

8 ROBOT Construction Rules (R)

The rules listed below explicitly address legal parts and materials and how those parts and materials may be used on a REBUILT ROBOT. A ROBOT is an electromechanical assembly built by the *FIRST* Robotics Competition team to play the current season's game and includes all the basic systems required to be an active participant in the game –power, communications, control, BUMPERS, and movement about the FIELD. A BUMPER is a protective assembly designed to attach to the exterior of the ROBOT and constructed as specified in section [8.4 BUMPER Rules](#).

There are many reasons for the structure of the rules, including safety, reliability, parity, creation of a reasonable design challenge, adherence to professional standards, impact on the competition, and compatibility with the [Kit of Parts \(KOP\)](#). The KOP is the collection of items listed on the current season's Kickoff Kit Checklists, distributed to the team via *FIRST* Choice in the current season, or paid for completely (except shipping) with a Product Donation Voucher (PDV) from the current season.

Another intent of these rules is to have all energy sources and active actuation systems on the ROBOT (e.g. batteries, compressors, motors, servos, cylinders, and their controllers) drawn from a well-defined set of options. This is to ensure that all teams have access to the same actuation resources and that the INSPECTORS are able to accurately and efficiently assess the legality of a given part.

ROBOTS are made up of COMPONENTS and MECHANISMS. A COMPONENT is any part in its most basic configuration, which cannot be disassembled without damaging or destroying the part or altering its fundamental function. A MECHANISM is an assembly of COMPONENTS that provide specific functionality on the ROBOT. A MECHANISM can be disassembled (and then reassembled) into individual COMPONENTS without damage to the parts.

Many rules in this section reference Commercial-Off-The-Shelf (COTS) items. A COTS item must be a standard (i.e. not custom order) part commonly available from a VENDOR for all teams for purchase. To be a COTS item, the COMPONENT or MECHANISM must be in an unaltered, unmodified state (with the exception of installation or modification of any software). Items that are no longer commercially available but are functionally equivalent to the original condition as delivered from the VENDOR are considered COTS and may be used.

Example 1: A team orders 2 ROBOT grippers from RoboHands Corp. and receives both items. They put 1 in their storeroom and plan to use it later. Into the other, they drill "lightening holes" to reduce weight. The first gripper is still classified as a COTS item, but the second gripper is now a FABRICATED ITEM, as it has been modified.

Example 2: A team obtains openly available blueprints of a drive module commonly available from Wheels-R-Us Inc. and has local machine shop "We-Make-It, Inc." manufacture a copy of the part for them. The produced part is not a COTS item, because it is not commonly carried as part of the standard stock of We-Make-It, Inc.

Example 3: A team obtains openly available design drawings from a professional publication during the pre-season and uses them to fabricate a gearbox for their ROBOT during the build period following Kickoff. The design drawings are

considered a COTS item and may be used as “raw material” to fabricate the gearbox. The finished gearbox itself would be a FABRICATED ITEM, and not a COTS item.

Example 4: A COTS part that has non-functional label markings added would still be considered a COTS part, but a COTS part that has device-specific mounting holes added is a FABRICATED ITEM.

Example 5: A team has a COTS single-board processor version 1.0, which can no longer be purchased. Only the COTS single-board processor version 2.0 may be purchased. If the COTS single-board processor version 1.0 is functionally equivalent to its original condition, it may be used.

Example 6: A team has a COTS gearbox which has been discontinued. If the COTS gearbox is functionally equivalent to its original condition, it may be used.

A VENDOR is a legitimate business source for COTS items that satisfies all the following criteria:

- A. has a Federal Tax Identification number. In cases where the VENDOR is outside of the United States, they must possess an equivalent form of registration or license with the government of their home nation that establishes and validates their status as a legitimate business licensed to operate within that country.
- B. is not a “wholly owned subsidiary” of a FIRST Robotics Competition team or collection of teams. While there may be some individuals affiliated with both a team and the VENDOR, the business and activities of the team and VENDOR must be completely separable.
- C. should maintain sufficient stock or production capability so they are able to ship any general (i.e., non-FIRST unique) product within 5 business days of receiving a valid purchase request. It is recognized that certain unusual circumstances (such as such as a global supply chain disruption and/or 1,000 FIRST teams all ordering the same part at once from the same VENDOR) may cause atypical delays in shipping due to backorders for even the largest VENDORS. Such delays due to higher-than-normal order rates are excused. This criterion may not apply to custom-built items from a source that is both a VENDOR and a fabricator.

For example, a VENDOR may sell flexible belting that the team wishes to procure to use as treads on their drive system. The VENDOR cuts the belting to a custom length from standard shelf stock that is typically available, welds it into a loop to make a tread, and ships it to a team. The fabrication of the tread takes the VENDOR 2 weeks. This would be considered a FABRICATED ITEM, and the 2-week ship time is acceptable. Alternately, the team may decide to fabricate the treads themselves. To satisfy this criterion, the VENDOR would just have to ship a length of belting from shelf stock (i.e. a COTS item) to the team within 5 business days and leave the welding of the cuts to the team.

- D. makes their products available to all FIRST Robotics Competition teams. A VENDOR must not limit supply or make a product available to just a limited number of FIRST Robotics Competition teams.

The intent of this definition is to be as inclusive as possible to permit access to all legitimate sources, while preventing ad hoc organizations from providing

special-purpose products to a limited subset of teams in an attempt to circumvent the cost accounting rules.

FIRST desires to permit teams to have the broadest choice of legitimate sources possible, and to obtain COTS items from the sources that provide them with the best prices and level of service available. Teams also need to protect against long delays in availability of parts that will impact their ability to complete their ROBOT. The build season is brief, so the VENDOR must be able to get their product, particularly *FIRST* unique items, to a team in a timely manner.

Ideally, chosen VENDORS should have national distributors (e.g. Home Depot, Lowes, MSC, McMaster-Carr, etc.). Remember, *FIRST* Robotics Competition events are not always near home – when parts fail, local access to replacement materials is often critical.

A FABRICATED ITEM is any COMPONENT or MECHANISM that has been altered, built, cast, constructed, concocted, created, cut, heat treated, machined, manufactured, modified, painted, produced, surface coated, or conjured partially or completely into the final form in which it will be used on the ROBOT.

Note that it is possible for an item (typically raw materials) to be neither COTS nor a FABRICATED ITEM. For example, a 120.0in (3.048m) length of aluminum which has been cut into 60.0in (1.52m) pieces by the team for storage or transport is neither COTS (it's not in the state received from the VENDOR), nor a FABRICATED ITEM (the cuts were not made to advance the part towards its final form on the ROBOT).

Teams may be asked to provide documentation proving the legality of non-REBUILT KOP items during inspection where a rule specifies limits for a legal part (e.g. pneumatic items, current limits, COTS electronics, etc.).

Some of these rules make use of English unit requirements for parts. If your team has a question about a metric-equivalent part's legality, please e-mail your question to the *FIRST* Robotics Competition Kit of Parts team at frcparts@firstinspires.org for an official ruling. To seek approval for alternate devices for inclusion in future *FIRST* Robotics Competition seasons, please contact the Kit of Parts team at frcparts@firstinspires.org with item specifications.

Teams should acknowledge the support provided by the corporate sponsors and mentors with an appropriate display of their school and sponsors names and/or logos (or the name of the supporting youth organization, if appropriate).

FIRST Robotics Competition can be a full-contact competition and may include rigorous game play. While the rules aim to limit severe damage to ROBOTS, teams should design their ROBOTS to be robust.

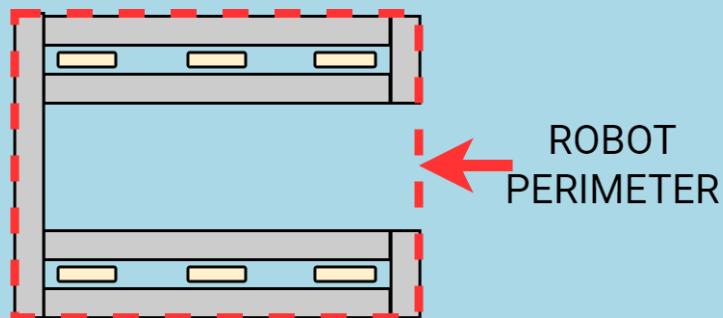
8.1 General ROBOT Design

R101 *ROBOT PERIMETER must be fixed. The ROBOT (excluding BUMPERS) must have a ROBOT PERIMETER, contained within the BUMPER ZONE and established while in the ROBOT'S STARTING CONFIGURATION, that is comprised of fixed, non-articulated structural elements of the ROBOT. Minor protrusions no greater than 0.25in (0.64cm) such as bolt heads, fastener ends, weld beads, and rivets are not considered part of the ROBOT PERIMETER.

To determine the ROBOT PERIMETER, wrap a piece of string around the outer most parts of the ROBOT (excluding BUMPERS) at the BUMPER ZONE described in [R405](#) and pull it taut. The string outlines the ROBOT PERIMETER.

Example: A ROBOT'S chassis is shaped like the letter 'U', with a large gap between chassis elements on the front of the ROBOT. When wrapping a taut string around this chassis, the string extends across the gap and the resulting ROBOT PERIMETER is a rectangle with 4 sides.

Figure 8-1 ROBOT PERIMETER example



R102 *STARTING CONFIGURATION – no overhang. In the STARTING CONFIGURATION (the physical configuration in which a ROBOT starts a MATCH), no part of the ROBOT shall extend outside the vertical projection of the ROBOT PERIMETER, with the exception of its BUMPERS and minor protrusions such as bolt heads, fastener ends, rivets, cable ties, etc.

If a ROBOT is designed as intended and each side is pushed up against a vertical wall (in STARTING CONFIGURATION and with BUMPERS removed), only the ROBOT PERIMETER (or minor protrusions) will be in contact with the wall.

The allowance for minor protrusions in this rule is intended to allow protrusions that are both minor in extension from the ROBOT PERIMETER and cross-sectional area.

If a ROBOT uses interchangeable MECHANISMS per [I103](#), Teams should be prepared to show compliance with this rule and [R105](#) in all configurations.

R103 *ROBOT weight limit. The ROBOT weight must not exceed 115.0lb (52.16kg). When determining weight, the basic ROBOT structure and all elements of all additional MECHANISMS that might be used in a single configuration of the ROBOT shall be weighed together (see [I103](#)). For the purposes of determining compliance with the weight limitations, the following items are excluded:

- A. ROBOT BUMPERS,
- B. ROBOT battery and its associated half of the Anderson cable quick connect/disconnect pair (including wire, the associated cable lugs, connecting bolts, and insulation), and
- C. tags used for location detection systems if provided by the event.

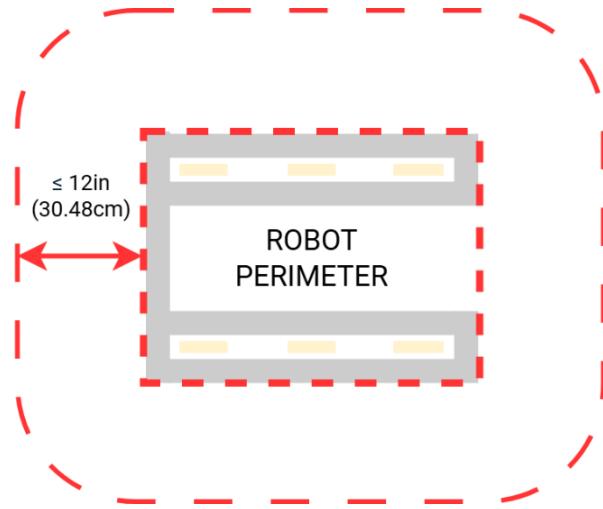
R104 STARTING CONFIGURATION – max size. A ROBOT'S STARTING CONFIGURATION may not have a ROBOT PERIMETER greater than 110.0in (2.794m) and may not be more than 30in (76.2cm) tall.

Be sure to consider the size of the ROBOT on its cart to make sure it will fit through doors. Also consider the size of the ROBOT to ensure that it will fit into a shipping crate, vehicle, etc.

Note that rules contained in section [8.4 BUMPER Rules](#) may impose additional restrictions on ROBOT design.

R105 ROBOT horizontal extension limit. ROBOTS may not extend more than 12in (30.48cm) beyond the vertical projection of their ROBOT PERIMETER.

Figure 8-2 ROBOT PERIMETER extension



Teams should expect to have to demonstrate a ROBOT'S ability to constrain itself per above during inspection. Constraints may be implemented with either hardware or software.

