UNIVERSAL INSTRUMENT LANDING SYSTEM (ILS) INTERLOCK CONTROLLER WITH REMOTING CAPABILITY

BY

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ABSTRACT

Instrument Landing Systems (ILS) provide vertical and lateral guidance to landing aircraft. The lateral guidance aligns the aircraft horizontally with the extended centerline of the runway while the vertical guidance ensures the proper descent angle for landing. This allows an aircraft to make a landing at an airport that cannot be seen from higher altitudes due to weather, clouds, and/or poor visibility.

The approach path provided by the ILS also ensures an obstacle free corridor. The ILS utilizes ground based electronics and an aircraft receiver. The ground based electronics radiates an amplitude modulated VHF signal through an antenna array. The combined signal in space has different modulation based upon its orientation to the antenna array. The aircraft receiver uses this signal to determine its alignment.

Due to safety requirements, Federal Aviation Administration (FAA) Orders, and International Civil Aviation Organization (ICAO) Standards, an ILS must use an interlock system to prevent more than one ILS from radiating opposite approaches to the same runway or when operation of more than one ILS causes an interference problem with the signal in space reception of the desired ILS signal. This interlock system interfaces more than one ILS and must be controlled by Air Traffic personnel.

Since there is not a common specification for controlling an ILS, individual manufactures are free to use different methods for interlocking their system. The Federal government buys ILSs from competitive bidding. The result is different vender equipment ends up at various airports causing unique interlock designs. Furthermore, until recently, interlocked ILSs were not remoted off airport. Therefore, a universal ILS interlock with remoting capability is needed.

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1.0 INTRODUCTION

Aircraft today fly under two types of rules—Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). Under VFR, the pilot is responsible for avoiding other aircraft. Depending upon the airspace, the pilot may or may not be utilizing Air Traffic Control. Since the pilot is responsible for avoiding other aircraft, the pilot must be able to visually navigate. This means the pilot is not authorized to fly into clouds and must have a minimum visibility range as set by different air spaces. Under these rules, a pilot may not fly to and land at an airport he/she cannot see from the air. The meteorological conditions that allow VFR flight is called VFR Meteorological Conditions (VMC). When the meteorological conditions are such that VFR flight is not allowed, it is called Instrument Meteorological Conditions (IMC). IFR flights can occur in VMC or IMC.

Unlike VFR, IFR flight requires Air Traffic Control. Air Traffic assigns flight altitudes and is responsible for the pilot avoiding other aircraft. Air Traffic provides this safety by using altitude separation, RADAR, pilot position reporting, etc. The pilot is authorized to fly into clouds and low visibility areas. Since the pilot might not be able to see the outside references such as a horizon or visible land marks, the pilot must fly relying on instrumentation. Often times, the pilot may have the aircraft above the clouds and begin a descent to an airport for a landing that he/she cannot see.

1.1 Options for Landing

The pilot accomplishes this by different means. If the weather at the airport has a ceiling greater than 1000 ft above ground level (1000 AGL), Air Traffic Control might vector the pilot to the runway and monitor his/her decent until the pilot makes visual contact with the runway. If the ceiling is less than 1000 AGL, the runway must have a landing aid for the pilot to make a landing. Landing aids are classified as either non-precision, or precision. Non-precision approaches allow the aircraft to descend below 1000 AGL but must have visual contact with the runway usually by 500 AGL. Non-precision approaches provide lateral guidance only, not vertical guidance. As a result, the approach usually uses a stair step method of decent. In a stair step decent, the pilot flies at a level altitude until the point when the pilot may descend to a lower altitude. The pilot then flies level at that altitude until allowed to descend to the next lower altitude. Finally, the pilot maintains the altitude for the missed approach. The pilot flies at that altitude until he/she makes visual contact with the runway or reaches the missed approach point (MAP). If the pilot reaches the MAP without seeing the runway, he/she is not authorized to land and must execute the published missed approach.

Precision Landing aides provide both lateral guidance and vertical guidance to the aircraft. The most common precision landing system is known as the Instrument Landing Systems (ILS). The ILS provides lateral guidance via a localizer and vertical guidance via a glide slope. Although landing systems require both ground based electronics and airborne electronics (receivers, auto pilots, etc.), this thesis will focus on the ground based electronics of the ILS and its specifications and performance.

1.2 ILS Characteristics

The usable distance of an ILS is usually 18 nautical miles for lateral guidance and 12 nautical miles for vertical guidance. ILSs are classified as either Category

(CAT) I, II, or III . CAT I ILSs typically have the MAP at 200 ft AGL. CAT II ILSs have the MAP at 100 ft AGL. CAT III ILS has a MAP less than 100 ft AGL. Associated with each ILS is one of four levels of integrity and continuity of service as listed in Table 1 on the following page. Integrity is defined as the probability of not radiating an out-of-tolerance signal. Continuity of Service (CoS) is defined as the probability of radiating a signal-in-space that is never out-of-tolerance during a given time interval. CoS can also be measured by the Mean Time Between Outage (MTBO) where and outage is defined as an unanticipated cessation of signal-in-space.

Localizer or Glide Slope			
Level	Integrity	Continuity of Service (CoS)	Mean Time Between Outage (MTBO) hours
1	Not demonstrated, or less than required for Level 2		
2	0.9999999 in any one landing	0.999996 in any period of 15 seconds	1000
3	0.9999999995 in any one landing	0.999998 in any period of 15 seconds	2000
4	0.9999999995 in any one landing	0.999998 in any period of 30 seconds (localizer) of 15 seconds (glide slope)	4000 (localizer) 2000 (glide slope)

Table 1: Integrity and Continuity of Service Objectives[1]

From the table above, there is only a 1 in 10,000,000 chance that an errant signal would radiate during a landing for a level 2 ILS. This means that the executive monitoring system either failed to detect an out-of-tolerance signal-in-space, or the executive monitoring system detected the error but failed to turn off the transmitter. Had the executive monitoring system properly detected an out-of-tolerance signal-in-space and turned off that transmitter, the integrity of the system would have been upheld. Turning off the main transmitter for a level 2 or higher ILS results in a transfer to a standby transmitter. This is not considered an outage for the MTBO calculation. Remember that an outage occurs when there is a disruption or loss of the signal-in-space, not simply a failure of a redundant sub-system.

A level 2 ILS also has to demonstrate an MTBO of 1000 hours or greater for the life of its operation. In other words, it is not calculated by a moving average method. If a facility degrades below 1000 hours MTBO, it gets down-graded to a level 1. To go back to a level 2 is not as simple as demonstrating another 1000 hours without an outage. It would have to demonstrate enough outage free time to average 1000 hours MTBO since first placed in service.

1.3 Regulatory And International Requirements

The United States of America (US) regulates the aviation industry through the Federal Aviation Administration (FAA). Like most United Nation (UN) countries, the US places a priority on International Civil Aviation Organization (ICAO) compliance. ICAO does not have regulatory authority. It provides Standards and Recommended Practices that are adopted through international diplomacy. As a result, the FAA, like many civil aviation authorities from other countries, adopts into their Orders and Law, similar language found in ICAO.

The FAA requires an interlock system for multiple ILSs at an airport when they share a common frequency, they face each other on a common runway, or they cause interference effects, typically from aircraft receiver cross modulation. The interlock must be remotely controlled, include an activation delay greater than or equal to 20 seconds, and must use a failsafe design.[2] The failsafe design must ensure

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[1] ICAO Annex 10, 2006 Table C-2
[2] FAA Order 6750.16D (Siting Criteria for ILS) 1-14

that both ILSs are not radiating at the same time. If the interlock control fails, either both ILSs should turn off, or they both should remain in their last state. The interlock design cannot be handled procedurally where Air Traffic turns one system off, waits 20 seconds, and then turns the other one. This would allow an error of turning both on at the same time or not ensuring the full deactivation delay. Furthermore, the interlock cannot be controlled by personnel other than Air Traffic. Air Traffic authorizes use of the ILS by issuing clearances. The ILSs must not be turned off while a pilot is authorized to fly an ILS approach.

1.4 Changes In Industry

Prior to 1995, the US did not consider ILS interlocks as a difficult issue. The US did not have many CAT II or CAT III systems. Most manufacturers of ILSs used either a direct current (d.c.) method of control and monitoring or an audio tone method with simple frequency detection. It was fairly easy to interface different systems together under a unique site specific interlock. Several FAA Regions also developed local monitor/control panels for Air Traffic so that as an airport acquired more ILSs, there was a consistent ILS monitor/control panel for Air Traffic regardless of the actual electronics on the airfield. There was also a culture that believed the interface designs could not fail in an unsafe condition so no reliability analysis was needed.

Then around 1995, a new generation of ILSs was produced and procured in the US. The contract award went to Wilcox who made the Mark20 ILS (an ILS capable of CAT III). It incorporated the same fail-safe interlock design with the ILSs used by the FAA in that it required a positive signal from the ATCT to the field facilities to interlock them on. Loss of that signal (either intentionally or by accident) resulted in that facility turning off. This approach safeguarded against opposing ILSs radiating at the same time. However, the Mark20 ILS differed in that it used a serial data communication for its Remote Indication and Control Equipment (RICE).

