

EXHIBIT D-7

Invalidity of U.S. Patent No. 9,641,204 by WO2012/129768 to Peroulas et al. (“Peroulas”)

The Asserted Claims of U.S. Patent No. 9,641,204 (“the ’204 Patent”) are anticipated and/or rendered obvious in view of WO2012/129768 to Peroulas et al. (“Peroulas”) alone or in combination with other prior art. Peroulas was filed on March 28, 2011 and was published on October 4, 2012. Peroulas, thus, is prior art to the ’204 Patent at least under [list relevant statutes—e.g., §§ 102(a), 102(b), and/or 102(e)].

As described in detail below, Peroulas anticipates Asserted Claims 1–15 of the ’204 Patent. In addition, to the extent that Smart RF asserts that Peroulas or citations below are insufficient, every limitation set forth in the claim was predictable and obvious in view of the knowledge and progression of the art. As such, it would have been obvious to one of ordinary skill in the art at the time of the alleged invention, based on the explicit and implicit teaching of this reference and the prior art, the knowledge of one of ordinary skill in the art, and/or the nature of the claimed invention and the problem(s) purportedly being solved to take the purportedly missing element from the art and combine it with the other elements in prior art identified in the cover pleading or herein.

This claim chart is based on Defendants’ present understanding of the asserted claims, Smart RF’s vague and overbroad infringement contentions (and corresponding, implicit claim constructions), and Defendants’ investigations to date. Defendants are not adopting Smart RF’s apparent constructions, nor are Defendants admitting to the accuracy of any particular construction. Defendants reserve all rights to amend this invalidity claim chart in light of any claim-construction developments or any amendment to Smart RF’s infringement contentions. Further, as discovery is ongoing and Defendants continue to seek discovery from third parties regarding the references identified in Defendants’ invalidity contentions as well as other potential prior art, Defendants reserve the right to amend or supplement this claim chart identified in connection with Defendants’ continuing investigation. At minimum, Defendants intend to revise their invalidity contentions as appropriate to include discovery from third parties as discovery progresses. The claim chart below identifies where each limitation of the asserted claims of the ’204 Patent can be found in Peroulas. The citations provided below are exemplary, rather than exhaustive, and Defendants reserve the right to rely upon any other portion of the cited references.

Claim No.	’204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
1[pre]	A transmitter comprising:	To the extent the preamble is limiting, Peroulas discloses and/or renders obvious a transmitter. <i>See, e.g.,</i> “The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion

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		<p>functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB_2 302 are centered at ωHz and have bandwidths B_i and B_2 respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB_2 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB_2 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p>
1[a]	<p>a power amplifier configured to amplify modulated concurrent multi-band signals to provide amplified concurrent multi-band signals;</p>	<p>Peroulas discloses and/or renders obvious a power amplifier configured to amplify modulated concurrent multi-band signals to provide amplified concurrent multi-band signals.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband</p>

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		<p>input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at</p>

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		<p>f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies. The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD₁ and PD₂ sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB₁ 301 and BB₂ 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p>
1[b]	<p>a concurrent digital multi-band predistortion block configured to effect predistortion of the modulated concurrent multi-band signals to compensate for a non-linearity of the power amplifier; and</p>	<p>Peroulas discloses and/or renders obvious a concurrent digital multi-band predistortion block configured to effect predistortion of the modulated concurrent multi-band signals to compensate for a non-linearity of the power amplifier.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion</p>

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		<p>functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB_2 302 are centered at ωHz and have bandwidths B_i and B_2 respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB_2 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB_2 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB_2 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD_2, and the MIMO pre- distortion module 307 processes baseband signals BB_i 301 and BB_2 302 with a MIMO pre- distortion function. Signals PD_i and PD_2 are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD_2 to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p>
1[c]	a signal observation feedback loop configured to effect concurrent sampling of the amplified concurrent multi-band signals at a subsampling frequency lower than twice a highest signal frequency in the amplified concurrent multi-band signals	<p>Peroulas discloses and/or renders obvious a signal observation feedback loop configured to effect concurrent sampling of the amplified concurrent multi-band signals at a subsampling frequency lower than twice a highest signal frequency in the amplified concurrent multi-band signals.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion</p>

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	the amplified concurrent multi-band signals.	<p>functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital</p>

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		<p>pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{ci}-(f_{c2}-f_{ci})$ and $f_{c2}+(f_{c2}-f_{ci})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the \hat{p}, H_a, and h_a vectors and matrices (a is either 1 or 2), a vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1,0,0,0}$ and $h_{2,0,0,0}$ will both be set to 1 and all other values for $h_{1,a,b,c}$ and $h_{2,a,b,c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in \hat{h}_j^k and $h_{2,j}^k$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the h_{j,k_1,k_2} and h_{2,j,k_1,k_2} values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the \hat{h}_{j,k_1} and $h_{2,j}^k$ values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters (P_{0i}, P_{02}), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_1 301 and BB_2 302 have bandwidths B_1 and B_2 respectively, and both signal BB_1 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to larger one of B_1 and B_2, which are not a function of $B_{\text{dead space}}$- Besides, as the pre-distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_1 301 and</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$.</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{\text{mm},s} = 7 * \max(f_1, f_2)$” 29:16-23.</p>
2	<p>The transmitter of claim 1, wherein said concurrent digital multi-band predistortion block further comprises:</p> <p>a plurality of digital baseband signal predistorter blocks, each baseband signal predistorter block having a plurality of first inputs and a single output, the plurality of first inputs corresponding in number to the multiple bands of the multi-band transmitter and each first</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 1, wherein said concurrent digital multi-band predistortion block further comprises: a plurality of digital baseband signal predistorter blocks, each baseband signal predistorter block having a plurality of first inputs and a single output, the plurality of first inputs corresponding in number to the multiple bands of the multi-band transmitter and each first input corresponding to a single frequency channel.</p> <p>See claim 1, <i>supra</i>, which is incorporated by reference herein.</p> <p>See also, e.g.,</p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one</p>

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	input corresponding to a single frequency channel.	<p>output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ωHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital</p>