R106 Horizontal extension – one direction at a time. ROBOTS may not extend beyond their ROBOT PERIMETER in more than one direction (i.e. over more than 1 side of the ROBOT) at a time. The extension may not reach outside the projection of that side of the ROBOT PERIMETER. For the purposes of this rule, a round or circular section of FRAME PERIMETER is considered to have an infinite number of sides. MOMENTARY and inconsequential extensions in multiple directions are an exception to this rule.

Examples of MOMENTARY and inconsequential actions include a wire or cable tie swinging out of the ROBOT PERIMETER, including while an extension is deployed out a different side.

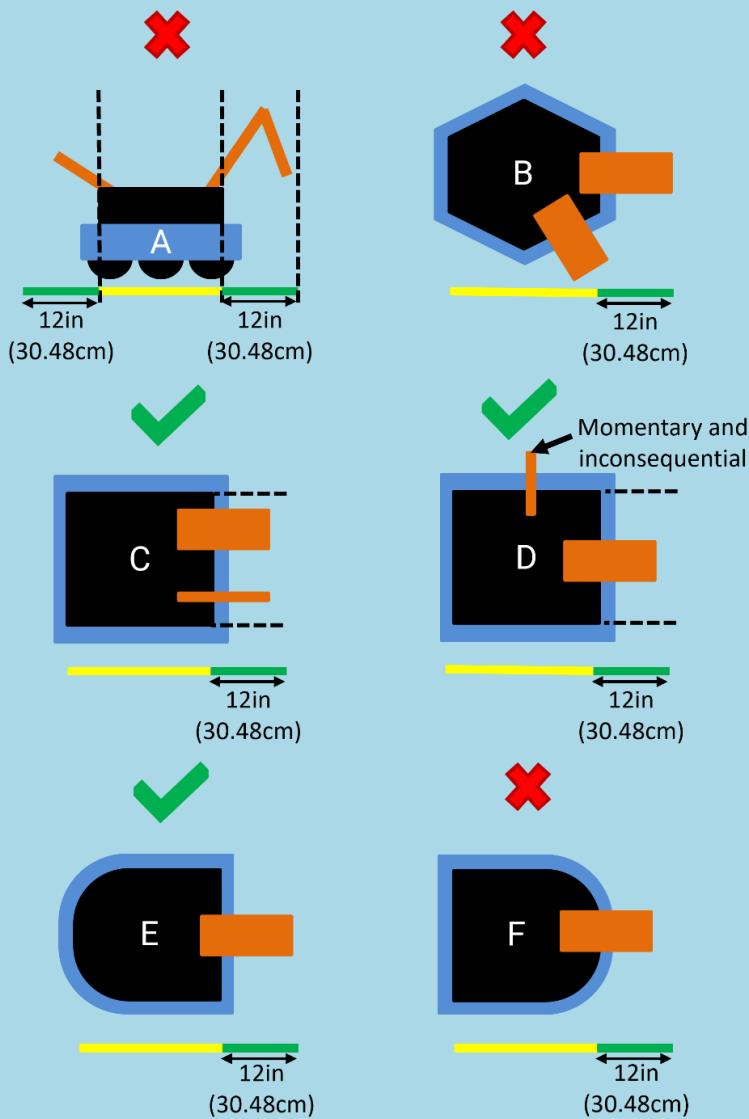
Examples of compliance and non-compliance of this rule are shown in [Figure 8-3](#).

Yellow bars represent the limits of the ROBOT PERIMETER and are drawn in the same orientation of the ROBOT'S PERIMETER.

Green bars represent a measured extension from the ROBOT PERIMETER that does not exceed the limit defined in [R105](#).

- ROBOT A violates this rule for extending in more than one direction
- ROBOT B violates this rule for extending in more than one direction
- ROBOT C does not violate this rule
- ROBOT D does not violate this rule as the additional extension is momentary and inconsequential
- ROBOT E does not violate this rule
- ROBOT F violates this rule for extending in more than one direction by extending over a round segment of ROBOT PERIMETER.

Figure 8-3 Examples of compliance and non-compliance of this rule



R107 ROBOT vertical extension limit. ROBOTS may not extend such that their total height exceeds 30.0in (76.2cm).

This measurement is intended to be made as if the ROBOT is resting on a flat floor (without changing the ROBOT configuration), not relative to the current height of the ROBOT from the FIELD carpet at any given time (i.e. the measurement is made perpendicular to the ROBOT PERIMETER polygon).

R108 ROBOT extension floor interaction ROBOT extensions may not interact with the carpet, BUMPS, or TOWER BASE such that the BUMPERS are lifted out of the BUMPER ZONE (see R405).

8.2 ROBOT Safety & Damage Prevention

R201 *No digging into carpet. Traction devices must not have surface features that could damage the ARENA (e.g. metal, sandpaper, inflexible studs, cleats, hook-loop fasteners or similar attachments). Traction devices include all parts of the ROBOT that are designed to transmit any propulsive and/or braking forces between the ROBOT and FIELD carpet.

R202 *No exposed sharp edges. Protrusions from the ROBOT and exposed surfaces on the ROBOT shall not pose hazards to the ARENA elements (including SCORING ELEMENTS) or people.

Note that the use of acrylic or other materials which may break into jagged pieces is not explicitly prohibited, but any such breakage must be corrected immediately to comply with this rule.

R203 *General safety. ROBOT parts shall not be made from hazardous materials, be unsafe, cause an unsafe condition, or interfere with the operation of other ROBOTS.

Examples of items that will violate this rule include (but are not limited to):

- A. shields, curtains, or any other devices or materials designed or used to obstruct or limit the vision of any DRIVE TEAM members and/or interfere with their ability to safely control their ROBOT,
- B. speakers, sirens, air horns, or other audio devices that generate sound at a level sufficient to be a distraction,
- C. any devices or decorations specifically intended to jam or interfere with the remote sensing capabilities of another ROBOT, including vision systems, acoustic range finders, sonars, infrared proximity detectors, etc. (e.g. including imagery on your ROBOT that utilizes or closely mimics 36h11 AprilTags),
- D. lasers other than those listed as IEC/EN 60825-1 "Class 1" or IEC/EN 62471 "Exempt,"
- E. flammable gasses,
- F. any device intended to produce flames or pyrotechnics,
- G. hydraulic fluids or hydraulic items,
- H. switches or contacts containing liquid mercury,
- I. circuitry used to create voltages in excess of 24 Volts,
- J. any ballast not secured sufficiently, including loose ballast e.g. sand, ball bearings, etc., such that it may become loose during a MATCH,

- K. hazardous materials (e.g. lead, whether encapsulated or not) used on the ROBOT,
- L. high intensity light sources used on the ROBOT (e.g. super bright LED sources marketed as 'military grade' or 'self-defense') may only be illuminated for a brief time while targeting and may need to be shrouded to prevent any exposure to participants. Complaints about the use of such light sources will be followed by re-inspection and possible disablement of the device, and
- M. Bright lights which flash more than approximately 5 times per second, per [E108](#).

R204 *Leave SCORING ELEMENTS at the FIELD. ROBOTS must allow removal of SCORING ELEMENTS from the ROBOT and the ROBOT from FIELD elements while DISABLED and powered off.

ROBOTS will not be re-enabled after the MATCH, so teams must be sure that SCORING ELEMENTS and ROBOTS can be quickly, simply, and safely removed.

Teams are encouraged to consider [G501](#) when developing their ROBOTS.

R205 *Don't contaminate the FIELD. Liquids, gels, greases and fine particles must not contaminate the FIELD or other ROBOTS.

R206 *Don't damage SCORING ELEMENTS. ROBOT elements likely to come in contact with a SCORING ELEMENT shall not pose a significant hazard to the SCORING ELEMENT.

SCORING ELEMENTS are expected to undergo a reasonable amount of wear and tear as they are handled by ROBOTS, such as scratching or marking. Gouging, tearing off pieces, or routinely marking SCORING ELEMENTS are violations of this rule.

8.3 Budget Constraints & Fabrication Schedule

R301 *Individual item cost limit. No individual, non-KOP item or software shall have a Fair Market Value (FMV) that exceeds \$600 USD. The total cost of COMPONENTS purchased in bulk may exceed \$600 USD as long as the cost of an individual COMPONENT does not exceed \$600 USD.

Teams should be ready to show INSPECTORS documentation of FMV for any COMPONENTS that appear to be in the range of the \$600 USD limit.

The Analog Devices IMU MXP Breakout Board, P/N ADIS16448, does not have a published FMV. This device is considered to comply with this rule regardless of its true FMV.

The FMV of a COTS item is its price defined by a VENDOR for the part or an identical functional replacement. This price must be generally available to all FIRST Robotics Competition teams throughout the build and competition season (i.e. short-term sale prices or coupons do not reflect FMV), however teams are only expected to make a good faith effort at determining the item price and are not expected to monitor prices of ROBOT items throughout the season. The FMV is the cost of the item itself and does not include any duties, taxes, tariffs, shipping, or other costs that may vary by locality.

The FMV of COTS software is the price, set by the VENDOR, to license the software (or piece of the software) that runs on the ROBOT for the period from Kickoff to the end of the *FIRST* Championship. The FMV of software licensed free-of-cost, including through the Virtual KOP, for use on the ROBOT is \$0.

The FMV of FABRICATED parts is the value of the material and/or labor, except for labor provided by team members (including sponsor employees who are members of the team), members of other teams, and/or event provided machine shops. Material costs are accounted for as the cost of any purchasable quantity that can be used to make the individual part (i.e. the purchasable raw material is larger than the FABRICATED part).

Example 1: A team orders a custom bracket made by a company to the team's specification. The company's material cost and normally charged labor rate apply.

Example 2: A team receives a donated sensor. The company would normally sell this item for \$450 USD, which is therefore its FMV.

Example 3: A team purchases titanium tube stock for \$400 USD and has it machined by a local machine shop. The machine shop is not considered a team sponsor but donates 2 hours of expended labor anyway. The team must include the estimated normal cost of the labor as if it were paid to the machine shop and add it to the \$400 USD.

Example 4: A team purchases titanium tube stock for \$400 USD and has it machined by a local machine shop that is a recognized sponsor of the team. If the machinists are considered members of the team, their labor costs do not apply. The total applicable cost for the part would be \$400 USD.

It is in the best interests of the teams and *FIRST* to form relationships with as many organizations as possible. Recognizing supporting companies as sponsors of, and members in, the team is encouraged, even if the involvement of the sponsor is solely through the donation of fabrication labor.

Example 5: A team purchases titanium tube stock for \$400 USD and has it machined by another team. The total applicable cost for the part would be \$400 USD.

Example 6: A team purchases a widget at a garage sale or online auction for \$300, but it's available for sale from a VENDOR for \$700. The FMV is \$700.

If a COTS item is part of a modular system that can be assembled in several possible configurations, then each individual module must fit within the price constraints defined in this rule.

If the modules are designed to assemble into a single configuration, and the assembly is functional in only that configuration, then the total cost of the complete assembly including all modules must fit within the price constraints defined in this rule.

In summary, if a VENDOR sells a system or a kit, a team must use the entire system/kit FMV and not the value of its COMPONENT pieces.

Example 7: VENDOR A sells a gearbox that can be used with a number of different gear sets, and can mate with 2 different motors they sell. A team purchases the gearbox, a gear set, and a motor, then assembles them together. Each part is treated separately for the purpose of determining FMV since the purchased pieces can each be used in various configurations.

Example 8: VENDOR B sells a robotic arm assembly that a team wants to use. However, it costs \$630 USD, so they cannot use it. The VENDOR sells the "hand", "wrist", and "arm" as separate assemblies, for \$210 USD each. A team wishes to purchase the 3 items separately, then reassemble them. This would not be legal, as they are really buying and using the entire assembly, which has a Fair Market Value of \$630 USD.

Example 9: VENDOR C sells a set of wheels or wheel modules that are often used in groups of 4. The wheels or modules can be used in other quantities or configurations. A team purchases 4 and uses them in the most common configuration. Each part is treated separately for the purpose of determining FMV, since the purchased pieces can be used in various configurations.

R302 *MAJOR MECHANISM, from this year only. MAJOR MECHANISMS, as defined in [I101](#), created before Kickoff are not permitted.

Neither this rule nor the language in this blue box define specific thresholds for how much of a MAJOR MECHANISM must be constructed after Kickoff. This rule expects and requires the team's honest assessment of whether they built the MAJOR MECHANISMS of their ROBOT after Kickoff.

