Hitless Space Diversity STL Enables IP+Audio in Narrow STL Bands

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Howard Friedenberg, Senior RF Engineer
Sunil Naik, Director of Engineering
Moseley Associates, Inc.
Santa Barbara, CA, USA

www.moseleysb.com

Contacts:
Howardf@moseleysb.com
snaik@moseleysb.com
(805) 968-9621

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Howard Friedenberg
Moseley Associates, Inc.
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ABSTRACT

HD Radio™ poses a new challenge to STLs, requiring the ability to transport an Ethernet channel at 300 kbps along side a 44.1 kHz sampled AES digital stereo pair and ultimately fit them into a single 300 kHz STL channel. This requirement is only possible with latest generation digital STLs operating with very high efficiency, e.g. 128 QAM. As QAM rates are increased, also is the sensitivity to multipath. "Hitless" switching enables real time space diversity antenna systems to combat instantaneous multipath fading on microwave paths that commonly occurs in Spring and Fall seasons. In this paper Moseley presents a new "hitless" switched transfer panel that completes a space diversity protected STL link which enables reliable link implementation at 128 QAM.

INTRODUCTION

Since its introduction a few years back the Digital Studio-Transmitter Link (STL) operating in the 950 MHz band has become an industry standard workhorse supplanting the venerable analog STL for wireless high quality audio transport. When first introduced its foremost application was in carrying an AES digital audio pair to the transmitter, along with a serial data channel for remote control.

With time the configurability of the digital STL opened the eyes of broadcasters to a variety of applications not long ago imagined. Today, along with the traditional program channels, multiple (4 & 6) channel linear uncompressed configurations, and advanced data applications such as HD Radio™, IP services, and RBDS join the transport path to the transmitter.

With these new applications requiring more and more throughput, the size of the STL channel has become the limiting factor. Higher data-packing requirements require higher modulation efficiency and added modulation complexity. As a result the transmission becomes more delicate, requiring greater received signal and is less tolerant to interference and multipath fading. Due to the tremendous investment broadcasters have in existing 950 MHz band STL infrastructure, the industry will be well served by techniques that allow greater payload utilization of the STL equipment and licenses they have in place.

In this paper we will be looking at issues that affect STL transmission reliability as they pertain to newer high rate applications. Path reliability and keeping your station on-air is the name of the game. Fading mitigation techniques must be implemented to handle these higher level data packing modulations effectively against channel impairments and to maintain consistent path integrity. Receive site frequency and space diversity techniques are a major tool in battling these effects. We'll describe how to properly implement STL diversity techniques with a "hitless" transfer switch.

Digital STL Revolution

What sets the digital STL apart from its own analog counterparts is it can do something that analog STLs can't. In a digital STL, multiple audio and data channels can be multiplexed together into a single stream for transport over a single STL channel. The digital STL then can adapt its data capacity based on these user applications. This requires increasing spectral efficiency or transmitted bits/sec per Hertz of bandwidth by increasing the number of states of Quadrature Amplitude Modulation (QAM) or the QAM constellation. This ultimately allows the digital STL to squeeze more audio and data into a fixed Part 74 BAS channel. Figure 1 depicts how QAM constellation determines the maximum composite data rates that can be packed into 500 kHz, 300 kHz and 200 kHz channels.

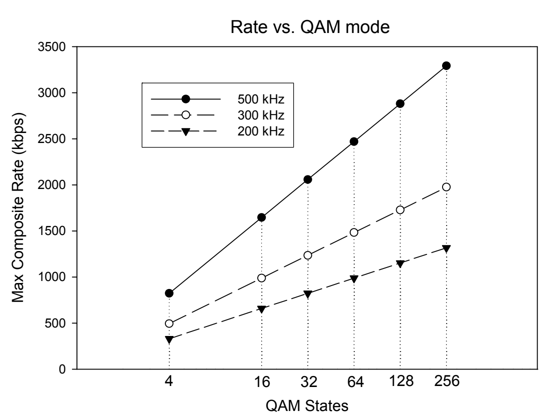

Figure 1 – Maximum Achievable Data Rates for QAM Constellations and Channel Bandwidths

Early adopter applications employed linear 16-bit 32 ks/s or 44.1 ks/s audio pairs to replace analog and compressed digital STL equipment. These applications worked reliably, providing only a modest challenge to the data packing capabilities of the digital STL. This application allows the use of very robust 16 QAM modulation to transport 1024 or 1411 kbps.

In contrast the new high-speed applications task the digital STL to much higher data packing efficiencies. Increasing QAM level complexity by adding more decision states, for instance, 16-QAM to 64-QAM to 128-QAM, and so on, increases spectral efficiency allowing us to pack increasingly more program and data capacity into the fixed STL channel as shown above in Figure 1.

