Technical Tidbits

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From early 1996 to early 2000, we included one technical tidbit in each monthly meeting notice for the local Colorado Springs & Pueblo meeting of communications engineers. Following is a compilation of these technical tidbits, organized into five categories: radio wave propagation & antennas, transmission lines, interference, receivers, and miscellaneous. These tidbits are not intended to be a handbook for radio engineers. In fact, most are obscure results that you won't find in the handbooks.

Radio Wave Propagation & Antennas

Q: What is a simple formula for calculating free space loss?

A: A useful formula for free space loss in dB is the following:

$$L = 22 + 20 \log_{10}\left(\frac{S}{\lambda}\right)$$

where S is the path distance and λ is the wavelength of the RF carrier. S and λ must be in the same units. A formula for calculating wavelength in meters is $\lambda = 300/f_{MHz}$. For example, consider an FM broadcast STL link from Cheyenne Mountain to Tiffany Square. The path distance is about 12 miles or 19.3 kilometers (19,300 meters). The wavelength is 0.3158 meters. The free space path loss is 117.7 dB.

Q: My land mobile radio base station antenna has 120° beamwidth in the horizontal plane and a mechanical beamtilt of -3° in the direction of the city of license. What is the beamtilt at the edge of the beam, at +/- 60°?

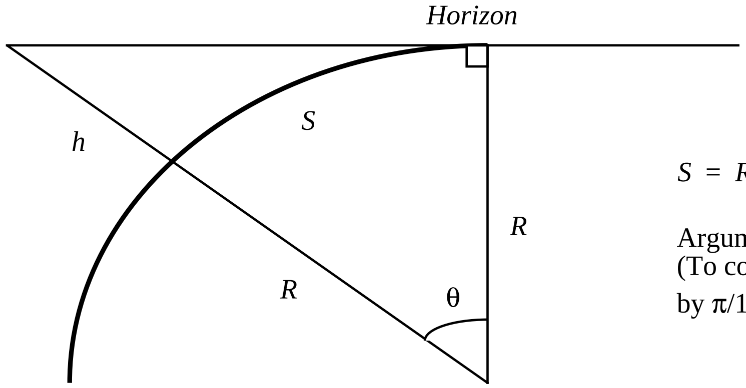
A: Electrical beamtilt ensures the same tilt in all directions. Mechanical beamtilt, on the other hand, varies from a maximum downtilt in the tilt direction to 0° tilt at +/- 90° azimuth and actually tilts upward behind the base station site. Here is the expression (without derivation) for the mechanical beamtilt, γ, at an arbitrary angle, α, from the center of the beam when the beamtilt at center is θ degrees:

$$\gamma = \arctan(\cos\alpha \tan\theta)$$

If the main beamtilt is -3°, the beamtilt at the edge of beam (at α = +/- 60°) is -1.5°.

Q: If my FM broadcast transmit antenna is 3,500’ above the surrounding terrain, how far is it to the radio horizon?

A: First, we need to know that the effective earth radius, *R*, for radio waves is typically 4/3 the actual earth radius (*R* = 5,278 miles). This effect is due to refraction in the earth’s atmosphere. To compute the distance to the radio horizon, *S*, we use the following formula which can be derived using the diagram below and high school trigonometry and geometry:



$$S = R\,\theta = R\cos^{-1}[R/(R+h)]$$

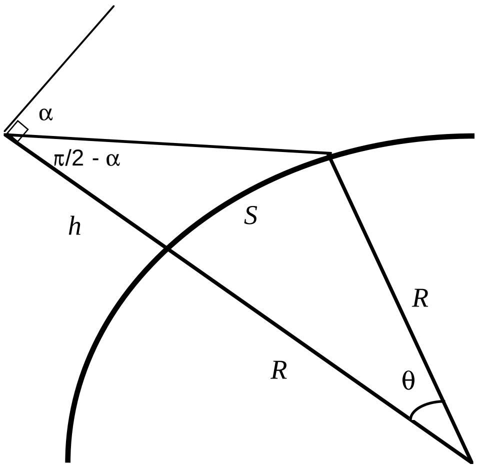
Argument of inverse cosine must be in radians
(To convert from degrees to radians, multiply
by $\pi/180$, $\pi = 3.14159$)

For *h* = 3,500’ (0.663 miles), the distance to the radio horizon is 83.6 miles. If your signal has not been squashed by free space loss at this distance, it will soon be gone due to diffraction losses over the earth’s surface.

Q: What is the appropriate downward beamtilt for my PCS antenna to place the main beam on downtown Colorado Springs? My antenna is 3,500 feet above the city and 6 miles away.