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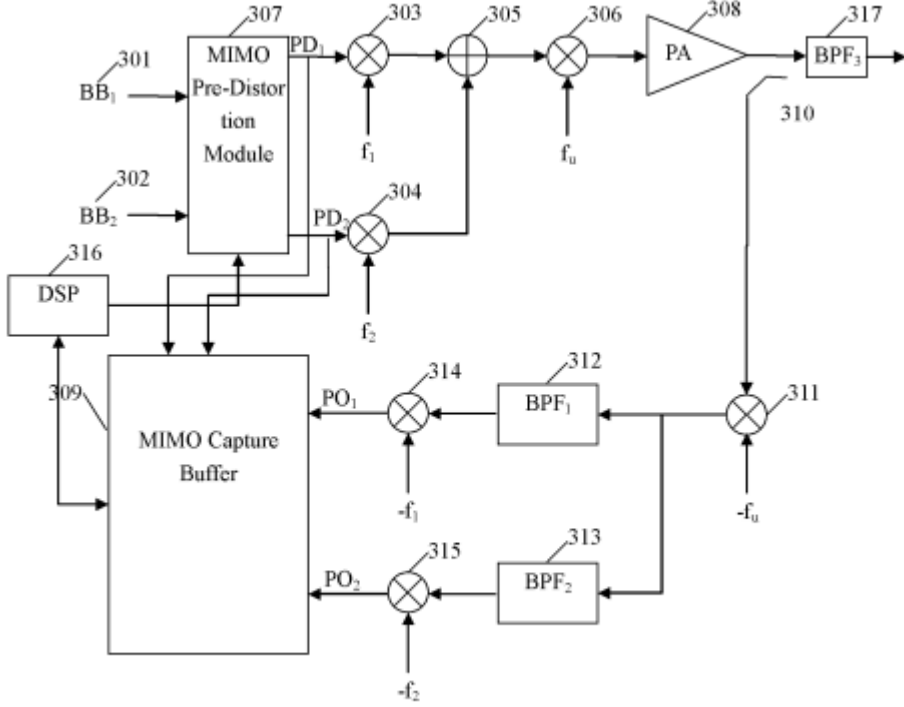
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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the \hat{p}, H_a, and h_a vectors and matrices (a is either 1 or 2), an vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1,0,0,0}$ and $h_{2,0,0,0}$ will both be set to 1 and all other values for $h_{1,a,b,c}$ and $h_{2,a,b,c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $\hat{h}_{j,k}$ and $h_{2,j,k}$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the h_{j,k_1,k_2} and h_{2,j,k_1,k_2} values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the \hat{h}_{j,k_1} and h_{2,j,k_1} values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters (P_{0i}, P_{02}), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_1 301 and BB_2 302 have bandwidths B_1 and B_2 respectively, and both signal BB_1 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to larger one of B_1 and B_2, which are not a function of $B_{\text{dead space}}$- Besides, as the pre-distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_1 301 and</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$.</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{,mm-,,} = 7 * \max(5_1, 5_2)$” 29:16-23.</p>
3[a]	<p>The transmitter of claim 2, wherein said concurrent digital multi-band predistortion block further comprises:</p> <p>a plurality of digital baseband signal predistorter blocks, each baseband signal predistorter block having a plurality of first inputs and a single output, the plurality of first inputs corresponding in number to the multiple bands of the multi-band transmitter and each first</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 2, wherein said concurrent digital multi-band predistortion block further comprises: a plurality of digital baseband signal predistorter blocks, each baseband signal predistorter block having a plurality of first inputs and a single output, the plurality of first inputs corresponding in number to the multiple bands of the multi-band transmitter and each first input corresponding to a single frequency channel.</p> <p><i>See claim 2, supra, which is incorporated by reference herein.</i></p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband</p>

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	input corresponding to a single frequency channel and	<p>input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ω_{Hz} and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital</p>

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		<p>pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{ci}-(f_{c2}-f_{ci})$ and $f_{c2}+(f_{c2}-f_{ci})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD₂ sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB₂ 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		 <p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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3[b]	<p>wherein the signal observation feedback loop includes an analyzing and modeling stage directly connected to each of the plurality of outputs of said digital multi-band predistortion block for receiving the respective predistorted signals and for using said received predistorted signals in controlling said digital multi-band predistortion block.</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 2, wherein the signal observation feedback loop includes an analyzing and modeling stage directly connected to each of the plurality of outputs of said digital multi-band predistortion block for receiving the respective predistorted signals and for using said received predistorted signals in controlling said digital multi-band predistortion block..</p> <p><i>See claim 2, supra, which is incorporated by reference herein.</i></p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband</p>

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		<p>input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ωHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital</p>

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		<p>pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{ci}-(f_{c2}-f_{ci})$ and $f_{c2}+(f_{c2}-f_{ci})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD₂ sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB₂ 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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4[a]	<p>The transmitter of claim 3, wherein said analyzing and modeling stage further comprises:</p> <p>a plurality of outputs connected to and for updating the parameters of said digital baseband signal predistorter block;</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 3, wherein said analyzing and modeling stage further comprises: a plurality of outputs connected to and for updating the parameters of said digital baseband signal predistorter block.</p> <p><i>See</i> claim 3, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure</p>

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		<p>to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre- distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre- distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the p^{\wedge}, H_a, and h_a vectors and matrices (a is either 1 or 2), an vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1;0;0;0}$ and $h_{2;0;0;0}$ will both be set to 1 and all other values for $h_{1; a b c}$ and $h_{2; a b c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $j^{\wedge} k$ and $h_{2j}^{\wedge} k$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the $h_{ij;ki,k2}$ and $h_{2j;ki,k2}$ values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the $j^{\wedge} ki$ and $h_{2j}^{\wedge} k$ values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters ($P0_i$, $P0_2$), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_i 301 and BB_2 302 have bandwidths B_i and B_2 respectively, and both signal BB_i 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to lager one of B_i and B_2, which are not a function of $B_{\text{deadspace}}$- Besides, as the pre- distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_i 301 and</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$).</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{,mm-,,} = 7 * \max(5_1, 5_2)$” 29:16-23.</p>
4[b]	a plurality of inputs connected to said outputs of said signal observation feedback loop.	<p>Peroulas discloses and/or renders obvious the transmitter of claim 3, wherein said analyzing and modeling stage further comprises: a plurality of inputs connected to said outputs of said signal observation feedback loop.</p> <p><i>See</i> claim 3, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure</p>

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		<p>to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre- distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre- distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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5	<p>The transmitter of claim 3, wherein said analyzing and modeling stage is further configured to:</p> <p>perform time alignment of complex baseband signals from sampling said outputs of said power amplifier; and perform the reconstruction of the complex baseband signals from sampling said outputs of said power amplifier.</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 3, wherein said analyzing and modeling stage is further configured to: perform time alignment of complex baseband signals from sampling said outputs of said power amplifier; and perform the reconstruction of the complex baseband signals from sampling said outputs of said power amplifier.</p> <p><i>See claim 3, supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one</p>

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		<p>output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre- distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre- distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital</p>

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		<p>pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{ci}-(f_{c2}-f_{ci})$ and $f_{c2}+(f_{c2}-f_{ci})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD₂ sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB₂ 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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6	<p>The transmitter of claim 2, wherein said signal observation feedback loop further is further configured to:</p> <p>down-convert samples of the RF signals at said output of the power amplifier; and</p> <p>extract from said down-converted samples a baseband equivalent for all frequency channels.</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 2, wherein said signal observation feedback loop further is further configured to: down-convert samples of the RF signals at said output of the power amplifier; and extract from said down-converted samples a baseband equivalent for all frequency channels.</p> <p><i>See claim 2, supra, which is incorporated by reference herein.</i></p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every</p>

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		<p>pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ω_{Hz} and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_1 and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the \hat{p}, H_a, and h_a vectors and matrices (a is either 1 or 2), an vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1,0,0,0}$ and $h_{2,0,0,0}$ will both be set to 1 and all other values for $h_{1,a,b,c}$ and $h_{2,a,b,c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $\hat{h}_{j,k}$ and $h_{2,j,k}$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the h_{j,k_1,k_2} and h_{2,j,k_1,k_2} values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the \hat{h}_{j,k_1} and h_{2,j,k_1} values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters ($P0_1$, $P0_2$), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_1 301 and BB_2 302 have bandwidths B_1 and B_2 respectively, and both signal BB_1 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to larger one of B_1 and B_2, which are not a function of $B_{\text{deadspace}}$- Besides, as the pre-distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_1 301 and</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$.</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{,mm-,,} = 7 * \max(5_1, 5_2)$” 29:16-23.</p>
7	<p>The transmitter of claim 2, wherein said signal observation feedback loop further comprises for each channel an RF filter;</p> <p>a signal down conversion block;</p> <p>and</p> <p>an analog-to-digital converter (ADC).</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 2, wherein said signal observation feedback loop further comprises for each channel an RF filter; a signal down conversion block; and an analog-to-digital converter (ADC).</p> <p><i>See</i> claim 2, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every</p>