Table 1 displays commonly shipped configurations showing associated QAM modes and aggregate data rates for standard 500 kHz Part 74 BAS allocations.

Rate (kbps)	QAM mode	Audio Channels x Rate (ks/s)
1411	16	2 x 44.1
1544	16	T1
1680	32	2 x 44.1 + 2 x 44.1 (MPEG256)
1728	32	2 x 44.1 + Ethernet 304kbps
1808	32	2 x 44.1 + 2 x 48 (MPEG384)
2048	32	4 x 32
2176	64	2 x 44.1(24bit)
2816	128	4 x 44.1
3072	256	6 x 32 or 4 x 48

Table 1 - Audio Configurations in a 500 kHz STL Channel

From Table 1 we see our latest driving application, adding a 300 kbps Ethernet pipe for the HD Radio™ Exporter with 44.1 ks/s analog stereo channels, raises the modulation requirement from 16QAM to 32QAM to fit in a 500 kHz channel. Moving from 16 bit dynamic range to 24 bit dynamic range raises the modulation to a 64QAM constellation. Four 44.1 ks/s channels are possible in 500 kHz at 128 QAM.

Next, taking our driving application, Ethernet pipe plus stereo pair, to narrow channel allocations we find our modulation requirements moving into the 64 QAM and 128 QAM realm. Narrow channel applications facilitate channel splits, spectral-efficient channel (SEC) and international allocations. Table 2 displays common audio configurations adapted to narrow channel applications.

Rate (kbps)	QAM mode	Audio Channels	Allocation Bandwidth (kHz)
1024	64	2x32	200
1411	128	2x44.1	250
1728	128	2x44.1+Ethernet 304 kbps	300

Table 2 - Narrow Channel Audio Configurations

From Table 2 we see the IP pipe plus 44.1 ks/s pair application fits into a 300 kHz SEC but requires a change in modulation from 32 QAM to 128 QAM. It becomes clear from Table 1 and 2 that the digital STL is adaptable to many applications.

PLANNING FOR A DIGITAL STL

System Gain vs. Channel Capacity

An obvious question is how does channel capacity impact system planning? There is a fundamental tradeoff between data packing and receive threshold. With increasing QAM constellation more signal-to-noise ratio (S/N) is required to receive error-free data. Hence higher data requirements raises threshold, and lowers system gain for the STL path. Also the higher S/N requirement creates a link that is more sensitive to transmission path disruptions and background noise. Figure 2 shows how changing the QAM states impacts the receive threshold level on the Moseley Starlink SL9003Q digital STL.

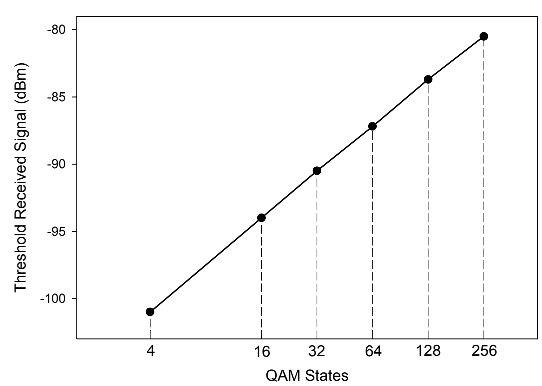

Figure 2 - Starlink Receiver Threshold in 500 kHz Channels

The immediate effect of increasing link capacity and hence QAM constellation on a Line-Of-Site (LOS) link is to reduce path length and/or fade margin. Every 6 dB that is lost in receive threshold translates to a loss of half of effective LOS link range.

Noise and Interference: C/N, C/I, and T/I

A secondary effect of increasing QAM states, but equally as important in volatile RF environments, is a loss of noise and interference immunity. For instance, in the busy Part 74 spectrum, occasionally, a user can have difficulty achieving the thresholds indicated in Figure 2. The discrepancy most frequently results from unexpected noise or interference. This condition worsens at higher data rates and QAM modes.

In digital radios there are three metrics that are helpful in assessing interference from background noise, co-channel, and adjacent channel interference. These are carrier-to-noise ratio (C/N), carrier-to-interference ratio (C/I), and threshold-to-noise ratio (T/I).

C/N. *Carrier-to-noise ratio* (C/N) defines the minimum amount of carrier power above noise power within its defined channel bandwidth required for an acceptable error rate. It is an ideal measure that does not account for interference, but regardless, a link must achieve sufficient C/N to operate. As the capacity of the digital STL increases with increasing QAM states so does the required carrier power to achieve sufficient error-free performance. Since the noise floor remains the same this means the C/N increases with QAM mode. Table 3 presents the C/N requirements for a digital STL.

