Transmission Considerations for Polarization-Smart Antennas

Samuel Miller and Joseph Shapira
Celletra Ltd., P.O. Box 106, 1 Tavor Building,
Yokne'am Industrial Park, Yokne'am, Israel, 20692
SMiller@Celletra.com JShapira@Celletra.com

Abstract - Recent field trials in the wireless 1900MHz band revealed that the averaged-in-time polarization measurements of the received wave is co-polarized with the original transmitted polarization of the wave, and is highly correlated over a substantial frequency bandwidth. The polarization smart-antenna transmitter is realized at the base-transceiver-station (BTS), and is based on the above trial results. In performing the *polarization – matching* algorithm, the appropriate transmit polarization is matched to the averaged receive polarization, for each individual radio link (i.e. per each Mobile Station - MS), and is maintained dynamically. This recovers a substantial part of the polarization shadow link losses, and serves to reduce the forward power control variation and the average transmit power of the Base Station, as well as the induced self-interference. This paper discusses several BTS transmission architectures for the implementation of polarization-matching and presents quantitative power overloading, power efficiency and relative interference performance results per each configuration. Finally, an optimal architecture is presented for a multi-user polarization smart-antenna transmitter.

1 Introduction

The transmission in the wireless cellular communications has been shown to stay essentially polarized through the channel [2]. Polarization mismatch between the fixed BTS antenna and each of the MS's is inevitable, resulting in "polarization shadow" that varies with the MS attitude and is compensated by additional transmit power from the BTS, either by the individual user power control or by overall power raise. This penalizes both the cost and the grade of service of the network: it necessitates the use of higher power Power-Amplifiers (PA) (by 3 to 10 dB), the cost of which is a substantial portion of that of the BTS, and induces unnecessary intercell interference.

A polarization matching technique for the BTS transmission has been proposed in [2]. This paper analyses the alternative architectures for the transmission complex. A novel RF transformation introduced here facilitates maximal efficiency of the Power Amplifiers involved.

The Polarization Matching (hereafter *PolMatch™*) introduced here differs from the transmit polarization diversity techniques proposed, mainly in conjunction of the 3G systems [4], in that the *PolMatch™* generates a single Electromagnetic wave, properly polarized, by coherent RF combining of the two orthogonal wave components, while the diversity schemes transmit different codes or delay by the orthogonal branches, with no RF coherence. The net result is that the diversity transmission requires twice the total power over that of the *PolMatch™* transmission[1].

A preferred *PolMatch*™ algorithm operates at baseband, per user, and outputs a pair of weights that determine the levels and relative phase of the transmissions through two cross-polarized transmit antennas such that the resultant wave is at the matched polarization orientation. The resulting composite transmitted signal is the superposition of all individual users' transmissions. The implications on the transmission equipment architecture, and most importantly the power amplifiers, depend upon the multiple access régime (e.g. FDM/TDMA, CDMA, etc.) and upon the implementation of the polarization rotations.

Several implementation architectures for the polarization matching transmission are discussed in section 2. An important aspect considered relates to the base-band and radio-frequency (RF) realizations of various parts of the system. Section 3 discusses some relevant radio transmission performance measures and presents analysis results for the previously considered architectures. Section 4 summarizes with conclusions.

2 BTS Transmission Architectures

Given a desired transmit polarization (that is derived by the *PolMatch™* algorithm [2] from the receptions at the base-station of the same user), it is required to transmit the users' information at any slant angle in (-90°, 90°) off the vertical reference orientation. Ignoring calibration

[1] This is true for a non-fading noisy channel. Fading channels impose additional considerations [4].

issues (that may relate to impedance matching imperfections, phase and amplitude imbalance between parallel branches, etc.) the implementation of *PolMatch™* requires two orthogonally polarized antennas, which simultaneously transmit two replicas of the transmitted waveform, with predetermined electrical phase shift and relative gains between them. The two antennas are realized preferably as slant-linear ± 45° antennas.