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		<p>pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ω_{Hz} and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_1 and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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8	<p>The transmitter of claim 2, wherein said signal observation feedback loop further comprises:</p> <p>a single subsampling-based receiver to down-convert samples output from a concurrent multi-band transmitter.</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 2, wherein said signal observation feedback loop further comprises: a single subsampling-based receiver to down-convert samples output from a concurrent multi-band transmitter.</p> <p><i>See</i> claim 2, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every</p>

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		<p>pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ω Hz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_1 and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$).</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{\text{mm},s} = 7 * \max(5_1, 5_2)$” 29:16-23.</p>
9	<p>The transmitter of claim 8, wherein said single subsampling-based receiver further comprises:</p> <p>an RF filter;</p> <p>a track and hold (T&H) block; and</p> <p>an analog-to-digital converter (ADC).</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 8, wherein said single subsampling-based receiver further comprises: an RF filter; a track and hold (T&H) block; and an analog-to-digital converter (ADC).</p> <p><i>See</i> claim 8, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure</p>

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		<p>to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the p^{\wedge}, H_a, and h_a vectors and matrices (a is either 1 or 2), an vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1;0;0,0}$ and $h_{2;0,0,0}$ will both be set to 1 and all other values for $h_{1 a b c}$ and $h_{2 a b c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $j^{\wedge} k$ and $h_{2 j}^{\wedge} k$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the $h_{j;ki,k2}$ and $h_{2j;ki,k2}$ values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the $j^{\wedge} ki$ and $h_{2 j}^{\wedge} k$ values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters ($P0_i$, $P0_2$), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_i 301 and BB_2 302 have bandwidths B_i and B_2 respectively, and both signal BB_i 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to lager one of B_i and B_2, which are not a function of Bdeadspace- Besides, as the pre- distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_i 301 and</p>

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10	The transmitter of claim 1, wherein the subsampling frequency is greater than two times a signal bandwidth of the modulated concurrent multi-band signals.	<p>Peroulas discloses and/or renders obvious the transmitter of claim 1, wherein the subsampling frequency is greater than two times a signal bandwidth of the modulated concurrent multi-band signals.</p> <p><i>See</i> claim 1, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every</p>

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		<p>pre-distortion functions into one combined signal; and a power amplifier (PA), which is configured to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at ω_{i} and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre-distortion module 307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the p^{\wedge}, H_a, and h_a vectors and matrices (a is either 1 or 2), an vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1;0;0;0}$ and $h_{2;0;0;0}$ will both be set to 1 and all other values for $h_{1 a b c}$ and $h_{2 a b c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $j^{\wedge} k$ and $h_{2 j^{\wedge} k}$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the $h_{j;ki,k2}$ and $h_{2j;ki,k2}$ values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the $j^{\wedge} ki$ and $h_{2 j^{\wedge} k}$ values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters ($P0_i$, $P0_2$), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_i 301 and BB_2 302 have bandwidths B_i and B_2 respectively, and both signal BB_i 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to lager one of B_i and B_2, which are not a function of Bdeadspace- Besides, as the pre- distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_i 301 and</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$).</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{\text{mm}}, = 7 * \max(5_1, 5_2)$” 29:16-23.</p> <p>“Currently, if one wishes to transmit two signals with high efficiency over two different bands, the dual band digital pre-distortion (DB-DPD) system shown in FIG. 1 may be used. Complex baseband signals BB₁ 101 and BB₂ 102 are centered at OHz and have a bandwidth of B₁ and B₂ respectively. The intent of the DB-DPD system is that BB₁ and BB₂ will appear on the power amplifier's output centered at frequencies f_{c1} and f_{c2} respectively.</p> <p>Signals BB₁ 101 and BB₂ 102 are sent into frequency shifters 103 and 104 respectively, and the frequency shifters 103 and 104 shift the frequencies of the signals BB₁ 101 and BB₂ 102 to f₁ and f₂ respectively. These two shifted signals are combined by an adder 105 and then forwarded to a pre-distortion module 106, which processes the combined signal by a pre-distortion function. The output of the pre-distortion module 106 is then sent to a final frequency shifter 107 which shifts the frequency by f_u. It should be clear that f₁+f_u=f_{c1} and f₂+f_u=f_{c2}. Also,</p>

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		<p>In this application, a device which shifts the center frequency of a signal is called a 'frequency shifter'. Other equivalent terminology exists such as 'upconverter' and 'downconverter', but this application will use the term 'frequency shifter'.</p> <p>The output of the final frequency shifter 107 is sent to a power amplifier (PA) 108, and the PA 108 produces the final signal which will be transmitted.” 1:7-22.</p> <p>“Wherein p_d in is the signal input into the pre-distortion function and p_d out is the signal produced by the pre-distortion function, n is the sample index. M and L represent the memory depth and nonlinearity length of the above example of a pre-distortion function respectively. The actual values used for M and L will vary based on the actual PA that is being used but typically, M will be a rather small number around 4 and L will be around 10.</p> <p>One method that can be used to calculate the coefficients $h_{j;k}$ is the indirect learning architecture. The concept of the indirect learning architecture is that a model, which models the input of the PA based on the output of the PA, is created. Once such a model is created, the model is used directly as the pre-distortion function. For example, suppose that several samples input into and output from the PA are captured and are denoted as p_j for the samples input into the PA, and p_0 for the samples output from the PA. The required number of samples varies from one PA to another PA but typically, the required number of samples is between 2000 and 10000.</p> <p>These samples are typically observed using a capture buffer 111. The capture buffer 111 has two inputs. One input of the capture buffer 111 comes from the output of the pre-distortion module 106. The other input of the capture buffer 111 first comes from a coupler 110 which extracts a small portion (typically less than 1% of the output power) of the signal coming from the PA. The most important property of the coupler is that it produces a signal that very accurately represents the actual output of the PA, but at a significantly reduced power level. This extracted signal is forwarded to a frequency shifter 109 which shifts the signal back down in frequency by f_u. The output of this frequency shifter 109 is connected to the other input of the capture buffer 111. The capture buffer 111 is typically controlled by a Digital Signal Processor (DSP) 112 which, through the use of a trigger signal, indicates when the capture buffer 111 should begin capturing data. Once</p>

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		<p>the capture buffer 111 receives a trigger signal, it begins to capture data until the memory of the capture buffer 111 has been completely filled.” 2:6-3:4.</p> <p>“The pre-distortion module will produce output samples at a sampling rate of at least $B_{PD,OUT}$. Thus, the larger $B_{PD,IN}$ is, the more stringent the requirements on the pre-distortion function are. Specifically, the sampling rate of the output of the pre-distortion module, and the minimum rate at which the pre-distortion module must calculate output samples, is:</p> $f_{s,PDout} = \frac{1}{T_{PD,m}} = \frac{1}{T_{B1} + T_{B2} + T_{B \text{ deadspace}}}$ <p>Thus, although the final signal to be transmitted from the PA only contains energy over a frequency range totaling $B_1 + B_2$, the sampling rate of the pre-distortion module is severely degraded by $B_{\text{deadspace}}$. For example, suppose that B_1 and B_2 are 5 MHz and 10 MHz respectively and suppose further that $B_{\text{deadspace}}$ is 200 MHz. Although only 15 MHz of information will be transmitted by the PA, the output of the pre-distortion module will need to run at a frequency of about 1.5 GHz!</p> <p>Note that typically, the sampling rate of the data input into the pre-distortion module will be equal to the sampling rate of the data output from the pre-distortion function:</p> <p>Eq 13 $f_{s,PDout} \sim f_{s,PDin}$ Furthermore, the sampling rate of all the processing before the pre-distortion function will also typically be at the same rate as $f_{s,PDin}$.</p> <p>It can be seen from above description that the minimum sampling rate required by the prior art is expressed in Eq 14:</p> <p>Eq 14 $f_{s,mm, \text{ prior art}} \sim \frac{1}{T_{B1} + T_{B2} + T_{B \text{ deadspace}}}$ And the implementation cost of the prior art is related to $f_{s,mm, \text{ prior art}}$. The larger $f_{s,mm, \text{ prior art}}$, the larger the implementation cost is. Thus, the implementation cost of the prior art depends on $B_{\text{deadspace}}$ and can become immense if $B_{\text{deadspace}}$ is very large. It would be beneficial if a solution existed to reduce the implementation cost of a dual band pre-distortion transmitter. Furthermore, it would also be beneficial if a solution</p>

