Gap Analysis between Defence and Commercial Standards

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Introduction

The push towards the use of commercial-off-the-shelf (COTS) equipment in military environments could lead to systems that are more vulnerable if incorrectly assessed for electromagnetic compatibility (EMC). In general, the commercial standards applied to COTS equipment are less onerous than defence standards.

The UK EMC standard for defence procurement, Def Stan 59-411 includes a risk assessment approach in its Part 1 "Management and Planning" for COTS equipment. An important step in this risk analysis is the ability to perform a "gap analysis" to compare the EMC compliance evidence of the COTS equipment against the EMC test requirements of Def Stan 59-411 Part 3 "Test Methods and Limits for Equipment and Sub-Systems".

In order to compare tests performed on COTS equipment against defence standards, the differences in the test methods and limits must be identified and accounted for in the comparison. Due to the multitude of commercial standards used today, there is the possibility of numerous comparisons therefore the approach adopted was to develop a set of EXCEL spreadsheet gap analysis tools. By using these gap analysis tools, a user can select the commercial standard of interest and determine whether the commercial standard is more or less stringent than the Def Stan 59-411 limit and the margin applicable. It also shows the frequency range addressed by the commercial standard to allow a user to identify untested frequency bands. Based on this information a user can determine the risk of deploying an equipment meeting the commercial standard in an environment represented by the Def Stan 59-411 standard.

The gap analysis tools address the differing test methods and limits in both Def Stan 59-411 Part 3 Annex A (Man worn man portable) and Annex B (LRU and Sub-System Equipment). The gap analysis tools also address Def Stan 59-41, the predecessor to Def Stan 59-411 as the test limits also differ.

The scope of the tests addressed is; DCE01, DCE02, DRE01, DRE02, DRE03, DCS01, DCS02, DCS03, DRS01, DRS02, DRS03 as shown in Tables 1 and 2. Test DCE03 (exported transients) is not addressed as there is no similar commercial standard. Tests related to transient susceptibility are not included in this paper.

This paper looks at the key factors required for comparing commercial and defence standards and raises the issue of the "uncertainty" of the analysis and quantifying the uncertainty contributions due to the assumptions made.

Although the focus of this paper is comparing commercial standards to defence standards, the gap analysis tools work equally well for demonstrating whether the results of defence testing are more or less onerous than harmonised commercial standards for the purpose of demonstrating compliance with the EMC Directive 2004/108/EC and CE Marking defence equipment when required.

EMC Tests

The correspondence between Def Stan 59-411 and example commercial standards test phenomena is shown below in Tables 1 and 2 (frequency ranges shown are the maximum covered but do not apply to all tests):

Commercial Test Title (examples)	Def Stan 59-411 Test Title
EN 55022/11 Class A/B, EN 55014-1, EN 55015, EN 60945 Conducted disturbance mains port 9 kHz – 30 MHz	DCE01 Power line conducted emissions 20Hz – 150MHz
EN 55022, Conducted common mode disturbance telecommunication port 150kHz – 30MHz	DCE02 Signal, control and secondary power line conducted emissions 20Hz – 150MHz
EN 55022/11 Class A/B, EN 60945 Radiated disturbance 150kHz – 2GHz	DRE01/DRE03 Electric field radiated emission 10kHz – 18GHz
EN 55011, EN 55015 Magnetic field strength 9kHz – 30MHz	DRE02 Magnetic field radiated emission 20Hz – 100kHz

Table 1 – Emission Tests

Commercial Test Title (examples)	Def Stan 59-411 Test Title
EN 61000-4-16 Immunity to conducted, common mode disturbances 15Hz – 150kHz	DCS01 Power line conducted susceptibility 20Hz – 50kHz
EN 61000-6-1/6-2 Residential/Industrial limits, EN 61000-4-6 Immunity to conducted disturbances induced by radiofrequency fields 150kHz – 80MHz	DCS02 Power and signal line conducted susceptibility 50kHz – 400MHz
EN 61000-4-16 Immunity to conducted, common mode disturbances 15Hz – 150kHz	DCS03 Signal line conducted susceptibility 20Hz – 50kHz
EN 61000-6-1/6-2 Residential/Industrial limits, EN 55024, EN 61000-4-8 Power frequency magnetic field immunity test 50Hz, 60Hz	DRS01 Magnetic field radiated susceptibility 20Hz – 100kHz
EN 61000-6-1/6-2 Residential/Industrial limits, EN 61000-4-3 Radiated, RF, electromagnetic field immunity test 80MHz – 2700MHz	DRS02 Electric field radiated susceptibility 10kHz – 18GHz
EN 61000-4-8 Power frequency magnetic field immunity test, DC	DRS03 DC magnetostatic field radiated susceptibility