This meant that interlocking a Mark20 ILS with a non-Mark20 ILS became more difficult. Logically, there should have been 3 approaches to chose from: 1) Make the Mark20 ILS look like the non-Mark20 ILS from the view point of the ATCT. This would allow using the non-Mark20 RICE; 2) Make the non-Mark20 ILS look like a Mark20 ILS from the viewpoint of the ATCT. This would allow using the Mark20 RICE; or 3) Develop a new RICE that would interface to both systems.

Because the FAA acquisition office did not specify a standard interlock interface in the equipment specification, there was not a national design effort solve this issue. Rather, each of 9 regions within the FAA developed their own solution and site adapted their designs. This led to a variety of interlock designs that even varied within regions. Although the primary issue was how to interlock the ILSs, a secondary issue dealt with the monitor and control panel used by Air Traffic.

1.5 Problems Arising From Lack Of Standardization

In some locations, the ILS monitor and control panel from each system was installed in the ATCT CAB. In this scenario, one panel would indicate an alarm or would lose power when the other panel was active and vice-versa. This approach was often chosen for its simplicity. By installing a relay bank controlled by an external switch, each ILS could receive its interlock signal from its control unit depending upon the state of the relay bank. Each ILS could utilize its 20 second delay built by the manufacturer of that equipment. If the 20 second delay was derived at each facility, only the interlock signal had to go through the relay bank. If, however, the 20 second delay was derived from the control unit at the ATCT, a power on reset of that equipment would usually reset the 20 second timer. Therefore, power to the control unit would go through the relay bank.

That approach usually caused space problems in the ATCT CAB. Air Traffic control requires more and more systems to handle the increase in traffic congestion. This usually means that during the life of the ATCT, more panels are installed in the CAB without the size of the CAB consoles increasing. There is always a need to decrease the space used by systems in the CAB rather than increasing the space requirements. Air Traffic only needs the selected ILS to be displayed in the CAB. For this reason, the Mark20 Remote Status and Interlock Unit (RSIU) combines both ILS information to a common panel and only displays the information for the ILS interlocked on. That panel has the dimensions of roughly 10 inches by 9 inches (90 square inch surface area). Often times, a CAB did not have the space available for the addition of this panel without removal of the ILS panel for the non-Mark20.

This thesis answers the following question: With respect to Instrument Landing Systems, is a universal interlock control system needed and what are the design considerations that should be addressed?

2.0 DESIGN CONSIDERATIONS

ILS interlocks have specifications and requirements governed by FAA Orders and ICAO Annex 10. Although these are the minimum requirements for an interlock, there are other requirements that are specific to the FAA. Although the FAA verifies the correct operation of ILSs in the United States, not all ILSs are maintained by the FAA. There are cases where a City or State will procure and maintain a navigational aid such as an ILS. These facilities are referred to as non-Fed Facilities (not Federal). They undergo Federal Inspections but are not owned, operated, or maintained by the FAA. A unique scenario at a non-Fed facility would not have a compelling reason to adhere to requires of standardization. This Thesis will address concerns specific to the FAA.

2.1 Maintainability

The ILS Interlock system needs to be easy to maintain. This would include Technical Instruction (TI) Manuals. The FAA TI manuals are very structured and need to include the following sections: 1) General Information; 2) Technical Description; 3) Operation; 4) Standards and Tolerances; 5) Periodic Maintenance; 6) Maintenance Procedures; 7) Corrective Maintenance; 8) Parts List; 9) Installation; 10) Software; and 11) Diagrams. Ideally, the interlock system would never fail. However, should failures occur, or be discovered during routine maintenance, the failures need to be fixed. By providing adequate site spares, the down time can be reduced and the system returned to service sooner. The mean time to return to service (MTRS) can be reduced by designing line replaceable units (LRUs) rather than component level troubleshooting.

Depending upon the specific ILS location, true economic damage can be caused if an ILS is not available for use. For example, parallel runways at a major airport Hub might allow that airport to have a capacity of landing 120 airplanes an hour. If meteorological conditions require the use of an ILS to land, that airport would need an ILS for each runway approach. Should one ILS became unavailable (due to maintenance or an unscheduled outage), that airport's capacity would be reduced to 60 landings per hour. This could cause an excess of airplanes scheduled to arrive at that airport. The result is delays or cancelled flights from departing airports scheduled to fly to that airport. Airplanes already enroute might be delayed or diverted until the congestion is cleared.

Other economic impacts include fuel requirement increases that can be caused by having an ILS out of service. When a pilot plans a flight, that pilot must ensure there is enough fuel to reach their destination plus a specified reserve amount for safety. If IMC is forecasted at the destination airport, there is the chance the conditions could worsen or the navigational aids fail at that location. The pilot then must increase the fuel reserve to fly from that airport to an alternate airport in addition to the required safety reserve. That alternate airport either has to have forecasted conditions higher than minimum VFR, or have a monitored navigation aid with minimums lower than forecasted conditions. The loss of service of an ILS at a qualified alternate airport might disqualify that airport to be used as an alternate. This would result in more fuel requirements to reach an airport further away. Since fuel adds weight to an aircraft, increasing the required fuel reduces the available passenger/cargo allowances thus reducing revenue. Lastly, lift is created at the expense of drag which reduces fuel efficiency. A heavier plane requires more fuel to take off and reach desired altitude than a lighter plane. If the plane is not maxed out on weight due to revenue generating passengers/cargo, adding more fuel increases the operation of that flight. Because of these concerns, the FAA also measures the availability of each ILS.

The availability of a system is dependant upon its reliability and the required maintenance. Availability is defined as the ratio of time the system is available for use during a set period of time to that time period. Availability (A) is expressed as a percentage:

$$A = \frac{D \times 24 \text{ hours/day} - (t_M + t_O)}{D \times 24 \text{ hours/day}} \times 100\%$$

Where,

D = number of days in period (e.g. 365 days)
t_M = Time (hours) system is unavailable due to maintenance
t_O = Time (hours) system is unavailable due to failure resulting in an outage. Note: a failure that does not result in a loss of service such as a failure of a redundant unit, is not defined as an outage.

Typically, Availabilities are measured over 1 year and 5 year periods. Availability is used as a performance and efficiency measurement. By doing a trend analysis on availability, sites becoming maintenance intensive can be identified. This can help predict when the reliability of that system is decreasing. If realized in time, facilities can be up-graded or replaced prior to falling below acceptable levels of availability and reliability.

2.2 Training

Along with a TI manual, formalized training needs to be developed for the interlock system. This training can either be incorporated into the formal training of

ILS, or as a stand alone training course. Not all locations that have an ILS require an interlock system. Many smaller airports have one or two ILSs that do not require an interlock. A cost benefit analysis should be used to determine the best course of action. This training needs to address a theory of operation, troubleshooting techniques including fault isolation, and how to bypass the interlock system so that an ILS can be used while the interlock system is being restored.

2.3 Supply/Support

Not all sites will experience the same number and types of failures. It is not economical to buy and store enough spares to cover every system for as long as the need for that system exists. It is cheaper to buy a limited number of spares and then replace or repair damaged spares to maintain an adequate supply stock. The FAA has a major Depot in Oklahoma City for this purpose. The design should identify appropriate amount of site sparing needed to reduce MTRS and identify sparing that is not required on site. An example of an appropriate site spare might be a LRU that is a single point of failure resulting in a system failure. An example of an appropriate off site spare might be a redundant power supply. Should one power supply fail, the system continues to operate while the spare is ordered from the Depot.

The Depot should have the ability to trouble shoot and repair failed units, or purchase replacement units when the supply stock runs low.

2.4 Life Cycle Management

Design considerations must include a strategy for a life cycle management of the interlock system. The interlock system needs to be available for the life of the ILSs it interfaces. Most ILSs have a life expectancy of 20 years but have been pushed to 30 and 40 years. If the parts needed for the interlock system becomes obsolete, spare units could become unavailable for purchase. Once sparing stock runs out, systems would no longer be available. Several options to deal with this include: 1) buying enough spares upfront to avoid obsolescence. This method is expensive and runs the risk of buying too many spares or requiring a complete redesign when stock runs too low. 2) Enter a long term contract with the supplier that parts would be stocked and available for purchase for a specified duration. This also raises the price for the guarantee that parts are available. You pay more when you need parts but you do not buy what you do not need. If the system life is extended beyond the guarantee stock period, you run the risk of needing a complete redesign. 3) By designing a modular system with clearly defined input/output functions, modular units can be redesigned when necessitated by obsolescence. These modular units can replace the failed units without a redesign of the system. The major advantage with this approach is it prevents overstocking of units that prove very reliable yet provides flexibility for units that prove less reliable.