A: This is similar to the problem published in the July 1996 issue of the *Transmitter*. In that issue, we wanted to know the distance to the radio horizon. Now we want to know the look-down angle (beamtilt) for a given height difference and horizontal distance. The geometry of the problem is shown below where α is the angle we want to find.

First, we need to know that the effective earth radius, *R*, for radio waves is typically 4/3 the actual earth radius (*R* = 5,278 miles). This effect is due to refraction in the earth’s atmosphere. The equations to solve this problem are shown in the figure below:



$\theta = S/R$ radians

$$\alpha = 90 - \arctan\left[\frac{R \sin\theta}{(R+h) - R\cos\theta}\right] \text{ degrees}$$

(To convert from degrees to radians, multiply by $\pi/180$, $\pi = 3.14159$)

For this example, S = 6 miles, so θ = 0.00114 rads or 0.07 degrees. The elevation, h, is 3,500 feet or 0.66 miles. Solving the equation for beamtilt angle, we get α = 6.34 degrees. In practice, we might settle for less beamtilt to ensure we reach Pueblo and outlying areas. To ensure good coverage of close-in locations, we should incorporate null fill in the antenna pattern.

Q: The FCC has now included mobile radio base station transmitters in its RF radiation hazard rules. What is a good rule of thumb for calculating safe distances?

A: Maximum exposure levels are usually specified in units of power density, e.g., Watts/m^2. If there are no reflecting surfaces nearby, the power will fall off with distance squared. Thus, the power density in the main beam of the antenna is calculated from

$$S = \frac{P_t \, G_d \, 1.64}{4 \pi d^2}$$

where P_t is the transmitter power, G_d is the gain relative to a half-wave dipole, and 1.64 is the gain of a half wave dipole relative to an isotropic antenna. This equation can be solved for distance easily. For example, the maximum exposure level in the VHF band is 10 W/m^2. If the station operates at 100 W into an antenna with a gain of 10, the safe distance is 3.6 meters (12 feet).

Q: I am installing cell sites for my employer, Giant Pacific Telephone Company. Someone told me that my cell site tower can affect the pattern of an AM Broadcast directional array. Is this true, and if so, what am I required to do about it?

A: Yes, this is true. Tower structures in the vicinity of AM broadcast towers can alter the AM antenna pattern. The FCC requires that wireless service providers notify the AM station if construction will occur within 1 kilometer of a non-directional station and 3 kilometers of a directional station. The wireless service provider must show through measurements that the tower does not affect the pattern of the AM station. If the pattern is affected by the tower, the service provider must "detune" the tower to bring the AM pattern back to its original specification.[1]

Q: How do I convert a field strength reading of 20 V/m to milliwatts/cm^2?

A: Ohm's law applies to electric and magnetic fields as well as voltage and current. The impedance of free space is 377 ohms. Therefore if the electric field is E, the power density is $E^2/377$. So 20 V/m is 1.06 W/m^2 or 0.106 mW/cm^2.

Q: If my 50 Ohm antenna has an antenna factor of 17.4 dB/m at 471.25 MHz (Channel 14-TV), what is the gain in dBd?

A: The appropriate equation is the following:

$$G = -K + 20 \log10(F) -32 \ \text{dB}$$

where G is the gain in dBd, K is the antenna factor in dB/m, and F is the frequency in MHz. For our example, the gain is 4.1 dBd.

Q: According to the FCC and my own field measurements, I should have adequate signal strength to get an excellent picture from our HDTV transmitter just about anywhere in Colorado Springs. But we have high bit-error rates and poor picture quality in many locations. What could be causing this problem, sun spots?

A: Your problem is delay spread. The same multipath propagation that causes ghosting on your analog signal causes delay spread and high bit-error rates on your digital signal. The DTV signal operates at a very high signaling rate which means the pulse duration is very short. Multiple signals arriving at the receiver at slightly different time delays (~ 500 ns) cause a "smearing" of the receive pulse. This smearing cannot be corrected completely by the receiver's equalizer and error correction decoder.

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[1] See FCC Part 22.371, "Disturbance of AM Broadcast Station Antenna Patterns." Note that PCS operators are governed by Part 24 which has no equivalent rule. However, it is good practice to voluntarily meet the requirements of Part 22.371.

Possible solutions include directional transmit antennas to avoid reflections from the mountains, better receive antenna pointing, more directional receive antennas, and better receiver equalizers. It is important that any field measurements include both signal strength *and* delay spread.