QAM Mode	10^{-6} Threshold RSL (dBm)	C/N (dB)
16Q	-94	16
32Q	-91	19
64Q	-88	22
128Q	-84	26
256Q	-81	29

Table 3 – QAM Threshold, C/N

From Table 3 the noise floor (N) required to achieve threshold indicated is easily calculated. Using an example at 64 QAM:

$$N|_{64Q} = -88 \text{ dBm(threshold)} - 22 \text{ dB(C/N)} = -110 \text{ dBm}$$

By inspection of Table 3 it is seen that the noise floor is the same for all QAM modes, -110 dBm, in 500 kHz channels. Deviation from this noise floor is subtracted directly from achievable threshold, and hence from available fade margin.

Background noise can come from many sources at a transmit site but most often it is related to FM broadcast transmitter out-of-band noise finding its way to the receiver input. A simple method to verify that sufficient STL receive noise floor exists is to turn off the STL transmitter and check the receive signal level (RSL) on the STL receiver. With the STL transmitter off the RSL should now be indicating only received input noise. If the RSL is greater than -110 dBm then simply add the C/N value for the QAM mode in use to determine the new threshold. To this resultant value the fade margin is added to determine the minimum receive level.

C/I. *Carrier-to-Interference ratio* (C/I) characterizes the digital STL's ability to cope with interference when operating at nominal receive levels. C/I defines both in-band (co-channel) and out-of-band (adjacent-channel) performance for a given radio.

C/I is characterized at typical receive levels, typically 20 to 30 dB above threshold, and compared against an interfering signal of similar modulation and data rate. The interfering signal is moved across the band with its level adjusted to produce an error rate of 10^{-6} (1 error in 1 million bits received). This measurement paints an accurate picture of how a radio will perform against co-channel and adjacent channel interference for a radio in normal operation, or in other terms.

The C/I curve is plotted for the Starlink SL9003Q digital STL for available QAM constellation states in Figure 3. The shape of the curve generally follows the shape of the IF filter selectivity in a well designed radio as it does here. If it diverges from this shape then there are other nefarious intermodulation mechanisms at work inside the radio.

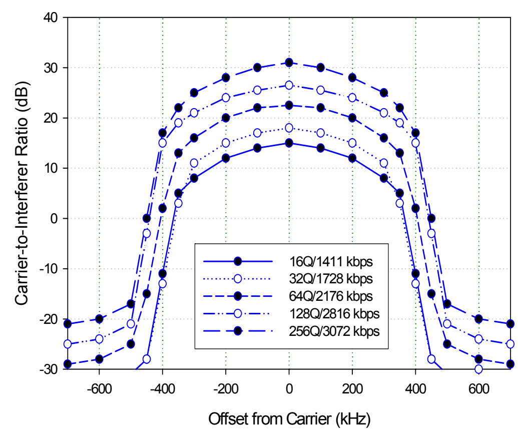

Figure 3 - Starlink Receiver Carrier-to-Interference (C/I) in 500 kHz channels

The C/I curve is used to determine allowable interference by subtracting the carrier power value from the C/I value. For instance, the curve value at 0 kHz offset defines the level of co-channel interference (I) to generate 10^{-6} bit-error-rate (BER). If a desired 16 QAM carrier's level at the receiver input is -60 dBm then,

$$I|_{16Q,\text{ co-chnl}} = -60 \text{ dBm(RSL)} - 16 \text{ dB(C/I@0kHz)} = -76 \text{ dBm}$$

Increasing constellation from 16 QAM to 64 QAM drops the link's resiliency to co-channel noise by 6 dB, from 16 dB to 22 dB. In the above example the co-channel tolerance drops to -82 dBm. Or in other terms this is equivalent to giving the interfering signal a 4x power advantage.

The C/I measurement characterizes out-of-band interference at the offset of the channel spacing frequency. Using the above example with a 16 QAM -60 dBm received signal,

$$I|_{16Q,\ adj\text{-}chnl} = -60\ \text{dBm(RSL)} + 32\ \text{dB(C/I@500kHz)} = -28\ \text{dBm}$$

This receiver can therefore tolerate an interfering signal of like modulation that is 32 dB *above* its own level at one channel away from the carrier.

T/I. *Threshold-to-Interference* (T/I) curves characterize allowable interference that a radio can tolerate when operating at threshold. By definition they indicate the absolute level of interference to degrade a victim's radio threshold, and hence fade margin, by 1 dB.

The concept of the T/I curve is quite important. In essence if a radio link is truly to realize its design fade margin then the interference levels must fall below the values calculated using these curves.

The T/I value is measured with the desired channel operating at 10^{-6} threshold and a like interfering signal swept across the band whose level is adjusted until a 10^{-5} threshold is achieved. The T/I of the Starlink SL9003Q is shown below in Figure 4 for 16, 64, and 256 QAM.

