9 ROBOT CONSTRUCTION RULES

This section of the 2021 *FIRST*® Robotics Competition Game Manual presents rules relevant to the construction of a 2021 *FIRST* Robotics Competition ROBOT. ROBOTS must pass Inspection at each *FIRST* Robotics Competition event to confirm compliance before being allowed to compete in a Qualification or Playoff MATCH, per Inspection & Eligibility Rules.

9.1 Overview

The rules listed below explicitly address legal parts and materials and how those parts and materials may be used on a 2021 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.

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 2020 and 2021 Kickoff Kit checklists, distributed to the team via *FIRST* Choice in the 2020 and/or 2021 season, or paid for completely (except shipping) with a Product Donation Voucher (PDV) from the 2020 and/or 2021 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 a COTS or custom 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 two (2) ROBOT grippers from RoboHands Corp. and receives both items. They put one 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.** must be able to ship any general (i.e., non-*FIRST* unique) product within five business days of receiving a valid purchase request. It is recognized that certain unusual circumstances (such as 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.
- **D.** should maintain sufficient stock or production capability to fill teams' orders within a reasonable period during the season (less than 1 week). (Note that 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 two weeks. This would be considered a FABRICATED ITEM, and the two-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 five business days and leave the welding of the cuts to the team.
- **E.** 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 it 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 20 ft. (~610 cm) length of aluminum which has been cut into 5 ft. (~152 cm) 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 legality of non-2020 or 2021 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 frcparts@firstinspires.org for an official ruling. To seek approval for alternate devices for inclusion in future *FIRST* Robotics Competition seasons, please contact 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.

9.2 General ROBOT Design

R1. The ROBOT (excluding BUMPERS) must have a FRAME 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 ¼ in. (~6 mm) such as bolt heads, fastener ends, weld beads, and rivets are not considered part of the FRAME PERIMETER.

> To determine the FRAME PERIMETER, wrap a piece of string around the ROBOT (excluding BUMPERS) at the BUMPER ZONE described in R18 and pull it taut. The string outlines the FRAME PERIMETER.
>
> Example: A ROBOT'S chassis is shaped like the letter 'V', 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 FRAME PERIMETER is a triangle with three sides.

R2. 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 FRAME 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 FRAME PERIMETER (or minor protrusions) will be in contact with the wall.

The allowance for minor protrusions in R2 is intended to allow protrusions that are both minor in extension from the FRAME PERIMETER and cross-sectional area.

If a ROBOT uses interchangeable MECHANISMS per I3, Teams should be prepared to show compliance with R2 and R4 in all configurations.

R3. A ROBOT'S STARTING CONFIGURATION may not have a FRAME PERIMETER greater than 120 in. (~304 cm) and may not be more than 45 in. (~114 cm) 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 the BUMPER Rules contained in BUMPER Rules may impose additional restrictions on ROBOT design.

R4. ROBOTS may not extend more than 12 in. (~30 cm) beyond their FRAME PERIMETER (see Figure 9-1)

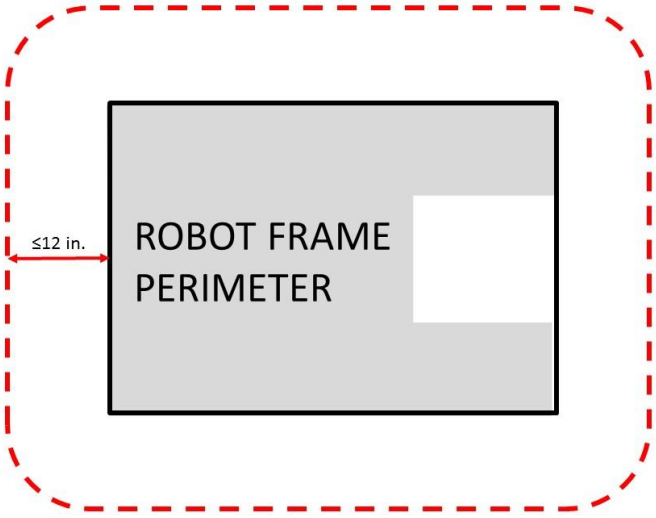

Figure 9-1 FRAME PERIMETER extension

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.

See Game Rules: ROBOTS for height and extension restrictions for various areas of the FIELD.

R5. The ROBOT weight must not exceed 125 lbs. (~56 kg). 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 I3).

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 no more than 12 in. (~30 cm) of cable per leg, the associated cable lugs, connecting bolts, and insulation)
- **C.** tags used for location detection systems if provided by the event

9.3 ROBOT Safety & Damage Prevention

R6. Traction devices must not have surface features that could damage the ARENA (e.g. metal, sandpaper, hard plastic 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.

R7. Protrusions from the ROBOT and exposed surfaces on the ROBOT shall not pose hazards to the ARENA elements (including the POWER CELLS) or people.

R8. 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 R8 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 DRIVERS and/or COACHES 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, to a reasonably astute observer, mimics the retro-reflective features of vision targets described in Vision Targets)
d. Exposed lasers other than Class I.
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. Exposed, untreated hazardous materials (e.g. lead weights) used on the ROBOT. These materials may be permitted if painted, encapsulated or otherwise sealed to prevent contact. These materials may not be machined in any way at an event.
l. Tire sealant

m. 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.

Teams should provide MSD Sheets for any materials they use that might be considered questionable during ROBOT Inspection.

R9. ROBOTS must allow removal of game pieces 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 game pieces and ROBOTS can be quickly, simply, and safely removed.

Teams are encouraged to consider rule C7 when developing their ROBOTS.

R10. Lubricants may be used only to reduce friction within the ROBOT. Lubricants must not contaminate the FIELD or other ROBOTS.

9.4 Budget Constraints & Fabrication Schedule

R11. This rule has been removed for the 2021 season.

R12. No individual, non-KOP item or software used on the ROBOT shall have a Fair Market Value that exceeds $500 USD. The total cost of COMPONENTS purchased in bulk may exceed $500 USD as long as the cost of an individual COMPONENT does not exceed $500 USD.

Teams should be ready to show inspectors documentation of Fair Market Value (FMV) for any COMPONENTS that appear to be in the range of the $500 USD limit.

The Analog Devices ADIS16448 IMU MXP Breakout Board does not have a published FMV. This device is considered to comply with R12 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 component 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 two (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. Teams are encouraged to be expansive in recruiting and including organizations in their team, as that exposes more people and organizations to FIRST. 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 R12.

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 R12.

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

Example 1: VENDOR A sells a gearbox that can be used with a number of different gear sets, and can mate with two 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 2: VENDOR B sells a robotic arm assembly that the team wants to use. However, it costs $700 USD, so they cannot use it. The VENDOR sells the "hand", "wrist", and "arm" as separate assemblies, for $200 USD each. A team wishes to purchase the three items separately, then reassemble them. This would not be legal, as they are really buying and using the entire assembly, which has a FMV of $700 USD.

Example 3: VENDOR C sells a set of wheels or wheel modules that are often used in groups of four. The wheels or modules can be used in other quantities or configurations. A team purchases four 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.

R13. This rule has been removed for the 2021 season.

R14. This rule has been removed for the 2021 season.

R15. This rule has been removed for the 2021 season.