Q: I learned in college that propagation loss is given by the free space loss equation. In other words, radio waves attenuate as distance squared ($\gamma = 2$). However, recently I hear that mobile radio channels have values of gamma from 1.5 to 6. What is going on?

A: Free space loss is given by the equation:

$$L_{fs} = \left(\frac{4\pi d}{\lambda}\right)^2$$

where d is the distance from the transmitting antenna and λ is the radio frequency wavelength. In mobile radio environments, path obstructions and local reflections result in a typical path loss of 40 dB per decade rather than 20 dB per decade as predicted by the free space loss equation. Interestingly, tall buildings along both sides of city streets create a waveguide effect and the value of gamma can actually be less than 2.

Q: Because of terrain, foliage, and man-made obstructions, the path loss for mobile radio is typically larger than for free space. In fact, path loss is often modeled as proportional to distance to the fourth power rather than distance squared. But if my tower is 100’ high, a user near the tower will probably see free space loss while someone farther away might see 40 dB per decade. How do I account for this?

A: It is common to create a breakpoint where the path loss changes from 20 dB per decade to 40 dB per decade. Selecting the distance for the breakpoint can be tricky. It will depend on the height of the tower and the surrounding terrain.

Q: Why are so many homeowner’s television antennas damaged during the holiday season?

A: This mystery has puzzled scientists for years. The FCC and the National Association of Broadcasters (NAB) recently commissioned a study to get to the bottom of this important problem. The two organizations hired the consulting firm of Dewey, Screwum & Howe, P.C. to investigate. So far, the only evidence collected are a patch of red felt, one reindeer hair, and shingles showing hoof damage. The FBI crime laboratory in Washington D.C. is analyzing these samples at the time of this writing. Film at 11.

Transmission Lines

Q: What is the peak power for a four station FM combiner?

A: In the worst case, the signals from the four transmitters will be in phase and the voltages will add. Power is proportional to the square of the voltage, so the peak power is $P_{pk} = n^2 P_{avg}$, where n is the number of stations and P_{avg} is the average power for one of the stations. For example, if we combine four stations at 25 kW each, the peak power is 400 kW. Next month: How much is too much?

* * *

Q: What is the maximum peak power for 6 1/8” rigid coaxial line (50 Ohm) with air dielectric?

A: If the manufacturer does not give a peak power rating, find the DC average power rating. This is also the peak power rating. The dielectric strength of air is less at higher elevations, so the line must be derated for altitude. For example, at 10,000 feet, the peak power rating must be derated to 46% of the sea level value. Manufacturers rarely provide altitude derating curves, probably because a single FM or TV station will almost always exceed the average power rating before peak. This is not necessarily true for combined stations. Peak power rating for 6” rigid line is 3000 kW at sea level. Derated for 10,000’: 1,380 kW.

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Q: What is the difference between a good direct current (DC) ground and a good radio frequency (RF) ground?

A: Regardless of frequency, we want a low impedance path from radio equipment to an equipotential ground plane. The difference between a good DC ground and a good RF ground is the difference in impedance at low and high frequencies. This difference is driven by two physical phenomena: skin effect and reactance.

Skin effect is a property of conductors that causes current to flow at the surface of the conductor at higher frequencies. The higher the frequency, the closer to the surface the current flows. Because resistance is inversely proportional to the cross sectional area of the part of the conductor that carries current, the resistance of a solid copper wire increases with frequency. Skin effect is why high power coaxial lines have relatively large diameter *hollow* inner conductors. Current flows on the surface of the conductor, so why waste money on extra copper?

Impedance has two parts, resistance and *reactance*:

$$Z = R + \mathrm{j}X \quad \text{Ohms}$$

The real part of Z is the resistance, R, and the imaginary part is the reactance, X. The letter j

denotes the imaginary part and is equal to the square root of -1. Most ground conductors are inductive at RF frequencies and the reactance of an inductor is given by $X = \omega L$, where L is the inductance, $\omega = 2\pi f$, and f is the radio frequency in Hertz. At high frequencies, the reactive part of the impedance dominates. For example, at 100 MHz, a one foot straight section of AWG # 6 copper wire has an impedance of 190 Ohms, almost purely reactive.

Geometries and bends of conductors affect their inductance. The inductance of copper strap is about half that of copper wire for the same cross sectional area. Sharp bends act like partial turn coils and significantly raise inductance. Thus, where possible, ground conductors should be short sections of strap with no sharp bends.

Q: I have a brand new cellular radio base station antenna with high reflected power. The antenna specification for VSWR is 1.3 maximum. If my forward power is 100 watts and my reflected power is 5 watts, what is the VSWR?