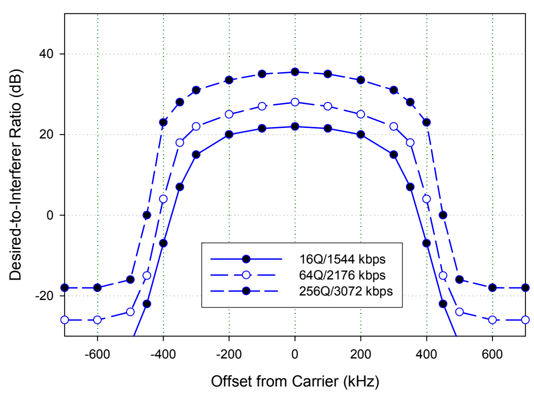

Figure 4 - Starlink Receiver Threshold-to-Interference (T/I) in 500 kHz channels

The T/I curve is used by subtracting the threshold value from the T/I value. Using the 16 QAM example

$$I|_{16Q,\ co\text{-}chnl} = -94\ \text{dBm(threshold)} - 22\ \text{dB(T/I@0kHz)} = -116\ \text{dBm}$$

Using this T/I method the maximum tolerable co-channel interference to achieve fade margin design for the SL9003Q is therefore -116 dBm.

This level is 6 dB below the required -110 noise floor calculated from Table 3. Again, this is true of all QAM modes; the maximum tolerable co-channel interference is -116 dBm, 6 dB below the required noise floor. This is because of basic noise power addition. Adding one noise signal that is 6 dB below a second noise signal will raise that signal by 1 dB, the requirement for T/I.

For allowable adjacent channel interference using the T/I method we find allowable adjacent channel inference to be:

$$I|_{16Q,\ adj\text{-}chnl} = -94\ \text{dBm(threshold)} + 27\ \text{dB(T/I@0kHz)} = -67\ \text{dBm}$$

Therefore -67 dBm is the highest absolute level for an adjacent-channel signal to allow this radio to achieve its fade margin design value.

Interference and Noise vs. Channel Capacity

From the C/N, C/I, and T/I performance we can make a few important observations. It is seen from Table 3 that as channel capacity increases with each step increase in QAM constellation so increases the C/N by approximately 3 dB, similarly lowering threshold by 3 dB.

Also, as channel capacity increases so does the link's sensitivity to in-band and out-of-band interference as shown in Figure 4 and 5. Though these observations are apparent to some they quite often are overlooked in lieu of salesmanship and enthusiasm for these new high-throughput applications. These are important tradeoffs for folks with difficult STL paths.

In practice, crowded transmit locals may produce unexpected raised noise floors and interference so utilizing the highest QAM modes, 256 QAM for instance, may be something of an academic exercise.

Field experience has shown in these challenging environments the highest link reliability is achieved in the lower capacity modes, 16 QAM and 32 QAM. These are the most trouble-free modes, and most resilient to interference and background noise as the data suggests.

There are many 64 QAM and 128 QAM Starlink SL9003Q systems in operation in the field as well. These links do require much closer attention to system planning, fade margins, elevations, and diversity. As a general rule the lower the QAM constellation the greater will be the path robustness.

Fading Effects

System planning is all about providing sufficient fade margin to avoid having a faded signal drop below the receive threshold. An example of a fading signal with inadequate fade margin is shown in Figure 5.

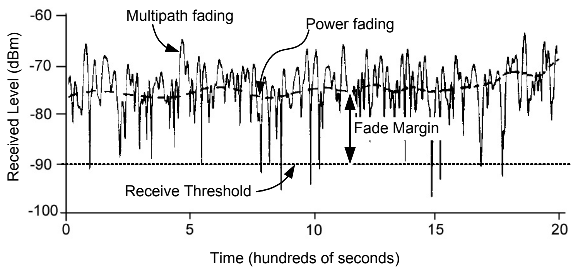

Figure 5 – Multipath and Power Fading

There are generally two types of fading, multipath and power fading. Power fading, also called attenuation fading, results from atmospheric propagation conditions such as subrefraction (path blocked from earth bulge), superrefraction (ray is bent away from the receive antenna) and ducting (ray is trapped in atmospheric layering and directed away from receive antenna. Power fading varies relatively slowly in time in comparison to multipath fading.

Multipath fading is the result of destructive interference between the direct ray and one or more rays reflected from an object or refracted in the atmosphere. This is shown in Figure 6.