Attempts to exploit loopholes in the definition of MAJOR MECHANISM in order to bypass this requirement are in the spirit of neither this rule nor FIRST Robotics Competition. Examples of exploitation include:

- Pre-assembling significant portions of a MAJOR MECHANISM prior to Kickoff and attaching those assemblies together post-Kickoff,
- Removing a small COMPONENT of a MAJOR MECHANISM prior to Kickoff such that it is no longer a MAJOR MECHANISM and replacing it after Kickoff.

R303 *Create new designs and software, unless they're public. ROBOT software and designs created before Kickoff are only permitted if the source files (complete information sufficient to produce the design) are available publicly prior to Kickoff.

Example 1: A team realizes that the transmission designed and built in the fall perfectly fits their need for a transmission to drive the ROBOT arm. They build an exact copy of the transmission from the original design plans and bolt it to the ROBOT. This would be prohibited, as the transmission – although made during the competition season – was built from detailed designs developed prior to Kickoff.

Example 2: A team developed an omni-directional drive system for the 2019 competition. In July 2019 they refined and improved the control software, written in C++, to add more precision and capabilities. They decided to use a similar system for the REBUILT competition. They copied large sections of unmodified code over into the control software of the new ROBOT, also written in C++. This would be a violation of the schedule constraint and is not allowed.

Example 3: The same team decides to use LabVIEW as their software environment for REBUILT. Following Kickoff, they use the previously developed C++ code as a reference for the algorithms and calculations required to implement their omni-directional control solution. Because they developed new LabVIEW code as they ported over their algorithms, this is permitted.

Example 4: A different team develops a similar solution during the fall and plans to use the developed software on their competition ROBOT. After completing the software, they post it in a generally accessible public forum and make the code available to all teams. Because they have made their software publicly available before Kickoff, they can use it on their ROBOT.

Example 5: A team develops a transmission prior to Kickoff. After completing the project, they publish the CAD files on a generally accessible public forum and make them available to all teams. Because they have made the design publicly available before Kickoff, they can use the design to create an identical transmission, fabricated after Kickoff, for use on their REBUILT ROBOT.

8.4 BUMPER Rules

A BUMPER is a required assembly which attaches to the ROBOT frame. BUMPERS protect ROBOTS from damaging/being damaged by other ROBOTS and FIELD elements.

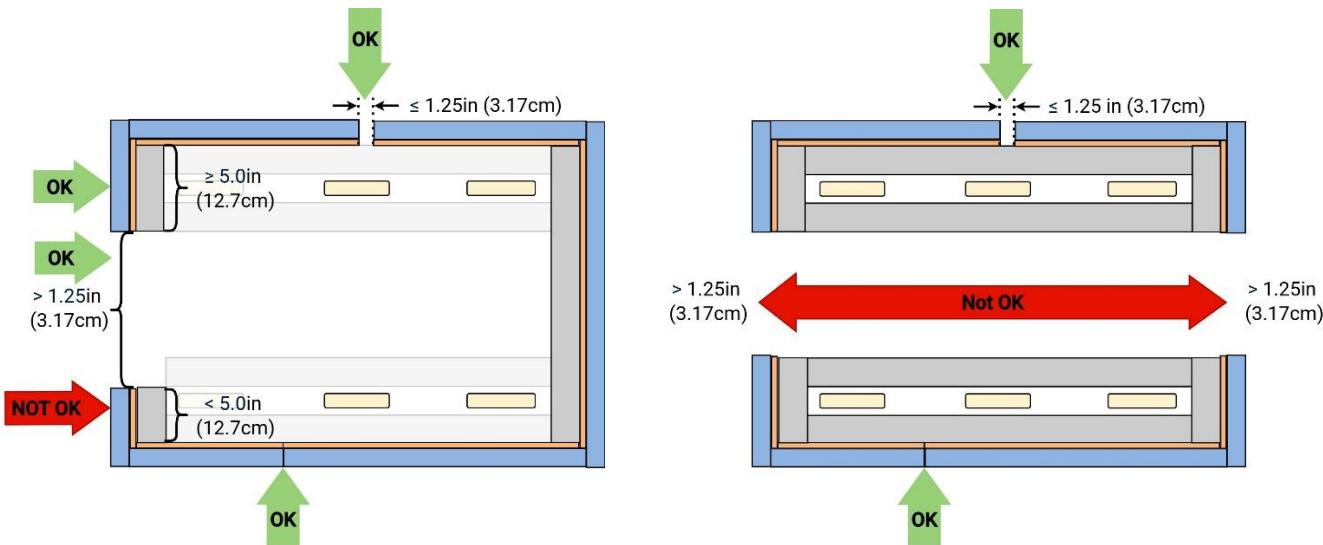
A BUMPER guide providing additional information on materials and design based on historical best practices may be found under the Mechanical Resources section of the [Technical Resources page](#). Teams may also reference the [KitBot Instructions](#) for a detailed step-by-step on how to build bumpers for the KitBot.

All dimensions specified in this section are nominal and will be measured during inspection with a tolerance of 0.25in (0.63cm) unless otherwise specified. This means that maximums specified have a tolerance of +0.25in (0.63cm) and minimums specified have a tolerance of -0.25in (0.63cm). Teams are encouraged to design to the nominal dimension and reserve the tolerance for unexpected deviation such as manufacturing error or tolerance stack-up.

R401 *BUMPERS almost all around. ROBOTS are required to use BUMPERS to protect the entire ROBOT PERIMETER. Gaps of less than 1.25in (3.17cm) between adjacent segments are permitted as long as all corners are filled per R406. A single gap larger than 1.25in (3.17cm) is permitted, as long as at least 5.0in (12.7cm) of ROBOT PERIMETER on each side of each corner is protected by BUMPER.

An arc is considered to have infinite corners and therefore may not have a gap larger than 1.25in (3.17cm).

Figure 8-4 BUMPER coverage requirements



R402 *BUMPER construction. BUMPERS must consist of the following:

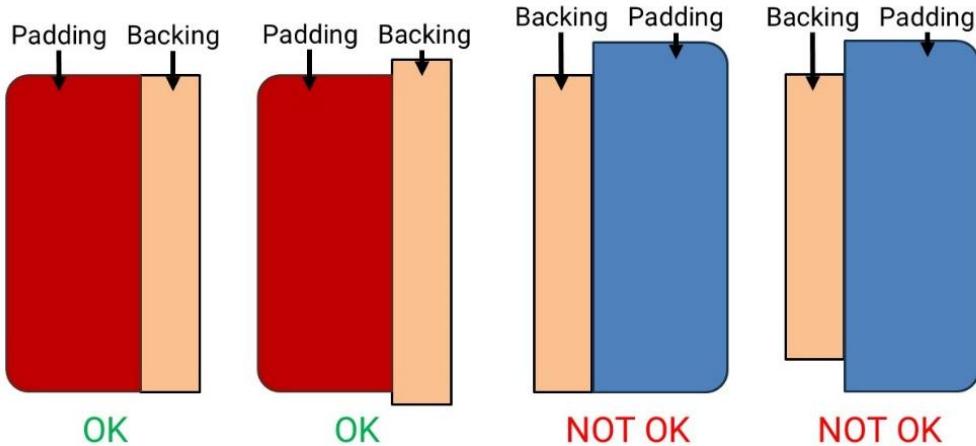
- A. **Padding** – A minimum of 2.25in (5.72cm) depth of foam padding, at least 4.5in (11.43cm) tall consisting of solid blocks, sheets, or stacked rods of one or more of the following materials:
 - i. Solid pool noodles or backer rod
 - ii. Solid polyethylene closed cell foam (including crosslinked) with density between 1.5 and 3.0lb/ft³ (24.03 to 48.05kg/m³)
 - iii. Solid EVA closed cell foam with density between 2.0 and 6.0lb/ft³ (32.04 to 96.11kg/m³)
 - iv. Foam floor tiles

Multiple types, shapes, and/or layers of foam may be used within a single BUMPER.

Teams should be prepared to provide information about the padding material used in their BUMPERS. Teams do not need to have a separate material sample or expose padding for direct inspection to show compliance with this rule.

- B. **Backing** – A backer at least 4.5in (11.43cm) tall which supports the padding (i.e. padding is not cantilevered other than in corners) and facilitates installation and removal of the BUMPER from the ROBOT (as noted in [R410](#)). Additional elements may be added to strengthen the backing, fill space between the BUMPER and ROBOT frame, serve as part of the attachment system, or for any other purpose.

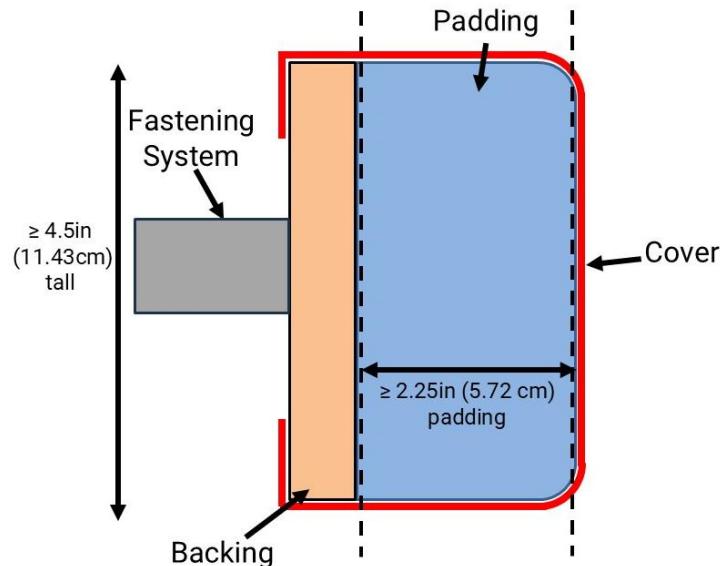
Figure 8-5 BUMPER backing supporting padding (cross section)



- C. **Cover** – Cloth (as noted in [R411](#)) which covers all outward, upward and downward facing surfaces of padding such that no padding is exposed to interaction with the FIELD or other ROBOTS.
- D. **Fastening System** – BUMPERS must attach to the ROBOT PERIMETER with a rigid fastening system to form a tight, robust connection to the main structure/frame (e.g. not attached with hook-and-loop tape, tape, or cable ties). The fastening system must be designed to withstand vigorous game play. All removable fasteners (e.g. bolts, locking pins, quick release pins, etc.) may be considered part of either the BUMPERS or ROBOT for determination of weight per [R103](#) and [R408](#).

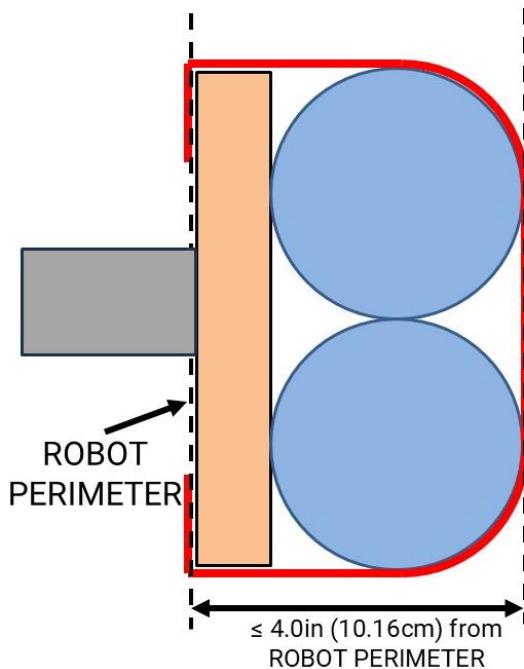
The BUMPER Rules provide teams significant freedom in choosing designs and materials. For information on a reference design, see the Bumper Guide under the Mechanical Resources section of the [Technical Resources Page](#).

Figure 8-6 BUMPER Cross Section Example



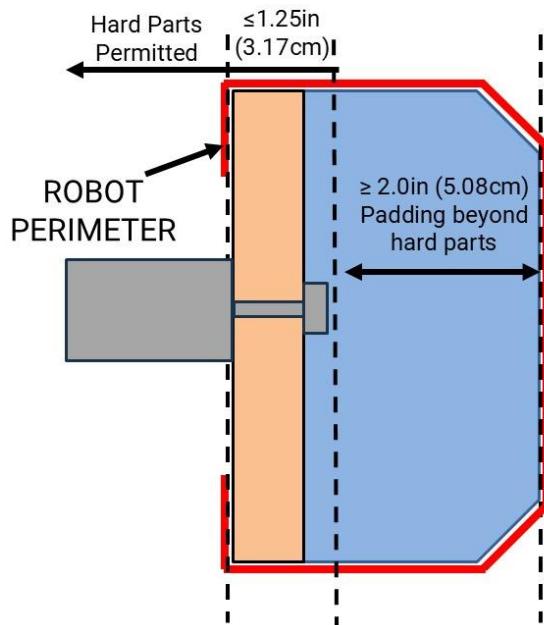
R403 *BUMPER extension limit. BUMPERS must not extend more than 4.0in (10.16cm) from the ROBOT PERIMETER.

