iMAT – Revolutionary Antenna Technology from SkyCross

By Frank Caimi,
Chief Technical Officer
SkyCross, Inc.

To obtain the benefits of MIMO or diversity communications systems, antennas typically must be properly configured to take advantage of the independent signal paths that can exist in the communications channel environment. [1] With proper design, one antenna's radiation is prevented from traveling into the neighboring antenna and being absorbed by the opposite load circuitry. Typically, a combination of antenna separation and polarization is used to achieve the required signal isolation and independence. However, when the area inside devices is extremely limited, this approach often is not effective in meeting industrial design and performance criteria. As a result, the industry has settled for single antenna solutions or diversity configurations with poorly performing ancillary antennas.

SkyCross has introduced a novel solution to this problem. iMAT, Isolated Mode Antenna Technology, allows a single antenna structure to be configured with multiple feed points. Each feed provides high isolation, low correlation, and high per-feed radiation efficiency without the need to design and place multiple antennas in a small space.

The antenna design relies upon higher order modal excitation of a single radiating structure from one feedpoint with the realization that isolation can be achieved at feedpoints located elsewhere on the same structure. An added benefit is that the antenna pattern produced by each feed can be sufficiently different so signals transmitted or received between the different feed points are essentially independent—a requirement for higher gain diversity systems and high-throughput MIMO communications.

MIMO Metrics and Correlation Coefficient

For a MIMO communications system to fully exploit independence of signal channels, the transmitter and receiver must utilize multiple antennas with prescribed metrics. Since the signals may arrive from different directions, the antennas should exhibit characteristics that allow for highest independence of the received signals. One such characteristic is antenna pattern independence—measured by the pattern correlation coefficient. The pattern correlation coefficient can be calculated from full sphere antenna pattern measurements and is given in terms of the electrical field components by [2]:

$$\rho_p = \frac{\int_0^{2\pi}\int_0^{\pi/2} A_{12}\sin\theta\,d\theta\,d\varphi}{\sqrt{\int_0^{2\pi}\int_0^{\pi/2} A_{11}\sin\theta\,d\theta\,d\varphi}\sqrt{\int_0^{2\pi}\int_0^{\pi/2} A_{22}\sin\theta\,d\theta\,d\varphi}}$$

$$where \quad A_{mn}(\theta,\phi) = XE_{\theta m}(\theta,\phi)E^*_{\theta n}(\theta,\phi) + E_{\phi m}(\theta,\phi)E^*_{\phi n}(\theta,\phi)$$

$$and\ the\ cross-polarization\ power\ ratio \quad X = S_\theta / S_\varphi$$

This equation is specific to a two-antenna system and produces a coefficient whose magnitude is normalized to unity based on electric field components measured in a 3-D antenna range. If the antennas produce completely orthogonal patterns, the coefficient magnitude is zero. Conversely, two antennas with the same field component pattern produce a coefficient magnitude equal to one. Because MIMO communications systems rely on separate spatio-temporal channels to achieve greater information transfer capacity, it is desirable to establish separate spatial directional response for each antenna to obtain the necessary channel independence. This creates a preference for sufficient pattern independence to produce a correlation coefficient magnitude below a certain threshold. Although, it is the correlation of the signal waveform envelope that is the desired metric, it is not directly calculable from antenna pattern measurements and is usually approximated as from Equation 1. The communications channel itself is also involved in achieving separate or independent spatio-temporal paths, and modifications to Equation 1 for those effects can be included for completeness [3, 4].