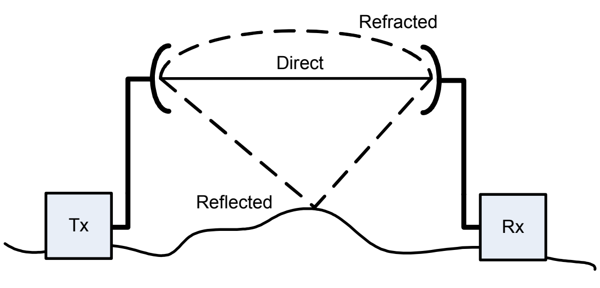

Figure 6 – Multipath Mechanisms

This fading mechanism can produce fairly rapid fades, often with a frequency selective component. Multipath can also produce some very deep fades when the direct and reflected rays add 180 degrees out of phase. Diversity techniques are the only effective method to combat these deep fades.

Fading occurs during periods of atmospheric stratification where layers have different refractive gradients during temperature inversions. This is most common under windless conditions, when hot and humid, and during late evenings and early mornings. Multipath fading is a function of path length, frequency, climate, and terrain.

Path Reliability

Fading is the foremost consideration in path reliability. The goal is to choose a fade margin to provide sufficient reliability for the link. For a traditional long-haul telecom link a preferred goal for path availability is 99.999%, referred to as the “five-nines”. Link availability (A) is defined as follows:

A = uptime / (uptime + downtime)

We also often speak in terms of unavailability (U) defined as follows:

U = 1 – A

So, 99.999% availability translates to 0.001% (1 - 0.99999) unavailability or about 6 seconds of outage per week, 5 minutes per year. For STL links a practical value of 99.9% availability of the worst month is the minimum used. This comes out to10 minutes of outage per week during the worst month.

For line-of-sight links the fading probability, availability, and conversely the unavailability, are related to a modified Rayleigh probability distribution defined by industry accepted methods, Vigants-Barnett, KQ Factor, and ITU-R P.530-6 through P.530-9. Path calculation software such as *Pathloss 4.0* implements these equations rather painlessly to aid system planning.

For this discussion the Vigants-Barnett method [1, 2] is generally a good approximation for fading probability (P_f) under most conditions:

$$P_f = 2.5\times10^{-6}\cdot a\cdot b\cdot D^3\cdot f\cdot 10^{\frac{-M_f}{10}}$$

where

D	=	path length in miles
f	=	frequency in GHz
a	=	terrain factor
		4 over water or flat terrain
		1 for average terrain
		¼ for mountainous terrain
b	=	climate factor
		½ for hot, humid climate
		¼ for average temperate climate
		⅛ for cool, dry climate
M_f	=	fade margin

For an example Figure 5 plots fading probability for a 35 mile path during a humid month, and somewhat smooth terrain (a=2).

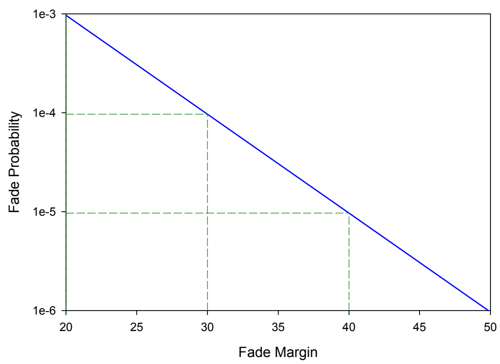

Figure 7 – Fading Probability

We see the slope is always 10 dB per decade of probability, meaning every 10 dB improvement in fade margin corresponds to an order of magnitude improvement in reliability and link availability. To find availability for this example:

$$A = (1 - \text{Fade Probability}) \times 100\%$$

So roughly for our 35 mile link we find we need a minimum of 20 dB for 99.9% availability, 30 dB for 99.99% reliability, and 40 dB for 99.999% availability.

Increasing Reliability – Dealing with Multipath

Multipath is the sworn enemy of path reliability. Techniques for dealing with multipath include diversity, increased fade margin, and adaptive equalization.

Adaptive equalization, which digitally corrects for channel phase and amplitude variations, is helpful in resolving frequency selective fading characteristics. It must be provided by design of the STL radio link selected by the user at the time of purchase. It is built into specific STL products, as can be found with the Starlink SL9003Q. If the radio has not been designed with adaptive equalization it may not be added at a later time without replacing the radio. Hence make sure that adaptive equalization is offered when purchasing a digital STL.

Fade margin may be increased with higher gain antennas, lower loss cabling, and/or transmit amplification. Of the three, however, linear transmit amplification can be quite costly for digital radio links. The "amplitude" varying component of the Quadrature Amplitude Modulation places a back-off requirement on the linear power amplifier output power. Usually this is on the order of 10 dB to 12 dB for the higher QAM modes, 64-QAM and 128-QAM respectively. For example, achieving a 10 W average output for a 64 QAM link would require a 100 W linear power amplifier.

