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Working Explanation of Three-Antenna Gain Measuring Technique

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At times there is a need to measure the gain of an individual antenna. This may come about by not having the manufacture antenna gain information or the antenna is specially designed and the gain has never been measured.

This paper presents a working level description of the well-established three-antenna method for determining antenna gain. The theory and an example are presented.

The fundamental mathematical principle used in the three-antenna method is to establish and solve three simultaneous equations for three unknown antenna gains. Referring to figure 1 the transmission gain formula is:

(1) $P_R = P_T + C_{L1} + G_A + T_L + G_C + C_{L2}$

The use of (1) is then employed along with the three antennas (A, B, C) to establish the three simultaneous equations. The component values in (1) that are known and measurable are the transmit power (P_T) and the cable losses (C_{L1}, C_{L2}). The transmission loss (T_L) is calculable.

Transmission loss also referred to as path loss can be quite complex to calculate depending on the mathematical model used. For the purposes of this paper the free-space path loss model will be used. This is a good approximation under the assumption that the distance between the transmit and receive antennas are in close proximity to each other. However, the separation distance must be at least 10 wavelengths to ensure far-field antenna transmission characteristics. The free-space path loss equation for distance in feet is:

(2) $T_L = -37.87 + 20*Log_{10}(d_{ft}) + 20*Log_{10}(f_{Mhz})$

Rearranging terms in (1) and combining known values into a constant result in obtaining the following three simultaneous gain equations:

(3) $P_{R1} = G_A + G_C + T_L + K$ Where $K = P_T + C_{L1} + C_{L2}$

$P_{R2} = G_A + G_B + T_L + K$

$P_{R3} = G_B + G_C + T_L + K$

Adjusting the transmit power to equal the combined cable losses ($P_T + C_{L1} + C_{L2} = 0$) and introducing a delta term yields:

(4) $\Delta_1 = G_A + G_C$ Where $\Delta_1 = P_{R1} - T_L$

$\Delta_2 = G_A + G_B$ $\Delta_2 = P_{R2} - T_L$

$\Delta_3 = G_B + G_C$ $\Delta_3 = P_{R3} - T_L$

Solving (4) for the three antenna gains yields:

(5) $G_A = ½ (\Delta_1 + \Delta_2 - \Delta_3)$

$G_B = ½ (\Delta_2 + \Delta_3 - \Delta_1)$

$G_C = ½ (\Delta_1 + \Delta_3 - \Delta_2)$

EXAMPLE:

The working parameters for this example are:

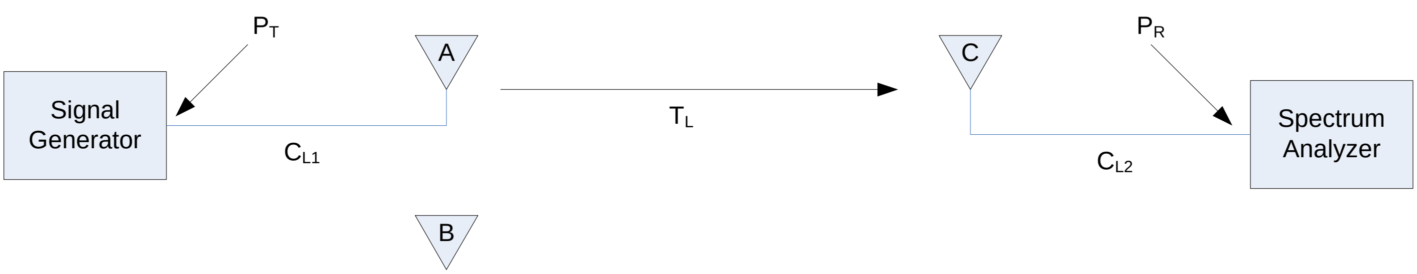
- Unknown gain for three antennas
- Frequency of operation = 2450 MHz
- Total setup cable loss of 1.4 dB

Steps taken to determine the three antenna gains.

1) The Signal Generator (SG) output power is adjusted to equal the total cable loss. Hence, the received power when connected directly to the SG via cables is $P_R = 0$ dBm.
2) The antenna separation distance of 10 feet was chosen, which is more then adequate to meet the far-field requirement.
3) The path loss is calculated to be $T_L = 49.9$ dB.
4) Antennas A and C are placed into the system
5) The receiver power is measured to be $P_{R1} = -46.6$ dBm
6) $\Delta_1 = 3.3$ dB
7) Antenna C is replaced with antenna B.
8) The receiver power is measured to be $P_{R2} = -46.3$ dBm
9) $\Delta_2 = 3.6$ dB
10) Antenna A is replaced with antenna C.
11) The receiver power is measured to be $P_{R3} = -46$ dBm
12) $\Delta_3 = 3.9$ dB.
13) The antenna gains are:

$$G_A = ½ (\Delta_1 + \Delta_2 - \Delta_3) = 1.5 \text{ dB}$$
$$G_B = ½ (\Delta_2 + \Delta_3 - \Delta_1) = 2.1 \text{ dB}$$
$$G_C = ½ (\Delta_1 + \Delta_3 - \Delta_2) = 1.8 \text{ dB}$$

Figure 1
Three-Antenna Gain Measurement Setup



Transmission Equation (dB)

$P_R = P_T + C_{L1} + G_A + T_L + G_C + C_{L2}$

P_R – Received Power
P_T – Signal Generator output power
C_{L1} – Transmit cable loss
G_A – Antenna (A) gain
T_L – Transmission path loss
G_C – Antenna (C) gain
C_{L2} – Receiver cable loss