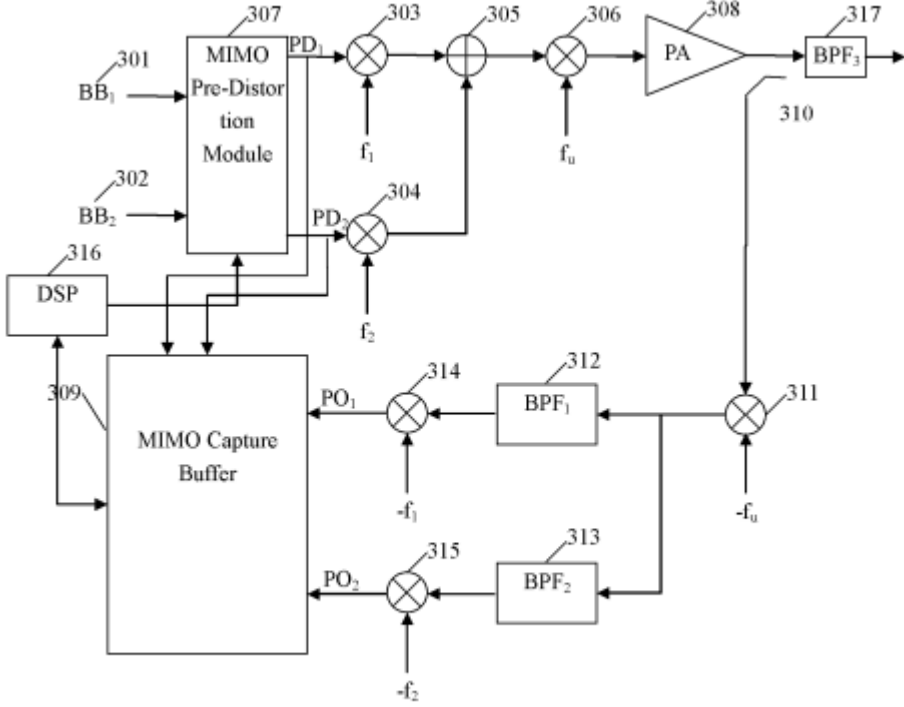
Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>existed such that the implementation cost of a dual band pre-distortion transmitter would not be a function of Bdeadspace” 5:6-6:5.</p> <p>“This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BBi 301 and BB₂ 302 are centered at OHz and have bandwidths Bi and B₂ respectively. The intent of the multiband digital pre-distorter is that BBi 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BBi 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.</p> <p>Baseband signals BBi 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PDi and PD₂, and the MIMO pre- distortion module 307 processes baseband signals BBi 301 and BB₂ 302 with a MIMO pre- distortion function. Signals PDi and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PDi and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.</p> <p>Preferably the combined signal is forwarded to a final frequency shifter 306 which shifts the combined frequency by f_u. It should be clear that</p> <p>$f_1+f_u=f_{c1}$ and $f_2+f_u=f_{c2}$. Also, $f_{c2}-f_{c1}=f_2-f_1$.</p> <p>Below the situation to be described is one in which the combined signal is forwarded to a final frequency shifter 306.</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>If there is the final frequency shifter 306 in the multiband digital pre-distorter, the output of the final frequency shifter 306 is sent to a power amplifier (PA) 308; or if there is no final frequency shifter 306, the output of the adder 305 is sent directly to a power amplifier (PA) 308. The PA 308 produces the final signal which will be transmitted.</p> <p>The PA 308 is typically a low efficiency device and one method that can be used to improve its efficiency is to drive it into its nonlinear region. The problem is that the more the PA is driven into its nonlinear region, the higher the amount of distortion is introduced by the PA.</p> <p>The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies. The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_1 and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_1 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.</p> <p>Although many functions can be used for the MIMO pre-distortion function, one two-input two-output pre-distortion function that can be used for the MIMO pre-distortion function in this example is given in equations Eq 15 and Eq 16:</p> <p>Eq 15 $\frac{3}{4} \frac{3}{4} (\gg) = (n - Jf$</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		$\sum_{j=0}^{M-1} \sum_{k_1=0}^{L_1-1} \sum_{k_2=0}^{L_2-1} h_{1,j,k_1,k_2} BB_1(n-j) BB_1(n-j) ^{k_1} BB_2 $ <p>M-1 i_j-1 L₂-1</p> <p>Eq 16 $\sum_{j=0}^{M-1} \sum_{k_1=0}^{L_1-1} \sum_{k_2=0}^{L_2-1} h_{1,j,k_1,k_2} BB_1(n-j) BB_1(n-j) ^{k_1} BB_2$</p> <p>Wherein, M represents the memory depth of the PA 308. That is, the PAs 308 output is considered to be a function of the current input sample and the previous M-1 input samples. L₁ and L₂ represent the nonlinearity length and the interband crosscorrelation degree of the MIMO pre-distortion model. The actual values used for M, L₁, and L₂ will vary based on the actual PA 308 that is used but typically, M will be a rather small number typically between 1 and 6. The values of L₁ and L₂ will be slightly larger than M and typically between 3 and 15. The coefficients h_{1,j,k_1,k_2} are chosen such that the cascade of the MIMO pre-distortion function 307, the PA 308, and BPF₃ 317 will be linear overall. And each equation such as Eq 15 and Eq 16 is called a pre-distortion function.” 22:17-24:22.</p>
11	<p>The transmitter of claim 1, wherein the subsampling frequency f_s is in a range $2f_u/n \leq f_s \leq 2h/(n-1)$ where $1 \leq n \leq f_u/B$, and where B is a bandwidth of the amplified concurrent multi-band signals, and f_l, f_u, are respective lower and upper frequencies of the bandwidth, and n is an integer.</p>	<p>Peroulas discloses and/or renders obvious the transmitter of claim 1, wherein the subsampling frequency f_s is in a range $2f_u/n \leq f_s \leq 2h/(n-1)$ where $1 \leq n \leq f_u/B$, and where B is a bandwidth of the amplified concurrent multi-band signals, and f_l, f_u, are respective lower and upper frequencies of the bandwidth, and n is an integer.</p> <p>See claim 1, <i>supra</i>, which is incorporated by reference herein.</p> <p>See, e.g.,</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorer.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB_2 302 are centered at ωHz and have bandwidths B_i and B_2 respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB_2 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB_2 302 are sampled at a rate of f_s and that $f_{c1} < f_{c2}$. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB_2 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD_2, and the MIMO pre- distortion module 307 processes baseband signals BB_i 301 and BB_2 302 with a MIMO pre- distortion function. Signals PD_i and PD_2 are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD_2 to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_1 and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_1 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		 <p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the p^{\wedge}, H_a, and h_a vectors and matrices (a is either 1 or 2), an vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1;0;0;0}$ and $h_{2;0;0;0}$ will both be set to 1 and all other values for $h_{1; a b c}$ and $h_{2; a b c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $j^{\wedge} k$ and $h_{2j}^{\wedge} k$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the $h_{ij;ki,k2}$ and $h_{2j;ki,k2}$ values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the $j^{\wedge} ki$ and $h_{2j}^{\wedge} k$ values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters (PO_i, PO_2), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_i 301 and BB_2 302 have bandwidths B_i and B_2 respectively, and both signal BB_i 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to lager one of B_i and B_2, which are not a function of $B_{\text{deadspace}}$- Besides, as the pre- distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_i 301 and</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$).</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{\text{mm},s} = 7 * \max(5_1, 5_2)$” 29:16-23.</p> <p>“Currently, if one wishes to transmit two signals with high efficiency over two different bands, the dual band digital pre-distortion (DB-DPD) system shown in FIG. 1 may be used. Complex baseband signals BB₁ 101 and BB₂ 102 are centered at OHz and have a bandwidth of B₁ and B₂ respectively. The intent of the DB-DPD system is that BB₁ and BB₂ will appear on the power amplifier's output centered at frequencies f_{c1} and f_{c2} respectively.</p> <p>Signals BB₁ 101 and BB₂ 102 are sent into frequency shifters 103 and 104 respectively, and the frequency shifters 103 and 104 shift the frequencies of the signals BB₁ 101 and BB₂ 102 to f₁ and f₂ respectively. These two shifted signals are combined by an adder 105 and then forwarded to a pre-distortion module 106, which processes the combined signal by a pre-distortion function. The output of the pre-distortion module 106 is then sent to a final frequency shifter 107 which shifts the frequency by f_u. It should be clear that f₁+f_u=f_{c1} and f₂+f_u=f_{c2}. Also,</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>In this application, a device which shifts the center frequency of a signal is called a 'frequency shifter'. Other equivalent terminology exists such as 'upconverter' and 'downconverter', but this application will use the term 'frequency shifter'.</p> <p>The output of the final frequency shifter 107 is sent to a power amplifier (PA) 108, and the PA 108 produces the final signal which will be transmitted.” 1:7-22.</p> <p>“Wherein p_d in is the signal input into the pre-distortion function and p_d out is the signal produced by the pre-distortion function, n is the sample index. M and L represent the memory depth and nonlinearity length of the above example of a pre-distortion function respectively. The actual values used for M and L will vary based on the actual PA that is being used but typically, M will be a rather small number around 4 and L will be around 10.</p> <p>One method that can be used to calculate the coefficients $h_{j;k}$ is the indirect learning architecture. The concept of the indirect learning architecture is that a model, which models the input of the PA based on the output of the PA, is created. Once such a model is created, the model is used directly as the pre-distortion function. For example, suppose that several samples input into and output from the PA are captured and are denoted as p_j for the samples input into the PA, and p_0 for the samples output from the PA. The required number of samples varies from one PA to another PA but typically, the required number of samples is between 2000 and 10000.</p> <p>These samples are typically observed using a capture buffer 111. The capture buffer 111 has two inputs. One input of the capture buffer 111 comes from the output of the pre-distortion module 106. The other input of the capture buffer 111 first comes from a coupler 110 which extracts a small portion (typically less than 1% of the output power) of the signal coming from the PA. The most important property of the coupler is that it produces a signal that very accurately represents the actual output of the PA, but at a significantly reduced power level. This extracted signal is forwarded to a frequency shifter 109 which shifts the signal back down in frequency by f_u. The output of this frequency shifter 109 is connected to the other input of the capture buffer 111. The capture buffer 111 is typically controlled by a Digital Signal Processor (DSP) 112 which, through the use of a trigger signal, indicates when the capture buffer 111 should begin capturing data. Once</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>the capture buffer 111 receives a trigger signal, it begins to capture data until the memory of the capture buffer 111 has been completely filled.” 2:6-3:4.</p> <p>“The pre-distortion module will produce output samples at a sampling rate of at least $B_{PD,OUT}$. Thus, the larger $B_{PD,IN}$ is, the more stringent the requirements on the pre-distortion function are. Specifically, the sampling rate of the output of the pre-distortion module, and the minimum rate at which the pre-distortion module must calculate output samples, is:</p> $f_{s,PDout} = \frac{1}{T_{PD,m}} = \frac{1}{T_{PD,m} \{B_1 + B_2 + B_{\text{deadspace}}\}}$ <p>Thus, although the final signal to be transmitted from the PA only contains energy over a frequency range totaling $B_1 + B_2$, the sampling rate of the pre-distortion module is severely degraded by $B_{\text{deadspace}}$. For example, suppose that B_1 and B_2 are 5 MHz and 10 MHz respectively and suppose further that $B_{\text{deadspace}}$ is 200 MHz. Although only 15 MHz of information will be transmitted by the PA, the output of the pre-distortion module will need to run at a frequency of about 1.5 GHz!</p> <p>Note that typically, the sampling rate of the data input into the pre-distortion module will be equal to the sampling rate of the data output from the pre-distortion function:</p> <p>Eq 13 $f_{s,PDout} \sim f_{s,PDin}$ Furthermore, the sampling rate of all the processing before the pre-distortion function will also typically be at the same rate as $f_{s,PDin}$.</p> <p>It can be seen from above description that the minimum sampling rate required by the prior art is expressed in Eq 14:</p> <p>Eq 14 $f_{s,mm,prior\ art} \sim \frac{1}{T_{PD,m}} \{B_1 + B_2 + B_{\text{deadspace}}\}$ And the implementation cost of the prior art is related to $f_{s,mm,prior\ art}$. The larger $f_{s,mm,prior\ art}$, the larger the implementation cost is. Thus, the implementation cost of the prior art depends on $B_{\text{deadspace}}$ and can become immense if $B_{\text{deadspace}}$ is very large. It would be beneficial if a solution existed to reduce the implementation cost of a dual band pre-distortion transmitter. Furthermore, it would also be beneficial if a solution</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>existed such that the implementation cost of a dual band pre-distortion transmitter would not be a function of Bdeadspace” 5:6-6:5.</p> <p>“This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BBi 301 and BB₂ 302 are centered at OHz and have bandwidths Bi and B₂ respectively. The intent of the multiband digital pre-distorter is that BBi 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BBi 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.</p> <p>Baseband signals BBi 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PDi and PD₂, and the MIMO pre- distortion module 307 processes baseband signals BBi 301 and BB₂ 302 with a MIMO pre- distortion function. Signals PDi and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PDi and PD₂ to fi and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.</p> <p>Preferably the combined signal is forwarded to a final frequency shifter 306 which shifts the combined frequency by fu. It should be clear that</p> $f_1+f_u=f_{c1} \text{ and } f_2+f_u=f_{c2}. \text{ Also, } f_{c2}-f_{c1}=f_2-f_1.$ <p>Below the situation to be described is one in which the combined signal is forwarded to a final frequency shifter 306.</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		<p>If there is the final frequency shifter 306 in the multiband digital pre-distorter, the output of the final frequency shifter 306 is sent to a power amplifier (PA) 308; or if there is no final frequency shifter 306, the output of the adder 305 is sent directly to a power amplifier (PA) 308. The PA 308 produces the final signal which will be transmitted.</p> <p>The PA 308 is typically a low efficiency device and one method that can be used to improve its efficiency is to drive it into its nonlinear region. The problem is that the more the PA is driven into its nonlinear region, the higher the amount of distortion is introduced by the PA.</p> <p>The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies. The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD₁ and PD₂ sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB₁ 301 and BB₂ 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.</p> <p>Although many functions can be used for the MIMO pre-distortion function, one two-input two-output pre-distortion function that can be used for the MIMO pre-distortion function in this example is given in equations Eq 15 and Eq 16:</p> <p>Eq 15 $\frac{3}{4} \frac{3}{4} (\gg) = (n - Jf$</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
		$\sum_{j=0}^{M-1} \sum_{k_1=0}^{L_1-1} \sum_{k_2=0}^{L_2-1} h_{1,j,k_1,k_2} BB_1(n-j) BB_1(n-j) ^{k_1} BB_2 $ <p>M-1 i_j-1 L₂-1</p> <p>Eq 16 $\sum_{j=0}^{M-1} \sum_{k_1=0}^{L_1-1} \sum_{k_2=0}^{L_2-1} h_{1,j,k_1,k_2} BB_1(n-j) BB_1(n-j) ^{k_1} BB_2$</p> <p>Wherein, M represents the memory depth of the PA 308. That is, the PAs 308 output is considered to be a function of the current input sample and the previous M-1 input samples. L₁ and L₂ represent the nonlinearity length and the interband crosscorrelation degree of the MIMO pre-distortion model. The actual values used for M, L₁, and L₂ will vary based on the actual PA 308 that is used but typically, M will be a rather small number typically between 1 and 6. The values of L₁ and L₂ will be slightly larger than M and typically between 3 and 15. The coefficients h_{1,j,k_1,k_2} are chosen such that the cascade of the MIMO pre-distortion function 307, the PA 308, and BPF₃ 317 will be linear overall. And each equation such as Eq 15 and Eq 16 is called a pre-distortion function.” 22:17-24:22.</p>
12[pre]	A method at transmitter comprising:	<p>To the extent the preamble is limiting, Peroulas discloses and/or renders obvious a method at [sic] transmitter.</p> <p>See, claim 1[pre], <i>supra</i>, which is incorporated by reference herein.</p>
12[a]	amplifying a modulated concurrent multi-hand signal to provide an amplified concurrent multi-band signal;	<p>Peroulas discloses and/or renders obvious amplifying a modulated concurrent multi-hand signal to provide an amplified concurrent multi-band signal [sic].</p> <p>See, claim 1[a], <i>supra</i>, which is incorporated by reference herein.</p>