2.5 Positive Interlock Design

Hazardously Misleading Information (HMI) is the term used for identifying signals-in-space that could cause errant navigation. This can be caused by interference from another source, or from a single navigational aid that is radiating an out of tolerance signal. The Navigation frequency band is protected spectrum regulated by the Federal Communications Commission (FCC). The FCC coordinates all frequency licenses, regardless of the frequency or modulation scheme, with the FAA to ensure that granting of those licenses will not cause interference with Air

Navigation nor Air Communications. Almost all of navigation frequency interference comes from other navigational aids.

Aircraft navigation receivers are designed to measure the Radio Frequency (RF) carrier strength as well as the total AM modulation percentage. Thresholds for each are defined and receivers are required to indicate an error when either of these thresholds is not met. When both thresholds are met, the receiver assumes the signal is valid for navigation and develops navigational instructions. These instructions could be compromised if the modulated signals either have interference from outside sources, or if the navigational equipment itself is mistuned and allowed to radiate an out of tolerance signal.

Interlock systems are required to ensure that only one of the interlocked ILSs is radiating at a time. The primary hazard interlock systems mitigate is HMI. Since HMI could result in fatalities, the interlock function cannot be handled procedurally. It must be automated so that Air Traffic cannot inadvertently turn on multiple ILSs at the same time under the same interlock requirements. Although the interlock system does not prevent an ILS from radiating an out of tolerance signal, the ILS itself monitors its radiated signal and turns off if it detects an out of tolerance parameter. Therefore, the interlock system only needs to protect against HMI.

2.6 Fail-Safe Design

Interlock systems are also required to be designed so that a failure results in a safe configuration. The accepted failure states are either all ILSs turn off, or all ILSs remain in their current state. A commonly used design approach requires communication between the field equipment (localizers and glide slopes) and the interlock controller. If the communication path is broken, that facility turns off. This prevents a facility from staying on due to a communication fault while the interlock controller turns on a different ILS. This method of required communications prevents HMI caused by an interlock failure. Since the probability of relays or switches failing in a state where the common connection shorts with both the normally open and normally closed connection is extremely low, this mechanical means of ensuring positive control switching is often used.

2.7 Console Requirements

Console space is always at a premium inside an ATCT. A new ATCT at an airport might only be built every 30 to 40 years at a cost of several million dollars. The space inside the CAB is fixed from the day the tower opens. As the airport expands and new technologies add additional equipment in the CAB, that space is not increased. There is a constant evolution of optimizing the equipment layout used by Air Traffic. This includes moving panels to where they are needed most and moving panels to make room for additional equipment. ILS monitor and control panel dimensions have not been specified by government contracts. This led to different manufacturers developing panels of different sizes. It also led to panels from one vender not being compatible with ILSs from other venders.

Prior to 1995, these panels usually consisted of switches and lamps using direct current voltage levels. As a result, various custom panels were designed and installed by FAA engineering workforce at the Regional Level to accommodate space limitations in Tower Cabs. The interlock system that drove these panels also were not compatible with different vender ILSs. Often, it was easier to locally redesign the interlock controller to interface directly with each vender ILS and drive a single monitor and control panel in the CAB. After 1995, manufactures switched from discrete controls to the CAB panel to a microprocessor based system using a data stream to reconstruct all the panel indications. These panels were bigger (around 900 square inches) and handled only one runway. A large airport supporting ILSs on 6 runways would require a console space of roughly 30 inches by 18 inches. Since other vender systems were not compatible with these panels, initial installations included monitor and control panels from both venders with mechanical switches to select between panels. This quickly became a space problem.

2.8 Remoting Capabilities

Recent changes in FAA Orders now require that ILSs are monitored 24 hours per day by Air Traffic personnel. They also state that where interlocks are required, Air Traffic personnel must have control 24 hours per day. If the primary Air Traffic facility monitoring and controlling the interlocked ILSs is not manned 24 hours, monitoring and control must be remoted to another Air Traffic facility during the periods of closure. Previous policy did not require this capability. Rather, the ILSs were left in a night configuration. This night configuration was usually based on the predominate winds for an airport.

As an example, an airport with an Air Traffic Control Tower (ATCT) that is only operated 18 hours per day and has 2 ILSs servicing runway 12/30 might have winds that favor landing on runway 30 sixty percent of the time. Regardless of the wind direction at the time the ATCT closes for the evening, the ATCT shut down procedures might include always selecting the ILS for runway 30. This information would either be published, or broadcasted on an Airport Traffic Information System (ATIS). During the time the ATCT is closed, ILS approaches can only be made to runway 30. There is not an option to switch the interlock control to allow an ILS approach to runway 12 during this period.

Air speed is the vector sum of the aircraft's ground speed and wind speed projected on the longitudinal axis of the aircraft. A plane traveling at 160 knots indicated air speed with a 60º head wind of 30 knots would have a ground speed of 145 knots [160 knots - 30 knots x cos(60º) = 145 knots]. Conversely, if the wind was a 60º tail wind of 30 knots, the resultant ground speed would 175 knots. Minimum flight speeds are based upon airspeed, not ground speed. Ground speed, however, determines the length of runway required for aircraft to take off and land. Since aircrafts land at preferred air speeds, an aircraft landing with a tail wind requires more length to stop than the same aircraft landing with a head wind. Even if there is adequate runway length, it is safer to land at lower ground speeds. Rare problems such as a tire blow out are easier to handle at lower speeds. Therefore, it is more desirable to land into the wind. Remoting capability is now required because it allows the option of switching which ILS is available during the period the ATCT is closed.

3.0 EVOLUTION OF DESIGN

The following depicts the approaches I have used for the last 10 years addressing this problem. The designs underwent a continuous improvement process with the lessons learned and experience gained passed onto the national level for development of a national standardized interlock system.

3.1 Kansas City International (MCI)—New ATCT

Around 1995, the FAA procured a new ILS capable of Category III service called a Mark20 ILS. Part of a first article deployment includes evaluation at an airport prior to national acceptance and widespread installations. Kansas City International was chosen for the evaluation location. That system was installed on a runway that had an ILS servicing the opposite end. Therefore, an interlock was required. The other ILS, however, was not a Mark20. It was a Mark 1F which used a different method for monitoring and control. The requirement for an interlock prompted the FAA Systems Engineering group in Oklahoma City to design an interface that made the Mark 1F ILS look like a Mark20 ILS with respect to the monitor and control signals sent to the Mark20 interlock system. Although that interface worked, it was very costly. A national decision was made not to provide or support that interlock solution elsewhere. The nine FAA Regions were left to provide and support local interlock interfaces. This also left the ATCT at Kansas City with a variety of monitor and control panels for the ILSs controlled by Air Traffic.

Around 1996, work began at Kansas City International to build a new ATCT. In addition to CAB console space limitations, Air Traffic added the requirement that all ILS controls should use the same panel regardless of the vender specific equipment installed on the airfield. This requirement would standardize training and procedures for Air Traffic at that location.

As the electronics engineer responsible for the navigation facilities associated with this project, I was faced with 3 options: 1) Make all the ILSs monitor and control signals the same as Mark20 ILS and use the Mark20 interlock system; 2) Make the Mark20 ILS monitor and control signals the same as the existing ILS monitor and control system; 3) Develop a new interlock system that is compatible with the different ILSs. The solution used was a hybrid of options.

The Mark20 system used a Remote Control Status Unit (RCSU) that communicated from the ATCT to the field facilities using a data communication scheme at 2400 Baud. The protocol was not well documented. Each RCSU then connected to a Remote Status and Interlock Unit (RSIU) that was used by Air Traffic. Each RCSU communicated to the RSIU via a simplex data communication for status and discrete d.c. levels from the RSIU for control. This protocol was also not fully documented. The company that designed the Mark20 ILS had previously designed the RCSU and also an Universal Local Control Status Unit (ULCSU). This ULCSU had 26 optocouplers for discrete d.c. inputs with 4 relays for outputs. The ULCSU was easy to interface to the other ILSs. The RCSU could be reprogrammed to use the ULCSU as if the RCSU were communicating with a Mark20. The RSIU could then be used to interlock and control the various ILSs at Kansas City International.

There still existed a problem with CAB console space. The interlock issue had been resolved but the RSIU used more space than previous panels. A new panel for Air Traffic needed to be designed. National discussions on interlock issues raised the problem at Dallas-Fort Worth International. That airport had three control towers. The east and west towers were staffed during the day by Air Traffic with each tower controlling half of the airport traffic. Then at night when there was less traffic congestion, the center tower was staffed and the whole airport was controlled from the single ATCT. With that need in mind, I designed a panel for Air Traffic that was 75% smaller than the RSIU but had the capability of switching control from one panel to another. Up to four panels could be daisy chained together but only one panel would have control. All four panels would display the ILS status. Only the panel with control would sound an aural alarm and only that panel could control the ILS (change the interlock state, silence aural alarms, toggle the Far Field Monitor bypass). In addition, all panels had a Lamp Test button. This button would light all the LEDs when pushed to verify no LEDs were not functioning. The controller responsible for landings on a runway needs to know the status of the ILS for that runway. It is also necessary not to change the interlock and turn off an ILS that currently in use. Therefore, control and alarm acknowledgements should be at one location only.