Figure 8-7 BUMPER Extension Limit



R404 *BUMPERS must be soft. Hard parts of BUMPERS must not extend more than 1.25in (3.17cm) out from the ROBOT PERIMETER. Only padding (per R402-A), cover (per R402-C, including any coatings or markings), and soft fasteners used to secure padding or cover are permitted beyond this limit. Padding must extend at least 2.0in (5.08cm) beyond any hard parts of the BUMPER. There is no limit on how far BUMPER hard parts may extend inside the ROBOT FRAME PERIMETER.

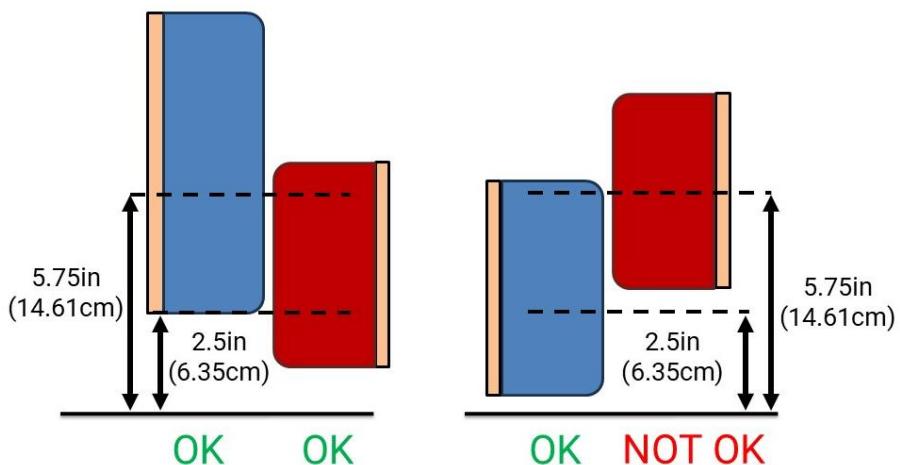
Figure 8-8 BUMPER Hard Parts Limit



Hard parts include any items which are likely to cause damage to the cloth or padding of other BUMPERS such as nuts and bolts, cable ties, hard plastics, etc.

- R405 *BUMPERS interact with BUMPERS.** While navigating the FIELD normally, all BUMPERS must have padding (per [R402-A](#)) supported by backing (per [R402-B](#)) entirely filling the BUMPER ZONE, a space between 2.5in (6.35cm) and 5.75in (14.61cm) from the floor.

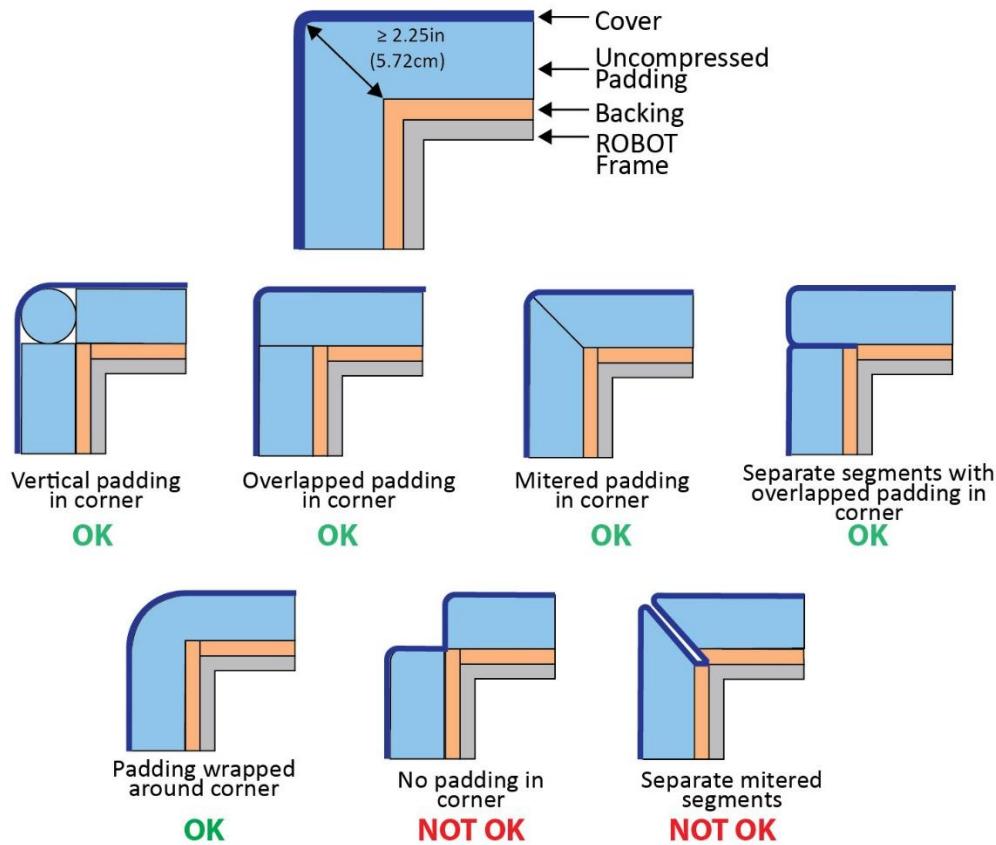
Figure 8-9 BUMPER ZONE examples



This measurement is intended to be made in a ROBOT'S expected configuration(s) while navigating the FIELD and is relative to whatever surface the ROBOT is currently driving on. BUMPERS leaving the BUMPER ZONE due to ROBOTS inadvertently tipping is not a violation of this rule.

- R406 *Fill BUMPER corners.** Corner joints between BUMPERS must be filled with uncompressed padding material extending at least 2.25in (5.72cm) from the corner with no gaps or voids. Examples of implementation are shown in [Figure 8-10](#).

Figure 8-10 Uncompressed corner padding



Separate bumper segments meeting at a miter in the corner are not considered to "fill" the corner due to the cloth covering and do not meet the requirements of this rule.

- R407 *BUMPERS shouldn't be wedges.** BUMPERS must not act as wedges when interacting with other BUMPERS.

Examples of BUMPERS which might act as a wedge, and may invite additional scrutiny, include:

- A. BUMPERS utilizing softer foam towards the top of a BUMPER profile,
- B. BUMPERS utilizing excessively rounded profiles such as a single semi-circle, and
- C. BUMPERS with tapered or stepped padding such that the padding is thinner or thicker towards the top or bottom.

- R408 *Weight limit with BUMPERS.** The total weight of the ROBOT (as described in [R103](#)) with BUMPERS must not exceed 135.0lb (61.23kg)

- R409 *BUMPERS should be passive.** BUMPERS must be fixed relative to the ROBOT PERIMETER. BUMPERS may not contain any moving elements (beyond compression and flex of BUMPER materials) or electrical elements.

R410 *BUMPERS must come off. BUMPERS must be designed for installation and removal to facilitate inspection and weighing.

As a guideline, BUMPERS should be able to be installed or removed by 2 people in fewer than 5 minutes.

R411 *BUMPERS indicate your ALLIANCE. Each ROBOT must be able to display red or blue BUMPER covers to reflect their ALLIANCE color, as assigned in the MATCH schedule distributed at the event (as described in section [10.1 MATCH Schedules](#)). Contrasting markings on outward, upward, or downward facing surfaces of the BUMPER cover, other than the following, are prohibited:

- A. those required per [R412](#),
- B. hook-and-loop tape, snap fasteners, or functional equivalents backed by the hard parts of the BUMPER,
- C. solid white FIRST logos between 4.75in (12.06cm) and 5.25in (13.33cm) wide (i.e. comparable to those available in the REBUILT Virtual Kit), and
- D. narrow areas of underlying cloth exposed at seams, corners, or folds.

R412 *Team number on BUMPERS. Team numbers must be displayed and positioned on the BUMPER cover in at least 3 locations approximately 90 degrees apart such that an observer walking around the perimeter of the ROBOT can unambiguously tell the team's number from most points of view, from as far as approximately 720.0in (18.29m). Team numbers must meet the following additional criteria:

- A. consist of only white Arabic numerals at least 3.75in (9.53cm) high, at least 0.5in (1.27cm) in stroke width,

The 0.5in (1.27cm) stroke width requirement applies to the majority of the stroke. Font elements less than 0.5in (1.27cm) such as serifs, rounded edges, small hairlines or gaps, etc. are permitted as long as the majority of the stroke meets the sizing requirement and the numbers are unambiguous.
- B. must not wrap around sharp corners (less than 135.0°) of the ROBOT PERIMETER,
- C. must not split individual digits such that the team number is ambiguous, and

As a guideline, spacing between digits or groups of digits which exceeds ~4.0in (10.16cm) may be ambiguous.

- D. may not substitute logos or icons for numerals.

There is no prohibition against splitting team numbers onto different sections of BUMPER. The intent is that the team's number is clearly visible and unambiguous so that Judges, REFEREES, Announcers, and other teams can easily identify competing ROBOTS.

This marking is intended to display the team number only, not to intentionally change the surface characteristics of the BUMPER. Excessive material usage as part of any team number marking will invite close scrutiny.

8.5 Motors & Actuators

R501 *Allowable motors. The only motors and actuators permitted include the following (in any quantity):

Table 8-1 Motor allowances

Motor Name	Part Numbers Available	
AndyMark 9015	am-0912	AndyMark 9015
AndyMark NeveRest	am-3104	
AndyMark PG	am-2161 (alt. PN am-2765)	am-2194 (alt. PN am-2766)
AndyMark RedLine Motor	am-3775	am-3775a
AndyMark Snow Blower Motor	am-2235	am-2235a
Banebots	am-3830 M7-RS775-18 RS775WC-8514	M5 – RS550-12 RS550VC-7527 RS550
CIM	FR801-001 M4-R0062-12 AM802-001A 217-2000 PM25R-44F-1005	PM25R-45F-1004 PM25R-45F-1003 PMR25R-45F-1003 PMR25R-44F-1005 am-0255
CTR Electronics Minion	24-777378	WCP-1691
CTR Electronics/VEX Robotics Falcon 500	217-6515 am-6515	19-708850 am-6515_Short
Current/former KOP automotive motors	Denso AE235100-0160 Denso 5-163800-RC1 Denso 262100-3030	Denso 262100-3040 Bosch 6 004 RA3 194-06 Johnson Electric JE-PLG-149 Johnson Electric JE-PLG-410
Playing with Fusion Venom	BDC-10001	
REV Robotics HD Hex	REV-41-1291	
REV Robotics NEO Brushless	REV-21-1650 (v1.0 or v1.1)	am-4258 am-4258a
REV Robotics NEO 550	REV-21-1651	am-4259
REV Robotics NEO Vortex	REV-21-1652	am-5275
Thrifty Bot Pulsar 775	TTB-0350	
VEX BAG	217-3351	

Motor Name	Part Numbers Available	
VEX Mini-CIM	217-3371	
West Coast Products Kraken x44	WCP-0941	
West Coast Products Kraken x60	WCP-0940	am-5274
West Coast Products RS775 Pro	217-4347	
Fans, no greater than 120mm (nominal) size and rated electrical input power no greater than 10 watts (W) continuous duty at 12 volts (VDC)		
Hard drive motors part of a legal COTS computing device		
Factory installed vibration and autofocus motors resident in COTS computing devices (e.g. rumble motor in a smartphone).		
PWM COTS rotational servos with stall current ≤ 4A and mechanical output power ≤ 8W at 6V. PWM COTS linear servos with max stall current ≤ 1A at 6V.		
Motors integral to a COTS sensor (e.g. LIDAR, scanning sonar, etc.), provided the device is not modified except to facilitate mounting		
1 compressor compliant with R806 and used to compress air for the ROBOT'S pneumatic system		
COTS brushed motors, linear actuators, electrical solenoid actuators, or electromagnets rated for 12V and wired to an approved power regulating device downstream of a breaker 20A or less. Electrical solenoid actuators or electromagnets used at 24V must be rated for 24V.		

For servos, note that the roboRIO is limited to a max current output of 2.2A on the 6V rail (12.4W of electrical input power). Teams should make sure that their total servo power usage remains below this limit at all times.

