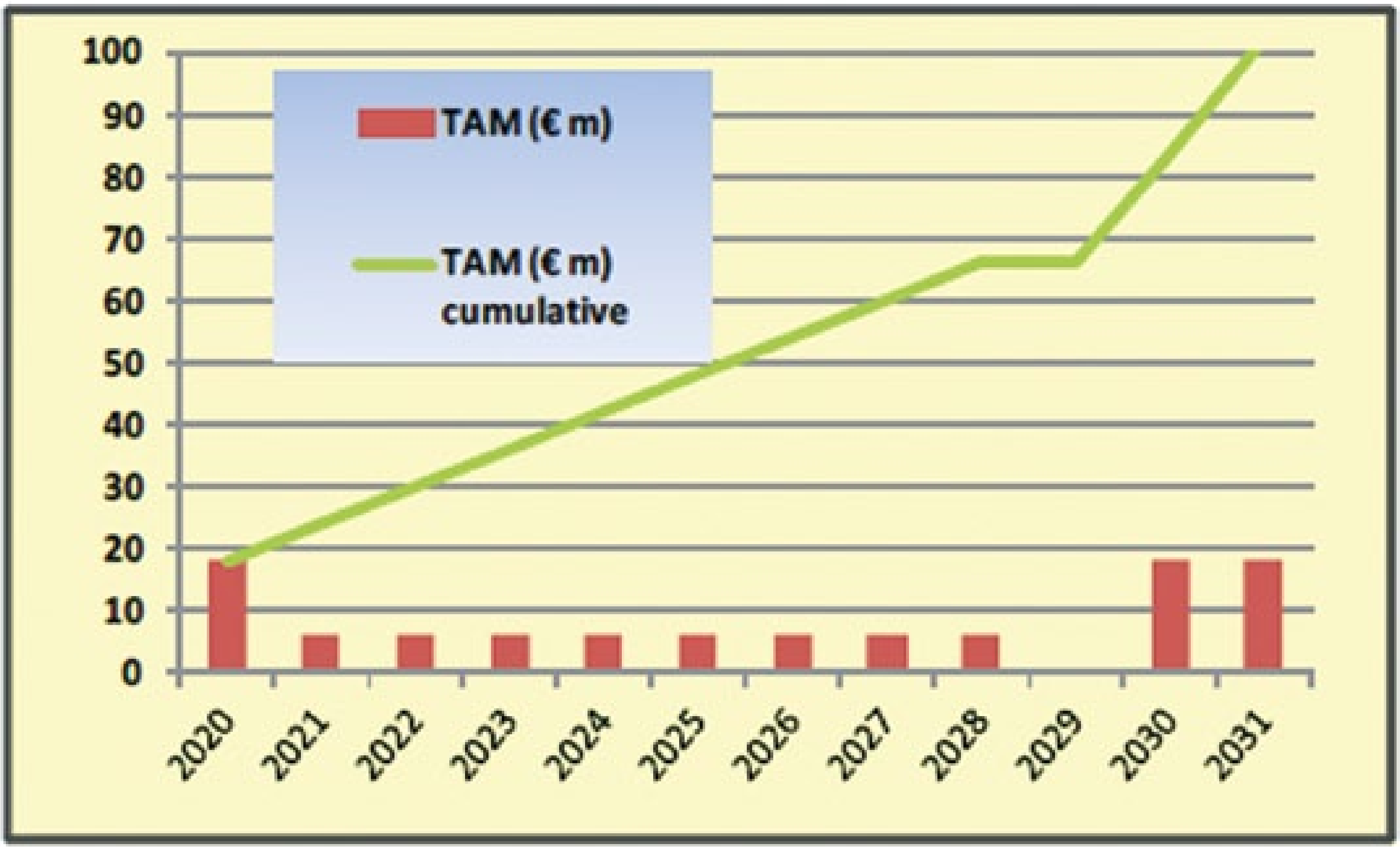

Figure 5. Estimated Q/V-band Market — Million Euros

Analysis Of The Space-qualified Q/V-Band TWT Market

Ka-band development started about 20 years ago at the start of the 1990's. Some ten years later, operators launched Ka-band transponders to secure frequency rights and to undertake experiments in advance of commercial deployment. Approximately ten years further on (2010), Ka-band is in full commercial exploitation.