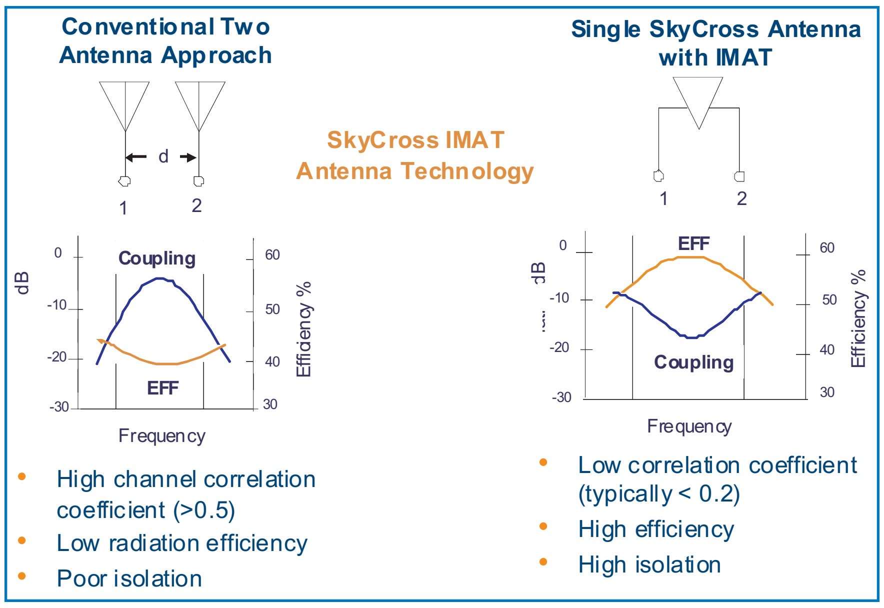

Figure 1. Illustration of the typical coupling behavior of closely spaced antennas versus the single antenna solution using iMAT technology.

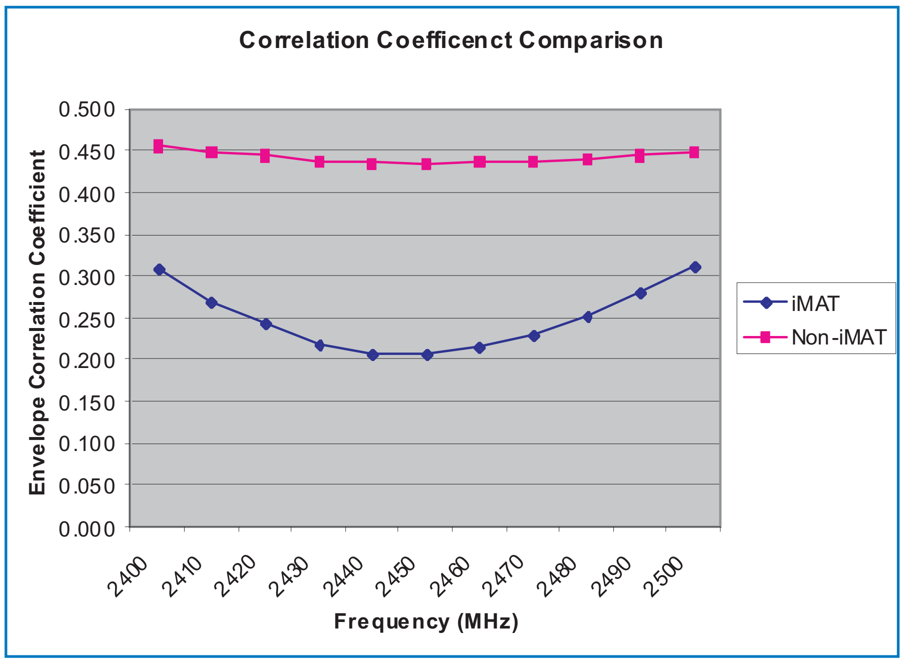

Figure 2. Example of Envelope Correlation Coefficient produced by two closely spaced monopoles and iMAT antenna of equivalent size.

