How Wire Fails

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ABSTRACT:

Wire and cable can fail from a number of causes. This paper is an overview of the various failure modes wire can exhibit, how to predict each and how to help prevent it. Often, installers or users mistakenly suspect one failure mode when in fact another (or even none) is to blame. This article will also present an analysis template to determine just which failure mode might be expected.

ACRONYMS:

PE: polyethylene
PP: polypropylene
PVC: polyvinyl chloride
RL: return loss

FAILURE MODES:

Wire and cable can fail in a number of ways. These include:

INSTALLATION FAILURE: The wire or cable was not installed correctly, or not installed to correct installation practices or industry standards. This can often involve poor connector choice or incorrect connector installation.

ENVIRONMENTAL FAILURE: The wire or cable is not intended for the place it is installed. This may involve outdoor, direct-burial or other ruggedness requirements, or cable installed in electronically "noisy" areas without adequate protection, or in high or low-temperature applications where the cable is not manufactured for such environments.

OPERATIONAL FAILURE: The inherent limitations of the wire or cable were not understood by the designer, purchaser or installer. The cable can be run too far or a poorly-manufactured version may be substituted for one of higher quality. This is commonly known as the "just as good" syndrome.

MANUFACTURING FAILURE: The wire or cable was incorrectly manufactured, incorrectly labeled, or incorrectly tested. Cable could be made on machinery out of tolerance, in need of maintenance, or not designed for the precision required in many current designs. This can include substandard or flawed product being sold as "normal" product. Cable failures of this kind may or may not be apparent to the designer, purchaser or installer.

INSTALLATION FAILURE:

Installation failure can be caused by the wire or cable not being installed correctly, or not installed to correct installation practices or industry standards. This can often involve poor connector choice or incorrect connector installation.

General Installation Guidelines:

Here is a chart of standard practices for audio and video cable:

Type of Cable	Specification	Standard Practice	Comments
microphone	reliability	cable preparation	combing out braid/sleeving
		soldered pins	insulation displacement ?
line-level analog audio	bend radius	≥ 4 times diameter	not critical
	pull strength	each cable different	consult manufacturer
digital audio	bend radius	≥ 4 times diameter	affects impedance
	pull strength	each cable different	consult manufacturer
baseband video	bend radius	≥ 10 times diameter	solid vs foam
	pull strength	each cable different	consult manufacturer
	connector choice	analog	50Ω or 75Ω, not critical
digital video	bend radius	≥ 10 times diameter	gas-injected foam
	pull strength	each cable different	consult manufacturer
	connector choice	SD - SDI (270 Mbps)	75Ω (to 400 MHz)
		HD -SDI (1.5 Gbps)	75Ω (to 2.25 GHz)
		1080p/60	75Ω (to 4.5 GHz)
broadband video	reliability	installer quality?	F connector standard
	pull strength	long runs/aerial	messengered
	performance	DBS = 2.25GHz	high velocity foam

Conduit Issues

Question	Reason	Answer	Comments
How many cables will be pulled through each conduit?	Only so much room.	In the states, the standard is 40% fill.	Pull force requirements go up exponentially after 40 %
How straight a run is it?	The straighter the run, the easier the pull.	MAXIMUM of two 90º bends in one pull.	Combine angles for max. of 180º
Correct cable choice?	Some cables pull easier than others	Stiff cables with shiny jackets pull better than flexible cables with matte jackets.	Why buy fancy super-flexible cables with braid or serve shields just to install them in conduit? Buy *install-grade* cables.
Has the architect changed the size of the conduit in a cost-cutting measure?	It happens!	Did you change the cable pulls to follow the change in diameter?	A change from one size to the next size down will almost guarantee you will exceed conduit fill and maximum pull strength.
Pulling tools and methods	Makes life easier!	Snake/fish tape, pulling compounds, pulling basket	Maybe non-conduit “plenum” cable isn't so expensive after all!

How to Determine Conduit Fill:

Determine area of conduit. Figure internal diameter, not external. Manufacturer of cable should provide circular area for each cable. You can then simply add the cable areas until you reach 40% of conduit area.