Interest in Q/V-band payloads has recently commenced. Assuming a similar time frame for Q/V-band as for Ka-band development, initial Q/V-band tubes may be required in advance of 2020 for satellite launches during 2020. Full commercial exploitation is then expected around 2030. Some operators, such as Telesat, are moving faster and plan to have Q/V-band capability on their satellite, due for launch in 2016/2017. Seeding the technical supply base in this way, *i.e.*, by launching a Q/V-band payload, is likely to stimulate it further to develop all the necessary components for Q/V-band communications (as it did for Ka-band).

Arguments for a shorter or longer time frame for Q/V-band are feasible: the demand for ever increasing high-speed data communications may hasten the deployment of Q/V-band; conversely, just as the Ka-band time frame was lengthened by a few years due to the dot-com bust (around 2000 to 2001), current and future, unforeseen world economic events may slow demand for Q/V-band. A 20 years time frame, therefore, does not appear unrealistic.

Earlier, the number of Q/V-band tubes by the end of this decade was calculated to be about 90 to 100. Initially, a payload is expected to comprise about 12 tubes (eight active, four spare). Using *Figure 1* as a guide to a possible Q/V-band market, the assumption is that an initial requirement will be for 90 tubes, with that dropping to a conservative 30 per annum, followed by a conservative rise back up to 90 around 2030. These reduced figures are because Ka-band satellites are still being planned and deployed for at least the next five years, with each having a life time of approximately 15 (till 2025) to 20 (till 2030) years. It is, therefore, unlikely that there will be satellites with major (or only) Q/V-band payloads requiring significant numbers of tubes due to the coverage that will be achieved with operators' current Ka-band plans.

These assumed figures are a rough, first order guesstimate, which have been used to calculate a *Total Addressable Market* (**TAM**) over the period 2020 to 2030. Assuming a selling price of 200,000 euros per tube, a revenue stream estimate can be offered: *Figure 4* shows the number of tubes for the market and *Figure 5* shows the same information in revenue terms. The total cumulative TAM over the period is estimated as 102 million euros. The revenue figure is a straight linear calculation; it ignores, for example:

- Reducing sales price, e.g., due to improved manufacturing and competition
- Reducing manufacturing cost, e.g., due to efficiency, experience, and volume; or increasing cost due to materials becoming in short-supply (such as gold, copper, etc.)
- Inflation (net present value has not been considered).

Comments made previously show that other space applications (e.g., military satellite communications, inter-satellite communications) may, in time, also wish to use Q/V-band. It is difficult to quantify (even guess) Q/V-band requirements at this early stage – interest is just forming, especially for military satcoms.

Frequency band	Frequency range (GHz)			Waveguide frequency bands (GHz)		
	low		upper	low		upper
L	1	to	2			
S	2	to	4	2.60	to	3.95
C	4	to	8	5.85	to	8.2
X	8	to	12	8.2	to	12.4
Ku	12	to	18	12.4	to	18.0
K	18	to	26.5	15.0	to	26.5
Ka	**26.5**	**to**	**40**	26.5	to	40.0
Q	**30**	**to**	**50**	33	to	50
U	40	to	60	40	to	60
V	**50**	**to**	**75**	50	to	75
E	60	to	90	60	to	90
W	75	to	110	75	to	110
F	90	to	140	90	to	140

Table 5. Frequency bands and their designations.

However, this implies that more space-qualified Q/V-band tubes may be required than estimated above from, say, about 2025 onwards.

In Closing

It is clear that there is a nascent Q/V-band market – it is developing through technical studies, both theoretical and empirical (e.g., ESA's Q/V-band experiment, commercial studies), and potential market demand. Most satellite operators suggest a time line of some five to ten years; Telesat have firm commitment to launch a Q/V-band payload in 2016/17.