Claim No.	'204 Patent	Exemplary Evidence of Anticipation and/or Obviousness
12[b]	predistorting the modulated concurrent multi-hand signal to compensate for a non-linearity of the power amplifier:	Peroulas discloses and/or renders obvious predistorting the modulated concurrent multi-hand signal to compensate for a non-linearity of the power amplifier. <i>See, claim 1[b], supra, which is incorporated by reference herein.</i>
12[c]	subsampling of the amplified concurrent multi-band signals at a subsampling frequency lower than twice a highest signal frequency in the amplified multi-band signal: and	Peroulas discloses and/or renders obvious subsampling of the amplified concurrent multi-band signals at a subsampling frequency lower than twice a highest signal frequency in the amplified multi-band signal. <i>See, claim 1[c], supra, which is incorporated by reference herein.</i>
12[d]	controlling the predistorting by the subsampled concurrent multi-band signal.	Peroulas discloses and/or renders obvious controlling the predistorting by the subsampled concurrent multi-band signal. <i>See, claim 1[c], supra, which is incorporated by reference herein.</i>
13	The method of claim 12, wherein the subsampling frequency is greater than two times a signal bandwidth of the modulated concurrent multi-band signal.	Peroulas discloses and/or renders obvious the method of claim 12, wherein the subsampling frequency is greater than two times a signal bandwidth of the modulated concurrent multi-band signal. <i>See claims 10 and 12, supra, which is incorporated by reference herein.</i>
14	The method of claim 12, wherein the subsampling frequency is	Peroulas discloses and/or renders obvious the method of claim 12, wherein the subsampling frequency is chosen to avoiding aliasing between replicas.