ENVIRONMENTAL FAILURE:

Environmental failure means the wire or cable is not intended for the place it is installed. This may involve outdoor, direct-burial or other ruggedness requirements, or cable installed in electronically "noisy" areas without adequate protection, or in high or low-temperature applications where the cable is not manufactured for such environments.

	Construction		Special Difference	Jacket	Comment
Outdoor	Crush-resistant internal components		Gel-filled to avoid water penetration	High-density black PE	No fire-rating
Noisy area w/ audio	analog	braid	high braid coverage	PVC	Below 10 MHz
	digital	foil	folded foil	PVC	Wide bandwidth
Noisy area w/ video	analog	double braid	high braid coverage	PVC	6 MHz
	digital	foil/braid	high braid coverage	PVC	Out to 4.5 GHz is possible.

OPERATIONAL FAILURE:

Operational failure is caused by inherent limitations of the wire or cable which were not understood by the designer, purchaser or installer. The cable can be run too far or a poorly-manufactured version may be substituted for one of higher quality. This is commonly known as the "just as good" syndrome.

Here's how to determine the construction and performance quality of various *audio cables*:

	Center	Insulation	Shield	Jacket
Good	copper	PVC	Serve/spiral	PVC
Better	copper	PP	Foil	PVC
Best	Solid copper	PE	Braid French Braid	PVC
Notes	Copper with perfect surface (skin effect)	Pick by capacitance	Foil for RFI Braid for DC to 10 MHz	PVC (colors?)

While there are no "standards" for analog audio, with a very low frequency range (20 Hz to 20 KHz), the wavelengths are so long that the impedance of the cable itself is of no consequence. What does affect performance is capacitance, resistance, and shield effectiveness. Flexibility, flex-life and ruggedness may also be a consideration.

Here's a chart to determine the quality of *baseband video cable*:

	Center Conductor	Dielectric	Shield	Jacket	Comments
Analog	solid copper	solid PE (best)	double braid	PE (fire?)	6 MHz bandwidth
		foam PE (good)	braid	PVC	
Digital	solid copper	foam PE	foil/braid	PVC	Out to 4.5 GHz
Notes	no copper-clad steel	NO PVC	Shield effectiveness	Plenum versions	

Here's a chart to determine the quality of *broadband (CATV) video cable*:

	Conductor	Dielectric	Shield	Jacket	Frequency
Analog	copper-clad steel 50 MHz and above	foam PE	foil/braid	PVC if indoor only	1 GHz
Digital	copper-clad steel 50 MHz and above	foam PE	foil/braid	PVC if indoor only	DBS = 2.25 GHz
Notes	30-50 MHz interactive?	foam velocity $\geq$80%		High-density black PE if outdoor	Higher bandwidths coming.

MANUFACTURING FAILURE:

Manufacturing failure means the wire or cable was incorrectly manufactured, incorrectly labeled, or incorrectly tested. This can include substandard or flawed product being sold as "normal" product. Manufacturers may also be using old machinery, machinery in need of maintenance or which is otherwise out of adjustment. Manufacturers may also be using older machinery not designed to produced cutting-edge technology products. Cable failures of this kind may or may not be apparent to the designer, purchaser or installer.

Return Loss:

If you can get a graph of return loss (RL) on a cable, this can tell you a lot. Because of the complexity, most manufacturers only test an occasional roll of cable. Precision video cables should be 100% tested, every foot. RL tells you how stable the impedance is down a length of cable. High return loss indicates that much of the signal will be reflected back to the source and not show up at the destination.

Periodicity is the accumulated errors built up because of periodic flaws in the cable. For instance, say you have a wheel in your extruder which is out of round. This may stretch the center conductor making it microscopically thinner at one point. Or the dielectric might come out slightly smaller in diameter for each turn of the wheel. While such a change is very minor, and may not even be readable with test gear, or noticeable in use, this flaw will be added over and over and over again each time the wheel turns.

This now adds the dimension of multiple flaws at the same spacing. If you have a flaw that repeats over and over, the distance between these flaws corresponds to a wavelength of a specific frequency. This anomaly will show up not just at that one frequency (the "fundamental") but also at every harmonic of that frequency. With increasing distance, this minor flaw could be a major cause of RL, and can easily cause a cable to fail. And there is nothing in the manufacturers catalog to tell you. You can't even tell by looking at the cable. Belden's digital precision video cables have a return loss guarantee: -23 dB from 5 MHz to 1.6 GHz, and -21 dB from 1.6 GHz to 4.5 GHz. Any manufacturer of precision video cables should provide you with similar numbers.