Thus, the conceptual implementation of *PolMatch™* as depicted in Figure 1 is straightforward.

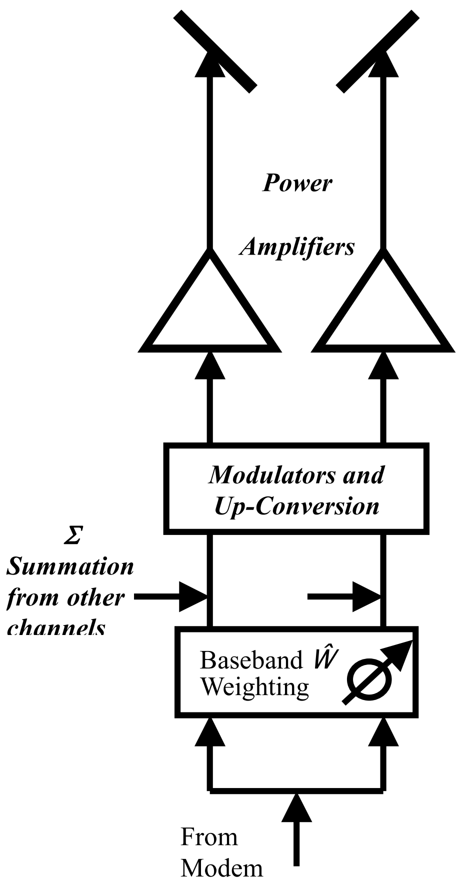


Figure 1: Basic Implementation of *PolMatch™*

The baseband processor produces two replicas of the information signal (as complex *I-Q* vectors) with an appropriate complex weight applied to one arm (with reference to the other). This weight is simplified to an *amplitude* weight plus sign when the antenna pair has a common phase center. The two replicas are applied to dual coherent modulators (sharing a common local oscillator - LO) and up-converters, then to a pair of linear power amplifiers and get transmitted via the cross-polarized antennas. Alternative approaches, such as implementing the *PolMatch™* in RF/IF are possible.

In the basic scheme presented above, it is assumed that the total transmit power required is preserved, or even *reduced* per given scenario. The reason is that by using *PolMatch™* we save on the required power per mobile and reduce the generated amount of interference. Thus, the total power emitted from the base-station is reduced, compared with a fixed vertically polarized single antenna and power-amplifier situation.

Each of the two power amplifiers in Figure 1 would be expected to deliver up-to 50% of the total output power. However this is not the case and due to *overloading* the amplifiers are required to produce more power. This is discussed in detail in Section 3. Note that systems that employ power-control in down link will continue to operate with the *PolMatch™* by managing the modulus of the weight vector.

A second implementation architecture[2] is presented in Figure 2. The purpose here is to guarantees a fixed maximum power requirement for the amplifiers.

The network produces two equal-power versions of the transmission signal per user, and creates a controllable phase difference between them[3]. These two equal level signals are applied to the power amplifiers. Thus optimum utilization of the two amplifiers is always guaranteed. The hybrid divider produces a sum and a difference signal at its outputs, which are not necessarily of equal amplitudes but are always at 90° phase difference. The final 90° shift on one arm co-aligns back the two signals to be applied to the cross-polarized antennas. Note that the splitting and phase shift operations prior to power amplification must be performed per user. This may be performed at baseband (or IF or Low-Power RF). All the users' two channel (equal power) outputs are summed in each arm to enter the power amplifier and further into one of the dual-polarized antennas.

The phasor diagram in Figure 3 will be used to explain the operation of the network of Figure 2. The input vector is split into equal vectors, one of which is rotated by a phase shift operation. The resulting (equal size) phasors are denoted *A* and *B*. The vector sum of *A* and *B* is denoted (*A*+*B*), and the difference (*A*-*B*). It is easy to see that the sum and difference vectors bisect each of the angles at their edges, and since the two angles (each belonging to a different rhombus) are complementing to 180°, the angle between the sum and difference vectors

[2] Patent Pending.

