bacnet experts

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Best Practices for MS/TP Wiring

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TUTORIAL

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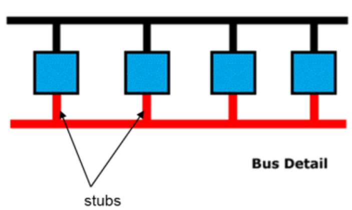
Introduction

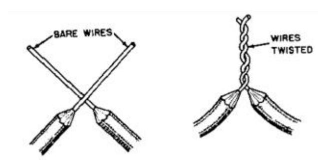
Master-Slave/Token-Passing (MS/TP) is a media access control (MAC) layer technology defined in the communications standard known as BACnet (ANSI/ASHRAE 135-2016). MS/TP is widely used and deployed all over the world with estimates ranging into the tens of millions of deployed devices. This article will discuss the theory and best practice to use when designing and implementing networks of MS/TP devices. Experience has shown that those who follow these principles will generally have efficient and reliable MS/TP communications. The root cause of communications issues in MS/TP networks can most often be traced to deviations from these recommendations.

What is MS/TP?

As a MAC layer, MS/TP provides a means of conveying a message from one device to another. Most of what MS/TP is involves the signaling of 0s and 1s organized into discrete packages called *packets* or *message frames*, and the rules that are associated with arbitrating how devices find each other and negotiate to take turns using the communications network. In this article we'll be primarily concerned with the electrical aspects of this signaling and wiring rules that result in more reliable communication.



MS/TP uses a *daisy-chained communications bus*. The network itself uses a twisted-pair plus shield type of wire. The pair is like the rails of a ladder with individual devices wired across the rails like rungs. The wires that form the rung are called *stubs*. For electrical reasons we want to make the lengths of stubs as short as possible.



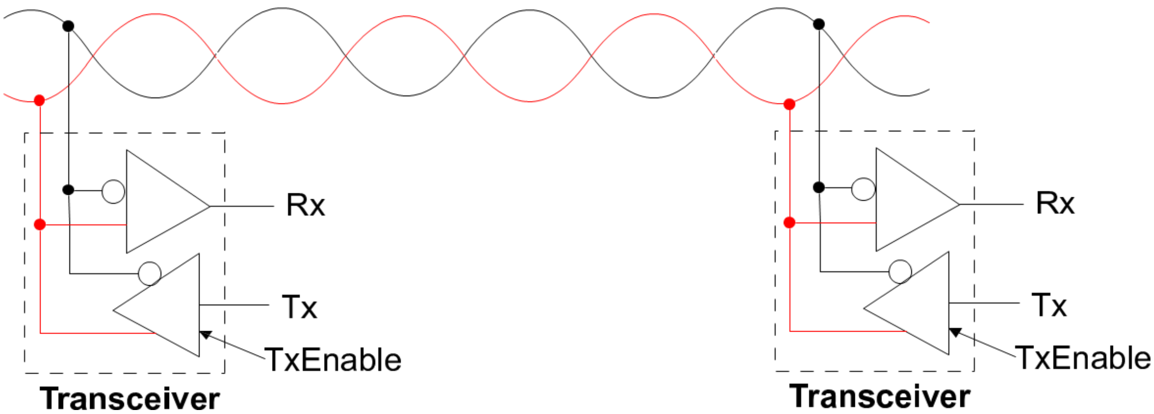
That's why MS/TP specifies the use of daisy-chain wiring. Daisy-chaining means landing the network wires on screw terminals that are directly part of the device itself.

Some BACnet devices include two sets of screw terminals, one for incoming and one for outgoing wires. But usually there is a single pair so the daisy chain must be created by twisting incoming and outgoing wire ends rattail fashion and capturing the twist in the corresponding screw terminal for the network. Be sure not to expose too much bare twisted wire so that adjacent wires don't short, or use crimp sleeves.

The shield wire should enter the wire cabinet and shields should also be daisy-chained together and then taped or covered. In some cases devices have "empty" screw terminals where shields can be landed. It is VERY IMPORTANT to assure that shields are connected to ground at only one location along the bus! Typically MS/TP networks will have a single router or large controller in addition to many small devices. It can be convenient to use the router/controller as the single grounding point and as an end node at one extreme of the network or the other.