Diversity techniques refer to utilizing two independent receiving and antenna systems that are separated in either space or frequency or both.

Space diversity uses two vertically separated receive antennas to provide two signal paths.

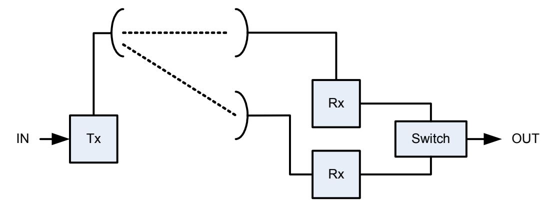

Figure 8 – Space Diversity

Space diversity is usually considered the most effective method for dealing with multipath. Improvement in reliability comes from the reduced probability that both antennas will be adversely affected by the multipath fade at the same time. The greater the spacing between the antennas the lower the correlation between paths and the greater the improvement to reliability.

Frequency diversity uses two signal frequencies with separate receive-transmit pairs that may operate on a common antenna. The transmitters are combined with a branching network or duplexer. The receivers are split with a power splitter.

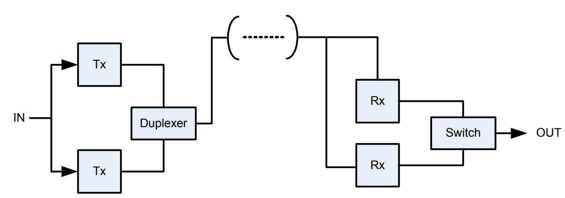

Figure 9 – Frequency Diversity

Improvement in reliability comes from the reduced probability that both frequencies will be adversely affected by the multipath fade at the same time. The greater the spacing between the transmit frequencies the lower the correlation between paths and the greater the improvement to reliability. Also, frequency diversity shares the same antenna system so antenna system costs and tower loading are reduced.

Practically speaking the 950 MHz Part 74 BAS band can be fairly congested in urban locations and available channels are in short supply. Finding two available 950 MHz frequencies separated by a sufficient amount may be something of a challenge.

Typical frequency diversity spacing is about 2%. This comes to 19 MHz in the 950 MHz band. The best frequency separation available in this band is 8 MHz if the furthest channels are used. For these reasons space diversity tends to be more practical for STL applications. However we do not rule out frequency diversity. We'll demonstrate that even a separation much less than 1% will add ample link reliability.

DIVERSITY IMPROVEMENT

The degree of improvement provided by diversity depends on the degree of correlation between the two fading signals. In practice, because of limitations in allowable antenna separation or frequency spacing, the fading correlation tends to be high. Fortunately, improvement in link availability remains quite significant even for high correlations [3].

An improvement factor can be determined to characterize the enhancement of reliability based on space or frequency diversity.

The *space diversity improvement factor* I_{sd} [2] modifies the fading probability as follows:

$$I_{sd} = 7 \times 10^5 \cdot \frac{S^2}{D} \cdot f \cdot 10^{\frac{M_f}{10}}$$

where

S = antenna separation in ft
D = path length in miles
f = frequency in GHz
M_f = fade margin

The space diversity fade probability P_{sd} is then given by:

$$P_{sd} = \frac{P_f}{I_{sd}}$$

The fade margin on the two antennas is assumed to be equal. I_{sd} is limited to a maximum improvement of 200. Antenna separations that yield an improvement less than 5 should not be used. Below this value the performance benefit is to low to justify the complexity and cost of a diversity implementation.

Antenna spacing should be between a minimum of 20 feet to a maximum of 75 feet. Spacing less than 20 feet will yield little improvement and spacing greater than 75 feet will see little incremental additional improvement. A separation of at least 30 feet should be employed when possible.

In Figure 10, using the path example from above we examine space diversity improvement for various antenna spacings, comparing that to a link with no diversity. The separation plots are displayed for a diversity improvement factor values $I_{sd} > 1$.

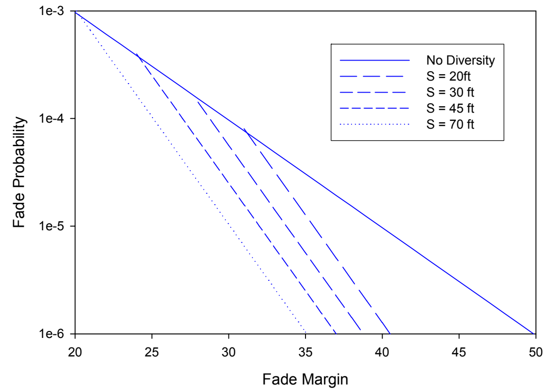

Figure 10 –Space diversity improvement @ 950 MHz for various antenna spacings

We can see from Figure 10 that space diversity increases the fade margin improvement from 10 dB to 20 dB per decade of probability. This means that link availability will improve two orders of magnitude for each 10 dB improvement in fade margin in a multipath environment compared to only one order of magnitude for the equivalent link without diversity.