A: Voltage standing wave ratio is given by

$$\mathrm{VSWR} = \frac{1+|\rho|}{1-|\rho|}$$

where ρ is the reflection coefficient,

$$\rho = \frac{V_r}{V_f} = \sqrt{\frac{P_r}{P_f}}$$

Using these equations, we find the VSWR is 1.58. Better send that antenna back!

Q: I have a 75 Ohm antenna that I want to use with a 50 Ohm transmitter and a 50 Ohm transmission line. My transmitter can stand a VSWR of 1.4. Will this configuration work?

A: VSWR as a function of source impedance, Z_0, and load impedance, Z_l, is given by:

$$\mathrm{VSWR} = Z_l/Z_0$$

(If the load impedance is less than the source impedance, VSWR is the inverse of above.) In our case, VSWR = 1.5. Guess it won’t work.

Interference

Q: My paging transmitter (152.48 MHz) puts out a third harmonic that falls near one of Channel Communications receivers (454.44 MHz). Channel's receiver operates at 454.45 MHz, but the bandwidth of the harmonic is three times normal bandwidth and the upper FSK frequency of the harmonic falls within 2.5 kHz of Channel's center frequency. If I install a bandpass cavity at the output of my transmitter, will this solve the problem?

A: Not necessarily. Coaxial bandpass cavities often pass the third harmonic as well as the fundamental frequency. You need to install a lowpass filter. Note that some filters are advertised as "harmonic filters" when in fact they are just notch filters tuned to the second harmonic. They will not attenuate the third harmonic. On congested sites (like Cheyenne Mountain), transmitters should employ the following configuration: transmitter — dual junction isolator — low pass filter — bandpass cavity filter — antenna. Note that the order is important. The isolator is a non-linear ferrite device that will generate harmonics. The low pass filter will attenuate these products.

Q: I am constructing a new UHF television broadcast facility on Mt. Morrison, outside Denver, CO. The FCC and the Department of Commerce require that I limit my signal to 30 mV/m at Table Mountain, north of Boulder. Desktop predictions show a signal level of 288 mV/m for my 5 MW ERP station at Table Mountain using a "skull" pattern Dielectric antenna. How do I reduce my signal at Table Mountain by 20 dB without losing coverage in the Denver area?

A: The preferred method is to install a high gain antenna on the tower below your main antenna with a coupler and phase shifter. The objective is to radiate equal power from each antenna in the direction of Table Mountain, but exactly 180° out of phase. We want to put the smallest possible power into the cancelling antenna so we don't rob power from the main antenna. The usual approach is to use a 15' grid antenna with an approximate gain of 30 dBd. If the gain of the main antenna is 16.5 dBd, we need 111 kW into the main antenna and just 5 kW into the cancelling dish.

Measurements are made at Table Mountain with a FIM-72 or equivalent to first align the dish and then adjust the phase and coupling level. To minimize ground reflections, the FIM-72 antenna should be mounted 30' above the ground.

Q: I have a 150 MHz paging transmitter that is causing interference to a 450 MHz receiver. We've isolated the problem to my transmitter, but I find it hard to believe that my transmitter is the culprit because I have both an isolator and a bandpass cavity filter installed. What could be the problem?

A: Your third harmonic is probably causing the interference. Bandpass cavities typically pass harmonics of the fundamental frequency. You need a low pass filter at the output of your transmitter. Note that this should be a *true* low pass, not a “harmonic” filter. Many harmonic filters are just notch filters tuned to the 2nd harmonic.

Q: I have an intermodulation problem in an overdriven receive amplifier. I know the equation for the power of the intermodulation product given the power levels of each of interferer, P_0, and the output third order intercept, IOP_3, but this equation only applies to equal power interferers. How does one handle unequal power interferers?

A: The equation for the power level of the third order intermodulation product (2A-B) created by two equal power interfering signals is the following:

$$P_{im} = 3\,P_0 - 2\,\mathrm{IOP}_3 \tag{1}$$

where all terms are in dBm. The IEEE recommends the following approximation when the power levels are unequal:

$$P_0 = (2\,P_{max} + P_{min})/3 \tag{2}$$

In other words, the value of P_0 to be used in the original equation is a weighted average of the stronger signal, P_{max}, and the weaker signal, P_{min}. As an example, consider a receive multicoupler amplifier with two interfering signals, measured at the output of the amplifier at P_{max} = +3 dBm and P_{min} = -10 dBm. The amplifier has a third order intercept of + 38.2 dBm. The equivalent power level of the interferers is -1.3 dBm. Substituting into Equation (1), we get an intermodulation product of P_{im} = -80.5 dBm.