Termination, Loading and Biasing

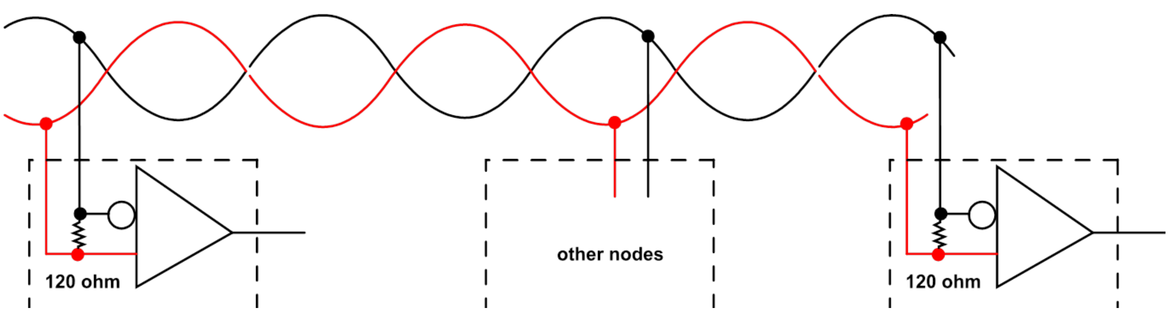
Electrically, MS/TP uses a type of signaling known as EIA-485. With EIA-485, devices use a single twisted pair which carries a differential voltage relative to a shared ground:



Each node uses a *transceiver* that consists of a differential receiver and differential driver whose legs are connected together on the "plus" and "minus" sides. When the node is "listening" the driver TxEnable is deasserted putting the driver into a high impedance tri-state mode. When the node needs to transmit, the driver TxEnable is asserted, applying the Tx state to the differential bus. This means that only one driver can be asserted at any time.

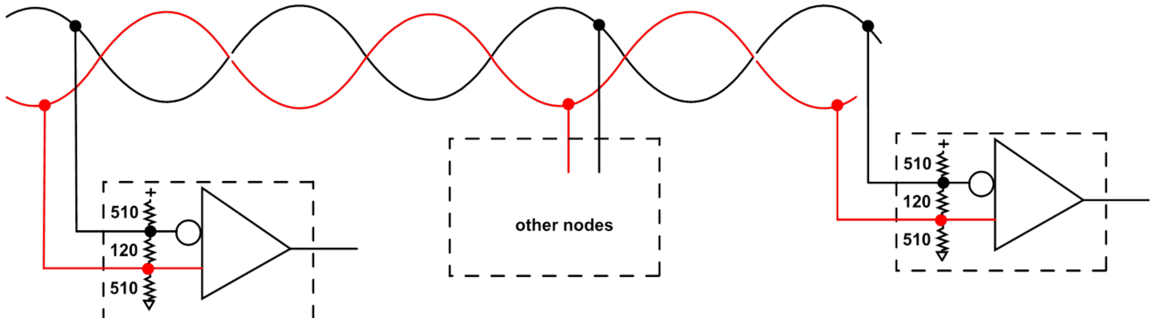
The EIA-485 standard models each transceiver as an idealized 12KΩ impedance (load) and specifies that each driver shall be required to source no more than 60mA. This works out to 32 *unit loads*. A lot has changed since the EIA-485 standard was created and today there are transceivers designed with higher impedance (½, ¼, and even ⅛ load). Under some circumstances we can take advantage of this and have more than 32 *devices* on a segment.

MS/TP allows the total length of the twisted pair bus to be up to 4000 feet (1200m) using datarates from 9600, 19200, 38400, 57600 or 76800 bps. At 115200 bps the length must be degraded to 3280 feet (1000m).