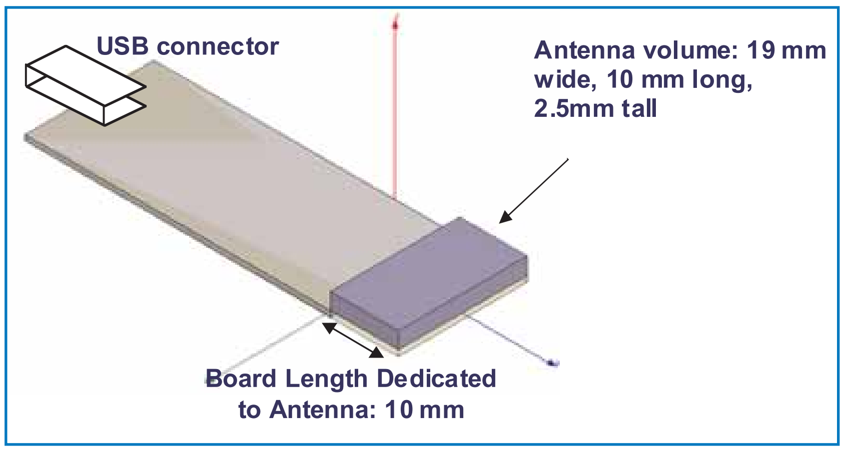

Figure 3. Example WiMAX USB antenna illustrating small antenna volume of 19 mm wide by 10 mm high and extending away from PCB distal end by 10 mm, and measured correlation coefficient less than 0.4 and efficiency of 68 percent for the same antenna

Antenna Coupling or Isolation

One of the primary difficulties of using closely spaced antennas is RF coupling, and the subsequent energy loss into the source resistance of adjacent feedpoints. The situation is as shown in Figure 1 for two antennas spaced at a small fraction of a wavelength. The leftmost figure indicates the increase in coupling between two antennas as the excitation frequency is passed through resonance. A typical metric for coupling is the port s-parameter S21 -- here approximately -4 dB peak in the band of interest. The curve illustrated is fairly typical for closely spaced antennas of similar polarization.

By contrast, the iMAT approach illustrated rightmost in Figure 1 shows a reduction of coupling between feedpoints as frequency is swept through resonance -- reaching a maximum of -20 dB. Since iMAT provides sufficiently large isolation between feedpoints, the effect of unwanted coupling between antennas becomes negligible from the standpoint of antenna efficiency or Total Radiated Power (TRP), and results in an improvement of several dB (a factor of 1.5 or more) compared to similar non-iMAT solutions.

Antenna Pattern and Correlation Coefficient

The antenna pattern for the iMAT antenna is also substantially different from the independent antenna case provided the phase between the feeds is assumed identical in both cases. The antenna pattern exhibits independence depending on which feed or port is excited, and therefore the correlation coefficient computed from the pattern is generally smaller than with independent separately located antennas in close proximity. The far-field pattern differences due to separate port excitation generally provide an improvement in signal independence by sampling different spatial channels as shown in Figure 2.

iMAT WiMAX/WiFi Technology Example

To illustrate the effects and the benefit of the iMAT approach, refer to Figure 3 showing an example of a USB antenna application for the 2.4 to 2.5 GHz band. A typical USB device consists of a printed circuit board (PCB) assembly, enclosed in a plastic housing, with USB connector at one end. The space available for the antennas is opposite the connector and occupies 19 mm of device width, 10 mm of length and 2.5 mm of height. The PCB between the antennas and the USB connector consists of a nearly continuous RF conductive substrate.

Three different antenna solutions are shown to illustrate the performance benefits achievable. The first consists of two meanderline monopoles configured for the specified form factor. The distance available for the radiator beyond the substrate is 10 mm, or $\lambda/12$ in free-space; however, the monopoles are made an effective $\lambda/4$ length through the use of a meanderline, slow-wave structure. The second case uses the same two meanderline monopoles, but with an added metal shielding strip extending from the substrate ground and between the two monopoles. The third case considered utilizes the iMAT antenna consisting of a similarly loaded half-wave electrical length resonator with two separate feedpoints configured to achieve high inter-port isolation.

A comparison of measured performance for the three solutions is shown in Figure 4. Each of the three approaches yields a low VSWR of 2 or better over the band. However, the coupling, (S_{21}) for the monopoles is poor, about -4dB as shown in Figure 4a. The addition of the isolation tab between the monopole antennas provides marginal improvement of S_{21} to about -6 dB, whereas the iMAT solution has considerably better isolation, with S_{21} values between -10 and -15 dB in the designated band.

Since the S_{21} value has a direct impact on efficiency due to signal loss to the neighboring antenna and its associated load, better efficiency is obtained for the iMAT case versus the other solutions as shown in Figure 4b. Similarly, the iMAT solution produces more diverse antenna patterns and smaller envelope correlation coefficient of 0.3 versus 0.5 as calculated from Equation 1.