Receivers

Q: The FCC will narrow my 25 kHz LMR channel to 12.5 kHz later this year. If I reduce the FM deviation by a factor of 2 to stay within the new channel spacing, how does this reduction affect the baseband signal-to-noise ratio in my LMR receiver?

A: FM is a non-linear modulation technique that exhibits a threshold effect and signal-to-noise improvement over linear (e.g., AM) modulation. The FM signal-to-noise improvement factor is proportional to the square of the frequency deviation. Therefore, if we lower our deviation by a factor of 2, we reduce the baseband signal-to-noise ratio by 6 dB. If we assume that path loss is proportional to distance squared (i.e., free space loss), then the coverage boundary is reduced by a factor of 2 and the coverage *area* is reduced by a factor of $2^2 = 4$. (Area of circle = πr^2) Do I now need four times the base stations? Come to the meeting and find out!

Q: What is the necessary receiver bandwidth to capture an FM signal without causing unacceptable distortion?

A: The rule of thumb is Carson's rule:

$$B = 2(\Delta f + f_m)$$

where Δf is the maximum frequency deviation and f_m is the highest frequency of the modulating signal. For example, in land mobile radio, typical values are $\Delta f = 5$ kHz and $f_m = 3$ kHz, so the required bandwidth is 16 kHz. For FM and TV broadcast, the following numbers apply:

	Δf	f_m	B
FM Broadcast	75 kHz	15 kHz	180 kHz
TV Broadcast (Mono)	25 kHz	15 kHz	80 kHz
TV Broadcast (Stereo)	~50 kHz	15 kHz	~ 130 kHz

Q: If I have a transmission line with 3 dB loss between my antenna and the radio and the radio has a noise figure of 6 dB, what is my overall noise figure and the noise floor of my radio? The equivalent noise bandwidth of the receiver is 12.6 kHz. If I put a preamp at the antenna with a noise figure of 3 dB and a gain of 30 dB, how does this improve my overall noise figure and noise threshold?

A: In general, the system noise figure for two amplifiers in series is given by

$$NF_{total} = NF_1 + (NF_2 - 1)/G_1$$

where NF_1 is the noise figure of the first amplifier, NF_2 is the noise figure of the second amplifier and G_1 is the gain of the first amplifier. All units are ratios (not dB). In this case the first "amplifier" is the cable and the noise figure is 3 dB and the gain is -3 dB. The answer is 2 + (4-1)/(0.5) = 8 or 9 dB. The noise floor is given by

$$\text{Noise Floor} = -174 \text{ dBm} + 10 \log_{10}(12{,}600) + 9 = -124 \text{ dBm}$$

In the second case, we have three amplifiers in series and the equation is:

$$NF_{total} = NF_1 + (NF_2 - 1)/G_1 + (NF_3 - 1)/(G_1 G_2)$$

where the first amplifier is now the preamp, the second amplifier is the cable and the third amplifier is the radio. Solving for total noise figure, we get NF_{total} = 3 dB. Thus, the high gain of the preamp makes the preamp's noise figure the dominant contributor to the total noise figure. The noise threshold is improved by 6 dB to - 130 dBm.

Q: I have an 800 MHz SMR system on Cheyenne Mountain and my noise floor measures high on all my receive channels. I am using a 20 dB preamplifier and a 10 channel multicoupler. Is the high noise floor caused by site interference?

A: Not necessarily. The preamplifier and the multicoupler amplifier amplify the thermal noise floor as well as desired signals. For example, if we have a preamplifier with a gain of 20 dB and we neglect cable losses, the thermal noise floor in a 30 kHz bandwidth will be amplified from –129.2 dBm to –109.2 dBm.

Q: I have an underground BDA system with power combiners. How do the power combiners affect noise figure at the head end where all branches of the system are combined before they go to the receiver?

A: All distributed antenna systems have a relatively high noise figure on the uplink path. This is an inherent property of distributed antenna systems. The system gains and losses must be balanced very carefully to ensure the noise figure is minimized. At the same time, signals must stay below the non-linear point of each amplifier to preclude intermodulation interference. These two requirements are sometimes at odds with each other.

To illustrate one aspect of the uplink noise figure problem, consider the example shown in Figure 1 below. Two slave uplink (mobile to base) amplifiers are combined into one signal that is fed to the distribution amplifier and eventually to the radio receiver at the head end. Because the Radiax® for each bidirectional slave amplifier originates from a different physical location, one of the slave amplifiers contains our desired signal, the other contains just noise. Let's assume that the desired signal comes from Slave 2. If the gains and noise figures of the two amplifiers are identical, then the noise power at the output of the power combiner doubles and the signal-to-noise ratio drops by 3 dB (assuming input noise levels are identical).