[3] This may be performed at 'low power' (baseband – preferably, or RF, or even IF, if a dual coherent up-converter is used).

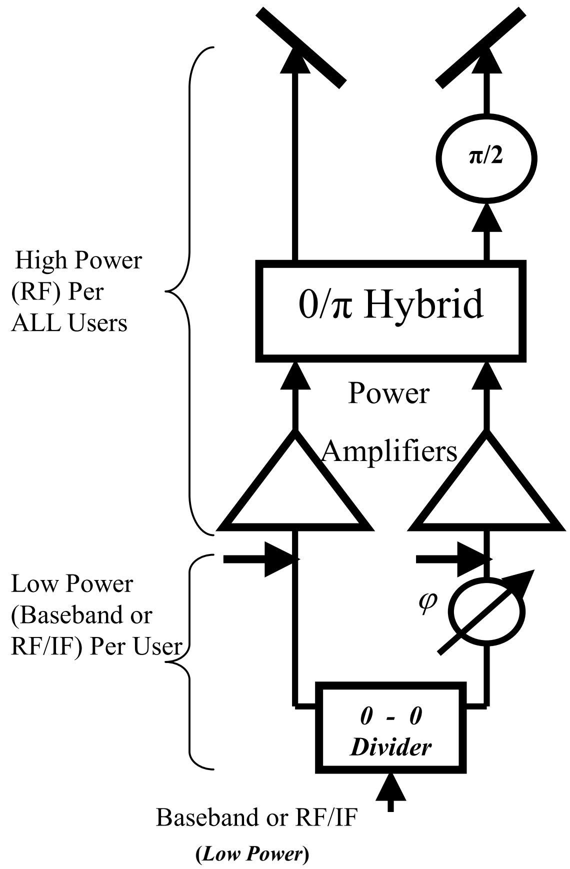


Figure 2: Improved Implementation of PolMatch

is 90°. A final rotation of the sum (or the difference) by 90° co-aligns the two vectors. When applied to the cross-polarized antennas, a linear polarization that is determined by the ratio of their magnitudes will be produced[4].

It is easy to show that for a polarization angle ψ, the required electrical phase shift ϕ is:

$$\psi = tg^{-1}\sqrt{\frac{A^2 + B^2 - 2AB\cos\phi}{A^2 + B^2 + 2AB\cos\phi}} \tag{1}$$

and with $A=B$ we get:

$$\psi = \frac{\phi}{2} \tag{2}$$

Thus, the polarization slant angle equals *one half* the electrical phase shift. The size of the resultant polarization slanted vector will be $\sqrt{2}*A$ regardless of ϕ (or ψ), thus the resultant power is the power sum of the outputs of the two amplifiers (per user).

The equal power components, per active user, that drive each of the two power amplifiers in the above scheme guarantees uniform and efficient utilization of those amplifiers, also for a collection of active users.

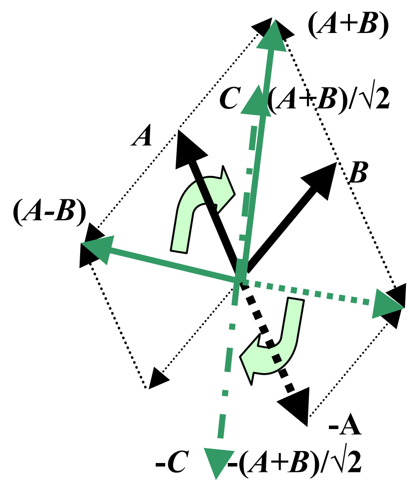


Figure 3: Phasor Diagram for the Improved Scheme

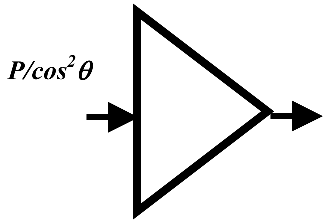
Formation of each of the *unequal components* that sum to constitute the slanted polarization vector is performed after power amplification in the 0°/180° hybrid combiner. Since the transmissions from all users are equally split between the two arms, and are uncorrelated, their power sum in the two arms is also equal. This realization method guarantees full loading of the two power amplifiers for any *PolMatch™* setting per any user.