R16. During an event a team is attending (regardless of whether the team is physically at the event location), the team may neither work on nor practice with their ROBOT or ROBOT elements outside of the hours that pits are open, with the following exceptions:

- **A.** OPERATOR CONSOLE,
- **B.** BUMPERS (a protective assembly designed to attach to the exterior of the ROBOT and constructed as specified in BUMPER Rules),
- **C.** battery assemblies as described in R5-B,
- **D.** FABRICATED ITEMS consisting of one COTS electrical device (e.g. a motor or motor controller) and attached COMPONENTS associated with any of the following modifications:
  - i. wires modified to facilitate connection to a ROBOT (including removal of existing connectors)
  - ii. connectors and any materials to secure and insulate those connectors added (Note: passive PCBs such as those used to adapt motor terminals to connectors are considered connectors)
  - iii. motor shafts modified and/or gears, pulleys, or sprockets added
  - iv. motors modified with a filtering capacitor as described in the Blue Box below R56
- **E.** COTS items with any of the following modifications:
  - i. Non-functional decoration or labeling
  - ii. Assembly of COTS items per manufacturer specs, unless the result constitutes a MAJOR MECHANISM as defined in I1
- **F.** Software development
- **G.** Batteries may be charged during the designated Load-in time

For the purposes of this rule, official events begin at the start of the first designated Load-in period, according to the Public Schedule. If the Public Schedule is not available or the Public Schedule does not include a Load-in period, the event begins at 6 AM local time. Examples of activity prohibited by R16 include:

a. Working on the ROBOT at the team's shop after Load-in for the event has begun
b. Working on ROBOT parts at night at the team's hotel.

Note that E8 and E20 impose additional restrictions on work done on the ROBOT or ROBOT materials while attending an event.

One purpose of R16 is to increase equity between teams with significant travel to an event and those nearby (close teams would otherwise have an advantage by being able to work on their ROBOT, in their shop, until it's time to go to the event).

9.5 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. Criteria used in writing these rules includes the following:

- Minimize variety of BUMPERS so teams can expect consistency
- Minimize the amount of design challenge in creating BUMPERS
- Minimize cost of BUMPER materials
- Maximize use of relatively ubiquitous materials

R17. ROBOTS are required to use BUMPERS to protect all outside corners of the FRAME PERIMETER. For adequate protection, at least 6 in. (~16 cm) of BUMPER must be placed on each side of each outside corner (see Figure 9-2 BUMPER corner examples) and must extend to within ¼ in. (~6 mm) of the FRAME PERIMETER corner. If a FRAME PERIMETER side is shorter than 12 in. (~31 cm), that entire side must be protected by BUMPER (see Figure 9-3). A round or circular FRAME PERIMETER, or segment of the FRAME PERIMETER, is considered to have an infinite number of corners, therefore the entire frame or frame segment must be completely protected by BUMPER(S).

The dimension defined in R17 is measured along the FRAME PERIMETER. The portion of the BUMPER that extends beyond the corner of the FRAME PERIMETER is not included in the 6 in. (~16 cm) requirement. See Figure 9-2.

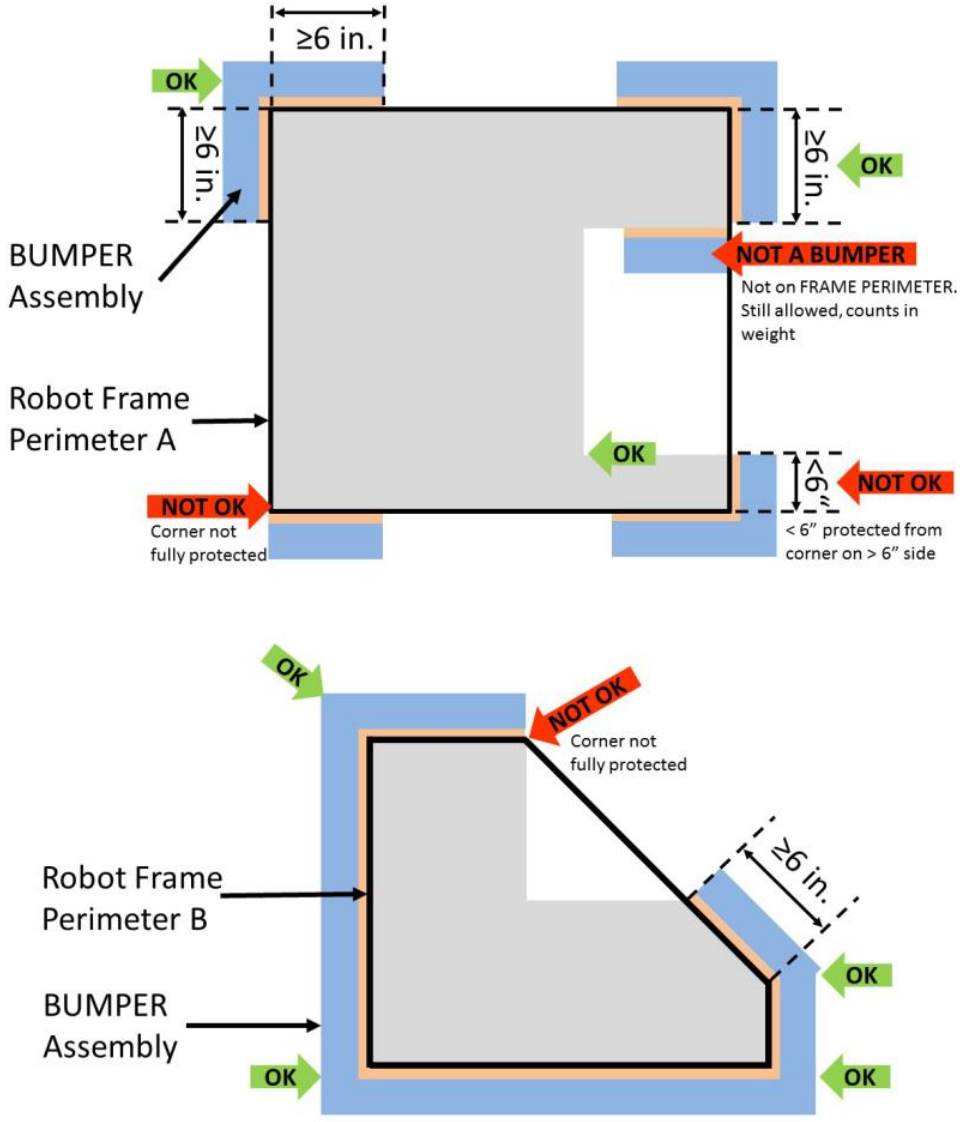

Figure 9-2 BUMPER corner examples

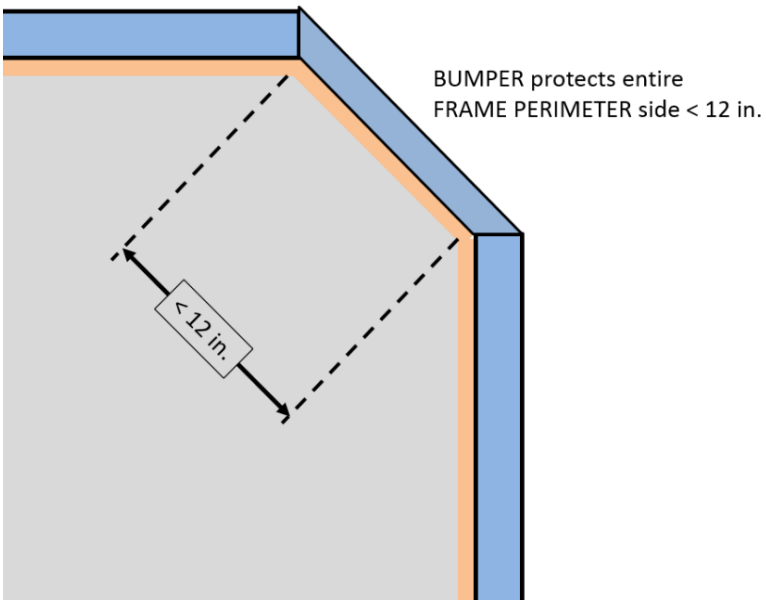

Figure 9-3 BUMPER around full side/corner

R18. Except as allowed per G16, BUMPERS must be located entirely within the BUMPER ZONE, which is the volume contained between the floor and a virtual horizontal plane 7½ in. (~19 cm) above the floor in reference to the ROBOT standing normally on a flat floor. BUMPERS do not have to be parallel to the floor.