Compound migration.

If cables are used outdoors, or in harsh environments, the chemicals that make up the jacket are critical. If they are low quality materials, they can leach or "migrate" into the dielectric. This is another good reason for a foil as part of the shield. Foil helps prevent this.

If the chemical constituents of the jacket migrate into the dielectric, it can radically change the dielectric constant of the material. This means that capacitance and impedance will also change. And that will cause a dramatic rise in RL. Bad news!

Testing:

One key difference between manufacturers is how or how often they test their cables. If it is precision video cable, for instance, every roll should be sweep tested. Ask what frequencies it is swept to. If it is swept below 400 MHz, it is unlikely that this cable was intended for SD-SDI digital video. HD-SDI normally requires sweeping up to 3 GHz or more.

Solutions:

Consider each company's market history. Ask other users. What is the company history? Many companies who have made wire and cable for many years, have only recently been making audio and video cables. What is their historic position in the audio and video industry? Do they offer a product warranty. What does it cover? How long is it? How long have they *had a warranty*?

FAILURE MODE TABLE

	Analog Audio	Digital Audio	Analog Video	Digital Video	Broadband	Machine Control	Data
Installation		Too hard a pull	Too hard a pull	Too hard a pull	Too hard a pull	Too hard a pull	Too hard a pull
	Exceed bend radius	Exceed bend radius	Exceed bend radius	Exceed bend radius	Exceed bend radius	Exceed bend radius	Exceed bend radius
Environmental	Indoor version used outdoor	Indoor version used outdoor	Indoor version used outdoor	Indoor version used outdoor		Indoor version used outdoor	Indoor version used outdoor
Operational	wrong dielectric	wrong dielectric	wrong dielectric	wrong dielectric	wrong dielectric		wrong dielectric
				wrong connector	Poor quality connector		
Manufacturing		Excessive impedance variation		Excessive RL	Excessive RL		Excessive impedance variation

SUCCESS MODE TABLE

IDEAL CHOICES LISTED BELOW
DOES NOT APPLY TO PLENUM CABLES

	Analog Audio	Digital Audio	Analog Video	Digital Video	Broadband	Machine Control	Data
Installation		Pull within spec	Pull within spec	Pull within spec	Pull within spec	Pull within spec	Pull within spec
		Bend radius observed	Bend radius observed	Bend radius observed	Bend radius observed	Bend radius observed	Bend radius observed
Environmental	Correct indoor/outdoor construction	Correct indoor/outdoor construction	Correct indoor/outdoor construction	Correct indoor/outdoor construction	Correct indoor/outdoor construction	Correct indoor/outdoor construction	Correct indoor/outdoor construction
Operational	polyethylene polypropylene	foamed polyethylene	solid polyethylene	High-density hard-cell foamed polyethylene	foamed polyethylene	polyethylene polypropylene	solid polyethylene foamed polyethylene
Manufacturing	foil coverage		every roll swept	every roll swept	RL specs		every roll swept and tested

Choose the Best

	Analog Audio	Digital Audio	Analog Video	Digital Video	Broadband	Machine Control	Data
Conductor	Copper/ tinned copper	copper	copper	Bare copper	copper-clad steel	Copper/ tinned copper	copper
Insulation/ Dielectric	PP PE	PE	PE/ foamed PE	foamed PE	foamed PE	PVC PP PE foamed PE	PE/ foamed PE
Shield	braid foil	braid foil foil/braid	braid	foil/braid	foil/braid	foil braid foil/braid	none foil
Shield Material	Copper/ tinned copper	Copper/ tinned copper	copper tinned copper	foil+copper or tinned copper	foil + aluminum or tinned copper	foil braid foil + braid	none foil
Jacket	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Features	low capacitance	110Ω impedance	75Ω impedance	75Ω impedance	75Ω impedance	varies	100Ω impedance
U.S. Standards	none	AES/EBU	SMPTE	SMPTE	SCTE	Many	TIA/EIA
European Standards	none	AES/EBU	CCIR	CCIR	?	?	ISO/IEC