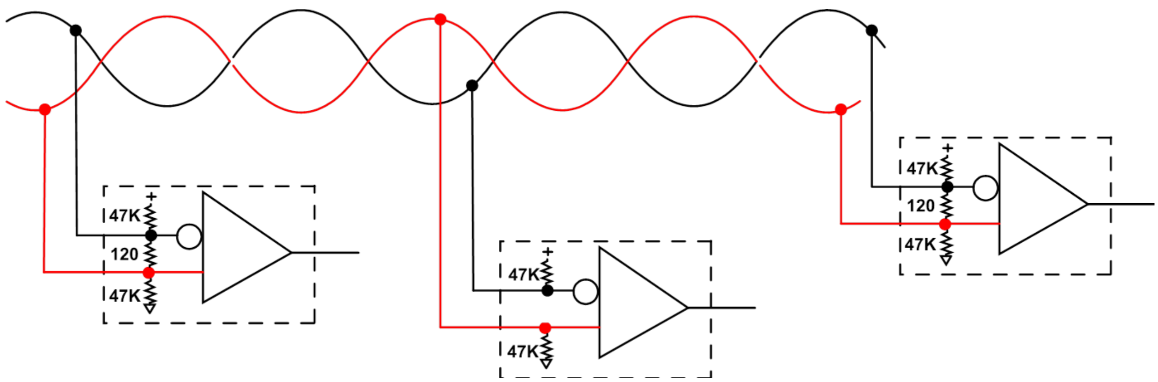
The standard also requires that both extreme ends of the network bus shall have 120Ω termination resistors across the receiver. Termination is important over longer distances and higher speeds to eliminate reflections.

When there is an active driver asserted the voltage differential is reliably held in the 0 or 1 state by the driver. However when all drivers are tri-state (all deasserted) the differential floats at an indeterminate level. This can cause undesirable effects including random transitions that receivers can interpret as valid data bits. To help overcome these effects, BACnet MS/TP specifies the use of active *biasing*.



The extreme end nodes of the network bus are enhanced to include *pullup and pulldown biasing* resistors. The values chosen for these resistors must be small enough to provide more than 200mV of voltage drop across each receiver, and large enough that they do not exceed the driver's ability to overcome the bias which would prevent transmitting data. MS/TP specifies the use of 510Ω resistors for end point (network) biasing.

Unfortunately there is some difference of opinion within the industry regarding whether *network biasing* is the best approach to use. The standard indicates a strong preference for network biasing, but allows an alternative called *local biasing*. With local biasing each node has biasing resistors but the values are much larger. The larger values provide less bias so the effect is localized to the node itself, and also less power is required to be sourced by the node's power supply. MS/TP specifies values of 47KΩ for these types of biasing resistors:



Since the standard allows both types of biasing philosophy there is always the possibility that a given MS/TP segment may include a mixture of types. For network segments containing 32 or fewer nodes that is not a problem. However, when you want to have the same MS/TP segment include more than 32 nodes, the biasing philosophy becomes very important.

Although the mathematics is somewhat complicated, it boils down to some simple rules.

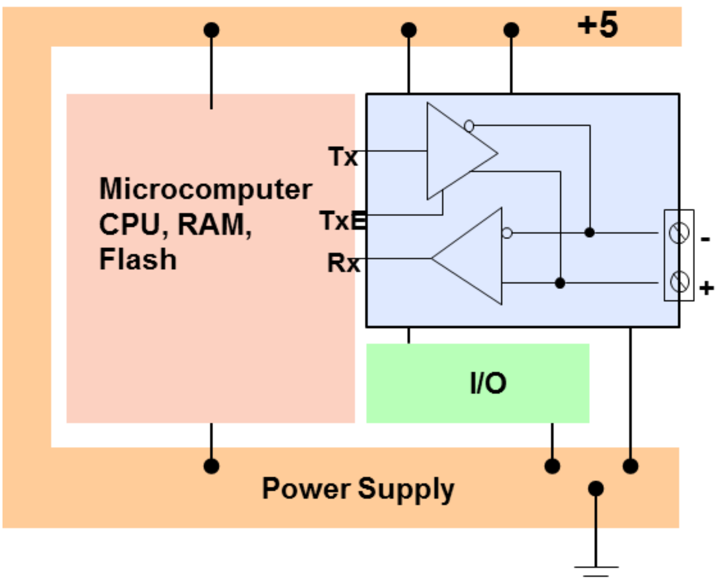
- If there are any locally biased (47K) nodes on the segment, the segment is limited to 32 or fewer nodes unless *repeaters* are used.
- If all of the nodes use partial-load transceivers, e.g. all ¼ load, and network biasing is used, then you can extend the total number of nodes based on load. For example all ¼ load transceivers can have up to 128 nodes without repeaters.