> 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 height of the ROBOT from the FIELD carpet. Examples include:
>
> Example 1: A ROBOT that is at an angle while navigating the FIELD has its BUMPERS outside the BUMPER ZONE. If this ROBOT were virtually transposed onto a flat floor, and its BUMPERS are in the BUMPER ZONE, it meets the requirements of R18.
>
> Example 2: A ROBOT deploys a MECHANISM which lifts the BUMPERS outside the BUMPER ZONE (when virtually transposed onto a flat floor). This violates R18.

R19. BUMPERS must not be articulated (relative to the FRAME PERIMETER).

R20. BUMPERS (the entire BUMPER, not just the cover) must be designed for quick and easy installation and removal to facilitate Inspection and weighing.

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

R21. Each ROBOT must be able to display primarily Red or Blue BUMPERS to MATCH their ALLIANCE color, as assigned in the MATCH schedule distributed at the event (as described in MATCH Schedules). A BUMPER is considered primarily Red or Blue if all displayed BUMPER surfaces other than corners (i.e. everywhere the BUMPER is backed by the FRAME PERIMETER) displays the appropriate color. Any visible fabric other than the primary color must be a solid color. See Figure 9-4. BUMPER Markings visible when installed on the ROBOT, other than the following, are prohibited:

A. those required per R22,
B. hook-and-loop fastener or snap fasteners backed by the hard parts of the BUMPER, and
C. solid white *FIRST* logos between 4¾ in. (~12 cm) and 5¼ in. wide (~13 cm) (i.e. comparable to those available in the 2021 Virtual Kit).

The FRAME PERIMETER facing surfaces and short perpendicular "ends" of BUMPERS are not "displayed" and thus R21 does not apply.

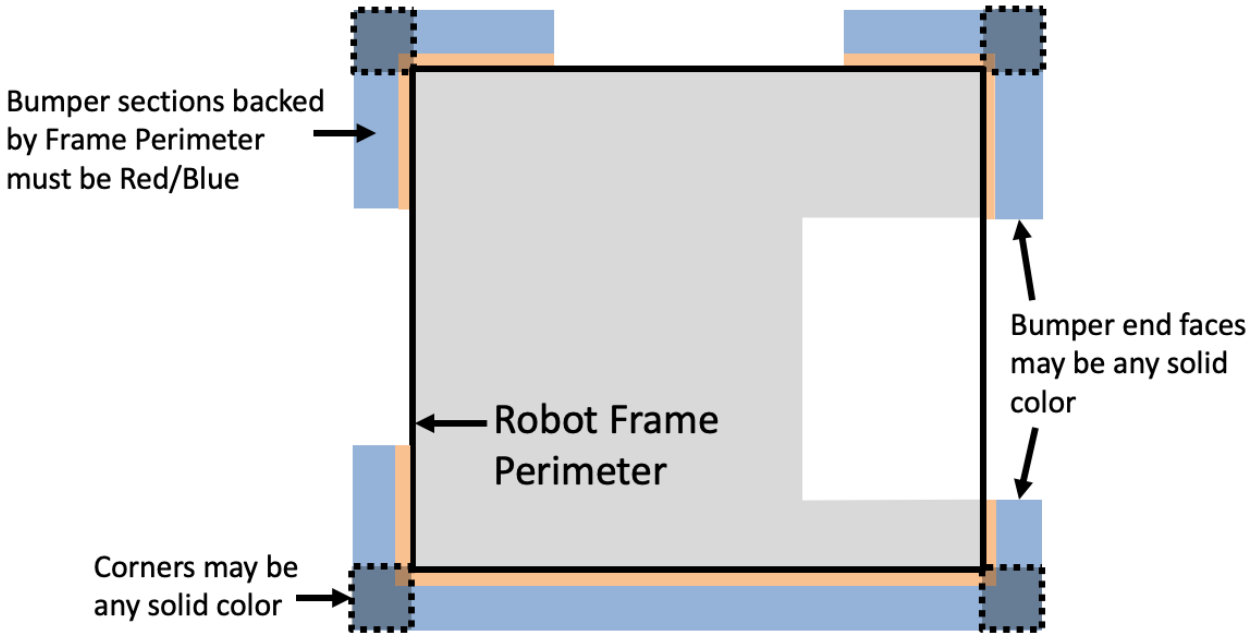

Figure 9-4 BUMPER color example

R22. Team numbers must be displayed and positioned on the BUMPERS such that an observer walking around the perimeter of the ROBOT can unambiguously tell the team's number from any point of view and meet the following additional criteria:

A. consist of only Arabic numerals at least 4 in. (~11 cm) high, at least ½ in. (~13 mm) in stroke width, and be either white in color or outlined in white with a minimum 1/16 in. (~2 mm) outline

The ½ in. (~13 mm) stroke width requirement applies to the majority of the stroke. Font elements less than ½ in. (~13 mm) 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 160 degrees) of the FRAME PERIMETER
C. 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.

R23. Each set of BUMPERS (including any fasteners and/or structures that attach them to the ROBOT) must weigh no more than 15 lbs. (~6 kg).

If a multi-part attachment system is utilized (e.g. interlocking brackets on the ROBOT and the BUMPER), then the elements permanently attached to the ROBOT will be considered part of the ROBOT, and the elements attached to the BUMPERS will be considered part of the BUMPER. Each element must satisfy all applicable rules for the relevant system.

R24. BUMPERS must be constructed as follows (see Figure 9-7):

A. be backed by ¾ in. (nominal) thick (~19mm) by 5 in. ± ½ in. (~127 mm ± 12.7 mm) tall plywood, Oriented Strand Board (OSB) or solid wood (with the exception of balsa). Small clearance pockets and/or access holes in the wood backing are permitted, as long as they do not significantly affect the structural integrity of the BUMPER.

¾ in. Plywood and OSB refer to items sold by VENDORS as that material and thickness, teams may not fabricate their own plywood or OSB. Other engineered woods such as Fiberboard or Particle Board are not likely to survive the rigors of *FIRST* Robotics Competition gameplay and thus not permitted in R24-A.

Note: ¾ in. plywood is now often marked according to the actual dimension ($^{23}/_{32}$ in.) not the nominal size. Plywood sold as $^{23}/_{32}$ in. meets the requirements of R24-A.

B. hard BUMPER parts allowed per R24-A, -E, -F, and -G must not extend more than 1 in. (~25 mm) beyond the FRAME PERIMETER (measured as shown in Figure 9-5).

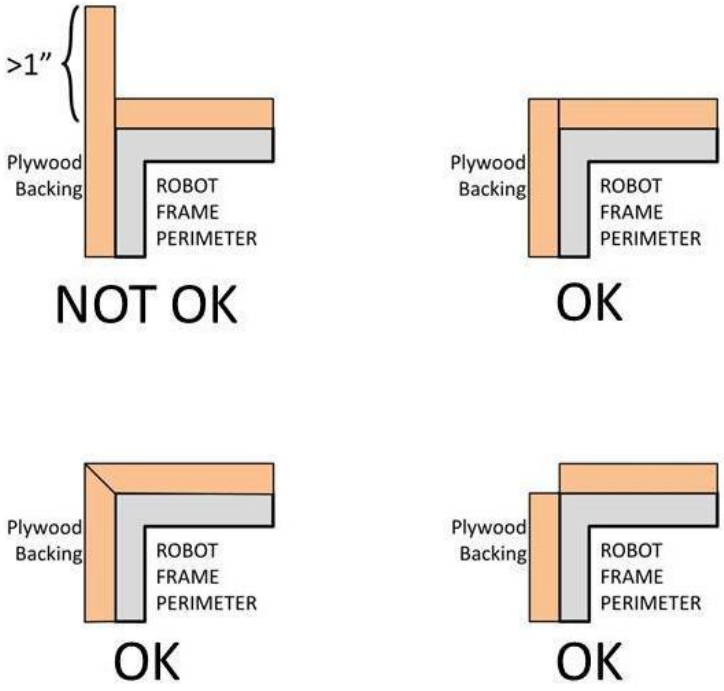

Figure 9-5 Hard parts of BUMPER corners

C. use a stacked pair of approximately 2½ in. (nominal, ~63mm) round, petal, or hex "pool noodles" (solid or hollow) as the BUMPER cushion material (see Figure 9-7). All pool noodles used in a BUMPER set (e.g. Red set of BUMPERS) may not be modified (with the exception of cutting to length or cutting to facilitate mating pool noodles at the corners as required by R25) or deformed and must be the same diameter, cross-section, and density (e.g. all round hollow or all hex solid). Cushion material may extend up to 2½ in. (~63 mm) beyond the end of the plywood (see Figure 9-8). To assist in applying the fabric covering, soft fasteners may be used to attach the pool noodles to the wood backing, so long as the cross section in Figure 9-7 is not significantly altered (e.g. tape compressing the pool noodles).

