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Trouble-Shooting RS-485 (or Finding the Signal Leak)

RobustDC Application Note #6

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The Problem

Trouble-shooting RS-485 multi-drop is sometimes like a string of old-fashion Christmas tree lights -- one bad bulb brings the whole string down. Worse yet, the faulty RS-485 device may communicate fine back in your work-shop, yet still bring the whole line down when placed back in the field! Talk about frustrating situations! Worse, many vendors will return such a unit to you as "fixed" or "not faulty". This app note covers some common RS-485 failures and a procedure for trouble-shooting.

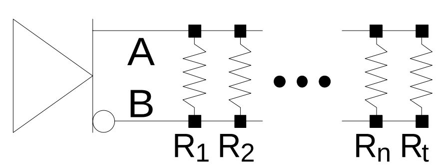
The Symptoms

A common type of RS-485 failure is partial or complete damage to an interface chip due to surge or over-voltage conditions. The symptoms may be as following:

- The RS-485 multi-drop line is completely down -- often after a lightning storm. Testing may prove the master RS-485 device is functioning normally. The master (control room) device is often protected by lightning surge devices, while not all of the field devices may be.
- The "end" of RS-485 multi-drop line disappears. This may be a hard failure, or the number of devices off-line may fluctuate -- now the last 3 are gone while last hour the last 4 were gone.
- The error rate of the RS-485 multi-drop line increases to a higher than normal level.

Obviously there can be other causes for these failures, such a loose connection or faulty master device. But assuming these two causes have been ruled out, you can try the following test.

Background to the RS-485 Field Test



Potentially, one or more of the RS-485 devices is placing too much load on bus for the transmitting RS-485 device to over come. RS-485 uses a differential voltage (V_{diff}) signal between the A and B (or '-' and '+') wires. To communicate, a transmitter must force the voltage potentials of the A and B wires to the levels defined by the standard to represent the desired signal: $A_V - B_V > +200mV$ for binary 0 and $A_V - B_V < -200mV$ for binary 1. If the wires are just floating, this is easy to do. However, each RS-485 receiver places a small load (resistance) shorting these two wire together (R_1, R_2, to

R_n, above). The terminating resisters (R_t) also add a large load to be overcome. Therefore the transmitter must supply enough current to drive the voltage potentials apart and overcome these loads. The EIA/RS-485 standard requires a transmitter to be capable to supply at least 65mA in this effort -- while also being self-limiting to never more than 250mA in the even of a short circuit. If the two wires are just shorted together, V_{diff} between A and B will be 0 and the transmitter supply as much power as it is designed to supply and the current limiting portion of the IC will become active. *(Just a robustness note: the standard states that any transmitter must be able to function in this mode indefinitely without damage.)*

Assuming your two wires are not just shorted together (you can test this by powering off the system and measuring the resistance), then the magic number "32" and the term "unit load" become important. The EIA/RS-485 standard is defined so that any transmitter can supply only 65mA to drive 32 receivers and 54 Ω of terminating resistance and still maintain a suitably strong signal -- more than ±200mV. In this case each receiver represents 1 "unit load" of resistance between the wires. If you are interested, some companies now sell chips with only ¼ unit load, so you could in theory place 128 devices on a single RS-485 bus.

An example may help prepare you for the test below. Suppose that with only the terminating resisters present - no receiver loads - our driver hits its supply current limit with a V_{diff} of 600mV between A and B. This value varies: active RS-485 masters with software RTS control can generally maintain a V_{diff} of 3 to 4 V (3000-4000mV), while passive RS-485 masters with automatic turn-around generally only maintain a V_{diff} of 400 to 600mV. As we add receivers, each receiver will add a small load and cause V_{diff} to drop. Assuming we start with 600mV and require a minimum V_{diff} of 200mV, then we can add 32 receivers only if on average each has less than a 12.5mV effect on V_{diff}.