Although Kansas City International only had one ATCT, they utilized this feature by adding ILS panels at different consoles in the CAB. During heavy traffic periods, different controllers would be responsible for different runways and were stationed at positions giving them the best view of that runway. During the night, however, staffing was reduced and responsibilities for the individual runways were combined. This combined position was located where the controller had the best view of all runways. Switching control to various positions meant controllers did not have to leave their position to acknowledge alarms or change runway configurations.

This design met the requirements for Kansas City International and offered a future benefit. Several ILSs at Kansas City International were identified to be replaced with Mark20 ILSs on the contract award for Mark20 ILSs. By making the existing ILSs communicate with the ATCT as if they were a Mark20 ILS, no tower work would be needed during the ILS change outs. This meant additional ILS interlock interfaces would not be needed, the ATCT panels would remain the same, and labor costs at the ATCT for the change out were practically eliminated.

This design had the following down sides: 1) The equipment cost to make a Mark1F look like a Mark20 required purchasing several ULCSUs and an RSIU for each ILS. At that time, the cost was around $30K per ILS for the interfaces; 2) Discrete wires were used from the RSIU to the new ATCT panel for driving all of the indicator LEDs and controls. This resulted in each ILS panel requiring 23 pairs of cable. For all of the ILSs at Kansas City International, equipment racks requiring 200 pairs of cable for interconnect wiring between the field equipment and the ATCT panels were needed. This makes troubleshooting problems difficult to isolate and increases the chances of an intermittent connection.

The panels designed to make this system work were: 1) KC-462[3]. The KC-462 is the panel used in the CAB to display the ILS status. If that panel has control, it will also sound an aural alarm for state changes and give the controller the options to silence and acknowledge alarms, toggle Far Field Monitor bypass, and change the selected ILS for interlock on; and 2) KC-905 Option 0. The KC-905

[3] Panel designs in Central Region are under configuration management. Unique numbers are assigned by the FAA Kansas City Staging Area. The KC designation refers to panels built in Kansas City.

Option 0 panel took the outputs of the RSIU and added a buffer to drive the KC-462 panels. It can drive over 4 KC-462 panels over 500 ft away.

3.2 Eppley Airfield (OMA)—Runway 14R ILS

Eppley Airfield located in Omaha, NE, was the next airport in Central Region (MO, IA, KS, and NE) to receive a Mark20 ILS and face an interlock problem. The scope of that project included installing a new Mark20 ILS that needed to be interlocked with the ILS supporting the opposite end of that runway, and to standardize the CAB monitor and control panels for all the ILSs at Eppley. Engineering projects often occur simultaneously or prior to installation of other projects. Such was the case for Omaha, NE. The engineering for that project was begun and actually installed prior to the installation at Kansas City International. The benefits of the CAB monitor and control panel used at Kansas City International were kept, however, a decision not to use ULCSUs and additional RCSUs for ILSs that were not Mark20 was made in a effort to reduce costs.

To make each ILS at Eppley look like a Mark 20 ILS would have cost around $30K per ILS. By designing a new interlock panel that interfaced directly to the CAB monitor and control panels, each ILS could be interfaced at a cost of around $4K each.

Mark 1F ILSs were typically interlocked in Central Region using a +24 Vdc system to energize relays at the field facility to interlock that facility on. When a facility is interlocked on, internal monitoring will still turn off the transmitter if an out of tolerance condition is detected. +24 Vdc is also sent from the facility back to the tower to indicate the transmitter was on and radiating normal.

The new interface could interlock Mark 1F with Mark 1F. Whether or not it was used to interlock two ILSs, it could still drive the CAB panels. The Interface panel used at Kansas City International could interlock Mark 20 ILS with Mark 20 ILS. If the Mark 20 ILS was not interlocked, it could still drive the CAB panels. By utilizing a relay bank driven by the interlock status of the Mark 20 RSIU, the outputs of the two panels could be switched to drive the CAB panel. This allowed for an inexpensive way to interlock a Mark 1F with a Mark 20 ILS and still retain the positive control interlock and fail-safe requirements. The interlock panel to drive the relay bank was named a KC-244 panel.

3.3 Wichita Mid-Continent (ICT)—Runway 01L ILS

The project at Wichita, Kansas was very similar to Omaha, NE. The engineering for Omaha was duplicated and similar panels fabricated for Wichita. The KC-462 panels were updated to improve maintainability. The original panels used in Omaha had 28 LEDs and 3 pushbuttons with individual wires routed inside the chassis to a single carrier board. The connectors on the back of the chassis were also directly wired to the carrier board. The result looked like a rats nest. The individual LEDs could also be pushed out of the front panel and into the chassis. The rework used ribbon cable connectors on the back of the chassis to plug into the carrier board. The front panel also used a printed circuit board (PCB) to hold the LEDs and push buttons in place. The two PCBs were then connected by ribbon cable connectors. Replacement panels were shipped to Omaha so the prototype panels could be replaced.

After the panels were installed at Wichita, however, the local technicians pointed out a needed enhancement for the KC-905 Option 1. That panel provided a means to interlock each Mark 1F ILS and drive the KC-462 CAB panels. It did not, however, provide status indications directly on the KC-905 Opt 1 panel. The technicians have a daily requirement to verify the states of each ILS. The KC-462 panels are located in the CAB which means the technicians would need to enter the CAB and potentially interrupt the controllers to verify the status of the ILSs. Another drawback was the KC-462 panel only displayed the ILS selected and did not display the opposite runway end ILS. Some facilities such as markers and glide slopes on different frequencies do not have to be interlocked. For example, when an ILS for runway 36 is selected to be interlocked on, the localizer for runway 18 is turned off. The glide slope, middle marker, etc. for runway 18 would remain on. The technician would like to know if those facilities are in alarm or in normal. If they are in alarm, he/she can begin troubleshooting that facility and tell air traffic those systems are not available if air traffic wishes to switch which ILS approach is active. Under the Omaha configuration, the technician would need to make a site visit to each facility to verify its status, or if traffic allows, have air traffic switch ends and then back for verification. Having air traffic switch ends is not always an option and also pulls the controller away from other duties. Driving to each facility can take anywhere from 20 minutes to an hour depending on the access roads and aircraft traffic at the airport.

3.4 Des Moines International (DSM)—Runway 05 ILS

To resolve this issue, the KC-905 Option 1 was redesigned and named KC-905 Option 2. The KC-905 Option 1 had 4 inputs and used D Flip Flops for capturing state changes and latching an aural alarm signal for the KC-462. The inputs were designed for a +24V input to indicate normal and absence of input to indicate alarm. The four inputs were typically a localizer, DME, glide slope, and middle marker all supporting the same ILS. It did not display the status of the four inputs. It did provide relay contact closures to implement a reset for each system input. The relay contacts were configured normally closed and would momentarily open upon a reset request. This reset could only be initiated from the KC-462 panel.

The redesign of the KC-905 Option 1 occurred during the project at Des Moines, IA. This project also involved interlocking a Mark 20 ILS with a Mark 1F and standardizing the CAB panels. It had an additional requirement of displaying remote ILSs that had status reporting only from Aimes, IA, and Newton, IA.

The KC-905 Option 2 added inputs for 11 facilities. It incorporated an internal interlock relay to eliminate the KC-244. It used a microcontroller to configure several options determined by dip switch settings. These options included 1) using the KC-905 Option 2 to interlock two Mark 1F systems and generate an aural alarm only for the facilities associated with the selected ILS; 2) using the KC-905 Option 2 to monitor and control 2 stand alone ILSs that were not interlocked. The output would drive two separate KC-462 panels each with separate alarms corresponding to the associated ILS; and 3) provide up to 11 discrete statuses. This option required a CAB panel different than KC-462 and was labeled KC-464. This panel could be used for combining remote ILSs as well as any item air traffic wanted to monitor such as the status of an on-airfield VOT (VOR Test Transmitter that allows pilots to verify correct alignment of their VOR receiver.

The KC-905 Option 2 essentially combined two KC-905 Option 1 panels and the KC-244 panel together reducing space, complexity, and cost. It added enhancements for technicians such as status monitoring of all facilities and paralleled the resets for each facility. The reset relays were enhanced to independently provide either normally-open momentary-closed contacts, or normally-closed momentary-open contacts for greater flexibility in using the resets. The d.c. input ranges for each facility was change to allow either a normal indication with an input of 10 Vdc to 50 Vdc, or a normal indication with an input of 15Vdc to 1.7 Vdc. This could now accommodate TTL inputs as well as DC voltages sent over field cables. An overview document was produced to explain the options and different configurations available for the KC-905 Option 2.