All pool noodles used on a ROBOT must be the same in order to maintain the desired interaction between ROBOTS in the cases of BUMPER-to-BUMPER contact. BUMPERS containing pool noodles of vastly different construction may cause a "ramp" effect when interacting with other BUMPERS.

Minor noodle compression as a result of smoothing BUMPER fabric or rounding a FRAME PERIMETER corner is not considered deformed. Any compression beyond that, e.g. for the purposes of flattening the noodle, is deformation and a violation of R24-C.

D. be covered with a rugged, smooth cloth. (multiple layers of cloth and seams are permitted if needed to accommodate R21 and/or R22, provided the cross section in Figure 9-7 is not significantly altered).

Silk and bedding are not considered rugged cloths, however 1000D Cordura is. Tape (e.g. gaffer's tape) matching the BUMPER color is allowed to patch small holes on a temporary basis.

It is expected that there may be multiple layers of cloth as fabric is folded to accommodate the corners and seams of BUMPERS.

The cloth must completely enclose all exterior surfaces of the wood and pool noodle material when the BUMPER is installed on the ROBOT. The fabric covering the BUMPERS must be solid in color.

BUMPER corners and "ends", shown in Figure 9-4, must be solid in color, but do not need to be the same color as the rest of the BUMPER, as described in R21.

E. optionally use metal angle, as shown in Figure 9-7 or other fasteners (e.g. staples, screws, adhesives, etc.) to clamp cloth.

F. optionally use metal brackets (i.e. angle or sheet metal) or other fasteners (e.g. staples, screws, adhesives, etc.) to attach BUMPER segments to each other (see Figure 9-6).

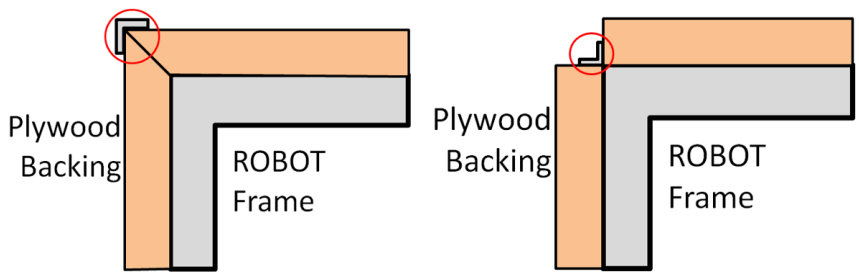

Figure 9-6 Hard parts of BUMPER corners

G. must attach to the FRAME PERIMETER of the ROBOT 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, or tie-wraps). The attachment system must be designed to withstand vigorous game play. All removable fasteners (e.g. bolts, locking pins, pip-pins, etc.) will be considered part of the BUMPERS.

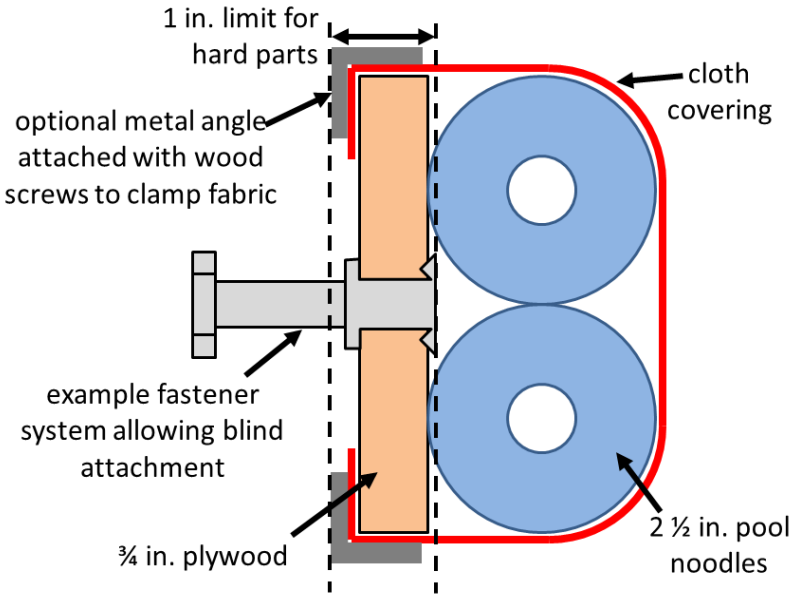

Figure 9-7 BUMPER vertical cross section

R25. Corner joints between BUMPERS must be filled with pool noodle material. Examples of implementation are shown in Figure 9-8.

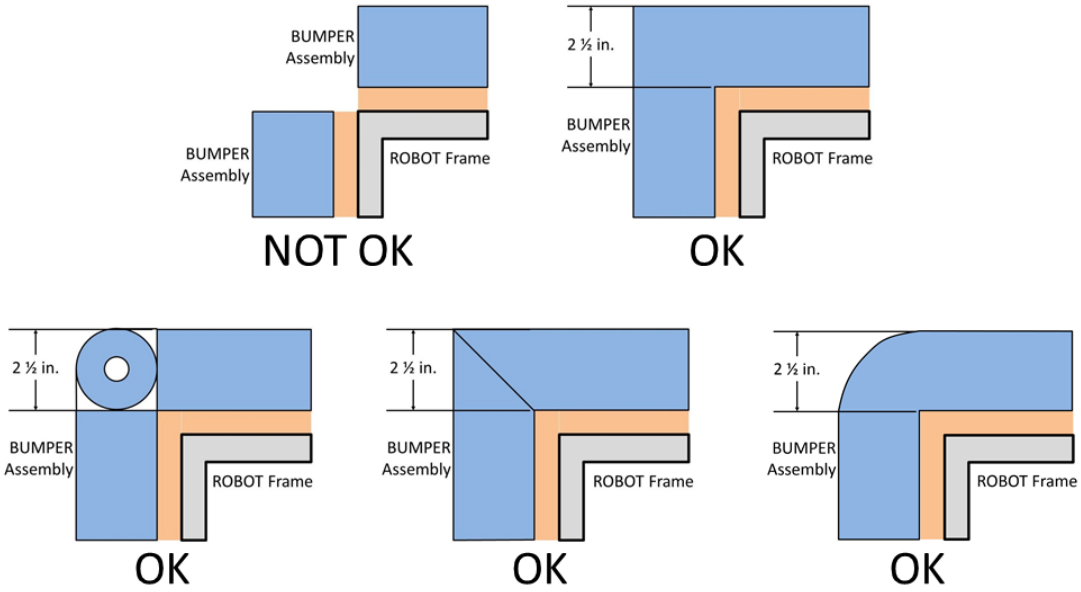

Figure 9-8 Soft parts of BUMPER corners

R26. BUMPERS must be supported by the structure/frame of the ROBOT (see Figure 9-9). To be considered supported, a minimum of ½ in. (~13 mm) at each end of each BUMPER wood segment must be backed by the FRAME PERIMETER (≤¼ in. gap, ~6mm). "Ends" exclude hard BUMPER parts which extend past the FRAME PERIMETER permitted by R24-B. Additionally, any gap between the backing material and the frame:

- **A.** must not be greater than ¼ in. (~6 mm) deep, or
- **B.** not more than 8 in. (~20 cm) wide

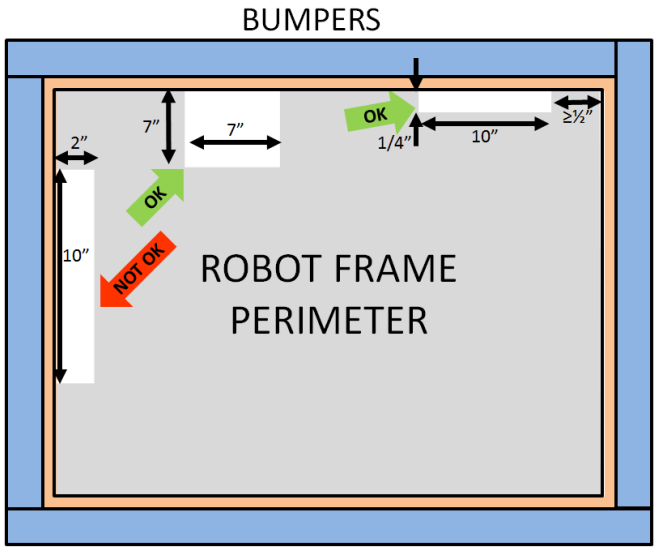

Figure 9-9 BUMPER support examples

The intent of this rule is to make sure the BUMPER wood is properly supported to minimize the likelihood of breakage on impact. Flexible ROBOT elements, such as thin plastic, do not accomplish this intent and are not considered "structure/frame" of the ROBOT.

9.6 Motors & Actuators

R27. The only motors and actuators permitted on 2021 ROBOTS include the following (in any quantity):

Table 9-1 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/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
Nidec Dynamo BLDC Motor	am-3740	DM3012-1063
Playing with Fusion Venom	BDC-10001	
REV Robotics HD Hex Motor	REV-41-1291	
REV Robotics NEO Brushless	REV-21-1650	
REV Robotics NEO 550	REV-21-1651	
VEX BAG	217-3351	
VEX Mini-CIM	217-3371	
West Coast Products RS775 Pro	217-4347	
Electrical solenoid actuators, no greater than 1 in. (nominal) stroke and rated electrical input power no greater than 10 watts (W) continuous duty at 12 volts (VDC)		
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 servos with a retail cost < $75.		
Motors integral to a COTS sensor (e.g. LIDAR, scanning sonar, etc.), provided the device is not modified except to facilitate mounting		
One (1) compressor compliant with R79 and used to compress air for the ROBOT'S pneumatic system		

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.

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, 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 the table above. These motors may be used with or without the provided gearbox.

R28. 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 9-1 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.** The wiring harness of the Nidec Dynamo BLDC Motor may be modified as documented by *FIRST* in the "Nidec Dynamo BLDC Motor with Controller" article.
- **G.** Minimal labeling applied to indicate device purpose, connectivity, functional performance, etc.
- **H.** Any number of #10-32 plug screws may be removed from the Falcon 500.
- **I.** Insulation may be applied to electrical terminals.

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.

R29. With the exception of servos, fans, or motors integral to sensors of COTS computing devices permitted in R27, 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
  - i. DMC 60/DMC 60c Motor Controller (P/N: 410-334-1, 410-334-2)
  - ii. Jaguar Motor Controller (P/N: MDL-BDC, MDL-BDC24, and 217-3367) connected to PWM only
  - iii. Nidec Dynamo BLDC Motor with Controller to control integral actuator only (P/N 840205-000, am-3740)
  - iv. SD540 Motor Controller (P/N: SD540x1, SD540x2, SD540x4, SD540Bx1, SD540Bx2, SD540Bx4, SD540C)
  - v. Spark Motor Controller (P/N: REV-11-1200)
  - vi. Spark MAX Motor Controller (P/N: REV-11-2158)
  - vii. Talon FX Motor Controller (P/N: 217-6515, 19-708850, am-6515, am-6515_Short) for controlling integral Falcon 500 only
  - viii. Talon Motor Controller (P/N: CTRE_Talon, CTRE_Talon_SR, and am-2195)
  - ix. Talon SRX Motor Controller (P/N: 217-8080, am-2854, 14-838288)
  - x. Venom Motor with Controller (P/N: BDC-10001) for controlling integral motor only

xi. Victor 884 Motor Controller (P/N: VICTOR-884-12/12)
xii. Victor 888 Motor Controller (P/N: 217-2769)
xiii. Victor SP Motor Controller (P/N: 217-9090, am-2855, 14-868380)
xiv. Victor SPX Motor Controller (P/N: 217-9191, 17-868388, am-3748)

B. Relay Modules

i. Spike H-Bridge Relay (P/N: 217-0220 and SPIKE-RELAY-H)
ii. Automation Direct Relay (P/N: AD-SSR6M12-DC-200D, AD-SSRM6M25-DC-200D, AD-SSR6M40-DC-200D)

C. Pneumatics controllers

i. Pneumatics Control Module (P/N: am-2858, 217-4243)

Note: The Automation Direct Relays are single directional. Per R30 they may not be wired together in an attempt to provide bi-directional control.

R30. Each power regulating device may control electrical loads per Table 9-2. Unless otherwise noted, each power regulating device shall control one and only one electrical load.

Table 9-2 Power regulating device allotments

Electrical Load	Motor Controller	Relay Module	Pneumatics Controller
AndyMark RedLine Motor Banebots CIM REV Robotics NEO Brushless REV Robotics NEO 550 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 NeverRest Snow Blower Motor	Yes (up to 2 per controller)	Yes	No
CTR Electronics/VEX Falcon 500 Nidec Dynamo BLDC Motor w/ Controller Playing With Fusion Venom	Yes (integrated controller only)	No	No
Compressor	No	Yes	Yes
Pneumatic Solenoid Valves	No	Yes[1]	Yes (1 per channel)
Electric Solenoids	Yes[1]	Yes[1]	Yes (1 per channel)
CUSTOM CIRCUITS[2]	Yes[1]	Yes[1]	Yes (1 per channel)

[1] Multiple low-load, pneumatic solenoid valves (relay only), electric solenoids or CUSTOM CIRCUITS may be connected to a single relay module or motor controller. This would allow one (1) relay module or motor controller to drive multiple pneumatic actions or multiple CUSTOM CIRCUITS. No other electrical load can be connected to a relay module used in this manner.

[2] A CUSTOM CIRCUIT is any electrical COMPONENT of the ROBOT other than motors, pneumatic solenoids, roboRIO, PDP, PCM, VRM, RSL, 120A breaker, motor controllers, relay modules (per R29-B), wireless bridge, electrical solenoid actuators, or batteries.

R31. Servos must be connected to, and only to, one 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)

9.7 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.

R32. The only legal source of electrical energy for the ROBOT during the competition, the ROBOT battery, must be one and only one 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:7.1 in. x 3 in. x 6.6 in., +/- .1 in. for each dimension (~ 180 mm x 76mm x 168 mm, +/- 2.5 mm for each dimension)
- **E.** Nominal weight: 11lbs. to 14.5 lbs. (~5 kg. to 6.5 kg.)
- **F.** Terminals: Nut and bolt style

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)
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.)

R33. COTS USB battery packs with a capacity of 100Wh or less (20000mAh at 5V) and 2.5 Amp max output per port, or batteries integral to and part of a COTS computing device or self-contained

camera (e.g. laptop batteries, GoPro style camera, etc.) 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.