Servo mechanical output power is approximated by the following formula (using 6V data reported by manufacturer): Mechanical Output Power (in W) = 0.25 x (Stall Torque in N·m) x (No Load Speed in rad/s). [This calculator from the FIRST Tech Challenge documentation](#) can be used to help calculate output power from inputs of various units.

Given the extensive amount of motors allowed on the ROBOT, teams are encouraged to consider the total power available from the ROBOT battery during the design and build of the ROBOT. Drawing large amounts of current from many motors at the same time could lead to drops in ROBOT battery voltage that may result in tripping the main breaker or trigger the brownout protection of the roboRIO. For more information about the roboRIO brownout protection and measuring current draw using the PDP/PDH, see [roboRIO Brownout and Understanding Current Draw](#).

AndyMark PG Gearmotors are sold with labeling based on the entire assembly. Assemblies labeled am-3651 through am-3656 contain legal motors specified in [Table 8-1](#). These motors may be used with or without the provided gearbox.

R502 *Only 4 propulsion motors. A ROBOT may not have more than 4 propulsion motors. A propulsion motor is a motor that enables the ROBOT to move around the FIELD surface. Motors that generate small amounts of thrust as a secondary or incidental feature are not considered propulsion motors.

Examples that are not considered propulsion motors include:

- A. motors that primarily alter the alignment of a wheel in contact with the FIELD surface (such as a swerve steering motor),
- B. motors that run MECHANISM wheels (e.g. for SCORING ELEMENT manipulation) that occasionally happen to contact the carpet, but without enough force to generate significant thrust, and
- C. motors that change the speed of the drive wheels using a shifting MECHANISM without significantly contributing to propulsion.

R503 *Don't modify motors (mostly). The integral mechanical and electrical system of any motor must not be modified. Motors, servos, and electric solenoids used on the ROBOT shall not be modified in any way, except as follows:

- A. The mounting brackets and/or output shaft/interface may be modified to facilitate the physical connection of the motor to the ROBOT and actuated part.
- B. The electrical leads may be trimmed to length as necessary and connectors or splices to additional wiring may be added.
- C. The locking pins on the window motors (P/N 262100-3030 and 262100-3040) may be removed.
- D. The connector housings on KOP automotive motors listed in [Table 8-1](#) may be modified to facilitate lead connections.
- E. Servos may be modified as specified by the manufacturer (e.g. re-programming or modification for continuous rotation).
- F. Minimal labeling may be applied to indicate device purpose, connectivity, functional performance, etc.
- G. Any number of #10-32 plug screws may be removed from the Falcon 500 and the Kraken X60.
- H. Insulation may be applied to electrical terminals.
- I. Repairs, provided the original performance and specifications are unchanged.
- J. Maintenance recommended by the manufacturer.

The intent of this rule is to allow teams to modify mounting tabs and the like, not to gain a weight reduction by potentially compromising the structural integrity of any motor.

R504 *Power (most) actuators off of approved devices. With the exception of servos, fans, or motors integral to sensors of COTS computing devices permitted in [R501](#), each actuator must be controlled by a power regulating device. The only power regulating devices for actuators permitted on the ROBOT include:

- A. motor controllers:
 - a. Koors40 Motor Controller (P/N am-5600),
 - b. Spark Flex Motor Controller (P/N REV-11-2159, am-5276)
 - c. Spark Motor Controller (P/N REV-11-1200, am-4260),
 - d. Spark MAX Motor Controller (P/N REV-11-2158, am-4261),

- e. Talon FX Motor Controller (P/N 217-6515, 19-708850, am-6515, am-6515_Short, WCP-0940, WCP-0941) for controlling integral Falcon 500, Kraken X60, Kraken X44 only,
 - f. Talon FXS Motor Controller (P/N 24-708883, WCP-1692)
 - g. Talon Motor Controller (P/N CTRE_Talon, CTRE_Talon_SR, and am-2195),
 - h. Talon SRX Motor Controller (P/N 217-8080, am-2854, 14-838288),
 - i. Thrifty Nova (P/N TTB-0100),
 - j. Venom Motor with Controller (P/N BDC-10001) for controlling integral motor only,
 - k. Victor SP Motor Controller (P/N 217-9090, am-2855, 14-868380), and
 - l. Victor SPX Motor Controller (P/N 217-9191, 17-868388, am-3748).
- B. relay modules:
- a. Spike H-Bridge Relay (P/N 217-0220 and SPIKE-RELAY-H),
 - b. Automation Direct Relay (P/N AD-SSR6M12-DC-200D, AD-SSRM6M25-DC-200D, AD-SSR6M40-DC-200D), and
 - c. Power Distribution Hub (PDH) switched channel (P/N REV-11-1850) for controlling non-actuator CUSTOM CIRCUITS only.
- C. pneumatics controllers:
- a. Pneumatics Control Module (P/N am-2858, 217-4243) and
 - b. Pneumatic Hub (P/N REV-11-1852).
- D. servo controllers:
- a. Servo Hub (P/N REV-11-1855)

Note: The Automation Direct Relays are single directional. Per [R504](#) they may not be wired together in an attempt to provide bi-directional control.

R505 ***Don't overload controllers.** Each power regulating device may control electrical loads per [Table 8-2](#). Unless otherwise noted, each power regulating device shall control 1 and only 1 electrical load.

Table 8-2 Power regulating device allotments

Electrical Load	Motor Controller	Relay Module	Pneumatics Controller
AndyMark RedLine Motor Banebots CIM CTR Electronics Minion REV Robotics NEO Brushless REV Robotics NEO 550 REV Robotics NEO Vortex ThriftyBot Pulsar 775 VEX Mini-CIM WCP RS775 Pro	Yes	No	No
AndyMark 9015 VEXpro BAG	Yes (up to 2 per controller)	No	No

AndyMark PG KOP Automotive Motors NeveRest Snow Blower Motor REV Robotics HD Hex	Yes (up to 2 per controller)	Yes	No
Other Brushed Motor Linear Actuator	Yes (20A breaker max)	Yes (20A breaker max)	No
CTR Electronics/VEX Falcon 500 Playing With Fusion Venom WCP Kraken X44 WCP Kraken X60	Yes (integrated controller only)	No	No
Compressor	No	Yes	Yes
Pneumatic Solenoid Valves	No	Yes (multiple)	Yes (1 per channel)
Electric Solenoids	Yes (multiple)	Yes (multiple)	Yes (1 per channel)
CUSTOM CIRCUITS	Yes (multiple)	Yes (multiple)	Yes (multiple)

R506 *Control servos safely. Servos must be connected to, and only to, 1 of the following:

- A. PWM ports on the roboRIO,
- B. PWM ports on a WCP Spartan Sensor Board (P/N WCP-0045),
- C. REV Robotics Servo Power Module (P/N REV-11-1144), or
- D. REV Robotics Servo Hub (P/N REV-11-1855).

8.6 Power Distribution

In order to maintain safety, the rules in this section apply at all times while at the event, not just while the ROBOT is on the FIELD for MATCHES.

R601 *Battery limit – everyone has the same power. The only legal source of electrical energy for the ROBOT during the competition, the ROBOT battery, must be 1 and only 1 non-spillable sealed lead acid (SLA) battery with the following specifications:

- A. Nominal voltage: 12V
- B. Nominal capacity at 20-hour discharge rate: minimum 17Ah, maximum 18.2Ah
- C. Shape: Rectangular
- D. Nominal Dimensions: 7.1in x 3.0in x 6.6in, +/- 0.1in for each dimension (18.03cm x 7.62cm x 16.76cm, +/-0.25cm for each dimension)
- E. Nominal weight: 11.0lb to 14.5lb (4.99kg to 6.57kg)
- F. Terminals: Nut and bolt style
- G. Battery vents must not be obstructed.

"Nut and bolt style" refers to any style battery terminal where the connector is secured to the battery using a threaded fastener.

Examples of batteries which meet these criteria include:

- A. Enersys (P/N NP18-12, NP18-12B, NP18-12BFR),
- B. MK Battery (P/N ES17-12),
- C. Battery Mart (P/N SLA-12V18),
- D. Sigma (P/N SP12-18),
- E. Universal Battery (P/N UB12180),
- F. Power Patrol (P/N SLA1116),
- G. Werker Battery (P/N WKA12-18NB),
- H. Power Sonic (P/N PS-12180NB),
- I. Yuasa (P/N NP18-12B),
- J. Panasonic (P/N LC-RD-1217),
- K. Interstate Batteries (P/N BSL1116), and
- L. Duracell Ultra Battery (P/N DURA12-18NB).

Teams should be aware that they may be asked to provide documentation of the specifications of any battery not listed above.

Batteries should be charged in accordance with manufacturer's specification.
(Please see the [FIRST Safety Manual](#) for additional information.)

R602 *Other batteries for cameras or computers only. COTS USB battery packs with a capacity of 100Wh or less (27000mAh at 3.7V) with 5V/5A max output or 12V/5A max output using USB-PD per port, batteries integral to and part of a COTS computing device or self-contained camera (e.g. laptop batteries, GoPro style camera, etc.), or batteries used to power CMOS/RTC features may be used to power COTS computing devices and any peripheral COTS input or output devices connected to the COTS computing device provided they are:

- A. securely fastened to the ROBOT,
- B. connected only using unmodified COTS cables, and
- C. charged according to manufacturer recommendations.

A COTS computing device is a non-roboRIO device used to process or collect sensor information (e.g. a "smart flashlight" is not a COTS computing device).

R603 *Charge batteries with safe connectors. Any battery charger used to charge a ROBOT battery must have the corresponding Anderson SB connector installed.

R604 *Charge batteries at a safe rate. Any battery charger used to charge a ROBOT battery may not be used such that it exceeds 6-Amp average charge current.

R605 *Batteries are not ballast. No batteries other than those allowed per [R601](#) and [R602](#) are allowed on the ROBOT, whether or not they are being used to supply power.

For example, teams may not use additional batteries as extra weight on their ROBOTS.

R606 *Secure the battery. The ROBOT battery must be secured such that it will not dislodge during vigorous ROBOT interaction including if the ROBOT is turned over or placed in any arbitrary orientation.

R607 *Insulate battery connections. Each electrical terminal on the ROBOT battery, main breaker, and their connections (lugs, stripped wire ends, etc.) to the wire must be fully insulated at all times.

R608 *Limit non-battery energy. Non-electrical sources of energy used by the ROBOT (i.e., stored at the start of a MATCH) shall come only from the following sources:

- compressed air stored in the pneumatic system that has been charged in compliance with [R806](#) and [R807](#),
- a change in the altitude of the ROBOT center of gravity,
- storage achieved by deformation of ROBOT parts,
- closed-loop COTS pneumatic (gas) shocks, or
- air-filled (pneumatic) wheels.

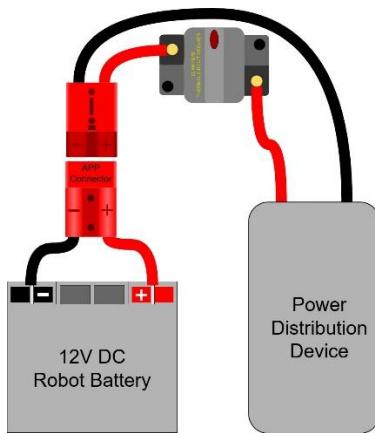
R609 *Connect main power safely. The following devices shall be connected with 6 AWG (7 SWG or 16 mm²) copper wire or larger as shown in [Figure 8-11](#):

- 1 ROBOT battery,
- a single pair of Anderson Power Products (or APP) 2-pole SB type connectors,
- a single main 120-Amp (120A) surface mount circuit breaker (Cooper Bussman P/N CB185-120, CB185F-120, CB285-120 CB285F-120, CB285120F or Optifuse P/N 153120, 253120), and
- a single main power distribution device (PD):
 - CTR Electronics Power Distribution Panel (PDP) P/N am-2856, 217-4244, 14-806880,
 - CTR Electronics Power Distribution Panel 2.0 (PDP 2.0) P/N 24-806880, WCP-1690
 - REV Robotics Power Distribution Hub (PDH) P/N REV-11-1850
 - AndyMark Power Distribution (AMPD) P/N am-5754

No additional devices or modifications shall be permitted with the following exceptions:

- Monitoring circuitry permitted by [R625](#),
- SB-50 to SB-120 adapters, provided they have been presented for Inspection,
- Termination of wires with appropriate cable lugs, and/or

Figure 8-11 Electrical connection diagram



"SB type" refers to SB type only (e.g. SB-50, SB-120, etc.), not SBS or any other part type beginning with SB. All batteries supplied by FIRST (such as Spare Parts and international batteries) will have a red or pink SB50 connector installed which may not be removed.