3.5 St. Louis International (STL)—New ATCT

During the projects at Omaha, Wichita, and Des Moines, the engineering for the new ATCT at St. Louis was completed. It had similar requirements to Kansas City International. Because of the likelihood of upgrading the ILSs to Mark20, it was determined to use ULCSUs and additional RCSUs for all non-Mark20 ILSs. At this time, however, the Washington Program Office for Towers initiated a new requirement—ATCTs taller than 150 ft could not run copper cables up the tower shaft. Instead, all connectivity had to be accomplished via fiber optics. The ATCT at St. Louis was taller than 150 feet so it had to conform to this new requirement. Other engineers on the project determined the best way to convert the d.c. signals used for the ILSs controls to fiber was through a Programmable Logic Controller (PLC) based system. The initial plan was to convert the signals at the base of the Tower and then reconstruct them at the top. This would accommodate the KC-462 panels. It was quickly pointed out that the GE Fanuc system could interface with a touch screen computer monitor. Rather than reconstruct the dc signals at the top and use the KC-462 panels, touch screen monitors were used. Additional systems were then integrated into the PLC system and that system was named a Tower Computer Control System (TCCS).

Shortly after the RSIUs were connected to the TCCS, another problem was encountered. The remote inputs to the RSIU are fed directly to the base of an NPN transistor without any noise suppression. Previous designs using a KC-905 Option 0 provided a TTL input to the RSIU within 1 foot and noise suppression was not needed. The TCCS PLC outputs were roughly 20 ft from the RSIU. Although the PLC provided either a ground or +5 Vdc output to the RSIU, noise coupled on the cable was sufficient to indicate a request that was not intended. For a runway select, the RSIU required a request followed by a second request. This gave Air Traffic the ability to cancel an accidental runway select request. The controller sequence to change the interlock is as follows: The controller pushed the runway select button. The RSIU sounds an aural alarm. If the controller pushes the alarm silence button, the request is canceled. If, however, the controller pushed the runway select button again without silencing the alarm, the RSIU changes interlock states.

When the remote input to RSIU requests an interlock change, the RSIU does not generate an aural alarm on its remote output. It stays armed for a runway select until either another request for interlock change is made, or an alarm silence is requested. There is no gated window in the RSIU for this function. If a runway select request is made once and no alarm silence request is made, the RSIU will change interlocks on the next runway select even if it is days later.

At St. Louis, runway 6/24 was changing interlock states about every 6 hours without a fault in the TCCS system. By placing an o-scope on the input to the RSIU, noise could be seen on the cable from the PLCs to the RSIU. This problem was resolved by placing external noise suppression close to the RSIU inputs. The noise suppression consisted of a simple pi filter using two parallel capacitors around a series inductor. The filter required the PLC to output a ¼ second pulsed +5 Vdc rather than a momentary +5 Vdc. This resolve the remote input problem.

The RCSUs have battery back up and it was recommended to install the batteries. Because the ATCT was on an UPS system with engine generator backups, local technicians decided not to install the batteries. Several years later, during the installation of an UPS bypass switch, the tower lost commercial power and the engine generators did not turn on. After power was restored, systems were brought up in order of importance and convenience. The tower did not have the TCCS system running when the technicians informed Airtraffic they had the ILSs back on. The technicians and controllers did not confirm which ILSs were supposed to be on. The design of the Mark20 RSIU did not remember the last state upon power up. The design assumed the battery back up would prevent the RSIU from powering down. As a result, the RSIU had a set power up state. The initial engineering for new ATCT pointed out this feature and had the ILSs default to the predominate winds. The winds in St. Louis would favor approaches to runway 30s about 60% of the time so that was the default configuration. The power failure, however, occurred while the airport was configured for runway 12s.

As a result, the controllers cleared pilots for ILS approaches to runway 12 when runway 30 was selected. The pilots reported back they had no signal so technicians were dispatched to the field facilities to bypass the interlock and bring up runway 12s. When the TCCS came up, the confusion was realized. The TCCS displayed runway 30s were selected instead of runway 12s. After the technicians went back to the field facilities to unbypass the interlocks, the system was fully working again.

3.6 Spirit of St. Louis (SUS)—AFSS

During the flood of 1993, the Automated Flight Service Station (AFSS) from Chesterfield, MO, was temporarily relocated to St. Peters, MO. After the levees were built up and repaired, a project was approved to move the AFSS back to Chesterfield. The new facility would be 2 stories with all the equipment on the second floor. This would put the facility above the 500 year flood plane for that area. The new AFSS would be on Spirit of St. Louis (SUS) airport property.

In addition to providing normal AFSS services, this facility would also provide advisory information for the airport when the SUS ATCT was closed. As a result, there was an added requirement to remote the ILS and Approach Lighting System (ALS) controls from the ATCT to the AFSS during the time the ATCT was closed. Connectivity between the ATCT and the AFSS would be by fiber optics.

Rather than use PLCs again, I decided the best approach would be to use a communication card in the fiber system and use serial communication between the two facilities. It was anticipated that one day, control would switch to St. Louis Terminal Radar Approach Control (TRACON) rather than the AFSS since that is the Air Traffic facility involved in the final approach phase into Chesterfield when the ATCT is closed. By designing around data cards for the fiber system, modems could be used to send control over telephone circuits or the FAA's Low Density Remote Communication Link (LDRCL) which is a microwave system. This approach would require designing: 1) a new interlock controller that would concentrate the ILS status and controls into a data stream; 2) a new ALS controller that would concentrate the ALS status and controls into a data stream; 3) a new ILS monitor and control panel for Air Traffic; and 4) a new ALS control panel for Air Traffic.

The ILS interlock controller design was built upon the KC-905 Option 2. It had the same inputs including the built in interlock relay. In addition, an input was added to select which ILS Air Traffic panel would have control. In the Kansas City design, the KC-462 panel assumed control when a ground was fed to the individual panel. A rotary switch in the Tower CAB would allow Air Traffic to select which KC-462 panel had control. Because the new ILS Air Traffic panels could be located in different facilities, the interlock unit needed to know which panel was selected. Each panel would be assigned a unique ID. The interlock unit would broadcast to all units the ID that had control. Then each ILS Air Traffic panel would indicate control or monitoring only based upon that panels internal ID. The new ILS interlock controller was named a KC-905 Option 3.

The front panel of the KC-905 Option 3 looked the same as the KC-905 Option 2. It provided 11 status indications of Normal, Alarm, or not used. It indicated the status of the built-in interlock relay and also had a smart reset button. The smart reset button would only reset facilities in alarm that were not interlocked off. The back of the KC-905 Option 3 was different in that it did not provide discrete outputs to drive the KC-462 panels. Rather, it had a DB-9 connector to communicate with the new ILS Air Traffic panel. Three communication specifications were considered: RS-232, RS-422, and RS-485.

RS-232 had the limitations of needing to be within 50 ft of each device. Most distances from the maintenance equipment room to the Tower CAB range from 75 ft to 250 ft. This limitation would mean short haul modems would also be necessary. Another disadvantage is that RS-232 is a point to point communication. The controller unit would require a separate communication port for each Air Traffic panel to which it needed to communicate. The advantage is that most computers have an RS-232 communication port which could be used in future applications. RS-232 modems are also readily available for use over telco or fiber systems.

RS-422 uses two wires for determination of a high or low. The A line is high while the B line is low for a High bit. The A line is low while the B line is high for a Low bit. By using a comparator looking for greater than 150mV difference between the lines, this 5 Vdc system can reliably drive communications for 5000 ft. No additional short haul modems are needed. Because it is a balanced pair, noise coupled on the line will change the potential of both lines nearly equally. The disadvantage is the communication is point to point. This would also require the interlock controller to have a separate communication port for each Air Traffic panel. Advantages include RS-422 modems are available for telco and fiber systems.

RS-422 can be configured for a 2-wire half duplex bidirectional communication or for a 4-wire full duplex communication. Since FAA telco orders require using 4-wire systems (2 wires for transmit and 2 wires for receive), RS-422 meets the FAA requirements for telco without using additional 2 to 4 wire hybrid converters.

RS-485 has the same specifications as RS-422 with one exception. RS-485 supports a tri-state in which it neither sends a low or high bit. Each A and B line has a pull up resistor tying the lines high. The RS-485 driver uses an open-collector transistor configuration to tie the desired A or B line low when enabled. When the RS-485 driver is not enabled, neither line is pulled low so another device on the bus can take control. This will allow multiple Air Traffic panels on a single communication port from the interlock controller. The interlock controller will always be enabled so it can communicate using either RS-422 or RS-485. All of the Air Traffic panels will have the receive input enabled and receive the data from the interlock unit. Only the Air Traffic panel with control will have its RS-485 transmitter enabled. The others will be in a tri-state, or not enabled. Each Air Traffic panel will have a unique ID. The interlock controller will broadcast which ID has control.

RS-485 has introduced another problem. Most modems do not support RS-485. The reason is the tri-state. The Modem must know the baud rate and bit length in order to determine how long to gate on the RS-485 enable. Too short or too long results in communication errors (lost bits, parity, check sum, etc). The fiber equipment used at Chesterfield did not have RS-485 cards but they did have RS-422 cards. A converter was also needed.