R34. Any battery charger used to charge a ROBOT battery must have the corresponding Anderson SB connector installed.

R35. Any battery charger used to charge a ROBOT battery may not be used such that it exceeds 6-Amp peak charge current.

R36. No batteries other than those allowed per R32 and R33 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.

R37. 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.

R38. 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.

R39. 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:

- **A.** compressed air stored in the pneumatic system that has been charged in compliance with R79 and R80,
- **B.** a change in the altitude of the ROBOT center of gravity,
- **C.** storage achieved by deformation of ROBOT parts,
- **D.** closed-loop COTS pneumatic (gas) shocks, and
- **E.** air-filled (pneumatic) wheels.

R40. The one (1) ROBOT battery, a single pair of Anderson Power Products (or APP) 2-pole SB type connectors, the one (1) main 120-amp (120A) surface mount circuit breaker (Cooper Bussman P/N: CB185-120, CB185F-120, CB285-120), and the one (1) CTR Electronics Power Distribution Panel (PDP, P/N: am-2856, 217-4244, 14-806880) shall be connected with 6 AWG (7 SWG or 16 mm2) copper wire or larger, with no additional devices or modifications, as shown in Figure 9-10.

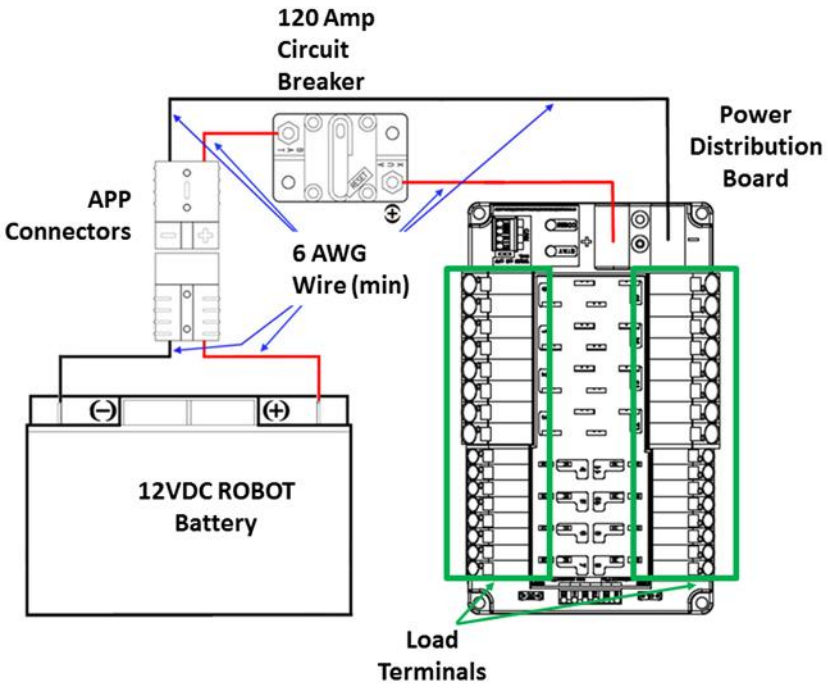

Figure 9-10 Electrical connection diagram

> "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 2020 KOP mate with the Red SB50 connector.

R41. All circuits, with the exceptions of those listed in R46 and R48, must connect to, and have power sourced solely by, a single protected 12VDC WAGO connector pair (i.e. the Load Terminals, as shown in Figure 9-10) of the one (1) CTR Electronics Power Distribution Panel, not the M6 cap screws.

R42. All wiring and electrical devices, including all Control System COMPONENTS, shall be electrically isolated from the ROBOT frame. The ROBOT frame must not be used to carry electrical current.

> R42 is checked by observing a >3kΩ resistance between either the (+) or (-) post within the APP connector that is attached to the PDP 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 R42.

R43. 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 during a MATCH.

R44. The PDP, associated wiring, and all circuit breakers must be visible for Inspection.

R45. Any active electrical item that is not an actuator (specified in R27) or core Control System item (specified in R66) is considered a CUSTOM CIRCUIT. CUSTOM CIRCUITS shall not produce voltages exceeding 24V.

R46. The roboRIO power input must be connected to the dedicated supply terminals on the PDP shown in Figure 9-11. No other electrical load shall be connected to these terminals.

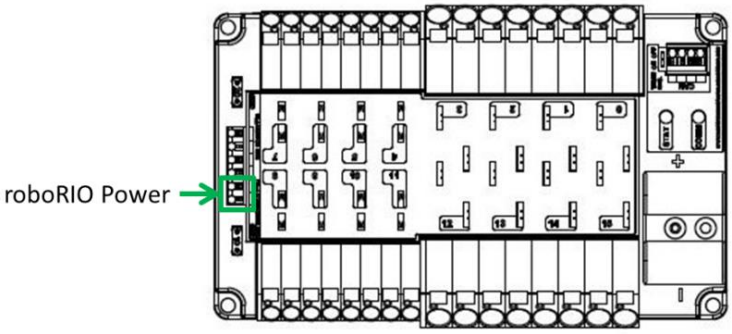

Figure 9-11 roboRIO power source

R47. The Wireless Bridge (Radio) power must be supplied directly by the 12V 2A output of a CTR Electronics Voltage Regulator Module (VRM) (P/N: am-2857, 217-4245) and must be the only load connected to those terminals.

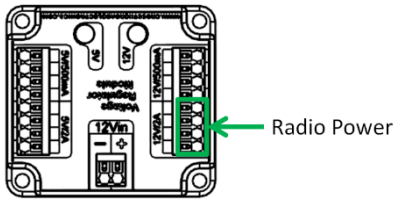

Figure 9-12 Radio power source

Note that this wiring is different from the wiring for the radio used in 2015, but is identical to the wiring from 2016-2020. When using a 2015 VRM with the OM5P-AN or OM5P-AC

radio, the radio should be connected as described above, not to the terminals labeled "Radio".

Note that this prohibits using any 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 radio port labeled "18-24v POE".

R48. The VRM supplying power to the Wireless Bridge per R47 must be connected to the designated supply terminals at the end of the PDP, and not the main WAGO connectors along the sides of the PDP as shown in Figure 9-13. With the exception of a single CTR Electronics Pneumatics Control Module (PCM, P/N: am-2858), no other electrical load shall be connected to these PDP terminals.

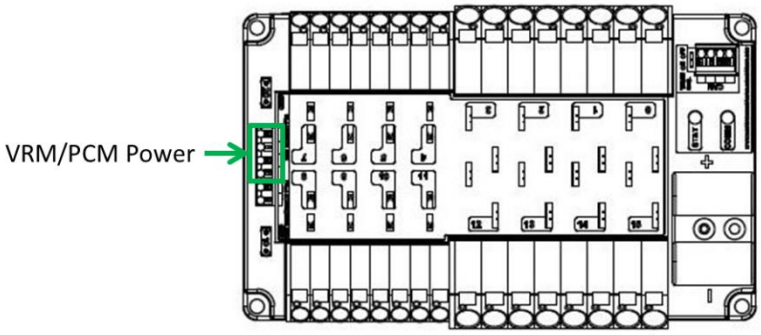

Figure 9-13 VRM and PCM power source

Please reference How to Wire an FRC Robot for Wireless Bridge wiring information.

R49. Only one wire shall be connected to each WAGO connector on the PDP.

If multi-point distribution of circuit power is needed (e.g. to provide power to multiple PCMs and/or VRMs from one 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 WAGO connector to power the circuit.

R50. The only circuit breakers permitted for use in the PDP are:

- **A.** Snap Action VB3-A Series, terminal style F57
- **B.** Snap Action MX5-A or MX5-L Series, 40A rating or lower

R51. The fuses in the PDP shall only be replaced with functionally identical fuses (mini automotive blade fuses with values matching those printed on the PDP).

Note that these fuses must be pressed very firmly to seat properly. Improper seating can cause component reboots during impacts.