Next we examine *frequency diversity improvement factor* I_{fd} [4]. This improvement factor modifies the fading probability by the following:

$$I_{fd} = 50 \cdot \frac{\Delta f}{f^2 \cdot D} \cdot 10^{\frac{M_f}{10}}$$

where

Δf = frequency separation in GHz
D = path length in miles
f = frequency in GHz
M_f = fade margin

The frequency diversity fade probability P_{fd} is then given by:

$$P_{fd} = \frac{P_f}{I_{fd}}$$

Figure 11 plots the improvement for diversity against a link with no diversity. The separation plots are displayed for a diversity improvement factor values $I_{fd} > 1$.

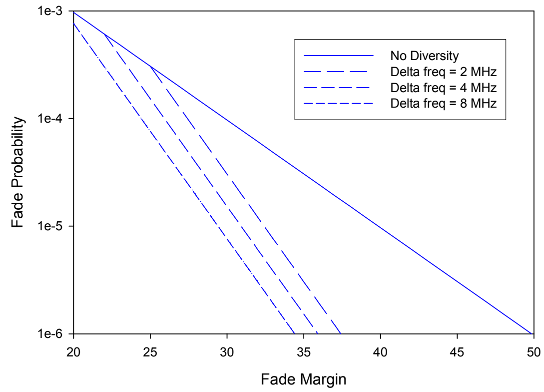

Figure 11 – Frequency diversity improvement @ 950 MHz for various frequency spacings

Figure 11 shows that it takes a surprisingly small frequency separation between diversity systems to yield significant improvement in path availability. Less than 1% separation is quite sufficient.

From Figures 10 and 11 we see that both space and frequency diversity improve path availability at 10 times the rate with increasing fade margin than a link without diversity. From this we can conclude that even though the higher capacity link will eat up fade margin by way of higher carrier-to-noise and carrier-to-interference requirements, diversity, either space or frequency, can add substantial reliability to these higher capacity links.

Implementing Diversity Design

Diversity is used to protect LOS radio links from fading and/or equipment failure. Traditionally STL diversity simply meant it was a one-for-one (1:1) protected link. It provided backup for equipment failure, offering a cold-standby transfer from one failed piece of equipment to a working piece of equipment. Main and backup STL share a single antenna.

True space or frequency diversity, as has been discussed, requires two active paths. Space diversity requires two receive antennas and two switched receivers. Frequency diversity uses two radio links on separate frequencies sharing the same antenna. Data is received from both paths, and requires an instantaneous synchronized transfer between two active data streams.

In either scenario the transfer panel is making a bit-wise decision on which receive data stream is healthiest based on bit-error information supplied from the receivers. The transfer panel then switches to that best data stream without creating any errors in the switchover. This is termed as a" hitless" transfer switch transfer. There is no interruption to service during the switchover. In comparison with a non-hitless transfer panel commonly used for equipment failure backup, the switch over could possibly be as long as the fade itself in some cases.

Figure 12 displays the internal operation of a hitless diversity receiver terminal. This block is based on the Moseley TP-HLS hitless transfer panel.

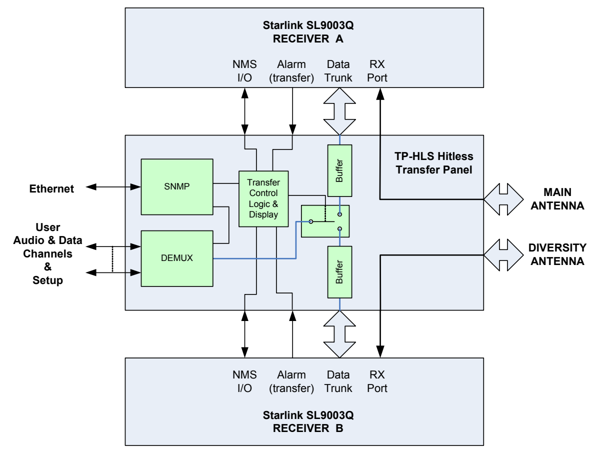

Figure 12 – Diversity Receiver Terminal with Moseley TP-HLS Hitless Transfer Panel

The TP-HLS buffers the output of each receiver and utilizes virtual frame alignment to synchronize each frame received from main and diversity receivers. Normally the main receiver data is utilized for primary data until that receiver presents a bit-error alarm to the transfer panel. When error alarm is received the buffered data is switched to the diversity receiver path.