With this last idea in mind, we now have a basis for our test. Normal RS-485 interface receivers will cause the V_{diff} of an idle RS-485 bus to drop between 1mV to 8mV. Major surge damage may cause the on-chip over-voltage protection diodes to start "leaking" either wire (A or B) to ground or +5v. Such minor surge or over-voltage damage may cause the V_{diff} to drop hundreds of mV when this receiver is attached to the RS-485 multi-drop.

This also explains the mystery of a device "talking" fine on the work-bench, but killing the field multi-drop line. Suppose the master device can maintain an idle V_{diff} of 600mV. By the time the resistance of the field wires and surge devices is added, this may only be 400mV at the remote field termination of the RS-485 bus. If we now place on the bus 20 normal RS-485 receivers each with an 8mV impact on V_{diff}, then this remote value may fall to 240mV. While this is low, it is still above the required ±200mV. Enter our damaged device whose receiver has a 150mV impact on V_{diff},. When tested alone, a master device with an idle V_{diff} of 600mV is pulled down to 450mV -- well above 200mV and so data communication works fine on the test bench. But place the damaged device back in the field where we only had 40mV "spare" signal and we end up with a V_{diff} of only 90mV and part or all of the RS-485 multi-drop line may stop working.

● Test for faulty RS-485 interface ICs

So the test is to measure the impact of each receiver on the idle RS-485 bus V_{diff}. ***This test is very easy if you have had the good foresight to install an isolation switch at each device in the field*** -- especially if the field is considered a hazardous location and opening terminal boxes can take 10 minutes each. If not, remember to add these to your *future* projects.

The following steps are a rough guide only. The values you will see will vary and you may have to apply "expert knowledge" and personal judgment to obtain valid results. You will need at least 2 people, a good digital voltage meter (DVM), and perhaps a pair of radios. *Keep in mind that talking on radios within 1 or 2 meters of unshielded RS-485 wires or open junction boxes will cause considerable voltage noise.*

1. Stop all data communications on the RS-485 bus, but *do not* power any of the devices off. If data communications is still running, V_{diff} may be rapidly changing from (for example) +300mV to -300mV and your DVM when show garbage. Some people have suggested using the Min/Max feature of modern DVMs to try this test on a running RS-485, but this may double or triple the time this test requires plus seems too error prone to me.
2. Go to the remote end of the bus and measure V_{diff}. If it is less than 200mV or greater than 3V, then your problem may be a damaged receiver either loading the device too much (a "leaky" connection) or pulling one or both wires to ground or +V. You should also look at the absolute voltage of both A and B. They should also be roughly symmetrical around 2.5V, for example 2.1/2.8v or 1.0/4.3v. If one is 0V and the other is 2.4v, then either your grounding is bad or one of the wires may be shorted to ground.
3. Return to the master device and disconnect it from the field. Verify its V_{diff} when disconnected is greater than 400mV and just be safe, connect a known-good slave device to it to verify it is working correctly.
4. Reconnect the master RS-485 device and select a good place to measure V_{diff} as your standard. Since we are interested more in changes to V_{diff} than in absolute voltages, the actual spot you pick is not so important. The best place is of course the farthest from the master RS-485 device, which should be the site of the lowest V_{diff}.
5. *If you do not have isolation switches for each device:* You may find it easier to do this test in reverse -- that is to record the current bad V_{diff} and isolate devices until it jumps up to a good value. Since your "standard" V_{diff} is now changing at each measurement, this requires more math and provides more chances for mistakes. But if reducing down-time is more important than finding all marginal receivers, this procedure may be best. Start with the devices you expect are damaged first. Lightning damage usually happens at the physical extremes of a multi-drop system.

The rest of this test assumes you do have isolation switches, so if you don't you'll have to use your head to relate the steps below to your situation.

6. *If you have isolation switches for each device:* good for you! Follow this procedure. Isolate all devices and record the final V_{diff} as your target standard. This value should be at least 300mV or you have some other problem in the system.

   The rest of this test is quite straight forward -- one at a time connect each device, measure the resulting V_{diff}, and then re-isolate the device.