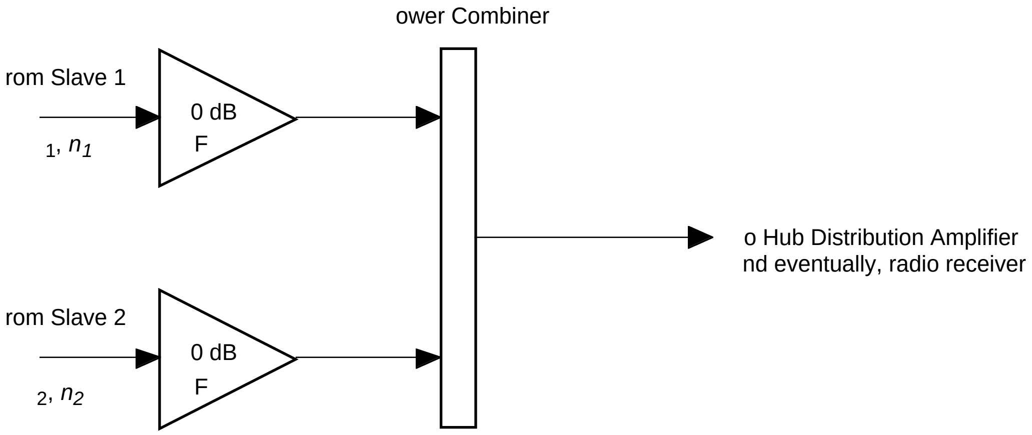

Figure 1 - Balanced slave combining

Now consider a case where the gains are unbalanced. It might be desirable to have higher gain in one slave because the Radiax is long or it may have many power splitters. Consider the hypothetical example shown in Figure 2:

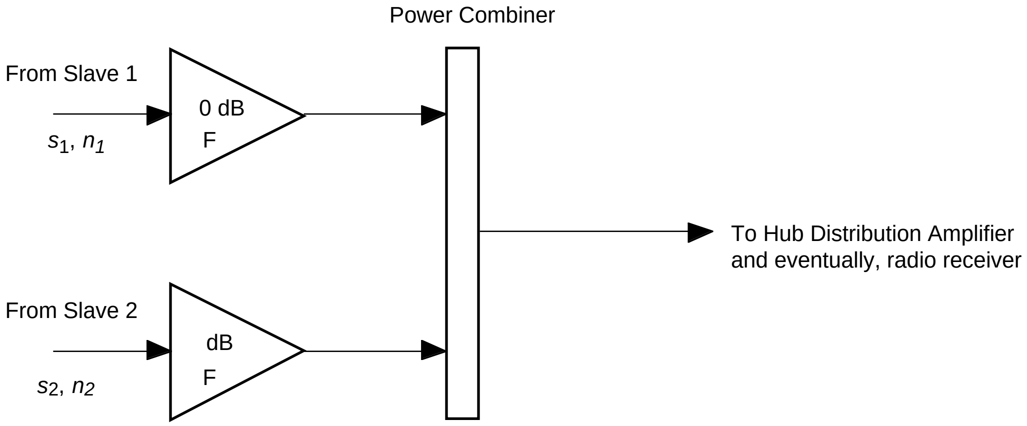

Figure 2 - Unbalanced slave combining

In this case, Slave 1 has a gain of 10 dB while Slave 2 has a gain of 3 dB. The output of the power combiner is the sum of the two desired signals plus the sum of the noise. The amplified noise power in branch 1 is at least 10 times the input noise power while the amplified noise power in branch 2 is just 2 times the input noise power. Because of the higher noise coming from Slave 1, the signal from Slave 2 will have its signal-to-noise ratio degraded by a factor of (10 + 2)/2 = 6 or 7.8 dB in addition to the degradation caused by the noise figure of the slave amplifier.

The higher noise figure means we must have a stronger signal at the receiver to achieve good quality communications. This means that a normally strong signal (e.g., -80 dBm) may not be strong enough. Power control targets may require adjustment upward for cellular and ESMR systems.

Miscellaneous

Q: Why is it that I can abuse my CD’s (finger prints, scratches, coffee stains, cracks, big holes, etc.) and I hear no noticeable impairment of the audio output?