Table 2 - Susceptibility Tests

Conducted Emission Factors

The COTS interference characteristics are unknown, therefore the emission analysis must be performed assuming both broadband and narrowband interference in turn, as the correction factors differ in each case.

For a narrowband emission, peak, quasi-peak and average detectors produce the same indicated value. For impulsive emissions, the quasi-peak may be lower than peak depending on the repetition rate of the emission (as defined in EN 55016-1-1 for Band B), see Figure 1. The quasi-peak response varies from 0 dB difference (repetition rates >10 kHz) to -28.5 dB (repetition rates <1 Hz). The assumption made for power line conducted emissions is a repetition rate of 100 Hz giving a quasi-peak response correction factor (CF) of 6 dB. The rationale is that COTS equipment is typically 50 Hz mains powered and therefore impulsive interference repetition rates relating to mains frequency zero-crossings will be typically 100 Hz. The possibility of other repetition rates is addressed as an uncertainty contribution of; +22.5, -6 dB about the chosen 6 dB correction factor.

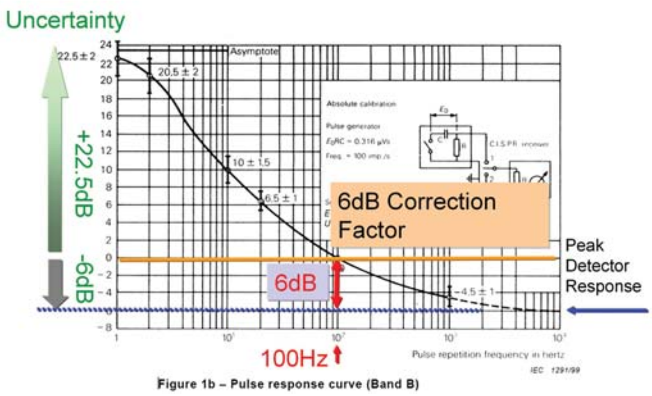

Figure 1 – Quasi-Peak Detector Correction

Narrowband interference with a bandwidth narrower than the test bandwidth has the same level regardless of increased bandwidth, therefore no correction factor applies to the narrowband analysis. Broadband interference with a bandwidth larger than the test bandwidth will have a level dependent on the bandwidth used, see Figure 2. Therefore the broadband analysis includes a bandwidth CF. The CF is derived by taking the ratio of the commercial standard bandwidth defined in EN 55016-1-1 to the Def Stan 59-411 bandwidth (assuming broadband emissions are coherent).

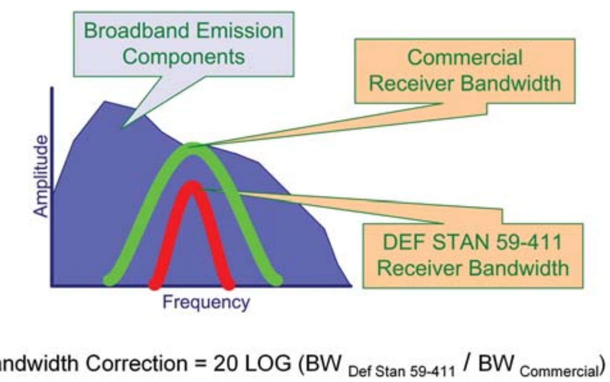

Figure 2 – Bandwidth Correction

Due to the allowable tolerances in bandwidth, there is an uncertainty contribution derived from the worst case combinations of maximum and minimum bandwidth permitted.