Repeaters are special devices that include two or more sets of EIA-485 transceivers. Data incoming to one set causes the other set(s) to retransmit the same data with low latency (delay). Repeaters are bidirectional so there is some logic within them that determines which side is transmitting at any given time and enables/disables the EIA-485 drivers accordingly.

So which philosophy is “better?” Because of the ubiquity of partial-load transceivers, and the generally cost-sensitive nature of MS/TP devices, the BACnet standard leans toward the use of two point network biasing which allows devices to exploit the additional device possibilities without requiring repeaters. On the other hand, advocates of the 47K philosophy argue that their approach is easier to remember and apply because all nodes are the same and repeater cost is only incurred in larger population network segments. They would also argue that repeater cost is similar to the cost of dual end point biasing, if implemented as a separate device accessory. The other camp would argue that a slight increase in power supply capacity would allow any node to fill the role of end point biasing source. Suffice it to say that there is no clear consensus on a best approach even after 15 years as a standard and many millions of installed nodes.

Non-isolated Power

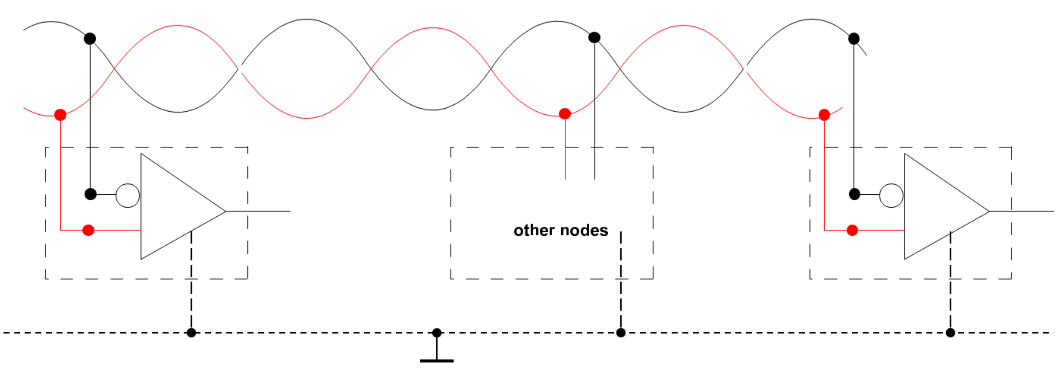
A typical microcomputer-based controller device that implements MS/TP has several important parts. We will greatly oversimplify this view with the following block diagram:



The Microcomputer, memory, Input/Output (I/O) and EIA-485 components share access to a power supply circuit that provides appropriate voltage(s) to all of the individual components. Of particular interest is that the *ground reference* for the entire device is the same as the power supply ground.

This is important to remember because it’s one of the things that make the two-wire EIA-485 concept work.

Recall that the differential voltage signal in EIA-485 is referenced to a ground return path. In this case it’s clear that this ground is the same as the power supply ground for the transceiver and also for the whole device. Because all of the devices have power supplies that use the same AC power in the same building, they all theoretically share the same Earth ground point where AC power enters the building.



So in effect there is an implicit shared "third wire" in addition to the twisted pair that is common to the MS/TP devices on the same segment.

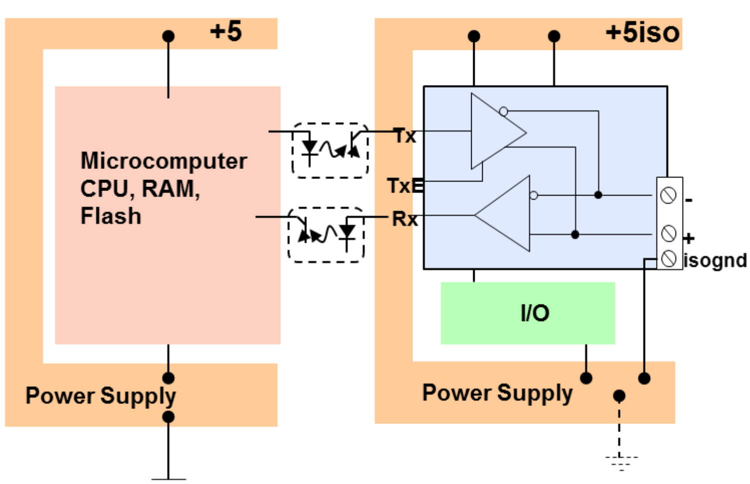
The good aspect of this is that a third wire isn't needed because the nodes share this same ground reference. However there are some bad aspects as well.