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	chosen to avoiding aliasing between replicas.	<p><i>See</i> claims 10 and 12, <i>supra</i>, which is incorporated by reference herein.</p> <p><i>See, e.g.,</i></p> <p>“The present invention discloses a pre-distorter, which comprises: a pre-distortion module, which is configured to pre-distort a plurality of baseband input signals by an equal number of pre-distortion functions to obtain equal number of pre-distorted signals respectively, wherein all of the baseband input signals input into every pre-distortion function, and each pre-distortion function has one output; an adder, which is configured to combine all of the pre-distorted signals output from every pre-distortion functions into one combined signal; and a power amplifier (PA), which is configure to amplify the combined signal, wherein the cascade of the pre-distortion functions and the PA are linear overall. And the present invention also discloses a method for distorting. The present invention reduces the implementation cost of a pre-distorter.” Abstract.</p> <p>“The goal of the pre-distortion function, which is also a non-linear function, is to create a signal to be sent to the PA such that the output signal of the PA contains little or no distortion. In other words, although the pre-distortion function and the PA are individually non-linear, the cascade of the pre-distortion function and the PA produces a system that is linear overall.”1:27-2:2.</p> <p>“Below the present invention will be described in detail by presenting particular examples.</p> <p>This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BB_i 301 and BB₂ 302 are centered at OHz and have bandwidths B_i and B₂ respectively. The intent of the multiband digital pre-distorter is that BB_i 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BB_i 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.” 22:16-25.</p> <p>“Baseband signals BB_i 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PD_i and PD₂, and the MIMO pre- distortion module</p>

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		<p>307 processes baseband signals BB_i 301 and BB₂ 302 with a MIMO pre-distortion function. Signals PD_i and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PD_i and PD₂ to f_i and f_2 respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre-distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.” 22:26-23:9.</p> <p>“The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{ci}-(f_{c2}-f_{ci})$ and $f_{c2}+(f_{c2}-f_{ci})$- Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies.</p> <p>The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_i and PD₂ sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_i 301 and BB₂ 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.” 23:21-24:8.</p>

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		<p style="text-align: center;">FIG. 3</p> <p>Fig. 3.</p> <p>“In one example, this model is created by capturing the samples of several signals using a MIMO capture buffer 309. The number of samples required to be captured by the MIMO capture buffer 309 varies based on the PA 308 and the type of signals to be transmitted, but typically, between 2000 and 10000 samples of each signal coming into the MIMO capture buffer 309 will need to be captured.” 25:10-14.</p> <p>“Two of the signals recorded by the MIMO capture buffer 309 in this example are PDi and PD2, which are produced by the multiple input multiple output (MIMO) pre-distortion module 307. The</p>