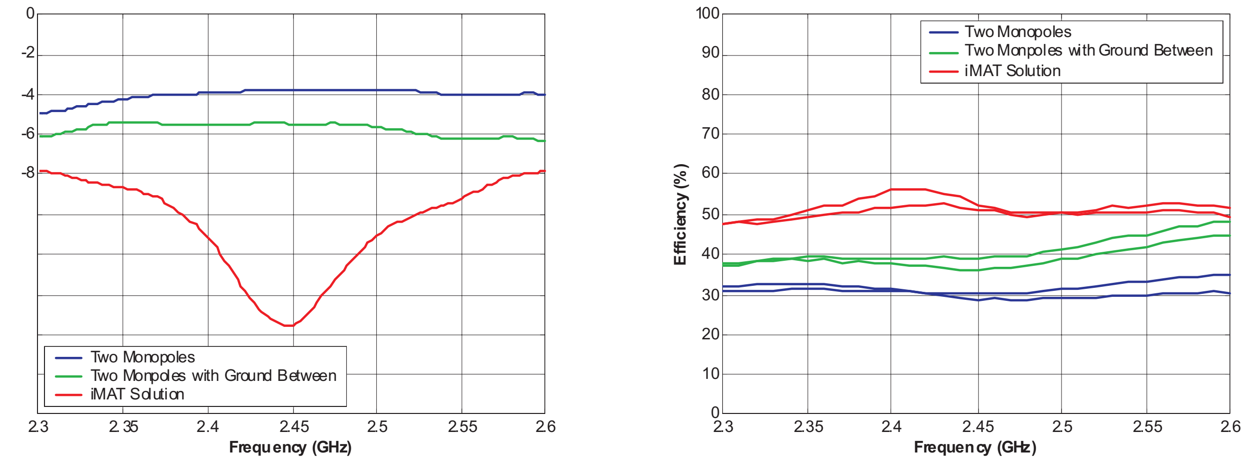

Figure 4. Comparison of a) Isolation S21, and b) Radiation Efficiency for 3 cases: two monopoles, two monopoles with ground plane isolation tab, and iMAT antenna showing advantages from the isolated mode methodology.

- Equivalent of three antennas in a single whip-type assembly with three cables
- Uses a combined monopolar structure with three isolated ports
- 56 mm long
- 10 mm diameter

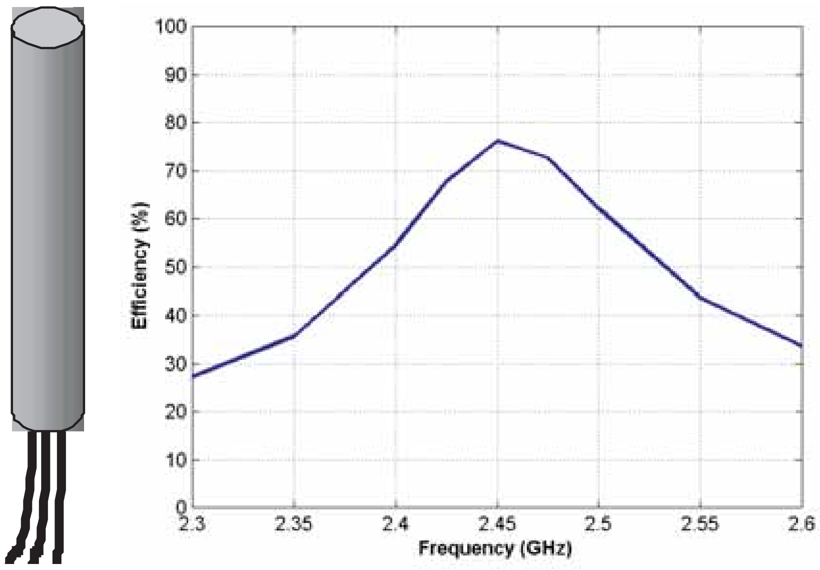

Figure 5. Single element iMAT 802.11n antenna a) Physical Configuration, and b) Radiation efficiency versus frequency for one of 3 feed ports.

Envelope correlation coefficient values less than 0.5 to 0.7 are desirable for MIMO and diversity communications systems and in many applications are difficult to obtain by placement of individual antennas on small platforms. An advantage of the iMAT solution, however, is that it is ready-made, requiring little additional engineering design. In addition, for those antenna systems not able to achieve low correlation values, the benefits of iMAT include improved system capacity and data rates.