A well designed hitless transfer switch should also provide the user with activity indications and full statistics, such as accumulated bit errors, loss-of-frame errors, etc. Figure 13 displays the TP-HLS front panel controls and display that allow the user full access to health status, statistics, and configuration.

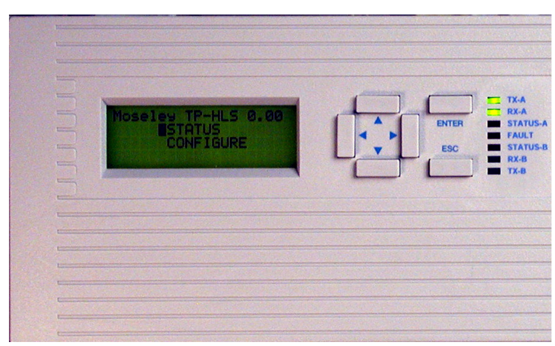

Figure 13 – TP-HLS Hitless Transfer Panel Display and Controls

An existing 1:1 protected STL terminal can easily be converted to a diversity terminal. The existing transfer panel may be replaced with the hitless transfer panel. A second antenna is added to the tower with adequate spacing from to the primary antenna. Note that the second antenna should have the same fade margin as the primary antenna. In practice it may not always be possible to achieve sufficient spacing on a given tower due to loading. However, adding a second antenna for diversity with a reasonable spacing should give an appreciable amount of multipath resilience resulting from the 10x reliability improvement due to diversity.

Figures 14 and 15 show diversity protected full-duplex applications. Figure 14 presents a diversity repeater application. From the block diagram it is seen that the TP-HLS offers hot-standby protection of the transmitter. The transmitter switching provides only failure diversity and is not hitless.

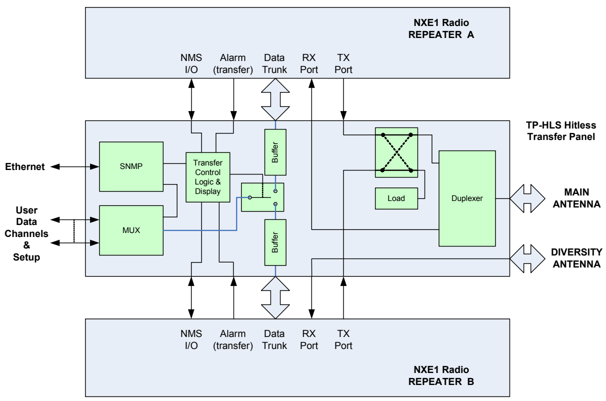

Figure 14 – Diversity Repeater STL Terminal with Moseley TP-HLS Hitless Transfer Panel

Figure 15 shows a diversity protected bidirectional T1/E1 radio terminal in operation.

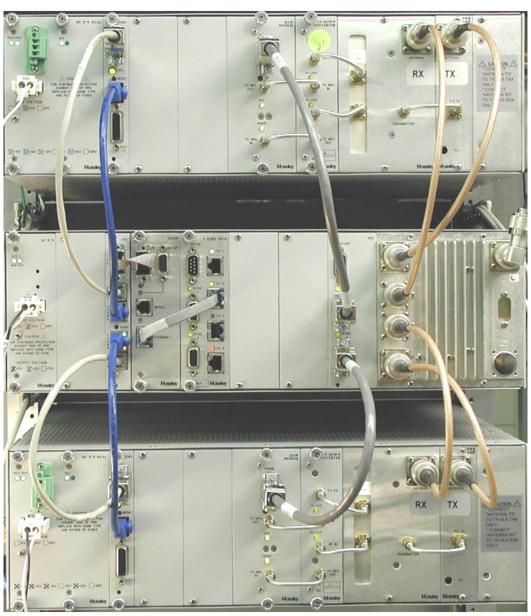

Figure 15 – Diversity T1/E1 Radio Terminal with Moseley TP-HLS Hitless Transfer Panel

CONCLUSION

New applications, the implementation of HD Radio™, and congested spectrums challenge the digital STL to higher channel capacities. Higher throughputs require higher modulation complexities. These higher modulation modes are more sensitive to both multipath interference and background noise.

Good system planning is paramount in utilizing the highest channel capacities of the digital STL. This includes diversity techniques to provide sufficient path reliability. Diversity techniques greatly enhance the availability of links operating in these higher capacity modes. It has been demonstrated that either frequency or space diversity implementations will realize a 10x improvement in reliability for the same increase in fade margin for a non-diversity link in a multipath environment.

The ability to implement a hitless switch allows these diversity techniques to protect full time links such as the digital STL. The result of this advance is the ability to employ higher QAM rates and benefit from the increased payload which can be packed into a narrow-band STL channel.

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