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		<p>other two signals recorded by the MIMO capture buffer 309 are derived from a signal output from a coupler 310 which extracts a small portion (typically less than 1% of the PA output power) of the signal output from the PA 308. The key property of the coupler 310 is that it produces a signal which is an accurate representation of the actual output of the PA 308. The output of the coupler 310 is connected to a frequency shifter 311 which shifts the signal down by f_u Hz.” 25:15-22.</p> <p>“It should be clear to one skilled in the art that although this application describes a specific method to construct the p^{\wedge}, H_a, and h_a vectors and matrices (a is either 1 or 2), a vast number of variations are possible that do not depart from the scope of this application. For example, any two rows of can be exchanged as long as the same rows of H_a are exchanged. Furthermore, any two columns (j and k) of H_a can be exchanged as long as the same rows (j and k) of h_a are exchanged.” 28:8-13.</p> <p>“The general operation of the multiband digital pre-distorter is that when the multiband digital pre-distorter is first turned on, initially, $h_{1;0;0,0}$ and $h_{2;0,0,0}$ will both be set to 1 and all other values for $h_{1 a b c}$ and $h_{2 a b c}$ will be set to zero. When some samples are captured by the MIMO capture buffer 309, the samples are analyzed by the DSP so as to produce the vectors and h_2 and all of values in $j^{\wedge} k$ and $h_{2 j^{\wedge} k}$. After these values have been calculated, the DSP transmits these values to the MIMO pre-distortion module and all of the $h_{j;ki,k2}$ and $h_{2j;ki,k2}$ values of the MIMO pre-distortion function in the MIMO pre-distortion module will be simultaneously updated and replaced with the $j^{\wedge} ki$ and $h_{2 j^{\wedge} k}$ values.” 28:14-21.</p> <p>“The sampling rates of the signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals coming from the feedback frequency shifters (PO_i, PO_2), are usually the same, which are represented in this application by a variable f_s.” 28:26-29:2.</p> <p>“According to the pre-distortion functions expressed in Eq 15 and Eq 16, because the signals BB_i 301 and BB_2 302 have bandwidths B_i and B_2 respectively, and both signal BB_i 301 and BB_2 302 are baseband signals, so the bandwidths of the signal output from the Eq 15 and Eq 16 are equal to larger one of B_i and B_2, which are not a function of $B_{\text{deadspace}}$- Besides, as the pre-distortion function in the prior art (such as the dual band digital pre-distortion system shown in FIG. 1), the MIMO pre-distortion function in this example expands the bandwidth of the signal going through it for the purpose of sufficiently linearizing the PA 308. For example, although signals BB_i 301 and</p>

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		<p>BB₂ have bandwidths B₁ and B₂ respectively, the bandwidth of PD₁ and PD₂ respectively coming out of the MIMO pre-distortion function will be much larger than the larger one of B₁ and B₂. Although the actual bandwidth of PD₁ depends on the specific power amplifier being used and the specific signals being transmitted, typically, this bandwidth will be about 5 to 7 times the larger one of B₁ and B₂. In order to simplify the description in this application, it will be assumed that the bandwidth of PD₁ and PD₂ will be $7 * \max(B_1, B_2)$.” 29:3-15.</p> <p>“It has been previously stated that the bandwidth of the PO₁ and PO₂ signals will be about 6B₁ and 6B₂ respectively. Thus, the maximum bandwidth that must be supported by any of the baseband signals of interest (signals input into the MIMO pre-distortion function, signals output from the MIMO pre-distortion function, and signals (PO₁, PO₂) coming from the feedback frequency shifters 314 and 315) will be $7 * \max(B_1, B_2)$).</p> <p>Thus, in the example of the present invention, the minimum sampling frequency of the system, and the frequency at which the MIMO pre-distortion function will operate, is:</p> <p>Eq 29 $f_{\text{mm}}, = 7 * \max(5_1, 5_2)$” 29:16-23.</p> <p>“Currently, if one wishes to transmit two signals with high efficiency over two different bands, the dual band digital pre-distortion (DB-DPD) system shown in FIG. 1 may be used. Complex baseband signals BB₁ 101 and BB₂ 102 are centered at OHz and have a bandwidth of B₁ and B₂ respectively. The intent of the DB-DPD system is that BB₁ and BB₂ will appear on the power amplifier's output centered at frequencies f_{c1} and f_{c2} respectively.</p> <p>Signals BB₁ 101 and BB₂ 102 are sent into frequency shifters 103 and 104 respectively, and the frequency shifters 103 and 104 shift the frequencies of the signals BB₁ 101 and BB₂ 102 to f₁ and f₂ respectively. These two shifted signals are combined by an adder 105 and then forwarded to a pre-distortion module 106, which processes the combined signal by a pre-distortion function. The output of the pre-distortion module 106 is then sent to a final frequency shifter 107 which shifts the frequency by f_u. It should be clear that f₁+f_u=f_{c1} and f₂+f_u=f_{c2}. Also,</p>

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		<p>In this application, a device which shifts the center frequency of a signal is called a 'frequency shifter'. Other equivalent terminology exists such as 'upconverter' and 'downconverter', but this application will use the term 'frequency shifter'.</p> <p>The output of the final frequency shifter 107 is sent to a power amplifier (PA) 108, and the PA 108 produces the final signal which will be transmitted.” 1:7-22.</p> <p>“Wherein p_d in is the signal input into the pre-distortion function and p_d out is the signal produced by the pre-distortion function, n is the sample index. M and L represent the memory depth and nonlinearity length of the above example of a pre-distortion function respectively. The actual values used for M and L will vary based on the actual PA that is being used but typically, M will be a rather small number around 4 and L will be around 10.</p> <p>One method that can be used to calculate the coefficients $h_{j;k}$ is the indirect learning architecture. The concept of the indirect learning architecture is that a model, which models the input of the PA based on the output of the PA, is created. Once such a model is created, the model is used directly as the pre-distortion function. For example, suppose that several samples input into and output from the PA are captured and are denoted as p_j for the samples input into the PA, and p_0 for the samples output from the PA. The required number of samples varies from one PA to another PA but typically, the required number of samples is between 2000 and 10000.</p> <p>These samples are typically observed using a capture buffer 111. The capture buffer 111 has two inputs. One input of the capture buffer 111 comes from the output of the pre-distortion module 106. The other input of the capture buffer 111 first comes from a coupler 110 which extracts a small portion (typically less than 1% of the output power) of the signal coming from the PA. The most important property of the coupler is that it produces a signal that very accurately represents the actual output of the PA, but at a significantly reduced power level. This extracted signal is forwarded to a frequency shifter 109 which shifts the signal back down in frequency by f_u. The output of this frequency shifter 109 is connected to the other input of the capture buffer 111. The capture buffer 111 is typically controlled by a Digital Signal Processor (DSP) 112 which, through the use of a trigger signal, indicates when the capture buffer 111 should begin capturing data. Once</p>

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		<p>the capture buffer 111 receives a trigger signal, it begins to capture data until the memory of the capture buffer 111 has been completely filled.” 2:6-3:4.</p> <p>“The pre-distortion module will produce output samples at a sampling rate of at least $B_{PD,OUT}$. Thus, the larger $B_{PD,IN}$ is, the more stringent the requirements on the pre-distortion function are. Specifically, the sampling rate of the output of the pre-distortion module, and the minimum rate at which the pre-distortion module must calculate output samples, is:</p> $f_{s,PDout} = \frac{1}{T_{PD,m}} = \frac{1}{T_{PD,m}^{(B_1 + B_2 + B_{\text{deadspace}})}}$ <p>Thus, although the final signal to be transmitted from the PA only contains energy over a frequency range totaling $B_1 + B_2$, the sampling rate of the pre-distortion module is severely degraded by $B_{\text{deadspace}}$. For example, suppose that B_1 and B_2 are 5 MHz and 10 MHz respectively and suppose further that $B_{\text{deadspace}}$ is 200 MHz. Although only 15 MHz of information will be transmitted by the PA, the output of the pre-distortion module will need to run at a frequency of about 1.5 GHz!</p> <p>Note that typically, the sampling rate of the data input into the pre-distortion module will be equal to the sampling rate of the data output from the pre-distortion function:</p> <p>Eq 13 $f_{s,PDout} \sim f_{s,PDin}$ Furthermore, the sampling rate of all the processing before the pre-distortion function will also typically be at the same rate as $f_{s,PDin}$.</p> <p>It can be seen from above description that the minimum sampling rate required by the prior art is expressed in Eq 14:</p> <p>Eq 14 $f_{s,mm,prior\ art} \sim \frac{1}{T_{PD,m}^{(B_1 + B_2 + B_{\text{deadspace}})}}$ And the implementation cost of the prior art is related to $f_{s,mm,prior\ art}$. The larger $f_{s,mm,prior\ art}$, the larger the implementation cost is. Thus, the implementation cost of the prior art depends on $B_{\text{deadspace}}$ and can become immense if $B_{\text{deadspace}}$ is very large. It would be beneficial if a solution existed to reduce the implementation cost of a dual band pre-distortion transmitter. Furthermore, it would also be beneficial if a solution</p>