R52. Each branch circuit must be protected by one and only one circuit breaker on the PDP per Table 9-3. No other electrical load can be connected to the breaker supplying this circuit.

Table 9-3 Branch circuit protection requirements

Branch Circuit	Circuit Breaker Value	Quantity Allowed Per Breaker
Motor Controller	Up to 40A	1
CUSTOM CIRCUIT	Up to 40A	1
Automation Direct Relay 40A (*6M40*)	Up to 40A	1
Fans permitted per Table 9-1 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 – with compressor	20A	1
Additional VRM (non-radio)/Additional PCM (non-compressor)	20A	3 total
Automation Direct Relay 12A (*6M12*)	Up to 10A	1

R52 does not prohibit the use of smaller value breakers in the PDP or any fuses or breakers within CUSTOM CIRCUITS for additional protection.

R53. All circuits shall be wired with appropriately sized insulated copper wire (SIGNAL LEVEL cables don't have to be copper):

Table 9-4 Breaker and wire sizing

Application	Minimum Wire Size
31 – 40A protected circuit	12 AWG (13 SWG or 4 mm2)
21 – 30A protected circuit	14 AWG (16 SWG or 2.5 mm2)
6 – 20A protected circuit	18 AWG (19 SWG or 1 mm2)
Between the PDP dedicated terminals and the VRM or PCM	
Compressor outputs from the PCM	
Between the PDP and the roboRIO	22 AWG (22 SWG or 0.5 mm2)
≤5A protected circuit	
VRM 2A circuits	24 AWG (24 SWG or .25mm2)
roboRIO PWM port outputs	26 AWG (27 SWG or 0.14 mm2)
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 signals, PCM Solenoid outputs, VRM 500mA outputs and Arduino outputs)	28 AWG (29 SWG or .08 mm2)

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 R53.

> 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 R53 (e.g. wire samples and evidence that they are the required size).

R54. 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 R8.

R55. 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:

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

Exceptions to this rule include:

- **C.** Wires that are originally attached to legal devices and any extensions to these wires using the same color as the manufacturer.
- **D.** Ethernet cable used in POE cables.

R56. CUSTOM CIRCUITS shall not directly alter the power pathways between the ROBOT battery, PDP, motor controllers, relays (per R29-B), motors and actuators (per R27), pneumatic solenoid valves, or other elements of the ROBOT control system (items explicitly mentioned in R66). 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 will not be considered a violation of R56 or R73.
>
> Acceptable signal filters must be fully insulated and must be one of the following:
>
> - A one microfarad (1 µF) 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).
> - A resistor may be used as a shunt load for the PWM control signal feeding a servo.

9.8 Control, Command & Signals System

R57. ROBOTS must be controlled via one (1) programmable National Instruments roboRIO (P/N: am3000), with image version FRC_roboRIO_2020_v10 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.

R58. One (1) OpenMesh Wireless Bridge (P/N: OM5P-AN or OM5P-AC), 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.

R59. The roboRIO Ethernet PORT must be connected to the Wireless Bridge PORT labeled "18-24 vPOE," closest to the power connector (either directly, via a network switch, 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 try directly connecting from the radio to roboRIO as part of troubleshooting efforts.

R60. Communication between the ROBOT and the OPERATOR CONSOLE is restricted as follows:

A. Network ports:

i. HTTP 80: Camera connected via switch on the ROBOT, bi-directional
ii. HTTP 443: Camera connected via switch on the ROBOT, bi-directional
iii. UDP/TCP 554: Real-Time Streaming Protocol for h.264 camera streaming, bi-directional
iv. UDP 1130: Dashboard-to-ROBOT control data, uni-directional
v. UDP 1140: ROBOT-to-Dashboard status data, uni-directional
vi. UDP/TCP 1180-1190: Camera data from the roboRIO to the Driver Station when the camera is connected the roboRIO via USB, bi-directional
vii. TCP/UDP 1250: CTRE Diagnostics Server, bi-directional
viii. TCP 1735: SmartDashboard, bi-directional
ix. UDP/TCP 5800-5810: Team Use, bi-directional

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 DS if the team chooses not to use the camera on USB).

B. Bandwidth: no more than 4 Mbits/second.

> Note that the 4 Mbit 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 Mbits/second data rate (with about 100 Kbit used for ROBOT control and status), at some events wireless conditions may not accommodate this.

R61. The roboRIO, Driver Station software, and Wireless Bridge must be configured to correspond to the correct team number, per the procedures defined in Getting Started with the 2021 Control System.

R62. All signals must originate from the OPERATOR CONSOLE and be transmitted to the ROBOT via the ARENA Ethernet network.

R63. No form of wireless communication shall be used to communicate to, from, or within the ROBOT, except those required per R58, R62, and tags used for location detection systems if provided by the event.

> 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 R63 doesn't apply.

R64. The Wireless Bridge must be mounted on the ROBOT such that the diagnostic lights are visible to ARENA personnel.

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

R65. ROBOTS must use at least one (1), but no more than two (2), diagnostic ROBOT Signal Lights (RSL) (P/N: 855PB-B12ME522).

Any RSL must be:

- **A.** mounted on the ROBOT such that it is easily visible while standing 3 ft. (~ 100 cm) in front of the ROBOT,
- **B.** connected to the "RSL" supply terminals on the roboRIO, and
- **C.** wired for solid light operation, by placing a jumper between the "La" and "Lb" terminals on the light per Figure 9-14.

> Please see How to Wire an FRC Robot for connection details.

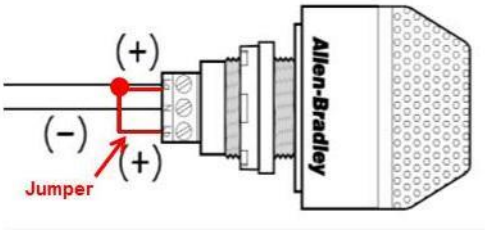

Figure 9-14 RSL jumper wiring

R66. The Driver Station software, roboRIO, Power Distribution Panel, Pneumatics Control Modules, Voltage Regulator Modules, RSL, 120A breaker, motor controllers, relay modules (per R29-B), Wireless Bridge, 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 application 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 data port.
O. Electrical tape may be applied to the aluminum plate inside the Wireless Bridge.
P. The input terminal cover from the Power Distribution Panel may be omitted (no other element may be installed using the threaded holes to install something in place of the PDP terminal cover).

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 RMA 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 article.

R67. 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).

R68. Every relay module (per R29-B), servo controller, and PWM motor controller shall be connected to a corresponding port (relays to Relay ports, servo controllers 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 R69). They shall not be controlled by signals from any other source, with the exception of the Nidec Dynamo motor controller which must also be connected to the roboRIO Digital I/O.

R69. If a motor is controlled via the MXP, its power regulating device must be connected by one 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 one approved ACTIVE DEVICE:

i. Kauai Labs navX MXP
ii. RCAL MXP Daughterboard
iii. REV Robotics RIOduino
iv. REV Robotics Digit Board
v. West Coast Products Spartan Sensor Board
vi. 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 one MXP pin does not prevent other MXP pins from being used in accordance with R69-B.

R70. Each CAN motor controller must be controlled with signal inputs sourced from the roboRIO and passed via either a PWM (wired per R68) 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 R57).

R71. Each PCM must be controlled with signal inputs sourced from the roboRIO and passed via a CAN-bus connection from the roboRIO (either directly or daisy-chained via another CAN-bus device).

R72. The PDP CAN interface must be connected to the CAN-bus on the roboRIO (either directly or daisy-chained via another CAN-bus device).

> For documentation on how to wire the CAN-bus connections of the PDP see How to Wire an FRC Robot.

R73. The CAN-bus must be connected to the roboRIO CAN port.