Def Stan 59-411 power line conducted emissions are measured via a current probe (in dBµA) into a Line Impedance Stabilization Network (LISN) impedance of 50Ω/5µH as defined in Def Stan 59-411 Part 3. Commercial standards (e.g. EN 55022) measure voltage (dBµV) into an Artificial Mains Network (AMN) impedance of 50Ω/50µH V Network (Band A and Band B) as defined in EN 55016-1-2, see Figure 3. The voltage limit at the AMN can be converted into current using the AMN impedance given in EN 55016-1-2 from ohms law:

dBµA = dBµV – dB• (AMN CF)

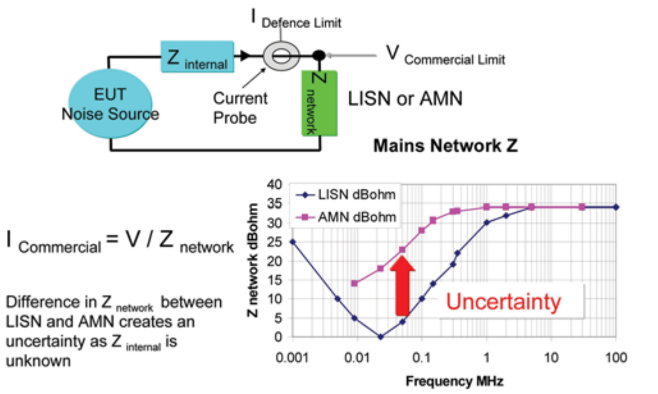

Figure 3 – Mains Network Correction

Due to the impedance difference between the LISN and AMN, the interference current differs dependent on the COTS internal impedance. As the internal impedance is unknown, a CF cannot be applied to account for the difference, therefore the difference in impedance is treated as an uncertainty contribution. The contribution magnitude is derived by assuming either the internal impedance is high (>> LISN or AMN impedance) giving rise to a maximum uncertainty of +19 dB or the internal impedance is low (<< LISN or AMN impedance) giving rise to an uncertainty of -0 dB.

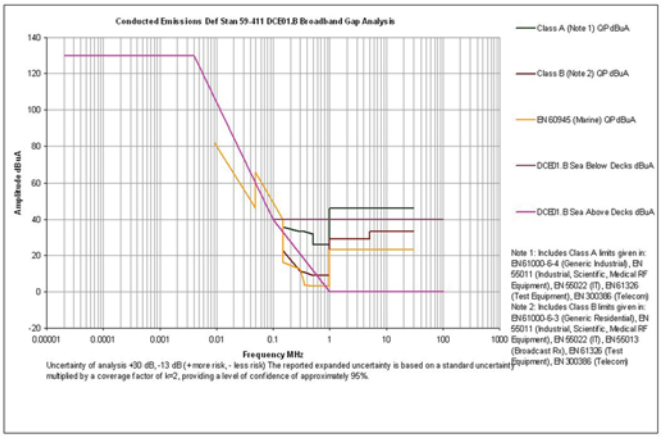

Figure 4 – Example Broadband Emission Gap Analysis – DCE01 Power – Sea Systems

The conducted emissions broadband analysis therefore considers Quasi-Peak detector limit with Quasi-Peak CF, bandwidth CF, and AMN CF. The narrowband analysis considers the average detector limit with AMN CF.

Figure 4 and 5 show an example of broadband and narrowband gap analysis for DCE01 (power line emissions) against Class A and B and EN 60945 commercial standards.