In a laboratory setting with devices on a test bench, this works great. In a real world situation where the network wiring is pulled through ceilings and placed in close proximity to other electrical devices, particularly magnetic coil devices like fluorescent ballasts, motors and so forth, it is possible and quite common for electrical transient pulses to become inductively coupled onto the network wiring. While the differential signal measuring is mostly immune to this kind of noise because it tends to be induced equally into both sides of the differential, it can and does affect the ground potential on the power supplies of non-isolated devices. The net effect is to disturb the ground reference not only for the EIA-485 transceivers but also for the CPU, memory and I/O components in the devices on the network as well. This can have many different side effects ranging from mild to severe, such as causing the CPU to reset unintentionally, interfere with communications and other bad effects. Keep in mind that to a non-isolated device, the whole MS/TP segment is a 4000 foot long antenna for gathering transients.

MS/TP specifies the use of shielded twisted pair wiring. This means that the twisted pair is wrapped with foil or braided copper shielding along its whole length. By connecting the shield at a single ground point, induced transients are mostly reduced and channeled to ground. This helps reduce the effects of transients on the communications signals, but does nothing to prevent ground transient effects.

Isolated Power

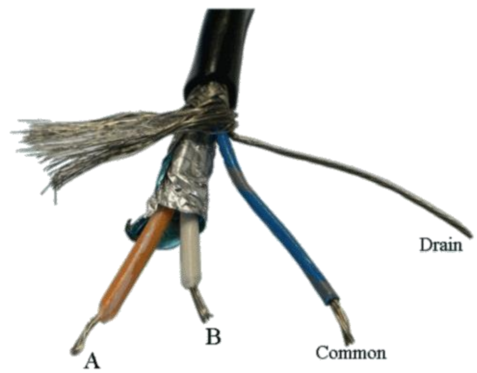
Clearly it would be desirable to design the EIA-485 circuits in a way that would reduce or eliminate transient intrusion into the sensitive internals of the microcomputer(s) and their memory, I/O and communications components. In some kinds of MS/TP devices, such as variable frequency drives (VFDs), the motor control circuits themselves can be a source for disruptive transients. In those cases it is more than desirable, it's necessary. This is usually accomplished by *isolating* the power supply for the EIA-485 components (or disruptive I/O components or both) from the power supply used for other internals. This greatly simplified diagram shows how this works:



The EIA-485 components (and in some cases also I/O components) instead of being directly coupled to the microcomputer, are connected using *optical isolators* which convert electrical signals to pulses of light and back to electrical signals again within the isolation chip itself. There is a second power supply that uses its own transformer isolation to provide power for the isolated side of the circuit. Note that the ground for the isolated side is not connected to the non-isolated side and is brought out to its own terminal.

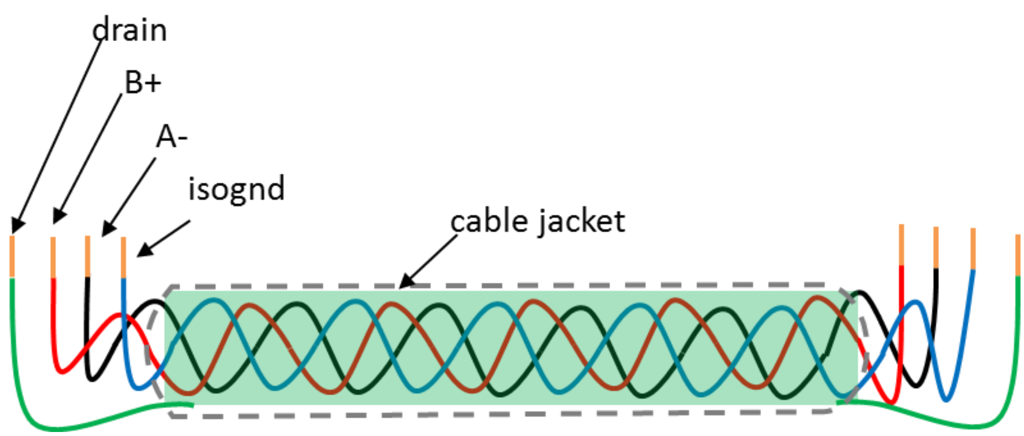
Because isolated EIA-485 power has its own ground, electrical transients that may be induced onto this ground do not affect the microcomputer. However introducing an isolated ground creates a new problem.