3 Transmission Performance Measures

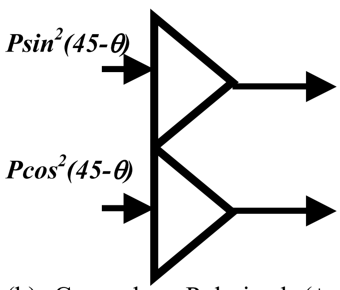
An important consideration in wireless communication radio systems is that of the power resource. Higher than necessary transmitted power leads to excessive self-interference, reduces efficiency, and requires larger

[4] The vectors $C = (A+B)/\sqrt{2}$ and $-C$ denote the outputs of an ideal hybrid divider.

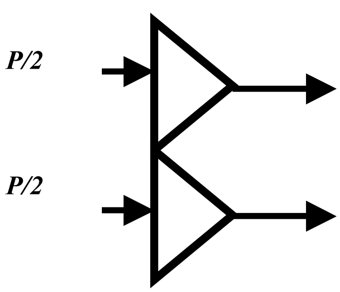
power amplifiers at the BTS, as well as extra space and air-conditioning. In this section we illustrate transmission power measures for several configurations, summarized schematically in Figure 4.



(a) Vertically (*mismatched*) Polarized Transmission



(b) Crossed – Polarized (± 45°) *PolMatch* with Weighting at Inputs to PA's



(c) Crossed – Polarized (± 45°) *PolMatch* with Weighting at Outputs of PA's

Figure 4: Loading of Power Amplifiers

Vertically polarized transmissions from the base stations, as in Figure 4(a), result in a polarization mismatch and thus require higher transmitted power with increased generated self-interference. The situation worsens for slant-polarized transmission from a single antenna, sometimes implemented in combination with polarization diversity antennas. The polarization mismatch reaches even higher values for part of the users, and has to be compensated by transmission of higher power. In the *PolMatch*™ realizations (Figures 1 and 2) the polarization mismatch losses are recovered. The amplifiers are driven per user as in 4(b) and 4(c), respectively. The polarization of the MS user in Figure 4 is θ degrees off vertical.

The power efficiency of the alternative transmission schemes can be evaluated by assuming a statistical power and polarization distribution model per user, and a number of users *k*. It is then possible to generate a cumulative distribution function (CDF) per configuration, that indicates the power requirements from the power amplifiers, referred to *P*.

As an illustration, it was assumed that each user has a uniform required power distribution between 0 –10 dB, and independent uniform polarization θ between –60 to 60 degrees. Figure 5 presents the total normalized power requirements for all users, with the number of users a parameter. The results are for 1, 10 and 50 users.

The three cases denoted by *a, b,* and *c* in each set of figures in Figure 5 correspond to the configurations (a), (b), and (c) of Figure 4, respectively.

For *k* users, each requiring maximum power *P*, the total required power is normalized to *kP*. This corresponds to the 0 dB point on the abscissa. Any power required above 0 dB represents an *overload* of the nominal amplifier. Practically, higher power Power-Amplifiers will be required due to a (positive) overload with non-vanishing probability.

For a single user there is a significant overload due to the $(\cos\theta)^{-1}$ field-strength factor in configuration 4(a). For the above statistical assumptions, overloads of 5 dB per user (over *P*) may occur. In case *b* there is a similarly possible overload due to the $2\sin^2(45-\theta)$ (similarly with $2\cos^2(45-\theta)$), per user (referred to *P/2* per amplifier). In case *c* there is no overload.