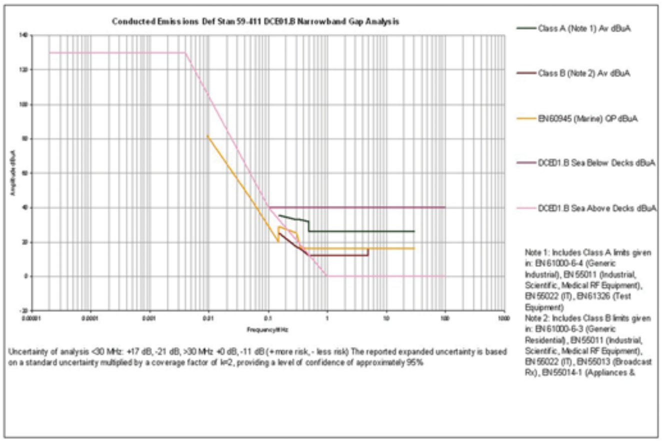

Figure 5 – Example Narrowband Emission Gap Analysis – DCE01 Power – Sea Systems

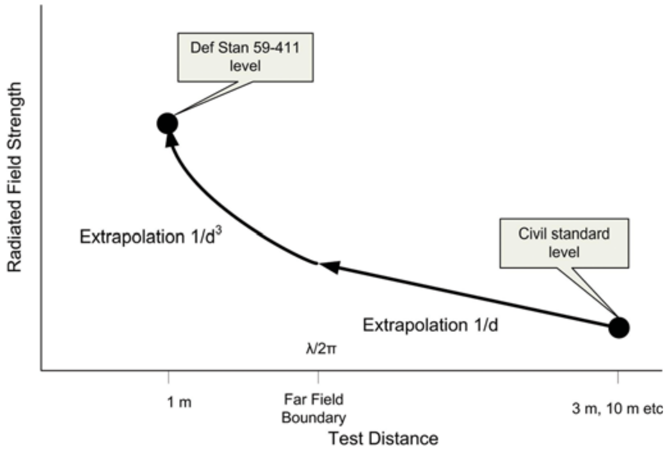

Figure 6 – Field Extrapolation

Radiated Emission Factors

As for conducted emissions, the COTS interference characteristics are unknown, therefore the emission analysis must be performed assuming both broadband and narrowband interference in turn, as the correction factors differ in each case.

The rationale for a detector correction factor (CF) is the same as for conducted emissions with the difference that the quasi-peak detector response in the frequency range 30 MHz to 1 GHz is given in EN 55016-1-1 for Band C & D and the CF at 100 Hz is 12 dB.

The rationale for bandwidth CF is the same as for conducted emissions applied to the bandwidth values applicable to the test frequency range.

Since Def Stan 59-411 radiated emission limits correspond to a test distance of 1 m and commercial standards to test distances of 3 m or 10 m, it is necessary to extrapolate the commercial standard limits to a test distance of 1 m in order to make a comparison of test severity.

The "far field" level is inversely proportional to distance (1/distance), i.e. doubling the distance reduces the field by half or 6dB. The "near field" level (closer to the EUT) may reduce at a greater rate (e.g. inversely proportional to the square or cube of the distance). However the rate of decay is dependent on the nature of the EUT radiating mechanisms which are generally unknown. Extrapolation in the near field is assumed (worst case) as inversely proportional to the cube of the distance (1/distance^3).

The near to far field boundary is not a sudden transition and is determined in terms of a function of the wavelength. The greater the distance selected to the far field boundary the lower the measurement uncertainty arising from the assumption of extrapolation inversely proportional to distance beyond the far field boundary. To achieve a 3dB uncertainty (defined in EN 55016-2-3) which is considered adequate for a risk assessment approach, the boundary is defined by:

Far field boundary from EUT (m) = λ / 2 π where λ is the wavelength (m), see Figure 6.

Analysis uncertainty contributions arise from the quasi-peak detector CF, bandwidth CF and for the assumptions in field extrapolation.

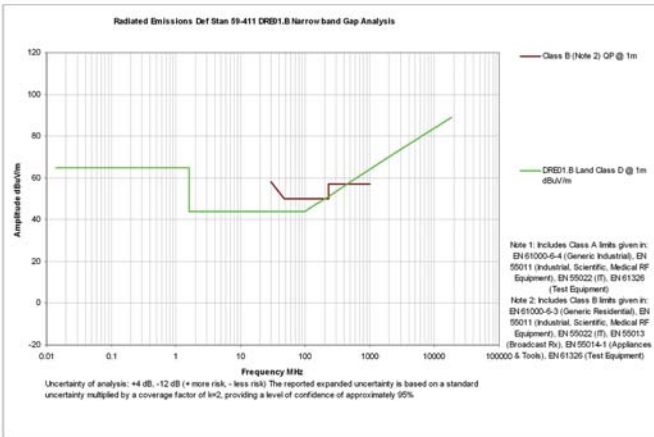

Figure 7 – Example Narrowband Radiated Emission Gap Analysis – DRE01 – Land Class D vs Class B

Conducted Susceptibility Factors

Def Stan 59-411 test DCS02 specifies limits including modulation measured as peak (rms). Modulation schemes are CW, AM and pulse, details are dependent on service category. Commercial standard limits are specified as peak (rms) unmodulated carrier CW with 80% AM to be applied. 80% modulation results in an increase in peak voltage/current level of 1.8. The modulation CF to be applied to give the actual peak level in dB is:

Modulation CF dB = 20 log (1.8) = 5.1 dB

The relative severity of the different types of modulation schemes utilised will depend on the susceptibility characteristics of the particular COTS equipment and will not be known. Therefore it is assumed that the modulation schemes are equivalent.