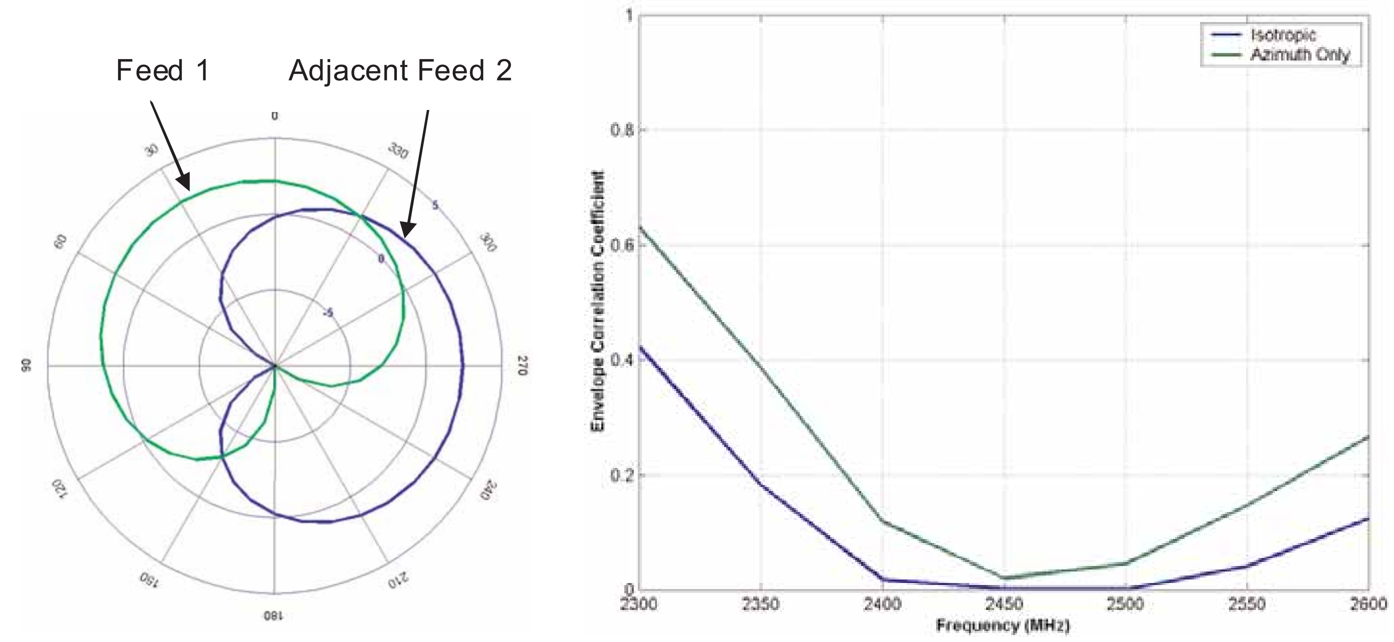

Figure 6. Pattern independence and low correlation coefficient needed for MIMO and diversity applications are benefits of the 802.11n iMAT implementation. a) Azimuthal far-field pattern for different feeds showing independence, and b) Envelope correlation coefficient taken for either 3D pattern (blue) or azimuthal pattern (green).

Three Antenna Example for 802.11n:

The 802.11n standard specifies a 3-antenna solution to provide MIMO capability. Generally, three antennas require sufficient spacing to reduce coupling between elements. The iMAT solution is the single antenna radiating structure with three separate feed cables as shown in Figure 5a.

VSWR for each feed is below 2:1 (RL<-10 dB), and the isolation between each feed is nominally -10 dB over the 2.4 to 2.5 GHz band. Unlike most closely spaced antennas, the isolation improves as the frequency is swept through the resonance where the VSWR or return loss is optimized. This is a distinguishing characteristic of the antenna using iMAT versus using separate, closely spaced radiators.

Shown in Figure 5b is the radiation efficiency for excitation at only one of the feeds, since each is identical due to the symmetric design of the antenna element. With proper tuning the efficiency exceeds 60 percent across the entire ISM band, as shown. Similarly spaced conventional monopole or dipole radiating elements exhibit efficiency much less in this frequency regime and with the specified element spacing.

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