For *k* users (10 and 50 in Figure 5) the probability of exceeding the power amplifier maximum specified mean power decreases, depending on the statistics of *P* and θ per user and the number of users *k*. Note that for 10 users an overload of almost 3 dB is possible in cases *a* and *b*. The probability of overloading with 50 users is very small. However, even in this case of "large-numbers" configuration *c* provides a margin that is better than that of configuration *b* by approximately 2.6 dB. Usually, to avoid overload of the power amplifiers a peak (total) power limit is applied at the base-station. This means that some users will be deprived of the power they need to sustain quality communications.

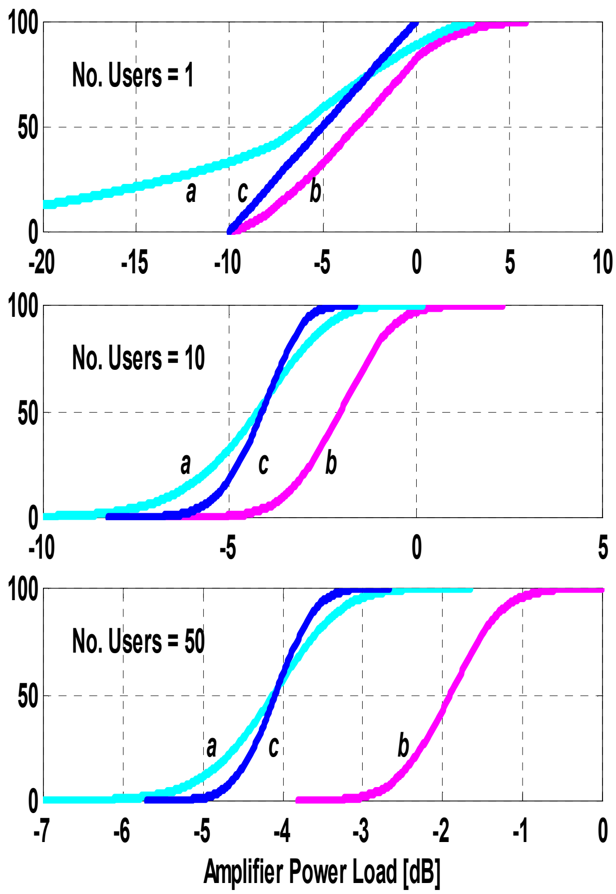


Figure 5: Total Power Load [dB] CDF

These users may be only a few percent out of the total population of served users – however, this is the worst case group that reduces the service performance score and to which the BTS is required to improve service! The third case (configuration *c*) is the most efficient: it guarantees each power amplifier to provide exactly *P/2* for a power requirement *P* by each user and thus is fully (and most efficiently) loaded. The *PolMatch*^{TM} control is maintained by phase only, and is performed (practically) per user at baseband.

Another observation is that the power spread range in cases *a* and *b* is larger than that in case *c*. This imposes larger dynamic range requirements from the power amplifiers.

4 Summary and Conclusions

Several transmission architectures were presented for the implementations of transmit polarization matching (*PolMatch*^{TM}) at base-stations. The power overloading of the power amplifiers was analyzed and characteristic results discussed, with immediate implications on the efficiency, generated self-interference, and cost of the system.

A transmission configuration that achieves the best possible efficiency was presented and analyzed.

Acknowledgement

The authors would like to thank Yitzhak Chazzan for contributions to this work.

References

[1] W.C. Jakes (Ed.), *Microwave Mobile Communications*, IEEE Press (Classic Reissue of the Wiley 1974 edition), Piscataway, New-Jersey, 1994.

[2] J. Shapira and S. Miller: "A Novel Polarization-Smart Antenna," IEEE 51st Vehicular Technology Conference, May 2001, Rhodes, Greece.

[3] K. Kalliola, H. Laitinen, K. Sulonen, L. Vuokko, P. Vainikainen, "Directional Radio Channel Measurements at Mobile Station in Different Radio Environments at 2.15 GHz," 4th EPMCC, February 20-22, 2001, Vienna

[4] J. Shapira and S. Miller: "Polarization Transmit Diversity," 4th EPMCC, February 20-22, 2001, Vienna