Def Stan 59-411 test DCS01 specifies the test signal in Voltage (rms) superimposed on the supply voltage coupled via a transformer. Commercial standards test EN 61000-4-16 specifies the test signal in Voltage (rms) open circuit superimposed on the supply voltage. The test signal is coupled via a coupling network onto the power line under test. The power line is terminated in a decoupling network. The standard indicates that the line impedance is typically 150Ω. The test generator and coupling network source impedance is also 150Ω creating a voltage divider with a factor of 2. Using this factor provides the voltage injected on the line:

dBµV injected = dBµV open circuit – 6 dB

Def Stan 59-411 test DCS02 specifies the test signal as current (dBµA) injected with a current probe. Power lines under test are terminated in a LISN impedance. Signal lines are terminated in the representative terminating equipment. Commercial standards specify the test signal as open circuit emf voltage. The test signal is coupled via a coupling decoupling network (CDN) onto the line under test. The standard indicates that the line impedance is typically 150Ω. The voltage applied to the line under test is half the open circuit voltage. The equivalent test current in a 150Ω line impedance is therefore derived from ohms law:

I = V open circuit / 2 x 150 or

dBµA injected = dBµV open circuit – 49.5

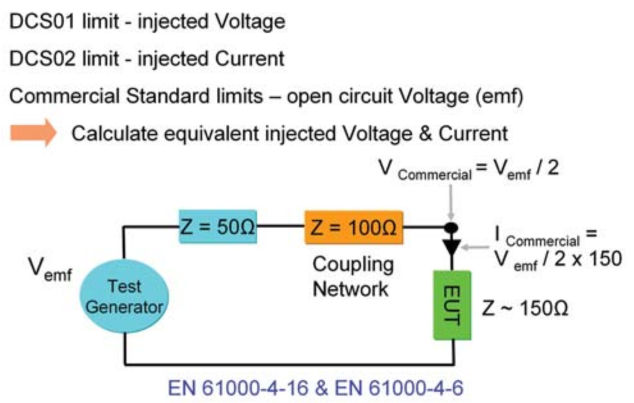

Figure 8 – Coupling Device Correction

Def Stan 59-411 test DCS03 specifies the test signal as current (dBµA) injected into a test wire inductively coupled over a minimum 1 m length with 3 turns on the signal line or cable. The signal line is terminated in the representative terminating equipment. Commercial standards test EN 61000-4-16 specifies the test signal in Voltage (rms) open circuit superimposed on the signal line giving rise to an injected voltage as discussed for test DCS01. By calculating the mutual inductance of the Def Stan 59-411 test wire for an assumed worst case wire configuration (e.g. 5 mm minimum wire separation, 50 mm above the ground plane), a CF can be derived to convert the commercial standard level into an equivalent current in a test wire. The full derivation is not included here but the equivalent current in a test wire for the assumed configuration stated is given by:

dBµA = dBµV injected +108.5 - 20 Log (f Hz)

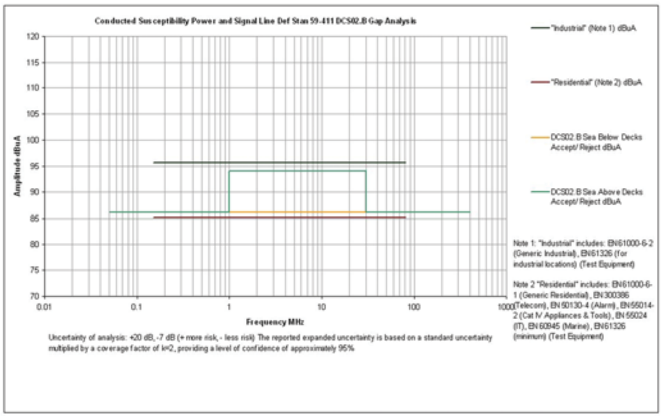

Figure 9 – Example Conducted Susceptibility Gap Analysis – DCS02 – Sea Systems

Analysis uncertainty contributions arise from the coupling network CF, calibration techniques, injection position (DCS02) and test wire assumptions (DCS03).