To convert the communications, a new panel was designed and named a KC-477. This panel would convert 2 separate RS-485 communication ports to RS-422. It used a microcontroller and incorporated limited signal processing to clean up and reconstruct the data bits. Since the data was routed through the microcontroller, the design was enhanced to function like an audio jack panel. An audio jack panel allows communication between equipment and line (usually telco) and has a monitor position to allow technicians to monitor the audio. It also has a jack position where the technician can break the connection between the equipment and line and connect test equipment directly to either the equipment or line. This aids in isolating problems.

The KC-477 has a 3 position switch labeled: RS-485; Monitor; and RS-422. This switch is located above a DB-9 connector labeled RS-232. When the switch is in the RS-485 position, the KC-477 converts the full duplex communications from the RS-485 to the RS-232 port. When the switch is in the Monitor position, the KC-477 converts the full duplex communications from the RS-485 to the RS-422 port. It also transmits the bidirectional communication between those two ports on the RS-232 port. The RS-232 receive port has no function in this switch position. This monitor position allows a laptop or computer to monitor the communications between the RS-485 and RS-422 ports. It can be used for trouble shooting or data logging. When the switch is in the RS-422 position, the KC-477 converts the full duplex communications from the RS-422 port to the RS-232 port.

The KC-477 has also added traditional modem LEDs to monitor the communications between RS-485 and RS-422. Two color LEDs (red/green) indicate transmit and receive from each port. A green light indicates a low is present. A red light indicates a high is present. This visual indication gives the technician a quick indication if the interlock unit and Air Traffic panels are communicating.

Since the KC-477 provides a monitor RS-232 port, it was decided the data stream would use visible ASCII characters so a terminal emulation program could readily display and capture data. The data is broken down to six bit blocks but transmitted as bytes, or 8 bit segments. Binary code 00100000, or decimal value 32, is added to the six bits resulting in a range of binary code range of 00100000 to 01011111, or decimal range of 32 to 95. ASCII[4] decimal code 32 to 95 are text printable characters. This allowed the most significant bit to be used for parity encoding. Using a program like Windows HyperTerminal, the technician can easily see the stability of the data stream to the Air Traffic panel and the reply from the Air Traffic panel to the interlock controller.

The Air Traffic panel was based on the KC-462 panel. It was named KC-474. The front panel was identical to the KC-462 using the same LED indicators and push button switches. From the Air Traffic controller's perspective, the two panels are identical with one exception. Since the KC-474 panel is receiving data, there needed to be a communication fault indication. The KC-474 panel receives an update data stream 5 times per second. If it fails to receive a valid data stream within 3 seconds, it initiates a communication fault indication. A communication fault can occur because no data is received or when data is being received with parity errors. During

[4] American Standard Code for Information Interchange-published as a standard in 1967, last updated 1986.

the 3 second window, the KC-474 displays the last valid data. Whenever a valid data stream is received, the KC-474 immediately updates the indications.

When a communication fault is initiated, the KC-474 will begin a flash routine where all LEDs blink for about 5 seconds and then go blank. Without a communication fault, the runway LED for the selected ILS is always on. With a communication fault, the runway LED is also off. A KC-474 panel with a communication fault looks like a panel without power; however, when the Lamp Test button is pushed, all the LEDs will turn on if the panel has power. The KC-905 Option 3 would stay in its current interlock configuration upon a communication fault.

If the KC-474 panel had control when it went into a communication fault, it also forces an aural alarm so that the controller acknowledges there is a loss of monitoring but not necessarily a facility in alarm. Air Traffic can continue authorizing approaches to an ILS that has lost remote monitoring. The facility must be down graded to CAT I approaches without monitoring if it were a CAT II/III ILS. The KC-474 panel that had control when the communication fault occurred continues to have the control indication LED turned on while the other LEDs are off. This reminds the controller that he or she does not have the ability to switch runways. Upon return of a valid data stream, even during the blink routine, all panels return to displaying the correct status. The panel with control will also sound an aural alarm upon return of communication so that the controller acknowledges control and monitoring has returned.

Each KC-474 has a selectable ID. The KC-905 Option 3 indicates which ID has control through the data stream. It also pauses before repeating the data streams to allow the KC-474 to respond with any pending requests. If no requests are pending, the KC-474 doesn't respond. Whenever a new KC-474 gets control, it sounds an aural alarm so that the controller acknowledges receipt of control.

The existing ALS control panel for Air Traffic at Chesterfield consisted of: a toggle switch to select between Air to Ground, Off, or Ground to Ground operations; a rotary switch to select between low, medium, and high intensity; and another toggle switch to select whether or not sequence flasher were on or off. This panel routed +48 Vdc to the ALS to energize control relays at the facility.

Air to Ground function allows a pilot to sequence through the different intensities. This is commonly used at airports without an ATCT or when the ATCT is closed. The pilot clicks his/her mike on the Common Traffic Advisory Frequency (CTAF) 3 times for low intensity, 5 times for high intensity, and 7 times for low intensity. The ALS then stays on for 15 minutes until turning off to conserve electricity. The pilot is encouraged to cycle through the intensities since rapidly changing intensities causes thermal shock and reduces the life of the incandescent lamps.

Ground to Ground function keeps the ALS on all the time at the intensity selected. The controller must select off to keep the ALS off. In order not to reduce the life expectancy of the incandescent approach lights, the controllers have to procedurally step through the different intensities. To go from an off setting to high intensity with sequence flashers on, the controller would have to do the following: 1) turn the sequence flashers to off; 2) turn the intensity to low; 3) turn the switch to ground to ground and wait 2 seconds. Selecting ground to ground would turn on the ALS to the selected intensity and flasher indication; 4) turn on the sequence flasher and wait 2 seconds; 5) change the intensity to medium and wait 2 seconds; 6) change the intensity to high. To turn off the ALS, the controller needs to reverse the steps above.

A new ALS panel was designed and was called a KC-905 Option 4. This panel controlled two separate ALSs—one for each end of a runway. A microcontroller chip was used to create a communication scheme similar to the KC-905 Option 3 panel for remoting status and selecting different Air Traffic panels for control. The microcontroller would control latching relays and sense the state of the relays for routing +48 Vdc to the appropriate ALS relays. The KC-904 Option 4 did not use the +48 Vdc for power. That voltage was simply routed through the KC-905 Option 4. By using latching relays, the ALS would stay in the last state upon a communication fault or power failure of the KC-905 Option 4. In addition, the KC-905 Option 4 had a bypass switch and mechanical switches. In the bypass position, all +48 Vdc signals were routed through the mechanical switches instead of the latching relays. In the normal position, all +48 Vdc signals were routed through the latching relays instead of the mechanical switches.

Since the microcontroller controlled the latching relays, the Ground to Ground functions were automated. The Air Traffic controller could select high intensity with sequence flashers on directly from an off position and the KC-905 Option 4 would step through the intensities with 2 second delays until the desired configuration was achieved. This freed the controller to attend to other activities.

The KC-905 Option 4 also sent the data in a visible ASCII format for the same benefit as the ILS control system. The data stream would indicate which Air Traffic panel ID had control and would also indicate if the KC-905 Option 4 was in bypass. The KC-477 panels supported 2 separate data inputs so one could be used for ILS and the other could be used for ALS.

The new Air Traffic panel for the ALS was called a KC-476. It had indications for each runway end as well as two LEDs for each requested state. When the KC-476 did not have control, each set of LEDs would turn on indicating the current state of the ALS. If the KC-476 panel had control, a requested change in the ALS configuration would result with a single LED on for the current state of the ALS and another LED for that blinked to indicate the desired state. Once the current state and desired state matched, both LEDs for that state would remain on.

In the previous example of changing from an off state to high intensity with flashers on, the controller would simply change the Off switch to Ground to Ground, intensity to High, and Flashers on, in any order. The KC-476 would blink high intensity and blink Flashers on. Two seconds later, a single LED would indicate Low intensity while a single LED blinked High and a single LED blinked Flashers on. Next, the both Flashers on LEDs would stay on while a single LED indicated Low intensity and a single LED blinked High. This process would continue until both High LEDs remained on.

The KC-476 also had a similar communication fault indication by going into a blink pattern for 5 seconds and then blank no longer indicating the runways. Lamp test would distinguish between loss of power and communication fault. In the event the panel with the communication fault had control, an aural alarm would also sound.

To support the complexity of this new system, a technical instruction manual was written detailing the operation of the system, troubleshooting flow charts, standards and tolerances, corrective and preventive maintenance, etc. On site training was provided to the local technicians as well as Air Traffic at the Chesterfield ATCT and new AFSS. 100% sparing was provided so the technicians could set up mock system. This mock system would ensure they had working spares on site and would also allow local refresher and new training on the system.

The new AFSS opened on April 15, 2000. This system remains in use at Chesterfield ATCT. The AFSS has been contracted out and was consolidated to Fort Worth, TX in July 2007. The contract did not allow for ILS/ALS monitoring and control so this system was remoted to the St. Louis TRACON where the original panels built in 1999 remain in service.