A: In 1979, Philips Corp. of the Netherlands and Sony Corp. of Japan joined forces to establish a standard for the new compact disc (CD) digital audio system. Philips had been working on the audio compact disc since 1969 and was looking for a partner. The company wanted to prevent the proliferation of incompatible designs and figured that if the two giants could agree on a standard, the rest of the industry would follow their lead. Philips was right. Today, all compact disc players use the Philips-Sony standard.

At the time of the first meetings between Philips and Sony, Philips had nearly perfected the optics of its compact disc players, but Philips' engineers were having serious problems controlling errors. The slightest scratch or dust particle would obliterate hundreds of bits and cause a "blast like a cannon shot or thunderclap”.

To appreciate Philips error-control problems, it helps to understand the basics of how compact disc players work. The recording medium for CD players is a plastic disc 120 mm in diameter used to store digitized audio in the form of minute *pits* that are optically scanned by a laser. The audio waveform is sampled at 44.1 k samples/s to provide a listening bandwidth of 20 kHz. Each audio sample is uniformly quantized to one of 2^{16} levels. The resulting dynamic range is 96 dB and the total harmonic distortion is less than 0.005 %. Channel errors usually come from two sources: (1) small unwanted particles, air bubbles, or pit inaccuracies from the manufacturing process, and (2) fingerprints, scratches, or dust particles from handling. Before it collaborated with Sony, Philips was very careful in its demonstrations to play only exceptionally clean discs because its prototype could not tolerate the smallest dust particles, much less scratches and fingerprints. The average consumer is not nearly as careful, so a much more rugged system was required. That was Sony's contribution.

Sony was an ideal partner for Philips because it had practical experience in error correction that the Philips engineers lacked. After a year of design meetings, Sony and Philips adopted a powerful error control scheme that used multiple layers of interleaving and Reed-Solomon codes. This error-control scheme is called the *cross-interleave Reed-Solomon code (CIRC)*. The CIRC controls errors through a hierarchy of four techniques:

- The decoder provides a level of forward error correction.
- If the error burst exceeds the capability of forward error correction, the decoder provides a level of erasure correction.
- If the error burst exceeds the capability of erasure correction, the decoder hides unreliable samples by *interpolating* between reliable neighbors.

- If the error burst exceeds the capability of the interpolator, the decoder blanks out, or *mutes* the system for the duration of the unreliable samples.

The resulting performance of the CIRC scheme is summarized in Table 1.

Table 1 - Error Control Performance of the CIRC	
Max correctable burst	~4 000 bits (2.5 mm on disc)
Max interpolatable burst	~ 12,000 bits (8 mm)
Undetected error samples (clicks)	Less than one every 750 hours at BER of 10^{-3}
New discs typically have BER of	~ 10^{-4}

The CIRC encoding scheme was a tremendous success. It converted a channel that could not tolerate minute dust particles to one that is immune to all but the roughest handling. The compact disc can endure 8 mm holes punched through the disc without noticeable effect!

Q: What did you learn at NAB this year?

A: I learned how to play KENO and how to calculate the odds of winning. Here's how the game is played: Each player has a card with 80 numbers. The player picks a set of numbers from the 80 and turns his card into the KENO girl. The player can pick from 1 to 15 numbers. The casino computer randomly selects 20 numbers from the 80. The more numbers the player picks correctly, the more he wins. The ticket pays different amounts depending on how many numbers were picked and how many are correct. For example, if you pick three numbers and bet $ 2, you win $ 2 for two correct numbers and $ 84 if all three are correct. The probability of winning is given by the hypergeometric distribution (dust off your old probability textbook).

Using this formula, we computed the expected (or average) winnings for each case. Turns out that the best odds are for picking one number. You can only win $ 6.00, but the *expected* (average) winnings are $ 1.50. The worst choice is 11 numbers where the expected winnings are $ 1.36. However, you can win $ 100,000 if you get all 11 numbers correct! The odds aren't bad — 16 in a billion.

Note that KENO has at best a 75% payback whereas the slots pay 98%.

Q: If Albert Einstein was a radio engineer, what would be his famous equation?

A: $E = mc^2$ +/- 3 dB

Q: Sometimes when I download files from the Internet, the file will be corrupt, but there is no indication of an error during the download. What's going on?