The pink connectors included in the KOP mate with the red SB50 connector.

While pure copper wire is recommended, copper-clad aluminum wire is considered copper wire

- R610 *1 breaker/fuse per circuit.** All circuits, with the exceptions of those listed in [R615](#) and [R617](#), must connect to, and have power sourced solely by, a single protected connector pair of the PD. Circuits must not connect to the main power input of the PD.
- R611 *The ROBOT frame is not a wire.** All wiring and electrical devices shall be electrically isolated from the ROBOT frame. The ROBOT frame must not be used to carry electrical current.

Compliance with this rule is checked by observing a $>120\Omega$ resistance between either the (+) or (-) post within the APP connector that is attached to the PD and any point on the ROBOT.

All legal motor controllers with metal cases are electrically isolated. They may be mounted directly to ROBOT frame COMPONENTS.

Note that some cameras, decorative lights, and sensors (e.g. some encoders, some IR sensors, etc.) have grounded enclosures or are manufactured with conductive plastics. These devices must be electrically isolated from the ROBOT frame to ensure compliance with this rule.

- R612 *Must be able to turn ROBOT on and off safely.** The 120A circuit breaker must be quickly and safely accessible from the exterior of the ROBOT. This is the only 120A circuit breaker allowed on the ROBOT.

Examples considered not “quickly and safely accessible” include breakers covered by an access panel or door, or mounted on, underneath or immediately adjacent to moving COMPONENTS.

It is strongly recommended that the 120A circuit breaker location be clearly and obviously labeled so it can be easily found by FIELD STAFF if needed.

While the main breaker must be accessible, consider positioning or shielding it such that it’s protected from accidental actuation (e.g. it’s unlikely to be hit by a SCORING ELEMENT during game play).

- R613 *Electrical system must be inspectable.** The PD, associated wiring, and all circuit breakers must be visible for inspection.

“Visible for inspection” does not require that the items be visible when the ROBOT is in STARTING CONFIGURATION, provided the team can make the items viewable during the inspection process.

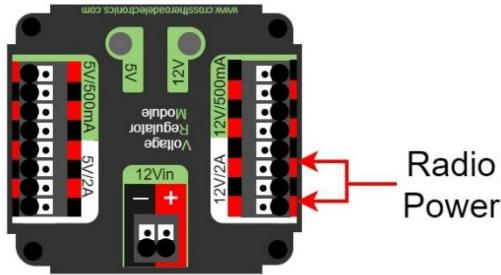
- R614 *No high voltage allowed.** Any active electrical item that is not an actuator (specified in [R501](#)) or core control system item (specified in [R710](#)) is considered a CUSTOM CIRCUIT. CUSTOM CIRCUITS shall not produce measurable voltages exceeding 24V with the exception of COTS Power-over-Ethernet (PoE) injector devices used with COTS Ethernet cables and COTS receiving devices (i.e. not a breakout or adapter).

R615 *Power roboRIO as specified. The roboRIO power input must be connected directly to a non-switched pair of protected output terminals of a PD with a 10A fuse or circuit breaker installed.

R616 *Power radio as specified – Part 1. The wireless bridge (radio) power must be connected based on the radio type:

- A. For VH-109 radios, radio power must be sourced from one or both of:
 - a. Injected into the “RIO” port of the radio using a passive injector or modified Ethernet cable connected directly to a PD, and/or
 - b. Wired directly to the 12V power input of the radio from a PD.
- B. For OM5P radios (China events only), radio power must be sourced from only one of:
 - a. the 12V/2A output of a CTR Electronics Voltage Regulator Module (VRM) (P/N am-2857, 217-4245), as shown in [Figure 8-12](#), and must be the only load connected to any of the 12V/2A terminals or

Figure 8-12 Radio power source from a VRM



- b. using an Ethernet cable between a REV Radio Power Module (RPM) (P/N REV-11-1856) and the “18-24v PoE” port.

Note that this prohibits using any other active PoE injector device to power the radio but does not prohibit using any PASSIVE CONDUCTORS to inject the VRM power into an Ethernet cable plugged into the OM5P radio port labeled “18-24v PoE.”

Please reference [How to Wire an FRC Robot](#) for wireless bridge wiring information.

R617 *Power radio as specified – Part 2. The device supplying power to the wireless bridge per [R616](#) must be connected directly to a non-switched pair of protected output terminals of a PD with a 10A fuse or circuit breaker installed with the exception of the PDP 1.0 shared VRM/PCM pairs which may be protected with a 20A fuse or circuit breaker.

R618 *Use PD terminals as designed. Only 1 wire shall be connected to each terminal on the PD.

If multi-point distribution of circuit power is needed (e.g. to provide power to multiple PCMs and/or VRMs from a single 20A circuit), then all incoming wires may be appropriately spliced into the main lead (e.g. using an insulated terminal block, crimped splice or soldered wire splice), and the single main lead inserted into the terminal to power the circuit.

R619 *Only use specified circuit breakers in a PD. The only circuit breakers permitted for use in the PD are:

- Snap Action VB3-A Series or AT2-A, terminal style F57, 40A rating or lower,
- Snap Action MX5-A or MX5-L Series, 40A rating or lower,
- REV Robotics ATO auto-resetting breakers 40A rating or lower,
- CTR Electronics ATO auto-resetting breakers 40A rating or lower, and
- Any ATM circuit breaker with value less than or equal to the fuses permitted per [R620](#).

R620 *Only use specified fuses in PD. The only fuses permitted for use in the PD are automotive blade fuses with the following values:

- for the PDP, ATM style fuses with values matching the value printed on the device's corresponding fuse holder,
- for all PDs ATC/ATO style fuses with values 10A or lower, and
- for the PDH, ATM style fuses with values 15A or lower with the exception of a single 20A fuse for powering a PCM or PH.

Note that these fuses must be pressed very firmly to seat properly. Improper seating can cause a device to reboot upon impact.

R621 *Protect circuits with appropriate circuit breakers. Each branch circuit must be protected by 1 and only 1 circuit breaker or fuse on the PD per [Table 8-3](#). No other electrical load can be connected to the breaker or fuse supplying this circuit with the exception of devices downstream of a permitted motor power adapter board placed between the PD and a motor controller (WCP-1380, RF-4003, RF-4004, RF-4005).

Table 8-3 Branch circuit protection requirements

Branch Circuit	Circuit Breaker/ Fuse Value	Quantity Allowed Per Breaker
Motor Controller	Up to 40A	1
CUSTOM CIRCUIT	Up to 40A	No limit
Automation Direct Relay 40A (*6M40*)	Up to 40A	1
Fans permitted per R501 and not already part of COTS computing devices.	Up to 20A	No limit
Spike Relay Module	Up to 20A	1
Automation Direct Relay 25A (*6M25*)	Up to 20A	1
PCM/PH – with compressor	Up to 20A	1
Servo Power Module/Servo Hub	Up to 20A	1
Additional VRM (non-radio)/Additional PCM/PH (non-compressor)	Up to 20A	3 total

Automation Direct Relay 12A (*6M12*)	Up to 10A	1
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This rule does not prohibit the use of smaller value breakers in the PD or any fuses or breakers within CUSTOM CIRCUITS for additional protection.

Fans permitted per [R501](#) may also be included within CUSTOM CIRCUITS.

- R622** ***Use appropriately sized wire.** All circuits shall be wired with appropriately sized insulated copper wire (SIGNAL LEVEL cables don't have to be copper):

Table 8-4 Breaker and wire sizing

Application	Minimum Wire Size
31 – 40A breaker protected circuit	12 AWG (13 SWG or 4 mm ²)
21 – 30A breaker protected circuit	14 AWG (16 SWG or 2.5 mm ²)
6 – 20A breaker protected circuit	18 AWG
11-20A fuse protected circuit	(19 SWG or 1 mm ²)
Between the PDP dedicated terminals and the VRM/RPM or PCM/PH	
Compressor outputs from the PCM/PH	
Motor power adapter board protected circuit	22 AWG
≤5A breaker protected circuit	(22 SWG or 0.5 mm ²)
≤10A fuse protected circuit	
VRM 2A circuits	24 AWG
≤2A fuse protected circuit	(24 SWG or .25 mm ²)
VH-109 Passthrough per R626	Cat5e/6/7/8 cable, 2 pairs total (1 pair V+, 1 pair ground)
roboRIO PWM port outputs	26 AWG
≤1A fuse protected circuit	(27 SWG or 0.14 mm ²) Cat5e/6/7/8 cable, single pair total
SIGNAL LEVEL circuits (i.e. circuits which draw ≤1A continuous and have a source incapable of delivering >1A, including but not limited to roboRIO non-PWM outputs, CAN	28 AWG (29 SWG or .08 mm ²)

signals, PCM/PH Solenoid outputs, VRM 500mA outputs, RPM outputs, and Arduino outputs)

Wires that are recommended by the device manufacturer or originally attached to legal devices are considered part of the device and by default legal. Such wires are exempt from this rule, provided they are powered by the smallest value fuse or breaker which permits proper device operation.

In order to show compliance with these rules, teams should use wire with clearly labeled sizes if possible. If unlabeled wiring is used, teams should be prepared to demonstrate that the wire used meets the requirements of this rule (e.g. wire samples and evidence that they are the required size).

While pure copper wire is recommended, copper-clad aluminum wire is considered copper wire.

R623 *Use only appropriate connectors. Branch circuits may include intermediate elements such as COTS connectors, splices, COTS flexible/rolling/sliding contacts, and COTS slip rings, as long as the entire electrical pathway is via appropriately gauged/rated elements.

Slip rings containing mercury are prohibited per [R203](#).

R624 *Use specified wire colors (mostly). All non-SIGNAL LEVEL wiring with a constant polarity (i.e., except for outputs of relay modules, motor controllers, or sensors) shall be color-coded along their entire length from the manufacturer as follows:

- red, yellow, white, brown, or black-with-stripe on the positive (e.g. +24VDC, +12VDC, +5VDC, etc.) connections,
- black or blue for the common or negative side (-) of the connections

Exceptions to this rule include:

- wires that are originally attached to legal devices and any extensions to these wires using the same color as the manufacturer,
- Ethernet cable used in PoE cables.

R625 *Don't modify critical power paths. CUSTOM CIRCUITS shall not directly alter the power pathways between the ROBOT battery, PD, motor controllers, relays (per [R504-B](#)), motors and actuators (per [R501](#)), pneumatic solenoid valves, or other elements of the ROBOT control system (items explicitly mentioned in [R710](#)). Custom high impedance voltage monitoring or low impedance current monitoring circuitry connected to the ROBOT'S electrical system is acceptable, if the effect on the ROBOT outputs is inconsequential.

A noise filter may be wired across motor leads or PWM leads. Such filters will not be considered CUSTOM CIRCUITS and violate neither this rule nor [R712](#).

Acceptable signal filters must be fully insulated and must be 1 of the following:

- 1 microfarad (1 μ F) or less, non-polarized, capacitor may be applied across the power leads of any motor on your ROBOT (as close to the actual motor leads as reasonably possible) or

- a resistor may be used as a shunt load for the PWM control signal feeding a servo.

R626 *VH-109 PoE passthrough. The VH-109 PoE output may be used only under the following conditions:

- A. The device being powered is a COTS device or COTS adapter connected to a single COTS device with current draw $\leq 2A$ at 12V.
- B. The connection is made using standard Cat5e/6/7/8 cable.
- C. The VH-109 is powered using the 12V input terminals with 18AWG wire or larger (it may additionally be powered using the PoE input if desired).

8.7 Control, Command & Signals System

R701 *Control the ROBOT with a roboRIO. ROBOTS must be controlled via 1 programmable NI roboRIO or roboRIO 2.0 (P/N am3000 or am3000a, both versions referred to throughout this manual as “roboRIO”), with image version 2026_v1.2 or later.

There are no rules that prohibit co-processors, provided commands originate from the roboRIO to enable and disable all power regulating devices. This includes motor controllers legally wired to the CAN bus.

R702 *Communicate with the ROBOT with the specified radio. 1 Vivid Hosting wireless bridge (P/N: VH-109, WCP-1538), that has been configured with the appropriate encryption key for your team number at each event, is the only permitted device for communicating to and from the ROBOT during the MATCH. Events held in China are the exceptions to this rule and must use an OpenMesh (P/N: OM5P-AN or OM5P-AC) radio.