The EIA-485 standard specifies a wide range of +12 to -7 volts relative to the reference ground. Modern transceivers have protection built-in that shuts down the transceiver if these voltages are exceeded. Many designs use microfuses and extremely fast switching transorbs for protection also. But even with these measures it is still possible to actually damage some transceivers with sufficiently large transients. When there are two or more devices on the same network, both of which use isolated power, if their isolated ground references are not tied together then it is possible for the two "floating" references to be at different levels, thus their combined voltage range can easily push outside of the design spec during transients. As a result, the 135-2010 BACnet standard introduced new guidelines governing best practice for MS/TP. Under the new standard, it is strongly recommended that isolated devices have their isolated ground references tied together through a third wire.



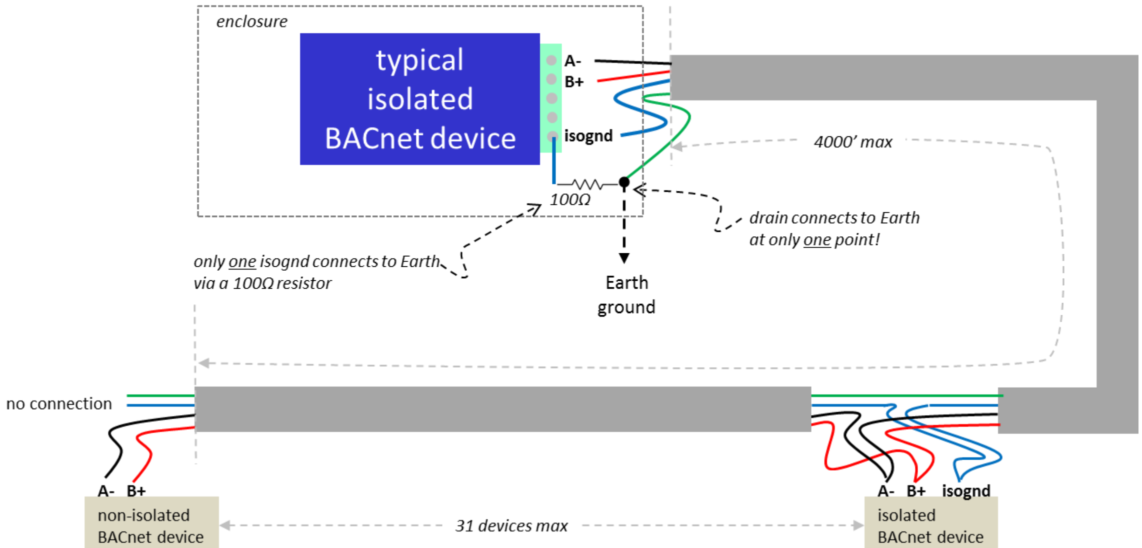
Although it is possible to do this with a separate wire, the best practice is to use (or retrofit with) *shielded twisted triple* which is also called *1.5 pair*. When daisy-chaining the segment into a device cabinet, the *common* wire is landed on each isolated ground terminal. The drain daisy-chains through cabinets but is only grounded at one point.

Anatomy of 1½ pair cable



Mixed Networks

Sometimes it is necessary or desirable to have a mixed network that incorporates some number of non-isolated MS/TP devices and some number of isolated ones. The issue is how to reconcile the ground reference used by the isolated devices (through the third common wire) and the implied Earth ground used by the non-isolated devices. The answer is that the common third wire is tied to the Earth ground through a current-limiting 100Ω resistor.



Summary

MS/TP can provide low cost reliable operation under a wide range of conditions. However, careful planning for new construction and diligent research when retrofitting existing networks is essential to reap the benefits that MS/TP has to offer. Biasing, loading and wiring become particularly important in any mixed device network segment. Failure to take these factors into account is the number one cause of field issues with MS/TP, and also the easiest to prevent using best practices.