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		<p>existed such that the implementation cost of a dual band pre-distortion transmitter would not be a function of Bdeadspace” 5:6-6:5.</p> <p>“This example will describe two baseband input signals as an example, but the present invention is not limited to two baseband input signals. The architecture of the multiband digital pre-distorter (dual band digital pre-distorter in this example) according to this example is shown in FIG. 3. The baseband signals BBi 301 and BB₂ 302 are centered at OHz and have bandwidths Bi and B₂ respectively. The intent of the multiband digital pre-distorter is that BBi 301 and BB₂ 302 appear on the output of the PA 308 centered at f_{c1} and f_{c2} respectively. Without loss of generality, the discussion here will assume that both signals BBi 301 and BB₂ 302 are sampled at a rate of f_s and that f_{c1}<f_{c2}. Further restrictions on the sampling rate f_s will be presented later in this application.</p> <p>Baseband signals BBi 301 and BB₂ 302 are sent into a multiple input multiple output (MIMO) pre-distortion module 307 to produce signals PDi and PD₂, and the MIMO pre- distortion module 307 processes baseband signals BBi 301 and BB₂ 302 with a MIMO pre- distortion function. Signals PDi and PD₂ are sent into frequency shifters 303 and 304 which shift the frequency of the signals PDi and PD₂ to f_i and f₂ respectively. Then these shifted signals are combined by an adder 305. Wherein the MIMO pre-distortion function includes at least two pre-distortion functions, and each pre-distortion function has two inputs and one output. The number of the inputs for each pre-distortion function is equal to the number of the baseband signals input into the multiband digital pre-distorter, and the number of the pre- distortion functions is equal to the number of the baseband signals input into the multiband digital pre-distorter.</p> <p>Preferably the combined signal is forwarded to a final frequency shifter 306 which shifts the combined frequency by f_u. It should be clear that</p> $f_1+f_u=f_{c1} \text{ and } f_2+f_u=f_{c2}. \text{ Also, } f_{c2}-f_{c1}=f_2-f_1.$ <p>Below the situation to be described is one in which the combined signal is forwarded to a final frequency shifter 306.</p>

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		<p>If there is the final frequency shifter 306 in the multiband digital pre-distorter, the output of the final frequency shifter 306 is sent to a power amplifier (PA) 308; or if there is no final frequency shifter 306, the output of the adder 305 is sent directly to a power amplifier (PA) 308. The PA 308 produces the final signal which will be transmitted.</p> <p>The PA 308 is typically a low efficiency device and one method that can be used to improve its efficiency is to drive it into its nonlinear region. The problem is that the more the PA is driven into its nonlinear region, the higher the amount of distortion is introduced by the PA.</p> <p>The output of the PA 308 is connected to a bandpass filter BPF₃ 317 which filters out harmonics of the carrier frequencies f_{c1} and f_{c2}. As known to someone skilled in the art, if a non-linear PA is presented with a signal centered at f_{c1} and f_{c2}, the output of the PA will contain desired signals at f_{c1} and f_{c2}, but it will also contain energy at frequencies $f_{c1}-(f_{c2}-f_{c1})$ and $f_{c2}+(f_{c2}-f_{c1})$. Stated in general terms, BPF₃ 317 will remove the distortion products introduced by the PA 308 far away from the transmission carrier frequencies f_{c1} and f_{c2} whereas the rest of the application will remove the distortion products introduced by the PA 308 nearby and on top of the carrier frequencies. The goal of the MIMO pre-distortion function (which is also a non-linear function) is to produce signals PD_1 and PD_2 sent to the PA 308 such that the output of the BPF₃ 317 only contains signals BB_1 301 and BB_2 302 centered at frequencies f_{c1} and f_{c2}. No system is perfect and the output of the BPF₃ 317 in this example will also contain some distortions, but the MIMO pre-distortion function in this example attempts to minimize these distortions as much as possible. Although the MIMO pre-distortion function and the PA 308 are individually nonlinear, the cascade of the MIMO pre-distortion function, the PA 308, and BPF₃ 317 produces a system that is linear overall.</p> <p>Although many functions can be used for the MIMO pre-distortion function, one two-input two-output pre-distortion function that can be used for the MIMO pre-distortion function in this example is given in equations Eq 15 and Eq 16:</p> <p>Eq 15 $\frac{3}{4} \frac{3}{4} (\gg) = (n - Jf$</p>

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		$\sum_{j=0}^{M-1} \sum_{k_1=0}^{L_1-1} \sum_{k_2=0}^{L_2-1} h_{1,j,k_1,k_2} BB_1(n-j) BB_1(n-j) ^{k_1} BB_2 $ <p>M-1 i_j-1 L₂-1</p> <p>Eq 16 $\sum_{j=0}^{M-1} \sum_{k_1=0}^{L_1-1} \sum_{k_2=0}^{L_2-1} h_{1,j,k_1,k_2} BB_1(n-j) BB_1(n-j) ^{k_1} BB_2$</p> <p>Wherein, M represents the memory depth of the PA 308. That is, the PAs 308 output is considered to be a function of the current input sample and the previous M-1 input samples. L₁ and L₂ represent the nonlinearity length and the interband crosscorrelation degree of the MIMO pre-distortion model. The actual values used for M, L₁, and L₂ will vary based on the actual PA 308 that is used but typically, M will be a rather small number typically between 1 and 6. The values of L₁ and L₂ will be slightly larger than M and typically between 3 and 15. The coefficients h_{1,j,k_1,k_2} are chosen such that the cascade of the MIMO pre-distortion function 307, the PA 308, and BPF₃ 317 will be linear overall. And each equation such as Eq 15 and Eq 16 is called a pre-distortion function.” 22:17-24:22.</p>
15	<p>The method of claim 14, wherein the chosen subsampling frequency f_s for a given signal bandwidth and carrier frequency f_c is in the range $2f_u/n \leq f_s \leq 2h/(n-1)$ where $1 \leq n \leq f_u/B$ and where B is a bandwidth of the amplified concurrent multi band signal, and f_L, f_u are respective lower and upper frequencies of the bandwidth, and n is an integer.</p>	<p>Peroulas discloses and/or renders obvious the method of claim 14, wherein the chosen subsampling frequency f_s for a given signal bandwidth and carrier frequency f_c is in the range $2f_u/n \leq f_s \leq 2h/(n-1)$ where $1 \leq n \leq f_u/B$ and where B is a bandwidth of the amplified concurrent multi band signal, and f_L, f_u are respective lower and upper frequencies of the bandwidth, and n is an integer.</p> <p>See claims 11 and 14, <i>supra</i>, which is incorporated by reference herein.</p>