- **A.** Additional switches, sensor modules, CUSTOM CIRCUITS, third-party modules, etc. may also be placed on the CAN-bus.
- **B.** No device that interferes with, alters, or blocks communications among the roboRIO and the PDP, PCMs, and/or CAN Motor Controllers on the bus will be permitted.

> Only one wire should be inserted into each Weidmuller CAN connector terminal. For documentation on how to wire the CAN-bus connections of the roboRIO, PCM, PDP and CAN motor controllers, see How to Wire an FRC Robot.

9.9 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.

R74. 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.

R75. All pneumatic items must be COTS pneumatic devices and either:

- **A.** rated by their manufacturers for pressure of at least 125psi (~862 kPa), or

B. installed downstream of the primary relieving regulator (see R82), and rated for pressure of at least 70psi (~483 kPa).

Any pressure specification such as “working,” “operating,” “maximum,” etc. may be used to satisfy the requirements of R75.

It is recommended that all pneumatic items be rated by their manufacturers for a working pressure of at least 60 psi (~414 kPa).

R76. All pneumatic COMPONENTS must be used in their original, unaltered condition. Exceptions are as follows:

A. tubing may be cut,
B. wiring for pneumatic devices may be modified to interface with the control system,
C. assembling and connecting pneumatic COMPONENTS using the pre-existing threads, mounting brackets, quick-connect fittings, etc.,
D. removing the mounting pin from a pneumatic cylinder, provided the cylinder itself is not modified,
E. 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. Consider pneumatic COMPONENTS sacred.

R77. The only pneumatic system items permitted on ROBOTS include the items listed below.

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 psi (~862 kPA) and capable of relieving at least 1 scfm (~472 cm3/s).

C. Solenoid valves with a maximum ⅛ in. (nominal, ~3 mm) NPT, BSPP, or BSPT port diameter or integrated quick connect ¼ in. (nominal, ~6mm) outside diameter tubing connection,
D. Additional pneumatic tubing, with a maximum ¼ in. (nominal, ~6 mm) 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 R86-A 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 psi (~413 kPa),
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. One (1) compressor that is compliant with R79,
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
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)

R78. 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 9-15.

A. One (1) *FIRST* Robotics Competition legal compressor (per R79)
B. Pressure relief valve (per R77-B) connected via legal rigid fittings (e.g. brass, nylon, etc.)
C. Nason pressure switch, P/N SM-2B-115R/443
D. At least one pressure vent plug
E. Stored pressure gauge (upstream from Primary Regulator, must show psi or kPa)
F. Working pressure gauge (downstream from Primary Regulator, must show psi or kPa)
G. Working pressure regulator

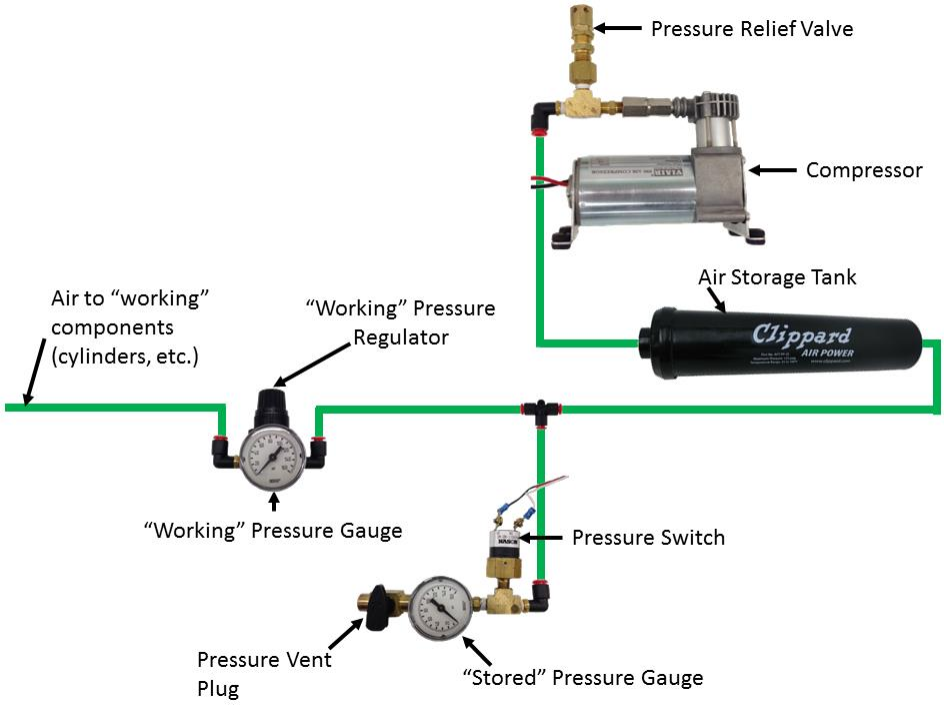

Figure 9-15 Pneumatic circuitry

R79. Throughout an event, compressed air on the ROBOT must be provided by its one onboard compressor only. Compressor specifications must not exceed nominal 1.1 cfm (~519 cm3/s) flow rate @ 12VDC at any pressure.

> A ROBOT'S compressor may be substituted by another compressor, but a ROBOT may only have one 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 PSI, are rated for intermittent pressures greater than 125 PSI and therefore meet the requirements of R75.

R80. Stored air pressure on the ROBOT must be no greater than 120 psi (~827 kPa). No stored air pressure intended for the ROBOT may be located off-board the ROBOT.

R81. Working air pressure (air pressure used to actuate devices) on the ROBOT must be no greater than 60 psi (~413 kPa) and must be provided through a single primary adjustable, relieving, pressure regulator.

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

R82. 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 psi (~793 kPa) working pressure.

R83. Pressure gauges must be placed in easily visible locations upstream and downstream of the regulator to display the stored and working pressures.

R84. 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 psi (~861 kPa). 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 Pneumatics Manual.

R85. The pressure switch requirements are:

- **A.** It must be Nason P/N: SM-2B-115R/443.
- **B.** It 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.
- **C.** The two wires from the pressure switch must be connected directly to the pressure switch input of the PCM controlling the compressor or, if controlled using the roboRIO and a relay, to the roboRIO.
- **D.** 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.

R86. 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.

R87. The outputs from multiple solenoid valves must not be plumbed together.

9.10 OPERATOR CONSOLE

R88. 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. Autonomous/Teleoperated) and operating state (Enable/Disable) to the ROBOT. The Driver Station software must be revision 21.0 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 competition MATCHES.

R89. The OPERATOR CONSOLE, the set of COMPONENTS and MECHANISMS used by the DRIVERS and/or HUMAN PLAYER to relay commands to the ROBOT, must include a graphic display to present the Driver Station 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.

R90. Devices hosting the Driver Station software must only interface with the Field Management System (FMS) via the Ethernet cable provided at the PLAYER STATION (e.g. not through a switch). Teams may connect the FMS Ethernet cable to their Driver Station device 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 pigtails on the Ethernet port used to connect to the FMS. Such pigtails will reduce wear and tear on the device's port and, with proper strain relief employed, will protect the port from accidental damage.

R91. The OPERATOR CONSOLE must not

- **A.** be longer than 60 in. (~152 cm)
- **B.** be deeper than 14 in. (~35 cm) (excluding any items that are held or worn by the DRIVERS during the MATCH)
- **C.** extend more than 6 ft. 6 in. (~198 cm) above the floor
- **D.** attach to the FIELD (except as permitted by G26)

> There is a 54 in. (~137 cm) long by 2 in. (nominal) wide strip of hook-and-loop tape ("loop" side) along the center of the PLAYER STATION support shelf that should be used to secure the OPERATOR CONSOLE to the shelf, per G26. See PLAYER STATION for details.
>
> Please note that while there is no hard weight limit, OPERATOR CONSOLES that weigh more than 30 lbs. (~13 kg.) will invite extra scrutiny as they are likely to present unsafe circumstances.

R92. 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.

R93. 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.