Figure 9 shows an example gap analysis for DCS02 (power and signal line susceptibility) against "residential", "industrial" and EN 60945 commercial standards.

Radiated Susceptibility Factors

Def Stan 59-411 test DRS02 specifies limits including modulation measured as peak (rms) as discussed for conducted susceptibility giving rise to a modulation CF of 5.1dB to correct commercial standard limits.

Both Def Stan 59-411 and commercial standards specify the field strength in V/m (or dBµV/m) established at the equipment under test (EUT) position, therefore field extrapolation is not applicable and the levels can be equated directly.

Def Stan 59-411 specifies that the field shall be monitored adjacent to the EUT using a small omni-directional sensor. The field is therefore monitored at a single location in general. Commercial standards (EN 61000-4-3) specify the concept of a uniform area of illumination which is a vertical area at the face of the EUT 1.5 m x 1.5 m with minimum height of 0.8 m above the ground plane. The uniform area is calibrated empty with an unmodulated signal. The field is considered uniform if the levels are within -0 dB to +6 dB over 75% of the area (12 out of 16 measurement points). During the test the EUT is placed in the pre-calibrated field but the field is not monitored. The field levels may change due to the affect of the EUT but experience has shown that the levels can increase or reduce close to the EUT so there is no general CF that can be applied. It is assumed therefore that the calibration methods are equivalent.

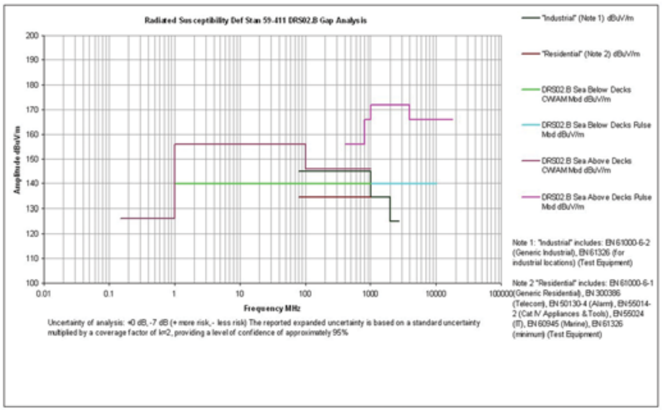

Figure 10 – Example Radiated Susceptibility Gap Analysis – DRS02 – Sea Systems

Def Stan 59-411 test DRS01 magnetic field susceptibility specified in dBpT can be related to commercial standards specified in A/m (or dBμA/m) from the units conversion:

dBpT = dBμA/m + 2 dB

Def Stan 59-411 test DRS03 DC magnetostatic field susceptibility specified in A/m can be related directly to commercial standards specified in A/m as the methods are nearly identical, however the use of commercial standards (EN 61000-4-8) at DC is uncommon except for some rail equipment.

Analysis uncertainty contributions arise from the calibration techniques.

Figure 10 shows an example gap analysis for DRS02 (radiated susceptibility) against "residential", "industrial" and EN 60945 commercial standards.

Uncertainty

A set of gap analysis uncertainty statements have been calculated using the guidance of UKAS LAB34.

The degree of uncertainty was shown to be large compared to normal test measurement uncertainties. The uncertainty for emission tests was higher than for susceptibility tests.

Emission gap analysis uncertainties ~30 dB
Conducted susceptibility gap analysis uncertainties ~20 dB (excludes DCS03 ~30 dB)
Radiated susceptibility gap analysis uncertainties ~7 dB

For emission tests the larger uncertainty components were due to the quasi-peak detector function and differences between coupling devices (LISN and AMN). For susceptibility tests the larger uncertainty components were due to the coupling device for conducted tests and field calibration for radiated tests.

Conclusions

This paper has shown that a gap analysis between Defence Standard 59-411 and commercial standards is possible as part of a risk assessment process for utilising COTS equipment in a military environment. The analysis can be conveniently undertaken via a set of spreadsheet based tools.

The paper has also shown that the uncertainties associated with the gap analysis are significant and further study is required to validate the assumptions made and quantify the uncertainty contributions.

Acknowledgement

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