Significant commercial activity is unlikely before the start of the next decade and, if Q/V-band development follows a similar path to Ka-band, large-scale Q/ V-band payload deployments are probably 15 to 20 years away. From the available data, the space-qualified Q/V-band TWT market is unlikely to be large for some time to come. Further acceleration of demand for high-data rate communications, especially from rural areas and from the developing World, would help to grow the market. Other services that put pressure on Ka-band spectrum (*e.g.*, DBS) would also increase demand for more spectrum, thus potentially moving some services to Q/V-band.

Appendix A: Frequency Bands

Frequency bands are defined in several ways, with slight frequency band-edge differences. Table 5 illustrates the frequency bands and compares them with the waveguide frequency bands[63]. The diagram shows a detailed view of the K-band frequency usage[64] in the United States, allocations between 27 to 40GHz, as at 1996. Some of these applications could move to Q/V-band in the future.

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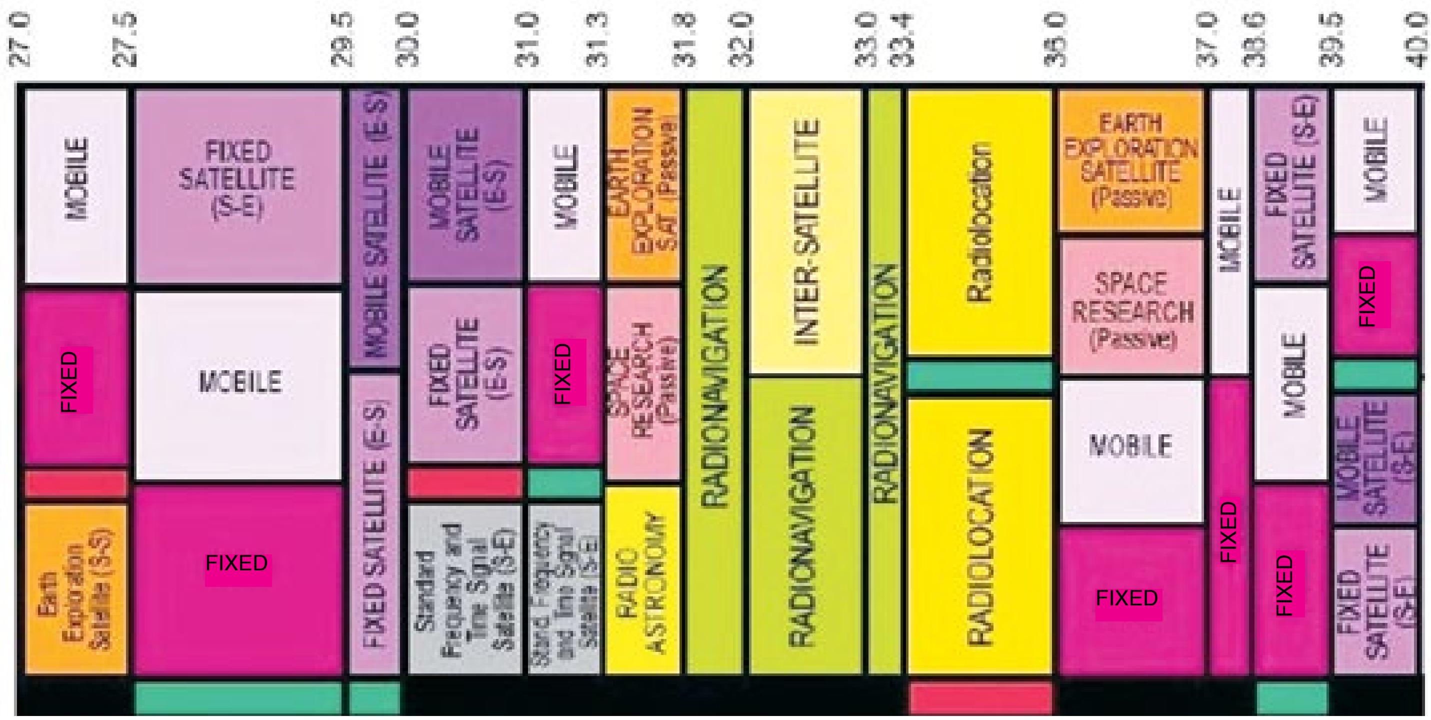

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