R703 *Use specific Ethernet port for roboRIO. The roboRIO Ethernet port must be connected as specified:

- A. For VH-109 v1.5 radios: to the port labeled “RIO” either directly, via a Cat5 Ethernet pigtail, or via a passive PoE injector cable or adapter.
- B. For VH-109 v1.0 radios (either directly or via Cat5 Ethernet pigtail):
 - a. to the radio port labeled “RIO” via a passive PoE injector cable or adapter (whether or not it is used to power the radio), or an Ethernet cable with the appropriate wires removed on the roboRIO end. All wires or adapters used must be fully insulated, or
 - b. to the radio port labeled “AUX 1” or “AUX 2” with the corresponding DIP switch in the off (default) position.
- C. For OM5P radios (China events only): to the wireless bridge port labeled “18-24v PoE” (either directly, via a network switch, via an RPM, or via a Cat5 Ethernet pigtail).

Note: Placing a switch between the roboRIO and radio may impede the ability for FIELD STAFF to troubleshoot roboRIO connection issues on the FIELD. Teams may be asked to connect directly between the radio and the roboRIO as part of troubleshooting efforts.

If not using the “RIO” port of the VH-109 1.0, it is strongly recommended to cover the port to prevent accidental damage to devices such as laptops which may occur if attached to this port.

- R704 *Only use allowed ports and bandwidth to communicate with the ROBOT.** Communication between the ROBOT and the OPERATOR CONSOLE may not exceed the following and is restricted to network ports listed in [Table 8-5](#):

- A. 7.0Mbits/second for Vivid Hosting wireless bridge radios
- B. 4.0Mbits/second for OpenMesh radios

Table 8-5 Open FMS ports

Port	Designation	Bi-directional?
UDP/TCP 1180-1190	Camera data from the roboRIO to dashboard software when the camera is connected the roboRIO via USB	Yes
TCP 1735	SmartDashboard	Yes
UDP 1130	Dashboard-to-ROBOT control data	Yes
UDP 1140	ROBOT-to-Dashboard status data	Yes
HTTP 80	Camera connected via switch on the ROBOT	Yes
HTTP 443	Camera connected via switch on the ROBOT	Yes
UDP/TCP 554	Real-Time Streaming Protocol for h.264 camera streaming	Yes
UDP/TCP 1250	CTRE Diagnostics Server	Yes
UDP/TCP 5800-5810	Team use	Yes

Teams may use these ports as they wish if they do not employ them as outlined above (i.e. TCP 1180 can be used to pass data back and forth between the ROBOT and the Driver Station Software if the team chooses not to use the camera on USB).

Note that the 4.0Mbit limit will be strictly enforced by the wireless bridge.

The [FMS Whitepaper](#) has more details on how to check and optimize bandwidth usage.

While FIRST makes every effort to provide a wireless environment that allows teams access to a full 4.0Mbits/second data rate (with about 100.0Kbit used for ROBOT control and status), at some events wireless conditions may not accommodate this.

- R705 *Configure devices for your team number.** The roboRIO, Driver Station Software, and wireless bridge must be configured to correspond to the correct team number, per the procedures defined in the [FIRST Robotics Competition Control System documentation](#).

- R706 *Don't bypass the ARENA network.** All signals must originate from the OPERATOR CONSOLE and be transmitted to the ROBOT via the ARENA Ethernet network.

R707 *Limited wireless allowed. The only forms of wireless communication that may be used to communicate to, from, or within the ROBOT, include:

- those required per [R702](#) and [R706](#),
- tags used for location detection systems if provided by the event, and
- RFID or NFC systems used exclusively within the ROBOT.

Devices that employ signals in the visual spectrum (e.g. cameras) and non-RF sensors that don't receive human-originated commands (e.g. "beam break" sensors or IR sensors on the ROBOT used to detect FIELD elements) are not wireless communication devices and thus this rule doesn't apply.

R708 *Wireless bridge must be visible. The wireless bridge must be mounted on the ROBOT such that the diagnostic lights are visible to FIELD STAFF.

Teams are encouraged to mount the wireless bridge away from noise generating devices such as motors, PCM(s)/PH(s), and VRM(s)/RPM(s).

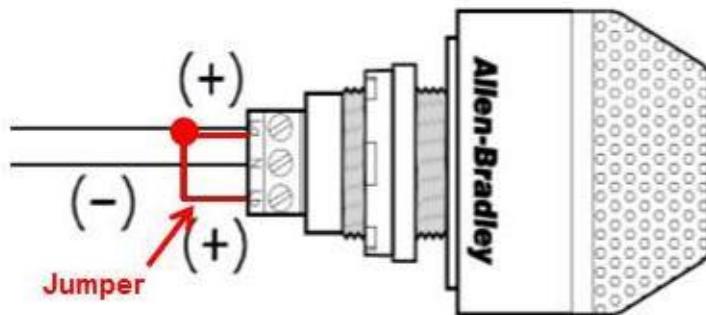
R709 *ROBOTS must have a signal light. ROBOTS must use at least 1, but no more than 2, diagnostic ROBOT Signal Light (RSL) (P/N 855PB-B12ME522 and/or am-3583).

Any RSL must be:

- mounted on the ROBOT such that it is easily visible while standing 36.0in (91.44cm) away from at least one side of the ROBOT,
- connected to the "RSL" supply terminals on the roboRIO, and
- if using the 855PB-B12ME522, wired for solid light operation, by placing a jumper between the "La" and "Lb" terminals on the light per [Figure 8-13](#).

Please see [How to Wire an FRC ROBOT](#) for connection details.

Figure 8-13 855PB-B12ME522 jumper wiring



R710 *Only specified modifications to control system devices permitted. The Driver Station Software, roboRIO, PD, PCM(s)/PH(s), VRM(s)/RPM(s), RSL, 120A breaker, motor controllers, MXP devices used to control actuators per [R713-C](#), relay modules (per [R504-B](#)), wireless bridge, PD breakers and fuses, Servo Power Module, Servo Hub, motor power adapter boards, and batteries shall not be tampered with, modified, or adjusted in any way (tampering includes drilling, cutting, machining, rewiring, disassembling, painting, etc.), with the following exceptions:

Please note that the Driver Station Software is a separate application from the Dashboard. The Driver Station Software may not be modified, while teams are expected to customize their Dashboard code.

- A. User programmable code in the roboRIO may be customized.
- B. Motor controllers may be calibrated as described in owner's manuals.
- C. Fans may be attached to motor controllers and may be powered from the power input terminals.
- D. If powering the compressor, the fuse on a Spike H-Bridge Relay may be replaced with a VB3A-20A Snap-Action circuit breaker.
- E. Wires, cables, and signal lines may be connected via the standard connection points provided on the devices.
- F. Fasteners (including adhesives) may be used to attach the device to the OPERATOR CONSOLE or ROBOT or to secure cables to the device.
- G. Thermal interface material may be used to improve heat conduction.
- H. Labeling may be applied to indicate device purpose, connectivity, functional performance, etc.
- I. Jumpers may be changed from their default location.
- J. Limit switch jumpers may be removed from a Jaguar motor controller and a custom limit switch circuit may be substituted.
- K. Device firmware may be updated with manufacturer supplied firmware.
- L. Integral wires on motor controllers may be cut, stripped, and/or connectorized.
- M. Devices may be repaired, provided the performance and specifications of the device after the repair are identical to those before the repair.
- N. The cover may be removed from the Talon SRX or Talon FX data port.
- O. Electrical tape may be applied to the aluminum plate inside the wireless bridge.
- P. The input terminal cover from the PDP may be omitted (no other element may be installed using the threaded holes to install something in place of the PDP terminal cover).
- Q. The roboRIO 2.0 SD card may be replaced with an SD card of any capacity.
- R. adding insulating material to exposed conductors.
- S. replacing control system power terminal blocks (e.g. RSL power connector) with functional equivalents.
- T. tape may be applied for debris protection.
- U. VH-109 v1.0 may be upgraded to VH-109 v1.5 using manufacturer materials and instructions.

Please note that while repairs are permitted, the allowance is independent of any manufacturer's warranty. Teams make repairs at their own risk and should assume that any warranty or return options are forfeited. Be aware that diagnosing and repairing COMPONENTS such as these can be difficult.

For more information about modification O, please see [this OM5P-AC Radio Modification article](#).

- R711 *Don't connect motor outputs to roboRIO.** Neither 12VDC power nor relay module or motor controller outputs shall be directly connected to the roboRIO, with the exception of the designated 12VDC input.
- R712 *Control PWM controllers from the roboRIO.** Every relay module (per [R504-B](#)), servo, Servo Power Module, and PWM motor controller shall be connected to a corresponding port (relays to Relay ports, servos, and PWM controllers to PWM ports) on the roboRIO (either directly or through a WCP Spartan

Sensor Board) or via a legal MXP connection (per [R713](#)). They shall not be controlled by signals from any other source.

R713 *Only approved MXP devices can control actuators. If a motor is controlled via the MXP, its power regulating device must be connected by 1 of the following methods:

- A. directly to any PWM pins,
- B. via a network of PASSIVE CONDUCTORS used to extend the PWM pins, or
- C. via 1 approved ACTIVE DEVICE:
 - a. Kauai Labs navX MXP
 - b. Kauai Labs navX2 MXP
 - c. RCAL MXP Daughterboard
 - d. REV Robotics RIOduino
 - e. REV Robotics Digit Board
 - f. West Coast Products Spartan Sensor Board
 - g. Huskie Robotics HUSKIE 2.0 Board

A PASSIVE CONDUCTOR is any device or circuit whose capability is limited to the conduction and/or static regulation of the electrical energy applied to it (e.g. wire, splices, connectors, printed wiring board, etc.).

An ACTIVE DEVICE is any device capable of dynamically controlling and/or converting a source of electrical energy by the application of external electrical stimulus.

The “network of PASSIVE CONDUCTORS” only applies to the pins being used for PWM output to motors or servos. This means that connecting an ACTIVE DEVICE, such as a sensor to 1 MXP pin does not prevent other MXP pins from being used in accordance with B.

R714 *Control CAN motor controllers from the roboRIO. Each CAN motor controller must be controlled with enable/disable inputs sourced from the roboRIO and passed via either a PWM (wired per [R713](#)) or CAN bus (either directly or daisy-chained via another CAN bus device) signal, but both shall not be wired simultaneously on the same device.

As long as the CAN bus is wired legally so that the heartbeat from the roboRIO is maintained, all closed loop control features of the CAN motor controller may be used. (That is, commands originating from the roboRIO to configure, enable, and specify an operating point for all CAN motor controller closed loop modes fit the intent of [R701](#)).

“Wired directly” includes via any series of PASSIVE CONDUCTORS (i.e. star or hub configurations using only PASSIVE CONDUCTORS are permitted.)

R715 *Control PCM, PH, and Servo Hub from roboRIO. Each Pneumatic Control Module (PCM), Pneumatic Hub (PH), and Servo Hub must be controlled with signal inputs sourced from the roboRIO and passed via a CAN bus connection from the built-in CAN on the roboRIO (either directly or daisy-chained via another CAN bus device).

- R716 *Don't alter the CAN bus.** No device that interferes with, alters, or blocks communications among the roboRIO and the PCMs/PHs, and/or CAN motor controllers on the bus will be permitted.

Only 1 wire should be inserted into each Weidmuller CAN connector terminal. For documentation on how to wire the CAN bus connections see [How to Wire an FRC ROBOT](#).

- R717 *USB to CAN adapter permitted.** Additional CAN bus connections may be added to the roboRIO using the CTR Electronics CANivore™ (P/N 21-678682, WCP-1522) USB-to-CAN adapter.

Any additional CAN bus added in this manner satisfies the requirements of [R714](#) (i.e. you may connect motor controllers to this additional bus).

8.8 Pneumatic System

In order to maintain safety, the rules in this section apply at all times while at the event, not just while the ROBOT is on the FIELD for MATCHES.

- R801 *Only use explicitly permitted pneumatic parts.** To satisfy multiple constraints associated with safety, consistency, inspection, and constructive innovation, no pneumatic parts other than those explicitly permitted in this section shall be used on the ROBOT.

- R802 *No custom pneumatics and meet minimum pressure ratings.** All pneumatic items must be COTS pneumatic devices and either:

- rated by their manufacturers for pressure of at least 125.0psi (861.8kPa, 8.618Bar), or
- installed downstream of the primary relieving regulator (see [R809](#)), and rated for pressure of at least 70.0psi (482.6kPa, 4.826Bar).

Any pressure specification such as "working," "operating," "maximum," etc. may be used to satisfy the requirements of this rule.