3.7 St. Louis International (STL)—Runway 30L LDA

Runway 12L/30R and runway 12R/30L at St. Louis International are the primary runways for landing commercial traffic in St. Louis. Since those runways were built, safety regulations were put into place nation wide that require parallel runways to have a lateral separation of 4300 feet[5] for simultaneous or landings. Those two runways are only separated by 1985 feet. Typical separation for landing

[5] Lateral runway separation for simultaneous ILS approaches can be reduced to 3000 feet for parallel approaches or 3400 feet converging approaches is Precision Runway Monitoring (PRM) Radar is used.

aircraft on a single runway is 5 Nautical Miles (NM). Since the two runways don't have the required horizontal separation, an aircraft flying an ILS approach to 30R needs to stay 5 NM behind a plane flying an ILS approach to either 30L or 30R. The number of planes that can land or take off in an hour at an airport defines that airport's capacity. In the preceding example, St. Louis would have the same capacity with one runway closed as it would with both runways open. The above scenario is also called single runway capacity even if more runways are open.

To increase capacity, a Localizer Displaced Array (LDA) was installed on Runway 30L and 12L. An LDA is a localizer that is not aligned with a runway. At St. Louis, these two LDAs were placed parallel to the runways on the outside to increase the horizontal separation and allow near simultaneous approaches. The pilot flying an LDA approach would fly a course that is offset from but parallel to the runway. At the MAP, the pilot could turn inward and align with the runway if he/she can visually see the runway since the separation distances are different once the pilot is flying visually. This requires an S-turn maneuver within 2 miles of the airport. The result is a staggered alignment of aircraft. One airplane would fly the ILS for 30R. A second airplane would fly the LDA for 30L trailing the first plane by 2 miles. Once the second plane hits the MAP, the first plane is landing. A third plane would have to trail the second plane by 5 miles because that plane is still flying an ILS when the second plane turns in for a landing. The pattern continues and capacity at St. Louis is increased by 42% (20 planes can align for landing in 70 NM using LDA compared to 14 planes can align in single runway capacity).

Around 1985, a Trans World Airline (TWA) pilot noticed he could tune in one ILS receiver on the 30L ILS and a second ILS receiver on the 30L LDA and would get Glide Slope information for the LDA approach. Glide Slope information allows a pilot to maintain a constant decent rate which saves fuel and money for the airlines. Every time a plane levels off altitude, it has to make throttle adjustments and burn more fuel. Since the LDA procedure is similar to a localizer only approach, it incorporates a stair step method of altitude changes. The 30L LDA approach was not approved for use with the 30L Glide Slope. The LDA approach also required a an S-Turn maneuver on short final which is less desirable than gradual adjustments prior to landing. Through that pilot's efforts, the FAA was petitioned to develop an angled LDA approach with a Glide Slope.

The project for the LDA with Glide Slope project was approved for St. Louis around 1998. The angled approach was intended to accomplish two objectives: 1) provide a constant decent via a Glide Slope; and 2) reduce the amount of S-Turn maneuvering on short final. The course of the LDA was determined by FAA flight procedures division and in cooperation with pilots flying simulators. The siting of the localizer antenna array had to be on that course. Due to space limitations constrained by the airport layout, the localizer had to be located around 4000 feet beyond the stop end of runway 30L. This would cause an interference problem with the ILS approach to 12R due to the close proximity of flying over the 30L LDA array while tuned to the 12R Localizer frequency. FAA Orders and ICAO standards require an additional interlock in cases of interference. This means the three localizers, 12R, 30L, and 30L

LDA, had to be under an interlock that allowed only one of the three systems to be on at a time.

The new 3-way interlock also had to interface to the existing TCCS at St. Louis. The new design was built with several configurations. It could interface a stand alone ILS to the TCCS. It could interface two ILSs under a single interlock to the TCCS. And It could interface three ILSs under a single interlock to the TCCS. The new design was called a KC-2081 Option 2 and incorporated the external pi filters needed when the TCCS was first put in at St. Louis. This would make all the TCCS ILS interfaces with noise suppression as a line replaceable unit. The previous interface used a single runway select signal from the TCCS as an input to the RSIU. The RSIU would toggle between the two ILSs to select which one was interlocked on. As stated previously, the RSIU did not return to the last state upon power reset. It also did not limit the time between the double pulse required to change runways. The KC-2081 used a microcontroller to first validate a runway select request. It required two consecutive pulses to occur within 8 seconds to be considered valid. The pulse shapes were also digitally processed to distinguish between noise and intended pulses. This was in addition to the hardware pi filters.

The KC-2081 also determined interlock states by latching relays controlled by the microcontroller. Upon a power on reset, the ILSs would return to the previous interlock state. After the engineering was approved but before the LDA was installed, national guidance came out restricting the use of non-standard equipment without first getting a National Change Proposal (NCP) approved. Usually, NCPs were submitted to change an item under configuration management. This would include equipment modifications and changes to FAA Orders. Interlocks were not under configuration management. Local management wanted the interlock design baselined through the NCP process so an NCP was submitted.

Prior to the NCP being regionally approved, the following items had to be developed and approved: 1) Provide the specific FAA Order reference and ICAO references requiring a 3-way interlock; 2) develop a technical instruction manual for the 3-way interlock; 3) Develop a Regional Approved training course with assigned training number for training records on the 3-way interlock; 4) Provide training to all the site technicians at Lambert; 5) Provide made to print fabrication plans for replacing the sparing to the site in case the internal FAA fabrication shop disbanded; 6) Provide a Failures Mode Effects and Criticality Analysis (FMECA) Report to demonstrate the reliability of the design; and 7) Provide 100% on site sparing.

Without any support help, I completed the above requirements in 11 months. It was then routed for national approval. Meanwhile, the project requirements kept changing. Airport capacity was causing delays nation wide and the FAA devised 2 strategies for increasing capacity. The long term strategy was to build more runways. This process usually takes about 15 years due to planning, budget, land acquisition, etc. A new runway can cost 1 to 2 billion dollars and will involve lawsuits if eminent domain is required. The short term strategy was to make better use of existing runways. The advent of PRM would allow airports to increase capacity that had parallel runways with lateral separation greater than 3000 feet but less than 4300 feet. For airports with parallel runways closer than 3000 feet lateral separation, a Simultaneous Offset Instrument Approach (SOIA) would be developed. The concept was to add an LDA with an angled course 3 degrees offset from the runway course. A Glide Slope would also be added. By using PRM, the LDA course could converge and simultaneous approaches on the LDA and the parallel runway ILS could occur. For airports that met this criteria, the capacity would double. Airports like St. Louis that had an existing LDA would see an increase in capacity of 40% (28 planes in 70 NM with SOIA compared to 20 planes in 70 NM with LDA and parallel ILS). Figure 1 below shows an LDA configuration and a SOIA configuration.