A: Hard to say exactly. However, the error detection code may have failed. Two error detection codes are commonly used in computer communications, the 16-bit CRC and the 32-bit CRC. CRC = cyclic redundancy check. CRCs are also known as shortened Hamming codes. The CRC will fail when channel errors turn a valid codeword into another valid (but incorrect) codeword. The detector can't tell the difference and thinks the packet is error free. Longer CRCs are generally better. A rule of thumb (which is not rigorous) is that the probability of undetected error is upper bounded by 2^{-r}, where r is the number of parity bits in the code (16 or 32). Therefore, a 16-bit CRC is bounded by 1.53E-5 and a 32-bit CRC is bounded by 2.33E-10. For example, consider a 10 MB file organized into packets of 256 bits (32 bytes), each with a 16 bit CRC. The file has 312,500 packets. On average, there will be 1.53E-5 (312,500) = 4.8 packets with undetected errors per download.

Q: What are the cellular and PCS airlink standards and which service companies use which standards?

A: The main airlink standards are analog FM cellular (AMPS), narrow band AMPS (NAMPS), time division multiple access (TDMA), iDEN, GSM, and code division multiple access (CDMA). GSM and iDEN are forms of TDMA. CDMA is a spread spectrum multiple access technique. The service providers in Colorado Springs are as follows:

Company	Airlink Standard
AT&T Wireless	AMPS and TDMA
AirTouch	AMPS, NAMPS and CDMA
Nextel	iDEN
Sprint PCS	CDMA
Western Wireless (Voice Stream)	GSM
US West Wireless	CDMA

If you find one cell phone that works on all these networks, let me know. Perhaps the word "standard" is a misnomer.

Q: What is pulse code modulation?

A: Pulse Code Modulation or PCM, is a technique to digitize human speech. It is commonly used in the telephone network. The first step in creating a PCM signal is to bandlimit the analog speech waveform to 4 kbps. Then we sample the waveform at the minimum rate (Nyquist rate) of 8 kbps. Each sample is 8 bits, so the composite bit rate is 8,000 x 8 = 64 kbps. By comparison, audio CD's use a sampling rate of 44 kHz with 16 bit samples.

In cellular phones, PCM is often used as the first step in speech compression. The 64 kbps PCM signal is then typically compressed to 8 kbps using techniques like code excited linear prediction (CELP).

Q: How do I test resistance to earth of my building ground system?

A: Use the fall-of-potential method as described in IEEE Standard 142-1991. This method is widely accepted in industry as the proper technique for measuring resistance-to-earth. Figure 1 is a simplified model of the fall-of-potential method. The resistance-to-earth of the electrode under test is simply *V/I* where *V* is the voltage reading at the voltmeter and *I* is the current reading at the ammeter.

When using the fall-of-potential method, the correct reading is found when the *P* distance is 62% of the *C* distance. It is also important that the *C* distance be large relative to the largest dimension (the diagonal) of the earth electrode system. An AC voltage source is used, but harmonics of 60 Hz should be avoided. Biddle makes a complete line of earth testers.

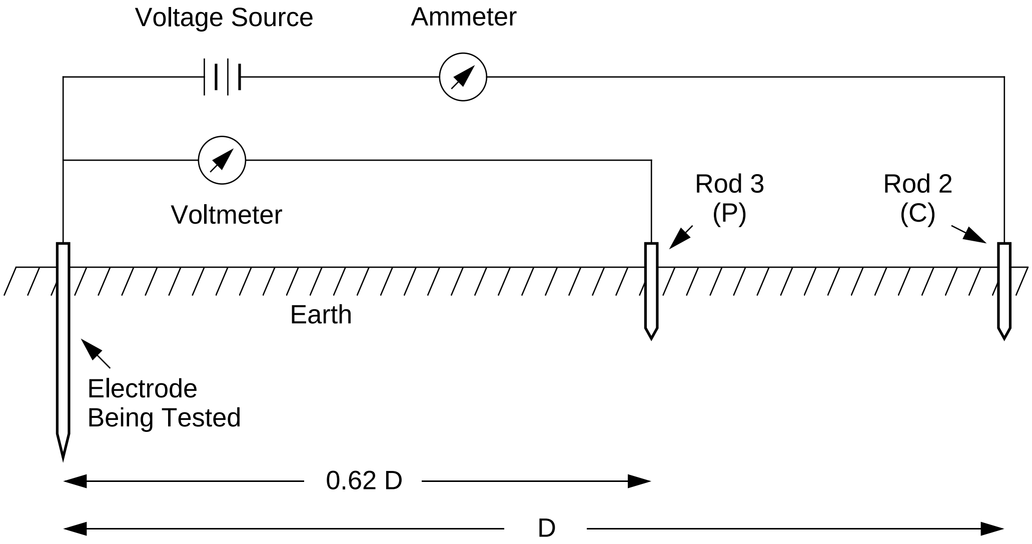

Figure 1 - Fall-of-Potential Method