It is recommended that all pneumatic items be rated by their manufacturers for a working pressure of at least 60.0psi (413.7kPa, 4.137Bar).

- R803 *Don't modify pneumatics.** All pneumatic COMPONENTS must be used in their original, unaltered condition. Exceptions are as follows:

- tubing may be cut,
- wiring for pneumatic devices may be modified to interface with the control system,
- assembling and connecting pneumatic COMPONENTS using the pre-existing threads, mounting brackets, quick-connect fittings, etc.,
- removing the mounting pin from a pneumatic cylinder, provided the cylinder itself is not modified, and
- labeling applied to indicate device purpose, connectivity, functional performance, etc.

Do not, for example, paint, file, machine, or abrasively remove any part of a pneumatic COMPONENT – this would cause the part to become a prohibited item.

R804 *Only use specific pneumatic devices. The only pneumatic system items permitted on ROBOTS include the following items:

- A. pneumatic pressure vent plug valves functionally equivalent to those provided in the KOP,

Examples of acceptable valves include Parker PV609-2 or MV709-2.

- B. pressure relief valves functionally equivalent to those provided in the KOP,

Examples of acceptable valves include Norgren 16-004-011, 16-004-003 or McMaster-Carr 48435K714.

To be considered functionally equivalent the valve must be preset or adjustable to 125.0psi (861.8kPa, 8.618Bar) and capable of relieving at least 1.0scfm (471.9cm³/s).

- C. solenoid valves with a maximum 1/8in (nominal, 0.31cm) NPT, BSPP, or BSPT port diameter or integrated quick connect 1/4in (nominal, 0.64cm) outside diameter tubing connection,
- D. additional pneumatic tubing, with a maximum 1/4in (nominal, 0.64cm) outside diameter,
- E. pressure transducers, pressure gauges, passive flow control valves (specifically “needle valve”), manifolds, and connecting fittings (including COTS pneumatic U-tubes),
- F. check and quick exhaust valves, provided that the requirements of [R813](#) are still met,
- G. shutoff valves which relieve downstream pressure to atmosphere when closed (may also be known as 3-way or 3-way exhausting valves),
- H. pressure regulators with the maximum outlet pressure adjusted to no more than 60.0psi (413.7kPa, 4.137Bar),
- I. pneumatic cylinders, pneumatic linear actuators, and rotary actuators,
- J. pneumatic storage tanks (with the exception of white Clippard tanks P/N AVT-PP-41),
- K. 1 compressor that is compliant with [R806](#),
- L. debris or coalescing (water) filters, and
- M. Venturi valves (note: the high-pressure side of a Venturi valve is considered a pneumatic device and must follow all pneumatic rules. The vacuum side of a Venturi valve is exempt from the pneumatic rules per “a” in the blue box below).

The following devices are not considered pneumatic devices and are not subject to pneumatic rules (though they must satisfy all other rules):

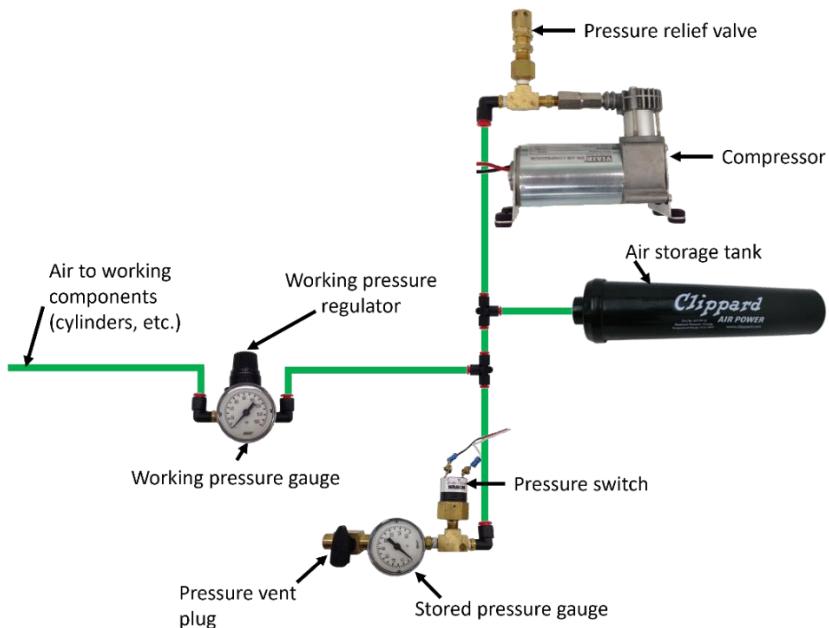
- A. a device that creates a vacuum,
- B. closed-loop COTS pneumatic (gas) shocks,
- C. air-filled (pneumatic) wheels, and
- D. pneumatic devices not used as part of a pneumatic system (i.e. used in a way that does not allow them to contain pressurized air)

R805 *If using pneumatics, these parts are required. If pneumatic COMPONENTS are used, the following items are required as part of the pneumatic circuit and must be used in accordance with this section, as illustrated in [Figure 8-14](#).

- A. 1 FIRST Robotics Competition legal compressor (per [R806](#)),
- B. a pressure relief valve (per [R804-B](#)) connected and calibrated (per [R811](#)),

- C. a Nason pressure switch (P/N SM-2B-115R/443) and/or REV Robotics Analog Pressure Sensor (P/N REV-11-1107) connected and wired per [R812](#),
- D. at least 1 pressure vent plug plumbed (per [R813](#)),
- E. stored pressure gauge and working pressure gauge (per [R810](#)), and
- F. 1 primary working pressure regulator (per [R808](#)).

Figure 8-14 Pneumatic circuitry



R806 *Compressed air from ROBOT compressor only. Throughout an event, compressed air on the ROBOT must be provided by its 1 onboard compressor only. Compressor specifications must not exceed nominal 1.1cfm (519.1cm³/s) flow rate @ 12VDC at any pressure.

A ROBOT'S compressor may be substituted by another compressor, but a ROBOT may only have 1 designated compressor at a time, and all compressed air on the ROBOT must be sourced from a single compressor.

Note: Viair C-series compressors, which have a max working pressure of 120.0psi, are rated for intermittent pressures greater than 125.0psi and therefore meet the requirements of this rule.

R807 *Air storage pressure limit. Stored air pressure on the ROBOT must be no greater than 120.0psi (~827 kPa, 8.2 Bar). No stored air pressure intended for the ROBOT may be located off-board the ROBOT.

R808 *Working air pressure limit. Working air pressure (air pressure used to actuate devices) on the ROBOT must be no greater than 60.0psi (413.7kPa, 4.137Bar) and must be provided through a single primary adjustable, relieving, pressure regulator. Additional regulators may be located downstream of the single primary regulator.

Examples of acceptable valves include Norgren regulator P/N R07-100-RNEA and Monnier P/N 101-3002-1.

- R809 *Limited devices at high pressure.** Only the compressor, relief valve, pressure switch, pressure vent plug, pressure gauge, storage tanks, tubing, pressure transducers, filters, and connecting fittings may be in the high-pressure pneumatic circuit upstream from the regulator.

It is recommended that all COMPONENTS in the high-pressure pneumatic circuit upstream from the regulator be rated for at least 115.0psi (792.9kPa, 7.929Bar) working pressure.

- R810 *Pressure gauges must be visible.** Pressure gauges must be placed in easily visible locations upstream and downstream of the regulator to display the stored and working pressures, respectively. Pressure gauges must show pressure in psi, kPa, or Bar.

- R811 *Relief valve requirements.** The relief valve must be attached directly to the compressor or attached by legal hard fittings (e.g. brass, nylon, etc.) connected to the compressor output port.

Teams are required to check and/or adjust the relief valve to release air at 125.0psi (861.8kPa, 8.618Bar). The valve may or may not have been calibrated prior to being supplied to teams.

Instructions for adjusting the pressure relief valve can be found in the [Pneumatic Manual](#).

- R812 *Pressure switch requirements.** The pressure switch must be connected to the high-pressure side of the pneumatic circuit (i.e. prior to the pressure regulator) to sense the stored pressure of the circuit. It must be either:

- A. Nason P/N SM-2B-115R/443 (wired as described) and/or

The 2 wires from the pressure switch must be connected directly to the pressure switch input of the PCM/PH controlling the compressor or, if controlled using the roboRIO and a relay, to the roboRIO. If connected to the roboRIO, the roboRIO must be programmed to sense the state of the switch and operate the relay module that powers the compressor to prevent over-pressuring the system.

- B. REV Robotics P/N REV-11-1107 (wired as described)

The analog output of the sensor must be connected directly to analog input 0 of the PH (with firmware version 22.0.2 or newer) controlling the compressor.

The REV Robotics Analog Pressure Sensor may only be used with PH compressor control and may not be used with PCM compressor control.

- R813 *Vent plug requirements.** Any pressure vent plug must be:

- A. connected to the pneumatic circuit such that, when manually operated, it will vent to the atmosphere to relieve all stored pressure in a reasonable amount of time and
- B. placed on the ROBOT so that it is visible and easily accessible.

- R814 *Don't connect solenoid outputs together.** The output air from multiple solenoid valves must not be combined.

Manifolds, shuttle valves, and other devices which do not combine output airflow, even though it may be plumbed into the same device, are not violations of this rule.

8.9 OPERATOR CONSOLE

- R901 *Use the specified Driver Station Software.** The Driver Station Software provided by National Instruments ([install instructions found here](#)) is the only application permitted to specify and communicate the operating mode (i.e. AUTO/TELEOP) and operating state (Enable/Disable) to the ROBOT. The Driver Station Software must be version 26.0 or newer.

Teams are permitted to use a portable computing device of their choice (laptop computer, tablet, etc.) to host the Driver Station Software while participating in MATCHES.

- R902 *The OPERATOR CONSOLE must have a visible display.** The OPERATOR CONSOLE, the set of COMPONENTS and MECHANISMS used by the DRIVERS and/or HUMAN PLAYERS to relay commands to the ROBOT, must include a graphic display to present the Driver Station Software diagnostic information. It must be positioned within the OPERATOR CONSOLE so that the screen display can be clearly seen during inspection and in a MATCH.

- R903 *Connect FMS Ethernet directly to the OPERATOR CONSOLE.** Devices hosting the Driver Station Software must only interface with the FMS via the Ethernet cable provided at the DRIVER STATION (e.g. not through a switch). Teams may connect the FMS Ethernet cable to the device running the Driver Station Software directly via an Ethernet pigtail, or with a single-port Ethernet converter (e.g. docking station, USB-Ethernet converter, Thunderbolt-Ethernet converter, etc.). The Ethernet port on the OPERATOR CONSOLE must be easily and quickly accessible.

Teams are strongly encouraged to use pigtailed on the Ethernet port used to connect to the FMS. Such pigtailed will reduce wear and tear on the device's port and, with proper strain relief employed, will protect the port from accidental damage.

- R904 *OPERATOR CONSOLE physical requirements.** The OPERATOR CONSOLE must not

- be longer than 60.0in (1.524m),
- be deeper than 16.0in (40.64cm) (excluding any items that are held or worn by the DRIVERS during the MATCH),
- extend more than 78.0in (1.981m) above the floor, or
- attach to the FIELD, except via the loop tape as described in section [5.9.1 DRIVER STATIONS](#) or clamping to the DRIVER STATION support shelf (as long as the shelf is not damaged).

There is a 54.0in (1.372m) long by 2.0in (nominal, 5.08cm) wide strip of hook-and-loop tape ("loop" side) along the center of the DRIVER STATION support shelf that should be used to secure the OPERATOR CONSOLE to the shelf. See section [5.9.1 DRIVER STATIONS](#) for details.

Please note that while there is no hard weight limit, OPERATOR CONSOLES that weigh more than 30lb (13.61kg) will invite extra scrutiny as they are likely to present unsafe circumstances.

- R905 *FIELD wireless only.** Other than the system provided by the FIELD, no other form of wireless communications shall be used to communicate to, from, or within the OPERATOR CONSOLE.

Examples of prohibited wireless systems include, but are not limited to, active wireless network cards and Bluetooth devices. For the case of the *FIRST* Robotics Competition, a motion sensing input device (e.g. Microsoft Kinect) is not considered wireless communication and is allowed.

R906 *No unsafe OPERATOR CONSOLES. OPERATOR CONSOLES shall not be made using hazardous materials, be unsafe, cause an unsafe condition, or interfere with other DRIVE TEAMS or the operation of other ROBOTS.

R907 *No AC inverters. OPERATOR CONSOLES must not contain AC inverters.