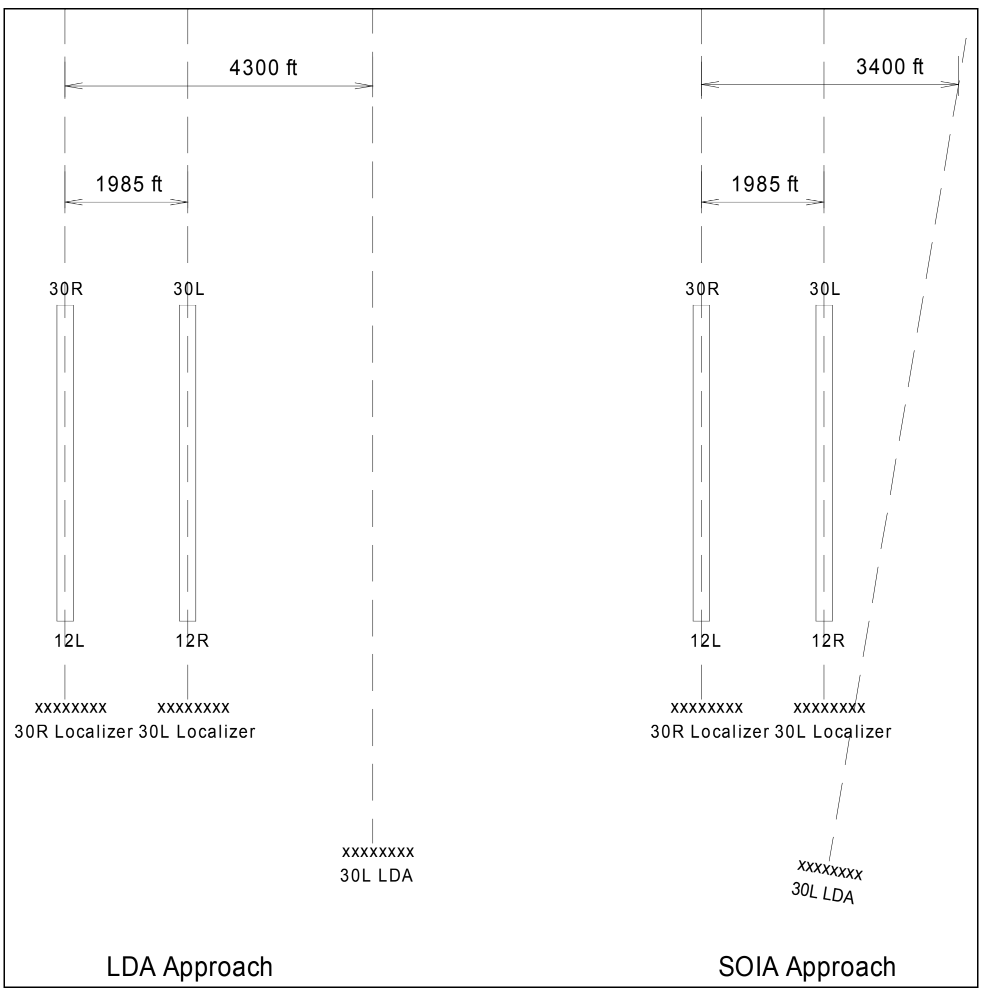

Figure 1: LDA Approach and SOIA Approach

As a result, the LDA with Glide Slope project at St. Louis was delayed until the SOIA requirements were developed. The Washington Program Office did not want to commission the facility in St. Louis if it did not conform to the new national standard. Because the project was delayed, the Navigation Configuration Control Board (CCB) would not approve the NCP for the 3-way interlock. By 2004, after reviewing the NCP with all non-concurrences removed, the CCB final denied the NCP on the basis they believed it modified the TCCS which they had no authority to approve.

The 3-way interlock design was modified to add two enhancements: 1) a manual bypass switch was added to bypass the latching relays and control the ILS interlock even if the microcontroller lost power or if the TCCS failed and could not request a runway select; and 2) an external lockout relay was added that broke the connection from the TCCS to the interlock interface. The second option was added to help the TCCS system pass a safety assessment. The TCCS has no ability to turn on multiple ILSs at the same time under a single interlock. That function is handled by the interlock interface. The TCCS did have the ability to turn off an ILS by means of requesting a runway select change. If there was an error in the TCCS source code, that could result in a loss of an ILS during an ILS approach. The new design was called a KC-2081 Option 3.

For Cat I and Cat II approaches, loss of signal is detected by the pilot and he or she has time to execute a missed approach. For Cat III approaches, however, the pilot is committed to landing once he or she is less than 50 feet above the ground. In Cat III conditions, the pilot can still be flying in zero visibility. With the loss of the localizer and glide slope, the plane will hit the ground and damage or fatalities will occur. By locking out the TCCS during Cat III operations, no reliability study on the TCCS software is required.

In keeping the FAA's commitment to increase capacity, the FAA administer publicly announced the SOIA approach would be published by October 2005. A new NCP was submitted as a change to the Mark 20 Technical Instruction Manual. The single picture showing a typical interlock scenario with 2 ILSs was modified to show an optional third ILS and the new interlock interface. All references to the TCCS connectivity was removed and the Administrator's promise was added as a time critical justification for approving the NCP. The NCP was approved and the SOIA approach was published for St. Louis in October 2005.

3.8 Western Nebraska Regional (BFF)—Runway 12 ILS

Western Nebraska Regional airport, located in Scottsbluff Nebraska, has an ILS on Runway 30. A Congressional Mandate required an ILS to be installed on Runway 12, the opposite end of Runway 30. FAA Orders and ICAO Standards require opposing ILSs to be interlocked. Order 6750.16D had a change in 2005 that also requires ILSs to be monitored 24 hours by Air Traffic personnel. Furthermore, if the ILS is interlocked, control must also be available or remoted to Air Traffic personnel.

Scottsbluff project would complete a universal interlock design. The KC-474 would be the Air Traffic panel that could be located on site or remoted. Control of the KC-474 could be switched for cases where an ATCT was not opened 24 hours per day. The KC-905 Option 3 could interlock Mark 1F ILSs. All that was needed was an interlock panel for a Mark 20 ILS that could also drive the KC-474 panels. Scottsbluff was getting a Mark 20 ILS. Order 6750.16D also clarified that regionally designed Air Traffic panels could be used without NCP approval if it did not change the failsafe interlock. Therefore, a decision was made to use ULCSUs on the Mark 1F ILS installed on Runway 12 and the Mark 20 RSIU to handle interlock. The new interface design was similar to the St. Louis initial TCCS interface. It would use the discrete outputs and inputs of the RSIU along with a microcontroller to drive the KC-474 panels. The interface also had inputs for selecting control. The control could be selected either by direct wiring at the interface unit or by software. The new interface would poll the KC-474 panels indicating control but every 16th poll would send a request for control. A separate unit would respond to this polling with the current or new KC-474 panel ID that should have control. The new interface panel would then change control. This would allow the control selection to be made remotely. The new interface panel was named KC-2081 Option 4. The new control selector unit was named KC-659.

4.0 FUTURE CONSIDERATIONS

Future ILS contract purchases should specify status communication and interlock control signals. This will make all future interlock systems and Air Traffic panels compatible with all vender supplied systems. The FAA should assume responsibility for the interlock design. This will ensure the ILSs cannot erroneously radiate due to an interlock design flaw. The design should also incorporate a method to remote monitoring and control to various locations.

In addition, the failsafe concept of interlock should be changed. The current method is intended to prevent HMI. This is achieved by preventing an interlocked ILS to radiate if it loses communication with the interlock controller. The result is the active ILS will shut down during a communication fault with the interlock controller. A Cat II/III ILS that shuts down due to a communication fault with the interlock controllers has an unscheduled outage. This outage affects its demonstrated reliability as outlined in the FAA and ICAO Continuity of Service requirements. Too many outages results in a down grade of that facility.

A better way to implement an Interlock is called state persistence. In this case, any ILS that loses communication with the interlock controller should remain in its current interlock state—on if previously selected, or off if not previously selected. To implement this method, localizers, glide slopes, etc would have to be modified. In addition, the interlock controller must ensure communications with both ILSs before making a change. The required steps for the interlock controller would be: verify no communication fault exists; direct the active ILS to turn off; verify that ILS turned off; direct the other ILS to turn on. If those steps cannot be accomplished, the interlock controller needs to indicate which steps could not be performed and prevent any additional changes until the problem is fixed. Under this configuration, the ILS will never shut down due to a communication fault with the interlock controller. For Cat II/III ILSs, that means the communication fault will not affect its reliability.

Current ILSs requiring interlocks would need to be retrofitted or modified to the new status and control protocol and state persistence interlock. This must take place at sites interlocked with a new system.

The interlock system should also be able to handle a variety of interlock scenarios. Except for the isolated St. Louis case, the designs presented in this thesis only cover a 2 ILS interlock. It is possible that multiple interference combinations could prevent unique interlock configurations. A universal interlock system that could also incorporate various configurations would be beneficial. If that unit uses software to configure and ensure a positive interlock, the source code and design must conform to RTCA/DO 278.

5.0 CONCLUSIONS

Standardizing the interlock, monitoring, and control system for ILSs is needed. It would benefit the large workforce in the FAA that uses and maintains those systems by providing a common understanding. One training course could be developed and a national sparing stock could be maintained and deployed where needed. This reduces cost. There is also a safety reason to standardize this system. And finally, a standard system can be made very reliable. As the system fails in one location, improvements to the design can be implemented to all locations via field modifications. Reliability of the ILS affects the availability of the system. Since availability affects airport capacity, fewer delays results with more available systems.

The methods and designs presented in this thesis offer a solution that is available today but one that can still be improved upon. To gain the benefits and safety required with a universal approach, the FAA as an Agency needs to take an active roll in standardizing a system that addresses all the previous problems and anticipates future expansion needs.

6.0 REFERENCES

Aeronautical Telecommunications - Annex 10 to the Convention on International Civil Aviation, International Civil Aviation Organization (ICAO), July 2006.

FAA Order 6750.16D, Siting Criteria for Instrument Landing Systems.

FAA Order 6750.49A Change 5, Maintenance of Instrument Landing System (ILS) Facilities.

FAA Order 7110.65R, Air Traffic Control, February 2006.

FAA Order 8260.3B Change 19, United States Standard for Terminal Instrument Procedures (TERPS).

FAA Order 8200.39A, Flight Inspection of Precision Runway Monitors/Final Monitor Aid Display System, August 2002.

FAA Notice 8200.71, Simultaneous Offset Instrument Approach (SOIA) Localizer and Glide Slope Inspections, October 2004.

FAA Order JO 6750.57, Instrument Landing System Continuity of Service Requirements and Procedures, June 2007.

Facility System Equipment Profiles (FSEP) Data 2/23/06, FAA Database.

Universal Interlock Controller Conceptual Design Review PowerPoint presentation, April 2006.

RTCO/DO 278, Guidelines For Communication, Navigation, Surveillance, and Air Traffic Management (CNS/ATM) Systems Software Integrity Assurance, March 2002.