6a. If the ***device is good***, it should have little impact on V_{diff} -- for example a drop of from 1 to 8mV.

6b. V_{diff} should not increase when adding receivers! If V_{diff} increases more than a few mV, then this ***device is bad*** and either injecting a voltage or pulling one of the wires toward ground.

6c. If V_{diff} drops by a more than 50mV, then this ***device is definitely bad***. But bad here is a relative term. If you only have 1 or 2 devices, a 50mV drop may be Ok for now. However, if your have 20 or 30 devices on the bus, a 50mV drop is not acceptable. You decide.

6d. If V_{diff} drops by from 8 to 50mV, then this ***device is marginal***. Again, your discretion.

7. Pick a target final V_{diff} such as 200mV or 250mV. If you have a "marginal" network design due to distance, abundant lightning protection, or poor cable quality you may have to be satisfied with less than 200mV or upgrade the system in general.

8. Sort the devices in order based on the impact each had on V_{diff}. Starting with the best devices (least impact), reconnect devices until V_{diff} reaches your minimum target level. Device still isolated are your "bad" devices, so sit down and plan your repairs.

You have finished the test. If your RS-485 problems were as described above, then you can now restart the system and have good RS-485 data communications. If you still have problems, then this was not your problem -- or not your *only* problem.

Example Test Results

Below is a table of values from an actual site (a truck loading facility in Malaysia). A ground shift during a lightning storm damaged a 4-wire RS-485 network with 22 devices and caused complete communications failure. Being a petroleum refinery with explosion proof terminal boxes, they had the good sense to include isolation switches in the terminal box for the RS-485 stub to each device. The test was easy to do.

TX refers to the V_{diff} between the transmit wire pair in mV, and RX refers to the V_{diff} between the receive wire pair in mV. The initial V_{diff} before isolating any devices was 79mV and 45mV for TX and RX. Devices FQIC028, 30, 40, 52, 86, and 88 were considered damaged and once all other devices were reactivated, the final V_{diff} in the field was 229mV and 242mV for TX and RX.

Device	TX w/o	TX with	TX Drop		RX w/o	RX with	RX Drop	
FQIC028	420	372	48	<<<<	436	411	25	????
FQIC030	420	388	32	????	436	337	99	<<<<
FQIC032	420	420	0		436	435	1	
FQIC034	420	419	1		436	435	1	
FQIC036	420	419	1		436	435	1	
FQIC038	420	419	1		436	435	1	
FQIC040	420	342	78	<<<<	436	335	101	<<<<
FQIC042	420	419	1		436	436	0	
FQIC044	420	391	29	????	436	427	9	
FQIC046	420	419	1		436	435	1	
FQIC048	420	419	1		436	436	0	
FQIC050	420	414	6		436	433	3	
FQIC052	420	480	-60	<<<<	436	294	142	<<<<
FQIC072	420	419	1		436	426	10	
FQIC074	420	387	33	????	436	425	11	
FQIC076	420	419	1		436	436	0	
FQIC078	420	419	1		436	436	0	
FQIC080	420	414	6		436	433	3	
FQIC082	420	414	6		436	432	4	
FQIC084	420	414	6		436	433	3	
FQIC086	420	-28	448	<<<<	436	231	205	<<<<
FQIC088	420	640	-220	<<<<	436	227	209	<<<<
FQIC094	420	408	12		436	430	6	
FQIC096	420	423	-3		436	437	-1	

Notice the extreme impact devices FQIC086 and 88 had on V_{diff}! Device FQIC086 actually changed the polarity of V_{diff}, while device FQIC088 caused V_{diff} to increase by 50%. Physically, devices FQIC052, 86 and 88 are the farthest from the control room, while 28 is the closest. On site, the RS-485 network worked once devices FQIC052, 86 and 88 were isolated, even with a V_{diff} of only about 100mV. Devices FQIC028, 30, and 40 communicated unpredictably on site, but worked fine on the test bench.

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